TABLE 1.—TEMPERATURE CONVERSION TABLE *

The numbers in **boldface type** refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from degrees Fahrenheit to Centigrade, the equivalent will be be found in the column on the left, while if converting from degrees Centigrade to Fahrenheit the answer will be found in the column on the right.

– 459.4 to 28			29 to 140			150 to 890			900 to 1650			1660 to 2410			2420 to 3000		
C		F	C		F	C		F	C		F	C		F	C		F
—273	**—459.4**	...	—1.67	**29**	84.2	66	**150**	302	482	**900**	1652	904	**1660**	3020	1327	**2420**	4388
—268	**—450**	...	—1.11	**30**	86.0	71	**160**	320	488	**910**	1670	910	**1670**	3038	1332	**2430**	4406
—262	**—440**	...	—0.56	**31**	87.8	77	**170**	338	493	**920**	1688	916	**1680**	3056	1338	**2440**	4424
—257	**—430**	...	0	**32**	89.6	82	**180**	356	499	**930**	1706	921	**1690**	3074	1343	**2450**	4442
—251	**—420**	...	0.56	**33**	91.4	88	**190**	374	504	**940**	1724	927	**1700**	3092	1349	**2460**	4460
—246	**—410**	...	1.11	**34**	93.2	93	**200**	392	510	**950**	1742	932	**1710**	3110	1354	**2470**	4478
—240	**—400**	...	1.67	**35**	95.0	99	**210**	410	516	**960**	1760	938	**1720**	3128	1360	**2480**	4496
—234	**—390**	...	2.22	**36**	96.8	100	**212**	414	521	**970**	1778	943	**1730**	3146	1366	**2490**	4514
—229	**—380**	...	2.78	**37**	98.6	104	**220**	428	527	**980**	1796	949	**1740**	3164	1371	**2500**	4532
—223	**—370**	...	3.33	**38**	100.4	110	**230**	446	532	**990**	1814	954	**1750**	3182	1377	**2510**	4550
—218	**—360**	...	3.89	**39**	102.2	116	**240**	464	538	**1000**	1832	960	**1760**	3200	1382	**2520**	4568
—212	**—350**	...	4.44	**40**	104.0	121	**250**	482	543	**1010**	1850	966	**1770**	3218	1388	**2530**	4586
—207	**—340**	...	5.00	**41**	105.8	127	**260**	500	549	**1020**	1868	971	**1780**	3236	1393	**2540**	4604
—201	**—330**	...	5.56	**42**	107.6	132	**270**	518	554	**1030**	1886	977	**1790**	3254	1399	**2550**	4622
—196	**—320**	...	6.11	**43**	109.4	138	**280**	536	560	**1040**	1904	982	**1800**	3272	1404	**2560**	4640
—190	**—310**	...	6.67	**44**	111.2	143	**290**	554	566	**1050**	1922	988	**1810**	3290	1410	**2570**	4658
—184	**—300**	...	7.22	**45**	113.0	149	**300**	572	571	**1060**	1940	993	**1820**	3308	1416	**2580**	4676
—179	**—290**	...	7.78	**46**	114.8	154	**310**	590	577	**1070**	1958	999	**1830**	3326	1421	**2590**	4694
—173	**—280**	...	8.33	**47**	116.6	160	**320**	608	582	**1080**	1976	1004	**1840**	3344	1427	**2600**	4712
—169	**—273**	—459.4	8.89	**48**	118.4	166	**330**	626	588	**1090**	1994	1010	**1850**	3362	1432	**2610**	4730
—168	**—270**	—454	9.44	**49**	120.2	171	**340**	644	593	**1100**	2012	1016	**1860**	3380	1438	**2620**	4748
—162	**—260**	—436	10.0	**50**	122.0	177	**350**	662	599	**1110**	2030	1021	**1870**	3398	1443	**2630**	4766
—157	**—250**	—418	10.6	**51**	123.8	182	**360**	680	604	**1120**	2048	1027	**1880**	3416	1449	**2640**	4784
—151	**—240**	—400	11.1	**52**	125.6	188	**370**	698	610	**1130**	2066	1032	**1890**	3434	1454	**2650**	4802
—146	**—230**	—382	11.7	**53**	127.4	193	**380**	716	616	**1140**	2084	1038	**1900**	3452	1460	**2660**	4820
—140	**—220**	—364	12.2	**54**	129.2	199	**390**	734	621	**1150**	2102	1043	**1910**	3470	1466	**2670**	4838
—134	**—210**	—346	12.8	**55**	131.0	204	**400**	752	627	**1160**	2120	1049	**1920**	3488	1471	**2680**	4856
—129	**—200**	—328	13.3	**56**	132.8	210	**410**	770	632	**1170**	2138	1054	**1930**	3506	1477	**2690**	4874
—123	**—190**	—310	13.9	**57**	134.6	216	**420**	788	638	**1180**	2156	1060	**1940**	3524	1482	**2700**	4892
—118	**—180**	—292	14.4	**58**	136.4	221	**430**	806	643	**1190**	2174	1066	**1950**	3542	1488	**2710**	4910
—112	**—170**	—274	15.0	**59**	138.2	227	**440**	824	649	**1200**	2192	1071	**1960**	3560	1493	**2720**	4928
—107	**—160**	—256	15.6	**60**	140.0	232	**450**	842	654	**1210**	2210	1077	**1970**	3578	1499	**2730**	4946
—101	**—150**	—238	16.1	**61**	141.8	238	**460**	860	660	**1220**	2228	1082	**1980**	3596	1504	**2740**	4964
— 95.6	**—140**	—220	16.7	**62**	143.6	243	**470**	878	666	**1230**	2246	1088	**1990**	3614	1510	**2750**	4982
— 90.0	**—130**	—202	17.2	**63**	145.4	249	**480**	896	671	**1240**	2264	1093	**2000**	3632	1516	**2760**	5000

−84.4	−120	−184	17.8	**64**	147.2	254	**490**	914	677	**1250**	2282	1099	**2010**	3650	1521	**2770**	5018
−78.9	−110	−166	18.3	**65**	149.0	260	**500**	932	682	**1260**	2300	1104	**2020**	3668	1527	**2780**	5036
−73.3	−100	−148	18.9	**66**	150.8	266	**510**	950	688	**1270**	2318	1110	**2030**	3686	1532	**2790**	5054
−67.8	−90	−130	19.4	**67**	152.6	271	**520**	968	693	**1280**	2336	1116	**2040**	3704	1538	**2800**	5072
−62.2	−80	−112	20.0	**68**	154.4	277	**530**	986	699	**1290**	2354	1121	**2050**	3722	1543	**2810**	5090
−56.7	−70	−94	20.6	**69**	156.2	282	**540**	1004	704	**1300**	2372	1127	**2060**	3740	1549	**2820**	5108
−51.1	−60	−76	21.1	**70**	158.0	288	**550**	1022	710	**1310**	2390	1132	**2070**	3758	1554	**2830**	5126
−45.6	−50	−58	21.7	**71**	159.8	293	**560**	1040	716	**1320**	2408	1138	**2080**	3776	1560	**2840**	5144
−40.0	−40	−40	22.2	**72**	161.6	299	**570**	1058	721	**1330**	2426	1143	**2090**	3794	1566	**2850**	5162
−34.4	−30	−22	22.8	**73**	163.4	304	**580**	1076	727	**1340**	2444	1149	**2100**	3812	1571	**2860**	5180
−28.9	−20	−4	23.3	**74**	165.2	310	**590**	1094	732	**1350**	2462	1154	**2110**	3830	1577	**2870**	5198
−23.3	−10	14	23.9	**75**	167.0	316	**600**	1112	738	**1360**	2480	1160	**2120**	3848	1582	**2880**	5216
−17.8	**0**	32	24.4	**76**	168.8	321	**610**	1130	743	**1370**	2498	1166	**2130**	3866	1588	**2890**	5234
−17.2	**1**	33.8	25.0	**77**	170.6	327	**620**	1148	749	**1380**	2516	1171	**2140**	3884	1593	**2900**	5252
−16.7	**2**	35.6	25.6	**78**	172.4	332	**630**	1166	754	**1390**	2534	1177	**2150**	3902	1599	**2910**	5270
−16.1	**3**	37.4	26.1	**79**	174.2	338	**640**	1184	760	**1400**	2552	1182	**2160**	3920	1604	**2920**	5288
−15.6	**4**	39.2	26.7	**80**	176.0	343	**650**	1202	766	**1410**	2570	1188	**2170**	3938	1610	**2930**	5306
−15.0	**5**	41.0	27.2	**81**	177.8	349	**660**	1220	771	**1420**	2588	1193	**2180**	3956	1616	**2940**	5324
−14.4	**6**	42.8	27.8	**82**	179.6	354	**670**	1238	777	**1430**	2606	1199	**2190**	3974	1621	**2950**	5342
−13.9	**7**	44.6	28.3	**83**	181.4	360	**680**	1256	782	**1440**	2624	1204	**2200**	3992	1627	**2960**	5360
−13.3	**8**	46.4	28.9	**84**	183.2	366	**690**	1274	788	**1450**	2642	1210	**2210**	4010	1632	**2970**	5378
−12.8	**9**	48.2	29.4	**85**	185.0	371	**700**	1292	793	**1460**	2660	1216	**2220**	4028	1638	**2980**	5396
−12.2	**10**	50.0	30.0	**86**	186.8	377	**710**	1310	799	**1470**	2678	1221	**2230**	4046	1643	**2990**	5414
−11.7	**11**	51.8	30.6	**87**	188.6	382	**720**	1328	804	**1480**	2696	1227	**2240**	4064	1649	**3000**	5432
−11.1	**12**	53.6	31.1	**88**	190.4	388	**730**	1346	810	**1490**	2714	1232	**2250**	4082			
−10.6	**13**	55.4	31.7	**89**	192.2	393	**740**	1364	816	**1500**	2732	1238	**2260**	4100			
−10.0	**14**	57.2	32.2	**90**	194.0	399	**750**	1382	821	**1510**	2750	1243	**2270**	4118			
−9.44	**15**	59.0	32.8	**91**	195.8	404	**760**	1400	827	**1520**	2768	1249	**2280**	4136			
−8.89	**16**	60.8	33.3	**92**	197.6	410	**770**	1418	832	**1530**	2786	1254	**2290**	4154			
−8.33	**17**	62.6	33.9	**93**	199.4	416	**780**	1436	838	**1540**	2804	1260	**2300**	4172			
−7.78	**18**	64.4	34.4	**94**	201.2	421	**790**	1454	843	**1550**	2822	1266	**2310**	4190			
−7.22	**19**	66.2	35.0	**95**	203.0	427	**800**	1472	849	**1560**	2840	1271	**2320**	4208			
−6.67	**20**	68.0	35.6	**96**	204.8	432	**810**	1490	854	**1570**	2858	1277	**2330**	4226			
−6.11	**21**	69.8	36.1	**97**	206.6	438	**820**	1508	860	**1580**	2876	1282	**2340**	4244			
−5.56	**22**	71.6	36.7	**98**	208.4	443	**830**	1526	866	**1590**	2894	1288	**2350**	4262			
−5.00	**23**	73.4	37.2	**99**	210.2	449	**840**	1544	871	**1600**	2912	1293	**2360**	4280			
−4.44	**24**	75.2	37.8	**100**	212.0	454	**850**	1562	877	**1610**	2930	1299	**2370**	4298			
−3.89	**25**	77.0	43	**110**	230	460	**860**	1580	882	**1620**	2948	1304	**2380**	4316			
−3.33	**26**	78.8	49	**120**	248	466	**870**	1598	888	**1630**	2966	1310	**2390**	4334			
−2.78	**27**	80.6	54	**130**	266	471	**880**	1616	893	**1640**	2984	1316	**2400**	4352			
−2.22	**28**	82.4	60	**140**	284	477	**890**	1634	899	**1650**	3002	1321	**2410**	4370			

Interpolation factors

C		F
0.56	**1**	1.8
1.11	**2**	3.6
1.67	**3**	5.4
2.22	**4**	7.2
2.78	**5**	9.0
3.33	**6**	10.8
3.89	**7**	12.6
4.44	**8**	14.4
5.00	**9**	16.2
5.56	**10**	18.0

* Prepared by Alfred Sauveur; used by the kind permission of Mrs. Sauveur.

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 120 (WHOLE VOLUME)

SMITHSONIAN PHYSICAL TABLES

NINTH REVISED EDITION
(Fourth Reprint)

PREPARED BY
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CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION PRESS
1969

Standard Book Number 87474-015-0

Library of Congress Catalog Card Number 54-60067

Distributed in the United States and Canada
by Random House, Inc.

Distributed in the United Kingdom and Europe
by David & Charles (Publishers), Ltd.
South Devon House, Newton Abbot, Devon

Printed in the United States of America

PREFACE TO THE NINTH REVISED EDITION

This edition of the Smithsonian Physical Tables consists of 901 tables giving data of general interest to scientists and engineers, and of particular interest to those concerned with physics in its broader sense. The increase in size over the Eighth Edition is due largely to new data on the subject of atomic physics. The tables have been prepared and arranged so as to be convenient and easy to use. The index has been extended. Each set of data given herein has been selected from the best sources available. Whenever possible an expert in each field has been consulted. This has entailed a great deal of correspondence with many scientists, and it is a pleasure to add that, almost without exception, all cooperated generously.

When work first started on this edition, Dr. E. U. Condon, then director of the National Bureau of Standards, kindly consented to furnish any assistance that the scientists of that institution were able to give. The extent of this help can be noted from an inspection of the book. Dr. Wallace R. Brode, associate director, National Bureau of Standards, gave valuable advice and constructive criticism as to the arrangement of the tables.

D. H. Menzel and Edith Jenssen Tebo, Harvard University, Department of Astronomy, collected and arranged practically all the tables on astronomy.

A number of experts prepared and arranged groups of related data, and others either prepared one or two tables or furnished all or part of the data for certain tables. Care has been taken in each case to give the names of those responsible for both the data and the selection of it. A portion of the data was taken from other published sources, always with the consent and approval of the author and publisher of the tables consulted. Due credit has been given in all instances. Very old references have been omitted. Anyone in need of these should refer to the Eighth Edition.

It was our intention to mention in this preface the names of all who took part in the work, but the list proved too long for the space available. We wish, however, to express our appreciation and thanks to all the men and women from various laboratories and institutions who have been so helpful in contributing to this Ninth Edition.

Finally, we shall be grateful for criticism, the notification of errors, and new data for use in reprints or a new edition.

W. E. FORSYTHE

Astrophysical Observatory
Smithsonian Institution
January 1951

EDITOR'S NOTE

The ninth edition of the Physical Tables was first published in June 1954. In the first reprint (1956), the second reprint (1959), and the third (1964) a few misprints and errata were corrected.

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(For detailed breakdown of tables, see index.)

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INTRODUCTION

UNITS OF MEASUREMENT

The quantitative measure of anything is expressed by two factors—one, a certain definite amount of the kind of physical quantity measured, called the unit; the other, the number of times this unit is taken. A distance is stated as 5 meters. The purpose in such a statement is to convey an idea of this distance in terms of some familiar or standard unit distance. Similarly quantity of matter is referred to as so many grams; of time, as so many seconds, or minutes, or hours.

The numerical factor definitive of the magnitude of any quantity must depend on the size of the unit in terms of which the quantity is measured. For example, let the magnitude factor be 5 for a certain distance when the mile is used as the unit of measurement. A mile equals 1,760 yards or 5,280 feet. The numerical factor evidently becomes 8,800 and 26,400, respectively, when the yard or the foot is used as the unit. Hence, to obtain the magnitude factor for a quantity in terms of a new unit, multiply the old magnitude factor by the ratio of the magnitudes of the old and new units; that is, by the number of the new units required to make one of the old.

The different kinds of quantities measured by physicists fall fairly definitely into two classes. In one class the magnitudes may be called extensive, in the other, intensive. To decide to which class a quantity belongs, it is often helpful to note the effect of the addition of two equal quantities of the kind in question. If twice the quantity results, then the quantity has extensive (additive) magnitude. For instance, two pieces of platinum, each weighing 5 grams, added together weigh 10 grams; on the other hand, the addition of one piece of platinum at 100° C to another at 100° C does not result in a system at 200° C. Volume, entropy, energy may be taken as typical of extensive magnitudes; density, temperature and magnetic permeability, of intensive magnitudes.

The measurement of quantities having extensive magnitude is a comparatively direct process. Those having intensive magnitude must be correlated with phenomena which may be measured extensively. In the case of temperature, a typical quantity with intensive magnitude, various methods of measurement have been devised, such as the correlation of magnitudes of temperature with the varying lengths of a thread of mercury.

Fundamental units.—It is desirable that the fewest possible fundamental unit quantities should be chosen. Simplicity should regulate the choice—simplicity first, psychologically, in that they should be easy to grasp mentally, and second, physically, in permitting as straightforward and simple definition as possible of the complex relationships involving them. Further, it seems desirable that the units should be extensive in nature. It has been found possible to express all measurable physical quantities in terms of five such units: first, geometrical considerations—length, surface, etc.—lead to the need of a length; second, kinematical considerations—velocity, acceleration, etc.—introduce time; third, mechanics—treating of masses instead of immaterial points—introduces matter with the need of a fundamental unit of mass; fourth, electrical, and fifth, thermal considerations require two more such quantities. The discovery of new classes of phenomena may require further additions.

As to the first three fundamental quantities, simplicity and good use sanction the choice of a length, L, a time interval, T, and a mass, M. For the measurement of electrical quantities, good use has sanctioned two fundamental quantities—the dielectric constant, K, the basis of the "electrostatic" system, and the magnetic permeability, μ, the basis of the "electromagnetic" system. Besides these two systems involving electrical considerations, there is in common use a third one called the "absolute" system, which will be referred to later. For the fifth, or thermal fundamental unit, temperature is generally chosen.[1]

Derived units.—Having selected the fundamental or basic units—namely, a measure of length, of time, of mass, of permeability or of the dielectric constant, and of temperature—it remains to express all other units for physical quantities in terms of these. Units depending on powers greater than unity of the basic units are called "derived units." Thus, the unit volume is the volume of a cube having each edge a unit of length. Suppose that the capacity of some volume is expressed in terms of the foot as fundamental unit and the volume number is wanted when the yard is taken as the unit. The yard is three times as long as the foot and therefore the volume of a cube whose edge is a yard is $3 \times 3 \times 3$ times as great as that whose edge is a foot. Thus the given volume will contain only 1/27 as many units of volume when the yard is the unit of length as it will contain when the foot is the unit. To transform from the foot as old unit to the yard as new unit, the old volume number must be multiplied by 1/27, or by the ratio of the magnitude of the old to that of the new unit of volume. This is the same rule as already given, but it is usually more convenient to express the transformations in terms of the fundamental units directly. In the present case, since, with the method of measurement here adopted, a volume number is the cube of a length number, the ratio of two units of volume is the cube of the ratio of the intrinsic values of the two units of length. Hence, if l is the ratio of the magnitude of the old to that of the new unit of length, the ratio of the corresponding units of volume is l^3. Similarly the ratio of two units of area would be l^2, and so on for other quantities.

CONVERSION FACTORS AND DIMENSIONAL FORMULAE

For the ratio of length, mass, time, temperature, dielectric constant, and permeability units the small bracketed letters, $[l]$, $[m]$, $[t]$, $[\theta]$, $[k]$, and $[\mu]$ will be adopted. These symbols will always represent simple numbers, but the magnitude of the number will depend on the relative magnitudes of the units the ratios of which they represent. When the values of the numbers represented by these small bracketed letters as well as the powers of them involved in any particular unit are known, the factor for the transformation is at once obtained. Thus, in the above example, the value of l was 1/3, and the power involved in the expression for volume was 3; hence the factor for transforming from cubic feet to cubic yards was l^3 or $1/3^3$ or 1/27 These factors will be called *conversion factors.*

[1] Because of its greater psychological and physical simplicity, and the desirability that the unit chosen should have extensive magnitude, it has been proposed to choose as the fourth fundamental quantity a quantity of electrical charge, e. The standard units of electrical charge would then be the electronic charge. For thermal needs, entropy has been proposed. While not generally so psychologically easy to grasp as temperature, entropy is of fundamental importance in thermodynamics and has extensive magnitude. (Tolman, R. C., The measurable quantities of physics, Phys. Rev., vol. 9, p. 237, 1917.)

To find the symbolic expression for the conversion factor for any physical quantity, it is sufficient to determine the degree to which the quantities, length, mass, time, etc., are involved. Thus a velocity is expressed by the ratio of the number representing a length to that representing an interval of time, or $[L/T]$, and acceleration by a velocity number divided by an interval-of-time number, or $[L/T^2]$, and so on, and the corresponding ratios of units must therefore enter in precisely the same degree. The factors would thus be for the just-stated cases, $[l/t]$ and $[l/t^2]$. Equations of the form above given for velocity and acceleration which show the dimensions of the quantity in terms of the fundamental units are called *dimensional equations.* Thus $[E]=[ML^2T^{-2}]$ will be found to be the dimensional equation for energy, and $[ML^2T^{-2}]$ the dimensional formula for it. These expressions will be distinguished from the conversion factors by the use of bracketed capital letters.

In general, if we have an equation for a physical quantity,

$$Q=CL^aM^bT^c,$$

where C is a constant and L, M, T represent length, mass, and time in terms of one set of units, and it is desired to transform to another set of units in terms of which the length, mass, and time are L_1, M_1, T_1, we have to find the value of L_1/L, M_1/M, T_1/T, which, in accordance with the convention adopted above, will be l, m, t, or the ratios of the magnitudes of the old to those of the new units.

Thus $L_1=Ll$, $M_1=Mm$, $T_1=Tt$, and if Q_1 be the new quantity number,

$$\begin{aligned} Q_1 &= CL_1{}^aM_1{}^bT_1{}^c, \\ &= CL^al^aM^bm^bT^ct^c=Ql^am^bt^c, \end{aligned}$$

or the conversion factor is $[l^am^bt^c]$, a quantity precisely of the same form as the dimension formula $[L^aM^bT^c]$.

Dimensional equations are useful for checking the validity of physical equations. Since physical equations must be homogeneous, each term appearing in them must be dimensionally equivalent. For example, the distance moved by a uniformly accelerated body is $s=v_0t+\frac{1}{2}at^2$. The corresponding dimensional equation is $[L]=[(L/T)T]+[(L/T^2)T^2]$, each term reducing to $[L]$.

Dimensional considerations may often give insight into the laws regulating *physical phenomena.*[2] For instance, Lord Rayleigh, in discussing the intensity of light scattered from small particles, in so far as it depends upon the wavelength, reasons as follows:[3]

The object is to compare the intensities of the incident and scattered ray; for these will clearly be proportional. The number (i) expressing the ratio of the two amplitudes is a function of the following quantities:—V, the volume of the disturbing particle; r, the distance of the point under consideration from it; λ, the wavelength; c, the velocity of propagation of light; D and D', the original and altered densities: of which the first three depend only on space, the fourth on space and time, while the fifth and sixth introduce the consideration of mass. Other elements of the problem there are none, except mere numbers and angles, which do not depend upon the fundamental measurements of space, time, and mass. Since the ratio i, whose expression we seek, is of no dimensions in mass, it follows at once that D and D' occur only under the form $D:D'$, which is a simple number and may therefore be omitted. It remains to find how i varies with V, r, λ, c.

Now, of these quantities, c is the only one depending on time; and therefore, as i is of no dimensions in time, c cannot occur in its expression. We are left, then, with V, r, and λ; and from what we know of the dynamics of the question, we may be sure that i varies directly as V and inversely as r, and must therefore be proportional to $V \div \lambda^2 r$, V being of three di-

[2] Buckingham, E., Phys. Rev., vol. 4, p. 345, 1914; also Philos. Mag., vol. 42, p. 696, 1921.
[3] Philos. Mag., ser. 4, vol. 41, p. 107, 1871. See also Robertson, Dimensional analysis, Gen. Electr. Rev., vol. 33, p. 207, 1930.

mensions in space. In passing from one part of the spectrum to another λ is the only quantity which varies, and we have the important law:

When light is scattered by particles which are very small compared with any of the wavelengths, the ratio of the amplitudes of the vibrations of the scattered and incident light varies inversely as the square of the wavelength, and the intensity of the lights themselves as the inverse fourth power.

The dimensional and conversion-factor formulae for the more commonly occurring derived units are given in Table 30.

TABLE 2.—SOME FUNDAMENTAL DEFINITIONS

Part 1.—Geometrical and mechanical units [4]

Activity (power).—Time rate of doing work; unit, the watt.

Angle (ϕ).—The ratio of the length of its circular arc to its radius; unit, the radian.

Angstrom.—Unit of wavelength $= 10^{-10}$ meter. (See Table 522.)

Angular acceleration $\left(\alpha = \frac{d\,\omega}{d\,t}\right)$.—The rate of change of angular velocity.

Angular momentum ($I\omega$).—The product of its moment of inertia about an axis through its center of mass perpendicular to its plane of rotation and its angular velocity.

Angular velocity.—The time rate of change of angle.

Area.—Extent of surface. Unit, a square whose side is the unit of length. The area of a surface is expressed as $S = CL^2$, where the constant C depends on the contour of the surface and L is a linear dimension. If the surface is a square and L the length of a side, C is unity; if a circle and L its diameter, C is $\pi/4$. (See Table 31.)

Atmosphere.—Unit of pressure. (See Table 260.)

English normal = 14.7 lb/in.^{2} = 29.929 in.Hg = 760.18 mmHg (32°F)
U. S. = 760 mmHg (0°C) = 29.921 in.Hg = 14.70 lb/in.^{2}

Avogadro number.—Number of molecules per mole, 6.0228×10^{23} molecules/mole.

Bar.[4a]—International unit of pressure 10^6 dyne/cm^2.
Barye.—cgs pressure unit, one dyne/cm^2.

Carat.—The diamond carat standard in U. S. = 200 mg. Old standard = 205.3 mg = 3.168 grains. The gold carat: pure gold is 24 carats; a carat is 1/24 part.

Circular area.—The square of the diameter = 1.2733 × true area. True area = 0.785398 × circular area.

Circular inch.—Area of circle 1 inch in diameter.

Cubit = 18 inches

[4] For dimensional formula see Table 30, part 2.
[4a] Some writers have used this term for 1 dyne/cm^2.

Dalton (atomic mass unit M_0).—Unit of mass, 1/16 mass of oxygen ($_8O^{16}$) atom, 1.66080×10^{-24} g (Phys. scale). (See Table 26.)

Density.—The mass per unit volume. The specific gravity of a body is the ratio of a density to the density of a standard substance. Water and air are commonly used as the standard substance.

Digit.—3/4 in.; 1/12 the apparent diameter of the sun or moon.

Diopter.—Unit of "power of a lens." The diopter = the reciprocal of the focal length in meters.

Dyne.—The cgs, unit of force = that unbalanced force which acting for 1 second on body of 1 gram mass produces a velocity change of 1 cm/sec.

Energy.—The work done by a force produces either a change in the velocity of a body or a change of its shape or position or both. In the first case it produces a change of kinetic energy, in the second, of potential energy.

Erg.—The cgs unit of work and energy = the work done by 1 dyne acting through 1 centimeter.

Fluidity.—Reciprocal of viscosity.

Foot-pound.—The work which will raise 1 pound body 1 foot high for standard g.

Foot-poundal.—The work done when a force of 1 poundal acts through 1 foot.

Force (f).—Force is the agent that changes the motion of bodies and is measured by the rate of change of momentum it produces on a free body.

Gal = gravity standard = an acceleration of 1 cm sec^{-2}.

Giga = 10^9.

Gram.—The standard of mass in the metric system. (See Table 31.)

Gram-centimeter.—The cgs gravitation unit of work.

Gram-molecule.—The mass in grams of a substance numerically equal to its molecular weight.

Gravitation constant.—(G, in formula $F = Gm_1m_2/r^2$) $= 6.670 \times 10^{-8}$ dyne cm^2 g^{-2}.

Gravity (g).—The attraction of the earth for any mass. It is measured by the acceleration produced on the mass under standard conditions. This acceleration g equals 980.665 cm sec^{-2} or 32.17 ft sec^{-2}.

Horsepower.—A unit of mechanical power. The English and American horsepower is defined by some authorities as 550 foot-pounds/sec and by others as 746 watts. The continental horsepower is defined by some authorities as 75 kgm/sec and by others as 736 watts.

Joule.—Unit of work (energy) = 10^7 ergs. Joules = ($volts^2 \times$ sec)/ohms = watts $\times$ sec = $amperes^2 \times$ ohms $\times$ sec = volts $\times$ amperes $\times$ sec.

Kilodyne.—1,000 dynes. About 0.980 gram weight.

Kinetic energy.—The energy associated with the motion $= \frac{mv^2}{2}$ in ergs if m is in grams and v in cm/sec.

Linear acceleration $\left(a = \frac{dv}{dt}\right)$.—The rate of change of velocity.

Liter.—See Table 32.

Loschmidt number.—The number of molecules per cm^3 of an ideal gas at 0°C and normal pressure $= 2.6870 \times 10^{19}$ molecules/cm^3.

Megabaryes.—Unit of pressure = 1,000,000 baryes = 1 bar = 0.987 atmosphere.

Meter.—See Table 31.

Micro.—A prefix indicating the millionth part. (See Table 901.)

Micron (μ) = one-millionth of a meter = one-thousandth of a millimeter.

Mil.—One-thousandth of an inch.

Mile.—Statute = 5,280 feet; nautical or geographical = 6,080.20 feet.

Milli.—A prefix denoting the thousandth part.

Modulus of elasticity.—Ratio of stress to strain. The dimension of strain, a change of length divided by a length, or change of volume divided by a volume, is unity.

Mole or mol.—Mass equal numerically to molecular weight of substance.

Momentum ($M = mv$).—The quantity of motion in the Newtonian sense; the product of the mass and velocity of the body.

Moment of inertia (I) of a body about an axis is the Σmr^2, where m is the mass of a particle of the body and r its distance from the axis.

Newton.—The unit of force in the MKS system $= 10^5$ dynes. (See Table 3, part 2.)

Pound weight.—A force equal to the earth's attraction for a mass of 1 pound. This force, acting on 1 lb mass, will produce an acceleration of 32.17 ft/sec^2.

Poundal.—The ft-lb sec unit of force. That unbalanced force which acting on a body of 1 lb mass produces an acceleration of 1 ft/sec^2.

Pi (π) = 3.1416. (See Table 11.)

Power.—Activity $\left(p = \frac{dW}{dt}\right)$ is the time rate of doing work.

Radian.—An angle subtended by an arc equal to the radius. This angle equals $180°/\pi = 57.29578° = 57°17'45'' = 206265''$.

Resilience.—The work done per unit volume of a body in distorting it to the elastic limit or in producing rupture.

Slug.—Mass (32.17 lb) acquiring acceleration 1 ft sec^{-2} when continuously acted upon by force of 1 lb weight.

Strain.—The deformation produced by a stress divided by the original dimension.

Stress.—The force per unit area of a body that tends to produce a deformation.

Tenth-meter.—10^{-10} meter = 1 angstrom.

Torque, moment of a couple, about an axis is the product of a force and the distance of its line of action from the axis.

Volume.—Extent of space. Unit, a cube whose edge is the unit of length. The volume of a body is expressed as $V = CL^3$. The constant C depends on the shape of the bounding surfaces.

Velocity $\left(v = \frac{dL}{dt}\right)$ is distance traversed per unit time.

Viscosity.—The property of a liquid by virtue of which it offers resistance to flow. The coefficient of viscosity is the tangential force that must be applied to the upper surface of a 1-cm cube of the liquid on an edge to produce a velocity of 1 cm/sec in the face when the lower face is at rest.

Work (W).—The work done by an unbalanced force is the product of the force by the component of the resulting displacement produced in the direction of the force.

Young's modulus.—Ratio of longitudinal stress within the proportional limit to the corresponding longitudinal strain.

Part 2.—Heat Units [5]

Blackbody.—A body that absorbs all the radiation that falls upon it. From this definition and certain assumptions it can be shown that its total radiation = σT^4 (Stefan-Boltzmann Law) and that the spectral distribution of the radiation is given by the Planck Law: [5a]

$$J_\lambda = \frac{Ac_1\lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1}$$

Brightness temperature (S).—The temperature of a non-blackbody determined from its brightness (with an optical pyrometer, see Table 77) as if it were a blackbody. Such temperatures are always less than the true temperatures.

British thermal unit (Btu).—The amount of heat required to raise 1 pound of water at 60°F, 1°F. This unit is defined for various temperatures, but the general usage seems to be to take the Btu as equal to 252 calories. (See calorie. See Table 7.)

Calorie.—The amount of heat necessary to raise 1 gram of water at 15°C, 1°C.

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[5] For dimensional formulas see Table 30, part 2.

[5a] An easier way to write this exponential term is:

$$J_\lambda = c_1\lambda^{-5}/\left[\left(exp\left(\frac{c_2}{\lambda T}\right)\right) - 1\right]$$

This form will be used hereafter.

There are various calories depending upon the interval chosen. Sometimes the unit is written as the gram-calorie or the kilogram-calorie, the meaning of which is evident. There is some tendency to define the calorie in terms of its mechanical equivalent. Thus the National Bureau of Standards defines the calorie as 4.18400 joules. At the International Steam Table Conference held in London in 1929 the international calorie was defined as 1/860 of the international watt hour (see Table 7), which made it equal to 4.1860 international joules. With the adoption of the absolute system of electrical units, this becomes 1/859.858 watt hours or 4.18674 joules. The Btu was defined at the same time as 251.996 international calories. Thus, until such a time as these differences are taken care of, there will be some confusion.

Celsius temperature scale.—The present-day designation of the scale formerly known as the Centigrade scale.

Centigrade temperature scale.—The temperature scale that divides the interval between the ice point, taken as 0°C, and the boiling point of water with 100°.

Coefficient of thermal expansion.—Ratio of the change of length per unit length (linear), or change of volume per unit volume (voluminal), to the change of temperature.

Color temperature[6] (T_S).—The color temperature of a non-blackbody is the temperature at which it is necessary to operate the blackbody so that the color of its emitted light will match that of the source studied.

Emissivity.—Ratio of the energy radiated at any temperature by a non-blackbody to that radiated by a blackbody at the same temperature. The spectral emissivity is for a definite wavelength, and the total emissivity is for all wavelengths.

Enthalpy.—Total energy that a system possesses by virtue of its temperature. Thus, where U is the internal energy, then the enthalpy $= U + PV$ where PV represents the external work.

Entropy.—A measure of the extent to which the energy of the system is unavailable.

Fahrenheit temperature scale.—A scale based on the freezing point of water taken as 32° and the boiling point of water taken as 212°.

Graybody.—A body that has a constant emissivity for all wavelengths.

Heat.—Energy transferred by a thermal process. Heat can be measured in terms of the dynamical units of energy, as the erg, joule, etc., or in terms of the amount of energy required to produce a definite thermal change in some substance, as for example the energy required per degree to raise the temperature of a unit mass of water at some temperature. The mechanical unit of heat has the dimensional formula of energy (ML^2T^{-2}). The thermal unit (H), as used in many of these tables, is ($M\theta$) where θ denotes a temperature interval.

Joule's equivalent (J) or the mechanical equivalent of heat.—Conversion factor for changing an expression of mechanical energy into an expression of thermal energy or vice versa (4.1855 J/cal).

[6] Gen. Electr. Rev., vol. 47, p. 26, 1944.

Kelvin temperature scale.—Scale of temperature based on equal work for equal temperatures for a working substance in a carnot cycle = Celsius (Centigrade) scale + 273.16.

Langley (*ly*).—A new unit of radiation, surface density, has been suggested [7] which equals 1 calorie (15°C) per cm^2.

Latent heat.—Quantity of heat required to change the state of a unit mass of matter.

Pyron.—A unit of radiant intensity = 1 cal cm^{-2} min^{-1}.

Radiant energy.—Energy traveling in the form of electromagnetic waves.

Radiant temperature.—The temperature obtained by use of a total radiation pyrometer when sighted upon a non-blackbody. This is always less than the true temperature.

Rankin temperature scale.—Absolute Fahrenheit scale = Fahrenheit scale + 459.7.

Reaumur temperature scale.—A scale based upon the freezing point of water taken as 0°R and the boiling point of water taken as 80°R.

Specific heat.—Ratio of the heat capacity of a substance to the heat capacity of an equal mass of water. When so expressed, the specific heat is a dimensionless number.

Standard temperature.—A temperature that depends upon some characteristic of some substance, such as the melting, boiling, or freezing point, that is used as a reference standard of temperature.

Thermal capacitance.—The heat capacity of a body is the limiting value, as T approaches zero, of the ratio $\frac{\Delta Q}{\Delta T}$, where ΔT is the rise in temperature resulting from the addition to the body of a quantity of heat equal to ΔQ.

Thermal conductivity.—Quantity of heat, Q, which flows normally across a surface of unit area per unit of time and per unit of temperature gradient normal to the surface. In thermal units it has the dimensional formula $(H\theta^{-1}L^{-1}T^{-1})$ or $(ML^{-1}T^{-1})$, in mechanical units $(MLT^{-3}\theta^{-1})$.

Thermodynamic temperature.—See Kelvin temperature scale.

Thermodynamics.—Study of the flow of heat.

Thermodynamic laws: *Zeroth law.*—Two systems that are in thermal equilibrium with a third are in thermal equilibrium with each other. *First law:* When equal quantities of mechanical effect are produced by any means whatever from purely thermal effects, equal quantities of heat are put out of existence or are created. *Second law:* It is impossible to transfer heat from a cold body to a hot body without the performance of mechanical work. *Third law:* It is impossible by any means whatever to superpose only the images of several light sources to obtain an image brighter than the brightest of the source.

[7] Aldrich et al., Science, vol. 106, p. 225, 1947.

Part 3.—Electric and Magnetic Units

A system of units of electric and magnetic quantities requires four fundamental quantities. A system in which length, mass, and time constitute three of the fundamental quantities is known as an "absolute" system. There are two absolute systems of electric and magnetic units. One is called the electrostatic, in which the fourth fundamental quantity is the dielectric constant, and one is called the electromagnetic, in which the fourth fundamental quantity is magnetic permeability. Besides these two systems there will be described a third, to be known as the absolute system, that was introduced January 1, 1948. (See Table 4.)

In the electrostatic system, unit quantity of electricity, Q, is the quantity which exerts unit mechanical force upon an equal quantity a unit distance from it in a vacuum. From this definition the dimensions and the units of all the other electric and magnetic quantities follow through the equations of the mathematical theory of electromagnetism. The mechanical force between two quantities of electricity in any medium is

$$F=\frac{QQ'}{Kr^2},$$

where K is the dielectric constant, characteristic of the medium, and r the distance between the two points at which the quantities Q and Q' are located. K is the fourth quantity entering into dimensional expressions in the electrostatic system. Since the dimensional formula for force is $[MLT^{-2}]$, that for Q is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$.

The electromagnetic system is based upon the unit of the magnetic pole strength (see Table 466). The dimensions and the units of the other quantities are built up from this in the same manner as for the electrostatic system. The mechanical force between two magnetic poles in any medium is

$$F=\frac{mm'}{\mu r^2},$$

in which μ is the permeability of the medium and r is the distance between two poles having the strengths m and m'. μ is the fourth quantity entering into dimensional expressions in the electromagnetic system. It follows that the dimensional expression for magnetic pole strength is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

The symbols K and μ are sometimes omitted in the dimensional formulae so that only three fundamental quantities appear. There are a number of objections to this. Such formulae give no information as to the relative magnitudes of the units in the two systems. The omission is equivalent to assuming some relation between mechanical and electrical quantities, or to a mechanical explanation of electricity. Such a relation or explanation is not known.

The properties K and μ are connected by the equation $1/\sqrt{K\mu}=v$, where v is the velocity of an electromagnetic wave. For empty space or for air, K and μ being measured in the same units, $1\sqrt{K\mu}=c$, where c is the velocity of light in vacuo, 2.99776×10^{10} cm per sec. It is sometimes forgotten that the omission of the dimensions of K or μ is merely conventional. For instance, magnetic field intensity and magnetic induction apparently have the same dimensions when μ is omitted. This results in confusion and difficulty in understanding the theory of magnetism. The suppression of μ has also led to the use of the "centimeter" as a unit of capacity and of inductance; neither is physically the same as length.

Capacitance of an insulated conductor is proportional to the ratio of the quantity of electricity in a charge to the potential of the charge. The dimensional formula is the ratio of the two formulae for electric quantity and potential or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}/M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$ or $[LK]$.

Conductance of any part of an electric circuit, not containing a source of electromotive force, is the ratio of the current flowing through it to the difference of potential between its ends. The dimensional formula is the ratio of the formulae for current and potential or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}K^{\frac{1}{2}}/M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$ or $[LT^{-1}K]$.

Electrical conductivity, like the corresponding term for heat, is quantity per unit area per unit potential gradient per unit of time. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}/L^2(M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}/L)T]$ or $[T^{-1}K]$.

Electric current (statampere-unit quantity) is quantity of electricity flowing through a cross section per unit of time. The dimensional formula is the ratio of the formulae for electric quantity and for time or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}/T]$ or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}K^{\frac{1}{2}}]$.

Electric field intensity strength at a point is the ratio of the force on a quantity of electricity at a point to the quantity of electricity. The dimensional formula is therefore the ratio of the formulae for force and electric quantity or $[MLT^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$.

Electric potential difference and electromotive force (emf) (statvolt-work = 1 erg).—Change of potential is proportional to the work done per unit of electricity in producing the change. The dimensional formula is the ratio of the formulae for work and electrical quantity or $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}K^{-\frac{1}{2}}]$.

Electric surface density of an electrical distribution at any point on a surface is the quantity of electricity per unit area. The dimensional formula is the ratio of the formulae for quantity of electricity and for area or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}K^{\frac{1}{2}}]$.

Quantity of electricity has the dimensional formula $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}K^{\frac{1}{2}}]$, as shown above.

Resistance is the reciprocal of conductance. The dimensional formula is $[L^{-1}TK^{-1}]$.

Resistivity is the reciprocal of conductivity. The dimensional formula is $[TK^{-1}]$.

Specific inductive capacity is the ratio of the inductive capacity of the substance to that of a standard substance and therefore is a number.

Exs.—Find the factor for converting quantity of electricity expressed in ft-grain-sec units to the same expressed in cgs units. The formula is $[m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}k^{\frac{1}{2}}]$, in which $m = 0.0648$, $l = 30.48$, $t = 1$, $k = 1$; the factor is $0.0648^{\frac{1}{2}} \times 30.48^{\frac{3}{2}}$, or 42.8.

Find the factor required to convert electric potential from mm-mg-sec units to cgs units. The formula is $[m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}k^{-\frac{1}{2}}]$, in which $m = 0.001$, $l = 0.1$, $t = 1$, $k = 1$; the factor is $0.001^{\frac{1}{2}} \times 0.1^{\frac{1}{2}}$, or 0.01.

Find the factor required to convert electrostatic capacity from ft-grain-sec and specific-inductive capacity 6 units to cgs units. The formula is $[lk]$ in which $l = 30.48$, $k = 6$; the factor is 30.48×6, or 182.88.

Many of the magnetic quantities are analogues of certain electric quantities. The dimensions of such quantities in the electromagnetic system differ from those of the corresponding electrostatic quantities in the electrostatic system only in the substitution of permeability μ for K.

Conductance is the reciprocal of resistance, and the dimensional formula is $[L^{-1}T\mu^{-1}]$.

Conductivity is the quantity of electricity transmitted per unit area per unit potential gradient per unit of time. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}/L^2(M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}/L)T]$ or $[L^{-2}T\mu^{-1}]$.

Current, I (abampere-unit magnetic field, $r=1$ cm), flowing in circle, radius r, creates magnetic field at its center, $2\pi I/r$. Dimensional formula is product of formulae for magnetic field intensity and length or $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$.

Electric field intensity is the ratio of electric potential or electromotive force and length. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-2}\mu^{\frac{1}{2}}]$.

Electric potential, or **electromotive force** (emf) (abvolt-work = 1 erg), as in the electrostatic system, is the ratio of work to quantity of electricity. The dimensional formula is $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{1}{2}}\mu^{-\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}\mu^{\frac{1}{2}}]$.

Electrostatic capacity is the ratio of quantity of electricity to difference of potential. The dimensional formula is $[L^{-1}T^2\mu^{-1}]$.

Intensity of magnetization (I) of any portion of a magnetized body is the ratio of the magnetic moment of that portion and its volume. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}\mu^{\frac{1}{2}}/L^3]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic field strength, magnetic intensity or magnetizing force (J) is the ratio of the force on a magnetic pole placed at the point and the magnetic pole strength. The dimensional formula is therefore the ratio of the formulae for a force and magnetic quantity, or $[MLT^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$.

Magnetic flux (Φ) characterizes the magnetized state of a magnetic circuit. Through a surface enclosing a magnetic pole it is proportional to the magnetic pole strength. The dimensional formula is that for magnetic pole strength.

Magnetic induction (B) is the magnetic flux per unit of area taken perpendicular to the direction of the magnetic flux. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}/L^2]$ or $[M^{\frac{1}{2}}L^{-\frac{1}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic moment (M) is the product of the pole strength by the length of the magnet. The dimensional formula is $[M^{\frac{1}{2}}L^{\frac{5}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic pole strength or **quantity of magnetism** (m) has already been shown to have the dimensional formula $[M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$.

Magnetic potential or **magnetomotive force** at a point is measured by the work which is required to bring unit quantity of positive magnetism from zero potential to the point. The dimensional formula is the ratio of the formulae for work and magnetic quantity $[ML^2T^{-2}/M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}\mu^{\frac{1}{2}}]$ or $[M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}\mu^{-\frac{1}{2}}]$.

Magnetic reluctance is the ratio of magnetic potential difference to magnetic flux. The dimensional formula is $[L^{-1}\mu^{-1}]$.

Magnetic susceptibility (κ) is the ratio of intensity of magnetization produced and the intensity of the magnetic field producing it. The dimensional formula is $[M^{\frac12}L^{-\frac12}T^{-1}\mu^{\frac12}/M^{\frac12}L^{-\frac12}T^{-1}\mu^{-\frac12}]$ or $[\mu]$.

Mutual inductance of two circuits is the electromotive force produced in one per unit rate of variation of the current in the other. The dimensional formula is the same as for self-inductance.

Peltier effect, coefficient of, is measured by the ratio of the quantity of heat and quantity of electricity. The dimensional formula is $[ML^2T^{-2}/M^{\frac12}L^{\frac12}\mu^{-\frac12}]$ or $[M^{\frac12}L^{\frac32}T^{-2}\mu^{\frac12}]$, the same as for electromotive force.

Quantity of electricity is the product of the current and time. The dimensional formula is $[M^{\frac12}L^{\frac12}\mu^{-\frac12}]$.

Resistance of a conductor is the ratio of the difference of potential between its ends and the constant current flowing. The dimensional formula is $[M^{\frac12}L^{\frac32}T^{-2}\mu^{\frac12}/M^{\frac12}L^{\frac12}T^{-1}\mu^{-\frac12}]$ or $[LT^{-1}\mu]$.

Resistivity is the reciprocal of conductivity as just defined. The dimensional formula is $[L^2T^{-1}\mu]$.

Self-inductance is for any circuit the electromotive force produced in it by unit rate of variation of the current through it. The dimensional formula is the product of the formulae for electromotive force and time divided by that for current or $[M^{\frac12}L^{\frac32}T^{-2}\mu^{\frac12}\times T\div M^{\frac12}L^{\frac12}T^{-1}\mu^{-\frac12}]$ or $[L\mu]$.

Thermoelectric power is measured by the ratio of electromotive force and temperature. The dimensional formula is $[\mathrm{M}^{\frac12}L^{\frac32}T^{-2}\mu^{\frac12}\theta^{-1}]$.

Exs.—Find the factor required to convert intensity of magnetic field from ft-grain-min units to cgs units. The formula is $[m^{\frac12}l^{-\frac12}t^{-1}\mu^{-\frac12}]$; $m = 0.0648$, $l = 30.48$, $t = 60$, and $\mu = 1$; the factor is $0.0648^{\frac12}\times 30.48^{-\frac12}$, or 0.046108.

How many cgs units of magnetic moment make one ft-grain-sec unit of the same quantity? The formula is $[m^{\frac12}l\,t^{-1}\mu^{\frac12}]$; $m = 0.0648$. $l = 30.48$, $t = 1$, and $\mu = 1$; the number is $0.0648^{\frac12}\times 30.48^{\frac52}$, or 1305.6.

If the intensity of magnetization of a steel bar is 700 in cgs units, what will it be in mm-mg-sec units? The formula is $[m^{\frac12}l^{\frac12}t^{-1}\mu^{\frac12}]$; $m = 1000$, $l = 10$, $t = 1$, $\mu = 1$; the intensity is $700\times 1000^{\frac12}\times 10^{\frac12}$, or 70000.

Find the factor required to convert current from cgs units to earth-quadrant-10^{-11} gram-sec units. The formula is $[m^{\frac12}l^{\frac12}t^{-1}\mu^{-\frac12}]$; $m = 10^{11}$, $l = 10^{-9}$, $\mu = 1$; the factor is $10^{\frac{11}{2}}\times 10^{-\frac92}$, or 10.

Find the factor required to convert resistance expressed in cgs units into the same expressed in earth-quadrant-10^{-11} gram-sec units. The formula is $[lt^{-1}\mu]$; $l = 10^{-9}$, $t = 1$, $\mu = 1$; the factor is 10^{-9}.

TABLE 3.—FUNDAMENTAL STANDARDS

Part 1.—Selection of fundamental quantities

The choice of the nature of the fundamental quantities already made does not sufficiently define the system for measurements. Some definite unit or arbitrarily chosen standard must next be taken for each of the fundamental quantities. This fundamental standard should have the qualities of permanence, reproducibility, and availability and be suitable for accurate measures. Once chosen and made it is called the primary standard and is generally kept at some central bureau—for instance, the International Bureau of Weights and Measures at Sèvres, France. A primary standard may also be chosen and made for derived units (e.g., the new absolute (1948) ohm standard), when it is simply a standard closely representing the unit and accepted for practical purposes, its value having been fixed by certain measuring processes. Secondary or reference standards are accurately compared copies, not necessarily duplicates, of the primaries for use in the work of standardizing laboratories and the production of working standards for everyday use.

Standard of length.—The primary standard of length which now almost universally serves as the basis for physical measurements is the meter. It is defined as the distance between two lines at 0° C on a platinum-iridium bar deposited at the International Bureau of Weights and Measures. This bar is known as the International Prototype Meter, and its length was derived from the "métre des Archives," which was made by Borda. Borda, Delambre, Laplace, and others, acting as a committee of the French Academy, recommended that the standard unit of length should be the ten-millionth part of the length, from the equator to the pole, of the meridian passing through Paris. In 1795 the French Republic passed a decree making this the legal standard of length, and an arc of the meridian extending from Dunkirk to Barcelona was measured by Delambre and Mechain for the purpose of realizing the standard. From the results of that measurement the meter bar was made by Borda. The meter is now defined as above and not in terms of the meridian length; hence, subsequent measures of the length of the meridian have not affected the length of the meter.

Standard of mass.—The primary standard of mass now almost universally used as the basis for physical measurements is the kilogram. It is defined as the mass of a certain piece of platinum-iridium deposited at the International Bureau of Weights and Measures. This standard is known as the International Prototype Kilogram. Its mass is equal to that of the older standard, the "kilogram des Archives," made by Borda and intended to have the same mass as a cubic decimeter of distilled water at the temperature of 4° C.

Copies of the International Prototype Meter and Kilogram are possessed by the various governments and are called National Prototypes.

Standard of time.—The unit of time universally used is the mean solar second, or the 86400th part of the mean solar day. It is based on the average time of one rotation of the earth on its axis relatively to the sun as a point of reference = 1.002 737 91 sidereal second.

Standard of temperature.—The standard scale of temperature, adopted by the International Committee of Weights and Measures (1887), depends on the constant-volume hydrogen thermometer. The hydrogen is taken at an initial pressure at 0° C of 1 meter of mercury, 0° C, sea-level at latitude 45°. The scale is defined by designating the temperature of melting ice as 0° and of condensing steam as 100° under standard atmospheric pressure.

Thermodynamic (Kelvin) Scale (Centigrade degrees).—Such a scale independent of the properties of any particular substance, and called the thermodynamic, or absolute scale, was proposed in 1848 by Lord Kelvin. The temperature is proportional to the average kinetic energy per molecule of a perfect gas.

International temperature scale.—See Table 37.

Numerically different systems of units.—The fundamental physical quantities which form the basis of a system for measurements have been chosen and the fundamental standards selected and made. Custom has not however generally used these standards for the measurement of the magnitudes of quantities but rather multiples or submultiples of them. For instance, for very small quantities the micron (μ) or one-millionth of a meter is often used. The following table [8] gives some of the systems proposed, all built upon the fundamental standards already described. The centimeter-gram-second (cm-g-sec or cgs) system proposed by Kelvin is the only one generally accepted.

Part 2.—Some proposed systems of units

	Weber and Gauss	Kelvin cgs	Moon 1891	Giorgi MKS (Prim. Stds.)	France 1914	B. A. Com., 1863	Practical (B. A. Com., 1873)	Strout 1891
Length	mm	cm	dm	m	m	m	10^9 cm	10^9 cm
Mass	mg	g	Kg	Kg	10^6 g	g	10^{-11} g	10^{-9} g
Time	sec	sec	$\frac{\text{sec}}{10}$	sec	sec	sec	sec	sec

Further, the choice of a set of fundamental physical quantities to form the basis of a system does not necessarily determine how that system shall be used in measurements. In fact, upon any sufficient set of fundamental quantities, a great many different systems of units may be built. The electrostatic and electromagnetic systems are really systems of electric quantities rather than units. They were based upon the relationships $F = QQ'/Kr^2$ and $mm'/\mu r^2$, respectively. Systems of units built upon a chosen set of fundamental physical quantities may differ in two ways: (1) the units chosen for the fundamental quantities may be different; (2) the defining equations by which the system is built may be different.

The electrostatic system generally used is based on the centimeter, gram, second, and dielectric constant of a vacuum. Other systems have appeared, differing from this in the first way—for instance using the foot, grain, and second in place of the centimeter, gram, and second. A system differing from it in the second way is that of Heaviside which introduces the factor 4π at different places than is usual in the equations. There are similarly several systems of electromagnetic units in use.

Gaussian systems.—"The complexity of the interrelations of the units is increased by the fact that not one of the systems is used as a whole, consistently for all electromagnetic quantities. The 'systems' at present used are therefore combinations of certain of the systems of units."

Some writers [9] on the theory of electricity prefer to use what is called a Gaussian system, a combination of electrostatic units for purely electrical quantities and electromagnetic units for magnetic quantities. There are two such Gaussian systems in vogue—one a combination of cgs electrostatic and cgs electromagnetic systems, and the other a combination of the two corresponding Heaviside systems.

When a Gaussian system is used, caution is necessary when an equation contains both electric and magnetic quantities. A factor expressing the ratio between the electrostatic and electromagnetic units of one of the quantities has to be introduced. This factor is the first or second power of c, the number

[8] Circular 60 of the National Bureau of Standards, Electric Units and Standards, 1916. The subsequent matter in this introduction is based upon this circular.

[9] For example, A. G. Webster, Theory of electricity and magnetism, 1897; J. H. Jeans, Electricity and magnetism, 1911; H. A. Lorentz, The theory of electrons, 1909; and O. W. Richardson, The electron theory of matter, 1914.

of electrostatic units of electric charge in one electromagnetic unit of the same. There is sometimes a question as to whether electric current is to be expressed in electrostatic or electromagnetic units, since it has both electric and magnetic attributes. It is usually expressed in electrostatic units in the Gaussian system.

It may be observed from the dimensions of K given in Table 2, part 3, that $[1/K\mu]=[L^2/T^2]$ which has the dimensions of a square of a velocity. This velocity was found experimentally to be equal to that of light, when K and μ were expressed in the same system of units. Maxwell proved theoretically that $1/\sqrt{K\mu}$ is the velocity of any electromagnetic wave. This was subsequently proved experimentally. When a Gaussian system is used, this equation becomes $c/\sqrt{K\mu}=v$. For the ether $K=1$ in electrostatic units and $\mu=1$ in electromagnetic units. Hence $c=v$ for the ether, or the velocity of an electromagnetic wave in the ether is equal to the ratio of the cgs electromagnetic to the cgs electrostatic unit of electric charge. This constant c is of primary importance in electrical theory. Its most probable value is 2.99776×10^{10} centimeters per second.

Part 3.—Electrical and magnetic units

Absolute ("practical") electromagnetic system (1948).—This electromagnetic system is based upon the units of 10^9 cm, 10^{-11} g, the sec and μ of the ether. The principal quantities are the resistance unit, the ohm $=10^9$ emu units; the current unit, the ampere $=10^{-1}$ emu units; and the electromotive force unit, the volt $=10^8$ emu units. (See Table 6.)

The International electric units.—The units used before January 1, 1948, in practical electrical measurements, however, were the "International Units." They were derived from the "practical" system just described, or as the latter is sometimes called, the "absolute" system. These international units were based upon certain concrete standards that were defined and described. With such standards electrical comparisons can be more accurately and readily made than could absolute measurements in terms of the fundamental units. Two electric units, the international ohm and the international ampere, were chosen and made as nearly equal as possible to the ohm and ampere of the "practical" or "absolute" system.[10]

QUANTITY OF ELECTRICITY

The unit of quantity of electricity is the coulomb. The faraday is the quantity of electricity necessary to liberate 1 gram equivalent in electrolysis. It is equivalent to 96,488 absolute coulombs (Birge).

Standards.—There are no standards of electric quantity. The silver voltameter may be used for its measurement since under ideal conditions the mass of metal deposited is proportional to the amount of electricity which has flowed.

CAPACITY

The unit used for capacity is the microfarad or the one-millionth of the farad, which is the capacity of a condenser that is charged to a potential of 1 volt by 1 coulomb of electricity. Capacities are commonly measured by comparison with standard capacities. The values of the standards are determined by

[10] There was, however, some slight error in these values that had to be taken into account for accurate work. (See Table 5.)

measurement in terms of resistance and time. The standard is some form of condenser consisting of two sets of metal plates separated by a dielectric. The condenser should be surrounded by a metal shield connected to one set of plates rendering the capacity independent of the surroundings. An ideal condenser would have a constant capacity under all circumstances, with zero resistance in its leads and plates, and no absorption in the dielectric. Actual condensers vary with the temperature, atmospheric pressure, and the voltage, frequency, and time of charge and discharge. A well-constructed air condenser with heavy metal plates and suitable insulating supports is practically free from these effects and is used as a standard of capacity.

Practically, air-condenser plates must be separated by 1 mm or more and so cannot be of great capacity. The more the capacity is increased by approaching the plates, the less the mechanical stability and the less constant the capacity. Condensers of great capacity use solid dielectrics, preferably mica sheets with conducting plates of tinfoil. At constant temperature the best mica condensers are excellent standards. The dielectric absorption is small but not quite zero, so that the capacity of these standards found varies with different methods of measurement, so for accurate results care must be taken.

INDUCTANCE

The henry, the unit of self-inductance and also the unit of mutual inductance, is the inductance in a circuit when the electromotive force induced in this circuit is 1 volt, while the inducing current varies at the rate of 1 ampere per second.

Inductance standards.—Inductance standards are measured in international units in terms of resistance and time or resistance and capacity by alternate-current bridge methods. Inductances calculated from dimensions are in absolute electromagnetic units. The ratio of the international to the absolute henry is the same as the ratio of the corresponding ohms.

Since inductance is measured in terms of capacity and resistance by the bridge method about as simply and as conveniently as by comparison with standard inductances, it is not necessary to maintain standard inductances. They are however of value in magnetic, alternating-current, and absolute electrical measurements. A standard inductance is a circuit so wound that when used in a circuit it adds a definite amount of inductance. It must have either such a form or so great an inductance that the mutual inductance of the rest of the circuit upon it may be negligible. It usually is a wire coil wound all in the same direction to make self-induction a maximum. A standard, the inductance of which may be calculated from its dimensions, should be a single layer coil of very simple geometrical form. Standards of very small inductance, calculable from their dimensions, are of some simple device, such as a pair of parallel wires or a single turn of wire. With such standards great care must be used that the mutual inductance upon them of the leads and other parts of the circuit is negligible. Any inductance standard should be separated by long leads from the measuring bridge or other apparatus. It must be wound so that the distributed capacity between its turns is negligible; otherwise the apparent inductance will vary with the frequency.

POWER AND ENERGY

Power and energy, although mechanical and not primarily electrical quantities, are measurable with greater precision by electrical methods than in any other way. The watt and the electric units were so chosen in terms of the cgs units that the product of the current in amperes by the electromotive force in volts gives the power in watts (for continuous or instantaneous values). The watt is defined as the energy expended per second by an unvarying electric current of 1 ampere under an electric pressure of 1 volt.

Standards and measurements.—No standard is maintained for power or energy. Measurements are always made in electrical practice in terms of some of the purely electrical quantities represented by standards.

MAGNETIC UNITS

Cgs units are generally used for magnetic quantities. American practice is fairly uniform in names for these units: the cgs unit of magnetomotive force is called the *gilbert;* magnetic intensity, the *oersted;* magnetic induction, the *gauss;* magnetic flux, the *maxwell,* following the definitions of the American Institute of Electrical Engineers (1894).

Oersted, the cgs emu of magnetic intensity exists at a point where a force of 1 dyne acts upon a unit magnetic pole at that point, i.e., the intensity 1 cm from a unit magnetic pole.

Maxwell, the cgs emu magnetic flux is the flux through a cm^2 normal to a field at 1 cm from a unit magnetic pole.

Gauss, the cgs emu of magnetic induction has such a value that if a conductor 1 cm long moves through the field at a velocity of 1 cm/sec, length and induction mutually perpendicular, the induced emf is 1 abvolt.

Gilbert, the cgs emu of magnetomotive force is a field such that it requires 1 erg of work to bring a unit magnetic pole to the point.
A unit frequently used is the ampere-turn. It is a convenient unit since it eliminates 4π in certain calculations. It is derived from the "ampere turn per cm." The following table shows the relations between a system built on the ampere-turn and the ordinary magnetic units.[11]

[11] Dellinger, International system of electric and magnetic units, Nat. Bur. Standards Bull., vol. 13, p. 599, 1916.

Part 4.—The ordinary and the ampere-turn magnetic units

Quantity		Ordinary magnetic units	Ampere-turn units	Ordinary units in 1 ampere-turn unit
Magnetomotive force	$\mathfrak{F}$	gilbert	ampere-turn	$4\pi/10$
Magnetizing force	H	gilbert per cm	ampere-turn per cm	$4\pi/10$
Magnetic flux	Φ	maxwell	maxwell	1
Magnetic induction	B	{ maxwell per cm^2 gauss	{ maxwell per cm^2 gauss	1
Permeability	μ			1
Reluctance	R	oersted	{ ampere-turn per maxwell	$4\pi/10$
Magnetization intensity	J		maxwell per cm^2	$1/4\pi$
Magnetic susceptibility	κ			$1/4\pi$
Magnetic pole strength......	m		maxwell	$1/4\pi$

TABLE 4.—THE NEW (1948) SYSTEM OF ELECTRICAL UNITS[12]

In pursuance of a decision of the International Committee on Weights and Measures, the National Bureau of Standards introduced, as of January 1, 1948, revised values of the units of electricity. This consummated a movement, initiated in 1927 by the American Institute of Electrical Engineers, asking that the National Bureau of Standards undertake the additional research necessary in order that the absolute ohm and absolute ampere based on the cgs electromagnetic system and the absolute volt, watt, and other units derived from them could be legalized in place of the international ohm and ampere and their derived units. This work was done, and the magnitude of the old international units in terms of the adopted absolute units is given in Table 5. This means that the electrical units now in use represent, as nearly as it is possible to make them, exact multiples of the cgs emu system, with the numerical relations shown in Table 6. Units of the new system will actually be maintained, as were the old international units, by groups of standard resistors and of standard cells, and consequently the change to be made is most simply represented by stating the relative magnitudes of the ohms and of the volts of the two systems.

During the period of transition to the new units, in order to avoid any doubt as to the units used in giving precise data, the International Committee on Weights and Measures recommended that the abbreviations *int.* and *abs.* be used with the names of the electrical units. In a few years this will be unnecessary, except when referring to old data.

The international units were intended to be exact multiples of the units of the centimeter-gram-second electromagnetic system, but to facilitate their reproduction, the ampere, the ohm, and the volt were defined by reference to three physical standards, namely (1) the silver voltameter, (2) a specified column of mercury, and (3) the Clark standard cell. This procedure was recommended by the International Electrical Congress of 1893 in Chicago and was incorporated in an Act of Congress of July 12, 1894. However, modifications of the international system were found to be necessary or expedient for several reasons. The original proposals were not sufficiently specific to give the precision of values that soon came to be required, and the independent definitions of three units brought the system into conflict with the customary simple form of Ohm's Law, $I = E/R$. Furthermore, with the establishment of national standardizing laboratories in several of the larger countries, other laboratories no longer needed to set up their own primary standards, and facility of reproduction of those standards became less important than the reliability of the units.

In preparation for the expected change in units, laboratories in several countries made absolute measurements of resistance and of current. The results of these measurements and the magnitudes of the international units as maintained in the national laboratories of France, Great Britain, Germany, Japan, the U.S.S.R., and the United States were correlated by periodic comparisons of standard resistors and of standard cells sent to the International Bureau of Weights and Measures. Nearly all the absolute measurements at the National Bureau of Standards were carried out under the direct supervision of Harvey L. Curtis, and the results of such measurements at the Bureau accepted by the International Committee on Weights and Measures at its meeting in Paris in October 1946 are as follows:

1 mean international ohm = 1.00049 absolute ohms
1 mean international volt = 1.00034 absolute volts

[12] Nat. Bur. Standards Circ. C-459, 1947.

The mean international units to which the above equations refer are the averages of units as maintained in the national laboratories of the six countries (France, Germany, Great Britain, Japan, U.S.S.R., and U.S.A.) which took part in this work before the war. The units maintained by the National Bureau of Standards differ from these average units by a few parts in a million, so that the conversion factors for adjusting values of standards in this country will be as follows:

1 mean international ohm U.S. = 1.000495 absolute ohms
1 mean international volt U.S. = 1.000333 absolute volts

Other electrical units will be changed by amounts shown in Table 5. The factors given should be used in converting values given in international units in National Bureau of Standards certificates to the new absolute system.

TABLE 5.—RELATIVE MAGNITUDE OF THE OLD INTERNATIONAL ELECTRICAL UNITS AND THE NEW 1948 ABSOLUTE ELECTRICAL UNITS

1 mean international ohm	= 1.00049	absolute	ohms
1 mean international volt	= 1.00034	absolute	volts
1 international ohm (U.S.)	= 1.000495	absolute	ohms
1 international volt (U.S.)	= 1.00033	absolute	volts
1 international ampere	= 0.999835	absolute	ampere
1 international coulomb	= 0.999835	absolute	coulomb
1 international henry	= 1.000495	absolute	henries
1 international farad	= 0.999505	absolute	farad
1 international watt	= 1.000165	absolute	watts
1 international joule	= 1.000165	absolute	joules

TABLE 6.—RELATIVE VALUES OF THE THREE SYSTEMS OF ELECTRICAL UNITS

Quantity	Symbol	Absolute unit		Electromagnetic system emu		Electrostatic system * esu
Current strength ...	I	1 ampere	=	10^{-1} abampere	=	3×10^{9} statampere
Potential difference..	E	1 volt	=	10^{8} abvolts	=	1/300 statvolt
Resistance	R	1 ohm	=	10^{9} abohms	=	$(1/9) \times 10^{-11}$ statohm
Energy	W	1 joule	=	10^{7} ergs	=	10^{7} ergs
Power	P	1 watt	=	10^{7} ergs/sec	=	10^{7} ergs/sec
Capacitance	C	1 farad	=	10^{-9} abfarads	=	9×10^{11} statafarad
Inductance	L	1 henry	=	10^{9} abhenries	=	$(1/9) \times 10^{-11}$ statahenry
Charge	Q	1 coulomb	=	10^{-1} abcoulomb	=	3×10^{9} statcoulomb

* Where 3 occurs it is to be taken as 2.99776 (from velocity of light). Where 9 occurs (not as an exponent), it is the square of this number.

TABLE 7.—CONVERSION FACTORS FOR UNITS OF ENERGY *

Units		g mass (energy equiv.)	joule	cal	I.T. cal	Btu	kw-hr
1 g mass (energy equiv.)	=	1	8.98656×10^{13}	2.14784×10^{13}	2.14664×10^{13}	8.51775×10^{10}	2.49627×10^{7}
1 joule	=	1.112772×10^{-14}	1	0.239006	0.238849	0.947831×10^{-3}	2.77778×10^{-7}
1 cal	=	4.65584×10^{-14}	4.1840 †	1	0.999346	3.96573×10^{-3}	1.16222×10^{-6}
1 I.T. cal ‡	=	4.65888×10^{-14}	4.18674	1.000654	1	3.96832×10^{-3}	1.162983×10^{-6}
1 Btu	=	1.174019×10^{-11}	1.055040×10^{3} †	2.52161×10^{2}	2.51996×10^{2}	1	2.93066×10^{-4}
1 kw-hr	=	4.00598×10^{-8}	3.6×10^{6}	8.60421×10^{5}	8.59858×10^{5}	3.41220×10^{3}	1
1 hp-hr	=	2.98727×10^{-8}	2.684525×10^{6}	6.41617×10^{5}	6.41197×10^{5}	2.54448×10^{3}	0.745701
1 ft-lb (wt.)	=	1.50872×10^{-14}	1.355821	0.324049	0.323837	1.285089×10^{-3}	3.76614×10^{-7}
1 ft³-lb (wt.)/in.²	=	2.17256×10^{-12}	1.952382×10^{2}	46.6630	46.6325	0.1850529	5.42328×10^{-5}
1 liter-atm	=	1.127548×10^{-12}	1.013278×10^{2}	24.2179	24.2021	0.0960416	2.81466×10^{-5}
1 quantum ($\lambda = .6\mu$)	=	3.6829×10^{-33}	3.3096×10^{-19}	7.91021×10^{-20}	7.90504×10^{-20}	3.13676×10^{-22}	9.19342×10^{-26}
1 Mev	=	1.78270×10^{-27}	1.60203×10^{-13}	3.82894×10^{-14}	3.82644×10^{-14}	1.51845×10^{-16}	4.44998×10^{-20}
1 amu §	=	1.66035×10^{-24}	1.49208×10^{-10}	3.56616×10^{-11}	3.56379×10^{-11}	1.41422×10^{-13}	4.14453×10^{-17}

Units		hp-hr	ft-lb (wt.)	ft³-lb (wt.)/in.²	liter-atm	quantum ($\lambda = .6\mu$)	Mev	amu
1 g mass (energy equiv.)	=	3.34754×10^{7}	6.62814×10^{13}	4.60287×10^{11}	8.86880×10^{11}	2.71503×10^{32}	5.60961×10^{26}	6.02308×10^{23}
1 joule	=	3.72505×10^{-7}	0.737561	5.12195×10^{-3}	9.86896×10^{-3}	3.02125×10^{18}	6.24222×10^{12}	6.70232×10^{9}
1 cal	=	1.558562×10^{-6}	3.08595	2.14302×10^{-2}	4.12917×10^{-2}	1.26409×10^{19}	2.61175×10^{13}	2.80425×10^{10}
1 I.T. cal ‡	=	1.559582×10^{-6}	3.08797	2.14443×10^{-2}	4.13187×10^{-2}	1.26491×10^{19}	2.61346×10^{13}	2.80608×10^{10}
1 Btu	=	3.93008×10^{-4}	7.78156×10^{2}	5.40386	10.41215	3.18754×10^{21}	6.58580×10^{15}	7.07121×10^{12}
1 kw-hr	=	1.341020	2.655218×10^{6}	1.843902×10^{4}	3.55282×10^{4}	1.08765×10^{25}	2.24720×10^{19}	2.41283×10^{16}
1 hp-hr	=	1	1.98000×10^{6}	1.3750×10^{4}	2.64935×10^{4}	8.11062×10^{24}	1.67574×10^{19}	1.79926×10^{16}
1 ft-lb (wt.)	=	5.05051×10^{-7}	1	6.94444×10^{-3}	1.338054×10^{-2}	4.09627×10^{18}	8.46334×10^{12}	9.08711×10^{9}
1 ft³-lb (wt.)/in.²	=	7.27273×10^{-5}	1.44×10^{2}	1	1.926797	5.89862×10^{20}	1.21872×10^{15}	1.30855×10^{12}
1 liter-atm	=	3.77452×10^{-5}	74.7354	0.518996	1	3.06136×10^{20}	6.32519×10^{14}	6.79131×10^{11}
1 quantum ($\lambda = .6\mu$)	=	1.23286×10^{-25}	2.44116×10^{-19}	1.69531×10^{-21}	3.266520×10^{-21}	1	2.06593×10^{-6}	2.21839×10^{-9}
1 Mev	=	5.96751×10^{-20}	1.18157×10^{-13}	8.20535×10^{-16}	1.58100×10^{-15}	4.84001×10^{5}	1	1.07371×10^{-3}
1 amu §	=	5.55790×10^{-17}	1.10046×10^{-10}	7.64208×10^{-13}	1.147247×10^{-12}	4.50776×10^{8}	9.31354×10^{2}	1

* Adapted from National Bureau of Standards Tables.
† Definition of calorie and Btu.
‡ As defined for International Steam Tables.
§ Unit atomic weight energy equivalent.

TABLE 8.—FORMER ELECTRICAL EQUIVALENTS *

Abbreviations: int., international; emu, electromagnetic units; esu, electrostatic units; cgs, centimeter-gram-second units.

RESISTANCE:

1 international ohm =
- 1.00051 absolute ohms
- 1.0001 int. ohms (France, before 1911)
- 1.00016 Board of Trade units (England, 1903)
- 1.01358 B. A. units
- 1.00283 "legal ohms" of 1884
- 1.06300 Siemens units

1 absolute ohm =
- 0.99949 int. ohms
- 1 "practical" emu
- 10^9 cgs emu
- 1.11262×10^{-12} cgs esu

CURRENT:

1 international ampere =
- 0.99995 absolute ampere
- 1.00084 int. amperes (U. S. before 1911)
- 1.00130 int. amperes (England, before 1906)
- 1.00106 int. amperes (England, 1906-08)
- 1.00010 int. amperes (England, 1909-10)
- 1.00032 int. amperes (Germany, before 1911)
- 1.0002 int. amperes (France, before 1911)

1 absolute ampere =
- 1.00005 int. amperes
- 1 "practical" emu
- 0.1 cgs emu
- 2.99776×10^9 esu

ELECTROMOTIVE FORCE:

1 international volt =
- 1.00046 absolute volts
- 1.00084 int. volts (U. S. before 1911)
- 1.00130 int. volts (England, before 1906)
- 1.00106 int. volts (England, 1906-08)
- 1.00010 int. volts (England, 1909-10)
- 1.00032 int. volts (Germany, before 1911)
- 1.00032 int. volts (France, before 1911)

1 absolute volt =
- 0.99954 int. volt
- 1 "practical" emu
- 10^8 cgs emu
- 0.00333560 cgs esu

QUANTITY OF ELECTRICITY:

(Same as current equivalents.)

1 international coulomb =
- 1/3600 ampere-hour
- 1/96494 faraday

CAPACITY:

1 international farad =
- 0.99949 absolute farad

1 absolute farad =
- 1.00051 int. farads
- 1 "practical" emu
- 10^{-9} cgs emu
- 8.98776×10^{11} cgs esu

INDUCTANCE:

1 international henry =
- 1.00051 absolute henries

1 absolute henry =
- 0.99949 int. henry
- 1 "practical" emu
- 10^9 emu
- 1.11262×10^{-12} cgs esu

ENERGY AND POWER:

(standard gravity = 980.665 cm/sec^{-2})-

1 international joule =
- 1.00041 absolute joules

1 absolute joule =
- 0.99959 int. joule
- 10^7 ergs
- 0.737560 standard foot-pound
- 0.101972 standard kilogram-meter
- 0.277778×10^{-6} kilowatt-hour

RESISTIVITY:

1 ohm-cm = 0.393700 ohm-inch
- = 10,000 ohm (meter, mm^2)
- = 12,732.4 ohm (meter, mm)
- = 393,700 microhm-inch
- = 1,000,000 microhm-cm
- = 6,015,290 ohm (mil, foot)

1 ohm (meter, gram) = 5710.0 ohm (mile, pound)

MAGNETIC QUANTITIES:

1 int. gilbert	= 0.99995 absolute gilbert
1 absolute gilbert	= 1.00005 int. gilberts
1 int. maxwell	= 1.00046 absolute maxwells
1 absolute maxwell	= 0.99954 int. maxwell
1 gilbert	= 0.7958 ampere-turn
1 gilbert per cm	= 0.7958 ampere-turn per cm
	= 2.021 ampere-turns per inch
1 maxwell	= 1 line
	= 10^{-8} volt-second
1 maxwell per cm^2	= 6.452 maxwells per in.^{2}

* This table is now superseded by the adoption of the new system of electrical units in January 1948 and is given for reference only.

TABLE 9.—DERIVATIVES AND INTEGRALS

$d\,ax$	$= a\,dx$	$\int x^n dx$	$= \frac{x^{n+1}}{n+1}$, unless $n = -1$
$d\,uv$	$= \left(u\frac{dv}{dx} + v\frac{du}{dx}\right)dx$	$\int \frac{dx}{x}$	$= \log x$
$d\,\frac{u}{v}$	$= \left(\frac{v\frac{du}{dx} - u\frac{dv}{dx}}{v^2}\right)dx$	$\int e^x dx$	$= e^x$
$d\,x^n$	$= nx^{n-1}\,dx$	$\int e^{ax} dx$	$= \frac{1}{a}e^{ax}$
$d\,f(u)$	$= d\,\frac{f(u)}{du}\cdot\frac{du}{dx}\cdot dx$	$\int x^m e^{ax} dx$	$= \frac{x^m e^{ax}}{a} - \frac{m}{a}\int x^{m-1}e^{ax}dx$
$d\,e^x$	$= e^x\,dx$	$\int \log x\,dx$	$= x\log x - x$
$d\,e^{ax}$	$= a\,e^{ax}\,dx$	$\int u\,dv$	$= uv - \int v\,du$
$d\log_e x$	$= \frac{1}{x}\,dx$	$\int (a+bx)^n dx$	$= \frac{(a+bx)^{n+1}}{(n+1)b}$
$d\,x^x$	$= x^x\,(1+\log_e x)\,dx$		
$d\sin x$	$= \cos x\,dx$	$\int (a^2+x^2)^{-1}dx$	$= \frac{1}{a}\tan^{-1}\frac{x}{a} = \frac{1}{a}\sin^{-1}\frac{x}{\sqrt{x^2+a^2}}$
$d\cos x$	$= -\sin x\,dx$	$\int (a^2-x^2)^{-1}dx$	$= \frac{1}{2a}\log\frac{a+x}{a-x}$
$d\tan x$	$= \sec^2 x\,dx$	$\int (a^2-x^2)^{-\frac{1}{2}}dx$	$= \sin^{-1}\frac{x}{a}$, or $-\cos^{-1}\frac{x}{a}$
$d\cot x$	$= -\csc^2 x\,dx$	$\int x(a^2\pm x^2)^{-\frac{1}{2}}dx$	$= \pm(a^2\pm x^2)^{\frac{1}{2}}$
$d\sec x$	$= \tan x\sec x\,dx$	$\int \sin^2 x\,dx$	$= -\frac{1}{2}\cos x\sin x + \frac{1}{2}x$
$d\csc x$	$= -\cot x\cdot\csc x\,dx$	$\int \cos^2 x\,dx$	$= \frac{1}{2}\sin x\cos x + \frac{1}{2}x$
$d\sin^{-1}x$	$= (1-x^2)^{-\frac{1}{2}}\,dx$	$\int \sin x\cos x\,dx$	$= \frac{1}{2}\sin^2 x$
$d\cos^{-1}x$	$= -(1-x^2)^{-\frac{1}{2}}\,dx$	$\int (\sin x\cos x)^{-1}dx$	$= \log\tan x$
$d\tan^{-1}x$	$= (1+x^2)^{-1}\,dx$	$\int \tan x\,dx$	$= -\log\cos x$
$d\cot^{-1}x$	$= -(1+x^2)^{-1}\,dx$	$\int \tan^2 x\,dx$	$= \tan x - x$
$d\sec^{-1}x$	$= x^{-1}(x^2-1)^{-\frac{1}{2}}\,dx$	$\int \cot x\,dx$	$= \log\sin x$
$d\csc^{-1}x$	$= -x^{-1}(x^2-1)^{-\frac{1}{2}}\,dx$	$\int \cot^2 x\,dx$	$= -\cot x - x$
$d\sinh x$	$= \cosh x\,dx$	$\int \csc x\,dx$	$= \log\tan\frac{1}{2}x$
$d\cosh x$	$= \sinh x\,dx$	$\int x\sin x\,dx$	$= \sin x - x\cos x$
$d\tanh x$	$= \mathrm{sech}^2 x\,dx$	$\int x\cos x\,dx$	$= \cos x + x\sin x$
$d\coth x$	$= -\mathrm{csch}^2 x\,dx$	$\int \tanh x\,dx$	$= \log\cosh x$
$d\,\mathrm{sech}\,x$	$= -\mathrm{sech}\,x\tanh x\,dx$	$\int \coth x\,dx$	$= \log\sinh x$
$d\,\mathrm{csch}\,x$	$= -\mathrm{csch}\,x\cdot\coth x\,dx$	$\int \mathrm{sech}\,x\,dx$	$= 2\tan^{-1}e^x = gd\,u$
$d\sinh^{-1}x$	$= (x^2+1)^{-\frac{1}{2}}\,dx$	$\int \mathrm{csch}\,x\,dx$	$= \log\tanh\frac{x}{2}$
$d\cosh^{-1}x$	$= (x^2-1)^{-\frac{1}{2}}\,dx$	$\int x\sinh x\,dx$	$= x\cosh x - \sinh x$
$d\tanh^{-1}x$	$= (1-x^2)^{-1}\,dx$	$\int x\cosh x\,dx$	$= x\sinh x - \cosh x$
$d\coth^{-1}x$	$= (1-x^2)^{-1}\,dx$	$\int \sinh^2 x\,dx$	$= \frac{1}{2}(\sinh x\cosh x - x)$
$d\,\mathrm{sech}^{-1}x$	$= -x^{-1}(1-x^2)^{-\frac{1}{2}}\,dx$	$\int \cosh^2 x\,dx$	$= \frac{1}{2}(\sinh x\cosh x + x)$
$d\,\mathrm{csch}^{-1}x$	$= -x^{-1}(x^2+1)^{-\frac{1}{2}}\,dx$	$\int \sinh x\cosh x\,dx$	$= \frac{1}{4}\cosh(2x)$

$$(x+y)^n = x^n + \frac{x}{1} x^{n-1} y + \frac{n(n-1)}{2!} x^{n-2} y^2 + \ldots \frac{n(n-1)\ldots(n-m+1)}{m!} x^{n-m} y^m + \ldots \qquad (y^2 < x^2)$$

$$(1 \pm x)^n = 1 \pm nx + \frac{n(n-1)x^2}{2!} \pm \frac{n(n-1)(n-2)x^2}{3!} + \ldots + \frac{(\pm 1)^k n!\, x^k}{(n-k)!\, k!} + \ldots \qquad (x^2 < 1)$$

$$(1 \pm x)^{-n} = 1 \mp nx + \frac{n(n+1)}{2!} x^2 \mp \frac{n(n+1)(n+2)\, x^3}{3!} + \ldots (\mp 1)^k \frac{(n+k-1)x^k}{(n-1)!\, k!} + \ldots \qquad (x^2 < 1)$$

$$(1 \pm x)^{-1} = 1 \mp x + x^2 \mp x^3 + x^4 \mp x^5 + \ldots \qquad (x^2 < 1)$$

$$(1 \pm x)^{-2} = 1 \mp 2x + 3x^2 \mp 4x^3 + 5x^4 \mp 6x^5 + \ldots \qquad (x^2 < 1)$$

$$f(x+h) = f(x) + hf'(x) + \frac{h^2}{2!} f''(x) + \ldots + \frac{h^n}{n!} f^{(n)}(x) + \ldots \qquad \text{Taylor's series}$$

$$f(x) = f(o) + \frac{x}{1} f'(o) + \frac{x^2}{2!} f''(o) + \ldots \frac{x^n}{n!} f^{(n)}(o) + \ldots \qquad \text{Maclaurin's series}$$

$$e = \lim\left(1 + \frac{1}{n}\right)^n = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \frac{1}{4!} + \ldots$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \ldots \qquad (x^2 < \infty)$$

$$a^x = 1 + x \log a + \frac{(x \log a)^2}{2!} + \frac{(x \log a)^3}{3!} + \ldots. \qquad (x^2 < \infty)$$

$$\log x = \frac{x-1}{x} + \frac{1}{2}\left(\frac{x-1}{x}\right)^2 + \frac{1}{3}\left(\frac{x-1}{x}\right)^3 + \ldots \qquad (x > \tfrac{1}{2})$$

$$= (x-1) - \tfrac{1}{2}(x-1)^2 + \tfrac{1}{3}(x-1)^3 - \ldots \qquad (2 > x > 0)$$

$$= 2\left[\frac{x-1}{x+1} + \frac{1}{3}\left(\frac{x-1}{x+1}\right)^3 + \frac{1}{5}\left(\frac{x-1}{x+1}\right)^5 + \ldots.\right] \qquad (x > 0)$$

$$\log(1+x) = x - \tfrac{1}{2}x^2 + \tfrac{1}{3}x^3 - \tfrac{1}{4}x^4 + \ldots. \qquad (x^2 < 1)$$

$$\sin x = \frac{1}{2i}(e^{ix} - e^{-ix}) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots \qquad (x^2 < \infty)$$

$$\cos x = \frac{1}{2}(e^{ix} + e^{-ix}) = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \ldots = 1 - \text{versin}\, x \qquad (x^2 < \infty)$$

$$\tan x = x + \frac{x^3}{3} + \frac{2x^5}{15} + \frac{17x^7}{315} + \frac{62}{2835} x^9 + \ldots \qquad \left(x^2 < \frac{\pi^2}{4}\right)$$

$$\sin^{-1} x = \frac{\pi}{2} - \cos^{-1} x = x + \frac{x^3}{6} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{x^5}{5} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}\cdot\frac{x^7}{7} + \ldots \qquad (x^2 < 1)$$

$$\tan^{-1} x = \frac{\pi}{2} - \cot^{-1} x = x - \frac{1}{3}x^3 + \frac{1}{5}x^5 - \frac{1}{7}x^7 + \ldots \qquad (x^2 < 1)$$

$$= \frac{\pi}{2} - \frac{1}{x} + \frac{1}{3x^3} - \frac{1}{5x^5} + \ldots \qquad (x^2 > 1)$$

$$\sinh x = \frac{1}{2}(e^x - e^{-x}) = x + \frac{x^3}{3!} + \frac{x^5}{5!} + \frac{x^7}{7!} + \ldots \qquad (x^2 < \infty)$$

$$\cosh x = \frac{1}{2}(e^x + e^{-x}) = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{x^6}{6!} + \ldots \qquad (x^2 < \infty)$$

(continued)

$$\tanh x = x - \frac{1}{3}x^3 + \frac{2}{15}x^5 - \frac{17}{315}x^7 + \dots \qquad (x^2 < \tfrac{1}{4}\pi^2)$$

$$\sinh^{-1} x = x - \frac{1}{2}\frac{x^3}{3} + \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{x^5}{5} - \frac{1}{2}\cdot\frac{3}{4}\cdot\frac{5}{6}\frac{x^7}{7} + \dots \qquad (x^2 < 1)$$

$$= \log 2x + \frac{1}{2}\frac{1}{2x^2} - \frac{1}{2}\frac{3}{4}\frac{1}{4x^4} + \frac{1}{2}\frac{3}{4}\frac{5}{6}\frac{1}{6x^6} - \dots \qquad (x^2 > 1)$$

$$\cosh^{-1} x = \log 2x - \frac{1}{2}\frac{1}{2x^2} - \frac{1}{2}\frac{3}{4}\frac{1}{4x^4} - \frac{1}{2}\frac{3}{4}\frac{5}{6}\frac{1}{6x^6} - \dots \qquad (x^2 > 1)$$

$$\tanh^{-1} x = x + \frac{1}{3}x^3 + \frac{1}{5}x^5 + \frac{1}{7}x^7 + \dots \qquad (x^2 < 1)$$

$$\mathrm{gd}\, x = \phi = x - \frac{1}{6}x^3 + \frac{1}{24}x^5 - \frac{61}{5040}x^7 + \dots \qquad (x \text{ small})$$

$$= \frac{\pi}{2} - \mathrm{sech.}\, x - \frac{1}{2}\frac{\mathrm{sech}^3 x}{3} - \frac{1}{2}\frac{3}{4}\frac{\mathrm{sech}^5 x}{5} - \dots \qquad (x \text{ large})$$

$$x = \mathrm{gd}^{-1}\phi = \phi + \frac{1}{6}\phi^3 + \frac{1}{24}\phi^5 + \frac{61}{5040}\phi^7 + \dots \qquad \left(\phi < \frac{\pi}{2}\right)$$

$$f(x) = \frac{1}{2}b_0 + b_1 \cos\frac{\pi x}{c} + b_2 \cos\frac{2\pi x}{c} + \dots$$

$$+ a_1 \sin\frac{\pi x}{c} + a_2 \cos\frac{2\pi x}{c} + \dots (-c < x < c)$$

$$a_m = \frac{1}{c}\int_{-c}^{+c} f(x)\sin\frac{m\pi x}{c}\,dx$$

$$b_m = \frac{1}{c}\int_{-c}^{+c} f(x)\cos\frac{m\pi x}{c}\,dx$$

TABLE 11.—MATHEMATICAL CONSTANTS

	Numbers	Logarithms
$e = 2.71828\ 18285$	$\pi = 3.14159\ 26536$	0.49714 98727
$e^{-1} = 0.36787\ 94412$	$\pi^2 = 9.86960\ 44011$	0.99429 97454
$M = \log_{10}e = 0.43429\ 44819$	$\frac{1}{\pi} = 0.31830\ 98862$	9.50285 01273
$(M)^{-1} = \log_e 10 = 2.30258\ 50930$	$\sqrt{\pi} = 1.77245\ 38509$	0.24857 49363
$\log_{10}\log_{10}e = 9.63778\ 43113$	$\frac{\sqrt{\pi}}{2} = 0.88622\ 69255$	9.94754 49407
$\log_{10}2 = 0.30102\ 99957$	$\frac{1}{\sqrt{\pi}} = 0.56418\ 95835$	9.75142 50637
$\log_e 2 = 0.69314\ 71806$	$\frac{2}{\sqrt{\pi}} = 1.12837\ 91671$	0.05245 50593
$\log_{10}x = M\cdot\log_e x$	$\sqrt{\frac{\pi}{2}} = 1.25331\ 41373$	0.09805 99385
$\log_B x = \log_e x\cdot\log_B e$	$\sqrt{\frac{2}{\pi}} = 0.79788\ 45608$	9.90194 00615
$= \log_e x \div \log_e B$	$\frac{\pi}{4} = 0.78539\ 81634$	9.89508 98814
$\log_e\pi = 1.14472\ 98858$	$\frac{\sqrt{\pi}}{4} = 0.44311\ 34627$	9.64651 49450
$\rho = 0.47693\ 62762$ *	$\frac{4}{3}\pi = 4.18879\ 02048$	0.62208 86093
$\log\rho = 9.67846\ 03565$	$\frac{e}{\sqrt{2\pi}} = 1.08443\ 75514$	0.03520 45477

* Probable error, modulus of precision.

TABLE 12.—FACTORIALS

Part 1.—Numerical

n	$\frac{1}{n!}$	$n! = 1.2.3.4 \ldots n$	n
1	1.	1	1
2	0.5	2	2
3	.16666 66666 66666 66666 66667	6	3
4	.04166 66666 66666 66666 66667	24	4
5	.00833 33333 33333 33333 33333	120	5
6	0.00138 88888 88888 88888 88889	720	6
7	.00019 84126 98412 69841 26984	5040	7
8	.00002 48015 87301 58730 15873	40320	8
9	.00000 27557 31922 39858 90653	3 62880	9
10	.00000 02755 73192 23985 89065	36 28800	10
11	0.00000 00250 52108 38544 17188	399 16800	11
12	.00000 00020 87675 69878 68099	4790 01600	12
13	.00000 00001 60590 43836 82161	62270 20800	13
14	.00000 00000 11470 74559 77297	8 71782 91200	14
15	.00000 00000 00764 71637 31820	130 76743 68000	15
16	0.00000 00000 00047 79477 33239	2092 27898 88000	16
17	.00000 00000 00002 81145 72543	35568 74280 96000	17
18	.00000 00000 00000 15619 20697	6 40237 37057 28000	18
19	.00000 00000 00000 00822 06352	121 64510 04088 32000	19
20	.00000 00000 00000 00041 10318	2432 90200 81766 40000	20

Part 2.—Logarithmic

Logarithms of the products 1.2.3.......n, n from 1 to 100.

n	log ($n!$)	n	log ($n!$)	n	log ($n!$)	n	log ($n!$)
1	0.000000	**26**	26.605619	**51**	66.190645	**76**	111.275425
2	0.301030	27	28.036983	52	67.906648	77	113.161916
3	0.778151	28	29.484141	53	69.630924	78	115.054011
4	1.380211	29	30.946539	54	71.363318	79	116.951638
5	2.079181	30	32.423660	55	73.103681	80	118.854728
6	2.857332	**31**	33.915022	**56**	74.851869	**81**	120.763213
7	3.702431	32	35.420172	57	76.607744	82	122.677027
8	4.605521	33	36.938686	58	78.371172	83	124.596105
9	5.559763	34	38.470165	59	80.142024	84	126.520384
10	6.559763	35	40.014233	60	81.920175	85	128.449803
11	7.601156	**36**	41.570535	**61**	83.705505	**86**	130.384301
12	8.680337	37	43.138737	62	85.497896	87	132.323821
13	9.794280	38	44.718520	63	87.297237	88	134.268303
14	10.940408	39	46.309585	64	89.103417	89	136.217693
15	12.116500	40	47.911645	65	90.916330	90	138.171936
16	13.320620	**41**	49.524429	**66**	92.735874	**91**	140.130977
17	14.551069	42	51.147678	67	94.561949	92	142.094765
18	15.806341	43	52.781147	68	96.394458	93	144.063248
19	17.085095	44	54.424599	69	98.233307	94	146.036376
20	18.386125	45	56.077812	70	100.078405	95	148.014099
21	19.708344	**46**	57.740570	**71**	101.929663	**96**	149.996371
22	21.050767	47	59.412668	71	103.786996	97	151.983142
23	22.412494	48	61.093909	73	105.650319	98	153.974368
24	23.792706	49	62.784105	74	107.519550	99	155.970004
25	25.190646	50	64.483075	75	109.394612	100	157.970004

TABLE 13.—FORMULAS FOR MOMENTS OF INERTIA, RADII OF GYRATION, AND WEIGHTS OF VARIOUS SHAPED SOLIDS

In each case the axis is supposed to traverse the center of gravity of the body. The axis is one of symmetry. The mass of a unit of volume is w.

Body	Axis	Weight	Moment of inertia I_0	Square of radius of gyration ρ_0^2
Sphere of radius r	Diameter	$\frac{4\pi w r^3}{3}$	$\frac{8\pi w r^5}{15}$	$\frac{2r^2}{5}$
Spheroid of revolution, polar axis $2a$, equatorial diameter $2r$	Polar axis	$\frac{4\pi w a r^2}{3}$	$\frac{8\pi w a r^4}{15}$	$\frac{2r^2}{5}$
Ellipsoid, axis $2a$, $2b$, $2c$..	Axis $2a$	$\frac{4\pi w abc}{3}$	$\frac{4\pi w abc(b^2+c^2)}{15}$	$\frac{b^2+c^2}{5}$
Spherical shell, external radius r, internal r'.......	Diameter	$\frac{4\pi w(r^3-r'^3)}{3}$	$\frac{8\pi w(r^5-r'^5)}{15}$	$\frac{2(r^5-r'^5)}{5(r^3-r'^3)}$
Ditto, insensibly thin, radius r, thickness dr.....	Diameter	$4\pi w r^2 dr$	$\frac{8\pi w r^4 dr}{3}$	$\frac{2r^2}{3}$
Circular cylinder, length $2a$, radius r	Longitudinal axis $2a$	$2\pi w a r^2$	$\pi w a r^4$	$\frac{r^2}{2}$
Elliptic cylinder, length $2a$, transverse axes $2b$, $2c$...	Longitudinal axis $2a$	$2\pi w abc$	$\frac{\pi w abc(b^2+c^2)}{2}$	$\frac{b^2+c^2}{4}$
Hollow circular cylinder, length $2a$, external radius r, internal r'.......	Longitudinal axis $2a$	$2\pi w a(r^2-r'^2)$	$\pi w a(r^4-r'^4)$	$\frac{r^2+r'^2}{2}$
Ditto, insensibly thin, thickness dr	Longitudinal axis $2a$	$4\pi w a r dr$	$4\pi w a r^3 dr$	r^2
Circular cylinder, length $2a$, radius r	Transverse diameter	$2\pi w a r^2$	$\frac{\pi w a r^2(3r^2+4a^2)}{6}$	$\frac{r^2}{4}+\frac{a^2}{3}$
Elliptic cylinder, length $2a$, transverse axes $2a$, $2b$...	Transverse axis $2b$	$2\pi w abc$	$\frac{\pi w abc(3c^2+4a^2)}{6}$	$\frac{c^2}{4}+\frac{a^2}{3}$
Hollow circular cylinder, length $2a$, external radius r, internal r'.......	Transverse diameter	$2\pi w a(r^2-r'^2)$	$\frac{\pi w a}{6}\left\{\begin{matrix}3(r^4-r'^4)\\+4a^2(r^2-r'^2)\end{matrix}\right\}$	$\frac{r^2+r'^2}{4}+\frac{a^2}{3}$
Ditto, insensibly thin, thickness dr	Transverse diameter	$4\pi w a r dr$	$\pi w a(2r^3+\frac{4}{3}a^2 r)dr$	$\frac{r^2}{2}+\frac{a^2}{3}$
Rectangular prism, dimensions $2a$, $2b$, $2c$.........	Axis $2a$	$8wabc$	$\frac{8wabc(b^2+c^2)}{3}$	$\frac{b^2+c^2}{3}$
Rhombic prism, length $2a$, diagonals $2b$, $2c$........	Axis $2a$	$4wabc$	$\frac{2wabc(b^2+c^2)}{3}$	$\frac{b^2+c^2}{6}$
Ditto	Diagonal $2b$	$4wabc$	$\frac{2wabc(c^2+2a^2)}{3}$	$\frac{c^2}{6}+\frac{a^2}{3}$

For further mathematical data see Smithsonian Mathematical Tables, Becker and Van Orstrand (Hyperbolic, Circular and Exponential Functions); Smithsonian Mathematical Formulae and Tables of Elliptic Functions, Adams and Hippisley; Smithsonian Elliptic Functions Tables, Spenceley; Smithsonian Logarithmic Tables, Spenceley and Epperson; Functionentafeln, Jahnke und Emde (xtgx, x^{-1}tgx, Roots of Transcendental Equations, $a+bi$ and $re^{\theta i}$, Exponentials, Hyperbolic Functions, $\int_0^x \frac{\sin u}{u}du$, $\int_x^\infty \frac{\cos u}{u}du$, $\int_\infty^{-x}\frac{e^{-u}}{u}du$, Fresnel Integral, Gamma Function, Gauss Integral $\frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2}dx$, Pearson Function $e^{-\frac{1}{2}\pi\nu}\int_0^\pi \sin^r\, e^{\nu r}dx$, Elliptic Integrals and Functions, Spherical and Cylindrical Functions, etc.). For further references see under Tables, Mathematical, in the 16th ed. Encyclopædia Britannica. See also Carr's Synopsis of Pure Mathematics and Mellor's Higher Mathematics for Students of Chemistry and Physics.

											P.P.				
N	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**1**	**2**	**3**	**4**	**5**
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	5	7	9
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6
36	5563	5575	5587	5589	5611	5623	5635	5647	5658	5670	1	2	4	5	6
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	6
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4

(*continued*)

N	0	1	2	3	4	5	6	7	8	9	P.P. 1	2	3	4	5
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	3	3
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2

(*continued*)

N	0	1	2	3	4	5	6	7	8	9	10
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102	0086	0090	0095	0099	0103	0107	0111	0116	0120	0124	0128
103	0128	0133	0137	0141	0145	0149	0154	0158	0162	0166	0170
104	0170	0175	0179	0183	0187	0191	0195	0199	0204	0208	0212
105	0212	0216	0220	0224	0228	0233	0237	0241	0245	0249	0253
106	0253	0257	0261	0265	0269	0273	0278	0282	0286	0290	0294
107	0294	0298	0302	0306	0310	0314	0318	0322	0326	0330	0334
108	0334	0338	0342	0346	0350	0354	0358	0362	0366	0370	0374
109	0374	0378	0382	0386	0390	0394	0398	0402	0406	0410	0414
110	0414	0418	0422	0426	0430	0434	0438	0441	0445	0449	0453
111	0453	0457	0461	0465	0469	0473	0477	0481	0484	0488	0492
112	0492	0496	0500	0504	0508	0512	0515	0519	0523	0527	0531
113	0531	0535	0538	0542	0546	0550	0554	0558	0561	0565	0569
114	0569	0573	0577	0580	0584	0588	0592	0596	0599	0603	0607
115	0607	0611	0615	0618	0622	0626	0630	0633	0637	0641	0645
116	0645	0648	0652	0656	0660	0663	0667	0671	0674	0678	0682
117	0682	0686	0689	0693	0697	0700	0704	0708	0711	0715	0719
118	0719	0722	0726	0730	0734	0737	0741	0745	0748	0752	0755
119	0755	0759	0763	0766	0770	0774	0777	0781	0785	0788	0792
120	0792	0795	0799	0803	0806	0810	0813	0817	0821	0824	0828
121	0828	0831	0835	0839	0842	0846	0849	0853	0856	0860	0864
122	0864	0867	0871	0874	0878	0881	0885	0888	0892	0896	0899
123	0899	0903	0906	0910	0913	0917	0920	0924	0927	0931	0934
124	0934	0938	0941	0945	0948	0952	0955	0959	0962	0966	0969
125	0969	0973	0976	0980	0983	0986	0990	0993	0997	1000	1004
126	1004	1007	1011	1014	1017	1021	1024	1028	1031	1035	1038
127	1038	1041	1045	1048	1052	1055	1059	1062	1065	1069	1072
128	1072	1075	1079	1082	1086	1089	1092	1096	1099	1103	1106
129	1106	1109	1113	1116	1119	1123	1126	1129	1133	1136	1139
130	1139	1143	1146	1149	1153	1156	1159	1163	1166	1169	1173
131	1173	1176	1179	1183	1186	1189	1193	1196	1199	1202	1206
132	1206	1209	1212	1216	1219	1222	1225	1229	1232	1235	1239
133	1239	1242	1245	1248	1252	1255	1258	1261	1265	1268	1271
134	1271	1274	1278	1281	1284	1287	1290	1294	1297	1300	1303
135	1303	1307	1310	1313	1316	1319	1323	1326	1329	1332	1335
136	1335	1339	1342	1345	1348	1351	1355	1358	1361	1364	1367
137	1367	1370	1374	1377	1380	1383	1386	1389	1392	1396	1399
138	1399	1402	1405	1408	1411	1414	1418	1421	1424	1427	1430
139	1430	1433	1436	1440	1443	1446	1449	1452	1455	1458	1461
140	1461	1464	1467	1471	1474	1477	1480	1483	1486	1489	1492
141	1492	1495	1498	1501	1504	1508	1511	1514	1517	1520	1523
142	1523	1526	1529	1532	1535	1538	1541	1544	1547	1550	1553
143	1553	1556	1559	1562	1565	1569	1572	1575	1578	1581	1584
144	1584	1587	1590	1593	1596	1599	1602	1605	1608	1611	1614
145	1614	1617	1620	1623	1626	1629	1632	1635	1638	1641	1644
146	1644	1647	1649	1652	1655	1658	1661	1664	1667	1670	1673
147	1673	1676	1679	1682	1685	1688	1691	1694	1697	1700	1703
148	1703	1706	1708	1711	1714	1717	1720	1723	1726	1729	1732
149	1732	1735	1738	1741	1744	1746	1749	1752	1755	1758	1761

(*continued*)

N	0	1	2	3	4	5	6	7	8	9	10
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151	1790	1793	1796	1798	1801	1804	1807	1810	1813	1816	1818
152	1818	1821	1824	1827	1830	1833	1836	1838	1841	1844	1847
153	1847	1850	1853	1855	1858	1861	1864	1867	1870	1872	1875
154	1875	1878	1881	1884	1886	1889	1892	1895	1898	1901	1903
155	1903	1906	1909	1912	1915	1917	1920	1923	1926	1928	1931
156	1931	1934	1937	1940	1942	1945	1948	1951	1953	1956	1959
157	1959	1962	1965	1967	1970	1973	1976	1978	1981	1984	1987
158	1987	1989	1992	1995	1998	2000	2003	2006	2009	2011	2014
159	2014	2017	2019	2022	2025	2028	2030	2033	2036	2038	2041
160	2041	2044	2047	2049	2052	2055	2057	2060	2063	2066	2068
161	2068	2071	2074	2076	2079	2082	2084	2087	2090	2092	2095
162	2095	2098	2101	2103	2106	2109	2111	2114	2117	2119.	2122
163	2122	2125	2127	2130	2133	2135	2138	2140	2143	2146	2148
164	2148	2151	2154	2156	2159	2162	2164	2167	2170	2172	2175
165	2175	2177	2180	2183	2185	2188	2191	2193	2196	2198	2201
166	2201	2204	2206	2209	2212	2214	2217	2219	2222	2225	2227
167	2227	2230	2232	2235	2238	2240	2243	2245	2248	2251	2253
168	2253	2256	2258	2261	2263	2266	2269	2271	2274	2276	2279
169	2279	2281	2284	2287	2289	2292	2294	2297	2299	2302	2304
170	2304	2307	2310	2312	2315	2317	2320	2322	2325	2327	2330
171	2330	2333	2335	2338	2340	2343	2345	2348	2350	2353	2355
172	2355	2358	2360	2363	2365	2368	2370	2373	2375	2378	2380
173	2380	2383	2385	2388	2390	2393	2395	2398	2400	2403	2405
174	2405	2408	2410	2413	2415	2418	2420	2423	2425	2428	2430
175	2430	2433	2435	2438	2440	2443	2445	2448	2450	2453	2455
176	2455	2458	2460	2463	2465	2467	2470	2472	2475	2477	2480
177	2480	2482	2485	2487	2490	2492	2494	2497	2499	2502	2504
178	2504	2507	2509	2512	2514	2516	2519	2521	2524	2526	2529
179	2529	2531	2533	2536	2538	2541	2543	2545	2548	2550	2553
180	2553	2555	2558	2560	2562	2565	2567	2570	2572	2574	2577
181	2577	2579	2582	2584	2586	2589	2591	2594	2596	2598	2601
182	2601	2603	2605	2608	2610	2613	2615	2617	2620	2622	2625
183	2625	2627	2629	2632	2634	2636	2639	2641	2643	2646	2648
184	2648	2651	2653	2655	2658	2660	2662	2665	2667	2669	2672
185	2672	2674	2676	2679	2681	2683	2686	2688	2690	2693	2695
186	2695	2697	2700	2702	2704	2707	2709	2711	2714	2716	2718
187	2718	2721	2723	2725	2728	2730	2732	2735	2737	2739	2742
188	2742	2744	2746	2749	2751	2753	2755	2758	2760	2762	2765
189	2765	2767	2769	2772	2774	2776	2778	2781	2783	2785	2788
190	2788	2790	2792	2794	2797	2799	2801	2804	2806	2808	2810
191	2810	2813	2815	2817	2819	2822	2824	2826	2828	2831	2833
192	2833	2835	2838	2840	2842	2844	2847	2849	2851	2853	2856
193	2856	2858	2860	2862	2865	2867	2869	2871	2874	2876	2878
194	2878	2880	2882	2885	2887	2889	2891	2894	2896	2898	2900
195	2900	2903	2905	2907	2909	2911	2914	2916	2918	2920	2923
196	2923	2925	2927	2929	2931	2934	2936	2938	2940	2942	2945
197	2945	2947	2949	2951	2953	2956	2958	2960	2962	2964	2967
198	2967	2969	2971	2973	2975	2978	2980	2982	2984	2986	2989
199	2989	2991	2993	2995	2997	2999	3002	3004	3006	3008	3010

Radians	Degrees	Sines		Cosines		Tangents		Cotangents			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.0000	0°00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90°00′	1.5708
0.0029	10	.0029	7.4637	1.0000	.0000	.0029	7.4637	343.77	2.5363	50	1.5679
0.0058	20	.0058	.7648	1.0000	.0000	.0058	.7648	171.89	.2352	40	1.5650
0.0087	30	.0087	.9408	1.0000	.0000	.0087	.9409	114.59	.0591	30	1.5621
0.0116	40	.0116	8.0658	.9999	.0000	.0116	8.0658	85.940	1.9342	20	1.5592
0.0145	50	.0145	.1627	.9999	.0000	.0145	.1627	68.750	.8373	10	1.5563
0.0175	1°00′	.0175	8.2419	.9998	9.9999	.0175	8.2419	57.290	1.7581	89°00′	1.5533
0.0204	10	.0204	.3088	.9998	.9999	.0204	.3089	49.104	.6911	50	1.5504
0.0233	20	.0233	.3668	.9997	.9999	.0233	.3669	42.964	.6331	40	1.5475
0.0262	30	.0262	.4179	.9997	.9999	.0262	.4181	38.188	.5819	30	1.5446
0.0291	40	.0291	.4637	.9996	.9998	.0291	.4638	34.368	.5362	20	1.5417
0.0320	50	.0320	.5050	.9995	.9998	.0320	.5053	31.242	.4947	10	1.5388
0.0349	2°00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88°00′	1.5359
0.0378	10	.0378	.5776	.9993	.9997	.0378	.5779	26.432	.4221	50	1.5330
0.0407	20	.0407	.6097	.9992	.9996	.0407	.6101	24.542	.3899	40	1.5301
0.0436	30	.0436	.6397	.9990	.9996	.0437	.6401	22.904	.3599	30	1.5272
0.0465	40	.0465	.6677	.9989	.9995	.0466	.6682	21.470	.3318	20	1.5243
0.0495	50	.0494	.6940	.9988	.9995	.0495	.6945	20.206	.3055	10	1.5213
0.0524	3°00′	.0523	8.7188	.9986	9.9994	.0524	8.7194	19.081	1.2806	87°00′	1.5184
0.0553	10	.0552	.7423	.9985	.9993	.0553	.7429	18.075	.2571	50	1.5155
0.0582	20	.0581	.7645	.9983	.9993	.0582	.7652	17.169	.2348	40	1.5126
0.0611	30	.0610	.7857	.9981	.9992	.0612	.7865	16.350	.2135	30	1.5097
0.0640	40	.0640	.8059	.9980	.9991	.0641	.8067	15.605	.1933	20	1.5068
0.0669	50	.0669	.8251	.9978	.9990	.0670	.8261	14.924	.1739	10	1.5039
0.0698	4°00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86°00′	1.5010
0.0727	10	.0727	.8613	.9974	.9989	.0729	.8624	13.727	.1376	50	1.4981
0.0756	20	.0756	.8783	.9971	.9988	.0758	.8795	13.197	.1205	40	1.4952
0.0785	30	.0785	.8946	.9969	.9987	.0787	.8960	12.706	.1040	30	1.4923
0.0814	40	.0814	.9104	.9967	.9986	.0816	.9118	12.251	.0882	20	1.4893
0.0844	50	.0843	.9256	.9964	.9985	.0846	.9272	11.826	.0728	10	1.4864
0.0873	5°00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85°00′	1.4835
0.0902	10	.0901	.9545	.9959	.9982	.0904	.9563	11.059	.0437	50	1.4806
0.0931	20	.0929	.9682	.9957	.9981	.0934	.9701	10.712	.0299	40	1.4777
0.0960	30	.0958	.9816	.9954	.9980	.0963	.9836	10.385	.0164	30	1.4748
0.0989	40	.0987	.9945	.9951	.9979	.0992	.9966	10.078	.0034	20	1.4719
0.1018	50	.1016	9.0070	.9948	.9977	.1022	9.0093	9.7882	0.9907	10	1.4690
0.1047	6°00′	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84°00′	1.4661
0.1076	10	.1074	.0311	.9942	.9975	.1080	.0336	9.2553	.9664	50	1.4632
0.1105	20	.1103	.0426	.9939	.9973	.1110	.0453	9.0098	.9547	40	1.4603
0.1134	30	.1132	.0539	.9936	.9972	.1139	.0567	8.7769	.9433	30	1.4574
0.1164	40	.1161	.0648	.9932	.9971	.1169	.0678	8.5555	.9322	20	1.4544
0.1193	50	.1190	.0755	.9929	.9969	.1198	.0786	8.3450	.9214	10	1.4515
0.1222	7°00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83°00′	1.4486
0.1251	10	.1248	.0961	.9922	.9966	.1257	.0995	7.9530	.9005	50	1.4457
0.1280	20	.1276	.1060	.9918	.9964	.1287	.1096	7.7704	.8904	40	1.4428
0.1309	30	.1305	.1157	.9914	.9963	.1317	.1194	7.5958	.8806	30	1.4399
0.1338	40	.1334	.1252	.9911	.9961	.1346	.1291	7.4287	.8709	20	1.4370
0.1367	50	.1363	.1345	.9907	.9959	.1376	.1385	7.2687	.8615	10	1.4341
0.1396	8°00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82°00′	1.4312
0.1425	10	.1421	.1525	.9899	.9956	.1435	.1569	6.9682	.9431	50	1.4283
0.1454	20	.1449	.1612	.9894	.9954	.1465	.1658	6.8269	.8342	40	1.4254
0.1484	30	.1478	.1697	.9890	.9952	.1495	.1745	6.6912	.8255	30	1.4224
0.1513	40	.1507	.1781	.9886	.9950	.1524	.1831	6.5606	.8169	20	1.4195
0.1542	50	.1536	.1863	.9881	.9948	.1554	.1915	6.4348	.8085	10	1.4166
0.1571	9°00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81°00′	1.4137
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
		Cosines		Sines		Cotangents		Tangents		Degrees	Radians

* Taken from B. O. Peirce's Short table of integrals, Ginn & Co.

(*continued*)

Radians	Degrees	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.		
0.1571	9°00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81°00′	1.4137
0.1600	10	.1593	.2022	.9872	.9944	.1614	.2078	6.1970	.7922	50	1.4108
0.1629	20	.1622	.2100	.9868	.9942	.1644	.2158	6.0844	.7842	40	1.4079
0.1658	30	.1650	.2176	.9863	.9940	.1673	.2236	5.9757	.7764	30	1.4050
0.1687	40	.1679	.2251	.9858	.9938	.1703	.2313	5.8708	.7687	20	1.4021
0.1716	50	.1708	.2324	.9853	.9936	.1733	.2389	5.7694	.7611	10	1.3992
0.1745	10°00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80°00′	1.3963
0.1774	10	.1765	.2468	.9843	.9931	.1793	.2536	5.5764	.7464	50	1.3934
0.1804	20	.1794	.2538	.9838	.9929	.1823	.2609	5.4845	.7391	40	1.3904
0.1833	30	.1822	.2606	.9833	.9927	.1853	.2680	5.3955	.7320	30	1.3875
0.1862	40	.1851	.2674	.9827	.9924	.1883	.2750	5.3093	.7250	20	1.3846
0.1891	50	.1880	.2740	.9822	.9922	.1914	.2819	5.2257	.7181	10	1.3817
0.1920	11°00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79°00′	1.3788
0.1949	10	.1937	.2870	.9811	.9917	.1974	.2953	5.0658	.7047	50	1.3759
0.1978	20	.1965	.2934	.9805	.9914	.2004	.3020	4.9894	.6980	40	1.3730
0.2007	30	.1994	.2997	.9799	.9912	.2035	.3085	4.9152	.6915	30	13.701
0.2036	40	.2022	.3058	.9793	.9909	.2065	.3149	4.8430	.6851	20	1.3672
0.2065	50	.2051	.3119	.9787	.9907	.2095	.3212	4.7729	.6788	10	1.3643
0.2094	12°00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78°00′	1.3614
0.2123	10	.2108	.3238	.9775	.9901	.2156	.3336	4.6382	.6664	50	1.3584
0.2153	20	.2136	.3296	.9769	.9899	.2186	.3397	4.5736	.6603	40	1.3555
0.2182	30	.2164	.3353	.9763	.9896	.2217	.3458	4.5107	.6542	30	1.3526
0.2211	40	.2193	.3410	.9757	.9893	.2247	.3517	4.4494	.6483	20	1.3497
0.2240	50	.2221	.3466	.9750	.9890	.2278	.3576	4.3897	.6424	10	1.3468
0.2269	13°00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77°00′	1.3439
0.2298	10	.2278	.3575	.9737	.9884	.2339	.3691	4.2747	.6309	50	1.3410
0.2327	20	.2306	.3629	.9730	.9881	.2370	.3748	4.2193	.6252	40	1.3381
0.2356	30	.2334	.3682	.9724	.9878	.2401	.3804	4.1653	.6196	30	1.3352
0.2385	40	.2363	.3734	.9717	.9875	.2432	.3859	4.1126	.6141	20	1.3323
0.2414	50	.2391	.3786	.9710	.9872	.2462	.3914	4.0611	.6086	10	1.3294
0.2443	14°00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76°00′	1.3265
0.2473	10	.2447	.3887	.9696	.9866	.2524	.4021	3.9617	.5979	50	1.3235
0.2502	20	.2476	.3937	.9689	.9863	.2555	.4074	3.9136	.5926	40	1.3206
0.2531	30	.2504	.3986	.9681	.9859	.2586	.4127	3.8667	.5873	30	1.3177
0.2560	40	.2532	.4035	.9674	.9856	.2617	.4178	3.8208	.5822	20	1.3148
0.2589	50	.2560	.4083	.9667	.9853	.2648	.4230	3.7760	.5770	10	1.3119
0.2618	15°00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75°00′	1.3090
0.2647	10	.2616	.4177	.9652	.9846	.2711	.4331	3.6891	.5669	50	1.3061
0.2676	20	.2644	.4223	.9644	.9843	.2742	.4381	3.6470	.5619	40	1.3032
0.2705	30	.2672	.4269	.9636	.9839	.2773	.4430	3.6059	.5570	30	1.3003
0.2734	40	.2700	.4314	.9628	.9836	.2805	.4479	3.5656	.5521	20	1.2974
0.2763	50	.2728	.4359	.9621	.9832	.2836	.4527	3.5261	.5473	10	1.2945
0.2793	16°00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74°00′	1.2915
0.2822	10	.2784	.4447	.9605	.9825	.2899	.4622	3.4495	.5378	50	1.2886
0.2851	20	.2812	.4491	.9596	.9821	.2931	.4669	3.4124	.5331	40	1.2857
0.2880	30	.2840	.4533	.9588	.9817	.2962	.4716	3.3759	.5284	30	1.2828
0.2909	40	.2868	.4576	.9580	.9814	.2994	.4762	3.3402	.5238	20	1.2799
0.2938	50	.2896	.4618	.9572	.9810	.3026	.4808	3.3052	.5192	10	1.2770
0.2967	17°00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73°00′	1.2741
0.2996	10	.2952	.4700	.9555	.9802	.3089	.4898	3.2371	.5102	50	1.2712
0.3025	20	.2979	.4741	.9546	.9798	.3121	.4943	3.2041	.5057	40	1.2683
0.3054	30	.3007	.4781	.9537	.9794	.3153	.4987	3.1716	.5013	30	1.2654
0.3083	40	.3035	.4821	.9528	.9709	.3185	.5031	3.1397	.4969	20	1.2625
0.3113	50	.3062	.4861	.9520	.9786	.3217	.5075	3.1084	.4925	10	1.2595
0.3142	18°00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72°00′	1.2566
		Cosines Nat.	Cosines Log.	Sines Nat.	Sines Log.	Cotangents Nat.	Cotangents Log.	Tangents Nat.	Tangents Log.	Degrees	Radians

(*continued*)

Radians	Degrees	Sines		Cosines		Tangents		Cotangents			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.3142	18°00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72°00′	1.2566
0.3171	10	.3118	.4939	.9502	.9778	.3281	.5161	3.0475	.4839	50	1.2537
0.3200	20	.3145	.4977	.9492	.9774	.3314	.5203	3.0178	.4797	40	1.2508
0.3229	30	.3173	.5015	.9483	.9770	.3346	.5245	2.9887	.4755	30	1.2479
0.3258	40	.3201	.5052	.9474	.9765	.3378	.5287	2.9600	.4713	20	1.2450
0.3287	50	.3228	.5090	.9465	.9761	.3411	.5329	2.9319	.4671	10	1.2421
0.3316	19°00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71°00′	1.2392
0.3345	10	.3283	.5163	.9446	.9752	.3476	.5411	2.8770	.4589	50	1.2363
0.3374	20	.3311	.5199	.9436	.9748	.3508	.5451	2.8502	.4549	40	1.2334
0.3403	30	.3338	.5235	.9426	.9743	.3541	.5491	2.8239	.4509	30	1.2305
0.3432	40	.3365	.5270	.9417	.9739	.3574	.5531	2.7980	.4469	20	1.2275
0.3462	50	.3393	.5306	.9407	.9734	.3607	.5571	2.7725	.4429	10	1.2246
0.3491	20°00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70°00′	1.2217
0.3520	10	.3448	.5375	.9387	.9725	.3673	.5650	2.7228	.4350	50	1.2188
0.3549	20	.3475	.5409	.9377	.9721	.3706	.5689	2.6985	.4311	40	1.2159
0.3578	30	.3502	.5443	.9367	.9716	.3739	.5727	2.6746	.4273	30	1.2130
0.3607	40	.3529	.5477	.9356	.9711	.3772	.5766	2.6511	.4234	20	1.2101
0.3636	50	.3557	.5510	.9346	.9706	.3805	.5804	2.6279	.4196	10	1.2072
0.3665	21°00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69°00′	1.2043
0.3694	10	.3611	.5576	.9325	.9697	.3872	.5879	2.5826	.4121	50	1.2014
0.3723	20	.3638	.5609	.9315	.9692	.3906	.5917	2.5605	.4083	40	1.1985
0.3752	30	.3665	.5641	.9304	.9687	.3939	.5954	2.5386	.4046	30	1.1956
0.3782	40	.3692	.5673	.9293	.9682	.3973	.5991	2.5172	.4009	20	1.1926
0.3811	50	.3719	.5704	.9283	.9677	.4006	.6028	2.4960	.3972	10	1.1897
0.3840	22°00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68°00′	1.1868
0.3869	10	.3773	.5767	.9261	.9667	.4074	.6100	2.4545	.3900	50	1.1839
0.3898	20	.3800	.5798	.9250	.9661	.4108	.6136	2.4342	.3864	40	1.1810
0.3927	30	.3827	.5828	.9239	.9656	.4142	.6172	2.4142	.3828	30	1.1781
0.3956	40	.3854	.5859	.9228	.9651	.4176	.6208	2.3945	.3792	20	1.1752
0.3985	50	.3881	.5889	.9216	.9646	.4210	.6243	2.3750	.3757	10	1.1723
0.4014	23°00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67°00′	1.1694
0.4043	10	.3934	.5948	.9194	.9635	.4279	.6314	2.3369	.3686	50	1.1665
0.4072	20	.3961	.5978	.9182	.9629	.4314	.6348	2.3183	.3652	40	1.1636
0.4102	30	.3987	.6007	.9171	.9624	.4348	.6383	2.2998	.3617	30	1.1606
0.4131	40	.4014	.6036	.9159	.9618	.4383	.6417	2.2817	.3583	20	1.1577
0.4160	50	.4041	.6065	.9147	.9613	.4417	.6452	2.2637	.3548	10	1.1548
0.4189	24°00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66°00′	1.1519
0.4218	10	.4094	.6121	.9124	.9602	.4487	.6520	2.2286	.3480	50	1.1490
0.4247	20	.4120	.6149	.9112	.9596	.4522	.6553	2.2113	.3447	40	1.1461
0.4276	30	.4147	.6177	.9100	.9590	.4557	.6587	2.1943	.3413	30	1.1432
0.4305	40	.4173	.6205	.9088	.9584	.4592	.6620	2.1775	.3380	20	1.1403
0.4334	50	.4200	.6232	.9075	.9579	.4628	.6654	2.1609	.3346	10	1.1374
0.4363	25°00′	.4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65°00′	1.1345
0.4392	10	.4253	.6286	.9051	.9567	.4699	.6720	2.1283	.3280	50	1.1316
0.4422	20	.4279	.6313	.9038	.9561	.4734	.6752	2.1123	.3248	40	1.1286
0.4451	30	.4305	.6340	.9026	.9555	.4770	.6785	2.0965	.3215	30	1.1257
0.4480	40	.4331	.6366	.9013	.9549	.4806	.6817	2.0809	.3183	20	1.1228
0.4509	50	.4358	.6392	.9001	.9543	.4841	.6850	2.0655	.3150	10	1.1199
0.4538	26°00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64°00′	1.1170
0.4567	10	.4410	.6444	.8975	.9530	.4913	.6914	2.0353	.3086	50	1.1141
0.4596	20	.4436	.6470	.8962	.9524	.4950	.6946	2.0204	.3054	40	1.1112
0.4625	30	.4462	.6495	.8949	.9518	.4986	.6977	2.0057	.3023	30	1.1083
0.4654	40	.4488	.6521	.8936	.9512	.5022	.7009	1.9912	.2991	20	1.1054
0.4683	50	.4514	.6546	.8923	.9505	.5059	.7040	1.9768	.2960	10	1.1025
0.4712	27°00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63°00′	1.0996
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
		Cosines		Sines		Cotangents		Tangents		Degrees	Radians

(continued)

Radians	Degrees	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.		
0.4712	27°00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63°00′	1.0996
0.4741	10	.4566	.6595	.8897	.9492	.5132	.7103	1.9486	.2897	50	1.0966
0.4771	20	.4592	.6620	.8884	.9486	.5169	.7134	1.9347	.2866	40	1.0937
0.4800	30	.4617	.6644	.8870	.9479	.5206	.7165	1.9210	.2835	30	1.0908
0.4829	40	.4643	.6668	.8857	.9473	.5243	.7196	1.9074	.2804	20	1.0879
0.4858	50	.4669	.6692	.8843	.9466	.5280	.7226	1.8940	.2774	10	1.0850
0.4887	28°00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62°00′	1.0821
0.4916	10	.4720	.6740	.8816	.9453	.5354	.7287	1.8676	.2713	50	1.0792
0.4945	20	.4746	.6763	.8802	.9446	.5392	.7317	1.8546	.2683	40	1.0763
0.4974	30	.4772	.6787	.8788	.9439	.5430	.7348	1.8418	.2652	30	1.0734
0.5003	40	.4797	.6810	.8774	.9432	.5467	.7378	1.8291	.2622	20	1.0705
0.5032	50	.4823	.6833	.8760	.9425	.5505	.7408	1.8165	.2592	10	1.0676
0.5061	29°00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61°00′	1.0647
0.5091	10	.4874	.6878	.8732	.9411	.5581	.7467	1.7917	.2533	50	1.0617
0.5120	20	.4899	.6901	.8718	.9404	.5619	.7497	1.7796	.2503	40	1.0588
0.5149	30	.4924	.6923	.8704	.9397	.5658	.7526	1.7675	.2474	30	1.0559
0.5178	40	.4950	.6946	.8689	.9390	.5696	.7556	1.7556	.2444	20	1.0530
0.5207	50	.4975	.6968	.8675	.9383	.5735	.7585	1.7437	.2415	10	1.0501
0.5236	30°00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60°00′	1.0472
0.5265	10	.5025	.7012	.8646	.9368	.5812	.7644	1.7205	.2356	50	1.0443
0.5294	20	.5050	.7033	.8631	.9361	.5851	.7673	1.7090	.2327	40	1.0414
0.5323	30	.5075	.7055	.8616	.9353	.5890	.7701	1.6977	.2299	30	1.0385
0.5352	40	.5100	.7076	.8601	.9346	.5930	.7730	1.6864	.2270	20	1.0356
0.5381	50	.5125	.7097	.8587	.9338	.5969	.7759	1.6753	.2241	10	1.0327
0.5411	31°00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59°00′	1.0297
0.5440	10	.5175	.7139	.8557	.9323	.6048	.7816	1.6534	.2184	50	1.0268
0.5469	20	.5200	.7160	.8542	.9315	.6088	.7845	1.6426	.2155	40	1.0239
0.5498	30	.5225	.7181	.8526	.9308	.6128	.7873	1.6319	.2127	30	1.0210
0.5527	40	.5250	.7201	.8511	.9300	.6168	.7902	1.6212	.2098	20	1.0181
0.5556	50	.5275	.7222	.8496	.9292	.6208	.7930	1.6107	.2070	10	1.0152
0.5585	32°00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58°00′	1.0123
0.5614	10	.5324	.7262	.8465	.9276	.6289	.7986	1.5900	.2014	50	1.0094
0.5643	20	.5348	.7282	.8450	.9268	.6330	.8014	1.5798	.1986	40	1.0065
0.5672	30	.5373	.7302	.8434	.9260	.6371	.8042	1.5697	.1958	30	1.0036
0.5701	40	.5398	.7322	.8418	.9252	.6412	.8070	1.5597	.1930	20	1.0007
0.5730	50	.5422	.7342	.8403	.9244	.6453	.8097	1.5497	.1903	10	0.9977
0.5760	33°00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57°00′	0.9948
0.5789	10	.5471	.7380	.8371	.9228	.6536	.8153	1.5301	.1847	50	0.9919
0.5818	20	.5495	.7400	.8355	.9219	.6577	.8180	1.5204	.1820	40	0.9890
0.5847	30	.5519	.7419	.8339	.9211	.6619	.8208	1.5108	.1792	30	0.9861
0.5876	40	.5544	.7438	.8323	.9203	.6661	.8235	1.5013	.1765	20	0.9832
0.5905	50	.5568	.7457	.8307	.9194	.6703	.8263	1.4919	.1737	10	0.9803
0.5934	34°00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56°00′	0.9774
0.5963	10	.5616	.7494	.8274	.9177	.6787	.8317	1.4733	.1683	50	0.9745
0.5992	20	.5640	.7513	.8258	.9169	.6830	.8344	1.4641	.1656	40	0.9716
0.6021	30	.5664	.7531	.8241	.9160	.6873	.8371	1.4550	.1629	30	0.9687
0.6050	40	.5688	.7550	.8225	.9151	.6916	.8398	1.4460	.1602	20	0.9657
0.6080	50	.5712	.7568	.8208	.9142	.6959	.8425	1.4370	.1575	10	0.9628
0.6109	35°00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55°00′	0.9599
0.6138	10	.5760	.7604	.8175	.9125	.7046	.8479	1.4193	.1521	50	0.9570
0.6167	20	.5783	.7622	.8158	.9116	.7089	.8506	1.4106	.1494	40	0.9541
0.6196	30	.5807	.7640	.8141	.9107	.7133	.8533	1.4019	.1467	30	0.9512
0.6225	40	.5831	.7657	.8124	.9098	.7177	.8559	1.3934	.1441	20	0.9483
0.6254	50	.5854	.7675	.8107	.9089	.7221	.8586	1.3848	.1414	10	0.9454
0.6283	36°00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54°00′	0.9425
		Cosines Nat.	Cosines Log.	Sines Nat.	Sines Log.	Cotangents Nat.	Cotangents Log.	Tangents Nat.	Tangents Log.	Degrees	Radians

(*continued*)

Radians	Degrees	Sines		Cosines		Tangents		Cotangents			
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
0.6283	36°00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54°00′	0.9425
0.6312	10	.5901	.7710	.8073	.9070	.7310	.8639	1.3680	.1361	50	0.9396
0.6341	20	.5925	.7727	.8056	.9061	.7355	.8666	1.3597	.1334	40	0.9367
0.6370	30	.5948	.7744	.8039	.9052	.7400	.8692	1.3514	.1308	30	0.9338
0.6400	40	.5972	.7761	.8021	.9042	.7445	.8718	1.3432	.1282	20	0.9308
0.6429	50	.5995	.7778	.8004	.9033	.7490	.8745	1.3351	.1255	10	0.9279
0.6458	37°00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53°00′	0.9250
0.6487	10	.6041	.7811	.7969	.9014	.7581	.8797	1.3190	.1203	50	0.9221
0.6516	20	.6065	.7828	.7951	.9004	.7627	.8824	1.3111	.1176	40	0.9192
0.6545	30	.6088	.7844	.7934	.8995	.7673	.8850	1.3032	.1150	30	0.9163
0.6574	40	.6111	.7861	.7916	.8985	.7720	.8876	1.2954	.1124	20	0.9134
0.6603	50	.6134	.7877	.7898	.8975	.7766	.8902	1.2876	.1098	10	0.9105
0.6632	38°00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52°00′	0.9076
0.6661	10	.6180	.7910	.7862	.8955	.7860	.8954	1.2723	.1046	50	0.9047
0.6690	20	.6202	.7926	.7844	.8945	.7907	.8980	1.2647	.1020	40	0.9018
0.6720	30	.6225	.7941	.7826	.8935	.7954	.9006	1.2572	.0994	30	0.8988
0.6749	40	.6248	.7957	.7808	.8925	.8002	.9032	1.2497	.0968	20	0.8959
0.6778	50	.6271	.7973	.7790	.8915	.8050	.9058	1.2423	.0942	10	0.8930
0.6807	39°00′	.6293	9.7989	.7771	0.8905	.8098	9.9084	1.2349	0.0916	51°00′	0.8901
0.6836	10	.6316	.8004	.7753	.8895	.8146	.9110	1.2276	.0890	50	0.8872
0.6865	20	.6338	.8020	.7735	.8884	.8195	.9135	1.2203	.0865	40	0.8843
0.6894	30	.6361	.8035	.7716	.8874	.8243	.9161	1.2131	.0839	30	0.8814
0.6923	40	.6383	.8050	.7698	.8864	.8292	.9187	1.2059	.0813	20	0.8785
0.6952	50	.6406	.8066	.7679	.8853	.8342	.9212	1.1988	.0788	10	0.8756
0.6981	40°00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50°00′	0.8727
0.7010	10	.6450	.8096	.7642	.8832	.8441	.9264	1.1847	.0736	50	0.8698
0.7039	20	.6472	.8111	.7623	.8821	.8491	.9289	1.1778	.0711	40	0.8668
0.7069	30	.6494	.8125	.7604	.8810	.8541	.9315	1.1708	.0685	30	0.8639
0.7098	40	.6517	.8140	.7585	.8800	.8591	.9341	1.1640	.0659	20	0.8610
0.7127	50	.6539	.8155	.7566	.8789	.8642	.9366	1.1571	.0634	10	0.8581
0.7156	41°00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49°00′	0.8552
0.7185	10	.6583	.8184	.7528	.8767	.8744	.9417	1.1436	.0583	50	0.8523
0.7214	20	.6604	.8198	.7509	.8756	.8796	.9443	1.1369	.0557	40	0.8494
0.7243	30	.6626	.8213	.7490	.8745	.8847	.9468	1.1303	.0532	30	0.8465
0.7272	40	.6648	.8227	.7470	.8733	.8899	.9494	1.1237	.0506	20	0.8436
0.7301	50	.6670	.8241	.7451	.8722	.8952	.9519	1.1171	.0481	10	0.8407
0.7330	42°00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48°00′	0.8378
0.7359	10	.6713	.8269	.7412	.8699	.9057	.9570	1.1041	.0430	50	0.8348
0.7389	20	.6734	.8283	.7392	.8688	.9110	.9595	1.0977	.0405	40	0.8319
0.7418	30	.6756	.8297	.7373	.8676	.9163	.9621	1.0913	.0379	30	0.8290
0.7447	40	.6777	.8311	.7353	.8665	.9217	.9646	1.0850	.0354	20	0.8261
0.7476	50	.6799	.8324	.7333	.8653	.9271	.9671	1.0786	.0329	10	0.8232
0.7505	43°00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47°00′	0.8203
0.7534	10	.6841	.8351	.7294	.8629	.9380	.9722	1.0661	.0278	50	0.8174
0.7563	20	.6862	.8365	.7274	.8618	.9435	.9747	1.0599	.0253	40	0.8145
0.7592	30	.6884	.8378	.7254	.8606	.9490	.9772	1.0538	.0228	30	0.8116
0.7621	40	.6905	.8391	.7234	.8594	.9545	.9798	1.0477	.0202	20	0.8087
0.7650	50	.6926	.8405	.7214	.8582	.9601	.9823	1.0416	.0177	10	0.8058
0.7679	44°00′	.6947	9.8418	.7193	0.8569	.9657	9.9848	1.0355	0.0152	46°00′	0.8029
0.7709	10	.6967	.8431	.7173	.8557	.9713	.9874	1.0295	.0126	50	0.7999
0.7738	20	.6988	.8444	.7153	.8545	.9770	.9899	1.0235	.0101	40	0.7970
0.7767	30	.7009	.8457	.7133	.8532	.9827	.9924	1.0176	.0076	30	0.7941
0.7796	40	.7030	.8469	.7112	.8520	.9884	.9949	1.0117	.0051	20	0.7912
0.7825	50	.7050	.8482	.7092	.8507	.9942	.9975	1.0058	.0025	10	0.7883
0.7854	45°00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45°00′	0.7854
		Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.		
		Cosines		Sines		Cotangents		Tangents		Degrees	Radians

TABLES 16-25.—TREATMENT OF EXPERIMENTAL DATA *

TABLE 16.—METHODS OF AVERAGING DATA

When a number of measurements are made of any quantity variations will be found. The question is: What is the best representative value for the quantity thus measured: and how shall the precision of the measurements be stated? The arithmetic mean of all the readings is generally taken as the best value. To tell something about the precision of the final result any one of five measures of variation which are discussed in books dealing with this subject may be given. These measures of deviation are:

$p =$ probable error

$a =$ the average deviation (from the arithmetic mean)

$\sigma =$ the standard deviation

$1/h =$ the reciprocal of the modulus of precision

$k/w =$ the reciprocal of the "precision constant"

Of these precision indexes the standard deviation, σ, is most easily computed. For the set of observed values $x_1, x_2 \ldots x_n$ of equal weight, the σ for a single observation is given by

$$\sigma = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}} \cong \sqrt{\frac{\Sigma(x-\bar{x})^2}{n}}$$

and for the mean by

$$\sigma = \frac{\sigma}{\sqrt{n}} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n(n-1)}} \cong \sqrt{\frac{\Sigma(x-\bar{x})^2}{n^2}}$$

The ratios of these precision indexes to one another for a normal (or Gaussian) distribution are:

$$p : a : \sigma : 1/h : k/w :: 0.476936 : 1/\sqrt{\pi} : \sqrt{(1/2)} : 1.000 : \sqrt{\pi}$$

or roughly as $p : a : \sigma : 1/h : k/w :: 7 : 8 : 10 : 14 : 25$

Most experimental data can be represented by an equation of some form. One of the recommended methods for determining the coefficients of such equations is the use of a least-squares solution. This means that an attempt is made to find values for the coefficients such that the sum of the squares of the deviations of the experimental points from the resulting curve has the least possible value. Certain tables are of help in making such solutions (Tables 16-26), and reference should be made to books or papers on this subject for their use.

An example of one method of finding the coefficients of such selected equations (based on "Treatment of Experimental Data," by Worthing and Geffner, published by Wiley, 1943) follows.

Part 1.—Least squares adjustment of measurements of linearly related quantities

Let $Q_1, Q_2 \ldots Q_k$ be the k adjusted, but initially unknown, values of the linearly related quantities. Let $X_1, X_2 \ldots X_n$ be $n(>k)$ measured values of Q's or of linear combinations of two or more, Q's.

Let $\Delta_1, \Delta_2 \ldots \Delta_n$ be the adjustments or corrections that must be applied to the measured X's to yield consistent least-squares values for the Q's. See below for a simple illustration.

As *observation equations* we have

$$\begin{aligned} a_1Q_1 + b_1Q_2 + \ldots k_1Q_k - X_1 &= \Delta_1 \\ a_2Q_1 + b_2Q_2 + \ldots k_2Q_k - X_2 &= \Delta_2 \\ &\ldots\ldots \\ a_nQ_1 + b_nQ_2 + \ldots k_nQ_k - X_n &= \Delta_n \end{aligned} \qquad (1)$$

of which $a_i, b_i \ldots k_i$ are constants, whose values are frequently $+1$, -1, or 0.

From the observation equations k *normal equations* are formed. For equally weighted observed values of X, they are

$$\begin{aligned} [a_ia_i]Q_1 + [a_ib_i]Q_2 + [a_ic_i]Q_3 + \ldots [a_ik_i]Q_k - [a_iX_i] &= 0 \\ [b_ia_i]Q_1 + [b_ib_i]Q_2 + [b_ic_i]Q_3 + \ldots [b_ik_i]Q_k - [b_iX_i] &= 0 \\ &\ldots\ldots \\ [k_ia_i]Q_1 + [k_ib_i]Q_2 + [k_ic_i]Q_3 + \ldots [k_ik_i]Q_k - [k_iX_i] &= 0 \end{aligned} \qquad (2)$$

* Prepared by the late A. G. Worthing, of the University of Pittsburgh.

(continued)

of which, as representative bracketed [ ] coefficients, we have

$$[a_i a_i] = a_1 a_1 + a_2 a_2 + a_3 a_3 + \ldots a_n a_n$$
$$[a_i b_i] = a_1 b_1 + a_2 b_2 + a_3 b_3 + \ldots a_n b_n \qquad (3)$$
$$[a_i X_i] = a_1 X_1 + a_2 X_2 + a_3 X_3 + \ldots a_n X_n$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$[k_i a_i] = k_1 a_1 + k_2 a_2 + k_3 a_3 + \ldots k_n a_n$$

Solutions of equation (2) yield the least-squares adjusted values of $Q_1, Q_2 \ldots Q_k$.

For unequally weighted values of X, that is $w_1, w_2, \ldots w_n$ for $X_1 X_3 \ldots X_n$, the *normal equations* become

$$[w_i a_i a_i]Q_1 + [w_i a_i b_i]Q_2 + [w_i a_i c_i]Q_3 + \ldots [w_i a_i k_i]Q_k - [w_i a_i X_i] = 0$$
$$[w_i b_i a_i]Q_1 + [w_i b_i b_i]Q_2 + [w_i b_i c_i]Q_3 + \ldots [w_i b_i k_i]Q_k - [w_i b_i X_i] = 0 \qquad (4)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$[w_i k_i a_i]Q_1 + [w_i k_i b_i]Q_2 + [w_i k_i c_i]Q_3 + \ldots [w_i k_i k_i]Q_k - [w_i k_i X_i] = 0$$

of which

$$[w_i a_i a_i] = w_1 a_1 a_1 + w_2 a_2 a_2 + w_3 a_3 a_3 + \ldots w_n a_n a_n$$
$$[w_i a_i b_i] = w_1 a_1 b_1 + w_2 a_2 b_2 + w_3 a_3 b_3 + \ldots w_n a_n b_n \qquad (5)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$[w_i k_i a_i] = w_1 k_1 a_1 + w_2 k_2 a_2 + w_3 k_3 a_3 + \ldots w_n k_n a_n$$

The weights $w_1, w_2 \ldots w_n$ associated with the $X_1, X_2 \ldots X_n$ and with the successive observation equations are taken as inversely proportional to the squares of the probable errors (or of the standard deviations) of the corresponding X's. It is customary to take simple rounded numbers for the proportional values. A precise set of 28, 50, 41, and 78 may be rounded to 3, 5, 4, and 8.

As a simple application, consider the elevations of stations B, C, and D above A. Let those elevations in order be Q_1, Q_2, and Q_3. Let the quantities measured and the observed elevations be such as to yield the following observation equations:

$$\begin{aligned} Q_1 - 10\text{ ft} &= \Delta_1 \\ Q_2 - 18\text{ ft} &= \Delta_2 \\ Q_3 - 4\text{ ft} &= \Delta_3 \\ -Q_1 + Q_2 - 9\text{ ft} &= \Delta_4 \\ Q_2 - Q_3 - 12\text{ ft} &= \Delta_5 \\ Q_1 - Q_3 - 5\text{ ft} &= \Delta_6 \end{aligned} \qquad (6)$$

The coefficients a_1, b_1, and c_1 are seen to be 1, 0, and 0. The values of the other coefficients are obvious. Substitution in equation (2) yields for the normal equations

$$\begin{aligned} 3Q_2 - Q_2 - Q_3 - 6\text{ ft} &= 0 \\ -Q_1 + 3Q_2 - Q_3 - 39\text{ ft} &= 0 \\ -Q_1 - Q_2 + 3Q_3 + 13\text{ ft} &= 0 \end{aligned} \qquad (7)$$

Solutions of equation (7) yield $9\frac{1}{2}$ ft, $17\frac{3}{4}$ ft, and $4\frac{3}{4}$ ft for the elevations of B, C, and D above A.

Part 2.—Least-squares equations of the type $y = a + bx$, to represent a series of observed (x,y) values

For equally weighted pairs of (x,y) of which the errors of measurement are associated with the determinations of the y's

$$a = \frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{n\Sigma x^2 - (\Sigma x)^2} = \frac{\overline{x^2}\,\bar{y} - \bar{x}\,\overline{xy}}{\overline{x^2} - \bar{x}^2}$$

$$b = \frac{n\Sigma xy - \Sigma x \Sigma y}{n\Sigma x^2 - (\Sigma x)^2} = \frac{\bar{x}\bar{y} - \overline{xy}}{\overline{x^2} - \bar{x}^2} \qquad (8)$$

of which

$$n\bar{x} = \Sigma x,\ n\overline{x^2} = \Sigma x^2,\ \overline{xy} = n\Sigma xy$$
$$\bar{n}^2\bar{x}^2 = (\Sigma x)^2, \text{ etc.}$$

(continued)

The probable errors of the a and the b of equation (8) are given by

$$p_a = 0.675\sqrt{\frac{1}{n-2}\left[\frac{\overline{x^2}\,\overline{y^2} - 2\bar{x}\,\bar{y}\,\overline{xy} + \overline{x^2}\,\bar{y}^2}{\overline{x^2} - \bar{x}^2} - a^2\right]}$$

$$p_b = 0.675\sqrt{\frac{1}{n-2}\left[\frac{\overline{y^2} - \bar{y}^2}{\overline{x^2} - \bar{x}^2} - b^2\right]} \qquad (9)$$

For unequally weighted measurements of which the errors of measurement are associated with the determinations of the y's,

$$a = \frac{\Sigma w_i x_i^2 \Sigma w_i y_i - \Sigma w_i x_i \Sigma w_i x_i y_i}{\Sigma w \Sigma w_i x_i^2 - (\Sigma w_i x_i)^2}$$

$$b = \frac{\Sigma w \Sigma w_i x_i y_i - \Sigma w_i x_i \Sigma w_i y_i}{\Sigma w \Sigma w_i x_i^2 - (\Sigma w_i x_i)^2} \qquad (10)$$

Where the errors of measurement are associated with the x-determination only, the corresponding coefficients of an equation of the type $x = a' + b'y$ can be obtained by merely interchanging x and y in equation (8).

Where the errors of measurement are associated with both the x- and the y- determinations, the expressions are complicated.[13]

[13] Worthing, A. G., and Geffner, J., Treatment of experimental data, p. 259, John Wiley and Sons, New York, 1943. Used by permission.

Part 3.—Least-squares equation of the type $y = a + bx + cx^2 + dx^3$ to represent a series of observed (x, y) values

For the general case involving irregularly spaced x-values, the formulae for a, b, c, etc., are very complex.[14] However, for the case of equally weighted observations with errors of measurement associated entirely with the y-values in which succeeding x-values are equally spaced, the mechanics of the computations for least-squares constants are very greatly simplified, thanks to tables computed by Baily[15] and by Cox and Matuschak.[16] The procedure requires a change of the x-variable to yield a new X-variable with a zero-value at the midpoint of the series. In case of an even number of terms, the shift is given by

$$X_e = \frac{x - \bar{x}}{\Delta x} \qquad (11)$$

of which Δx is the even spacing between successive x-values; and, if the number of terms is odd, the shift is given by

$$X_0 = \frac{x - \bar{x}}{\Delta x/2} \qquad (12)$$

The further procedure consists in determining the appropriate summations indicated in Table 17, the appropriate k-terms given as a function of the number of terms n in Tables 19 and 20, combining the appropriate summations and k-terms, to give parameters for the equation $y = f(X)$, and finally transferring the function to the original coordinate system to yield $y = f_2(x)$.

How to apply the simplified procedure to determine the coefficient of x^2 in the least-squares equation $y = a + bx + cx^2$ to represent the xy values of the first two columns of the following tabulations is shown in the remainder of the tabulation.

x (sec)	y (cm)	X	X^2y (cm)	
				$c' = k_5 \Sigma X^2 y - k_4 \Sigma y$
3	12.0	−5	300.0	$n = 6$
6	20.6	−3	185.4	$k_5 = 16{,}741{,}071 \times 10^{-10}$
9	33.7	−1	33.7	$k_4 = 19{,}531{,}250 \times 10^{-9}$
12	51.1	+1	51.1	$k_5 \Sigma X^2 y = 6.2005$ cm
15	72.9	+3	656.1	$k_4 \Sigma y = 5.6523$ cm
18	99.1	+5	2477.5	$c' = 0.5482$ cm
	——		———	$\Delta x = 3$ sec
	289.4		3703.8	$c = 4c'/(\Delta x)^2 = 0.244$ cm/sec^2

[14] Birge, R. T., and Shea, J. D., Univ. California Publ. Math., vol. 2, p. 67, 1927; Worthing, A. G., and Geffner, J., Treatment of experimental data, p. 250, John Wiley and Sons, New York, 1943.
[15] Baily, J. L., Ann. Math. Statistics, vol. 2, p. 355, 1931.
[16] Cox, G. C., and Matuschak, Margaret, Journ. Phys. Chem., vol. 45, p. 362, 1941.

TABLE 17.—SHOWING THE MAKE-UP OF THE CONSTANTS OF THE LEAST-SQUARES EQUATION OF THE TYPE $y = a + bx + cx^2 + dx^3$ FOR EQUATIONS OF VARYING DEGREES WHEN THE ABBREVIATED METHOD OF BAILEY AND OF COX AND MATUSCHAK IS USED *

This method is applicable only when succeeding values of x have a common difference and are equally weighted. The independent variable, changed if necessary, must have a zero value at the midpoint of the series with succeeding values differing by unity if the number of terms is odd and by two if even. Values for the various k's, as computed by Cox and Matuschak, are to be found in Tables 14 and 20.

Degree of equation	Parameters			
	a	*b*	*c*	*d*
1	$k_1\Sigma y$	$k_2\Sigma xy$		
2	$k_3\Sigma y - k_4\Sigma x^2y$	$k_2\Sigma xy$	$k_5\Sigma x^2y - k_4\Sigma y$	
3	$k_3\Sigma y - k_4\Sigma x^2y$	$k_6\Sigma xy - k_7\Sigma x^3y$	$k_5\Sigma x^2y - k_4\Sigma y$	$k_8\Sigma x^3y - k_7\Sigma xy$

* For references, see footnotes 15 and 16, p. 39.

TABLE 18.—VALUES OF $P = \frac{2}{\sqrt{\pi}}\int_0^{hx} e^{-(hx)^2}d(hx)$

P, the probability of an observational error having a value positive or negative equal to or less than x when h is the measure of precision, $P = \frac{2}{\sqrt{\pi}}\int_0^{hx} e^{-(hx)^2}d(hx)\cdot h^2 = (\frac{1}{2}m\Delta x^2)$ where m = no. obs. of deviation Δx.

hx	0	1	2	3	4	5	6	7	8	9
0.0		.01128	.02256	.03384	.04511	.05637	.06762	.07886	.09008	.10128
.1	.11246	.12362	.13476	.14587	.15695	.16800	.17901	.18999	.20094	.21184
.2	.22270	.23352	.24430	.25502	.26570	.27633	.28690	.29742	.30788	.31828
.3	.32863	.33891	.34913	.35928	.36936	.37938	.38933	.39921	.40901	.41874
.4	.42839	.43797	.44747	.45689	.46623	.47548	.48466	.49375	.50275	.51167
0.5	.52050	.52924	.53790	.54646	.55494	.56332	.57162	.57982	.58792	.59594
.6	.60386	.61168	.61941	.62705	.63459	.64203	.64938	.65663	.66378	.67084
.7	.67780	.68467	.69143	.69810	.70468	.71116	.71754	.72382	.73001	.73610
.8	.74210	.74800	.75381	.75952	.76514	.77067	.77610	.78144	.78669	.79184
.9	.79691	.80188	.80677	.81156	.81627	.82089	.82542	.82987	.83423	.83851
1.0	.84270	.84681	.85084	.85478	.85865	.86244	.86614	.86977	.87333	.87680
.1	.88021	.88353	.88679	.88997	.89308	.89612	.89910	.90200	.90484	.90761
.2	.91031	.91296	.91553	.91805	.92051	.92290	.92524	.92751	.92973	.93190
.3	.93401	.93606	.93807	.94002	.94191	.94376	.94556	.94731	.94902	.95067
.4	.95229	.95385	.95538	.95686	.95830	.95970	.96105	.96237	.96365	.96490
1.5	.96611	.96728	.96841	.96952	.97059	.97162	.97263	.97360	.97455	.97546
.6	.97635	.97721	.97804	.97884	.97962	.98038	.98110	.98181	.98249	.98315
.7	.98379	.98441	.98500	.98558	.98613	.98667	.98719	.98769	.98817	.98864
.8	.98909	.98952	.98994	.99035	.99074	.99111	.99147	.99182	.99216	.99248
.9	.99279	.99309	.99338	.99366	.99392	.99418	.99443	.99466	.99489	.99511
2.0	.99532	.99552	.99572	.99591	.99609	.99626	.99642	.99658	.99673	.99688
.1	.99702	.99715	.99728	.99741	.99753	.99764	.99775	.99785	.99795	.99805
.2	.99814	.99822	.99831	.99839	.99846	.99854	.99861	.99867	.99874	.99880
.3	.99886	.99891	.99897	.99902	.99906	.99911	.99915	.99920	.99924	.99928
.4	.99931	.99935	.99938	.99941	.99944	.99947	.99950	.99952	.99955	.99957
2.5	.99959	.99961	.99963	.99965	.99967	.99969	.99971	.99972	.99974	.99975
.6	.99976	.99978	.99979	.99980	.99981	.99982	.99983	.99984	.99985	.99986
.7	.99987	.99987	.99988	.99989	.99989	.99990	.99991	.99991	.99992	.99992
.8	.99992	.99993	.99993	.99994	.99994	.99994	.99995	.99995	.99995	.99996
.9	.99996	.99996	.99996	.99997	.99997	.99997	.99997	.99997	.99997	.99998
3.0	.99998	.99999	.99999	1.00000						

TABLE 19.—VALUES OF THE CONSTANTS, k_n, ENTERING LEAST-SQUARES SOLUTIONS, USING THE ABBREVIATED METHOD OF BAILY AND OF COX AND MATUSCHAK, WHEN THE NUMBER OF TERMS, n, IS ODD*

The numbers in parentheses show the negative powers of 10 by which the adjacent numbers must be multiplied in order to obtain appropriate k_n's. To illustrate, k_2 for $n = 13$ is $54,945,055 \times 10^{-10}$.

n	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8
3	3333 3333(8)	5000 0000(8)	1000 0000(7)	1000 0000(7)	1500 0000(7)			
5	2000 0000	1000 0000	4857 1429(8)	1428 5714(8)	7142 8571(9)	9027 7778(8)	2361 1111(8)	6944 4444(9)
7	1428 5714	3571 4286(9)	3333 3333	4761 9048(9)	1190 4762	2625 6614	3240 7407(9)	4629 6296(10)
9	1111 1111	1666 6667	2554 1126	2164 5022	3246 7532(10)	1143 3782	8277 2166(10)	7014 5903(11)
11	9090 9091(9)	9090 9091(10)	2074 5921	1165 5012	1165 5012	6037 9435(9)	2881 3779	1618 7516
13	7692 3077	5494 5055	1748 2517	6993 0070(10)	4995 0050(11)	3584 6098	1214 0637	4856 2549(12)
15	6666 6667	3571 4286	1511 3122	4524 8869	2424 0465	2304 5899	5830 6799(11)	1745 7125
17	5882 3529	2450 9803	1331 2693	3095 9752	1289 9897	1570 2041	3081 6420	7166 6093(13)
19	5263 1579	1754 3860	1189 7391	2211 4109	7371 3696(12)	1118 3168	1752 5617	3257 5497
21	4761 9048	1298 7013	1075 5149	1634 5211	4457 7848	8248 5070(10)	1056 2015	1605 1694
23	4347 8261	9881 4229(11)	9813 6646(9)	1242 2360	2823 2637	6259 0791	6672 0719(12)	8445 6606(14)
25	4000 0000	7692 3077	9024 1546	9651 8357(11)	1858 0453	4862 3545	4382 3595	4692 0337
27	3703 7037	6105 0061	8352 4904	7662 8352	1263 1047	3852 7423	2974 5336	2728 9299
29	3448 2759	4926 1084	7774 0700	6179 7058	8828 1512(13)	3104 7316	2076 4076	1650 5625
31	3225 8065	4032 2581	7270 7048	5056 1230	6320 1537	2538 6983	1485 0296	1032 7049
33	3030 3030	3342 2460	6828 6552	4189 3590	4620 6166	2102 4471	1084 7991	6655 2091(15)
35	2857 1429	2801 1204	6437 3464	3510 0035	3441 1799	1760 7811	8073 4407(13)	4402 0942
37	2702 7027	2370 7918	6088 5061	2970 0030	2605 2658	1489 3734	6108 7522	2979 8791
39	2564 1026	2024 2915	5775 5692	2535 3684	2001 6066	1271 0408	4691 0081	2059 2661
41	2439 0244	1742 1603	5493 2589	2181 5961	1558 2829	1093 4097	3650 4910	1449 7581
43	2325 5814	1510 1178	5237 2849	1890 7166	1227 7380	9474 1490(11)	2875 1015	1037 9428
45	2222 2222	1317 5231	5004 1234	1649 3485	9778 7451(14)	8263 1159	2289 2527	7545 3288(16)
47	2127 6596	1156 3367	4790 8525	1447 3875	7866 2362	7250 1033	1841 0171	5561 9852
49	2040 8163	1020 4082	4595 0295	1277 1066	6385 5329	6396 2170	1494 1103	4152 6134
51	1960 7843	9049 7738(12)	4414 5960	1132 5285	5227 0545	5671 3855	1222 7830	3136 9497

* For references, see footnotes 15 and 16, p. 39.

TABLE 20.—VALUES OF THE CONSTANTS, k_n, ENTERING LEAST-SQUARES SOLUTIONS, USING THE ABBREVIATED METHOD OF BAILY AND OF COX AND MATUSCHAK, WHEN THE NUMBER OF TERMS, n, IS EVEN *

The numbers in parentheses show the negative powers of 10 by which the adjacent numbers must be multiplied in order to obtain appropriate k_n's.

n	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8
4	2500 0000(8)	5000 0000(9)	6406 2500(8)	7812 5000(9)	1562 5000(9)	6336 8056(8)	7118 0556(9)	8680 5556(10)
6	1666 6667	1428 5714	3945 3125	1953 1250	1674 1071(10)	1126 7499	4870 7562(10)	2411 2654(11)
8	1250 0000	5952 3810(10)	2890 6250	7812 5000(10)	3720 2381(11)	4196 3534(9)	9732 7441(11)	2630 4714(12)
10	1000 0000	3030 3030	2289 0625	3906 2500	1183 7121	2040 1329	2964 3389	5058 5988(13)
12	8333 3333(9)	1748 2517	1897 3214	2232 1429	4682 8172(12)	1149 4485	1146 6157	1348 9597
14	7142 8571	1098 9011	1621 0938	1395 0893	2146 2912	7125 6741(10)	5186 5517(12)	4463 4695(14)
16	6250 0000	7352 9412(11)	1415 5506	9300 5952(11)	1094 1877	4725 9999	2622 0143	1722 7426
18	5555 5556	5159 9587	1256 5104	6510 4167	6046 8266(13)	3296 7149	1440 7871	7465 2181(15)
20	5000 0000	3759 3985	1129 7349	4734 8485	3560 0365	2391 7243	8448 3844(13)	3540 8149
22	4545 4545	2823 2637	1026 2784	3551 1364	2205 6748	1790 5616	5218 8071	1805 8156
24	4166 6667	2173 9130	9402 3164(9)	2731 6434	1425 2052	1375 4794	3364 5781	9775 0702(16)
26	3846 1538	1709 4017	8675 3091	2146 2912	9539 0720(14)	1079 5940	2248 0302	5561 6779
28	3571 4286	1368 3634	8052 8846	1717 0330	6578 6704	8629 5508(11)	1548 2276	3301 1249
30	3333 3333	1112 3471	7513 9509	1395 0893	4655 4704	7006 8080	1094 4042	2031 9424
32	3125 0000	9164 2229(12)	7042 7390	1148 8971	3369 1996	5767 1532	7913 1009(14)	1290 8811
34	2941 1765	7639 4194	6627 2213	9574 1423(12)	2486 7902	4803 7846	5836 2361	8431 4304(17)
36	2777 7778	6435 0064	6258 0624	8062 4358	1867 7458	4043 7597	4380 6481	5643 7105
38	2631 5789	5471 0581	5927 9058	6853 0703	1424 7547	3436 0952	3339 8722	3861 1239
40	2500 0000	4690 4315	5630 8741	5774 0602	1102 0751	2944 4203	2582 2837	2693 8074
42	2380 9524	4051 5355	5362 2160	5073 0520	8632 5332(15)	2542 3116	2021 9092	1912 8753
44	2272 7273	3523 6081	5118 0477	4411 3495	6839 3016	2210 2564	1601 3580	1380 2431
46	2173 9130	3083 5646	4895 1643	3859 9309	5475 0792	1933 6316	1281 5606	1010 5351
48	2083 3333	2713 8515	4690 8968	3396 7392	4424 7580	1701 3314	1035 4426	7497 7742(18)
50	2000 0000	2400 9604	4503 0048	3004 8077	3607 2121	1504 8177	8439 3542(15)	5631 4922

* For references, see footnotes 15 and 16, p. 39.

x	e^x	log e^x	e^{-x}	x	e^x	log e^x	e^{-x}
1/64	1.0157	0.00679	0.98450	1/3	1.3956	0.14476	0.71653
1/32	.0317	.01357	.96923	1/2	.6487	.21715	.60653
1/16	.0645	.02714	.93941	3/4	2.1170	.32572	.47237
1/10	.1052	.04343	.90484	1	.7183	.43429	.36788
1/9	.1175	.04825	.89484	5/4	3.4903	.54287	.28650
1/8	1.1331	0.05429	0.88250	3/2	4.4817	0.65144	0.22313
1/7	.1536	.06204	.86688	7/4	5.7546	.76002	.17377
1/6	.1814	.07238	.84648	2	7.3891	.86859	.13534
1/5	.2214	.08686	.81873	9/4	9.4877	.97716	.10540
1/4	.2840	.10857	.77880	5/2	12.1825	1.08574	.08208

TABLE 22.—FURTHER VALUES OF P

This table gives the values of the probability *P*, as defined in Table 18, corresponding to different values of x/r where r is the "probable error." The probable error r is equal to $0.47694/h$.

$\frac{x}{r}$	0	1	2	3	4	5	6	7	8	9
0.0	.00000	.00538	.01076	.01614	.02152	.02690	.03228	.03766	.04303	.04840
0.1	.05378	.05914	.06451	.06987	.07523	.08059	.08594	.09129	.09663	.10197
0.2	.10731	.11264	.11796	.12328	.12860	.13391	.13921	.14451	.14980	.15508
0.3	.16035	.16562	.17088	.17614	.18138	.18662	.19185	.19707	.20229	.20749
0.4	.21268	.21787	.22304	.22821	.23336	.23851	.24364	.24876	.25388	.25898
0.5	.26407	.26915	.27421	.27927	.28431	.28934	.29436	.29936	.30435	.30933
0.6	.31430	.31925	.32419	.32911	.33402	.33892	.34380	.34866	.35352	.35835
0.7	.36317	.36798	.37277	.37755	.38231	.38705	.39178	.39649	.40118	.40586
0.8	.41052	.41517	.41979	.42440	.42899	.43357	.43813	.44267	.44719	.45169
0.9	.45618	.46064	.46509	.46952	.47393	.47832	.48270	.48705	.49139	.49570
1.0	.50000	.50428	.50853	.51277	.51699	.52119	.52537	.52952	.53366	.53778
1.1	.54188	.54595	.55001	.55404	.55806	.56205	.56602	.56998	.57391	.57782
1.2	.58171	.58558	.58942	.59325	.59705	.60083	.60460	.60833	.61205	.61575
1.3	.61942	.62308	.62671	.63032	.63391	.63747	.64102	.64454	.64804	.65152
1.4	.65498	.65841	.66182	.66521	.66858	.67193	.67526	.67856	.68184	.68510
1.5	.68833	.69155	.69474	.69791	.70106	.70419	.70729	.71038	.71344	.71648
1.6	.71949	.72249	.72546	.72841	.73134	.73425	.73714	.74000	.74285	.74567
1.7	.74847	.75124	.75400	.75674	.75945	.76214	.76481	.76746	.77009	.77270
1.8	.77528	.77785	.78039	.78291	.78542	.78790	.79036	.79280	.79522	.79761
1.9	.79999	.80235	.80469	.80700	.80930	.81158	.81383	.81607	.81828	.82048
2.0	.82266	.82481	.82695	.82907	.83117	.83324	.83530	.83734	.83936	.84137
2.1	.84335	.84531	.84726	.84919	.85109	.85298	.85486	.85671	.85854	.86036
2.2	.86216	.86394	.86570	.86745	.86917	.87088	.87258	.87425	.87591	.87755
2.3	.87918	.88078	.88237	.88395	.88550	.88705	.88857	.89008	.89157	.89304
2.4	.89450	.89595	.89738	.89879	.90019	.90157	.90293	.90428	.90562	.90694
2.5	.90825	.90954	.91082	.91208	.91332	.91456	.91578	.91698	.91817	.91935
2.6	.92051	.92166	.92280	.92392	.92503	.92613	.92721	.92828	.92934	.93038
2.7	.93141	.93243	.93344	.93443	.93541	.93638	.93734	.93828	.93922	.94014
2.8	.94105	.94195	.94284	.94371	.94458	.94543	.94627	.94711	.94793	.94874
2.9	.94954	.95033	.95111	.95187	.95263	.95338	.95412	.95484	.95557	.95628
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
3	.95698	.96346	.96910	.97397	.97817	.98176	.98482	.98743	.98962	.99147
4	.99302	.99431	.99539	.99627	.99700	.99760	.99808	.99848	.99879	.99905
5	.99926	.99943	.99956	.99966	.99974	.99980	.99985	.99988	.99991	.99993

TABLE 23.—VALUES OF THE FACTOR $0.6745\sqrt{\frac{1}{n-1}}$

This factor occurs in the equation $r_s = 0.6745\sqrt{\frac{\Sigma v^2}{n-1}}$ for the probable error of a single observation, and other similar equations.

n	0	1	2	3	4	5	6	7	8	9
00			0.6745	0.4769	0.3894	0.3372	0.3016	0.2754	0.2549	0.2385
10	0.2248	0.2133	.2034	.1947	.1871	.1803	.1742	.1686	.1636	.1590
20	.1547	.1508	.1472	.1438	.1406	.1377	.1349	.1323	.1298	.1275
30	.1252	.1231	.1211	.1192	.1174	.1157	.1140	.1124	.1109	.1094
40	.1080	.1066	.1053	.1041	.1029	.1017	.1005	.0994	.0984	.0974
50	0.0964	0.0954	0.0944	0.0935	0.0926	0.0918	0.0909	0.0901	0.0893	0.0886
60	.0878	.0871	.0864	.0857	.0850	.0843	.0837	.0830	.0824	.0818
70	.0812	.0806	.0800	.0795	.0789	.0784	.0779	.0774	.0769	.0764
80	.0759	.0754	.0749	.0745	.0740	.0736	.0732	.0727	.0723	.0719
90	.0715	.0711	.0707	.0703	.0699	.0696	.0692	.0688	.0685	.0681

TABLE 24.—VALUES OF THE FACTOR $0.6745\sqrt{\frac{1}{n(n-1)}}$

This factor occurs in the equation $r_0 = 0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}}$ for the probable error of the arithmetical mean.

n		1	2	3	4	5	6	7	8	9
00			0.4769	0.2754	0.1947	0.1508	0.1231	0.1041	0.0901	0.0795
10	0.0711	0.0643	.0587	.0540	.0500	.0465	.0435	.0409	.0386	.0365
20	.0346	.0329	.0314	.0300	.0287	.0275	.0265	.0255	.0245	.0237
30	.0229	.0221	.0214	.0208	.0201	.0196	.0190	.0185	.0180	.0175
40	.0171	.0167	.0163	.0159	.0155	.0152	.0148	.0145	.0142	.0139
50	0.0136	0.0134	0.0131	0.0128	0.0126	0.0124	0.0122	0.0119	0.0117	0.0115
60	.0113	.0111	.0110	.0108	.0106	.0105	.0103	.0101	.0100	.0098
70	.0097	.0096	.0094	.0093	.0092	.0091	.0089	.0088	.0087	.0086
80	.0085	.0084	.0083	.0082	.0081	.0080	.0079	.0078	.0077	.0076
90	.0075	.0075	.0074	.0073	.0072	.0071	.0071	.0070	.0069	.0068

Part 1.—Values of the factor $0.8453\sqrt{\frac{1}{n(n-1)}}$

This factor occurs in the approximate equation $r = 0.8453 \frac{\Sigma|v|}{\sqrt{n(n-1)}}$ for the probable error of a single observation.

n		1	2	3	4	5	6	7	8	9
00			0.5978	0.3451	0.2440	0.1890	0.1543	0.1304	0.1130	0.0996
10	0.0891	0.0806	.0736	.0677	.0627	.0583	.0546	.0513	.0483	.0457
20	.0434	.0412	.0393	.0376	.0360	.0345	.0332	.0319	.0307	.0297
30	.0287	.0277	.0268	.0260	.0252	.0245	.0238	.0232	.0225	.0220
40	.0214	.0209	.0204	.0199	.0194	.0190	.0186	.0182	.0178	.0174
50	0.0171	0.0167	0.0164	0.0161	0.0158	0.0155	0.0152	0.0150	0.0147	0.0145
60	.0142	.0140	.0137	.0135	.0133	.0131	.0129	.0127	.0125	.0123
70	.0122	.0120	.0118	.0117	.0115	.0113	.0112	.0111	.0109	.0108
80	.0106	.0105	.0104	.0102	.0101	.0100	.0099	.0098	.0097	.0096
90	.0094	.0093	.0092	.0091	.0090	.0089	.0089	.0088	.0087	.0086

Part 2.—Values of $0.8453 \frac{1}{n\sqrt{n-1}}$

This factor occurs in the approximate equation $r_0 = 0.8453 \frac{\Sigma|v|}{n\sqrt{n-1}}$ for the probable error of the arithmetical mean.

n		1	2	3	4	5	6	7	8	9
00			0.4227	0.1993	0.1220	0.0845	0.0630	0.0493	0.0399	0.0332
10	0.0282	0.0243	.0212	.0188	.0167	.0151	.0136	.0124	.0114	.0105
20	.0097	.0090	.0084	.0078	.0073	.0069	.0065	.0061	.0058	.0055
30	.0052	.0050	.0047	.0045	.0043	.0041	.0040	.0038	.0037	.0035
40	.0034	.0033	.0031	.0030	.0029	.0028	.0027	.0027	.0026	.0025
50	0.0024	0.0023	0.0023	0.0022	0.0022	0.0021	0.0020	0.0020	0.0019	0.0019
60	.0018	.0018	.0017	.0017	.0017	.0016	.0016	.0016	.0015	.0015
70	.0015	.0014	.0014	.0014	.0013	.0013	.0013	.0013	.0012	.0012
80	.0012	.0012	.0011	.0011	.0011	.0011	.0011	.0010	.0010	.0010
90	.0010	.0010	.0010	.0009	.0009	.0009	.0009	.0009	.0009	.0009

Some of the most important results of physical science are embodied in the numerical magnitudes of various universal physical constants. The accurate determination of such constants has engaged the time and labor of many of the most eminent scientists. Some of these constants can be evaluated by various methods. The experiments used to study and measure these constants, in many instances have yielded some function of two or more of the constants (see Table 26) such as h/e; e/m, F/N, h/m, mN, $F(e/m)$, $e^2/(m/h)$, etc., rather than the direct value of the constant. Each of the many relations has been investigated by various experimenters at various times, and each investigation normally produces a result more or less different from that of any other investigation. Under such conditions there arises a general and continuous need for a searching examination of the most probable value of each important constant. This makes necessary some comparison and analysis of all these experimental data to arrive at the most probable value. An important factor in such work is that there are but few of the constants that do not require for their evaluation a knowledge of certain other constants. These relations are so extensive that most of the physical constants can be calculated from the value of five or six of the selected principal constants and certain ratios.

Many such critical reviews of these natural constants and conversion factors have appeared in the last 30 to 40 years. The data and discussion given here for the constants and their probable errors are the values arrived at by three physicists, R. T. Birge,[17] J. W. DuMond, and J. A. Bearden, and their associates, who have made some very careful reviews and critical studies of the published experimental data on these general physical constants and have published several papers giving what they consider as the most probable value. Reference should be made to their original papers for details.

Birge says in his 1941 paper that as a result of such critical work the situation in respect to these constants has vastly improved over values of about 10 years ago, and again one can say that such studies have resulted in more work and thus a more accurate set of constants.

In 1941 Birge[17] published a very extended list of physical constants and gave calculated values of many other physical constants that depend upon the fundamental constants. Because of the extent of this list, and also because so many of the relations among these constants are given therein, this 1941 list is given here. Almost all these constants in this table (Table 26) are accurate within the limits given.

DuMond and Cohen[18] prepared a table of some of these constants for the Atomic Energy Commission. A part of this appeared in the July 1953 issue of the Review of Modern Physics. Table 27 gives their values of a number of these physical constants.

Bearden and Watts[18a] in 1950 made a study of values of a number of physical constants, using some new values in their calculations. They are continuing this work and are now[18b] offering some new and more accurate values. Table 28 contains their 1950 values (corrected for their newer values) and newer calculated values of some additional constants.

A comparison of the final values of these fundamental physical constants arrived at by these physicists shows in a real manner the accuracy that may now be claimed. A number of the principal radiation constants were taken from these tables (Tables 26-28) and are given in Table 53. These values have been used for the calculations in the tables in this book since they were available when the work was started and since the newer values would make no practical changes.

[17] Phys. Rev. Suppl., vol. 1, p. 1, 1929; Rev. Mod. Phys., vol. 13, p. 233, 1941; Amer. Journ. Phys., vol. 13, p. 63, 1945.

[18] Phys. Rev., vol. 58, p. 457, 1940; Rev. Mod. Phys., vol. 20, p. 82, 1948.

[18a] Bearden, J. A., and Watts, H. M., Phys. Rev., vol. 81, p. 73, 1951.

[18b] Bearden, Earle, Minkowski, and Thomsen, private communication from J. A. Bearden.

TABLE 26.—GENERAL PHYSICAL CONSTANTS ACCORDING TO BIRGE *

Part 1.—Principal constants and ratios

Velocity of light	c	$= (2.99776 \pm 0.00004) \times 10^{10}$ cm sec^{-1}
Gravitation constant	G	$= (6.670 \pm 0.005) \times 10^{-8}$ dyne cm^2 g^{-2}
Liter (= 1000 ml)	l	$= 1000.028 \pm 0.002$ cm^3
Volume of ideal gas (0°C, A_0)	V_0	$= (22.4146 \pm 0.0006) \times 10^3$ cm^3 atm^{-1} mole^{-1}
	V'_0	$= 22.4140 \pm 0.0006$ l atm^{-1} mole^{-1}
Volume of ideal gas (0°C, A_{45})	V_{45}	$= (22.4157 \pm 0.0006) \times 10^3$ cm^3 atm^{-1} mole^{-1}
	V'_{45}	$= 22.4151 \pm 0.0006$ l atm^{-1} mole^{-1}
Atomic weights (see Part 2).		
Standard atmosphere	A_0	$= 1.013246 \pm 0.000004) \times 10^6$ dyne cm^{-2}
45° atmosphere	A_{45}	$= (1.013195 \pm 0.000004) \times 10^6$ dyne cm^{-2}
Ice-point (absolute scale)	T_0	$= 273.16 \pm 0.01$°K
Joule equivalent	J_{15}	$= 4.1855 \pm 0.0004$ abs joule/cal$_{15}$
Joule equivalent (electrical)	J'_{15}	$= 4.1847 \pm 0.0003$ int joule/cal$_{15}$
Faraday constant:		
(1) Chemical scale	F	$= 96501._2 \pm 10$ int coul/g equiv.
		$= 96487._7 \pm 1.0$ abs coul/g equiv.
		$= 9648.7_7 \pm 1.0$ abs emu/g equiv.
	F'	$= Fc = (2.89247 \pm 0.00030) \times 10^{14}$ abs esu/g equiv.
(2) Physical scale	F	$= 96514._0 \pm 10$ abs coul/g equiv.
		$= 9651.4_0 \pm 1.0$ abs emu/g equiv.
	F'	$= Fc = (2.89326 \pm 0.00030) \times 10^{14}$ abs esu/g equiv.
Avogadro number (chemical scale)	N_0	$= (6.0228_3 \pm 0.0011) \times 10^{23}$ molecules/mole
Electronic charge	e	$= F/N_0 = (1.60203_3 \pm 0.00034) \times 10^{-20}$ abs emu
	e'	$= ec = (4.8025_1 \pm 0.0010) \times 10^{-10}$ abs esu
Specific electronic charge	e/m	$= (1.7592 \pm 0.0005) \times 10^7$ abs emu/g
	e'/m	$= ec = (5.2766 \pm 0.0015) \times 10^{17}$ abs esu/g
Planck's constant	h	(see Part 4)

Part 2.—Atomic weights

(1) Physical scale ($O^{16} = 16.0000$)

$_1H^1 = 1.00813 \pm 0.00001_7$ $\qquad$ $_1H^2 = 2.01473 \pm 0.00001_9$

$_1H = 1.00827_6 \pm 0.00001_7$

(from H^1/H^2 abundance $= 6900 \pm 100$)

$_2He^4 = 4.00389 \pm 0.00007$

$_6C^{12} = 12.00386 \pm 0.0004$ $\qquad$ $_6C^{13} = 13.00761 \pm 0.00015$

$C = 12.01465 \pm 0.00023$

(from C^{12}/C^{13} abundance $= 92 \pm 2$)

$_7N^{14} = 14.00753 \pm 0.00005$ $\qquad$ $_7N^{15} = 15.0049 \pm 0.0002$

$N = 14.01121 \pm 0.00009_5$

(from N^{14}/N^{15} abundance $= 270 \pm 6$)

$_8O^{16} = 16.0000$ $\qquad$ $_8O^{17} = 17.0045$ $\qquad$ $_8O^{18} = 18.0049$

$O = 16.00435_7 \pm 0.00008_0$

[from abundance $O^{16} : O^{18} : O^{17} = (506 \pm 10) : 1 : (0.204 \pm 0.008)$]

(2) Chemical scale ($0 = 16.0000$)

Ratio physical to chemical scale:

$r = (16.004357 \pm 0.000086)/16 = 1.00272 \pm 0.000005$

$H^1 = 1.00785_6 \pm 0.00001_8$ (from physical scale)

$H^2 = 2.01418_2 \pm 0.00002_1$ (from physical scale)

$H = 1.00800_2 \pm 0.00001_8$ (from physical scale)

$He^4 = 4.00280 \pm 0.00007$ (from physical scale)

$C = 12.01139 \pm 0.00024$ (from physical scale)

$N = 14.00740 \pm 0.00012$ (from physical scale)

$N = 14.0086 \pm 0.0007$ (direct observation)

$Na = 22.994 \pm 0.003$

$Cl = 35.457 \pm 0.001$

$Ca = 40.080 \pm 0.005$

$Ag = 107.880 \pm 0.002$

$I = 126.915 \pm 0.004$

* Unless otherwise specified, all quantities in this table that involve the mol or the gram equivalent are on the chemical scale of atomic weights.

(*continued*)

TABLE 26.—GENERAL PHYSICAL CONSTANTS ACCORDING TO BIRGE (continued)

Part 3.—Additional quantities evaluated or used in connection with Part 1

Quantity	Symbol	Value
Ratio of esu to emu (direct)	c'	$= (2.9971_2 \pm 0.0001) \times 10^{10}$ cm$^{1/2}$ sec$^{-1/2}$ ohm$^{1/2}$ $= (2.9978_4 \pm 0.0001_0) \times 10^{10}$ cm/sec
Ratio of esu to emu (indirect)	c'	$= c = (2.99776 \pm 0.0004) \times 10^{10}$ cm/sec
Average density of earth	δ	$= 5.517 \pm 0.004$ g/cm^3
Maximum density of water	$\delta_m(H_2O)$	$= 0.999972 \pm 0.000002$ g/cm^3
Acceleration of gravity (standard)	g_0	$= 980.665$ cm/sec^2
Acceleration of gravity (45°)	g_{45}	$= 980.616$ cm/sec^2
Density of oxygen gas (0°C, A_{45})	L_1	$= 1.42897 \pm 0.0003$ g/liter
Limiting density of oxygen gas (0°C, A_{45})	L_{lim}	$= 1.427609 \pm 0.000037$ g/liter
Factor converting oxygen (0°C, A_{45}) to ideal gas	$1 - \alpha$	$= 1.000953_5 \pm 0.000009_4$
Specific gravity of Hg (0°C, A_0) referred to air-free water at maximum density	ρ_0	$= 13.59542 \pm 0.00005$
Density of Hg (0°C, A_0)	D_0	$= 13.59504_0 \pm 0.00005_7$ g/cm^3
Electrochemical equivalents (chemical scale):		
Silver (apparent)	E_{Ag}	$= (1.11800 \pm 0.00012) \times 10^{-3}$ g/int coul
Silver (corrected)	E_{Ag}	$= (1.11807 \pm 0.00012) \times 10^{-3}$ g/abs coul
Iodine (apparent)	E_I	$= (1.315026 \pm 0.000025) \times 10^{-3}$ g/int coul
Iodine (corrected)	E_I	$= (1.31535 \pm 0.00014) \times 10^{-3}$ g/abs coul
Effective calcite grating space (18°C) Siegbahn system	d''_{18}	$= 3.02904 \times 10^{-8}$ cm
True calcite grating space (20°C) Siegbahn system	d'_{20}	$= 3.02951_2 \times 10^{-8}$ cm
True calcite grating space (20°C) cgs system	d_{20}	$= (3.03567_4 \pm 0.00018) \times 10^{-8}$ cm
Ratio of grating and Siegbahn scales of wavelengths	λ_g/λ_s	$= 1.002034 \pm 0.000060$
Density of calcite (20°C)	ρ	$= 2.71029 \pm 0.00003$ g/cm^3
Structural constant of calcite (20°C)	Φ	$= 1.09594 \pm 0.00001$
Molecular weight of calcite (chemical scale)	M	$= 100.091_4 \pm 0.005$
Rydberg constant for hydrogen (H^1)	R_H	$= 109677.581_2 \pm 0.007_5$ cm^{-1} (I.A. scale)
Rydberg constant for deuterium (H^2)	R_D	$= 109707.419_3 \pm 0.007_5$ cm^{-1} (I.A. scale)
Rydberg constant for helium	R_{He}	$= 109722.263 \pm 0.012$ cm^{-1} (I.A. scale)
Rydberg constant for infinite mass	R_∞	$= 109737.303 \pm 0.017$ cm^{-1} (I.A. scale) or ± 0.05 cm^{-1} (cgs system)

(*continued*)

TABLE 26.—GENERAL PHYSICAL CONSTANTS ACCORDING TO BIRGE (continued)

Part 4.—Partial list of derived quantities

Planck's constant:

$$h = \left\{\frac{2\pi^2 c^3 F^5}{R_\infty N_0^5 (e/m)}\right\}^{1/3} \ldots\ldots\ldots\ldots = (6.624_2 \pm 0.002_4) \times 10^{-27} \text{ erg sec}$$

$$h/e = \left\{\frac{2\pi^2 c^3 F^2}{R_\infty N_0^2 (e/m)}\right\}^{1/3} \ldots\ldots\ldots\ldots = (4.1349_0 \pm 0.0007_1) \times 10^{-7} \text{ erg sec abs emu}^{-1}$$

$$h/e' = h/(ec) = \left\{\frac{2\pi^2 F^2}{R_\infty N_0^2 (e/m)}\right\}^{1/3} = (1.3793_3 \pm 0.0002_3) \times 10^{-17} \text{ erg sec abs esu}^{-1}$$

Atomic weight of electron: .... $E = F/(e/m)$

(Physical scale) .... $= (5.4862_4 \pm 0.0017) \times 10^{-4}$

(Chemical scale) .... $= (5.4847_5 \pm 0.0017) \times 10^{-4}$

Band spectra constant connecting wave number and moment of inertia:

$$h/(8\pi^2 c) = \left\{\frac{F^5}{256\pi^4 R_\infty N_0^5 (e/m)}\right\}^{1/3} \ldots\ldots = (27.98_{65} \pm 0.01_0) \times 10^{-40} \text{ g cm}$$

Boltzmann constant:

$K = R_0/N_0 = V_0 A_0/(T_0 N_0)$ .... $= (1.38047_4 \pm 0.00026) \times 10^{-16}$ erg/deg

Charge in electrolysis of 1 gram of H

$F/H = 9572.1_{73} \pm 1.0$ abs. emu/g

Charge in electrolysis of one gram of H^1 .... $e/M_H{}^1 = F\,H' = 9573.5_{60} \pm 1.0$ abs emu/g

Compton shift at 90°:

$$h/(mc) = \left\{\frac{2\pi^2 F^2 (e/m)^2}{R_\infty N_0^2}\right\}^{1/3} \ldots\ldots\ldots = (0.024265_{14} \pm 0.000005_7) \times 10^{-8} \text{ cm}$$

Energy in ergs of one abs volt-electron:

$E_0 = 10^8 e = 10^8 F/N_0$ .... $= (1.60203_3 \pm 0.00034) \times 10^{-12}$ erg

Energy in calories per mole for one abs volt-electron per molecule:

$$\frac{F(\text{abs coul/gram-equiv.})}{J_{15}(\text{abs joules/cal})} \ldots\ldots\ldots\ldots = 23052_{.85} \pm 3_{.2} \text{ cal}_{15} \text{ mole}^{-1}$$

Fine structure constant:

$$\alpha = 2\pi(e')^2/(hc) = \left\{\frac{4\pi R_\infty F(e/m)}{N_0}\right\}^{1/3} = (7.2976_6 \pm 0.0008_6) \times 10^{-3}$$

$1/\alpha = 137.030_2 \pm 0.016$

$\alpha^2 = (5.3256 \pm 0.0013) \times 10^{-5}$

Gas constant per mole:

$R_0 = V_0 A_0/T_0$ .... $= (8.31436 \pm 0.00038) \times 10^7$ erg deg^{-1} mole^{-1}

$R'_0 = R_0 \times 10^{-7}/J_{15}$ .... $= 1.98646_7 \pm 0.00021$ cal$_{15}$ deg^{-1} mole^{-1}

$R''_0 = V''_0/T_0$ .... $= (8.20544_7 \pm 0.00037) \times 10^{-2}$ l atm deg^{-1} mole^{-1}

$R'''_0 = R_0/A_0 = V_0/T_0$ .... $= 82.0566_7 \pm 0.0037$ cm^3 atm deg^{-1} mole^{-1}

also:

$R_0 T_0 = V_0 A_0$ .... $= (2.27115_0 \pm 0.00006) \times 10^{10}$ erg mole^{-1}

Loschmidt number (0°C, A_0) $n_0 = N_0/V_0$. $= (2.6870_{12} \pm 0.0005_0) \times 10^{19}$ molecules/cm^3

Magnetic moment of one Bohr magneton:

$$\mu_1 = (h/4\pi)(e/m) = \frac{1}{4\pi}\left\{\frac{2\pi^2 c^3 F^5 (e/m)^2}{R_\infty N_0^5}\right\}^{1/3} \ldots\ldots\ldots = (0.9273_{45} \pm 0.0003_7) \times 10^{-20} \text{ erg/gauss}$$

Magnetic moment per mole for one Bohr magneton per molecule:

$$\mu_1 N_0 = \frac{1}{4\pi}\left\{\frac{2\pi^2 c^3 F^5 (e/m)^2}{R_\infty N_0^2}\right\}^{1/3} \ldots\ldots = 5585.2_4 \pm 1.6 \text{ erg gauss}^{-1} \text{ mole}^{-1}$$

Mass of α-particle..$M\alpha = (He - 2E)/N_0 = (6.6442_2 \pm 0.0012) \times 10^{-24}$ g

(continued)

TABLE 26.—GENERAL PHYSICAL CONSTANTS ACCORDING TO BIRGE (concluded)

Mass of atom of unit atomic weight,

$$M_0 = 1/N_0 = (1.66035 \pm 0.00031) \times 10^{-24} \text{ g}$$

Mass of electron;

$$m = e/(e/m) = (F/N_0)/(e/m) = (9.1066_0 \pm 0.0032) \times 10^{-28} \text{ g}$$

Mass of H¹ atom......... $M_H 1 = H^1/N_0 = (1.67339_3 \pm 0.0031) \times 10^{-24}$ g

Mass of proton...... $M_P = (H^1 - E)/N_0 = (1.67248_2 \pm 0.00031) \times 10^{-24}$ g

Ratio mass H¹ atom to mass electron:

$$M_H 1/m = (e/m)(H^1/F) \ldots\ldots\ldots\ldots = 1837.5_{01} \pm 0.5_6$$

Ratio mass proton to mass electron:

$$M_p/m = (e/m)\left(\frac{(H^1 - E)}{F}\right) \ldots\ldots\ldots = 1836.5_{01} \pm 0.5_6$$

First radiation constant..... $c_1{}^{**} = 8\pi hc = (4.9908 \pm 0.0024) \times 10^{-15}$ erg cm

$$= hc^2 = (0.59542 \pm 0.0024) \times 10^{-5} \text{ erg cm}^2 \text{ sec}^{-1}$$

$$= 2\pi hc^2 = (3.7403 \pm 0.0024) \times 10^{-5} \text{ erg cm}^2 \text{ sec}^{-1}$$

Second radiation constant:

$$c_2 = hc/k = \frac{T_0 c^2}{V_0 A_0}\left\{\frac{2\pi^2 F^5}{R_\infty N_0^2 (e/m)}\right\}^{1/3} = 1.4384_8 \pm 0.0003_4 \text{ cm deg}$$

Specific charge of α-particle:

$$2e/M_\alpha = \frac{2F}{He - 2E} \ldots\ldots\ldots\ldots\ldots\ldots = 4822.3_3 \pm 0.5_1 \text{ abs emu/g}$$

Specific charge of proton:

$$e/M_P = \frac{F}{H^1 - E} \ldots\ldots\ldots\ldots\ldots\ldots = 9578.7_7 \pm 1.0 \text{ abs emu/g}$$

Radiation density constant,

$$a = 8\pi^5 k^4/(15c^3 h^3) =$$

$$\left(\frac{V_0 A_0}{T_0}\right)^4 \frac{4\pi^3 N_0 R_\infty (e/m)}{15 c^6 F^5} \ldots\ldots\ldots\ldots = (7.569_{42} \pm 0.004_9) \times 10^{-15} \text{ erg cm}^{-3} \text{ deg}^{-4}$$

Stefan-Boltzmann constant: †

$$\sigma = ac/4 = 2\pi^5 k^4/(15c^2 h^3) \ldots\ldots\ldots = \left(\frac{V_0 A_0}{T_0}\right)^4 \frac{\pi^3 N_0 R_\infty (e/m)}{15(Fc)^5}$$

$$= (5.672_{83} \pm 0.003_7) \times 10^{-5} \text{ erg cm}^{-2} \text{ deg}^{-4} \text{ sec}^{-1}$$

Wien's displacement-law constant..... $A = c_2/4.965114 = 0.28971_8 \pm 0.00007$ cm deg

Wavelength associated with 1 abs volt:

$$\lambda_0 = 10^{-8} c^2 (h/e') = \frac{c^2}{10^8}\left\{\frac{2\pi^2 F^2}{R_\infty N_0^2 (e/m)}\right\}^{1/3} = (12395._4 \pm 2._1) \times 10^{-8} \text{ cm abs volt}$$

Wave number associated with 1 abs volt:

$$s_0 = 1/\lambda_0 = \frac{10^8}{c^2}\left\{\frac{R_\infty N_0^2 (e/m)}{2\pi^2 F^2}\right\}^{1/3} = 8067.4_9 \pm 1.4 \text{ cm/abs volt}$$

Zeeman displacement per gauss $(e/m)/(4\pi c) = 4.6699_1 \pm 0.0013) \times 10^{-5}$ cm/gauss

** J_λ may be defined in several ways and this determines the value of c_1. If $J_\lambda d\lambda$ gives the energy density of unpolarized radiation in range $d\lambda$, then $c_1 = 8\pi hc$. If $J_\lambda d\lambda$ gives the emission of linearly polarized light, in range $d\lambda$ per unit solid angles perpendicular to the surface, then $c_1 = hc^2$. If this expression $J_\lambda d\lambda$ denotes the emission of radiation in range $d\lambda$, per unit surface from one side in all directions (2π solid angle) then $c_1 = 2\pi hc^2$. See Table 53.

† For 2π solid angle.

Part 5.—Birge's 1944 values of 3 constants

e, Electronic charge....................	$= (4.8021 \pm 0.0006) \times 10^{-10}$ abs esu
N_0, Avogadro number..................	$= (6.02338 \pm 0.00043) \times 10^{23}$ molecules mole⁻¹ (chemical scale)
F, Faraday constant....................	$= 96487.7 \pm 10$ abs coul (chemical scale)

TABLE 27.—TABLE OF LEAST-SQUARES ADJUSTED OUTPUT VALUES OF PHYSICAL CONSTANTS (BY DuMOND AND ASSOCIATES)

(November 1952)

Part 1.—Auxiliary constants used

These auxiliary constants are quantities which are uncorrelated (observationally) with the variables of the least-squares adjustment.

Rydberg wave number for infinite mass. $R_\infty = 109737.309 \pm 0.012\ cm^{-1}$

Rydberg wave numbers for the light nuclei

$R_H = 109677.576 \pm 0.012\ cm^{-1}$

$R_D = 109707.419 \pm 0.012\ cm^{-1}$

$R_{He^3} = 109717.345 \pm 0.012\ cm^{-1}$

$R_{He^4} = 109722.267 \pm 0.012\ cm^{-1}$

Atomic mass of neutron .... $n = 1.008982 \pm 0.000003$

Atomic mass of hydrogen .... $H = 1.008142 \pm 0.000003$

Atomic mass of deuterium .... $D = 2.014735 \pm 0.000006$

Gas constant per mole (physical scale). $R_0 = (8.31662 \pm 0.00038) \times 10^7$ erg mole^{-1} deg^{-1}C

Standard volume of a perfect gas (physical scale) .... $V_0 = 22420.7 \pm 0.6\ cm^3\ atmos^{-1}\ mole^{-1}$

Part 2.—Least-squares adjusted output values

(The quantity following each ± sign is the standard error by external consistency)

Velocity of light .... $c = 299792.9 \pm 0.8$ km sec^{-1}

Avogadro's constant (physical scale)... $N = (6.02472 \pm 0.00036) \times 10^{23}$ (molecules mol)$^{-1}$

Loschmidt's constant (physical scale)....

$L_0 = N/V_0 = (2.68713 \pm 0.00016) \times 10^{19}$ molecules cm^{-3}

Electronic charge .... $e = (4.80288 \pm 0.00021) \times 10^{-10}$ esu

$e' = e/c = (1.60207 \pm 0.00007) \times 10^{-20}$ emu

Electron rest mass.................... $m = (9.1085 \pm 0.0006) \times 10^{-28}$ g

Proton rest mass............ $m_p = M_p/N = (1.67243 \pm 0.00010) \times 10^{-24}$ g

Neutron rest mass............ $m_n = n/N = (1.67474 \pm 0.00010) \times 10^{-24}$ g

Planck's constant .... $h = (6.6252 \pm 0.0005) \times 10^{-27}$ erg sec

$\hbar = h/(2\pi) = (1.05444 \pm 0.00009) \times 10^{-27}$ erg sec

Conversion factor from Siegbahn X-units to milliangstroms .... $\lambda_g/\lambda_s = 1.002063 \pm 0.000034$

Faraday constant (physical scale) $F = Ne = (2.89360 \pm 0.00007) \times 10^{14}$ esu (g mol)$^{-1}$

$F' = Ne/c = (9652.01 \pm 0.25)$ emu (gm mol)$^{-1}$

Charge-to-mass ratio of the electron.. $e/m = (5.27299 \pm 0.00016) \times 10^{17}$ esu g^{-1}

$e'/m = e/(mc) = (1.7588 \pm 0.00005) \times 10^7$ emu g^{-1}

Ratio h/e .... $h/e = (1.37943 \pm 0.00005) \times 10^{-17}$ erg sec (esu)$^{-1}$

Fine structure constant ...... $\alpha = e^2/(\hbar c) = (7.29726 \pm 0.00008) \times 10^{-3}$

$1/\alpha = 137.0377 \pm 0.0016$

$\alpha/2\pi = (1.161396 \pm 0.000013) \times 10^{-3}$

$\alpha^2 = (5.32501 \pm 0.00012) \times 10^{-5}$

$1 - (1 - \alpha^2)^{\frac{1}{2}} = (0.266254 \pm 0.000006) \times 10^{-4}$

Atomic mass of the electron (physical scale) .... $Nm = (5.48760 \pm 0.00013) \times 10^{-4}$

Ratio of mass of hydrogen to mass of proton [a]

$$H/H^+ = \left[1 - \frac{Nm}{H}(1 - \tfrac{1}{2}\alpha^2)\right]^{-1} = 1.000544610 \pm 0.000000013$$

Atomic mass of proton.............. $H^+ = 1.007593 \pm 0.000003$

Ratio of proton mass to electron mass...

$H^+/Nm = 1836.13 \pm 0.04$

Reduced mass of electron in hydrogen atom .... $\mu = mH^+/H = (9.1035 \pm 0.0006) \times 10^{-28}$ g

Schrödinger constant for a fixed nucleus

$2m/\hbar^2 = (1.63844 \pm 0.00016) \times 10^{27}$ erg^{-1} cm^{-2}

Schrödinger constant for the hydrogen atom .... $2\mu/\hbar^2 = (1.63755 \pm 0.00016) \times 10^{27}$ erg^{-1} cm^{-2}

First Bohr radius.......... $a_0 = \hbar^2/(me^2) = (5.29171 \pm 0.00006) \times 10^{-9}$ cm $= \alpha/(4\pi R_\infty)$

[a] The binding energy of the electron in the hydrogen atom has been included in the quantity. The mass of the electron when found in the hydrogen atom is not m but more correctly $m\ (1 - 1/2\ \alpha^2 + \cdot\cdot)$.

(*continued*)

TABLE 27.—TABLE OF LEAST-SQUARES ADJUSTED OUTPUT VALUES OF PHYSICAL CONSTANTS (continued)

Radius of electron orbit in normal H^1, referred to center of mass............
$a_0' = a_0(1-\alpha^2)^{\frac{1}{2}} = (5.29157 \pm 0.00006) \times 10^{-9}$ cm

Separation of proton and electron in normal H^1 ....$a_0'' = a_0' R_\infty/R_H = (5.29445 \pm 0.00006) \times 10^{-9}$ cm

Compton wavelength of the electron......
$\lambdabar_{ce} = h/(mc) = (24.2625 \pm 0.0006) \times 10^{-11}\text{ cm} = \alpha^2/(2R_\infty)$
$\lambdabar_{ce} = \lambda_{ce}/(2\pi) = (3.86150 \pm 0.00009) \times 10^{-11}\text{ cm} = \alpha^2/(4\pi R_\infty)$

Compton wavelength of the proton......
$\lambda_{cp} = h/m_pc = (13.2139 \pm 0.0004) \times 10^{-14}$ cm
$\lambdabar_{cp} = \lambda_{cp}/(2\pi) = (2.10307 \pm 0.00007) \times 10^{-14}$ cm

Compton wavelength of the neutron.....
$\lambda_{cn} = h/m_nc = (13.1958 \pm 0.0004) \times 10^{-14}$ cm
$\lambdabar_{cn} = \lambda_{cn}/(2\pi) = (2.10017 \pm 0.00007) \times 10^{-14}$ cm

Classical electron radius....$r_0 = e^2/(mc^2) = (2.81784 \pm 0.00010) \times 10^{-13}\text{ cm} = \alpha^3/(4\pi R_\infty)$
$r_0^2 = (7.9402 \pm 0.0005) \times 10^{-26}\text{ cm}^2$

Thompson cross section........... $\frac{8}{3}\pi r_0^2 = (6.65196 \pm 0.0005) \times 10^{-25}\text{ cm}^2$

Fine structure doublet separation in hydrogen ....
$$\Delta E_H = \frac{1}{16} R_H \alpha^2 \left[1 + \frac{\alpha}{\pi} + \left(\frac{5}{8} - \frac{5.946}{\pi^2} \right) \alpha^2 \right]$$
$= 0.365869 \pm 0.000008\text{ cm}^{-1}$
$= 10968.49 \pm 0.25\text{ Mc sec}^{-1}$

Fine structure separation in deuterium...
$\Delta E_D = \Delta E_H\, R_D/R_H = 0.365969 \pm 0.000008\text{ cm}^{-1}$
$= 10971.48 \pm 0.25\text{ Mc/sec}^{-1}$

Zeeman displacement per gauss.........
$(e/mc)/(4\pi c) = (4.66879 \pm 0.00015) \times 10^{-5}\text{ cm}^{-1}\text{ gauss}^{-1}$

Boltzmann's constant ....$k = R_0/N = (1.38042 \pm 0.00010) \times 10^{-16}\text{ ergs deg}^{-1}$
$k = (8.6164 \pm 0.0004) \times 10^{-5}\text{ ev deg}^{-1}$
$1/k = 11605.7 \pm 0.5\text{ deg ev}^{-1}$

First radiation constant.......$c_1 = 8\pi hc = (4.9919 \pm 0.0004) \times 10^{-15}$ erg cm

Second radiation constant......$c_2 = hc/k = (1.43884 \pm 0.00008)$ cm deg

Atomic specific heat constant........$c_2/c = (4.79946 \pm 0.00027) \times 10^{-11}$ sec deg

Wien displacement law constant [b]..$\lambda_{max}T = c_2/(4.96511423) = 0.28979 \pm 0.00005$ cm deg

Stefan-Boltzmann constant ....
$\sigma = (\pi^2/60)(k^4/\hbar^3c^2) = (0.56686 \pm 0.00005) \times 10^{-4}\text{ erg cm}^{-2}\text{ deg}^{-4}\text{ sec}^{-1}$

Sackur-Tetrode constant ....$S_0/R_0 = \frac{5}{2} + ln\{(2\pi R_0)^{3/2}\ h^{-3}\ N^{-4}\}$
$= -5.57324 \pm 0.00011$
$S_0 = -(46.3505 \pm 0.0017) \times 10^7\text{ erg mole}^{-1}\text{ deg}^{-1}$

Bohr magneton ....
$\mu_0 = he/(4\pi mc) = \frac{1}{2} e \lambdabar_{ce} = (0.92732 \pm 0.00006) \times 10^{-20}\text{ erg gauss}^{-1}$

Anomalous electron moment correction...
$\left[1 + \frac{\alpha}{2\pi} - 2.973 \frac{\alpha^2}{\pi^2} \right] = \mu_e/\mu_0 = 1.001145356 \pm 0.000000013$

Magnetic moment of the electron......$\mu_e = (0.92838 \pm 0.00006) \times 10^{-20}\text{ erg gauss}^{-1}$

Nuclear magneton ....
$\mu_n = he/(4\pi m_pc) = \mu_0 Nm/H^+ = 0.505038 \pm 0.000036) \times 10^{-23}\text{ erg gauss}^{-1}$

Proton moment ....$\mu = 2.79277 \pm 0.00006$ nuclear magnetons
$= (1.41045 \pm 0.00009) \times 10^{-23}\text{ erg gauss}^{-1}$

Gyromagnetic ratio of the proton in hydrogen (uncorrected for diamagnetism)
$\gamma' = (2.67520 \pm 0.00008) \times 10^4\text{ radians sec}^{-1}\text{ gauss}^{-1}$

Gyromagnetic ratio of the proton (corrected) ....$\gamma = (2.67527 \pm 0.00008) \times 10^4\text{ radians sec}^{-1}\text{ gauss}^{-1}$

Multiplier of (Curie constant)$^{\frac{1}{2}}$ to give magnetic moment per molecule. $(3k/N)^{\frac{1}{2}} = (2.62178 \pm 0.00017) \times 10^{-20}\ (\text{erg mole deg}^{-1})^{\frac{1}{2}}$

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[b] The numerical constant 4.96511423 is the root of the transcendental equation $x = 5\ (1 - e^{-x})$.

(continued)

TABLE 27.—TABLE OF LEAST-SQUARES ADJUSTED OUTPUT VALUES OF PHYSICAL CONSTANTS (concluded)

Mass-energy conversion factors	1 g =	$(5.60999 \pm 0.00025) \times 10^{26}$ Mev
	1 electron mass =	0.510984 ± 0.000016 Mev
	1 atomic mass unit =	931.162 ± 0.024 Mev
	1 proton mass =	938.232 ± 0.024 Mev
	1 neutron mass =	939.526 ± 0.024 Mev
Quantum energy conversion factors	$1\ ev =$	$(1.60207 \pm 0.00007) \times 10^{-12}$ erg
	$E/\tilde{\nu} =$	$(1.98620 \pm 0.00016) \times 10^{-16}$ erg cm
	$E\lambda_g =$	$(12397.8 \pm 0.5) \times 10^{-8}$ ev-cm
	$E\lambda_s =$	12372.2 ± 0.4 k volt-x units
	$E/\nu =$	$(6.6252 \pm 0.0005) \times 10^{-27}$ erg sec
	$E/\nu =$	$(4.13544 \pm 0.00015) \times 10^{-15}$ ev-sec
	$\tilde{\nu}/E =$	$(5.0347 \pm 0.0004) \times 10^{15}$ cm^{-1} erg^{-1}
	$\tilde{\nu}/E =$	(8065.98 ± 0.30) cm^{-1} ev^{-1}
	$\nu/E =$	$(1.50938 \pm 0.00012) \times 10^{26}$ sec^{-1} erg^{-1}
	$\nu/E =$	$(2.41812 \pm 0.00009) \times 10^{14}$ sec^{-1} ev^{-1}
de Broglie wavelengths, λ_D of elementary particles [c]		
Electrons	$\lambda_{De} =$	(7.27373 ± 0.00016) cm^2 sec^{-1}/v
	=	$(1.55226 \pm 0.00008) \times 10^{-13}$ cm (erg)$^{1/2}/\sqrt{E}$
	=	$(1.226377 \pm 0.000032) \times 10^{-7}$ cm (ev)$^{1/2}/\sqrt{E}$
Protons	$\lambda_{Dp} =$	$(3.96145 \pm 0.00013) \times 10^{-3}$ cm^2 sec^{-1}/v
	=	$(3.62261 \pm 0.00020) \times 10^{-15}$ cm (erg)$^{1/2}/\sqrt{E}$
	=	$(2.86208 \pm 0.00012) \times 10^{-9}$ cm (ev)$^{1/2}/\sqrt{E}$
Neutrons	$\lambda_{Dn} =$	$(3.95599 \pm 0.00013) \times 10^{-3}$ cm^2 sec^{-1}/v
	=	$(3.62005 \pm 0.00020) \times 10^{-15}$ cm (erg)$^{1/2}/\sqrt{E}$
	=	$(2.86005 \pm 0.00012) \times 10^{-9}$ cm (ev)$^{1/2}/\sqrt{E}$
Energy of 2200 m/sec neutron	$E_{2200} =$	0.0252977 ± 0.0000006 ev
Velocity of 1/40 ev neutron	$v_{0.025} =$	2187.017 ± 0.028 m/sec
The Rydberg and related derived constants		
	$R_\infty =$	109737.309 ± 0.012 cm^{-1}
	$R_\infty c =$	$(3.289847 \pm 0.000008) \times 10^{15}$ sec^{-1}
	$R_\infty hc =$	$(2.17961 \pm 0.00018) \times 10^{-11}$ ergs
	$\dfrac{R_\infty hc^2 \times 10^{-8}}{e} =$	13.6050 ± 0.0005 ev
Hydrogen ionization potential	$I_0 =$	13.5978 ± 0.0005 ev
	=	$R_H \dfrac{hc^2}{e}\left[1 + \dfrac{\alpha^2}{4} + \cdots\right] \times 10^{-8}$

[c] These formulas apply only to non-relativistic velocities. If the velocity of the particle is not negligible compared to the velocity of light, c, or the energy not negligible compared to the rest mass energy, we must use $\lambda_D = \lambda_c[\epsilon(\epsilon + 2)]^{-1/2}$ where λ_c is the appropriate Compton wavelength and ϵ is the kinetic energy measured in units of the particle rest mass.

TABLE 28.—GENERAL PHYSICAL CONSTANTS ACCORDING TO BEARDEN AND ASSOCIATES *

Part 1 † (atomic weights according to the physical scale unless otherwise indicated)

Least-squares adjusted values of the fundamental atomic constants

Quantity	Symbol	Value
Atomic mass of hydrogen	$H =$	$(1.008142 \pm .000003)$
Atomic mass of deuterium	$D =$	$(2.014735 \pm .000006)$
Atomic mass of deuteron	$d =$	$(2.014186 \pm .000006)$
Atomic mass of proton	$M =$	$(1.007593 \pm .000003)$
Atomic mass of electron	$Nm =$	$(5.48756 \pm .00018) \times 10^{-4}$
Electron mass	$m =$	$(9.10818 \pm .00079) \times 10^{-28}$ g
Reduced electron mass in hydrogen atom	$\mu =$	$(9.10322 \pm .00072) \times 10^{-28}$ g
Ratio proton mass to electron mass	$M/mN =$	$(1836.139 \pm .054)$
Ratio of Siegbahn X-unit to milliangstrom	$\lambda_g/\lambda_s =$	$(1.002058 \pm .000039)$
Ratio of physical to chemical scales of atomic weights	$r =$	$(1.0002783 \pm .0000005)$
Faraday	$F =$	$(9652.14 \pm .33)$ emu (g-equiv)$^{-1}$
Electron charge	$e =$	$(4.80283 \pm .00022) \times 10^{-10}$ esu
Specific electronic charge	$e/m =$	$(5.27309 \pm .00024) \times 10^{17}$ esu g^{-1}
Planck's constant	$h =$	$(6.62509 \pm .00059) \times 10^{-27}$ erg sec
Planck's constant $\times 1/2\pi$	$\hbar =$	$(1.05442 \pm .00009) \times 10^{-27}$ erg sec
	$h/e =$	$(1.37941 \pm .00006) \times 10^{-17}$ erg sec (esu)$^{-1}$
	$h/m =$	$(7.27377 \pm .00017)$ cm^2 sec^{-1}
Avogadro's number	$N =$	$(6.02487 \pm .00045) \times 10^{23}$ molecules (g-mol)$^{-1}$
Boltzmann's constant	$k =$	$(1.38039 \pm .00010) \times 10^{-16}$ erg deg^{-1}
Loschmidt's number	$n_0 =$	$(2.68719 \pm .00020) \times 10^{19}$ molecules cm^{-3}
Rydberg for infinite mass	$R_\infty =$	$(109737.311 \pm .012)$ cm^{-1}
Rydberg for hydrogen	$R_H =$	$(109677.578 \pm .012)$ cm^{-1}
Rydberg for deuterium	$R_D =$	$(109707.419 \pm .012)$ cm^{-1}
Gas constant per mole	$R_0 =$	$(8.31665 \pm .00034) \times 10^{7}$ erg mol^{-1} deg^{-1}
Molar volume	$V_0 =$	$(2.24207 \pm .00004) \times 10^{4}$ cm^3 mol^{-1}
Fine structure constant	$\alpha =$	$(7.29729 \pm .00008) \times 10^{-3}$
	$1/\alpha =$	$(137.0371 \pm .0016)$
Velocity of light	$c =$	$(2.997925 \pm .000008) \times 10^{10}$ cm sec^{-1}
First radiation constant	$c_1 =$	$(4.99175 \pm .00044) \times 10^{-15}$ erg cm
Second radiation constant	$c_2 =$	$(1.43884 \pm .00004$ cm deg
Stefan-Boltzmann constant	$\sigma =$	$(5.66858 \pm .00053) \times 10^{-5}$ erg cm^{-2} deg^{-4} sec^{-1}
Wien displacement law constant	$\lambda_{max} T =$	$(.289789 \pm .000009)$ cm deg
Bohr magneton	$\mu_0 =$	$(.927313 \pm .000055) \times 10^{-20}$ erg gauss^{-1}
Theoretical magnetic moment of electron	$\mu_e =$	$(.928375 \pm .000055) \times 10^{-20}$ erg gauss^{-1}
First Bohr radius	$a_0 =$	$(5.29173 \pm .00006) \times 10^{-9}$ cm
Conversion factor for atomic mass units to Mev	$E_0 =$	$(9.31145 \pm .0032) \times 10^{2}$ Mev (amu)$^{-1}$
Conversion factor for grams to Mev	$E_g =$	$(5.61003 \pm .00026) \times 10^{26}$ Mev g^{-1}
Wavelength associated with 1 ev	$\lambda_0 =$	$(1.23976 \pm .00005) \times 10^{-4}$ cm
Wave number associated with 1 ev	$\nu_0 =$	$(8.06611 \pm .00035) \times 10^{3}$ cm^{-1} ev^{-1}

* For reference, see footnote 18a, p. 46.
† Private communication by J. A. Bearden. Data presented at May 1953 meeting of Physical Society at Washington by Bearden, Earle, Minkowski, Thomsen, Johns Hopkins University.

Part 2 ‡

Quantity	Symbol	Value
Multiplier of (Curie constant)$^{1/2}$ to give magnetic moment per molecule	$\sqrt{3k/N} =$	$(2.62173 \pm .00009) \times 10^{-21}$ (erg mol deg^{-1})$^{1/2}$
Atomic specific heat constant	$h/k =$	$(4.79903 \pm .00023) \times 10^{-11}$ sec deg
Schrödinger constant for fixed nucleus	$2m/h^2 =$	$(1.638995 \pm .000045) \times 10^{27}$ erg^{-1} cm^{-2}
Schrödinger constant for H^1 atom	$2\mu/h^2 =$	$(1.638103 \pm .000045) \times 10^{27}$ erg^{-1} cm^{-2}
Energy associated with unit wave number	$E_1 =$	$(1.985698 \pm .000048) \times 10^{-16}$ erg
Speed of 1 ev electron	$v_0 =$	$(5.931098 \pm .000046) \times 10^{7}$ cm sec^{-1}

(continued)

‡ For reference, see footnote 18a, p. 46.

TABLE 28.—GENERAL PHYSICAL CONSTANTS ACCORDING TO BEARDEN AND ASSOCIATES (concluded)

Energy equivalent of electron mass. . . $mc^2 = (.510969 \pm .000009)$ Mev
Energy associated with 1°K. . . . .
$(R_0/F) \times 10^{-8} = (8.61632 \pm .00042) \times 10^{-5}$ ev
Temperature associated with 1 ev. . . . . $T_0 = (11605.9 \pm .6)$ deg K
Grating space calcite at 20°C. . . . . $d_{20} = (3.03567 \pm .00005) \times 10^{-8}$ cm
Density of calcite at 20°C. . . . . $\rho = (2.71030 \pm .00003)$ g cm^{-3}
Compton wavelength of electron. . . . $h/mc = (2.426045 \pm .000025) \times 10^{-10}$ cm
Zeeman displacement per gauss $e/(4\pi mc) = (4.668885 \pm .00008) \times 10^{-5}$ cm^{-1} gauss^{-1}
Doublet separation in hydrogen. . . . .
$\frac{1}{16} R_H \alpha^2 = (.3649900 \pm .0000037)$ cm^{-1}

TABLE 29.—SPELLING AND ABBREVIATIONS OF THE COMMON UNITS OF WEIGHT AND MEASURE

The spelling of the metric units is that adopted by the International Committee on Weights and Measures and given in the law legalizing the metric system in the United States (1866). The use of the same abbreviation for singular and plural is recommended. It is also suggested that only small letters be used for abbreviations except in the case of A for acre, where the use of the capital letter is general.

Unit	Abbreviation	Unit	Abbreviation
acre	A	kilogram	kg
are	a	kiloliter	kl
avoirdupois	av	kilometer	km
barrel	bbl	link	li.
board foot	bd ft	liquid	liq
bushel	bu	liter	l
carat, metric	c	meter	m
centare	ca	metric ton	t
centigram	cg	micron	μ
centiliter	cl	mile	mi
centimeter	cm	milligram	mg
chain	ch	milliliter	ml
cubic centimeter	cm^3	millimeter	mm
cubic decimeter	dm^3	millimicron	$m\mu$
cubic dekameter	dkm^3	minim	min. or ♏
cubic foot	ft^3	ounce	oz
cubic hectometer	hm^3	ounce, apothecaries'	oz ap *or* ℥
cubic inch	$in.^3$	ounce, avoirdupois	oz av
cubic kilometer	km^3	ounce, fluid	fl oz
cubic meter	m^3	ounce, troy	oz t
cubic mile	mi^3	peck	pk
cubic millimeter	mm^3	pennyweight	dwt
cubic yard	yd^3	pint	pt
decigram	dg	pound	lb
deciliter	dl	pound, apothecaries'	lb ap
decimeter	dm	pound, avoirdupois	lb av
decistere	ds	pound, troy	lb t
dekagram	dkg	quart	qt
dekaliter	dkl	rod	rd
dekameter	dkm	scruple, apothecaries'	s ap *or* ℈
dekastere	dks	square centimeter	cm^2
dram	dr	square chain	ch^2
dram, apothecaries'	dr ap *or* ʒ	square decimeter	dm^2
dram, avoirdupois	dr av	square dekameter	dkm^2
dram, fluid	fl dr	square foot	ft^2
fathom	fath	square hectometer	hm^2
foot	ft	square inch	$in.^2$
firkin	fir	square kilometer	km^2
furlong	fur	square meter	m^2
gallon	gal	square mile	mi^2
grain	gr	square millimeter	mm^2
gram	g	square rod	rd^2
hectare	ha	square yard	yd^2
hectogram	hg	stere	s
hectoliter	hl	ton	tn
hectometer	hm	ton, metric	t
hogshead	hhd	troy	t
hundredweight	cwt	yard	yd
inch	in.		

TABLE 30.—DIMENSIONAL EQUATIONS OF FUNDAMENTAL AND DERIVED UNITS

Conversion factors.—The dimensional formulas given in this table have many uses. One is to assist in changing a quantity from one system of units to another (see page 2). A simple scheme for transforming an expression from one set of units to another is given in Weniger's text, "Fundamentals of College Physics." Place the known number of the quantity with its units properly given, equal to an unknown number, x, of the same quantity properly expressed in the desired units. Proceed to cancel, treating the units just like algebraic quantities. Suppose it be desired to express 60 meters per second in miles per hour. Write:

$$\frac{60\ \text{m}}{\text{sec}} = \frac{x\ \text{mi}}{\text{hr}}$$

Cancel *sec* and *hr* and write 3600 near the larger unit. Cancel *m* and *mi* and write 1609.3 near the larger unit. This gives:

$$\frac{60\ \text{m}}{\text{sec}} = \frac{x\ \text{mi}}{\text{hr}} \quad \frac{1609.3}{3600} \quad 26.82$$

Solving, $X = 134$, and the desired expression is 134 mi/hr.

More complicated expressions are handled in a similar manner. In a heat-flow problem, suppose it becomes necessary to express 15 Btu $\text{hr}^{-1}\ \text{ft}^{-2}$ with a temperature gradient of 1°F per ft in terms of cal $\text{sec}^{-1}\ \text{cm}^{-2}$ with a gradient of 1°C/cm. Write:

$$\frac{15\ \text{Btu}}{\text{hr ft}^2} \times \frac{\text{ft}}{°\text{F}} = \frac{x\ \text{cal}}{\text{sec cm}^2} \times \frac{\text{cm}}{°\text{C}}$$

Cancel *ft* in numerator and denominator, and *cm* similarly. Remember that 1 Btu is 252 cal, and cancel. A *sec* goes into 1 *hr* 3600 times. Cancel *cm* and *ft* and write 30.48. Remember that 9°F equal 5°C. Solving, $x = 0.062$. (See Table 2.)

If the numeric before the known quantity is unity, x comes out as the conversion factor for these units.

The dimensional formulæ lack one quality which is needed for completeness, an indication of their vector characteristics; such characteristics distinguish plane and solid angle, torque and energy, illumination and brightness.

Part 1.—Fundamental units

The fundamental units most commonly used are: length [l]; mass [m]; time [t]; temperature [θ]; and for the electrostatic system, dielectric constant [k]; for the electromagnetic system, permeability [μ]. The formulæ will also be given for the International System of electric and magnetic units based on the units length, resistance [r], current [i], and time.

When writing fractions, using the solidus, care is required to make the meaning definite: i.e., Btu/hr/ft²(°F/m), or Btu/(hr)(ft²)(°F/m) is not clear, but Btu/[hr × ft² × (°F/m] is definite.

(*continued*)

TABLE 30.—DIMENSIONAL EQUATIONS OF FUNDAMENTAL AND DERIVED UNITS (continued)

Part 2.—Derived units (geometric and heat)

Name of unit	Conversion factor $[m^x l^y t^z]$ x	y	z
Area, surface	0	2	0
Volume	0	3	0
Angle	0	0	0
Solid angle	0	0	0
Curvature	0	—1	0
Angular velocity	0	0	—1
Linear velocity	0	1	—1
Angular acceleration	0	0	—2
Linear acceleration	0	1	—2
Density	1	—3	0
Moment of inertia	1	2	0
Intensity of attraction	0	1	—2
Momentum	1	1	—1
Moment of momentum	1	2	—1
Angular momentum	1	2	—1
Force	1	1	—2
Moment of couple, torque	1	2	—2
Work. energy	1	2	—2
Power, activity	1	2	—3
Intensity of stress	1	—1	—2
Modulus of elasticity	1	—1	—2
Compressibility	—1	1	2
Resilience	1	—1	—2
Viscosity	1	—1	—1

Name of units (Heat and light)	Conversion factor $[m^x l^y t^z \theta^v]$ x	y	z	v
Quantity of heat:				
thermal units	1	0	0	1
thermometric units	0	3	0	1
dynamical units	1	2	—2	0
Coefficient of thermal expansion	0	0	0	—1
Thermal conductivity:				
thermal units	1	—1	—1	0
thermometric units or diffusivity	0	2	—1	0
dynamical units	1	1	—3	—1
Thermal capacity	1	0	0	0
Latent heat:				
thermal units	0	0	0	1
dynamical units	0	2	—2	0
Joule's equivalent	0	2	—2	—1
Entropy:				
heat in thermal units	1	0	0	0
heat in dynamical units	1	2	—2	1
Luminous intensity	0	0	0	1*
Illumination	0	—2	0	1*
Brightness	0	—2	0	1*
Visibility	—1	—2	3	1*
Luminous efficiency	—1	—2	3	1*

* For these formulæ the numbers in the last column are the exponents of *F* where *F* refers to the luminous flux. For definitions of these quantities see Tables 70 and 72.

(*continued*)

Part 3.—Derived units (electrical and magnetic)

		Conversion factor												
		Electrostatic system $m^x l^y t^z k^v$				Electromagnetic system $m^x l^y t^z \mu^v$				emu/esu †	Absolute system $r^x i^y l^z t^v$			
Name of unit	Symbol *	x	y	z	v	x	y	z	v		x	y	z	v
Quantity of electricity	Q	1/2	3/2	—1	1/2	1/2	1/2	0	—1/2	c	0	1	0	1
Electric displacement	D	1/2	—1/2	—1	1/2	1/2	—3/2	0	—1/2	c	0	1	—2	1
Electric surface density	D	1/2	—1/2	—1	1/2	1/2	—3/2	0	—1/2	c	0	1	—2	1
Electric field intensity	ε	1/2	—1/2	—1	—1/2	1/2	1/2	—2	1/2	1/c	1	1	1	0
Electric potential	V	1/2	1/2	—1	—1/2	1/2	3/2	—2	1/2	1/c	1	1	0	0
Electromotive force	E	1/2	1/2	—1	—1/2	1/2	3/2	—2	1/2	1/c	1	1	0	0
Electrostatic capacity	C	0	1	0	1	0	—1	2	—1	c^2	—1	0	0	0
Dielectric constant	K	0	0	0	1	0	—2	2	—1	c^2	—1	0	—1	1
Specific inductive capacity	—	0	0	0	0	0	0	0	0		0	0	0	0
Current	I	1/2	3/2	—2	1/2	1/2	1/2	—1	—1/2	c	0	1	0	0
Electric conductivity	γ	0	0	—1	1	0	—2	1	—1	c^2	—1	0	—1	0
Resistivity	ρ	0	0	1	—1	0	2	—1	1	$1/c^2$	1	0	1	0
Conductance	g	0	1	—1	1	0	—1	1	—1	c^2	—1	0	0	0
Resistance	R	0	—1	1	—1	0	1	—1	1	$1/c^2$	1	0	0	0
Magnetic pole strength	m	1/2	1/2	0	—1/2	1/2	3/2	—1	1/2	1/c	1	1	0	1
Quantity of magnetism	m	1/2	1/2	0	—1/2	1/2	3/2	—1	1/2	1/c	1	1	0	1
Magnetic flux	Φ	1/2	1/2	0	—1/2	1/2	3/2	—1	1/2	1/c	1	1	0	1
Magnetic field intensity	H	1/2	1/2	—2	1/2	1/2	—1/2	—1	—1/2	c	0	0	—1	0
Magnetizing force	H	1/2	1/2	—2	1/2	1/2	—1/2	—1	—1/2	c	0	0	—1	0
Magnetic potential	Ω	1/2	3/2	—2	1/2	1/2	1/2	—1	—1/2	c	0	1	0	0
Magnetomotive force	𝔉	1/2	3/2	—2	1/2	1/2	1/2	—1	—1/2	c	0	1	0	0
Magnetic moment	—	1/2	3/2	0	—1/2	1/2	5/2	—1	1/2	1/c	1	1	1	1
Intensity magnetization	J	1/2	—3/2	0	—1/2	1/2	—1/2	—1	1/2	1/c	1	1	—2	1
Magnetic induction	B	1/2	—3/2	0	—1/2	1/2	—1/2	—1	1/2	1/c	1	1	—2	1
Magnetic susceptibility	κ	0	—2	2	—1	0	0	0	1	$1/c^2$	1	0	—1	1
Magnetic permeability	μ	0	—2	2	—1	0	0	0	1	$1/c^2$	1	0	—1	1
Current density	—	1/2	—1/2	—2	1/2	1/2	—3/2	—1	—1/2	c	0	1	—2	0
Self-inductance	𝔏	0	—1	2	—1	0	1	0	1	$1/c^2$	1	0	0	1
Mutual inductance	𝔐	0	—1	2	—1	0	1	0	1	$1/c^2$	1	0	0	1
Magnetic reluctance	ℜ	0	1	—2	1	0	—1	0	—1	c^2	—1	0	0	—1
Thermoelectric power ‡	—	1/2	1/2	—1	—1/2‡	1/2	3/2	—2	1/2‡	1/c	1	1	0	0‡
Peltier coefficient ‡	—	1/2	1/2	—1	—1/2‡	1/2	3/2	—2	1/2‡	1/c	1	1	0	0‡

* As adopted by American Institute of Electrical Engineers, 1915.
† c is the velocity of an electromagnetic wave in the ether $= 3 \times 10^{10}$ approximately.
‡ This conversion factor should include $[\theta^{-1}]$.

TABLE 31.—FUNDAMENTAL UNITS OF LENGTH, AREA, VOLUME, AND MASS

(As established by administrative action, National Bureau of Standards)

Part 1.—Some definitions and legal relations

1 in.* = (1/0.3937) cm = 2.54000508 cm
1 lb * = 453.5924277 g
1 gal * = 231 in.^{3} = 3.785329 liter
1 I.T. cal † = 4.18674 joules
= 1.000654 cal_{15}
1 Btu † = 251.996 I.T. cal
= 252.161 cal_{15}

Part 2.—Conversion factors, units of length

	cm	m	in.	ft	yd
1 cm =	1	0.01	0.3937	0.032808333	0.010936111
1 m =	100	1	39.37	3.2808333	1.0936111
1 in. =	2.5400051	0.025400051	1	0.083333333	0.027777778
1 ft =	30.480061	0.30480061	12	1	0.33333333
1 yd =	91.440183	0.91440183	36	3	1

Part 3.—Conversion factors, units of area

	cm^2	m^2	in.^{2}	ft^2	yd^2
1 cm^2 =	1	10^{-4}	0.15499969	1.0763867×10^{-3}	1.1959853×10^{-4}
1 m^2 =	10^4	1	1549.9969	10.763867	1.1959853
1 in.^{2} =	6.4516258	6.4516258×10^{-4}	1	6.9444444×10^{-3}	7.7160494×10^{-4}
1 ft^2 =	929.03412	0.092903412	144	1	0.11111111
1 yd^2 =	8361.3070	0.83613070	1296	9	1

Part 4.—Conversion factors, units of volume

	cm^3	in.^{3}	ft^3	ml	liter	gal
1 cm^3 =	1	0.061023378	3.5314455×10^{-5}	0.9999720	0.9999720×10^{-3}	2.6417047×10^{-4}
1 in.^{3} =	16.387162	1	5.7870370×10^{-4}	16.38670	1.638670×10^{-2}	4.3290043×10^{-3}
1 ft^3 =	2.8317017×10^4	1.728×10^3	1	2.831622×10^4	28.31622	7.4805195
1 ml =	1.000028	0.06102509	3.531544×10^{-5}	1	0.001	2.641779×10^{-4}
1 liter =	1.000028×10^3	61.02509	0.03531544	10^3	1	0.2641779
1 gal =	3.7854345×10^3	231	0.13368056	3.785329×10^3	3.785329	1

Part 5.—Conversion factors, units of mass

	g	kg	lb	metric ton	ton
1 g =	1	10^{-3}	2.2046223×10^{-3}	10^{-6}	1.1023112×10^{-6}
1 kg =	10^3	1	2.2046223	10^{-3}	1.1023112×10^{-3}
1 lb =	4.5359243×10^2	0.45359243	1	4.5359243×10^{-4}	0.0005
1 metric ton =	10^6	10^3	2204.6223	1	1.1023112
1 ton =	9.0718486×10^5	907.18486	2000	0.90718486	1

* Legal relation. † As defined by International Steam Table Conference, London, 1929.

TABLE 32.—TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES*

Part 1.—Metric to customary

	Linear			
	Meters to inches	Meters to feet	Meters to yards	Kilometers to miles
1	39.3700	3.28083	1.093611	0.62137
2	78.7400	6.56167	2.187222	1.24274
3	118.1100	9.84250	3.280833	1.86411
4	157.4800	13.12333	4.374444	2.48548
5	196.8500	16.40417	5.468056	3.10685
6	236.2200	19.68500	6.561667	3.72822
7	275.5900	22.96583	7.655278	4.34959
8	314.9600	26.24667	8.748889	4.97096
9	354.3300	29.52750	9.842500	5.59233

	Capacity				
	Milliliters or cubic centimeters to fluid drams	Centiliters to fluid ounces	Liters to quarts	Decaliters to gallons	Hectoliters to bushels
1	0.27	0.338	1.0567	2.6418	2.8378
2	0.54	0.676	2.1134	5.2836	5.6756
3	0.81	1.014	3.1701	7.9253	8.5135
4	1.08	1.353	4.2268	10.5671	11.3513
5	1.35	1.691	5.2836	13.2089	14.1891
6	1.62	2.029	6.3403	15.8507	17.0269
7	1.89	2.367	7.3970	18.4924	19.8647
8	2.16	2.705	8.4537	21.1342	22.7026
9	2.43	3.043	9.5104	23.7760	25.5404

	Square			
	Square centimeters to square inches	Square meters to square feet	Square meters to square yards	Hectares to acres
1	0.1550	10.764	1.196	2.471
2	0.3100	21.528	2.392	4.942
3	0.4650	32.292	3.588	7.413
4	0.6200	43.055	4.784	9.884
5	0.7750	53.819	5.980	12.355
6	0.9300	64.583	7.176	14.826
7	1.0850	75.347	8.372	17.297
8	1.2400	86.111	9.568	19.768
9	1.3950	96.875	10.764	22.230

	Mass			
	Milligrams to grains	Kilograms to grains	Hectograms to ounces avoirdupois	Kilograms to pounds avoirdupois
1	0.01543	15432.36	3.5274	2.20462
2	0.03086	30864.71	7.0548	4.40924
3	0.04630	46297.07	10.5822	6.61387
4	0.06173	61729.43	14.1096	8.81849
5	0.07716	77161.78	17.6370	11.02311
6	0.09259	92594.14	21.1644	13.22773
7	0.10803	108026.49	24.6918	15.43236
8	0.12346	123458.85	28.2192	17.63698
9	0.13889	138891.21	31.7466	19.84160

	Cubic			
	Cubic centimeters to cubic inches	Cubic decimeters to cubic inches	Cubic meters to cubic feet	Cubic meters to cubic yards
1	0.0610	61.023	35.314	1.308
2	0.1220	122.047	70.269	2.616
3	0.1831	183.070	105.943	3.924
4	0.2441	244.094	141.258	5.232
5	0.3051	305.117	176.572	6.540
6	0.3661	366.140	211.887	7.848
7	0.4272	427.164	247.201	9.156
8	0.4882	488.187	282.516	10.464
9	0.5492	549.210	317.830	11.771

	Mass		
	Quintals to pounds av.	Milliers or tonnes to pounds av.	Kilograms to ounces troy
1	220.46	2204.6	32.1507
2	440.92	4409.2	64.3015
3	661.39	6613.9	96.4522
4	881.85	8818.5	128.6030
5	1102.31	11023.1	160.7537
6	1322.77	13227.7	192.9045
7	1543.24	15432.4	225.0552
8	1763.70	17637.0	257.2059
9	1984.16	19841.6	289.3567

In the United States since 1893 all units in the above table have been derived from the same standards of length and mass. Therefore all equivalents (except those involving the liter) depend only on numerical definitions. The liter is the volume of one kilogram of pure water at the temperature of its maximum density and under a pressure equivalent to 760 millimeters of mercury. The liter was determined by the International Bureau of Weights and Measures in 1910 to equal 1.000027 dm^3. (National Bureau of Standards.)

* Quoted from sheets issued by the National Bureau of Standards.

(*continued*)

TABLE 32.—TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES (continued)

Part 2.—Customary to metric

	Linear					Capacity			
	Inches to millimeters	Feet to meters	Yards to meters	Miles to kilometers		Fluid drams to milliliters or cubic centimeters	Fluid ounces to milliliters	Liquid quarts to liters	Gallons to liters
1	25.4001	0.304801	0.914402	1.60935	1	3.70	29.57	0.94633	3.78533
2	50.8001	0.609601	1.828804	3.21869	2	7.39	59.15	1.89267	7.57066
3	76.2002	0.914402	2.743205	4.82804	3	11.09	88.72	2.83900	11.35600
4	101.6002	1.219202	3.657607	6.43739	4	14.79	118.29	3.78533	15.14133
5	127.0003	1.524003	4.572009	8.04674	5	18.48	147.87	4.73167	18.92666
6	152.4003	1.828804	5.486411	9.65608	6	22.18	177.44	5.67800	22.71199
7	177.8004	2.133604	6.400813	11.26543	7	25.88	207.01	6.62433	26.49733
8	203.2004	2.438405	7.315215	12.87478	8	29.57	236.58	7.57066	30.28266
9	228.6005	2.743205	8.229616	14.48412	9	33.27	266.16	8.51700	34.06799

	Square					Mass			
	Square inches to square centimeters	Square feet to square decimeters	Square yards to square meters	Acres to hectares		Grains to milligrams	Avoirdupois ounces to grams	Avoirdupois pounds to kilograms	Troy ounces to grams
1	6.452	9.290	0.836	0.4047	1	64.7989	28.3495	0.45359	31.10348
2	12.903	18.581	1.672	0.8094	2	129.5978	56.6991	0.90718	62.20696
3	19.355	27.871	2.508	1.2141	3	194.3968	85.0486	1.36078	93.31044
4	25.807	37.161	3.345	1.6187	4	259.1957	113.3981	1.81437	124.41392
5	32.258	46.452	4.181	2.0234	5	323.9946	141.7476	2.26796	155.51740
6	38.710	55.742	5.017	2.4281	6	388.7935	170.0972	2.72155	186.62088
7	45.161	65.032	5.853	2.8328	7	453.5924	198.4467	3.17515	217.72437
8	51.613	74.323	6.689	3.2375	8	518.3913	226.7962	3.62874	248.82785
9	58.065	83.613	7.525	3.6422	9	583.1903	255.1457	4.08233	279.93133

	Cubic			
	Cubic inches to cubic centimeters	Cubic feet to cubic meters	Cubic yards to cubic meters	Bushels to hectoliters
1	16.387	0.02832	0.765	0.35239
2	32.774	0.05663	1.529	0.70479
3	49.161	0.08495	2.294	1.05718
4	65.549	0.11327	3.058	1.40957
5	81.936	0.14159	3.823	1.76196
6	98.323	0.16990	4.587	2.11436
7	114.710	0.19822	5.352	2.46675
8	131.097	0.22654	6.116	2.81914
9	147.484	0.25485	6.881	3.17154

1 mile (statute)	=	5280 feet
1 mile (nautical)	=	6080.20 feet
1 Gunter's chain	=	20.1168 meters
1 sq. statute mile	=	259.000 hectares
1 fathom	=	1.829 meters
1 nautical mile	=	1853.25 meters
1 foot	=	0.304801 meter
1 avoir. pound	=	453.5924 grams
15432.356 grains	=	1.000 kilogram
1 liter	=	1000.028 ± .004 cm^3

The length of the nautical mile given above, and adopted by the U. S. Coast and Geodetic Survey many years ago, is defined as that of a minute of arc of a great circle of a sphere whose surface equals that of the earth (Clarke's Spheroid of 1866).

(*continued*)

TABLE 32.—TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES

(concluded)

Part 3.—Miscellaneous equivalents of U. S. and metric weights and measures [19]

(For other equivalents than those below, see Tables 30, 31, and 33.)

LINEAR MEASURES

1 mil (.001 in.) = 25.4001 μ
1 in. = .000015783 mile
1 hand (4 in.) = 10.16002 cm
1 link (.66 ft) = 20.11684 cm
1 span (9 in.) = 22.86005 cm
1 fathom (6 ft) = 1.828804 m
1 rod (5½ yd) (25 links) = 5.02910 m
1 chain (4 rods) = 20.11684 m
1 light year (9.5×10^{12} km) = 5.9×10^{12} miles
1 parsec (31×10^{12} km) = 19×10^{12} miles
$\frac{1}{64}$ in. = .397 mm $\frac{1}{32}$ in. = .794 mm
$\frac{1}{16}$ in. = 1.588 mm $\frac{1}{8}$ in. = 3.175 mm
$\frac{1}{4}$ in. = 6.350 mm $\frac{1}{2}$ in. = 12.700 mm
1 angstrom unit = .0000000001 m
1 micron (μ) = .000001 m = .00003937 in.
1 millimicron (mμ) = .000000001 m
1 m = 4.970960 links = 1.093611 yd
 = .198838 rod = .0497096 chain

SQUARE MEASURES

1 sq. link (62.7264 in.²) = 404.6873 cm²
1 sq. rod (625 sq. links) = 25.29295 m²
1 sq. chain (16 sq. rods) = 404.6873 m²
1 acre (10 sq. chains) = 4046.873 m²
1 sq. mile (640 acres) = 2.589998 km²
1 km² = .3861006 sq. mile
1 m² = 24.7104 sq. links = 10.76387 ft²
 = .039537 sq. rod = .00247104 sq. chain

CUBIC MEASURES

1 board foot (144 in.³) = 2359.8 cm³
1 cord (128 ft³) = 3.625 m³

CAPACITY MEASURES

1 minim (♏) = .0616102 ml
1 fl. dram (60 ♏) = 3.69661 ml
1 fl. oz (8 fl. dr) = 1.80469 in.³
 = 29.5729 ml
1 gill (4 fl. oz.) = 7.21875 in.³ = 118.292 ml
1 liq. pt (28.875 in.³) = .473167 l
1 liq. qt (57.75 in.³) = .946333 l
1 gallon (4 qt, 231 in.³) = 3.785332 l
1 dry pt (33.6003125 in.³) = .550599 l
1 dry qt (67.200625 in.³) = 1.101198 l
1 pk (8 dry qt, 537.605 in.³) = 8.80958 l
1 bu (4 pk, 2150.42 in.³) = 35.2383 l
1 firkin (9 gallons) = 34.06799 l
1 liter = .264178 gal = 1.05671 liq. qt
 = 33.8147 fl. oz = 270.518 fl. dr
1 ml. = 16.2311 minims.
1 dkl. = 18.1620 dry pt = 9.08102 dry qt
 = 1.13513 pk = .28378 bu

MASS MEASURES

Avoirdupois weights

1 grain = .064798918 g
1 dram av. (27.34375 gr) = 1.771845 g
1 oz av. (16 dr av.) = 28.349527 g
1 lb av. (16 oz av. or 7000 gr)
 = 14.583333 oz ap. (℥) or oz t.
 = 1.2152778 or 7000/5760 lb ap. or t.
 = 453.5924277 g
1 kg = 2.204622341 lb av.
1 g = 15.432356 gr = .5643833 dr av.
 = .03527396 oz av.
1 short hundred weight (100 lb)
 = 45.359243 kg
1 long hundred weight (112 lb)
 = 50.802352 kg
1 short ton (2000 lb)
 = 907.18486 kg
1 long ton (2240 lb)
 = 1016.04704 kg
1 metric ton = 0.98420640 long ton
 = 1.1023112 short tons

Troy weights

1 pennyweight (dwt 24 gr) = 1.555174 g
 gr, oz, pd are same as apothecary

Apothecaries' weights

1 gr = 64.798918 mg
1 scruple (℈, 20 gr) = 1.2959784 g
1 dram (ʒ, 3 ℈) = 3.8879351 g
1 oz (℥, 8 ʒ) = 31.103481 g
1 lb (12℥, 5760 gr) = 373.24177 g
1 g = 15.432356 gr = 0.771618 ℈
 = 0.2572059 ʒ = .03215074 ℥
1 kg = 32.150742 ℥ = 2.6792285 lb

1 metric carat = 200 mg = 3.0864712 gr

U. S. ½ dollar should weigh 12.5 g and the smaller silver coins in proportion.

[19] Taken from Circular 47 of the National Bureau of Standards, 1915, which see for more complete tables. .

TABLE 33.—EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES *

(For U. S. Weights and Measures, see Table 32.)

Part 1.—Metric to imperial

LINEAR MEASURE

1 millimeter (mm) (.001 m)	=	0.03937 in.
1 centimeter (.01 m)	=	0.39370 in.
1 decimeter (.1 m)	=	3.93701 in.
1 METER (m) . . .	=	39.370113 in. 3.280843 ft 1.09361425 yd
1 dekameter (10 m) . .	=	10.93614 yd
1 hectometer (100 m) . .	=	109.361425 yd
1 kilometer (1,000 m) . .	=	0.62137 mile
1 myriameter (10,000 m) . .	=	6.21372 miles
1 micron	=	0.001 mm

SQUARE MEASURE

1 cm²	=	0.1550 in.²
1 dm² (100 cm²) . .	=	15.500 in.²
1 m² or centiare (100 dm²)	=	10.7639 ft² 1.1960 yd²
1 are (100 m²) . . .	=	119.60 yd²
1 hectare (100 ares or 10,000 m²)	=	2.4711 acres

CUBIC MEASURE

1 cm³ (1,000 mm³). .	=	0.0610 in.³
1 dm³ (1,000 cm³) .	=	61.024 in.³
1 m³ or stere (1,000 dm³) . .	=	35.3148 ft³ 1.307954 yd³

MEASURE OF CAPACITY

1 milliliter (ml) (.001 liter)	=	0.0610 in.³
1 centiliter (.01 liter)	=	0.61024 in.³ 0.0710 gill
1 deciliter (.1 liter)	=	0.176 pint
1 LITER (1,000 cu. centimeters or 1 cu. decimeter)	=	1.75980 pints
1 dekaliter (10 liters)	=	2.200 gallons
1 hectoliter (100 ")	=	2.75 bushels
1 kiloliter (1,000 ")	=	3.437 quarters

APOTHECARIES' MEASURE

1 cm³ (1 gram w't)	=	0.03520 fluid ounce 0.28157 fluid drachm 15.43236 grains weight
1 mm³	=	0.01693 minim

AVOIRDUPOIS WEIGHT

1 milligram (mg) . .	=	0.01543 grain
1 centigram (.01 gram)	=	0.15432 grain
1 decigram (.1 ")	=	1.54324 grains
1 GRAM	=	15.43236 grains
1 dekagram (10 grams)	=	5.64383 drams
1 hectogram (100 ")	=	3.52739 oz
1 KILOGRAM (1,000 ")	=	2.2046223 lb 15432.3564 grains
1 myriagram (10 kg)	=	22.04622 lb
1 quintal (100 ")	=	1.96841 cwt
1 millier or tonne (1,000 kg) . .	=	0.9842 ton

TROY WEIGHT

1 GRAM . . .	=	0.03215 oz troy. 0.64301 pennyweight 15.43236 grains

APOTHECARIES' WEIGHT

1 GRAM . . .	=	0.25721 drachm 0.77162 scruple 15.43236 grains

NOTE.—The METER is the length, at the temperature of 0°C, of the platinum-iridium bar deposited at the International Bureau of Weights and Measures at Sèvres, near Paris, France.

The present legal equivalent of the meter is 39.370113 inches, as above stated.

The KILOGRAM is the mass of a platinum-iridium weight deposited at the same place.

The LITER contains 1 kilogram weight of distilled water at its maximum density (4°C), the barometer being at 760 millimeters.

* In accordance with the schedule adopted under the Weights and Measures (metric system) Act, 1897.

(continued)

TABLE 33.—EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES (continued)

(For U. S. Weights and Measures, see Table 32.)

Part 2.—Metric to imperial, multiples

	Linear measure					Measure of capacity			
	Millimeters to inches	Meters to feet	Meters to yards	Kilometers to miles		Liters to pints	Dekaliters to gallons	Hectoliters to bushels	Kiloliters to quarters
1	0.03937011	3.28084	1.09361	0.62137	1	1.75980	2.19975	2.74969	3.43712
2	0.07874023	6.56169	2.18723	1.24274	2	3.51961	4.39951	5.49938	6.87423
3	0.11811034	9.84253	3.28084	1.86412	3	5.27941	6.59926	8.24908	10.31135
4	0.15748045	13.12337	4.37446	2.48549	4	7.03921	8.79902	10.99877	13.74846
5	0.19685056	16.40421	5.46807	3.10686	5	8.79902	10.99877	13.74846	17.18558
6	0.23622068	19.68506	6.56169	3.72823	6	10.55882	13.19852	16.49815	20.62269
7	0.27559079	22.96590	7.65530	4.34960	7	12.31862	15.39828	19.24785	24.05981
8	0.31496090	26.24674	8.74891	4.97097	8	14.07842	17.59803	21.99754	27.49692
9	0.35433102	29.52758	9.84253	5.59235	9	15.83823	19.79778	24.74723	30.93404

	Square measure					Weight (Avoirdupois)			
	Square centimeters to square inches	Square meters to square feet	Square meters to square yards	Hectares to acres		Milligrams to grains	Kilograms to grains	Kilograms to pounds	Quintals to hundredweights
1	0.15500	10.76393	1.19599	2.4711	1	0.01543	15432.356	2.20462	1.96841
2	0.31000	21.52786	2.39198	4.9421	2	0.03086	30864.713	4.40924	3.93683
3	0.46500	32.29179	3.58798	7.4132	3	0.04630	46297.069	6.61387	5.90524
4	0.62000	43.05572	4.78397	9.8842	4	0.06173	61729.426	8.81849	7.87365
5	0.77500	53.81965	5.97996	12.3553	5	0.07716	77161.782	11.02311	9.84206
6	0.93000	64.58357	7.17595	14.8263	6	0.09259	92594.138	13.22773	11.81048
7	1.08500	75.34750	8.37194	17.2974	7	0.10803	108026.495	15.43236	13.77889
8	1.24000	86.11143	9.56794	19.7685	8	0.12346	123458.851	17.63698	15.74730
9	1.39501	96.87536	10.76393	22.2395	9	0.13889	138891.208	19.84160	17.71572

	Cubic measure			Apothecaries' measure		Avoirdupois (*cont.*)	Troy weight		Apothecaries' weight
	Cubic decimeters to cubic inches	Cubic meters to cubic feet	Cubic meters to cubic yards	Cubic centimeters to fluid drachms		Milliers or tonnes to tons	Grams to ounces troy	Grams to pennyweights	Grams to scruples
1	61.02390	35.31476	1.30795	0.28157	1	0.98421	0.03215	0.64301	0.77162
2	122.04781	70.62952	2.61591	0.56314	2	1.96841	0.06430	1.28603	1.54324
3	183.07171	105.94428	3.92386	0.84471	3	2.95262	0.09645	1.92904	2.31485
4	244.09561	141.25904	5.23182	1.12627	4	3.93683	0.12860	2.57206	3.08647
5	305.11952	176.57379	6.53977	1.40784	5	4.92103	0.16075	3.21507	3.85809
6	366.14342	211.88855	7.84772	1.68941	6	5.90524	0.19290	3.85809	4.62971
7	427.16732	247.20331	9.15568	1.97098	7	6.88944	0.22506	4.50110	5.40132
8	488.19123	282.51807	10.46363	2.25255	8	7.87365	0.25721	5.14412	6.17294
9	549.21513	317.83283	11.77159	2.53412	9	8.85786	0.28936	5.78713	6.94456

(*continued*)

TABLE 33.—EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES (continued)

(For U. S. Weights and Measures, see Table 32.)

Part 3.—Imperial to metric

LINEAR MEASURE

1 inch	= 25.400 millimeters
1 foot (12 in.) . .	= 0.30480 meter
1 YARD (3 ft) . .	= 0.914399 meter
1 pole (5½ yd) . .	= 5.0292 meters
1 chain (22 yd or 100 links)	= 20.1168 meters
1 furlong (220 yd)	= 201.168 meters
1 mile (1,760 yd) .	= 1.6093 kilometers
1 yard	= 1420210. × $Cd_r\lambda$ (Tutton 1932)

SQUARE MEASURE

1 in.²	= 6.4516 cm²
1 ft² (144 in.²) . .	= 9.2903 dm²
1 YD² (9 ft²) . . .	= 0.836126 m²
1 perch (30¼ yd²)	= 25.293 m²
1 rood (40 perches)	= 10.117 ares
1 ACRE (4840 yd²)	= 0.40468 hectare
1 mi² (640 acres)	= 259.00 hectares

CUBIC MEASURE

1 in.³	= 16.387 cm³
1 ft³ (1728 in.³)	= 0.028317 m³ or 28.317 dm³
1 YD³ (27 ft³). .	= 0.76455 m³

APOTHECARIES' MEASURE

1 gallon (8 pints or 160 fluid ounces)	= 4.5459631 liters
1 fluid ounce, f ℥ (8 drachms)	= 28.4123 cm³
1 fluid drachm, f ʒ (60 minims)	= 3.5515 cm³
1 minim, ♏ (0.91146 grain weight)	= 0.05919 cm³

NOTE.—The apothecaries' gallon is of the same capacity as the Imperial gallon.

MEASURE OF CAPACITY

1 gill	= 1.42 deciliters
1 pint (4 gills) . .	= 0.568 liter
1 quart (2 pt) . .	= 1.136 liters
1 GALLON (4 qt) . .	= 4.5459631 liters
1 peck (2 gal) . .	= 9.092 liters
1 bushel (8 gal) . .	= 3.637 dekaliters
1 quarter (8 bu) . .	= 2.909 hectoliters

AVOIRDUPOIS WEIGHT

1 grain	= 64.8 milligrams
1 dram	= 1.772 grams
1 ounce (16 dr) . .	= 28.350 grams
1 POUND (16 oz or 7,000 grains)	= 0.45359243 kg
1 stone (14 lb) . .	= 6.350 kg
1 quarter (28 lb)	= 12.70 kg
1 hundredweight (112 lb)	= 50.80 kg; 0.5080 quintal
1 ton (20 cwt) . .	= 1.0160 tonnes or 1016 kilograms

TROY WEIGHT

1 troy OUNCE (480 grains av)	= 31.1035 grams
1 pennyweight (24 grains)	= 1.5552 grams

NOTE.—The troy grain is of the same weight as the avoirdupois grain.

APOTHECARIES' WEIGHT

1 ounce (8 drachms) . .	= 31.1035 grams
1 drachm, ʒi (3 scruples)	= 3.888 grams
1 scruple, ℈i (20 grains)	= 1.296 grams

NOTE.—The apothecaries' ounce is of the same weight as the troy ounce. The apothecaries' grain is also of the same weight as the avoirdupois grain.

NOTE.—The YARD is the length at 62°F, marked on a bronze bar deposited with the Board of Trade.

The POUND is the weight of a piece of platinum weighed in vacuo at the temperature of 0°C, and which is also deposited with the Board of Trade.

The GALLON contains 10 lb weight of distilled water at the temperature of 62°F, the barometer being at 30 inches.

(*continued*)

TABLE 33.—EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES (concluded)

(For U. S. Weights and Measures, see Table 32.)

Part 4.—Imperial to metric, multiples

	Linear measure					Measure of capacity			
	Inches to centimeters	Feet to meters	Yards to meters	Miles to kilometers		Quarts to liters	Gallons to liters	Bushels to dekaliters	Quarters to hectoliters
1	2.539998	0.30480	0.91440	1.60934	1	1.13649	4.54596	3.63677	2.90942
2	5.079996	0.60960	1.82880	3.21869	2	2.27298	9.09193	7.27354	5.81883
3	7.619993	0.91440	2.74320	4.82803	3	3.40947	13.63789	10.91031	8.72825
4	10.159991	1.21920	3.65760	6.43737	4	4.54596	18.18385	14.54708	11.63767
5	12.699989	1.52400	4.57200	8.04671	5	5.68245	22.72982	18.18385	14.54708
6	15.239987	1.82880	5.48640	9.65606	6	6.81894	27.27578	21.82062	17.45650
7	17.779984	2.13360	6.40080	11.26540	7	7.95544	31.82174	25.45739	20.36591
8	20.319982	2.43840	7.31519	12.87474	8	9.09193	36.36770	29.09416	23.27533
9	22.859980	2.74320	8.22959	14.48408	9	10.22842	40.91367	32.73093	26.18475

	Square measure					Weight (avoirdupois)			
	Square inches to square centimeters	Square feet to square decimeters	Square yards to square meters	Acres to hectares		Grains to milligrams	Ounces to grams	Pounds to kilograms	Hundredweights to quintals
1	6.45159	9.29029	0.83613	0.40468	1	64.79892	28.34953	0.45359	0.50802
2	12.90318	18.58058	1.67225	0.80937	2	129.59784	56.69905	0.90718	1.01605
3	19.35477	27.87086	2.50838	1.21405	3	194.39675	85.04858	1.36078	1.52407
4	25.80636	37.16115	3.34450	1.61874	4	259.19567	113.39811	1.81437	2.03209
5	32.25794	46.45144	4.18063	2.02342	5	323.99459	141.74763	2.26796	2.54012
6	38.70953	55.74173	5.01676	2.42811	6	388.79351	170.09716	2.72155	3.04814
7	45.16112	65.03201	5.85288	2.83279	7	453.59243	198.44669	3.17515	3.55616
8	51.61271	74.32230	6.68901	3.23748	8	518.39135	226.79621	3.62874	4.06419
9	58.06430	83.61259	7.52513	3.64216	9	583.19026	255.14574	4.08233	4.57221

	Cubic measure			Apothecaries' Measure		Avoirdupois (*cont.*)	Troy weight		Apothecaries' weight
	Cubic inches to cubic centimeters	Cubic feet to cubic meters	Cubic yards to cubic meters	Fluid drachms to cubic centimeters		Tons to milliers or tonnes	Ounces to grams	Pennyweights to grams	Scruples to grams
1	16.38702	0.02832	0.76455	3.55153	1	1.01605	31.10348	1.55517	1.29598
2	32.77404	0.05663	1.52911	7.10307	2	2.03209	62.20696	3.11035	2.59196
3	49.16106	0.08495	2.29366	10.65460	3	3.04814	93.31044	4.66552	3.88794
4	65.54808	0.11327	3.05821	14.20613	4	4.06419	124.41392	6.22070	5.18391
5	81.93511	0.14158	3.82276	17.75767	5	5.08024	155.51740	7.77587	6.47989
6	98.32213	0.16990	4.58732	21.30920	6	6.09628	186.62088	9.33104	7.77587
7	114.70915	0.19822	5.35187	24.86074	7	7.11233	217.72437	10.88622	9.07185
8	131.09617	0.22653	6.11642	28.41227	8	8.12838	248.82785	12.44139	10.36783
9	147.48319	0.25485	6.88098	31.96380	9	9.14442	279.93133	13.99657	11.66381

TABLE 34.—VOLUME OF A GLASS VESSEL FROM THE WEIGHT OF ITS EQUIVALENT VOLUME OF MERCURY OR WATER

If a glass vessel contains at t°C, P grams of mercury, weighed with brass weights in air at 760 mmHg pressure, then its volume in cm³

$$\text{at the same temperature, } t : V = PR = P\frac{p}{d},$$

$$\text{at another temperature, } t_1 : V = PR_1 = P\frac{p}{d}\{1 + \gamma(t_1 - t)\}$$

p = the weight, reduced to vacuum, of the mass of mercury or water which, weighed with brass weights, equals 1 gram;
d = the density of mercury or water at t°C,
and γ the cubical expansion coefficient of glass.

Temperature t	Water R	Water $R_1, t_1 = 10°$	Water $R_1, t_1 = 20°$	Mercury R	Mercury $R_1, t_1 = 10°$	Mercury $R_1, t_1 = 20°$
0°	1.001192	1.001443	1.001693	0.0735499	0.0735683	0.0735867
1	1133	1358	1609	5633	5798	5982
2	1092	1292	1542	5766	5914	6098
3	1068	1243	1493	5900	6029	6213
4	1060	1210	1460	6033	6144	6328
5	1068	1193	1443	6167	6259	6443
6	1.001092	1.001192	1.001442	0.0736301	0.0736374	0.0736558
7	1131	1206	1456	6434	6490	6674
8	1184	1234	1485	6568	6605	6789
9	1252	1277	1527	6702	6720	6904
10	1333	1333	1584	6835	6835	7020
11	1.001428	1.001403	1.001653	0.0736969	0.0736951	0.0737135
12	1536	1486	1736	7103	7066	7250
13	1657	1582	1832	7236	7181	7365
14	1790	1690	1940	7370	7297	7481
15	1935	1810	2060	7504	7412	7596
16	1.002092	1.001942	1.002193	0.0737637	0.0737527	0.0737711
17	2261	2086	2337	7771	7642	7826
18	2441	2241	2491	7905	7757	7941
19	2633	2407	2658	8039	7872	8057
20	2835	2584	2835	8172	7988	8172
21	1.003048	1.002772	1.003023	0.0738306	0.0738103	0.0738288
22	3271	2970	3220	8440	8218	8403
23	3504	3178	3429	8573	8333	8518
24	3748	3396	3647	8707	8449	8633
25	4001	3624	3875	8841	8564	8748
26	1.004264	1.003862	1.004113	0.0738974	0.0738679	0.0738864
27	4537	4110	4361	9108	8794	8979
28	4818	4366	4616	9242	8910	9094
29	5110	4632	4884	9376	9025	9210
30	5410	4908	5159	9510	9140	9325

TABLE 35.—EFFECT OF AIR ON WEIGHING

Reductions of weighings in air to vacuo

When the weight M in grams of a body is determined in air, a correction is necessary for the buoyancy of the air equal to $M\delta(1/d - 1/d_1)$ where δ = the density (wt. of 1 cm³ in grams = 0.0012) of the air during the weighing, d the density of the body, d_1 that of the weights. δ for various barometric values and humidities may be determined from Tables 631-632. The following table is computed for $\delta = 0.0012$. The corrected weight = $M + kM/1000$.

Density of body weighed d	Correction factor, k: Pt. Ir. weights $d_1 = 21.5$	Brass weights 8.4	Quartz or Al. weights 2.65	Density of body weighed d	Correction factor, k: Pt. Ir. weights $d_1 = 21.5$	Brass weights 8.4	Quartz or Al. weights 2.65
.5	+2.34	+2.26	+1.95	1.6	+0.69	+0.61	+0.30
.6	+1.94	+1.86	+1.55	1.7	+ .65	+ .56	+ .25
.7	+1.66	+1.57	+1.26	1.8	+ .62	+ .52	+ .21
.75	+1.55	+1.46	+1.15	1.9	+ .58	+ .49	+ .18
.80	+1.44	+1.36	+1.05	2.0	+ .54	+ .46	+ .15
.85	+1.36	+1.27	+0.96	2.5	+ .43	+ .34	+ .03
.90	+1.28	+1.19	+ .88	3.0	+ .34	+ .26	− .05
.95	+1.21	+1.12	+ .81	4.0	+ .24	+ .16	− .15
1.00	+1.14	+1.06	+ .75	6.0	+ .14	+ .06	− .25
1.1	+1.04	+0.95	+ .64	8.0	+ .09	+ .01	− .30
1.2	+0.94	+ .86	+ .55	10.0	+ .06	− .02	− .33
1.3	+ .87	+ .78	+ .47	15.0	+ .03	− .06	− .37
1.4	+ .80	+ .71	+ .40	20.0	+ .004	− .08	− .39
1.5	+ .75	+ .66	+ .35	22.0	− .001	− .09	− .40

TABLE 36.—REDUCTIONS OF DENSITIES IN AIR TO VACUO

(This correction may be accomplished through the use of the above table for each separate weighing.)

If s is the density of the substance as calculated from the uncorrected weights, S its true density, and L the true density of the liquid used, then the vacuum correction to be applied to the uncorrected density, s, is $0.0012\ (1 - s/L)$.

Let W_s = uncorrected weight of substance, W_l = uncorrected weight of the liquid displaced by the substance, then by definition, $s = LW_s/W_l$. Assuming D to be the density of the balance of weights, $W_s\{1 + 0.0012(1/S - 1/D)\}$ and $W_l\{1 + 0.0012(1/L - 1/D)\}$ are the true weights of the substance and liquid respectively (assuming that the weighings are made under normal atmospheric corrections, so that the weight of 1 cm³ of air is 0.0012 gram).

Then the true density $S = \dfrac{W_s\{1 + 0.0012(1/S - 1/D)\}}{W_l\{1 + 0.0012(1/L - 1/D)\}}\, L$

But from above $W_s/W_l = s/L$, and since L is always large compared with 0.0012,

$$S - s = 0.0012(1 - s/L)$$

The values of $0.0012(1 - s/L)$ for densities up to 20 and for liquids of density 1 (water), 0.852 (xylene), and 13.55 (mercury) follow:

Density of substance s	Corrections: $L = 1$ Water	$L = 0.852$ Xylene	$L = 13.55$ Mercury	Density of substance s	Corrections: $L = 1$ Water	$L = 13.55$ Mercury
0.8	+0.00024	—	—	11.	−0.0120	+0.0002
0.9	+ .00012	—	—	12.	− .0132	+ .0001
1.	0.0000	−0.0002	+0.0011	13.	− .0144	0.0000
2.	− .0012	− .0016	+ .0010	14.	− .0156	0.0000
3.	− .0024	− .0030	+ .0009	15.	− .0168	− .0001
4.	− .0036	− .0044	+ .0008	16.	− .0180	− .0002
5.	− .0048	− .0058	+ .0008	17.	− .0192	− .0003
6.	− .0060	− .0073	+ .0007	18.	− .0204	− .0004
7.	− .0072	− .0087	+ .0006	19.	− .0216	− .0005
8.	− .0084	− .0101	+ .0005	20.	− .0228	− .0006
9.	− .0096	− .0115	+ .0004			
10.	− .0108	− .0129	+ .0003			

TABLE 37.—THE INTERNATIONAL TEMPERATURE SCALE OF 1948[20]

The International Temperature Scale that was adopted in 1927 was revised during 1948 and is designed to conform as nearly as practicable to the thermodynamic Celsius[21] (Centigrade) scale as now known. This 1948 International Temperature Scale incorporates certain refinements based on experience to make it more uniform and reproducible than its predecessor. The new scale is essentially the same as the one it displaces, but it was improved by changing certain formulas and values for temperatures and constants.

Only three of the revisions in the definition of the scale result in appreciable changes in the numerical values assigned to measured temperatures. The change in the value for the silver point from 960.5°C to 960.8°C changes temperatures measured with the standard thermocouple. The adoption of a different value for the radiation constant c_2 changes all temperatures above the gold point, while the use of the Planck radiation formula instead of the Wien formula affects the very high temperatures. (See Table 40 for the magnitude of the changes due to these two causes for high temperatures.) The 1948 temperature scale, like the 1927 scale, is based upon six fixed points (Table 38) and upon specified formulas for the relations between temperature and the indications of the instruments calibrated at these fixed points. Temperature on the 1948 scale will be designated as °*C*, or °*C* (Int. 1948) and denoted by the symbol t.

The means available for interpolation between the fixed points lead to a division of the scale into four parts:

(a) From 0°C to the freezing points of antimony the temperature t is defined by the formula

$$R_t = R_0(1 + At + Bt^2)$$

where R_t is the resistance, at temperature t, of a standard platinum resistance thermometer.

(b) From the oxygen point (Table 38) to 0°C the temperature t is similarly defined by the formula

$$R_t = R_0[1 + At + Bt^2 + C(t - 100)t^3]$$

(c) From the freezing point of antimony to the gold point (Table 38) the temperature t is defined by the formula

$$E = a + bt + ct^2,$$

where E is the electromotive force of a standard thermocouple of platinum and platinum-rhodium alloy, when one junction is at 0°C and the other at temperature t.

Recommendations are given for the construction, calibration, and use of these two types of measuring devices.

(d) Above the gold point the temperature t is defined by the formula

$$\frac{J_t}{J_{Au}} = \frac{\exp[c_2/(\lambda(t_{Au} + T_0))] - 1}{\exp[c_2/(\lambda(t + T_0))] - 1} \, ^*$$

where J_t and J_{Au} are the radiant energies per unit wavelength interval at wavelength λ, emitted per unit time by unit area of a blackbody at temperature t, and at the gold point t_{Au}, respectively.

c_2 is 1.438 cm degrees.

T_0 is the temperature of the ice point in °K.

λ is a wavelength of the visible spectrum.

e is the base of Naperian logarithms.

Secondary fixed points.—In addition to the six fundamental and primary fixed points (Table 38), a number of secondary fixed points are available and may be useful for various purposes. Some of the more constant and reproducible of these fixed points and their temperatures on the International Temperature Scale of 1948 are listed in Table 41. The relation between this new temperature scale and the thermodynamic Celsius scale is discussed in this paper also.

The resulting changes in the 1927 International Temperature Scale below the gold point (1063°C) to correct it to the 1948 International Temperature Scale are given in Table 39.

The use of the Planck formula and a wavelength interval within the visible spectrum to determine temperatures presupposes the use of an optical pyrometer. (See Table 77.)

[20] Nat. Bur. Standards Journ. Res., vol. 42, p. 209, 1949.

[21] The General Conference, held in October 1948, decided to discontinue the use of the words "Centesimal" and "Centigrade" and to replace them by "Celsius." See also Nat. Bur. Standards Techn. News Bull., vol. 33, p. 110, 1949.

* See footnote 5a, p. 7.

TABLE 38.—FUNDAMENTAL AND PRIMARY FIXED POINTS UNDER THE STANDARD PRESSURE OF 1013250 DYNES/CM²

	Temperature °C
Temperature of equilibrium between liquid oxygen and its vapor (oxygen point)	— 182.970
Temperature of equilibrium between ice and air saturated water (ice point) *fundamental fixed point*	0
Temperature of equilibrium between liquid water and its vapor (steam point) *fundamental fixed point*	100
Temperature of equilibrium between liquid sulfur and its vapor (sulfur point)	444.600
Temperature of equilibrium between solid and liquid silver (silver point)	960.8
Temperature of equilibrium between solid and liquid gold (gold point)	1063.0

TABLE 39.—DIFFERENCES BETWEEN THE INTERNATIONAL TEMPERATURE SCALES OF 1948 AND 1927 IN THE THERMOCOUPLE RANGE

Temperature					
°C (Int. 1948)	°C (Int. 1948) minus °C (Int. 1927)	°C (Int. 1948)	°C (Int. 1948) minus °C (Int. 1927)	°C (Int. 1948)	°C (Int. 1948) minus °C (Int. 1927)
630.5	.00	800	.42	950	.32
650	+.08	839.5	$.43_0$ (max.)	960.8	.30
700	.24	850	.43	1000	.20
750	.35	900	.40	1050	.05
				1063	.00

TABLE 40.—CORRESPONDING TEMPERATURES ON THE INTERNATIONAL TEMPERATURE SCALES OF 1948 AND 1927

°C (Int. 1948)	°C (Int. 1927)	Corresponding Fahrenheit temperatures (1948)	(1927)	°C (Int. 1948)	°C (Int. 1927)	Corresponding Fahrenheit temperatures (1948)	(1927)
630.50	630.50	1166.9	1166.9	2100	2107	3812	3825
650	649.92	1202	1201.9	2200	2208	3992	4007
700	699.76	1292	1291.6	2300	2310	4172	4189
750	749.65	1382	1381.4	2400	2411	4352	4372
				2500	2512	4532	4554
800	799.58	1472	1471.2				
850	849.57	1562	1561.2	2600	2613	4712	4736
900	899.60	1652	1651.3	2700	2715	4892	4919
950	949.68	1742	1741.4	2800	2816	5072	5102
				2900	2918	5252	5285
960.80	960.50	1761.4	1760.9	3000	3020	5432	5468
1000	999.80	1832	1831.6				
1050	1049.95	1922	1921.9	3100	3122	5612	5651
1063.00	1063.00	1945.4	1945.4	3200	3223	5792	5834
				3300	3325	5972	6018
1100	1100.2	2012	2012	3400	3428	6152	6202
1200	1200.6	2192	2193	3500	3530	6332	6386
1300	1301.1	2372	2374				
1400	1401.7	2552	2555	3600	3632	6512	6570
1500	1502.3	2732	2736	3700	3735	6692	6754
				3800	3837	6872	6939
1600	1603.0	2912	2917	3900	3940	7052	7124
1700	1703.8	3092	3099	4000	4043	7232	7309
1800	1804.6	3272	3280				
1900	1905.5	3452	3462	4100	4146	7412	7495
2000	2006.4	3632	3644	4200	4249	7592	7681
				4300	4353	7772	7867

	Temperature °C (Int. 1948)
Temperature of equilibrium between solid carbon dioxide and its vapor..	—78.5
$t_p = -78.5 + 12.12\left(\frac{p}{p_0} - 1\right) - 6.4\left(\frac{p}{p_0} - 1\right)^2$	
Temperature of freezing mercury	—38.87
Temperature of equilibrium between ice, water and its vapor (triple point)	+ 0.0100
Temperature of transition of sodium sulfate decahydrate	32.38
Temperature of triple point of benzoic acid	122.36
Temperature of equilibrium between naphthalene and its vapor	218.0
$t_p = 218.0 + 44.4\left(\frac{p}{p_0} - 1\right) - 19\left(\frac{p}{p_0} - 1\right)^2$	
Temperaure of freezing tin	231.9
Temperature of equilibrium between benzophenone and its vapor	305.9
$t_p = 305.9 + 48.8\left(\frac{p}{p_0} - 1\right) - 21\left(\frac{p}{p_0} - 1\right)^2$	
Temperature of freezing cadmium	320.9
Temperature of freezing lead	327.3
Temperature of equilibrium between mercury and its vapor	356.58
$t_p = 356.58 + 55.552\left(\frac{p}{p_0} - 1\right) - 23.03\left(\frac{p}{P_0} - 1\right)^2 + 14.0\left(\frac{p}{p_0} - 1\right)^3$	
Temperature of freezing zinc	419.5
Temperature of freezing antimony	630.5
Temperature of freezing aluminum	660.1
Temperature of freezing copper in a reducing atmosphere	1083
Temperature of freezing nickel	1453
Temperature of freezing cobalt	1492
Temperature of freezing palladium	1552
Temperature of freezing platinum	1769
Temperature of freezing rhodium	1960
Temperature of freezing iridium	2443
Temperature of melting tungsten	3380

TABLE 42.—CORRESPONDING TEMPERATURES ON THE INTERNATIONAL TEMPERATURE SCALE OF 1948 AND RESULTS USING WIEN'S EQUATION

t, °C (Int. 1948)	t_w, °C	t, °C (Int. 1948)	t_w, °C	t, °C (Int. 1948)	t_w, °C
1063	1063.0	2500	2500.2	4000	4005.4
1500	1500.0	3000	3000.7	4500	4511.3
2000	2000.0	3500	3502.1	5000	5021.5

TABLE 43.—CORRECTION FOR TEMPERATURE OF EMERGENT MERCURIAL THERMOMETER THREAD

When the temperature of a portion of a thermometer stem with its mercury thread differs much from that of the bulb, a correction is necessary to the observed temperature unless the instrument has been calibrated for the experimental conditions. This stem correction is proportional to $n\beta(T - t)$, where n is the number of degrees in the exposed stem, β the apparent coefficient of expansion of mercury in the glass, T the measured temperature, and t the mean temperature of the exposed stem. For temperatures up to 100°C, the value of β is for Jena 16^{III} or Greiner and Friedrich resistance glass, 0.000159, for Jena 59^{III}, 0.000164, and when of unknown composition it is best to use a value of about 0.000155. The formula requires a knowledge of the temperature of the emergent stem. This may be approximated in one of three ways: (1) by a "fadenthermometer"; (2) by exploring the temperature distribution of the stem and calculating its mean temperature; and (3) by suspending along the side of, or attaching to, the stem, a single thermometer.

TABLE 44.—STEM CORRECTION FOR CENTIGRADE THERMOMETER[22]

Values of $0.000155n(T - t)$

n	(T − t) 10°	20°	30°	40°	50°	60°	70°	80°
10°C	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.12
20	0.03	0.06	0.09	0.12	0.16	0.19	0.22	0.25
30	0.05	0.09	0.14	0.19	0.23	0.28	0.33	0.37
40	0.06	0.12	0.19	0.25	0.31	0.37	0.43	0.50
50	0.08	0.16	0.23	0.31	0.39	0.46	0.54	0.62
60	0.09	0.19	0.28	0.37	0.46	0.56	0.65	0.74
70	0.11	0.22	0.33	0.43	0.54	0.65	0.76	0.87
80	0.12	0.25	0.37	0.50	0.62	0.74	0.87	0.99
90	0.14	0.28	0.42	0.56	0.70	0.84	0.98	1.12
100	0.16	0.31	0.46	0.62	0.78	0.93	1.08	1.24

[22] Taken from Smithsonian Meteorological Tables.

TABLE 45.—REDUCTION OF GAS THERMOMETERS TO THERMODYNAMIC SCALE

The final standard scale is Kelvin's thermodynamic scale, independent of the properties of any substance, a scale resulting from the use of a gas thermometer using a perfect gas. A discussion of this is given by Buckingham,[22a] "The thermodynamic correction of the centigrade constant-pressure scale at the given temperature is very nearly proportional to the constant pressure at which the gas is kept" and "the thermodynamic correction to the centigrade constant-volume scale is approximately proportional to the initial pressure at the ice point." These two rules are very convenient, since from the corrections for any one pressure, one can calculate approximately those for the same gas at any other pressure.

The highest temperature possible is limited by the container for the gas. Day and Sosman carried a platinum-rhodium gas thermometer up to the melting point of palladium. For most work, however, the region of the gas thermometer should be considered as ending at about 1000°C (1273°K).

NOTE: All corrections in the following table are to be added *algebraically*.

273.16°K (ice point)

Temp. °C	Constant pressure = 100 cm He	H	N	Constant vol., $p_0 = 100$ cm, $t_0 = 0$°C He	H	N
− 240	—	+ 1.0	—	+ 0.02	+ 0.18	—
− 200	+ 0.13	+ .26	—	+ .01	+ .06	—
− 100	+ .04	+ .03	+ 0.40	.000	+ .010	+ 0.06
− 50	+ .012	+ .02	+ .12	.000	+ .004	+ .02
+ 25	− .003	− .003	− .020	.000	.000	− .006
+ 50	− .003	− .003	− .025	.000	.000	− .006
+ 75	− .003	− .003	− .017	.000	.000	− .004
+ 150	+ .007	+ .01	+ .04	+ .000	+ .001	+ .01
+ 200	+ .01	+ .02	+ .11	.000	+ .002	+ .04
+ 450	+ .1	+ 0.04	+ .5	0.00	+ 0.01	+ .2
+ 1000	+ 0.3	—	+ 1.7	—	—	+ .7
+ 1500	—	—	+ 3.	—	—	+ 1.3

[22a] Bull. Nat. Bur. Standards, vol. 8, p. 239, 1912.

TABLE 46.—SOME OLD THERMOELECTRIC TEMPERATURE SCALES *

Comparisons

Prior to the adoption of the 1927 International Temperature Scale, the Pt-Pt10% Rh thermocouple was almost universally used for scales 450° to 1100°C, and defining equations were quadratic or cubic depending upon the number of calibration points.

The scale based on the work of Holborn and Day was calibrated at the freezing point of Zn (419.0°C), Sb (630.6°C), and Cu (1084.1°C), and a quadratic equation, $E = a + vt + ct^2$, for interpolation. This was almost universally used from 1900-1909. Work of Waidner, Burgess, 1909, and Day, Sosman, 1910-1912, necessitated a readjustment. In 1912 the Bureau of Standards redefined its scale, assigning values determined with the resistance thermometer to the Zn and Sb points, while the freezing point of Cu was taken as 1083.0°C. This 1912 scale, used from 1912-1916, will be called the Zn, Sb, Cu temperature scale.

A scale proposed by Sosman and revised by Adams was realized by using a standard reference table, giving the average *t*-emf relation for thermocouple used by Day and Sosman. A deviation curve, determined by any other couple by calibration at several points would be plotted relating the difference between observed emf and the emf from the reference table against the obs. emf of the couple. This scale, although very convenient, is not completely defined and no comparison is made here.

In 1916, the Physikalische-Technische Reichsanstalt adopted a scale with the couple calibrated at the Sd point (320.9°C), Sb (630°C), Au (1063°C), and Pd (1557°C). No comparison will be made here.

A scale adopted by the Bureau of Standards in 1916 was defined by calibration at the Zn and Al points with a Cu point (1083.0°C). This was used from 1916-1926 and is here designated the Zn, Al, Cu scale.

The scale adopted by the P.-T.R. and the Bureau of Standards in 1924 was calibrated at Zn and Sb points (determined by resistance thermometer), the Ag point (960.5°C), and the Au point (1063.0°C). It will be designated the Zn, Sb, Ag, Au scale.

The 1927 7th Annual Conference of Weights and Measures (31 nations) unanimously adopted what is between 660° and 1063°C the Zn, Sb, Ag, Cu scale with the Zn point omitted. The table below shows a comparison of the various scales. The following values for the freezing points were used:

Zn 419.47°C	Al 659.23°C	Au	1063.0°C
Sb 630.52°C	Ag 960.5°C	Cu (reducing atm^c)	1083.0°C

Temperature differences between 1927 I.T.S. and various older scales

°C	I.T.S.-ZnSb-Cu	I.T.S.-ZnAl-Cu	I.T.S.-ZnSb-AgAu	°C	I.T.S.-ZnSb-Cu	I.T.S.-ZnAl-Cu	I.T.S.-ZnSb-AgAu	°C	I.T.S.-ZnSb-Cu	I.T.S.-ZnAl-Cu	I.T.S.-ZnSb-AgAu
600	—°.08	°.00	—°.04	900	—°.26	—°.21	—°.03	1050	—°.04	—°.03	°.00
700	— .16	— .08	— .08	950	— .23	— .18	— .01	1063	— .01	.00	.00
750	— .24	— .16	— .09	960.5	— .21	— .16	.00	1083	+ .04	+ .03	— .01
800	— .28	— .20	— .08	1000	— .15	— .12	.01	1100	+ .08	+ .08	— .03
850	— .29	— .22	— .06								

REFERENCE TABLES FOR THERMOCOUPLES [23]

The emf developed by thermocouples of the same materials, even very carefully made, differ slightly for the same temperature. It has been found convenient to compare the emf of a couple being calibrated with that of a standard thermocouple of the same materials. If the differences in emf's between the standard and the calibrated couple be plotted against the temperature, the temperature for an observed emf can be read very accurately. Reference tables for three types of thermocouples follow.

* These values are now superseded by the introduction of the 1948 International Temperature Scale and are given for reference only.

[23] Taken from Nat. Bur. Standards Res. Papers RP 1080, RP 767, and RP 530.

TABLE 47.—REFERENCE TABLE FOR Pt TO Pt-10 PERCENT Rh THERMOCOUPLE

(Emf's are expressed in microvolts and temperatures in °C. Cold junctions at 0°C)

E micro-volts	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000
0	0	146.9	264.9	373.6	477.6	578.0	675.2	769.7	861.2	950.2	1037.0	1121.8	1205.4	1288.5	1371.8	1455.4	1539.5	1624.0
100	17.7	159.4	276.1	384.1	487.8	587.9	684.8	779.0	870.2	959.0	1045.6	1130.2	1213.7	1296.8	1380.2	1463.8	1547.9	1632.5
200	34.4	171.7	287.2	394.6	498.0	597.7	694.3	788.2	879.2	967.8	1054.1	1138.6	1222.1	1305.1	1388.5	1472.2	1556.4	1641.1
300	50.2	183.8	298.2	405.1	508.1	607.5	703.8	797.4	888.2	976.5	1062.2	1147.0	1230.4	1313.5	1396.9	1480.6	1564.8	1649.6
400	65.4	195.8	309.2	415.6	518.2	617.3	713.3	806.6	897.2	985.2	1071.1	1155.3	1238.7	1321.8	1405.2	1489.0	1573.3	1658.1
500	80.0	207.5	320.1	426.0	528.3	627.0	722.8	815.8	906.1	993.9	1079.6	1163.7	1247.0	1330.1	1413.6	1497.4	1581.7	1666.6
600	94.1	219.2	330.9	436.4	538.3	636.7	732.2	824.9	914.9	1002.6	1088.1	1172.0	1255.3	1338.4	1421.9	1505.8	1590.2	1675.1
700	107.8	230.8	341.6	446.7	548.3	646.4	741.7	834.0	923.8	1011.2	1096.6	1180.4	1263.6	1346.8	1430.3	1514.2	1598.6	1683.6
800	121.7	242.3	352.3	457.0	558.2	656.0	751.1	843.1	932.6	1019.8	1105.0	1188.7	1271.9	1355.1	1438.6	1522.6	1607.0	1692.1
900	134.1	253.6	363.0	467.3	568.1	665.6	760.4	852.2	941.4	1028.4	1113.4	1197.1	1280.2	1363.5	1447.0	1531.0	1615.5	1700.6
1000	146.9	264.9	373.6	477.6	578.0	675.2	769.7	861.2	950.2	1037.0	1121.8	1205.4	1288.5	1371.8	1455.4	1539.5	1624.0	1709.1

TABLE 48.—REFERENCE TABLE FOR Pt TO Pt-10 PERCENT Rh THERMOCOUPLE

(Emf's are expressed in microvolts and temperatures in °F. Cold junctions at 32°F)

E micro-volts	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000
0	32.0	296.3	508.9	704.5	891.7	1072.3	1247.4	1417.4	1582.2	1742.5	1898.8	2051.3	2201.9	2351.5	2501.4	2652.1	2803.5	2955.6
100	63.9	318.8	529.0	723.5	910.1	1090.0	1264.6	1434.1	1598.4	1758.3	1914.2	2066.4	2216.8	2366.4	2516.5	2667.1	2818.7	2970.9
200	93.9	340.9	549.0	742.4	928.4	1107.7	1281.8	1450.7	1614.6	1774.0	1929.6	2081.5	2231.7	2381.4	2531.6	2682.2	2833.9	2986.2
300	122.4	362.7	568.9	761.2	946.6	1125.4	1290.0	1467.3	1630.7	1789.8	1945.0	2096.6	2246.7	2396.4	2546.6	2697.3	2849.1	3001.6
400	149.7	384.3	588.7	780.0	964.7	1143.0	1316.1	1483.9	1646.8	1805.4	1960.3	2111.7	2261.7	2411.4	2561.6	2712.5	2864.3	3016.9
500	176.0	405.6	608.3	798.8	982.8	1160.5	1333.1	1500.4	1662.8	1821.1	1975.6	2126.7	2276.6	2426.4	2576.6	2727.6	2879.5	3032.2
600	201.4	426.6	627.6	817.5	1000.8	1178.0	1350.0	1516.9	1678.8	1836.7	1990.8	2141.8	2291.5	2441.4	2591.7	2742.8	2894.8	3047.6
700	225.9	447.5	646.9	836.1	1018.8	1195.5	1366.9	1533.3	1694.8	1852.3	2006.0	2156.9	2306.5	2456.4	2606.8	2758.0	2910.0	3063.0
800	249.9	468.2	666.2	854.7	1036.7	1212.9	1383.8	1549.6	1710.7	1867.8	2021.1	2171.9	2321.5	2471.4	2621.9	2773.1	2925.2	3078.4
900	273.3	488.6	685.4	873.2	1054.5	1230.2	1400.6	1565.9	1726.6	1883.3	2036.2	2186.9	2336.5	2486.4	2637.0	2788.3	2940.4	3093.8
1000	296.3	508.9	704.5	891.7	1072.3	1247.4	1417.4	1582.2	1742.5	1898.8	2051.3	2201.9	2351.5	2501.4	2652.1	2803.5	2955.6	3109.2

TABLE 49.—CORRESPONDING VALUES OF TEMPERATURE AND ELECTROMOTIVE FORCE FOR IRON-CONSTANTAN THERMOCOUPLES

(Reference junctions at 0°C)

Temp. °C	Electromotive force mv	Temp. °C	Electromotive force mv	Temp. °C	Electromotive force mv	Temp. °C	Electromotive force mv
		0	.00	400	22.06	800	45.68
		10	.52	410	22.61	810	46.33
		20	1.05	420	23.16	820	46.99
		30	1.58	430	23.71	830	47.65
		40	2.12	440	24.26	840	48.30
		50	2.66	450	24.81	850	48.96
		60	3.20	460	25.36	860	49.62
		70	3.75	470	25.91	870	50.28
		80	4.30	480	26.46	880	50.94
		90	4.85	490	27.01	890	51.59
		100	5.40	500	27.57	900	52.22
		110	5.95	510	28.13	910	52.84
		120	6.51	520	28.69	920	53.43
		130	7.07	530	29.25	930	54.02
		140	7.63	540	29.81	940	54.61
		150	8.19	550	30.38	950	55.21
		160	8.75	560	30.95	960	55.80
		170	9.31	570	31.52	970	56.39
		180	9.87	580	32.10	980	56.99
		190	10.43	590	32.68	990	57.59
— 200	— 8.27	200	10.99	600	33.26	1000	58.19
— 190	— 8.02	210	11.55	610	33.85		
— 180	— 7.75	220	12.11	620	34.44		
— 170	— 7.46	230	12.67	630	35.02		
— 160	— 7.14	240	13.23	640	35.62		
— 150	— 6.80	250	13.79	650	36.22		
— 140	— 6.44	260	14.35	660	36.82		
— 130	— 6.06	270	14.90	670	37.43		
— 120	— 5.66	280	15.45	680	38.04		
— 110	— 5.25	290	16.00	690	38.66		
— 100	— 4.82	300	16.55	700	39.28		
— 90	— 4.38	310	17.11	710	39.90		
— 80	— 3.93	320	17.66	720	40.53		
— 70	— 3.47	330	18.21	730	41.16		
— 60	— 3.00	340	18.76	740	41.80		
— 50	— 2.52	350	19.31	750	42.45		
— 40	— 2.03	360	19.86	760	43.09		
— 30	— 1.53	370	20.41	770	43.74		
— 20	— 1.03	380	20.96	780	44.39		
— 10	— 0.52	390	21.51	790	45.04		
0	.00	400	22.06	800	45.68		

TABLE 50.—CORRESPONDING VALUES OF TEMPERATURE AND ELECTROMOTIVE FORCE FOR IRON-CONSTANTAN THERMOCOUPLES

(Reference junctions at 32°F)

Temp. °F	Electromotive force mv	Temp. °F	Electromotive force mv	Temp. °F	Electromotive force mv	Temp. °F	Electromotive force mv	Temp. °F	Electromotive force mv
		0	— .92	500	14.35	1000	29.69	1500	46.70
		10	— .63	510	14.65	1010	30.00	1510	47.06
		20	— .35	520	14.96	1020	30.32	1520	47.43
		30	— .06	530	15.27	1030	30.63	1530	47.79
		40	+ .23	540	15.57	1040	30.95	1540	48.16
		50	.52	550	15.88	1050	31.27	1550	48.52
		60	.82	560	16.19	1060	31.59	1560	48.89
		70	1.11	570	16.49	1070	31.91	1570	49.25
		80	1.41	580	16.80	1080	32.23	1580	49.62
		90	1.70	590	17.11	1090	32.55	1590	49.98
		100	2.00	600	17.42	1100	32.87	1600	50.35
		110	2.30	610	17.72	1110	33.19	1610	50.71
		120	2.60	620	18.03	1120	33.52	1620	51.08
		130	2.90	630	18.33	1130	33.85	1630	51.45
		140	3.20	640	18.64	1140	34.17	1640	51.81
		150	3.50	650	18.94	1150	34.50	1650	52.17
		160	3.81	660	19.25	1160	34.83	1660	52.51
		170	4.11	670	19.55	1170	35.16	1670	52.84
		180	4.42	680	19.86	1180	35.48	1680	53.17
		190	4.72	690	20.17	1190	35.82	1690	53.50
— 300	— 7.87	200	5.03	700	20.47	1200	36.15	1700	53.83
— 290	— 7.75	210	5.34	710	20.78	1210	36.48	1710	54.16
— 280	— 7.55	220	5.64	720	21.08	1220	36.82	1720	54.48
— 270	— 7.38	230	5.95	730	21.39	1230	37.16	1730	54.81
— 260	— 7.20	240	6.26	740	21.69	1240	37.50	1740	55.14
— 250	— 7.02	250	6.57	750	22.00	1250	37.84	1750	55.47
— 240	— 6.83	260	6.88	760	22.30	1260	38.18	1760	55.80
— 230	— 6.63	270	7.19	770	22.61	1270	38.52	1770	56.13
— 220	— 6.43	280	7.50	780	22.91	1280	38.86	1780	56.46
— 210	— 6.22	290	7.81	790	23.22	1290	39.21	1790	56.79
— 200	— 6.01	300	8.12	800	23.52	1300	39.55	1800	57.12
— 190	— 5.79	310	8.43	810	23.83	1310	39.89		
— 180	— 5.57	320	8.75	820	24.13	1320	40.24		
— 170	— 5.34	330	9.06	830	24.44	1330	40.59		
— 160	— 5.11	340	9.37	840	24.74	1340	40.94		
— 150	— 4.87	350	9.68	850	25.05	1350	41.30		
— 140	— 4.63	360	10.00	860	25.36	1360	41.65		
— 130	— 4.38	370	10.31	870	25.66	1370	42.01		
— 120	— 4.13	380	10.62	880	25.97	1380	42.36		
— 110	— 3.88	390	10.93	890	26.28	1390	42.72		
— 100	— 3.63	400	11.24	900	26.58	1400	43.08		
— 90	— 3.37	410	11.56	910	26.89	1410	43.44		
— 80	— 3.11	420	11.87	920	27.20	1420	43.80		
— 70	— 2.85	430	12.18	930	27.51	1430	44.16		
— 60	— 2.58	440	12.49	940	27.82	1440	44.52		
— 50	— 2.31	450	12.80	950	28.13	1450	44.88		
— 40	— 2.04	460	13.11	960	28.44	1460	45.24		
— 30	— 1.76	470	13.42	970	28.75	1470	45.61		
— 20	— 1.48	480	13.73	980	29.06	1480	45.97		
— 10	— 1.20	490	14.04	990	29.38	1490	46.33		
0	— .92	500	14.35	1000	29.69	1500	46.70		

TABLE 51.—STANDARD FAHRENHEIT TABLE FOR CHROMEL-ALUMEL* THERMOCOUPLES

Temp. °F	Electromotive force in millivolts (reference junction at 32°F)										
	0	10	20	30	40	50	60	70	80	90	100
0	— .68	— .47	— .26	— .04	+ .18	.40	.62	.84	1.06	1.29	1.52
100	1.52	1.74	1.97	2.20	2.43	2.66	2.89	3.12	3.36	3.59	3.82
200	3.82	4.05	4.28	4.51	4.74	4.97	5.19	5.42	5.64	5.87	6.09
300	6.09	6.31	6.53	6.75	6.98	7.20	7.42	7.64	7.87	8.09	8.31
400	8.31	8.53	8.76	8.98	9.20	9.43	9.66	9.88	10.11	10.33	10.56
500	10.56	10.79	11.02	11.25	11.47	11.70	11.93	12.16	12.39	12.62	12.85
600	12.85	13.08	13.31	13.55	13.78	14.01	14.24	14.48	14.71	14.94	15.18
700	15.19	15.42	15.65	15.89	16.12	16.36	16.59	16.83	17.06	17.30	17.53
800	17.53	17.76	18.00	18.23	18.47	18.71	18.94	19.18	19.42	19.65	19.89
900	19.89	20.13	20.37	20.60	20.84	21.08	21.31	21.55	21.79	22.02	22.26
1000	22.26	22.50	22.73	22.97	23.21	23.44	23.68	23.92	24.15	24.39	24.63
1100	24.63	24.86	25.10	25.34	25.58	25.81	26.05	26.28	26.52	26.76	26.99
1200	26.99	27.22	27.46	27.69	27.92	28.15	28.38	28.62	28.86	29.10	29.34
1300	29.34	29.57	29.80	30.03	30.26	30.49	30.72	30.95	31.18	31.41	31.64
1400	31.64	31.87	32.10	32.33	32.56	32.79	33.02	33.25	33.48	33.70	33.93
1500	33.93	34.16	34.39	34.61	34.84	35.07	35.29	35.52	35.74	35.97	36.19
1600	36.19	36.41	36.64	36.86	37.09	37.31	37.54	37.76	37.99	38.21	38.43
1700	38.43	38.65	38.87	39.09	39.31	39.53	39.75	39.96	40.18	40.40	40.62
1800	40.62	40.83	41.05	41.27	41.48	41.70	41.91	42.13	42.34	42.56	42.78
1900	42.78	42.99	43.21	43.42	43.63	43.84	44.05	44.27	44.48	44.69	44.90
2000	44.90	45.11	45.32	45.53	45.74	45.95	46.16	46.37	46.58	46.79	47.00
2100	47.00	47.21	47.41	47.62	47.83	48.03	48.24	48.44	48.65	48.85	49.05
2200	49.05	49.25	49.46	49.66	49.86	50.06	50.26	50.46	50.66	50.86	51.06
2300	51.06	51.25	51.45	51.65	51.84	52.04	52.23	52.43	52.62	52.81	53.01
2400	53.01	53.20	53.39	53.58	53.78	53.97	54.16	54.35	54.54	54.73	54.92
2500	54.92										

* Hoskins Thermocouple.

TABLES 52-57.—THE BLACKBODY AND ITS RADIANT ENERGY

TABLE 52.—SYMBOLS AND DEFINING EXPRESSIONS FOR RADIANT ENERGY[23a]

Radiant energy is energy traveling in the form of electromagnetic waves. It is measured in units of energy such as ergs, joules, calories, and kilowatt hours. Some units, symbols, and abbreviations used in discussing radiant energy are as follows:

Designation	Symbol and defining expression	Unit	Proposed term[23a]
Radiant energy	U	......	Radiant energy
Spectral radiant energy.	$U_\lambda = \frac{dU}{d\lambda}$	......	Spectral radiant energy
Radiant energy density.	$u = \frac{dU}{dV}$	erg/cm^3	Radiant energy density
Radiant flux	$\phi(P) = \frac{dU}{dt}$	watt, erg/sec	Radiant flux (radiance *)
Radiant flux density...	$W = \frac{d\phi}{dA}$	$watt/cm^2$	Radiant flux density (radiancy *)
Radiant intensity of a source	$J = \frac{d\phi}{d\omega}$	watt/steradian	Radiant intensity
Spectral radiant intensity	$J_\lambda = \frac{dJ}{d\lambda}$	watt/steradian	Spectral radiant intensity
Radiant flux density of a source per unit solid angle	$B,(N) = \frac{dW}{d\omega}$	watt/(steradian cm^2)	Steradiancy *
Radiant intensity of a source per unit area..	$B = \frac{dJ}{dA}$	watt/(steradian cm^2)	Steradiancy *
Radiant flux per unit area	$E = \frac{d\phi}{dA}$	......	Irradiancy

The standard radiator is the blackbody, which may be defined as a body that absorbs all the radiation that falls upon it, i.e., it neither reflects nor transmits any of the incident radiation. From this simple definition and some very plausible assumptions it can be shown that the blackbody radiates more energy than any other temperature radiator when both are at the same temperature. The total amount of energy (i.e., for all wavelengths) radiated by a blackbody depends upon the temperature raised to the fourth power and a constant σ that had to be measured:

$$W = \sigma T^4$$

If a blackbody is radiating to another blackbody it will at the same time receive radiation from the second blackbody and, under the proper geometrical conditions, the net radiation lost by the first blackbody is

$$W = \sigma(T_1^4 - T_2^4)$$

The spectral distribution of this radiation is given by the Planck equation:

$$J_\lambda \doteq c_1\lambda^{-5}/[\exp(c_2/\lambda T) - 1] \dagger$$

For values of the product λT less than 3000μ deg, the Wien equation

$$J_\lambda = c_1\lambda^{-5}/[\exp(c_2/\lambda T)]$$

gives values that are correct to better than 1 percent.

The values of a number of the radiation constants have been selected from Table 26 and are given in Table 53. All the blackbody calculations given were made with these constants. Some calculated results[24] for the total radiation W for a series of temperatures and of J_λ for a range of temperatures and for wavelengths have been calculated and are given in Tables 54-56.

[23a] Rev. Sci. Instr., vol. 7, p. 322, 1936. * These terms apply only to a source. The term "radiance" is not recommended as a substitute for radiant flux; however, if a single term is desired to express the radiant flux from a source, the word "radiance" is suggested as the most logical. † See footnote 5a, p. 7.

[24] For a more extensive list of values of J_λ reference should be made to two papers by Parry Moon: Journ. Math. and Phys., vol. 16, p. 133, 1937; Publ. Electr. Eng., Massachusetts Institute of Technology, 1947.

Velocity of light	$c = 2.99776 \times 10^{10}$ cm sec^{-1}
Planck's constant	$h = 6.6242 \times 10^{-27}$ erg sec
Boltzmann's constant	$k = 1.3805 \times 10^{-16}$ erg deg^{-1}
Stefan-Boltzmann constant *	$\sigma = 5.673 \times 10^{-5}$ erg cm^{-2} deg^{-4} sec^{-1}
Wien's displacement law	$J_\lambda = Ac_1\lambda^{-5}F(\lambda T)$
The principal corollaries are:	$\lambda_m T = b$
	$\frac{J_m}{AT^5} = b_1$

The first corollary is sometimes given as the Wien's displacement law, and b as the displacement constant.

Wien displacement constant	$b = 0.2897$ cm deg
First radiation constant †	
All lengths in cm, $d\lambda = 1$ cm	$c_1 = 3.740 \times 10^{-5}$ erg sec^{-1} cm^2
Area cm^2, λ in μ, $d\lambda = 0.01\mu$	$c_1 = 3.740 \times 10^9$ erg sec^{-1} cm^2
Second radiation constant	$c_2 = 1.4380$ cm deg

The unit of energy chosen for the above values is the erg. Any other unit of energy (or power) may be used if the proper conversion factor is used (Table 7).

Values of c_2 used at different times.—This second radiation constant has been determined many times in the last 40 years. Shown below are the values used at different times. [A new determination of the value of c_2 by G. A. W. Rutgers (Physica, vol. 15, p. 985, 1949) gives two values: 14325. ± 20 and 14310. ± 20 μ deg.]

Date	National Bureau of Standards	Nela Park
1911	14500μ °K	14500μ °K
1915	—	14460
1917	14350	14350
1922	14320 ‡	14350
1925	14320 §	14320
1936	14320 ‖	14320
1944	14320	14320
1949	14380	—

* For 2π solid angle. † For the general case, c_1 may be written in the following symbolic form:

$$c_1 = \text{numeric}\ \frac{(\text{wavelength unit})^5 \times \text{power unit}}{\text{area} \times \text{wavelength interval} \times \text{solid angle}}$$

This form shows that the value of the numeric depends upon the several units used—in this case 5. If J_{λ_0} is the normal intensity, i.e., per unit solid angle perpendicular to the surface, πJ_{λ_0} gives the radiation per 2π solid angle. The energy radiated within a unit solid angle around the normal, is 0.92 J_0. The above values are for a plane blackbody; for a spherical blackbody the radiation for 2π solid angle equals $2\pi J_0$.

For calculations the use of the radiation constants σ and c_2 as given follows directly and causes but little trouble. The numeric for c_2 must be expressed in the unit of wavelength times the absolute temperature. If the wavelength is expressed in μ the numeric becomes 14380.

When Planck's equation is used for calculations, it may be written as follows for blackbody of area A:

$$J_\lambda d\lambda = (Ac_1\lambda^{-5}/[\exp(c_2/\lambda T) - 1])d\lambda$$

where $d\lambda$ is the wavelength interval for which the radiation is to be calculated. The first value of c_1 given in the table is for all dimensions in centimeters—a condition almost never met in practice. The second value is for the wavelength expressed in microns and $d\lambda = 0.01\mu$.

If this second value of c_2 be used in calculation with Planck's equation and summed step by step, the results will be the total energy per second, per 2π solid angle, per unit area for the wavelength interval covered, λ expressed in μ.

‡ I. G. Priest, in January 1922, used $c_2 = 14350$ in his work on color temperature. § J. F. Skogland, in 1929, used $c_2 = 14330$ in his tables of spectral energy distribution of a blackbody. ‖ D. B. Judd, in 1933, used $c_2 = 14350$ in his calculations related to the I.C.I. standard observer.

TABLE 54.—RADIATION IN ERGS ($W \times 10^n$) AND GRAM-CALORIES ($W' \times 10^{n'}$) PER CM^2 PER SEC, FOR 2π SOLID ANGLE, FROM A PERFECT RADIATOR AT t° FROM —270°C TO +56°C AND FOR T FROM 300°K TO 5500°K

$\sigma = 5.672 \times 10^{-5}$ erg cm^{-2} deg^{-4} sec^{-1}

Temp. °C	erg cm^{-2} sec^{-1} W	n	cal cm^{-2} sec^{-1} W'	n'
—270	5.656	—3	1.351	—10
—250	1.632	1	3.899	— 7
—200	1.625	3	3.883	— 5
—190	2.713	3	6.482	— 5
—180	4.272	3	1.021	— 4
—160	9.301	3	2.222	— 4
—150	1.305	4	3.118	— 4
—140	1.783	4	4.261	— 4
—130	2.382	4	5.693	— 4
—120	3.121	4	7.458	— 4
—110	4.020	4	9.605	— 4
—100	5.100	4	1.219	— 3
— 90	6.383	4	1.525	— 3
— 80	7.896	4	1.887	— 3
— 70	9.662	4	2.309	— 3
— 60	1.171	5	2.798	— 3
— 50	1.407	5	3.361	— 3
— 40	1.676	5	4.006	— 3
— 30	1.983	5	4.738	— 3
— 20	2.330	5	5.567	— 3
— 10	2.720	5	6.500	— 3
— 8	2.804	5	6.700	— 3
— 6	2.890	5	6.904	— 3
— 4	2.977	5	7.114	— 3
— 2	3.067	5	7.327	— 3
0	3.158	5	7.546	— 3
2	3.252	5	7.769	— 3

Temp. °C	erg cm^{-2} sec^{-1} W	n	cal cm^{-2} sec^{-1} W'	n'
4	3.347	5	7.998	—3
6	3.445	5	8.231	—3
8	3.545	5	8.470	—3
10	3.646	5	8.713	—3
12	3.751	5	8.962	—3
14	3.857	5	9.216	—3
16	3.965	5	9.475	—3
18	4.076	5	9.740	—3
20	4.189	5	1.001	—2
22	4.305	5	1.029	—2
24	4.423	5	1.057	—2
26	4.543	5	1.086	—2
28	4.666	5	1.115	—2
30	4.791	5	1.145	—2
32	4.919	5	1.175	—2
34	5.049	5	1.206	—2
36	5.182	5	1.238	—2
38	5.317	5	1.271	—2
40	5.455	5	1.304	—2
42	5.596	5	1.337	—2
44	5.739	5	1.371	—2
46	5.885	5	1.406	—2
48	6.034	5	1.442	—2
50	6.186	5	1.478	—2
52	6.341	5	1.515	—2
54	6.498	5	1.553	—2
56	6.658	5	1.591	—2

Temp. °K	erg cm^{-2} sec^{-1} W	n	cal cm^{-2} sec^{-1} W'	n'
300 *	4.5944	5	1.0978	—2
373.16	1.0998	6	2.6280	—2
400	1.4520	6	3.4700	—2
500	3.5450	6	8.4707	—2
600	7.3509	6	1.7565	—1
700	1.3619	7	3.2542	—1
800	2.3233	7	5.5515	—1
900	3.7214	7	8.8922	—1
1000	5.6720	7	1.3553	0
1500	2.8715	8	6.8614	0
2000	9.0752	8	2.1685	1
2500	2.2156	9	5.2942	1
3500	8.5115	9	2.0338	2
4500	2.3259	10	5.5577	2
5500	5.1902	10	1.2402	3

* Energy radiated from 3000°K can be obtained from the value for this temperature by multiplying it by 10^4. Likewise for other temperatures that are 10 times the values given in the table.

TABLE 55.—CALCULATED SPECTRAL INTENSITIES J_λ FOR A RANGE OF WAVELENGTHS FOR A BLACKBODY OF UNIT AREA FOR A RANGE OF TEMPERATURES FROM 50°K TO 25,000°K *

These values have been calculated for $c_1 = \frac{3740 \text{ micron}^5 \text{ watts}}{\text{cm}^2\, d\lambda\, 2\pi \text{ solid angles}}$; $c_2 = 14380\mu$: deg; $d\lambda = 0.1\mu$, J_λ = tabular $J_\lambda \times 10^n$ watts for cm² for 2π solid angle per 0.1μ.

	50°		75°		100°		150°		200°	
λ	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n
1.0	4.675	—122	2.0145	—80	1.3224	—59	8.679	—39	2.2235	—28
1.5	2.6529	— 81	1.5131	—53	1.1427	—39	8.634	—26	7.503	—19
2.0	4.133	— 61	2.7124	—40	6.949	—30	1.7803	—19	2.8499	—14
2.5	4.186	— 49	1.8865	—32	4.005	—24	8.501	—16	1.2384	—11
3.0	3.5716	— 41	2.6982	—27	2.344	—20	2.0377	—13	6.007	—10
3.5	1.4652	— 35	1.1519	—23	1.0214	—17	9.057	—12	8.529	— 9
4.0	2.1714	— 31	5.564	—21	8.906	—16	1.4255	—10	5.703	— 8
5.0	1.2515	— 25	2.6566	—17	3.8701	—13	5.638	— 9	6.806	— 7
6.0	7.326	— 22	6.367	—15	1.8773	—11	5.534	— 8	3.0050	— 6
7.0	3.1917	— 19	2.8304	—13	2.6652	—10	2.5096	— 7	7.701	— 6
8.0	2.7831	— 17	4.455	—12	1.7823	— 9	7.131	— 7	1.4265	— 5
9.0	8.386	— 16	3.5449	—11	7.288	— 9	1.4984	— 6	2.1492	— 5
10.0	1.2094	— 14	1.7620	—10	2.1269	— 8	2.5671	— 6	2.8224	— 5
12.0	5.867	— 13	1.7294	— 9	9.391	— 8	5.100	— 6	3.7662	— 5
14.0	8.3288	— 12	7.843	— 9	2.4062	— 7	7.393	— 6	4.115	— 5
16.0	5.570	— 11	2.2284	— 8	4.458	— 7	8.937	— 6	4.032	— 5
18.0	2.2775	— 10	4.682	— 8	6.716	— 7	9.674	— 6	3.7137	— 5
20.0	6.647	— 10	8.022	— 8	8.820	— 7	9.763	— 6	3.3001	— 5
25.0	3.8640	— 9	1.7882	— 7	1.2204	— 6	8.458	— 6	2.2874	— 5
30.0	1.0564	— 8	2.5801	— 7	1.2857	— 6	6.571	— 6	1.5411	— 5
40.0	2.7563	— 8	3.0513	— 7	1.0313	— 6	3.6674	— 6	7.255	— 6
50.0	3.8137	— 8	2.6437	— 7	7.148	— 7	2.0625	— 6	3.7257	— 6
75.0	3.4809	— 8	1.3255	— 7	2.7160	— 7	6.084	— 7	9.800	— 7
100.0	2.2338	— 8	6.445	— 7	1.1788	— 7	2.3256	— 7	3.5536	— 7

	273.16°		300°		373.16°		500°		600°	
λ	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n
1.0	5.132	— 20	5.698	—18	6.870	—14	1.2094	— 9	1.4597	— 7
1.5	2.8227	— 13	6.520	—12	3.4290	— 9	2.3203	— 6	5.667	— 5
2.0	4.329	— 10	4.562	— 9	5.009	— 7	6.647	— 5	7.302	— 4
2.5	2.7422	— 8	1.8043	— 7	7.741	— 6	3.8640	— 4	2.6287	— 3
3.0	3.6847	— 7	1.7710	— 6	4.061	— 5	1.0564	— 3	5.223	— 3
3.5	2.0910	— 6	8.031	— 6	1.1772	— 4	1.9230	— 3	7.570	— 3
4.0	7.029	— 6	2.2819	— 5	2.3911	— 4	2.7563	— 3	9.152	— 3
5.0	3.2026	— 5	8.215	— 5	5.383	— 4	3.8137	— 3	9.9983	— 3
6.0	7.443	— 5	1.6321	— 4	7.825	— 4	4.018	— 3	9.024	— 3
7.0	1.2065	— 4	2.3657	— 4	9.085	— 4	3.7175	— 3	7.496	— 3
8.0	1.5856	— 4	2.8600	— 4	9.310	— 4	3.2227	— 3	6.007	— 3
9.0	1.8307	— 4	3.0957	— 4	8.875	— 4	2.7040	— 3	4.748	— 3
10.0	1.9447	— 4	3.1245	— 4	8.102	— 4	2.2338	— 3	3.7449	— 3
12.0	1.8931	— 4	2.8201	— 4	6.312	— 4	1.5050	— 3	2.3601	— 3
14.0	1.6573	— 4	2.3425	— 4	4.736	— 4	1.0224	— 3	1.5319	— 3
16.0	1.3798	— 4	1.8770	— 4	3.5255	— 4	7.085	— 4	1.0272	— 3
18.0	1.1229	— 4	1.4838	— 4	2.6366	— 4	5.021	— 4	7.103	— 4
20.0	9.057	— 5	1.1703	— 4	1.9919	— 4	3.6384	— 4	5.049	— 4
25.0	5.309	— 5	6.600	— 5	1.0432	— 4	1.7735	— 4	2.3814	— 4
30.0	3.2185	— 5	3.9044	— 5	5.890	— 5	9.570	— 5	1.2584	— 4
40.0	1.3385	— 5	1.5780	— 5	2.2537	— 5	3.4705	— 5	4.451	— 5
50.0	6.414	— 6	7.442	— 6	1.0306	— 5	1.5393	— 5	1.9460	— 5
75.0	1.5488	— 6	1.7613	— 6	2.3463	— 6	3.3726	— 6	4.189	— 6
100.0	5.398	— 7	6.081	— 7	7.954	— 7	1.1225	— 6	1.3811	— 6

* For reference, see footnote 23, p. 74.

(*continued*)

TABLE 55.—CALCULATED SPECTRAL INTENSITIES J_λ FOR A RANGE OF WAVELENGTHS FOR A BLACKBODY OF UNIT AREA FOR A RANGE OF TEMPERATURES FROM 50°K TO 25,000°K (continued)

	800°		1000°		1200°		1400°		1600°	
λ	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n
.10	3.2241	—70	1.3224	—54	3.3883	—44	9.2178	—37	3.4723	—31
.20	1.0851	—32	6.949	—25	1.1123	—19	5.8022	—16	3.5613	—13
.30	1.4647	—20	2.3444	—15	6.9122	—12	2.0790	—9	1.5016	—7
.40	1.1129	—14	8.906	—11	3.5633	—8	2.5732	—6	6.376	—5
.45	9.103	—13	2.6834	—9	5.517	—7	2.4766	—5	4.295	—4
.50	2.9182	—11	3.8701	—8	4.671	—6	1.4334	—4	1.8689	—3
.55	4.759	—10	3.2828	—7	2.5627	—5	5.761	—4	5.947	—3
.60	4.692	—9	1.8773	—6	1.0193	—4	1.7677	—3	1.5023	—2
.65	3.1506	—8	7.950	—6	3.1748	—4	4.421	—3	3.1867	—2
.70	1.5675	—7	2.6652	—5	8.178	—4	9.435	—3	5.907	—2
.75	6.1514	—6	7.425	—5	1.8135	—3	1.7774	—2	9.847	—2
.80	1.9924	—6	1.7823	—4	3.5650	—3	3.0296	—2	1.5079	—1
.90	1.3423	—5	7.288	—4	1.0450	—2	7.001	—2	2.9157	—1
1.00	5.840	—5	2.1269	—3	2.3367	—2	1.2943	—1	4.674	—1
1.50	3.0769	—3	3.3803	—2	1.6712	—1	5.236	—1	1.2341	0
2.00	1.4607	—2	8.820	—2	2.9286	—1	6.916	—1	1.3213	0
2.50	2.8902	—2	1.2204	—1	3.1995	—1	6.398	—1	1.0814	0
3.00	3.8565	—2	1.2857	—1	2.8888	—1	5.185	—1	8.100	—1
4.00	4.129	—2	1.0313	—1	1.9221	—1	3.0340	—1	4.318	—1
5.00	3.3793	—2	7.148	—2	1.1984	—1	1.7597	—1	2.3772	—1
10.00	7.429	—3	1.1643	—2	1.6158	—2	2.0858	—2	2.5678	—2
50.00	2.7665	—5	3.5918	—5	4.419	—5	5.2487	—5	6.0751	—5
100.00	1.8994	—6	2.4184	—6	2.9379	—6	3.4566	—6	3.9787	—6

	1800°		2000°		2200°		2400°		2600°		2800°	
λ	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n	J_λ	n
.10	7.543	—27	2.2235	—23	1.5338	—20	3.5592	—18	3.5731	—16	1.8569	—14
.20	5.249	—11	2.8499	—9	7.485	—8	1.1402	—6	1.1424	—5	8.235	—5
.30	4.190	—6	6.007	—5	5.308	—4	3.2616	—3	1.5160	—2	5.657	—2
.40	7.740	—4	5.703	—3	2.9228	—2	1.1408	—1	3.6108	—1	9.695	—1
.45	3.9513	—3	2.3321	—2	9.967	—2	3.3440	—1	9.313	—1	2.2404	0
.50	1.3771	—2	6.806	—2	2.5154	—1	7.477	—1	1.8796	0	4.142	0
.55	3.6546	—2	1.5618	—1	5.126	—1	1.3800	0	3.1902	0	6.543	0
.60	7.935	—2	3.0050	—1	8.932	—1	2.2141	0	4.773	0	9.222	0
.65	1.4810	—1	5.0622	—1	1.3838	0	3.1988	0	6.502	0	1.1941	1
.70	2.4599	—1	7.701	—1	1.9592	0	4.267	0	8.244	0	1.4500	1
.75	3.7284	—1	1.0817	0	2.5864	0	5.348	0	9.890	0	1.6755	1
.80	5.254	—1	1.4265	0	3.2297	0	6.382	0	1.1360	1	1.8625	1
.90	8.845	—1	2.1492	0	4.444	0	8.146	0	1.3606	1	2.1128	1
1.00	1.2691	0	2.8224	0	5.430	0	9.371	0	1.4880	1	2.2133	1
1.50	2.4072	0	4.115	0	6.391	0	9.241	0	1.2651	1	1.6591	1
2.00	2.1930	0	3.3001	0	4.626	0	6.151	0	7.852	0	9.709	0
2.50	1.6350	0	2.2874	0	3.025	0	3.8351	0	4.707	0	5.631	0
3.00	1.1538	0	1.5411	0	1.964	0	2.4167	0	2.8935	0	3.3905	0
4.00	5.735	—1	7.255	—1	8.855	—1	1.0518	0	1.2233	0	1.3989	0
5.00	3.0360	—1	3.7257	—1	4.439	—1	5.171	—1	5.917	—1	6.674	—1
10.00	3.0578	—2	3.5536	—2	4.054	—2	4.558	—2	5.064	—2	5.571	—2
50.00	6.908	—5	7.7413	—5	8.570	—5	9.401	—5	1.0229	—4	1.1061	—4
100.00	4.497	—6	5.020	—6	5.537	—6	6.062	—6	6.573	—6	7.097	—6

(*continued*)

TABLE 55.—CALCULATED SPECTRAL INTENSITIES J_λ FOR A RANGE OF WAVELENGTHS FOR A BLACKBODY OF UNIT AREA FOR A RANGE OF TEMPERATURES FROM 50°K TO 25,000°K (concluded)

λ	3000° J_λ	3000° n	3200° J_λ	3200° n	3500° J_λ	3500° n	4000° J_λ	4000° n	5000° J_λ	5000° n
.10	5.698	—13	1.1396	—11	5.3650	—10	9.1199	—8	1.2094	—4
.20	4.562	—4	2.0402	—3	1.3998	—2	1.8251	—1	6.647	0
.30	1.7710	—1	4.807	—1	1.7358	0	9.616	0	1.0564	2
.40	2.2819	0	4.825	0	1.2640	1	4.565	1	2.7563	2
.45	4.795	0	9.330	0	2.1962	1	6.877	1	3.4034	2
.50	8.215	0	1.4957	1	3.2321	1	9.032	1	3.8137	2
.55	1.2195	1	2.1028	1	4.237	1	1.0789	2	4.004	2
.60	1.6321	1	2.6895	1	5.113	1	1.2052	2	4.018	2
.65	2.0227	1	3.2083	1	5.807	1	1.2825	2	3.9080	2
.70	2.3657	1	3.6313	1	6.303	1	1.3168	2	3.7175	2
.75	2.6465	1	3.9491	1	6.611	1	1.3165	2	3.4810	2
.80	2.8600	1	4.164	1	6.754	1	1.2903	2	3.2227	2
.90	3.0957	1	4.327	1	6.662	1	1.1884	2	2.7040	2
1.00	3.1245	1	4.228	1	6.248	1	1.0561	2	2.2338	2
1.50	2.1026	1	2.5919	1	3.4032	1	4.9320	1	8.487	1
2.00	1.1703	1	1.3818	1	1.7181	1	2.3215	1	3.6384	1
2.50	6.600	0	7.607	0	9.178	0	1.1922	1	1.7735	1
3.00	3.9044	0	4.432	0	5.247	0	6.650	0	9.570	0
4.00	1.5780	0	1.7598	0	2.0369	0	2.5076	0	3.4705	0
5.00	7.442	—1	8.217	—1	9.391	—1	1.1372	0	1.5393	0
10.00	6.081	—2	6.593	—2	7.361	—2	8.657	—2	1.1225	—1
50.00	1.1897	—4	1.2732	—4	1.3978	—4	1.6064	—4	2.0216	—4
100.00	1.9581	—5	8.130	—6	8.926	—6	1.0219	—5	1.2808	—5

λ	6000° J_λ	6000° n	8000° J_λ	8000° n	10,000° J_λ	10,000° n	15,000° J_λ	15,000° n	20,000° J_λ	20,000° n	25,000° J_λ	25,000° n
.10	1.4597	—2	5.840	0	2.1268	2	2.5671	4	2.8224	5	1.1917	6
.20	7.302	1	1.4607	3	8.820	3	9,763	4	3.3001	5	6.981	5
.30	5.223	2	3.8565	3	1.2857	4	6.571	4	1.5411	5	2.6523	5
.40	9.152	2	4.129	3	1.0313	4	3.6571	4	7.255	4	1.1370	5
.45	9.906	2	3.8032	3	8.653	3	2.7323	4	5.1415	4	7.825	4
.50	9.9983	2	3.3793	3	7.148	3	2.0625	4	3.7257	4	5.542	4
.55	9.6424	2	2.9415	3	5.869	3	1.5762	4	2.7563	4	4.026	4
.60	9.024	2	2.5311	3	4.816	3	1.2201	4	2.0780	4	2.9907	4
.65	8.279	2	2.1601	3	3.9614	3	9.563	3	1.5936	4	2.2654	4
.70	7.496	2	1.8485	3	3.2718	3	7.586	3	1.2456	4	1.7461	4
.75	6.728	2	1.5780	3	2.7160	3	6.084	3	9.800	3	1.3667	4
.80	6.007	2	1.3494	3	2.2670	3	4.931	3	7.836	3	1.0845	4
.90	4.748	2	9.945	2	1.6067	3	3.3311	3	5.178	3	7.078	3
1.00	3.7449	2	7.429	2	1.1643	3	2.3256	3	3.5536	3	4.810	3
1.50	1.2494	2	2.1278	2	3.0625	2	5.505	2	8.008	2	1.0537	3
2.00	5.049	1	8.024	1	1.1106	2	1.9004	2	2.7017	2	3.5077	2
2.50	2.3814	1	3.6391	1	4.926	1	8.194	1	1.1494	2	1.4804	2
3.00	1.2584	1	1.8756	1	2.5026	1	4.088	1	5.684	1	7.280	1
4.00	4.451	0	6.438	0	8.443	0	1.3487	1	1.8549	1	2.3625	1
5.00	1.9460	0	2.7665	0	3.5918	0	5.664	0	7.741	0	9.818	0
10.00	1.3811	—1	1.8994	—1	2.4184	—1	3.7177	—1	5.020	—1	6.318	—1
50.00	2.4375	—4	3.2700	—4	4.099	—4	6.185	—4	8.254	—3	1.0318	—3
100.00	1.5391	—5	2.0663	—5	2.5793	—5	3.8748	—5	5.194	—5	6.448	—5

Auxiliary table for a short method of calculating J_λ for any temperature. (Menzel, Harvard University.)

Let J_0 = intensity for $T_0 = 10{,}000$ °K; for another temperature T °K:

$$J/J_0 = [\lambda_0^5(\exp(c_2/\lambda_0 T_0) - 1)]/[\lambda^5(\exp(c_2/\lambda T) - 1)]$$

For ease of calculation T_0 was taken as 10,000 °K. J_λ = tabular $J_\lambda \times 10^n$ watts, for cm² for 2π solid angle per 0.1μ. Choose $\lambda = \lambda_0 T_0/T$; then $J_\lambda = J_0(T/T_0)^5$. As an example find J_λ for 0.5μ and 6000 °K from value of J_λ for 0.3μ given in Table 55. 0.5μ = 0.3μ *10,000*/6000. J_λ for 0.3μ = 1.2857×10^4. J_λ for λ = 0.5μ = $1.2857 \times 10^4 \times (6{,}000/10{,}000)^5 = 9.998 \times 10^3$.

10,000°											
λ	J_λ	n	λ	J_λ	n	λ	J_λ	n	λ	J_λ	n
.0100	1.3224	−49	.1450	2.8776	3	.5500	5.869	3	4.500	5.383	0
.0150	1.1427	−29	.1500	3.3806	3	.6000	4.816	3	5.000	3.5918	0
.0200	6.949	−20	.1600	4.458	3	.6500	3.9614	3	6.000	1.7761	0
.0250	4.005	−14	.1700	5.586	3	.7000	3.2718	3	7.000	9.756	−1
.0300	2.3444	−10	.1800	6.716	3	.7500	2.7160	3	8.000	5.797	−1
.0350	1.0214	−7	.1900	7.805	3	.8000	2.2670	3	9.000	3.6548	−1
.0400	8.906	−6	.2000	8.820	3	.8500	1.9031	3	10.00	2.4184	−1
.0450	2.6833	−4	.2100	9.735	3	.9000	1.6067	3	12.00	1.1807	−1
.0500	3.8700	−3	.2200	1.0536	4	.9500	1.3641	3	14.00	6.433	−2
.0550	3.2828	−2	.2300	1.1215	4	1.000	1.1643	3	16.00	3.7904	−2
.0600	1.8773	−1	.2400	1.1769	4	1.100	8.613	2	18.00	2.3790	−2
.0650	7.950	−1	.2500	1.2204	4	1.200	6.494	2	20.00	1.5667	−2
.0700	2.6652	0	.2600	1.2524	4	1.300	4.980	2	25.00	6.4692	−3
.0750	7.427	0	.2700	1.2739	4	1.400	3.8782	2	30.00	3.1346	−3
.0800	1.7823	1	.2800	1.2859	4	1.500	3.0625	2	35.00	1.6954	−3
.0850	3.7891	1	.2900	1.2895	4	1.600	2.4487	2	40.00	9.979	−4
.0900	7.288	1	.3000	1.2857	4	1.700	1.9805	2	45.00	6.236	−4
.0950	1.2894	2	.3200	1.2601	4	1.800	1.6183	2	50.00	4.099	−4
.1000	2.1269	2	.3400	1.2163	4	1.900	1.3348	2	55.00	2.8042	−4
.1050	3.3049	2	.3600	1.1606	4	2.000	1.1106	2	60.00	1.9793	−4
.1100	4.881	2	.3800	1.0977	4	2.200	7.867	1	65.00	1.4390	−4
.1150	6.899	2	.4000	1.0313	4	2.400	5.724	1	70.00	1.0698	−4
.1200	9.391	2	.4200	9.640	3	2.600	4.262	1	80.00	6.306	−5
.1250	1.2365	3	.4400	8.977	3	2.800	3.2372	1	90.00	3.9340	−5
.1300	1.5819	3	.4600	8.335	3	3.000	2.5026	1	100.00	2.5793	−5
.1350	1.9732	3	.4800	7.724	3	3.500	1.4015	1			
.1400	2.4062	3	.5000	7.148	3	4.000	8.443	0			

The adoption of a new value for c_2 changes the calculated values for J_λ by an amount that varies indirectly with both the wavelength and the temperature for values of $\lambda T < 3000$, as follows:

$$\frac{dJ_\lambda}{J_\lambda} = \frac{-dc_2}{\lambda T}$$

that is, a larger value of c_2 results in a smaller value of J_λ. Values of this correction factor for this change in c_2 have been calculated and are given in the tables for five temperatures and a range of wavelengths that cover the visible spectrum. As these percentage correction factors are given they are the percentage of the J_λ for 14320μ deg that must be subtracted from it to give J_{14380}.

A change in c_2 also results in a different value of the extrapolated temperature as measured with an optical pyrometer for a definite ratio of brightness. Thus

$$\left(\frac{1}{T_0} - \frac{1}{T_1}\right) = \frac{c_2^1}{c_2}\left(\frac{1}{T_0} - \frac{1}{T_0^1}\right)$$

To the accuracy necessary for most work, values for other wavelengths, other temperatures, or other values of c_2 within these ranges can be found by interpolation.

Part 1.—Percentage change in J_λ for a change in c_2 from 14320 to 14380μ degrees

λ in μ	2000 °K	2300 °K	2600 °K	2900 °K	3200 °K	λ in μ	2000 °K	2300 °K	2600 °K	2900 °K	3200 °K
.32	9.8	8.5	7.5	6.7	6.0	.58	5.3	4.6	4.1	3.6	3.3
.34	9.2	7.9	7.0	6.3	5.7	.60	5.1	4.4	3.9	3.5	3.2
.36	8.7	7.5	6.6	5.9	5.3	.62	4.9	4.3	3.8	3.4	3.1
.38	8.2	7.1	6.3	5.6	5.0	.64	4.8	4.1	3.7	3.3	3.0
.40	7.8	6.7	5.9	5.3	4.8	.66	4.6	4.0	3.6	3.2	2.9
.42	7.4	6.4	5.7	5.0	4.6	.68	4.5	3.9	3.5	3.1	2.8
.44	7.0	6.1	5.4	4.8	4.4	.70	4.4	3.8	3.4	3.0	2.7
.46	6.7	5.8	5.1	4.6	4.2	.72	4.2	3.7	3.3	2.9	2.6
.48	6.4	5.6	4.9	4.4	4.0	.74	4.1	3.6	3.2	2.8	2.6
.50	6.2	5.3	4.7	4.2	3.8	.76	4.0	3.5	3.1	2.8	2.5
.52	5.9	5.1	4.5	4.1	3.7	.78	3.9	3.4	3.0	2.7	2.4
.54	5.7	4.9	4.4	3.9	3.5	.80	3.8	3.3	2.9	2.6	2.3
.56	5.5	4.8	4.2	3.8	3.4						

Part 2.—Change in temperatures, ΔT, extrapolated from 1336 to the temperature T given, c_2 changed from 14320 to 14380μ degrees

T°K	1500°K	1800°K	2000°K	2500°K	3000°K	3500°K	4000°K	5000°K
ΔT	—.6	—2.4	—4.1	—8.7	—15.5	—22.3	—33.0	—56.4

Photometry is the measurement of light, and light has been defined by the Illuminating Engineering Society as radiant energy evaluated according to its capacity to produce visual sensations.

TABLE 58.—THE EYE AS A MEASURING INSTRUMENT FOR RADIATION

Part 1.—Theory

As a measuring instrument for radiation, the eye is very selective, that is, it does not respond equally to radiation of various wavelengths. The data in Part 2 give the relative sensitivity of the eye to radiation of different wavelengths. Another peculiarity of the eye is that its relative sensitivity changes with the intensity of the radiation that falls upon it. This is shown by the data in Table 59. Also the absolute sensitivity of the eye varies with the intensity of the radiation that falls upon it. This is shown by the data given in Table 60.

The data[25] on which Table 60 is based are not very extensive, but inasmuch as there is now some active work on this subject by Lowry of the Eastman Kodak Co. there should soon be available data for a wider range of field brightness. The data in Table 59 show that the sensitivity of the eye to radiation of lower intensity increases faster toward the blue end of the spectrum than in the red end. This is called the Purkinje effect.

For light measurement at very low brightness care must be taken as to the standards used. From the data given in Table 59 it can be shown that sources giving light of different colors that were rated as equal by the average eye adapted to a field brightness of about 1 to 2 millilamberts would be rated quite differently for low field brightness, that is, for the eye adapted to a field brightness of 10^{-5} millilamberts.

If the brightness given by two sources such as daylight and a carbon lamp be set equal for a field brightness 1 to 2 millilamberts and then these brightnesses both reduced mechanically to about 10^{-5} millilamberts, the field of the daylight source would seem to be about 2½ times as bright as that of the carbon lamp.

[25] Blanchard, Phys. Rev., vol. 11, p. 81, 1918; Stiles and Crawford, Proc. Roy. Soc. London, ser. B, vol. 112, p. 428, 1933; Lowry, Journ. Opt. Soc. Amer., vol. 18, p. 29, 1929.

Part 2.—Relative luminosity factors[26] [K_λ] (unity at wavelength of maximum luminosity)

λ in mμ	Standard factors	Values interpolated at intervals of one millimicron								
		1	2	3	4	5	6	7	8	9
380	.00004	.000045	.000049	.000054	.000059	.000064	.000071	.000080	.000090	.000104
390	.00012	.000138	.000155	.000173	.000193	.000215	.000241	.000272	.000308	.000350
400	.0004	.00045	.00049	.00054	.00059	.00064	.00071	.00080	.00090	.00104
410	.0012	.00138	.00156	.00174	.00195	.00218	.00244	.00274	.00310	.00352
420	.0040	.00455	.00515	.00581	.00651	.00726	.00806	.00889	.00976	.01066
430	.0116	.01257	.01358	.01463	.01571	.01684	.01800	.01920	.02043	.02170
440	.023	.0243	.0257	.0270	.0284	.0298	.0313	.0329	.0345	.0362
450	.038	.0399	.0418	.0438	.0459	.0480	.0502	.0525	.0549	.0574
460	.060	.0627	.0654	.0681	.0709	.0739	.0769	.0802	.0836	.0872
470	.091	.0950	.0992	.1035	.1080	.1126	.1175	.1225	.1278	.1333
480	.139	.1448	.1507	.1567	.1629	.1693	.1761	.1833	.1909	.1991
490	.208	.2173	.2270	.2371	.2476	.2586	.2701	.2823	.2951	.3087
500	.323	.3382	.3544	.3714	.3890	.4073	.4259	.4450	.4642	.4836
510	.503	.5229	.5436	.5648	.5865	.6082	.6299	.6511	.6717	.6914
520	.710	.7277	.7449	.7615	.7776	.7932	.8082	.8225	.8363	.8495
530	.862	.8739	.8851	.8956	.9056	.9149	.9238	.9320	.9398	.9471
540	.954	.9604	.9661	.9713	.9760	.9803	.9840	.9873	.9902	.9928
550	.995	.9969	.9983	.9994	1.0000	1.0002	1.0001	.9995	.9984	.9969
560	.995	.9926	.9898	.9865	.9828	.9786	.9741	.9691	.9638	.9581
570	.952	.9455	.9386	.9312	.9235	.9154	.9069	.8981	.8890	.8796
580	.870	.8600	.8496	.8388	.8277	.8163	.8046	.7928	.7809	.7690
590	.757	.7449	.7327	.7202	.7076	.6949	.6822	.6694	.6565	.6437
600	.631	.6182	.6054	.5926	.5797	.5668	.5539	.5410	.5282	.5156
610	.503	.4905	.4781	.4658	.4535	.4412	.4291	.4170	.4049	.3929
620	.381	.3690	.3570	.3449	.3329	.3210	.3092	.2977	.2864	.2755
630	.265	.2548	.2450	.2354	.2261	.2170	.2082	.1996	.1912	.1830
640	.175	.1672	.1596	.1523	.1452	.1382	.1316	.1251	.1188	.1128
650	.107	.1014	.0961	.0910	.0862	.0816	.0771	.0729	.0688	.0648
660	.061	.0574	.0539	.0506	.0475	.0446	.0418	.0391	.0366	.0343
670	.032	.0299	.0280	.0263	.0247	.0232	.0219	.0206	.0194	.0182
680	.017	.01585	.01477	.01376	.01281	.01192	.01108	.01030	.00956	.00886
690	.0082	.00759	.00705	.00656	.00612	.00572	.00536	.00503	.00471	.00440
700	.0041	.00381	.00355	.00332	.00310	.00291	.00273	.00256	.00241	.00225
710	.0021	.001954	.001821	.001699	.001587	.001483	.001387	.001297	.001212	.001130
720	.00105	.000975	.000907	.000845	.000788	.000736	.000688	.000644	.000601	.000560
730	.00052	.000482	.000447	.000415	.000387	.000360	.000335	.000313	.000291	.000270
740	.00025	.000231	.000214	.000198	.000185	.000172	.000160	.000149	.000139	.000130
750	.00012	.000111	.000103	.000096	.000090	.000084	.000078	.000074	.000069	.000064
760	.00006	.000056	.000052	.000048	.000045	.000042	.000039	.000037	.000035	.000032

[26] I.E.S. Nomenclature and photometric standards, American Standards Association, ASA C-42, 1941.

TABLE 59.—RELATIVE LUMINOSITY DATA FOR VARIOUS FIELD BRIGHTNESSES [27]

(Logarithms of field brightness in first line)

Wave-length mμ	ICI	—0.5	—1.0	—1.5	—2.0	—2.5	—3.0	—3.5	—4.0	—4.187 *	—4.50	—5.00
350	.....	....	....	....	....	....	....	....	.0002	.000265	.0003	.0003
360	.....	....	....	....	....	....	.0003	.0004	.0007	.00073	.0008	.0008
370	.....	....	....	....	.0002	.0005	.0009	.0013	.0018	.0019	.0020	.0022
380	.00004	.0000	.0001	.0002	.0008	.0015	.0025	.0034	.0045	.0048	.0051	.0055
390	.00012	.0001	.0002	.0008	.0022	.0040	.0063	.0083	.0104	.0112	.0119	.0127
400	.0004	.0004	.0008	.0022	.0059	.0098	.0147	.0185	.0228	.0243	.0253	.0270
410	.0012	.0014	.0023	.0062	.0140	.0227	.0305	.0370	.0452	.0485	.0500	.0530
420	.0040	.0044	.0069	.0152	.0280	.0427	.0580	.0690	.0820	.087	.0900	.0950
430	.0116	.0121	.0165	.0292	.0505	.0755	.101	.118	.138	.145	.149	.157
440	.023	.0240	.0300	.0496	.0850	.123	.160	.183	.216	.225	.230	.239
450	.038	.0395	.0490	.0810	.136	.187	.237	.268	.310	.321	.326	.339
460	.060	.0627	.0775	.127	.202	.277	.339	.376	.423	.434	.441	.455
470	.091	.0960	.118	.191	.301	.394	.467	.510	.551	.560	.568	.576
480	.139	.146	.180	.288	.432	.540	.604	.649	.685	.695	.702	.714
490	.208	.220	.274	.426	.592	.688	.734	.782	.814	.827	.830	.842
500	.323	.340	.416	.603	.744	.826	.864	.902	.930	.932	.941	.948
510	.503	.524	.617	.766	.876	.935	.962	.977	.992	.997	.997	.999
520	.710	.726	.792	.894	.965	.992	.999	.988	.974	.963	.960	.953
530	.862	.872	.910	.972	1.000	.982	.951	.924	.883	.871	.862	.848
540	.954	.959	.979	1.000	.969	.909	.842	.796	.744	.734	.715	.697
550	.995	.997	1.000	.971	.886	.785	.698	.642	.583	.555	.552	.531
560	.995	.992	.973	.898	.760	.640	.543	.478	.419	.390	.388	.365
570	.952	.944	.907	.782	.617	.485	.384	.330	.281	.263	.260	.243
580	.870	.860	.802	.648	.468	.340	.259	.218	.182	.167	.164	.155
590	.757	.742	.673	.509	.333	.227	.166	.137	.112	.102	.101	.0945
600	.631	.616	.544	.374	.224	.145	.101	.0830	.0670	.0613	.060	.0560
610	.503	.490	.416	.257	.142	.0870	.0600	.0488	.0388	.0366	.0348	.0324
620	.381	.366	.296	.168	.0845	.0504	.0344	.0280	.0225	.0212	.0202	.0188
630	.265	.250	.197	.102	.0480	.0282	.0194	.0156	.0127	.0118	.0114	.0105
640	.175	.162	.122	.0590	.0270	.0146	.0107	.0085	.0070	.00653	.0062	.0058
650	.107	.0990	.0710	.0327	.0147	.0084	.0058	.0046	.0037	.00353	.0034	.0032
660	.061	.0560	.0390	.0174	.0078	.0045	.0031	.0025	.0020	.00189	.0018	.0017
670	.032	.0303	.0206	.0090	.0041	.0024	.0017	.0013	.0011	.00098	.0010	.0009
680	.017	.0153	.0103	.0046	.0022	.0014	.0009	.0007	.0006	.00050	.0005	.0005
690	.0082	.0076	.0052	.0024	.0011	.0007	.0004	.0003	.0003	.00025	.0002	.0002
700	.0041	.0038	.0026	.0012	.0006	.0003	.0002	.0002	.00016	.00013	.0001	.0001
710	.0021	.0019	.0014	.0006	.0003	.0002	.0001	....	....	....	....	....
720	.00105	.0010	.0007	.0003	.0001	....	....	....	....	....	....	....
730	.00052	.0005	.0003	.0001	....	....	....	....	....	....	....	....
740	.00025	.0002	.0002	....	....	....	....	....	....	....	....	....
750	.00012	.0001	....	....	....	....	....	....	....	....	....	....
760	.00006	....	....	....	....	....	....	....	....	....	....	....
770	.00003	....	....	....	....	....	....	....	....	....	....	....

[27] L. A. Jones, private communication.
* Average of Weaver and Hecht's values.

TABLE 60.—BLANCHARD'S DATA RELATING INSTANTANEOUS THRESHOLD TO FIELD BRIGHTNESS **

Field brightness * millilamberts	Instantaneous threshold †	Relative sensitivity ‡ (n)	Ratio §	Relative value of maximum
100.	1.9×10^{-1}	.047	4.6	.047
10.	4.2×10^{-2}	.21	4.7	.21
1.	8.9×10^{-3}	1.0	4.7	1.00
.1	1.9×10^{-3}	4.67	4.6	4.95
.032	8.9×10^{-4}	10.0	...	12.0
.01	4.2×10^{-4}	21.4	4.7	29.5
.0032	1.9×10^{-4}	46.7	...	70.0
.001	8.9×10^{-5}	100.0	4.7	161.0
.0001	1.9×10^{-5}	467.0	4.6	822.0
.00001	4.2×10^{-6}	2140.	...	3900.
.0	1.8×10^{-7} ‖	48600.	...	88500.

** For reference, see footnote 25, p. 87.
* The field brightnesses are values obtained by mechanically increasing or reducing values measured at photopic levels. † Taken from smooth curve drawn through Blanchard's data. The unit will depend upon definition. As these figures stand they are brightnesses for this radiation measured at photopic levels and reduced mechanically to values given. ‡ For radiation from a source at a color temperature of 2680 °K. § This is the ratio of the eye sensitivity to that of the eye adapted to the next lower (one-tenth) field brightness for this radiation. ‖ Minimum threshold from Taylor's value.

TABLE 61.—THE SENSIBILITY OF THE EYE *

Part 1.—Contrast or photometric sensibility

For the following table the eye was adapted to a field of 0.1 millilambert and the sensitizing field flashed off. A neutral gray test spot (angular size at eye, 5 × 2.5°) the two halves of which had the contrast indicated (½ transparent, ½ covered with neutral screen of transparency = contrast indicated) was then observed and the brightness of the transparent part measured necessary to just perceive the contrast after the lapse of the various times. One eye only used, natural pupil. Values are log brightness of brighter field in millilamberts.

Time in seconds	0	1	2	5	10	20	40	60
Contrast: 0.00....	—2.80	—3.47	—3.82	—4.30	—4.49	—4.60	—4.89	—5.03
0.39....	—2.63	—3.36	—3.58	—3.74	—3.85	—3.97	—4.06	—4.23
0.67....	—2.40	—3.00	—3.13	—3.22	—3.21	—3.33	—3.46	—3.48
0.87....	—2.10	—2.46	—2.49	—2.48	—2.55	—2.54	—2.67	—2.73
0.97....	—1.20	—1.57	—1.67	—1.69	—1.59	—1.63	—1.73	—1.78

Part 2.—Glare Sensibility

When an eye is adapted to a certain brightness and is then exposed suddenly to a much greater brightness, the latter may be called glaring if uncomfortable and instinctively avoided. Observers naturally differ widely. The data are the means of three observers, and are log brightnesses in millilamberts. The glare intensity may be taken as roughly 1700 times the cube root of the field intensity in millilamberts. Angle of glare spot, 4°.

Log. field	—6.0	—4.0	—2.0	—1.0	.0	+1.0	2.0	3.0	4.0
Log. glare	1.35	1.90	2.60	2.90	3.28	3.60	3.90	4.18	4.48

Part 3.—Rate of adaptation of sensibility

This table furnishes a measure of the rate of increase of sensibility after going from light into darkness, and the values were obtained immediately from the instant of turning off the sensitizing field. Both eyes were used, natural pupil, angular size of test spot, 4.9°, viewed at 35 cm. Retinal light persists only 10 to 20 minutes when one has been recently in darkness, then in a dimly lighted room; it persists fully an hour when a subject has been in bright sunlight for some time. A person who has worked much in the dark "gets his eyes" quicker than one who has not, but his final sensitiveness may be no greater.

Sensitizing field	Logarithmic thresholds in millilamberts after										
	0 sec	1 sec	2 sec	5 sec	10 sec	20 sec	40 sec	60 sec	5 min	30 min	60 min
White 0.1 ml...	—2.79	—3.82	—4.13	—4.50	—4.75	—4.96	—5.16	—5.32	—5.68	—5.91	—6.06
1.0 ml...	—2.20	—2.99	—3.27	—3.79	—4.15	—4.51	—4.82	—5.06	—5.52	—5.86	—6.04
10.0 ml...	—1.60	—2.30	—2.53	—3.08	—3.54	—3.94	—4.31	—4.61	—5.22	—5.83	—6.01
100.0 ml...	—0.90	—1.66	—2.00	—2.46	—2.64	—2.88	—3.20	—3.84	—4.76	—5.77	—5.97
Blue 0.1 ml...	—2.82	—3.92	—4.36	—4.91	—5.27	—5.53	—5.68	—5.81	—6.23	—	—
Green 0.1 ml...	—2.69	—4.08	—4.39	—4.82	—5.11	—5.26	—5.43	—5.56	—5.80	—	—
Yellow 0.1 ml...	—2.61	—3.84	—4.17	—4.41	—4.65	—4.78	—5.02	—5.09	—5.39	—	—
Red 0.1 ml...	—2.32	—2.69	—2.98	—3.37	—3.57	—3.65	—3.73	—3.80	—4.02	—	—

* For reference, see footnote 25, p. 87.

TABLE 62.—MINIMUM ENERGY NECESSARY TO PRODUCE THE SENSATION OF LIGHT

Ives	38 $\times 10^{-10}$ erg sec	Astrophys. Journ., vol. 44, p. 124, 1916.
Russell	7.7 $\times 10^{-10}$ " "	Astrophys. Journ., vol. 45, p. 60, 1917.
Reeves	19.5 $\times 10^{-10}$ " "	Astrophys. Journ., vol. 46, p. 167, 1917.
Buisson	12.6 $\times 10^{-10}$ " "	Journ. de phys., vol. 7, p. 68, 1917.
Taylor	Minimum threshold for dark-adapted eye, a surface, at a brightness of 1.8 $\times 10^{-7}$ millilamberts, source color temperature 2850 °K.	Journ. Opt. Soc. Amer., vol. 32, p. 506, 1942.
Hecht	2.2-5.7 $\times 10^{-10}$ ergs at cornea, considering losses the amount of energy that reaches the retina is such that 1 quanta is absorbed by from 5-14 retinal rods.	Journ. Opt. Soc. Amer., vol. 32, p. 42, 1942.

TABLE 63.—APPARENT DIAMETER OF PUPIL AND FLUX DENSITY AT RETINA

Flashlight measures of the pupil (both eyes open) viewed through the eye lens and adapted to various field intensities. For eye accommodated to 25 cm, ratio apparent to true pupil, 1.02, for the unaccommodated eye, 1.14. The pupil size varies considerably with the individual. It is greater with one eye closed; e.g., it was found to be for 0.01 millilambert, 6.7 and 7.2 mm; for 0.6 ml, 5.3 and 6.5; for 6.3 ml, 4.1 and 5.7; for 12.6 ml, 4.1 and 5.7 mm for both eyes and one eye open respectively for a certain individual. At the extreme intensities the two values approach each other. The ratio of the extreme pupil openings is about $\frac{1}{16}$, whereas the light intensities investigated vary over 1,000,000-fold.

Field millilamberts	Observed	(1.14/1.02) × obs.	Effective area	Flux at retina, lumens per mm²
.00001	8 mm	8.96 mm	64 mm²	8.4×10^{-12}
.001	7.6	8.51	57	7.6×10^{-10}
.1	6.5	7.28	42	5.6×10^{-8}
10	4.0	4.48	16	2.1×10^{-6}
1000	2.07	2.35	4.3	5.8×10^{-5}

TABLE 64.—MISCELLANEOUS EYE DATA

Light passing to the retina traverses in succession (*a*) front surface of the cornea (curvature, 7.9 mm); (*b*) cornea (equivalent water path for energy absorption, 0.06 cm); (*c*) back surface cornea (curv., 7.9 mm); (*d*) aqueous humour (equiv. H_2O, 0.34 cm, $n = 1.337$); (*e*) front surface lens (c, 10 mm); (*f*) lens (equiv. H_2O, 0.42 cm, $n = 1.445$); (*g*) back surface lens (c, 6 mm); (*h*) vitreous humour (equiv. H_2O, 1.46 cm, $n = 1.337$). An equivalent simple lens has its principal point 2.34 mm behind (*a*), nodal point 0.48 mm in front of (*g*), posterior principal focus 22.73 mm behind (*a*), anterior principal focus 12.83 mm in front of (*a*), curvature, 5.125 mm. At the rear surface of the retina (0.15 mm thick) are the rods ($30 \times 2\mu$) and cones (10 (6 outside fovea) μ long). Rods are more numerous, 2 to 3 between 2 cones, over 3,000,000 cones in eye. Macula lutea, yellow spot, on temporal side, 4 mm from center of retina, long axis 2 mm. Central depression, fovea centralis, 0.3 mm diameter, 7000 cones alone present, 6×2 or 3μ. In region of distinct vision (fovea centralis) smallest angle at which two objects are seen separate is 50″ to 70″ = 3.65 to 5.14μ at retina; 50 cones in 100μ here; 4μ between centers, 3μ to cone, 1μ to interval. Distance apart for separation greater as depart from fovea. No vision in blind spot, nasal side, 2.5 mm from center of eye, 15 mm in diameter.

Persistence of vision as related to color and intensity is measured by increasing speed of rotating sector until flicker disappears: for color, 0.4μ, 0.031 sec; 0.45μ, 0.020 sec; 0.5μ, 0.015 sec; 0.57μ, 0.012 sec; 0.68μ, 0.014 sec; 0.76μ, 0.018 sec; for intensity, 0.06 meter-candle, 0.028 sec; 1 mc, 0.020 sec; 6 mc, 0.014 sec; 100 mc, 0.010 sec; 142 mc, 0.007 sec.

Sensibility to small differences in color has two pronounced maxima (in yellow and green) and two slight ones (extreme blue, extreme red). The sensibility to small differences in intensity is nearly independent of the intensity (Fechner's law) as indicated by the following data due to König:

I/I_0	1,000,000	100,000	10,000	1000	100	50	10	5	1	0.1	I_0 in mc
dI/I, white....	.036	.019	.018	.018	.030	.032	.048	.059	.123	.377	.00072
.60 μ....	—	.024	.016	.020	.028	.038	.061	.103	.212	—	.0056
.50 μ....	—	—	.018	.018	.024	.025	.036	.049	.080	.133	.00017
.43 μ....	—	—	—	.018	.025	.027	.040	.049	.074	.137	.00012

TABLE 65.—DISTRIBUTION COEFFICIENTS FOR EQUAL-ENERGY STIMULUS

1931 I.C.I. standard observer[28]

The fact that almost any color can be produced by the proper mixture of red, green, and blue light, has been used as a basis of a system of color specifications that has been adopted by the International Commission on Illumination. In the system adopted by that Commission in 1931, the primaries are called the *X*, *Y*, and *Z* stimuli. The properties of the standard observer are given by his tristimulus specifications of the spectrum stimuli as a function of wavelength. This table gives this specification for the equal energy spectrum.

[28] Judd, D. B., Journ. Opt. Soc. Amer., vol. 23, p. 359, 1933.

(*continued*)

TABLE 65.—DISTRIBUTION COEFFICIENTS FOR EQUAL-ENERGY STIMULUS (concluded)

Wave-length (mμ)	Coefficients			Wave-length (mμ)	Coefficients		
	$\bar{x}$	$\bar{y}$	$\bar{z}$		$\bar{x}$	$\bar{y}$	$\bar{z}$
380	.0014	.0000	.0065	580	.9163	.8700	.0017
385	.0022	.0001	.0105	585	.9786	.8163	.0014
390	.0042	.0001	.0201	590	1.0263	.7570	.0011
395	.0076	.0002	.0362	595	1.0567	.6949	.0010
400	.0143	.0004	.0679	600	1.0622	.6310	.0008
405	.0232	.0006	.1102	605	1.0456	.5668	.0006
410	.0435	.0012	.2074	610	1.0026	.5030	.0003
415	.0776	.0022	.3713	615	.9384	.4412	.0002
420	.1344	.0040	.6456	620	.8544	.3810	.0002
425	.2148	.0073	1.0391	625	.7514	.3210	.0001
430	.2839	.0116	1.3856	630	.6424	.2650	.0000
435	.3285	.0168	1.6230	635	.5419	.2170	.0000
440	.3483	.0230	1.7471	640	.4479	.1750	.0000
445	.3481	.0298	1.7826	645	.3608	.1382	.0000
450	.3362	.0380	1.7721	650	.2835	.1070	.0000
455	.3187	.0480	1.7441	655	.2187	.0816	.0000
460	.2908	.0600	1.6692	660	.1649	.0610	.0000
465	.2511	.0739	1.5281	665	.1212	.0446	.0000
470	.1954	.0910	1.2876	670	.0874	.0320	.0000
475	.1421	.1126	1.0419	675	.0636	.0232	.0000
480	.0956	.1390	.8130	680	.0468	.0170	.0000
485	.0580	.1693	.6162	685	.0329	.0119	.0000
490	.0320	.2080	.4652	690	.0227	.0082	.0000
495	.0147	.2586	.3533	695	.0158	.0057	.0000
500	.0049	.3230	.2720	700	.0114	.0041	.0000
505	.0024	.4073	.2123	705	.0081	.0029	.0000
510	.0093	.5030	.1582	710	.0058	.0021	.0000
515	.0291	.6082	.1117	715	.0041	.0015	.0000
520	.0633	.7100	.0782	720	.0029	.0010	.0000
525	.1096	.7932	.0573	725	.0020	.0007	.0000
530	.1655	.8620	.0422	730	.0014	.0005	.0000
535	.2257	.9149	.0298	735	.0010	.0004	.0000
540	.2904	.9540	.0203	740	.0007	.0003	.0000
545	.3597	.9803	.0134	745	.0005	.0002	.0000
550	.4334	.9950	.0087	750	.0003	.0001	.0000
555	.5121	1.0002	.0057	755	.0002	.0001	.0000
560	.5945	.9950	.0039	760	.0002	.0001	.0000
565	.6784	.9786	.0027	765	.0001	.0000	.0000
570	.7621	.9520	.0021	770	.0001	.0000	.0000
575	.8425	.9154	.0018	775	.0000	.0000	.0000
580	.9163	.8700	.0017	780	.0000	.0000	.0000
Totals..	.....	.....	.....	...	21.3713	21.3714	21.3715

TABLE 66.—RELATIVE MAGNITUDE OF UNITS OF ILLUMINATION

Units	Lux	Phot	Milliphot	Foot-candle
1 lux =	1	.0001	.1	.0929
1 phot =	10,000	1.	1000.	929.
1 milliphot =	10	.001	1.	.929
1 foot-candle	10.76	.001076	1.076	1.

TABLE 67.—VISUAL RANGE OF WHITE LIGHTS[29]

Candlepower c candles at visual threshold of steady point source of white light seen against white background brightness b millimicrolambert (mμL) at range r sea miles through an atmosphere of attenuation a per sea mile is given by

$$C = 3.7 \times 10^{-3}(1 + b)^{\frac{1}{2}} r^2 a^{-r},$$

which is valid within a factor of 3 for b from total darkness to full daylight. For practical signaling or navigation multiply c by at least 100.

Range r sea mile	Threshold c candles, $b = 100$ mμ L, at night $a = 1$	$a = 0.8$	$a = 0.6$	$a = 0.4$
1	.04	.05	.06	.09
2	.15	.23	.41	.9
3	.33	.65	1.5	5.2
5	.91	2.9	12	90
7	1.8	8.6	62	1100
10	3.6	34	610	35000

[29] Knoll, H. A., Tousey, R., and Hulburt, E. O., Journ. Opt. Soc. Amer., vol. 36, p. 480, 1946.

TABLE 68.—THE BRIGHTNESS OF THE SUN

From the definition of a lumen, the lumen output from a point source within a unit solid angle is numerically equal to the candlepower of the source. This also holds for any radiating source that behaves as a point, such as a spherical blackbody,* or any spherical radiator of uniform brightness that obeys the Lambert cosine law of radiation, providing the measurements are made at such a distance from the source that the inverse square law is obeyed. (See Table 74.) As an example of this, consider the brightness of the sun. The sun when directly overhead on a clear day gives an illumination of about 10,000 foot-candles. This is equal to 10,000 lumens per ft.^{2} (See Table 73.) To change this to lumens for a unit solid angle, multiply by the radius of the earth's orbit squared (i.e., 2.41×10^{23} ft^2). Thus, the candlepower of the sun is 2.41×10^{27}. To get the brightness per cm^2 divide this by the projected area of the sun in cm^2 (i.e., 1.52×10^{22}), which gives about 160,000 c/cm^2 for the brightness of the sun as observed at the earth's surface. This, of course, assumes that the sun's surface is of uniform brightness and that its radiation obeys the Lambert cosine law. The data (Table 813) on the distribution of energy of the solar spectrum give a brightness of the sun of 146,000 c/cm^2.

* The lumens within a unit solid angle around the normal from a plane blackbody is equal to 0.92 times the normal intensity.

TABLE 69.—SOME OBSOLETE PHOTOMETRIC STANDARDS

(In use prior to 1948.)

In Germany the Hefner lamp was most used; in England the Pentane lamp and sperm candles; in France the Carcel lamp was preferred; in America the Pentane and Hefner lamps were used to some extent, but candles were largely employed in gas photometry. For the photometry of electric lamps, and in accurate photometric work, electric lamps, standardized at a national standardizing institution, were employed.

The "international candle" designated the value of the candle as maintained by co-operative effort between the national laboratories of England, France, and America; and the value of various photometric units in terms of this is given in the following table (Circular No. 15 of the Bureau of Standards):

1 international candle = 1 Pentane candle.
1 international candle = 1 Bougie decimale.
1 international candle = 1 American candle.
1 international candle = 1.11 Hefner unit.
1 international candle = 0.104 Carcel unit.

1. Standard Pentane lamp, burning pentane............. 10.0 candles.
2. Standard Hefner lamp, burning amyl acetate.......... 0.9 candles.
3. Standard Carcel lamp, burning colza oil............. 9.6 candles.
4. Standard English sperm candle, approximately........ 1.0 candles.

The international candle was in reality taken from the candlepower of a number of incandescent lamps, operated under definite conditions and kept at the standard laboratories of France, Britain, and the United States.

(Adapted from Reports of Committee on Nomenclature and Standards of Illuminating Engineering Society, 1942.)

Apostilb = 0.1 millilambert.

Brightness of a luminous surface may be expressed in two ways:

(1) $b_I = dI/dA \cos\theta$ where θ is the angle between normal to surface and the line of sight; normal brightness when θ is zero.

(2) $b_F = dF/dA$ assuming that the surface is a perfect diffuser, obeying cos law of emission or reflection. Unit, the lambert.

Candle per cm² = 3.1416 lamberts = 1 stilb.

Candle per in.² = .4868 lambert = 486.8 millilamberts.

Foot-candle = 1 lumen incident per ft² = 1.076 milliphots = 10.76 lux.

Illumination on surface = E = flux density on surface = dF/dA (A is surface area) = F/A when uniform. Units, meter-candle, foot-candle, phot, lux.

Lambert, the cgs unit of brightness, is the brightness of a perfectly diffusing surface radiating or reflecting one lumen per cm². Equivalent to a perfectly diffusing surface with illumination of one phot. A perfectly diffusing surface emitting one lumen per ft² has a brightness of 1.076 millilamberts. Brightness in candles per cm² is reduced to lamberts by multiplying by π.

Lambert = 1 lumen emitted per cm² of a perfectly diffusing surface.

Lambert = .3183 candle per cm² = 2.054 candles per in².

Lumen is emitted by .07958 spherical candle.

Lumen emitted per ft² = 1.076 millilamberts (perfect diffusion).

Luminous efficiency = F/Φ expressed in lumens/watt.

Luminous flux = F or Ψ = rate of flow of radiation measured according to power to produce visual sensation. Although strictly thus defined, for photometric purposes it may be regarded as an entity, since the rate of flow for such purposes is invariable. Unit is the *lumen,* the flux emitted in a unit solid angle (steradian) by a point source of unit candle power.

Luminous intensity of (approximate) point source = I = solid-angle (ω) density of luminous flux in direction considered = $dF/d\omega$, or F/ω when the intensity is uniform. Unit, the *candle.*

Luminosity factor of radiation of wave-length λ = K_λ = ratio of luminous to radiant flux for that λ, = F_λ/Φ_λ.

Lux = 1 lumen incident per m² = .0001 phot = .1 milliphot.

Mechanical equivalent of light = ratio of Φ/F for the λ of max. visibility expressed in (ergs/sec)/lumen or watts/lumen; it is the reciprocal of max. luminosity. See Table 58.

Millilambert = .929 lumen per ft² (perfect diffusion).

Milliphot = .001 phot = .929 foot-candle.

Phot = 1 lumen incident per cm² = 10,000 lux = 1000 milliphots.

Photon = small bundle of energy ($h\nu$), also called a quantum.

Radiant flux = Φ = rate of flow of radiation as energy, measured as ergs per second or watts.

Specific luminous radiation, E' = luminous flux density emitted by a surface, or the flux emitted per unit of emissive area, expressed in lumens per cm². For surfaces obeying Lambert's cosine law, $E' = \pi b_0$.

Spectral luminous flux at wavelength $\lambda = (K_\lambda)(\Phi_\lambda)$. Spectral luminous curve expresses this as a function of λ and is different for various sources.

One spherical candle emits 12.57 lumens.

Uniform point source of one candle emits 4π lumens.

TABLE 71.—RELATIVE MAGNITUDES OF UNITS OF BRIGHTNESS

Units		Candle per cm² (Stilb)	Lambert	Milli-lambert	Candle per in.²	Foot-lambert
1 candle per cm²	=	1.	3.142	3142.	6.452	2919.
1 lambert	=	.3183	1.	1000.	2.054	929.
1 millilambert	=	.000318	.001	1.	.00205	.929
1 candle per in.²	=	.1550	.487	487.	1.	452.
1 foot-lambert	=	.000342	.001076	1.076	.00221	1.

1 candle per ft.² = 3.142 foot-lamberts.

1 stilb = 1 candle per cm²

1 apostilb = 0.1 millilambert.

TABLE 72.—THE WAIDNER-BURGESS STANDARD OF LIGHT INTENSITY[30]

This standard of light intensity is the brightness of a blackbody at the temperature of freezing platinum. The blackbody used was made of thorium oxide and was immersed in the melting platinum; very pure platinum (99.997 percent) was used. Reproducible to 0.1 percent, the brightness was found to be 58.84 international candles per cm.^{2} This Waidner-Burgess standard, taking the brightness of the blackbody at the freezing point of platinum as 60 candles per cm^2, was adopted by the International Committee on Weights and Measures in 1937 as the new unit of light intensity and was put into effect January 1, 1948.[31]

The light from the blackbody at the temperature of freezing platinum is not greatly different in color from that given by carbon-filament standard lamps, as the color temperature of the lamp filaments is about 2100 °K, whereas the freezing point of platinum is 2042 °K. In this range of color the new unit of intensity is about 1.9 percent smaller than the old international candle, and sources of light are correspondingly given higher numerical ratings. However, when light sources of higher color temperature are compared with these basic standards, the accepted spectral luminosity factors give slightly lower values for the "whiter" sources than were obtained by visual measurements when the present international units were established. The difference between the two scales therefore grows less as the color temperature of the sources measured is increased, and for sources in the range of ordinary vacuum tungsten-filament lamps, around 2500 °K, the new scale crosses the international scale as used in the United States. Furthermore, when the range of standards was extended to gas-filled tungsten-filament lamps and other new types, the measurements were made by methods nearly in accord with the luminosity factors. Consequently the present ratings of tungsten-filament lamps in this country will be practically unaffected by the change, no type being changed by more than 1 percent.

[30] Wensel, Roeser, Barbrow, and Caldwell, Nat. Bur. Standards Journ. Res., vol. 6, p. 1103, 1931.
[31] Nat. Bur. Standards Circ. C-459, 1947.

TABLE 73.—SYMBOLS AND DEFINING EXPRESSIONS FOR PHOTOMETRY *

Designation	Symbol and defining equation	Unit	Proposed term
Luminous flux	F	Lumen	lm
Luminous intensity (candlepower)	$I = \frac{dF}{d\omega}$	Candle	c
Illumination †	$E = \frac{dF}{dA}$	Foot-candle Lux, Phot	ft-c lx, ph
Quantity of light	$Q = F\,dt$ t = time in hours	Lumen-hour	lm-hr
Brightness ‡	$B = \frac{dI}{dA \cos \phi}$	Candle per unit area Stilb	c/in.^{2} c/cm^2 sb = c/cm^2

The mechanical equivalent of light m is the least amount of mechanical energy in watts necessary to produce 1 lumen. This energy must, of course, produce light at the wavelength ($\lambda = 0.556\mu$) where the average eye has its maximum sensitivity.

Suppose B_0 is the brightness of a blackbody in candles per cm^2, then

$$B_0 = \frac{1}{m\pi}\int [c_1\lambda^{-5}/(\exp(c_2/\lambda T) - 1)]K_\lambda d\lambda$$

where K_λ is the relative luminosity factor (Table 58). The integration is taken over the visible spectrum. The constant c_1 is to be so chosen as to give the energy per unit wavelength for a 2π solid angle, then m is the mechanical equivalent of light. Using the new value of the brightness of the blackbody at the platinum point (60 candles/cm^2) and making the above calculation for the platinum point (2042.16 °K) using the new radiation constants (Table 53), gives $m = 0.00147$ watts/lumen. The reciprocal of this, 680 lumens/watt, is the value generally given.

Equivalents and conversion factors for photometry.—The total flux from a source of unit spherical candlepower is 12.57 lumens.

1 lux = 1 lumen incident per m^2

1 phot = 1 lumen incident per cm^2

1 foot-candle = 1 lumen incident per ft^2

* For reference, see footnote 26, p. 87. † See Table 66. ‡ See Table 71.

TABLE 74.—APPARENT CANDLEPOWER OF DISK OR LINE SOURCE AT VARIOUS DISTANCES

d = distance; L = length or diameter of (disk) source.

d/L	Candlepower, percent: Line	Candlepower, percent: Disk	d/L	Candlepower, percent: Line	Candlepower, percent: Disk
5	99.31	99.0	12	99.88	99.83
10	99.83	99.74	15	99.94	99.90
			20	99.98	99.95

TABLE 75.—SPECTRAL LUMINOUS INTENSITIES

From Planck's equation and constants given in Table 53 and the relative luminosity factors (Table 58) the spectral luminous intensities were calculated for a series of wavelengths ($d\lambda = .01\mu$), and for a number of temperatures and then reduced to equal total luminous intensities. These relative values for the brightness (photometric) of the blackbody at different temperatures hold for measurements made with a field brightness above about 1 millilambert but do not hold for measurements made for low field brightness. Some time ago some engineers engaged in photometry found a need for agreement for a standard for low intensity. It was then decided [32] to use a source at a color temperature of 2360 °K. Recently [33] the International Committee on Weights and Measures adopted the blackbody at the freezing point of platinum (2042°K) as the standard for low-intensity brightness in photometry.

λ in μ	2000 °K	2042.16 °K *	2100 °K	2200 °K	2300 °K	2400 °K	2500 °K	2600 °K	2700 °K	2800 °K	2900 °K	3000 °K
.38	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
.39	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
.40	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00001
.41	.00000	.00000	.00001	.00001	.00001	.00001	.00001	.00001	.00002	.00002	.00002	.00002
.42	.00002	.00002	.00002	.00003	.00004	.00004	.00005	.00006	.00007	.00007	.00008	.00009
.43	.00008	.00008	.00009	.00011	.00013	.00015	.00018	.00020	.00023	.00025	.00028	.00030
.44	.00019	.00021	.00023	.00028	.00032	.00037	.00042	.00047	.00053	.00058	.00064	.00069
.45	.00041	.00044	.00049	.00057	.00065	.00074	.00083	.00093	.00102	.00111	.00121	.00131
.46	.00083	.00088	.00096	.00111	.00125	.00140	.00155	.00171	.00186	.00202	.00217	.00233
.47	.00157	.00167	.00180	.00204	.00228	.00252	.00276	.00301	.00325	.00349	.00372	.00396
.48	.00297	.00313	.00336	.00374	.00413	.00452	.00490	.00528	.00565	.00602	.00638	.00673
.49	.00544	.00570	.00606	.00667	.00728	.00786	.00845	.00902	.00957	.01011	.01063	.01114
.50	.01024	.01067	.01125	.01223	.01318	.01411	.01501	.01587	.01670	.01750	.01827	.01901
.51	.01915	.01983	.02075	.02229	.02376	.02517	.02652	.02780	.02903	.03019	.03131	.03237
.52	.03217	.03313	.03442	.03654	.03853	.04042	.04220	.04387	.04545	.04694	.04834	.04967
.53	.04609	.04721	.04871	.05112	.05336	.05544	.05739	.05919	.06087	.06243	.06388	.06524
.54	.05972	.06086	.06236	.06475	.06692	.06890	.07072	.07238	.07390	.07530	.07659	.07776
.55	.07240	.07341	.07473	.07678	.07861	.08022	.08168	.08297	.08412	.08517	.08613	.08695
.56	.08356	.08432	.08528	.08675	.08800	.08905	.08996	.09073	.09139	.09198	.09243	.09284
.57	.09167	.09207	.09255	.09323	.09374	.09409	.09433	.09449	.09457	.09459	.09455	.09447
.58	.09545	.09544	.09539	.09518	.09488	.09449	.09405	.09358	.09307	.09256	.09203	.09150
.59	.09408	.09366	.09307	.09203	.09098	.08992	.08889	.08786	.08686	.08591	.08498	.08409
.60	.08833	.08757	.08654	.08483	.08319	.08163	.08013	.07873	.07739	.07611	.07491	.07379
.61	.07890	.07791	.07658	.07443	.07243	.07056	.06882	.06720	.06570	.06428	.06296	.06173
.62	.06663	.06554	.06409	.06178	.05966	.05774	.05595	.05432	.05281	.05141	.05012	.04893
.63	.05143	.05039	.04904	.04689	.04495	.04322	.04162	.04018	.03886	.03765	.03654	.03552
.64	.03752	.03663	.03547	.03366	.03204	.03061	.02930	.02813	.02708	.02610	.02522	.02442
.65	.02523	.02455	.02366	.02228	.02107	.02000	.01904	.01818	.01741	.01671	.01608	.01550
.66	.01576	.01528	.01466	.01371	.01287	.01215	.01150	.01092	.01041	.00995	.00953	.00916
.67	.00902	.00872	.00833	.00773	.00721	.00677	.00637	.00602	.00571	.00544	.00519	.00497
.68	.00521	.00502	.00477	.00440	.00408	.00381	.00357	.00335	.00317	.00300	.00285	.00272
.69	.00272	.00262	.00248	.00227	.00209	.00194	.00181	.00169	.00159	.00150	.00142	.00135
.70	.00147	.00141	.00133	.00121	.00111	.00102	.00095	.00088	.00083	.00078	.00073	.00069
.71	.00081	.00077	.00073	.00066	.00060	.00055	.00051	.00047	.00044	.00041	.00039	.00037
.72	.00044	.00041	.00039	.00035	.00032	.00029	.00026	.00024	.00023	.00021	.00020	.00019
.73	.00023	.00022	.00020	.00018	.00016	.00015	.00014	.00013	.00012	.00011	.00010	.00009
.74	.00012	.00011	.00010	.00009	.00008	.00007	.00007	.00006	.00006	.00005	.00005	.00005
.75	.00006	.00006	.00005	.00005	.00004	.00004	.00003	.00003	.00003	.00003	.00002	.00002
.76	.00003	.00003	.00003	.00002	.00002	.00002	.00002	.00002	.00001	.00001	.00001	.00001
Relative light output:	.775	1.000	1.399	2.398	3.927	6.178	9.383	13.810	19.765	27.594	37.661	50.372
λ max:	.5825	.5820	.5805	.5785	.5770	.5755	.5745	.5730	.5715	.5705	.5695	.5685

[32] Weaver, K. S., Journ. Opt. Soc. Amer., vol. 38, p. 278, 1949; vol. 40, p. 60, 1950.
[33] Terrien, Journ. Opt. Soc. Amer., vol. 39, p. 888, 1949.
* Platinum point.

TABLE 76.—BRIGHTNESS OF BLACKBODY, CROVA WAVELENGTH, MECHANICAL EQUIVALENT OF LIGHT, LUMINOUS INTENSITY, AND LUMINOUS EFFICIENCY OF BLACKBODY

The values of the luminous intensity I in candles and the luminous flux F in lumens have been calculated using Planck's equation and the values of the luminosity factors K_λ given in Table 58. The basis of these values is the value of the Waidner-Burgess standard of light intensity.

The following equation is used:

$$B_0 = \frac{1}{m\pi}\int J(\lambda T) K_\lambda d\lambda,$$

where $B_0 = 60$ candles per cm², $T = 2042.16$ °K, and $m =$ the minimum mechanical equivalent of light expressed in watts per lumen.

The radiation constants (Table 53) used in these calculations and the value given in the table as the brightness of the blackbody at this temperature (2042.16) give for the *reciprocal of the mechanical equivalent of light 680 lumens per watt.* This means that 1 watt of radiated energy at about $\lambda = 0.555\mu$ will give 680 lumens.

White light has sometimes been defined as that emitted by a blackbody at a temperature of 6000 °K.

The crova wavelength for a blackbody is that wavelength λ_c, at which the spectral luminous intensity varies at the same rate as the total luminous intensity varies for a change in the temperature.

Temperature °K	Total intensity watts/cm² *	Brightness candles/cm²	Lumens/cm²	Lumens/watt	Crova wave-length
1200	11.16	.0140	.04	003_5	
1400	21.79	.245	.77	$.03_5$	
1600	37.18	2.145	6.74	.18	
1700	47.38	5.28	16.57	.35	.584μ
1800	59.55	11.78	37.00	.62	
1900	73.92	24.23	76.11	1.03	
2000	90.76	46.47	1.460×10^2	1.61	.578
2042.16	98.65	60.00 †	1.885×10^2	1.91	
2200	1.3288×10^2	1.439×10^2	4.520×10^2	3.40	
2500	2.2158×10^2	5.628×10^2	1.7679×10^3	7.98	.572
2700	3.0146×10^2	1.186×10^3	3.726×10^3	12.36	
3000	4.5946×10^2	3.021×10^3	9.491×10^3	20.7	.568
3500	8.5122×10^2	1.031×10^4	3.183×10^4	37.4	.564
4000	1.4521×10^3	2.525×10^4	7.932×10^4	54.6	.562
4500	2.3260×10^3	5.158×10^4	1.620×10^5	69.7	.560
5000	3.5453×10^3	9.164×10^4	2.879×10^5	81.2	.558
5500	5.1906×10^3	1.4705×10^5	4.620×10^5	89.0	.557
6000	7.3514×10^3	2.186×10^5	6.868×10^5	93.4	.556
6500	1.0126×10^4	3.065×10^5	9.629×10^5	95.1	.555
7000	1.3619×10^4	4.103×10^5	1.289×10^6	94.6	.555
7500	1.7948×10^4	5.294×10^5	1.663×10^6	92.7	
8000	$2\ 3234 \times 10^4$	6.630×10^5	2.083×10^6	89.6	.554
10,000	5.6724×10^4	1.3221×10^6	4.153×10^6	73.2	

* Calculated, $\sigma = 5.6724 \times 10^{-12}$, watts cm^{-2} deg^{-4}.
† Brightness, Waidner-Burgess standard. See Table 69.

An optical pyrometer is a device for measuring the temperature of a high-temperature radiating body by comparing its brightness for a selected wavelength interval (within the visible spectrum to be sure) with that of some standard selected source. The wavelength, or wavelength interval, is generally selected by the use of a red glass in the eyepiece. This gives rise to the term effective wavelength. (See Table 562.) The effective wavelength of a monochromatic screen for a definite temperature interval has been defined as the wavelength for which the relative brightness, as calculated from Wien's equation for this temperature interval, is the same as the ratio of the integral luminosities for these two temperatures, as measured through the red screen.

Various devices are used to make these comparisons, and different devices have been used as the comparison source. It seems that most users of the optical pyrometer today prefer to use the disappearing-filament type, which has a small filament as the comparison source.

The optical pyrometer as generally calibrated gives the true temperature of blackbodies but not of other radiators. If one radiating characteristic of any other radiator—e.g., its emissivity—is known, true temperatures can be determined of such radiators, e.g., an incandescent tungsten filament, by the use of the optical pyrometer. The emissivities of a number of sources are given in Table 78.

The true temperature T of a non-blackbody may be determined from its brightness temperature, S_λ (the apparent temperature), and its emissivity e_λ from the following relation:

$$\frac{1}{T} - \frac{1}{S_\lambda} = \frac{\lambda \log e_\lambda}{c_2 \log e}$$

For some calculated values see Table 79.

This entire subject is extensively treated in "Temperature, Its Measurement and Control," a report of a symposium on this subject published by the Reinhold Publishing Co. in 1941.

TABLES 78-84.—EMISSIVITIES OF A NUMBER OF MATERIALS

TABLE 78.—NORMAL SPECTRAL EMISSIVITIES FOR SOME ELEMENTS AND ALLOYS

The emissivity, spectral or total, of any non-blackbody shows the relation between the intensity of its radiation and that of the blackbody when both are at the same temperature. Spectral emissivities have been measured for a number of materials for different temperatures and different wavelength intervals and are shown in Part 1.

Part 1.—At temperatures generally above 1000 °K[34]

Room temperature values are given in a few instances where they, along with values at higher temperatures, form a connected series and where the values given for the higher temperatures depend on those given for low temperatures.

Material	Temperature °K	Emissivity: Red λ in μ	Red e_λ	Green λ in μ	Green e_λ	Blue λ in μ	Blue e_λ	Remarks
Carbon	1600	.66	.89					
	2500	.66	.84					
Copper	1275	.66	.105					Solid
	1350	.66	.120					Solid
	1375	.66	.150					Liquid
	1450	.66	.140					Liquid
	1500	.66	.13					Liquid
Iron	1000	.66	.27					Solid
	1480-1500	.65	.37					Solid and liquid
Konal	1200	.665	.43					
Molybdenum	300	.665	.420			.467	.425	
	1300	.665	.378			.467	.395	
	2000	.665	.353			.467	.380	
	2750	.665	.332			.467	.365	
Nickel	1200-1650	.665	.375	.535	.425	.460	.450	Solid
Tantalum	300	.665	.493			.467	.565	
	1400	.665	.442			.467	.505	
	2100	.665	.415			.467	.460	
	2800	.665	.390			.467	...	

[34] Worthing, A. G., Temperature radiation emissivities and emittances, Temperature, Its Measurement and Control, p. 1184, Reinhold Publishing Co., 1941.

Part 2.—Emissivity of a number of metals at their melting point[35]

(e_λ expressed in percent)

Metal	λ = .55μ Solid	λ = .55μ Liquid	λ = .65μ Solid	λ = .65μ Liquid	Metal	λ = .55μ Solid	λ = .55μ Liquid	λ = .65μ Solid	λ = .65μ Liquid
Beryllium	61	81	61	61	Niobium	61	..	49	40
Chromium	53	..	39	39	Palladium	38	..	33	37
Cobalt	..	..	36	37	Platinum	38	..	33	38
Copper	38	36	10	15	Rhodium	..	..	29	30
Erbium	..	30	55	38	Silver	<35	<35	4	7
Gold	<38	<38	14	22	Thorium	36	..	36	40
Iridium	..	..	30	..	Titanium	75	75	63	65
Iron	..	..	37	37	Uranium	77	..	54	34
Manganese	..	..	59	59	Vanadium	29	..	35	32
Molybdenum	..	..	43	40	Ytterbium	..	..	35	35
Nickel	44	46	36	37	Zirconium	..	..	32	30

[35] International Critical Tables.

(continued)

TABLE 78.—NORMAL SPECTRAL EMISSIVITIES FOR SOME ELEMENTS AND ALLOYS (concluded)

Part 3.—Emissivities of tungsten[36]

Temperature °K	Wavelength .30μ	.38	.467	.665	.8	1.0	1.5	1.8	2.0	2.5	3.0	4.0	Total emissivity
1200	.503	.495	.482	.452	.428	.390	.275	.177	.148	.127	.116	.100	.138
1500	.502	.492	.476	.445	.422	.385	.280	.191	.164	.145	.132	.115	.192
1800	.500	.488	.472	.439	.417	.382	.284	.206	.180	.161	.148	.127	.236
2000	.498	.485	.469	.435	.414	.380	.287	.215	.191	.170	.158	.135	.259
2200	.496	.482	.466	.431	.410	.378	.290	.225	.201	.180	.167	.144	.278
2500	.493	.477	.462	.425	.405	.375	.295	.240	.217	.195	.180	.155	.301
2600	.492	.476	.460	.423	.403	.373	.297	.245	.222	.200	.184	.159	.309
2700	.491	.475	.459	.421	.401	.372	.298	.249	.228	.205	.188	.163	.315
2800	.490	.473	.458	.419	.399	.371	.299	.254	.233	.210	.192	.167	.321
2900	.489	.472	.456	.417	.398	.370	.300	.259	.239	.215	.197	.170	.329
3000	.488	.470	.455	.415	.396	.368	.302	.264	.245	.220	.200	.173	.334
3200	.486	.468	.452	.411	.392	.366	.305	.273	.255	.231	.208	.180	.341
3400	.484	.465	.450	.407	.388	.363	.308	.283	.265	.241	.216	.186	.348

[36] Forsythe, W. E., and Adams, E. Q., Journ. Opt. Soc. Amer., vol. 35, p. 108, 1945.

For $\lambda = 1.27\mu$ the spectral emissivity is constant and equals 0.335.

Part 4.—Emissivities of some metals specially prepared by heat-treating and out-gassing[37]

Element	λ in μ	Emissivity	Temperature °K	Element	λ in μ	Emissivity	Temperature °K
Chromium	.66	.334	1050-1560	Palladium ..		.311	1200-1400
Cobalt		.327	1240-1378			.291	1200-1400
		.342	1378-1450	Platinum ...		.295-.310	1200-1800
Iron α		.344	below 1178	Rhodium ...		.242	1300-2000
γ		.325	1178-1677	Tantalum ..		.439-.384	1200-2400
δ		.337	1677-1725	Thorium ...		.380	1300-1700
Molybdenum ..		.382	1300-2100	Tungsten ...		.46	1200 2200
Nickel		.350	1200-1400	Uranium ...	.6605	.453	1180-1320
Niobium		.374	1300-2200			.416	1325-1370

[37] Private communication from Wahlin, taken from data by Wahlin and Knop, L. V. Whitney, Wahlin and Wright, Worthing, Fiske, Phys. Rev.

TABLE 79.—CORRECTIONS IN °C TO ADD TO BRIGHTNESS TEMPERATURE READINGS, FOR DIFFERENT EMISSIVITY, TO OBTAIN THE TRUE TEMPERATURE *

Pyrometer using red light, wavelength, $\lambda = .665\mu$, and $c_2 = 14380\mu$ °K at observed temperatures degrees Kelvin, of

Emissivity	1000	1100	1200	1300	1400	1500	1600	1700	1800
.10	119.2	145.9	175.8	208.9	245.3	285.1	328.6	375.7	426.8
.20	80.4	98.1	117.7	139.3	162.8	188.5	216.3	246.2	278.4
.30	59.0	71.8	85.9	101.4	118.3	136.7	156.5	177.7	200.5
.40	44.2	53.8	64.3	75.8	88.3	101.8	116.4	132.0	148.6
.50	33.1	40.2	48.0	56.5	65.8	75.8	86.5	98.0	110.2
.60	24.2	29.3	35.0	41.2	47.9	55.1	62.9	71.1	79.9
.70	16.8	20.3	24.2	28.5	33.1	38.0	43.4	49.0	55.1
.80	10.4	12.6	15.1	17.7	20.5	23.6	26.9	30.3	34.1
.85	7.5	9.3	10.9	12.6	14.9	17.1	19.5	22.0	24.7
.90	4.9	5.9	7.1	8.3	9.6	11.0	12.6	14.2	15.9
.95	2.4	2.9	3.4	4.0	4.7	5.3	6.1	6.9	7.7

* The values given in this table also give the correction for a window having a transmission given in column 1 for different temperatures of the source when this window is used between the source and the pyrometer.

(*continued*)

TABLE 79.—CORRECTIONS IN °C TO ADD TO BRIGHTNESS TEMPERATURE READINGS, FOR DIFFERENT EMISSIVITY, TO OBTAIN THE TRUE TEMPERATURE (concluded)

Emissivity	Pyrometer using red light, wavelength, $\lambda = .665\mu$, and $c_2 = 14380\mu$ °K at observed temperatures degrees Kelvin, of							
	1900	2000	2200	2400	2600	2800	3000	3600
.10	481.9	541.2	673.0	823.9	995.2	1189.5	1408.3	2237.8
.20	312.9	349.8	430.7	521.9	623.8	737.2	862.5	1317.6
.30	224.8	250.6	307.0	370.1	440.0	517.2	601.6	902.4
.40	166.3	185.2	226.1	271.7	330.4	377.0	436.9	648.0
.50	123.2	137.0	166.9	200.0	236.4	276.1	319.2	469.6
.60	89.3	99.2	120.6	144.2	170.1	198.3	228.9	334.6
.70	61.5	68.2	82.8	98.9	116.5	135.6	156.2	227.2
.80	38.0	42.1	51.1	60.9	71.6	83.3	95.9	138.9
.85	27.5	30.5	37.0	44.1	51.8	60.2	69.2	100.1
.90	17.7	19.7	23.8	28.4	33.3	38.7	44.5	64.2
.95	8.6	9.5	11.5	13.7	16.1	18.7	21.5	31.0

TABLE 80.—COMPUTATION OF TOTAL EMISSIVITY VALUES FOR VARIOUS GLASS SAMPLES AT LOW TEMPERATURES[38]

Sample	Thickness (mm)	Apparent emissivity *			Computed transmittance †			Temperature differential ‡			Corrected emissivity		
		500 °C	320 °C	100 °C	500	320	100	500	320	100	475	320	100
Fused quartz	1.96	.78	.80	.75	.266	.134	.023	19	8	1	.67	.76	.775
Corex D	3.40	.80	.80	.76	.113	.041	.002	49	18	2	.91	.90	.83
Nonex	1.57	.82	.82	.78	.145	.041	.004	31	12	1.5	.82	.87	.835

Dissipating of energy by lamp bulbs.—The bulb of a 120-volt 500-watt lamp dissipates 18.5 percent of the input energy to the lamp. About 10 percent is lost by radiation and 8.5 percent by conduction and convection by the surrounding air. The losses from other similar lamp bulbs probably agree with this.

[38] Barnes, B. T., Forsythe, W. E., and Adams, E. Q. Journ. Opt. Soc. Amer., vol. 37, p. 804, 1947.
* Assuming no radiation transmitted through sample from heater and no temperature gradient.
† Assuming all of sample at heater temperature. ‡ Between front and back surfaces.

TABLE 81.—RELATIVE EMISSIVITIES FOR TOTAL RADIATION

Emissive power of blackbody = 1. Receiving surface platinum black at 25°C; oxidized at 600 + °C.

	Temperature, °C		
	200	400	600
Silver	.020	.030	.038
Platinum (1)	.060	.086	.110
Oxidized zinc	—	.110	—
Oxidized aluminum	.113	.153	.192
Calorized copper, oxidized..............	.180	.185	.190
Cast iron	.210	—	—
Oxidized nickel	.369	.424	.478
Oxidized monel	.411	.439	.463
Calorized steel, oxidized...............	.521	.547	.570
Oxidized copper	.568	.568	.568
Oxidized brass	.610	.600	.589
Oxidized lead	.631	—	—
Oxidized cast iron......................	.643	.710	.777
Oxidized steel	.790	.788	.787

For radiation properties of bodies at temperatures so low that the radiations of wavelength greater than 20μ or thereabouts are important, doubt must exist because of the possible and perhaps probable lack of blackness of the receiving body to radiations of those wavelengths or greater. For instance, see Tables 568 and 573 for the transparency of soot.

TABLE 82.—TOTAL EMISSIVITY VALUES OF VARIOUS MATERIALS AT LOW TEMPERATURES *

Material	Condition	At 100°C	320°C	500°C
Alleghany alloy No. 66	Polished	.11		
Alleghany metal	No. 4 polish	.13		
Aluminum	Commercial sheet	.09		
Aluminum	Polish	.095		
Aluminum	Rough polish	.18		
Aluminum paint	......	.29		
Brass	Polished	.059		
Carbon	Rough plate	.77	.77	.72
Carbon, graphitized	Rough plate	.76	.75	.71
Chromium	Polished	.075		
Copper	Polished	.052		
Copper-nickel	Polished	.059		
Iron	Dark gray surface	.31		
Iron	Roughly polished	.27		
Lamp black	Rough deposit	.84		.78
Molybdenum	Polished	.071		
Nickel	Polished	.072		
Nickel-silver	Polished	.135		
Radiator paint, black	......	.84		
Radiator paint, bronze	......	.51		
Radiator paint, cream	......	.77		
Radiator paint, white	......	.79		
Silver	Polished	.052		
Stainless steel	Polished	.074		
Steel	Polished	.066		
Tin	Polished	.069		
Tin	Commercial coat	.084		
Tungsten	Polished coat	.066		
Zinc	Commercial coat	.21		

* For reference, see footnote 38, p. 100.

TABLE 83.—PERCENTAGE EMISSIVITIES OF METALS AND OXIDES

True temperature °C		500	600	700	800	900	1000	1100	1200
60 FeO.40 Fe_2O_3 = Fe heated in air	Total	85	85	86	87	87	88	88	89
	$\lambda = .65\mu$	—	—	—	98	97	95	93	92
NiO	Total	—	54	62	68	72	75	81	86
	$\lambda = .65\mu$	—	—	98	96	94	92	88	87

Platinum:

True temp. °C	0	100	200	300	400	500	750	1000	1200	1400	1600	1700
App.* temp. °C	—	—	—	—	—	—	—	486	630	780	930	1005
Total emiss. Pt.	3.1	4.0	5.1	6.1	7.0	8.0	10.3	12.4	14.0	15.5	16.9	17.5

Oxides: $\lambda = .65\mu$	NiO	Co_3O_4	Fe_3O_4	Mn_3O_4	TiO_2	ThO_2	Y_2O_3	BeO	NbO_x	V_2O_3	Cr_2O_3	U_3O_8
Solid	89	77	63	..	52	57	61	37	71	69	60	30
Liquid	68	63	53	47	51	69	..	..	..	..	..	31

* As observed with total radiation pyrometer sighted on the platinum.

TABLE 84.—TOTAL RADIATION FROM BARE AND SOOT-COVERED NICKEL [39] (watts/cm²)

°K	400	500	600	700	800	900	1000	1200	1400
Soot-covered Ni	.096	.28	.59	1.87	3	3	4.8	...	...
Polished Ni initial heat	.0092	.032	.079	.166	.31	.55	.91	2.17	4.49
" " after above	.0066	.023	.058	.123	.24	.44	.76	2.04	4.49

[39] Barnes, Phys. Rev., vol. 34, p. 1026, 1929.

TABLE 85.—CHARACTERISTICS OF TUNGSTEN[40]

Temperature °K T	Average luminous emissivity e_v	Brightness temperature $S_{.665\mu}$	Color temperature T_c	Radiation temperature T_R	Relative lengths at different temperatures L/L_0	Thermal conductivity $\frac{\text{watts}}{\text{cm °K}}$	Atomic heats $\frac{\text{cal}}{\text{g-atom °C}}$	Thomson effect microvolts Degree	Resistivity ‡ microhms-cm ρ	$\frac{T}{\rho}\frac{d\rho}{dT}$	Normal brightness (candles/cm²) B_n	$\frac{T}{B}\frac{dB}{dT}$	Total radiation intensity (watts/cm²) n §	$\frac{T}{\eta}\frac{d\eta}{dT}$	Luminous efficiency lumens/watt eff.	$\frac{T}{\text{eff.}}\frac{d(\text{eff.})}{dT}$	Rate of vaporization g cm⁻² sec⁻¹ v: M	Rate of vaporization: n	$\frac{T}{v}\frac{dv}{dT}$
300					1.0000				5.65	1.209			.00110						
400					1.0005				8.00	1.209			.00495						
500					1.0010				10.48	1.209			.0150						
600					1.0014				13.07	1.209			.0385						
700					1.0018				15.75	1.209			.0850						
800					1.0023				18.51	1.209			.1730	5.47					
900					1.0028				21.53	1.209			.333	5.50					
1000	.464	966	1006	581	1.0032	.84 †	6.20		24.26	1.209			.600	5.51					
1100	.463	1058	1108	659	1.0036	.87 †	6.35		27.23	1.209			1.01	5.53					
1200	.462	1149	1210	738	1.0041	.90 †	6.50		30.26	1.195			1.63	5.53					
1300	.460	1240	1312	819	1.0046	.93	6.65		33.29	1.195			2.54	5.52					
1400	.459	1330	1414	905	1.0052	.96	6.80		36.37	1.195			3.82	5.48	.09	11.8			
1500	.457	1420	1517	991	1.0057	.99	6.95		39.49	1.195			5.54	5.41	.20	10.8			
1600	.456	1509	1619	1080	1.0063	1.01	7.10		42.65	1.195	.94	15.2	7.72	5.31	.40	10.0	3.6	—20	67
1700	.455	1597	1722	1167	1.0069	1.04	7.25		45.84	1.195	2.27	14.4	10.53	5.18	.71	9.3	1.81	—18	63
1800	.454	1684	1825	1254	1.0075	1.07	7.40	—18	49.05	1.195	5.06	13.7	14.05	5.02	1.15	8.7	5.75	—17	59
1900	.453	1771	1933	1342	1.0081	1.09	7.55	—20	52.30	1.195	10.19	13.0	18.30	4.89	1.86	8.1	1.29	—15	56
2000	.452	1857	2044	1428	1.0088	1.11	7.70	—22	55.58	1.195	19.54	12.3	23.45	4.80	2.74	7.5	2.09	—14	53
2100	.450	1943	2151	1514	1.0094	1.13	7.85	—24	58.89	1.195	35.0	11.7	29.55	4.73	3.89	6.9	2.59	—13	50
2200	.449	2026	2261	1601	1.0101	1.15	8.00	—26	62.23	1.195	59.1	11.2	36.75	4.68	5.38	6.4	2.55	—12	48
2300	.448	2109	2371	1688	1.0108	1.17	8.15	—28	65.60	1.195	97.00	10.8	45.10	4.64	7.13	6.0	2.04	—11	46
2400	.447	2192	2479	1775	1.0116	1.19	8.30	—30	68.99	1.195	151.0	10.3	54.90	4.61	9.21	5.6	1.36	—10	44
2500	.446	2274	2584	1859	1.0124	1.21	8.45		72.41	1.195	226.0	9.9	66.1	4.59	11.46	5.3	7.86	—10	42
2600	.444	2356	2690	1945	1.0132	1.23 *			75.85	1.195	333	9.6	79.2	4.57	14.01	5.0	3.94	— 9	40
2700	.443	2437	2797	2031	1.0140	1.25 *			79.32	1.195	480	9.2	93.8	4.56	16.93	4.7	1.75	— 8	38
2800	.442	2516	2905	2116	1.0149 *	1.27 *			82.81	1.195	665	8.9	110.0	4.55	20.03	4.4	6.98	— 8	36
2900	.441	2595	3013	2202	1.016 *				86.32	1.195	910	8.6	129.5	4.54	23.20	4.1	2.44	— 7	35
3000	.440	2673	3121	2286	1.017 *				89.85	1.195	1215	8.3	151.0	4.53	26.60	3.8	8.20	— 7	34

[40] Forsythe, W. E., and Adams, E. Q., Journ. Opt. Soc. Amer., vol. 35, pp. 108-113, 1945.

* Data given in this table apply to aged tungsten filament. For emissivities, see Table 78. † These values are extrapolated. ‡ These depend on the dimensions at room temperatures. § Surrounded by a blackbody at 0°K $\sigma = 5.67$ watts cm² deg⁻⁴.

TABLE 86.—RADIATION AND OTHER PROPERTIES OF TANTALUM [41]

°K	Emissivity .665μ	Emissivity .463μ	Temperature Brightness .665μ °K	Temperature Color °K	Temperature Radiation °K	Resistivity μ-ohm-cm	Radiation watt/cm²	$\frac{Tdn}{ndT}$	Total emissivity
300	.493	.56	....	....	....	....	....	....	....
1000	.459	.52	966	....	....	....	....	....	....
1200	.450	.51	1149	....	....	....	....	....	....
1400	.442	.50	1329	....	....	....	....	....	....
1600	.434	.49	1506	1642	1062	67.6	7.3	4.80	.194
1800	.426	.48	1680	1859	1222	74.1	12.8	4.80	.213
2000	.418	.47	1851	2075	1390	80.5	21.2	4.80	.232
2200	.411	.46	2018	2288	1556	86.9	33.4	4.80	.251
2400	.404	.45	2180	2497	1730	92.9	50.7	4.80	.269
2600	.397	.44	2339	2705	1901	99.1	75	4.80	.287
2800	.390	..	2495	2911	2080	105.0	106	4.80	.304
3000	.384	..	2647	....	....	....	....	....	....
3300 mp	.375	..	2870	....	....	....	....	....	....

[41] Worthing, A. G., Phys. Rev., vol. 28, p. 190, 1926.

TABLE 87.—RADIATION AND OTHER PROPERTIES OF MOLYBDENUM *

°K	Emissivity .665μ	Emissivity .475μ	Temperature Brightness $S_{.665\mu}$ °K	Temperature Color °K	Temperature Radiation °K	Resistivity μ-ohm-cm	Brightness normally candles/cm²	Radiation intensity watts/cm²	Luminous efficiency lumens/watt
273	.420	.425	....	....	....	5.14	....	....	....
1000	.390	.403	958	1004	557	23.9	.0001	.55	....
1400	.375	.393	1316	1411	864	35.2	.089	3.18	.093
1600	.367	.388	1489	1616	1024	41.1	.765	6.30	.40
1800	.360	.383	1658	1823	1187	47.0	4.13	11.3	1.22
2000	.353	.379	1824	2032	1354	53.1	15.9	19.2	2.75
2200	.347	.375	1986	2244	1523	59.2	48.5	30.7	5.28
2400	.341	.371	2143	2456	1693	65.5	123	47.0	8.70
2600	.336	.368	2297	2672	1866	71.8	270	69.5	13.0
2800	.331	.365	2448	2891	2039	78.2	540	98	18.4
2895	.328	.363	2519	2997	2122	81.4	730	116	....

* For reference, see footnote 41, above.

TABLE 88.—RELATION BETWEEN BRIGHTNESS TEMPERATURE AND COLOR TEMPERATURE FOR VARIOUS SUBSTANCES

Brightness temperature	Corresponding color temperature for— Untreated carbon	Gem	Platinum	Nernst glower	Osmium	Tantalum	Tungsten
1400°K	1414	....	1568°K	1538	1444	1507	1492
1500	1515	....	1692	1642	1562	1631	1607
1600	1616	1620	1821	1747	1680	1758	1723
1700	1718	1735	1952	1852	1799	1883	1841
1800	1820	1852	2086	1954	1919	2010	1961
1900	1923	1962	....	2053	2045	2137	2082
2000	2028	2064	....	2146	2168	2265	2206
2200	2240	2255	....	2310	2427	2500	2457
2400	....	....	....	....	2688	2785	2718
2600	....	....	....	....	....	....	2988
3000	....	....	....	....	....	....	3564

TABLE 89.—COLOR MINUS BRIGHTNESS TEMPERATURE FOR CARBON

Brightness temp. °K....	1600°	1700°	1800°	1900°	2000°	2100°	2200°
Color—brightness	2	7	12	16	22	28	33

TABLE 90.—RELATIVE BLUE BRIGHTNESS, B, AND BRIGHTNESS IN CANDLES PER CM² C, OF SOME INCANDESCENT OXIDES AT VARIOUS RED (0.665μ) BRIGHTNESS TEMPERATURES, S_λ

	$S = 1500$		1700		1800		1900		2000	
Material	*B*	*C*	*B*	*C*	*B*	*C*	*B*	*C*	*B*	*C*
Blackbody	.026	.91	.27	5.3	.74	12.0	1.80	24.0	3.9	47.0
Tungsten	.038	.84	.41	5.9	1.11	14	2.7	33	6.3	74
Urania, gas air and oxy-gas...	.028	1.02	.31	6.6	.84	15	2.0	35	4.5	78
Ceria, pure: Oxy-gas.........	.035	1.08	.32	6.3	.83	14	1.9	31	4.0	62
yellow: "	.032	1.04	.32	7.1	.85	17	2.0	40	4.0	88
brown: "	.033	1.15	.30	6.7	.83	15	1.68	33	3.5	68
Oxides of Ce group: Oxy-gas.	.031	.97	.34	6.3	.92	14	2.3	33	5.0	71
Neodymia: Oxy-gas	.032	1.17	.33	6.9	.92	15	2.3	33	5.0	64
Lanthana: "	.033	1.11	.34	6.6	.89	15	2.1	33	4.5	64
Erbia: "	.047	1.71	.45	8.1	1.17	16	2.7	33	5.6	63
Yttria, pure: Oxy-gas........	.067	1.18	.61	7.3	1.56	17	3.6	32	7.3	63
95% pure: "	.047	1.20	.46	7.3	1.19	16	2.8	36	5.9	75
Zirconia: Oxy-gas	.058	.73	.55	3.6	1.43	8	3.3	15	7.0	30
Thoria: "	.033	1.44	.56	7.5	1.40	16	3.1	32	6.3	63
Alumina: "	.076	1.45	.87	9.4	2.5	22	6.1	49	13.6	103
Beryllia: "	.086	1.62	.99	9.7	2.8	22	6.9	49	15.4	104
Magnesia: "	.21	2.4	1.31	11.0	2.8	22	5.6	43	10.2	79
Thoria 1% ceria: Oxy-gas....	.078	1.45	.70	8.6	1.71	19	4.1	43	8.4	90
1% urania: "	.069	1.33	.67	8.3	1.77	19	4.1	44	8.7	93
trace urania: "	.059	1.33	.68	8.3	1.93	19	4.8	44	10.5	93
1% neodymia: "	.046	1.43	.43	7.1	1.14	15	2.6	29	5.5	56
1% Mn oxide: "	.035	1.13	.37	6.1	1.01	13	2.4	28	5.3	56

TABLE 91.—COLOR TEMPERATURE, BRIGHTNESS TEMPERATURE, AND BRIGHTNESS OF VARIOUS ILLUMINANTS

Source	T_c	$S(\lambda = .665)$	Brightness c/cm²
Gas flame:			
Batswing	2160		
Candle shape about 10 cm high....	1875		
Hefner as a whole..................	1880		
Candle:			
Sperm	1930		
Paraffin	1925		
Pentane 10-cp. std..................	1920		
Kerosene:			
Flat wick	2055	1500	1.27
Round wick	1920	1530	1.51
4 wpc carbon......................	2080	2030	54.9
3.1 wpc treated carbon..............	2165	2065	70.6
2.5 wpc gem......................	2195	2130	78.1
2 wpc osmium......................	2185	2035	60.8
2 wpc tantalum......................	2260	2000	53.1
Acetylene as a whole..............	2380		
One spot	2465	1660	6.69
Mees burner	2360	1730	10.8
1.25 wpc tungsten..................	2400	2150	125
2.3 wpc Nernst....................	2400	2320	258
Sun:			
Outside atmosphere	6500		224000
At earth's surface..............	5600		165000
Clear sky	....		.4
Moon	....		.5
Welsbach mantle	....		9.0

TABLE 92.—CHARACTERISTICS OF SOME CARBON ARCS *

Low intensity and high intensity carbon arcs

Positive carbon	Amperes	Arc † volts	Lumens per arc watt
Low-intensity carbons			
10 mm low intensity..........	20	55	14.9
12 " " "	32	55	15.7
13 " " "	40	55	16.3
High-intensity projection carbons			
6 mm "suprex"..............	40	37	28.6
7 " "	50	37	29.7
8 " "	70	40	34.6
9 " rotating positive	85	58	26.4
11 " " "	115	55	32.5
13.6 " " "	125	68	27.0
" " " "	150	78	35.0
" " " "	170	75	33.6
16 " " "	225	75	32.2
High-intensity searchlight carbons			
10 mm rotating positive......	100	75	32.3
12 " " "	120	75	33.0
16 " " "	150	78	32.0
16 " " "	195	90	31.5

Vertical trim ac and dc flame arcs

Carbons: Upper	Carbons: Lower	Amperes	Arc volts	Upper polarity	Lumens per arc watt
½" WF	½" WF			+	
Photo ‡	Photo ‡	40	55 ac	—	39
"	"	40	55 dc	+	55
"	"	40	55 dc	—	50
½" 2F §	"	40	55 dc	—	44

Alternating-current high-intensity carbon arcs

Carbon	Amperes	Arc volts	Lumens per arc watt
7 mm	65	26 ac	60.5
8 mm	80	29 ac	61.5
9 mm	95	26 ac	68.5

* Data furnished by W. W. Lozier of National Carbon Co. † All direct-current power. ‡ "National" white flame photographic carbons, rare earth cored. § "National" 2F carbon, neutral cored.

TABLE 93.—EFFICIENCIES OF SOME EARLY INCANDESCENT LAMPS OF ABOUT 60-WATT SIZE [42]

	Lumens per watt	Life
Edison's early carbon lamp..........................	1.8	600 hr
Treated carbon lamp................................	3.2	600
Gem lamp	4.0	600
Nernst glower	5.0	600
Tantalum lamp	4.9	900
Osmium lamp	4.9	
Tungsten lamp (1907)................................	7.8	1,000
Tungsten lamp (1949) coiled coil......................	14.0	1,000

[42] Forsythe, W. E., and Adams, E. Q., Bull. Denison Sci. Lab., vol. 32, p. 70, 1937.

TABLE 94.—INCREASE IN TUNGSTEN LAMP EFFICIENCY OVER A PERIOD OF YEARS

Lamp	Date measured	Temperature °K	Efficiency in lumens per watt
100-watt squirted filament	1908 †	2,355	8.8
100-watt drawn wire	1909 †	2,360	9.3
100-watt drawn wire	1915 †	2,475	10.3
100-watt gas-filled	1921	2,740	12.6
100-watt gas-filled	1932	2,800	14.3
100-watt gas-filled	1936	2,845	14.9
100-watt gas-filled *	1936	2,855	15.5
100-watt gas-filled * coiled coil	1948	2,860	16.3

* 750 hours life. † Vacuum lamps.

TABLE 95.—TEMPERATURE AND EFFICIENCY OF SOME TUNGSTEN-FILAMENT LAMPS *

General service

Lamp watts	Life (hrs)	lpw	Temperature °K	Max. bare bulb † Temp. °C	Base † Temp. °C
6 ‡	1500	6.9	2400	34	31 §
25 ‡	1000	10.5	2585	43	42
40	1000	11.9	2750	127	105
60 coiled coil	1000	14.0	2770	122	90
100 coiled coil	750	16.3	2850	127	94
500	1000	20.3	2940	198	100
1000	1000	21.0	3000		
1500	1000	22.0	3050		

Lamp	Volts	Current	Watts	Life (hrs)	Lumens	lpw	Temp. °K	Candle-power ¶
Street series		6.6		2000	1000	16.0	2870	
		6.6		2000	6000	19.2	2940	
		20.0		2000	6000	20.1	2995	
		20.0		2000	15,000	21.0	3010	
CX	120		60	500		13.6	2840	
	120		500	500		21.8	3030	
Studio or airport lighting	120		5000	75		32.7	3350 ª	
	120		10,000	75		32.7	3350 ª	
Floodlight	120		500	800		17.6	2925	
	120		1500	800		20.8	3170	
Projection lamps		Area ‖						
Monoplane	120	151	500	50	13,250	26.5	3270 ª	1545
Biplane	120	65	500	25		26.0	3270 ª	1700
	120	135	1000	25		27.6	3360 ª	4045
Coiled coil								
4 seg.	120	19	50	50	790	15.8	2920	80
3 seg.	120	41	100	50	1850	19.2	2950	185
3 seg.	120	55	200	50	4240	21.2	2985	390
Photographic lamps								
Photoflood								
No. 1	120		250	2	8650		3430 ª	
R2	120		500	6			3350 ª	
4	120		1000	10	33,500		3410 ª	
Two large lamps (monoplane)								
10 kw.	120	83.3	10,000		280,000	28	3300	33,000
50 kw.	120	416	50,000		1,400,000	28	3300	166,000

* Data furnished by W. E. Forsythe and E. M. Watson, of the General Electric Co. † These values furnished by W. H. Fisher, Nela Park. ‡ Vacuum lamps, all others are gas-filled. § Temperature at junction of base and bulb. ‖ Area of coil in mm². ¶ Candlepower in direction used. ª Color temperature.

(*continued*)

TABLE 95.—TEMPERATURE AND EFFICIENCY OF SOME TUNGSTEN-FILAMENT LAMPS (concluded)

Lamp for type B Kodachrome

Lamp	Volts	Current	Watts	Life (hr)	Lumens	lpw	Temp. °K	Candle-power ¶
	120		500	60	13,300		3200 [a]	
	120		1500	100	41,000		3200 [a]	
	120		5000	150	138,000		3200 [a]	
Some small lamps								
Sewing machine ..	120				122	7.5	2345 [a]	
Sign (clear)	120				80	8.0	2400 [a]	
Photocell exciter..	10				1000		3100 [a]	
	10				1600		3100 [a]	
	8.5				680		3200 [a]	
	8				160		2660 [a]	
	4				30		2935 [a]	

Lamp	Volts	Candle-power	Watts per spherical candle	Temp. °K
Flashlight PR2	2.38	.80	1.45	2735
Flashlight PR3	3.57	1.55	1.17	2770
Flashlight 136	1.25	.19	4.10	2550
Flashlight 31	6.15	2.15	.87	2745
Hand lantern 248...........	2.50	1.45	1.35	2620
Flashlight 605	6.15	4.2	.88	3030
Radio Panel No. 44.........	6.15	.60	1.5	2400
Grain-o-wheat surgical	1.5	.028	6.0	2115
Christmas tree	120	4.7	1.0	2625
Automobile lamps				
Rear, instrument bd.	6.85	2.9	1.32	2820
Step, aux. headlight	13.5	2.9	1.27	2810
Dome, panel	6.9	6.3	1.01	2915
Signal	6.75	14.4	.80	2980
Dome, panel	13.5	6.3	.99	2870

TABLE 96.—SOME CHARACTERISTICS OF FLUORESCENT CHEMICALS *

Phosphor	Lamp color	Exciting range,† A	Sensitivity peak, A	Emitted range, A	Emitted peak, A
Calcium tungstate	blue	2200-3000	2720	3100-7000	4400
Magnesium tungstate ...	blue-white	2200-3200	2850	3600-7200	4800
Zinc silicate	green	2200-2960	2537	4600-6400	5250
Calcium halophosphates..	white	2000-2600	2500	3500-6800	4800, 5800
Cadmium silicate	yellow-pink	2200-3200	2400	4800-7400	5950
Cadmium borate	pink	2200-3600	2500	5200-7500	6150
BL phosphor $BaSi_2O_5$ with Pb	blue ultra	2200-2700	2500	3100-4100	3500
Calcium phosphate with Ce and Mn...........	red	2200-3400	3130	5600-8100 plus UV	6500

* Data furnished by H. C. Froelich, of Nela Park. † 2200 A was lower limit of measurements.

TABLE 97.—ENGINEERING DATA ON SOME LAMPS OF THE INTEGRAL, ALL-GLASS SEALED BEAM TYPE *

Number of lamp	Bulb	Design volts	Watts	Design life (hrs)	Approx. max.† beam cp.	Approx. spread to 10% max. (degrees) Hor.	Vert.	Filament shielding	Service
4015	PAR-36	6.2	35	300	8,000	40	5	C	Auto fog
4509	"	13.0	100	25	110,000	12	5	None	Airplane landing
4510	"	6.4	25	300	600	80	20	None	Auto utility
4515	"	6.4	30	100	50,000	5½	4½	B	Auto spot
150PAR/SP	PAR-38	115	150	2,000	10,500 ‡	30	30	None	General service spot
150PAR/FL	"	"	"	"	3,400 ‡	60	60	"	General service flood
4012A	PAR-46	6.2	35	300	8,800	40	5	C	Auto fog (amber)
4013	"	6.4	25	300	800	80	20	None	Tractor
4412A	"	12.8	35	300	8,000	40	5	C	Auto fog (amber)
4435	"	"	30	100	85,000	6	6	B	Auto spot
4523	"	28	250	25	225,000	17	11	A	Airplane landing
4535	"	6.4	30	100	90,000	5½	4½	B	Auto spot
4537	"	13	100	25	200,000	12	5	A	Airplane landing
4570	"	28	150	300	30,000	50	10	None	Airplane taxiing
4030	PAR-56	6.4	45/35	300/500	32,000 §	30	6	None	Sealed beam headlamp
4430	"	12.8	50/40	300/500	29,000 §	"	"	"	" " "
200PAR	"	30	200	500	200,000	12	9	"	Locomotive headlamp
250PAR	"	12.5	250	100	80,000	36	7	"	Airport approach
4560	PAR-64	28	600	25	600,000	12	9	A	Airplane landing
300PAR64/2	"	115	300	100	200,000	11	9	None	Flashing signal

* Data furnished by Application Engineering Department, Lamp Division, General Electric Co., Nela Park, Cleveland, Ohio. † Individual lamps may vary from the values listed. ‡ Approx. initial mean cp. in 10° cone. § Driving beam (major filament).

A, 120° cylindrical shield to side of filament. B, Hemispherical shield in front of filament masking all direct light. C, 90° spherical shield in front of filament masking all upward direct light.

TABLE 98.—MERCURY ARCS *

	Sunlight lamps			Blacklight lamps		General lighting lamps					
	S–4	RS	S–1	B–H4	C–H4 (Spot) E–H4 (Flood)	A–H4	A–H5	A–H1 B–H1	D–H1 E–H1	A–H6	A–H9
Lamp watts (rated)	100	275	400	100	100	100	250	450	400	1000	3000
Watts, with single-lamp transformer	120	...	500	120	123	120	290	452	450	1085	3165
Watts, with tulamp transformer	...	...	...	...	...	...	280/lamp	438/lamp	438/lamp	...	...
Lumens at 100 hours	3300	reflector type lamps not rated in lumens	...	...	not rated in lumens	3300	11,000	15,000	20,000	...	120,000
Lumens (approx. initial)	...		7200	black light bulb		...	...	...	...	65,000	...
Lamp lpw at 100 hours	33		...			33	44	37.5	50	...	40
Initial lpw	...		18			...	...	...	...	65	...
Over-all lumens per watt (single-lamp trans.)	268	...	14.4	...	...	27.5	39.3	34.2	45.6	59.8	37.8
Rated life, hours (see note)	...	...		1000	1000	1000	4000	4000	3000	75	5000
Bulb	A–21	R–40	PS–22	T–16	PAR–38	T–10	T–18	T–16	T–20	T–2	T–9½
Finish	clear	I.F. reflector type	I.F.	natural red purple	alum. reflector & clear lens	clear	clear	clear	clear	clear	clear
Base	admed.	medium	mogul	admed.	admed. skt.	any	mogul	mogul	mogul	3/16" sleeve	s.c. term.
Burning position	any	any	base up	any	any	admed.	any	(see note)	any	horiz.	any
Max. over-all length, inches	5¼	7	6 7/16	5½	5 7/16	5⅝	8	13	11	3¼	55
Light center length, inches	3 7/16	...	5	3 7/16	...	3 7/16	5	7¾	7	...	...
Pressure, atm.	8	2	.9	8	3	8	...	1.2	...	110	.7
Number of electrodes	3	3	2	3	8	3	3	3	3	2	2
Lamp operating volts	130	110–125 (50–60) cycles AC	14	130	130	130	135	135	135	840	535
Lamp starting current, amps	1.3	3.2	9.5	1.3	1.3	1.3	2.9	5	5	2.5	9.3
Lamp operating current, amps	.9	2.5	30	.9	.9	.9	2.1	3.2	3.2	1.4	6.1
Supply voltage (primary volts)	118–236	110–125	115	118–236	118–236	118–236	118–236	118–236	118–236	118–236	230–460–575
Transformer secondary open circuit voltage	245	no trans.	33	245	245	245	250	220	220	1200	850
Power factor, percent	50–90	90	50	50–90	50–90	50–90	50–90–95	60–90–95	60–90–95	...	90
Starting time to full output	3 min	3 min	5 min	3 min	3 to 8 min	3 min	10 min	7 min	8 min	4 sec	8 min
Restarting time	3 min	5 min	0	3 min	3 to 8 min	3 min	4 min	7 min	5 min	2 sec	7 min

NOTE.—Rated lives of black-light and general-lighting lamps listed above are based on specified test conditions with the lamps turned off and restarted no oftener than once every 5 burning hours. The life rating of the A–H1, B–H1, and A–H9 lamps is 6,000 hours for 10 hours per start. At 10 hours per start, the rated life of the A–H5 is 5,000 hours, and the E–Hi 4,000 hours. If the A–H9 lamp is started once every 144 burning hours (six 24-hour days), the life rating is 10,000 hours. The life of S–4, RS, and S–1 lamps is estimated to be 1,000, 600, and 800 applications respectively. A–Hi is for base-up burning. B–Hi base down.

* Prepared by C. L. Amick, General Electric Co., Nela Park.

TABLE 99.—CHARACTERISTICS OF SOME FLUORESCENT LAMPS *

Dimensions, electrical data

Nominal lamp watts †	4	6	8	13	14	15 (T-8)	15 (T-12)	20	25	30	40 (T-12)	40 (T-17)	85	100
Nom. length ‡	6″	9″	12″	21″	15″	18″	18″	24″	33″	36″	48″	60″	60″	60″
Diameter	⅝″	⅝″	⅝″	⅝″	1½″	1	1½″	1½″	1½″	1	1½″	2⅛″	2⅛″	2⅛″
Bulb	T-5	T-5	T-5	T-5	T-12	T-8	T-12	T-12	T-12	T-8	T-12	T-17	T-17	T-17
Lamp amps §	.125	.145	.16	.16	.395	.31	.33	.36	.52	.355	.42	.40	1.6	1.50
Lamp volts §	36	48	57	100	38	55	46	59	53	98	106	110	57	71

Lumen output and brightness—4500 white lamps ‖

	4	6	8	13	14	15 (T-8)	15 (T-12)	20	25	30	40 (T-12)	40 (T-17)	85	100
Lumens		200	310	545	460	585	555	860		1380	2100	2100	4000	4000
Lumens/watt		33	39	42	33	39	37	43		46	53	53	47	40
Brightness:														
Footlamberts		2500	2770	2520	1310	1980	1250	1360		2120	1610	920	1760	1760
Candles/in.²		5.5	6.1	5.6	2.9	4.4	2.8	3.0		4.7	3.6	2.0	3.9	3.9

4500 white slimline lamps for multiple operation

Nominal length, inches	Dim. inches	Bulb	Lamp current, Ma	Nominal lamp watts	Lamp volts	Rec. min. starting voltage	Footlamberts and (candles/in.²)	Lumen output and lpw
42	¾	T-6	120	18	175	450	1570(3.5)	990(55)
			200	25	150		2090(4.7)	1320(53)
			300	33	130		2570(5.7)	1620(49)
64	¾	T-6	120	27.5	270	600	1580(3.5)	1570(57)
			200	39	230		2170(4.8)	2150(55)
			300	51	200		2620(5.8)	2600(57)
72	1	T-8	120	26	240	600	1200(2.7)	1590(61)
			200	38	220		1700(3.8)	2250(59)
			300	51	200		2200(4.9)	2850(56)
96	1	T-8	120	34	320	750	1200(2.7)	2100(62)
			200	51	295		1700(3.8)	3050(60)
			300	69	265		2200(4.9)	3950(57)

* Data taken from reports by General Electric Lamp Department and from reports by Sylvania Electric Products. † Add auxiliary watts for total. ‡ Nominal length includes the lamp and two standard lampholders. § Approximate. ‖ See Table 96.

TABLE 100.—CHARACTERISTICS * OF TYPICAL PHOTOFLASH LAMPS

Lamp class	Lamp designation	Voltage range for operation	Time to full peak	Flash duration at ½ peak †	Total light (lumen seconds)	Peak lumens	Mean color temp °K	Bulb	Maximum over-all length (inches)	Base
Fast	SM	3	6	7	4.7 ‡	.90 §	3300	B11	2⅜	S.S.Bay
	SF	3–9	6	5	5.0	.80	3400	B12	2⅜	S.C.Bay
Medium	5	3	21	13	16	1.2	3800	B11	2⅝	S.C.Bay
	Press 25	3–9	20	14	20	1.25	4000	B12	2⅜	S.C.Bay
	0	3–125	20	14	20	1.2	4000	S13	3 13/16	Medium
	11	3	21	13	30	1.8	3800	A15	4	Medium
	Press 40	3–125	20	17	30	1.6	4000	A15	3 15/16	Medium
	22	3–125	21	14	63	4.0	3800	A19	5	Medium
	2	3–125	20	18	62	3.0	4000	A19	4¾	Medium
Slow	50	3–125	30	17	95	5.0	3800	A21	5⅜	Medium
	3	3–125	30	18	110	5.0	4000	A23	6⅝	Medium
Focal plane	6	3	..	30	16	.62	3800	B11	2⅝	S.C.Bay
	26	.....	..	24	15	.60	3800	....	..	....
	31	3	..	53	77	1.5	3800	A21	5⅜	Medium
	2A	3–9	..	64	77	1.0	4000	A21	5⅜	Medium
Blue for color photography	5B	3	21	13	7.5	.55	6000	B11	2⅝	S.C.Bay
	Press 25B	3–9	20	14	8.0	.50	6000	B12	2⅜	S.C.Bay
	11B	.....	21	14	13.0	.82	6000	....	..	....
	Press 40B	.....	20	17	14	.75	6000	....	..	....
	22B	3–125	21	14	29	1.8	6000	A19	5	Medium
	2B	3–125	20	18	28	1.35	6000	A19	4¾	Medium
	50B	3–125	30	17	43	2.3	6000	A21	5⅜	Medium
	3B	3–125	30	18	50	2.25	6000	A23	6⅝	Medium

* The data given for the light and time characteristics and for the color temperature of the lamps are average values for a large number of lamps. Individual lamps may differ considerably from these averages. Prepared by Adelaide Easley, General Electric Lamp Division. † Milliseconds. ‡ x 10^3. § x 10^6.

TABLE 101.—PHYSICAL AND ELECTRICAL CHARACTERISTICS OF FLASHTUBES AND FLASHLAMPS DESIGNED PRIMARILY FOR PHOTOGRAPHIC APPLICATIONS

Flashtube *	Outer bulb	Base	Approx. helical source dimen. Width	Approx. helical source dimen. Height	Design volts	Max. watt-sec at design voltage	Approx. lumen-sec at max. rating & design volts	Approx. peak mega-lumens at max. rating & design volts	Approx. micro-sec flash duration above ⅓ peak	Approx. micro-sec flash duration above ½ peak
FT-210..	T-10 IF	Octal 3-Pin	1⅛"	1⅝"	2,000	200	7,000	25.0	300	200
FT-214..	T-12½	Giant 5-Pin	1⅛	1⅝	2,000	200	7,000	25.0	300	200
FT-220..	PAR-46	3-Scr. Term.	1⅛	1⅝	2,000	200	7,000	25.0	300	200
FT-403..	T-18 IF	Large 3-Pin	1⅞	2⅜	2,000	480	18,000	45.0	475	350
FT-503..	T-18 IF	Large 3-Pin	1⅞	2⅜	4,000	2,000 †	100,000	150.0	700	550

Flash-lamps ‡	Bulb diameter	Base	Maximum energy input watt-sec.	Volts	Light duration milli-sec	Peak lumens
5804X	1¼"	4 Pin	100	2250-2850	.09- .19	40 million
48U4X	2⅛	4 Pin	600	" "	.27- .7	62
68N9T·	1½	5 Pin	200	900-1000	.3 -1.2	30
88P9M	1½	5 Pin	300	2000-2500	.12- .6	45
1TZ	..	Special	1000	2000-2850	2. -4.	35

* Data furnished by L. R. Benjamin, General Electric Co., Nela Park, Cleveland, Ohio. † With approximately 0.5 millihenry of inductance in series with each 100 microfarads of capacity. ‡ Data taken from circular of Amglo Corporation, Chicago, Ill.

TABLE 102.—COLOR OF LIGHT EMITTED BY VARIOUS SOURCES

Source	Color, percent white	Hue	Source	Color, percent white	Hue
Sunlight	100	—	N-filled tungsten, .50 wpc.....	45	584
Average clear sky...........	60	472	N-filled tungsten, .35 wpc.....	53	584
Standard candle	13	593	Mercury vapor arc...........	70	490
Hefner lamp	14	593	Helium tube	32	598
Pentane lamp	15	592	Neon tube	6	605
Tungsten glow lamp, 1.25 wpc.	35	588	Crater of carbon arc, 1.8 amp..	59	585
Carbon glow lamp, 3.8 wpc....	25	592	Crater of carbon arc, 3.2 amp..	62	585
Nernst glower, 1.50 wpc.......	31	587	Crater of carbon arc, 5.0 amp..	67	583
N-filled tungsten, 1.00 wpc.....	34	586	Acetylene flame (flat).........	36	586

TABLES 103-110.—COOLING BY RADIATION AND CONVECTION

TABLE 103.—AT ORDINARY PRESSURES

According to McFarlane the rate of loss of heat by a sphere placed in the center of a spherical enclosure which has a blackened surface, and is kept at a constant temperature of about 14° C, can be expressed by the equations

$$e = .000238 + 3.06 \times 10^{-6}t - 2.6 \times 10^{-8}t^2,$$

when the surface of the sphere is blackened, or

$$e = .000168 + 1.98 \times 10^{-6}t - 1.7 \times 10^{-8}t^2,$$

when the surface is that of polished copper. In these equations, e is the amount of heat lost in cgs units, that is, the quantity of heat, small calories, radiated per second per square centimeter of surface of the sphere, per degree difference of temperature t, and t is the difference of temperature between the sphere and the enclosure. The medium through which the heat passed was moist air. The following table gives the results.

Difference of temperature t	Value of e: Polished surface	Value of e: Blackened surface	Ratio
5	.000178	.000252	.707
10	.000186	.000266	.699
15	.000193	.000279	.692
20	.000201	.000289	.695
25	.000207	.000298	.694
30	.000212	.000306	.693
35	.000217	.000313	.693
40	.000220	.000319	.693
45	.000223	.000323	.690
50	.000225	.000326	.690
55	.000226	.000328	.690
60	.000226	.000328	.690

TABLE 104.—AT DIFFERENT PRESSURES

Experiments made in Tait's Laboratory show the effect of pressure of the enclosed air on the rate of loss of heat. In this case the air was dry and the enclosure kept at about 8°C.

Polished surface t	Polished surface et	Blackened surface t	Blackened surface et
Pressure 76 cmHg			
63.8	.00987	61.2	.01746
57.1	.00862	50.2	.01360
50.5	.00736	41.6	.01078
44.8	.00628	34.4	.00860
40.5	.00562	27.3	.00640
34.2	.00438	20.5	.00455
29.6	.00378	—	—
23.3	.00278	—	—
18.6	.00210	—	—
Pressure 10.2 cmHg			
67.8	.00492	62.5	.01298
61.1	.00433	57.5	.01158
55	.00383	53.2	.01048
49.7	.00340	47.5	.00898
44.9	.00302	43.0	.00791
40.8	.00268	28.5	.00490
Pressure 1 cmHg			
65	.00388	62.5	.01182
60	.00355	57.5	.01074
50	.00286	54.2	.01003
40	.00219	41.7	.00726
30	.00157	37.5	.00639
23.5	.00124	34.0	.00569
—	—	27.5	.00446
—	—	24.2	.00391

TABLE 105.—COOLING OF PLATINUM WIRE IN COPPER ENVELOPE

Bottomley gives for the radiation of a bright platinum wire to a copper envelope when the space between is at the highest vacuum attainable the following numbers:

$t = 408°$ C, $et = 378.8 \times 10^{-4}$, temperature of enclosure 16° C.

$t = 505°$ C, $et = 726.1 \times 10^{-4}$, " " 17° C.

It was found at this degree of exhaustion that considerable relative change of the vacuum produced very small change of the radiating power. The curve of relation between degree of vacuum and radiation becomes asymptotic for high exhaustions. The following table illustrates the variation of radiation with pressure of air in enclosure.

Temp. of enclosure 16° C, $t = 408°$ C		Temp. of enclosure 17° C, $t = 505°$ C	
Pressure in mm	et	Pressure in mm	et
740.	8137.0×10^{-4}	.094	1688.0×10^{-4}
440.	7971.0 "	.053	1255.0 "
140.	7875.0 "	.034	1126.0 "
42.	7591.0 "	.013	920.4 "
4.	6036.0 "	.0046	831.4 "
.444	2683.0 "	.00052	767.4 "
.070	1045.0 "	.00019	746.4 "
.034	727.3 "	Lowest reached but not measured	726.1 "
.012	539.2 "		
.0051	436.4 "		
.00007	378.8 "		

TABLE 106.—EFFECT OF PRESSURE ON LOSS OF HEAT AT DIFFERENT TEMPERATURES

The temperature of the enclosure was about 15° C. The numbers give the total radiation in calories per square centimeter per second.

Temp. of wire in °C	Pressure in mmHg 10.0	1.0	.25	.025	About .1 μ
100	.14	.11	.05	.01	.005
200	.31	.24	.11	.02	.0055
300	.50	.38	.18	.04	.0105
400	.75	.53	.25	.07	.025
500	—	.69	.33	.13	.055
600	—	.85	.45	.23	.13
700	—	—	—	.37	.24
800	—	—	—	.56	.40
900	—	—	—	—	.61

Note.—An interesting feature (because of its practical importance in electric lighting) is the effect of difference of surface condition on the radiation of heat. The energy required to keep up a certain degree of incandescence in a lamp when the filament is dull black and when it is "flashed" with coating of hard carbon, was found to be as follows:

Dull black filament, 57.9 watts.
Bright " " 39.8 watts.

TABLE 107.—CONDUCTION OF HEAT ACROSS AIR SPACES (ORDINARY TEMPERATURES)

Loss of heat by air from surfaces takes place by radiation, conduction, and convection. The two latter are generally inextricably mixed. For horizontal air spaces, upper surface warm, the loss is all radiation and conduction; with warm lower surface the loss is greater than for similar vertical space.

Vertical spaces: The following table shows that for spaces of less than 1 cm width the loss is nearly proportional to the space width, when the radiation is allowed for; for greater widths the increase is less rapid, then reaches a maximum, and for yet greater widths is slightly less.

Heat conduction and thermal resistances, radiation eliminated, air space 20 cm high

Air space, cm	Heat conduction cal hr^{-1} cm^{-1} $^{\circ}C^{-1}$ Temperature difference				Thermal resistance Reciprocal of conductance Temperature difference			
	10°	15°	20°	25°	10°	15°	20°	25°
.5	.46	.46	.46	.46	2.17	2.17	2.17	2.17
1.0	.24	.24	.24	.24	4.25	4.20	4.15	4.10
1.5	.160	.172	.182	.192	6.25	5.80	5.50	5.20
2.0	.161	.178	.200	.217	6.20	5.60	5.00	4.60
3.0	.172	.196	.208	.217	5.80	5.10	4.80	4.60

Variation with height of air space: Max. thermal resistance = 4.0 at 1.4 cm air space, 10 cm high; 6.0 at 1.6 cm, 20 cm high; 8.9 at 2.5 cm, 60 cm high.

TABLE 108.—CONVECTION OF HEAT IN AIR AT ORDINARY TEMPERATURES *

In very narrow layers of air between vertical surfaces at different temperatures the convection currents, in the main, flow up one side and down the other, with eddyless (streamline) motion. It follows that these currents transport heat to or from the surfaces only when they turn and flow horizontally, from which fact it follows, in turn, that the convective heat transfer is independent of the height of the surface. It is, according to the laws of eddyless flow, proportional to the square of the temperature difference, and to the cube of the distance between the surfaces. As the flow becomes more rapid (e.g., for a 20° difference and a distance of 1.2 cm) turbulence enters, and the above relations begin to change. For the dimensions tested, convection in horizontal layers was a little over twice that in vertical.

Heat transfer, in the usual cgs unit, i.e., calories per second per degree of thermal head per cm^2 of flat surface at 22.8° mean temperature

Where two values are given, they show the range among determinations with different methods of getting the temperature of the outer plate. It will be seen that the value of the convection is practically unaffected by this difference of method.

Thermal head	8 mm gap		12 mm gap		24 mm gap	
	Total	Convection	Total	Convection	Total	Convection
.99°	—	—	.000 083 9 .000 084 8	—	.000 065	—
1.98°	.000 109 110	—	.000 084 0 .000 085 2	.000 000 1 000 4	—	—
4.95°	.000 111	.000 001	.000 086 6 88 1	.000 002 8 003 7	.000 090	over .000 025
9.89°	.000 112 113	.000 003 003	.000 093 7 95 2	.000 010 .000 011	.000 106	over .000 040
19.76°	.000 116	.000 007	.000 107 7 109 4	.000 024 026	.000 126	over .000 060

* See Table 80.

TABLE 109.—CONVECTION AND CONDUCTION OF HEAT BY GASES AT HIGH TEMPERATURES

The loss of heat from wires at high temperatures occurs as if by conduction across a thin film of stationary gas adhering to the wire (vertical and horizontal losses very similar). Thickness of film is apparently independent of temperature of wire, but probably increases with the temperature of the gas and varies with the diameter of the wire according to the formula $b \log (^b/a) = 2B$, where B = constant for any gas, b = diameter of film, a, of wire. The rate of convection (conduction) of heat is the product of two factors, one the shape factor, s, involving only a and B, the other a function ϕ of the heat conductivity of the gas. If W = the energy loss in watts/cm, then $W = s(\phi_2 - \phi_1)$, s may be found from the relation

$$\frac{s}{\pi} e^{-\frac{2\pi}{s}} = \frac{a}{B}; \quad \phi = 4.19 \int_0^T k dt,$$

where k is the heat conductivity of the gas at temperature T in calories/cm° C. ϕ_2 is taken at the temperature T_2 of the wire, ϕ_1 at that of the atmosphere. The following may be taken as the conductivities of the corresponding gases at high temperatures:

For hydrogen .... $k = 28 \times 10^{-6} \sqrt{T}\{(1 + .0002T)/(1 + 77T^{-1})\}$
air .... $k = 4.6 \times 10^{-6} \sqrt{T}\{(1 + .0002T)/(1 + 124T^{-1})\}$
mercury vapor ... $k = 2.4 \times 10^{-6} \sqrt{T}\{1/(1 + 960T^{-1})\}$.

To obtain the heat loss: B may be assumed proportional to the viscosity of the gas and inversely proportional to the density. For air [see Table 110 part 2] B may be taken as 0.43 cm; for H_2, 3.05 cm; for Hg vapor as 0.078. Obtain s from Part 1 below from a/B; then from Part 2 obtain ϕ_2 and ϕ_1 for the proper temperatures; the loss will be $s(\phi_2 - \phi_1)$ in watts/cm.

Part 1.—s as function of a/B

s	a/B	s	a/B	s	a/B	s	a/B
.0	.0	5.0	.453	10	1.696	30	7.738
.5	$.735 \times 10^{-6}$	5.5	.558	12	2.263	32	8.370
1.0	$.584 \times 10^{-3}$	6.0	.671	14	2.844	34	8.995
1.5	$.725 \times 10^{-2}$	6.5	.788	16	3.438	36	9.622
2.0	2.75×10^{-2}	7.0	.908	18	4.040	38	10.25
2.5	.0644	7.5	1.032	20	4.645	40	10.87
3.0	.1176	8.0	1.160	22	5.263	42	11.50
3.5	.185	8.5	1.291	24	5.877	44	12.14
4.0	.265	9.0	1.424	26	6.505	46	12.77
4.5	.354	9.5	1.561	28	7.122	48	13.14
5.0	.453	10.0	1.696	30	7.738	50	14.03

Part 2.—Table of ϕ in watts per cm as function of absolute temp. (°K)

T° K	H_2	Air	Hg	T° K	H_2	Air	Hg
0	.0000	.0000	—	1500°	4.787	.744	.1783
100	.0329	.0041	—	1700	5.945	.931	.228
200	.1294	.0168	—	1900	7.255	1.138	.284
300	.278	.0387	—	2100	8.655	1.363	.345
400	.470	.0669	—	2300	10.18	1.608	.411
500	.700	.1017	.0165	2500	11.82	1.871	.481
700	1.261	.189	.0356	2700	13.56	—	.556
900	1.961	.297	.0621	2900	15.54	—	.636
1100	2.787	.426	.0941	3100	17.42	—	.719
1300	3.726	.576	.1333	3300	19.50	—	.807
1500	4.787	.744	.1783	3500	21.79	—	.898

Part 1.—Wires of platinum sponge served as radiators to room-temperature surroundings

Diameter wire, cm	Absolute temperatures 900°	1000°	1100°	1200°	1300°	1400°	1500°	1600°	1700°	1800°	1900°	2000°
	Observed heat losses in watts per cm											
.0690	1.70	2.26	3.01	3.88	4.92	6.18	7.70	9.63	12.15	15.33	19.25	23.75
.0420	1.35	1.75	2.26	2.84	3.53	4.29	5.33	6.60	8.25	10.20	12.45	14.75
.0275	1.12	1.40	1.76	2.23	2.73	3.23	3.91	4.67	5.72	7.00	8.64	10.45
.0194	.92	1.15	1.39	1.74	2.12	2.54	3.04	3.64	4.32	5.10	6.10	7.35
	Heat losses corrected for radiation, watts per cm (A-C)											
.0690	.91	1.05	1.23	1.36	1.45	1.51	1.54	1.66	2.00	2.56	3.40	4.30
.0420	.87	1.02	1.17	1.31	1.42	1.45	1.57	1.76	2.08	2.43	2.80	3.26
.0275	.80	.92	1.05	1.22	1.35	1.37	1.46	1.50	1.67	1.91	2.32	2.70
.0194	.70	.81	.89	1.03	1.15	1.23	1.31	1.40	1.47	1.51	1.64	1.88
	Computed radiation, watts per cm, $\sigma = 5.61 \times 10^{-12}$ *											
.0690	.79	1.21	1.78	2.52	3.47	4.67	6.16	7.97	10.15	12.77	15.85	19.45
.0420	.48	.73	1.09	1.53	2.11	2.84	3.74	4.84	6.17	7.77	9.65	11.85
.0275	.32	.48	.71	1.01	1.38	1.86	2.45	3.17	4.05	5.09	6.32	7.75
.0195	.22	.34	.50	.71	97	1.31	1.73	2.24	2.85	3.59	4.46	5.47
	Conduction loss by silver leads, watts per cm											
.0420	.42	.46	.49	.61	.75	.88	1.00	1.07	1.13	1.22	—	—
.0275	.18	.21	.28	.35	.43	.48	.55	.57	.60	.67	—	—
.0195	.06	.08	.08	.09	.11	.12	.14	.15	.22	.23	—	—
	Convection loss by air, watts per cm											
.0420	.45	.56	.68	.70	.67	.57	.59	.69	.95	1.21	—	—
.0275	.62	.71	.77	.87	.92	.89	.91	.93	1.07	1.24	—	—
.0195	.64	.73	.81	.94	1.04	1.11	1.17	1.25	1.29	1.30	—	—

* This value is lower than the presently (1950) accepted value of 5.67.

Part 2.—Wires of bright platinum 40-50 cm long served as radiators to surroundings at 300° K

Diameter wire, cm	Absolute temperatures 500°	700°	900°	1100°	1300°	1500°	1700°	1900°	
	Observed energy losses in watts per cm								
.0510	.22	.52	.90	1.42	2.03	2.89	4.10	5.65	
.02508	.17	.39	.68	1.02	1.45	2.00	2.68	3.55	
.01262	.13	.31	.53	.79	1.11	1.46	1.95	2.71	
.00691	.12	.29	.48	.72	.99	1.33	1.79	2.48	
.00404	.11	.24	.41	.61	.84	1.14	1.54	2.13	
	Energy radiated in watts per cm *								
.0510	.002	.013	.049	.137	.323	.67	1.25	2.15	
.02508	.001	.007	.024	.067	.159	.33	.62	1.06	
.01262	.001	.003	.012	.034	.080	.17	.31	.53	
.00691	.000	.002	.007	.019	.044	.09	.17	.29	
.00404	.000	.001	.004	.011	.026	.05	.10	.17	
	"Convection" losses in watts per cm								
.0510	.22	.51	.85	1.28	1.71	2.22	2.85	3.50	
.02508	.17	.38	.66	.95	1.29	1.67	2.06	2.49	
.01262	.13	.31	.52	.75	1.03	1.29	1.64	2.18	
.00691	.12	.29	.47	.70	.95	1.24	1.62	2.19	
.00404	.11	.24	.41	.60	.81	1.09	1.44	1.96	
	Thickness of theoretical conducting air film in cm								
.0510	.28	.30	.33	.33	.36	.37	.35	.36	Means .34
.02508	.30	.37	.37	.41	.45	.45	.51	.56	.43
.01262	.42	.42	.44	.49	.56	.69	.69	.47	.54
.00691	.31	.32	.38	.40	.43	.47	.38	.26	.37
.00404	.27	.43	.43	.47	.56	.47	.40	.25	.41
Means	.31	.37	.39	.42	.49	.49	.47	.38	.43†

* Computed with $\sigma = 5.32$, blackbody efficiency of platinum as follows (Lummer and Kurlbaum): 492°K, .039; 654°, .060; 795°, .075; 1108°, .112; 1481°, .154; 1761°K, .180. † Weighted mean.

TABLES 111-125—TEMPERATURE CHARACTERISTICS OF MATERIALS

TABLE 111.—MELTING AND BOILING POINTS OF THE CHEMICAL ELEMENTS

(Metals in boldface type are often used as standard melting points.)

Element	Symbol and atomic No.	Melting point °C	Boiling point °C
Actinium	Ac 89	1197	
Aluminum	Al 13	660.1	2450
Antimony	Sb 51	630.5	1637
Argon	Ar 18	− 189.37	− 185.86
Arsenic	As 33	817	613
Astatine	At 85		
Barium	Ba 56	710	1637
Beryllium	Be 4	1283	2480
Bismuth	Bi 83	271.3	1560
Boron	B 5		
Bromine	Br 35	− 7.20	59
Cadmium	Cd 48	321.03	765
Calcium	Ca 20	850	1492
Carbon	C 6		
Cerium	Ce 58	804	2900
Cesium	Cs 55	28.64	685
Chlorine	Cl 17	− 100.99	− 34.06
Chromium	Cr 24	1903	2640
Cobalt	Co 27	1492	3150
Copper	Cu 29	1083.0	2580
Dysprosium	Dy 66	1500	2300
Erbium	Er 68	1500	2600
Europium	Eu 63		
Fluorine	F 9	− 219.61	− 188.44
Francium	Fr 87		
Gadolinium	Gd 64	1420	
Gallium	Ga 31	29.80	2240
Germanium	Ge 32	938	2800
Gold	Au 79	1063.0	2700
Hafnium	Hf 72	2220	5200
Helium	He 2		− 269.93
Holmium	Ho 67	1500	
Hydrogen	H 1	− 259.19	− 252.76
Indium	In 49	156.61	2000
Iodine	I 53	113.6	183
Iridium	Ir 77	2443	
Iron	Fe 26	1535	2900
Krypton	Kr 36	− 157.3	− 153.35
Lanthanum	La 57	920	3370
Lead	Pb 82	327.3	1750
Lithium	Li 3	180.55	1331
Lutetium	Lu 71	1700	
Magnesium	Mg 12	650	1120
Manganese	Mn 25	1244	2050
Mercury	Hg 80	− 38.87	356.57
Molybdenum	Mo 42	2610	
Neodymium	Nd 60	1024	
Neon	Ne 10	− 248.59	− 246.08
Nickel	Ni 28	1453	2850
Niobium	Nb 41	2480	5000
Nitrogen	N 7	− 209.97	− 195.80
Osmium	Os 76	2700	4400
Oxygen	O 8	− 218.79	− 182.97
Palladium	Pd 46	1552	3100
Phosphorus	P 15	44.2	280
Platinum	Pt 78	1769	3800
Plutonium	Pu 94	639	
Polonium	Po 84	254	960
Potassium	K 19	63.2	766
Praseodymium	Pr 59	935	3000
Promethium	Pm 61		
Protactinium	Pa 91		
Radium	Ra 88	700	
Radon	Rn 86	− 71	− 62
Rhenium	Re 75	3150	5600
Rhodium	Rh 45	1960	3960
Rubidium	Rb 37	38.8	701
Ruthenium	Ru 44	2400	4000
Samarium	Sm 62	1050	1600
Scandium	Sc 21	1400	3900
Selenium	Se 34	217.4	684.8
Silicon	Si 14	1410	
Silver	Ag 47	960.8	2190
Sodium	Na 11	97.82	890
Strontium	Sr 38	770	1370
Sulfur	S 16	119	444.60
Tantalum	Ta 73	2980	5500
Technetium	Tc 43		
Tellurium	Te 52	450	990
Terbium	Tb 65	1450	
Thallium	Tl 81	303.6	1460
Thorium	Th 90	1695	4250
Thulium	Tm 69	1650	
Tin	Sn 50	231.91	2600
Titanium	Ti 22	1675	3300
Tungsten	W 74	3380	5500
Uranium	U 92	1132	4000
Vanadium	V 23	1890	3400
Xenon	Xe 54	− 112.5	− 108.1
Ytterbium	Yb 70	824	
Yttrium	Y 39		
Zinc	Zn 30	419.50	908
Zirconium	Zr 40	1852	4400

TABLE 112.—MELTING PARAMETERS OF ARGON [43]

Pressure, kg/cm^2	Melting point	$\frac{dT}{dp}$	Δv (cm^3/g)	Latent heat kg cal/g
1	83.9° K.	.0238	.0795	280
1,000	106.4	.0211	.0555	280
2,000	126.3	.0192	.0425	279
3,000	144.9	.0178	.0340	277
4,000	161.9	.0165	.0280	275
5,000	177.8	.0155	.0240	276
6,000	192.9	.0146	.0210	277

[43] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 70, p. 25, 1935.

TABLE 113.—MELTING TEMPERATURES IN °C FOR A NUMBER OF LIQUIDS AS A FUNCTION OF PRESSURE [44]

Pressure kg/cm²	Ethyl alcohol	n-Butyl alcohol	Ethyl bromide	n-Propyl bromide	Chloroform	Carbon bisulfide	Chlorobenzene	Methylene chloride	Water
0	−117.3°C	−89.8°C	−119°C	−110°C	− 63.5°C	−111.6°C	− 45.2°C	−96.7°C	..
5,000	− 76	−33	− 70	− 56	+ 10	− 51	+ 25	−46	..
10,000	− 39	+12	− 29	− 8	+ 76	0	+ 80 + 30 }*	0	..
15,000	− 5	+49	+ 5	+ 34	+137	+ 46	+130	+42	+52.5°C
20,000	+ 25	+80	+ 34	+ 71	+192	+ 89	+166	+82	+72.8
25,000	54	108	58	105	243	130	222	120	102.8
30,000	82	132	80	138	..	170	..	157	137.1
35,000	109	155	..	169	..	209	..	..	166.6
40,000	..	..	..	197	..	..	..	..	192.3

[44] Bridgman, P. W., Journ. Phys. Chem., vol. 9, p. 795, 1941.
* Second modification of the solid.

TABLE 114.—VOLUME-PRESSURE RELATION FOR ARGON *

Volume, cm³

Pressure kg/cm²	+55°C	+25°C	0°C	−90°C	−101.4°C	−117°C	−135.1°C	−153.5°C	−172°C
700	—	1.262	1.179	—	—	—	—	—	—
800	—	1.175	1.105	—	—	—	—	.724	.690
1,000	—	1.060	1.006	—	—	—	—	.697	—
1,300	—	.962	.920	—	—	—	—	.677	—
1,600	—	.898	.864	—	—	—	—	.657	—
2,000	.880	.846	.818	—	—	—	—	—	—
2,500	.831	.808	.785	—	.687	—	.653	—	—
3,500	.772	.751	.733	.661	.656	.638	—	—	—
4,500	.730	.712	.697	.641	.632	—	—	—	—
5,500	.698	.682	.669	.624	—	—	—	—	—
6,000	.685	—	—	—	—	—	—	—	—
10,000	.617	—	—	—	—	—	—	—	—
12,000	.596	—	—	—	—	—	—	—	—
15,000	.573	—	—	—	—	—	—	—	—

* For reference, see footnote 43, p. 117.

TABLE 115.—MELTING PARAMETERS OF NITROGEN *

Pressure kg/cm² p	Melting point	$\frac{dT}{dp}$	ΔV (cm³/g)	Latent heat kg cal/g
1	63.2° K	.0209	.072	218
1,000	82.3	.0176	.058	271
2,000	98.6	.0153	.047	302
3,000	113.0	.0135	.040	334
4,000	125.8	.0124	.033	335
5,000	137.8	.0117	.029	342
6,000	149.2	.0112	.026	346

* For reference, see footnote 43, p. 117.

TABLE 116.—VOLUME-PRESSURE RELATION FOR NITROGEN *

Volume, cm^3

Pressure kg/cm^2	+23.5°C	0°C	−50°C	−100°C	−140°C
3,000	1.2374	1.2069	1.1422	1.0754	1.0226
4,000	1.1615	1.1391	1.0881	1.0327	.9876
5,000	1.1061	1.0870	1.0451	.9997	.9613
6,000	1.0652	1.0487	1.0117	.9729	.9412

* For reference, see footnote 43, p. 117.

TABLE 117.—EFFECT OF PRESSURE ON MELTING POINT

Substance	Melting point at 1 kg/cm^2	Highest experimental pressure kg/cm^2	dt/dp at 1 kg/cm^2	Δt (observed) for 1000 kg/cm^2
Hg	−38.85	12,000	.00511	5.1 *
K	59.7	2,800	.0136	13.8
Na	97.62	12,000	.00860	+12.3 †
Bi	271.0	12,000	−.00342	− 3.5 †
Sn	231.9	2,000	.00317	3.17
Bi	270.9	2,000	−.00344	− 3.44
Cd	320.9	2,000	.00609	6.09
Pb	327.4	2,000	.00777	7.77

* Δt (observed) for 10,000 kg/cm^2 is 50.8°. † Na melts at 177.5° at 12,000 kg/cm^2; K at 179.6°; Bi at 218.3°; Pb at 644°. Luckey obtains melting point for tungsten as follows: 1 atm, 3623°K; 8, 3594; 18, 3572; 28, 3564.

TABLE 118.—EFFECT OF PRESSURE ON FREEZING OF WATER *

Pressure kg/cm^2	Freezing point	Phases in equilibrium
1	.0	Ice I—liquid
1,000	− 8.8	Ice I—liquid
2,000	−20.15	Ice I—liquid
2,115	−22.0	Ice I—ice III—liquid (triple point)
3,000	−18.40	Ice III—liquid
3,530	−17.0	Ice III—ice V—liquid (triple point)
4,000	−13.7	Ice V—liquid
6,000	− 1.6	Ice V—liquid
6,380	+ .16	Ice V—ice VI—liquid (triple point)
8,000	12.8	Ice VI—liquid
12,000	37.9	Ice VI—liquid
16,000	57.2	Ice VI—liquid
20,000	73.6	Ice VI—liquid

* For reference, see footnote 43, p. 117.

TABLE 119.—EFFECT OF PRESSURE ON BOILING POINT

Metal	Pressure	°C	Metal	Pressure	°C	Metal	Pressure	°C
Bi	10.2 cmHg	1200	Ag	26.3 cmHg	1780	Pb	20.6 cmHg	1410
Bi	25.7 cmHg	1310	Cu	10.0 cmHg	1980	Pb	6.3 atm	1870
Bi	6.3 atm	1740	Cu	25.7 cmHg	2180	Pb	11.7 atm	2100
Bi	11.7 atm	1950	Sn	10.1 cmHg	1970	Zn	11.7 atm	1230
Bi	16.5 atm	2060	Sn	26.2 cmHg	2100	Zn	21.5 atm	1280
Ag	10.3 cmHg	1660	Pb	10.5 cmHg	1315	Zn	53.0 atm	1510

TABLE 120.—DENSITIES AND MELTING AND BOILING POINTS OF INORGANIC COMPOUNDS *

Substance	Chemical formula	Density about 20°C	Melting point, °C	Boiling point, °C	Pressure mmHg
Aluminum chloride	$AlCl_3$	2.44	190 ‡	182.7	752
nitrate	$Al(NO_3)_3 + 9H_2O$	...	70.0	134 †	...
oxide	Al_2O_3	4.00	2050	2580	53
Ammonia	NH_3	...	− 77.7	− 33.35	760
Ammonium nitrate	NH_4NO_3	1.72	169.6	210 †	...
phosphite	$NH_4H_2PO_3$	...	123	145 †	...
sulfate	$(NH_4)_2SO_4$	1.77	146.9 †	... †	...
Antimony pentachloride	$SbCl_5$	2.35	2.8	140	68
trichloride	$SbCl_3$	3.14	73.4	223	760
Arsenic hydride	AsH_3	...	−113.5	− 54.8	760
trichloride	$AsCl_3$	2.20	− 18	130.2	760
Barium chloride	$BaCl_2$	3.86	962	1560	760
nitrate	$Ba(NO_3)_2$	3.24	592	...	...
perchlorate	$Ba(ClO_4)_2$	...	505	...	...
Bismuth trichloride	$BiCl_3$	4.75	232.5	447	760
Boric acid	H_3BO_3	1.46	185	...	...
anhydride	B_2O_3	1.79	450	...	...
Borax (sodium borate)	$Na_2B_4O_7$	2.36	741	1570 †	...
Cadmium chloride	$CdCl_2$	4.05	561	...	...
nitrate	$Cd(NO_3)_2 + 4H_2O$	2.45	59.5	...	...
Calcium chloride	$CaCl_2$	2.26	774.0	...	...
chloride	$CaCl_2 + 6H_2O$	1.68	29.6	200	...
nitrate	$Ca(NO_3)_2$	2.36	561	...	...
nitrate	$Ca(NO_3)_2 + 4H_2O\alpha$	1.82	42.3	...	...
oxide	CaO	3.40	2570	2850	...
Carbon tetrachloride	CCl_4	1.59	− 24	76.7	760
dioxide	CO_2	...	− 56.6 §	− 78.5	subl.
disulfide	CS_2	1.26	−111.6	46.2	760
monoxide	CO	...	−207	−192	760
trichloride	C_2Cl_6	1.63	184	185	...
Chloric (per) acid	$HClO_4$	1.764	−112	39 †	56
Chlorine dioxide	ClO_2	...	− 59	9.9	731
Chrome alum	$KCr(SO_4)_2 + 12\,H_2O$	1.83	89	...	...
nitrate	$Cr_2(NO_3)_6 + 18\,H_2O$	...	37	170	760
Chromium oxide	CrO_3	5.21	1990	...	...
Cobalt sulfate	$CoSO_4$	3.710	989	...	...
Cupric chloride	$CuCl_2$	3.05	498	†	...
nitrate	$Cu(NO_3)_2 + 3\,H_2O$	2.05	114.5	170 †	760
Cuprous chloride	Cu_2Cl_2	3.7	421	1366±	760
Hydrogen bromide	HBr	...	− 88.5	− 67.0	760
chloride	HCl	...	−111.3	− 83.7	755
fluoride	HF	.99	− 92.3	19.4	755
iodide	HI	...	− 50.8	− 35.7	760
peroxide	H_2O_2	1.5	− 2	152.1	47
phosphide	PH_3	...	133.5	− 87.4	...
sulfide	H_2S	...	− 82.9	− 62	...
Iron chloride	$FeCl_3$	2.80	282	315	...
nitrate	$Fe(NO_3)_3 + 9\,H_2O$	1.68	47.2	†	...
sulfate	$FeSO_4 + 7\,H_2O$	1.90	64	†	...
Lead chloride	$PbCl_2$	5.8	501	950±	760
Magnesium chloride	$MgCl_2$	2.18	708	1412	...
oxide	MgO	3.4	2800	...	...
nitrate	$Mg(NO_3)_2 + 6\,H_2O$	1.46	100	†	760
sulfate	$MgSO_4$	2.66	1124 †	...	...
Manganese chloride	$MnCl_2 + 4\,H_2O$	2.01	58	†	760
nitrate	$Mn(NO_3)_2 + 6\,H_2O$	1.82	26	129 †	760
sulfate	$MnSO_4$	3.25	700	850 †	...
Mercuric chloride	$HgCl_2$	5.42	276	302	...

* Prepared by F. C. Kracek, Geophysical Laboratory, Carnegie Institution of Washington.
† Decomposes. ‡ At 2.5 atm pressure. § At 5.2 atm pressure.

(continued)

TABLE 120.—DENSITIES AND MELTING AND BOILING POINTS OF INORGANIC COMPOUNDS (concluded)

Substance	Chemical formula	Density about 20°C	Melting point, °C	Boiling point, °C	Pressure mmHg
Mercurous chloride	Hg_2Cl_2	7.10	302±	384	...
Nickel carbonyl	NiC_4O_4	1.32	− 25	43	760
nitrate	$Ni((NO_3)_2 + 6 H_2O$	2.05	56.7	136.7†	760
oxide	NiO	6.69	2090	...	...
Nitric acid	HNO_3	1.502	− 42	86	760
anhydride	N_2O_5	1.64	30	48†	760
oxide	NO	...	−163.6	−151.8	760
peroxide	N_2O_4	1.49	− 9.3	21.3†	760
Nitrous anhydride	N_2O_3	1.45	−102	3.5†	760
oxide	N_2O	...	−102.4	3.5†	760
Phosphoric acid (ortho)	H_3PO_4	1.83	42.45	...	...
Phosphorous acid	H_3PO_3	1.65	73.6	...	...
disulfide	P_3S_6	...	298	337‖	760
oxychloride	$POCl_3$	1.68	1.3	108	760
pentasulfide	P_2S_5	2.03	276	514	760
trichloride	PCl_3	1.57	− 91	75.5	750
trisulfide	P_4S_3	2.03	172.5	407.5	760
Potassium acid phosphate	KH_2PO_4	2.34	252.6 †	...	...
carbonate	K_2CO_3	2.43	891	...	...
chlorate	$KClO_3$	2.34	368.4	400 †	...
chloride	KCl	1.99	776	1500	760
chromate	K_2CrO_4	2.72	968.3	†	...
cyanide	KCN	1.52	634	...	...
dichromate	$K_2Cr_2O_7$	2.69	398	...	...
hydroxide	KOH	2.04	360	1320	760
nitrate	KNO_3	2.10	334	400†	...
perchlorate	$KClO_4$	2.52	610	410 †	760
sulfate	K_2SO_4	2.66	1076	†	...
Silver chloride	AgCl	5.56	455	1550	...
nitrate	$AgNO_3$	4.35	212	444 †	...
perchlorate	$AgClO_4$	2.81	486 †	...	...
phosphate	Ag_3PO_4	6.37	849	...	...
metaphosphate	$AgPO_3$	...	482	...	...
sulfate	$AgSO_4$	5.45	652	1085†	...
Sodium carbonate	Na_2CO_3	2:51	851	†	...
chlorate	$NaClO_3$	2.48	248	†	...
chloride	NaCl	2.17	801	1413	760
hydroxide	NaOH	2.13	318	...	...
hyposulfite	$Na_2O_4 + 2 H_2O$	...	52 †	†	760
metaphosphate	$NaPO_3$	2.18	640	subl. >1100	...
nitrate	$NaNO_3$	2.26	310	380†	...
perchlorate	$NaClO_4$	2.53	482 †	†	...
pyrophosphate	$Na_4P_2O_7$	2.45	880	...	...
sulfate	Na_2SO_4	2.67	884	†	...
sulfate	$Na_2SO_4 + 10 H_2O$	1.46	32.88	...	...
tetraborate	$Na_2B_4O_7$	2.36	741	1570	760
Sulfur dioxide	SO_2	...	− 72.7	− 10	760
trioxide	$SO_{3}\alpha$	1.91	16.8	44.9	760
Sulfuric acid	H_2SO_4	1.83	10.5	338 †	760
acid	$H_2SO_4 + H_2O$	1.79	8.61	290 †	760
acid (pyro)	$H_2S_2O_7$	1.89	35	†	...
Tin, stannic chloride	$SnCl_4$	2.23	− 33	114	760
stannous chloride	$SnCl_2$	3.39(245°)	246	623	760
Water	H_2O	0.998	0	100	760
Zinc chloride	$ZnCl_2$	2.91	262	732	760
nitrate	$Zn(NO_3)_2 + 6 H_2O$	2.06	36.4†	131	760
sulfate	$ZnSO_4 + 7 H_2O$	1.97	39 †	†	...

‖ At 10.5 mmHg pressure.

TABLE 121.—DENSITIES AND MELTING AND BOILING POINTS OF ORGANIC COMPOUNDS

Substance	Chemical formula	Density g/cm³	Temp. °C	Melting point °C	Boiling point °C	Pressure 1 atm unless otherwise stated
Paraffin series: C_nH_{2n+2}. Normal compounds only						
Methane	CH_4	.415	−164	−184	−161.4	
Ethane	C_2H_6	.546	− 88	−172.0	− 88.3	
Propane	C_3H_8	.595	− 44	−189.9	− 42.0	
Butane	C_4H_{10}	.6011	0	−135.0	+ .6	
Pentane	C_5H_{12}	.631	20	−138.0	+ 36.2	
Hexane	C_6H_{14}	.660	20	− 94.3	69.0	
Heptane	C_7H_{16}	.684	20	− 90.0	98.4	
Octane	C_8H_{18}	.704	17	− 56.5	124.6	
Nonane	C_9H_{20}	.718	20	− 53	150.6	
Decane	$C_{10}H_{22}$	.747	20	− 32.0	174	
Undecane	$C_{11}H_{24}$	.741	20	− 26.5	197	
Dodecane	$C_{12}H_{26}$	.768	20	− 12	216	
Tridecane	$C_{13}H_{28}$	.757	20	− 6.2	234	
Tetradecane	$C_{14}H_{30}$	.765	20	+ 5.5	252.5	
Pentadecane	$C_{15}H_{32}$	.772	20	+ 10	270.5	
Hexadecane	$C_{16}H_{34}$	.775	20	20	287.5	
Heptadecane	$C_{17}H_{36}$	.778	20	22.5	303	
Octadecane	$C_{18}H_{38}$	.777	20	28	317	
Nonadecane	$C_{19}H_{40}$	.777	32	32	330	
Eicosane	$C_{20}H_{42}$	.778	37	38	205	15 mmHg
Heneicosane	$C_{21}H_{44}$	.775	45	40.4	215	15 mmHg
Docosane	$C_{22}H_{46}$	.778	44	44.4	224.5	15 mmHg
Tricosane	$C_{23}H_{48}$	.779	48	47.7	320.7	
Tetracosane	$C_{24}H_{50}$	.779	61	54	324	
Pentacosane	$C_{25}H_{52}$	.779	20	54	284	40 mmHg
Hexacosane	$C_{26}H_{54}$	.779	20	60	296	40 mmHg
Heptacosane	$C_{27}H_{56}$	.779	60	59.5	270	15 mmHg
Octacosane	$C_{28}H_{58}$	.779	20	65	318	40 mmHg
Nonacosane	$C_{29}H_{60}$	.780	20	63.6	348	40 mmHg
Triacontane	$C_{30}H_{62}$	.780	20	70	235	1.0 mmHg
Hentriacontane	$C_{31}H_{64}$	.781	68	68.1	302	15 mmHg
Dotriacontane	$C_{32}H_{66}$	.775	79	75	310	15 mmHg
Tetratriacontane	$C_{34}H_{70}$	.781	20	76.5	255	1.0 mmHg
Pentatriacontane	$C_{35}H_{72}$	.782	75	74.7	331	15 mmHg
Hexatriacontane	$C_{36}H_{74}$	.782	76	76.5	265	1.0 mmHg
Olefines or the Ethylene series: C_nH_{2n}. Normal compounds only						
Ethylene	C_2H_4	.566	−102	−169.4	−103.8	
Propylene	C_3H_6	.609	− 47	−185.2	− 47.0	
Butylene	C_4H_8	.635	− 13.5			
Amylene	C_5H_{10}	.651	20	−139	+ 36.4	
Hexylene	C_6H_{12}	.67	0	− 98	69	
Heptylene	C_7H_{14}	.703	20	− 10	96–99	
Octylene	C_8H_{16}	.722	17	104	123	
Nonylene	C_9H_{18}	.73	15		149.9	
Decylene	$C_{10}H_{20}$	.763	0	− 87	172	
Undecylene	$C_{11}H_{22}$	.763	20		193	
Dodecylene	$C_{12}H_{24}$	.762	15	− 31.5	96	15 mmHg
Tridecylene	$C_{13}H_{26}$	.80	0		232.7	
Tetradecylene	$C_{14}H_{28}$	.775	20	− 12	246	
Pentadecylene	$C_{15}H_{30}$	.814			247	
Hexadecylene	$C_{16}H_{32}$	.789	20	+ 4	274	
Octadecylene	$C_{18}H_{36}$	.791	20	+ 19	179	15 mmHg
Eicosylene	$C_{20}H_{40}$	.871	0		395	
Cerotene	$C_{27}H_{54}$			58		
Melene	$C_{30}H_{60}$	.890	20	63	380	

(*continued*)

TABLE 121.—DENSITIES AND MELTING AND BOILING POINTS OF ORGANIC COMPOUNDS (continued)

Substance	Chemical formula	Density g/cm³	Temp. °C	Melting point °C	Boiling point °C	Pressure 1 atm unless otherwise stated
Acetylene series: C_nH_{2n-2}. Normal compounds only						
Acetylene	C_2H_2	.613	−80	−81.8	−83.6	
Allylene	C_3H_4	.660	−13	−104.7	−27.5	
Ethylacetylene	C_4H_6	.668	0	−130	+18.5	
Propylacetylene	C_5H_8	.722	0	−95	+40	
Butylacetylene	C_6H_{10}			−150	71.5	
Amylacetylene	C_7H_{12}	.738	13	−70	110.5	
Hexylacetylene	C_8H_{14}	.770	0		125	
Undecylidene					213	
Dodecylidene		.810	−9	−9	105	15 mmHg
Tetradecylidene		.806	+6.5	+6.5	134	" " "
Hexadecylidene		.804	20	20	160	" " "
Octadecylidene		.802	30	30	184	" " "
Monatomic alcohols: $C_nH_{2n+1}OH$. Normal compounds only						
Methyl alcohol	CH_3OH	.792	20	−97.8	64.5	
Ethyl alcohol	C_2H_5OH	.789	20	−117.3	78.5	
Propyl alcohol	C_3H_7OH	.804	20	−127	97.8	
Butyl alcohol	C_4H_9OH	.810	20	−89.8	117.7	
Amyl alcohol	$C_5H_{11}OH$	.817	20	−78.5	137.9	
Hexyl alcohol	$C_6H_{13}OH$	.820	20	−51.6	155.8	
Heptyl alcohol	$C_7H_{15}OH$	.817	22	−34.6	175.8	
Octyl alcohol	$C_8H_{17}OH$	.827	20	−16.3	194	
Nonyl alcohol	$C_9H_{19}OH$	.828	20	−5	215	
Decyl alcohol	$C_{10}H_{21}OH$	.829	20	+7	231	
Undecyl alcohol	$C_{11}H_{23}OH$	.833	20	+19	146	30 mmHg
Dodecyl alcohol	$C_{12}H_{25}OH$	.831	20	24	259	
Tridecyl alcohol	$C_{13}H_{27}OH$	.822	31	30.5	156	15 mmHg
Tetradecyl alcohol	$C_{14}H_{29}OH$	.824	38	38	167	15 mmHg
Pentadecyl alcohol	$C_{15}H_{31}OH$			46		
Cetyl alcohol	$C_{16}H_{33}OH$	.798	79	49.3	344	
Octadecyl alcohol	$C_{18}H_{37}OH$	.812	59	58.5	210.5	15 mmHg
Alcoholic ethers: $C_nH_{2n+2}O$						
Dimethyl ether	C_2H_6O	.6606	20	−138	−24.9	
Diethyl ether	$C_4H_{10}O$	.714	20	−116.3	+34.5	β—123.3 b. pt.
Dipropyl ether	$C_6H_{14}O$	.747	20	−122	89	
Di-n-butyl ether	$C_8H_{18}O$	.769	20		149	
Di-sec-butyl ether	"	.756	21		121	
Di-iso-butyl ether	"	.762	20		122.5	
Diamyl ether	$C_{10}H_{22}O$	.774	20		190	
Di-iso-amyl ether	"	.783	12		172.2	
Dihexyl ether	$C_{12}H_{26}O$				208.8	
Diheptyl ether	$C_{14}H_{30}O$	.815	0		260	
Dioctyl ether	$C_{16}H_{34}O$	.820	0		291.8	
Ethyl ethers: $C_nH_{2n+2}O$						
Ethyl-methyl	C_3H_8O	.73	20		+7.9	
" -propyl	$C_5H_{12}O$	.747	20	<— 79	61.4	
" -isopropyl	"	.745	0		54	
" -n. butyl	$C_6H_{14}O$	.752	20		91.4	
" -iso-butyl	"	.751	20		80	
" -iso-amyl	$C_7H_{16}O$	.764	18		112	
" -n. hexyl	$C_8H_{18}O$	.63			137	
" -n. heptyl	$C_9H_{20}O$	.790	16		166.6	
" -n. octyl	$C_{10}H_{22}O$	.794	17		183	

(continued)

TABLE 121.—DENSITIES AND MELTING AND BOILING POINTS OF ORGANIC COMPOUNDS (concluded)

Miscellaneous

Substance	Chemical formula	Density and temperature °C		Melting point °C	Boiling point °C
Acetic acid	CH_3COOH	1.115	0	16.7	118.5
Acetone	CH_3COCH_3	.792	0	− 94.6	56.1
Aldehyde	C_2H_4O	.783	0	−124	20.8
Aniline	$C_6H_5NH_2$	1.038	0	− 6	183.9
Beeswax	...	.96±	...	62	...
Benzene	C_6H_6	.879	20	5.48	80.2
Benzoic acid	$C_7H_6O_2$	1.293	4	121	249
Benzophenone	$(C_6H_5)_2CO$	1.090	50	48	305.9
Butter	...	.90	...	25	...
Camphor	$C_{10}H_{16}O$	.99	10	176	209
Carbolic acid	C_6H_5OH	1.060	21	41	182
Carbon bisulfide	CS_2	1.292	0	−108	46.2
tetrachloride	CCl_4	1.582	21	− 28	76.7
Chlorobenzene	C_6H_5Cl	1.111	15	− 40	132
Chloroform	$CHCl_3$	1.4989	15	− 63.3	61.2
Cyanogen	C_2N_2	...	...	− 35	−21
Ethyl bromide	C_2H_5Br	1.45	15	−117	38.4
chloride	C_2H_5Cl	.918	8	−141.6	12
ether	$C_4H_{10}O$	.716	0	−116	34.6
iodide	C_2H_5I	1.944	14	108	72
Formic acid	$HCOOH$	1.242	0	8.6	100.8
Gasoline	...	.68±	...	...	70–90
Glucose	$CHO(HCOH)_4CH_2OH$	1.56	...	146	...
Glycerine	$C_3H_8O_3$	1.269	0	17	290
Iodoform	CHI_3	4.01	25	119	...
Lard	...	.90	...	29±	...
Methyl chloride	CH_3Cl	.0992	−24	− 98	−24.1
iodide	CH_3I	2.285	15	− 64	42.3
Naphthalene	$C_6H_4 \cdot C_4H_4$	1.152	15	80	218
Nitrobenzene	$C_6H_5O_2N$	1.212	7.5	5	211
Nitroglycerine	$C_3H_5N_3O_9$	1.60	...	3	...
Oleomargarine	...	.92–.93	20	35–38	...
Olive oil	...	.92	...	20±	300±
Oxalic acid	$C_2H_2O_4 \cdot 2H_2O$	1.68	...	190	...
Paraffin wax, soft	...	...	...	35–52	350–390
hard	...	...	...	52–56	390–430
Pyrogallol	$C_6H_3(OH)_3$	1.46	40	133	293
Spermaceti	...	.95	15	45±	...
Starch	$C_6H_{10}O_5$	1.56	...	none	...
Stearine	$(C_{18}H_{35}O_2)_3C_3H_5$	.925	65	71	...
Sugar, cane	$C_{12}H_{22}O_{11}$	1.588	20	160	...
Tallow, beef	...	.94	15	27–38	...
mutton	...	.94	15	32–41	...
Tartaric acid	$C_4H_4O_6$	1.754	...	170	...
Toluene	$C_6H_5CH_3$	.822	0	− 92	110.31
Xylene (o)	$C_6H_4(CH_3)_2$	.863	20	− 28	142
(m)	$C_6H_4(CH_3)_2$	.864	20	54	140
(p)	$C_6H_4(CH_3)_2$	.861	20	15	138

Metals	Melting points, °C Percentage of metal in second column 0	10	20	30	40	50	60	70	80	90	100
Pb Sn	327	295	276	262	240	220	190	185	200	216	232
Bi	327	290	—	—	179	145	126	168	205	—	271
Te	327	710	790	880	917	760	600	480	410	425	452
Ag ...	327	460	545	590	620	650	705	775	840	905	961
Na	327	360	420	400	370	330	290	250	200	130	97.5
Cu	327	870	920	925	945	950	955	985	1005	1020	1083
Sb	327	250	275	330	395	440	490	525	560	600	630
Al Sb	660	750	840	925	945	950	970	1000	1040	1010	630
Cu	660	630	600	560	540	580	610	755	930	1055	1083
Au	660	675	740	800	855	915	970	1025	1055	675	1063
Ag	660	625	615	600	590	580	575	570	650	750	961
Zn	660	640	620	600	580	560	530	510	475	425	419
Fe	660	860	1015	1110	1145	1145	1220	1315	1425	1500	1533
Sn	660	645	635	625	620	605	590	570	560	540	232
Sb Bi	631	610	590	575	555	540	520	470	405	330	271
Ag	631	595	570	545	520	500	505	545	680	850	961
Sn	631	600	570	525	480	430	395	350	310	255	232
Zn	631	555	510	540	570	565	540	525	510	470	419
Ni Sn	1453	1380	1290	1200	1235	1290	1305	1230	1060	800	232
Na Bi	97.5	425	520	590	645	690	720	730	715	570	271
Cd	97.5	125	185	245	285	325	330	340	360	390	321
Cd Ag ...	321	420	520	610	700	760	805	850	895	940	961
Tl	321	300	285	270	262	258	245	230	210	235	303
Zn	321	280	270	295	313	327	340	355	370	390	419
Au Cu ...	1063	910	890	895	905	925	975	1000	1025	1060	1083
Ag ...	1063	1062	1061	1058	1054	1049	1039	1025	1006	982	961
Pt	1063	1125	1190	1250	1320	1380	1455	1530	1610	1685	1769
K Na	63	17.5	—10	—3.5	5	11	26	41	58	77	97.5
Hg	63	—	—	—	—	90	110	135	162	265	—
Tl	63	133	165	188	205	215	220	240	280	305	303
Cu Ni	1083	1180	1240	1290	1320	1335	1380	1410	1430	1440	1453
Ag	1083	1035	990	945	910	870	830	788	814	875	961
Sn	1083	1005	890	755	725	680	630	580	530	440	232
Zn	1083	1040	995	930	900	880	820	780	700	580	419
Ag Zn	961	850	755	705	690	660	630	610	570	505	419
Sn	961	870	750	630	550	495	450	420	375	300	232
Na Hg	97.5	90	80	70	60	45	22	55	95	215	—

TABLE 123.—MELTING POINT °C OF LOW-MELTING-POINT ALLOYS *

	Percent						
Cadmium	10.8	10.2	14.8	13.1	6.2	7.1	6.7
Tin	14.2	14.3	7.0	13.8	9.4	—	—
Lead	24.9	25.1	26.0	24.3	34.4	39.7	43.4
Bismuth	50.1	50.4	52.2	48.8	50.0	53.2	49.9
Solidification at	65.5°	67.5°	68.5°	68.5°	76.5°	89.5°	95°

	Percent									
Lead	32.0	25.8	25.0	43.0	33.3	10.7	50.0	35.8	20.0	70.9
Tin	15.5	19.8	15.0	14.0	33.3	23.1	33.0	52.1	60.0	9.1
Bismuth	52.5	54.4	60.0	43.0	33.3	66.2	17.0	12.1	20.0	20.0
Solidification at	96°	101°	125°	128°	145°	148°	161°	181°	182°	234°

* See Table 201.

TABLE 124.—REVERSIBLE TRANSITIONS IN CRYSTALS *

Values are given, for the more important crystals, of the inversion temperature in °C, the heat of inversion in cal/g and the inversion volume change in cm^3/g. No monotropic inversions have been included.

h_i, inversion temperature on heating; m, metastable inversion temperature; e, estimated; g, gradual inversion (not to be confused with slow retarded inversions).

Substance	Phases	Transition t°C	Pressure atm	Transition heat cal/g	Transition volume change cm^3/g
$AgClO_4$	....	158	....	....	....
$AgBrO_3$	....	98.5	....	....	....
AgI	I-II	146	1	5.72	.0086
		99.4	2720	4.95	.0101
	I-III	99.4	2720	4.22	.0140
	II-III	99.4	2720	.76	.0241
Ag_2S	....	175	....	3.85	....
Ag_2Se	....	133	....	5.65	....
Ag_2SO_4	....	412	....	....	....
$AgNO_3$	....	159.5	....	3.37	.0025
$AlBr_3$	....	70	....	....	....
As_2O_3	....	275	....	6	....
As_2S_2	red-black	267	....	....	....
As_2S_3	red-yellow	170	....	....	....
Bi_2O_3	....	704 †	....	....	....
$BaCl_2$	....	924	....	....	....
$BaClO_4$	....	284	....	....	....
$BaSO_4$	....	1149	....	....	....
$BaCO_3$	....	811 & 982	....	....	....
Br_3O_8	....	— 35	....	....	....
CO	*g*	—212.8	....	5.4	....
CH_4	*g*	—252.7	....	1.15	....
CH_3OH	*g*	—112	....	4.8	....
CCl_4	I-II	— 48.5	1	7.1	.026 [e]
		115	8460	9.8	.0173
	II-III	115	8460	.9	.0054
	I-III	115	8460	10.7	.0227
CBr_4	I-II	46.2	1	5.04	.0205
		112.6	2110	4.58	.0150
	I-III	112.6	2110	.25	.0029
	II-III	112.6	2110	4.66	.0121
CH_2I_2	L-I-II	8.6	180	....	....
	L-II-III	42.8	1930	....	....
	I-II-IV	9.4	325	....	....
	II-III-IV	38	1825	....	....
CH_4N_2O	I-II	102.3	6535	2.34	.0480
(Urea)	I-III	102.3	6535	10.14	.0486
	II-III	102 3	6535	7.80	.0006
CH_3COOH	L-I	16.68	1	45	.1560
		55.7	2033	46.4	.0862
	L-II	55.7	2033	48.2	.0992
	I-II	55.7	2033	1.85	.0130
CH_3CONH_2	L-I	127	5220	60.9	.0319
(Acetamide)	L-II	127	5220	58.5	.0649
	I-II	127	5220	2.41	.0330
$(CH_3)_2CO$ ‡	I-II	—140 to —150	....	<.5	....
C_2Cl_6	I-II	71.1	1	6.93	.0280
(Perchlor ethane)	II-III	42.7	1	2.63	.0097
$C_3H_7NO_2$ (Urethane)	L-I	47.9	1	40.7	.0599
		66.2	2270	37.9	.0253
	L-II	66.2	2270	35.9	.0355
		76.8	4090	34.4	.0184
	L-III	76.8	4090	40.6	.0640
	I-II	66.2	2270	2.07	.0102
		25.5	3290	1.64	.0092
	II-III	76.8	4090	6.12	.0456
		25.5	3290	5.50	.0482
	I-III	25.5	3290	3.87	.0574

* Arranged by F. C. Kracek, Geophysical Laboratory, Carnegie Institution. All other footnotes at end of table.

(continued)

TABLE 124.—REVERSIBLE TRANSITIONS IN CRYSTALS (continued)

Substance	Phases	Transition t°C	Pressure atm	Transition heat cal/g	Transition volume change cm³/g
C_6H_6 (Benzene)	I-II	100	11680	8.68	.0105
		218	11680	7.73[e]	.0132[e]
	L-I	5.4	1	30.2	.1317
		218	11680	33.25[e]	.0369[e]
	L-II	218	11680	25.5[e]	.0501[e]
C_6H_5OH (Phenol)	L-I	40.9	1	29.8	.0567
		64	2015	24.8	.0270
	L-II	64	2015	30	.0825
	I-II	64	2015	5.2	.0555
$CH_3C_6H_4OH$ (o.Cresol).	L-I	30.8	1	33.8	.0838
		103.2	5900	34.2	.0317
	L-II	103.2	5900	35	.0555
	I-II	103.2	5900	.8	.0238
Camphor §	I-II	87.1	1	.25	.00187
$C_6H_{11}OH$	I-II	−9	1	9.38	....
$C_6H_5NH_2HNO_3$	....	97.6	....	....	....
$CaSO_4$	....	1193	....	....	....
$CaCO_3$[r]	I-II	970	high CO_2	....	....
$CaO.SiO_2$	....	1190 ± 10	....	Ca. 10	....
$2CaO.SiO_2$	....	1420, 675	....	....	10%, 675
Co	Curie point	~1100	....	1.3	....
	I-II	1015	....	....	....
	II-III	400	....	....	....
CoO	....	350 ± 10	....	....	....
CoOH	....	223	....	11.8	....
CsCl	....	460	....	8	....
$CsClO_4$	....	219	....	....	....
Cs_2SO_4	....	660	....	....	....
$CsNO_3$	....	153.5	1	4.3	.00405
$Cs_2Ca_2(SO_4)_3$	....	722	....	....	....
Cu_2Br_2	I-II-III	390, 470	....	....	....
Cu_2I_2	I-II-III	402, 440	1	....	....
	II-III	200	9600	1.091	.00485
	II-III	100	11560	.948	.00535
Cu_2S	....	91	....	5.6	....
Cu_2Se	....	110	....	5.4	....
Cu_2Te	....	351, 387	....	....	....
Fe	Curie point	730	....	6.7 ±	....
	β-γ	920	....	6.7 ±	....
	γ-δ	1400	....	2	....
Fe_3O_4	Curie point	570 ±	....	....	....
Fe_2O_3	II-III	−163 to −148	....	2.25	....
	I-II	500 ±	....	....	....
FeS	....	140	....	....	....
FeS_2	pyrite, marcasite	....	....	....	....
Fe_2P	....	80	....	....	....
Fe_3P	....	440	....	....	....
$FeTiO_3$	....	215	....	....	....
HgI_2	red-yellow	127.5	....	1.3	.00342
Hg_2I_2	green-yellow	....	....	.5 ±	....
HgS	cinnabar / metacinnabar	386 ±	....	....	....
ICl	ruby-brown	....	....	....	....
KOH	....	248	5500	27.1	....
$KClO_3$	I-II	255	....	....	....
	II-III	$P = 5500 + 10.9t$			
	$\Delta v_t = .02510 - 2.2t \times 10^{-6}$ $\Delta h_t = .165$ at 0°, .281 at 200°				
$KClO_4$	....	295	....	....	....
K_2S	I-II	146.4	1	.765	.00095
		$t = 146.4 + .0124p$			
KNO_3	I-II	127.7	1	10.5	.00484
		128	81	10.3	.0049
	I-III	128	81	5.6	.0138
	II-III	128	81	4.7	.0089
		21.3	2840	1.3	.0156
	III-IV	21.3	2840	5.1	.0284
	II-IV	21.3	2840	3.8	.0440

(continued)

TABLE 124.—REVERSIBLE TRANSITIONS IN CRYSTALS (continued)

Substance	Phases	Transition t°C	Pressure atm	Transition heat cal/g	Transition volume change cm³/g
K_2SO_4		588	....	13	....
$KHSO_4$	I-II	180.5	1	.71	.00066
		198.6	1773	2.29	.00197
	II-III	164.2	1	3.61	.00566
		118.2	2810	3.30	.00570
	II-IV	198.6	1773	.166	.00113
		118.2	2810	.134	.00110
	I-IV	198.6	1773	2.03	.00310
	III-IV	118.2	2810	3.44	.00680
KPO_3	....	450	....	....	....
$K_4P_2O_7$	....	278	....	....	....
K_2CO_3	....	410	....	....	....
KCNS	....	143	1	3.10	.00306
$K_2Pb(SO_4)_2$	....	544	....	....	....
K_2CdI_4	....	215	....	....	....
K_2CrO_4	....	666	....	12.6	....
$K_2Cr_2O_7$	....	243	....	1.40	....
K_2MoO_4	....	327, 454, 477	....	....	....
K_2WO_4	....	388	....	8.2	....
	....	575	....	1.6	....
$K_2Ca_2(SO_4)_3$	....	937	....	....	....
$K_2Sr(SO_4)_3$	....	775	....	....	....
$KLiSO_4$	....	435	....	....	....
KNO_2	I-II	—.3	5000	11.7	.0315
		122.3	10000	7.15	.0378
$K_2O(SiO_2)_2$	....	290	....	....	....
$2K_2O(Al_2O_3)(SiO_2)_4$ [a]	....	714	....	....	....
$LiClO_3$	....	41.5, 99	....	....	....
Li_2SO_4	....	580	....	55 ± 1	....
$(MgO)_8(B_2O_3)_8MgCl$	....	266	....	1.8	....
$MgO.SiO_2$ [b]	....	....	....	....	....
Mn	....	742, 1191	....	....	....
$MnSO_4$	....	860	....	....	....
MnO_2	....	—185 to —175	....	.88	....
MnO	....	—153 to —163	....	2.08	....
N_2	....	—237.6	....	1.9 [g]	....
NH_4Cl	....	—30.5 [g]	....	....	....
	I-II	184.3	....	16.3	.0985
NH_4Br	....	—38 [g]	....	....	....
	I-II	137.8	1	7.78	.0647
NH_4I	....	—42.5 [g]	....	....	....
	I-II	—17.6	1	4.80	.0561
NH_4ClO_4	....	240	....	....	....
NH_4HSO_4	I-II-III	126.2	1800	....	....
	II-III-IV	176.9	5480	....	....
$(NH_4)_3H(SO_4)_2$	....	134	....	....	....
NH_4CNS	I-II	120	....	....	....
	II-III	87.7	1	10.36	.0409
NH_4NO_3	L-I	169.5	1	16	.051
	I-II	125.5	1	12.9	.01351
		186.7	8730	12.6	.00475
	I-VI	186.7	8730	12.3	.00855
	II-VI	169.2	8870	.27	.00309
		186.7	8730	.33	.00380
	II-III	84	1	4	.00758
		63.3	830	2.48	.00925
	III-IV	32	1	4.67	.02026
		63.3	830	4.03	.02135
	II-IV	63.3	830	6.51	.01210
		169.2	8870	11.84	.01267
	IV-VI	169.2	8870	12.1	.00958
	IV-V	—18	1	1.6	.017
NaOH	....	300	....	24.7	....
$NaClO_4$	....	308	....	....	....
$NaClO_3$	....	248	....	....	....
Na_2SO_4	IV-III	185	....	8.6	.0034
	III-I	241	....	15.5	.0070

(*continued*)

TABLE 124.—REVERSIBLE TRANSITIONS IN CRYSTALS (concluded)

Substance	Phases	Transition t°C	Pressure atm	Transition heat cal/g	Transition volume change cm³/g
$NaF.Na_2SO_4$	....	105	....	....	....
Na_2CO_3	....	430	....	....	....
$NaNO_3$	....	275 [g]	....	(8±2)	(.0081)
Na_3AlF_6	....	568	....	59	....
Na_2MoO_4	....	424, 585, 623	....	....	....
Na_2WO_4	I-L	581.6	....	25.1	.018
	II-I	588.8	....	3.3	.00
	III-II	695.5	....	19.4	.035
$NaAlSiO_4$	neph.—carn.	1250	....	....	....
	carnegieite	226, 650–690	....	cal	....
$NaC_2H_3O_2$ [c]	....	198 [d]	....	....	....
Ni	Curie point	355	....	....	....
Ni_3S_2	....	545	....	....	....
Ni_5As_2	....	970	....	....	....
Oxygen	I-II	—229.5	....	6.2	....
	II-III	—249.5	....	.75	....
Phosphorus	L-I	44.2	1	4.90	.0193
		196	6000	6.53	.0120
	I-II	.1	6000	43.9	.00846
		68.4	12000	55.2	.00684
PbO	red-yellow	587	....	....	....
$PbSO_4$	....	870	....	13.4	....
$PbCrO_4$	....	707, 783	....	....	....
$PbWO_4$	....	877	....	....	....
RbOH	....	245	....	16.8	....
$RbClO_4$	....	279	....	....	....
Rb_2SO_4	....	653	....	....	....
$Rb_2Ca_2(SO_4)_3$	....	787, 915	....	....	....
$RbLiSO_4$	....	142	....	....	....
$RbNO_3$	I-II	219	....	....	....
	II-III	164.4	1	7.12	.00688
	....	218.6	5810	5.93	.00434
RbCl	....	50	5525	....	....
RbBr	....	50	4925	....	....
RbI	....	50	4050	....	....
Sulphur	I-II	95.5	1	2.7	....
	L-I-II	155	1410	....	....
Sb_2O_3	rhomb.-reg.	570	....	....	....
$SbCl_3$	I-II-III	65, 69.5	....	....	....
SiO_2 [e]	I-II	573	....	2.6	....
SiO_2 [f]	I-II	215	....	2.7	....
SiO_2 [h]	I-II	150 [h]	....	.63	....
	II-III	104 [h]	....	.96	....
SiO_2	e, h	867	....	8.7 [e]	....
	e, f	1250	....	25 [e]	....
	h, f	1470	....	7.5 [e]	....
Sn	....	161	....	.2	small
	....	18	....	4.4	....
SnO_2	....	430, 540	....	....	....
$SrSO_4$	....	1152	....	....	....
$SrCO_3$	....	925	high CO_2	....	....
$TlClO_4$	....	226	....	....	....
TlI	....	173	....	....	....
$TlNO_3$	I-II	144.6	1	2.86	.00244
	II-III	75	1	.89	.00073
Tl picrate	....	44	....	....	.018
Tl	....	230	....	.3 ±	....
$TiBr_4$	....	—15	....	....	....
W_2C	....	2400	....	....	....
ZnS [g]	....	1020	....	....	....
ZrO_2	....	ca 1000	....	....	....

† Third modification at room temperature. ‡ Acetone. § Five other modifications; not accurately located. ¶ Very beautiful for demonstration purposes. *a* Leucite. *b* Probably pentamorphic, inv. at 1150° and 1300°C. *c* Acetate. *d* Sluggish. *e* Quartz. *f* Cristobalite. *g* Zincblende and wurtzite. *h* Tridymite.

TABLE 125.—TRANSFORMATION AND MELTING TEMPERATURES OF LIME-ALUMINA-SILICA COMPOUNDS AND EUTECTIC MIXTURES *

Substance	Percent CaO	Al_2O_3	SiO_2	Transformation	Temp. °C
$CaSiO_3$	48.2	—	51.8	Melting †	1540±2
$CaSiO_3$	48.2	—	51.8	α to β and reverse	1200±2
Ca_2SiO_4	65.	—	35.	Melting	2130±10
"	65.	—	35.	γ to β and reverse	675±5
"	65.	—	35.	β to α and reverse	1420±2
$Ca_3Si_2O_7$	58.2	—	41.8	Dissociation into Ca_2SiO_4 and liquid	1475±5
Ca_3SiO_5	73.6	—	26.4	Dissociation into Ca_2SiO_4 and CaO	1900±5
$Ca_3Al_2O_6$	62.2	37.8	—	Dissociation into CaO and liquid	1535±5
$Ca_5Al_6O_{14}$	47.8	52.2	—	Melting	1455±5
$CaAl_2O_4$	35.4	64.6	—	Melting	1600±5
$Ca_3Al_{10}O_{18}$	24.8	75.2	—	Melting	1720±10
Al_2SiO_5	—	62.8	37.1	Melting	1816±10
$CaAl_2Si_2O_8$	20.1	36.6	43.3	Melting	1550±2
$Ca_2Al_2SiO_7$	40.8	37.2	22.0	Melting	1590±2
$Ca_3Al_2SiO_8$	50.9	30.9	18.2	Dissociation into $Ca_2SiO_4+Ca_2Al_2SiO_7$ and liquid	1335±5

Eutectics

Crystalline phases	Percent CaO	Al_2O_3	SiO_2	Melting temp. °C
$CaSiO_3$,SiO_2	37	—	63.	1436
Ca,SiO_3 3CaO,2SiO_2	54.5	—	45.5	1455±
Ca_2SiO_4 CaO.	67.5	—	32.5	2065±
Al_2SiO_5,SiO_2	—	13.	87.	1610
Al_2SiO_5,Al_2O_3	—	64.	36.	1810
$CaAl_2Si_2O_8$ $CaSiO_3$	34.1	18.6	47.3	1299
$CaAl_2Si_2O_8$ SiO_2	10.5	19.5	70.	1359
$CaAl_2Si_2O_8$ SiO_2,$CaSiO_3$	23.2	14.8	62.	1165
$Ca_2Al_2SiO_7$ Ca_2SiO_4	49.6	23.7	26.7	1545
Al_2O_3 $CaAl_2Si_2O_8$	19.3	39.3	41.4	1547
$CaAl_2Si_2O_8$ Al_2SiO_5,SiO_2	9.8	19.8	70.4	1345
$Ca_2Al_2SiO_7$ $Ca_3Al_{10}O_{18}$	35.	50.8	14.2	1552
$Ca_2Al_2SiO_7$ $CaAl_2O_4$	37.8	52.9	9.3	1512
$Ca_2Al_2SiO_7$ $CaAl_2O_4$ $Ca_3Al_{10}O_{18}$	37.5	53.2	9.3	1505
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$	30.2	36.8	33.	1385
$Ca_2Al_2SiO_7$ $Ca_3Si_2O_7$ $CaSiO_3$	47.2	11.8	41.	1310
$Ca_2Al_2SiO_7$ $CaSiO_3$	45.7	13.2	41.1	1316

Eutectics

Crystalline phases	Percent CaO	Al_2O_3	SiO_2	Melting temp. °C
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$ Ca_2SiO_4	38.	20.	42.	1265
$CaAl_2Si_2O_8$ $Ca_2Al_2SiO_7$ Al_2O_3	29.2	39.	31.8	1380
Ca_2SiO_4 $CaAl_2O_4$ $Ca_5Al_6O_{14}$	49.5	43.7	6.8	1335

Quintuple points

Crystalline phases	CaO	Al_2O_3	SiO_2	Melting temp. °C
$Ca_2Al_2SiO_7$ $Ca_3Si_2O_7$ Ca_2SiO_4	48.2	11.9	39.9	1335
$Ca_2Al_2SiO_7$ Ca_2SiO_4 $CaAl_2O_4$	48.3	42.	9.7	1380
$CaAl_2Si_2O_8$ Al_2O_3 Al_2SiO_5	15.6	36.5	47.9	1512
$Ca_3Al_{10}O_{18}$ $Ca_2Al_2SiO_7$ Al_2O_3	31.2	44.5	24.3	1475

Quadruple points

Crystalline phases	CaO	Al_2O_3	SiO_2	Melting temp. °C
3CaO.2SiO_2 2CaO.SiO_2	55.5	—	44.5	1475

* The majority of these determinations are by G. A. Rankin.
† The accuracy of the melting points is 5 to 10 units. (Geophysical Laboratory.)

TABLE 126.—LOWERING OF FREEZING POINTS BY SALTS IN SOLUTION

In the first column is given the number of gram-molecules (anhydrous) dissolved in 1000 g of water; the second contains the molecular lowering of the freezing point; the freezing point depression is the product of these two columns. After the chemical formula is given the molecular weight. Temperatures in °C.

g mol / 1000 g H_2O	Molecular lowering
$Pb(NO_3)_2$, 331.0	
.000362	5.5°
.001204	5.30
.002805	5.17
.005570	4.97
.01737	4.69
.5015	2.99
$Ba(NO_3)_2$, 261.5	
.000383	5.6°
.001259	5.28
.002681	5.23
.005422	5.13
.008352	5.04
$Cd(NO_3)_2$, 236.5	
.00298	5.4°
.00689	5.25
.01997	5.18
.04873	5.15
$AgNO_3$, 167.0	
.1506	3.32°
.5001	2.96
.8645	2.87
1.749	2.27
2.953	1.85
3.856	1.64
.0560	3.82
.1401	3.58
.3490	3.28
KNO_3, 101.9	
.0100	3.5
.0200	3.5
.0500	3.41
.100	3.31
.200	3.19
.250	3.08
.500	2.94
.750	2.81
1.000	2.66
$NaNO_3$, 85.09	
.0100	3.6°
.0250	3.46
.0500	3.44
.2000	3.345
.500	3.24
.5015	3.30
1.000	3.15
1.0030	3.03
NH_4NO_3, 80.11	
.0100	3.6°
.0250	3.50
.0500	3.47°
.1000	3.42
.2000	3.32
.500	3.26
1.000	3.14
$LiNO_3$, 69.07	
.0398	3.4°
.1671	3.35
.4728	3.35
1.0164	3.49
$Al_2(SO_4)_3$, 342.4	
.0131	5.6°
.0261	4.9
.0543	4.5
.1086	4.03
.217	3.83
$CdSO_4$, 208.5	
.000704	3 35°
.002685	3.05
.01151	2.69
.03120	2.42
.1473	2.13
.4129	1.80
.7501	1.76
1.253	1.86
K_2SO_4, 174.4	
.00200	5.4°
.00398	5.3
.00865	4.9
.0200	4.76
.0500	4.60
.1000	4.32
.200	4.07
.454	3.87
$CuSO_4$, 159.7	
.000286	3.3°
.000843	3.15
.002279	3.03
.006670	2.79
.01463	2.59
.1051	2.28
.2074	1.95
.4043	1.84
.8898	1.76
$MgSO_4$, 120.4	
.000675	3.29
.002381	3.10
.01263	2.72
.0580	2.65
.2104	2.23
.4978	2.02°
.8112	2.01
1.5233	2.28
$BaCl_2$, 208.3	
.00200	5.5°
.00498	5.2
.0100	5.0
.0200	4.95
.04805	4.80
.100	4.69
.200	4.66
.500	4.82
.586	5.03
.750	5.21
$CdCl_2$, 183.3	
.00299	5.0°
.00690	4.8
.0200	4.64
.0541	4.11
.0818	3.93
.214	3.39
.429	3.03
.858	2.71
1.072	2.75
$CuCl_2$, 134.5	
.0350	4.9°
.1337	4.81
.3380	4.92
.7149	5.32
$CoCl_2$, 129.9	
.0276	5.0°
.1094	4.9
.2369	5.03
.4399	5.30
.538	5.5
$CaCl_2$, 111.0	
.0100	5.1°
.05028	4.85
.1006	4.79
.5077	5.33
.946	5.3
2.432	8.2
3.469	11.5
3.829	14.4
.0478	5.2
.153	4.91
.331	5.15
.612	5.47
.998	6.34
$MgCl_2$, 95.26	
.0100	5.1°
.0500	4.98
.1500	4.96
.3000	5.186
.6099	5.69
KCl, 74.60	
.02910	3.54°
.05845	3.46
.112	3.43
.3139	3.41
.476	3.37
1.000	3.286
1.989	3.25
3.269	3.25
$NaCl$, 58.50	
.00399	3.7°
.0100	3.67
.0221	3.55
.04949	3.51
.1081	3.48
.2325	3.42
.4293	3.37
.700	3.43
NH_4Cl, 53.52	
.0100	3.6°
.0200	3.56
.0350	3.50
.1000	3.43
.2000	3.396
.4000	3.393
.7000	3.41
$LiCl$, 42.48	
.00992	3.7°
.0455	3.5
.09952	3.53
.2474	3.50
.5012	3.61
.7939	3.71
$BaBr_2$, 297.3	
.100	5.1°
.150	4.9
.200	5.00
.500	5.18
$AlBr_3$, 267.0	
.0078	1.4°
.0559	1.2
.1971	1.07
.4355	1.07

(continued)

TABLE 126.—LOWERING OF FREEZING POINTS BY SALTS IN SOLUTION (concluded)

g mol / 1000 g H_2O	Molecular lowering
$CdBr_2$, 272.3	
.00324	5.1°
.00718	4.6
.03627	3.84
.0719	3.39
.1122	3.18
.220	2.96
.440	2.76
.800	2.59
$CuBr_2$, 223.5	
.0242	5.1°
.0817	5.1
.2255	5.27
.6003	5.89
$CaBr_2$, 200.0	
.0871	5.1°
.1742	5.18
.3484	5.30
.5226	5.64
$MgBr_2$, 184.28	
.0517	5.4°
.103	5.16
.207	5.26
.517	5.85
KBr, 119.1	
.0305	3.61°
.1850	3.49
.6801	3.30
.250	3.78
.500	3 56
CdI_2, 366.1	
.00210	4.5°
.00626	4.0
.02062	3.52
.04857	2.70
.1360	2.35
.333	2.13
.684	2.23
.888	2.51
KI, 166.0	
.0651	3.5°
.2782	3.50
.6030	3.42
1.003	3.37
SrI_2, 341.3	
.054	5.1°
.108	5.2
.216	5.35
.327	5.52
NaOH, 40.06	
.02002	3.45°
.05005	3.45
.1001	3.41
.2000	3.407
KOH, 56.16	
.00352	3.60°
.00770	3.59
.02002	3.44
.05006	3.43
.1001	3.42
.2003	3.424
.230	3.50
.465	3.57
CH_3OH, 32.03	
.0100	1.8°
.0301	1.82
.2018	1.811
1.046	1.86
3.41	1.88
6.200	1.944
C_2H_5OH, 46.04	
.000402	1.67°
.004993	1.67
.0100	1.81
.02892	1.707
.0705	1.85
.1292	1.829
.2024	1.832
.5252	1.834
1.0891	1.826
1.760	1.83
3.901	1.92
7.91	2.02
11.11	2.12
18.76	1.81
.0173	1.80
.0778	1.79
K_2CO_3, 138.30	
.0100	5.1°
.0200	4.93
.0500	4.71
.100	4.54
.200	4.39
Na_2CO_3, 106.10	
.0100	5.1°
.0200	4.93
.0500	4.64
.1000	4.42
.2000	4.17
Na_2SO_3, 126.2	
.1044	4.51°
.3397	3.74
.7080	3.38
Na_2HPO_4, 142.1	
.01001	5.0°
.02003	4.84
.05008	4.60
.1002	4.34
Na_2SiO_3, 122.5	
.01052	6.4°
.05239	5.86
.1048	5.28
.2099	4.66
.5233	3.99
HCl, 36.46	
.00305	3.68°
.00695	3.66
.0100	3.6
.01703	3.59
.0500	3.59
.1025	3.56
.2000	3.57
.3000	3 612
.464	3.68
.516	3.79
1.003	3.95
1.032	4.10
1.500	4.42
2.000	4.97
2.115	4.52
3.000	6.03
3.053	4.90
4.065	5.67
4.657	6.19
HNO_3, 63.05	
.02004	3.55°
.05015	3.50
.0510	3.71
.1004	3.48
.1059	3.53
.2015	3.45
.250	3.50
.500	3.62
1.000	3.80
2.000	4.17
3.000	4.64
H_3PO_2, 66.0	
.1260	2.90°
.2542	2.75
.5171	2.59
1.071	2.45
H_3PO_3, 82.0	
.0745	3.0°
.1241	2.8
.2482	2.6
1.00	2.39
H_3PO_4, 98.0	
.0100	2.8°
.0200	2.68
.0500	2.49
.1000	2.36
.2000	2.25
.472	2.20°
.944	2.27
1.620	2.60
$(COOH)_2$, 90.02	
.01002	3.3°
.02005	3.19
.05019	3.03
.1006	2.83
.2022	2.64
.366	2.56
.648	2.3
$C_3H_5(OH)_3$, 92.06	
.0200	1.86°
.1008	1.86
.2031	1.85
.535	1.91
2.40	1.98
5.24	2.13
$(C_2H_5)_2O$, 74.08	
.0100	1.6°
.0201	1.67
.1011	1.72
.2038	1.702
Dextrose, 180.1	
.0198	1.84°
.0470	1.85
.1326	1.87
.4076	1.894
1.102	1.921
Levulose, 180.1	
.0201	1.87°
.2050	1.871
.554	2.01
1.384	2.32
2.77	3.04
$C_{12}H_{22}O_{11}$, 342.2	
.000332	1.90°
.001410	1.87
.009978	1.86
.0201	1.88
.1305	1.88
H_2SO_4, 98.08	
.00461	4.8°
.0100	4.49
.0200	4.32
.0461	4.10
.100	3.96
.200	3.85
.400	3.98
1.000	4.19
1.500	4.96
2.000	5.65
2.500	6.53

TABLE 127.—RISE OF BOILING POINT PRODUCED BY SALTS DISSOLVED IN WATER

This tables gives the number of g of the salt which, when dissolved in 100 g of water, will raise the boiling point by the amount stated in the headings of the different columns. The pressure is supposed to be 76 cmHg.

Salt	1°C	2°	3°	4°	5°	7°	10°	15°	20°	25°
$BaCl_2+2H_2O$	15.0	31.1	47.3	63.5	(71.6 gives 4°.5 rise of temp.)					
$CaCl_2$	6.0	11.5	16.5	21.0	25.0	32.0	41.5	55.5	69.0	84.5
$Ca(NO_3)_2+2H_2O$	12.0	25.5	39.5	53.5	68.5	101.0	152.5	240.0	331.5	443.5
KOH	4.7	9.3	13.6	17.4	20.5	26.4	34.5	47.0	57.5	67.3
$KC_2H_3O_2$	6.0	12.0	18.0	24.5	31.0	44.0	63.5	98.0	134.0	171.5
KCl	9.2	16.7	23.4	29.9	36.2	48.4	(57.4 gives a rise of 8°.5)			
K_2CO_3	11.5	22.5	32.0	40.0	47.5	60.5	78.5	103.5	127.5	152.5
$KClO_3$	13.2	27.8	44.6	62.2						
KI	15.0	30.0	45.0	60.0	74.0	99.5	134.	185.0	(220 gives 18°.5)	
KNO_3	15.2	31.0	47.5	64.5	82.0	120.5	188.5	338.5		
$K_2C_4H_4O_6+\frac{1}{2}H_2O$	18.0	36.0	54.0	72.0	90.0	126.5	182.0	284.0		
$KNaC_4H_4O_6$	17.3	34.5	51.3	68.1	84.8	119.0	171.0	272.5	390.0	510.0
$KNaC_4H_4O_6+4H_2O$	25.0	53.5	84.0	118.0	157.0	266.0	554.0	5510.0		
$LiCl$	3.5	7.0	10.0	12.5	15.0	20.0	26.0	35.0	42.5	50.0
$LiCl+2H_2O$	6.5	13.0	19.5	26.0	32.0	44.0	62.0	92.0	123.0	160.5
$MgCl_2+6H_2O$	11.0	22.0	33.0	44.0	55.0	77.0	110.0	170.0	241.0	334.5
$MgSO_4+7H_2O$	41.5	87.5	138.0	196.0	262.0					
$NaOH$	4.3	8.0	11.3	14.3	17.0	22.4	30.0	41.0	51.0	60.1
$NaCl$	6.6	12.4	17.2	21.5	25.5	33.5	(40.7 gives 8°.8 rise)			
$NaNO_3$	9.0	18.5	28.0	38.0	48.0	68.0	99.5	156.0	222.0	
$NaC_2H_3O_2+3H_2O$	14.9	30.0	46.1	62.5	79.7	118.1	194.0	480.0	6250.0	
$Na_2S_2O_3$	14.0	27.0	39.0	49.5	59.0	77.0	104.0	152.0	214.5	311.0
Na_2HPO_4	17.2	34.4	51.4	68.4	85.3					
$Na_2C_4H_4O_6+2H_2O$	21.4	44.4	68.2	93.9	121.3	183.0	(237.3 gives 8°.4 rise)			
$Na_2S_2O_3+5H_2O$	23.8	50.0	78.6	108.1	139.3	216.0	400.0	1765.0		
$Na_2CO_3+10H_2O$	34.1	86.7	177.6	369.4	1052.9					
$Na_2B_4O_7+10H_2O$	39.	93.2	254.2	898.5	(5555.5 gives 4°.5 rise)					
NH_4Cl	6.5	12.8	19.0	24.7	29.7	39.6	56.2	88.5		
NH_4NO_3	10.0	20.0	30.0	41.0	52.0	74.0	108.0	172.0	248.0	337.0
$(NH_4)_2SO_4$	15.4	30.1	44.2	58.0	71.8	99.1	(115.3 gives 108.2)			
$SrCl_2+6H_2O$	20.0	40.0	60.0	81.0	103.0	150.0	234.0	524.0		
$Sr(NO_3)_2$	24.0	45.0	63.6	81.4	97.6					
$C_4H_6O_6$	17.0	34.4	52.0	70.0	87.0	123.0	177.0	272.0	374.0	484.0
$C_2H_2O_4+2H_2O$	19.0	40.0	62.0	86.0	112.0	169.0	262.0	540.0	1316.0	50000.0
$C_6H_8O_7+H_2O$	29.0	58.0	87.0	116.0	145.0	208.0	320.0	553.0	952.0	

Salt	40°C	60°	80°	100°	120°	140°	160°	180°	200°	240°
$CaCl_2$	137.5	222.0	314.0							
KOH	92.5	121.7	152.6	185.0	219.8	263.1	312.5	375.0	444.4	623.0
$NaOH$	93.5	150.8	230.0	345.0	526.3	800.0	1333.0	2353.0	6452.0	—
NH_4NO_3	682.0	1370.0	2400.0	4099.0	8547.0	∞				
$C_4H_6O_6$	980.0	3774.0	(infinity gives 170)							

TABLE 128.—FREEZING MIXTURES

Column 1 gives the name of the principal refrigerating substance, *A* the proportion of that substance, *B* the proportion of a second substance named in the column, *C* the proportion of a third substance, *D* the temperature of the substances before mixture, *E* the temperature of the mixture, *F* the lowering of temperature, *G* the temperature when all snow is melted, when snow is used, and *H* the amount of heat absorbed in heat units (calories when *A* is grams). Temperatures are in °C.

Substance	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
$NaC_2H_3O_2$ (cryst.) ..	85	H_2O–100	—	10.7	4.7	15.4	—	—
NH_4Cl	30	" "	—	13.3	— 5.1	18.4	—	—
$NaNO_3$	75	" "	—	13.2	— 5.3	18.5	—	—
$Na_2S_2O_3$ (cryst.)....	110	" "	—	10.7	— 8.0	18.7	—	—
KI	140	" "	—	10.8	—11.7	22.5	—	—
$CaCl_2$ (cryst.)	250	" "	—	10.8	—12.4	23.2	—	—
NH_4NO_3	60	" "	—	13.6	—13.6	27.2	—	—
$(NH_4)_2SO_4$	25	" 50	NH_4NO_3–25	—	—	26.0	—	—
NH_4Cl	25	" "	" "	—	—	22.0	—	—
$CaCl_2$	25	" "	" "	—	—	20.0	—	—
KNO_3	25	" "	NH_4Cl–25	—	—	20.0	—	—
Na_2SO_4	25	" "	" "	—	—	19.0	—	—
$NaNO_3$	25	" "	" "	—	—	17.0	—	—
K_2SO_4	10	Snow 100	—	— 1	— 1.9	.9	—	—
Na_2CO_3 (cryst.) ...	20	" "	—	— 1	— 2.0	1.0	—	—
KNO_3	13	" "	—	— 1	— 2.85	1.85	—	—
$CaCl_2$	30	" "	—	— 1	—10.9	9.9	—	—
NH_4Cl	25	" "	—	— 1	—15.4	14.4	—	—
NH_4NO_3	45	" "	—	— 1	—16.75	15.75	—	—
$NaNO_3$	50	" "	—	— 1	—17.75	16.75	—	—
NaCl	33	" "	—	— 1	—21.3	20.3	—	—
$H_2SO_4 + H_2O$ (66.1% H_2SO_4)	1	" 1.097	—	— 1	—37.0	36.0	—37.0	.0
	1	" 1.26	—	— 1	—36.0	35.0	—30.2	17.0
	1	" 1.38	—	— 1	—35.0	34.0	—25.0	27.0
	1	" 2.52	—	— 1	—30.0	29.0	—12.4	133.0
	1	" 4.32	—	— 1	—25.0	24.0	— 7.0	273.0
	1	" 7.92	—	— 1	—20.0	19.0	— 3.1	553.0
	1	" 13.08	—	— 1	—16.0	15.0	— 2.1	967.0
$CaCl_2 + 6H_2O$	1	" .35	—	0	—	—	.0	52.1
	1	" .49	—	0	—	—	—19.7	49.5
	1	" .61	—	0	—	—	—39.0	40.3
	1	" .70	—	0	—	—	—54.9*	30.0
	1	" .81	—	0	—	—	—40.3	46.8
	1	" 1.23	—	0	—	—	—21.5	88.5
	1	" 2.46	—	0	—	—	— 9.0	192.3
	1	" 4.92	—	0	—	—	— 4.0	392.3
Alcohol at 4°	77	" 73	—	0	—30.0	—	—	—
	—	CO_2 solid	—	—	—72.0	—	—	—
Chloroform	—	" "	—	—	—77.0	—	—	—
Ether	—	" "	—	—	—77.0	—	—	—
Liquid SO_2	—	" "	—	—	—82.0	—	—	—
NH_4NO_3	1	H_2O–.75	—	20	5.0	—	—	33.0
	1	" .94	—	20	— 4.0	—	—	21.0
	1	" "	—	10	— 4.0	—	—	34.0
	1	" "	—	5	— 4.0	—	—	40.5
	1	Snow "	—	0	— 4.0	—	—	122.2
	1	H_2O–1.20	—	10	—14.0	—	—	17.9
	1	Snow "	—	0	—14.0	—	—	129.5
	1	H_2O–1.31	—	10	—17.5*	—	—	10.6
	1	Snow "	—	0	—17.5*	—	—	131.9
	1	H_2O–3.61	—	10	— 8.0	—	—	.4
	1	Snow "	—	0	— 8.0	—	—	327.0

* Lowest temperature obtained.

TABLE 129.—ANTIFREEZING SOLUTIONS *

(For automobile radiators, etc.)

Percent by volume	Percent by volume in water with freezing points and specific gravities				
	10	20	30	40	50
Typical commercial methanol antifreeze	−5.2°C	−12.0°C	−21.1°C	−32.2°C	−45.0°C
Sp. gr. at 15°C/15°C	.986	.975	.963	.950	.935
Typical commercial ethanol antifreeze	−3.3°C	−7.7°C	−14.2°C	−22.0°C	−30.6°C
Sp. gr. at 15°C/15°C	.988	.977	.967	.955	.938
Commercial glycerine † antifreeze	−1.6°C	−4.7°C	−9.5°C	−15.4°C	−23.0°C
Sp. gr. at 15°C/15°C	1.023	1.048	1.074	1.101	1.128
Typical commercial ethylene glycol † antifreeze	−3.8°C	−8.8°C	−15.5°C	−24.3°C	−36.5°C
Sp. gr. at 15°C/15°C	1.015	1.030	1.045	1.060	1.074

* This table was prepared from data furnished by F. G. Church, of the National Carbon Co., and A. J. Kathman, of Procter & Gamble Co. † Glycerine and ethylene glycol are practically nonvolatile. All types must be suitably inhibited to prevent cooling-system corrosion. Commercial antifreeze solutions based on ethylene glycol (Prestone) and on glycerine (Zerex) are in use at the present time.

TABLES 130-141.—HEAT FLOW AND THERMAL CONDUCTIVITY

TABLE 130.—CONVERSION FACTORS BETWEEN UNITS OF HEAT FLOW

	$\frac{\text{joules}}{\text{sec cm}^2}$ or watts/cm²	$\frac{\text{cal}}{\text{sec cm}^2}$	$\frac{\text{kilocal}}{\text{hr m}^2}$	$\frac{\text{Btu}}{\text{hr ft}^2}$	hp/ft²	watts/in.²
1 watts/cm² =	1	.2390	8602.	3171.	1.246	6.452
1 $\frac{\text{cal}}{\text{sec cm}^2}$ =	4.185	1	36000.	1.327×10^4	5.212	27.00
1 $\frac{\text{kilocal}}{\text{hr m}^2}$ =	1.163×10^{-4}	2.778×10^{-5}	1	.3687	1.448×10^{-4}	7.500×10^{-4}
1 $\frac{\text{Btu}}{\text{hr ft}^2}$ =	3.153×10^{-4}	7.535×10^{-5}	2.713	1	3.928×10^{-4}	2.035×10^{-3}
1 hp/ft² =	.8027	.1918	6905.	2546.	1	5.179
1 watt/in.² =	.1550	3.704×10^{-2}	1333.	491.5	.1931	1

TABLE 131.—THERMAL CONDUCTIVITY OF VARIOUS SUBSTANCES

Part 1.—Various Substances

Substance, temperature °C	k_t cgs
Aniline BP 183, — 160	.000112
Carbon, gas	.010
Carbon, graphite	.012
Carborundum	.00050
Concrete, cinder	.00081
stone	.0022
Diatomaceous earth	.00013
Earth's crust	.004
Fire-brick	.00028
Fluorite, —190	.093
Fluorite, 0	.025
Glycerine, —160	.00077
Iceland spar, —190	.038
Iceland spar, 0	.0103

Substance, temperature °C	k_t cgs
Lime	.00029
Mica	.0018
Flagstone ⊥ to cleavage	.0063
Micaceous ∥ to cleavage	.0044
Naphthalene MP 79, —160	.0013
Naphthalene MP 79	.00081
Naphthol—β MP 122, —160	.00068
Naphthol, 0	.00062
Nitrophenol MP 114, —160	.00106
Nitrophenol, 0	.00065
Paraffin MP 54, —160	.00062
Paraffin, 0	.00059

Substance, temperature °C	k_t cgs
Quartz ⊥ to axis, —190	.0586
" , 0	.0173
" , 100	.0133
Quartz ∥ to axis, 0	.0325
Rock salt, 0	.0167
Rock salt, 30	.0150
Rubber, vulcanized, —160	.00033
Rubber, 0	.00037
Rubber, para	.00045
Sawdust	.00012
Snow, fresh, dens.=.11	.00026
Vaseline, 20	.00022
Vulcanite	.00087

Part 2.—Rocks [45]

Rock	Temp. °C	Conductivity, K $\frac{\text{watts}}{\text{cm deg}}$
Granite	100	23.8×10^{-3}
	500	15.9
Barre, Vt.	0	27.9
	50	26.2
	100	24.7
	200	23.0
Granite gneiss	...	28-18
Granite schist	...	27.2
Quartz monzonite, Calif.	0	31.6
	100	29.2
Basalt	...	22-18

Rock	Temp. °C	Conductivity, K $\frac{\text{watts}}{\text{cm deg}}$
Limestone:		
Japan	...	25 to 9×10^{-3}
Penna.		
∥ to bed	0	34.5
⊥ to bed	0	25.5
Chalk	...	9.2
Marble (17 varieties)	30	32-21
Black	124	16
White	125	14
Sandstone, Boreland bore	17	41.8
Soapstone	...	34

Rock	Temp. °C	Conductivity, K $\frac{\text{watts}}{\text{cm deg}}$
Slate:		
Wales	30	20×10^{-3}
Penna.		
⊥ to bed	0	19.4
Madoc	120	16
Shale	...	17-10
Silty clay	17	15.4
Fireclay, Boreland bore	17	18.3
Rocksalt, Holford	17	72

[45] Birch, Francis, Handbook of physical constants, Geological Society of America, 1942. Used by permission.

TABLE 132.—THERMAL CONDUCTIVITY OF WATER AND SALT SOLUTIONS

Substance	°C	k_t cgs
Water	0	.00150
	11	.00147
	25	.00136
	20	.00143

Solution in water	Density	°C	k_t cgs
$CuSO_4$	1.160	4.4	.00118
KCl	1.026	13.	.00116
NaCl	1.178	4.4	.00115
"	—	26.3	.00135

Solution in water	Density	°C	k_t cgs
H_2SO_4	1.054	20.5	.00126
"	1.180	21.	.00130
$ZnSO_4$	1.134	4.5	.00118
"	1.136	4.5	.00115

TABLE 133.—CONVERSION FACTORS BETWEEN UNITS OF HEAT FLOW FOR DIFFERENT GRADIENTS

	$\frac{\text{cal}}{\text{sec cm}^2}\frac{\text{cm}}{°\text{C}}$	$\frac{\text{watts}}{\text{cm}^2}\frac{\text{cm}}{°\text{C}}$	$\frac{\text{kg cal}}{\text{hr m}^2}\frac{\text{m}}{°\text{C}}$	$\frac{\text{Btu}}{\text{ft}^2\text{ hr}}\frac{\text{ft}}{°\text{F}}$	$\frac{\text{hp}}{\text{ft}^2}\frac{\text{in.}}{°\text{C}}$	$\frac{\text{hp}}{\text{ft}^2}\frac{\text{ft}}{°\text{F}}$	$\frac{\text{hp}}{\text{ft}^2}\frac{\text{in.}}{°\text{F}}$	$\frac{\text{watts}}{\text{in.}^2}\frac{\text{in.}}{°\text{C}}$
$1\ \frac{\text{cal}}{\text{sec cm}^2}\frac{\text{cm}}{°\text{C}} =$	1.	4.185	360	241.9	2.053	9.503×10^{-2}	1.141	10.63
$1\ \frac{\text{watts}}{\text{cm}^2}\frac{\text{cm}}{°\text{C}} =$	.2390	1.	86.02	57.78	.4907	2.271×10^{-2}	.2727	2.540
$1\ \frac{\text{kg cal}}{\text{hr m}^2}\frac{\text{m}}{°\text{C}} =$	2.778×10^{-3}	1.163×10^{-2}	1.	6.720×10^{-1}	5.703×10^{-3}	2.640×10^{-4}	3.170×10^{-3}	2.953×10^{-2}
$1\ \frac{\text{Btu}}{\text{ft}^2\text{ hr}}\frac{\text{ft}}{°\text{F}} =$	4.134×10^{-3}	1.730×10^{-2}	1.488	1.	8.487×10^{-3}	3.929×10^{-4}	4.717×10^{-3}	4.394
$1\ \frac{\text{hp}}{\text{ft}^2}\frac{\text{in.}}{°\text{C}} =$	.4871	2.039	175.4	117.8	1.	4.629×10^{-2}	.5558	5.178
$1\ \frac{\text{hp}}{\text{ft}^2}\frac{\text{ft}}{°\text{F}} =$	10.52	44.03	3787.	2546.	21.60	1.	12.00	111.8
$1\ \frac{\text{hp}}{\text{ft}^2}\frac{\text{in.}}{°\text{F}} =$	.8764	3.668	315.5	212.0	1.8	8.333×10^{-2}	1.	9.316
$1\ \frac{\text{watts}}{\text{in.}^2}\frac{\text{in.}}{°\text{C}} =$	9.407×10^{-2}	.3937	33.87	22.76	.1931	8.939×10^{-3}	.1073	1.

TABLE 134.—THERMAL CONDUCTIVITY, METALS AND ALLOYS

The coefficient k is the quantity of heat in small calories which is transmitted per second through a plate one centimeter thick per square centimeter of its surface when the difference of temperature between the two faces of the plate is 1°C. The coefficient k is found to vary with the absolute temperature of the plate, and is expressed approximately by the equation $k_t = k_0[1 + \alpha(t - t_0)]$. k_0 is the conductivity at t_0, the lower temperature of the bracketed pairs in the table, k_t that at temperature t, and α is a constant. k_t in g-cal per degree C per sec across $cm^3 = 0.239 \times k_t$ in watts per degree C per sec across cm^3.

Substance	t°C	k_t cgs	α
Aluminum	—190	.497	—
"	30	.497	+.0030
"	76.4	.550	
Antimony	0	.0442	—.00104
"	100	.0396	
Bismuth	—186	.025	—
"	18	.0194	—.0021
"	100	.0161	
Brass	—160	.181	—
"	17	.260	—
" , yellow	0	.204	+.0024
" , red	0	.246	+.0015
Cadmium, pure	—160	.239	—
" "	18	.222	—.00038
"	100	.215	
Constantan	18	.0540	+.00227
(60 Cu + 40 Ni)	100	.0640	
Copper,* pure	—160	1.079	—
" "	18	.918	—.00013
" "	100	.908	
German silver	0	.070	+.0027
Gold	—190	.793	—.00007
"	17	.705	
Graphite	17	.037	+.0003
Iridium	17	.141	—.0005
Iron,† pure	18	.161	—.0008
" "	100	.151	
Iron, wrought	—160	.152	—
Iron, polycrystalline	30	.173	—.0008
Iron, polycrystalline	100	.163	
Iron, polycrystalline	200	.147	
Iron, polycrystalline	800	.071	
Iron, steel, 1% C	18	.108	—.0001
" " " "	100	.107	
Lead, pure	—160	.092	—
" "	18	.083	—.0001
" "	100	.081	
Magnesium	0 to 100	.376	—
Manganin	—160	.035	—
" (84 Cu + 4	18	.0519	+.0026
Ni 12 Mn)	100	.0630	

Substance	t°C	k_t cgs	α
Mercury	0	.0148	+.0055
"	50	.0189	
Molybdenum	17	.346	—.0001
Nickel	—160	.129	—
"	18	.1420	—
"	0	.1425	—.00032
"	100	.1380	
"	200	.1325	—.00095
"	700	.069	
"	1000	.064	—.00047
"	1200	.058	
Palladium	18	.1683	+.0010
"	100	.182	
Platinum	18	.1664	+.00051
"	100	.1733	
Pt 10% Ir	17	.074	+.0002
Pt 10% Rh	17	.072	+.0002
Platinoid	18	.060	—
Potassium	5.0	232	—.0013
"	57.4	.216	
Rhodium	17	.210	—.0010
Silver, pure	—160	.998	—
"	18	1.006	—.00017
"	100	.992	
Sodium	5.7	.321	—.0012
"	88.1	.288	
Steel	18	.110	—
Tantalum	17	.130	—.0001
"	1700	.174	—
"	1900	.186	+.00032
"	2100	.198	
Tin	0	.155	—.00069
"	100	.145	
" , pure	—160	.192	—
Tungsten	17	.476	—.0001
"	1600	.249	+.00023
"	2000	.272	
"	2400	.294	+.00016
"	2800	.313	
Wood's alloy	—	.319	—
Zinc, pure	—160	.278	—
Zinc, polycrystalline	0	.280	—
Zinc, polycrystalline	200	.250	
Zinc, polycrystalline	400	.231	
Zinc, liquid	500	.144	—

* Copper: 100-197°C, $k_t = 1.043$; 100-268°, 0.969; 100-370°, 0.931; 100-541°, 0.902.
† Iron: 100-727°C, $k_t = 0.202$; 100-912°, 0.184; 100-1245°, 0.191.

TABLE 135.—THERMAL CONDUCTIVITY OF INSULATING MATERIALS *

Material	Density g/cm³	t°C	Conductivity joule/(cm² sec °C/cm)	Conductivity cal/(cm² sec °C/cm)
Air, 76 cmHg	.00129	0	.00023	.000055
Asbestos wool	.40	−100	.00068	.000162
" "	.40	0	.00090	.000215
" "	.40	+100	.00101	.00024
" with 85 percent MgO	.3	30	.00075	.000179
Brick, very porous, dry	.71	20	.00174	.00042
" machine-made, dry	1.54	0	.00038	.000091
" " " moist, 1.2% vol.		50	.00096	.00023
Calorox, fluffy mineral matter	.064	30	.00032	.000076
Celluloid, white	1.4	30	.00021	.000050
Cement mortar	2.0	90	.0055	.0013
Chalk			.0092	.0022
Charcoal	.18	20	.00055	.00013
Coke dust	1.0	20	.0015	.00036
Concrete	1.6	0	.008	.002
Cork	.05	0	.00032	.000076
"	.05	100	.00041	.000098
"	.35	0	.00061	.000146
"	.35	100	.00079	.000189
Cotton, tightly packed	.08	−150	.00038	.000091
" " "	.08	0	.00056	.000133
" " "	.08	+150	.00076	.00018
Cotton wool tightly packed	.08	30	.00042	.00010
Diatomite (binders may increase 100%)	.20	0	.00052	.00012
Diatomite, ditto	.20	400	.00094	.00022
" "	.50	0	.00086	.00021
" "	.50	400	.00157	.00037
Ebonite	1.19	−190	.00138	.00033
"	1.19	−78	.00157	.00038
"	1.19	0	.00160	.00038
Felt, flax fibers	.18	30	.00047	.00011
" hair	.27	30	.00036	.000086
" wool	.15	40	.00063	.000151
" "	.33	30	.00052	.000124
Flannel				.000023
Fuller's earth	.53	30	.00101	.00024
Glass, lead		15	.0060	.00143
" soda	2.59	20	.0072	.00172
" "	2.59	100	.0076	.00182
" wool	.22	50	.00042	.000100
" "	.22	100	.00050	.000120
" "	.22	200	.00065	.000155
" "	.22	300	.00081	.000195
Graphite, 100 mesh	.48	40	.0018	.00044
" 40 "	.42	40	.0038	.00093
" 20 to 40 mesh	.70	40	.0129	.0031
Horsehair, compressed	.17	20	.00051	.000122
Ice	.92	0	.022	.0053
Leather, chamois		85	.00063	.000151
" cowhide		85	.00176	.000421
" sole	1.0	30	.0016	.00038
Linen		20	.00086	.00021
Linoleum, cork	.54	20	.00080	.000191
Mica, average		50	.0050	.0012

* Compiled from the International Critical Tables, which see for more complete data.

(*continued*)

TABLE 135.—THERMAL CONDUCTIVITY OF INSULATING MATERIALS (continued)

Material	Density g/cm³	t°C	Conductivity joule/(cm² sec °C/cm)	Conductivity cal/(cm² sec °C/cm)
Micanite		30	.0021–.0042	.00050–.00010
Mineral wool	.15	30	.00042	.00010
" "	.30		.00052	.00012
Paper, rice		40	.00046	.00011
" blotting		20	.00063	.00015
Paraffin wax	.89	30	.0023	.00055
Peat, dry	.19	30	.00052	.00012
" blocks	.84	20	.0017	.00041
Poreclain		90	.0104	.0025
Rubber, rigid sponge, hard	.09	25	.00037	.000088
" sponge, vulcanized	.22	20	.00054	.00013
" commercial, 40% rubber		25	.0028	.00067
" " 92% "		25	.0016	.00038
Sawdust	.20	30	.00060	.000143
Shellac			.0023	.0006
Silk			.00040	.00010
" scrap from spinning mill	.10	—200	.00023	.000055
" " " " "	.10	—100	.00037	.000088
" " " " "	.10	0	.000495	.000118
" " " " "	.10	50	.00056	.000134
Snow	.25	0	.0016	.00038
Steel wool	.15	55	.00080	.000191
" "	.08	55	.00090	.00022
Wool, pure	.09	30	.00036	.000086
" " very loose packing	.04	30	.00042	.00010
Woods: Ash ⊥ to grain	.74	20	.0017	.00041
" ‖ " "	.74	20	.0031	.00074
Balsa ⊥ to grain	.11	30	.00045	.000084
Boxwood	.90	20	.0015	.00036
Cedar ⊥ to grain	.48		.0011	.00027
Cypress ⊥ to grain	.46	30	.00096	.00023
Fir ⊥ to grain	.54	20	.0014	.00033
" ‖ to grain	.54	20	.0035	.00081
Lignum vitae	1.16	20	.0025	.00060
" "	1.16	100	.0030	.00072
Mahogany, ⊥ to grain	.70	20	.0016	.00038
" ‖ to grain	.70	20	.0031	.00074
Oak, ⊥ to grain	.82	15	.0021	.00050
" ‖ to grain	.82	15	.0036	.00086
Pine, pitch, ⊥ to grain		30	.0015	.00036
" Virginia, ditto	.55	30	.0014	.00033
" white, ditto	.45	60	.0011	.00026
" " ‖ to grain	.45	60	.0026	.00062
Sprdce, ⊥ to grain	.41		.0011	.00026
Teak, ⊥ to grain	.64	15	.00175	.00042
" ‖ to grain	.64	15	.0038	.00091
Walnut, ⊥ to grain	.65	20	.0014	.00033
Rocks: Basalt		20	.020	.0048
Chalk			.0092	.0022
Granite	2.8		.022	.0053
Limestone, very variable	2.0	20	.010	.0024
Slate, ⊥ to cleavage		95	.014	.0033
" ‖ to cleavage		95	.025	.0060
Sandstone, air-dried	2.2	20	.013	.0031
" freshly cut	2.3	20	.017	.0041

(*continued*)

TABLE 135.—THERMAL CONDUCTIVITY OF INSULATING MATERIALS (concluded)

Substance	Density g/cm³	°C	k_t cgs	Substance	k_t cgs
Asbestos fiber	.201	500	.00019	Asbestos paper	.00043
85% magnesia asbestos	.216	100	.00016	Blotting paper	.00015
		500	.00017	Portland cement	.00071
Cotton	.021	100	.000111	Chalk	.0020
"	.101	"	.000071	Ebonite, *t*, 49°	.00037
Eiderdown	.0021	150	.00015	Glass, mean	.002
"	.109	"	.000046	Ice	.0057
Lampblack, Cabot number 5.	.193	100	.000074	Leather, cow-hide	.00042
		500	.000107	" chamois	.00015
Quartz, mesh 200	1.05	500	.00024	Linen	.00021
Poplox, popped Na_2SiO_3	.093	200	.000091	Silk	.000095
		500	.000160	Caen stone, limestone	.0043
				Free stone, sandstone	.0021

Substance	Density g/cm³	k_t cgs at 20°C	k_t cgs at 100°C	Substance	Density g/cm³	k_t cgs at 20°C	k_t cgs at 100°C
Brick, fire	1.73	.00110	.00109	Boxwood	0.90	.00036	.00041
Carbon, gas	1.42	.0085	.0095	Greenheart	1.08	.00112	.00110
Ebonite	1.19	.00014	.00013	Lignumvitæ	1.16	.00060	.00072
Fiber, red	1.29	.00112	.00119	Mahogany	0.55	.00051	.00060
Glass, soda	2.59	.00172	.00182	Oak	0.65	.00058	.00061
Silica, fused	2.17	.00237	.00255	Whitewood	0.58	.00041	.00045

Substance	g/cm³	Conductivity 100°C	200°C	300°C	400°C	500°C	Safe temp.
Air-cell asbestos	.231	.00034	.00043	.00050	—	—	320
Cork, ground	.168	.00015	.00019	—	—	—	180
Diatomite	.326	.00028	.00032	.00037	.00042	.00046	600
Infusorial earth, natural	.506	.00034	.00032	.00040	—	—	
" " h'd pressed blocks	.321	.00030	.00029	.00033	.00036	—	400
Magnesium carbonate	.450	.00023	.00025	.00025	—	—	300
Vitribestos	.362	.00049	.00066	.00079	.00090	.00102	600

TABLE 136.—THERMAL CONDUCTIVITY OF VARIOUS SUBSTANCES[46]

Material	Temperature °C	k cgs	Material	Temperature °C	k cgs
Amorphous carbon	37-163	.028-.003	Brick: carborundum	150-1200	.0032-.027
	100-360	.089	building	15-1100	.0018-.0038
	100-842	.129	graphite	300-700	.024
Concrete:			light diatomite	200-600	.00025-00032
insulating	250-750	.00045-.00051	magnesia	50-1130	.0027-.0072
sand cement	400-900	.0025-.0031	Glass silk: density		
Graphite (artificial)	100-390	.338	.055	15	.000096
	100-914	.291	.083	17	.000092
	2800-3200	.002	.16	9	.000071
	500-700	.31-.22	.21	10	.000075
Limestone	40	.0046-.0057	Granite	100	.0045-.0050
			Stoneware mixtures	70-1000	.0029-.0053

Description	Percent composition: Silica	Titanium oxide	Alumina	Ferric oxide	Calcium oxide	Magnesium oxide	Alkali oxides	Density g/cm³	k, cgs
Fireclay, pottery quality	56.46	1.84	36.79	2.58	.38	.60	1.24	2.0	.0025
Fireclay, fine quality	56.46	1.84	36.79	2.58	.38	.60	1.24	2.05	.0020
Aluminous	52.0	2.7	41.3	2.5	—	—	—	2.0	.0028
Silica	95.16	.57	1.46	.85	1.96	.08	.21	1.81	.0036

[46] Griffiths, E., Journ. Inst. Fuel, vol. 15, p. 111, 1942.

TABLE 137.—THERMAL CONDUCTIVITY OF ORGANIC MATERIALS AND WATER

Part 1

Substance	°C	k_t cgs	Substance	°C	k_t cgs	Substance	°C	k_t cgs
Acetic acid	9–15	$.0_3472$	Carbon disulfide ..	0	$.0_3387$	Oils: olive	—	$.0_3395$
Alcohols: methyl..	11	$.0_352$	Chloroform	9–15	$.0_3288$	castor	—	$.0_3425$
ethyl....	11	$.0_346$	Ether	9–15	$.0_3303$	Toluene	0	$.0_3349$
amyl....	0	$.0_3345$	Glycerine	25	$.0_368$	Vaseline	25	$.0_344$
Aniline	0	$.0_3434$	Oils: petroleum ..	13	$.0_3355$	Xylene	0	$.0_3343$
Benzene	9–15	$.0_3333$	turpentine ..	13	$.0_3325$			

Part 2 *

Substance	Temp. °C	Conductivity at 1 atm watt cm⁻¹ deg⁻¹	Substance	Temp. °C	Conductivity at 1 atm watt cm⁻¹ deg⁻¹	Substance	Temp. °C	Conductivity at 1 atm watt cm⁻¹ deg⁻¹
Normal pentane.	30	1.347×10^{-3}	Carbon disulfide.	30	1.599×10^{-3}	Water	30	6.026×10^{-3}
	75	1.285		75	1.515		75	6.445
Sulfuric ether..	30	1.377	Petroleum ether.	30	1.306	Water	0	5.524
	75	1.347		75	1.264		10	5.692
							20	5.859
Acetone	30	1.795	Kerosene	30	1.494		30	6.026
	75	1.687		75	1.394		40	6.194
							50	6.361
							60	6.529
							70	6.696
							80	6.863

* For reference, see footnote 45, p. 136.

TABLE 138.—THERMAL CONDUCTIVITY OF GASES

The conductivity of gases, $k_t = \frac{1}{4}(9\gamma - 5)\mu C_v$, where γ is the ratio of the specific heats, C_p/C_v, and μ is the viscosity coefficient (Jeans, Dynamical theory of gases, 1916). Theoretically k_t should be independent of the density and has been found to be so by Kundt and Warburg and others within a wide range of pressure below one atm. It increases with the temperature.

Gas	t°C	k_t cgs	Gas	t°C	k_t cgs	Gas	t°C	k_t cgs
Air*	—191	.0000180	CO_2	100	.0000496	Hg	203	.0000185
"	0	.0000566	C_2H_4	0	.0000395	N_2	—191	.0000183
"	100	.0000719	He	—193	.000146	"	0	.0000568
A	—183	.0000142	"	0	.000344	"	100	.0000718
"	0	.0000388	"	100	.000398	O_2	—191	.0000172
"	100	.0000509	H_2	—192	.000133	"	0	.0000570
CO	0	.0000542	"	0	.000416	"	100	.0000743
CO_2	— 78	.0000219	"	100	.000499	NO	8	.000046
"	0	.0000332	CH_4	0	.0000720	N_2O	0	.0000353

* Air: $k_n = 5.22$ (10^{-5}) cal cm⁻¹ sec⁻¹ deg C⁻¹; 5.74 at 22°; temp. coef. = .0029.

TABLE 139.—DIFFUSIVITIES

The diffusivity of a substance $= h^2 = k/c\rho$, where k is the conductivity for heat, c the specific heat and ρ the density (Kelvin). The values are mostly for room temperatures, about 18° C.

Material	Diffusivity	Material	Diffusivity
Aluminum	.860	Coal	.002
Antimony	.135	Concrete (cinder)	.0032
Bismuth	.069	Concrete (stone)	.0048
Brass (yellow)	.339	Concrete (light slag)	.006
Cadmium	.467	Cork (ground)	.0017
Copper	1.140	Ebonite	.0010
Gold	1.209	Glass (ordinary)	.0057
Iron (wrought, also mild steel)	.173	Granite	.0127
Iron (cast, also 1% carbon steel)	.121	Ice	.0112
Lead	.245	Limestone	.0081
Magnesium	.932	Marble (white)	.0097
Mercury	.45	Paraffin	.00098
Nickel	.155	Rock material (earth aver.)	.0118
Palladium	.261	Rock material (crustal rocks)	.0064
Platinum	.243	Sandstone	.0113
Silver	1.700	Snow (fresh)	.0033
Tin	.407	Soil (clay or sand, slightly damp)	.005
Zinc	.413	Soil (very dry)	.0031
Air 1 atm	.179	Water	.0017
Asbestos (loose)	.0025	Wood (pine, cross grain)	.00068
Brick (average fire)	.0052	Wood (pine with grain)	.0023
Brick (average building)	.0044		

TABLE 140.—THERMAL CONDUCTIVITY—LIQUIDS, PRESSURE EFFECT [47]

No.*	Liquid	°C	Conductivity at 0 kg/cm² (cgs)	Conductivity relative to unity (0 kg/cm²) as function of pressure in kg/cm²							
				1000	2000	4000	6000	8000	10000	11000	12000
1	Methyl	30	.000505	1.201	1.342	1.557	1.724	1.864	1.986	2.043	2.097
	alcohol	75	.000493	1.212	1.365	1.601	1.785	1.939	2.072	2.133	2.191
2	Ethyl	30	.000430	1.221	1.363	1.574	1.744	1.888	2.014	2.070	2.122
	alcohol	75	.000416	1.233	1.400	1.650	1.845	2.007	2.152	2.217	2.278
3	Isopropyl	30	.000367	1.205	1.352	1.570	1.743	1.894	2.028	2.091	2.150
	alcohol	75	.000363	1.230	1.399	1.638	1.812	1.962	2.093	2.154	2.211
4	Normal butyl	30	.000400	1.181	1.307	1.495	1.648	1.780	1.900	1.955	2.008
	alcohol	75	.000391	1.218	1.358	1.559	1.720	1.859	1.985	2.043	2.099
5	Isoamyl	30	.000354	1.184	1.320	1.524	1.686	1.828	1.955	2.013	2.069
	alcohol	75	.000348	1.207	1.348	1.557	1.724	1.868	1.998	2.063	2.126
6	Ether	30	.000329	1.305	1.509	1.800	2.009	2.177	2.322	2.388	2.451
		75	.000322	1.313	1.518	1.814	2.043	2.231	2.394	2.469	2.537
7	Acetone	30	.000429	1.184	1.315	1.511	1.659	1.786	1.900	Freezes	
		75	.000403	1.181	1.325	1.554	1.738	1.891	2.024	2.083	2.137
8	Carbon	30	.000382	1.174	1.310	1.512	1.663	1.783	1.880	1.923	1.962
	bisulphide	75	.000362	1.208	1.366	1.607	1.789	1.935	2.054	2.107	2.154
9	Ethyl	30	.000286	1.193	1.327	1.517	1.657	1.768	1.858	1.895	1.928
	bromide	75	.000273	1.230	1.390	1.609	1.772	1.907	2.022	2.073	2.121
10	Ethyl	30	.000265	1.125	1.232	1.394	1.509	1.592	1.662	1.694	1.724
	iodide	75	.000261	1.148	1.265	1.442	1.570	1.671	1.757	1.799	1.837
11	Water	30	.00144	1.058	1.113	1.210	1.293	1.366	1.428	1.456	Freezes
		75	.00154	1.065	1.123	1.225	1.308	1.379	1.445	1.476	1.506
12	Toluol	30	.000364	1.159	1.286	1.470	1.604	1.716		(2.394†)	
		75	.000339	1.210	1.355	1.573	1.738	1.872	1.987	2.039	2.089
13	Normal	30	.000322	1.281	1.483	1.777	1.987	2.163	2.325	2.404	2.481
	pentane	75	.000307	1.319	1.534	1.855	2.112	2.335	2.543	2.642	2.740
14	Petroleum	30	.000312	1.266	1.460	1.752	1.970	2.143	2.279	2.333	2.379
	ether	75	.000302	1.268	1.466	1.780	2.026	2.232	2.409	2.488	2.561
15	Kerosene	75	.000333	1.185	1.314	1.502	1.654	1.792	1.925	1.990	2.054

[47] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 59, p. 158, 1923.
* 1, 2, 6, 8, 12, 13, extreme purity; 3, 4, 5, 7, 9, 10, 11, very pure; 14, 15, commercial.
† Toluol freezes at 9900 kg/cm² at 30°. The figure at 11000 is for the solid.

TABLE 141.—THERMAL RESISTIVITIES AT 20°C EXPRESSED IN FOURIERS FOR A cm^3

The *fourier*[48] is defined as that thermal resistance that will transfer heat energy at the rate of 1 joule per sec (1 watt) for each degree (C) temperature difference between the terminal surfaces (equivalent roughly to a prism of Ag or Cu 4 cm long by 1 cm^2 cross section).

Silver	.239	Water	170	Rubber * (over 90%)	700
Copper	.258	Mica * (⊥ to laminations	200	Wood (Virginia pine across grain)	710
Aluminum	.49	Firebrick *	200	Paper *	1000
Brass (30% Zn)	.93	[Firebrick 25°C to 1000°C]	90	Asbestos * (wool)	1100
Iron	1.6	Brick masonry *	250	Cork *	2000
Nickel	1.7	Leather *	600	Cotton batting (loose)	2500
Steel (1% C)	2.1	Hydrogen	600	Wool (loose)	2500
Constantan	4.4	Hard rubber	610	Air	4100
Mercury	12.0	Helium	690	Carbon dioxide	6700
[Ice at 0°C]	45				
Glass *	133				
Concrete *	140				

[48] Harper, D. R., Journ. Washington Acad. Sci., vol. 18, p. 469, 1928.

* Substances marked with the asterisk vary widely in thermal conductivity according to composition. For limits of such variation, consult International Critical Tables, vol. 2. The figure listed above for any such material represents the author's estimate of the "best guess" for use in those cases where the composition of the material is not specified.

In preparing this table, the author has consulted vol. 2, I.C.T. For still other materials, grateful acknowledgment is made to the staff of the National Bureau of Standards for advice in selecting most probable values in the light of present information.

TABLE 142.—EXPANSION OF THE ELEMENTS *

Part 1.—Coefficients of linear † thermal expansion of chemical elements (Polycrystalline)

Element	Temperature or temperature range °C	Coefficient of linear thermal expansion × 10^6 per °C	Authority
Aluminum	−191 to 0	18.0	1,3**
	+ 20 to 100	23.8	
	20 to 300	25.7	
	20 to 600	28.7	
Antimony ‡	−190 to 20	8. to 10.	4,5,6
	+ 20 to 100	8.4 to 11.0	
	20 to 300	9.2 to 11.4	
	20 to 500	9.5 to 11.6	
Arsenic	40	5.6	7
Barium	0 to 300	18.1 to 21.0	8
Beryllium	−120 to 0	8.1	9,10
	+ 20 to 100	12.3	
	20 to 300	14.0	
	20 to 700	16.8	
	1200	23.7	
Bismuth ‡	−190 to 17	13. to 17.	5,11
	− 15 to 100	13. to 14.	
	+ 75 to 265	17.4	
Boron	20 to 750	8.3	12
Cadmium	−220	20.6	13,4
	−160	27.4	
	+ 10	29.7	
	20 to 100	31.8	
Calcium	−150	18.0	8,14,
	− 50	20.9	15
	+ 30	22.5	
	20 to 100	25.2	
	0 to 300	22.0	
Carbon	−180 to 0	.4	16.17,
Diamond	0 to 78	1.2	18
	0 to 400	2.8	
	0 to 750	4.5	
Graphite	20 to 100	.6 to 4.3	
	20 to 400	1.3 to 4.8	
	20 to 800	1.8 to 5.3	
Chromium	−216 to 0	4.1	19,20
	−100 to 0	5.1	
	0 to 100	5.7 to 8.3	
	0 to 300	7.8 to 8.9	
	0 to 700	9.1 to 10.3	
Cobalt	20 to 100	12.4	21,22
	20 to 400	14.0	
Copper	−253 to 10	11.7	1,25,
	−191 to 16	14.1	26,27,
	+ 25 to 100	16.8	28,29,
	25 to 300	17.8	30
	0 to 500	18.2	
	0 to 1000	20.3	
Germanium	20 to 230	6.0	31
	230 to 450	7.3	
	450 to 840	7.5	
Gold	−190 to 16	13.1	1,5,
	0 to 100	14.2	30,32
	0 to 400	14.9	
	0 to 700	15.8	
	0 to 900	16.5	
Indium	−180 to 20	26.7	33
	+ 20 to 100	30.5	
Iridium	−183 to 19	5.7	5,34
	+ 18 to 100	6.6	
	0 to 1000	7.9	
	0 to 1700	8.7	
Iron	−182 to 0	9.1	1,35
	−100 to 0	10.4	30,36
	0 to 20	11.6	
	20 to 100	12.1	
	20 to 300	13.4	
	20 to 600	14.7	
	20 to 900	15.0	
Lead	−190 to 20	26.7	2,5,
	+ 20 to 100	29.2	37,38,
	20 to 200	30.0	39,40,
	20 to 300	31.3	41,42
Lithium	−178	17.0	43,44
	− 98	36.3	
	− 3	45.7	
	0 to 95	56.	
Magnesium	−190 to 20	21.3	5,30,
	20 to 100	25.9	32,39,
	20 to 300	28.0	45,46,
	20 to 500	29.8	47
Manganese:			46,48
Alpha phase	−190 to 0	15.9	
	−183 to 0	17.6	
	0 to 20	22.3	
	0 to 100	22.8	
	0 to 300	25.2	
Beta phase	−183 to 0	12.8 to 20.4	
	0 to 20	18.7 to 24.9	
Gamma phase	− 70 to 0	13.6	
	0 to 20	14.8	
Molybdenum §	−190 to 0	4.2	2,19,
	−100 to 0	4.8	46, 49,
	20 to 100	3.7 to 5.3	50, 51
	25 to 500	4.7 to 5.8	
	27 to 2127	7.2	
Neodymium	100 to 260	.4	52
Nickel	−253 to 10	8.1	1,36,
	−192 to 16	10.0	25,26,27,
	0 to 100	13.1	46,53a,
	0 to 300	14.4	118
	25 to 600	15.5	
	25 to 900	16.3	

* Compiled by Peter Hidnert and H. S. Krider, of the National Bureau of Standards.
† The coefficient of cubical expansion of an isotropic solid element may be taken as 3 times the coefficient of linear expansion within a high degree of approximation (See Part 3 for determined coefficients of cubical expansion of some chemical elements.)
** Numbers refer to authorities given at end of table.
‡ The coefficients of expansion depend upon the orientation of the constituent crystals.
§ The coefficients of expansion depend upon coarseness of grains and treatment of metal.

(*continued*)

Element	Temperature or temperature range °C	Coefficient of linear thermal expansion × 10⁶ per °C	Authority
Niobium	−212 to 0	5.8	14,23,
	−100 to 0	6.9	24
	0 to 100	7.2	
	0 to 300	7.5	
	20 to 1500	10.0	
Osmium	40	6.6	7
Palladium	−191 to 16	10.3	2,26,
	+ 16 to 100	12.4	54,55
	16 to 500	12.8	
	16 to 1000	13.8	
Platinum	−191 to 16	8.0	2,26,
	− 90 to 0	8.7	30,32,
	0 to 100	9.0	54,56
	0 to 300	9.2	
	0 to 500	9.6	
	0 to 1000	10.2	
Potassium	0 to 50	85.	57
Rhodium	−174	5.0	19,58,
	− 92	7.4	59,60
	− 28	7.9	
	0 to 100	8.4	
	0 to 500	9.7	
	0 to 1000	10.8	
	0 to 1500	12.1	
Rubidium	− 98 to 19	66.	61
Ruthenium	+ 13 to 32	6.8	7,62
	40	9.6	
	50	9.9	
Selenium:			63,37
Polycrystalline	− 78 to 19	20.3	
	+ 20 to 100	22.9	
	205	45.2	
Amorphous	− 78 to 0	42.7	
	0 to 21	48.7	
Amorphous, melted & cast	−160 to 0	37.3	
	0	43.9	
Silicon	−172	−0.4	14,58,
	− 87	+ .9	64
	+ 20 to 50	2.4	
	100	2.0	
	500	3.0	
	1000	3.3	
Silver	−250 to 0	14.9	2,30,
	−191 to 16	17.0	39
	0 to 100	19.4	26,65,
	20 to 300	20.2	66,67
	20 to 500	20.7	
	0 to 900	22.4	

Element	Temperature or temperature range °C	Coefficient of linear thermal expansion × 10⁶ per °C	Authority
Sodium	−193 to 0	59.8	44,68
	0 to 17	68.2	69
	0 to 50	70.	
	0 to 95	71.	
Tantalum	−190 to 20	6.2	2,46,
	+ 20 to 100	6.6	51,70
	20 to 300	6.6	
	20 to 500	6.6	
	27 to 1400	7.3	
	27 to 2400	7.8	
Tellurium	40	16.8	7
Thallium	0 to 100	29.4	64
	0 to 200	30.0	
Thorium	−216 to 20	9.8	14,71,
	+ 20 to 100	11.3	72
	20 to 300	12.1	
	20 to 600	13.7	
Tin	−183 to 20	15.8 to 22.6	4,5,
	+ 18 to 100	23.8 to 27.0	73,74
	25 to 200	24.	
Titanium	−195 to 20	6.8	14,72,
	+ 20 to 200	8.9	75,76,
	20 to 400	9.4	77
	20 to 600	9.9	
	20 to 800	10.1	
Tungsten (Wolfram)	−190 to 0	3.8	2,46,
	−100 to 0	4.2	78,79,
	0 to 100	4.4	80,81
	0 to 300	4.6	
	0 to 650	4.6	
	27 to 1000	4.7	
	27 to 1750	5.2	
	27 to 2400	5.8	
Vanadium	−183 to 0	6.6	14
	0 to 40	7.8	
Zinc ‡	−183 to 18	9. to 10.	5.13,
	+ 20 to 100	17. to 40.	32,38,
	20 to 200	30. to 40.	47,82
	20 to 300	34. to 39.	83
Zirconium	−183 to 0	4.0 to 5.1	14,19,
	0 to 20	4.6 to 5.9	72
	+ 20 to 200	5.4	
	20 to 400	6.1	
	20 to 700	7.1	

(continued)

Part 2.—Coefficients of linear¶ thermal expansion of chemical elements (crystals)

Element	Temperature or temperature range °C	Coefficient of linear thermal expansion per °C: Parallel to axis	Perpendicular to axis	Authority
Antimony	−215 to +20	16.0×10^{-6}	7.0×10^{-6}	6,7,19,84
	+ 15 to 25	15.6	...	
	0 to 100	16.8	...	
	20 to 200	...	8.4	
	20 to 400	...	8.1	
Arsenic	30 to 75	3.2 to 6.8	...	62
Beryllium	−150	1.6	2.8	19,85
	+ 10	8.6	11.7	
	18 to 220	10.4	15.0	
	18 to 454	13.1	15.7	
Bismuth	−140	15.9	10.5	19,86,87
	+ 30	16.2	11.6	
	20 to 260	16.5	...	
	20 to 240	...	12.0	
Cadmium	−190 to 18	48.2	18.5	13,88,89,90
	+ 20 to 100	50.4	18.9	
Carbon Graphite	−195 to 0	...	4.8	19,91,92
	0 to 40	...	6.6	
	0 to 500	17.2	1.3	
	0 to 1000	18.8	1.8	
	0 to 1500	20.7	2.0	
	0 to 2300	23.1	2.4	
	20 to 870	26.7	...	
Cobalt	33 to 100	16.1	12.6	89
Indium	− 17 to 9	56.	13.	93
	+ 23 to 87	45.0	11.7	94
Magnesium	20 to 100	26.4	25.6	95
	20 to 200	27.7	26.6	
Mercury	−190 to −160	42.6	33.4	96,97
	−188 to −79	47.0	37.5	
	−120	49.6	37.5	
Osmium	+ 50	5.8	4.0	98
	250	6.6	4.6	
	500	8.3	5.8	
Rhenium	20 to 1917	12.4	4.7	99
Ruthenium	50	8.8	5.9	98
	250	9.8	6.4	
	550	11.7	7.6	
Selenium	15 to 55	−17.9	...	100
	20 to 60	...	74.1	
Tellurium	20	− 1.6	27.2	100,101
	20 to 60	− 1.7	27.0	
Thallium	32 to 91	+72.	9.	94
Tin	−195 to 20	25.9	14.1	19,94,102
	0 to 20	29.0	15.8	
	+ 14 to 25	32.2	16.8	
	34 to 194	45.8	25.7	
Zinc	−190 to 18	49.5	11.3	13,32,88,103,104
	+ 20 to 100	64.0	14.1	
	0 to 250	56.	15.	
	20 to 400	59.	16.	
Zirconium	0 to 100	4.	13.	89,105

¶ If there is random orientation of the crystals in a polycrystalline element such as antimony or cadmium, the coefficient of linear expansion of the polycrystalline element may be computed from the following equation:

$$a = \frac{1}{3}\,(a_{\parallel} + 2a_{\perp})$$

where $a_{\parallel}$ is the coefficient of linear expansion of the crystal parallel to its axis, and $a_{\perp}$ is the coefficient of linear expansion of the crystal in the direction perpendicular to its axis. (See Part 1 for determined coefficients of linear expansion of polycrystalline elements.)

(continued)

Part 3.—Coefficients of cubical thermal expansion of chemical elements

Element	Temperature or temperature range °C	Coefficient of cubical thermal expansion × 10⁶ per °C	Authority
Cadmium	100	91.	106
	210	105.	
	250	110.	
Carbon:			
Diamond ...	27	3.2	107
	25 to 650	9.1	
Cesium	0 to 23	291.	108
Cobalt	100	35.6	106
	300	39.4	
Gallium	− 78 to 18	53.	109,
	0 to 29.6	55.	110
Iodine	−195 to 25	204. to 251.	111,
	+ 10 to 40	264.	112,
			113
Lithium	0 to 100	162.	114
	0 to 178	170.	
Nickel	100	38.2	106
	200	41.9	
	300	46.5	
Phosphorus ..	−273 to 19	317.	112,
	−195 to 19	398.	115
	− 79 to 19	362.	
	0 to 44	372.	
Potassium	0 to 55	240	57,
			108,
			114
Rubidium	0 to 38	270	108
Selenium:			
Compressed .	0 to 100	175	116
Not compressed ..	0 to 100	198	
Sodium	−186 to 17	186	111,
	0 to 53	207	69,
	0 to 79	208	114,
	20 to 95	226	108,
			117
Sulfur			
Rhombic ...	−273 to 18	139	112
	−195 to 18	164	116
	− 79 to 18	180	
Crystallized .	0 to 100	354	
Sicilian	0 to 100	260	
Tin	80	68	106
	140	78	
	190	89	
Zinc	50	89	32,
	200	104	106
	300	110	

Authorities

1. Nix and MacNair, 1941; 2. Nix and MacNair, 1942; 3. Hidnert, 1923; 4. Dorsey, 1907; 5. Grüneisen, 1910; 6. Hidnert, 1935; 7. Fizeau, 1869; 8. Cath and Steenis, 1936; 9. Hidnert and Sweeney, 1927; 10. Losana, 1939; 11. Jacobs and Goetz, 1937; 12. Dupuy & Hackspill, 1933; 13. Grüneisen & Goens, 1924; 14. Erfling, 1942; 15. Bastien, 1934; 16. Röntgen, 1912; 17. Joly, 1898; 18. Hidnert, 1934; 19. Erfling, 1939; 20. Hidnert, 1941; 21. Schulze, 1927; 22. Masumoto, 1931; 23. Hidnert and Krider, 1933; 24. Matthies, 1936; 25. Krupkowski, 1929; 26. Henning, 1907; 27. Aoyama and Ito, 1939; 28. Hidnert, 1922; 29. Dittenberger, 1902; 30. Esser and Eusterbrock, 1941; 31. Nitka, 1937; 32. Austin, 1932; 33. Hidnert and Blair, 1943; 34. Holborn and Valentiner, 1907; 35. Hidnert, 1942; 36. Souder and Hidnert, 1922; 37. Dorsey, 1908; 38. Lindemann, 1911; 39. Ebert, 1928; 40. Rauramo and Saarialho, 1911; 41. Friend and Vallance, 1924; 42. Hidnert and Sweeney, 1932; 43. Simon and Bergman, 1930; 44. Bridgman, 1936; 45. Hidnert and Sweeney, 1928; 46. Disch, 1921; 47. Schulze, 1921; 48. Erfling, 1940; 49. Schad and Hidnert, 1919; 50. Hidnert and Gero, 1924; 51. Worthing, 1926; 52. Jaeger, Bottema, and Rosenbohm, 1938; 53. Souder and Hidnert, 1922; 53a. Hidnert, 1930; 54. Scheel, 1907; 55. Holzmann, 1931; 56. Scheel and Heuse, 1907; 57. Hagan, 1911; 58. Valentiner and Wallot, 1915; 59. Sweeney, 1929; 60. Ebert, 1938; 61. Hume-Rothery and Lonsdale, 1945; 62. Bridgman, 1933; 63. Borelius and Paulson, 1946; 64. Schulze, 1930; 65. Keesom and Jansen, 1927; 66. Scheel, 1921; 67. Owen and Roberts, 1939; 68. Siegel and Quimby, 1938; 69. Hagan, 1883; 70. Hidnert, 1929; 71. Hidnert and Sweeney, 1933; 72. Kroll, 1939; 73. Grube and Vosskühler, 1934; 74. Bochvar and Maurakh, 1930; 75. Hidnert, 1943; 76. Greiner and Ellis, 1948; 77. Adenstedt, 1949; 78. Hidnert and Sweeney, 1924; 79. Dodge, 1918; 80. Forsythe, 1927; 81. Worthing , 1917; 82. Souder and Hidnert, 1924; 83. Bauer and Sieglerschmidt, 1929; 84. Bridgman, 1924; 85. Kossolapow and Trapesnikow, 1936; 86. Roberts, 1924; 87. Goetz and Hergenrother, 1932; 88. McLennan and Monkman, 1929; 89. Shinoda, 1934; 90. Kossolapow and Trapesnikow, 1935; 91. Pierry, 1946; 92. Backhurst, 1922; 93. Frevel and Ott, 1935; 94. Shinoda, 1933; 95. Goens and Schmid, 1931; 96. Hill, 1935; 97. Grüneisen and Sckell, 1934; 98. Owen and Roberts, 1937; 99. Becker, 1931; 100. Straumanis, 1940; 101. Bridgman, 1925; 102. Ievens, Straumanis, and Karlsons, 1938; 103. Staker, 1942; 104. Owen and Iball, 1933; 105. Pfaff, 1859; 106. Uffelmann, 1930; 107. Krishnan, 1944; 108. Hackspill, 1913; 109. Klemm, 1931; 110. Richards and Boyer, 1921; 111. Dewar, 1902; 112. Sapper and Biltz, 1931; 113. Straumanis and Sauka, 1942; 114. Bernini and Cantoni, 1914; 115. Leduc, 1891; 116. Spring, 1881; 117. Griffiths and Griffiths, 1915; 118. Schad, 1927.

TABLE 143.—COEFFICIENTS OF LINEAR THERMAL EXPANSION OF SOME ALLOYS *

Alloy †	Temperature or temperature range °C	Coefficient ‡ of linear thermal expansion × 10^6 per °C	Authority
Aluminum-beryllium, 4.2 to 32.7 Be	20 to 100	22.4 to 17.8	1 **
	20 to 500	26.6 to 22.2	
Aluminum-copper, 9.9 Cu	20 to 100	22.0	2
	20 to 300	23.8	
33.2 Cu	20 to 100	19.7	
	20 to 300	20.8	
Aluminum-nickel, 3.4 Ni	20 to 100	21.9	2
	20 to 300	23.7	
19.5 Ni	20 to 100	18.2	
	20 to 300	19.5	
Aluminum-silicon, 4.2 to 12.6 Si	20 to 100	22.2 to 19.4	3, 2
	20 to 300	24.8 to 22.1	
19.7 Si	20 to 100	18.5	
	20 to 300	19.0	
40 Si	20 to 100	14.7	
	20 to 300	17.1	
Aluminum-zinc, 0 to 50 Zn	20 to 100	23.6 to 26.5	4
Brass, 3 to 40 Zn	25 to 100	16.9 to 19.7	5
	25 to 300	17.7 to 21.2	
Bronze, 4.2 to 10.1 Sn	25 to 100	17.1 to 17.8	5
	25 to 300	17.8 to 19.0	
Cast iron	20 to 100	8.7 to 11.1	6
	20 to 400	11.5 to 12.7	
Cobalt-iron-chromium, 53.0 to 55.5 Co, 35.0 to 37.5 Fe, 9.0 to 10.5 Cr	20 to 60	—1.1 to +1.7	7
Copper-beryllium, 3.0 Cu	20 to 100	15.9 to 17.3	8
	20 to 300	16.4 to 17.4	
Copper-nickel, 19.5 Ni	—182 to 0	13.0	9
	0 to 40	14.7	
49.8 Ni	—182 to 0	11.8	
	0 to 40	13.7	
Copper-tin (see Bronze)			
Copper-zinc (see Brass)			
Dumet:			
Axial	20 to 300	6.1 to 6.8	10
Radial	20 to 300	8.0 to 10.0	
Duralumin	20 to 100	21.9 to 23.8	3
	20 to 500	25.4 to 27.6	
Fernico, 54 Fe, 31 Ni, 15 Co	25 to 300	5.0	11
Invar, 64 Fe, 36 Ni	0 to 100	0 to 2	12
Iron-aluminum, .5 to 10.5 Al	20 to 100	11.6 to 12.2	13
Iron-chromium, 1 to 40 Cr	20 to 100	12.4 to 9.4	12

* Compiled by Peter Hidnert and H. S. Krider, National Bureau of Standards.
† Chemical composition is given in percent by weight. ‡ Coefficient of expansion varies with composition and treatment. ** Numbers refer to authorities given at end of table.

(continued)

TABLE 143.—COEFFICIENTS OF LINEAR THERMAL EXPANSION OF SOME ALLOYS (continued)

Alloy	Temperature or temperature range °C	Coefficient of linear thermal expansion × 10^6 per °C	Authority
Iron-cobalt 9.9 to 49.4 Co	30 to 100	11.2 to 9.3	14
Iron-manganese, 2.8 to 14.4 Mn	20 to 100	12.7 to 16.9	13
Iron-nickel, 3.6 Ni	20 to 100	10.9	15, 12,
34.5 Ni	20 to 100	3.7	14
36 Ni	0 to 100	0 to 2	
40 to 50 Ni	30 to 100	4.1 to 9.7	
Iron-nickel-chromium, 6.6 to 74.7 Fe, 1.3 to 70.1 Ni, 4.9 to 26.7 Cr	20 to 100	8.7 to 18.4	16
	20 to 1000	13.1 to 20.6	
Iron-nickel-cobalt, 62.5 to 64.0 Fe, 30.5 to 34.0 Ni, 3.5 to 6.0 Co	20	.0 to .5	14, 17
61.3 Fe, 31.8 Ni, 6.0 Co	20 to 100	.9	
	20 to 240	2.4	
58.7 Fe, 32.4 Ni, 8.2 Co	20 to 200	1.7	
	20 to 295	2.6	
Iron-silicon, 1.0 to 8.4 Si	20 to 100	12.2 to 11.3	13
Kanthal (A, A-1, and D) §	20 to 100	11.4 to 11.7	18
	20 to 900	13.9 to 15.1	
Kovar (see Fernico)			
Lead-antimony, 2.9 to 39.6 Sb	20 to 100	28.2 to 20.4	8
Magnesium-aluminum, 10.4 Al	20 to 100	25.9	19, 20
	20 to 200	27.2	
30 Al	0 to 100	23.7	
	0 to 200	25.1	
Magnesium-tin, 20.4 Sn	30 to 100	24.3	21
	30 to 300	24.7	
46.3 Sn	30 to 100	21.1	
	30 to 300	21.3	
Magnesium-zinc, 20 Zn	40 to 100	29.5	22
50 Zn	40 to 100	30.2	
Manganin	20 to 100	18.1	23, 24
	0 to 400	18.9	
	0 to 800	21.1	
Monel Metal	25 to 100	13.5 to 14.5	15, 13
	25 to 600	15.9 to 16.7	
Nickel-chromium, 20.4 Cr	20 to 100	13.0	16, 25
	20 to 1000	17.2	
47.7 Cr	20 to 100	13.5	
	20 to 1000	17.7	
Nickel silver, 62.0 to 63.2 Cu, 10.0 to 20.2 Ni, 17.4 to 27.1 Zn	0 to 100	14.8 to 15.4	26
	0 to 400	16.8 to 17.4	

§ Composition of Kanthal: A: 68.5 Fe, 23.4 Cr, 6.2 Al, 1.9 Co, 0.06 C; A-1: 69.0 Fe, 23.4 Cr, 5.7 Al, 1.9 Co, 0.06 C; D: 70.9 Fe, 22.6 Cr, 4.5 Al, 2.0 Co, 0.09 C.

(*continued*)

TABLE 143.—COEFFICIENTS OF LINEAR THERMAL EXPANSION OF SOME ALLOYS (concluded)

Alloy	Temperature or temperature range °C	Coefficient of linear thermal expansion × 10^6 per °C	Authority
Platinum-iridium, 20 Ir	—190 to 0	7.5	27
	0 to 100	8.3	
	0 to 1000	9.6	
	0 to 1600	10.5	
Platinum-rhodium, 20 Rh	0 to 500	9.6	28
	0 to 1000	10.4	
	0 to 1400	11.0	
SAE carbon steels ‖	20 to 100	8.8 to 14.4	12
SAE stainless chromium irons	20 to 100	9.4 to 10.7	12
Speculum metal	20 to 100	16.0	29
Stainless steel, 12 Cr	20 to 100	10.0	30, 16
18 Cr, 8 Ni	20 to 100	16.4	
Stellite, 55 to 80 Co, 20 to 40 Cr, 0 to 10 W, 0 to 2 C	20 to 100	11.0 to 14.1	31
	20 to 600	13.6 to 16.5	
Tantalum carbide	20 to 2377	8.2	32
Tungsten carbide +5.9 Co	20 to 100	4.5	33
	20 to 400	5.2	
+13.0 Co	20 to 100	5.2	
	20 to 400	6.0	
Zinc-aluminum, 22.6 Al	20 to 100	26.0	34, 4
	20 to 200	28.3	
50 Al	20 to 100	26.5	
	20 to 200	27.6	

‖ Coefficients of expansion of other SAE steels (free-cutting, manganese, nickel, nickel-chromium, molybdenum, chromium, chromium-vanadium and chromium-nickel austenitic steels) are given in Metals Handbook of the American Society for Metals.

Authorities

1. Hidnert and Sweeney, 1927; 2. Kempf, 1933; 3. Hidnert, 1925; 4. Schulze, 1921; 5. Hidnert, 1921; 6. Bolton, 1936; 7. Masumoto, 1934; 8. Hidnert, 1936; 9. Aoyama and Ito, 1938; 10. Hull and Burger, 1934; 11. Hull, Burger, and Navias, 1941; 12. Various; 13. Schulze, 1928; 14. Masumoto, 1931; 15. Souder and Hidnert, 1922; 16. Hidnert, 1931; 17. Scott, 1930; 18. Hidnert, 1938; 19. Hidnert and Sweeney, 1928; 20. Takahasi and Kikuti, 1936; 21. Grube and Vosskuhler, 1934; 22. Grube and Burkhardt, 1929; 23. Schulze, 1933; 24. Ebert, 1935; 25. Dean, 1930; 26. Cook, 1936; 27. Physikalische-Technische Reichanstalt, 1920; 28. Day and Sosman, 1910; 29. Scheel, 1921; 30. Hidnert, 1928; 31. Souder and Hidnert, 1921; 32. Becker and Ewest, 1930; 33. Hidnert, 1937; 34. Hidnert, 1924.

TABLE 144.—COEFFICIENTS OF LINEAR THERMAL EXPANSION OF SOME MISCELLANEOUS MATERIALS *

Material	Temperature or temperature range °C	Coefficient of linear thermal expansion × 10⁶ per °C	Authority
Alum:			1**
Ammonium ..	20 to 50	9.5	
Ammonium chrome	20 to 50	10.6	
Potassium ...	20 to 50	11.0	
Thallium	20 to 50	13.1	
Amber	0 to 50	53	2
Bakelite	20 to 60	21 to 33	3
Beryl	20 to 100	.3 to 1.6	4
Brick, clay building	−10 to +40	3.0 to 12.4	5
Carborundum ..	0 to 500	7.3	6
	0 to 1000	8.4	
	0 to 1800	9.2	
Concrete	−13 to +27	6.8 to 12.7	7
	−13 to +88	7.5 to 14.0	
Dental amalgam.	20 to 50	22 to 28	8
Glass:			9
Miscellaneous.	0 to 300	.8 to 12.8	
Pyrex	20 to 100	3.1 to 3.5	
	20 to 300	3.0 to 3.6	
Granites (American)	−20 to 60	4.8 to 8.3	10
Ice	−250	−6.1	11
	−200	+.8	
	−150	16.8	
	−100	33.9	
	−50	45.6	
	0	52.7	
Magnesia	20 to 500	12.4	6,12,13
	20 to 1000	13.7	
Marble	25 to 100	5 to 16	3
Mica, muscovite:			
Parallel to cleavage plane	0 to 100	8.5	14
Perpendicular to cleavage plane †	20 to 300	8 to 25	15
Mica, phlogopite:			
∥ to cleavage plane	0 to 100	13.5	14
⊥ to cleavage plane †	20 to 100	1 to 179	15
Porcelain	20 to 200	1.6 to 19.6	3
Quartz, crystalline			16
∥ to axis	0 to 100	8.0	
	0 to 300	9.6	
	0 to 500	12.2	
⊥ to axis	0 to 100	14.4	
	0 to 300	16.9	
	0 to 500	20.9	
Quartz, fused (silica)	20 to 100	.5	9
	20 to 1000	.5	
Rocks (American):			17
Igneous	20 to 100	3.4 to 11.9	
Sedimentary ..	20 to 100	2.7 to 12.2	
Metamorphic..	20 to 100	2.3 to 11.0	
Rubber (hard)‡.	§	50 to 84	9
Slate	20 to 100	6.3 to 8.3	17
Tooth:			
Root	20 to 50	8.3	8
Across crown .	20 to 50	11.4	
Root and crown	20 to 50	7.8	
Wood:			
Along grain..	§	1 to 11	9
Across grain..		32 to 73	

* Compiled by Peter Hidnert and H. S. Krider, National Bureau of Standards. ** Numbers refer to authorities given below. † With load of 30 lb/in.² ‡ includes terms "ebonite" and "vulcanite." § Various temperature ranges between 0°C and 100°C.

Authorities

1. Klug and Alexander, 1942; 2. Sweeney, 1928; 3. Souder and Hidnert, 1919; 4. Geller and Insley, 1932; 5. Ross, 1941; 6. Ebert and Tingwaldt, 1936; 7. Koenitzer, 1936; 8. Souder and Peters, 1920; 9. Various; 10. Hockman and Kessler, 1950; 11. Jakob and Erk, 1928; 12. White, 1938; 13. Austin, 1931; 14. Ebert, 1935; 15. Hidnert and Dickson, 1945; 16. Compiled by Sosman, 1927; 17. Griffith, 1936.

If V_0 is the volume at 0° then at t° the expansion formula is $V_t = V_0(1 + \alpha t + \beta t^2 + \gamma t^3)$. The table gives values of α, β and γ and k, the true coefficient of cubical expansion, at 20° for some liquids and solutions. Δt is the temperature range of the observation.

Liquid	Δt °C	$\alpha\ 10^3$	$\beta\ 10^6$	$\gamma\ 10^8$	$k\ 10^3$ at 20°
Acetic acid	16–107	1.0630	.12636	1.0876	1.071
Acetone	0–54	1.3240	3.8090	— .87983	1.487
Alcohol:					
Amyl	—15–80	.9001	.6573	1.18458	.902
Ethyl, 30% by vol.	18–39	.2928	10.790	—11.87	—
" 50% "	0–39	.7450	1.85	.730	—
" 99.3% "	27–46	1.012	2.20	—	1.12
" 500 atm press	0–40	.866	—	—	—
" 3000 " "	0–40	.524	—	—	—
Methyl	0–61	1.1342	1.3635	.8741	1.199
Benzene	11–81	1.17626	1.27776	.80648	1.237
Bromine	0–59	1.06218	1.87714	— .30854	1.132
Calcium chloride:					
5.8% solution	18–25	.07878	4.2742	—	.250
40.9% "	17–24	.42383	.8571	—	.458
Carbon disulfide	—34–60	1.13980	1.37065	1.91225	1.218
500 atm pressure	0–50	.940	—	—	—
3000 " "	0–50	.581	—	—	—
Carbon tetrachloride	0–76	1.18384	.89881	1.35135	1.236
Chloroform	0–63	1.10715	4.66473	— 1.74328	1.273
Ether	—15–38	1.51324	2.35918	4.00512	1.656
Glycerine	—	.4853	.4895	—	.505
Hydrochloric acid:					
33.2% solution	0–33	.4460	.215	—	.455
Mercury	0–100	.18182	.0078	—	.18186
Olive oil	—	.6821	1.1405	— .539	.721
Pentane	0–33	1.4646	3.09319	1.6084	1.608
Potassium chloride:					
24.3% solution	16–25	.2695	2.080	—	.353
Phenol	36–157	.8340	.10732	.4446	1.090
Petroleum:					
Density .8467	24–120	.8994	1.396	—	.955
Sodium chloride:					
20.6% solution	0–29	.3640	1.237	—	.414
Sodium sulfate:					
24% solution	11–40	.3599	1.258	—	.410
Sulfuric acid:					
10.9% solution	0–30	.2835	2.580	—	.387
100.0%	0–30	.5758	— .432	—	.558
Turpentine	— 9–106	.9003	1.9595	— .44998	.973
Water	0–33	— .06427	8.5053	— 6.7900	.207

TABLE 146.—THERMAL EXPANSION OF GASES

Temperatures in °C

Coefficient at constant volume

Substance	Pressure cmHg	Coefficient × 100
Air	.6	.37666
"	1.3	.37172
"	10.0	.36630
"	25.4	.36580
"	75.2	.36660
" 0°–100°	100.1	.36744
"	76.0	.36650
"	200.0	.36903
"	2000.	.38866
"	10000.	.4100
Argon	51.7	.3668
Carbon dioxide	76.0	.36856
" "	1.8	.36753
" "	5.6	.36641
" "	74.9	.37264
" " 0°–20°	51.8	.36985
" " 0°–40°	51.8	.36972
" " 0°–100°	51.8	.36981
" " 0°–20°	99.8	.37335
" " 0°–100°	99.8	.37262
" " 0°–100°	100.0	.37248
Carbon monoxide	76.	.36667
Helium	56.7	.3665
Hydrogen 16°–132°	.0077	.3328
" 15°–132°	.025	.3623
" 12°–185°	.47	.3656
"	.93	.37002
"	11.2	.36548
"	76.4	.36504
" 0°–100°	100.0	.36626
Nitrogen 13°–132°	.06	.3021
" 9°–133°	.53	.3290
" 0°–20°	100.2	.36754
" 0°–100°	100.2	.36744
"	76.	.36682
Oxygen 11°–132°	.007	.4161
" 9°–132°	.25	.3984
" 11°–132°	.51	.3831
"	1.9	.36683
"	18.5	.36690
"	75.9	.36681
Nitrous oxide	76.	.3676
Sulfur dioxide SO_2	76.	.3845

Coefficient at constant pressure

Substance	Pressure cmHg	Coefficient × 100
Air	76.	.3671
"	257.	.3693
" 0°–100°	100.1	.36728
Hydrogen 0°–100°	100.0	.36600
"	200 Atm.	.332
"	400 "	.295
"	600 "	.261
"	800 "	.242
Carbon dioxide	76.	.3710
" " 0°–20°	51.8	.37128
" " 0°–40°	51.8	.37100
" " 0°–100°	51.8	.37073
" " 0°–20°	99.8	.37602
" " 0°–100°	99.8	.37410
" " 0°–20°	137.7	.37972
" " 0°–100°	137.7	.37703
" " 0°–7.5°	2621.	.1097
" " 64°–100°	2621.	.6574
Carbon monoxide	76.	.3669
Nitrous oxide	76.	.3719
Sulfur dioxide	76.	.3903
" "	98.	.3980
Water-vapor 0°–119°	76.	.4187
Water-vapor 0°–141°	76.	.4189
Water-vapor 0°–162°	76.	.4071
Water-vapor 0°–200°	76.	.3938
Water-vapor 0°–247°	76.	.3799

Thomson has given (Encycl. Brit. "Heat") the following for the calculation of the expansion, E, between 0° and 100°C. Expansion is to be taken as the change of volume under constant pressure:

Hydrogen, $E = .3662(1 - .00049\ V/v)$
Air, $E = .3662(1 - .0026\ V/v)$
Oxygen, $E = .3662(1 - .0032\ V/v)$
Nitrogen, $E = .3662(1 - .0031\ V/v)$
CO_2 $E = .3662(1 - .0164\ V/v)$

V/v is the ratio of the actual density of the gas at 0°C to what it would have at 0°C and 1 atm pressure.

TABLE 147.—SPECIFIC HEAT OF THE CHEMICAL ELEMENTS

When one temperature is given the true specific heat is given, otherwise the mean specific heat cal $°C^{-1} g^{-1}$ between the given limits.

Element	t°C	Sp ht
Aluminum	—250	.0039
	—200	.076
	—150	.1367
	—100	.1676
	— 50	.1914
	0	.2079
	100	.225
	300	.248
	600	.277
	16, 100	.212
Antimony	—207.1	.0322
	—150	.0412
	—100	.0448
	— 50	.0476
	0	.0494
	28	.0477
	20, 100	.0504
	500	.054
Arsenic	—216	.032
	—117.6	.0666
	18	.078
Barium	—185, +20	.068
Beryllium	—202	.017
	45, 50	.445
	0, 100	.425
Bismuth	—150	.0264
	—100	.0273
	— 50	.0282
	0	.0291
	20	.0294
	100	.0304
fluid	297	.0292
Boron	100	.287
	500	.472
	900	.510
	—76, 0	.168
	0, 100	.307
Bromine, (s)	—253.1	.0205
(s)	—173.1	.0659
(s)	— 73.1	.080
(s)	— 13.1	.088
(l)	13, 45	.107
Cadmium	—263	.0019
	—203.1	.0415
	—103.1	.0518
	27.9	.0552
	107.9	.0569
	277	.060
Cesium	0, 26	.0482
Calcium	24	.168
	100	.1625
	300	.1832
	600	.188
Carbon, graph.	—191, —79	.057
	—76, 0	.126
	—183	.0025
	— 66	.053
	11	.112
	85	.177
	896	.454
C, diamond	0	.1044
	223	.264
	823	.428
Cerium	—253, —196	.033
	20, 100	.0511
Chlorine	0, 24	.226
Chromium	—150	.0599
	—100	.0797
	— 50	.0941
	0	.1044
	100	.112
	500	.150
	600	.187
	18, 100	.111
Cobalt	—150	.0672
	—100	.0809
	— 50	.0914
	0	.1028
	20	.1001
	100	.1067
	200	.1134
Copper	—189	.0506
	—150	.0674
	—100	.0783
	— 50	.0862
	0	.0910
	100	.0939
	900	.1259
	18, 100	.0928
	18, 600	.0994
Gallium	—258.1	.0049
	—213.1	.044
	— 73.1	.084
Germanium	0, 100	.074
Gold	—258.1	.0018
	—252.8	.0040
	—209.5	.0211
	—150	.0266
	—100	.0281
	— 50	.0293
	0	.0302
	18	.0312
	100	.0314
Indium	0, 100	.057
Iodine	—263.2	.0037
	—255.9	.0118
	—221.1	.0353
	—90, +17	.0485
Iridium	—186, +18	.0282
	18, 100	.0323
Iron, pure	—256.2	.00067
	—240.7	.00355
	—214.0	.0194
	—172.6	.0512
	— 67.5	.0939
	0	.1043
α, β, γ	100	.115
	500	.163
	760	.320
	1000	.162
γ	100	.127
	700	.157
	1000	.162
Lanthanum	0, 100	.0448

(continued)

TABLE 147.—SPECIFIC HEAT OF THE CHEMICAL ELEMENTS (continued)

Element	t°C	Sp ht
Lead	−270	.00001
	−267	.00086
	−259	.0073
	−150	.0279
	−100	.0283
	− 50	.0289
	0	.0297
	100	.0320
	300	.0356
(l)	360	.0375
	500	.0370
Lithium	−183	.3
	−100	.600
	50	.96
	+190	1.374
Magnesium	−150	.1767
	−100	.2025
	− 50	.2228
	0	.2316
	100	.257
	300	.279
	600	.311
(l)	650, 775	.284
Manganese	−188, −79	.0820
	−79, +15	.1091
	60	.1211
	325	.1783
	20, 100	.1211
	−100	.0979
	0	.1072
	100	.1143
Mercury(s)	−263.3	.00552
	−267.2	.00620
	−259.8	.00783
	−245.6	.0172
	−220.2	.0255
	−163.7	.0298
	− 81.4	.0324
	− 43.1	.0337
(l)	− 33.1	.0338
	− 3.1	.0335
	+ 17	.0333
Molybdenum	−257	.0004
	−239.1	.0034
	−181.5	.0300
	−152.7	.0399
	− 34.5	.0561
	0	.0589
	+ 5.3	.0589
	+100	.0612
	250	.0632
Nickel	−258	.0008
	−247.9	.0024
	−201.2	.0363
	−150	.0660
	−100	.0817
	− 50	.0940
	0	.1032
	100	.1146
	500	.1270
	800	.1413
Osmium	19, 98	.0311
Palladium	−180, +18	.0528
	0	.0538
	100	.0564
	500	.0653
	900	.0717
	1500	.0766
Phosphorus, yellow	−136	.124
	− 40	.165
	+ 9	.189
red	−136	.107
	− 40	.182
	+ 9	.190
Platinum	−255.6	.0012
	−237.7	.0073
	−191.7	.0211
	−152.1	.0261
	− 64.8	.0307
	0	.0316
	500	.0349
	750	.0365
	1000	.0381
	1300	.0400
	20, 100	.0319
	20, 1000	.0346
Potassium	−258.4	.032
	−255.8	.045
	−201.3	.140
	− 53.1	.172
	+ 3.4	.177
(l)	90	.200
	181	.196
Rhenium	0, 20	.035
Rhodium	10, 97	.058
Rubidium (s)	0	.0802
(l)	50	.0908
Ruthenium	0, 100	.0611
Selenium	3	.072
	16.5	.075
	20.5	.077
	29.5	.085
	32	.127
	38	.131
	41.7	.130
	20	.09
Silicon	−212	.029
	−143.3	.087
	− 86.2	.126
	+ 13.9	.168
	18.2, 99.1	.181
	18.0, 900.6	.210
Silver	−238	.0146
	−150	.0461
	−100	.0505
	− 50	.0537
	0	.0557
	100	.0564
	300	.0601
	900	.0685
	20–900	.0650
	20-1200	.0880
Sodium	−256.1	.026
	−238.5	.108
	−155.5	.245
(l)	100	.32
Sulfur	−188, +18	.137
(l)	115, 160	.220
rhom	15, 96	.176
monoclinic	0, 52	.181
Tantalum	−201.7	.0205
	+380	.035
	900	.036
	1100	.043
	1400	.044

(*continued*)

TABLE 147.—SPECIFIC HEAT OF THE CHEMICAL ELEMENTS (concluded)

Element	t°C	Sp ht
Tellurium	—188, +18	.047
	15, 100	.0483
	15, 200	.0487
Thallium	—135	.288
	28	.311
	20, 100	.0326
Thorium	—253, —196	.0197
	0, 100	.0276
Tin	—203.5	.0385
	—186.7	.0422
	—150	.0450
	—100	.0483
	— 50	.0512
	0	.0536
	+ 25	.0548
	100	.0577
	1100	.0758
Titanium	—185, +20	.082
	0, 100	.1125
Tungsten	—247.1	.0012
	—218.4	.0098
	—173.1	.0205
	— 73.1	.0288
	+ 26.9	.0321
	100	.0320
	500	.0344
	1000	.0367
	1500	.0390
Uranium	0, 98	.0280
Vanadium	0, 100	.1153
Zinc	0, 100	.095
	—252.4	.0071
	—201.3	.0573
	—150	.0740
	—100	.0814
	— 50	.0871
	0	.0913
	100	.0957
	300	.1043
	400	.1089

TABLE 148.—FORMULAE FOR TRUE SPECIFIC HEATS

Element		Range °C
Antimony	$.0493 + .000012\,t$	0–500
Bismuth	$.0292 + .000012\,t$	0–200
Chromium	$.1055 + .00010\,t - .00000015\,t^2$	0–400
Cobalt	$.1000 + .000067\,t$	0–400
Copper	$.0915 + .000024\,t$	0–300
Iron	$.1060 + .000096\,t$	0–400
Lead	$.0295 + .00002\,t$	0–300
Magnesium	$.2370 + .000142\,t - .0000001\,t^2$	0–400
Nickel	$.1020 + .000118\,t - .00000006\,t^2$	0–300
Platinum	$.03162 + .00000617\,t + 2.33 \times 10^{-10}\,t^2$	0–1625
Silver	$.0556 + .000008\,t$	0–400
Tin	$.0525 + .000052\,t$	0–200
Zinc	$.0913 + .000044\,t$	0–300

TABLE 149.—HEAT CAPACITIES, TRUE AND MEAN SPECIFIC HEATS, AND LATENT HEATS AT FUSION

The constants a, b, and c of the equations for the heat capacity: $W = a + bt + ct^2$; for the mean specific heat: $s = at^{-1} + b + ct$; and for the true specific heat: $s' = b + 2ct$; the latent heats at fusion are also given.

Element	Temperature range °C	a	b	$c \times 10^6$	Latent heat cal/g
Cr	0–1500	—	.10233	33.47	—
Mo	0–1500	—	.06162	10.99	—
W	0–1500	—	.03325	1.07	—
Pt	0–1500	—	.03121	3.54	—
Sn	0–232	—	.06829	—	13.8
	232–1000	14.33	.07020	—18.30	—
Bi	0–270	—	.03141	5.22	10.2
	270–1000	10.31	.03107	5.41	—
Cd	0–321	—	.05550	6.28	10.8
	321–1000	6.30	.06952	6.37	—
Pb	0–327	—	.03591	11.47	5.47
	327–1000	6.07	.02920	— 3.30	—
Zn	0–419	—	.08777	43.48	23.0
	419–1000	14.34	.13340	—16.10	—
Sb	0–630	—	.05179	3.00	38.9
	630–1000	39.42	.05090	2.96	—
Al	0–657	—	.22200	38.57	94.0
	657–1000	102.39	.21870	24.00	—
Ag	0–961	—	.05725	5.48	26.0
	961–1300	53.17	.00710	28.30	—
Au	0–1064	—	.03171	1.30	15.9
	1064–1300	26.35	.01420	8.52	—
Cu	0–1084	—	.10079	3.05	41.0
	1084–1300	130.74	—.04150	65.6	—
Mn	0–1070	—	.12037	25.41	36.6
	1130–1210	— 7.41	.17700	—	24.14*
	1230–1250	3.83	.19800	—	—
Ni	0–320	—	.10950	52.40	56.1
	330–1451	.41	.12931	.11	1.33*
	1451–1520	50.21	.13380	—	—
Co	0–950	—	.09119	40.77	58.2
	1100–1478	22.00	.11043	14.57	14.70*
	1478–1600	57.72	.14720	—	—
Fe	0–725	—	.10545	56.84	49.4
	785–919	— 1.63	.1592	—	6.56*
	919–1404	18.31	.14472	.05	6.67*
	1405–1528	—77.18	.21416	—	1.94*
	1528–1600	70.03	.15012	—	—

* Allotropic heat of transformation: Mn, 1070–1130°; Ni, 320–330°; Co, 950–1100°; Fe, 725–785°; 919° ± 1; 1404.5° ± 0.5.

TABLE 150.—SPECIFIC HEAT OF VARIOUS SOLIDS

Part 1

Solid	Temperature °C	Specific heat cal/(g °C)
Alloys:		
Bell metal	15–98	.0858
Brass, red	0	.0899
" yellow	0	.0883
80 Cu + 20 Sn	14–98	.0862
Constantan, 60 Cu, 40 Ni	18	.0977
" " "	100	.1018
German silver	0–100	.0946
Lipowitz alloy: 24.97 Pb + 10.13 Cd + 50.66 Bi + 14.24 Sn	5–50	.0345
Lipowitz alloy	100–150	.0426
Manganin: 84 Cu, 4 Ni, 12 Mn	18	.0973
" " " "	100	.1004
Monel metal	20–1300	.127
Rose's alloy: 27.5 Pb + 48.9 Bi + 23.6 Sn	− 77–20	.0356
" "	20–89	.0552
Wood's alloy: 25.85 Pb + 6.99 Cd + 52.43 Bi + 14.73 Sn	5–50	.0352
Wood's alloy: (fluid)	100–150	.0426
Miscellaneous alloys:		
17.5 Sb + 29.9 Bi + 18.7 Zn + 33.9 Sn	20–99	.0566
37.1 Sb + 62.9 Pb	10–98	.0388
39.9 Pb + 60.1 Bi	16–99	.0316
63.8 Bi + 36.2 Sn	20–99	.0400
46.9 Bi + 53.1 Sn	20–99	.0450
Gas coal	20–1040	.3145
Glass, normal thermometer 16^{III}	19–100	.1988
French hard thermometer		.1869
crown	10–50	.161
flint	10–50	.117
Ice	− 80	.350
"	− 40	.434
"	− 20	.465
"	0	.487
India rubber (Para)	?–100	.481
Mica	20	.10
Paraffin	− 20– + 3	.377
"	− 19– +20	.525
"	0–20	.694
"	35–40	.622
" fluid	60–63	.712
Woods	20	.327

(*continued*)

Part 2 *

Compound	Mineral	C_p (joules per gram) for temperatures in °C −200°	0°	200°	400°	800°	1200°
Al_2O_3	corundum	.069	.72	1.00	1.10	1.19	1.26
$Al_2Si_2O_7 \cdot 2H_2O$ *	kaolin	...	.99	1.17	1.35	...	...
$2(AlF)O \cdot SiO_2$	topaz	...	(.83 at 50°)		...	...	...
$Be_3Al_2Si_6O_{18}$	beryl	...	(.84 at 50°)		...	...	...
$CaAl_2Si_2O_8$	anorthite	...	.70	.95	1.05	1.17	1.27
$CaCO_3$	calcite	.28	.793	1.00	1.13	...	...
CaF_2	fluorite	.22	.85	.89	.93	1.01	1.10
$CaMgSi_2O_6$	diopside	...	.69	.98	1.06	1.15	1.20
$CaSO_4 \cdot 2H_2O$	gypsum	.322	1.03	...	...	...	...
$CaWO_4$	scheelite	...	(.40 at 50°)		...	...	...
Fe_2O_3	hematite	...	.61	.79	.90	1.08	...
FeS	α troilite	.238	.606	...	...	...	...
	β troilite	...	...	.635	.66	.71	...
FeS_2	pyrite	.075	.500	.594	.69	...	...
H_2O	ice	.653	2.06	...	...	...	...
HgS	α cinnabar	...	.214	.227	.240	...	...
KCl	sylvite	.418	.682	.715	.749	...	...
KNO_3	α niter	.326	...	...	...	...	...
	β niter	...	1.19	...	...	...	...
	liquid	...	...	1.22	...	...	...
$Mg_3Al_2Si_3O_{12}$	garnet	...	(.74 at 58°)		...	...	...
$MgCO_3$	magnesite	.161	.864	...	...	...	...
MgO	periclase	.066	.870	1.09	1.16	1.24	1.30
$Mg_3H_2Si_4O_{12}$	talc	...	(.87 at 59°)		...	...	...
$NaCl$	halite	.466	.855	.915	.975	1.095	...
	liquid	...	...	...	...	1.14	...
$Na_2B_4O_7 \cdot 10H_2O$	borax	...	(.161 at 35°)		...	...	...
PbS	galena	.142	.207	.221	.235	...	...
SiO_2	α quartz	.173	.698	.969	1.129	...	...
	β quartz	...	...	...	...	1.174	1.327
	α cristobalite	.186	.69	1.01	...	...	...
	β cristobalite	...	...	...	1.074	1.171	1.21
	glass	.184	.70	.95	1.06	1.21	1.34
ZnS	α wurtzite, β sphalerite	.430	.45	.53	.56	.587	...

* For reference, see footnote 45, p. 136.

(continued)

Part 3

Rock	C_p (joules per gram) for temperatures in °C 0°	200°	400°	800°	1200°
Igneous					
Granite: 65% orthoclase, 25% quartz, 9% albite, 1% magnetite	.65	.95	1.07	1.13	...
Basalt: Syracuse, Aetna, Kilauea	.85	1.04	1.14_5	1.32	1.49
Metamorphic					
Gneiss	.74	1.01	...	...	...
Sandstone:	(.93 at 59°)				
Micaceous	(.73 at 50°)				
Japanese (mean of 4)	(.81 at 65°)				
English (mean of 8)	(.81 at 50°)				
Clay, amorphous	.75	.94	1.13	1.51	...
Limestone	(1.00 at 58°)				
English (mean of 3)	(.68 at 50°)				
Japanese (mean of 10)	(.83 at 65°)				

TABLE 151.—ATOMIC HEATS (50°K), SPECIFIC HEATS (50°K), ATOMIC VOLUMES OF THE ELEMENTS

Element	Specific heat *	Atomic heat †	Atomic volume	Element	Specific heat	Atomic heat	Atomic volume	Element	Specific heat	Atomic heat	Atomic volume
Li	.1924	1.35	13.0	Fe	.0175	.98	7.1	Sb	.0240	2.89	18.2
Be	.0137	.125	4.9	Ni	.0208	1.22	6.7	I	.0361	4.59	25.7
B	.0212	.24	4.5	Co	.0207	1.22	6.8	Te	.0288	3.68	21.2
C**	.0137	.16	5.1	Cu	.0245	1.56	7.1	Cs	.0513	6.82	71.0
C‡	.0028	.03	3.4	Zn	.0384	2.52	9.2	Ba‖	.0350	4.80	36.0
Na	.1519	3.50	23.6	As	.0258	1.94	15.9	La	.0322	4.60	22.6
Mg	.0713	1.74	14.1	Se	.0361	2.86	18.5	Ce	.0330	4.64	20.3
Al	.0413	1.12	10.0	Br	.0453	3.62	24.9	W	.0095	1.75	9.8
Si§	.0303	.86	14.2	Rb	.0711	6.05	55.8	Os	.0078	1.49	8.5
Si¶	.0303	.77	11.4	Sr¶	.0550	4.82	34.5	Ir	.0099	1.92	8.6
P, yel.	.0774	2.40	17.0	Zr	.0262	2.38	21.8	Pt	.0135	2.63	9.2
P, red.	.0431	1.34	13.5	Mo	.0141	1.36	9.3	Au	.0160	3.16	10.2
S	.0546	1.75	16.	Ru	.0109	1.11	9.0	Hg	.0232	4.65	14.8
Cl	.0967	3.43	24.6	Rh	.0134	1.38	8.5	Tl	.0235	4.80	17.2
K	.1280	5.01	44.7	Pd	.0190	2.03	9.2	Pb	.0240	4.96	18.3
Ca	.0714	2.86	25.9	Ag	.0242	2.62	10.2	Bi	.0218	4.54	21.3
Ti	.0205	.99	10.7	Cd	.0308	3.46	13.0	Th	.0197	4.58	21.1
Cr	.0142	.70	7.6	Sn	.0286	3.41	20.3	U	.0138	3.30	12.8
Mn	.0229	1.26	7.4								

* cal g^{-1} °C^{-1}. † cal g $atom^{-1}$ °C^{-1}. ** Graphite. ‡ Diamond. § Fused. ¶ Crystallized. ‖ Impure.

TABLE 152.—SPECIFIC HEAT OF WATER AND MERCURY[49]

(1 cal = 4.1840 J)

Specific heat of water						Specific heat of mercury			
Temp. °C	C_p cal g⁻¹ °C⁻¹	Temp. °C	C_p cal g⁻¹ °C⁻¹	Temp. °C	C_p cal g⁻¹ °C⁻¹	Temp. °C	C_p cal g⁻¹ °C⁻¹	Temp. °C	C_p cal g⁻¹ °C⁻¹
0	1.0080	25	.9989	70	1.0013	0	.03346	90	.03277
5	1.0043	26	.9989	75	1.0021	5	.03340	100	.03269
10	1.0019	27	.9988	80	1.0029	10	.03335	110	.03262
15	1.0004	28	.9987	85	1.0039	15	.03330	120	.03255
16	1.0002	29	.9987	90	1.0050	20	.03325	130	.03248
17	1.0000	30	.9987	95	1.0063	25	.03320	140	.03241
18	.9998	35	.9986	100	1.0076	30	.03316	150	.0324
19	.9996	40	.9987	120	1.0162*	35	.03312	170	.0322
20	.9995	45	.9989	140	1.0223*	40	.03308	190	.0320
21	.9993	50	.9992	160	1.0285*	50	.03300	210	.0319
22	.9992	55	.9996	180	1.0348*	60	.03294	...	...
23	.9991	60	1.0001	200	1.0410*	70	.03289	...	...
24	.9990	65	1.0006	220	1.0476*	80	.03284	...	...

[49] Nat. Bur. Standards Journ. Res., RP 1228, vol. 23, p. 197, 1939.
* Barnes-Regnault.

TABLE 153.—SPECIFIC HEAT OF VARIOUS LIQUIDS

Liquid	Temp °C	Spec heat cgs	Liquid	Temp °C	Spec heat cgs
Alcohol, ethyl	—20	.505	Ethyl ether	0	.529
" "	0	.548	Glycerine	15–50	.576
" "	40	.648	KOH + 30 H_2O	18	.876
Alcohol, methyl	5–10	.590	" + 100 "	18	.975
" "	15–20	.601	NaOH + 50 H_2O	18	.942
Anilin	15	.514	" + 100 "	18	.983
"	30	.520	NaCl + 10 H_2O	18	.791
"	50	.529	" + 200 "	18	.978
Benzole, C_6H_6	10	.340	Naphthalene, $C_{10}H_8$	80–85	.396
" "	40	.423	"	90–95	.409
" C_6H_6	65	.482	Nitrobenzole	14	.350
$CaCl_2$, sp. gr. 1.14	—15	.764	"	28	.362
" " " "	0	.775	Oils: Castor	—	.434
" " " "	+20	.787	Citron	5.4	.438
" " " 1.20	—20	.695	Olive	6.6	.471
" " " "	0	.712	Sesame	—	.387
" " " "	+20	.725	Turpentine	0	.411
" " " 1.26	—20	.651	Petroleum	21–58	.511
" " " "	0	.663	Sea water, sp. gr. 1.0043	17.5	.980
" " " "	+20	.676	" " " " 1.0235	17.5	.938
$CuSo_4$ + 50 H_2O	12–15	.848	" " " " 1.0463	17.5	.903
" + 200 "	12–14	.951	Toluol, C_6H_8	10	.364
" + 400 "	13–17	.975	"	65	.490
Diphenylamine,			"	85	.534
$C_{12}H_{11}N$	53	.464	$ZnSO_4$ + 50 H_2O	20–52	.842
"	65	.482	" + 200 "	20–52	.952

TABLE 154.—SPECIFIC HEAT OF LIQUID AMMONIA UNDER SATURATION CONDITIONS

Expressed in calories$_{20}$ per gram per degree C

Temp °C	0	1	2	3	4	5	6	7	8	9
−40	1.062	1.061	1.060	1.059	1.058	1.058	1.057	1.056	1.055	1.055
−30	1.070	1.069	1.068	1.067	1.066	1.065	1.064	1.064	1.063	1.062
−20	1.078	1.077	1.076	1.075	1.074	1.074	1.073	1.072	1.071	1.070
−10	1.088	1.087	1.086	1.085	1.084	1.083	1.082	1.081	1.080	1.079
− 0	1.099	1.098	1.097	1.096	1.094	1.093	1.092	1.091	1.090	1.089
+ 0	1.099	1.100	1.101	1.103	1.104	1.105	1.106	1.108	1.109	1.110
+10	1.112	1.113	1.114	1.116	1.117	1.118	1.120	1.122	1.123	1.125
+20	1.126	1.128	1.129	1.131	1.132	1.134	1.136	1.137	1.139	1.141
+30	1.142	1.144	1.146	1.148	1.150	1.152	1.154	1.156	1.158	1.160
+40	1.162	1.164	1.166	1.169	1.171	1.173	1.176	1.178	1.181	1.183

TABLE 155.—HEAT CONTENT OF SATURATED LIQUID AMMONIA

Heat content $= H = \epsilon + pv$, where ϵ is the internal or intrinsic energy.

Temperature °C	−50°	−40°	−30°	−20°	−10°	0°	+10°	+20°	+30°	+40°	+50°
$H = \epsilon + pv$	−53.8	−43.3	−32.6	−21.8	−11.0	0.0	+11.1	+22.4	−33.9	−45.5	−57.4

TABLE 156.—SPECIFIC HEAT OF MINERALS AND ROCKS

Substance	Temperature °C	Specific heat cgs
Andalusite	0–100	.168
Anhydrite, $CaSO_4$	0–100	.175
Apatite	15–99	.190
Asbestos	20–98	.195
Augite	20–98	.193
Barite, $BaSO_4$	10–98	.113
Beryl	15–99	.198
Borax, $Na_2B_4O_7$ fused	16–98	.238
Calcite, $CaCO_3$	0–50	.188
	0–100	.200
	0–300	.220
Cassiterite SnO_2	16–98	.093
Chalcopyrite	15–99	.129
Corundum	9–98	.198
Cryolite, $Al_2F_6 \cdot 6NaF$	16–99	.252
Fluorite, CaF_2	15–99	.215
Galena, PbS	0–100	.047
Garnet	16–100	.175
Hematite, Fe_2O_3	15–99	.164
Hornblende	20–98	.195
Hypersthene	20–98	.191
Labradorite	20–98	.195
Magnetite	18–45	.156
Malachite, $Cu_2CO_4H_2O$	15–99	.176
Mica (Mg)	20–98	.206
(K)	20–98	.208
Oligoclase	20–98	.205
Orthoclase	15–99	.188
Pyrolusite, MnO_2	17–48	.159
Quartz, SiO_2	12–100	.188
	0	.174
	350	.279
	400–1200	.305
Rock-salt	13–45	.219
Serpentine	16–98	.259
Siderite	9–98	.193
Spinel	15–47	.194
Talc	20–98	.209
Topaz	0–100	.210
Wollastonite	19–51	.178
Zinc blende, ZnS	0–100	.115
Zircon	21–51	.132
Rocks:		
Basalt, fine, black	12–100	.200
	20–470	.199
	470–750	.243
	750–880	.626
	880–1190	.323
Dolomite	20–98	.222
Gneiss	17–99	.196
	17–213	.214
Granite	12–100	.192
Kaolin	20–98	.224
Lava, Aetna	23–100	.201
	31–776	.259
Kilauea	25–100	.197
Limestone	15–100	.216
Marble	0–100	.21
Quartz sand	20–98	.191
Sandstone	—	.22
Aluminum oxide[50] (Corundum)	0	.1731
	100	.2157
	200	.2438
	300	.2611
	400	.2719
	500	.2799
	600	.2865
	700	.2919
	800	.2960
	900	.2995

[50] Nat. Bur. Standards Journ. Res., vol. 38, p. 593, 1947.

Part 1

Gases	Density g/liter (normal)	Heat capacity, C_p in J/g, Temperature °C			Constants in $C_p = a + bT - cT^{-2}$ J/g, Temperature = ° absolute			Temperature range °C
		0	400	1200	a	10^3b	$10^{-5}c$	
Air	1.2920	1.004	1.057	1.16	.968	.132	0	0–2000
Ammonia	.7598	2.06	2.74	3.86	1.822	1.395	.1102	0–1500
Argon *	1.782	.521	.521	.521	.521	0	0	0–
Bromine	7.1308	.225	.232	.236	.223	.01	0	0–1400
Carbon dioxide	1.9630	.82	1.12	1.32	.894	.7	.197	0–2000
Carbon monoxide	1.2492	1.04	1.103	1.245	.980	.18	0	0–2000
Chlorine	3.1638	.497	.511	.537	.488	.033	0	0–1700
Fluorine	1.6954	.774	.818	.906	.744	.11	0	0–2700
Helium *	.1785	5.2	5.2	5.2	5.2	0	0	0–
Hydrogen * H	.045	20.6	20.6	20.6	20.6	0	0	0–
H_2	.0899	14.23	14.87	16.14	13.796	1.59	0	0–2000
Hydrogen bromide	3.6104	.363	.381	.416	.352	.434	0	0–1700
Hydrogen chloride	1.6269	.795	.834	.911	.769	.096	0	0–1700
Hydrogen fluoride	.8926	1.431	1.50	1.634	1.384	.169	0	0–1700
Hydrogen iodide	5.7075	.234	.245	.266	.227	.027	0	0–1700
Hydrogen sulfide	1.5203	1.025	1.21	1.527	.962	.385	.0314	0–1500
Iodine	11.3250	.15	.15	.15	.15	0	0	0–
Krypton *	3.7365	.25	.25	.25	.25	0	0	0–
Mercury * Hg	8.9501	.104	.104	.104	.104	0	0	0–
Hg_2	17.9003	.094	.094	.094	.094	0	0	0–
Neon *	.9005	1.03	1.03	1.03	1.03	0	0	0–
Nitric oxide	1.3388	1.00	1.047	1.142	.968	.118	0	0–2000
Nitrogen	1.2499	1.037	1.08	1.21	.962	.167	—.021	0–1500
Nitrous oxide	1.9638	.85	.954	1.162	.779	.26	0	0–2000
Oxygen	1.4277	.916	1.025	1.143	.944	.136	.0486	0–2000
Phosphorus pentaoxide.	6.3371	—	1.084	1.084	1.084	0	0	360–1100
Potassium * K	1.744	.532	.532	.532	.532	0	0	0–
K_2	3.4889	.482	.482	.482	.482	0	0	0–1700
Sodium * Na	1.026	.904	.904	.904	.904	0	0	0–
Na_2	2.052	.82	.82	.82	.82	0	0	0–
Sulfur	2.8607	.565	.573	.589	.56	.0196	0	30–2000
Sulfur dioxide	2.858	.61	.79	.875	.762	.082	.132	0–2000
Water	—	1.847	2.052	2.478	1.69	.535	—.008	0–2000
Xenon *	5.8579	.158	.158	.158	.158	0	0	0–

** For reference, see footnote 45, p. 136.
* The heat capacity of an ideal monatomic gas (at constant pressure) is equal to $(5/2)R$.

(*continued*)

Part 2

Substance	Range of temperature °C	Specific heat (cgs) constant pressure C_p	Range of temperature °C	Mean ratio of specific heats C_p/C_v
Acetone, C_3H_6O	26–110	.3468		
Alcohol, C_2H_5OH	108–220	.4534	53	1.133
			100	1.134
Alcohol, CH_3OH	101–223	.4580	100	1.256
Benzene, C_6H_6	34–115	.2990	20	1.403
	35–180	.3325	60	1.403
	116–218	.3754	99.7	1.105
Chloroform, $CHCl_3$	27–118	.1441	22–78	1.102
	28–189	.1489	99.8	1.150
Ether, $C_4H_{10}O$	69–224	.4797	42–45	1.029
	25–111	.4280	12–20	1.024
Hydrochloric acid, HCl	13–100	.1940	20	1.389
	22–214	.1867	100	1.400
Mercury			310	1.666
Water vapor, H_2O	0	.4655	78	1.274
	100	.421	94	1.33
	180	.51	100	1.305

TABLE 158.—SPECIFIC HEAT OF SILICATES

Silicate	Mean specific heats cgs 0° C to				True-specific heats at				
	100°	500°	900°	1400°	0°C	100°	500°	1000°	1300°
Albite	.1948	.236	.256	—	.178	.211	.269	.294	—
" glass	.1977	.241	.264	—	—	—	—	—	—
Amphibole, Mg silicate	.2033	.246	.266	.273*	.185	.219	.279	.304	—
" glass	.2040	.247	—	—	—	—	—	—	—
Andesine	.1925	.233	.252	—	—	—	.265	—	—
" glass	.1934	—	.261	—	—	—	—	—	—
Anorthite	.1901	.229	.248	.267	.174	.205	.260	.286	.318
" glass	.1883	.230	—	—	—	—	—	—	—
Cristobalite	.1883	.242	.256	.268	—	—	—	—	—
Diopside	.1924	.231	.250	.260†	.176	.207	.262	.284	—
" glass	.1939	.233	—	—	—	—	—	—	—
Microcline	.1871	.226	.245	—	.171	.201	.258	.279	—
" glass	.1919	.232	.251	.259*	.176	.206	.264	.299	—
Pyroxene	.2039	.248	—	—	—	—	—	—	—
Quartz	.1868	.237	.259	.264*	.168	.204	.294	.285	—
Silica glass	.1845	.230	.251	—	.166	.202	.266	.29	—
Wollastonite	—	—	.234	—	—	—	—	—	—
" glass	.1852	.220	—	—	—	—	—	—	—
" pseudo	.1844	.217	.232	.244	.171	.197	.243	.262	.272

* 0°—1100°. † 0°—1250°.

TABLE 159.—LATENT HEAT OF FUSION AND VAPORIZATION[51]

(Kg cal/mol)

Part 1

Metals	Lm	L_v	Ionic substances	Lm	L_v	Molecular substances	Lm	L_v
Al	2.55	67.6	AgBr	2.18		A	.280	1.88
Ag	2.70	69.4	AgCl	3.15		CCl_4	.577	8.0
Au	3.03	90.7	$AgNO_3$	2.76		CH_4	.224	2.33
Bi	2.51	47.8	$BaCl_2$	5.75		C_6H_6	2.35	8.3
Cd	1.46	27.0	$CaCl_2$	6.03		CH_3COOH	2.64	20.3
Co	3.66	...	$HgBr_2$	4.62		CH_3OH	.525	9.2
Cr	3.93	89.4	HgI_2	4.50		C_2H_5OH	1.10	10.4
Cs	.50	18.7	KBr	2.84	159	Cl_2	1.63	7.43
Cu	3.11	81.7	KCl	6.41	165	CO	.200	1.90
Fe	3.56	96.5	$K_2Cr_2O_7$	8.77		CO_2	1.99	6.44
Ga	1.34	...	KF	6.28	190	H_2	.028	.22
Hg	.58	15.5	KNO_3	2.57		HBr	.620	5.79
In	.78	...	KOH	1.61		HCl	.506	4.85
K	.58	21.9	$LiNO_3$	6.06		H_2O	1.43	11.3
Mg	1.16	34.4	NaCl	7.22	183	N_2	.218	1.69
Mn	3.45	69.7	NaF	7.81	213	NH_3	1.84	7.14
Na	.63	26.2	$NaClO_3$	5.29		NO	.551	3.82
Ni	4.20	98.1	$NaNO_3$	3.76		O_2	.096	2.08
Pb	1.22	46.7	NaOH	1.60				
Pt	5.33	125.	$PbBr_2$	4.29				
Rb	.53	20.6	$PbCl_2$	5.65				
Sb	4.77	54.4	PbI_2	5.18				
Se	1.22	...	TlBr	5.99				
Sn	1.72	68.0	TlCl	4.26				
Tl	.76	43.0						
Zn	1.60	31.4						

Part 2

Substance	Composition	T°C	Lm Cal/g
Alloys: 30.5Pb + 69.5Sn	$PbSn_4$	183	17
36.9Pb + 63.1Sn	$PbSn_3$	179	15.5
63.7Pb + 36.3Sn	PbSn	177.5	11.6
77.8Pb + 22.2Sn	Pb_2Sn	176.5	9.54
Britannia metal, 9Sn + 1Pb	....	236	28.01
Rose's alloy, 24Pb + 27.3Sn + 48.7Bi	....	98.8	6.85
Wood's alloy {25.8Pb + 14.7Sn + 52.4Bi + 7Cd}	....	75.5	8.40
Ammonia	NH_3	−75	108
Benzole	C_6H_6	5.4	30.6
Ice	H_2O	0	79.63
"	"	0	79.59
" (from sea water)	{H_2O + 3.535 of solids}	− 8.7	54.0
Naphthalene	$C_{10}H_8$	79.87	35.62
Potassium nitrate	KNO_3	333.5	48.9
Phenol	C_6H_6O	25.37	24.93
Paraffin	....	52.40	35.10
Sodium	Na	97	31.7
" nitrate	$NaNO_3$	305.8	64.87
" phosphate	{Na_2HPO_4 $12H_2O$}	36.1	66.8
Spermaceti	....	43.9	36.98
Wax (bees)	....	61.8	42.3

[51] From Slater, John C., Introduction to chemical physics, McGraw-Hill Book Co., copyright 1939. Used by permission.

TABLE 160.—LATENT HEAT OF VAPORIZATION OF ELEMENTS

Element	t°C	Cal/g	Element	t°C	Cal/g
Sb	755	320	I	174	24
A	1 atm.	37.6	Kr	− 151	28
Ba	1537	308	Pb	1170	175
Bi	920	190	Li	1336	511
Br	60±	43	Mg	1110	136
Cd	778	240	Hg	358	71
Ca	143.9	101	N	− 195.6	47.6
Cl	− 63	63	O_2	− 182.9	50.9
F	− 188.2	40.5	Sr	1336	410
He	− 271.3	5.6	Xe	− 108.6	25.1
H_2	− 253	108	Zn	918	475

TABLE 161.—LATENT HEAT OF VAPORIZATION OF LIQUIDS

Substance	Formula	t°C	Latent heat vaporization cal/g	Total heat from 0°C cal/g
Alcohol: Ethyl	C_2H_6O	78.1	205	255
	"	0	236	236
	"	100	...	267
	"	150	...	285
Methyl	CH_4O	64.5	267	307
	"	0	289	...
	"	100	246	...
	"	150	206	...
	"	200	152	...
	"	238.5	44.2	...
Aniline	C_6H_7N	184	110	...
Benzene	C_6H_6	80.1	92.9	127.9
Carbon dioxide, solid	CO_2	...	...	138.7
liquid	"	−25	72.23	...
	"	0	57.48	...
	"	12.35	44.97	...
	"	22.04	31.8	...
	"	30.82	3.72	...
disulfide	CS_2	46.1	83.8	94.8
	"	0	90	90
	"	100	...	100.5
Chloroform	$CHCl_3$	60.9	58.5	72.8
Ether	$C_4H_{10}O$	34.5	88.4	107
	"	0	94	94
	"	50	...	115.1
	"	120	...	140
Ethyl bromide	C_2H_5Br	38.2	60.4	...
chloride	C_2H_5Cl	12.5	...	98
iodide	C_2H_5I	71	47	...
Heptane	C_7H_{16}	90	77.8	...
Hexane	C_6H_{14}	70	79.2	...
Octane	C_8H_{18}	130	70.0	...
Pentane	C_5H_{12}	30	85.8	...
Sulfur dioxide	SO_2	0	91.2	...
	"	65	68.4	...
Toluol	C_7H_8	111	86.0	...
Turpentine	$C_{10}H_{16}$	159.3	74.04	...

TABLE 162.—LATENT AND TOTAL HEAT OF VAPORIZATION, FORMULAE

$r =$ latent heat of vaporization at $t°$ C; H = total heat from fluid at 0° to vapor at $t°$ C. $T°$ refers to Kelvin scale. Same units as preceding table.

Substance	Formula	From	To
Acetone, C_3H_6O	$H = 140.5 + .36644t - .000516t^2$	− 3°	to 147°
	$= 139.9 + .23356t + .00055358t^2$	− 3	147
	$r = 139.9 - .27287t + .0001571t^2$	− 3	147
Benzene, C_6H_6	$H = 109.0 + .24429t - .0001315t^2$	7	215
Carbon dioxide	$r^2 = 118.485(31 - t) - .4707(31 - t)^2$	−25	31
Carbon bisulfide, CS_2	$H = 90.0 + .14601t - .0004123t^2$	− 6	143
	$H = 89.5 + .16993t - .0010161t^2 + .0_5342t^3$	− 6	143
	$r = 89.5 - .06530t - .0010976t^2 + .0_5342t^3$	− 6	143
Carbon tetrachloride, CCl_4	$H = 52.0 + .14625t - .000172t^2$	8	163
	$H = 51.9 + .17867t - .0009599t^2 + .0_53733t^3$	8	163
	$r = 51.9 - .01931t - .0010505t^2 + .0_53733t^3$	8	163
Chloroform, $CHCl_3$	$H = 67.0 + .1375t$	− 5	159
	$H = 67.0 + .14716t - .0000937t^2$	− 5	159
	$r = 67.0 - .08519t - .0001444t^2$	− 5	159
Ether, $C_4H_{10}O$	$H = 94.0 + .45000t - .0005556t^2$	− 4	121
	$r = 94.0 - .07900t - .0008514t^2$	− 4	121
Molybdenum	$r = 177000 - 2.5T$ (cal/g-atom)	——	
Nitrogen, N_2	$r = 68.85 - .2736T$	——	
Nitrous oxide, N_2O	$r^2 = 131.75(36.4 - t) - .928(36.4 - t)^2$	−20	36
Oxygen, O_2	$r = 69.67 - .2080T$	——	
Platinum	$r = 128000 - 2.5T$ (cal/g-atom)	——	
Sulfur dioxide	$r = 91.87 - .3842t - .000340t^2$	0	20
Tungsten	$r = 217800 - 1.8T$ (cal/g-atom)	——	
Water, H_2O	$H = 638.9 + .3745(t - 100) - .00099(t - 100)^2$	——	
	$r = 94.210(365 - t)^{.31249}$ (See Table 165)	0	100

TABLE 163.—LATENT HEAT OF VAPORIZATION OF AMMONIA

Calories per gram

°C	0	1	2	3	4	5	6	7	8	9
−40	331.7	332.3	333.0	333.6	334.3	334.9	335.5	336.2	336.8	337.5
−30	324.8	325.5	326.2	326.9	327.6	328.3	329.0	329.7	330.3	331.0
−20	317.6	318.3	319.1	319.8	320.6	321.3	322.0	322.7	323.4	324.1
−10	309.9	310.7	311.5	312.2	313.0	313.8	314.6	315.3	316.1	316.8
− 0	301.8	302.6	303.4	304.3	305.1	305.9	306.7	307.5	308.3	309.1
+ 0	301.8	300.9	300.1	299.2	298.4	297.5	296.6	295.7	294.9	294.0
+10	293.1	292.2	291.3	290.4	289.5	288.6	287.6	286.7	285.7	284.8
+20	283.8	282.8	281.8	280.9	279.9	278.9	277.9	276.9	275.9	274.9
+30	273.9	272.8	271.8	270.7	269.7	268.6	267.5	266.4	265.3	264.2
+40	263.1	262.0	260.8	259.7	258.5	257.4	256.2	255.0	253.8	252.6

TABLE 164.—"LATENT HEAT OF PRESSURE VARIATION" OF LIQUID AMMONIA

When a fluid undergoes a change of pressure, there occurs a transformation of energy into heat or vice versa, which results in a change of temperature of the substance unless a like amount of heat is abstracted or added. This change expressed as the heat so transformed per unit change of pressure is the "latent heat of pressure variation." It is expressed below as J g^{-1} kg^{-1} cm^2.

Temperature °C.	−44.1	−39.0	−24.2	−.2	+16.5	+26.5	+35.4	+40.3
Latent heat	− .055	− .057	− .068	−.088	− .107	− .123	− .140	− .150

TABLE 165.—THERMAL PROPERTIES OF SATURATED WATER AND STEAM

Accuracy: It is estimated that there is only 1 chance in 100 that the values given for H differ from the truth by as much as 1 part in 2000; it is equally unlikely that the values for L and H' are as much as 1.5 joules/g from the truth in the range of the experiments, 100°-270°C.

Temperature °C	Heat content of liquid, H joules/g	Latent heat, L joules/g	Heat content of vapor, H' joules/g	Entropy— of liquid Φ joules/g°C	Entropy— of vapor Φ^1 joules/g°C
0	0	2494.02	2494.02	0	9.132
10	42.02	2472.26	2514.28	.1511	8.884
20	83.83	2450.17	2534.00	.2962	8.656
30	125.59	2427.73	2553.32	.4363	8.446
40	167.34	2404.90	2572.24	.5719	8.253
50	209.11	2381.64	2590.75	.7032	8.074
60	250.90	2357.91	2608.81	.8305	7.909
70	292.75	2333.65	2626.40	.9543	7.756
80	334.66	2308.32	2643.48	1.0746	7.613
90	376.65	2283.38	2660.03	1.1918	7.480
100	418.75	2257.24	2675.99	1.3064	7.356
110	460.97	2230.35	2691.32	1.4177	7.240
120	503.36	2202.65	2706.01	1.5268	7.130
130	545.93	2174.04	2719.97	1.6335	7.027
140	588.71	2144.44	2733.15	1.7381	6.929
150	631.75	2113.76	2745.51	1.8407	6.837
160	675.06	2081.89	2756.95	1.9416	6.749
170	718.66	2048.72	2767.38	2.0406	6.664
180	762.72	2014.10	2776.82	2.1384	6.584
190	807.15	1977.89	2785.04	2.2348	6.506
200	852.02	1939.93	2791.95	2.3299	6.430
210	897.35	1900.00	2797.35	2.4239	6.357
220	943.24	1857.89	2801.13	2.5169	6.285
230	989.75	1813.33	2803.08	2.6091	6.213
240	1036.97	1766.02	2802.99	2.7007	6.143
250	1084.97	1715.59	2800.56	2.7919	6.072
260	1133.87	1661.60	2795.47	2.8828	6.000
270	1184.32	1603.51	2787.83	2.9746	5.927

Metric and common units, 0° to 220°C

Heat of liquid, q, heat required to raise 1 kg (1 lb) to corresponding temperature from 0°C. Heat of vaporization, r, heat required to vaporize 1 kg (1 lb) at corresponding temperature to dry saturated vapor against corresponding pressure. Total heat, $H = r + q$.

Temperature degrees C	Pressure			Heat of the liquid		Heat of vaporization		Heat equivalent of internal works		Temperature degrees F
	mmHg	kg/cm²	lb/in.²	kg cal	Btu	kg cal	Btu	kg cal	Btu	
t	p	p	p	q	q	r	r	ρ	ρ	t
0	4.579	.00623	.0886	.00	.0	595.4	1071.7	565.3	1017.5	32.0
5	6.541	.00889	.1265	5.04	9.1	592.8	1067.1	562.2	1011.9	41.0
10	9.205	.01252	.1780	10.06	18.1	590.2	1062.3	559.0	1006.2	50.0
15	12.779	.01737	.2471	15.06	27.1	587.6	1057.6	555.9	1000.5	59.0
20	17.51	.02381	.3396	20.06	36.1	584.9	1052.8	552.7	994.8	68.0
25	23.69	.03221	.4581	25.05	45.1	582.3	1048.1	549.5	989.7	77.0
30	31.71	.04311	.6132	30.04	54.1	579.6	1043.3	546.3	983.4	86.0
35	42.02	.05713	.8126	35.03	63.1	576.9	1038.5	543.1	977.6	95.0
40	55.13	.07495	1.0661	40.02	72.0	574.2	1033.5	539.9	971.7	104.0
45	71.66	.09743	1.3858	45.00	81.0	571.3	1028.4	536.5	965.7	113.0
50	92.30	.12549	1.7849	49.99	90.0	568.4	1023.2	533.0	959.6	122.0
55	117.85	.16023	2.279	54.98	99.0	565.6	1018.1	529.7	953.5	131.0
60	149.19	.20284	2.885	59.97	108.0	562.8	1013.1	526.4	947.5	140.0
65	187.36	.2547	3.623	64.98	117.0	559.9	1007.8	523.0	941.3	149.0
70	233.53	.3175	4.516	69.98	126.0	556.9	1002.5	519.5	935.0	158.9
75	289.0	.3929	5.589	74.99	135.0	554.0	997.3	516.0	928.8	167.0
80	355.1	.4828	6.867	80.01	144.0	551.1	991.9	512.6	922.6	176.0
85	433.5	.5894	8.383	85.04	153.1	548.1	986.5	509.1	916.3	185.0
90	525.8	.7149	10.167	90.07	162.1	544.9	980.9	505.4	909.9	194.0
91	546.1	.7425	10.560	91.08	163.9	544.3	979.8	504.7	908.5	195.8
92	567.1	.7710	10.966	92.08	165.7	543.7	978.7	504.0	907.2	197.6
93	588.7	.8004	11.384	93.09	167.5	543.1	977.6	503.3	906.0	199.4
94	611.0	.8307	11.815	94.10	169.3	542.5	976.5	502.6	904.7	201.2
95	634.0	.8620	12.260	95.11	171.2	541.9	975.4	501.9	903.4	203.0
96	657.7	.8942	12.718	96.12	173.0	541.2	974.2	501.1	902.1	204.8
97	682.1	.9274	13.190	97.12	174.8	540.6	973.1	500.4	900.8	206.6
98	707.3	.9616	13.678	98.13	176.6	539.9	971.9	499.6	899.4	208.4
99	733.2	.9970	14.180	99.14	178.5	539.3	970.8	498.9	898.2	210.2
100	760.0	1.0333	14.697	100.2	180.3	538.7	969.7	498.2	896.9	212.0
101	787.5	1.0707	15.229	101.2	182.1	538.1	968.5	497.5	895.5	213.8
102	815.9	1.1093	15.778	102.2	183.9	537.4	967.3	496.8	894.1	215.6
103	845.1	1.1490	16.342	103.2	185.7	536.8	966.2	496.1	892.9	217.4
104	875.1	1.1898	16.923	104.2	187.6	536.2	965.1	495.4	891.6	219.2
105	906.1	1.2319	17.522	105.2	189.4	535.6	964.0	494.7	890.3	221.0
106	937.9	1.2752	18.137	106.2	191.2	534.9	962.8	493.9	889.0	222.8
107	970.6	1.3196	18.769	107.2	193.0	534.2	961.6	493.1	887.6	224.6
108	1004.3	1.3653	19.420	108.2	194.8	533.6	960.5	492.4	886.3	226.4
109	1038.8	1.4123	20.089	109.3	196.7	532.9	959.3	491.6	885.0	228.2
110	1074.5	1.4608	20.777	110.3	198.5	532.3	958.1	490.9	883.6	230.6
111	1111.1	1.5106	21.486	111.3	200.3	531.6	956.9	490.2	882.3	231.8
112	1148.7	1.5617	22.214	112.3	202.1	530.9	955.7	489.4	880.9	233.6
113	1187.4	1.6144	22.962	113.3	203.9	530.3	954.5	488.7	879.5	235.4
114	1227.1	1.6684	23.729	114.3	205.8	529.6	953.3	487.9	878.2	237.2
115	1267.9	1.7238	24.518	115.3	207.6	528.9	952.1	487.1	876.8	239.0
116	1309.8	1.7808	25.328	116.4	209.4	528.2	950.8	486.3	875.4	240.8
117	1352.8	1.8393	26.160	117.4	211.2	527.5	949.5	485.5	873.9	242.6
118	1397.0	1.8993	27.015	118.4	213.0	526.9	948.4	484.8	872.6	244.4
119	1442.4	1.9611	27.893	119.4	214.9	526.2	947.2	484.0	871.3	246.2

(continued)

Metric and common units, 0° to 220°C

If A is the reciprocal of the mechanical equivalent of heat, p the pressure, s and σ the specific volumes of the liquid and the saturated vapor, $s-\sigma$, the change of volume, then the heat equivalent of the external work is $Apu = Ap(s-\sigma)$. Heat equivalent of internal work, $\rho = r - Apu$, Entropy $= \int dQ/T$, where dQ = amount of heat added at absolute temperature T.

Temperature degrees C	Heat equivalent of external work		Entropy of the liquid	Entropy of evaporation	Specific volume		Density		Temperature degrees F
	kg cal	Btu			m^3/kg	ft^3/lb	kg/m^3	lb/ft^3	
t	Apu	Apu	θ	$\frac{r}{T}$	s	s	$\frac{1}{s}$	$\frac{1}{s}$	t
0	30.1	54.2	.0000	2.1804	206.3	3304.	.00485	.000303	32.0
5	30.6	55.2	.0183	2.1320	147.1	2356.	.00680	.000424	41.0
10	31.2	56.1	.0361	2.0850	106.3	1703.	.00941	.000587	50.0
15	31.7	57.1	.0537	2.0396	77.9	1248.	.01283	.000801	59.0
20	32.2	58.0	.0709	1.9959	57.8	926.	.01730	.001080	68.0
25	32.8	59.0	.0878	1.9536	43.40	695.	.02304	.001439	77.0
30	33.3	59.9	.1044	1.9126	32.95	528.	.03035	.001894	86.0
35	33.8	60.9	.1207	1.8728	25.25	404.7	.03960	.002471	95.0
40	34.3	61.8	.1368	1.8341	19.57	313.5	.0511	.003190	104.0
45	34.8	62.7	.1526	1.7963	15.25	244.4	.0656	.004092	113.0
50	35.4	63.6	.1682	1.7597	12.02	192.6	.0832	.00519	122.0
55	35.9	64.6	.1835	1.7242	9.56	153.2	.1046	.00653	131.0
60	36.4	65.6	.1986	1.6899	7.66	122.8	.1305	.00814	140.0
65	36.9	66.5	.2135	1.6563	6.19	99.2	.1615	.01008	149.0
70	37.4	67.4	.2282	1.6235	5.04	80.7	.1984	.01239	158.0
75	38.0	68.5	.2427	1.5918	4.130	66.2	.2421	.01510	167.0
80	38.5	69.3	.2570	1.5609	3.404	54.5	.2938	.01835	176.0
85	39.0	70.2	.2711	1.5307	2.824	45.23	.3541	.02211	185.0
90	39.5	71.0	.2851	1.5010	2.358	37.77	.4241	.02648	194.0
91	39.6	71.3	.2879	1.4952	2.275	36.45	.4395	.02743	195.8
92	39.7	71.5	.2906	1.4894	2.197	35.19	.4552	.02842	197.6
93	39.8	71.6	.2934	1.4836	2.122	34.00	.4713	.02941	199.4
94	39.9	71.8	.2961	1.4779	2.050	32.86	.4878	.03043	201.2
95	40.0	72.0	.2989	1.4723	1.980	31.75	.505	.03149	203.0
96	40.1	72.1	.3016	1.4666	1.913	30.67	.523	.03260	204.8
97	40.2	72.3	.3043	1.4609	1.849	29.63	.541	.03375	206.6
98	40 3	72.5	.3070	1.4552	1.787	28.64	.560	.03492	208.4
99	40.4	72.6	.3097	1.4496	1.728	27.69	.579	.03611	210.2
100	40.5	72.8	.3125	1.4441	1.671	26.78	.598	.03734	212.0
101	40.6	73.0	.3152	1.4386	1.617	25.90	.618	.03861	213.8
102	40.6	73.2	.3179	1.4330	1.564	25.06	.639	.03990	215.6
103	40.7	73.3	.3205	1.4275	1.514	24.25	.661	.04124	217.4
104	40.8	73.5	.3232	1.4220	1.465	23.47	.683	.04261	219.2
105	40.9	73.7	.3259	1.4165	1.419	22.73	.705	.04400	221.0
106	41.0	73.8	.3286	1.4111	1.374	22.01	.728	.04543	222.8
107	41.1	74.0	.3312	1.4057	1.331	21.31	.751	.04692	224.6
108	41.2	74.2	.3339	1.4003	1.289	20.64	.776	.04845	226.4
109	41.3	74.3	.3365	1.3949	1.248	19.99	.801	.0500	228.2
110	41.4	74.5	.3392	1.3895	1.209	19.37	.827	.0516	230.0
111	41.4	74.6	.3418	1.3842	1.172	18.77	.853	.0533	231.8
112	41.5	74.8	.3445	1.3789	1.136	18.20	.880	.0550	233.6
113	41.6	75.0	.3471	1.3736	1.101	17.64	.908	.0567	235.4
114	41.7	75.1	.3498	1.3683	1.068	17.10	.936	.0585	237.2
115	41.8	75.3	.3524	1.3631	1.036	16.59	.965	.0603	239.0
116	41.9	75.4	.3550	1.3579	1.005	16.09	.995	.0622	240.8
117	42.0	75.6	.3576	1.3527	.9746	15.61	1.026	.0641	242.6
118	42.1	75.8	.3602	1.3475	.9460	15.16	1.057	.0659	244.4
119	42.2	75.9	.3628	1.3423	.9183	14.72	1.089	.0679	246.2

(continued)

Metric and common units, 0° to 220°C

Temperature degrees C	Pressure			Heat of the liquid		Heat of vaporization		Heat equivalent of internal works		Temperature degrees F
	mmHg	kg/cm²	lb/in.²	kg cal	Btu	kg cal	Btu	kg cal	Btu	
t	p	p	p	q	q	r	r	ρ	ρ	t
120	1489	2.024	28.79	120.4	216.7	525.6	946.0	483.4	870.0	248.0
121	1537	2.089	29.72	121.4	218.5	524.9	944.8	482.6	868.6	249.8
122	1586	2.156	30.66	122.5	220.4	524.2	943.5	481.8	867.1	251.6
123	1636	2.224	31.64	123.5	222.2	523.5	942.3	481.0	865.8	253.4
124	1688	2.294	32.64	124.5	224.1	522.8	941.0	480.2	864.3	255.2
125	1740	2.366	33.66	125.5	225.9	522.1	939.9	479.4	863.0	257.0
126	1795	2.440	34.71	126.5	227.7	521.4	938.6	478.6	861.6	258.8
127	1850	2.516	35.78	127.5	229.5	520.7	937.3	477.8	860.2	260.6
128	1907	2.593	36.88	128.6	231.4	520.0	936.1	477.0	858.8	262.4
129	1966	2.673	38.01	129.6	233.3	519.3	934.8	476.3	857.4	264.2
130	2026	2.754	39.17	130.6	235.1	518.6	933.6	475.5	856.0	266.0
131	2087	2.837	40.36	131.6	236.9	517.9	932.3	474.7	854.6	267.8
132	2150	2.923	41.57	132.6	238.7	517.3	931.1	474.0	853.2	269.6
133	2214	3.010	42.81	133.7	240.6	516.6	929.8	473.3	851.8	271.4
134	2280	3.100	44.09	134.7	242.4	515.9	928.5	472.5	850.4	273.2
135	2348	3.192	45.39	135.7	244.2	515.1	927.2	471.6	848.9	275.0
136	2416	3.285	46.73	136.7	246.0	514.4	925.9	470.8	847.5	276.8
137	2487	3.382	48.10	137.7	247.9	513.7	524.6	470.1	846.1	278.6
138	2560	3.480	49.50	138.8	249.7	513.0	923.3	469.3	844.6	280.4
139	2634	3.581	50.93	139.8	251.6	512.3	922.1	468.5	843.3	282.2
140	2710	3.684	52.39	140.8	253.4	511.5	920.7	467.6	841.8	284.0
141	2787	3.789	53.89	141.8	255.3	510.7	919.3	466.8	840.2	285.8
142	2866	3.897	55.43	142.8	257.1	510.1	918.1	466.1	838.9	287.6
143	2948	4.008	57.00	143.9	259.0	509.3	916.7	465.3	837.4	289.4
144	3030	4.121	58.60	144.9	260.8	508.6	915.4	464.4	835.9	291.2
145	3115	4.236	60.24	145.9	262.7	507.8	914.1	463.6	834.5	293.0
146	3202	4.354	61.92	146.9	264.5	507.1	912.8	462.8	833.1	294.8
147	3291	4.474	63.64	148.0	266.4	506.4	911.5	462.0	831.6	296.6
148	3381	4.597	65.39	149.0	268.2	505.6	910.1	461.2	830.1	298.4
149	3474	4.723	67.18	150.0	270.1	504.9	908.8	460.4	828.7	300.2
150	3569	4.852	69.01	151.0	271.9	504.1	907.4	459.5	827.2	302.0
151	3665	4.984	70.88	152.1	273.8	503.4	906.1	458.7	825.7	303.8
152	3764	5.118	72.79	153.1	275.6	502.6	904.7	457.9	824.2	305.6
153	3865	5.255	74.74	154.1	277.4	501.9	903.3	457.1	822.7	307.4
154	3968	5.395	76.73	155.1	279.2	501.1	901.9	456.3	821.2	309.2
155	4073	5.538	78.76	156.2	281.1	500.3	900.5	455.4	819.6	311.0
156	4181	5.684	80.84	157.2	283.0	499.6	899.2	454.6	818.2	312.8
157	4290	5.833	82.96	158.2	284.8	498.8	897.8	453.8	816.7	314.6
158	4402	5.985	85.12	159.3	286.7	498.1	896.5	453.0	815.3	316.4
159	4517	6.141	87.33	160.3	288.5	497.3	895.1	452.1	813.7	318.2
160	4633	6.300	89.59	161.3	290.4	496.5	893.7	451.2	812.2	320.0
161	4752	6.462	91.89	162.3	292.2	495.7	892.3	450.4	810.7	321.8
162	4874	6.628	94.25	163.4	294.1	494.9	890.9	449.5	809.2	323.6
163	4998	6.796	96.65	164.4	295.9	494.2	889.5	448.7	807.7	325.4
164	5124	6.967	99.09	165.4	297.7	493.4	888.1	447.9	806.2	327.2
165	5253	7.142	101.6	166.5	299.6	492.6	886.7	447.0	804.7	329.0
166	5384	7.320	104.1	167.5	301.5	491.9	885.4	446.3	803.3	330.8
167	5518	7.502	106.7	168.5	303.3	491.1	883.9	445.4	801.7	332.6
168	5655	7.688	109.4	169.5	305.1	490.3	882.5	444.6	800.1	334.4
169	5794	7.877	112.0	170.6	307.0	489.5	881.0	443.7	798.5	336.2

(continued)

Metric and common units, 0° to 220°C

Temperature degrees C	Heat equivalent of external work		Entropy of the liquid	Entropy of evaporation	Specific volume		Density		Temperature degrees F
	kg cal	Btu			m³/kg	ft³/lb	kg/m³	lb/ft³	
t	Apu	Apu	θ	$\frac{r}{T}$	s	s	$\frac{1}{s}$	$\frac{1}{s}$	t
120	42.2	76.0	.3654	1.3372	.8914	14.28	1.122	.0700	248.0
121	42.3	76.2	.3680	1.3321	.8653	13.86	1.156	.0721	249.8
122	42.4	76.4	.3705	1.3269	.8401	13.46	1.190	.0743	251.6
123	42.5	76.5	.3731	1.3218	.8158	13.07	1.226	.0765	253.4
124	42.6	76.7	.3756	1.3167	.7924	12.69	1.262	.0788	255.2
125	42.7	76.8	.3782	1.3117	.7698	12.33	1.299	.0811	257.0
126	42.8	77.0	.3807	1.3067	.7479	11.98	1.337	.0835	258.8
127	42.9	77.1	.3833	1.3017	.7267	11.64	1.376	.0859	260.6
128	43.0	77.3	.3858	1.2967	.7063	11.32	1.416	.0883	262.4
129	43.0	77.4	.3884	1.2917	.6867	11.00	1.456	.0909	264.2
130	43.1	77.6	.3909	1.2868	.6677	10.70	1.498	.0935	266.0
131	43.2	77.7	.3934	1.2818	.6493	10.40	1.540	.0961	267.8
132	43.3	77.9	.3959	1.2769	.6315	10.12	1.583	.0988	269.6
133	43.3	78.0	.3985	1.2720	.6142	9.839	1.628	.1016	271.4
134	43.4	78.1	.4010	1.2672	.5974	9.569	1.674	.1045	273.2
135	43.5	78.3	.4035	1.2623	.5812	9.309	1.721	.1074	275.0
136	43.6	78.4	.4060	1.2574	.5656	9.060	1.768	.1104	276.8
137	43.6	78.5	.4085	1.2526	.5506	8.820	1.816	.1134	278.6
138	43.7	78.7	.4110	1.2479	.5361	8.587	1.865	.1165	280.4
139	43.8	78.8	.4135	1.2431	.5219	8.360	1.916	.1196	282.2
140	43.9	78.9	.4160	1.2383	.5081	8.140	1.968	.1229	284.0
141	43.9	79.1	.4185	1.2335	.4948	7.926	2.021	.1262	285.8
142	44.0	79.2	.4209	1.2288	.4819	7.719	2.075	.1296	287.6
143	44.0	79.3	.4234	1.2241	.4694	7.519	2.130	.1330	289.4
144	44.2	79.5	.4259	1.2194	.4574	7.326	2.186	.1365	291.2
145	44.2	79.6	.4283	1.2147	.4457	7.139	2.244	.1401	293.0
146	44.3	79.7	.4307	1.2100	.4343	6.957	2.303	.1437	294.8
147	44.4	79.9	.4332	1.2054	.4232	6.780	2.363	.1475	296.6
148	44.4	80.0	.4356	1.2008	.4125	6.609	2.424	.1513	298.4
149	44.5	80.1	.4380	1.1962	.4022	6.443	2.486	.1552	300.2
150	44.6	80.2	.4405	1.1916	.3921	6.282	2.550	.1592	302.0
151	44.6	80.4	.4429	1.1870	.3824	6.126	2.615	.1632	303.8
152	44.7	80.5	.4453	1.1824	.3729	5.974	2.682	.1674	305.6
153	44.8	80.6	.4477	1.1778	.3637	5.826	2.750	.1716	307.4
154	44.8	80.7	.4501	1.1733	.3548	5.683	2.818	.1759	309.2
155	44.9	80.9	.4525	1.1688	.3463	5.546	2.888	.1803	311.0
156	45.0	81.0	.4549	1.1644	.3380	5.413	2.959	.1847	312.8
157	45.0	81.1	.4573	1.1599	.3298	5.282	3.032	.1893	314.6
158	45.1	81.2	.4596	1.1554	.3218	5.154	3.108	.1940	316.4
159	45.2	81.4	.4620	1.1509	.3140	5.029	3.185	.1988	318.2
160	45.3	81.5	.4644	1.1465	.3063	4.906	3.265	.2038	320.0
161	45.3	81.6	.4668	1.1421	.2989	4.789	3.345	.2088	321.8
162	45.4	81.7	.4692	1.1377	.2920	4.677	3.425	.2138	323.6
163	45.5	81.8	.4715	1.1333	.2855	4.571	3.503	.2188	325.4
164	45.5	81.9	.4739	1.1289	.2792	4.469	3.582	.2238	327.2
165	45.6	82.0	.4763	1.1245	.2729	4.368	3.664	.2289	329.0
166	45.6	82.1	.4786	1.1202	.2666	4.268	3.751	.2343	330.8
167	45.7	82.2	.4810	1.1159	.2603	4.168	3.842	.2399	332.6
168	45.7	82.4	.4833	1.1115	.2540	4.070	3.937	.2457	334.4
169	45.8	82.5	.4857	1.1072	.2480	3.975	4.032	.2516	336.2

(continued)

Metric and common units, 0° to 220°C

Temperature degrees C	Pressure			Heat of the liquid		Heat of vaporization		Heat equivalent of internal works		Temperature degrees F
	mmHg	kg/cm²	lb/in.²	kg cal	Btu	kg cal	Btu	kg cal	Btu	
t	p	p	p	q	q	r	r	ρ	ρ	t
170	5937	8.071	114.8	171.6	308.9	488.7	879.6	442.8	797.0	338.0
171	6081	8.268	117.6	172.6	310.7	487.9	878.3	441.9	795.6	339.8
172	6229	8.469	120.4	173.7	312.6	487.1	876.9	441.1	794.1	341.6
173	6379	8.673	123.4	174.7	314.5	486.3	875.4	440.2	792.5	343.4
174	6533	8.882	126.3	175.7	316.3	485.5	873.9	439.4	790.9	345.2
175	6689	9.094	129.4	176.8	318.2	484.7	872.4	438.5	789.3	347.0
176	6848	9.310	132.4	177.8	320.0	483.9	871.0	437.7	787.8	348.8
177	7010	9.531	135.6	178.8	321.8	483.1	869.5	436.8	786.2	350.6
178	7175	9.755	138.8	179.9	323.7	482.3	868.1	436.0	784.7	352.4
179	7343	9.983	142.0	180.9	325.6	481.4	866.6	435.0	783.1	354.2
180	7514	10.216	145.3	181.9	327.5	480.6	865.1	434.2	781.5	356.0
181	7688	10.453	148.7	183.0	329.3	479.8	863.6	433.3	779.9	357.8
182	7866	10.695	152.1	184.0	331.2	479.0	862.2	432.5	778.4	359.6
183	8046	10.940	155.6	185.0	333.0	478.2	860.7	431.6	776.9	361.4
184	8230	11.189	159.2	186.1	334.9	477.4	859.2	430.8	775.3	363.2
185	8417	11.44	162.8	187.1	336.8	476.6	857.7	429.9	773.7	365.0
186	8608	11.70	166.5	188.1	338.6	475.7	856.3	429.0	772.2	366.8
187	8802	11.97	170.2	189.2	340.5	474.8	854.7	428.0	770.5	368.6
188	8999	12.24	174.0	190.2	342.4	474.0	853.2	427.2	768.9	370.4
189	9200	12.51	177.9	191.2	344.2	473.2	851.7	426.3	767.4	372.2
190	9404	12.79	181.8	192.3	346.1	472.3	850.2	425.4	765.8	374.0
191	9612	13.07	185.9	193.3	347.9	471.5	848.7	424.5	764.2	375.8
192	9823	13.36	190.0	194.4	349.8	470.6	847.1	423.6	762.5	377.6
193	10038	13.65	194.1	195.4	351.7	469.8	845.6	422.8	761.0	379.4
194	10256	13.94	198.3	196.4	353.5	468.9	844.1	421.9	759.4	381.2
195	10480	14.25	202.6	197.5	355.4	468.1	842.5	421.0	757.7	383.0
196	10700	14.55	207.0	198.5	357.3	467.2	841.0	420.1	756.1	384.8
197	10930	14.87	211.4	199.5	359.2	466.4	839.5	419.2	754.6	386.6
198	11170	15.18	216.0	200.6	361.1	465.6	838.0	418.4	753.4	388.4
199	11410	15.51	220.6	201.6	362.9	464.7	836.4	417.4	751.3	390.2
200	11650	15.84	225.2	202.7	364.8	463.8	834.8	416.5	749.7	392.0
201	11890	16.17	230.0	203.7	366.7	462.9	833.8	415.6	748.1	393.8
202	12140	16.51	234.8	204.7	368.5	462.1	831.8	414.8	746.6	395.6
203	12400	16.85	239.7	205.8	370.4	461.2	830.2	413.8	744.9	397.4
204	12650	17.20	244.7	206.8	372.3	460.3	828.6	412.9	743.3	399.2
205	12920	17.56	249.8	207.9	374.1	459.4	827.0	412.0	741.6	401.0
206	13180	17.92	254.9	208.9	376.0	458.6	825.4	411.1	740.0	402.8
207	13450	18.29	260.1	210.0	377.9	457.7	823.8	410.2	738.3	404.6
208	13730	18.66	265.4	211.0	379.8	456.8	822.2	409.3	736.7	406.4
209	14010	19.04	270.8	212.0	381.6	455.9	820.6	408.4	735.1	408.2
210	14290	19.43	276.3	213.1	383.5	455.0	819.1	407.5	733.6	410.0
211	14580	19.82	281.9	214.1	385.4	454.1	817.4	406.6	731.9	411.8
212	14870	20.22	287.6	215.2	387.3	453.2	815.8	405.7	730.2	413.6
213	15170	20.62	293.3	216.2	389.2	452.4	814.3	404.9	728.7	415.4
214	15470	21.03	299.2	217.3	391.1	451.5	812.7	404.0	727.1	417.2
215	15780	21.45	305.1	218.3	392.9	450.6	811.0	403.1	725.4	419.0
216	16090	21.88	311.1	219.3	394.8	449.6	809.3	402.1	723.7	420.8
217	16410	22.31	317.3	220.4	396.7	448.7	807.7	401.2	722.1	422.6
218	16730	22.74	323.5	221.4	398.5	447.8	806.1	400.3	720.5	424.4
219	17060	23.19	329.8	222.5	400.4	446.9	804.5	399.4	718.9	426.2
220	17390	23.64	336.2	223.5	402.3	446.0	802.9	398.5	717.3	428.0

(continued)

Metric and common units, 0° to 220°C

Temperature degrees C	Heat equivalent of external work		Entropy of the liquid	Entropy of evaporation	Specific volume		Density		Temperature degrees F
	kg cal	Btu			m^3/kg	ft^3/lb	kg/m^3	lb/ft^3	
t	Apu	Apu	θ	$\frac{r}{T}$	s	s	$\frac{1}{s}$	$\frac{1}{s}$	t
170	45.9	82.6	.4880	1.1029	.2423	3.883	4.127	.2575	338.0
171	46.0	82.7	.4903	1.0987	.2368	3.794	4.223	.2636	339.8
172	46.0	82.8	.4926	1.0944	.2314	3.709	4.322	.2696	341.6
173	46.1	82.9	.4949	1.0901	.2262	3.626	4.421	.2758	343.4
174	46.1	83.0	.4972	1.0859	.2212	3.545	4.521	.2821	345.2
175	46.2	83.1	.4995	1.0817	.2164	3.467	4.621	.2884	347.0
176	46.2	83.2	.5018	1.0775	.2117	3.391	4.724	.2949	348.8
177	46.3	83.3	.5041	1.0733	.2072	3.318	4.826	.3014	350.6
178	46.3	83.4	.5064	1.0691	.2027	3.247	4.933	.3080	352.4
179	46.4	83.5	.5087	1.0649	.1983	3.177	5.04	.3148	354.2
180	46.4	83.6	.5110	1.0608	.1941	3.109	5.15	.3217	356.0
181	46.5	83.7	.5133	1.0567	.1899	3.041	5.27	.3288	357.8
182	46.5	83.8	.5156	1.0525	.1857	2.974	5.38	.3362	359.6
183	46.6	83.8	.5178	1.0484	.1817	2.911	5.50	.3435	361.4
184	46.6	83.9	.5201	1.0443	.1778	2.849	5.62	.3510	363.2
185	46.7	84.0	.5224	1.0403	.1740	2.787	5.75	.3588	365.0
186	46.7	84.1	.5246	1.0362	.1702	2.727	5.88	.3667	366.8
187	46.8	84.2	.5269	1.0321	.1666	2.669	6.00	.3746	368.6
188	46.8	84.3	.5291	1.0280	.1632	2.614	6.13	.3826	370.4
189	46.9	84.3	.5314	1.0240	.1598	2.560	6.26	.3906	372.2
190	46.9	84.4	.5336	1.0200	.1565	2.507	6.39	.3989	374.0
191	47.0	84.5	.5358	1.0160	.1533	2.456	6.52	.4072	375.8
192	47.0	84.6	.5381	1.0120	.1501	2.405	6.66	.4158	377.6
193	47.0	84.6	.5403	1.0080	.1470	2.355	6.80	.4246	379.4
194	47.0	84.7	.5426	1.0040	.1440	2.306	6.94	.4336	381.2
195	47.1	84.8	.5448	1.0000	.1411	2.259	7.09	.4426	383.0
196	47.1	84.9	.5470	.9961	.1382	2.214	7.23	.4516	384.8
197	47.2	84.9	.5492	.9922	.1354	2.169	7.38	.4610	386.6
198	47.2	85.0	.5514	.9882	.1327	2.126	7.53	.4704	388.4
199	47.3	85.1	.5536	.9843	.1300	2.083	7.69	.4801	390.2
200	47.3	85.1	.5558	.9804	.1274	2.041	7.84	.4900	392.0
201	47.3	85.2	.5580	.9765	.1249	2.001	8.00	.4998	393.8
202	47.3	85.2	.5602	.9727	.1225	1.962	8.16	.510	395.6
203	47.4	85.3	.5624	.9688	.1201	1.923	8.33	.520	397.4
204	47.4	85.3	.5646	.9650	.1177	1.885	8.50	.531	399.2
205	47.4	85.4	.5668	.9611	.1153	1.847	8.67	.541	401.0
206	47.5	85.4	.5690	.9572	.1130	1.810	8.85	.552	402.8
207	47.5	85.5	.5712	.9534	.1108	1.774	9.03	.564	404.6
208	47.5	85.5	.5733	.9496	.1086	1.739	9.21	.575	406.4
209	47.5	85.5	.5755	.9458	.1065	1.705	9.39	.587	408.2
210	47.5	85.5	.5777	.9420	.1044	1.673	9.58	.598	410.0
211	47.5	85.5	.5799	.9382	.1024	1.640	9.77	.610	411.8
212	47.5	85.6	.5820	.9344	.1004	1.608	9.96	.622	413.6
213	47.5	85.6	.5842	.9307	.0984	1.577	10.16	.634	415.4
214	47.5	85.6	.5863	.9269	.0965	1.546	10.36	.647	417.2
215	47.5	85.6	.5885	.9232	.0947	1.516	10.56	.660	419.0
216	47.5	85.6	.5906	.9195	.0928	1.486	10.78	.673	420.8
217	47.5	85.6	.5927	.9157	.0910	1.458	10.99	.686	422.6
218	47.5	85.6	.5948	.9120	.0893	1.430	11.20	.699	424.4
219	47.5	85.6	.5969	.9084	.0876	1.403	11.41	.713	426.2
220	47.5	85.6	.5991	.9047	.0860	1.376	11.62	.727	428.0

TABLE 167.—PROPERTIES OF SATURATED STEAM

Common units, 400° to 700°F

Abridged from Steam tables and Mollier's diagram, by Keenan. Printed by permission of the publisher, The American Society of Mechanical Engineers. For detailed discussion see Mechanical Engineering, February, 1929, v, specific vol., ft³/lb; h, total heat, enthalpy, Btu/lb; s, entropy, Btu lb^{-1} $°F^{-1}$. The strict definition of total heat (internal energy + $144/J$) is adhered to; zeros of both h and s are arbitrarily placed on the sat. liq. line at 32°F. No internal energy values are tabulated but may be easily found by subtracting 144 pv/J from the total heat. The energy unit, the Btu, is 778.57 ft-lb (J) is 1/180 of the change in total heat along the saturated liquid line between 32° and 212°F.

		Specific volume			Total heat			Entropy		
Temp. °F t	Abs. p. lb/in.²	Sat. liq. v_f	Evap. v_{fg}	Sat. vapor v_g	Sat. liq. h_f	Evap. h_{fg}	Sat. vap. h_g	Sat. liq. s_f	Evap. s_{fg}	Sat. vapor s_g
400	247.25	.01865	1.8421	1.8608	375.0	826	1200	.5668	.9602	1.5270
405	261.67	.01873	1.7428	1.7615	380.4	821	1201	.5730	.9491	1.5221
410	276.72	.01880	1.6493	1.6681	385.9	816	1202	.5792	.9381	1.5173
415	292.44	.01888	1.5615	1.5804	391.3	811	1202	.5854	.9271	1.5125
420	308.82	.01896	1.4792	1.4982	396.8	806	1203	.5916	.9161	1.5077
425	325.91	.01904	1.4022	1.4212	402.4	801	1203	.5978	.9052	1.5029
430	343.71	.01911	1.3295	1.3486	407.9	796	1203	.6039	.8942	1.4982
435	362.27	.01919	1.2610	1.2802	413.5	790	1204	.6101	.8833	1.4934
440	381.59	.01928	1.1965	1.2158	419.1	785	1204	.6162	.8724	1.4887
445	401.70	.01936	1.1356	1.1550	424.7	779	1204	.6224	.8616	1.4839
450	422.61	.0195	1.0782	1.0977	430	774	1204	.6284	.8507	1.4792
455	444.35	.0195	1.0241	1.0436	436	768	1204	.6346	.8398	1.4744
460	466.94	.0196	.9730	.9927	442	762	1204	.6407	.8290	1.4696
465	490.40	.0197	.9249	.9446	447	756	1204	.6468	.8180	1.4649
470	514.76	.0198	.8793	.8991	453	750	1204	.6530	.8071	1.4601
475	540.04	.0199	.8361	.8560	459	744	1203	.6592	.7962	1.4554
480	566.26	.0200	.7951	.8151	465	738	1203	.6654	.7852	1.4506
485	593.47	.0201	.7563	.7764	471	731	1202	.6716	.7742	1.4458
490	621.67	.0202	.7195	.7398	477	725	1202	.6779	.7632	1.4410
495	650.87	.0204	.6847	.7050	483	718	1201	.6842	.7521	1.4362
500	681.09	.0205	.6516	.6721	489	711	1200	.6904	.7410	1.4314
505	712.40	.0206	.6201	.6408	495	704	1199	.6968	.7299	1.4266
510	744.74	.0207	.5903	.6110	502	697	1198	.7031	.7187	1.4218
515	778.16	.0209	.5618	.5826	508	690	1197	.7094	.7075	1.4170
520	812.72	.0210	.5347	.5557	514	682	1196	.7158	.6963	1.4121
525	848.43	.0211	.5090	.5301	521	675	1195	.7222	.6851	1.4073
530	885.31	.0213	.4845	.5058	527	667	1193	.7286	.6738	1.4024
535	923.39	.0214	.4614	.4828	533	659	1192	.7350	.6625	1.3975
540	962.73	.0216	.4394	.4610	540	651	1191	.7414	.6512	1.3926
545	1003.4	.0218	.4184	.4401	547	643	1189	.7478	.6399	1.3877
550	1045.4	.0219	.3982	.4201	553	634	1188	.7543	.6285	1.3828
555	1088.7	.0221	.3789	.4010	560	626	1186	.7607	.6170	1.3778
560	1133.4	.0223	.3605	.3828	567	618	1184	.7672	.6056	1.3728
565	1179.7	.0225	.3429	.3654	574	609	1182	.7737	.5940	1.3677
570	1227.6	.0227	.3261	.3488	580	600	1180	.7802	.5825	1.3626
575	1276.7	.0229	.3101	.3330	587	591	1178	.7867	.5709	1.3576
580	1327.2	.0231	.2949	.3180	594	581	1176	.7932	.5592	1.3524
585	1379.2	.0234	.2804	.3037	602	572	1173	.7998	.5474	1.3472
590	1432.7	.0236	.2664	.2900	609	562	1171	.8064	.5356	1.3420
595	1487.8	.0239	.2530	.2769	616	552	1168	.8131	.5237	1.3368
600	1544.6	.0241	.2401	.2642	623	542	1166	.8198	.5118	1.3316
610	1663.2	.0247	.2159	.2406	638	521	1160	.8332	.4875	1.3208
620	1788.8	.0254	.1933	.2186	653	499	1153	.8470	.4623	1.3093
630	1921.9	.0261	.1721	.1982	670	475	1144	.8612	.4358	1.2970
640	2062.8	.0269	.1522	.1791	687	448	1135	.8763	.4073	1.2836
650	2211.4	.0278	.1331	.1610	705	417	1122	.8924	.3764	1.2688
660	2368.6	.0290	.1148	.1437	725	384	1109	.9097	.3426	1.2523
670	2534.2	.0304	.0966	.1269	748	344	1092	.9287	.3049	1.2336
680	2709.7	.0322	.0781	.1102	773	299	1071	.9499	.2619	1.2119
690	2896.8	.0347	.0589	.0936	803	241	1044	.9755	.2098	1.1852
700	3096.4	.0394	.0353	.0747	846	157	1003	1.0117	.1354	1.1471
705	3202.0	.0462	.0135	.0597	888	73	962	1.0472	.0630	1.1102
706.1	3226.0	.0522	0	.0522	925	0	925	1.0785	0	1.0785

TABLE 168.—PROPERTIES OF SUPERHEATED STEAM *

Common units, 212° to 3000°F

Abs. P. lb/in.[2] (Sat. t. °F)		Sat. water	Sat. steam	200 °F	300 °F	400 °F	500 °F	600 °F	700 °F	800 °F	900 °F	1000 °F
	v	.02	26.82	27.16	30.52	34.65	38.75	42.83	46.91	50.97	55.03	59.09
14.696	h	180.0	1150.2	1154.	1192.	1239.	1286.	1334.	1382.	1432.	1483.	1535.
(212.00)	s	.3119	1.7564	1.762	1.815	1.873	1.925	1.972	2.016	2.057	2.096	2.133
		.017	8.514	v	8.78	10.06	11.30	12.53	13.74	14.93	16.14	17.34
50		250.0	1173.5	h	1184.	1234.	1283.	1331.	1381.	1431.	1482.	1534.
(281.01)		.4111	1.6580	s	1.672	1.734	1.787	1.836	1.880	1.922	1.961	1.998
		.018	4.426	v	....	4.93	5.58	6.21	6.83	7.44	8.04	8.64
100		298.3	1186.6	h	....	1227.	1278.	1328.	1378.	1429.	1481.	1533.
(327.83)		.4742	1.6022	s	....	1.651	1.708	1.757	1.802	1.844	1.884	1.921
		.018	3.010	v	....	3.22	3.68	4.11	4.53	4.94	5.34	5.75
150		330.4	1194.	h	....	1219.	1273.	1324.	1376.	1427.	1479.	1532.
(358.43)		.5140	1.569	s	....	1.599	1.659	1.710	1.756	1.799	1.838	1.876
		.018	2.285	v	....	2.358	2.722	3.06	3.38	3.69	4.00	4.30
200		355.	1198.	h	....	1210.	1268.	1321.	1373.	1426.	1478.	1531.
(381.82)		.543	1.545	s	....	1.559	1.623	1.676	1.723	1.766	1.806	1.8438
		.0189	1.541	v	....	....	1.765	2.002	2.224	2.438	2.646	2.849
300		394.	1202.	h	....	....	1257.	1313.	1368.	1422.	1475.	1529.
(417.33)		.5883	1.510	s	....	....	1.569	1.626	1.675	1.719	1.760	1.798
		.0194	1.160	v	....	....	1.283	1.474	1.647	1.812	1.970	2.125
400		424.	1204.	h	....	....	1244.	1306.	1362.	1418.	1472.	1527.
(444.58)		.622	1.484	s	....	....	1.528	1.588	1.640	1.685	1.727	1.766
		.0198	.926	v = sp. vol.			.991	1.156	1.301	1.436	1.566	1.690
500		450.	1204.	h = total heat			1230.	1297.	1357.	1414.	1469.	1525.
		.649	1.463	s = entropy			1.491	1.558	1.611	1.659	1.701	1.740

Abs. P. lb/in.[2] (Sat. t. °F)	Sat. water	Sat. steam	500 °F	550 °F	600 °F	650 °F	700 °F	750 °F	800 °F	850 °F	900 °F	950 °F	1000 °F
	.0202	.768	.792	.873	.943	1.008	1.069	....	1.186	v	1.295	....	1.400
600	472.	1202.	1215.	1255.	1289.	1320.	1351.	....	1409.	h	1466.	....	1523.
(486.17)	.673	1.445	1.458	1.499	1.532	1.561	1.587	....	1.636	s	1.679	....	1.720
	.0206	.653	v	.725	.791	.849	.904	....	1.006	....	1.103	....	1.193
700	493.	1200.	h	1242.	1280.	1313.	1345.	....	1405.	....	1463.	....	1521.
(503.04)	.694	1.429	s	1.472	1.508	1.539	1.567	....	1.617	....	1.661	....	1.702
	.0209	.565	v	.613	.675	.729	.779	....	.872	.916	.958	.998	1.037
800	512.	1197.	h	1229.	1270.	1305.	1338.	....	1400.	1430.	1460.	1489.	1519.
(518.18)	.714	1.414	s	1.446	1.486	1.519	1.548	....	1.599	1.623	1.645	1.666	1.686
	.0213	.497	v	.523	.584	.636	.682	....	.768	.807	.845	.882	.917
900	530.	1193.	h	1214.	1260.	1297.	1332.	....	1396.	1427.	1457.	1487.	1517.
(531.95)	.731	1.401	s	1.421	1.466	1.500	1.530	....	1.583	1.607	1.630	1.652	1.672
	.0217	.442	v	.450	.511	.560	.604	.645	.684	.720	.755	.788	.820
1000	546.	1190.	h	1197.	1249.	1289.	1325.	1358.	1391.	1423.	1454.	1484.	1515.
(544.58)	.747	1.388	s	1.395	1.446	1.483	1.514	1.538	1.569	1.593	1.617	1.639	1.660
	.0239	.274	....	v	.279	.330	.368	.401	.432	.459	.484	.508	.530
1500	618.	1168.	....	h	1174.	1240.	1287.	1327.	1365.	1402.	1438.	1472.	1505.
596.08)	.815	1.336	....	s	1.342	1.403	1.444	1.478	1.509	1.537	1.564	1.589	1.612
	.0265	.188	....	....	v	.204	.247	.278	.305	.327	.349	.367	.384
2000	679.	1139.	....	....	h	1169.	1241.	1291.	1337.	1380.	1421.	1459.	1495.
(635.61)	.870	1.290	....	....	s	1.317	1.389	1.423	1.460	1.493	1.524	1.552	1.577
	.0301	.130	....	....	....	v	.168	.202	.227	.248	.267	.282	.298
2500	743.	1096.	....	....	....	h	1178.	1250.	1306.	1357.	1404.	1446.	1484.
(667.98)	.925	1.238	....	....	....	s	1.310	1.371	1.416	1.456	1.491	1.521	1.548
	.0367	.084	....	....	....	v	.0983	.1476	.1742	.1947	.212	.227	.240
3000	823.	1026.	....	....	....	h	1066.	1199.	1271.	1331.	1384.	1432.	1473.
(695.25)	.992	1.168	....	....	....	s	1.203	1.316	1.374	1.420	1.460	1.494	1.523

* Abridged from Steam tables and Mollier's diagram, by Keenan, 1930. Printed by permission of publisher, The American Society of Mechanical Engineers.

402° to 1000° F

Pressure (abs.) lb/in.²	Temperature °F	Heat of liquid above 32 °F Btu	Heat of vaporization Btu	Total heat Btu	Entropy of liquid above 32 °F	Entropy of vaporization	Total entropy	Specific volume ft³/lb	Weight lb/ft³
.4	402	13.81	128.15	141.96	.0209	.1487	.1696	114.50	.008733
.8	444	15.36	127.24	142.60	.0227	.1408	.1635	59.72	.016745
1.0	458	15.89	126.92	142.81	.0233	.1383	.1616	48.45	.02064
1.5	485	16.90	126.33	143.23	.0244	.1337	.1581	33.14	.03017
2.0	505	17.65	125.89	143.54	.0251	.1305	.1556	25.32	.03948
4.0	558	19.62	124.72	144.34	.0271	.1226	.1497	13.26	.07540
6.0	591	20.87	123.99	144.86	.0283	.1179	.1462	9.096	.10993
8.0	617	21.81	123.43	145.24	.0292	.1147	.1439	6.9630	.14361
10.0	637	22.58	122.98	145.56	.0299	.1121	.1420	5.6610	.17664
15.0	676	24.04	122.12	146.16	.0312	.1075	.1387	3.8923	.25691
20.0	706	25.15	121.46	146.61	.0322	.1042	.1364	2.983	.3352
25.0	730	26.05	120.93	146.98	.0330	.1016	.1346	2.429	.4117
30.0	751	26.81	120.48	147.29	.0336	.0995	.1331	2.053	.4871
35.0	769	27.49	120.08	147.57	.0342	.0977	.1319	1.7815	.5613
40.0	785	28.08	119.73	147.81	.0346	.0962	.1308	1.5762	.6344
45.0	799	28.62	119.42	148.04	.0351	.0949	.1300	1.4147	.7069
50	812	29.11	119.13	148.24	.0355	.0936	.1291	1.284	.7788
60	836	29.99	118.61	148.60	.0361	.0915	.1276	1.086	.9204
70	857	30.75	118.15	148.90	.0367	.0898	.1265	.9436	1.0597
80	875	31.44	117.75	149.19	.0372	.0882	.1254	.8349	1.1977
90	892	32.06	117.38	149.44	.0377	.0870	.1247	.7497	1.3338
100	907	32.63	117.05	149.68	.0381	.0856	.1237	.6811	1.4682
110	921	33.16	116.74	149.90	.0385	.0845	.1230	.6242	1.6020
120	934	33.66	116.44	150.10	.0389	.0835	.1224	.5767	1.7340
130	947	34.12	116.17	150.29	.0392	.0826	.1218	.5360	1.8656
140	958	34.55	115.92	150.47	.0395	.0818	.1213	.5012	1.9952
150	969	34.96	115.67	150.63	.0398	.0809	.1207	.4706	2.125
180	1000	36.09	115.01	151.10	.0406	.0788	.1194	.3990	2.506

TABLE 170.—PROPERTIES OF LIQUID AMMONIA

−100° to +250°F

	Saturation						Latent heat of pressure variation Btu/lb / lb/in.²	Variation of h with p, t constant Btu/lb / lb/in.²	Compressibility per lb/in.² × 10⁶
Temp. °F	Pressure (abs.) lb/in.²	Volume ft³/lb	Density lb/ft³	Specific heat Btu/lb °F	Heat content Btu/lb	Latent heat Btu/lb			
t	p	v	$\frac{1}{v}$	c	h	L	l	$\left(\frac{\partial h}{\partial p}\right)_t$	$-\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_t$
−100	1.24	.02197	45.52	(1.040)	(−63.0)	(633)			
− 90	1.86	.02216	45.12	(1.043)	(−52.6)	(628)			
− 80	2.74	.02236	44.72	(1.046)	(−42.2)	(622)			
− 70	3.94	.02256	44.32	(1.050)	(−31.7)	(616)			
− 60	5.55	.02278	43.91	1.054	−21.18	610.8	−.0016	.0026	4.4
− 50	7.67	.02299	43.49	1.058	−10.61	604.3	−.0017	.0026	4.6
− 40	10.41	.02322	43.08	1.062	.00	597.6	−.0018	.0025	4.8
− 30	13.90	.02345	42.65	1.066	+10.66	590.7	−.0019	.0025	5.1
− 20	18.30	.02369	42.22	1.070	+21.36	583.6	−.0020	.0024	5.4
− 10	23.74	.02393	41.78	1.075	32.11	576.4	−.0021	.0023	5.7
0	30.42	.02419	41.34	1.080	42.92	568.9	−.0022	.0022	6.0
+ 10	38.51	.02446	40.89	1.085	53.79	561.1	−.0024	.0021	6.4
+ 20	48.21	.02474	40.43	1.091	64.71	553.1	−.0025	.0020	6.8
30	59.74	.02503	39.96	1.097	75.71	544.8	−.0027	.0019	7.3
40	73.32	.02533	39.49	1.104	86.77	536.2	−.0029	.0018	7.8
50	89.19	.02564	39.00	1.112	97.93	527.3	−.0031	.0017	8.4
60	107.6	.02597	38.50	1.120	109.18	518.1	−.0033	.0015	9.1
70	128.8	.02632	38.00	1.129	120.54	508.6	−.0035	.0013	10.0
80	153.0	.02668	37.48	1.138	131.99	498.7	−.0038	.0011	10.9
90	180.6	.02707	36.95	1.147	143.54	488.5	−.0041	.0009	12.0
+100	211.9	.02747	36.40	1.156	155.21	477.8	−.0045	.0006	13.3
125	307.8	.02860	34.96	(1.189)	(185)	(449)			
150	433.2	.02995	33.39	(1.23)	(216)	(416)			
175	593.5	.03160	31.65	(1.29)	(248)	(377)			
200	794.7	.03375	29.63	(1.38)	(283)	(332)			
250	1347	.0422	23.7	(1.90)	(365)	(192)			

TABLE 171.—COMBUSTION CONSTANTS OF SOME SUBSTANCES[52]

Substance	Formula	Reciprocal of density m³/100 kg	Spec. gravity air = 1.000	Heat of combustion Btu/ft³	Heat of combustion kg cal/m³
Carbon	C	....	....	....	7840.*
Hydrogen	H_2	1172.	6.959×10^{-2}	275.0	2445.
Oxygen	O_2	73.7	1.1053	....	....
Carbon monoxide	CO	84.4	.9672	321.8	2860.
Paraffin series: C_nH_{2n+2}					
Methane	CH_4	147.0	.5543	913.1	8120.
Ethane	C_2H_6	77.6	1.04882	1641.	14,600
Propane	C_3H_8	52.2	1.5617	2385.	21,200
Isobutane	C_4H_{10}	39.5	2.06654	3105.	27,600
Olefin series: C_nH_{2n}					
Ethylene	C_2H_4	83.6	.9740	1513.2	13,450
Propylene	C_3H_6	56.3	1.4504	2186.	19,400
Isobutene	C_4H_8	42.2	1.9336	2869.	25,500
Aromatic series: C_nH_{2n-6}					
Benzene	C_6H_6	30.3	2.6920	3601.	32,000
Toluene	C_7H_8	25.6	3.1760	4284.	38,100
Xylene	C_8H_{10}	22.2	3.6618	4980.	44,300
Miscellaneous gases					
Acetylene	C_2H_2	89.5	.9107	1448.	12,870
Naphthalene	$C_{10}H_8$	18.4	4.4208	5654.	50,300
Methyl alcohol	CH_3OH	73.7	1.1052	768.0	6830.
Ethyl alcohol	C_2H_5OH	51.3	1.5890	1450.5	12,900
Ammonia	NH_3	136.5	.5961	365.1	3245.
Sulfur	S	....	....	....	2210.*
Hydrogen sulfide	H_2S	68.5	1.1898	596.	5300.

[52] Shnidman, Louis (ed.), Gaseous fuels, p. 118, Amer. Gas Assoc., 1948.
* Expressed in cal/g.

TABLE 172.—FLAME TEMPERATURES AS MEASURED BY VARIOUS METHODS *

Gas	Burner	Temp °C
Amyl acetate	Bunsen	1420
	Meker (center flame)	1700
	(edge of flame)	1850
Propane	Meker	1680
City gas	Bunsen	1760
City gas + air	Blast	1950
City gas + oxygen	"	2300
Carbon monoxide + air	"	1985
16% [methane (CH_4)] + air	"	1880
10% (90 CH_4 + 10% 0) + air	"	1905
16% (80 CH_4 + 20% 0) + air	"	1975
10.8% (75 CH_4 + 25% 0) + air	"	2005
22% (60 CH_4 + 40 H_2) + air	"	1910
32% (26 CH_4 + 94 H_2) + air	"	2015
H_2 + air	"	2045
9% (80 CH_4 + 20 C_2H_2) + air	"	1970
(15 CH_4 + 85 C_2H_2) + air	"	2275
Pittsburgh natural gas with air	"	1950
Butane-air	"	2000
Oxy-hydrogen	"	2800
Oxy-acetylene	"	3500

* See also Table 175.

TABLE 173.—HEATS OF COMBUSTION OF SOME CARBON COMPOUNDS[53]

Given in kg cal_{16} at constant pressure per gram-molecular weight in vacuo. When referred to constant volume the values should be 0.58 kg cal_{15} smaller (at about 18°C) for each condensed gaseous molecule. Combustion products are CO_2, liquid H_2O, etc. Benzoic acid was adopted at Lyons as a primary standard, its heat of combustion, 6324 g cal_{15} per gram in air, 6319 in vacuo. This is tacitly assumed as heat of isothermal combustion at 20°C. In absolute joules, 26,466 and 26,445 respectively. The following ratios may be taken as standard: Naphthalene/benzoic acid = 1.5201 (air); benzoic acid/sucrose = 1.6028 (air); naphthalene/sucrose = 2.4364 (air).

Compound	Formula	Molecular weight	kg cal_{16} per g mol
Isobutane (g)	C_4H_{10}	58	683.4
n-Hexane	C_6H_{14}	86.11	990.6
n-Heptane	C_7H_{16}	100.13	1143.6
n-Octane	C_8H_{18}	114.14	1304.2
Decane	$C_{10}H_{22}$	142.18	1610.2
Hexadecane (s)	$C_{16}H_{34}$	226.27	2559.1
Eicosane (s)	$C_{20}H_{42}$	282.34	3183.1
Amylene	C_5H_{10}	70	803.4
Hexylene	C_6H_{12}	84.10	952.6
Acetylene (g)	C_2H_2	26.02	312.0
Allylene (g)	C_3H_4	40	469
Trimethylene (g)	C_3H_6	42	496.8
Benzene	C_6H_6	78.05	782.8
Naphthalene (s)	$C_{10}H_8$	128.06	1231.4
Methyl-chloride (g)	CH_3Cl	50.5	168.7
Methylene-chloride (v)	CH_2Cl_2	85.0	106.8
Chloroform (l)	$CHCl_3$	119.5	89.2
" (v)	"	"	70.3
Carbon-tetrachloride (l)	CCl_4	154.0	37.3
Carbon-tetrachloride (v)	"	"	44.5
Carbon di-sulfide (l)	CS_2	76.0	394.5
" " (v)	"	"	246.6
Allyl alcohol	C_3H_6O	58.05	442.4
Formaldehyde (g)	CH_2O	30.02	134.1
Acetone (v)	C_3H_6O	58	435.8
Camphor (s)	$C_{10}H_{16}O$	152.13	1411
Sucrose: cane (s)	$C_{12}H_{22}O_{11}$	342.18	1349.6
milk (s), anhd.	"	"	1350.8
malt (s)	"	"	1351

Compound	Formula	Molecular weight	kg cal_{16} per g mol
Starch			4178.8
Glycogen			4186.8
Cellulose			4180.8
Formic acid	CH_2O_2	46.02	62.8
Acetic "	$C_2H_4O_2$	60.03	208.2
Propionic acid	$C_3H_6O_2$	74.05	367.2
n-butyric "	$C_4H_8O_2$	88.06	524.3
n-valeric "	$C_6H_{10}O_2$	102.08	681.6
Palmitic " (s)	$C_{16}H_{32}O_2$	256.26	2391
Stearic " (s)	$C_{18}H_{36}O_2$	284.29	2700
Lactic " (s)	$C_3H_6O_3$	90.05	326.0
Aniline	C_6H_7O	60.05	151.6
Urea (s)	CH_4N_2O	60.05	151.6
Nicotine	$C_{10}H_{14}N_2$	162.13	1427.7
Cyanogen (g)	C_2N_2	52.0	260.0
Trinitrotoluene (s)	$C_7H_6N_3O_6$	227.06	826
n-propyl "	C_3H_8O	60.06	482.0
n-butyl "	$C_4H_{10}O$	74.08	639.4
n-heptyl "	$C_7H_{16}O$	116.13	1104.9
Octyl "	$C_8H_{18}O$	130.14	1262.0
Cetyl " (s)	$C_{16}H_{34}O$	242.27	2504.5
Menthol (s)	$C_{10}H_{20}O$	156.16	1508.8
Phenol (s)	C_6H_6O	94.05	732.2
Thymol	$C_{10}H_{14}O$	150.11	1353.4
Dimethyl ether (g)	C_2H_6O	46	347.6
Methylethyl " (v)	C_3H_8O	60	503.4
Diethyl " (v)	$C_4H_{10}O$	74.08	660.3

[53] Karasch, Nat. Bur. Standards Journ. Res., vol. 2, p. 359, 1929.

TABLE 174.—HEATS OF COMBUSTION OF MISCELLANEOUS COMPOUNDS

Substance	Calories per g substance
Asphalt	9530
Butter	9200
Carbon: amorphous	8080
charcoal	8100
diamond	7860
graphite	7900
Copper (to CuO)	590
Dynamite, 75%	1290
Egg, white of	5700
Egg, yolk of	8100
Fats, animal	9500
Hemoglobin	5900
Hydrogen	33900
Iron (to Fe_2O_3)	1582
Magnesium (to MgO)	6080
Oils: cotton-seed	9500
lard	9300
olive	9400

Substance	Calories per g substance
Oils:	
petroleum:	
crude	11500
light	10000
heavy	10200
rape	9500
sperm	10000
Paraffin (to CO_2, H_2O l)	11140
Paraffin (to CO_2, H_2O g)	10340
Pitch	8400
Sulfur, rhombic	2200
Sulfur, monoclinic	2240
Tallow	9500
Woods: beech, 13% H^2O	4170
birch, 12% H_2O	4210
oak, 13% H_2O	3990
pine, 12% H_2O	4420

Part 1.—Coals

Coal		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Cal/g	Btu/lb
Lignite	Low grade	38.81	25.48	27.29	8.42	.97	7.09	37.45	.50	45.57	3526	6347
	High grade	33.38	27.44	29.62	9.56	.94	6.77	41.31	.67	40.75	3994	7189
Sub-bituminous	Low grade	22.71	34.78	36.60	5.91	.29	6.14	52.54	1.03	34.09	5115	9207
	High grade	15.54	33.03	46.06	5.37	.58	5.89	60.08	1.05	27.03	5865	10557
Bituminous	Low grade	11.44	33.93	43.92	10.71	4.94	5.39	60.06	1.02	17.88	6088	10958
	High grade	3.42	34.36	58.83	3.39	.58	5.25	77.98	1.29	11.51	7852	14134
Semi-bituminous	Low grade	2.7	14.5	75.5	7.3	.99	4.58	80.65	1.82	4.66	7845	14121
	High grade	3.26	14.57	78.20	3.97	.54	4.76	84.62	1.02	5.09	8166	14699
Semi-anthracite		2.07	9.81	78.82	9.30	1.74	3.62	80.28	1.47	3.59	7612	13702
Anthracite	Low grade	2.76	2.48	82.07	12.69	.54	2.23	79.22	.68	4.64	6987	12577
	High grade	3.33	3.27	84.28	9.12	.60	3.08	81.35	.79	5.06	7417	13351
Oven coke	Low grade	1.92	1.58	88.87	8.99	1.18	—	—	—	—	7946	14300
	High grade	1.14	.04	94.66	3.57	.69	—	—	—	—	8006	14410

Part 2.—Peats and Woods (air dried)

	Vol. hydrocarbon	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories per g	Btu per pound
Peats:										
Franklin County, N. Y.	67.10	28.99	3.91	.15	5.93	57.17	1.48	31.36	5726	10307
Sawyer County, Wis.	56.54	27.92	15.54	.29	4.71	51.00	1.92	26.54	4867	8761
Woods:										
Oak, dry	—	—	.37	—	6.02	50.16	.09	43.36	4620	8316
Birch, dry	—	—	.29	—	6.06	48.88	.10	44.67	4771	8588
Pine, dry	—	—	.37	—	6.20	50.31	.04	43.08	5085	9153

Part 3.—Liquid fuels *

Fuel	Gravity API †	Btu per pound	Btu per gallon
Aviation gasoline	68	20,420	120,700
Motor gasoline	58	20,120	125,800
Kerosene	42	19,810	134,700
Domestic fuel oil	32	19,450	141,200
Diesel fuel oil	28	19,350	143,100
Medium industrial fuel oil	18	18,930	149,400
Heavy industrial fuel oil	11	18,590	153,900
Petroleum ether	.68‡	22,000	12,220§
Alcohol, fuel or denatured with 7-9% water and denaturing material	.82‡	11,600	6,450§

* Prepared by E. W. Dean, Standard Oil Co. of New Jersey. † API (American Petroleum Industry) unit $= \frac{141.5}{\text{sp.g.}60°/60°} - 131.5$. ‡ Spec. gravity 15°C. § Calories per gram.

(continued)

TABLE 175.—HEAT VALUES AND ANALYSES OF VARIOUS FUELS (concluded)

Part 4.—Gases **

Substance	Spec. gravity Air = 1.000	Heat of combustion kg cal/m³	Flame temperature °C (no excess air)
Natural gas	.60–1.29	8040–17,400	1965
Propane (commercial) natural gas	1.55	20,950	2015
Propane (commercial) refinery gas	1.77	20,600	—
Butane (commercial) natural gas	2.04	26,350	2005
Butane (commercial) refinery gas	2.00	26,100	—
Butane-air	1.16	4590.	—
Oil gas	.37	4535.	2000
Coal gas	.47	4320.	1980
Producer gas	.86	1182.	1655
Blue gas	.57	2330.	—

** For reference, see footnote 52, p. 179.

Part 5.—Gross calorific values of crude petroleum [54]

Area	Density 20°/4°C	Btu/lb	Cal/g	Area	Density 20°/4°C	Btu/lb	Cal/g
Borneo	.898	19,370	10,760	California	.960	18,590	10,330
India	.863	18,800	10,490	Ohio	.838	19,710	10,950
Japan	.925	20,670	11,480	Oklahoma	.886	19,420	10,790
Poland	.899	20,010	11.120	Pennsylvania	.828	19,780	10,990
Rumania	.936	18,920	10,510	Texas	.943	18,950	10,520
Canada	.855	19,420	10,790	Argentina	.989	18,540	10,300
Mexico	.966	18,180	10,100	Patagonia	.948	18,970	10,540
Trinidad	.941	18,360	10,200				

[54] Science of Petroleum, vol. 2.

Part 6.—Sugars ¶

Sugar	kg cal/mol	Sugar	kg cal/mol
l-Sorbose	670.30	α-*d*-Glucose	669.58
β-*d*-Levulose	671.70	α-*d*-Glucose hydrate	666.73
α-*d*-Galactose	666.76	α-Monopalmitin	2778.78
β-Lactose	1345.47	β-Monopalmitin	2788.30
β-Maltose monohydrate	1360.50	Ascorbic acid	560.60
α-Lactose monohydrate	1354.66	α-D-Glucose pentaacetate	1718.62
Sucrose	1349.00	β-D-Glucose pentaacetate	1722.63

¶ Prepared by G. Stegeman, University of Pittsburgh.

Liquid	CCl_4	$CHCl_3$	4*	C_2H_5Br	32	39*	No. 40
Freezing point .... °C	—23	—63	—81	—119	—139	—145	—150±

Compositions: * No. 4; CCl_4, 49.4%; $CHCl_3$, 50.6%.
No. 32; $CHCl_3$, 19.7%; C_2H_5Br, 44.9%; $C_2H_2Cl_2$, 13.8%; C_2HCl_3, 21.6%.
No. 39; $CHCl_3$, 14.5%; C_2H_5Br, 33.4%; $C_2H_2Cl_2$, 10.4%; C_2HCl_3, 16.4%; CH_2Cl_2, 25.3%.
No. 40; $CHCl_3$, 17.9%; C_2H_5Cl, 9.3%; C_2H_5Br, 40.7%; $C_2H_2Cl_2$, 12.5%; C_2HCl_3, 19.6%.

Viscosities in centipoises:		—80°C	—90°	—100°	—110°	—120°	—130°	—140°	—145°	—150°
	C_2H_5Br	1.81	2.25	2.89	3.86	5.6	...	...	...	...
	No. 32	...	3.03	4.57	7.4	13.7	29.3	81	...	...
	No. 34	1.97	2.57	3.69	5.6	10	22.3	85	242	1480
	No. 40	...	2.88	3.89	5.9	10.2	22.5	71	170	631

* Because of volatility and oxidation of some, these liquids should be kept in well-stoppered bottles when not in use.

TABLE 177.—DATA ON EXPLOSIVES

Explosive	Vol. gas per g in cm³ = V	Calories per g = Q	Coefficient = QV ÷ 1000	Coefficient GP = 1	Calculated temperature Q/C C, sp. ht. gases = .24
Gunpowder	280	738	207	1	2240° C
Nitroglycerine	741	1652	1224	6	6880
Nitrocellulose, 13% N_2	923	931	859	4.3	3876
Cordite, Mk. I. (NG, 57; NC, 38; Vaseline, 5)	871	1242	1082	5.2	5175
Cordite, MD (NG, 30; NC, 65; Vaseline, 5)	888	1031	915	4.4	4225
Ballistite (NG, 50; NC, 50; Stabilizer, 5)	817	1349	1102	5.3	5621
Picric acid (Lyddite)	877	810	710	3.4	3375

Shattering power of explosive = vol. gas per g × cals/g × V_d × density where V_d is the velocity of detonation.

Trinitrotoluene: $V_d = 7000$ m/sec. Shattering effect = .87 picric acid.

Amatol (ammonium nitrate + trinitrotoluene, TNT): $V_d = 4500$ m/sec.

Ammonal (ammonium nitrate, TNT, Al): 1578 cal/g; 682 cm³ gas; $V_d = 4000$ m/sec.

Sabulite (ammonium nitrate, 78, TNT 8, Ca silicide 14): about same as ammonal.

TABLE 178.—TIME OF HEATING FOR EXPLOSIVE DECOMPOSITION

Temperature °C Time	170 sec	180 sec	190 sec	200 sec	220 sec	Ignition temperature °C †	 °C ‡
Black powder	*n*	*n*	*n*	*n*	*n*	440	—
Smokeless powder A	600	195	130	45	23	{300	—
Smokeless powder B	190	130	—	90	25		—
Celluloid pyroxylin	170	60	—	21	9	—	—
Collodion cotton	870	165	67	56	18	300	—
Celluloid *	160	100	60	50	30	590	450
Safety matches	*n*	340	240	150	60	—	—
Parlor matches	*n*	*n*	*n*	590	480	—	—
Cotton wool	—	—	—	—	—	900	—

n, failure to explode in twenty minutes.
* The decomposition of nitrocellulose in celluloid commences at about 100° C; above that the heat of decomposition may raise the mass to the ignition point if loss of heat is prevented. Above 170°, decomposition occurs with explosive violence as with nitrocellulose. Rate of combustion is 5 to 10 times that of poplar, pine, or paper of the same size and conditions. † Measured by contact with porcelain tube of given temperature. Average. ‡ Measured by contact with molten lead. Average.

TABLE 179.—CHEMICAL AND PHYSICAL PROPERTIES OF FIVE DIFFERENT CLASSES OF EXPLOSIVES

Explosive	Specific gravity	Number of large calories developed by 1 kg of the explosive	Pressure developed in own volume after elimination of surface influence	Unit disruptive charge by ballistic pendulum	Rate of detonation cartridges 1¼ in. diam.	Duration of flame from 100 g of explosive	Length of flame from 100 g	Cartridge 1¼ in. transmitted explosion at a distance of	Products of combustion from 200 g; gaseous, solid, and liquid, respectively	Ignition occurred in 4% fire damp & coal dust mixture with
			kg/cm²	g	m/sec	m/sec	In.	In.	g	g
(A) Forty percent nitroglycerin dynamite	1.22	1221.4	8235	227*	4688	.358	24.63	12	88.4 79.7 14.5	25
(B) FFF black blasting powder	1.25	789.4	4817	374† 458*	469.4‡	925.	54.32	—	154.4 126.9 4.1‖	25
(C) Permissible explosive; nitroglycerin class	1.10	760.5	5912	301*	3008	.471	27.79	4	103.9 65.1 15.4	1000
(D) Permissible explosive; ammonium nitrate class	.97	992.8	7300	279*	3438§	.483	25.68	1	89.8 27.5 75.5	800
(E) Permissible explosive; hydrated class	1.54	610.6	6597	434*	2479	.338	17.49	3	86.1 56.0 33.0	Over 1000

Chemical analyses

	Constituent	Percent
(A)	Moisture	.91
	Nitroglycerin	39.68
	Sodium nitrate	42.46
	Wood pulp	13.58
	Calcium carbonate	3.37
(B)	Moisture	.80
	Sodium nitrate	70.57
	Charcoal	17.74
	Sulfur	10.89
(C)	Moisture	7.89
	Nitroglycerin	24.02
	Sodium nitrate	36.25
	Wood pulp and crude fiber from grains	9.20
	Starch	21.31
	Calcium carbonate	.97
	Magnesium "	.36
(D)	Moisture	.23
	Ammonium nitrate	83.10
	Sulfur	.46
	Starch	2.61
	Wood pulp	1.89
	Poisonous matter	2.54
	Manganese peroxide	2.64
	Sand	6.53
(E)	Moisture	2.34
	Nitroglycerin	30.85
	Ammonium nitrate	9.94
	Sand	1.75
	Coal	11.98
	Clay	7.64
	Ammonium sulfate	8.96
	Zinc sulfate (7HO)	6.89
	Potassium sulfate	19.65

* One pound of clay tamping used. † Two pounds of clay tamping used. ‡ Rate of burning. § Cartridges 1⅜ in. diam. ‖ For 300 grams.

The total heat generated in a chemical reaction is independent of the steps from initial to final state. Heats of formation may therefore be calculated from steps chemically impracticable. Chemical symbols now represent the chemical energy in a gram-molecule or mol(c); treat reaction equations like algebraic equations: $CO + O = CO_2 + 68$ kg cal; subtract $C + 2\,O = CO_2 + 97$ kg cal, then $C + O = CO$ 29 kg cal. We may substitute the negative values of the formation heats in an energy equation and solve $MgCl_2 + 2\,Na = 2\,NaCl + Mg + x$ kg cal; $-151 = -196 + x$; $x = 45$ kg cal. Heats of formation of organic compounds can be found from the heats of combustion since burned to H_2O and CO_2. When changes are at constant volume, energy of external work is negligible; also generally for solid or liquid changes in volume. When a gas forms a solid or liquid at constant pressure, or vice versa, it must be allowed for. For N mols of gas formed (disappearing) at $T_K°$ the energy of the substance is decreased (increased) by $0.002 \cdot N \cdot T_K$ kg cal $H_2 + O = H_2O + 67.5$ kg cal at 18°C at constant volume; $\frac{1}{2}(2\,H_2 + O_2 - 2\,H_2O = 135.0 + 0.002 \times 3 \times 291 = 136.7) = 68.4$ kg cal.

The heat of solution is the heat, + or —, liberated by the solution of 1 mol of substance in so much water that the addition of more water will produce no additional heat effects. Aq signifies this amount of water; H_2O, one mol; $NH_3 + Aq = NH_4OH \cdot Aq + 8$ kg cal.

Part 1.—Heats of formation from elements in kilogram-calories

At ordinary temperatures

Compound	Heat of formation	Compound	Heat of formation	Compound	Heat of formation	Compound	Heat of formation
Al_2O_3	380.	HgO	21.4	KCl	105.7	Li_2SO_4	334.2
Ag_2O	6.5	Na_2O	100.	$LiCl$	93.8	$(NH_4)_2SO_4$	283.
BaO	126.	Nd_2O_3	435.	$MgCl_2$	151.0	Na_2SO_4	328.3
BaO_2	142.	NiO	57.9	$MnCl_2$	112.3	$MgSO_4$	301.6
Bi_2O_3	138.	P_2O_5 sgs	370.	$NaCl$	97.8	$PbSO_4$	216.2
CO am	29.0	PbO	50.3	$NdCl_3$	250.	Tl_2SO_4	221.0
CO di	26.1	PbO_2	62.4	NH_4Cl	76.3	$ZnSO_4$	229.6
CO_2 am	97.0	Pr_2O_3	412.	$NiCl_2$	74.5	$CaCO_3$	270.
CO_2 gr	94.8	Rb_2O	89.2	$PbCl_2$	83.4	$CuCO_3$	143.
CO_2 di	94.3	So_2 rh sgg	70.	$PdCl_2$	40.5	$FeCO_3$	179.
CaO	152.	SiO_2	191.0	$PtCl_4$	60.4	K_2CO_3	280.
CeO_2	225.	SnO	66.9	$SnCl_2$	80.8	$MgCO_3$	267.
Cl_2O g	—16.5	SnO_2 cr	137.5	$SnCl_4$	128.	Na_2CO_3	272.
CoO am	50.5	SrO_2	135.	$SrCl_2$	185.	$ZnCO_3$	194.
CoO cr	57.5	ThO_2	326.	$ThCl_4$	300.	$AgNO_3$	28.7
Co_3O_4	193.4	TiO_2 am	215.6	$TlCl$	48.6	$Ca(NO_3)_2$	209.
CrO_3	140.	TiO_2 cr	218.4	$RbCl$	105.9	$Cu(NO_3)_2 6\,H_2O$	92.9
Cs_2O	91.3	TlO_2	42.2	$ZnCl_2$	97.3	NHO_3 gggl	41.6
Cu_2O	42.3	WO_2	131.	HBr glg	8.6	KNO_3	119.2
CuO	37.2	WO_3	194.	NH_4Br	66.	$LiNO_3$	112.
FeO	65.7	ZnO	85.2	HI gsg	— 6.2	NH_4NO_3	88.3
Fe_2O_3	196.5	$AgCl$	29.2	HF ggg	38.	$NaNO_3$	111.0
Fe_3O_4	270.8	Ag_2Cl	29.5	Ag_2S	3.3	$TlNO_3$	58.2
H_2O ggl	68.4	$AlCl_3$	161.4	CS_2 sgg	—26.0	CH_4 sgg	20.
H_2O_2 ggl	46.8	AuCl y	5.81	CaS	90.8	C_2H_6 sgg	25.
Hg_2O	22.2	$AuCl_3$ y	22.8	$(NH_4)_2S$	66.2	C_2H_2 sgg	—53.
HgO	21.4	$BaCl_2$	197.	Cu_2S	18.3	HCN di gsgg	—30.5
K_2O	91.	$BeCl_2$	155.	CuS	11.6	NH_3 ggg	12.0
La_2O_3	447.	$BiCl_3$	90.6	H_2S gsg	2.73	$Ca(OH)_2$	230.
LiO_2	141.6	CCl_4 am	21.0	K_2S	103.4	NH_4OH	88.8
MgO	143.6	$CaCl_2$	187.	MgS	79.4	$NaOH$	102.
MnO	90.8	$CdCl_2$	93.2	Na_2S	89.3	$Na \cdot H_2O \cdot Aq—H$	44.*
MnO_2	123.	$CoCl_2$	76.5	PbS	19.3	$\frac{1}{2}(2\,Na \cdot O \cdot H_2O)$	68.*
Mn_3O_4	325.	$CuCl_2$	51.5	$CaSO_4$	262.	$\frac{1}{2}(Na_2O \cdot H_2O \cdot Aq)$	30.*
MoO_2	143.	$CuCl$	34.1	$CuSO_4$	111.5	KOH	103.5
MoO_3	174.	$FeCl_2$	82.1	H_2SO_4 sggg	193.	$K \cdot H_2O \cdot Aq–H$	45.*
N_2O ggg	—18.2	$FeCl_3$	96.0	$—SO_3 \cdot H_2O$*	21.3	$\frac{1}{2}(2\,K \cdot O \cdot H_2O)$	69.*
NO ggg	—21.6	HCl ggl	22.	Hg_2SO_4	175.	$\frac{1}{2}(K_2O \cdot H_2O \cdot Aq)$	35.5*
NO_2	— 8.1	$HgCl$	31.3	$HgSO_4$	165.		
Na_2O_4	— 2.6	$HgCl_2$	53.3	K_2SO_4	344.3		

am = amorphous: di = diamond; cr = crystal; g = gas; gr = graphite; l = liquid; rh = rhombic (sulfur); s = solid; y = yellow (gold).

* Heats of formation not from elements but as indicated.

(*continued*)

TABLE 180.—THERMOCHEMISTRY. CHEMICAL ENERGY DATA (concluded)

Part 2.—Heats of formation of ions in kilogram-calories

+ and — signs indicate signs of ions and the number of these signs the valency. For the ionization of each gram-molecule of an element divide the numbers in the table by the valency, e. g., 9.00 g Al = 9.00 g Al^{+} + 40.3 kg cal. When a solution is of such dilution that further dilution does not increase its conductivity, then the heats of formation of substances in such solutions may be found as follows: $FeCl_2Aq = +22.2 + 2 \times 39.1 = 100.4$ kg cal. $CuSO_4Aq = -15.8 + 214.0 = 198.2$ kg cal.

Ag +	— 25.3	NH_4 +	+ 32.7	AsO_4 — — —	+215.0	IO_3 —	+ 55.8
Al + + +	+121.0	NH_4O +	+ 37.5	Br —	+ 28.2	IO_4 —	+ 46.5
Co + +	+170.0	Na +	+ 57.3	BrO_3 —	+ 11.2	OH —	+ 54.4
Ca + +	+133.?	Ni + +	+ 16.0	CO_3 — —	+160.8	PO_4 — — —	+298.0
Cd + +	+ 18.4	Mg + +	+108.8	Cl —	+ 39.1	S_2O_3 — —	+138 6
Cu + +	— 16.0	Mn + +	+ 50.2	ClO —	+ 26.0	S_2O_6 — —	+278.2
Cu +	— 15.8?	Pb + +	+ 4.0	ClO_3 —	+ 23.4	S_4O_6 — —	+260.8
Fe + +	+ 22.2	Rb +	+625.0	ClO_4 —	— 38.7	SO_3 — —	+151.0
Fe + + +	— 9.3	Sn + + +	+ 3.3	HCO_3 —	+163.0	SO_4 — —	+214.0
H +	0.0	Sr + +	+119.6	HPO_2 —	+143.9	Se — —	— 35.6
Hg +	— 19.8	Tl +	+ 1.7	HPO_3 — —	+229.6	SeO_3 — —	+119.6
K +	+ 61.8	Zn + +	+ 35.0	HPO_4 — —	+304.8	SeO_4 — —	+144.8
Li +	+ 62.8			HS —	+ 1.2	Te — —	— 34.8
				NO_2 —	+ 27.0	TeO_3 — —	+ 77.0
				NO_3 —	+ 48.9	TeO_4 — —	+ 98.4
				I —	+ 13.1	S — —	— 12.6

TABLE 181.—IGNITION TEMPERATURES OF GASEOUS MIXTURES

Ignition temperature taken as temperature necessary for hot body immersed in gas to cause ignition; slow combination may take place at lower temperatures. Gases were mixed with air. Practically same temperatures as with O_2.

Benzene and air	1062° C	Ether and air	1033° C
Coal gas and air	878	Ethylene and air	1000
CO and air	931	Hydrogen and air	747

TABLE 182.—HEATS OF NEUTRALIZATION IN KILOGRAM-CALORIES

The heat generated by the neutralization of an acid by a base is equal, for each gram-molecule of water formed, to 13.7 kg cal plus the heat produced by the amount of un-ionized salt formed, plus the sum of the heats produced in the completion of the ionizations of the acid and the base.

Base	HCl·aq	HNO_3·aq	H_2SO_4·aq	HCN·aq	CH_3COOH·aq	H_2·CO_3·aq
KOH·aq	13.7	13.8	15.7	2.9	13.3	10.1
NaOH·aq	13.7	13.7	15.7	2.9	13.3	10.2
NH_4OH·aq	12.4	12.5	14.5	1.3	12.0	8.
½ $Ca(OH)_2$·aq	14.0	13.9	15.6	3.2	13.4	9.5
½ $Zn(OH)_2$·aq	9.9	9.9	11.7	8.1	8.9	5.5
½ $Cu(OH)_2$·aq	7.5	7.5	9.2	—	6.2	—

TABLE 183.—HEATS OF DILUTION OF H_2SO_4

In kilogram-calories by the dilution of 1 gram-molecule of sulfuric acid by m gram molecules of water.

m	1	2	3	5	19	49	99	199	399	1599
kg cal	6.38	9.42	11.14	13.11	16.26	16.68	16.86	17.06	17.31	17.86

TABLES 184-209.—PHYSICAL AND MECHANICAL PROPERTIES OF MATERIALS

Introduction and definitions.—The mechanical properties of most materials vary between wide limits; the following figures are given as being representative rather than what may be expected from an individual sample. Figures denoting such properties are commonly given either as specification or experimental values. Unless otherwise shown, the values below are experimental.

Credit for the information included on metals is due to the National Bureau of Standards [55] and the publications of the Aluminum Co. of America,[56] the American Brass Co., and the Chase Brass & Copper Co.[57]

Most of the data shown in these tables are as determined at ordinary room temperature, averaging 20°C (68°F). The properties of most metals and alloys vary considerably from the values shown when the tests are conducted at higher or lower temperatures.

The following definitions govern the more commonly confused terms shown in the tables. In all cases the stress referred to in the definitions is equal to the total load at that stage of the test divided by the original cross-sectional area of the specimen (or the corresponding stress in the extreme fiber as computed from the flexure formula for transverse tests).

Brinell hardness numeral (abbreviated B. h. n.).—Ratio of pressure on a sphere used to indent the material to be tested to the area of the spherical indention produced. The standard sphere used is a 10-mm-diameter hardened steel ball. The pressures used are 3000 kg for steel and 500 kg for softer metals, and the time of application of pressure is 30 seconds. Values shown in the tables are based on spherical areas computed in the main from measurements of the diameters of the spherical indentations, by the following formula:

$$\text{B. h. n.} = P \div \pi t D = P \div \pi D(D/2 - \sqrt{D^2/4 - d^2/4}).$$

P = pressure in kg, t = depth of indentation, D = diameter of ball, and d = diameter of indentation—all lengths being expressed in mm. Brinell hardness values have a direct relation to tensile strength, and hardness determinations may be used to define tensile strengths by employing the proper conversion factor for the material under consideration.

Elastic limit.—Stress which produces a permanent elongation (or shortening) of 0.001 percent of the gage length, as shown by an instrument capable of this degree of precision (determined from set readings with extensometer or compressometer). In transverse tests the extreme fiber stress at an appreciable permanent deflection.

Erichsen value.—Index of forming quality of sheet metal. The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical pointed tool. The depth of impression (or cup) in mm required to obtain fracture is the Erichsen value for the metal. Erichsen standard values for trade qualities of soft metal sheets are furnished by the manufacturer of the machine corresponding to various sheet thicknesses.

Alloy steels are commonly used in the heat-treated condition, as strength increases are not commensurate with increases in production costs for annealed alloy steels. Corresponding strength values are accordingly shown for annealed alloy steels and for such steels after having been given certain recommended heat treatments of the Society of Automotive Engineers. The heat

[55] Everhart, Lindlief, Kanegis, Weissler, and Siegel, Nat. Bur. Standards Circ. C-447, 1943.

[56] Selected from Nat. Bur. Standards Circ. C-447, Mechanical properties of metals and alloys, and from Alcoa's circular, Aluminum and its alloys.

[57] Chase Brass & Copper Co.'s circular, Copper and commercially important copper alloys, 1948; American Brass Co., Copper and copper alloys, 1945.

treatments followed in obtaining the properties shown are outlined on the pages immediately following the tables on steel. It will be noted that considerable latitude is allowed in the indicated drawing temperatures and corresponding wide variations in physical properties may be obtained with each heat treatment. The properties vary also with the size of the specimens heat treated. The drawing temperature is shown with the letter denoting the heat treatment, wherever the information is available.

Modulus of elasticity (Young's modulus).—Ratio of stress within the proportional limit to the corresponding strain—as determined with an extensometer. Note.—All moduli shown are obtained from tensile tests of materials, unless otherwise stated.

Modulus of rupture.—Maximum stress in the extreme fiber of a beam tested to rupture, as computed by the empirical application of the flexure formula to stresses above the transverse proportional limit.

Proportional limit (abbreviated P-limit).—Stress at which the deformation (or deflection) ceases to be proportional to the load (determined with extensometer for tension, compressometer for compression, and deflectometer for transverse tests).

Shore scleroscope hardness.—Height of rebound of diamond-pointed hammer falling by its own weight on the object. The hardness is measured on an empirical scale on which the average hardness of martensitic high carbon steel equals 100. On very soft metals a "magnifier" hammer is used in place of the commonly used "universal" hammer and values may be converted to the corresponding "universal" value by multiplying the reading by 4/7. The scleroscope hardness, when accurately determined, is an index of the tensile elastic limit of the metal tested.

Ultimate strength in tension or compression.—Maximum stress developed in the material during test.

Yield point.—Stress at which marked increase in deformation (or deflection) of specimen occurs without increase in load (determined usually by drop of beam or with dividers for tension, compression, or transverse tests).

TABLE 184.—INDUSTRIAL WOVEN-WIRE SCREENS *

Industrial wire cloth may be specified in any malleable metal, the physical characteristics of which will permit of its being commercially drawn into wire and woven into cloth. This industrial wire screen is manufactured with openings from about 15 inches to a very fine wire cloth with openings of .0017 inch, using for larger screens rods 2 inches in diameter and for the smaller-opening cloth, wire .0014 inch in diameter.

Industrial wire cloth specification, market grade

Mesh per lineal inch	Wire diameter inch	Opening inch	Percent open area	Mesh per lineal inch	Wire diameter inch	Opening inch	Percent open area
1 × 1	.080	.920	84.6	30 × 30	.013	.0203	37.1
2 × 2	.063	.437	76.4	35 × 35	.011	.0176	37.9
3 × 3	.054	.279	70.1	40 × 40	.010	.0150	36.0
4 × 4	.047	.203	65.9	50 × 50	.009	.0110	30.3
5 × 5	.041	.159	63.2	60 × 60	.0075	.0092	30.5
6 × 6	.035	.132	62.7	80 × 80	.0055	.0070	31.4
8 × 8	.028	.097	60.2	100 × 100	.0045	.0055	30.3
10 × 10	.025	.075	56.3	120 × 120	.0037	.0046	30.7
12 × 12	.023	.060	51.8	150 × 150	.0026	.0041	37.4
14 × 14	.020	.051	51.0	180 × 180	.0023	.0033	34.7
16 × 16	.018	.0445	50.7	200 × 200	.0021	.0029	33.6
18 × 18	.017	.0386	48.3	250 × 250	.0016	.0024	36.0
20 × 20	.016	.0340	46.2	270 × 270	.0016	.0021	32.2
24 × 24	.014	.0277	44.2	325 × 325	.0014	.0017	30.0

* Data furnished by the W. S. Tyler Co., Cleveland.

TABLE 185.—SOME PHYSICAL PROPERTIES OF THE ELEMENTS

Element	Relative hardness	Density at 20°C g/cm³	Melting point °C	Specific heat at r.-t. cal g^{-1} $°C^{-1}$	Latent heat of fusion cal/g	Coeff. of linear thermal expansion °C at r.-t. × 10^6	Thermal conductivity at r.-t. watts cm^{-1}	Electrical resistivity microhm-cm	Modulus of elasticity kg/mm²	Tensile strength kg/mm²
Actinium	...	...	1197*	...	...	...	...	...	...	...
Aluminum	2.9	2.70	660.1 ±.1	.226	93	22.9	2.18	2.65(20°C)	7250	6.3 (annealed)
Antimony	3	6.62	630.5 ±.1	.049	38.3	8.5–10.8†‡	.19	39.0(0°C)	7900	1.05 (wire)
Argon	...	1.6626[a]	—189.37±.5	.125	6.7	...	1.70[e]	...	...	...
Arsenic	3.5	5.73	817§	.082	...	4.7	...	35(20°C)	...	...
Barium	...	3.5	710 ±20	.068	...	...	...	...	...	...
Beryllium	3	1.82	1283 ±40	.425	...	11.4	1.64	5.88(0°C)	30000	12.0 (chill cast)
Bismuth	2.5	9.80	271.3 ±.1	.029	12.5	13.3	.084	106.8(0°C)	3200	...
Boron	9.5	2.3	2300 ±300	.309	...	2	...	1.8×10^{12}(0°C)	...	...
Bromine	...	3.12	—7.20±.2	.070	16.2	...	...	...	...	...
Cadmium	2.0	8.65	321.03±.1	.055	13.2	29.8	.91	6.83(0°C)	5500	7.2
Calcium	...	1.54	850 ±20	.157	...	25	...	3.43(0°C)	2100	5.7 (extruded)
Carbon (graphite)	10[a]	2.22	3700 ±100	.165	...	.6–4.3‖	.24	1375(0°C)	500	...
Cerium	2.5	6.9	864 ±50	.05	...	...	...	78(20°C)	...	9.05 (rolled)
Cesium	.2	1.9	28.64±2	.052	3.8	97	...	18.83(0°C)	...	...
Chlorine	...	...	—101.99±2	.226	23.0	...	.720[e]	...	...	...
Chromium	9	7.14	1903 ±50	.12	75.6	6.2	.69	14.1(20°C)	...	...
Cobalt	5	8.9	1492 ±20	.099	58.4	12.3	.69	5.60(0°C)	21000	24.4 (cast)
Copper	3.0	8.96	1083.0 ±.1	.092	50.6	16.5	3.94	1.67(20°C)	11000	22.5 (annealed)
Fluorine	...	...	—219.61±10	...	10.1	...	...	...	...	...
Gallium	1.5	5.91	29.80±.02	.079	19.2	18	...	53.4(0°C)	...	...
Germanium	6.2	5.36	938 ±10	.073	...	...	...	89×10^3(0°C)	...	...
Gold	2.5	19.3	1063.0 ±.0	.031	16.1	14.2	2.96	2.19(0°C)	7300	11.5 (rod cast)
Hafnium	...	11.4	2220*	...	...	...	...	...	...	...
Helium	...	.1664[d]	—271.4 ±.2¶	1.25	...	...	13.9[e]	...	...	...
Hydrogen	...	.08375[d]	—259.19±.1	3.415	15.0	...	17.0[e]	...	...	...
Indium	1.2	7.31	156.61±.1	.057	...	33	.24	8.37(0°C)	...	.30 (cast)
Iodine	...	4.93	113.6 ±1	.052	15.8	93	43.5[e]	1.3×10^{15}(20°C)	...	...
Iridium	6.5	22.4	2443 ±3	.032	...	6.5	.59	5.3(20°C)	52500	...
Iron	4	7.87	1535 ±3	.108	65	11.7	.79	9.71(20°C)	20000	20.5

* Computed. † Value depends on the crystal orientation in polycrystalline material. ‡ From 20° to 60°C. § At 36 atm. ‖ From 20° to 100°C. ¶ At 30 atm.
[a] Diamond. [d] ×10^{-3}. [e] ×10^{-4}.

(*continued*)

TABLE 185.—SOME PHYSICAL PROPERTIES OF THE ELEMENTS (continued)

Element	Relative hardness	Density at 20°C g/cm³	Melting point °C	Specific heat at r.-t. cal g⁻¹ °C⁻¹	Latent heat of fusion cal/g	Coeff. of linear thermal expansion °C at r.-t. × 10⁶	Thermal conductivity at r.-t. watts cm⁻¹	Electrical resistivity microhm-cm	Modulus of elasticity kg/mm²	Tensile strength kg/mm²
Krypton	...	3.488[d]	—157.3 ±.5	...	...	...	.89[e]	...	...	...
Lanthanum	...	6.15	920 ±5	.045	...	...	...	59(18°C)	...	...
Lead	1.5	11.34	327.3 ±.1	.030	6.3	28.7	.35	20.65(20°C)	1800	1.33
Lithium	.6	.53	180.55±5	.79	159	56	.71	8.55(0°C)	...	...
Magnesium	2	1.74	650 ±2	.249	70.0	25.2	1.55	4.33(18°C)	4600	9.15 (sand cast)
Manganese	5.0	7.44	1244 ±20	.107	64.8	23	...	...	16000	39.0 (annealed)
Mercury	1.5	13.55	—38.87±.02	.033	2.7	...	.084	94.1(0°C)	...	...
Molybdenum	6	10.2	2610 ±50	.065	...	4.9‖	1.46	5.17(0°C)	35000	120 (annealed wire)
Neodymium	...	7.05	1024 ±40	.045	...	...	...	79(18°C)	...	...
Neon	...	.8387[d]	—248.59±.3	...	...	...	4.57[e]	...	...	...
Nickel	5	8.9	1453 ±1	.112	73.8	13.3‖	.90	6.84(20°C)	21000	32.3
Niobium	...	8.57	2480 ±50	...	...	7.1	...	...	...	...
Nitrogen	...	1.1649[d]	—209.97±.3	.247	6.2	...	2.51[e]	...	...	...
Osmium	7.0	22.48	2700 ±200	.031	...	6.1	...	9.5(20°C)	...	...
Oxygen	...	1.3318[d]	—218.79±.3	.218	3.3	...	2.47[e]	...	...	...
Palladium	4.8	12.0	1552 ±1	.059	34.2	11.8	.70	10.8(20°C)	12000	14.0 (annealed)
Phosphorus (yellow)	...	1.82	44.2 ±.1	.177	5.0	125	...	10^{17}(11°C)	...	...
Platinum	4.3	21.45	1769 ±1	.032	27.1	8.9	.69	9.81(0°C)	15000	16 (annealed)
Polonium	...	...	254*	...	...	...	...	...	...	...
Potassium	.5	.86	63.2 ±1	.177	14.5	83	.99	6.15(0°C)	...	...
Praseodymium	...	6.63	935 ±50	.458	...	...	...	88(18°C)	...	...
Protactinium	...	...	3000*	...	...	...	...	...	...	...
Radium	...	5.0	700	...	...	...	...	...	...	...
Radon	...	4.40[b]	— 71	...	...	...	...	...	...	...
Rhenium	...	20	3150*	.035	...	...	...	...	...	...
Rhodium	6	12.44	1960 ±3	.060	...	8.1[c]	.88	4.3(0°C)	30000	...
Rubidium	.3	1.53	38.8 ±1	.080	6.1	90	...	12.5(20°C)	...	...
Ruthenium	6.5	12.2	2400 ±100	.061	...	9.1	...	10(18°C)	...	...

[b] At −62°C. [c] From 20° to 50°C.

(continued)

TABLE 185.—SOME PHYSICAL PROPERTIES OF THE ELEMENTS (concluded)

Element	Relative hardness	Density at 20°C g/cm³	Melting point °C	Specific heat at r.-t. cal g⁻¹ °C⁻¹	Latent heat of fusion cal/g	Coeff. of linear thermal expansion °C at r.-t. × 10⁶	Thermal conductivity at r.-t. watts cm⁻¹	Electrical resistivity microhm-cm	Modulus of elasticity kg/mm²	Tensile strength kg/mm²
Samarium	...	7.7	>1050	...	...	...	...	...	...	...
Scandium	...	2.5	1400	...	...	...	...	...	...	...
Selenium	2.0	4.81	217.4 ±5	.084	...	37	...	1.20(20°C)	...	...
Silicon	7.0	2.4	1410 ±20	.176	...	2.8–7.3	.84	85×10^{3}(20°C)	11000	...
Silver	2.7	10.49	960.8 ±.0	.056	24.3	18.9	4.08	1.62(20°C)	7200	15.1 (rod, annealed)
Sodium	.4	.97	97.82±.2	.295	27.5	71	1.35	4.2(0°C)	...	...
Strontium	1.8	2.6	770 ±10	...	25	...	...	22.76(20°C)	...	...
Sulfur (rhombic)	2.0	2.07	119 ±.2	.175	9.3	64‡	26.4[e]	2×10^{23}(20°C)	...	...
Tantalum	7	16.6	2980 ±100	.036	...	6.6	.54	14.6(18°C)	19000	50 (wire)
Technetium	...	...	2700*	...	...	...	...	...	...	...
Tellurium	2.3	6.24	450 ±10	.047	...	16.8‡	.060	...	2100	1.12 (wire)
Terbium	...	...	1450 ±5	...	...	...	...	...	...	...
Thallium	1.2	11.85	303.6 ±3	.031	7.2	28	.39	17.65(0°C)	...	...
Thorium	...	11.5	1695 ±150	.028	...	11.1‡	...	18.62(20°C)	...	56.0 (wire)
Tin	1.8	7.30	231.91±.1	.054	14.4	23	.64	11.5(20°C)	41100	1.4
Titanium	4.0	4.54	1675 ±100	.142	...	8.5	...	80(0°C)	8500	...
Tungsten	7	19.3	3380 ±20	.034	44	4.3	1.99	5.5(20°C)	35000	270 (wire)
Uranium	...	18.7	1132 ±1	.028	...	...	...	60(18°C)	...	...
Vanadium	...	5.68	1890 ±50	.115	...	...	...	...	...	...
Xenon	...	5.495[d]	−112.5 ±1	...	...	...	5.19[e]	...	...	...
Ytterbium	...	...	824	...	...	...	...	...	...	...
Yttrium	...	5.51	1490 ±200	...	...	...	...	...	...	...
Zinc	2.5	7.14	419.50±.1	.09	24.1	17–39†	1.1	5.92(20°C)	8400	10.5
Zirconium	4.5	6.4	1852 ±700	.066	...	5.6	...	41.0(0°C)	7500	30.0 (rod, annealed)

TABLE 186.—MECHANICAL PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS **

Composition	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion × 10^6 cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit and cycles kg/mm²	Hardness number
Pure and commercial aluminum												
Al-99.95	Annealed	...	...	2.8	...	...	.70	2.1 (.2% offset)	6.3	60 (2 in.)		15
Cu-4.5	Sand-cast; h.-t. and aged (195-T6)	2.75	.33	3.45	22.8	7200	...	15.5 (.2% perm.)	25	5 (2 in.)	4.6†	80
Al (commercial)	Hard-drawn (93% red)	2.71	.53	3.75	23.6	...	...	...	34	2 (2 in.)	..	..
Aluminum-copper-magnesium alloys												
Cu-2.5, Mg-.3	Wrought; h.-t. and aged (A17S-T)	2.74	.37	4.3	23.5	7200	...	17 (.2% perm.)	30	27*	9.5†	70
Aluminum-copper-magnesium-manganese alloys												
Cu-4.0, Mg-.5, Mn-.5	Wrought; annealed (17S-O)	2.79	.41	3.8	23.5	7200	...	7.0 (.2% perm.)	18	22* (2 in.)	7.7†	45
Cu-4.32, Mg-1.44, Mn-.48, Fe-.16	Plate, ½ in. w.-q. from 920° F (24S-T)	2.77	.29	5.7	23.2	...	...	34.0	48	20	18	120
Cu-4.4, Fe-.81, Mg-.67, Mn-.64, Si-.22	Rod, ¾ in. diam. h.-t. and aged	...	...	...	...	7600	26.4	29.4 (.1% perm.)	42.0	19.7 ($4\sqrt{area}$)	..	..
Cu-4.4, Mn-.8, Si-.8, Mg-.4	Forged; h.-t. and aged (14S-T)	2.80	.37	4.3	23.0	7200	...	39 (.2% perm.)	49	14 (2 in.)	11†	135
Cu-4.5, Mg-1.5, Mn-.6	Sheet, h.-t. and cold-worked (24S-RT)	...	...	...	23.2	7200	...	39 (.2% perm.)	49	13 (2 in.)	..	116
Aluminum-copper-nickel alloys												
Cu-4.0, Ni-2.0, Mg-1.51	Sand-cast; aged (142-T571)	2.78	.32	5.1	22.5	7200	...	20 (.2% perm.)	22	.5 (2 in.)	5.6†	85

** For reference, see footnote 56, p. 187.
* Values apply in general to all wrought forms except large-sized extrusions; elongations apply to ½ in. diameter test specimens. † 5×10^8.

(continued)

TABLE 186.—MECHANICAL PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS (continued)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion × 10^6	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit and cycles	Hardness number
		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Aluminum-copper-silicon alloys												
Cu–4.0, Si–3.0	Sand-cast (108)	2.73	.29	5.6	22.0	7200	...	10 (.2% perm.)	15	2 (2 in.)	6†	55
Cu–4.5, Si–2.5	Chill-cast: h.-t. (B195–T4)	2.78	.33	4.9	22.0	7200	...	13 (.2% perm.)	26	10 (2 in.)	6.7†	75
Cu–7.0, Si–2.0, Zn–1.5, Fe–1.2	Sand-cast	2.85	...	...	...	7200	...	9.8 (.2% offset)	13–16	0–1.5 (2 in.)	6.0†	55–80
Aluminum-copper-zinc alloys												
Cu–7.0, Zn–1.7, Fe–1.2	Sand-cast (112)	2.85	.29	5.7	22.0	7200	...	10.5 (.2% perm.)	17	1.5 (2 in.)	6.3†	70
Aluminum-magnesium alloys												
Mg–1.0, Si–.6 Cr–.25, Cu–.25	Wrought; ann. (61S–O)	2.70	.41	3.8	23.5	7200	...	5.6 (.2% perm.)	13	22 (2 in.)*	5.6†	30
Mg–1.3, Si–.7 Cr–.25	Wrought; h.-t. and aged (53S–T)	2.69	.37	4.3	23.5	7200	...	23 (.2% perm.)	27	20 (2 in.)*	7.7†	80
Mg–2.5, Cr–.25	Wrought; hard (52S–H)	2.68	.33	4.9	23.7	7200	...	25 (.2% perm.)	29	8 (2 in.)*	14.5†	85
Mg–3.8	Sand-cast (214)	2.61	.33	4.9	23.9	7200	...	8.4 (.2% perm.)	18	9 (2 in.)	3.9†	50
Mg–3.8, Zn–1.8	Chill-cast (A 214)	2.66	.32	5.1	23.9	...	...	11 (.2% perm.)	19	5 (2 in.)	..	60
Mg–10.00	Sand-cast h.-t. (220–T4)	2.52	.21	8.2	24.5	7200	...	18 (.2% perm.)	32	14 (2 in.)	4.9†	75
Auminum-manganese alloys												
Mn–1.2	Wrought; ann. (3S–O)	2.73	.46	3.4	23.6	7200	...	4.2 (.2% perm.)	11	40 (2 in.)*	4.9†	28
Mn–1.25, Mg–1.0	Annealed	2.72	...	...	...	...	...	7	18	20 (2 in.)	9.8	45

(continued)

TABLE 186.—MECHANICAL PROPERTIES OF ALUMINUM AND ALUMINUM ALLOYS (concluded)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion × 10⁶	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit and cycles	Hardness number
		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Aluminum-silicon alloys												
Si–5.0	Sand-cast (43)	2.64	.35	4.7	22.0	7200	...	6.3 (.2% perm.)	13	6 (2 in.)	4.6†	40
Si–12	Die-cast; ¼ in. diam. (13)	2.69	.37	4.4	20.0	7200	...	13 (.2% perm.)	23	1.8 (2 in.)	10.5†	..
Si–13	Die-cast (13)	...	.33	4.8	...	...	...	...	..	..	..	..
Aluminum-silicon-copper alloys												
Si–5.0, Cu–1.3, Mg–.5	Sand-cast; h.-t. and aged (355–T6)	2.66	.34	4.8	22.0	7200	...	18 (.2% perm.)	25	3.5 (2 in.)	6.0†	90
Si–5.0, Cu–4.0	Die-cast, ¼ in. diam. (85)	2.79	.27	6.1	20.9	7200	...	13 (.2% perm.)	25	2.7 (2 in.)	12†	..
Aluminum-silicon-magnesium alloys												
Si–1.0, Mg–.6	Heat-treated and aged	...	...	...	...	...	...	28 (.2% perm.)	24	14 (2 in.)	..	95
Si–7.0, Mg–.3	Sand-cast; aged (356–T51)	2.66	.40	4.0	21.4	7200	...	14 (.2% perm.)	18	2 (2 in.)	5.3†	60
Aluminum-silicon-nickel alloys												
Si–12, Ni–2.5, Mg–1.0, Cu–.8, Fe–.8	Chill-cast; aged (A132–T551)	2.70	.28	6.0	18.9	7200	...	20 (.2% perm.)	25	.5 (2 in.)	..	105
Aluminum-zinc alloys												
Zn–5.0, Mg–2.5, Cu–2.3, Ni–1.0, Ti–.1	Wrought; h.-t. and artificially aged	...	...	...	...	7000	...	44–52 (.1% offset)	50–60	10–16	19.5–20.5 (2×10^7)	160–180
Zn–25.0, Cu–3.0	Bar, ½ in. hot-rolled	3.29	...	...	...	7000	...	43.0 (yld. pt.)	50	21 (2 in.)	..	..

TABLE 187.—MECHANICAL PROPERTIES OF BRASSES AND BRONZES *

Name	Composition percent	Condition	Density g/cm³	Thermal conductivity at 20°C cgs	Resistivity microhm-cm	Thermal expansion cgs	Yield strength at ½% elongation under stress kg/mm²	Tensile strength kg/mm²	Elongation in 2 in. percent	Hardness No.
Brasses										
Muntz metal	Cu-61; Zn-39	.040″ strip; hot-rolled	8.48	.294	6.25	2.07×10^{-5}	14.1	38.0	45	F 80
		.040″ strip; cold-rolled					42.2	56.2	5	
Yellow brass	Cu-66; Zn-34	.040″ strip; .025mm ann.	8.47	.277	6.38	2.02×10^{-5}	14.1	36.5	56	F 73
		.040″ strip; .070mm ann.					10.5	32.3	64	F 60
		.040″ strip; hard (37%)					42.2	52.7	7	B 80
		.040″ strip; spring (60%)					45.7	63.2	3	B 88
		.100″ wire; rivet (10%)					31.6	42.2	30	...
		.100″ wire; spring (84%)					47.8	87.8	..	...
Cartridge brass, 70%......	Cu-70; Zn-30	.040″ strip; .025mm ann.	8.52	.294	6.25	1.98×10^{-5}	14.1	36.6	56	F 73
		.040″ strip; .070mm ann.					10.5	32.3	64	F 60
		.040″ strip; hard (37%)					42.2	53.4	7	B 83
		.040″ strip; spring (60%)					45.7	65.4	3	B 90
		.100″ wire; spring (84%)					47.8	90.0	..	...
Low brass, 80%..........	Cu-80; Zn-20	.040″ strip; .015mm ann.	8.67	.335	5.38	1.91×10^{-5}	12.6	33.1	47	F 75
		.040″ strip; .050mm ann.					10.5	30.2	55	F 60
		.040″ strip; hard (37%)					42.2	51.3	7	B 83
		.040″ strip; spring (60%)					45.7	63.2	3	B 90
		.100″ wire; spring (84%)					47.8	84.3	..	...
Jewelry bronze	Cu-87.5; Zn-12.5	.040″ strip; .015mm ann.	8.77	.413	4.20	1.85×10^{-5}	17.6	30.2	42	F 68
		.040″ strip; .030mm ann.					9.15	28.1	46	F 61
		.040″ strip; hard (37%)					40.1	47.1	5	B 73
		.040″ strip; spring (60%)					44.3	55.5	3	B 82
Commercial bronze, 90%..	Cu-90; Zn-10	.040″ strip; .015mm ann.	8.80	.45	3.92	1.84×10^{-5}	21.1	28.8	42	F 65
		.040″ strip; .030mm ann.					8.43	26.7	45	F 58
		.040″ strip; hard (37%)					38.7	43.6	5	B 70
		.040″ strip; spring (60%)					44.3	51.3	3	B 78

* For reference, see footnote 57, p. 187.

(continued)

TABLE 187.—MECHANICAL PROPERTIES OF BRASSES AND BRONZES (continued)

Name	Composition	Condition	Density	Thermal conductivity at 20°C	Resistivity microhm-cm	Thermal expansion	Yield strength at ½% elongation under stress	Tensile strength	Elongation in 2 in.	Hardness
	percent		g/cm³	cgs		cgs	kg/mm²	kg/mm²	percent	No.
Gilding, 95%	Cu-95; Zn-5	.040" strip; .015mm ann.	8.86	.55	3.08	1.80×10^{-5}	7.03	26.7	42	F 60
		.040" strip; .030mm ann.					5.62	25.3	44	F 52
		.040" strip; hard (37%)					33.7	38.6	6	B 62
		.040" strip; spring (60%)					40.1	44.3	5	B 72
Conductivity bronzes										
80% conductivity bronze	Cu-99; Cd-1.0	Hard-drawn	8.88	...	2.15	...	...	58.6	..	...
65% conductivity bronze	Cu-99.5; Sn-.5	Hard-drawn	8.88	...	2.65	...	...	52.8	..	...
55% conductivity bronze	Cu-98.7; Cd-.8; Sn-.5	Hard-drawn	8.88	...	3.13	...	...	63.3	..	...
Special brasses										
Naval brass	Cu-60; Zn-39.25; Sn-.75	.040" strip; light ann.	8.42	.278	6.62	2.17×10^{-5}	21.1	43.6	40	B 60
		.040" strip; quarter hard (11%)					40.8	49.2	17	B 75
		.50" strip; as hot-rolled					17.6	38.7	50	B 55
		1" rod; soft ann.					17.6	40.1	45	B 50
		1" rod; light ann.					21.1	44.3	40	B 57
		1" rod; quarter hard (9%)					35.2	49.2	28	B 78
		1" rod; half hard (18%)					37.3	52.8	20	B 82
Antimonial Admiralty	Cu-71; Zn-27.97 Sn-1; Sb-.035	1"×.05" tube; .025mm ann.	8.52	.265	6.89	2.02×10^{-5}	...	37.3	70	F 75
		1"×.05" tube; hard (35%)					...	59.8	15	B 88
Bushing bronze	Cu-90; Zn-9.5; Sn-.5	.040" strip; half hard	8.80	.45	4.53	1.84×10^{-5}	31.6	33.4	12.5	B 55
		hard					40.1	42.2	5	B 70
		extra hard					44.0	49.2	2.5	B 78
		light ann.					7.03	28.1	40	F 70

(continued)

TABLE 187.—MECHANICAL PROPERTIES OF BRASSES AND BRONZES (concluded)

Name	Composition percent	Condition	Density g/cm³	Thermal conductivity at 20°C cgs	Resistivity microhm-cm	Thermal expansion cgs	Yield strength at ½% elongation under stress kg/mm²	Tensile strength kg/mm²	Elongation in 2 in. percent	Hardness No.
Tin bronzes										
Phosphor bronze 5% (grade A)	Cu-95; Sn-4.75; P-.25	.040" strip; .035mm ann.	8.85	.157	12.28	1.78×10^{-5}	14.1	34.5	58	F 75, B 28
		.040" strip; hard (37%)					52.7	56.9	10	B 87
		.040" strip; spring (60%)					56.2	70.3	4	B 93
		.100" wire; spring (84%)					...	98.2	2	...
Phosphor bronze 8% (grade C)	Cu-92; Sn-7.75; P-.25	.040" strip; .035mm ann.	8.80	.120	15.65	1.82×10^{-5}	16.9	40.8	65	F-80; B-50
		.040" strip; hard (37%)					50.6	65.4	10	B 93
		.040" strip; spring (60%)					...	78.7	3	B 98
		.100" wire; spring (68%)					...	98.2	..	...
444 Bronze	Cu-88; Sn-4; Zn-4; Pb-4	.040" strip; .035mm ann.	8.88	.206	9.07	1.72×10^{-5}	...	31.6	55	F 65
		1" rod; hard (20%)					...	45.7	20	
Olympic bronze										
Olympic bronze, type A	Cu-96; Si-3; Zn-1	.040" strip; .070mm ann.	8.52	.087	24.6	1.80×10^{-5}	14.75	39.4	63	F 75
		.040" strip; spring (60%)					43.8	77.3	4	B 97
		1" rod; extra hard (50%)					42.2	75.9	13	B 95
		.100" wire; hard (60%)					45.7	87.9	5	...
		.100" wire; spring (80%)					49.3	102.0	3	...
Special engineering alloy										
Tellurium copper	Cu-99.5; Te-.5	⅛" rod, ½ hard (20%)	8.94	.848	1.915	1.79×10^{-5}	28.8	30.9	15	...

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS**

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Pure and commercial copper												
Oxygen-free copper (OFHC); Cu–99.997	Rod, ½ in. diam., cold-drawn (29% red) from .125 mm grain size	8.95	.93	1.706*	17.6*	12,500	...	34.5(.5% extn.)	36.0	14†	12.0(3×10⁸)	R_B 37
Oxygen-free copper (OFHC); Cu–99.996	Rod, ¾ in. diam., cold-drawn (36% red) from .135 mm grain size	...	...	...	...	12,300	...	33 (.5% extn.)	33.5	20†	...	...
Oxygen-free copper (OFHC); Cu–99.99	Rod, hard-drawn	...	...	...	...	13,000	3.45	12.7(.01%)	29.0	29§	...	...
Cu–99.95	Sheet, .020 in., soft	...	...	...	...	...	4.8	...	22.0	35†	7.7(10⁸)	...
"	Sheet, .020 in., cold-worked (21% red)	...	...	...	...	...	11.0	...	31.2	7.8†	9.1(10⁸)	R_B 33
Cu–99.94; 0–.030	Rod, drawn (37% red)	...	...	...	...	12,100	3.4	10.0(.01%)	26.0	32§	...	...
Electrotough-pitch copper	Rod, 1 in. diam., hot-rolled	8.92	.93	1.706*	17.6*	9,300	...	4.55(.01% perm.)	22.0	59†	2.8‡	41
Electrotough-pitch copper	Cold-rolled	...	...	...	...	...	7.0	15 (.01% perm.)	36.5	13†	11.0	...
Copper-aluminum alloys												
Al–3.96	Cast, annealed	...	...	...	...	...	4.30	6.1(.5% extn.)	24.3	84†	...	...
"	Forged, annealed	...	...	...	...	...	5.75	8.8(.5% extn.)	33.0	81†	...	...
Al–8.0	Sheet or plate, soft	7.78	.17	11.8*	17.8*	...	...	17 (.5% extn.)	42	60†	...	R_B 30
"	Sheet or plate, hard	...	...	...	...	10,500	...	42 (.5% extn.)	84	4†	...	R_B 99

** For references, see footnotes 55 and 57, p. 187.
* × 10^{-6}. † 2 in. ‡ Alternating torsion. § $4\sqrt{\text{area}}$.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition	Condition	Density	Thermal conductivity	Resistivity microhm-cm	Thermal expansion	Modulus of elasticity	Proportional limit	Yield strength	Tensile strength	Elongation	Endurance limit cycles	Hardness number
percent		cgs	cgs		cgs	kg/mm²	kg/mm²	kg/mm²	kg/mm²	percent	kg/mm²	
Al-9.78	Cast; w.-q. from 1650°F, ½ hr at 1200°F, f.c.	. . .	. . .	. . .	. . .	13,600	17.5	. . .	54.5	14‖	18.0(7×10⁷)	142
Al-10	Cast	7.5	. . .	. . .	. . .	8,500–10,500	7–8	14–17.5 (.5% perm.)	42–53	15–25†	. . .	90–100
Al-10.06, Fe-.13	Extruded to 1 19/32 in. diam., w.-q. from 1650°F at 1150°F, f.c.	7.57	. . .	. . .	. . .	14,000	11.9	. . .	54.5	36‖	24.0(6×10⁷)	128
Copper-aluminum-iron alloys												
Al-5.39, Fe-5.14	Forged	. . .	. . .	. . .	. . .	. . .	. . .	34.0(yld. pt.)	61.0	32†	. . .	119
Al-8, Fe-2.5	Rod, soft	7.75	. . .	. . .	. . .	. . .	. . .	20.2(.5% extn.)	51	50†	. . .	R_B 52
Al-8.6, Fe-2.9	Sand-cast	. . .	. . .	. . .	. . .	. . .	9.8	15–19	42–50	22–27†	. . .	109–124
Al-9, Fe-3	Forged	. . .	. . .	. . .	. . .	. . .	12.6	23.6(yld. pt.)	60.0	42†	. . .	130
Copper-aluminum-iron-manganese alloys												
Al-7.18, Fe-.62, Mn-.58	Sand-cast	. . .	. . .	. . .	. . .	. . .	. . .	12.3(yld. pt.)	39.0	52†	. . .	69
Al-9.9, Fe-3.2 Mn-2.9	Round bar, die-cast at 2155°F	7.42	. . .	. . .	. . .	. . .	. . .	22.5(.15% perm.)	63.0	10†	. . .	. . .
Copper-aluminum-iron-nickel alloys												
Al-5.0, Fe-3.07, Ni-1.91, Mn-.33	Rod, 1¼ in., diam., forged (75% red)	. . .	. . .	. . .	. . .	. . .	. . .	25.2(yld. pt.)	51.0	34†	. . .	130
Al-9.73, Fe-5.42, Ni-4.97	Rod, ¾ in. diam., forged	. . .	. . .	. . .	. . .	13,200	3.8	54.5(.1% perm.)	82	11§	. . .	. . .
Al-10.7, Fe-4, Ni-4	Forged, h.-t.	7.75	. . .	. . .	. . .	. . .	21	39–42	67–72	10–15†	. . .	190–217

‖ 8 in.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-aluminum-manganese alloys												
Al–7, Mn–1	Sheet, .2 in., cold-rolled (50% red)	...	...	...	...	...	54.0	...	74	12†	...	...
Al–10, Mn–1	Chill-cast	...	...	...	...	...	...	25.0(yld. pt.)	62.5	25†	...	...
Copper-aluminum-nickel alloys												
Al–7, Ni–1	Sheet, .2 in., cold-rolled (50% red)	...	...	...	...	...	60.0	...	80.0	6†	...	...
Al–9.4, Ni–7.4, Fe–4.1	Rod, 1 in. diam., chill-cast	7.57	...	...	...	...	...	4.03(.15% perm.)	67	5†	...	188
Al–10.1, Ni–7.6, Si–.4	Rod, 1 in. diam., chill-cast	7.58	...	...	...	...	...	44 (.15% perm.)	63.5	2†	...	...
Copper-aluminum-silicon alloys												
Al–7.2, Si–1.88, Fe–.11	Rod, 1 in. square, chill-cast from 2055°F	...	...	...	...	...	...	22.0(yld. pt.)	53.0	19[a]	...	139
Al–7.2, Si–1.88, Fe–.11	Rod, $\frac{3}{4}$ in. diam., forged	...	...	...	...	...	...	42 (yld. pt.)	69.5	25[a]	...	186
Copper-aluminum-zinc alloys												
Al–8.89, Zn–1.40, Fe–.15	Rod, $\frac{3}{4}$ in. diam., extruded and drawn	...	...	...	...	12,300	12.4	29.3(.01% perm.)	25.2	37§	...	...
Copper-arsenic alloys												
As–.33, Ag–.10	Rod, $\frac{7}{8}$ in. diam., drawn (7% red)	...	...	...	...	...	20.4	7.7(.01% perm.)	25.2	47§	...	. .
" "	Rod, $\frac{7}{8}$ in. diam., drawn (7% red) ann. 100 hr at 390°F	...	...	...	...	...	10.4	...	24.7	46§	...	. .

[a] 1.3 in.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-beryllium alloys												
Be–1.0	Quenched	8.6	...	...	...	...	...	14.7(yld. pt.)	30–35	50–55¶	...	65–70
"	Quenched and work-hardened	...	...	...	...	...	...	71.5(yld. pt.)	75	6¶	...	200
Be–2.2	Cast	...	...	...	...	...	...	30.0	44.0	14†	...	109
"	Cast, quenched from 1470°F, aged at 645°F	...	...	...	...	...	...	66.1	83.5	1†	...	400
Copper-beryllium-cobalt alloys												
Be–2, Co–.2	Soft, annealed	...	...	...	...	12,600	12.6	18.3(.2% extn.)	46.5	50†	...	...
" "	Heat-treated	...	...	...	...	13,300	60.5	102 (.2% extn.)	123	8†	...	...
" "	Rolled (21% red), h.-t.	...	...	...	...	12,700	83	121 (.2% extn.)	135	4†	...	...
" "	Rolled (37% red), h.-t.	...	...	...	...	12,600	73	126 (.2% extn.)	141	3†	...	...
Copper-beryllium-nickel alloys												
Be–2.16, Ni–.22, Fe–.11	Rod, ¾ in. diam., quenched from 1515°F, cold-drawn (15% red)	...	...	...	...	11,900	...	56.0(.5% extn.)	77	11†	...	...
Be–2.16, Ni–.22, Fe–.11	Rod, ¾ in. diam., quenched from 1515°F, cold-drawn (15% red) 3 hr at 570°F	...	...	...	...	13,000	...	64.5(.5% extn.)	150	2.8†	...	...
Be–2.14, Ni–.28 Fe–.06	Sheet, .040 in., w.-q. from 1470°F, cold-rolled (37% red) 2 hr at 525°F	...	...	...	...	12,900	39.0	...	136	2.0†	19.5	Rɢ 104

¶ 10 diam.

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-cadmium alloys												
Cd–.8	Wire, cold-drawn	...	...	...	...	12,700	...	...	71	...	...	...
Copper-chromium alloys												
Cr–.88, Si–.09	Rod, ½ in. diam., cold-worked (92% red)	...	...	...	...	13,900	...	46.5(.5% extn.)	51.0	7.5†	18.1(3×10⁸)	R_B 73
Copper-chromium-beryllium alloys												
Cr–.4, Be–.1	Rod, 1 in. diam., cast, quenched from 1700°F, aged 1 hr at 935°F	...	...	...	...	...	10.5–11.5	...	21–25	10–15	...	80
Copper-cobalt-beryllium alloys												
Co–2.6, Be–.4	Rod, 1 in. diam., cast, 1 hr at 1650°F, w.-q. 2-4 hr at 930°F	...	...	...	...	12,000	31.6	...	63.0	10†	...	220
Co–2.6, Be–.4	Rod, forged, 1 hr at 1650°F., w.-q. 2-4 hr at 930°F	...	...	...	...	12,000	31.6	...	70.3	20†	...	220
" "	Quenched, work-hardened, h.-t.	...	...	...	...	11,500	...	57.5(yld. pt.)	75	15¶	...	210
Copper-iron alloys												
Fe–25	Wire, .040 in. diam., cold-drawn (96% red)	...	...	...	...	...	...	...	97	...	...	...
Fe–50	Wire, .040 in. diam., cold-drawn (96% red)	...	...	...	...	...	...	...	136	...	...	...
"	Sand-cast	...	...	...	...	...	...	22.5(yld. pt.)	39.0	25†	...	130

(*continued*)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-lead-tin alloys												
Pb–8.61, Sn–5.36, Zn–.82, Sb–.34, Ni–.14	Cast from 2040°F	8.83	...	...	...	7,650	...	10.3(.1% offset)	21.4	17†	...	52
Pb–10; Sn–10	Sand-cast from 1750-1900°F	8.9	...	...	...	6,000	6.7–8.1	13–14	19–23	7–12†	...	50–70
Copper-manganese alloys												
Mn–13; Al–9	Soft	7.2	...	...	...	...	...	...	67	19	...	300
" "	Hard-rolled	...	...	...	...	...	...	...	95.5	1	...	510
Copper-nickel alloys												
Ni–30.48, Mn–.22, Fe–.07	Rod, ¾ in. diam., cold-drawn (15% red) from .030 mm grain size	...	...	...	...	15,200	...	44.8(.5% extn.)	47.3	23†	...	...
Ni–30.48, Mn–.22, Fe–.07	Rod, ¾ in. diam, cold-drawn (15% red) from .030 mm grain size 2 hr at 840°F	...	...	...	...	15,600	...	38.4(.5% extn.)	46.2	30†	...	...
Constantan												
Ni–45	Sand-cast	8.6	...	...	...	...	...	14.8(.2% offset)	39.4	32†	...	80
Ni–45, Mn–.5-1.0, Fe–.27, C–.05	Rod, ann. 4 hr at 1400°F	...	...	...	...	17,400	14.2	18.3(yld. pt.)	46.8	46†	...	R_B 54
Ni–44.77, Mn–.89, Fe–.66, C–.078	Rod, 1 hr at 1450° F, f.-c.	...	...	...	...	...	14.8	17.8(.01% perm.)	48.6	48†	19.6	86
Ni–44.77, Mn–.89, Fe–.66, C–.078	Rod, cold-rolled	...	...	...	...	...	...	38.5(.01% perm.)	72.5	15†	30.2(4×10⁷)	159

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-nickel-beryllium alloys												
Ni–2.0, Be–.2	Quenched from 1650°F, cold-drawn, (56% red)	...	...	...	...	...	...	...	46.8	4.3†	...	...
" "	Quenched from 1650°F, ½ hr at 930°F, cold-drawn (56% red)	...	...	...	...	...	...	...	85.5	2.5†	...	...
Copper-nickel-manganese alloys												
Ni–13.5, Mn–5, Al–1.5	Rod, 1 in. diam., extruded, cold-drawn (10% red)	...	...	...	...	...	12.6	35.4(.2%)	48.6	36†	...	V 157
"	Rod, 1 in. diam., cold-drawn, 2 hr at 1110°F	...	...	...	...	...	49.0	60.0(.2%)	77.0	21†	...	V 240
Copper-nickel-silicon alloys												
Cu–94.15, Ni–5.14, Si–rem.	Sheet, .020 in., soft	...	...	...	...	11,500	37.4	...	72.5	4.0†	9.8(10^8)	...
Copper-nickel-tin alloys												
Ni–29.08, Sn–.95, Fe–.25, C–.07	Rod, 1 in. diam., cold-drawn	...	...	...	...	15,000	...	39.0(.01% perm.)	61.3	3.8†	23.5(5×10^7)	143
Copper-nickel-zinc alloys												
Ni–20, Zn–5	Sheet or plate, soft	8.86	...	...	...	...	...	14.0(.5% extn.)	35.1	35†	...	R_B 25
" "	Sheet or plate, hard	...	...	...	...	13,300	...	30.2(.5% extn.)	60.0	5†	...	R_B 88
Ni–20.22, Zn–5.26, Mn–.25, Fe–.08, Mg–.06	Rod, ¾ in. diam., cold-drawn (15% red) from .060 mm grain size, 2 hr at 840°F	...	...	...	...	14,600	...	32.0(.5% extn.)	41.0	32†	...	...

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-silicon-manganese alloys												
Si–1.41, Mn–.21, Fe–.06	Rod, ½ in. diam., cold-worked (72% red)	...	...	...	...	12,000	...	48.0(.5% extn.)	61.8	10†	21.4(3×10^8)	R_B 86
Si–3, Mn–1	Sheet, .040 in., ann.	8.53	...	...	...	10,500	...	17 (.5% extn.)	42	65†	...	R_F 45
Copper-silver alloys												
Ag–.093, Fe–.007	Rod, 1 in. diam., drawn (10% red)	...	...	...	...	...	1.9	...	24.2	51§	...	...
" "	Rod, 1 in. diam., drawn (10% red) 2 hr at 570°F	...	...	...	...	14,000	5.7	...	24.1	51§	...	...
Copper-tin alloys												
Sn–.48	Rod, 1 in. diam., drawn (10% red)	...	...	...	...	13,600	3.16	...	32.4	33§	...	...
"	Rod, 1 in. diam., drawn (10% red) 2 hr at 570°F	...	...	...	...	13,800	20.2	...	31.6	37§	...	...
Sn–4.23, P–.13	Rod, ¾ in. diam., drawn ½ hr at 525°F	...	...	...	...	12,400	17.3	40.2(.1% extn.)	43.5	33§	15.5(5×10^7)	138
Copper-tin-lead alloys												
Sn–5.0, Pb–1, P–.1	Sheet, .04 in. hard	...	...	...	...	10,500	...	42.0(.5% extn.)	57.5	8†	...	R_B 90
Copper-tin-nickel alloys												
Sn–3.88, Ni–2.33, S–.58, P–.37	Sheet, cold-rolled, quenched from 1470°F, aged 1 hr at 930°F	...	...	...	...	12,300	26.6	...	51.4	22†	...	R_B 80

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (continued)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-zinc alloys												
Zn–.48	Rod, 1 in. diam., drawn (10% red)	...	...	...	...	13,900	1.27	...	24.2	49 §	...	...
Zn–15	Sheet, .040 in., cold-drawn (37% red)	8.5	.38	4.7*	18.6*	...	...	...	50	5 †	...	R_B 78
Gilding metal; Zn–5	Sheet, .040 in. soft	8.85	.57	3.1*	18.1*	...	...	...	25	44 †	...	R_F 45
Cu–90.10, Zn–rem	Rod, ½ in. diam., ann.	8.8	.45	4.1*	18.3*	...	...	8.1 (.5% extn.)	26	54 †	...	R_F 53
Cu–71.68, Fe–.02, Pb–.01, Zn–rem	Sheet, .020 in., cold-worked (37% red)	...	...	...	...	11,200	16.2	...	52.8	7.5 †	13.3 (10^8)	R_B 82
Zn–30.2	Cast	8.2	.29	6.4*	19.8*	...	...	10.2 (yld. pt.)	26.2	58 †	...	55
Zn–33	Sheet, hard	...	...	...	...	...	...	...	59.5	4 †	...	153
Cu–66.12, Zn–rem	Sheet, .025 in. (grain size, .035 mm)	...	...	...	...	...	...	...	35.7	62 †	...	...
Zn–34.6, Fe < .1	Rod, rolled	...	...	...	...	...	...	29.2 (yld. pt.)	36.9	40 †	...	101
Zn–41.04	Cast	...	...	...	...	...	...	13.8 (yld. pt.)	39.2	45 †	...	90
Copper-zinc-aluminum alloys												
Zn–16.35, Al–6.16, Mn–4.39, Fe–2.30	Sand-cast	...	...	...	...	...	16.1	...	64.0	28 †	...	...
Cu–63.35, Al–4.12, Mn–2.74, Fe–1.73, Pb–.25, Ni–.2, Zn–rem.	Cast from 2,100°F	7.90	...	...	...	9,800	...	41.8 (.5% perm.)	69.5	10	...	179
Zn–31.45, Al–4.10, Ni–3.0, Fe–1.45	Bar, 2½ in. square, cast	...	...	...	...	...	...	36.8 (.5% perm.)	70.0	12 †	...	159
Zn–33.57, Al–3.95, Ni–3.13	Bar, 2½ in. square, cast	...	...	...	...	...	...	41.0 (.5% perm.)	66.8	6.0 †	...	185
Copper-zinc-arsenic alloys												
Zn–29.41, As–.49	Cast	...	...	...	...	...	...	8.35 (yld. pt.)	23.1	36 †	...	58

(continued)

TABLE 188.—MECHANICAL PROPERTIES OF COPPER AND COPPER ALLOYS (concluded)

Composition percent	Condition	Density cgs	Thermal conductivity cgs	Resistivity microhm-cm	Thermal expansion cgs	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit cycles kg/mm²	Hardness number
Copper-zinc-iron alloys												
Zn–38.48, Fe–1.21, Sn–.72, Al–.1, Pb–.09	Rod, ½ in., hard-drawn	...	...	...	...	10,900	...	57.0	62.0	12†	...	178
Cu–56.85, Fe–1.50, Sn–.32, Al–.23, Mn–.20, Zn–rem.	Cast	8.26	...	...	...	10,000	9.15	...	49.0	33‖	12.0(2.5×10⁸)	93
Copper-zinc-manganese alloys												
Zn–33.1, Mn–4.2, Al–3.5	Round bar, die-cast from 1930°F	7.79	...	...	...	...	...	44.0(.15% perm.)	66.0	7†	...	187
Copper-zinc-nickel alloys												
Zn–9.89, Ni–2.32, Si–.57	Sheet, .020 in., quenched from 1470°F, aged 1 hr at 930°F	...	...	...	...	13,900	31.3	...	63.5	14†	13.0(10⁸)	R_B 86
Zn–19.8, Ni–2.37, Si–.57	Sheet, .020 in., quenched from 1470°F, aged 1 hr at 930°F	...	...	...	...	12,100	26.2	...	60.5	22†	11.2(10⁸)	R_B 85
Zn–30.12, Ni–2.36, Si–.66	Sheet, .040 in., hard-rolled	...	...	...	...	9,800	33.8	...	98.5	2.5†	...	R_B 98
Copper-zinc-tin alloys												
Zn–6, Sn–6	Sand-cast	8.65	...	...	...	...	...	11.2–12.6 (yld. pt.)	25–30	30–60	...	50–65
Admiralty brass: Zn–28, Sn–1	Sheet, ann.	8.53	...	...	...	10,500	...	...	31.6	60†	...	...
Naval brass: Cu–61.20, Sn–.43, Pb–.10, Zn–rem.	Rod, ¾ in. diam., rolled	8.42	...	...	...	10,800	23.5	...	48.0	27	14.8(10⁸)	...
Zn–41, Sn–1	Die-cast	8.47	...	...	...	...	...	21–25(yld. pt.)	39–42	15–20†	...	120–130

TABLE 189.—COPPER WIRE—SPECIFICATION VALUES

Copper wire: Hard-drawn (and **hard-rolled flat copper** of thicknesses corresponding to diameter of wire). Specification values. (A. S. T. M. B1-15, U. S. Navy Dept.)
Specific gravity 8.89 at 20°C (68°F).

Diameter		Minimum tensile strength		Minimum elongation, percent in
mm	in.	kg/mm²	lb/in.²	254 mm (10 in.)
11.68	.460	34.5	49,000	2.75
10.41	.410	35.9	51,000	3.25
9.27	.365	37.1	52,800	2.80
8.25	.325	38.3	54,500	2.40
7.34	.289	39.4	56,100	2.17
6.55	.258	40.5	57,600	1.98
5.82	.229	41.5	59,000	1.79
				in 1524 mm (60 in.)
5.18	.204	42.2	60,100	1.24
4.62	.182	43.0	61,200	1.18
4.12	.162	43.7	62,100	1.14
3.66	.144	44.3	63,000	1.09
3.25	.128	44.8	63,700	1.06
2.90	.114	45.2	64,300	1.02
2.59	.102	45.7	64,900	1.00
2.31	.091	46.0	65,400	.97
2.06	.081	46.2	65,700	.95
1.83	.072	46.3	65,900	.92
1.63	.064	46.5	66,200	.90
1.45	.057	46.7	66,400	.89
1.30	.051	46.8	66,600	.87
1.14	.045	47.0	66,800	.86
1.02	.040	47.1	67,000	.85

NOTE.—P-limit of hard-drawn copper wire must average 55 percent of ultimate tensile strength for four largest-size wires in table, and 60 percent of tensile strength for smaller sizes.

TABLE 190.—COPPER WIRE—MEDIUM HARD-DRAWN

(A. S. T. M. B2-15) Minimum and maximum strengths.

Diameter		Tensile strength: Minimum		Tensile strength: Maximum		Elongation, minimum percent
mm	in.	kg/mm²	lb/in.²	kg/mm²	lb/in.²	in 254 mm (10 in.)
11.70	.460	29.5	42,000	34.5	49,000	3.75
6.55	.258	33.0	47,000	38.0	54,000	2.50
						in 1524 mm (60 in.)
4.12	.162	34.5	49,000	39.5	56,000	1.15
2.59	.102	35.5	50,330	40.5	57,330	1.04
1.02	.040	37.0	53,000	42.0	60,000	.88

NOTE.—Representative values only from table in specifications are shown above. P-limit of medium hard-drawn copper averages 50 percent of ultimate strength.

TABLE 191.—COPPER WIRE—SOFT OR ANNEALED

(A. S. T. M. B3–15) Minimum values.

Diameter		Minimum tensile strength		Elongation in 254 mm (10 in.),
mm	in.	kg/mm²	lb/in.²	percent
11.70 to 7.37	.460 to .290	25.5	36,000	35
7.34 to 2.62	.289 to .103	26.0	37,000	30
2.59 to .53	.102 to .021	27.0	38,500	25
.51 to .08	.020 to .003	28.0	40,000	20

NOTE.—Experimental results show tensile strength of concentric-lay copper cable to approximate 90 percent of combined strengths of wires forming the cable.

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL **

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Aluminum steel								
C–.30–.40, Al–.90–1.40, Cr–.90–1.40, Mn–.40–.60, Mo–.15–.25	quenched from 1750°F, tempered at 1100°F	—	—	96	109	15(2 in.)	—	310
Carbon steels								
C–.08, Mn–.41 (open-hearth rimming)	strip, .104 in., rolled	—	—	27.0 (yld. pt.)	37.0	35(2 in.)	—	R_B 55
C–.12, Mn–.84, S–.12, P–.099 (free-cutting steel)	bar, 1⅛ in. diam., cold-rolled	21,400	—	(.001% offset) 53.4	58.5	18(2 in.)	—	V 205
C–.15–.25, Mn–.30–.50	rod, ⅛ in., cold-drawn	21,100	—	76.0	81.5	11(10 in.)	37.3	—
C–.27, Mn–.72, Si–.21	wrought, ann., at 1450°F; f.-c.	19,300	—	26.4	47.4	46(2 in.)	—	153
"	wrought, w.-q. from 1600°F, tempered at 1100°F	20,800	—	38.6	64.0	42(2 in.)	—	191
C–.45, Mn–.77, Si–.21	normalized 1 hr at 1600°F; room:	20,500	—	44.4	79.5	17(2 in.)	—	R_C 16
	— 40°F	—	—	—	—	—	—	R_C 20
	—108°F	20,000	—	52.0	91.5	16(2 in.)	—	R_C 22
"	¾ hr at 1475°F, w.-q., tempered 1 hr at 1000°F; room:	20,800	—	88	95.0	12(2 in.)	—	R_C 27
	— 40°F	—	—	—	—	—	—	R_C 29
	—108°F	20,200	—	95.5	106.5	14(2 in.)	—	R_C 29
C–.57, Mn–.65, Si–.17	oil-quenched from 1490°F, tempered at 860°F	—	—	68.5 (yld. pt.)	102.5	16(2 in.)	—	293
C–.91, Mn–.38, Si–.16 (acid open-hearth)	oil-quenched from 1575°F, tempered at 940°F	21,200	—	101.5 (.01% perm.) 126 (.2% perm.)	159	7(2 in.)	56.2 36.5* 71.7†	444
C–1.04, Mn–.36, Si–.16	⅓ hr at 1550°F, quenched in oil at 120°F, tempered ¼ hr at 800°F	21,000	—	101.5 (.01% perm.) 136.5 (.2% perm.)	166.5	5(2 in.)	68.8 86.5†	430–470

** For reference, see footnote 55, p. 187. * Reversed torsion. † Zero to maximum torsion.

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Chromium steel								
C-.20, Cr-.75, Mn-.57, Si-.21	bar, ¾ in. diam., normalized at 1700°F	—	—	39.4	53.5	35	—	131
C-.59, Cr-.82, Mn-.83, Si-.35	forged	—	—	60.0	101.5	7(2 in.)	—	286
Chromium-niobium steels								
C-.09, Cr-5.62, Nb-1.04	bar, 1 in. diam., rolled	—	—	69.0	77.3	16(2 in.)	—	192
Chromium-copper steels								
C-.11, Cr-.53, Cu-.37, Si-.82, P-.088	bar, 1 in. diam., normalized	—	—	39.7 (yld. pt.)	58	29(2 in.)	—	—
Chromium-molybdenum steels								
C-.08, Cr-5.81, Mo-.45	bar, ¾ in. diam., 4 hr at 1380°F, a.-c.	—	—	39.4 (yld. pt.)	60.5	29(2 in.)	—	149
C-.10, Cr-12.75, Mo-.35, Mn-.40, Si-.40, S-.30, Ni-.25	annealed	—	—	32.0 (.2% perm.)	52.7	30(2 in.)	30.3	152
	heat-treated	—	—	58.0 (.2% perm.)	73.8	20(2 in.)	39.0	217
Chromium-titanium steels								
C-.11, Cr-5.41, Ti-.75	bar, 1 in. diam., rolled 4 hr at 1380°F, a.-c.	—	—	19.7	43.0	37(2 in.)	—	112
Chromium-tungsten steels								
C-.46, Cr-11.94, W-4.80, Si-2.89, Mn-.49	oil-quenched from 1875°F, tempered at 1470°F	—	71.0	—	90.6	5(2 in.)	—	300
Chromium-vanadium steels								
C-.58, Cr-.73, V-.18, Mn-.68	annealed at 1500°F	—	34.8	—	65.0	28(2 in.)	—	163
"	water-quenched from 1650°F, tempered at 1050°F	—	—	98.5	127.5	14(2 in.)	—	351
C-.52, Cr-.88, V-.21, Mn-.66	⅔ hr at 1600°F, quenched in oil at 130°F, tempered 1 hr at 810°F	21,200	—	98.5 (.01% perm.) 16.1 (.01% perm.)	167	11(2 in.)	73 52.7* 90.0†	477–488

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Copper steels								
C–.08, Cu–.25, Mn–.38	sheet, .062 in., rolled	—	—	29.8	36.0	31(8 in.)	—	R_B 60
Graphitic steel								
C–1.50, Si–1.0, Mo–.25	annealed	—	—	34.8 (yld. pt.)	59.4	25(2 in.)	—	197
Iron								
TC–3.41, GC–2.85, CC–.56, Si–2.44, P–.63, Mn–.57, S–.070, Ti–.10	cast	5,620 (at ½ load)	—	—	14.1	—	6.60	159
Alloy cast iron: TC–2.61, GC–1.73, CC–.88, Si–2.38, Ni–1.08, Mn–.77, S–.105, Cr–.09	cast	11,400 (at ½ load)	—	—	36.1	—	17.0	270
Alloy cast iron: TC–2, Ni–18, Si–5, Cr–2, Mn–1, P–.01, S–.1	cast	—	—	—	12.9	1–4(2 in.)	—	110–170
Malleable cast iron: TC–1.75–2.30, Si–.85–1.20, Mn–<.40, P–<.20, S–<.12	cast, annealed	17,550	—	26.3 (yld. pt.)	40.0	22(2 in.)	17.6–18.6	110–145
Pure iron: Fe–99.99	rod, ¼ in., swaged ann. 4 hr at 1600°F	20,000	—	5.7–6.1 (.2% offset)	20–21	36–46(2 in.)	—	60
Wrought iron: C–.017, Si–.122, P–.084	longitudinal	—	—	21.0	33.0	15(2 in.)	21.5	—
Wrought iron: C–.017, Si–.122, P–.084	transverse	—	—	20.1	32.9	17(2 in.)	19.7	—
Manganese steels								
C–.35, Mn–1.71, Si–.30	cast	—	27.4	—	56.8	2.1(2 in.)	22.5	179
Molybdenum steels								
C–.23, Mo–.17, Mn–.67, Si–.52, Cu–.10	annealed at 1650°F	—	—	38.0	57.8	31(5 diam.)	—	—
C–.24, Mo–.22, Mn–.85, Si–.19	plate, ⅝ in., rolled	—	—	42.5 (yld. pt.)	62.0	30(2 in.)	—	194
C–.39, Cr–.86, Mo–.17, Mn–.56	oil-quenched from 1625°F, tempered at 500°F	—	—	116.5	149	6.5(2 in.)	—	388

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Nickel steels								
C-.43, Ni-3.47, Mn-.64, Si-.20	wrought, f.-c., from 1450°F	21,000	—	37.3	66.4	33(2 in.)	—	187
" " " "	wrought, o.-q., from 1450°F, tempered at 1100°F	19,800	—	57.8	82.2	34(2 in.)	—	226
C-.42, Ni-3.41, Mn-.66, Si-.21	bar, ¾ in. diam., wrought; ann. at 1550°F: 70°F	—	41.4	44.3 (yld. pt.)	70.0	26(2 in.)	—	195
	800°F	—	14.0	27.3 (yld. pt.)	55.0	30(2 in.)	—	
	1000°F	—	7.73	17.6 (yld. pt.)	32.7	39(2 in.)	—	
Nickel-chromium steels								
C-.37, Ni-1.28, Cr-.52, Mn-.55	bar, 1⅛ in. diam., h.-t.	20,000	—	17.6 (.001% offset)	92	18(2 in.)	—	—
C-.37, Ni-1.33, Cr-.65, Mn-.75, Si-.18	hot-rolled	—	—	52.1 (yld. pt.)	81	25(2 in.)	31.0*	—
C-.36, Ni-1.33, Mn-.60, Cr-.56, Si-.26, (basic open-hearth, deoxidized with Si and Al)	bar, ¾ in. diam., wrought; 1 hr at 1550°F, o.-q. tempered at 1000°F, grain size 7-8 (ASTM std.), normal:							
	85°F	—	83.0	92.0 (.2% perm.)	99	19(2 in.)	—	285
	900°F	—	12.3	36.8 (.2% perm.)	62.5	22(2 in.)	—	
	1000°F	—	3.87	17.9 (.2% perm.)	43.6	20(2 in.)	—	
	1200°F	—	.70	5.27 (.2% perm.)	21.3	51(2 in.)	—	
Nickel-chromium-molybdenum steel								
C-.32, Ni-1.92, Cr-.86, Mo-.30, Mn-.60, Si-.16	wrought, f.-c., from 1450°F	20,200	—	34.9	67.6	37(2 in.)	—	202
C-.32, Ni-1.92, Cr-.86, Mo-.30, Mn-.60, Si-.16	wrought, o.-q. from 1530°F, tempered at 1100°F	20,000	—	73.8	98.5	32(2 in.)	—	229

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (continued)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Nickel-molybdenum steels								
C-.41, Ni-1.96, Mo-.31	oil-quenched from 1525°F, tempered at 1200°F	—	67.7	85.0 (yld. pt.)	91.5	23	47.2	252
" " "	quenched from 1525°F into lead at 840°F (austempered)	—	42.8	74.0 (yld. pt.)	90.0	19	—	—
Nickel-copper steels								
C-.08, Ni-2.00, Cu-1.00, Mn-.55, Si-<.3	plate, ½-¾ in., rolled	—	—	38.7 (yld. pt.)	52.8	25(8 in.)	28.1	—
Silicon steels								
C-.07, Si-1.17, Mn-.32	rolled	—	—	33.4	47.5	30(3 in.)	—	130
Silicon-manganese steels								
C-.52, Si-1.95, Mn-1.05, Cr-.05	oil-quenched from 1600°F, tempered at 970°F	—	—	102.5 (.1% perm.)	139	15(2 in.)	67.7	—
C-.53, Si-1.96, Mn-.83	⅔ hr at 1600°F, quenched in oil at 130°F, tempered 1 hr at 860°F	20,500	—	92.8 (.01% perm.) 148 (.1% perm.)	166	12(2 in.)	78.7 97.0†	438-457
Stainless steel								
C-.17, Cr-18, Ni-8	water-quenched from 1100°F	—	21.1	—	65.4	68(2 in.)	26.7	170
C-.07, Cr-18.95, Ni-7.69	bar, ⅜ in. diam., cold-rolled	17,600	9.14	—	100.5	21(1.5 in.)	59.8	302
C-.13, Cr-24.5, Ni-20.3, Si-.85,	bar, 1 in. diam., rolled	—	—	28.1 (yld. pt.)	61.8	40(2 in.)	—	R_B 92
C-.11, Cr-16.2, Ni-11.5	water-quenched from 2010°F; room:	—	—	31.5 (yld. pt.)	65.8	48(2 in.)	—	—
	— 85°F	—	—	—	—	—	—	—
	—292°	—	—	83.0 (yld. pt.)	155	55(2 in.)	—	—

(continued)

TABLE 192.—MECHANICAL PROPERTIES OF IRON AND STEEL (concluded)

Composition percent	Condition	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
C–.08, Cr–18.58, Ni–9.68, Ti–.42	air-cooled from 1920°F	—	—	26.8	60.8	59(2 in.)	—	—
C–.07, Cr–18.2, Ni–9.42, Nb–.51	water-quenched from 2100°F	—	—	25.3	62.9	60(2 in.)	—	137
C–.40, Cr–15.21, Si–.59, Mn–.28, Ni–.18	bar, 1 in. diam., 1 hr at 1650°F, w.-q., tempered 1 hr at 1200°F	—	36.4	—	81.5	20(2 in.)	42.0 21.1*	—
C–.20, Cr–16.17, Mn–1.06, Si–.30	oil-quenched from 1740°F, tempered 3 hr at 840°F	23,100	35.7	62.5	133	10(2 in.)	—	357
C–.15, Cr–13.50, Si–.11	oil-quenched from 1740°F, tempered at 1110°F	22,000	57.8	77.3	92.8	21(2 in.)	—	285
" " "	oil-quenched from 1740°F, tempered at 1290°F	22,200	42.3	50.7	68.5	28(2 in.)	—	206
C–.09, Cr–16.53	sheet, .18 in., hot-rolled	—	—	73.0	93.5	4.5(8 in.)	—	R_E 103
" "	sheet, .18 in., ann.	—	—	34.5	49.2	20(8 in.)	—	R_B 82
C–.20, Cr–27.37, Mn–.32, Si–.28, Ni–.19	annealed	—	18.5	31.3	56.9	28(2 in.)	30.9	—
C–.08, Cr–5.81, Mo–.45	bar, ¾ in. diam., 4 hr at 1380°F, a.-c.	—	—	39.4 (yld. pt.)	60.4	29(2 in.)	—	149
Tungsten steels								
C–.71, W–17.30, Cr–3.86, V–.75	normalized at 1740°F; tempered at 1470°F	—	—	62 (yld. pt.)	92	19(2 in.)	—	—

TABLE 193.—STEEL WIRE—SPECIFICATION VALUES

S. A. E. carbon steel, No. 1050 or higher number specified (see carbon steels above). Steel used to be manufactured by acid open-hearth process, to be rolled, drawn, and then uniformly coated with pure tin to solder readily.

American or B. and S. wire gage	Diameter		Req'd twists in 203.2 mm or 8 in.	Weight		Req'd bends thru 90°	Spec. minimum tensile strength			
	mm	in.		kg/100 m	lb/100 ft		kg	lb	kg/mm²	lb/in.²
6	4.115	.162	16	10.44	7.01	5	2040	4500	154	219,000
7	3.665	.144	19	8.28	5.56	6	1680	3700	161	229,000
8	3.264	.129	21	6.55	4.40	8	1360	3000	164	233,000
9	2.906	.114	23	5.21	3.50	9	1135	2500	172	244,000
10	2.588	.102	26	4.12	2.77	11	910	2000	172	244,000
11	2.305	.091	30	3.28	2.20	14	735	1620	179	254,000
12	2.053	.081	33	2.60	1.74	17	590	1300	177	252,000
13	1.828	.072	37	2.06	1.38	21	470	1040	179	255,000
14	1.628	.064	42	1.64	1.10	25	375	830	181	258,000
15	1.450	.057	47	1.30	.87	29	300	660	182	259,000
16	1.291	.051	53	1.03	.69	34	245	540	186	264,000
17	1.150	.045	60	.81	.55	42	195	425	188	267,000
18	1.024	.040	67	.65	.43	52	155	340	190	270,000
19	.912	.036	75	.51	.34	70	125	280	193	275,000
20	.812	.032	85	.41	.27	85	100	225	197	280,000
21	.723	.028	96	.32	.22	105	80	175	200	284,000

NOTE.—Number of 90° bends specified above to be obtained by bending sample about 4.76 mm (.188 in.) radius, alternately, in opposite directions.

TABLE 194.—STEEL WIRE—EXPERIMENTAL VALUES

Data from tests at General Electric Co. laboratories. Commercial steel music wire (hardened).

Diameter		Ultimate strength tension		Diameter		Ultimate strength tension	
mm	in.	kg/mm²	lb/in.²	mm	in.	kg/mm²	lb/in.²
12.95	.051	226.0	321,500	6.35	.025	262.0	372,500
11.70	.046	249.0	354,000	4.55	.018	265.5	378,000
9.15	.036	253.0	360,000	2.55*	.010	386.5	550,000
7.60	.030	260.0	370,000	1.65*	.0065	527.0	750,000
				4.55†	.018	49.2	70,000

* For 4.55 mm wire drawn cold to indicated sizes. † For 4.55 mm (.018 in.) wire annealed in H_2 at 850°C.

TABLE 195.—PLOW-STEEL HOISTING ROPE (BRIGHT)

Wire rope to be of best plow-steel grade, and to be composed of 6 strands, 19 wires to the strand, with hemp center. Wires entering into construction of rope to have an elongation in 203.2 mm or 8 in. of about 2½ percent.

Diameter		Spec. minimum strength		Diameter		Spec. minimum strength	
mm	in.	kg	lb	mm	in.	kg	lb
9.5	⅜	5,215	11,500	38.1	1½	74,390	164,000
12.7	½	9,070	20,000	50.8	2	127,000	280,000
19.0	¾	20,860	46,000	63.5	2½	207,740	458,000
25.4	1	34,470	76,000	69.9	2¾	249,350	550,000

TABLE 196.—STEEL-WIRE ROPE—SPECIFICATION VALUES

Cast steel wire to be of hard crucible steel with minimum tensile strength of 155 kg/mm² or 220,000 lb/in.² and minimum elongation of 2 percent in 254 mm (10 in.).

Plow steel wire to be of hard crucible steel with minimum tensile strength of 183 kg/mm² or 260,000 lb/in.² and minimum elongation of 2 percent in 254 mm (10 in.).

Annealed steel wire to be of crucible cast steel, annealed, with minimum tensile strength of 77 kg/mm² or 110,000 lb/in.² and minimum elongation of 7 percent in 254 mm (10 in.).

Type A: 6 strands with hemp core and 19 wires to a strand (= 6 × 19), or 6 strands with hemp core and 18 wires to a strand with jute, cotton, or hemp center.

Type B: 6 strands with hemp core, and 12 wires to a strand with hemp center.

Type C: 6 strands with hemp core, and 14 wires to a strand with hemp or jute center.

Type AA: 6 strands with hemp core, and 37 wires to a strand (= 6 × 37) or 6 strands with hemp core and 36 wires to a strand with jute, cotton, or hemp center.

Description	Diameter		Approx. weight		Minimum strength	
	mm	in.	kg/m	lb/ft	kg	lb
Galv. cast steel, Type A	9.5	3/8	.31	.21	3,965	8,740
" " " " "	12.7	1/2	.55	.37	6,910	15,230
" " " " "	25.4	1	2.23	1.50	27,650	60,960
" " " " "	38.1	1 1/2	5.06	3.40	63,485	139,960
Galv. cast steel, Type AA	9.5	3/8	.35	.22	3,840	8,460
" " " " "	12.7	1/2	.58	.39	7,410	16,330
" " " " "	25.4	1	2.23	1.50	27,650	60,960
" " " " "	38.1	1 1/2	5.28	3.55	59,735	131,690
Galv. cast steel, Type B	9.5	3/8	.25	.17	2,995	6,600
" " " " "	12.7	1/2	.42	.28	5,210	11,500
" " " " "	25.4	1	1.68	1.13	20,890	46,060
" " " " "	38.1	1 1/2	3.94	2.65	47,965	105,740
Galv. cast steel, Type C	25.4	1	1.59	1.07	18,825	41,500
" " " " "	41.3	1 5/8	4.35	2.92	51,575	113,700
Galv. plow steel, Type A	9.5	3/8	.31	.21	4,690	10,340
" " " " "	12.7	1/2	.55	.37	8,165	18,000
" " " " "	25.4	1	2.23	1.50	32,675	72,040
" " " " "	36.5	1 7/16	4.66	3.13	69,140	152,430
Galv. plow steel, Type AA	9.5	3/8	.33	.22	4,540	10,000
" " " " "	12.7	1/2	.58	.39	8,750	19,300
" " " " "	25.4	1	2.35	1.58	32,250	71,100
" " " " "	41.3	1 5/8	6.18	4.15	83,010	183,000

TABLE 197.—STEEL-WIRE ROPE—EXPERIMENTAL VALUES

Wire rope purchased under Panama Canal Spec. 302 and tested by National Bureau of Standards, Washington, D. C.

Description and analysis	Diameter		Ultimate strength		Ultimate strength (net area)	
	mm	in.	kg	lb	kg/mm²	lb/in.²
Plow steel, 6 strands × 19 wires C .90, S .034, P .024, Mn .48, Si .172	50.8	2	137,900	304,000	129.5	184,200
Plow steel, 6 strands × 25 wires C .77, S .036, P .027, Mn .46, Si .152	69.9	2 3/4	314,800	694,000	151.2	214,900
Plow steel, 6 × 37 plus 6 × 19 C .58, S .032, P .033, Mn .41, Si .160	82.6	3 1/4	392,800	866,000	132.2	187,900
Monitor plow steel, 6 × 61 plus 6 × 19, C .82, S .025, P .019, Mn .23, Si .169	82.6	3 1/4	425,000	937,000	142.5	202,400

Recommended allowable load for wire rope running over sheave is one-fifth of specified minimum strength.

TABLE 198.—MECHANICAL PROPERTIES OF MISCELLANEOUS ALLOYS **

Composition percent	Condition	Density g/cm³	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Cadmium alloys									
Cu-1.5; Mg-.95	Cast	. . .	5,600	. . .	5.48 (.02% offset) 9.84 (.2% offset)	15.77	8.8(10 diam.)	3.8	42
Zn-5.0	Rod, 1 in. diam., chill-cast from 660°F; aged one month at r.-t.	8.55	. . .	. . .	. . .	9.2(rate of strain 6%/minute)	6.5(1.25 in.)	. . .	32
Cobalt alloys									
Fe-1.4; Ni-1.1; C-.24	Cast, ann. 2 hr at 1,650°F	. . .	20,800	. . .	. . .	. . .	. . .	. . .	. . .
Co-45-55; Cr-30-35; W-12-17	Cast	8.76	24,900	. . .	. . .	45.7	0(2 in.)	. . .	Rc 61
Gold alloys									
Cd-4.6; Cu-2.8; Zn-1.0	. . . .	. . .	. . .	9.28	. . .	30.8	55(2 in.)	. . .	44
Cu-6.3; Ag-2.1	Strip, $\frac{3}{8}$ in., ann. $\frac{1}{3}$ hr at 1365°F	. . .	. . .	13.2	. . .	32.1	35	. . .	. . .
Cu-15.6; Ag-6.0; Pt-2.78; Zn-2.38; Ni-1.98	Rod, $\frac{1}{8}$ in. diam., cast, w.-q. from 1290°F	. . .	9,140	37.6	. . .	48.5	4(3 in.)	. . .	. . .
Cu-17.95; Ni-17.60; Zn-6.0; Mn-.4	Sheet, .050 in., rolled (50% red) $\frac{1}{2}$ hr at 1290°F, a.-c.	. . .	. . .	. . .	45.0 (yld. pt.)	72.4	44(2 in.)	. . .	. . .
Cu-34.9; Ni-12.14; Ag-11.11	Sheet, .045 in., rolled (50% red), ann. $\frac{1}{3}$ hr at 1300°F, a.-c.	. . .	. . .	. . .	49.3 (yld. pt.)	63.5	19(1.25 in.)	. . .	RB 94
Ni-17.0; Cu-16.0; Zn-8.65	Sheet. .05 in., rolled (50% red), $\frac{1}{2}$ hr at 1380°F, a.-c.	. . .	. . .	. . .	45.3 (yld. pt.)	73.8	43(2 in.)	. . .	. . .

** For reference, see footnote 55, p. 187.

(continued)

TABLE 198.—MECHANICAL PROPERTIES OF MISCELLANEOUS ALLOYS (continued)

Composition percent	Condition	Density g/cm³	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Pd–16.1; Pt–7.0; Ir–1.2; Zn–.07	Strip, .006 in., w.-q. from 1290°F	...	14,050	35.1	...	61.8	4.6(8 in.)	...	...
Pt–9.3; Ag–.1; Zn–.02; Ni–.01	Strip, .006 in., w.-q. from 1290°F	...	7,000	6.32	...	24.6	24(8 in.)	...	...
Ag–10.0; Pt–6.1; Cu–5.9; Ir–.1	Rod, $\frac{1}{8}$ in. diam., cast, w.-q. from 1290°F	...	7,700	15.8	...	33.7	18(3 in.)	...	...
Lead alloys									
Sb–.80	Cable sheath, 1 in. o.-d. × $\frac{1}{8}$ in. wall, extruded, aged 131 days at r.-t.	...	...	...	...	3.09(rate of strain) .1(in./in.)/min	32(2.5 in.)	.722(10^7)	V 10
Linotype: Sb–11.5; Sn–4.4; Cu–.08	Cast	...	...	...	...	8.22	9.0(2 in.)	...	21
Monotype: Sb–15.3; Sn–8.3	Cast	...	...	...	...	8.4	4.0(2 in.)	...	22
Bi–.065; Cu–.013; Sb–.0015	Cable sheath, 2.87 in. o.-d. × .159 in. wall (ring specimen)	...	...	...	...	1.34	47	...	3.9
Magnesium alloys									
Al–4.40; Mn–.26	Rod, extruded from 2$\frac{15}{16}$ in. to $\frac{3}{4}$ in. diam. at 350-400°F	1.77	4,290	9.48	...	27.4	16(8 in.)	10.5(10^8)	58
Al–10; Mn>.1; Si<.5; Zn<.3	Cast, h.-t. and aged	...	4,570	...	13.4 (.2% offset)	25.3	2(2 in.)	6.3 (5×10^8)	69
Cu–13	Rod, 1 in. diam., hot-rolled	...	4,640	5.2	...	27.4	2.5($4\sqrt{area}$)	...	...
Manganese alloys									
Cu–18; Ni–10	....	...	12,240	...	...	77.0	6.5	...	...

(continued)

TABLE 198.—MECHANICAL PROPERTIES OF MISCELLANEOUS ALLOYS (concluded)

Composition percent	Condition	Density g/cm³	Modulus of elasticity kg/mm²	Proportional limit kg/mm²	Yield strength kg/mm²	Tensile strength kg/mm²	Elongation percent	Endurance limit kg/mm²	Hardness number
Nickel alloys									
Al–4.78; Mn–.26; C–.17; Fe–.07; Si–.05	Rod, 7/8 in. diam., hot-rolled, ann. 2 hr at 1650°F, slowly cooled	...	21,500	9.4	18.75 (.01% offset)	61.6	43(4$\sqrt{\text{area}}$)	...	...
Ni–80; Cr–13; Fe–rem.	Sheet ann.	...	21,800	...	...	55.0	...	...	...
Cr–20	Wrought	8.4	21,800	...	44.5 (yld. pt.)	77.4	30(10 in.)	...	...
Cu–29; Fe–1.5; Si–1.25; Mn.9; C–.2; S<.015	Sand-cast	8.80	18,300	...	24.5 (.2% offset)	49.0	30(2 in.)	...	140
Ni–60; Cr–15; Mo–7; Be–.6–1.0; Fe–rem.	Quenched	8.3	15,500	...	41.8 (yld. pt.)	88.0	30(4 in.)	...	195
Mo–30; Fe–5	Cast	9.24	21,600	...	38.5–40.0 (yld. pt.)	53–58	6–9(2 in.)	...	190–230
Silver alloys									
Cu–5.75; Cd–1.75	Sand-cast	...	...	3.6	9.9	20.7	40(2 in.)	...	73
Tin alloys									
Sb–6.87; Cu–5.69; Pb–.19; Fe–.03; As–.02	Cast	...	6,120	...	5.76 (.2% offset)	8.4	5.2(10 diam.)	2.39	23
Sb–10.01; Cu–9.88; Pb–.19; Fe–.08	Cast	...	5,980	...	6.88 (.2% offset)	7.5	.6(10 diam.)	2.32	27

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS *

Composition percent	Density	Resistivity microhms-cm	Temperature coeff. of resistance	Thermal conductivity cgs	Thermal expansion per °C	Tensile strength kg/mm²	Yield strength kg/mm²	Young's modulus kg/mm²	Hardness number Rockwell	Elongation 2 in. percent
Alloys for strength with lightness										
Duralumin (A 17 S) Al 97, Cu 2.5, Mg .3	2.74	4.3		.37		30		7200	70	
Super duralumin (24 S) Al 93, Cu 4.5, Mn .6 Mg 1.5	2.77	5.7		.29	20–200° 12.9×10^{-6}	50		7200	120	
Dow metal Mg 92, Al 8	1.81	13				23		4.6		
Beryllium alloys										
Beryllium †	1.83	4.3		.385	20–200° 12.4×10^{-6}	35	18.7	2.6×10^{4}	90–110	.0–2.5
Alloys †										
Be .45, Co 2.6, Bal Cu wrought	8.75	3.4		.50		81.	63.	1.26×10^{3}	C23–28	10–15
Be 2.60, Ni 1.10, Bal Cu	7.6	7.8		.18	20–200° 17×10^{-6}	112.	63.		C38	
Be 2.0, Co .5, Bal Cu cast	8.1	6.5		.30		115.	98.	1.33×10^{3}	C37–42	
Be 2.0, Co .3, Bal Cu wrought	8.21	12.7		.16		49.	21.	1.12×10^{3}	C85–95	.35–.50
Alloys for sealing to glass										
42% nickel iron § Fe 57, Ni 42, Mn 1	8.1	7.0	...	03	0–200° 5.4×10^{-6}	70.3		14.7×10^{3}	(Specific heat cgs .12)	

* For reference, see footnote 55, p. 187. For low-melting-point alloys, see Table 201; for special magnetic alloys, see Tables 470-476.

† Annealed and heat treated. A number of alloys with beryllium are made by different manufacturers with about these same compositions and properties. These alloys are valuable due to their endurance and wear resistance, for a nonmagnetic mateial, and, in addition, good heat and electrical conductivity and corrosion resistance. Most of the data are taken from a special American Machinist report, McGraw-Hill.

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (continued)

Composition percent	Density	Resistivity microhms-cm	Temperature coeff. of resistance	Thermal conductivity, cgs	Thermal expansion per °C	Tensile strength kg/mm²	Yield strength kg/mm²	Young's modulus kg/mm²	Hardness number Rockwell	Elongation 2 in. percent
Chrom iron Fe 70–72, Cr 28–30, Mn .5–.8	7.8	...	...		20–600° 11.4×10^{-6}					
Fernico Fe 54, Ni 28, Co 18					100–500° $4.2\text{–}5.4\times10^{-6}$					
Sealmet	7.6	6.4	...	.06	20–100° 10.3×10^{-6}	53.0		20.3×10^{3}	(Specific heat cgs .15)	
Dumet core Ni 42, Fe 58, Cu 20–30 total weight	...	...	...	...	Radial 8.0–10×10^{-6} Axial 6.1–6.5×10^{-6}					
Miscellaneous										
Constantin §[a] Cu 53.3, Ni 45, Mn 1, Fe .6	8.4	49	8×10^{-6}	.23	15	70		25.000	100	
Manganin §[b] Cu 84, Mn 12, Ni 4	8.5	44	$<10^{-6}$ at 25°C		18			17.900		
Nichrome §[a] 59.9 Ni, 25 Fe, 15 Cr, .1 C	8.08	100	4×10^{-4}		12					
Invar [c] Fe 63.8, Ni 36, C .2	8.05	81	1.08×10^{-3}		1.6	80		21.000	160	(Specific heat cgs .12)

§ There are several alloys of about this same composition that are made by different manufacturers. They all have about the same characteristics.

Uses:

[a] Heater and resistance.
[b] Standard resistances.
[c] Low thermal expansion.
[d] Thermocouples.
[e] Mirrors; is an exceedingly hard untarnishable metal.
[f] Mirrors and reflecting gratings; takes good polish and does not tarnish easily.
[g] An alloy sometimes used as a getter for clearing off last traces of gas in an evacuated vessel.
[h] Used for making special casting and in art work.

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (continued)

Composition percent	Density	Tensile strength kg/mm²	Linear thermal expansion per °C	Specific heat cgs	Resistivity microhm-cm	Thermal conductivity cgs	Temperature coeff. of resistance
Chromel R ‡ [d] 90 Ni, 10 Cr, other elements	8.73	67	13.1×10^{-6} 20–100°C	.107	4.25	1.92 watts	3.2 20–100
Alumel ‡ [d] 94.1 Ni 3, Mn 2, Al and other elements	8.60	60	12×10^{-6} 20–100°C	.125	25.	.297 watts	24.5
Stellite § [e] Co 59.5, Mo 7.25, Cr 10.8, Fe 31, Mn 2, C .9, Si .8	8.3		Brinell hardness–512 at 3000 kg Spectral reflecting factor: λ .15, .20, .30, .50, .75, 1.00, 2.00, 3.00, 4.00, 5.00, 8.00 .32, .42, .50, .64, .67, .689, .747, .792, .825, .848, .880				
Speculum metal [f] Cu 67, Sn 33			Spectral reflecting factor: λ .188, .200, .251, .288, .305, .357, .385, .420, .450, .500 .23, .25, .299, .377, .417, .51, .531, .564, .600, .632 λ .550, .600, .650, .700, 1.00, 1.50, 2.00, 3.00, 4.00, 5.00 .64, .648, .654, .668, .705, .750, .804, .862, .885, .891 λ 7.00, 9.00, 11.00, 14.00 .901, .922, .929, 936				
Misch metal § [g] Ce 50–70, Fe 1-5, La, Nd Pr							
Pewter [h] 85 Sn, 6.8 Cu, 6 Bi, 1.7 Sb							

‡ Hoskins Thermocouple (see Table 51).

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (continued)

Soldering and brazing alloys

Soft solder—composition

Pb	Sn	Soldering temperature	Flux	Used for
30	70	170°C	resin	copper
40	60	175	zinc chloride	brass, iron
50	50	190	zinc chloride + 25% HCl	zinc, lead

Hard solder—composition

Cd	Cu	Zn	Ag	Sn	Al	Sb	Pb	Au	Soldering temperature	Flux	Used for
.5	52	38	10						820°C	borax	iron
	34	38	50						695	"	copper
	16	4	80						740	"	brass
	3	18		63	13	2	1			non-	aluminum
	20		30					50		corrosive	gold

Brazing alloys—composition

Ni	Zn	Sn	Cu	Soldering temperature	Flux	Used for
	Rem		50–53	870°C	borax	steel
7–9	55–60		Rem	870	"	brass
	56–65	5–9	Rem	750	"	iron

(continued)

TABLE 199.—PHYSICAL PROPERTIES OF SOME SPECIAL-PURPOSE ALLOYS (concluded)

Carboloy cemented carbides

Grade designation	Composition WC	Co	TaC	TiC	Hardness Rockwell A 60 kg load	Density g/cm³	Traverse rupture strength psi	Young's modulus psi	Thermal expansion $in. \, in.^{-1} \, °F^{-1}$ 70°-1292°	Ultimate limit in compression psi	Torsion modulus psi
44A	94	6	...	...	91.0	14.95	240[j]	84.5[k]	2.8[l]	700[j]	36.0[k]
55A	87	13	...	...	88.2	14.2	340	79.0	3.38	610	32.5
77B	57	16	27	...	85.0	13.55	285	88.0	4.03	610	...
78B	82	10	...	8	90.5	12.55	225	...	...	...	...
831	61	7	...	32	92.5	9.1	165	88.5	3.89	725	36.0

Heat-treated steel[1]

	Hardness	Density	Traverse rupture strength	Young's modulus	Thermal expansion	Ultimate limit in compression	Torsion modulus
SAE 1095—.9 C, .3 Mn, .04 P, .05 S	$39R_c$	7.8	...	30	8.2	172	11.5
H.S.S.—17 W, 4 Cr, 1 V	$64R_c$	8.6	...	32.5	7.1	600	5.0

Hardness versus temperature, °F ¶

Grade	80°F	200	400	600	800	1000	1100	1200°F
831	92.8	93.7	92.3	90.6	89.5	84.3	83.3	81.7
78B	91.0	90.1	90.4	89.0	86.0	82.5	80.8	79.8
77B	87.4	87.0	85.8	82.8	82.5	79.0	77.9	76.1
44A	90.9	90.5	90.0	88.0	86.5	85.5	84.1	81.8
55A	88.0	88.0	87.1	85.5	83.0	79.5	77.0	75.2

[1] For comparison. [j] $\times 10^3$. [k] $\times 10^6$. [l] $\times 10^{-6}$. ¶ Prepared by N. A. Waldrop, Carboloy Co.

Metal or alloy approx. comp. percent	Condition	Density or weight: gm per cm³	Density or weight: lb per ft³	Tension, kg/mm²: P-limit	Tension, kg/mm²: Ultimate strength	Tension, lb/in.²: P-limit	Tension, lb/in.²: Ultimate strength	Percent: Elong. in 50.8 mm (2 in.)	Percent: Reduct. of area	Hardness: Brinell @ 500 kg	Hardness: Sclero-scope
Tungsten, W 99.2*	Ingot sintered, D = 5.7 mm or .22 in.	18.0	1124	—	12.7	—	18,000	0.0	0.0	—	—
	Swaged rod, D = .7 mm or .03 in.	—	—	—	151.0	—	215,000	4.0	28.0	—	—
	Drawn hard, D = .029 mm or .00114 in.	—	—	—	415.0	—	590,000	—	65.0	—	—
	Swaged and drawn hot 97.5% reduction	—	—	—	164.0	—	233,500	3.2	14.0	—	—
	Same as above and equiaxed at 2000° C in H_2 †	—	—	—	118.0	—	168,000	0.0	0.0	—	—
Zinc,‡ Zn:	Cast	7.0	437	(Impurities Pb, Fe, and Cd)				—	—	—	—
	Coarse crystalline	—	—	—	2.8 to	—	4,000 to	—	—	42 to	8 to
	Fine crystalline	—	—	—	8.4	—	12,000	—	—	48	10
	Rolled (with grain or direction of rolling)	—	—	2.0	19.0	2,900	27,000	—	—	—	—
	Rolled (across grain or direction of rolling)	—	—	4.1	25.3	5,800	36,000	—	—	—	—
	Drawn hard	7.1	443	—	7.0	—	10,000	—	—	—	—

* Commercial composition for some incandescent electric lamp filaments containing thoria (ThO_2) approx. 0.75 percent.

† Ordinary annealing treatment makes W brittle, and severe working, below recrystallization or equiaxing temperature, produces ductility. W rods which have been worked and recrystallized are stronger than sintered rods. The equiaxing temperature of worked tungsten, with a 5-min exposure, varies from 2200°C for a work rod with 24 percent reduction, to 1350°C for a fine wire with 100 percent reduction. Tungsten wire, D = 0.635 mm or 0.025 in.

‡ Compression on cylinder 25.4 mm (1 in.) by 65.1 mm (2.6 in.), at 20 percent deformation:
For spelter (cast zinc) free from Cd, av. 17.2 kg/mm² or 24,500 lb/in.²
For spelter with Cd 0.26, av. 27.4 kg/mm² or 39,000 lb/in.²
Modulus of rupture averages twice the corresponding tensile strength.
Shearing strength: rolled, averages 13.6 kg/mm² or 194,000 lb/in.²
Modulus of elasticity: cast, 7,750 kg/mm² or 11,025,000 lb/in.²
Modulus of elasticity: rolled, 8450 kg/mm² or 12,000,000 lb/in.²

TABLE 201.—LOW-MELTING ALLOYS *

Name	Composition, percent: Bi	Cd	Pb	Sn	Other	Melting point: °F	°C
Anatomical alloy	53.5	—	17	19	Hg 10.5	140	60
Wood's alloy	50	12.5	25	12.5	—	154.4	68
Quaternary eutectic alloy	49.5	10.10	27.27	13.13	—	158	70
Fusible alloy	38.4	15.4	30.8	15.4	—	159.8	71
Eutectic alloy (Bi-Cd-Pb)	51.6	8.1	40.2	—	—	196.7	91.5
Alloy for fine castings	50	—	32.2	17.8	—	212	100
Rose's alloy	50	—	28	22	—	212	100
Bismuth solder	40	—	40	20	—	235.4	113
Eutectic alloy (Bi-Sn)	57	—	—	43	—	280.4	138
Eutectic alloy (Bi-Cd)	60	40	—	—	—	291.2	144
Eutectic alloy (Bi-Pb-Sn)	13.7	—	44.8	41.5	—	320	160
Eutectic alloy (Cd-Sn)	—	32	—	68	—	350.6	177
Eutectic alloy (Pb-Sn)	—	—	38	62	—	361.4	183

* See also Table 123.

TABLE 202.—MECHANICAL PROPERTIES OF WHITE METAL BEARING ALLOYS (BABBITT METAL)

Experimental permanent deformation values from compression tests on cylinders 31.8 mm ($1\frac{1}{4}$ in.) diam. by 63.5 mm ($2\frac{1}{2}$ in.) long, tested at 21°C (70°F). (Set readings after removing loads.)

Alloy No.	Formula, percent				Pouring temp.		Weight		Permanent deformation @ 21°C						Hardness	
									@ 454 kg = 1000 lb		@ 2268 kg = 5000 lb		@ 4536 kg = 10,000 lb			
	Sn	Sb	Cu	Pb	°C	°F	g/cm³	lb/ft³	mm	in.	mm	in.	mm	in.	Brinell @ 21°C	500 kg @ 100°C
							Tin Base									
1	91.0	4.5	4.5	—	440	824	7.34	458	.000	.0000	.025	.0010	.380	.0150	28.6	12.8
2 *	89.0	7.5	3.5	—	432	808	7.39	461	.000	.0000	.038	.0015	.305	.0120	28.3	12.7
3	83.3	8.3	8.3	—	491	916	7.46	465	.025	.0010	.114	.0045	.180	.0070	34.4	15.7
4	75.0	12.0	3.0	10.0	360	680	7.52	469	.013	.0005	.064	.0025	.230	.0090	29.6	12.8
5	65.0	15.0	2.0	18.0	350	661	7.75	484	.025	.0010	.076	.0030	.230	.0090	29.6	11.8
							Lead Base									
6	20.0	15.0	1.5	63.5	337	638	9.33	582	.038	.0015	.127	.0050	.457	.0180	24.3	11.1
7	10.0	15.0	—	75.0	329	625	9.73	607	.025	.0010	.127	.0050	.583	.0230	24.1	11.7
8	5.0	15.0	—	80.0	329	625	10.04	627	.051	.0020	.229	.0090	1.575	.0620	20.9	10.3
9	5.0	10.0	—	85.0	319	616	10.24	640	.102	.0040	.305	.0120	2.130	.0840	19.5	8.6
10	2.0	15.0	—	83.0	325	625	10.07	629	.025	.0010	.254	.0100	3.910	.1540	17.0	8.9
11	—	15.0	—	85.0	325	625	10.28	642	.025	.0010	.254	.0100	3.020	.1190	17.0	9.9
12	—	10.0	—	90.0	334	634	10.67	666	.064	.0025	.432	.0170	7.240	.2850	14.3	6.4

* U. S. Navy Spec. 46M2b (Cu 3 to 4.5, Sn 88 to 89.5, Sb 7.0 to 8.0) covers manufacture of antifriction-metal castings. (Composition W.)

TABLE 203.—RIGIDITY MODULUS FOR A NUMBER OF MATERIALS

If to the four consecutive faces of a cube a tangential stress is applied, opposite in direction on adjacent sides, the modulus of rigidity is obtained by dividing the numerical value of the tangential stress per unit area (kg/mm²) by the number representing the change of angles on the nonstressed faces, measured in radians.

Substance	Rigidity modulus	Substance	Rigidity modulus	Substance	Rigidity modulus
Aluminum	3350	Iron, cast	6706	Steel cast	7458
" cast	2580	"	7975	" cast, coarse gr	8070
Brass	3550	"	6940	" silver-	7872
"	3715	"	8108	Tin, cast	1730
" cast, 60 Cu+12 Sn	3700	"	7505	"	1543
Bismuth, slowly cooled	1240	Magnesium, cast	1710	Zinc	3880
Bronze, cast, 88 Cu+12 Sn	4060	Nickel	7820	"	3820
Cadmium, cast	2450	Phosphor bronze	4359	Platinum	6630
Copper, cast	4780	Quartz fiber	2888	"	6220
"	4213	" "	2380	Glass	2350
"	4450	Silver	2960	"	2730
"	4664	"	2650	Clay rock	1770
Gold	2850	"	2566	Granite	1280
"	3950	" hard-drawn	2816	Marble	1190
Iron, cast	5210	Steel	8290	Slate	2290

TABLE 204.—VARIATION OF THE RIGIDITY MODULUS WITH THE TEMPERATURE

$n_t = n_o(1 - \alpha t - \beta t^2 - \gamma t^3)$, where t = temperature Centigrade

Substance	n_0	$\alpha 10^6$	$\beta 10^8$	$\gamma 10^{10}$	Substance	n_0	$\alpha 10^6$	$\beta 10^8$	$\gamma 10^{10}$
Brass	2652	2158	48	32	Iron	8108	206	19	−11
"	3200	455	36	—	"	6940	483	12	—
Copper	3972	2716	−23	47	Platinum	6632	111	50	− 8
"	3900	572	28	—	Silver	2566	387	38	11
					Steel	8290	187	59	− 9

$n_t^* = n_{15}[1 - \alpha(t - 15)]$

Substance	n	α	Substance	n	α	Substance	n	α
Copper	4.37*	α=.00039	Platinum	6.46*	α=.00012	Tin	1.50*	α=.00416
Copper (commercial)	3.80	.00038	Gold	2.45	.00031	Lead	.80	.00164
Iron	8.26	.00029	Silver	2.67	.00048	Cadmium	2.31	.0058
Steel	8.45	.00026	Aluminum	2.55	.00148	Quartz	3.00	.00012

* Modulus of rigidity in 10^{11} dynes per cm^2.

TABLE 205.—INTERIOR FRICTION AT LOW TEMPERATURES

C is the damping coefficient for infinitely small oscillations; T, the period of oscillation in seconds; N, the modulus of rigidity dynes/cm^2.

Substance		Cu	Ni	Au	Pd	Pt	Ag	Quartz
Length of wire in cm		22.5	22.2	22.3	22.2	23.0	17.2	17.3
Diameter in mm		.643	.411	.609	.553	.812	.601	.612
100°C	C	24.1	1.34	27.5	1.67	2.98	55.8	—
	T	2.381	3.831	3.010	2.579	1.143	1.808	—
	$N \times 10^{-11}$	3.32	7.54	2.55	5.08	5.77	2.71	—
0°C	C	5.88	.417	4.82	1.25	4.60	7.19	4.69
	T	2.336	3.754	2.969	2.571	1.133	1.759	1.408
	$N \times 10^{-11}$	3.45	7.85	2.62	5.12	—	2.87	2.26
−195°C	C	3.64	.556	6.36	.744	3.02	1.64	1.02
	T	2.274	3.577	2.902	2.552	1.111	1.694	1.425
	$N \times 10^{-11}$	3.64	8.65	2.74	5.19	6.10	3.18	2.20

TABLE 206.—RATIO, ρ, OF TRANSVERSE CONTRACTION TO LONGITUDINAL EXTENSION UNDER TENSILE STRESS

(Poisson's Ratio)

Metal	Pb	Au	Pd	Pt	Ag	Cu	Al	Bi	Sn	Ni	Cd	Fe
ρ	.45	.42	.39	.39	.38	.35	.34	.33	.33	.31	.30	.28

ρ for: marbles, .27; granites, .24; basic-intrusives, .26; glass, .23.

TABLE 207.—A SCALE OF HARDNESS BASED UPON THE RELATIVE HARDNESS OF SELECTED MATERIALS

Each material will scratch the one following it in the table.

10 Diamond	8 Topaz	6 Feldspar	4 Fluorite	2 Rock salt or gypsum
9 Corundum	7 Quartz	5 Apatite	3 Calcite	1 Talc

TABLE 208.—RELATIVE HARDNESS

Agate ....7.	Barite 3.3	Fluorite ......4.	Marble ....3–4.	Ross' metal.2.5–3.0
Alabaster 1.7	Bell-metal ....4.	Galena 2.5	Meerschaum 2–3.	Serpentine .3–4.
Alum 2–2.5	Beryl 7.8	Garnet ....7.	Mica 2.8	Silver ....2.5–3.
Aluminum ...2.9	Bismuth 2.5	Glass 4.5–6.5	Opal ....4–6.	Silver chloride 1.3
Amber 2–2.5	Boric acid ....3.	Gold .....2.5–3.	Orthoclase ....6.	Steel 5–8.5
Andalusite ...7.5	Brass ......3–4.	Graphite ....5–1.	Palladium 4.8	Stibnite ......2.
Anthracite ...2.2	Calamine .....5.	Gypsum ..1.6–2.	Phosphor-bronze .....4.	Sulfur ...1.5–2.5
Antimony 3.3	Calcite ....3.	Hematite .....6.	Platin-iridium 6.5	Talc ....1.
Apatite ......5.	Copper ...2.5–3.	Hornblende ...5.5	Platinum 4.3	Tin 1.5
Aragonite 3.5	Corundum ....9.	Iridium 6.5	Pyrite 6.3	Topaz ....8.
Arsenic 3.5	Diamond ....10.	Iridosmium ...7.	Quartz ....7.	Tourmaline ...7.3
Asbestos .....5.	Dolomite ..3.5–4.	Iron ....4–5.	Rock-salt ....2.	Wax (0°) 2
Asphalt ....1–2.	Feldspar ......6.	Kaolin ....1.		Wood's metal..3.
Augite ....6.	Flint ....7.	Loess (0°) 3		
		Magnetite ....6.		

TABLE 209.—RELATIVE HARDNESS OF THE ELEMENTS (MEANS)

*C .....10.	Ir 6.5	Zr 4.5	Al 2.9	Mg 2.0	In 1.2
B 9.5	Ge 6.2	Pt 4.3	Ag 2.7	Se 2.0	Tl 1.2
Cr .... 9.	Rh ..... 6.	Ti 4.0	Zn 2.5	Cd 2.0	Li 6
Ta .... 7.	Mo .... 6?	Fe ..... 4.	Au 2,5	Sr 1.8	K 5
Os .... 7.	Mn .... 5.	As 3.5	Ce 2.5	Sn 1.8	Na 4
W .... 7.	Co ..... 5.	Sb ..... 3.	Bi 2.5	Pb 1.5	Rb 3
Si .... 7.	Ni ..... 5.	Be ..... 3.	Te 2.3	Ga 1.5	Cs 2
Ru 6.5	Pd 4.8	Cu 3.0	S 2.0	Hg 1.5	

* Diamond.

TABLES 210–217.—CHARACTERISTICS OF SOME BUILDING MATERIALS

TABLE 210.—PROPERTIES OF MASONRY MORTARS[58]

Type of cement in mortar	Proportions by volume: Cement	Proportions by volume: Lime hydrate	Proportions by volume: Sand	Proportions by weight: Cement	Proportions by weight: Lime hydrate	Proportions by weight: Sand	Compressive strength psi *	Brick assemblage Bond strength in tension psi	Water retentivity percent	Shrinkage, 180 days in air percent
Portland	1	.2	3	1	.1	2.5	6400	69	73	.12
Portland	1	1	6	1	.5	5	1900	49	81	.15
Portland	1	2	9	1	1	7.5	800	40	83	.16
Masonry	1	0	3	1	0	3.5	1200	40	80	.14
Slag	1	.5	4.5	1	.3	4.5	1100	24	83	.23

[58] Watstein and Seese, Amer. Soc. Test. Mat. Bull., August 1947, p. 77
* Strength developed in actual building practice will tend to be lower than these laboratory values.

TABLE 211.—COMPRESSIVE AND TENSILE STRENGTH OF CONCRETES MADE WITH VARIOUS TYPES OF CEMENT[59]

Type of cement	Compressive strength * (lb/in.²) at— 1 day	3 days	7 days	28 days	3 mo.	1 yr	Tensile strength * (lb/in.²) at— 1 day	3 days	7 days	28 days	3 mo.	1 yr
	By weight—1 part cement to 6 parts sand and gravel											
Normal Portland (average of 5 brands)	—	1500	2500	4600	5400	5900	—	180	260	360	360	360
Moderate heat Portland (average of 4 brands)	—	1200	2200	4200	5400	6300	—	170	260	390	400	440
Portland-Pozzolan (average of 2 brands)	—	1000	2000	3800	4700	5000	—	150	230	360	340	380
High-early strength Portland (average of 3 brands)	1100	2900	4000	5700	—	5700	160	320	440	480	400	400
High Alumina	4000	4300	5000	5500	—	4100	300	330	290	280	—	220
	By weight—1 part cement to 4.5 parts sand and gravel											
Normal Portland (average of 5 brands)	—	2300	3600	5700	6500	7500	—	260	390	490	490	490
Moderate heat Portland (average of 4 brands)	—	1900	3300	5500	6600	7800	—	260	390	500	500	530
Portland-Pozzolan (average of 2 brands)	—	1600	2700	5000	5700	6100	—	220	310	440	440	490
High-early strength Portland (average of 3 brands)	1700	3600	4800	6100	—	7300	220	400	500	510	480	480
High Alumina	4600	—	5200	6300	—	4600	380	440	440	350	—	305

[59] Schuman and Tucker, Nat. Bur. Standards Journ. Res., vol. 31, p. 107, 1943.
* Strength developed in actual building practice will tend to be lower than these laboratory values.

TABLE 212.—EFFECT OF QUANTITY OF MIXING WATER ON STRENGTH OF CONCRETE[60]

W/C ratio, U. S. gal. per sack of cement (94#)	5.0	5.5	6.0	6.5	7.0	7.5
Compressive strength at 28 days—lb/in.^{2}	5000.0	4500.0	4100.0	3600.0	3300.0	2900.0

[60] Portland Cement Association, Design and control of concrete mixtures, 9th ed., p. 7.

TABLE 213.—COMPARISON OF STRENGTH AND ELASTIC PROPERTIES OF CONCRETE[61]

Modulus of elasticity psi $\times 10^{-6}$

Compressive strength psi *	Modulus of rupture psi	Compressive (secant)	Flexural (secant)	Dynamic (sonic)
2000	400	2.5	3.5	4.5
4000	600	4.	5.	5.5
6000	750	5.5	6.	6.5
8000	850	6.5	6.5	7.

Values given are approximations only since the ratios between the different properties depend on age, aggregates, cement, and other factors.

[61] Stanton, T. E., Amer. Soc. Test. Mat. Bull. No. 131, p. 17, 1944; Witte and Price, ibid., p. 20; Schuman and Tucker, Nat. Bur. Standards Journ. Res., vol. 31, p. 107, 1943; Gonnerman and Shuman, Proc. Amer. Soc. Test. Mat., vol. 28, p. 527, 1928.
* As determined on specimens with length to diameter ratio of 2.

TABLE 214.—EFFECT OF ENTRAINED AIR ON COMPRESSIVE STRENGTH OF CONCRETE[62]

Cement Sacks per yd^3	Percent change in strength due to 5 percent added air *	
	7-day	28-day
4.5	+9	+4
5.5	−12	−16
6.5	−17	−20

[62] Walker and Bloem, Journ. Amer. Concrete Inst., vol. 42, p. 629, 1946.
* Strengths given are for mixes in which full advantage was taken of the sand and water-content reductions made possible by the increased workability resulting from entrained air.

TABLE 215.—WEIGHTED AVERAGE STRENGTH AND WATER ABSORPTION FOR HARD AND SALMON BRICKS MADE IN U. S. A.[63]

	Compressive strength psi		Modulus of rupture psi		Water absorption percent		
	Average	Range	Average	Range	5 hr cold	48 hr cold	5 hr boiling
Weighted average all samples	7250		1150		10	11	14
Hard samples	7430	(16,000–4000)	1180	(2350–740)	10	11	13.5
Salmon	4090	(6500–2300)	680	(1440–300)	16	17	19

[63] McBurney and Lovewell, Proc. Amer. Soc. Test. Mat., vol. 33, p. 1, 1933.

TABLE 216.—ULTIMATE STRENGTHS OF BRICK MASONRY[64]

Brick strength lb/in.²	Cement mortar 1C:1/4-L:3S *	Cement-lime mortar 1C:1L;6S	Lime mortar 1L:3S	Brick strength lb/in.²	Cement mortar 1C:1/4-L:3S *	Cement-lime mortar 1C:1L;6S	Lime mortar 1L:3S
8000+	2000	1200	800	2500–4500	700	560	275
4500–8000	1000	800	400	1500–2500	500	400	150

[64] Nat. Bur. Standards Res. Pap. RP 108.
* C—portland cement; L—Lime; S—sand, proportions by volume. See American Standard Associations Building Code Requirements for Masonry (A41.1-1944).

TABLE 217.—STRENGTH AND STIFFNESS OF AMERICAN BUILDING STONE *

(All values in pounds per square inch.)

Stone	Density lb/ft³	Compressive strength (dry) psi	Flexure strength psi	Shear psi	Flexural modulus of elasticity psi	Compressive modulus of elasticity psi
Granite ...	165	24500 (7700-53,000)† (116 samples)	2810 (1430-5190) (5 samples)	4350 (3900-4600) (4 samples)	2,526,000-12,950,000	4,545,000-8,333,000
Limestone ..	148	2600-28,400	640-2000‡ 470-1900§	830-3840† 800-3100§	700,000-10,400,000‡	1,600,000-11,200,000‡
Marble	170	7850-29,530	900-4270		1,840,000-11,780,000	
Sandstone .	135	4470-34,900+	260-6570+			
Slate	170		500-14,100		9,800,000-18,000,000	

* Furnished by Herbert Insley, National Bureau of Standards. † Wet samples 12 percent less. ‡ Perpendicular to bed. § Parallel to bed.

TABLES 218-223.—PHYSICAL PROPERTIES OF LEATHER *

Most physical properties of leathers not only depend on the kind of skin and method of tannage but also vary widely from one hide to another of the same kind, from one location to another within the same hide, and in local random fashion. For example, the tensile strength of vegetable-tanned cattle hides shows coefficients of variation of 6 percent among bends (from different hides), 9 percent among locations (within a hide), and 11 percent for local random fluctuations.[65] The Federal Specifications Board in the United States requires that at least 7 pieces of leather be sampled for most physical tests.[66] In any use of a physical property of leather, such as designing an experiment or acceptance testing for commercial purchase, these variations and the consequent statistical precautions must be observed. The figures below, then, are illustrative, not precise values for any given type of leather.

* Prepared by R. Hobbs, National Bureau of Standards.
[65] Beek, J., and Hobbs, R. B., Journ. Amer. Leather Chem. Assoc., vol. 36, p. 190, 1941.
[66] Federal specification for leather and leather products, K_k-L-311. Government Printing Office, Washington, D. C., March 1945.

TABLE 218.—TENSILE STRENGTH AND ELONGATION OF LEATHER[67]

Kind of leather	Thickness 1/64 in.	Tensile strength lb/in.²	Elongation, percent at 1000 lb/in.²	Elongation, percent at break
Belting, vegetable-tanned steer	11	6000	6	25
Calfskin, chrome-tanned	3	4500	8	36
Calfskin, vegetable-tanned	3	6000	5	29
Cordovan, horsehide butt	3	2000	22	28
Deerskin, chrome-tanned	5	6500	26	58
Garment, chrome-tanned horse	4	6000	14	60
Kangaroo, chrome-tanned	2	7000	15	40
Kid, chrome-tanned	2	5000	19	59
Sheepskin, shearling	3	1500	25	38
Shoe upper, chrome retan	6	4500	15	40
Sole, vegetable-tanned steerhide	13	3500	4	15

[67] Wilson, J. A., Modern practice in leather manufacture, Reinhold Publishing Co., New York, 1941.

TABLE 219.—DIFFUSION CONSTANTS OF WATER VAPOR THROUGH LEATHER, AS FRACTIONS OF THE DIFFUSION CONSTANT THROUGH AIR (20°C)[68]

Heavy chrome upper	Box calf	Glove capeskin	Patent leather	Vegetable-tanned insole
.1–.2	.21–.26	.17–.26	.004	.09

[68] Progress in leather science, 1920-1945, British Leather Manufacturers' Res. Assoc., London, 1948.

TABLE 220.—REAL AND APPARENT DENSITIES OF LEATHER (70°F AND 65 PERCENT, RELATIVE HUMIDITY)[69]

Kind of leather	Apparent density	Real density
Raw bated skin	.41– .45	1.43
Formaldehyde tanned buckskin	.56	1.52
Chrome-tanned shoe upper	.88	1.34
Vegetable-tanned sole	1.03–1.15	1.46–1.49
Chrome-tanned sole	1.17	1.46
Formaldehyde-tanned suede	.50– .58	1.55–1.62
Vegetable-tanned goatskin	.65	1.52

[69] Kanagy, J. R., and Wallace, E. L., Journ. Amer. Leather Chem. Assoc., vol. 38, p. 314, 1943; Rose, H., ibid., p. 107.

TABLE 221.—COEFFICIENT OF CUBICAL EXPANSION OF LEATHER

(Measured in water between 25° and 75°C)[70]

Chrome	Chrome-vegetable	Vegetable	Alum-vegetable
$496–565 \times 10^{-6}$	$339–298 \times 10^{-6}$	$502–543 \times 10^{-6}$	$590–599 \times 10^{-6}$

Iron	Formaldehyde	Tendon collagen
592×10^{-6}	532×10^{-6}	538×10^{-6}

Compressibility.[71]—The lower limit of the coefficient of compressibility of vegetable-tanned sole leather has been estimated at 33×10^{-6} bar^{-1}. Commercial sole leathers subjected to 3000 lb/in.^{2} pressure for 3 minutes were compressed from 4 to 17 percent.

[70] Weir, C. E., Journ. Amer. Leather Chem. Assoc., vol. 44, p. 79, 1949.
[71] Weir, C. E., Journ. Amer. Leather Chem. Assoc., vol. 40, p. 404, 1945.

TABLE 222.—EFFECT OF RELATIVE HUMIDITY OF ATMOSPHERE AT 21°C ON PROPERTIES OF LEATHER[72]

Percent relative humidity	Tensile strength lb/in.^{2}	Stretch at 2000 lb/in.^{2} percent	Increase in thickness percent	Increase in area percent
		Vegetable-tanned calfskin		
0	4630	16	.0	.0
33	5210	19	2.3	5.2
52	5220	19	2.9	5.7
76	5280	21	4.6	6.4
97	—	21	9.6	7.3
		Chrome-tanned calfskin		
0	3170	19	.0	.0
33	4550	25	1.6	7.8
52	4840	23	1.9	8.9
76	5080	24	4.2	10.2
97	5420	25	14.0	14.0

[72] Evans, W. D., and Critchfield, C. L., Nat. Bur. Standards Journ. Res., vol. 11, p. 147, 1933.

TABLE 223.—THERMAL CONDUCTIVITY OF LEATHER *

cal cm^{-1} sec^{-1} °C^{-1}

Vegetable sole leather	Calfskin upper	Kid suede	Hide bellies
4.2×10^{-4}	2.0×10^{-4}	1.5×10^{-4}	2.3×10^{-4}

* For reference, see footnote 68, p. 232.

TABLES 224-229.—VALUES OF PHYSICAL CONSTANTS OF DIFFERENT RUBBERS *

Where a range is given, there are available several observations that differ. In most cases the differences are thought to be real, arising from differences in the rubber rather than from errors of observation. Where a single value is given, it is either because no other observations are available or because there seems to be no significant disagreement among values within the errors of observation. The latter values are marked with an asterisk (*). Where no values are given, no data have been found. Where dashes are shown, either the physical measurement is impossible or the values obtained are not significant. Values at 25°C and 1 atmosphere pressure.

Since these data were compiled from a number of sources, no specific references are given. A list of references follows:

Ball, J. M., and Maasen, G. C., American Society for Testing Materials Symposium on the Applications of Synthetic Rubbers, March 2, 1944. Bekkedahl, Norman, Natural rubbers—a general summary of their composition, properties, and uses, India Rubber World, vol. 116, p. 57, 1947; *also in* Compounding ingredients for rubber, published by India Rubber World, New York, 1947. Bekkedahl, N., and Roth, F. L., Unpublished observations of density and expansivity, 1948. Boonstra, B. B. S. T., Properties of elastomers, chap. 4 of vol. 3 of Elastomers and plastomers, their chemistry, physics, and technology, edited by R. Houwink, Elsevier Publishing Co., New York, 1948. Dawson, T. R., and Porritt, B. D., Rubber physical and chemical properties, Research Association of British Rubber Manufacturers, Croydon, England, 1935. Dillon, J. H., Prettyman, I. B., and Hall, G. L., Hysteretic and elastic properties of rubberlike materials under dynamic shear stresses, Journ. Appl. Phys., vol. 15, p. 309, 1944; Rubber Chem. Techn., vol. 17, p. 597, 1944. Hamill, W. H., Mrowca, B. A., and Anthony, R. L., Specific heats of hevea, GR-S, and GR-I stocks, Ind. Eng. Chem., vol. 38, p. 106, 1946; Rubber Chem. Techn., vol. 19, p. 622, 1946. Kemp, A. R., and Malm, F. S., Hard rubber (ebonite), chap. 18 *in* Chemistry and technology of rubber, edited by C. C. Davis and J. T. Blake, Reinhold Publishing Corporation, New York, 1937. Prettyman, I. B., Physical properties of natural and synthetic rubber stocks, Handbook of Chemistry and Physics, 30th ed., p. 1301, Chemical Rubber Publishing Co., Cleveland, Ohio, 1947. Rands, Robert D., Jr., Ferguson, W. Julian, and Prather, John L., Specific heat and increases of entropy and enthalpy of the synthetic rubber GR-S from 0° to 330° K, Nat. Bur. Standards Journ. Res., vol. 33, p. 63, 1944 (RP1595). Selker, Alan H., Scott, Arnold H., and McPherson, Archibald T., Electrical and mechanical properties of the system Buna S-Gilsonite, Nat. Bur. Standards Journ. Res., vol. 31, p. 141, 1943 (RP1554). Wildschut, A. J., Technological and physical investigations on natural and synthetic rubbers. Elsevier Publishing Co., New York, 1946. Wood, Lawrence A., Bekkedahl, Norman, and Roth, Frank L., The measurement of densities of synthetic rubbers, Nat. Bur. Standards Journ. Res., vol. 29, p. 391, 1942 (RP1507); Ind. Eng. Chem., vol. 34, p. 1291, 1942; Rubber Chem. Techn., vol. 16, p. 244, 1943. Wood, L. A., and Tilton, L. W., Refractive index of natural rubber at different wavelengths, Proc. Second Rubber Techn. Conf., p. 142 (Institution of the Rubber Industry, London), 1948; Nat. Bur. Standards Journ. Res., vol. 43, p. 57, 1949 (RP2004). Wood, Lawrence A., Synthetic rubbers: a review of their compositions, properties, and uses, Nat. Bur. Standards Circ. C427, 1940; Rubber Chem. Techn., vol. 13, p. 861, 1940; India Rubber World, vol. 102, p. 33, 1940. Wood, Lawrence A., Values of the physical constants of rubber, Proc. Rubber Techn. Conf., p. 933 (Institution of the Rubber Industry, London), 1938; Rubber Chem. Techn., vol. 12, p. 130, 1939.

* Prepared by Lawrence A. Wood, National Bureau of Standards.

	Unit	Unvulcanized	Pure-gum vulcanizate	Vulcanizate containing about 33% carbon black	Ebonite (hard rubber)
Density	$g\ cm^{-3}$	.906-.916	.92-1.0	1.12-1.15	1.13-1.18
Expansivity (1/V)(dV/dT)	$(deg\ C)^{-1}$	67×10^{-5}	66×10^{-5}	53×10^{-5}	19×10^{-5}
Thermal					
Thermal conductivity	$cal\ sec^{-1}\ cm^{-1}\ (deg\ C)^{-1}$	32×10^{-5}	34×10^{-5}	$39\text{-}45\times10^{-5}$	$39\text{-}42\times10^{-5}$
Specific heat	$cal\ g^{-1}\ (deg\ C)^{-1}$	.45	.44—.51	.36	.34
Heat of combustion	$cal\ g^{-1}$	10.82×10^{3}	10.63×10^{3}	9.61×10^{3}	7.92×10^{3}
Second-order transition temperature	deg C	—69 to —74	—72		+80
Optical					
Refractive index, n_D		1.5191	1.5264	——	1.6
dn_D/dT	$(deg\ C)^{-1}$	-37×10^{-5}	-37×10^{-5}	——	
Electrical					
Dielectric constant (1000 cps)		2.37-2.45	2.7		2.8-2.9
Loss factor, tan $(90^{c}-\theta)$ (1000 cps)		.002	.002		.005
Conductivity (1 min)	$mho\ cm^{-1}$	$2\text{-}40\times10^{-17}$	10^{-17}		10^{-17}
Mechanical					
Compressibility (1/V)(dV/dP)	bar^{-1}	54×10^{-6}	51×10^{-6}	37×10^{-6}	24×10^{-6}
Shear modulus	$dynes\ cm^{-2}$	——	4×10^{6}	20×10^{6}	
Initial slope of stress-strain curve	$dynes\ cm^{-2}$	——	$10\text{-}20\times10^{6}$	$30\text{-}60\times10^{6}$	55×10^{9}
Ultimate elongation	percent	——	750-850	550-650	3-8
Tensile strength	$kg\ cm^{-2}$		170-250	250-350	600-800
Complex dynamic shear modulus (60 cps), $\frac{\sigma'+i\sigma''}{\epsilon}$					
Real part G', $\frac{\sigma'}{\epsilon}$	$dynes\ cm^{-2}$		$3\text{-}10\times10^{6}$	25×10^{6}	
Imaginary part G'', $\frac{\sigma''}{\epsilon}$	$dynes\ cm^{-2}$		$.3\text{-}.6\times10^{6}$	3×10^{6}	
Resilience (ball rebound)	percent	75	75	45-55	

TABLE 225.—PROPERTIES OF GR-S (HYDROCARBON OF ABOUT 23.5 PERCENT BOUND STYRENE CONTENT)

	Unit	Unvulcanized	Pure-gum vulcanizate	Vulcanizate containing about 33% carbon black
Density	g cm^{-3}	.9325-.9335	.961	1.15
Expansivity (1/V)(dV/dT)	(deg C)$^{-1}$	66×10^{-5}	66×10^{-5}	53×10^{-5}
Thermal				
Specific heat	cal g^{-1} (deg C)$^{-1}$	.45	.43	.36
Second-order transition temperature	deg C	—59 to —64		
Optical				
Refractive index, n_D		1.534-1.535		——
dn_D/dT	(deg C)$^{-1}$	-37×10^{-5}		——
Electrical				
Dielectric constant (1000 cps)			2.85	
Loss factor, tan (90°—θ) (1000 cps)			.003	
Mechanical				
Shear modulus	dynes cm^{-2}	——		25×10^6
Initial slope of stress-strain curve	dynes cm^{-2}	——	$10\text{-}20\times10^6$	$30\text{-}60\times10^6$
Ultimate elongation	percent	——	400-600	400-600
Tensile strength	kg cm^{-2}	——	14-28	170-280
Complex dynamic shear modulus (60 cps), $\frac{\sigma'+i\sigma''}{\epsilon}$				
Real part G′, $\frac{\sigma'}{\epsilon}$	dynes cm^{-2}		5×10^6	55×10^6
Imaginary part G″, $\frac{\sigma''}{\epsilon}$	dynes cm^{-2}		$1\text{-}2\times10^6$	9×10^6
Resilience (ball rebound)	percent		65	40-50

TABLE 226.—PROPERTIES OF NEOPRENE (CHLOROBUTADIENE POLYMER)

	Unit	Unvulcanized	Pure-gum vulcanizate	Vulcanizate containing about 33% carbon black
Density	g cm^{-3}	1.23	1.30	
Expansivity (1/V)(dV/dT)	(deg C)$^{-1}$		61×10^{-5}	
Thermal				
Second-order transition temperature	deg C	—38 to —41		
Optical				
Refractive Index n_D		1.558		——
dn_D/dT	(deg C)$^{-1}$	-36×10^{-5}		——
Mechanical				
Shear modulus	dynes cm^{-2}	——		14×10^6
Initial slope of stress-strain curve	dynes cm^{-2}	——	$15\text{-}30\times10^6$	
Ultimate elongation	percent	——	800-1000	
Tensile strength	kg cm^{-2}	——	250-375	
Complex dynamic shear modulus (60 cps), $\frac{\sigma'+i\sigma''}{\epsilon}$				
Real part G′, $\frac{\sigma'}{\epsilon}$	dynes cm^{-2}		6×10^6	$30\text{-}36\times10^6$
Imaginary part G″, $\frac{\sigma''}{\epsilon}$	dynes cm^{-2}		1×10^6	6×10^6
Resilience (ball rebound)	percent		65	40-50

TABLE 227.—PROPERTIES OF GR-1 (BUTYL RUBBER, ISOBUTENE-ISOPRENE COPOLYMER)

	Unit	Unvulcanized	Pure-gum vulcanizate	Vulcanizate containing about 33% carbon black
Density	$g\ cm^{-3}$	.92	.93	1.13
Expansivity (1/V)(dV/dT)	$(deg\ C)^{-1}$		57×10^{-5}	46×10^{-5}
Thermal				
Second-order transition temperature	deg C	—67 to —73		
Optical				
Refractive Index n_D		1.5091		——
Electrical				
Dielectric constant			2.1-2.6	
Mechanical				
Shear modulus		——		18×10^6
Initial slope of stress-strain curve	$dynes\ cm^{-2}$	——	$7\text{-}15\times10^6$	$30\text{-}40\times10^6$
Ultimate elongation	percent	——	750-950	650-850
Tensile strength	$kg\ cm^{-2}$	——	180-210	180-210
Complex dynamic shear modulus (60 cps), $\frac{\sigma'+i\sigma''}{\epsilon}$				
Real part G′, $\frac{\sigma'}{\epsilon}$	$dynes\ cm^{-2}$		$4\text{-}10\times10^6$	36×10^6
Imaginary part G″, $\frac{\sigma''}{\epsilon}$	$dynes\ cm^{-2}$		$2\text{-}3\times10^6$	16×10^6
Resilience (ball rebound)	percent		8	7

TABLE 228.—COMPRESSION OF RUBBER[73]

Commercial soft-packing, black, density about 1.9 g/cm³ and $V_0 = 1$ cm³

ΔV

Pressure kg/cm²	20°C	−78.8°C	Pressure kg/cm²	20°C	−78.8°C	Pressure kg/cm²	20°C	−78.8°C
5,000	.1300	.0794	20,000	.2345	.1772	35,000	.2845	.2254
10,000	.1800	.1235	25,000	.2535	.1958	40,000	.2960	.2364
15,000	.2146	.1538	30,000	.2700	.2119	45,000	.3050	.2460
						50,000	.3124	.2540

[73] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 74, p. 50, 1940.

TABLE 229.—COMPRESSION OF SYNTHETIC AND NATURAL RUBBERS[74]

$\Delta V/V_0$

Pressure kg/cm² / Density	Duprene	Koroseal No. 89023	Neoprene No. 832	Buna S No. 8774	Ameripol D-7700	Hood 844A	Goodrich D-402	Goodrich D-420	Goodrich D-453	Goodrich D-453	Butyl gum	Butyl tread	Hevea gum	Hevea tread
	1.589	1.250	1.357	1.376	1.370	1.176	1.193	1.350	1.514	1.309	.967	1.125	.950	1.122
2000	.0302	.0511	.0460	.0465	.0367	.0407	.0422	.0385	.0329	.0432	.0519	.0423	.0535	.0462
5000	.0615	.0967	.0956	.0872	.0715	.0792	.0837	.0745	.0636	.0842	.0945	.0807	.1017	.0870
10,000	.0898	.1403	.1294	.1238	.1052	.1163	.1194	.1128	.0938	.1208	.1303	.1129	.1422	.1250
15,000	.1198	.1679	.1567	.1493	.1304	.1445	.1454	.1378	.1162	.1480	.1543	.1334	.1697	.1490
20,000	.1301	.1891	.1793	.1715	.1507	.1663	.1670	.1587	.1347	.1692	.1744	.1510	.1929	.1707
25,000	.1462	.2060	.1990	.1903	.1686	.1840	.1847	.1769	.1513	.1862	.1920	.1667	.2116	.1900
Pressure of discontinuity	3,500		4,800	6,300	4,900		4,800				6,200			6,500
Amount of discontinuity	2.0×10^{-6}		5.3×10^{-6}	3.4×10^{-6}	1.5×10^{-6}		3×10^{-6}				5×10^{-6}			2×10^{-6}
$\Delta V/V_0$ at discontinuity	.0516		.0939	.1012	.0707		.0851				.1083			.1026
Ratio of width of hysteresis loop to maximum displacement	.083	.059	.082	.087	.064	.067	.072	.080	.103	.077	.083	.090	.074	.073

[74] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 76, p. 22, 1942.

TABLE 230.—CHARACTERISTICS OF A NUMBER OF PLASTICS[75]

Material	Specific gravity	Luminous transmission 1/8″ thick	Refractive index n_D^{25}	Thermal expansion $\times 10^5$ cgs	Thermal conductivity $\times 10^4$ cgs	Specific heat cal/g	Resistivity ohm-cm	Dielectric strength, v/mm (1/8″)	Dielectric constant, 60 cps	Stress to yield psi *	Modulus of elasticity, psi $\times 10^{-5}$	Hardness, Rockwell
Acrylic plastic	1.18-1.19	.91	1.485-1.500	9	4-6	.35	$>10^{15}$	450-500	3.5-4.5	11000-14000	3.3-4.5	M88-M92
Nylon	1.14-1.09	...	1.53	10	5.8	.4	4.5×10^{13}	385	4.1	13000	4	R-118
Polyvinyl formal	1.2-1.3	.85-.91	1.5	7.7	3.7	...		300-600	3.6-3.7	9000-17000	26	M80-M90
Allyl and polyester......	1.10-1.46	...	1.53-1.56	8.0-10.	4.8-5.0	.26-.55	$>4\times10^{14}$	380	3.4-5.	21000-23000†	3-8.2	M85-M119
Cellulose nitrate	1.35-1.40	.89-.92	1.49-1.51	8.-12.	5.5	.3-.4	$10\text{-}15\times10^{10}$	300-600	7.-7.5	6000-11000	1.9-2.2	R95-R115
Polysterene	1.05-1.06	...	1.59-1.60	6.-8.	2.4-3.3	.32	$10^{17}\text{-}10^{19}$	500-700	2.4-2.6	11000-16000	4.-5.	M85-M95
Phenolic molding	1.3-1.5	...	...	3.-4.5	4.7	.35-.40	$1\text{-}100\times10^{11}$	...	5.-9.	...	8.-12.	M110-M120
Ethyl cellulose	1.12-1.14	...	1.47	10-20	3.8-7	.3-.75	$10^{12}\text{-}10^{14}$	350-500	...	11000-13000†	1.3-3.5	R100-R110

[75] Taken from Technical data on plastics, Plastic Mfg. Assoc., Inc., May 1948. For trade names see original reference.
* Compression. † To fracture.

TABLE 231.—PROPERTIES OF SOME OPTICAL PLASTICS [76]

Name	Polymer N_D^{20}	Polymer ν *	Monomer N_D^{20}	Boiling point °C ν
Allyl methacrylate	1.5196	49.0	1.4340 at 23°	55/30 mm
Benzyl mellacrylate	1.5680	36.5	1.514	233
4-cyctolaxyl-cyclohexyl metharcylate	1.5250	53.	1.4913	111/1 mm
Menthyl metharcylate	1.5064	54.5	...	...
Ethylene dimethacrylate	1.5063	53.4	1.4547	92/3 mm
Methyl methacrylate	1.490	56.25	1.417	100
Styrene	1.5916	31.0	1.5434	146
O-chlorostyrene	1.6098	31.0	1.567	47/37 mm
Pentachlorophenol methacrylate	1.608	22.5	...	(MP 88.5°C)
Vinyl naphthalene	1.6818	20.9	...	92–95/mm

[76] Polaroid Corporation, NDRC Report, Library of Congress PB 28553.
* See Table 523.

TABLE 232.—GENERAL PROPERTIES OF OPTICAL PLASTICS

	Cyclohexylmethacrylate	Sterene		Cyclohexylmethacrylate	Sterene
Index N_D20°C	1.50645	1.59165	Thermal exp. coeff.	9.0×10^{-5}/°C	8.0×10^{-5}/°C
Index tolerance	+.0015	+.0015	Thermal conductivity	2.31×10^{-4} (cgs)	2.21×10^{-4} cal sec^{-1} cm^{-1}°C
ν values	56.9	31.0	Index charge per °C	—.000131	—.000136
" " tolerance	+.5	+.3	Max. operating temp.	150°F	150°F
Partial dispersion					
N_F-N_C	.00895	.01920	Density	1.095 g/cm³	1.049 g/cm³
N_D-N_C	.00258	.00536	Moles hardness	2-3	2-3
N_F-N_D	.00638	.01384	Over-all visual transmittance through sample ⅜ in. thick	99.1%	99.9%

The values of the properties of natural fibers are influenced by their source, extent of processing or purification, age, temperature and moisture content when tested, and method of test. Those of man-made fibers not only reflect these influences but they can be and commonly are varied to meet the requirements of use by suitable modifications in composition and manipulation of the fibers during production. These facts and the lack of strictly comparable data for all the principal fibers led to the decision to show in the tables the range in values of the properties reported in recent literature rather than selected values. The azlons, made from different proteins, are lumped together and so are the ordinary, medium, and high-tenacity rayons and the several varieties of resin fibers of each kind. References to literature giving more information and more detailed information are as follows:

Textile World's synthetic fiber table, 1949 rev., compiled by C. W. Bendigo, editor, Textile World, September 1949. Chemical engineering materials of construction, Ind. and Eng. Chem., 2d ed., vol. 40, p. 1773, 1948; 3d ed., vol. 41, p. 2091, 1949. Fiber properties chart—1948, Plastics Catalogue Corporation, New York. Smith, H. DeWitt, Textile fibers—an engineering approach to an understanding of their properties and utilization, Proc. Amer. Soc. Test. Mat., vol. 44, p. 543, 1944. A. S. T. M. standards on textile materials. Amer. Soc. Test. Mat., October 1949. Die Unterscheidung der Textilfasern, 2d ed., Verlag Leeman, Zurich, 1949. Morehead, F. F., Some comparative data on the cross-sectional swelling of textile fibers, Textile Res. Journ., vol. 17, p. 96, 1947. Preston, J. M., The temperature of contraction of fibers as an aid to identification, Journ. Textile Inst., vol. 40, p. T767, 1949. Abbott, N. J., and Goodings, A. C., Moisture absorption, density, and swelling properties of nylon filaments, Journ. Textile Inst., vol. 40, p. T232, 1949. Hutton, E. A., and Gartside, Joan, The moisture regain of silk, Journ. Textile Inst., vol. 40, p. T161, 1949. Hutton, E. A., and Gartside, Joan, The adsorption and desorption of water by nylon at 25° C, Journ. Textile Inst., vol. 40, p. T170, 1949. MacMillan, W. G., Mukherjee, R. R., and Sen, M. K., The moisture relationships of jute, Journ. Textile Inst., vol. 37, p. T13, 1946. Albright, J. G., "Spider Silk," Science Teacher, October 1944.

* Prepared by W. D. Appel, of the National Bureau of Standards.

TABLE 233.—PHYSICAL PROPERTIES OF NATURAL FIBERS

	Cotton	Flax	Hemp	Jute	Ramie	Silk §	Wool
Density (g/cm^3)	1.50–1.55	1.50	1.48	1.48	1.51	1.25–1.35	1.28–1.33
Refractive index: epsilson	1.573–1.581	1.594–1.596	1.585–1.591	1.577	1.595–1.599	1.591–1.595	1.553–1.556
omega	1.529–1.534	1.528–1.532	1.526–1.530	1.536	1.527–1.540	1.538–1.543	1.542–1.547
Tensile strength (1000 lb/in.²)	42–125	...	...	...	...	45–83	15–28
Tenacity: dry (g/denier *)	2.1–6.3	...	...	...	...	2.9–5.2	1.0–1.7
wet (% of dry)	110–130	...	...	...	...	75–95	76–97
Elongation to break (%)	3–10	...	...	...	...	13–31	20–50
Recovery from strain							
Elongation (%)	2	...	...	...	...	2	2
Recovery "	74	...	...	...	...	92	99
Elongation "	5	...	...	...	...	20	20
Recovery "	45	...	...	...	...	33	63
Average stiffness †	57	270	200	185	167	15	4
Toughness index ‡	14	6	4	2	8	40	20
Moisture regain at 65% R. H. and 70°F (% of bone-dry weight)	6.0–8.5 (8.–11. mercerized)	7.0–8.5	8.0	10.6–13.6	6.0	8.1–15.5	13.0–16.2
Swelling in water, cross-section swelling (%)	21	47	...	...	37	19	26
Heat stability; temperature °C at or above which fiber							
contracts	...	...	...	...	...	Does not contract	240
loses strength	...	...	...	...	...	...	...
softens	...	...	...	...	...	...	...
melts	...	...	...	...	...	...	...
decomposes	...	...	...	...	...	chars	chars

* "Denier" is the weight in grams of 9,000 meters of the fiber. † The value for stiffness is a measure of the ability of the fiber substance to resist deformation. ‡ The toughness index is a measure of the ability of the fiber substance to absorb work. § Spider silk has a density of 1.30-1.37 and tensile strength of 60 (from golden garden spider).

TABLE 234.—PHYSICAL PROPERTIES OF RESIN AND RAYON FIBERS

	Rayons			Resins			
	Cupra-ammonium	Saponified acetate	Viscose *	Acrylic	Vinyl chloride acetate copolymer †	Vinyl chloride-acrylonitrile copolymer †	Vinylidine
Density (g/cm^3)	1.52–1.54	1.50–1.52	1.50–1.54	1.17	1.33–1.36	1.22–1.28	1.68–1.75
Refractive index: epsilon	1.548–1.552	1.547	1.539–1.550	...	1.536	1.536	1.60–1.63
omega	1.520–1.527	1.513	1.514–1.523	...	1.536	1.536	1.60–1.63
Tensile strength (1000 $lb/in.^2$)	33–42	136–138	29–88	59–75	34–80 [a]	65–75	15–60
Tenacity: dry (g denier ‡)	1.7–2.3	7.0	1.5–4.0	...	2.0–4.4	...	1.1–2.9
wet (% of dry)	59	85	44–65	...	100	...	100
Elongation to break (%)	10–17	6	9–30	...	14–35	...	15–30
Recovery from strain							
Elongation (%)	5	2	2	...	2	...	...
Recovery "	48	82	82	...	99	...	...
Elongation "	15	5	15–20	...	20	...	...
Recovery "	32	67	30–37	...	63	...	...
Average stiffness §	14	105	10–23	...	7–22	...	18
Toughness index ‖	13	19	17–20	...	25–30	...	56
Moisture regain at 65% R. H. and 70°F (% of bone-dry weight)	11.0–12.5	9.8–11.5	11.5–16.6	.9–2.0 [b]	.0–.5	.0–.5	.0
Swelling in water, cross-section swelling (%)	41–62	22	35–66	...	.2–4.3	...	.0
Heat stability; temperature °C at or above which fiber							
contracts	...	...	...	Does not contract	66–83	70–145	71–155
loses strength	...	100	130	125	...	...	...
softens	...	...	...	235	77	170	116–163
melts	149	...	...	...	200–260	190–200	150–160
decomposes	...	...	177–204	chars	...	...	...

* Including regular and high-tenacity varieties. † Including several varieties. ‡ "Denier" is the weight in grams of 9000 meters of the fiber. § The value given for stiffness is a measure of the ability of the fiber substance to resist deformation. ‖ The toughness index is a measure of the ability of the fiber substance to absorb work. [a] Staple 10-17. [b] At 60% R.H.

	Acetate * (cellulose)	Azlon (casein, soybean protein, zein	Glass	Nylon †	Polyethylene
Density (g/cm^3)	1.30–1.35	1.25–1.31	2.54–2.56	1.14	.92
Refractive index: epsilon	1.476–1.478	1.537–1.545	1.541–1.548	1.570–1.580	...
omega	1.470–1.473	1.537–1.545	1.541–1.548	1.520–1.530	...
Tensile strength (1000 lb/in.^{2})	20–30	10–19	204–220	65–117	11–30
Tenacity: dry (g/denier ‡)	1.2–1.5	.6–1.0	6.3–6.9	4.5–8.0	...
wet (% of dry)	60–65	35–50	99	85–90	...
Elongation to break (%)	23–50	12–15	2.0–3.7	14–25	...
Recovery from strain					
Elongation (%)	2	5	3	2	...
Recovery "	94	60	100	100	...
Elongation "	20	20	...	20	...
Recovery "	23	30	...	75	...
Average stiffness §	3–7	2	290	22–41	...
Toughnens index ‖	16–32	14	6	45	...
Moisture regain at 65% R. H. and 70°F (% of bone-dry weight)	6.0–6.5	10.0–15.5	.0	3.5–4.5	.0
Swelling in water, cross-section swelling (%)	7.9	5.0–10.0	.0	3.2	...
Heat stability; temperature °C at or above which fiber					
contracts	...	...	...	Does not contract	74
loses strength	90–107	100–171	316	140	...
softens	177–208	...	816	220	...
melts	...	...	...	...	104
decomposes	...	232–246	...	...	...

* Acetate rayon or estron. † Including regular and high-tenacity varieties. ‡ "Denier" is the weight in grams of 9000 meters of the fiber. § The value given for stiffness is a measure of the ability of the fiber substance to resist deformation. ‖ The toughness index is a measure of the ability of the fiber substance to absorb work.

Diameter	Linen yacht rope: Net wt lb/100ft	Linen yacht rope: Min. tensile strength lb	Manila bolt rope: Net wt lb/100ft	Manila bolt rope: Min. tensile strength lb	Nylon yacht rope: Net wt lb/100ft	Nylon yacht rope: Min. tensile strength lb	Saran rope †: Net wt lb/100ft	Saran rope †: Min. tensile strength lb	Sisal rope: Net wt lb/100ft	Sisal rope: Min. tensile strength lb	Cotton rope: Tensile strength lb
											120 (1/8″)
3/16″	—	—	1.27	460	.929	850	1.47	260	1.47	360	250
1/4″	2.02	925	1.71	605	1.66	1200	2.73	560	1.96	480	460
5/16″	2.98	1400	2.32	1045	2.59	1900	3.93	730	2.84	800	650
3/8″	4.42	1950	3.56	1400	3.75	2700	5.66	990	4.02	1080	850
7/16″	6.00	2425	5.59	1925	5.15	3700	—	—	5.15	1400	1000
1/2″	8.00	3200	7.05	2920	6.71	4700	10.3	1770	7.35	2120	1250
9/16″	10.3	4050	8.61	3800	8.41	6000	14.0	2630	10.2	2760	—
5/8″	12.4	4920	11.0	4850	10.2	7500	17.7	3120	13.1	3520	—
3/4″	15.4	5910	13.0	5950	15.0	11,000	23.2	4020	16.3	4320	—
13/16″	19.0	7075	16.2	7150	17.7	13,300	—	—	19.1	5200	—
7/8″	23.2	8460	19.2	8470	20.3	15,600	32.0	5700	22.0	6160	—
1″	27.3	10,020	23.0	9900	27.0	19,000	42.5	8000	26.5	7200	—
1 1/16″	32.9	11,000	27.0	11,550	30.0	23,000	—	—	30.7	8400	—
1 1/8″	37.8	12,300	31.8	13,200	34.0	26,000	—	—	35.2	9600	—
1 1/4″	43.5	14,500	36.9	14,850	41.0	32,000	67.0	12,000	40.8	10,800	—
1 5/16″	—	—	42.5	16,500	—	—	—	—	46.9	12,000	—
1 1/2″	—	—	53.5	20,400	—	—	—	—	58.8	14,800	—
1 3/4″	—	—	82.0	29,200	—	—	—	—	87.7	21,200	—
2″	—	—	98.0	34,100	—	—	—	—	105.	24,800	—
2 1/4″	—	—	143.	45,000	—	—	—	—	143.	32,800	—
2 1/2″	—	—	163.	51,000	—	—	—	—	163.	37,200	—
3″	—	—	235.	70,000	—	—	—	—	237.	51,200	—
3 1/4″	—	—	289.	85,000	—	—	—	—	292.	61,600	—

* Data from the Plymouth Rope Co. and Mr. Axelsson of Columbian Rope Co. Data on cotton rope furnished by Mr. Moss, Southeastern Cordage Co. † Excellent resistance to acids, alkalis, and most chemicals.

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES[77]

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Alder, red (*Alnus rubra*)	Wash.	98	.41	28	9,800	1,380	1.85	11,600	4,530	540	1,080	420
Apple (*Malus pumila var.*)	Va.	46	.67	47	12,800	1,270	2.31	15,700	3,120	1,300	1,740	—
Ash, Biltmore (*Fraxinus biltmoreana*)	Tenn.	42	.55	38	13,000	1,600	2.97	16,500	5,670	1,510	1,630	710
Ash, black (*Fraxinus nigra*)	Mich., Wis.	85	.49	34	12,600	1,600	1.57	—	4,520	940	1,570	700
Ash, blue (*Fraxinus quadrangulata*)	Ky.	39	.57	40	13,800	1,400	2.68	18,400	5,460	1,760	2,030	—
Ash, green (*F. pennsylvanica lanceolata*)	La., Mo.	48	.56	40	14,100	1,660	2.72	16,400	5,120	1,620	1,910	700
Ash, Oregon (*Fraxinus oregona*)	Oreg.	48	.55	38	12,700	1,360	2.08	13,300	4,100	1,540	1,790	720
Ash, pumpkin (*Fraxinus profunda*)	Mo.	51	.52	36	11,100	1,270	1.91	13,600	3,950	1,800	1,720	770
Ash, white (*Fraxinus americana*)	Ark., N. Y., W. Va., Vt., Mass.	42	.60	42	15,400	1,770	2.60	17,000	5,790	1,410	1,950	940
Aspen, bigtooth (*Populus grandidentata*)	Wis., Vt.	99	.39	27	9,100	1,430	1.25	11,400	4,090	560	1,080	390
Aspen, quaking (*Populus tremuloides*)	Wis., N. Mex.	94	.38	26	8,400	1,180	1.53	9,000	3,040	460	850	260
Basswood, American (*Tilia americana*)	Wis., Pa.	105	.37	26	8,700	1,460	1.37	9,800	3,800	450	990	350
Beech, American (*Fagus grandifolia*)	Ind., Pa., Vt.	54	.64	45	14,900	1,720	2.63	16,000	4,880	1,250	2,010	1,010

[77] Data taken from Forest Service Bull. 479, U. S. Dept. Agr.

(continued)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Birch, Alaska paper (*Betula papyrifera neolaskana*).	Alaska	58	.55	38	13,600	1,900	1.85	13,700	5,290	820	1,400	660
Birch, gray * (*Betula populifolia*)	N. H.	63	.51	35	9,800	1,150	1.46	10,400	2,670	920	1,340	—
Birch, paper (*Betula papyrifera*)	Wis., N H.	65	.55	38	12,300	1,590	1.80	12,400	3,610	740	1,210	—
Birch, sweet (*Betula lenta*)	Pa., N. H.	53	.65	46	16,900	2,170	2.72	24,800	6,330	1,340	2,240	950
Birch, yellow (*Betula lutea*)	Pa., Vt., Wis.	67	.62	43	16,600	2,010	2.89	17,200	6,130	1,190	1,880	920
Black-mangrove * (*Avicennia nitida*)	Fla.	42	.83	58	16,400	2,090	2.03	—	—	2,360	—	—
Buckeye, yellow (*Aesculus octandra*)	Tenn.	141	.36	25	7,500	1,170	1.26	10,000	3,010	440	960	520
Buckthorn, cascara * (*Rhamnus purshiana*)	Oreg.	61	.52	36	8,700	960	2.14	10,200	3,460	1,310	1,610	—
Bustic, willow * (*Dipholis salicifolia*)	Fla.	44	.88	62	—	—	—	18,400	4,950	—	—	—
Butterbough * (*Exothea paniculata*)	"	56	.80	56	14,900	1,910	2.34	—	4,520	2,530	2,260	—
Butternut (*Juglans cinerea*)	Tenn., Wis.	104	.38	27	8,100	1,180	1.59	11,200	4,200	5,110	1,170	440
Button-mangrove * (*Conocarpus erectus*)	Fla.	47	.71	50	10,260	1,580	1.70	—	—	1,630	—	—
California-laurel (*Umbellularia californica*)	Oreg.	70	.55	39	8,000	940	1.85	10,700	3,520	1,400	1,860	870
Catalpa, northern (*Catalpa speciosa*)	Ind.	72	.41	29	9,400	1,210	1.08	11,000	2,740	570	1,130	570

* Meager data, may not be fully representative of species.

(continued)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending			Impact bending	Compression		Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
					Modulus of rupture, lb/in.²	Modulus of elasticity, 1000×lb/in.²	P-limit, lb/in.²	P-limit, lb/in.²	Parallel to grain. P-limit, lb/in.²	Perpendicular to grain, P-limit lb/in.²		
Cherry, black (*Prunus serotina*)	Pa.	55	.50	35	12,300	1,490	3.11	13,600	5,960	850	1,700	560
Cherry, pin (*Prunus pennsylvanica*)	Tenn.	46	.39	27	8,500	1,270	1.51	10,100	3,900	520	1,030	320
Chestnut, American (*Castanea dentata*)	Md., Tenn.	122	.43	30	8,600	1,230	1.78	10,700	3,780	760	1,080	460
Chinquapin, golden (*Castanopsis chrsophylla*)	Oreg.	134	.46	32	10,700	1,240	3.11	10,900	4,150	680	1,260	—
Cottonwood, eastern (*Populus deltoides*)	Mo.	111	.40	28	8,500	1,370	1.39	7,300	3,490	470	930	580
Cottonwood, northern black (*Populus trichocarpa hastata*)	Wash.	132	.35	24	8,300	1,260	1.25	9,800	3,270	370	1,020	330
Cucumber tree (*Magnolia accuminata*)	Tenn.	80	.48	33	12,300	1,820	1.98	14,700	4,840	710	1,340	660
Dogwood, flowering (*Cornus florida*)	"	62	.73	51	14,900	1,530	3.10	14,600	—	1,920	2,260	—
Dogwood, Pacific (*Cornus nuttallii*)	Oreg.	52	.64	45	10,500	1,470	2.02	10,500	4,300	1,650	1,720	1,040
Doveplum * (*Coccolobis laurifolia*)	Fla.	52	.78	55	13,000	1,290	2.67	—	4,640	2,920	—	—
Elder, blueberry * (*Sambucus glauca*)	"	124	.52	36	9,200	1,030	1.56	10,500	3,860	760	—	—
Elm, American (*Ulmus americana*)	N. H., Pa., Wis.	89	.50	35	11,800	1,340	2.53	—	4,030	850	1,510	660
Elm, rock (*Ulmus thomasi*)	Wis.	48	.63	44	14,800	1,540	2.45	—	4,700	1,520	1,920	—
Elm, slippery (*Ulmus fulva*)	Ind., Wis.	85	.53	37	13,000	1,490	2.35	15,300	4,760	1,010	1,630	530
Eucalyptus, bluegum (*Eucalyptus globulus*)	Calif.	79	.74	52	16,000	2,370	3.28	20,500	8,190	1,720	1,840	—

(*continued*)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Eugenia, redberry * (*Eugenia confusa*)	Fla.	41	.87	61	16,200	2,040	—	—	—	2,790	1,850	—
False-mastic (*Sideroxylon foetidissimum*)	"	39	.93	65	10,200	1,780	1.39	14,100	3,940	2,830	1,470	710
Fig, Florida strangler * (*Ficus aurea*)	"	88	.44	31	7,200	800	1.03	—	—	—	—	—
Gumbo-limbo (*Bursera simaruba*)	"	99	.31	21	4,800	740	.85	6,300	1,720	560	800	360
Hackberry (*Celtis occidentalis*)	Ind., Wis.	65	.53	37	11,000	1,190	1.72	13,700	3,710	1,100	1,590	580
Hawthorn, pear * (*Crataegus calpodendron*)	Wis.	63	.68	47	14,600	1,270	2.50	—	—	1,580	—	—
Hickory, bitternut (*Carya cordiformis*)	Ohio	66	.66	46	17,100	1,790	2.73	23,600	—	2,070	—	—
Hickory, mockernut (*Carya tomentosa*)	Pa., Miss., W. Va.	59	.72	51	19,200	2,220	3.41	20,200	—	2,140	1,740	—
Hickory, nutmeg (*Carya myristicaeformis*)	Miss.	74	.60	42	16,600	1,700	2.04	—	—	1,930	—	—
Hickory, pignut (*Carya glabra*)	W. Va., Miss., Ohio, Pa.	54	.75	52	20,100	2,260	3.23	25,200	—	2,450	2,150	—
Hickory, shagbark (*Carya ovata*)	Miss., Ohio, W. Va., Pa.	60	.72	50	20,200	2,160	3.01	19,300	—	2,170	2,430	—
Hickory, shellbark (*Carya laciniosa*)	Ohio, Miss.	61	.69	48	18,100	1,890	2.29	22,800	—	2,220	2,110	—
Hickory, water * (*Carya aquatica*)	Miss.	80	.62	43	17,800	2,020	2.88	—	5,400	1,910	—	—
Holly, American (*Ilex opaca*)	Tenn.	82	.57	40	10,300	1,110	1.88	12,500	3,380	1,130	—	680
Honeylocust (*Gleditsia tricanthos*)	Ind., Mo.	63	—	—	14,700	1,630	2.74	15,400	5,250	2,280	2,250	900

(*continued*)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Hophornbeam, eastern (*Ostrya virginiana*)	Wis.	52	.70	49	14,100	1,700	2.96	14,200	5,780	1,500	1,790	—
Hornbeam, American * (*Carpinus caroliniana*)	Mass.	48	.70	49	12,200	1,080	.77	10,300	3,330	2,000	2,410	—
Leadwood * (*Krugiodendron ferreum*)	Fla.	32	1.15	81	18,200	2,980	1.02	16,500	3,400	2,860	—	—
Locust, black (*Robinia pseudoacacia*)	Tenn.	40	.69	48	19,400	2,050	4.62	21,100	6,800	2,260	2,480	640
Madrone, Pacific (*Arbutus mensiesii*)	Calif., Oreg.	68	.65	45	10,400	1,230	2.46	10,400	4,040	1,620	1,810	—
Magnolia, Fraser (*Magnolia fraseri*)	Tenn.	89	.44	31	10,100	1,400	1.86	13,800	4,180	620	1,150	660
Magnolia, southern * (*Magnolia grandiflora*)	La.	105	.50	35	11,200	1,400	1.90	13,600	3,420	1,060	1,530	740
Mangrove * (*Rhizophora mangle*)	Fla.	39	.96	67	21,700	2,950	3.80	—	6,170	3,300	2,860	—
Maple, bigleaf (*Acer macrophyllum*)	Wash.	72	.48	34	10,700	1,450	1.66	—	4,790	930	1,730	540
Maple, black * (*Acer nigrum*)	Ind.	65	.57	40	13,300	1,620	2.39	13,500	4,600	1,250	1,820	670
Maple, red (*Acer rubrum*)	N. H., Pa., Wis.	63	.54	38	13,400	1,640	2.84	—	4,650	1,240	1,850	—
Maple, silver (*Acer saccharinum*)	Wis.	66	.47	33	8,900	1,140	1.90	12,400	4,360	910	1,480	500
Maple, striped * (*Acer pennsylvanicum*)	Vt.	35	.46	32	10,900	1,360	1.08	11,400	—	800	1,320	—
Maple, sugar (*Acer saccharum*)	Ind., Pa., Vt., Wis.	58	.63	44	15,800	1,830	2.76	20,600	5.390	1,810	2,330	—
Mountain-laurel * (*Kalmia latifolia*)	Tenn.	62	.68	48	11,100	1,200	3.44	14,300	—	1,820	—	—

(continued)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Oak, black (*Quercus nigra*)	La.	81	.63	44	15,400	2,020	2.24	18,800	3,960	1,260	2,020	920
Oak, black (*Quercus velutina*)	Ark., Wis.	80	.61	43	13,900	1,640	2.15	14,400	4,750	1,150	1,910	—
Oak, bur (*Quercus macrocarpa*)	Wis.	70	.64	45	10,300	1,030	2.37	14,600	3,580	1,480	1,820	680
Oak, California black (*Quercus Kelloggii*)	Oreg., Calif.	106	.57	40	8,700	990	2.28	8,800	3,300	1,440	1,470	770
Oak, canyon live (*Quercus chrysolepsis*)	Calif.	62	.77	54	12,900	1,610	3.15	13,000	6,110	2,260	2,290	—
Oak, chestnut (*Quercus montana*)	Tenn.	72	.66	46	13,300	1,590	2.88	18,600	4,420	1,040	1,490	—
Oak, Gambel (*Quercus gambelli*)	Ariz.	61	.73	51	8,500	680	2.30	14,100	—	2,070	—	—
Oak, laurel (*Quercus laurifolia*)	La.	84	.63	44	12,600	1,690	2.02	14,700	4,640	1,310	1,830	790
Oak, live (*Quercus virginiana*)	Fla.	50	.89	62	18,400	1,980	2.19	21,300	5,120	3,510	2,660	1,010
Oak, northern red (*Quercus borealis*)	Ark., Ind., La., N. H., Tenn.	80	.63	44	14,300	1,820	2.33	17,600	4,580	1,250	1,780	800
Oak, Oregon white (*Quercus garryana*)	Oreg.	72	.72	50	10,300	1,100	2.28	11,900	3,960	2,110	2,020	830
Oak, pin (*Quercus palustris*)	Mass.	75	.63	44	14,000	1,730	2.22	12,300	4,620	1,260	2,080	1,050
Oak, post (*Quercus stellata*)	Ark., La.	69	.67	47	13,200	1,510	2.25	17,600	3,700	1,760	1,840	780
Oak, scarlet (*Quercus coccinea*)	Mass.	65	.67	47	17,400	1,910	2.92	16,100	5,550	1,380	1,890	870
Oak, southern red (*Quercus falcata*)	La.	90	.59	41	10,900	1,490	1.44	15,300	2,910	1,080	1,390	510

(*continued*)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Oak, swamp chestnut (*Quercus prinus*)	La.	76	.67	47	13,900	1,770	1.68	19,000	4,400	1,370	1,990	690
Oak, swamp red (*Q. falcata pagodacfolia*)	"	78	.68	47	18,100	2,280	3.09	23,900	6,350	1,540	2,000	840
Oak, swamp white * (*Quercus bicolor*)	Ind.	74	.72	50	17,700	2.050	2.88	22,300	5,830	1,470	2,000	830
Oak, white (*Quercus alba*)	Ark., Ind., La.	68	.68	48	15,200	1,780	2.27	17,100	4,760	1,320	2,000	800
Oak, willow * (*Quercus phellos*)	La.	94	.69	48	14,500	1,900	2.61	15,600	4,380	1,400	1,650	—
Osage-orange * (*Maclura pomiferum*)	Ind.	31	—	—	—	—	—	—	—	—	—	—
Palmetto, cabbage (*Sabal palmetto*)	Fla.	134	.39	27	4,700	560	.94	6,200	1,450	180	410	130
Paradise-tree (*Simarouba glauca*)	"	81	.34	24	5,300	850	.88	5,500	2,160	400	620	330
Pecan (*Carya illinoensis*)	Mo.	63	.66	46	13,700	1,730	2.81	17,400	5.180	2,130	2,080	—
Persimmon, common (*Diospyros virginiana*)	"	58	.74	52	17,700	2,010	3.49	18,400	6,390	2,460	2,160	1,200
Poisontree,* Florida (*Metopium toxiferum*)	Fla.	71	.53	37	10,600	1,290	1.25	—	—	800	—	—
Poplar, balsam (*Populus tacamahaca*)	Alaska, Vt.	112	.33	23	6,800	1,100	.98	8,000	2,920	370	790	350
Rhododendron, rosebay * (*Rhododendron, maximum*)	Tenn.	99	.57	40	11,000	1,110	2.30	—	—	1,400	—	—
Sassafras (*Sassafras albidum*)	"	67	.45	31	9,000	1,120	1.91	10,600	3,260	1,050	1,240	590

(*continued*)

TABLE 237.—MECHANICAL PROPERTIES OF HARDWOODS GROWN IN UNITED STATES (concluded)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Serviceberry, downy (*Amelanchier arborea*)	Tenn.	48	.74	52	16,900	1,880	3.44	21,000	6,340	1,790	1,590	—
Silverbell, Carolina (*Halesia carolina*)	"	70	.45	32	8,600	1.320	1.46	13,300	3,580	680	1,180	480
Sourwood (*Oxydendrum arboreum*)	"	69	.55	38	11,600	1,540	2.44	17,200	4,400	1,080	1,500	520
Sugarberry (*Celtis laevigata*)	Mo.	62	.51	36	9,900	1,140	2.18	11,600	3,970	1,240	1,280	—
Sumach, staghorn * (*Rhus typhina*)	Wis.	45	.47	33	10,200	1,190	2.84	—	—	1,010	—	—
Sweetgum (*Liquidambar styraciflua*)	Mo.	81	.49	34	11,900	1,490	2.57	16,800	4,700	860	1,610	800
Sycamore, American (*Platanus occidentalis*)	Ind., Tenn.	83	.49	34	10,000	1,420	1.66	10,500	3,710	860	1,470	720
Tupelo, black; blackgum (*Nyssa sylvatica*)	Tenn.	55	.50	34	9,600	1,200	2.54	14,500	3,470	1,150	1,340	500
Tupelo, water (*Nyssa aquatica*)	La., Mo.	97	.50	35	9,600	1,260	2.41	12,500	4,280	1,070	1,590	700
Walnut, black (*Juglans nigra*)	Ky.	81	.55	38	14,600	1,680	3.70	16,400	5,780	1,250	1,370	690
Walnut, little * (*Juglans rupestris*)	Ariz.	67	.57	40	14,200	1,480	2.60	11,100	—	—	—	—
Willow, black (*Salix nigra*)	Mo., Wis.	139	.37	26	6,200	720	1.94	7,700	2,020	480	1.050	460
Willow, Pacific (*Salix lasiandra*)	Oreg.	105	.44	31	8,500	1,310	1.37	11,000	3,120	630	1,160	530
Witch-hazel * (*Hamamelis virginiana*)	Tenn.	70	.61	43	15,200	1,460	3.17	—	—	1,370	—	—
Yellow-poplar (*Liriodendron tulipifera*)	Ky., Tenn.	64	.40	28	9,200	1,500	1.43	13,500	3,550	580	1,100	520

TABLE 238.—MECHANICAL PROPERTIES OF SOFT WOODS GROWN IN UNITED STATES **

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain, P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
Alaska-cedar (*Chamaecyparis nootkatensis*) .	Alaska, Oreg.	38	.44	31	11,100	1,420	2.06	12,200	5,210	770	1,130	360
Baldcypress (*Taxodium distichum*)	La., Mo.	91	.46	32	10,600	1,440	2.15	10,400	4,470	900	1,000	270
Douglas-fir (coast type) (*Pseudotsuga taxifolia*)	Wash., Oreg., Calif.	36	.48	34	11,700	1,920	1.96	12,700	6,450	910	1,140	300
Douglas-fir (intermediate type) (*Pseudotsuga taxifolia*)	Mont., Idaho, Calif.	48	.44	31	11,200	1,640	1.87	11,600	5,540	920	1,130	340
Douglas-fir (Rocky Mountain type) (*Pseudotsuga taxifolia*)	Wyo., Mont.	38	.43	30	9,600	1,400	1.60	12,100	4,660	820	1,070	330
Fir, alpine (*Abies lasiocarpa*)	Colo.	47	.33	23	7,100	900	—	7,000	3,740	600	1,020	—
Fir, balsam (*Abies balsamea*)	Wis.	117	.36	25	7,600	1,230	1.23	7,800	3,970	380	710	180
Fir, California red (*Abies magnifica*)	Calif.	116	.39	27	10,800	1,540	1.48	10,900	4,160	650	1,090	390
Fir, corkbark (*Abies lasiocarpa arizonica*) ...	N. Mex.	62	.30	21	6,900	1,030	1.09	8,200	3,820	470	840	280
Fir, grand (*Abies grandis*)	Mont., Oreg.	94	.40	28	9,300	1,630	1.22	12,000	4,420	620	930	240
Fir, noble (*Abies procera*)	Oreg.	36	.38	26	10,100	1,580	1.59	11,200	4,960	640	980	220
Fir, Pacific silver (*Abies amabilis*)	Wash.	66	.38	27	9,400	1,530	1.40	11,400	4,660	490	1,050	—
Fir, white (*Abies concolor*)	Calif., N. Mex.	115	.37	26	9,300	1,380	1.72	10,800	3,590	600	930	260
Hemlock, eastern (*Tsuga canadensis*)	Wis., Tenn., N. H., Vt.	111	.40	28	8,900	1,200	1.79	10,700	4,020	800	1,060	—

** For reference, see footnote 77, p. 246.

(*continued*)

TABLE 238.—MECHANICAL PROPERTIES OF SOFT WOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending			Impact bending	Compression		Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
					Modulus of rupture, lb/in.²	Modulus of elasticity, 1000×lb/in.²	P-limit, lb/in.²	P-limit, lb/in.²	Parallel to grain. P-limit, lb/in.²	Perpendicular to grain, P-limit lb/in.²		
Hemlock, mountain (*Tsuga mertensiana*)	Mont., Alaska	62	.47	33	11,200	1,320	2.36	13,300	4,620	1,030	1,230	320
Hemlock, western (*Tsuga heterophylla*)	Wash., Alaska, Oreg.	74	.42	29	10,100	1,490	1.82	12,400	5,340	680	1,170	310
Incense-cedar, California (*Libocedrus decurrens*)	Oreg., Calif.	108	.37	—	8,000	1,040	1.67	9,600	4,760	730	880	270
Juniper (*Juniperus pachyphloea*)	Ariz.	40	.51	36	6,700	650	2.74	5,600	—	1,700	—	—
Larch, western (*Larix occidentalis*)	Mont., Idaho, Wash.	58	.55	38	13,900	1,960	1.99	15,600	5,620	980	1,410	430
Pine, eastern white (*Pinus strobus*)	Wis., Minn., N. H.	73	.35	25	8,600	1,240	1.51	9,700	3,670	510	900	310
Pine, jack (*Pinus banksiana*)	Wis., Minn.	60	.43	30	9,900	1,350	1.43	12,200	3,380	600	1,170	420
Pine, Jeffrey (*Pinus jeffreyi*)	Calif.	101	.40	28	9,300	1,240	2.43	12,500	4,240	790	1,210	380
Pine, limber * (*Pinus flexilis*)	N. Mex.	68	.40	28	9,100	1,170	2.13	11,400	—	720	800	220
Pine, loblolly (*Pinus taeda*)	Fla., Md., N. C., S. C., Va.	81	.51	36	12,800	1,800	1.92	12,100	4,820	980	1,370	470
Pine, lodgepole (*Pinus contorta latifolia*)	Wyo., Colo., Mont.	65	.41	29	9,400	1,340	1.97	9,600	4,310	750	880	290
Pine, longleaf (*Pinus palustris*)	La., Miss., Fla., S. C.	63	.58	41	14,700	1,990	2.44	15,400	6,150	1,190	1,500	470
Pine, pitch (*Pinus rigida*)	Tenn., Mass.	79	.49	34	10,800	1,430	1,62	12,600	3,960	1,010	1,360	480

* Meager data, may not be fully representative of species.

(*continued*)

TABLE 238.—MECHANICAL PROPERTIES OF SOFT WOODS GROWN IN UNITED STATES (continued)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending: Modulus of rupture, lb/in.²	Static bending: Modulus of elasticity, 1000×lb/in.²	Static bending: P-limit, lb/in.²	Impact bending: P-limit, lb/in.²	Compression: Parallel to grain. P-limit, lb/in.²	Compression: Perpendicular to grain, P-limit lb/in.²	Shear parallel to grain: maximum shearing strength, lb/in.²	Tension perpendicular to grain: maximum tensile strength lb/in.²
Pine, pond (*Pinus rigida serotina*)	Fla.	56	.54	38	11,600	1,750	2.21	13,200	6,300	1,120	1,380	360
Pine, ponderosa (*Pinus ponderosa*)	Colo., Wash., Ariz., Mont., Calif.	91	.40	28	9,200	1,260	1.85	9,800	4,060	740	1,160	400
Pine, red (*Pinus resinosa*)	Wis., Minn.	92	.44	31	11,000	1,630	1.77	13,400	4,160	650	1,210	460
Pine, sand (*Pinus clausa*)	Fla.	36	.48	34	11,600	1,410	1.83	12,400	3,900	1,030	1,100	300
Pine, shortleaf (*Pinus eschinata*)	Ark., La., N. C., N. J., Ga.	81	.51	36	12,800	1,760	1.93	13,600	5,090	1,000	1,310	470
Pine, slash (*Pinus caribaea*)	Fla., La.	66	.61	43	15,900	2,060	2.76	15,800	6,280	1,390	1,730	570
Pine, sugar (*Pinus lambertiana*)	Calif.	137	.36	25	8,000	1,200	1.53	10,700	4,140	590	1,050	350
Pine, Table-Mountain (*Pinus pungens*)	Tenn.	75	.52	36	11,600	1,550	2.30	14,200	4,260	1,210	1,200	360
Pine, western white (*Pinus monticola*)	Mont., Idaho	54	.38	27	9,500	1,510	1.47	11,900	4,480	540	850	—
Pinyon (*Pinus edulis*)	Ariz.	60	.51	36	9,400	1,100	1.64	12,100	3,400	990	1,510	580
Port-Orford-cedar (*Chamaedyparis lawsoniana*)	Oreg.	43	.42	29	11,300	1,730	1.97	13,500	5,890	760	1,080	400
Redcedar, eastern (*Juniperus virginiana*)	Vt.	35	.47	33	8,800	880	1.01	8,500	—	1,140	—	—
Redcedar, southern (*Juniperus silicicola*)	Fla.	26	.44	31	9,400	1,170	1.88	10,200	5,190	1,000	750	—

(continued)

TABLE 238.—MECHANICAL PROPERTIES OF SOFT WOODS GROWN IN UNITED STATES (concluded)

Common and botanical name	Place of growth of material tested	Moisture content, green, %	Specific gravity, oven dry, based on volume at test	Weight per cubic foot, pounds	Static bending			Impact bending	Compression		Shear parallel to grain; maximum shearing strength, lb/in.²	Tension perpendicular to grain; maximum tensile strength lb/in.²
					Modulus of rupture, lb/in.²	Modulus of elasticity, 1000×lb/in.²	P-limit, lb/in.²	P-limit, lb/in.²	Parallel to grain. P-limit, lb/in.²	Perpendicular to grain, P-limit lb/in.²		
Redcedar western (*Thuja plicata*)	Mont., Alaska, Wash.	37	.33	23	7,700	1,120	1.44	8,600	4,360	610	860	220
Redwood (second growth, openly grown) (*Sequoia sempervirens*)	Calif.	146	.30	21	6,400	760	1.35	6,800	2,660	550	860	240
Redwood (second growth, closely grown) (*Sequoia sempervirens*)	Calif.	112	.34	24	8,300	1,120	1.50	9,100	3,750	640	930	280
Redwood (virgin) (*Sequoia sempervirens*)	Calif.	112	.40	28	10,000	1,340	2.04	10,200	4,560	860	940	240
Spruce, black * (*Picea mariana*)	N. H.	38	.40	28	10,300	1,530	1.34	13,400	4,520	650	1,030	—
Spruce, Engelmann (*Picea engelmannii*)	Mont., Idaho, Colo.	80	.34	24	8,700	1,280	1.34	10,400	3,589	540	1,030	350
Spruce, red (*Picea rubens*)	Tenn., N. H.	43	.38	28	10,200	1,520	1.73	11,900	4,610	580	1,080	350
Spruce, Sitka (*Picea sitchensia*)	Wash., Alaska, Oreg.	42	.40	28	10,200	1,570	1.62	11,400	4,780	710	1,150	370
Spruce, white (*Picea glauca*)	N. H., Alaska, Wis.	50	.40	28	9,800	1,340	1.76	10,300	3,700	570	1,080	360
Tamarack (*Larix laricina*)	Wis.	52	.53	37	11,600	1,640	2.19	12,500	4,780	990	1,280	400
White-cedar, Atlantic (*Chanaecyparis thyoides*)	N. H., N. C.	35	.32	23	6,800	930	1.46	7,600	2,740	500	800	220
White-cedar, northern (*Thuja occidentalis*)	Wis.	55	.31	22	6,500	800	1.72	7,100	2,630	380	850	240
Yew, Pacific (*Taxus brevifolia*)	Wash.	44	.62	44	15,200	1,350	3.59	12,100	4,730	2,110	2,230	—

TABLE 239.—DENSITY IN g/cm³ AND IN lb/ft³ OF DIFFERENT KINDS OF WOOD

Wood is to be seasoned and of average dryness. See also Tables 237 and 238.

Wood	g/cm³	lb/ft³	Wood	g/cm³	lb/ft³
Alder	.42– .68	26–42	Lancewood	.68–1.00	42–62
Apple	.66– .84	41–52	Lignum vitae	1.17–1.33	73–83
Ash	.65– .85	40–53	Linden or lime-tree	.32– .59	20–37
Balsa	<Cork		Locust	.67– .71	42–44
Bamboo	.31– .40	19–25	Logwood	.91	57
Basswood (See Linden)			Mahogany, Honduras	.65	41
			Mahogany, Spanish	.85	53
Beech	.70– .90	43–56	Maple	.62– .75	39–47
Birch	.51– .77	32–48	Oak	.60– .90	37–56
Blue gum	1.00	62	Pear-tree	.61– .73	38–45
Box	.95–1.16	59–72	Pine, eastern white	.35– .50	22–31
Bullet-tree	1.05	65	Pine, larch	.50– .56	31–35
Butternut	.38	24	Pine, pitch	.83– .85	52–53
Cedar	.49– .57	30–35	Pine, red	.48– .70	30–44
Cherry	.70– .90	43–56	Pine, Scotch	.43– .53	27–33
Cork	.22– .26	14–16	Pine, spruce	.48– .70	30–44
Dogwood	.76	47	Pine, yellow	,37– .60	23–37
Ebony	1.11–1.33	69–83	Plum-tree	.66– .78	41–49
Elm	.54– .60	34–37	Poplar	.35– .5	22–31
Greenheart	.93–1.04	58–65	Satinwood	.95	59
Hazel	.60– .80	37–49	Sycamore	.40– .60	24–37
Hickory	.60– .93	37–58	Teak, African	.98	61
Holly	.76	47	Teak, Indian	.66– .88	41–55
Iron-bark	1.03	64	Walnut	.64– .70	40–43
Juniper	.56	35	Water gum	1.00	62
Laburnum	.92	57	Willow	.40– .60	24–37

TABLE 240.—DENSITY (g/cm³) OF SOME FOREIGN WOODS ON THE AMERICAN MARKET *

Almon	.464	Olive	.94
Balsa	.11	Orangewood	.70
Boxwood, West Indian	.83– .88	Padouk	.89–1.29
Bullet-wood, Guiana	1.03–1.23	Prima vera	.58
Carreto	.84	Purple-heart	.72– .97
Cedar, Spanish	.38	Quebracho	1.25
Cocobola	1.20	Rosewood, Brazil	.77– .84
Cocus	1.25	Rosewood, Honduras	1.09–1.23
Fustic	.68	Sabicu	.90– .96
Koa	.83	Snakewood	1.05–1.33
Lauaan, red	.41	Tamarind	1.32
Mahogany, African	.55	Tanguile	.47– .51
Mahogany, E. Indian	.38	Wallaba	.93– .94
Mora	1.07–1.09	Zebrawood	1.03
Oak, English	.60– .78		

* Table prepared by W. N. Watkins, U. S. National Museum.

TABLES 241-253.—TEMPERATURE, PRESSURE, VOLUME, AND WEIGHT RELATIONS OF GASES AND VAPORS

TABLE 241.—SIMPLE GAS LAWS

Any amount of gas completely fills the space in which it is confined. The pressure it exerts upon the confining walls depends upon the temperature. A quantity of gas can not be specified by volume only; all three factors—volume, temperature, and pressure—must be stated. The relations between these three factors are expressed by means of the following equation,

$$pv = KT \tag{1}$$

in which p, v, and T represent simultaneous values of the pressure, volume, and absolute temperature of any definite quantity of gas, while K is a constant, the numerical value of which depends upon the quantity of gas considered and the units in which pressure, volume, and temperature are measured.

While the behavior of gases at atmospheric pressure closely approximates the equation (1), the relation is not exact. The expansion of air is nearer one-272d of its volume at 273.16°K per degree. For most practical purposes such errors may be neglected.

If we take weights of gases proportional to their molecular weights, a new relation of the greatest importance develops: *The value of the constant in equation (1) is the same for each gas.* It is customary to use as the unit of quantity, the mol, the number of grams of gas equal to the molecular weight. When 1 mol is the quantity considered, the resulting value of K is designated R.

Values of R in PV = RT for one mol of ideal gas.—1 bar = 10^6 dyne/cm^2 = 0.987 atm. 1 kg/cm^2 = 0.968 atm. Gram molar volume of ideal gas at 0°C = 22,414.1 cm^3. Pound molar volume of ideal gas at 32°F = 359.05 ft^3. Ice point, 0°C = 273.16°K; 32°F = 491.7°R. 1 liter = 1000.027 cm^3.

	Pressure	Volume	Energy	R
Temperature in degrees Kelvin, °K (per gram mol)				
			calories	1.98719
°C + 273.16°			abs joules	8.3144
	atm	cm^3		82.057
	atm	1		.08206
	bar	1		.08315
	kg/m^2	1		847.87
	kg/cm^2	1		.084787
	mmHg	1		62.365
Temperature in degrees Rankin, °R (per pound mol)				
	Pressure	Volume	Energy	R
°F + 459.7°			Btu	1.98588
			hp-hr	.00078047
			kw-hr	.00058189
	atm	ft^3		.73008
	cmHg	ft^3		55.486
	inHg	ft^3		21.845
	lb/in.^{2} abs	ft^3		10.729
	lb/in.^{2} abs	in.^{3}		18540.2

With the mol the unit of quantity, N the number of mol of gas, equation (1) becomes

$$pv = NRT \tag{2}$$

By the use of equation (2), the above table, and a table of molecular weights, the solution of any problem involving volumes, temperatures, pressures, and weights of gases is very simple.

Mixtures of gases.—Any quantity of gas fills the space in which it is confined and exerts a pressure upon the confining walls. If an additional quantity is added, the pressure is increased in direct proportion to the quantity added. One can regard the pressure exerted by each portion of the total quantity of gas as independent of the presence of the rest. This is true if the second portion of gas is different chemically from the first (Dalton's law), provided the gases do not react chemically.

(*continued*)

Vapor pressure and the effect of vapor pressure upon the measurement of gas.—If a volatile liquid is introduced, a portion evaporates and exerts a pressure on the confining walls. The amount evaporated and the pressure exerted are independent of the presence of any other gas. If there is enough so that not all evaporates and if time is allowed for equilibrium, the pressure is independent of the volume of space and of the amount of liquid left unevaporated; but it does depend upon the temperature. For each volatile liquid there is therefore a definite saturation pressure or vapor pressure corresponding to every temperature. See Tables 360-369.

When any gas is in contact with a volatile substance, the measured pressure is the pressure exerted by the gas plus the vapor pressure of the volatile material. With no change of temperature, this vapor pressure remains constant no matter how we change the total pressure. Hence for the purposes of volume conversion the saturated gas may be considered as a dry gas, the pressure of which is the partial pressure of the gas, or its equivalent, the difference between the total pressure and the saturated vapor pressure of the volatile material.

TABLE 242.—VOLUME CONVERSIONS, FACTOR Z, FOR HIGH PRESSURES *

In the measurement of gases at high pressures the quantity PV is no longer constant at constant temperature but varies with the pressure by amounts that differ for each gas. Consequently the relation $\frac{P_1V_1}{RT_1} = \frac{P_2V_2}{RT_2}$ no longer holds. As a correction factor, $Z = \frac{PV}{RT}$ is given for different values of some one or more of the variables. The values of Z for different gases as given in the table are for different pressures and temperatures. The values extend to pressures of 100-200 atm and to temperatures of 200°C. Values of this factor of hydrogen for temperatures ranging from 16°K to 600°K and for pressures ranging from a small fraction of an atmosphere (.01) to 100 atm are given in Table 254, Part 2.[78] The value of this factor can be calculated for a wide range of pressures using the data given in some of the following tables.

This tables gives values of volume correcting factor Z (V = 1 at 1 atm pressure and 0°C).

Atm	Air 0°C	Air 50°C	Air 100°C	Air 200°C	Argon 0°C	Argon 50°C	Argon 100°C	Argon 200°C	Neon 0°C
10	.9952	.9997	1.0021	1.0061	.9921	.9973	1.0000	1.0023	1.0045
25	.9877	.9987	1.0044	1.0084	.9784	.9918	.9984	1.0044	1.0119
50	.9782	.9996	1.0100	1.0177	.9577	.9842	.9971	1.0084	1.0235
75	.9722	1.002	1.0191	1.0277	.9403	.9783	.9971	1.0138	1.0358
100	.9712	1.0077	1.0253	1.0382	.9262	.9746	.9990	1.0197	(1.0492)

Atm	Helium 0°C	Helium 50°C	Helium 100°C	Hydrogen 0°C	Hydrogen 50°C	Hydrogen 100°C	Hydrogen 200°C	Oxygen 0°C	Oxygen 20°C	Oxygen 50°C	Oxygen 100 C
10	1.0050	1.0042	1.0035	1.0062	1.0056	1.0051	1.0042	.9908	.9933	.9965	.9993
25	1.0129	1.0108	1.0092	1.0156	1.0141	1.0127	1.0105	.9771	.9835	.9908	.9980
50	1.0260	1.0218	1.0185	1.0316	1.0285	.1.0255	1.0209	.9562	.9685	.9831	.9968
75	1.0392	1.0329	1.0279	1.0480	1.0429	1.0384	1.0315	.9378	—	.9771	.9971
100	1.0524	1.0440	1.0372	1.0646	1.0575	1.0514	1.0419	.9231	—	.9733	.9983
200	—	—	—	1.1333	1.1168	1.1036	1.0839	—	—	—	—

Atm	Nitrogen 0°C	Nitrogen 50°C	Nitrogen 100°C	Methane 0°C	Methane 50°C	Methane 100°C	Methane 200°C
10	.9975	1.0015	1.0035	.978	.989	.993	.999
50	.9835	1.0035	1.0125	.883	.941	.971	.997
100	.9835	1.0145	1.0295	.781	.896	.951	.998
150	1.0015	1.0385	1.0546	(.730)	.873	.943	1.004
200	—	1.0686	1.0836	—	.873	.950	1.020

* Adapted from data furnished by J. Hilsenrath, National Bureau of Standards.
[78] Woolley, Scott, and Brickwedde, Nat. Bur. Standards Res. Pap. RP 1932, vol. 41, 1948.

TABLE 243.—RELATIVE GAS VOLUMES AT VARIOUS PRESSURES

(Deduced by Cochrane, from the *pv* curves of Amagat and other observers.)

Relative volumes when the pressure is reduced from the value given at the head of the column to 1 atmosphere; see also Nat. Bur. Standards Circ. 279.

Gas (Temp. = 16°C)	Relative volume the gas will occupy when the pressure is reduced to atmospheric from					
	1 atm	50 atm	100 atm	120 atm	150 atm	200 atm
"Perfect" gas	1	50	100	120	150	200
Helium	1	...	94.6	112.5	141	...
Hydrogen	1	48.5	93.6	111.3	136.3	176.4
Nitrogen	1	50.5	100.6	120.0	147.6	190.8
Air	1	50.9	101.8	121.9	150.3	194.8
Argon	..	...	106.3	127.6	161	...
Oxygen	1	...	105.2	...	...	212.6
Oxygen (at 0°C)	1	52.3	107.9	128.6	161.9	218.8
Carbon dioxide	1	69	477*	485*	498*	515*

* Carbon dioxide is liquid at pressures greater than 90 atmospheres.

TABLE 244.—VAN DER WAAL'S CONSTANTS FOR IMPERFECT GASES[79]

Van der Waal developed an equation to represent the pressure, temperature, and volume relation of a real gas. One form of this equation is

$$\left[P + a\left(\frac{n}{V}\right)^2\right](V - nb) = nRt$$

n = number of molecules
$(V - nb)$ = effective volume
a = internal pressure constant [(dynes/cm^2) × (cm^3/mol)]
b = reduction in effective volume (V) per molecule (cm^3/mol)

P (dynes/cm^2), V (cm^3/mol), R, and T have their usual meanings.
The value of these constants (a and b) for various gases are given in the table. If Van der Waal's equation were correct, $V_c/3 = b$ (V_c critical volume).

[79] Slater, J. C., Introduction to chemical physics, page 408, 1939, McGraw-Hill Book Co. Used by permission of the publishers.

(*continued*)

TABLE 244.—VAN DER WAAL'S CONSTANTS FOR IMPERFECT GASES (concluded)

Gas	Formula	a	b	$Vc/3$	Molecular volume of liquid	Electric moments
Neon	Ne	0.21×10^{12}	17.1	14.7	16.7	0×10^{-18}
Helium	He	.035	23.6	20.5	27.4	0
Hydrogen	H_2	0.25	26.5	21.6	26.4	0
Nitric oxide	NO	1.36	27.8	19.1	23.7	
Water	H_2O	5.53	30.4	18.9	18.0	1.85
Oxygen	O_2	1.40	32.2	24.8	25.7	0
Argon	A	1.36	32.2	26.1	28.1	0
Ammonia	NH_3	4.22	36.9	24.2	24.5	1.44
Nitrogen	N_2	1.36	38.3	30.0	32.8	0
Carbon monoxide	CO	1.50	39.7	30.0	32.7	0.10
Krypton	Kr	2.35	39.7	36.0	38.9	0
Hydrogen chloride	HCl	3.72	40.7	29.8	30.8	1.03
Nitrous oxide	N_2O	3.61	41.1	32.3	44.0	.25
Carbon dioxide	CO_2	3.64	42.5	32.8	41.7	0
Methane	CH_4	2.28	42.6	32.9	49.5	0
Hydrogen sulfide	H_2S	4.49	42.7		35.4	.93
Hydrogen bromide	HBr	4.51	44.1		37.5	.78
Xenon	Xe	4.15	50.8	38.0	47.5	0
Acetylene	C_2H_2	4.43	51.3	37.5	50.2	0
Phosphine	PH_3	4.69	51.4	37.7	49.2	.55
Chlorine	Cl_2	6.57	56.0	41.0	41.2	0
Sulfur dioxide	SO_2	6.80	56.1	41.0	43.8	1.61
Ethylene	C_2H_4	4.46	56.1	42.3	49.3	0
Silicon hydride	SiH_4	4.38	57.6		47	0
Methylamine	CH_3NH_2	7.23	59.6		44.5	1.31
Ethane	CH_3–CH_3	5.46	63.5	47.6	54.9	0
Methyl alcohol	CH_3OH	9.65	66.8	39.0	40.1	1.73
Methyl chloride	CH_3Cl	7.56	64.5	45.4	49.2	1.97
Methyl ether	$(CH_3)_2O$	8.17	72.2			1.29
Carbon bisulfide	CS_2	11.75	76.6	67.5	59.0	
Dimethylamine	$(CH_3)_2NH$	9.77	79.6		66.2	
Propylene	C_3H_6	8.49	82.4		69.0	0
Ethyl alcohol	C_2H_5OH	12.17	83.8	41.0	57.2	1.63
Propane	CH_3–CH_2–CH_3	8.77	84.1		75.3	0
Chloroform	$CHCl_3$	15.38	102	77.1	80.2	1.05
Acetic acid	CH_3COOH	17.81	106	57.0	56.1	
Trimethylamine	$(CH_3)_3N$	13.20	108		89.3	
iso-Butane	$CH(CH_3)_3$	13.10	114		96.3	
Benzene	C_6H_6	18.92	120	85.5	86.7	0
n-Butane	$CH_3(CH_2)_2CH_3$	14.66	122		96.5	0
Ethyl ether	$(C_2H_5)_2O$	17.60	134	94.0	100	1.2
Triethylamine	$(C_2H_5)_3N$	27.5	183		139	
Naphthalene	$C_{10}H_8$	40.3	193		112	.69
n-Octane	$CH_3(CH_2)_6CH_3$	37.8	236	162	162	0
Decane	$CH_3(CH_2)_8CH_3$	49.1	289		195	0

TABLE 245.—CORRECTING FACTORS: SATURATED GAS VOLUME TO VOLUME AT 760 mmHg AND 0°C *

Multiply observed volumes of saturated gas by factor to correct to volume of dry gas at 760 mmHg pressure (0°C)

Temperature (°C)	Pressure mmHg											
	715	720	725	730	735	740	745	750	755	760	765	770
5°	.916	.922	.928	.935	.942	.948	.954	.961	.967	.974	.980	.986
6	.912	.918	.924	.931	.937	.944	.950	.957	.963	.970	.976	.982
7	.908	.914	.920	.927	.933	.940	.946	.952	.959	.965	.972	.978
8	.904	.910	.916	.923	.929	.936	.942	.948	.955	.961	.967	.974
9	.900	.906	.912	.919	.925	.932	.938	.944	.951	.957	.963	.970
10	.896	.902	.908	.915	.921	.928	.934	.940	.946	.953	.959	.966
11	.892	.898	.904	.911	.917	.924	.920	.936	.942	.949	.955	.962
12	.888	.894	.900	.907	.913	.919	.925	.932	.939	.945	.951	.957
13	.884	.890	.896	.903	.909	.915	.921	.928	.934	.940	.947	.953
14	.880	.886	.892	.899	.905	.911	.917	.924	.930	.936	.942	.949
15	.876	.882	.888	.895	.901	.907	.913	.920	.925	.932	.938	.944
16	.872	.878	.884	.890	.896	.903	.909	.915	.921	.928	.934	.940
17	.868	.874	.880	.886	.892	.898	.905	.911	.917	.923	.929	.936
18	.864	.870	.875	.882	.888	.894	.900	.907	.913	.919	.925	.931
19	.859	.865	.871	.878	.884	.890	.896	.902	.908	.915	.920	.927
20	.855	.861	.867	.874	.879	.886	.892	.898	.904	.910	.916	.922
21	.851	.857	.863	.869	.875	.881	.887	.893	.899	.906	.912	.918
22	.847	.853	.858	.865	.871	.877	.883	.888	.894	.901	.907	.913
23	.842	.848	.854	.860	.866	.872	.878	.884	.890	.897	.903	.909
24	.838	.844	.849	.856	.862	.868	.874	.880	.886	.892	.898	.904
25	.833	.839	.845	.851	.857	.863	.869	.875	.881	.888	.893	.899
26	.829	.835	.841	.847	.853	.859	.865	.871	.877	.883	.889	.895
27	.824	.830	.836	.842	.848	.854	.860	.866	.872	.878	.884	.890
28	.820	.825	.831	.837	.843	.849	.855	.861	.867	.873	.879	.885
29	.815	.821	.826	.832	.838	.844	.850	.856	.862	.868	.874	.880
30	.810	.816	.822	.828	.833	.840	.845	.851	.857	.863	.869	.875
31	.805	.811	.817	.823	.829	.835	.840	.846	.852	.858	.864	.870
32	.800	.806	.812	.818	.823	.830	.835	.841	.847	.853	.859	.865
33	.795	.801	.807	.813	.818	.824	.830	.836	.842	.848	.853	.860
34	.790	.796	.801	.807	.813	.819	.825	.831	.837	.842	.848	.854
35	.785	.790	.796	.802	.808	.814	.819	.825	.831	.837	.843	.849
36	.780	.785	.791	.797	.802	.808	.814	.820	.826	.832	.836	.843
37	.774	.780	.785	.791	.797	.803	.809	.814	.820	.826	.832	.838
38	.769	.774	.780	.786	.791	.796	.803	.809	.814	.820	.826	.832
39	.763	.768	.774	.780	.785	.790	.797	.803	.809	.814	.820	.826
40	.756	.763	.768	.774	.780	.786	.792	.797	.803	.809	.814	.820
41	.751	.757	.762	.768	.774	.780	.786	.791	.797	.803	.808	.814
42	.745	.751	.756	.762	.768	.774	.779	.785	.791	.796	.802	.808
43	.739	.745	.750	.756	.762	.767	.773	.779	.784	.790	.796	.802
44	.733	.738	.744	.750	.755	.761	.766	.772	.778	.784	.789	.795
45	.726	.732	.737	.743	.749	.754	.760	.766	.771	.777	.783	.788
46	.720	.725	.731	.737	.742	.748	.754	.759	.765	.770	.776	.782
47	.713	.719	.724	.730	.735	.741	.746	.752	.758	.764	.769	.775
48	.706	.712	.717	.723	.728	.734	.739	.745	.751	.756	.762	.768
49	.700	.705	.710	.716	.721	.727	.732	.738	.744	.750	.755	.761

* Abridged from Nat. Bur. Standards Circ. 279, 1926.

Part 1.—Ordinary temperatures

As a measure of the compressibility, it is customary to use a coefficient, $1 + \lambda = p_0v_0/p_1v_1$, p_0v_0 being at 0°C.

H_2	$1 + \lambda =$ .99939 ± .00001		CO	$1 + \lambda =$ 1.00081
N_2	1.00044	.00001	CO_2	1.00668
O_2	1.000094	.000013	N_2O	1.00747
He	.99948	.000005		
Ne	.99951	.000025		
A	1.00099	.000026		

Part 2.—Low temperatures

pv = 1 for 0°C, 1 atmosphere

Helium				Hydrogen			
t°C	*p* atm	*pv*	Density	*t*°C	*p* atm	*pv*	Density
.00	26.66	1.0146	26.28	.00	32.313	1.0188	31.715
"	38.95	1.0196	38.20	"	44.119	1.0266	43.284
."	58.58	1.0294	56.91	—103.57	38.41	.6376	38.41
—103.63	24.13	.6337	38.07	.58	51.49	.6433	80.04
"	49.96	.6479	77.08	—204.70	16.75	.2404	69.68
—269.69	.232	.01126	20.63	"	37.00	.2316	159.7
"	.353	.01041	33.92	"	44.63	.2300	194.0
—270.52	.0308	.00911	3 381	—257.26	.06698	.05783	1.1582
"	.0649	.00858	7.535	"	.13153	.057104	2.3031

Neon				Argon			
t°C	*p* atm	*pv*	Density	*t*°C	*p* atm	*pv*	Density
.0	23.06	1.0089	21.87	.0	20.58	.9856	20.88
"	30.79	1.0147	30.34	"	31.57	.9774	32.30
"	84.66	1.0408	81.35	—102.51	14.86	.5813	25.57
—200.1	61.66	.2337	763.8	"	45.09	.4706	95.80
"	79.92	.2293	348.6	"	62.24	.3939	158.01
—217.5	49.93	.1393	358.5	—130.38	12 77	.4663	27.39
"	64.97	.1269	511.8	—159.62	11.99	.4262	28.12
"	79.42	.1256	632.2	—149.60	11.15	.3821	29.18

Oxygen				Nitrogen			
t°C	*p* atm	*pv*	Density	*t*°C	*p* atm	*pv*	Density
0	20.92	.9813	21.32	0	33.14	.9886	33.52
"	49.79	.9573	52.01	"	43.08	.9860	43.70
— 80.03	21.01	.6550	32.09	"	58.63	.9834	59.62
"	34.18	.6213	55.02	— 81.10	30.17	.6516	46.13
"	61.88	.5464	13.23	"	45.47	.6270	72.52
—116.01	22.30	.4835	46.12	"	56.71	.6109	92.84
"	43.95	.3541	124.1	—146.32	22.92	.3340	68.62
"	55.05	.1667	330.2	"	30.14	.2656	113.48
				"	36.49	.1058	344.5

TABLE 247.—RELATIVE VOLUMES FOR O, AIR, N, AND H AT VARIOUS PRESSURES AND TEMPERATURES

(Volume at 0°C and 1 atm being taken as 1,000,000)

	Oxygen			Air			Nitrogen			Hydrogen		
Atm	0°	99°.5	199°.5	0°	99°.4	200°.4	0°	99°.5	199°.6	0°	99°.3	200°.5
100	9265	—	—	9730	—	—	9910	—	—	—	—	—
200	4570	7000	9095	5050	7360	9430	5195	7445	9532	5690	7567	9420
300	3208	4843	6283	3658	5170	6622	3786	5301	6715	4030	5286	6520
400	2629	3830	4900	3036	4170	5240	3142	4265	5331	3207	4147	5075
500	2312	3244	4100	2680	3565	4422	2780	3655	4515	2713	3462	4210
600	2115	2867	3570	2450	3180	3883	2543	3258	3973	2387	3006	3627
700	1979	2610	3202	2288	2904	3502	2374	2980	3589	2149	2680	3212
800	1879	2417	2929	2168	2699	3219	2240	2775	3300	1972	2444	2900
900	1800	2268	2718	2070	2544	3000	2149	2616	3085	1832	2244	2657
1000	1735	2151	—	1992	2415	2828	2068	—	—	1720	2093	—

TABLE 248.—RELATIVE VALUES OF pv FOR ETHYLENE

	pv at 0°C and 1 atm = 1									
Atm	0°	10°	20°	30°	40°	60°	80°	100°	137°.5	198°.5
46	—	.562	.684	—	—	—	—	—	—	—
48	—	.508	—	—	—	—	—	—	—	—
50	.176	.420	.629	.731	.814	.954	1.077	1.192	1.374	1.652
52	—	.240	.598	—	—	—	—	—	—	—
54	—	.229	.561	—	—	—	—	—	—	—
56	—	.227	.524	—	—	—	—	—	—	—
100	.310	.331	.360	.403	.471	.668	.847	1.005	1.247	1.580
150	.441	.459	.485	.515	.551	.649	.776	.924	1.178	1.540
200	.565	.585	.610	.638	.669	.744	.838	.946	1.174	1.537
300	.806	.827	.852	.878	.908	.972	1.048	1.133	1.310	1.628
500	1.256	1.280	1.308	1.337	1.367	1.431	1.500	1.578	1.721	1.985
1000	2.289	2.321	2.354	2.387	2.422	2.493	2.566	2.643	2.798	—

TABLE 249.—RELATIVE VALUES OF pv FOR CARBON DIOXIDE

Pressure in meters of mercury	Relative values of pv at—								
	18.2°C	35.1	40.2	50.0	60.0	70.0	80.0	90.0	100.0°C
30	liquid	2360	2460	2590	2730	2870	2995	3120	3225
50	—	1725	1900	2145	2330	2525	2685	2845	2980
80	625	750	825	1200	1650	1975	2225	2440	2635
110	825	930	980	1090	1275	1550	1845	2105	2325
140	1020	1120	1175	1250	1360	1525	1715	1950	2160
170	1210	1310	1360	1430	1520	1645	1780	1975	2135
200	1405	1500	1550	1615	1705	1810	1930	2075	2215
230	1590	1690	1730	1800	1890	1990	2090	2210	2340
260	1770	1870	1920	1985	2070	2166	2265	2375	2490
290	1950	2060	2100	2170	2260	2340	2440	2550	2655
320	2135	2240	2280	2360	2440	2525	2620	2725	2830

	Relative values of pv: pv at 0°C and 1 atm = 1										
Atm	0°	10°	20°	30°	40°	60°	80°	100°	137°	198°	258°
50	.105	.114	.680	.775	.750	.984	1.096	1.206	1.380	—	—
100	.202	.213	.229	.255	.309	.661	.873	1.030	1.259	1.582	1.847
150	.295	.309	.326	.346	.377	.485	.681	.878	1.159	1.530	1.818
300	.559	.578	.599	.623	.649	.710	.790	.890	1.108	1.493	1.820
500	.891	.913	.938	.963	.990	1.054	1.124	1.201	1.362	1.678	—
1000	1.656	1.685	1.716	1.748	1.780	1.848	1.921	1.999	—	—	—

TABLE 250.—COMPRESSIBILITY OF SULFUR DIOXIDE

Original volume 100000 under one atmosphere of pressure and the temperature °C of the experiments as indicated at the top of the different columns.

Pressure in atm	Corresponding volume for experiments at temperature— 58°.0	99°.6	183°.2
10	8560	9440	—
12	6360	7800	—
14	4040	6420	—
16	—	5310	—
18	—	4405	—
20	—	4030	—
24	—	3345	—
28	—	2780	3180
32	—	2305	2640
36	—	1935	2260
40	—	1450	2040
50	—	—	1640
60	—	—	1375
70	—	—	1130
80	—	—	930
90	—	—	790
100	—	—	680
120	—	—	545
140	—	—	430
160	—	—	325

Volume	Pressure in atmospheres for experiments at temperature— 58°.0	99°.6	183°.2
10000	—	9.60	—
9000	9.60	10.35	—
8000	10.40	11.85	—
7000	11.55	13.05	—
6000	12.30	14.70	—
5000	13.15	16.70	—
4000	14.00	20.15	—
3500	14.40	23.00	—
3000	—	26.40	29.10
2500	—	30.15	33.25
2000	—	35.20	40.95
1500	—	39.60	55.20
1000	—	—	76.00
500	—	—	117.20

TABLE 251.—COMPRESSIBILITY OF AMMONIA

Original volume 100000 under one atmosphere of pressure and the temperature °C of the experiments as indicated at the top of the different columns.

Pressure in atm	Corresponding volume for experiments at temperature— 46°.6	99°.6	183°.6
10	9500	—	—
12.5	7245	7635	—
15	5880	6305	—
20	—	4645	4875
25	—	3560	3835
30	—	2875	3185
35	—	2440	2680
40	—	2080	2345
45	—	1795	2035
50	—	1490	1775
55	—	1250	1590
60	—	975	1450
70	—	—	1245
80	—	—	1125
90	—	—	1035
100	—	—	950

Volume	Pressure in atmospheres for experiments at temperature— 30°.2	46°.6	99°.6	183°.0
10000	8.85	9.50		—
9000	9.60	10.45		—
8000	10.40	11.50	12.00	—
7000	11.05	13.00	13.60	—
6000	11.80	14.75	15.55	—
5000	12.00	16.60	18.60	19.50
4000	—	18.35	22.70	24.00
3500	—	18.30	25.40	27.20
3000	—	—	29.20	31.50
2500	—	—	34.25	37.35
2000	—	—	41.45	45.50
1500	—	—	49.70	58.00
1000	—	—	59.65	93.60

Actual volumes rest upon Amagat's doubtful values at 3000kg/cm². Densities at highest pressures indicate that the molecules or atoms are very nearly in contact in the sense of the kinetic theory.

	Hydrogen							Nitrogen				
	Vol. change cm³ g from 3000 kg/cm²		Volume cm³/g		pv at 65°C	Vol. cm³/mol		Vol. change at 68°C		Volume at 68°C		pv at 68°C
kg/cm²	30°C	65°C	30°C	65°C		30°C	65°C	cm³/g	cm³/mol	cm³/g	cm³/mol	
3000	.00	.00	11.64	12.17	3.18	23.47	24.53	.000	.00	1.290	36.13	4.68
4000	1.12	1.14	10.52	11.03	3.83	21.21	22.24	.089	2.49	1.201	33.64	5.82
5000	1.84	1.88	9.80	10.29	4.50	19.76	20.74	.152	4.25	1.138	31.88	6.89
7000	2.77	2.88	8.87	9.29	5.65	17.88	18.73	.234	6.56	1.056	29.57	8.95
10000	3.63	3.68	8.01	8.49	7.29	16.15	17.12	.308	8.61	.982	27.52	11.91
13000	4.32	4.21	7.32	7.96	8.66	14.76	16.05	.357	10.00	.933	26.13	14.70
15000	...	...	...	...	...	...	...	.382	10.70	.908	25.43	16.50

	Helium					Argon	
	Vol. change cm³/g 65°C	Total vol. change 30-95° cm³/g	Volume at 65°C		pv at 65°C	Vol. change at 55°C	
kg/cm²			cm³/g	cm³/mol		cm³/g	cm³/g atom
3000	.00	.613	5.54	22.16	2.31	.000	.00
4000	.77	.598	4.77	19.08	2.64	.049	1.96
5000	1.23	.589	4.31	17.24	2.99	.085	3.39
7000	1.77	.581	3.77	15.08	3.66	.134	5.34
10000	2.22	.576	3.32	13.27	4.60	.180	7.18
13000	2.48	.572	3.06	12.24	5.52	.209	8.34
15000	2.60	.570	2.94	11.76	6.11	.224	8.94

	Ammonia	
	Vol. change at 30°C	
kg/cm²	cm³/g	cm³/mol
1000	—.827	—14.1
2000	—.217	— 3.70
3000	.000	.00
5000	+.200	+ 3.41
7000	.310	5.28
10000	.409	6.97
12000	.461	7.85

[80] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 59, p. 173, 1924.

TABLE 253.—GAGE PRESSURE (lb/in.²) TO ATMOSPHERES (ABSOLUTE)*

lb/in.²	0	10	20	30	40	50	60	70	80	90
0	1.00	1.68	2.36	3.04	3.72	4.40	5.08	5.76	6.44	7.12
100	7.80	8.48	9.17	9.85	10.53	11.21	11.89	12.57	13.25	13.93
200	14.61	15.29	15.97	16.65	17.33	18.01	18.69	19.37	20.05	20.73
300	21.41	22.09	22.77	23.45	24.14	24.82	25.50	26.18	26.86	27.54
400	28.22	28.90	29.58	30.26	30.94	31.62	32.30	32.98	33.66	34.34
500	35.02	35.70	36.38	37.06	37.74	38.42	39.11	39.79	40.47	41.15
600	41.83	42.51	43.19	43.87	44.55	45.23	45.91	46.59	47.27	47.95
700	48.63	49.31	49.99	50.67	51.35	52.03	52.71	53.39	54.08	54.76
800	55.44	56.12	56.80	57.48	58.16	58.84	59.52	60.20	60.88	61.56
900	62.24	62.92	63.60	64.28	64.96	65.64	66.32	67.00	67.68	68.36
1,000	69.04	69.73	70.41	71.09	71.77	72.45	73.13	73.81	74.49	75.17
1,100	75.85	76.53	77.21	77.89	78.57	79.25	79.93	80.61	81.29	81.97
1,200	82.65	83.34	84.01	84.70	85.38	86.06	86.74	87.42	88.10	88.78
1,300	89.46	90.14	90.82	91.50	92.18	92.86	93.54	94.22	94.90	95.58
1,400	96.27	96.95	97.63	98.31	98.98	99.67	100.3	101.0	101.7	102.4
1,500	103.1	103.8	104.4	105.1	105.8	106.5	107.1	107.8	108.5	109.2
1,600	109.9	110.6	111.3	111.9	112.6	113.3	114.0	114.6	115.3	116.0
1,700	116.7	117.4	118.0	118.7	119.4	120.1	120.8	121.4	122.1	122.8
1,800	123.5	124.2	124.8	125.5	126.2	126.9	127.6	128.2	128.9	129.6
1,900	130.3	131.0	131.6	132.3	133.0	133.7	134.4	135.0	135.7	136.4
2,000	137.1	137.8	138.4	139.1	139.8	140.5	141.2	141.9	142.5	143.2
2,100	143.9	144.6	145.2	145.9	146.6	147.3	148.0	148.7	149.3	150.0
2,200	150.7	151.4	152.1	152.7	153.4	154.1	154.8	155.5	156.1	156.8
2,300	157.5	158.2	158.9	159.5	160.2	160.9	161.6	162.3	162.9	163.6
2,400	164.3	165.0	165.7	166.3	167.0	167.7	168.4	169.1	169.8	170.4
2,500	171.1	171.8	172.5	173.2	173.8	174.5	175.2	175.9	176.6	177.2
2,600	177.9	178.6	179.3	180.0	180.6	181.3	182.0	182.7	183.4	184.0
2,700	184.7	185.4	186.1	186.8	187.4	188.1	188.8	189.5	190.2	190.8
2,800	191.5	192.2	192.9	193.6	194.2	194.9	195.6	196.3	197.0	197.7
2,900	198.3	199.0	199.7	200.4	201.1	201.7	202.4	203.1	203.8	204.4

* Taken from Nat. Bur. Standards Circ. 279, 1926.

TABLES 254-260.—THERMAL PROPERTIES OF GASES [81]

The properties given in Tables 254 and 256-258 are taken from a series of tables of thermal properties of gases being compiled at the National Bureau of Standards at the suggestion of and with the cooperation of the National Advisory Committee for Aeronautics. The functions in these tables have been expressed in dimensionless form in order that they may be converted readily to any system of units. Conversion factors are listed for the most often used units. For more extensive data on various gases reference should be made to these tables.[82]

[81] Adapted from NBS-NACA Tables on thermal properties of gases, July 1949.
[82] Joseph Hilsenrath, Heat and Power Division, National Bureau of Standards.

TABLE 254.—PROPERTIES OF MOLECULAR HYDROGEN

Part 1.—Density, ρ/ρ_0

T °K/P	.01 atm	.1 atm	1 atm	10 atm	100 atm	T °R
20	.13679	1.3792				36
50	.054671	.54710	5.5112	59.510		90
100	.027333	.27333	2.7338	27.379	258.83	180
150	.018222	.18220	1.8211	18.117	168.78	270
200	.013666	.13665	1.3657	13.574	127.01	360
250	.010933	.10932	1.0927	10.863	102.35	450
300	.0091110	.091100	.91055	9.0575	85.896	540
350	.0078094	.078086	.78055	7.7682	74.086	630
400	.0068332	.068332	.68298	6.8006	65.165	720
450	.0060740	.060740	.60715	6.0474	58.185	810
500	.0054666	.054666	.54644	5.4448	52.563	900
550	.0049696	.049696	.49676	4.9518	47.941	990
600	.0045555	.045555	.45541	4.5400	44.070	1080

To convert tabulated value of	to	having the dimensions indicated below	multiply by
ρ/ρ_0	ρ	g cm^{-3}	8.98854×10^{-5}
		g liter^{-1}	.89888
		lb in.$^{-3}$	3.24734×10^{-6}
		lb ft^{-3}	5.61140×10^{-3}

Part 2.—Compressibility factor, $Z = PV/RT$

T °K/P	.01 atm	.1 atm	1 atm	10 atm	100 atm	T °R
20	.9991	.9909				36
50	.9999	.9992	.9919	.9186		90
100	1.0000	1.0000	.9998	.9983	1.0560	180
150	1.0000	1.0001	1.0006	1.0058	1.0796	270
200	1.0000	1.0001	1.0007	1.0068	1.0760	360
250	1.0000	1.0001	1.0006	1.0065	1.0682	450
300	1.0000	1.0001	1.0006	1.0059	1.0607	540
350	1.0000	1.0001	1.0005	1.0053	1.0541	630
400	1.0000	1.0000	1.0005	1.0048	1.0486	720
450	1.0000	1.0000	1.0004	1.0044	1.0439	810
500	1.0000	1.0000	1.0004	1.0040	1.0400	900
550	1.0000	1.0000	1.0004	1.0036	1.0366	990
600	1.0000	1.0000	1.0003	1.0034	1.0377	1080

(*continued*)

TABLE 254.—PROPERTIES OF MOLECULAR HYDROGEN (concluded)

Part 3.—Values of R for hydrogen for temperatures in °K

Pressure / Density	atm	kg/cm²	mmHg	lb/in.²
g/cm³	40.7027	42.0551	30934.0	598.167
mole/cm³	82.0567	84.7832	62363.1	1205.91
mole/liter	.0820544	.0847809	62.3613	1.20587
lb/ft³	.651994	.673658	495.515	9.58171
lb mole/ft³	1.31442	1.35809	998.959	19.3167

TABLE 255.—DENSITY OF GASES AND VAPORS **

The following table gives the density as the weight in grams of a liter (normal liter) of the gas at 0°C, 76 cmHg pressure, also the weight in lb/ft³, and standard gravity 930.665 cm/sec² (sea level, 45° latitude), the specific gravity referred to dry, carbon-dioxide-free air, and to pure oxygen. Dry, carbon-dioxide-free air is of remarkably uniform density; Guye, Kovacs, and Wourtzel found maximum variations in the density of only 7 to 8 parts in 10,000. For highest accuracy pure oxygen should be used as the standard gas for specific gravities. Observed densities are closely proportional to the molecular weights.

Gas	Formula	Molecular weight	Weight of normal liter in grams	Weight of normal ft³ in pounds	Specific gravity Air = 1	Specific gravity O_2 = 1
Acetylene	C_2H_2	26.036	1.173	.07323	.912	.825
Air	—	—	1.2920	.0806	1.000	.9047
Ammonia	NH_3	17.032	.7598	.04742	.5963	.5395
Argon	A	39.944	1.782	.1112	1.3787	1.2482
Arsene	AsH_3	77.93	3.48	.217	2.69	2.434
Butane-iso	C_4H_{10}	58.12	2.673	.1669	2.067	1.870
Butane-n	C_4H_{10}	58.12	2.519*	.15725*	2.085*	1.8868*
Carbon dioxide	CO_2	44.01	1.9630	.1225	1.5290	1.3834
Carbon monoxide	CO	28.010	1.2492	.0779	.9671	.8750
Carbon oxysulfide	COS	60.076	2.72	.170	2.10	1.90
Chlorine	Cl_2	70.914	3.1638	.1974	2.486	2.249
Chlorine monoxide	Cl_2O	86.914	3.89	.243	3.01	2.721
Ethane	C_2H_6	30.068	1.3566	.08469	1.0493	.9493
Ethylene	C_2H_4	28.052	1.2604	.07860	.9749	.8820
Fluorine	F_2	38.00	1.6954	.1058	1.311	1.187
Helium	He	4.003	.1785	.01114	.1381	.1249
Hydrogen	H_2	2.016	.08988	.005611	.06952	.06290
Hydrogen bromide	HBr	80.924	3.6104	.2252	2.8189	2.5503
Hydrogen chloride	HCl	36.465	1.6269	.1016	1.2678	1.1471
Hydrogen iodide	HI	127.93	5.7075	.3562	4.480	4.052
Hydrogen selenide	H_2Se	80.976	3.670	.229	2.839	2.568
Hydrogen sulfide	H_2S	34.082	1.5203	.0949	1.190	1.077
Krypton	Kr	83.7	3.7365	.2332	2.868	2.595
Methane	CH_4	16.042	.7152	.04462	.5544	.5016
Methyl chloride	CH_3Cl	50.491	2.3076	.1440	1.7825	1.6125
Methyl ether	$(CH_33)_2O$	46.068	2.1098	.13171	1.6318	1.4764
Methyl fluoride	CH_3F	34.034	1.5452	.09646	1.1951	1.0813
Mono methylamine	CH_3NH_2	31.058	1.396	.08715	1.080	.9769
Neon	Ne	20.183	.9005	.05621	.6963	.63004
Nitric oxide	NO	30.008	1.3388	.0836	1.0366	.9378
Nitrogen (chem.)	N_2	28.016	1.2499	.07803	.9672	.8751
Nitrogen (atm)	—	—	1.2568	.07846	.9722	.8795
Nitrosyl chloride	NOCl	65.465	2.992	.1868	2.314	2.094
Nitrous oxide	N_2O	44.016	1.9638	.123255	1.5297	1.3840
Oxygen	O_2	32.000	1.4277	.08915	1.10527	1.0000
Phosphine	PH_3	34.004	1.5294	.09548	1.1829	1.0702
Propane	C_3H_8	44.094	2.020	.1261	1.562	1.414
Silicon tetrafluoride	SiF_4	104.06	4.684	.2924	3.623	3.278
Sulfur dioxide	SO_2	64.066	2.858	.1784	2.2638	2.0482
Xenon	Xe	131.3	5.8579	.3657	4.525	4.094

** For reference, see footnote 45, p. 136.
* At 710 mmHg.

TABLE 256.—THERMAL PROPERTIES OF DRY AIR (IDEAL GAS STATE)

°K	Specific heat $\frac{C_p°}{R}$	Enthalpy $\frac{(H°-E_0°)}{RT_0}$	Entropy $\frac{S°}{R}$	°K	Specific heat $\frac{C_p°}{R}$	Enthalpy $\frac{(H°-E_0°)}{RT_0}$	Entropy $\frac{S°}{R}$
				400	3.5305	5.1182	24.9301
10	3.5009	.1238	12.0382	410	3.5349	5.2476	25.0173
20	3.4941	.2518	14.4622	420	3.5397	5.3771	25.1026
30	3.4926	.3796	15.8748	430	3.5447	5.5067	25.1859
40	3.4918	.5075	16.8832	440	3.5499	5.6366	25.2675
50	3.4915	.6353	17.6633	450	3.5555	5.7667	25.3473
60	3.4914	.7631	18.2990	460	3.5613	5.8969	25.4255
70	3.4914	.8909	18.8367	470	3.5673	6.0274	25.5022
80	3.4913	1.0188	19.3034	480	3.5735	6.1581	25.5773
90	3.4913	1.1466	19.7145	490	3.5799	6.2891	25.6511
100	3.4913	1.2744	20.0824	500	3.5865	6.4202	25.7235
110	3.4914	1.4022	20.4152	510	3.5933	6.5517	25.7946
120	3.4914	1.5300	20.7190	520	3.6003	6.6833	25.8644
130	3.4914	1.6578	20.9984	530	3.6075	6.8153	25.9330
140	3.4914	1.7856	21.2572	540	3.6149	6.9475	26.0005
150	3.4915	1.9134	21.4980	550	3.6224	7.0799	26.0669
160	3.4916	2.0413	21.7234	560	3.6300	7.2127	26.1323
170	3.4916	2.1691	21.9351	570	3.6377	7.3456	26.1966
180	3.4917	2.2969	22.1346	580	3.6456	7.4790	26.2599
190	3.4919	2.4247	22.3234	590	3.6535	7.6126	26.3223
200	3.4922	2.5526	22.5026	600	3.6615	7.7465	26.3838
210	3.4924	2.6804	22.6729	610	3.6696	7.8807	26.4444
220	3.4927	2.8083	22.8354	620	3.6778	8.0152	26.5041
230	3.4932	2.9362	22.9907	630	3.6860	8.1500	26.5630
240	3.4937	3.0641	23.1394	640	3.6943	8.2851	26.6211
250	3.4945	3.1920	23.2820	650	3.7027	8.4205	26.6785
260	3.4953	3.3199	23.4191	660	3.7111	8.5562	26.7351
270	3.4963	3.4479	23.5510	670	3.7195	8.6922	26.7910
280	3.4975	3.5759	23.6782	680	3.7279	8.8285	26.8461
290	3.4989	3.7040	23.8009	690	3.7363	8.9651	26.9006
300	3.5005	3.8321	23.9196	700	3.7447	9.1021	26.9544
310	3.5024	3.9603	24.0344	710	3.7531	9.2393	27.0076
320	3.5044	4.0885	24.1456	720	3.7614	9.3768	27.0601
330	3.5068	4.2169	24.2535	730	3.7698	9.5147	27.1121
340	3.5093	4.3453	24.3582	740	3.7782	9.6528	27.1634
350	3.5122	4.4738	24.4600	750	3.7865	9.7913	27.2142
360	3.5153	4.6024	24.5590	760	3.7947	9.9301	27.2644
370	3.5186	4.7312	24.6553	770	3.8030	10.0692	27.3141
380	3.5224	4.8601	24.7492	780	3.8112	10.2085	27.3632
390	3.5263	4.9891	24.8408	790	3.8194	10.3482	27.4118
400	3.5305	5.1182	24.9301	800	3.8275	10.4882	27.4599

Conversion factors

To convert tabulated value of	to	having the dimensions indicated below	multiply by
$C_p°/R$, $S°/R$	$C_p°$.$S°$	cal mol^{-1} °K^{-1}(or °C^{-1})	1.98719
		cal g^{-1} °K^{-1} (or °C^{-1})	.0686042
		joules g^{-1} °K^{-1} (or °C^{-1})	.287040
		Btu (lb mol)$^{-1}$ °R^{-1} (or °F^{-1})	1.98588
		Btu lb^{-1} °R^{-1} (or °F^{-1})	.0685590

(continued)

TABLE 256.—THERMAL PROPERTIES OF DRY AIR (IDEAL GAS STATE) (concluded)

°K	Specific heat $\frac{C_p^\circ}{R}$	Enthalpy $\frac{(H^\circ - E_0^\circ)}{RT_0}$	Entropy $\frac{S^\circ}{R}$	°K	Specific heat $\frac{C_p^\circ}{R}$	Enthalpy $\frac{(H^\circ - E_0^\circ)}{RT_0}$	Entropy $\frac{S^\circ}{R}$
800	3.8275	10.4882	27.4599	1900	4.3337	27.1375	31.0047
850	3.8670	11.1924	27.6931	1950	4.3452	27.9318	31.1175
900	3.9049	11.9037	27.9152	2000	4.3561	28.7281	31.2276
950	3.9409	12.6218	28.1273	2050	4.3666	29.5264	31.3353
1000	3.9750	13.3463	28.3303	2100	4.3767	30.3267	31.4407
1050	4.0070	14.0769	28.5250	2150	4.3864	31.1287	31.5438
1100	4.0371	14.8131	28.7121	2200	4.3958	31.9324	31.6447
1150	4.0653	15.5547	28.8922	2250	4.4048	32.7379	31.7436
1200	4.0917	16.3013	29.0658	2300	4.4135	33.5449	31.8405
1250	4.1166	17.0525	29.2333	2350	4.4219	34.3536	31.9355
1300	4.1398	17.8082	29.3953	2400	4.4301	35.1637	32.0287
1350	4.1615	18.5679	29.5519	2450	4.4380	35.9754	32.1201
1400	4.1820	19.3315	29.7036	2500	4.4456	36.7884	32.2099
1450	4.2012	20.0988	29.8507	2550	4.4530	37.6028	32.2980
1500	4.2193	20.8695	29.9935	2600	4.4602	38.4186	32.2845
1550	4.2364	21.6434	30.1321	2650	4.4672	39.2357	32.4695
1600	4.2525	22.4203	30.2669	2700	4.4740	40.0540	32.5531
1650	4.2678	23.2001	30.3979	2750	4.4807	40.8735	32.6353
1700	4.2823	23.9826	30.5255	2800	4.4871	41.6943	32.7160
1750	4.2962	24.7678	30.6499	2850	4.4933	42.5162	32.7955
1800	4.3093	25.5553	30.7711	2900	4.4994	43.3392	32.8737
1850	4.3218	26.3453	30.8893	2950	4.5053	44.1633	32.9507
1900	4.3337	27.1375	31.0047	3000	4.5109	44.9884	33.0264

Conversion factors

To convert tabulated value of	to	having the dimensions indicated below	multiply by
$(H^\circ - E_0^\circ)/RT_0$	$(H^\circ - E_0^\circ)$	cal mol^{-1}	542.821
		cal g^{-1}	18.7399
		joules g^{-1}	78.4079
		Btu $(lb\ mol)^{-1}$	976.437
		Btu lb^{-1}	33.7098

°K	Specific heat $C_p°/R$	Enthalpy $(H°-E_0°)/RT_0$	Entropy $S°/R$	°K	Specific heat $C_p°/R$	Enthalpy $(H°-E_0°)/RT_0$	Entropy $S°/R$
				400	3.5179	5.1257	24.0598
10	3.5019	.1246	11.1440	410	3.5206	5.2546	24.1467
20	3.5006	.2527	13.5707	420	3.5237	5.3835	24.2316
30	3.5004	.3809	14.9903	430	3.5270	5.5126	24.3154
40	3.5003	.5090	15.9970	440	3.5306	5.6417	24.3956
50	3.5003	.6372	16.7781	450	3.5344	5.7711	24.4750
60	3.5003	.7653	17.4163	460	3.5386	5.9005	24.5527
70	3.5003	.8934	17.9559	470	3 5430	6.0301	24.6289
80	3.5004	1.0216	18.4233	480	3.5476	6.1599	24.7035
90	3.5004	1.1497	18.8355	490	3.5526	6.2899	24.7767
100	3.5004	1.2779	19.2043	500	3.5578	6.4200	24.8486
110	3.5005	1.4060	19.5380	510	3.5632	6.5504	24.9191
120	3.5005	1.5342	19.8426	520	3.5688	6.6809	24.9883
130	3.5005	1.6623	20.1227	530	3.5747	6.8117	25.0563
140	3.5006	1.7905	20.3822	540	3.5808	6.9427	25.1232
150	3.5006	1.9186	20.6237	550	3.5871	7.0739	25.1890
160	3.5007	2.0468	20.8496	560	3.5936	7.2053	25.2537
170	3.5007	2.1749	21.0619	570	3.6003	7.3370	25.3173
180	3.5007	2.3031	21.2619	580	3.6072	7.4689	25.3800
190	3.5008	2.4312	21.4512	590	3.6142	7.6011	25.4417
200	3.5008	2.5594	21.6308	600	3.6214	7.7335	25.5025
210	3.5009	2.6876	21.8016	610	3.6287	7.8662	25.5625
220	3.5010	2.8157	21.9645	620	3.6362	7.9992	25.6215
230	3.5010	2.9439	22.1201	630	3.6437	8.1325	25.6798
240	3.5012	3.0721	22.2691	640	3.6514	8.2660	25.7372
250	3.5013	3.2002	22.4120	650	3.6591	8.3998	25.7939
260	3.5015	3.3284	22.5493	660	3.6670	8.5339	25.8498
270	3.5017	3.4566	22.6815	670	3.6749	8.6683	25.9050
280	3.5021	3.5848	22.8088	680	3.6829	8.8030	25.9595
290	3.5025	3.7130	22.9317	690	3.6909	8.9379	26.0133
300	3.5030	3.8412	23.0505	700	3.6990	9.0732	26.0665
310	3.5036	3.9695	23.1654	710	3.7071	9.2088	26.1190
320	3.5044	4.0978	23.2766	720	3.7152	9.3446	26.1709
330	3.5054	4,2261	23.3845	730	3.7234	9.4808	26.2222
340	3.5065	4.3544	23.4891	740	3.7316	9.6172	26.2729
350	3.5078	4.4828	23.5908	750	3.7398	9.7540	26.3231
360	3.5094	4.6113	23.6896	760	3.7480	9.8910	26.3727
370	3.5111	4.7398	23.7858	770	3.7562	10.0284	26.4217
380	3.5131	4.8683	23.8795	780	3.7643	10.1660	26.4702
390	3.5154	4.9970	23.9707	790	3.7725	10.3040	26.5183
400	3.5179	5.1257	24.0598	800	3.7806	10.4423	26.5658

Conversion factors

To convert tabulated value of	to dimensions indicated below	multiply by
$C_p°/R$, $S°/R$	cal mol^{-1} °K^{-1} (or °C^{-1})	1.98719
	cal g^{-1} °K^{-1} (or °C^{-1})	.0709305
	joules g^{-1} °K^{-1} (or °C^{-1})	.296774
	Btu (lb mol)$^{-1}$ °R^{-1} (or °F^{-1})	1.98588
	Btu lb^{-1} °R^{-1} (or °F^{-1})	.0708837

(continued)

°K	Specific heat $C_p°/R$	Enthalpy $(H°-E_0°)/RT_0$	Entropy $S°/R$	°K	Specific heat $C_p°/R$	Enthalpy $(H°-E_0°)/RT_0$	Entropy $S°/R$
800	3.7806	10.4423	26.5658	2900	4.4460	43.0145	31.9327
850	3.8207	11.1380	26.7962	2950	4.4503	43.8287	32.0088
900	3.8596	11.8409	27.0156	3000	4.4545	44.6437	32.0836
950	3.8970	12.5508	27.2253	3050	4.4585	45.4595	32.1573
1000	3.9326	13.2674	27.4261	3100	4.4624	46,2759	32.2298
1050	3.9664	13.9904	27.6188	3150	4.4663	47.0931	32.3013
1100	3.9982	14.7193	27.8040	3200	4.4699	47.9109	32.3716
1150	4.0281	15.4539	27.9824	3250	4.4735	48.7295	32.4409
1200	4.0562	16.1939	28.1544	3300	4.4770	49.5486	32.5093
1250	4.0825	16.9388	28.3206	3350	4.4804	50.3684	32.5766
1300	4.1072	17.6883	28.4812	3400	4.4836	51.1888	32.6430
1350	4.1303	18.4422	28.6366	3450	4.4868	52.0098	32.7085
1400	4.1518	19.2002	28.7872	3500	4.4900	52.8314	32.7731
1450	4.1720	19.9621	28.9333	3550	4.4930	53.6535	32.8368
1500	4.1909	20.7275	29.0751	3600	4.4960	54.4762	32.8996
1550	4.2086	21.4963	29.2128	3650	4.4988	55.2994	32.9617
1600	4.2252	22.2682	29.3467	3700	4.5016	56.1232	33.0229
1650	4.2408	23.0430	29.4769	3750	4.5044	56.9474	33.0834
1700	4.2554	23.8206	29.6037	3800	4.5071	57.7722	33.1431
1750	4.2692	24.6008	29.7273	3850	4.5097	58.5974	33.2020
1800	4.2821	25.3834	29.8477	3900	4.5123	59.4231	33.2602
1850	4.2943	26.1684	29.9652	3950	4.5148	60.2493	33.3177
1900	4.3057	26.9554	30.0799	4000	4.5173	61.0759	33.3745
1950	4.3166	27.7446	30.1919	4050	4.5197	61.9030	33.4306
2000	4.3268	28.5356	30.3013	4100	4.5221	62.7306	33.4861
2050	4.3365	29.3285	30.4083	4150	4.5245	63.5585	33.5409
2100	4.3457	30.1232	30.5129	4200	4.5268	64.3868	33.5951
2150	4.3544	30.9194	30.6152	4250	4.5290	65.2156	33.6487
2200	4.3627	31.7172	30.7154	4300	4.5312	66.0448	33.7017
2250	4.3705	32.5165	30.8135	4350	4.5334	66.8745	33.7541
2300	4.3780	33.3172	30.9097	4400	4.5356	67.7045	33.8059
2350	4.3852	34.1192	31.0039	4450	4.5377	68.5349	33.8572
2400	4.3920	34.9225	31.0963	4500	4.5398	69.3657	33.9079
2450	4.3985	35.7270	31.1869	4550	4.5419	70.1968	33.9581
2500	4.4047	36.5327	31.2759	4600	4.5440	71.0284	34.0077
2550	4.4106	37.3395	31.3631	4650	4.5460	71.8603	34.0569
2600	4.4163	38.1473	31.4488	4700	4.5480	72.6927	34.1055
2650	4.4218	38.9562	31.5330	4750	4.5500	73.5253	34.1536
2700	4.4270	39.7661	31.6157	4800	4.5520	74.3583	34.2013
2750	4.4320	40.5769	31.6970	4850	4.5540	75.1917	34.2484
2800	4.4369	41.3886	31.7769	4900	4.5559	76.0255	34.2952
2850	4.4415	42.2011	31.8554	4950	4.5579	76.8497	34.3415
2900	4.4460	43.0145	31.9327	5000	4.5598	77.6941	34.3873

Conversion factors

To convert tabulated value of	to dimensions indicated below	multiply by
$(H°-E_0°)/RT_0$	cal mol^{-1}	542.821
	cal g^{-1}	19.3754
	joules g^{-1}	81.0699
	Btu $(lb\ mol)^{-1}$	976.437
	Btu lb^{-1}	34.8528

°K	Specific heat $\frac{C_p°}{R}$	Enthalpy $\frac{(H°-E_0°)}{RT_0}$	Entropy $\frac{S°}{R}$	°K	Specific heat $\frac{C_p°}{R}$	Enthalpy $\frac{(H°-E_0°)}{RT_0}$	Entropy $\frac{S°}{R}$
				400	3.6212	5.1542	25.7140
10	3.5424	.1222	12.7490	410	3.7322	5.2869	25.8036
20	3.5145	.2513	15.1937	420	3.6435	5.4201	25.8912
30	3.5077	.3798	16.5980	430	3.6550	5.5537	25.9771
40	3.5044	.5081	17.6256	440	3.6668	5.6877	26.0612
50	3.5029	.6364	18.4116	450	3.6787	5.8222	26.1438
60	3.5023	.7646	19.0461	460	3.6907	5.9571	26.2248
70	3.5019	.8928	19.5837	470	3.7029	6.0924	26.3043
80	3.5016	1.0210	20.0535	480	3.7151	6.2282	26.3823
90	3.5015	1.1492	20.4656	490	3.7274	6.3644	26.4591
100	3.5014	1.2774	20.8348	500	3.7396	6.5011	26.5345
110	3.5013	1.4056	21.1684	510	3.7520	6.6382	26.6087
120	3.5013	1.5337	21.4732	520	3.7643	6.7758	26.6817
130	3.5013	1.6619	21.7534	530	3.7765	6.9138	26.7535
140	3.5013	1.7901	22.0129	540	3.7887	7.0523	26.8242
150	3.5013	1.9183	22.2545	550	3.8008	7.1912	26.8938
160	3.5015	2.0464	22.4804	560	3.8129	7.3306	26.9624
170	3.5017	2.1746	22.6927	570	3.8248	7.4704	27.0300
180	3.5020	2.3028	22.8929	580	3.8366	7.6106	27.0966
190	3.5025	2.4310	23.0823	590	3.8483	7.7513	27.1623
200	3.5032	2.5593	23.2619	600	3.8599	7.8924	27.2271
210	3.5042	2.6875	23.4329	610	3.8713	8.0339	27.2910
220	3.5056	2.8158	23.5959	620	3.8826	8.1758	27.3540
230	3.5073	2.9442	23.7518	630	3.8937	8.3181	27.4162
240	3.5095	3.0726	23.9011	640	3.9047	8.4609	27.4776
250	3.5122	3.2012	24.0444	650	3.9155	8.6040	27.5383
260	3.5155	3.3289	24.1822	660	3.9262	8.7476	27.5981
270	3.5193	3.4586	24.3150	670	3.9367	8.8915	27.6572
280	3.5238	3.5875	24.4430	680	3.9470	9.0358	27.7156
290	3.5288	3.7166	24.5668	690	3.9571	9.1805	27.7733
300	3.5344	3.8459	24.6865	700	3.9672	9.3255	27.8303
310	3.5407	3.9754	24.8025	710	3.9770	9.4709	27.8867
320	3.5476	4.1051	24.9150	720	3.9866	9.6167	27.9424
330	3.5551	4.2351	25.0243	730	3.9961	9.7628	27.9974
340	3.5631	4.3654	25.1305	740	4.0054	9.9093	28.0519
350	3.5717	4.4960	25.2340	750	4.0145	10.0561	28.1057
360	3.5807	4.6269	25.3347	760	4.0235	10.2032	28.1589
370	3.5902	4.8782	25.4329	770	4.0323	10.3507	28.2116
380	3.6002	4.8898	25.5288	780	4.0409	10.4985	28.2637
390	3.6105	5.0218	25.6224	790	4.0494	10.6466	28.3152
400	3.6212	5.1542	25.7140	800	4.0577	10.7950	28.3662

Conversion factors

To convert tabulated value of	to dimensions indicated below	multiply by
$\frac{C_p°}{R}$, $\frac{S°}{R}$	cal mol^{-1} °K^{-1} (or °C^{-1})	1.98719
	cal g^{-1} °K^{-1} (or °C^{-1})	.0620996
	joules g^{-1} °K^{-1} (or °C^{-1})	.259825
	Btu (lb mol)$^{-1}$ °R^{-1} (or °F^{-1})	1.98588
	Btu lb^{-1} °R^{-1} (or °F^{-1})	.0620587

(continued)

TABLE 258.—THERMAL PROPERTIES OF MOLECULAR OXYGEN (IDEAL GAS STATE) (concluded)

°K	Specific heat $C_p°/R$	Enthalpy $(H°-E_0°)/RT_0$	Entropy $S°/R$	°K	Specific heat $C_p°/R$	Enthalpy $(H°-E_0°)/RT_0$	Entropy $S°/R$
800	4.0577	10.7950	28.3662	2900	4.7824	45.2601	34.0470
850	4.0970	11.5414	28.6134	2950	4.7944	46.1366	34.1289
900	4.1327	12.2946	28.8486	3000	4.8062	47.0152	34.2096
950	4.1652	13.0541	29.0729	3050	4.8177	47.8961	34.2891
1000	4.1948	13.8193	29.2874	3100	4.8291	48.7790	34.3675
1050	4.2219	14.5896	29.4927	3150	4.8402	49.6640	34.4449
1100	4.2469	15.3647	29.6897	3200	4.8512	50.5509	34.5212
1150	4.2698	16.1442	29.8790	3250	4.8619	51.4398	34.5965
1200	4.2912	16.9278	30.0611	3300	4.8724	52.3307	34.6708
1250	4.3112	17.7151	30.2367	3350	4.8827	53.2236	34.7442
1300	4.3300	18.5059	30.4062	3400	4.8929	54.1183	34.8166
1350	4.3479	19.3002	30.5700	3450	4.9028	55.0148	34.8881
1400	4.3651	20.0976	30.7284	3500	4.9125	55.9130	34.9587
1450	4.3815	20.8981	30.8819	3550	4.9220	56.8132	35.0285
1500	4.3975	21.7016	31.0307	3600	4.9312	57.7150	35.0974
1550	4.4130	22.5080	31.1751	3650	4.9403	58.6183	35.1654
1600	4.4282	23.3171	31.3155	3700	4.9491	59.5233	35.2327
1650	4.4431	24.1290	31.4519	3750	4.9578	60.4301	35.2992
1700	4.4578	24.9437	31.5848	3800	4.9662	61.3384	35.3649
1750	4.4724	25.7609	31.7142	3850	4.9744	62.2482	35.4299
1800	4.4868	26.5809	31.8404	3900	4.9825	63.1594	35.4941
1850	4.5011	27.4036	31.9636	3950	4.9903	64.0721	35.5576
1900	4.5153	28.2288	32.0838	4000	4.9979	64.9862	35.6204
1950	4.5295	29.0565	32.2013	4050	5.0054	65.9022	35.6826
2000	4.5436	29.8869	32.3161	4100	5.0126	66.8193	35.7441
2050	4.5576	30.7198	32.4285	4150	5.0197	67.7371	35.8049
2100	4.5715	31.5554	32.5385	4200	5.0265	68.6561	35.8650
2150	4.5854	32.3935	32.6462	4250	5.0332	69.5765	35.9245
2200	4.5993	33.2341	32.7518	4300	5.0397	70.4983	35.9835
2250	4.6130	34.0771	32.8553	4350	5.0460	71.4217	36.0418
2300	4.6267	34.9227	32.9568	4400	5.0521	72.3461	36.0995
2350	4.6404	35.7709	33.0565	4450	5.0580	73.2715	36.1566
2400	4.6540	36.6217	33.1543	4500	5.0638	74.1976	36.2132
2450	4.6674	37.4747	33.2504	4550	5.0693	75.1246	36.2691
2500	4.6808	38.3302	33.3449	4600	5.0746	76.0528	36.3246
2550	4.6940	39.1882	33.4377	4650	5.0797	76.9827	36.3794
2600	4.7071	40.0487	33.5289	4700	5.0847	77.9135	36.4338
2650	4.7200	40.9114	33.6187	4750	5.0896	78.8445	36.4876
2700	4.7328	41.7765	33.7071	4800	5.0943	79.7760	36.5410
2750	4.7454	42.6440	33.7940	4850	5.0987	80.7086	36.5938
2800	4.7579	43.5138	33.8796	4900	5.1028	81.6423	36.6461
2850	4.7703	44.3858	33.9640	4950	5.1068	82.5770	36.6980
2900	4.7824	45.2601	34.0470	5000	5.1109	83.5122	36.7493

Conversion factors

To convert tabulated value of	to dimensions indicated below	multiply by
$\frac{H°-E_0°}{RT_0}$	cal mol^{-1}	542.821
	cal g^{-1}	16.9632
	joules g^{-1}	70.9742
	Btu $(lb\ mol)^{-1}$	976.437
	Btu lb^{-1}	30.5137

TABLE 259.—CRITICAL TEMPERATURES, PRESSURES, AND DENSITIES OF GASES **

Substance	Critical temperature (0°C)	Critical pressure (kg/cm^2)	Critical density (g/cm^3)
Acetylene	36	62	.231
Air	—140.7	37.2	.35* .31†
Alcohol (C_2H_6O)	243.1	63.1	.2755
Alcohol (CH_4O)	240.0	78.7	.272
Allylene	128	...	...
Ammonia	132.4	115.5	.235
Argon	—122	49.7	.531
Benzene	288.5	47.7	.304
Bromine	302	...	1.18
iso-Butane	134	37	...
n-Butane	153	36	...
Carbon dioxide	31.1	75.5	.46
Carbon disulfide	273	76	...
Carbon monoxide	—139	36.2	.311
Chlorine	144.0	78.7	.573
Chloroform	263	...	.516
Cyanogen	128	59	...
Ethane	32.1	48.8	.21?
Ether (ethyl)	193.8	35.5	.2625
Ethyl chloride	187.2	52	.33
Ethylene	9.7	50.9	.2159
Helium	—267.9	2.34	.0693
Hydrogen	—239.9	13.2	.0310
Hydrogen bromide	90	84	...
Hydrogen chloride	51.4	84.5	.42
Hydrogen iodide	151	82	...
Hydrogen sulfide	100.4	92	...
Iodine	553	...	...
Krypton	—63?	56?	.78?
Mercury	1460±20	1640±50	.5
Methane	—82.5	47.4	.162
Methyl chloride	143.1	65.8	.37?
Neon	—228.7	26.8	.484
Nitric oxide	—94?	65	.52?
Nitrogen	—147.1	34.7	.3110
Nitrous oxide	36.5	71.7	.45?
Oxygen	—118.8	51.4	.430
Phosgene	182	56	.52
Propane	95.6	43	...
Radon	104	64.1	...
Silicon hydride	—3.5	49.7	...
Sulfur	1040	...	...
Sulfur dioxide	157.2	80.1	.52?
Sulfur trioxide	218.3	86.5	.630
Water	374.0	224.9	.4
Xenon	16.6	60.2	1.155

** For reference, see footnote 45, p. 136.
* Plait point. † Critical point of contact.

TABLE 260.—CONVERSION FACTORS FOR VARIOUS PRESSURE UNITS*

(Equivalent value in various units)

	dyne/cm²	bar	mmHg 0°C	in.Hg 0°C	millibars	lb/in.²	lb/ft²	g/cm²	cm water 20°C	in. water 20°C	atm
1 dyne/cm² (barye)	$=1$	10^{-6}	$7\ 501\times10^{-4}$	2.953×10^{-5}	10^{-3}	1.4506×10^{-5}	2.0883×10^{-3}	1.0197×10^{-3}	1.0216×10^{-3}	4.022×10^{-4}	9.869×10^{-7}
1 bar	$=10^{6}$	1	7.5006×10^{2}	29.53	10^{3}	14.51	2.0883×10^{3}	1.0197×10^{3}	1.0216×10^{3}	4.022×10^{2}	.9869
1 mmHg (Tor)	$=1.3332\times10^{3}$	1.3332×10^{-3}	1	3.937×10^{-2}	1.3332	1.9339×10^{-2}	2.7847	1.3594	1.3620	.5363	1.3157×10^{-3}
1 in.Hg	$=3.386\times10^{4}$	3.386×10^{-2}	25.400	1	33.864	.4912	70.732	34.530	34.590	13.620	3.3417×10^{-2}
1 millibar	$=10^{3}$	10^{-3}	.7501	2.953×10^{-2}	1	1.4506×10^{-2}	2.0888	1.0197	1.0216	.4022	9.869×10^{-4}
1 lb/in.²	$=6.894\times10^{4}$	6.894×10^{-2}	51.71	2.0368	68.95	1	1.44×10^{2}	70.30	70.43	27.731	6.804×10^{-2}
1 lb/ft²	$=4.788\times10^{2}$	4.788×10^{-4}	.3591	1.414×10^{-2}	.4788	6.945×10^{-3}	1	.4882	.4891	.1926	4.725×10^{-4}
1 g/cm²	$=9.807\times10^{2}$	9.807×10^{-4}	.7356	2.8961×10^{-2}	.9807	1.4226×10^{-2}	2.0484	1	1.0018	.3945	9.678×10^{-4}
1 cm water 20°C	$=9.789\times10^{2}$	9.789×10^{-4}	.7342	2.891×10^{-2}	.9789	1.4198×10^{-2}	2.0446	.9981	1	.3937	9.661×10^{-4}
1 in. water 20°C	$=2.486\times10^{3}$	2.486×10^{-3}	1.865	7.343×10^{-2}	2.486	3.607×10^{-2}	5.193	2.535	2.5400	1	2.453×10^{-3}
1 atm	$=1.01325\times10^{6}$	1.01325	7.60×10^{2}	29.921	1.0133×10^{3}	14.70	2.1164×10^{3}	1.0332×10^{3}	1.0351×10^{3}	4.0758×10^{2}	1

* The table is based primarily upon the following data and assumptions: a, One atm pressure equals 760 mmHg at 0°C under standard gravity of 980.665 cm/sec². b, The density of mercury at 0°C is 13.5951 g/cm³. c, The density of water at 20°C is .99820.

TABLES 261-267.—THE JOULE-THOMSON EFFECT IN FLUIDS *

The Joule-Thomson effect is defined as the ratio of the change in temperature to the drop in pressure of a fluid driven by the drop in pressure through a porous partial blockage in the fluid flow tube. The space between the reading thermometers on each side of the porous obstruction is to be isolated as to exchange of heat energy but not as to work energy. Nor must the fluid gain a significant amount of directed kinetic energy between the thermometers. Under these circumstances the Joule-Thomson effect, $\mu = \left(\frac{dt}{dp}\right)_h$, where $h = u - pv =$ enthalpy, and since μ is a function of both t and p, the steps are preferably represented as infinitesimals. Since Δp is always negative, μ is positive when Δt is negative. For all the gases yet measured, μ is zero along a line in the tp plane called the inversion line.

* The material on the Joule-Thomson effect was supplied by J. R. Roebuck, of the University of Wisconsin.

TABLE 261.—THE JOULE-THOMSON EFFECT ON AIR (WATER AND CARBON DIOXIDE FREE) [83]

μ as a function of t and p, t in °C, p in atm, μ in °C/atm.

p/t	0°	25°	50°	75°	100°	125°	150°	200°	250°	280°
1 atm	.2746	.2320	.1956	.1614	.1355	.1140	.0961	.0645	.0409	.0303
20 "	.2577	.2173	.1830	.1508	.1258	.1060	.0883	.0580	.0356	.0255
60 "	.2200	.1852	.1571	.1293	.1062	.0886	.0732	.0453	.0254	.0162
100 "	.1822	.1550	.1310	.1087	.0884	.0731	.0600	.0343	.0165	.0073
140 "	.1446	.1249	.1070	.0889	.0726	.0599	.0482	.0250	.0092	+.0008
180 "	.1097	.0959	.0829	.0707	.0580	.0474	.0376	.0174	+.0027	—.0058
220 "	.0795	.0697	.0609	.0536	.0449	.0366	.0291	.0116	—.0025	—.0111

p/t	—150°	—140°	—120°	—100°	—75°	—50°	—25°	0°
1 atm		1.0755	.7370	.5895	.4795	.3910	.3225	.2745
20 "		1.0240	.7155	.5700	.4555	.3690	.3010	.2580
40 "	.0710	.4600	.6945	.5370	.4235	.3480	.2805	.2375
60 "	.0450	.1125	.5150	.4820	.3835	.3195	.2610	.2200
80 "	.0295	.0685	.2855	.3900	.3360	.2830	.2385	.2105
100 "	.0185	.0440	.1535	.2775	.2880	.2505	.2130	.1820
120 "	+.0045	.0265	.0940	.1955	.2325	.2165	.1905	.1620
140 "	—.0070	.0120	.0590	.1360	.1855	.1825	.1650	.1450
160 "	—.0145	+.0015	.0375	.0950	.1435	.1525	.1420	.1250
180 "	—.0255	—.0115	.0200	.0655	.1136	.1270	.1240	.1100
200 "	—.0330	—.0205	+.0080	.0440	.0855	.1065	.1090	.0950
220 "	—.0405	—.0290	—.0030	.0265	.0630	.0880	.0950	.0825

[83] Proc. Amer. Acad. Arts and Sci., vol. 60, p. 535, 1025; vol. 64, p. 287, 1930 (both corrected).

TABLE 262.—THE JOULE-THOMSON EFFECT ON HELIUM [84]

μ as a function to t (and independent of pressure up to 200 atm), t in °C, μ in °C/atm.

t°C	$-\mu \times 10^2$	t°C	$-\mu \times 10^2$	t°C	$-\mu \times 10^2$	t°C	$-\mu \times 10^2$	t°C	$-\mu \times 10^2$
300	5.97	150	6.45	50	6.31	— 50	6.05	—155	5.03
250	6.29	100	6.38	25	6.24	—100	5.84	—180	4.12
200	6.41	75	6.35	0	6.16	—140	5.40	—190	3.80

[84] Phys. Rev., vol. 43, p. 60, 1933 (corrected).

TABLE 263.—THE JOULE-THOMSON EFFECT ON ARGON[85]

μ as a function of t and p, t in °C, p in atm, μ in °C/atm.

t/p	1 atm	20	60	100	140	180	200
300°	.0643	.0607	.0530	.0445	.0370	.0370	.0276
250	.0980	.0910	.0785	.0665	.0555	.0485	.0468
200	.1377	.1280	.1102	.0950	.0823	.0715	.0675
150	.1845	.1720	.1485	.1285	.1123	.0998	.0945
125	.2105	.1980	.1707	.1480	.1300	.1153	.1100
100	.2413	.2277	.1975	.1715	.1490	.1320	.1255
75	.2695	.2557	.2285	.1993	.1710	.1505	.1415
50	.3220	.3015	.2650	.2297	.1947	.1700	.1580
25	.3720	.3490	.3077	.2628	.2213	.1890	.1745
0	.4307	.4080	.3600	.3010	.2505	.2050	.1883
− 25	.5045	.4805	.4210	.3460	.2763	.2140	.1950
− 50	.5960	.5720	.4963	.3970	.2840	.2037	.1860
− 75	.7100	.6895	.5910	.4225	.2480	.1537	.1215
− 87.5	.7780	.7610	.6450	.3910	.1903	.1027	.0773
−100	.8605	.8485	.6900	.2820	.1137	.0560	.0395
−112.5	.9680	.9560	.6530	.1240	.0515	+.0198	+.0087
−125	1.112	1.102	.1250	+.0415	+.0090	−.0100	−.0165
−137.5	1.333	1.342	+.0210	−.0020	−.0203	−.0350	−.0402
−150	1.812		−.0025	−.0277	−.0403	−.0595	−.0640
−160	2.385						
−170	3.017						

85 Phys. Rev., vol. 46, p. 785, 1934 (corrected).

TABLE 264.—THE JOULE-THOMSON EFFECT IN NITROGEN[86]

μ as a function of t and p, t in °C, p in atm, μ in °C/atm.

t/p	1 atm	20	33.5	60	100	140	180	200
300°C	.0140	.0096	.0050	−.0013	−.0075	−.0129	−.0160	−.0171
250	.0331	.0256	.0230	+.0160	+.0071	+.0009	−.0037	−.0058
200	.0558	.0472	.0430	.0372	.0262	.0168	+.0094	+.0070
150	.0868	.0776	.0734	.0628	.0482	.0348	.0248	.0228
125	.1070	.0973	.0904	.0786	.0621	.0459	.0347	.0326
100	.1292	.1173	.1100	.0975	.0768	.0582	.0462	.0419
75	.1555	.1421	.1336	.1191	.0941	.0740	.0583	.0543
50	.1855	.1709	.1621	.1449	.1164	.0915	.0732	.0666
25	.2217	.2060	.1961	.1729	.1400	.1105	.0874	.0779
0	.2656	.2494	.2377	.2088	.1679	.1316	.1015	.0891
− 25	.3224	.3013	.2854	.2528	.2001	.1506	.1101	.0932
− 50	.3968	.3734	.3467	.3059	.2332	.1676	.1120	.0909
− 75	.5033	.4671	.4318	.3712	.2682	.1735	.1026	.0800
− 87.5	.5710	.5247	.4854	.4096	.2808	.1619	.0933	.0733
−100	.6490	.5958	.5494	.4506	.2754	.1373	.0765	.0587
−112.5	.7430	.6841	.6208	.4923	.2254	.0932	.0488	.0346
−125	.8557	.7948	.7025	.4940	.1314	.0498	+.0167	+.0032
−137.5	.9972	.9364	.7964	.2364	.0638	+.0177	−.0181	−.0175
−150	1.2659	1.1246	.1704	.0601	+.0202	−.0056	−.0211	−.0284
−160	1.6328	+.0724	+.0311	+.0068	−.0088	−.0175	−.0263	−.0315
−170	2.0048	−.0108	−.0382					
−180	2.3923							

86 Phys. Rev., vol. 48, p. 45, 1935 (corrected).

TABLE 265.—THE JOULE-THOMSON EFFECT ON MIXTURES OF HELIUM AND ARGON ($\mu \times 10^2$)[87]

μ as a function of t and p, t in °C, p in atm, μ in °C/atm.

t °C/p	1	20	60	100	140	180	200
			Mixture No. 1; He 75.8 percent, A 24.2 percent				
250	—5.83	—5.95	—6.15	—6.37	—6.56	—6.77	—6.85
200	5.55	5.66	5.90	6.13	6.34	6.55	6.63
150	5.11	5.24	5.52	5.77	5.99	6.21	6.34
100	4.47	4.61	4.91	5.18	5.45	5.72	5.88
50	3.61	3.76	4.08	4.40	4.68	5.01	5.19
0	2.40	2.57	2.92	3.30	3.65	4.03	4.22
— 50	— .69	— .92	—1.32	—1.75	2.21	2.66	2.82
—100	+3.37	+2.82	+1.87	+ .79	— .14	— .65	— .78
			Mixture No. 2; He 50.6 percent, A 49.4 percent				
250	—2.84	—3.19	—3.65	—4.04	—4.21	—4.33	—4.34
200	1.67	2.07	2.71	3.15	3.40	3.55	3.57
150	— .13	— .67	—1.50	2.01	2.32	2.56	2.62
100	+1.84	+1.15	+ .11	— .59	—1.01	—1.32	1.48
50	4.50	3.66	2.37	+1.39	+ .70	+ .14	— .07
0	8.19	7.20	5.51	4.12	2.96	1.99	+1.57
— 50	13.84	12.61	10.27	8.14	6.28	4.53	3.63
—100			+17.79	+14.17	+10.36	+6.90	+5.40
			Mixture No. 3; He 33.5 percent, A 66.5 percent				
250	+1.34	+ .72	— .38	—1.03	—1.48	—1.68	—1.68
200	2.94	2.32	+1.25	+ .45	— .13	— .38	— .38
150	5.05	4.41	3.23	2.22	+1.41	+ .92	+ .83
100	7.80	7.10	5.69	4.55	3.63	2.86	2.54
50	12.12	11.28	9.40	7.73	6.32	5.41	5.01
0	18.40	17.18	14.43	12.05	9.88	7.93	6.88
— 50	27.90	25.82	21.93	17.96	13.83	9.63	7.73
—100	43.30	41.15	34.30	27.20	17.55	10.07	7.10
			Mixture No. 4; He 16.6 percent, A 83.4 percent				
250	5.75	5.15	3.85	2.70	1.90	1.20	.95
200	8.45	7.63	6.05	4.75	3.85	3.00	2.60
150	11.70	10.80	8.95	7.45	6.10	5.20	4.60
100	15.50	14.50	12.60	10.80	9.05	7.70	7.05
50	21.05	20.10	17.75	15.35	13.00	10.65	9.55
0	29.85	28.49	25.00	21.15	17.35	14.50	13.05
— 50	44.15	41.80	36.15	30.10	22.90	17.55	15.60
—100	70.80	66.10	51.00	29.95	19.75	11.35	8.00

[87] Journ. Chem. Phys., vol. 8, p. 627, 1940.

TABLE 266.—THE JOULE-THOMSON EFFECT IN CARBON DIOXIDE[88]

μ as a function of t and p, t in °C, p in atm, μ in °C/atm.

t/p	1 atm	20	60	73	100	140	180	200
300	.2650	.2425	.2080	.2002	.1872	.1700	.1540	.1505
250	.3075	.2885	.2625	.2565	.2420	.2235	.2045	.1975
200	.3770	.3575	.3400	.3325	.3150	.2890	.2600	.2455
150	.4890	.4695	.4430	.4380	.4155	.3760	.3102	.2910
125	.5600	.5450	.5160	.5068	.4750	.4130	.3230	.2915
100	.6490	.6375	.6080	.5920	.5405	.4320	.3000	.2555
90	.6900	.6785	.6500	.6300	.5680	.4290	.2738	.2300
80	.7350	.7240	.6955	.6725	.5973	.4050	.2343	.1960
70	.7855	.7750	.7465	.7175	.6192	.3505	.1875	.1600
60	.8375	.8325	.8060	.7675	.6250	.2625	.1405	.1245
50	.8950	.8950	.8800	.8225	.5570	.1720	.1025	.0930
40	.9575	.9655	.9705	.8760	.2620	.1075	.0723	.0660
30	1.0265	1.0430	1.0835	.2870	.1215	.0678	.0495	.0445
20	1.1050	1.1355	.1435	.1075	.0700	.0420	.0320	.0272
10	1.1910	1.2520	.0720	.0578	.0407	.0235	.0182	.0142
0	1.2900	1.4020	.0370	.0310	.0215	.0115	.0085	.0045
—25	1.6500	.0000	—.0028	—.0030	—.0050	—.0062	—.0080	—.0115
—50	2.4130	—.0140	—.0150	—.0165	—.0160	—.0183	—.0228	—.0248
—75		—.0200	—.0200	—.0232	—.0228	—.0240	—.0250	—.0290

[88] Journ. Amer. Chem. Soc., vol. 64, p. 400, 1942.

TABLE 267.—THE JOULE-THOMSON EFFECT IN MIXTURES OF HELIUM AND NITROGEN ($\mu \times 10^2$) [89]

μ as a function of t and p, t in °C, p in atm, μ in °C/atm.

t °C/p	1 atm	20	60	100	140	180	200
			Mixture No. 1; He 75.5 percent; N_2 24.5 percent				
250	−6.95	−6.90	−6.84	−6.83	−6.80	−6.77	−6.66
200	6.52	6.51	6.53	6.53	6.53	6.53	6.48
150	6.03	6.10	6.20	6.21	6.22	6.28	6.24
100	5.44	5.58	5.76	5.83	5.85	5.90	5.96
50	4.67	4.84	5.18	5.28	5.36	5.47	5.55
0	3.62	3.79	4.22	4.46	4.61	4.81	4.98
− 50	−1.98	−2.19	2.72	3.13	3.55	3.90	4.17
−100	+1.01	+ .52	− .33	−1.13	−1.96	−2.69	3.15
−125	3.61	2.72	+1.45	+ .23	1.02	1.89	−2.52
			Mixture No. 2; He 51.0 percent; N_2 49.0 percent				
250	−4.98	−4.93	−5.06	−5.06	−5.08	+5.20	−5.23
200	3.80	3.84	4.14	4.39	4.58	4.79	4.89
150	2.43	2.60	3.10	3.54	3.88	4.22	4.37
100	.83	1.07	1.74	2.40	2.95	3.46	3.67
50	+1.25	+ .89	+ .06	.86	1.63	2.25	2.56
0	4.06	3.50	2.50	+1.22	+ .14	.71	1.14
− 50	8.28	7.42	5.96	4.00	2.55	+1.29	+ .76
− 87.5	13.44	11.83	9.37	6.75	4.78	3.19	2.50
			Mixture No. 3; He 33.2 percent; N_2 66.8 percent				
250	−2.34	−2.51	−3.12	−3.69	−3.93	−4.18	−4.18
200	.96	1.27	1.92	2.65	2.94	3.22	3.37
150	+ .81	+ .38	.39	1.28	1.65	2.11	2.36
100	3.07	2.59	+1.52	+ .51	.20	.74	1.14
50	6.20	5.49	4.10	2.83	+1.80	+ .75	+ .28
0	10.62	9.66	7.60	5.99	4.34	2.62	1.84
− 50	18.00	16.31	12.91	10.22	7.68	4.77	3.69
− 87.5	27.53	24.74	19.14	14.75	10.80	6.63	5.26
			Mixture No. 4; He 16.6 percent; N_2 83.4 percent				
250	+ .27	− .04	− .82	−1.51	−2.05	−2.26	−2.34
200	2.25	+1.78	+ .78	.06	.72	1.27	1.43
150	4.54	4.03	2.76	+1.61	+ .78	+ .11	.30
100	7.57	6.86	5.32	4.00	2.78	1.78	+1.24
50	11.77	10.88	8.87	7.11	5.38	3.89	3.10
0	17.97	16.77	14.04	11.30	8.59	6.29	5.33
− 50	28.52	26.18	21.46	16.80	12.56	9.47	7.98
− 87.5	42.02	37.86	28.95	21.75	15.89	12.10	10.26

[89] Journ. Amer. Chem. Soc., vol. 60, p. 341, 1938 (corrected).

TABLE 268.—COMPRESSIBILITY OF LIQUIDS[90]

Part 1.—Relative volumes

P atm	Ethyl alcohol C_2H_5OH 20°C	80°C	Isobutyl alcohol C_4H_9OH 20°C	80°C	Ether $(C_2H_5)_2O$ 20°C	80°C	n-Proply alcohol C_3H_7OH 20°C	80°C	Amyl alcohol $C_5H_{11}OH$ 20°C	80°C	Ethyl iodide C_2H_5I 20°C	80°C
1	1.0212	1.0934	1.0195	1.0880	1.0315	—	1.0173	1.0865	1.0181	1.0814	1.0214	1.0935
500	.9782	1.0319	.9740	1.0262	.9668	1.0369	.9770	1.0305	.9788	1.0288	.9774	1.0351
1000	.9479	.9922	.9470	.9883	.9337	.9874	.9483	.9913	.9511	.9915	.9475	.9946
2000	.9059	.9380	.9078	.9385	.8850	.9189	.9124	.9424	.9138	.9427	.9070	.9397
3000	.8760	.9025	.8798	.9052	.8503	.8776	.8876	.9120	.8869	.9110	.8777	.9034
4000	.8517	.8756	.8575	.8802	.8246	.8481	.8677	.8893	.8658	.8877	.8555	.8760
6000	.8149	.8354	.8242	.8433	.7883	.8070	.8365	.8548	.8348	.8531	.8207	.8381
8000	.7888	.8061	.8001	.8181	.7613	.7779	.8138	.8301	.8116	.8273	.7937	.8099
10,000	.7671	.7830	.7802	.7976	.7380	.7535	.7958	.8114	.7918	.8060	.7725	.7877
12,000	.7485	.7648	.7631	.7799	.7178	.7326	.7814	.7952	.7754	.7902	.7554	.7706

P atm	Phosphorus trichloride PCl_3 20°C	80°C	Methyl alcohol CH_3OH 20°C	80°C	Ethyl chloride C_2H_5Cl 20°C	80°C	Carbon disulfide CS_2 20°C	80°C	Ethyl bromide C_2H_5Br 20°C	80°C	Acetone $(CH_3)_2CO$ 20°C	80°C
1	1.0234	1.1033	1.0238	1.1005	—	—	1.0235	1.1092	1.0275	—	1.0279	—
500	.9852	1.0443	.9811	1.0400	.9696	1.0358	.9854	1.0458	.9776	—	.9818	—
1000	.9577	1.0040	.9494	.9993	.9253	.9797	.9567	1.0061	.9460	.9988	.9526	1.0082
2000	.9184	.9531	.9064	.9429	.8749	.9128	.9151	.9525	.9022	.9381	.9076	.9467
3000	.8902	.9192	.8763	.9065	.8415	.8715	.8852	.9154	.8714	.9020	.8748	.9073
4000	.8679	.8933	.8523	.8782	.8167	.8422	.8620	.8870	.8479	.8742	.8504	.8786
6000	.8348	.8561	.8163	.8381	.7796	.8008	.8265	.8468	.8131	.8339	.8143	.8370
8000	.8105	.8292	.7907	.8102	.7533	.7728	.7990	.8188	.7868	.8056	.7866	.8066
10,000	.7902	.8077	.7696	.7875	.7320	.7501	.7774	.7962	.7656	.7825	freezes	.7821
12,000	.7741	.7898	.7527	.7709	.7148	.7301	.7609	.7758	.7495	.7648	"	.7617

Part 2.—$\beta = (1/V_0)(dV/dP)$

Substance	Temp °C	Pressure megabaryes	Compressibility per megabaryes $\beta\times 10^6$
Benzene	17	5	89
	20	200	77
	20	400	67
Chloroform	20	200	83
	20	400	70
Glycerine	15	5	22
Kerosene	20	500	55
	20	1,000	45
	20	12,000	8
Mercury	20	300	3.95
	22	500	3.97

Substance	Temp °C	Pressure megabaryes	Compressibility per megabaryes $\beta\times 10^6$
Mercury	22	1,000	3.91
	22	12,000	2.37
Oils: almond	15	5	53
castor	15	5	46
linseed	15	5	51
olive	15	5	55
rapeseed	20	—	59
Toluene	20	200	74
	20	400	64
Turpentine	20	—	74

[90] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 47, p. 345, 1911; vol. 48, p. 309, 1912; vol. 49, p. 3, 1913.

TABLE 269.—RELATIVE VOLUMES OF WATER FOR DIFFERENT PRESSURES [91]

Pressure kg/cm²	Temperatures 0°C	50°C	95°C
0	1.0000		
500	.9771		
1,000	.9567	.9741	.9984
1,500	.9396	.9582	.9812
2,000	.9248	.9439	.9661
3,000	.8996	.9201	.9409
4,000	.8795	.8997	.9194
5,000	.8626	.8824	.9009
6,000		.8668	.8849
7,000		.8530	.8705
8,000		.8407	.8577
9,000		.8296	.8461
10,000		.8192	.8352
11,000			.8256

TABLE 270.—RELATIVE VOLUMES OF ETHER FOR DIFFERENT PRESSURES [91]

Pressure kg/cm²	Temperatures 30°C	75°C
0	1.0495	
500	.9761	
1,000	.9364	
1,500	.9085	
2,000	.8858	
2,500	.8671	.8909
3,000	.8511	.8726
4,000	.8255	.8446
5,000	.8055	.8225
6,000	.7888	.8038
7,000	.7742	.7884
8,000	.7616	.7747
9,000	.7504	.7629
10,000	.7399	.7519
11,000	.7305	.7418
12,000	.7225	.7329

[91] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 66, p. 219, 1931.

TABLE 271.—COMPRESSIBILITY OF SOLIDS

If V is the volume of the material under a pressure P megabaryes and V_0 is the volume at atmospheric pressure, then the compressibility $\beta = -(1/V_0)\ (dV/dP)$. Its unit is cm²/megadynes (reciprocal megabaryes). $10^6/\beta$ is the bulk modulus in absolute units (dynes/cm²). The following values of β, arranged in order of increasing compressibility, are for $P = 0$ and room temperature. 1 megabarye = 10^6 dynes/cm² = 1.020 kg/cm² = 0.987 atm.

Substance	Compression per unit vol. per megabarye $\times 10^6$	Bulk modulus, dynes/cm² $\times 10^{12}$	Substance	Compression per unit vol. per megabarye $\times 10^6$	Bulk modulus, dynes/cm² $\times 10^{12}$
Tungsten	.27	3.7	Gallium	2.09	.48
Boron	.3	3.0	Cadmium	2.17	.46
Silicon	.32	3.1	Plate glass	2.23	.45
Platinum	.38	2.6	Lead	2.27	.44
Nickel	.43	2 3	Thallium	2.3	.43
Molybdenum	.46	2.2	Antimony	2.4	.42
Tantalum	.53	1.9	Quartz	2.7	.37
Palladium	.54	1.9	Magnesium	2.9	.34
Cobalt	.55	1.82	Bismuth	3 0	.33
Nichrome	.56	1.79	Graphite	3.0	.33
Iron	.60	1.67	Silica glass	3.1	.32
Gold	.60	1.67	Arsenic	4.5	.22
Pyrite	.7	1.4	Calcium	5.7	.175
Copper	.75	1.33	Strontium	8.4	.120
Manganese	.84	1.19	Phosphorus (red)	9.2	.109
Brass	.89	1.12	Selenium	12.0	.083
Chromium	.9	1.12	Ice	12 0	.083
Silver	.99	1.01	Sulfur	12.9	.078
Mg. silicate, crys.	1.03	.91	Iodine	13.0	.077
Mg. silicate	1.21	.82	Sodium	15.6	.064
Aluminum	1.33	.75	Hard rubber	19.4	
Calcite	1.39	.72	Phosphorus (white)	20.5	.049
Tin	1.89	.53			

TABLE 272.—COMPRESSIBILITY AND THERMAL EXPANSION OF PETROLEUM OILS [92]

It was found that the compressibility and thermal expansion of two samples of the same specific gravity, but from different sources, differed more than 30 percent at the higher temperatures, whereas oils of the same specific gravity and the same viscosity had the same compressibility and thermal expansion within rather narrow limits. In other words, with a knowledge of the specific gravity and viscosity of the oils, it was possible to represent all the measured volumes within less than .5 percent over the entire range of temperature and pressure covered by the measurements.

Kinematic viscosity 100°F, cgs	Specific gravity 60°/60°F	Pressure kg/cm²	Relative volumes						
			0°C	20°	50°	100°	200°	300°	400°
.020	.80	0	1.000	1.018	1.045	1.096	1.222	1.422	....
“	“	50	.996	1.014	1.041	1.089	1.205	1.370	(1.63)
“	.85	0	1.000	1.017	1 044	1.093	1.213	1.396	(1.71)
“	“	50	.997	1.014	1.040	1.086	1.197	1.352	(1.58)
“	.90	0	1.000	1.017	1.043	1.090	1.204	1.375	(1.67)
“	“	50	.997	1.013	1.038	1.084	1.191	1.337	(1.55)
.050	.80	0	1.000	1.017	1.043	1.089	1.202	1.369	(1.71)
“	“	50	.997	1.013	1.038	1.083	1.189	1.333	(1.56)
“	.85	0	1.000	1.016	1.041	1.087	1.194	1.349	(1.63)
“	“	50	.997	1.013	1.037	1.081	1.182	1.318	(1.51)
“	.90	0	1.000	1.016	1.040	1.084	1.188	1.331	(1.56)
“	“	50	.997	1.012	1.036	1.078	1.176	1.304	(1.48)
.100	.85	0	1.000	1.016	1.040	1.083	1.185	1.325	(1.54)
“	“	50	.997	1.012	1.036	1.078	1.174	1.299	(1.47)
“	.95	0	1.000	1.015	1.038	1.079	1.174	1.297	(1.47)
“	“	50	.997	1.012	1.034	1.074	1.164	1.276	(1.43)
.500	.85	0	1.000	1.015	1.038	1.078	1.170	1.289	(1.45)
“	“	50	.997	1.012	1.034	1.073	1.161	1.269	(1.41)
“	.95	0	1.000	1.014	1.036	1.074	1.161	1.269	(1.40)
“	“	50	.998	1.012	1.033	1.070	1.152	1.252	(1.37)
1.000	.85	0	1.000	1.015	1.037	1.076	1.165	1.279	(1.43)
“	“	50	.997	1.012	1.034	1.071	1.157	1.260	(1.39)
“	.95	0	1.000	1.014	1.035	1.073	1.157	1.261	(1.39)
“	“	50	.998	1.011	1.032	1.068	1.149	1.244	(1.36)
2.000	.85	0	1.000	1.014	1.036	1.075	1.162	1.270	(1.41)
“	“	50	.998	1.011	1.033	1.070	1.153	1.253	(1.37)
“	.95	0	1.000	1.014	1.035	1.071	1.153	1.254	(1.37)
“	“	50	.998	1.011	1.032	1.067	1.145	1.239	(1.35)
5.000	.85	0	1.000	1.014	1.035	1.073	1.157	1.261	(1.39)
“	“	50	.998	1.011	1.032	1.068	1.149	1.245	(1.36)
“	.95	0	1.000	1.013	1.034	1.069	1.148	1.244	(1.36)
“	“	50	.998	1.011	1.031	1.065	1.141	1.229	(1.33)
210°F, cgs	60°/60°F	kg/cm²	0°C	20°	50°	100°	200°	300°	400°
.100	.90	0	1.000	1.014	1.036	1.074	1.161	1.269	(1.41)
“	“	50	.998	1.011	1.032	1.070	1.152	1.252	(1.37)
“	.95	0	1.000	1.014	1.035	1.071	1.154	1.256	(1.38)
“	“	50	.998	1.011	1.032	1.067	1.147	1.241	(1.35)
“	1.00	0	1.000	1.014	1.034	1.070	1.149	1.247	(1.37)
“	“	50	.998	1.011	1.031	1.066	1.142	1.232	(1.34)
.200	.90	0	1.000	1.014	1.035	1.072	1.155	1.258	(1.39)
“	“	50	.998	1.011	1.031	1.067	1.147	1.241	(1.35)
“	1.00	0	1.000	1.013	1.033	1.067	1.144	1.237	(1.35)
“	“	50	.998	1.011	1.030	1.064	1.137	1.223	(1.32)
.440	.90	0	1.000	1.013	1.034	1.070	1.151	1.248	(1.36)
“	“	50	.998	1.011	1.031	1.066	1.143	1.234	(1.34)
“	1.00	0	1.000	1.012	1.032	1.066	1.140	1.228	(1.33)
“	“	50	.998	1.010	1.029	1.063	1.134	1.214	(1.31)
1.100	.90	0	1.000	1.013	1.033	1.068	1.146	1.241	(1.35)
“	“	50	.998	1.010	1.030	1.065	1.139	1.225	(1.33)
“	1.00	0	1.000	1.012	1.031	1.063	1.134	1.218	(1.32)
“	“	50	.998	1.010	1.028	1.060	1.128	1.205	(1.29)

[92] Jessup, R. S., Nat. Bur. Standards Journ. Res., vol. 5, p. 985, 1930.

$-\Delta V/V_0 = aP - bP^2$, where P is in bars (10^6 dyne/cm^2) and V_0 is the volume at 1 atm and 30°C (or room temp.). Pressure range, 1 — 12,000 bars unless otherwise noted. a = β_0 = initial compressibility. See also Table 271.

Element	30°C		75°C	
	$a \times 10^7$	$b \times 10^{12}$	$a \times 10^7$	$b \times 10^{12}$
Aluminum	13.65	4.9	13.98	4.9
Arsenic	31.6	—	—	—
Beryllium	7.95	2.2	8.06	2.3
Bismuth	29.70	22	30.44	31
Boron	5.58	.8	—	—
Cadmium (20°C)	22.5	—	—	—
Carbon (diamond) (25°C)	1.8	—	—	—
Carbon (graphite) (20°C)	30	—	—	—
Cerium (below 4000 bars)	46.49	—169	45.88	—159
Chromium	5.25	.9	5.37	.9
Cobalt	5.46	.8	5.54	.8
Copper	7.29	1.6	7.44	1.6
Germanium	14.35	4.8	14.63	5.7
Gold	5.84	2.0	5.77	.8
Hafnium	9.15	1.1	8.94	1.1
Iodine (20°C to 500 bars)	127	—	—	—
Iridium	2.69	0	2.82	.9
Iron	5.949	.83	6.007	.83
Lanthanum	35.78	13.9	35.65	16.4
Magnesium	30.08	27.5	30.02	24.0
Manganese	8.03	4.2	8.20	3.6
Molybdenum	3.63	— .3	3.64	— .4
Nickel	5.35	.9	5.41	.8
Niobium	5.77	.9	5.85	.9
Palladium	5.34	.9	5.37	.8
Platinum	3.63	.3	3.67	.3
Rhodium	3.64	1.5	3.73	1.5
Ruthenium	3.48	1.7	3.51	1.7
Silicon (20°C to 500 bars)	3.1	—	—	—
Silver	10.02	3.7	10.20	3.1
Tantalum	4.84	—1.1	4.98	—1.0
Thallium	35.5	—	37.4	—
Thorium	18.50	12.0	18.78	12.5
Titanium	8.09	—1.5	8.81	3.3
Tungsten	3.20	.1	3.20	.2
Vanadium	6.17	1.35	6.20	1.35
Zinc	16.93	8.6	—	—
Zirconium	11.15	6.3	11.24	6.8
Steel (20°C)	6.42	3.2	—	—
Manganin (20°C)	8.41	6.5	—	—

Element	Temp °C	Pressure, kg/cm² 4000	8000	12,000
Phosphorus	30	.0190*	.0342*	.0469*
red	75	.0189	.0344	.0476
Phosphorus	30	.0095	.0158	.0205
black	75	.0095	.0158	.0209
Mercury (liquid)	20	.01485*	.02754*	.03795*
Gallium (solid)	20	$\beta_0 = 20 \times 10^{-7}$		
(liquid)	30	$\beta_0 = 40 \times 10^{-7}$		

* $-\Delta V/V_0$.

TABLE 274.—VARIATION ($\Delta V/V_0$) OF THE VOLUME OF A NUMBER OF METALS WITH PRESSURE [93]

Pressure kg/cm²	Lithium	Sodium	Potassium	Rubidium	Cesium	Beryllium	Titanium	Zinc	Germanium	Zirconium	Lanthanum	Cerium	Praseodymium	Neodymium	Uranium
2,500	.0204	.0334	.0677	.0696	.0999	.0024	.0027	.0040	.0040	.0026	.0100	.0109	.0090	.0078	.0024
5,000	.0389	.0624	.1152	.1224	.1585	.0047	.0052	.0079	.0078	.0054	.0194	.0234	.0174	.0152	.0048
10,000	.0715	.1115	.1862	.1982	.2392	.0094	.0099	.0154	.0152	.0111	.0370	.0549	.0329	.0289	.0095
15,000	.1005	.1511	.2374	.2506	.2981	.0139	.0143	.0225	.0213	.0168	.0526	.1655‡	.0471	.0416	.0139
20,000	.1261	.1836	.2772	.2920	.3442	.0181	.0185	.0293	.0268	.0220	.0665	.1864	.0604	.0536	.0181
25,000	.1485	.2111	.3093	.3254	.3908*	.0219	.0224	.0358	.0323	.0267	.0827†	.2027	.0729	.0650	.0219
30,000	.1689	.2350	.3360	.3530	.4261	.0256	.0261	.0420	.0375	.0312	.0952	.2154	.0848	.0757	.0255
35,000	.1872	.2559	.3584	.3760	.4559	.0294	.0297	.0480	.0426	.0356	.1072	.2257	.0961	.0858	.0290
40,000	.2040	.2740	.3774	.3954	.4816	.0329	.0332	.0537	.0476	.0399	.1189	.2342	.1069	.0955	.0324

[93] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 76, p. 75, 1948.
* Transition at 23,300. Compressions .3716 and .3776. † Transition at 23,370. Compressions .0755 and .0781. ‡ Transition at 12,430. Compressions .0736 and .1504.

TABLE 275.—VARIATION OF THE VOLUME ($\Delta V/V_0$) FOR A NUMBER OF COMPOUNDS WITH PRESSURE FOR TWO TEMPERATURES [94]

Pressure kg/cm²	NH_4Cl cm³/1.536 g		NH_4Br cm³/2.548 g		NH_4I cm³/2.887 g		AgCl cm³/5.589 g		AgBr cm³/6.548 g		AgI cm³/5.709 g	
	20°C	−78.8°C	20°C	−78.8°C	20°C	−78.8°C	20°C	−78.8°C	20°C	−78.8°C	20°C	−78.8°C
5,000	.0269	.0217	.0257	.0244	.0316	.0321	.0113	.0107	.0111	.0103	.1769*	.1753*
10,000	.0489	.0395	.0487	.0462	.0590	.0582	.0216	.0207	.0215	.0202	.1896	.1868
15,000	.0668	.0545	.0694	.0656	.0822	.0804	.0312	.0301	.0313	.0297	.2001	.1969
20,000	.0818	.0675	.0880	.0829	.1019	.0989	.0401	.0389	.0404	.0386	.2095	.2061
25,000	.0949	.0794	.1049	.0984	.1188	.1144	.0484	.0471	.0496	.0476	.2180	.2145
30,000	.1070	.0906	.1203	.1124	.1332	.1279	.0562	.0549	.0584	.0562	.2257	.2222
35,000	.1176	.1010	.1340	.1250	.1456	.1397	.0634	.0621	.0665	.0641	.2326	.2291
40,000	.1278	.1111	.1465	.1364	.1570	.1504	.0704	.0690	.0743	.0716	.2396	.2362
45,000	.1372	.1207	.1576	.1466	.1676	.1608	.0772	.0755	.0818	.0789	.2462	.2428
50,000	.1462	.1301	.1676	.1557	.1775	.1702	.0838	.0818	.0890	.0858	.2525	.2490

Pressure kg/cm²	NaCl cm³/2.163 g		NaBr cm³/3.205 g		NaI cm³/3.667 g		KCl cm³/1.988 g		KBr cm³/2.75 g		KI cm³/3.123 g	
	20°	−78.8°C	20°	−78.8°C	20°	−78.8°C	20°	−78.8°C	20°	−78.8°C	20°	−78.8°C
5,000	.0192	.0177	.0228	.0216	.0296	.0290	.0257	.0241	.0295	.0272	.0351	.0335
10,000	.0365	.0341	.0430	.0413	.0553	.0547	.0478	.0452	.0547	.0511	.0648	.0623
15,000	.0523	.0494	.0610	.0594	.0778	.0772	.0667	.0645	.0758	.0720	.0905	.0868
20,000	.0664	.0634	.0771	.0756	.0974	.0966	.0841	.0807	.1989	.1933	.1970	.1932
25,000	.0798	.0763	.0916	.0904	.1145	.1139	.2111	.2055	.2138	.2078	.2149	.2105
30,000	.0919	.0880	.1047	.1037	.1294	.1288	.2225	.2158	.2267	.2202	.2296	.2244
35,000	.1029	.0987	.1166	.1157	.1424	.1421	.2324	.2255	.2379	.2308	.2421	.2363
40,000	.1130	.1084	.1274	.1263	.1538	.1538	.2419	.2340	.2479	.2399	.2532	.2466
45,000	.1223	.1172	.1373	.1357	.1638	.1642	.2501	.2418	.2569	.2481	.2629	.2554
50,000	.1309	.1250	.1464	.1439	.1728	.1738	.2579	.2497	.2650	.2552	.2715	.2630
Transitions												
Pressure:							20,060	20,590	18,430	19,400	18,200	19,010
ΔV:							.1133	.1120	.1052	.1044	.0850	.0872

[94] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 74, October 1940.
* Transition below this point.

TABLE 276.—COMPRESSIBILITY OF CRYSTALS **

Part 1.— $-\Delta V/V_0 = aP - bP^2$ where P is in bars (10^6 dyne/cm^2) and V_0 is the volume at 1 atm and 30°C (or room temp.)

Pressure range, 1–12,000 bars

Crystal and formulae	System	0°C a×10⁷	30°C a×10⁷	30°C b×10¹²	75°C a×10⁷	75°C b×10¹²
Andradite:						
$3CaO \cdot Fe_2O_3 \cdot 3SiO_2$	Cubic	—	6.73	.86	6.70	.86
Apatite: $3Ca_3P_2O_8 \cdot CaF_2$	Hexagonal	—	10.91	4.1	11.09	3.8
Argentite: Ag_2S	Cubic	30	—	—	25.1	33.5
Barite: $BaSO_4$	Orthorhombic	17.1–18.1	17.60	11.9	17.92	12.6
Beryl: $3BeO \cdot Al_2O_3 \cdot 6SiO_2$	Hexagonal	5.7	5.403	.94	5.407	.94
Calcite: $CaCO_3$	Trigonal	13.5	13.67	3.9	13.93	4.2
Cobaltite: $CoAs \cdot S$	Cubic	—	7.67	1.88	7.79	1.88
Fluorite: CaF_2	Hexagonal	12.6	12.26	6.49	12.59	6.61
Galena: PbS	Cubic	19.5–19.7	18.69	7.43	18.97	8.41
Garnet (pyrope):						
$3MgO \cdot Al_2O_3 \cdot 3SiO_2$	Cubic	—	5.45	.91	5.51	.91
Halite (Rock Salt): NaCl	Cubic	—	42.60	51	44.26	52.6
Hanksite:						
$KCl \cdot 2Na_2CO_3 \cdot 9Na_2SO_4$	Hexagonal	—	24.57	24.5	25.54	26.7
Jeffersonite	Monoclinic	—	9.088	3.94	9.551	5.56
Lithium fluoride: LiF	Cubic	—	15.20	5.5	15.91	5.7
Lithium iodide: LiI	Cubic	—	60.0	110.	—	—
Magnetite: Fe_3O_4	Cubic	5.4–5.7	5.47	.82	5.45	.82
Orthoclase: $KAl \cdot Si_3O_8$	Monoclinic	—	21.23	14.5	21.16	13.9
Periclase: MgO	Cubic	7.2	5.98	1	6.06	1
Potassium bromide: KBr	Cubic	—	67.0	105.3	68.8	105.2
Potassium fluoride: KF	Cubic	—	33.0	31.9	33.2	31.9
Potassium iodide: KI	Cubic	—	85.3	155.4	87.7	155.4
Pyrite: FeS_2	Cubic	7.1	6.80	.87	6.82	.87
Quartz: α SiO_2	Trigonal	—	27.06	24.0	27.54	24.7
Rochelle salt (see end of part 1)						
Sapphire (synthetic): Al_2O_3		3.8	3.36	—	—	—
Sphalerite: ZnS	Cubic	12.9–12.2	13.03	1.28	12.79	1.26
Spodumene: $LiAl \cdot Si_2O_6$	Monoclinic	—	7.033	1.49	7.073	2.28
Sylvite: KCl	Cubic	—	56.2	75.1	57.5	75.1
Tourmaline (black)	Trigonal	—	8.16	1.95	8.62	2.15
Topaz		—	6.109	1.06	6.075	1.06
Zircon: $ZrO_2 \cdot SiO_2$		8.6	—	—	—	—

Rochelle salt: $C_4H_4O_6KNa$:	Pressures kg/cm²	$-\Delta V/V_0$
	2000	.01080
	4000	.02016
	6000	.02885
	8000	.03716
	10,000	.04501
	12,000	.05237

** For reference, see footnote 45, p. 136.

(continued)

Part 2.—Elastic constants of rocks at ordinary pressure and temperature.

E = Young's modulus, in dynes cm^{-2}
G = Modulus of rigidity, in dynes cm^{-2}
σ = Poisson's ratio, dimensionless

The density is given, when known, in parentheses in the first column.

Rock	E dynes cm^{-2}	G dynes cm^{-2}	σ	Stress or stress range kg cm^{-2}
Granite, coarse gray,				
Quincy, Mass.	4.64×10^{11}	$(1.92)\times10^{11}$	.215	70–600
Quincy, Mass. from 100 ft depth (2.67)	3.48	...	...	11.2
Basalt, Ostritz	11.15	...	...	100–900
Diabase				
Westfield, Mass. (2.95)	8.00*	...	...	...
Marble				
Proctor, Vt. (2.71)	3.43	...	.141	11.2
	4.60	...	.190	56
	4.95*	2.17	...	...
Limestone				
Knoxville, Tenn.	6.21	(2.48)	.251	70–600
Montreal	6.35	(2.50)	.252	70–600
Dolomite, Pennsylvania (2.83)	7.10*	3.23	...	...
Sandstone				
Quartzitic, Penna. (2.66)	6.36	...	.115	11.2
Feldspathic, Ohio	1.58	(.61)	.290	70–600
Slate, Pennsylvania, || to cleavage plane	11.29*	4.65	...	...
Shale (2.63)	4.4 dry	...	...	200
	1.9 wet	...	...	...
Schist, Mica, Japan	1–6	...	...	...
Tuff, Japan	.3–3.6	...	...	...
Ice (.917) —5°C	.917*	.336	(.365)	...

* Dynamical measurements.

TABLE 277.—RELATIVE VOLUME OF QUARTZ CRYSTALS AND SIX GLASSES FOR DIFFERENT PRESSURES[95]

Pressure kg/cm^2	Quartz crystal	Quartz glass	Glass *A**	Pyrex glass	Glass *C* †	Glass *D* ‡	Borax glass
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
25,000	.946	.923	.934	.921	.945	.932	.877
30,000	.939	.909	.923	.907	.936	.924	.866
40,000	.926	.885	.905	.885	.920	.909	.845
50,000	.914	.864	.890	.867	.905	.894	.825
60,000	.902	.847	.875	.851	.891	.880	.808
70,000	.892	.832	.862	.838	.878	.867	.792
80,000	.883	.819	.849	.827	.866	.855	.778
90,000	.875	.808	.838	.817	.854	.844	.765
100,000	.868	.798	.828	.809	.842	.834	.753

[95] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 76, p. 68, 1948.
* Glass A is a potash lead silicate of very high lead content. † Glass C is a soda potash lime silicate. ‡ Glass D is a lead zinc borosilicate.

TABLE 278.—COMPRESSIBILITY OF GLASSES [96]

$\Delta V/V_0$

Pressure kg/cm²	Quartz glass	Pyrex	*A* *	*C* †	*D* ‡	Borax glass
5,000	.0141	.0153	.0159	.0121	.0144	.0345
10,000	.0295	.0308	.0300	.0239	.0281	.0631
15,000	.0452	.0465	.0425	.0352	.0411	.0857
20,000	.0610	.0622	.0535	.0449	.0542	.1054
25,000	.0772	.0786	.0656	.0549	.0678	.1228
30,000	.0933	.0920	.0770	.0654	.0806	.1376
35,000	.1068	.1032	.0866	.0742	.0927	.1518
40,000	.1194	.1133	.0964	.0830	.1049	.1648

[96] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 73, p. 74, 1938.
* Glass A is a potash lead silicate of very high lead content. † Glass C is a soda potash lime silicate. ‡ Glass D is a lead zinc borosilicate.

TABLE 279.—SPECIFIC GRAVITIES CORRESPONDING TO THE BAUMÉ SCALE

The specific gravities are for 15.56°C (60°F) referred to water at the same temperature as unity. For specific gravities less than unity the values are calculated from the formula:

$$\text{Degrees Baumé} = \frac{140}{\text{specific gravity}} - 130.$$

For specific gravities greater than unity from:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{specific gravity}}.$$

Specific gravities less than 1

Specific gravity	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	Degrees Baumé									
.60	103.33	99.51	95.81	92.22	88.75	85.38	82.12	78.95	75.88	72.90
.70	70.00	67.18	64.44	61.78	59.19	56.67	54.21	51.82	49.49	47.22
.80	45.00	42.84	40.73	38.68	36.67	34.71	32.79	30.92	29.09	27.30
.90	25.56	23.85	22.17	20.54	18.94	17.37	15.83	14.33	12.86	11.41
1.00	10.00									

Specific gravities greater than 1

Specific gravity	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	Degrees Baumé									
1.00	.00	1.44	2.84	4.22	5.58	6.91	8.21	9.49	10.74	11.97
1.10	13.18	14.37	15.54	16.68	17.81	18.91	20.00	21.07	22.12	23.15
1.20	24.17	25.16	26.15	27.11	28.06	29.00	29.92	30.83	31.72	32.60
1.30	33.46	34.31	35.15	35.98	36.79	37.59	38.38	39.16	39.93	40.68
1.40	41.43	42.16	42.89	43.60	44.31	45.00	45.68	46.36	47.03	47.68
1.50	48.33	48.97	49.60	50.23	50.84	51.45	52.05	52.64	53.23	53.80
1.60	54.38	54.94	55.49	56.04	56.58	57.12	57.65	58.17	58.69	59.20
1.70	59.71	60.20	60.70	61.18	61.67	62.14	62.61	63.08	63.54	63.99
1.80	64.44	64.89	65.33	65.76	66.20	66.62				

TABLE 280.—DEGREES API CORRESPONDING TO SPECIFIC GRAVITIES 60°/60°F

(15-56°/15.56°C) for petroleum oils.

In order to avoid confusion and misunderstanding the American Petroleum Institute, the Bureau of Mines, and the National Bureau of Standards have agreed that a scale based on the modulus 141.5 shall be used in the United States Petroleum Industry and shall be known as the API scale. The United States Baumé scale based on the modulus 140 will continue to be used for other liquids lighter than water.

$$\text{Calculated from the formula, degrees API} = \frac{141.5}{\text{sp. gr. } 60°/60° \text{ F}} - 131.5.$$

Degrees API 60°/60°F	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.6	104.33	100.47	96.73	93.10	89.59	86.19	82.89	79.69	79.59	73.57
.7	70.64	67.80	65.03	62.34	59.72	57.17	54.68	52.27	49.91	47.61
.8	45.38	43.19	44.06	38.98	36.95	34.97	33.03	31.14	29.30	27.49
.9	25.72	23.99	22.30	20.65	19.03	17.45	15.90	14.38	12.89	11.43
1.0	10.00									

TABLE 281.—DENSITY OF THE ELEMENTS, LIQUID OR SOLID

The density may depend considerably on previous treatment. To reduce to lb/ft³ multiply by 62.4.

Element	Physical state	g/cm³	°C*
Aluminum	commercial h'd d'n	2.70	20°
"	liquid	2.43	740
"	"	2.29	1000
Antimony	vacuo-distilled	6.618	20
"	ditto-compressed	6.691	20
"	amorphous	6.22	
"	liquid	6.55	631
Argon	"	1.40	−186
"	solid	1.65	−233
Arsenic	crystallized	5.73	14
"	amorph. br.-black	3.70	
"	yellow	3.88	
Barium	solid	3.78	
Beryllium	solid	1.85	
Bismuth	electrolytic	9.747	
"	vacuo-distilled	9.781	20
"	liquid	10.00	271
"	solid	9.67	271
Boron	crystal	2.535	
"	amorph. pure	2.45	
Bromine	liquid	3.12	
"	solid	4.2	−273
Cadmium	wrought	8.67	
"	vacuo-distilled	8.648	20
"	solid	8.37	318
"	liquid	7.99	318
Calcium		1.54	
Carbon	diamond	3.52	
"	graphite	2.25	
Cerium	electrolytic	6.79	
"	pure	7.02	
Cesium	solid	1.873	20
"	liquid	1.836	27
Chlorine	liquid	1.507	−33.6
"	solid	2.2	−273
Chromium		6.52–6.73	
"	pure	6.93	25
Cobalt		8.71	21
Copper	cast	8.30–8.95	
"	annealed	8.89	20
"	hard drawn	8.89	20
"	vacuo-distilled	8.9326	20
"	ditto-compressed	8.9376	20
"	liquid	8.217	
Erbium		4.77	
Fluorine	liquid	1.14	−200
"	solid	1.5	−273
Gallium		5.93	23
Germanium		5.46	20
Gold	cast	19.3	
"	vacuo-distilled	18.88	20
"	ditto-compressed	19.27	20
Hafnium	solid	13.3	
Helium	liquid	.15	−269
"	solid	.19	−273
Hydrogen	liquid	.070	−252
"	solid	.0763	−260
Indium		7.28	
Iodine		4.940	20
"	liquid	3.71	184
Iridium		22.42	17
Iron	pure	7.86	
"	gray cast	7.03–7.13	
"	white cast	7.58–7.73	
"	wrought	7.80–7.90	
"	liquid	6.88	
"	"	6.91	1200
Krypton	"	2.16	−146
"	solid	3.4	−273
Lanthanum		6.15	
Lead	vacuo-distilled	11.342	20
"	ditto-compressed	11.347	20
Lead	solid	11.005	325
"	liquid	10.597	400
"	"	10.078	850
Lithium		.534	20
Magnesium		1.741	
Manganese		7.3	
Mercury	liquid	13.596	0
"	"	13.546	20
"	"	13.690	−38.8
"	solid	14.193	−38.8
"	"	14.383	−188
Molybdenum		9.01	
Neodymium		7.00	
Neon		1.204	−245
Nickel		8.8	
Niobium		8.4	15
Nitrogen	liquid	.810	−195
"	"	.854	−205
"	solid	1.0265	−252.5
"	"	1.14	−273
Osmium		22.5	
Oxygen	liquid	1.132	−183.6
"	solid	1.426	−252.5
"	"	1.568	−273
Palladium		12.16	
Phosphorus	white	1.83	
"	red	2.20	
"	metallic	2.34	15
"	black	2.69	
Platinum		21.37	20
"	black	2.70	
Potassium		.870	20
"	solid	.851	62.1
"	liquid	.830	62.1
Praseodymium		6.48	25
Rhodium		12.44	
Rubidium		1.532	20
Ruthenium		12.1	19
Samarium		7.7–7.8	
Selenium		4.82	
Silicon	cryst.	2.42	20
"	amorph.	2.35	15
Silver	cast	10.42–10.53	
"	vacuo-distilled	10.492	20
"	vacuo-compressed	10.503	20
"	liquid	9.51	
Sodium		.9712	20
"	solid	.9519	97.6
"	liquid	.9287	97.6
"		1.0066	−188
Strontium	solid	2.60	
Sulfur	"	2.0–2.1	
	liquid	1.811	113
Tantalum		16.6	
Tellurium	crystallized	6.25	
"	amorphous	6.02	20
Thallium		11.86	
Thorium		11.00	17
Tin	white, cast	7.29	
"	" wrought	7.30	
"	" solid	7.184	226
"	liquid	6.99	226
"	gray	5.8	
Titanium		4.5	18
Tungsten		19.3	
Uranium		18.7	13
Vanadium		5.6	
Xenon	liquid	3.52	109
Yttrium		3.8	
Zinc	cast	7.04–7.16	
"	solid	4.32	−273
"	vacuo-distilled	6.92	20
"	ditto-compressed	7.13	20
"	liquid	6.48	
Zirconium		6.44	

* Where the temperature is not given, ordinary temperature is understood.

TABLE 282.—DENSITY IN g/cm³ AND lb/ft³ OF VARIOUS SOLIDS

NOTE.—The density of a specimen depends considerably on its state and previous treatment; especially is this the case with porous materials.

Material	g/cm³	lb/ft³	Material	g/cm³	lb/ft³
Agate	2.5 –2.7	156–168	Gum arabic	1.3 –1.4	80– 85
Alabaster:			Gypsum	2.31–2.33	144–145
Carbonate	2.69–2.78	168–173	Hematite	4.9 –5.3	306–330
Sulphate	2.26–2.32	141–145	Hornblende	3.0	187
Albite	2.62–2.65	163–165	Ice	.917	57.2
Amber	1.06–1.11	66– 69	Ilmenite	4.5 –5.	280–310
Amphiboles	2.9 –3.2	180–200	Ivory	1.83–1.92	114–120
Anorthite	2.74–2.76	171–172	Labradorite	2.7 –2.72	168–170
Anthracite	1.4 –1.8	87–112	Lava, basaltic	2.8 –3.0	175–185
Asbestos	2.0 –2.8	125–175	" trachytic	2.0 –2.7	125–168
Asphalt	1.1 –1.5	69– 94	Leather, dry	.86	54
Basalt	2.4 –3.1	150–190	" greased	1.02	64
Beeswax	.96– .97	60– 61	Lime, mortar	1.65–1.78	103–111
Beryl	2.69–2.7	168–168	" slaked	1.3 –1.4	81– 87
Biotite	2.7 –3.1	170–190	Limestone	2.68–2.76	167–171
Bone	1.7 –2.0	106–125	Litharge:		
Brick	1.4 –2.2	87–137	Artificial	9.3 –9.4	580–585
Butter	.86– .87	53– 54	Natural	7.8 –8.0	490–500
Calamine	4.1 –4.5	255–280	Magnetite	4.9 –5.2	306–324
Camphor	.99	62	Malachite	3.7 –4.1	231–256
Caoutchouc	.92– .99	57– 62	Marble	2.6 –2.84	160–177
Celluloid	1.4	87	Meerschaum	.99–1.28	62 –80
Cement, set	2.7 –3.0	170–190	Mica	2.6 –3.2	165–200
Chalk	1.9 –2.8	118–175	Muscovite	2.76–3.00	172–225
Charcoal, oak	.57	35	Ochre	3.5	218
" pine	.28– .44	18– 28	Oligoclase	2.65–2.67	165–167
Chrome yellow	6.00	374	Olivine	3.27–3.37	204–210
Chromite	4.32–4.57	270–285	Opal	2.2	137
Cinnabar	8.12	507	Orthoclase	2.58–2.61	161–163
Clay	1.8 –2.6	122–162	Paper	.7 –1.15	44– 72
Coal, soft	1.2 –1.5	75– 94	Paraffin	.87– .91	54– 57
Cocoa butter	.89– .91	56– 57	Peat	.84	52
Coke	1.0 –1.7	62–105	Pitch	1.07	67
Copal	1.04–1.14	65– 71	Porcelain	2.3 –2.5	143–156
Cork	.22– .26	14– 16	Porphyry	2.6 –2.9	162–181
Cork linoleum	.55	34	Pyrite	4.95–5.1	309–318
Corundum	3.9 –4.0	245–250	Quartz	2.65	165
Diamond:			Quartzite	2.73	170
Anthracitic	1.66	104	Resin	1.07	67
Carbonado	3.01–3.25	188–203	Rock salt	2.18	136
Diorite	2.52	157	Rubber, hard	1.19	74
Dolomite	2.84	177	" soft	1.1	69
Ebonite	1.15	72	Rutile	4.2	260
Emery	4.0	250	Sandstone	2.14–2.36	134–147
Epidote	3.25–3.5	203–218	Serpentine	2.50–2.65	156–165
Feldspar	2.55–2.75	159–172	Slag, furnace	2.0 –3.9	125–240
Flint	2.63	164	Slate	2.6 –3.3	162–205
Fluorite	3.18	198	Soapstone	2.6 –2.8	162–175
Gamboge	1.2	75	Starch	1.53	95
Garnet	3.15–4.3	197–268	Sugar	1.61	100
Gas carbon	1.88	117	Talc	2.7 –2.8	168–174
Gelatine	1.27	180	Tallow	.91– .97	57– 60
Glass, common	2.4 –2.8	150–175	Tar	1.02	66
" flint	2.9 –5.9	180–370	Topaz	3.5 –3.6	219–223
Glue	1.27	80	Tourmaline	3.0 –3.2	190–200
Granite	2.64–2.76	165–172	Wax, sealing	1.8	112
Graphite	2.30–2.72	144–170	Zircon	4.68–4.70	292–293

TABLE 283.—DENSITY IN g/cm³ AND lb/ft³ OF VARIOUS ALLOYS

Alloy	g/cm³	lb/ft³
Brasses: yellow, 70Cu + 30Zn, cast	8.44	527
" " " rolled	8.56	534
" " " drawn	8.70	542
" red, 90Cu + 10Zn	8.60	536
" white, 50Cu + 50Zn	8.20	511
Bronzes: 90Cu + 10Sn	8.78	548
" 85Cu + 15Sn	8.89	555
" 80Cu + 20Sn	8.74	545
" 75Cu + 25Sn	8.83	551
German silver: Chinese, 26.3Cu + 36.6Zn + 36.8Ni	8.30	518
" " Berlin (1) 52Cu + 26Zn + 22Ni	8.45	527
" " " (2) 59Cu + 30Zn + 11Ni	8.34	520
" " " (3) 63Cu + 30Zn + 6Ni	8.30	518
" " nickelin	8.77	547
Lead and tin: 87.5Pb + 12.5Sn	10.60	661
" " " 84Pb + 16Sn	10.33	644
" " " 77.8Pb + 22.2Sn	10.05	627
" " " 63.7Pb + 36.3Sn	9.43	588
" " " 46.7Pb + 53.3Sn	8.73	545
" " " 30.5Pb + 69.5Sn	8.24	514
Bismuth, lead, and cadmium: 53Bi + 40Pb + 7Cd	10.56	659
Wood's metal: 50Bi + 25Pb + 12.5Cd + 12.5Sn	9.70	605
Cadmium and tin: 32Cd + 68Sn	7.70	480
Gold and copper: 98Au + 2Cu	18.84	1176
" " " 96Au + 4Cu	18.36	1145
" " " 94Au + 6Cu	17.95	1120
" " " 90Au + 10Cu	17.16	1071
" " " 86Au + 14Cu	16.47	1027
Aluminum and copper: 10Al + 90Cu	7.69	480
" " " 5Al + 95Cu	8.37	522
" " " 3Al + 97Cu	8.69	542
Aluminum and zinc: 91Al + 9Zn	2.80	175
Platinum and iridium: 90Pt + 10Ir	21.62	1348
" " " 85Pt + 15Ir	21.62	1348
" " " 66.67Pt + 33.33Ir	21.87	1364
Carboloy	14.3	895
Constantan: 60Cu + 40Ni	8.88	554
Magnalium: 70Al + 30Mg	2.0	125
Manganin: 84Cu + 12Mn + 4Ni	8.5	530
Monel metal	8.87	554
Platinoid: German silver + little tungsten	9.0	560
Stellite: Co 59.5; Mo 22.5; Cr 10.8; Fe 3.1; Mn 2.0; C .9; Si .8	8 3	518

TABLE 284.—PHYSICAL PROPERTIES OF SOME LIGHT HYDROCARBONS[97]

Hydrocarbon	Formula	Molecular weight	Critical constants: Temperature	Critical constants: Pressure	Specific heats: C_p	Specific heats: C_v	Specific gravity Air = 1.000	Density	Volume gas per kl liquid	Vapor pressure at 20°K	Maximum flame temperature	Heating value after vaporization
			°C	atm	cal g⁻¹	°C⁻¹		kg/m³	m³/kl	atm	°C	kilo cal/m³
Methane	CH_4	16.04	82.1	45.8	.526	.400	.555	.678	—	—	1880	9,000
Ethylene	C_2H_4	28.05	9.72	50.9	.363	.296	.977	1.19	—	—	1975	14,350
Ethane	C_2H_6	30.07	32.3	48.2	.409	.347	1.048	1.282	294.2	38.3	1895	15,900
Propylene	C_3H_6	42.08	91.4	45.4	.363	.316	1.476	1.805	289	10.3	1935	21,100
Propane	C_3H_8	44.09	96.8	42.0	.388	.343	1.550	1.892	268	8.45	1925	22,800
Butadiene-1,3	C_4H_6	54.09	152.0	42.8	.349	.312	1.922	2.35	267	2.45	—	26,400
Butene-1	C_4H_8	56.10	143.9	39.2	.371	.334	1.998	2.44	246	2.6		28,200
cis-Butene-2	C_4H_8	56.10	160	41.5	.350	.315	2.004	2.45	255.5	18.5	1930	28,300
trans-Butene-2	C_4H_8	56.10	155.0	40.5	.376	.342	2.004	2.45	249.0	2.00		28,200
Isobutylene	C_4H_8	56.10	144.7	39.5	.375	.335	1.998	2.44	245.5	2.57	—	28,100
Isobutane	C_4H_{10}	58.12	133.7	36.5	.387	.348	2.077	2.54	222	3.06	1900	30,000
n-Butane	C_4H_{10}	58.12	152.2	37.5	.397	.361	2.084	2.55	229.5	2.13	1895	30,100

[97] Shnidman, Louis (ed.), Gaseous fuels, p. 34, American Gas Assoc., 1948.

TABLE 285.—DENSITY OF VARIOUS NATURAL AND ARTIFICIAL MINERALS

Name and formula	°C	Density in g/cm³	Sp. vol. cm³/g
Oxides			
Corundum Al_2O_3*	(0)	4.02	.249
Lime CaO *	(25)	3.42	.292
Magnesia MgO *	(25)	3.603	.2775
Ferrous oxide FeO *	(20)	5.7	.175
Hematite Fe_2O_3	(20)	5.25	.1905
Magnetite Fe_3O_4	(0)	5.172	.1933
Quartz SiO_2†	(20)	2.649	.3775
" " *	(25)	2.648	.3776
Cristobalite SiO_2	(25)	2.325	.4301
Vitreous silica	(0)	2.203	.4539
Rutile TiO_2	(0)	4.250	.2353
Ilmenite $(FeTi)_2O_3$	(0)	5.088	.1965
Silicates			
Sillimanite $Al_2O_3 \cdot SiO_2$	(25)	3.247	.3080
Mullite $3Al_2O_3 \cdot 2SiO_2$*	(25)	3.156	.3169
Albite $NaAlSi_3O_8$*	(25)	2.62	.382
Anorthite $CaAl_2Si_3O_8$*	(25)	2.757	.3627
Nephelite $NaAlSiO_4$*	(21)	2.619	.3818
Labradorite $Ab_{48}An_{52}$‡	(26)	2.695	.3711
Oligoclase $Ab_{78}An_{22}$‡	(25)	2.638	.3791
Orthoclase $KAlSi_3O_8$	(15)	2.554	.3915
" adularia	(15)	2.566	.3897
Microcline	(25)	2.557	.3911
Calcium orthosilicates			
α — Ca_2SiO_4	(25)	3.26	.307
β — Ca_2SiO_4	(25)	3.27	.306
γ — Ca_2SiO_4	(25)	2.965	.3373
Calcium metasilicates			
α — $CaSiO_3$ (ψ — Wollastonite)*	(25)	2.904	.3444
β — $CaSiO_3$ (pseudo-Wollastonite)	(25)	2.906	.3441
Diopside $CaMgSi_2O_6$	(28)	3.257	.3070
" $CaMgSi_2O_2$*	(25)	3.265	.3063
Enstatite $MgSiO_3$*	(25)	3.166	.3159
" $(MgSiO_3)_{88}(FeSiO_3)_{12}$	(25)	3.254	.3073
Hypersthene $(MgSiO_3)_{70}(FeSiO_3)_{30}$	(29)	3.415	.2928
Forsterite Mg_2SiO_4	(20)	3.223	.3103
Fayalite Fe_2SiO_4*	(15)	4.28	.234
Garnet—grossularite	(31)	3.544	.2822
" almandite	(31)	4.160	.2404
Jadeite	(31)	3.328	.3005
Miscellaneous substances			
Borax, anhydrous, $Na_2B_4O_7$*		2.27	.440
$CaCO_3$; aragonite	(0)	2.932	.3411
$CaCO_3$; calcite	(20)	2.7102	.3688
CaF_2; fluorite	(10)	3.180	.3145
Diamond	(25)	3.516	.2844
NaCl; rock salt	(20)	2.1632	.4623
Na_2SO_4V; thenardite *	(25)	2.664	.3754
Na_2SO_4III *	(25)	2.697	.3708
KCl; fine powder *	(30)	1.984	.5040
Pyrite FeS_2	(25)	5.012	.1995
Marcasite FeS_2	(25)	4.873	.2052

* Artificial. † Natural. ‡ Ab = albite; An = Anorthite.

TABLE 286.—DENSITY OF LIQUIDS

Density or mass in g/cm³ and in lb/ft³ of various liquids.

Liquid	g/cm³	lb/ft³	Temp. °C
Acetone	.792	49.4	20°
Alcohol, ethyl	.807	50.4	0
" methyl	.810	50.5	0
Aniline	1.035	64.5	0
Benzene	.899	56.1	0
Bromine	3.187	199.0	0
Carbolic acid (crude)	.950– .965	59.2–60.2	15
Carbon disulfide	1.293	80.6	0
Chloroform	1.489	93.0	20
Cocoa butter	.857	53.5	100
Ether	.736	45.9	0
Gasoline	.66 – .69	41.0–43.0	...
Glycerine	1.260	78.6	0
Japan wax	.875	54.6	100
Mercury	13.595	849	0
Milk	1.028–1.035	64.2–64.6	...
Naphtha (wood)	.848– .810	52.9–50.5	0
Naphtha (petroleum ether)	.665	41.5	15
Oils: Amber	.800	49.9	15
Anise-seed	.996	62.1	16
Beef-tallow	.931– 938	58.	...
Butterfat	.91 – .92	56.	...
Camphor	.910	56.8	...
Castor	.969	60.5	15
Clove	1.04 –1.06	65. –66.	25
Cocoanut	.925	57.7	15
Cod-liver	.92 – .93	58.	...
Cottonseed	.926	57.8	16
Creosote	1.040–1.100	64.9–68.6	15
Kerosene	.82	51.2	...
Lard	.920	57.4	15
Lavender	.877	54.7	16
Lemon	.844	52.7	16
Linseed (boiled)	.942	58.8	15
Neat's-foot	.913– .917	57.0–57.2	...
Oleomargarine	.92 – .93	...	...
Olive	.918	57.3	15
Palm	.905	56.5	15
Pentane	.650	40.6	0
"	.623	38.9	25
Peppermint	.90 – .92	56–57	25
Petroleum	.878	54.8	0
" (light)	.795– .805	49.6–50.2	15
Pine	.850– .860	53.0–54.0	15
Poppy	.924	57.7	...
Rapeseed (crude)	.915	57.1	15
" (refined)	.913	57.0	15
Resin	.955	59.6	15
Sperm	.88	55.	25
Soya-bean	.919	57.3	30
" "	.906	56.5	90
Train or whale	.918– .925	57.3–57.7	15
Turpentine	.873	54.2	16
Valerian	.965	60.2	16
Wintergreen	1.18	74.	25
Pyroligneous acid	.800	49.9	0
Water	1.000	62.4	4
Sea water	1.025	64.0	...

TABLE 287.—DENSITY OF PURE WATER FREE FROM AIR, 0° TO 41°C

Under standard pressure (76cmHg) at every tenth part of a degree from 0° to 41°C, in g/ml.*

Degrees C	Tenths of degrees 0	1	2	3	4	5	6	7	8	9	Mean differences
0	.999 8681	8747	8812	8875	8936	8996	9053	9109	9163	9216	+ 59
1	9267	9315	9363	9408	9452	9494	9534	9573	9610	9645	+ 41
2	9679	9711	9741	9769	9796	9821	9844	9866	9887	9905	+ 24
3	9922	9937	9951	9962	9973	9981	9988	9994	9998	0000	+ 8
4	1.000 0000	9999	9996	9992	9986	9979	9970	9960	9947	9934	— 8
5	.999 9919	9902	9884	9864	9842	9819	9795	9769	9742	9713	— 24
6	9682	9650	9617	9582	9545	9507	9468	9427	9385	9341	— 39
7	9296	9249	9201	9151	9100	9048	8994	8938	8881	8823	— 53
8	8764	8703	8641	8577	8512	8445	8377	8308	8237	8165	— 67
9	8091	8017	7940	7863	7784	7704	7622	7539	7455	7369	— 81
10	7282	7194	7105	7014	6921	6826	6729	6632	6533	6432	— 95
11	6331	6228	6124	6020	5913	5805	5696	5586	5474	5362	—108
12	5248	5132	5016	4898	4780	4660	4538	4415	4291	4166	—121
13	4040	3912	3784	3654	3523	3391	3257	3122	2986	2850	—133
14	2712	2572	2431	2289	2147	2003	1858	1711	1564	1416	—145
15	1266	1114	0962	0809	0655	0499	0343	0185	0026	9865	—156
16	.998 9705	9542	9378	9214	9048	8881	8713	8544	8373	8202	—168
17	8029	7856	7681	7505	7328	7150	6971	6791	6610	6427	—178
18	6244	6058	5873	5686	5498	5309	5119	4927	4735	4541	—190
19	4347	4152	3955	3757	3558	3358	3158	2955	2752	2549	—200
20	2343	2137	1930	1722	1511	1301	1090	0878	0663	0449	—211
21	0233	0016	9799	9580	9359	9139	8917	8694	8470	8245	—221
22	.997 8019	7792	7564	7335	7104	6873	6641	6408	6173	5938	—232
23	5702	5466	5227	4988	4747	4506	4264	4021	3777	3531	—242
24	3286	3039	2790	2541	2291	2040	1788	1535	1280	1026	—252
25	0770	0513	0255	9997	9736	9476	9214	8951	8688	8423	—261
26	.996 8158	7892	7624	7356	7087	6817	6545	6273	6000	5726	—271
27	5451	5176	4898	4620	4342	4062	3782	3500	3218	2935	—280
28	2652	2366	2080	1793	1505	1217	0928	0637	0346	0053	—289
29	.995 9761	9466	9171	8876	8579	8282	7983	7684	7383	7083	—298
30	6780	6478	6174	5869	5564	5258	4950	4642	4334	4024	—307
31	3714	3401	3089	2776	2462	2147	1832	1515	1198	0880	—315
32	0561	0241	9920	9599	9276	8954	8630	8304	7979	7653	—324
33	.994 7325	6997	6668	6338	6007	5676	5345	5011	4678	4343	—332
34	4007	3671	3335	2997	2659	2318	1978	1638	1296	0953	—340
35	0610	0267	9922	9576	9230	8883	8534	8186	7837	7486	—347
36	.993 7136	6784	6432	6078	5725	5369	5014	4658	4301	3943	—355
37	3585	3226	2866	2505	2144	1782	1419	1055	0691	0326	—362
38	.992 9960	9593	9227	8859	8490	8120	7751	7380	7008	6636	—370
39	6263	5890	5516	5140	4765	4389	4011	3634	3255	2876	—377
40	2497	2116	1734	1352	0971	0587	0203	9818	9433	9047	—384
41	.991 8661										

* According to P. Chappuis, Bureau International des Poids et Mesures.

TABLE 288.—VOLUME IN cm³ AT VARIOUS TEMPERATURES OF A cm³ OF WATER FREE FROM AIR AT THE TEMPERATURE OF MAXIMUM DENSITY, 0° to 36°C

Temp. °C	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.000132	125	118	112	106	100	095	089	084	079
1	073	069	064	059	055	051	047	043	039	035
2	032	029	026	023	020	018	016	013	011	009
3	008	006	005	004	003	002	001	001	000	000
4	000	000	000	001	001	002	003	004	005	007
5	008	010	012	014	016	018	021	023	026	029
6	032	035	039	042	046	050	054	058	062	066
7	070	075	080	085	090	095	101	106	112	118
8	124	130	137	142	149	156	162	169	176	184
9	191	198	206	214	222	230	238	246	254	263
10	272	281	290	299	308	317	327	337	347	357
11	367	377	388	398	409	420	430	441	453	464
12	476	487	499	511	522	534	547	559	571	584
13	596	609	623	636	649	661	675	688	702	715
14	729	743	757	772	786	800	815	830	844	859
15	873	890	905	920	935	951	967	983	998	015
16	1.001031	047	063	080	097	113	130	147	164	182
17	198	216	233	252	269	287	305	323	341	358
18	378	396	415	433	452	471	490	510	529	548
19	568	588	606	626	646	667	687	707	728	748
20	769	790	811	832	853	874	895	916	938	960
21	981	002	024	046	068	091	113	135	158	181
22	1.002203	226	249	271	295	319	342	364	389	412
23	436	459	483	507	532	556	581	605	629	654
24	679	704	729	754	779	804	829	854	879	905
25	932	958	983	010	036	061	088	115	141	168
26	1.003195	221	248	275	302	330	357	384	412	439
27	467	495	523	550	579	607	635	663	692	720
28	749	776	806	836	865	893	922	951	981	011
29	1.004041	069	100	129	160	189	220	250	280	310
30	341	371	403	432	464	494	526	557	588	619
31	651	682	713	744	777	808	840	872	904	936
32	968	001	033	066	098	132	163	197	229	263
33	1.005296	328	361	395	427	461	496	530	562	597
34	631	665	698	732	768	802	836	871	904	940
35	975	009	044	078	115	150	185	219	255	290

TABLE 289.—INFLUENCE OF PRESSURE ON VOLUME OF WATER *

kg/cm²	0°C	20°C	40°C	kg/cm²	20°C	40°C
1	1.0000	1.0016	1.0076	7,000	.8404	.8485
500	.9771	.9808	.9873	8,000	.8275	.8360
1,000	.9578	.9630	.9700	9,000	.8160	.8249
2,000	.9260	.9327	.9403	10,000	—	.8149
3,000	.9015	.9087	.9164	11,000	—	.8056
5,000	.8632	.8702	.8778	12,000	—	.7966
6,000	.8480	.8545	.8623	12,500	—	.7922

* Cf. Table 269.

TABLE 290.—DENSITY AND VOLUME OF WATER −10° TO +250°C

The mass of 1 cm^3 at 4°C is taken as unity.

Temp. °C	Density	Volume	Temp. °C	Density	Volume	Temp. °C	Density	Volume
−10	.99815	1.00186	**+20**	.99823	1.00177	**+50**	.98807	1.01207
− 9	843	157	21	802	198	51	762	254
− 8	869	131	22	780	220	52	715	301
− 7	892	108	23	757	244	53	669	349
− 6	912	088	24	733	268	54	621	398
− 5	.99930	1.00070	**25**	.99708	1.00293	**55**	.98573	1.01448
− 4	945	055	26	682	320	60	324	705
− 3	958	042	27	655	347	65	059	979
− 2	970	031	28	627	375	70	.97781	1.02270
− 1	979	021	29	598	404	75	489	576
+ 0	.99987	1.00013	**30**	.99568	1.00434	**80**	.97183	1.02899
1	993	007	31	537	465	85	.96865	1.03237
2	997	003	32	506	497	90	534	590
3	999	001	33	473	530	95	192	959
4	1.00000	1.00000	34	440	563	100	.95838	1.04343
5	.99999	1.00001	**35**	.99406	1.00598	**110**	.9510	1.0515
6	997	003	36	371	633	120	.9434	1.0601
7	993	007	37	336	669	130	.9352	1.0693
8	988	012	38	300	706	140	.9264	1.0794
9	981	019	39	263	743	150	.9173	1.0902
10	.99973	1.00027	**40**	.99225	1.00782	**160**	.9075	1.1019
11	963	037	41	187	821	170	.8973	1.1145
12	952	048	42	147	861	180	.8866	1.1279
13	940	060	43	107	901	190	.8750	1.1429
14	927	073	44	066	943	200	.8628	1.1590
15	.99913	1.00087	**45**	.99025	1.00985	**210**	.850	1.177
16	897	103	46	.98982	1.01028	220	.837	1.195
17	880	120	47	940	072	230	.823	1.215
18	862	138	48	896	116	240	.809	1.236
19	843	157	49	852	162	250	.794	1.259

Density or mass in g/cm³ and the volume in cm³ of 1 g of mercury.

Temp. °C	Mass g/cm³	Volume of 1 g in cm³	Temp. °C	Mass g/cm³	Volume of 1 g in cm³	Temp. °C	Mass g/cm³	Volume of 1 g in cm³
—10	13.6198	.0734225	**20**	13.5458	.0738233	**140**	13.2563	.0754354
— 9	6173	4358	21	5434	8367	150	2326	5708
— 8	6148	4492	22	5409	8501	160	2090	7064
— 7	6124	4626	23	5385	8635	170	1853	8422
— 6	6099	4759	24	5360	8768	180	1617	9784
— 5	13.6074	.0734893	**25**	13.5336	.0738902	**190**	13.1381	.0761149
— 4	6050	5026	26	5311	9036	200	1145	2516
— 3	6025	5160	27	5287	9170	210	0910	3886
— 2	6000	5293	28	5262	9304	220	0677	5260
— 1	5976	5427	29	5238	9437	230	0440	6637
— 0	13.5951	.0735560	**30**	13.5213	.0739572	**240**	13.0206	.0768017
1	5926	5694	31	5189	9705	250	12.9972	9402
2	5901	5828	32	5164	9839	260	9738	7090
3	5877	5961	33	5140	9973	270	9504	2182
4	5852	6095	34	5116	40107	280	9270	3579
5	13.5827	.0736228	**35**	13.5091	.0740241	**290**	12.9036	.0774979
6	5803	6362	36	5066	0374	300	8803	6385
7	5778	6496	37	5042	0508	310	8569	7795
8	5754	6629	38	5018	0642	320	8336	9210
9	5729	6763	39	4994	0776	330	8102	80630
10	13.5704	.0736893	**40**	13.4969	.0740910	**340**	12.7869	.0782054
11	5680	7030	50	4725	2250	350	7635	3485
12	5655	7164	60	4482	3592	360	7402	4921
13	5630	7298	70	4240	4936			
14	5606	7431	80	3998	6282			
15	13.5581	.0737565	**90**	13.3723	.0747631			
16	5557	7699	100	3515	8981			
17	5532	7832	110	3279	50305			
18	5507	7966	120	3040	1653			
19	5483	8100	130	2801	3002			

The following table gives the density of solutions of various salts in water. The numbers give the weight in g/cm³. For brevity the substance is indicated by formula only.

Substance	Weight of the dissolved substance in 100 parts by weight of the solution									Temp. °C
	5	10	15	20	25	30	40	50	60	
K_2O	1.047	1.098	1.153	1.214	1.284	1.354	1.503	1.659	1.809	15.
KOH	1.040	1.082	1.127	1.176	1.229	1.286	1.410	1.538	1.666	15.
Na_2O	1.073	1.144	1.218	1.284	1.354	1.421	1.557	1.689	1.829	15.
NaOH	1.058	1.114	1.169	1.224	1.279	1.331	1.436	1.539	1.642	15.
NH_3	.978	.959	.940	.924	.909	.896	—	—	—	16.
NH_4Cl	1.015	1.030	1.044	1.058	1.072	—	—	—	—	15.
KCl	1.031	1.065	1.099	1.135	—	—	—	—	—	15.
NaCl	1.035	1.072	1.110	1.150	1.191	—	—	—	—	15.
LiCl	1.029	1.057	1.085	1.116	1.147	1.181	1.255	—	—	15.
$CaCl_2$	1.041	1.086	1.132	1.181	1.232	1.286	1.402	—	—	15.
$CaCl_2+6H_2O$	1.019	1.040	1.061	1.083	1.105	1.128	1.176	1.225	1.276	18.
$AlCl_3$	1.030	1.072	1.111	1.153	1.196	1.241	1.340	—	—	15.
$MgCl_2$	1.041	1.085	1.130	1.177	1.226	1.278	—	—	—	15.
$MgCl_2+6H_2O$	1.014	1.032	1.049	1.067	1.085	1.103	1.141	1.183	1.222	24.
$ZnCl_2$	1.043	1.089	1.135	1.184	1.236	1.289	1.417	1.563	1.737	19.5
$CdCl_2$	1.043	1.087	1.138	1.193	1.254	1.319	1.469	1.653	1.887	19.5
$SrCl_2$	1.044	1.092	1.143	1.198	1.257	1.321	—	—	—	15.
$SrCl_2+6H_2O$	1.027	1.053	1.082	1.111	1.042	1.174	1.242	1.317	—	15.
$BaCl_2$	1.045	1.094	1.147	1.205	1.269	—	—	—	—	15.
$BaCl_2+2H_2O$	1.035	1.075	1.119	1.166	1.217	1.273	—	—	—	21.
$CuCl_2$	1.044	1.091	1.155	1.221	1.291	1.360	1.527	—	—	17.5
$NiCl_2$	1.048	1.098	1.157	1.223	1.299	—	—	—	—	17.5
$HgCl_2$	1.041	1.092	—	—	—	—	—	—	—	20.
Fe_2Cl_6	1.041	1.086	1.130	1.179	1.232	1.290	1.413	1.545	1.668	17.5
$PtCl_4$	1.046	1.097	1.153	1.214	1.285	1.362	1.546	1.785	—	—
$SnCl_2+2H_2O$	1.032	1.067	1.104	1.143	1.185	1.229	1.329	1.444	1.580	15.
$SnCl_4+5H_2O$	1.029	1.058	1.089	1.122	1.157	1.193	1.274	1.365	1.467	15.
LiBr	1.033	1.070	1.111	1.154	1.202	1.252	1.366	1.489	—	19.5
KBr	1.035	1.073	1.114	1.157	1.205	1.254	1.364	—	—	19.5
NaBr	1.038	1.078	1.123	1.172	1.224	1.279	1.408	1.563	—	19.5
$MgBr_2$	1.041	1.085	1.135	1.189	1.245	1.308	1.449	1.623	—	19.5
$ZnBr_2$	1.043	1.091	1.144	1.202	1.263	1.328	1.473	1.648	1.873	19.5
$CdBr_2$	1.041	1.088	1.139	1.197	1.258	1.324	1.479	1.678	—	19.5
$CaBr_2$	1.042	1.087	1.137	1.192	1.250	1.313	1.459	1.639	—	19.5
$BaBr_2$	1.043	1.090	1.142	1.199	1.260	1.327	1.483	1.683	—	19.5
$SrBr_2$	1.043	1.089	1.140	1.198	1.260	1.328	1.489	1.693	1.953	19.5
KI	1.036	1.076	1.118	1.164	1.216	1.269	1.394	1.544	1.732	19.5
LiI	1.036	1.077	1.122	1.170	1.222	1.278	1.412	1.573	1.775	19.5
NaI	1.038	1.080	1.126	1.177	1.232	1.292	1.430	1.598	1.808	19.5
ZnI_2	1.043	1.089	1.138	1.194	1.253	1.316	1.467	1.648	1.873	19.5
CdI_2	1.042	1.086	1.135	1.192	1.251	1.317	1.474	1.678	—	19.5
MgI_2	1.041	1.086	1.137	1.192	1.252	1.318	1.472	1.666	1.913	19.5
CaI_2	1.042	1.088	1.138	1.196	1.258	1.319	1.475	1.663	1.908	19.5
SrI_2	1.043	1.089	1.140	1.198	1.260	1.328	1.489	1.693	1.953	19.5
BaI_2	1.043	1.089	1.141	1.199	1.263	1.331	1.493	1.702	1.968	19.5
$NaClO_3$	1.035	1.068	1.106	1.145	1.188	1.233	1.329	—	—	19.5
$NaBrO_3$	1.039	1.081	1.127	1.176	1.229	1.287	—	—	—	19.5
KNO_3	1.031	1.064	1.099	1.135	—	—	—	—	—	15.
$NaNO_3$	1.031	1.065	1.101	1.140	1.180	1.222	1.313	1.416	—	20.2
$AgNO_3$	1.044	1.090	1.140	1.195	1.255	1.322	1.479	1.675	1.918	15.

(continued)

Substance	Weight of the dissolved substance in 100 parts by weight of the solution: 5	10	15	20	25	30	40	50	60	Temp. °C
NH_4NO_3	1.020	1.041	1.063	1.085	1.107	1.131	1.178	1.229	1.282	17.5
$Zn(NO_3)_2$	1.048	1.095	1.140	1.201	1.263	1.325	1.456	1.597	—	17.5
$Zn(NO_3)_2+6H_2O$	—	1.054	—	1.113	—	1.178	1.250	1.329	—	14.
$Ca(NO_3)_2$	1.037	1.075	1.118	1.162	1.211	1.260	1.367	1.482	1.604	17.5
$Cu(NO_3)_2$	1.044	1.093	1.143	1.203	1.263	1.328	1.471	—	—	17.5
$Sr(NO_3)_2$	1.039	1.083	1.129	1.179	—	—	—	—	—	19.5
$Pb(NO_3)_2$	1.043	1.091	1.143	1.199	1.262	1.332	—	—	—	17.5
$Cd(NO_3)_2$	1.052	1.097	1.150	1.212	1.283	1.355	1.536	1.759	—	17.5
$Co(NO_3)_2$	1.045	1.090	1.137	1.192	1.252	1.318	1.465	—	—	17.5
$Ni(NO_3)_2$	1.045	1.090	1.137	1.192	1.252	1.318	1.465	—	—	17.5
$Fe_2(NO_3)_6$	1.039	1.076	1.117	1.160	1.210	1.261	1.373	1.496	1.657	17.5
$Mg(NO_3)_2+6H_2O$	1.018	1.038	1.060	1.082	1.105	1.129	1.179	1.232	—	21.
$Mn(NO_3)_2+6H_2O$	1.025	1.052	1.079	1.108	1.138	1.169	1.235	1.307	1.386	8.
K_2CO_3	1.044	1.092	1.141	1.192	1.245	1.300	1.417	1.543	—	15.
$K_2CO_3+2H_2O$	1.037	1.072	1.110	1.150	1.191	1.233	1.320	1.415	1.511	15.
$Na_2CO_310H_2O$	1.019	1.038	1.057	1.077	1.098	1.118	—	—	—	15.
$(NH_4)_2SO_4$	1.027	1.055	1.084	1.113	1.142	1.170	1.226	1.287	—	19.
$Fe_2(SO_4)_3$	1.045	1.096	1.150	1.207	1.270	1.336	1.489	—	—	18.
$FeSO_4+7H_2O$	1.025	1.053	1.081	1.111	1.141	1.173	1.238	—	—	17.2
$MgSO_4$	1.051	1.104	1.161	1.221	1.284	—	—	—	—	15.
$MgSO_4+7H_2O$	1.025	1.050	1.075	1.101	1.129	1.155	1.215	1.278	—	15.
$Na_2SO_4+10H_2O$	1.019	1.039	1.059	1.081	1.102	1.124	—	—	—	15.
$CuSO_4+5H_2O$	1.031	1.064	1.098	1.134	1.173	1.213	—	—	—	18.
$MnSO_4+4H_2O$	1.031	1.064	1.099	1.135	1.174	1.214	1.303	1.398	—	15.
$ZnSO_4+7H_2O$	1.027	1.057	1.089	1.122	1.156	1.191	1.269	1.351	1.443	20.5
$Fe_2(SO_4)_3 \cdot K_2SO_4+24H_2O$	1.026	1.045	1.066	1.088	1.112	1.141	—	—	—	17.5
$Cr_2(SO_4)_3 \cdot K_2SO_4+24H_2O$	1.016	1.033	1.051	1.073	1.099	1.126	1.188	1.287	1.454	17.5
$MgSO_4+K_2SO_4+6H_2O$	1.032	1.066	1.101	1.138	—	—	—	—	—	15.
$(NH_4)_2SO_4+FeSO_4+6H_2O$	1.028	1.058	1.090	1.122	1.154	1.191	—	—	—	19.
K_2CrO_4	1.039	1.082	1.127	1.174	1.225	1.279	1.397	—	—	19.5
$K_2Cr_2O_7$	1.035	1.071	1.108	—	—	—	—	—	—	19.5
$Fe(Cy)_6K_4$	1.028	1.059	1.092	1.126	—	—	—	—	—	15.
$Fe(Cy)_6K_3$	1.025	1.053	1.070	1.113	—	—	—	—	—	13.
$Pb(C_2H_3O_2)_2+3H_2O$	1.031	1.064	1.100	1.137	1.177	1.220	1.315	1.426	—	15.
$2NaOH+As_2O_5+24H_2O$	1.020	1.042	1.066	1.089	1.114	1.140	1.194	—	—	14.

Substance	5	10	15	20	30	40	60	80	100	Temp. °C
SO_3	1.040	1.084	1.132	1.179	1.277	1.389	1.564	1.840	—	15.
SO_2	1.013	1.028	1.045	1.063	—	—	—	—	—	4.
N_2O_5	1.033	1.069	1.104	1.141	1.217	1.294	1.422	1.506	—	15.
$C_4H_6O_6$	1.021	1.047	1.070	1.096	1.150	1.207	—	—	—	15.
$C_6H_8O_7$	1.018	1.038	1.058	1.079	1.123	1.170	1.273	—	—	15.
Cane sugar	1.019	1.039	1.060	1.082	1.129	1.178	1.289	—	—	17.5
HCl	1.025	1.050	1.075	1.101	1.151	1.200	—	—	—	15.
HBr	1.035	1.073	1.114	1.158	1.257	1.376	—	—	—	14.
HI	1.037	1.077	1.118	1.165	1.271	1.400	—	—	—	13.
H_2SO_4	1.032	1.069	1.106	1.145	1.223	1.307	1.501	1.732	1.838	15.
H_2SiF_6	1.040	1.082	1.127	1.174	1.273	—	—	—	—	17.5
P_2O_5	1.035	1.077	1.119	1.167	1.271	1.385	1.676	—	—	17.5
$P_2O_5+3H_2O$	1.027	1.057	1.086	1.119	1.188	1.264	1.438	—	—	15.
HNO_3	1.028	1.056	1.088	1.119	1.184	1.250	1.373	1.459	1.528	15.
$C_2H_4O_2$	1.007	1.014	1.021	1.028	1.041	1.052	1.068	1.075	1.055	15.

TABLE 293.—DENSITY OF MIXTURES OF ETHYL ALCOHOL AND WATER IN g/ml

The densities in this table are numerically the same as specific gravities at the various temperatures in terms of water at 4°C as unity. Based upon work done at the National Bureau of Standards.

Percent C_2H_5OH by weight	Temperatures 10°C	15°C	20°C	25°C	30°C	35°C	40°C
0	.99973	.99913	.99823	.99708	.99568	.99406	.99225
1	785	725	636	520	379	217	034
2	602	542	453	336	194	031	.98846
3	426	365	275	157	014	.98849	663
4	258	195	103	.98984	.98839	672	485
5	098	032	.98938	817	670	501	311
6	.98946	.98877	780	656	507	335	142
7	801	729	627	500	347	172	.97975
8	660	584	478	346	189	009	808
9	524	442	331	193	031	.97846	641
10	393	304	187	043	.97875	685	475
11	267	171	047	.97897	723	527	312
12	145	041	.97910	753	573	371	150
13	026	.97914	775	611	424	216	.96989
14	.97911	790	643	472	278	063	829
15	800	669	514	334	133	.96911	670
16	692	552	387	199	.96990	760	512
17	583	433	259	062	844	607	352
18	473	313	129	.96923	697	452	189
19	363	191	.96997	782	547	294	023
20	252	068	864	639	395	134	.95856
21	139	.96944	729	495	242	.95973	687
22	024	818	592	348	087	809	516
23	.96907	689	453	199	.95929	643	343
24	787	558	312	048	769	476	168
25	665	424	168	.95895	607	306	.94991
26	539	287	020	738	442	133	810
27	406	144	.95867	576	272	.94955	625
28	268	.95996	710	410	098	774	438
29	125	844	548	241	.94922	590	248
30	.95977	686	382	067	741	403	055
31	823	524	212	.94890	557	214	.93860
32	665	357	038	709	370	021	662
33	502	186	.94860	525	180	.93825	461
34	334	011	679	337	.93986	626	257
35	162	.94832	494	146	790	425	051
36	.94986	650	306	.93952	591	221	.92843
37	805	464	114	756	390	016	634
38	620	273	.93910	556	186	.92808	422
39	431	079	720	353	.92979	597	208
40	238	.93882	518	148	770	385	.91992
41	042	682	314	.92940	558	170	774
42	.93842	478	107	729	344	.91952	554
43	639	271	.92897	516	128	733	332
44	433	062	685	301	.91910	513	108
45	226	.92852	472	085	692	291	.90884
46	017	640	257	.91868	472	069	660
47	.92806	426	041	649	250	.90845	434
48	593	211	.91823	429	028	621	207
49	379	.91995	604	208	.90805	396	.89979
50	162	776	384	.90985	580	168	750

(continued)

TABLE 293.—DENSITY OF MIXTURES OF ETHYL ALCOHOL AND WATER IN g/ml (concluded)

Percent C_2H_5OH by weight	Temperatures 10°C	15°C	20°C	25°C	30°C	35°C	40°C
50	.92162	.91776	.91384	.90985	.90580	.90168	.89750
51	.91943	555	160	760	353	.89940	519
52	723	333	.90936	534	125	710	288
53	502	110	711	307	.89896	479	056
54	279	.90885	485	079	667	248	.88823
55	055	659	258	.89850	437	016	589
56	.90831	433	031	621	206	.88784	356
57	607	207	.89803	392	.88975	552	122
58	381	.89980	574	162	744	319	.87888
59	154	752	344	.88931	512	085	653
60	.89927	523	113	699	278	.87851	417
61	698	293	.88882	466	044	615	180
62	468	062	650	233	.87809	379	.86943
63	237	.88830	417	.87998	574	142	705
64	006	597	183	763	337	.86905	466
65	.88774	364	.87948	527	100	667	227
66	541	130	713	291	.86863	429	.85987
67	308	.87895	477	054	625	190	747
68	074	660	241	.86817	387	.85950	507
69	.87839	424	004	579	148	710	266
70	602	187	.86766	340	.85908	470	025
71	365	.86949	527	100	667	228	.84783
72	127	710	287	.85859	426	.84986	540
73	.86888	470	047	618	184	743	297
74	648	229	.85806	376	.84941	500	053
75	408	.85988	564	134	698	257	.83809
76	168	747	322	.84891	455	013	564
77	.85927	505	079	647	211	.83768	319
78	685	262	.84835	403	.83966	523	074
79	442	018	590	158	720	277	.82827
80	197	.84772	344	.83911	473	029	578
81	.84950	525	096	664	224	.82780	329
82	702	277	.83848	415	.82974	530	079
83	453	028	599	164	724	279	.81828
84	203	.83777	348	.82913	473	027	576
85	.83951	525	095	660	220	.81774	322
86	697	271	.82840	405	.81965	519	067
87	441	014	583	148	708	262	.80811
88	181	.82754	323	.81888	448	003	552
89	.82919	492	062	626	186	.80742	291
90	654	227	.81797	362	.80922	478	028
91	386	.81959	529	094	655	211	.79761
92	114	688	257	.80823	384	.79941	491
93	.81839	413	.80983	549	111	669	220
94	561	134	705	272	.79835	393	.78947
95	278	.80852	424	.79991	555	114	670
96	.80991	566	138	706	271	.78831	388
97	698	274	.79846	415	.78981	542	100
98	399	.79975	547	117	684	247	.77806
99	094	670	243	.78814	382	.77946	507
100	.79784	360	.78934	506	075	641	203

TABLE 294.—DENSITY OF AQUEOUS MIXTURES OF METHYL ALCOHOL, CANE SUGAR, OR SULFURIC ACID

Percent by weight of substance	Methyl alcohol $D \frac{15°}{4°} C$	Cane sugar 20°	Sulfuric acid $D \frac{20°}{4°} C$	Percent by weight of substance	Methyl alcohol $D \frac{15°}{4°} C$	Cane sugar 20°	Sulfuric acid $D \frac{20°}{4°} C$
0	.99913	.998234	.99823	50	.91852	1.229567	1.39505
1	.99727	1.002120	1.00506	51	.91653	1.235085	1.40487
2	.99543	1.006015	1.01178	52	.91451	1.240641	1.41481
3	.99370	1.009934	1.01839	53	.91248	1.246234	1.42487
4	.99198	1.013881	1.02500	54	.91044	1.251866	1.43503
5	.99029	1.017854	1.03168	55	.90839	1.257535	1.44530
6	.98864	1.021855	1.03843	56	.90631	1.263243	1.45568
7	.98701	1.025885	1.04527	57	.90421	1.268989	1.46615
8	.98547	1.029942	1.05216	58	.90210	1.274774	1.47673
9	.98394	1.034029	1.05909	59	.89996	1.280595	1.48740
10	.98241	1.038143	1.06609	60	.89781	1.286456	1.49818
11	.98093	1.042288	1.07314	61	.89563	1.292354	1.50904
12	.97945	1.046462	1.08026	62	.89341	1.298291	1.51999
13	.97802	1.050665	1.08744	63	.89117	1.304267	1.53102
14	.97650	1.054900	1.09468	64	.88890	1.310282	1.54213
15	.97518	1.059165	1.10199	65	.88662	1.316334	1.55333
16	.97377	1.063460	1.10936	66	.88433	1.322425	1.56460
17	.97237	1.067789	1.11679	67	.88203	1.328554	1.57595
18	.97096	1.072147	1.12428	68	.87971	1.334722	1.58739
19	.96955	1.076537	1.13183	69	.87739	1.340928	1.59890
20	.96814	1.080959	1.13943	70	.87507	1.347174	1.61048
21	.96673	1.085414	1.14709	71	.87271	1.353456	1.62213
22	.96533	1.089900	1.15480	72	.87033	1.359778	1.63384
23	.96392	1.094420	1.16258	73	.86792	1.366139	1.64560
24	.96251	1.098971	1.17041	74	.86546	1.372536	1.65738
25	.96108	1.103557	1.17830	75	.86300	1.378971	1.66917
26	.95963	1.108175	1.18624	76	.86051	1.385446	1.68095
27	.95817	1.112828	1.19423	77	.85801	1.391956	1.69268
28	.95668	1.117512	1.20227	78	.85551	1.398505	1.70433
29	.95518	1.122231	1.21036	79	.85300	1.405091	1.71585
30	.95366	1.126984	1.21850	80	.85048	1.411715	1.72717
31	.95213	1.131773	1.22669	81	.84794	1.418374	1.73827
32	.95056	1.136596	1.23492	82	.84536	1.425072	1.74904
33	.94896	1.141453	1.24320	83	.84274	1.431807	1.75943
34	.94734	1.146345	1.25154	84	.84009	1.438579	1.76932
35	.94570	1.151275	1.25992	85	.83742	1.445388	1.77860
36	.94404	1.156238	1.26836	86	.83475	1.452232	1.78721
37	.94237	1.161236	1.27685	87	.83207	1.459114	1.79509
38	.94067	1.166269	1.28543	88	.82937	1.466032	1.80223
39	.93894	1.171340	1.29407	89	.82667	1.472986	1.80864
40	.93720	1.176447	1.30278	90	.82396	1.479976	1.81438
41	.93543	1.181592	1.31157	91	.82124	1.487002	1.81950
42	.93365	1.186773	1.32043	92	.81849	1.494063	1.82401
43	.93185	1.191993	1.32938	93	.81568	1.501158	1.82790
44	.93001	1.197247	1.33843	94	.81285	1.508289	1.83115
45	.92815	1.202540	1.34759	95	.80999	1.515455	1.83368
46	.92627	1.207870	1.35686	96	.80713	1.522656	1.83548
47	.92436	1.213238	1.36625	97	.80428	1.529891	1.83637
48	.92242	1.218643	1.37574	98	.80143	1.537161	1.83605
49	.92048	1.224086	1.38533	99	.79859	1.544462	
50	.91852	1.229567	1.39505	100	.79577	1.551800	

TABLE 295.—DENSITY, BRIX, AND BAUMÉ DEGREES, OF CANE-SUGAR SOLUTIONS

Degrees Brix, specific gravity, and degrees Baumé of sugar solutions.
Degrees Brix = percent sucrose by weight.

Specific gravities and degrees Baumé corresponding to the degrees Brix are for $\frac{20°}{20°}$ C.

The relation between the specific gravity and degrees Baumé is given by degrees Baumé = $145 - \frac{145}{\text{specific gravity}}$

Degrees Brix or percent sucrose by weight	Specific gravity at 20°/20°C	Degrees Baumé (modulus 145)	Degrees Brix or percent sucrose by weight	Specific gravity at 20°/20°C	Degrees Baumé (modulus 145)	Degrees Brix or percent sucrose by weight	Specific gravity at 20°/20°C	Degrees Baumé (modulus 145
.0	1.00000	.00	40.0	1.17853	21.97	80.0	1.41421	42.47
1.0	1.00389	.56	41.0	1.18368	22.50	81.0	1.42088	42.95
2.0	1.00779	1.12	42.0	1.18887	23.04	82.0	1.42759	43.43
3.0	1.01172	1.68	43.0	1.19410	23.57	83.0	1.43434	43.91
4.0	1.01567	2.24	44.0	1.19936	24.10	84.0	1.44112	44.38
5.0	1.01965	2.79	45.0	1.20467	24.63	85.0	1.44794	44.86
6.0	1.02366	3.35	46.0	1.21001	25.17	86.0	1.45480	45.33
7.0	1.02770	3.91	47.0	1.21538	25.70	87.0	1.46170	45.80
8.0	1.03176	4.46	48.0	1.22080	26.23	88.0	1.46862	46.27
9.0	1.03586	5.02	49.0	1.22625	26.75	89.0	1.47559	46.73
10.0	1.03998	5.57	50.0	1.23174	27.28	90.0	1.48259	47.20
11.0	1.04413	6.13	51.0	1.23727	27.81	91.0	1.48963	47.66
12.0	1.04831	6.68	52.0	1.24284	28.33	92.0	1.49671	48.12
13.0	1.05252	7.24	53.0	1.24844	28.86	93.0	1.50381	48.58
14.0	1.05677	7.79	54.0	1.25408	29.38	94.0	1.51096	49.03
15.0	1.06104	8.34	55.0	1.25976	29.90	95.0	1.51814	49.49
16.0	1.06534	8.89	56.0	1.26548	30.42	96.0	1.52535	49.94
17.0	1.06968	9.45	57.0	1.27123	30.94	97.0	1.53260	50.39
18.0	1.07404	10.00	58.0	1.27703	31.46	98.0	1.53988	50.84
19.0	1.07844	10.55	59.0	1.28286	31.97	99.0	1.54719	51.28
20.0	1.08287	11.10	60.0	1.28873	32.49	100.0	1.55454	51.73
21.0	1.08733	11.65	61.0	1.29464	33.00			
22.0	1.09183	12.20	62.0	1.30059	33.51			
23.0	1.09636	12.74	63.0	1.30657	34.02			
24.0	1.10092	13.29	64.0	1.31260	34.53			
25.0	1.10551	13.84	65.0	1.31866	35.04			
26.0	1.11014	14.39	66.0	1.32476	35.55			
27.0	1.11480	14.93	67.0	1.33090	36.05			
28.0	1.11949	15.48	68.0	1.33708	36.55			
29.0	1.12422	16.02	69.0	1.34330	37.06			
30.0	1.12898	16.57	70.0	1.34956	37.56			
31.0	1.13378	17.11	71.0	1.35585	38.06			
32.0	1.13861	17.65	72.0	1.36218	38.55			
33.0	1.14347	18.19	73.0	1.36856	39.05			
34.0	1.14837	18.73	74.0	1.37496	39.54			
35.0	1.15331	19.28	75.0	1.38141	40.03			
36.0	1.15828	19.81	76.0	1.38790	40.53			
37.0	1.16329	20.35	77.0	1.39442	41.01			
38.0	1.16833	20.89	78.0	1.40098	41.50			
39.0	1.17341	21.43	79.0	1.40758	41.99			

TABLE 296.—VELOCITY OF SOUND IN GASES [98]

Gas	Temp. °C	Velocity m/sec	Gas	Temp. °C	Velocity m/sec
Air, dry, 1 atm	0	331.7	Hydrogen bromide	0	200
" " 25 "	0	332.0	Hydrogen chloride	0	296
" " 50 "	0	334.7	Hydrogen iodide	0	157
" " 100 "	0	350.6	Hydrogen sulfide	0	289
" "	100	386	Illuminating gas	0	490.4
" "	500	553	Methane	0	430
" "	1000	700	Neon	0	435
Ammonia	0	415	Nitric oxide	10	324
Argon	0	319	Nitrogen	0	334
Carbon dioxide	0	259	Nitrous oxide	0	263
Carbon monoxide	0	338	Oxygen	0	316
Chlorine	0	206	Silicon tetrafluoride	0	167
Ethane	10	308	Sulfur dioxide	0	213
Ethylene	0	317	Vapors:		
Helium	0	965	alcohol	0	230.6
Hydrogen (heavy)	0	890	ether	0	179.2
Hydrogen (light)	0	1284	water	0	401
			"	100	404.8

* Tables 296 and 298-300 prepared by Urick and Weissler, Naval Research Laboratory.
[98] Bergmann, Ultrasonics, 3d ed., p. 223, Edwards Brothers, Ann Arbor, Mich., 1944.

TABLE 297.—VELOCITY OF SOUND IN SOLIDS

The velocity of sounds in solids varies as $\sqrt{E/\rho}$, where E is Young's modulus of elasticity and ρ the density. These constants for most materials vary through a somewhat wide range. The numbers can be taken only as rough approximations to the velocity in any particular case. When temperatures are not marked, between 10° and 20° is to be understood.

Substance	t°C	v m/sec	Substance	t°C	v m/sec
Ag hard	20	2678	Fe	200	4720
" "	100	2640	"	20	4990
" "	200	2480	"	100	4920
Al		5104	"	200	4790
Au hard	20	1743	Mg		4602
" "	100	1720	Ni		4973
Cd		2307	Pb		1322
Co		4724	Pd		3150
Cu	20	3560	Pt	20	2690
"	100	3290	"	100	2570
"	200	2950	"	200	2460
Fe	20	5130	Sn		2500
"	100	5300	Zn		3700
Ash, along the fiber		4670	Brick		3652
" across the rings		1390	Clay rock		3480
" along the rings		1260	Cork		500
Beech, along the fiber		3340	Granite		3950
" across the rings		1840	Marble		3810
" along the rings		1415	Paraffin	15	1304
Elm, along the fiber		4120	Slate		4510
" across the rings		1420	Tallow	16	390
" along the rings		1013	Tuff		2850
Fir, along the fiber		4640	Glass from		5000
Mahogany, along the fiber		4135	Glass to		6000
Maple, along the fiber		4110	Ivory		3013
Oak, along the fiber		3850	Vul. rubber (black)	0	54
Pine, along the fiber		3320	" " "	50	31
Poplar, along the fiber		4280	" " (red)	0	69
Sycamore, along the fiber		4460	" " "	70	34
			Wax	17	880
			"	28	441

TABLE 298.—VELOCITY OF SOUND IN LIQUIDS[99]

Liquid	Temperature °C	Sound velocity m/sec	Density g/ml	Liquid	Temperature °C	Sound velocity m/sec	Density g/ml
Acetone [c]	30	1146	.7788	Silicon tetrachloride [a]	30	766.2	1.4622
Alcohol, abs. ethyl [a]	30	1127.4	.7809	Silicone			
Alcohol methyl [a]	30	1088.9	.7816	DC 500-.65 cs [a]	30	873.2	.7535
Alcohol, n-dodecyl [a]	30	1388.0	.8269	DC 500-5.0 cs [a]	30	953.8	.9083
Benzene [d]	30	1276.4	.8685	DC 500-50 cs [a]	30	981.6	.9540
Carbon disulfide [b]	23	1149	1.258	Sorbitol, 83% solution			
Carbon tetrachloride [a]	30	905.8	1.5746	in water [a]	30	2040	1.31
Chloroform [b]	20	1002	1.488	Turpentine [b]	27	1280	.893
Ether [c]	30	949	.7019	Water (distilled) [e]	0	1403.5	
Ethylene glycol [a]	30	1643.5	1.1068		10	1448.0	
Glycerine [c]	30	1905	1.2553		20	1483.1	
Heptane [c]	30	1112	.6751		30	1509.9	
Heptene [d]	30	1082	.6910		40	1529.5	
Heptyne [a]	30	1159.3	.7243		50	1543.5	
Hexadecafluoro-					60	1551.5	
heptane [d]	30	528.8	1.64		70	1555.3	
Mercury [b]	20	1451	13.595		80	1554.6	
Methylene iodide [d]	20	973.3	3.325		86	1552.4	
					94	1549.0	

[99] References: a, Weissler, A., Journ. Amer. Chem. Soc., 1948 and 1949; also unpublished work with V. A. Del Grosso. b, Bergmann, L., Ultrasonics, 3d ed., p. 175, Edwards Brothers, Ann Arbor, Mich., 1944. c, Rao, M. R., Ind. Journ. Phys., vol. 14, p. 109, 1940. d, Lagemann, R. J., et al., Journ. Chem. Phys., vol. 16, p. 247, 1948; Journ. Amer. Chem. Soc., vol. 70, p. 2994, 1948. e, Randall, C. R., Nat. Bur. Standards Journ. Res., vol. 8, p. 95, 1932.

TABLE 299.—VELOCITY OF SOUND IN SEA WATER

(From various tables and formulae)

Depth in meters	°C	Sal. ppt	Meters per second: Heck & Service	Wood	Br. Adm. 1927	Br. Adm. 1939	Kuwahara
0	0	31	1445	1445	1440.3	1440.2	1440.3
"	10	"	1482	1484	1481.9	1481.9	1482.0
"	20	"	1508	1515	1514.3	1514.3	1514.3
"	30	"	—	1538	1539.0	1538.9	1539.1
0	0	35	1450	1450	1445.3	1445.4	1445.5
"	10	"	1489	1488	1486.6	1486.7	1486.8
"	20	"	1514	1519	1518.6	1518.7	1518.7
"	30	"	—	1543	1543.0	1543.1	1543.2
400	0	35	1454	—	1452.6	1452.7	1452.8
"	10	"	1492	—	1493.8	1493.9	1494.1
"	20	"	1518	—	1525.8	1525.9	1525.9
"	30	"	—	—	1550.3	1550.4	1550.6
3000	0	31	1490	—	1494.7	1494.6	1494.4
"	"	35	1498	—	1499.7	1499.8	1499.8

(From Kuwahara)

°C	Meters per second				
	S* = 31 ppt	S = 31 ppt	S = 35 ppt	S = 37 ppt	S = 39 ppt
0	1440.3	1442.9	1445.5	1448.1	1450.7
1	44.8	47.4	50.0	52.6	55.2
2	49.4	51.9	54.5	57.1	59.6
3	53.8	56.4	58.9	61.4	64.0
4	58.1	60.6	63.1	65.6	68.1
5	1462.3	1464.8	1467.3	1469.8	1472.3
6	66.5	68.9	71.4	73.9	76.3
7	70.5	73.0	75.4	77.9	80.3
8	74.5	76.9	79.3	81.7	84.2
9	78.3	80.7	83.1	85.5	87.9
10	1482.0	1484.4	1486.8	1489.2	1491.6
11	85.7	88.0	90.4	92.8	95.1
12	89.2	91.6	93.9	96.3	98.6
13	92.7	95.0	97.3	99.6	1502.0
14	96.0	98.3	1500.6	1502.9	05.2
15	1499.3	1501.6	1503.9	1506.2	1508.5
16	1502.5	04.7	07.0	09.3	11.5
17	05.6	07.9	10.1	12.3	14.6
18	08.6	10.8	13.0	15.2	17.5
19	11.5	13.7	15.9	18.1	20.3
20	1514.3	1516.5	1518.7	1520.9	1523.1
21	17.2	19.3	21.5	23.7	25.9
22	19.8	22.0	24.1	26.3	28.4
23	22.4	24.6	26.7	28.8	31.0
24	25.0	27.1	29.2	31.3	33.5
25	1527.5	1529.6	1531.7	1533.8	1535.9
26	29.9	32.0	34.1	36.2	38.3
27	32.3	34.3	36.4	38.5	40.6
28	34.6	36.6	38.7	40.8	42.9
29	36.9	39.0	41.0	43.1	45.1
30	1539.1	1541.2	1543.2	1545.3	1547.3

* Salinity (parts per thousand).

TABLE 301.—RELATIVE POWER AND FREQUENCY OF OCCURRENCE OF VOWEL AND CONSONANT SOUNDS[100]

Vowels

Vowel indicated by italics in words	Relative power	Relative frequency of occurrence	Vowel indicated by italics in words	Relative power	Relative frequency of occurrence
s*ee*	220	6.4	s*aw*	680	4.2
s*i*t	260	10.3	t*o*ne	470	4.7
h*a*te	370	4.8	f*oo*t	460	3.0
l*e*t	350	6.6	s*oo*n	310	6.3
s*a*t	490	6.9	s*u*n	510	4.1
f*a*ther	600	6.5			

Initial and final consonants

Consonant	Relative power	Relative frequency of occurrence: Initial	Final	Consonant	Relative power	Relative frequency of occurrence: Initial	Final
p	6	2.5	1.2	s	16	5.5	3.1
b	7	4.6	.4	z	16	.3	6.0
k	13	5.6	2.9	zh (azure)	20	.02	.01
g	15	4.3	.4	sh	80	1.7	.3
t	15	7.9	14.3	m	52	5.9	5.5
d	7	6.2	4.4	n	36	5.0	12.5
f	5	5.0	12.5	ng	73	...	3.6
v	12	1.3	4.2	l	100	4.3	8.4
th (voiced)	11	6.7	1.3	r	210	2.8	13.1
th (unvoiced)	1	6.7	1.3	ch	42	.6	.5
				j	23	.8	.1

* Data selected and arranged by Cyril M. Harris, Bell Telephone Laboratories.
[100] Fletcher, H., Speech and hearing, p. 74, D. VanNostrand, 1929. French, Carter, and Koenig, Bell System Techn. Journ., vol. 9, p. 290, 1930.

TABLE 302.—SOUND LEVELS OF NOISE IN VARIOUS LOCATIONS

It is customary to compare the pressure of all sounds in air with 0.0002 dynes/cm². The *sound-pressure level* of waves having a r.m.s. sound pressure of p dynes/cm² is defined as 20 $\log_{10}(p/0.0002)$ decibels.†

The following table gives some typical values of sound levels of noise in the locations indicated:

Location	Sound level in db	Location	Sound level in db
Electric power station, generating room	120	Average office	55
Boiler factory	110	Average residence with radio	50
Subway station, train passing	100	Average residence without radio	43
Streetcar	85	Quiet residence	35
Factory	75	Radio broadcast studio	30
Large store	65	Reference level, .0002 dynes/cm²	0

† The bel is a dimensionless unit for expressing the ratio of two values of power, the number of bels being the logarithm to the base 10 of the power ratio.

The decibel, abbreviated db, is one-tenth of a bel. When conditions are such that scalar ratios of pressure amplitudes or particle velocities are the square roots of the corresponding power ratios, the number of decibels by which the corresponding powers differ is expressed by

$$20 \log (p_1/p_2) \text{ db}$$

where p_1/p_2 represents the scalar ratio. This relationship is frequently applied where the scalar ratio is not the square root of the corresponding power ratio, but such usage should be accompanied by a specific statement of application.

TABLE 302A.—SPEECH POWER (Fig. 1)

In a study conducted by Dunn and White,[101] the "long-time-interval average" power of speech, obtained by averaging data over time intervals of more than a minute of continuous speech, for the average of a group of male speakers was found to be 34 microwatts. The corresponding value for female speakers was 18 microwatts. At least 1 percent of the ⅛-second intervals had an average power in excess of 230 microwatts for men and 150 microwatts for women, and a peak power in excess of 3600 microwatts for men and 1800 microwatts for women. The figure shows how the total power of average conversational speech is distributed with respect to frequency. These data give the power per cycles versus frequency and also the percentage power lying below a given frequency.

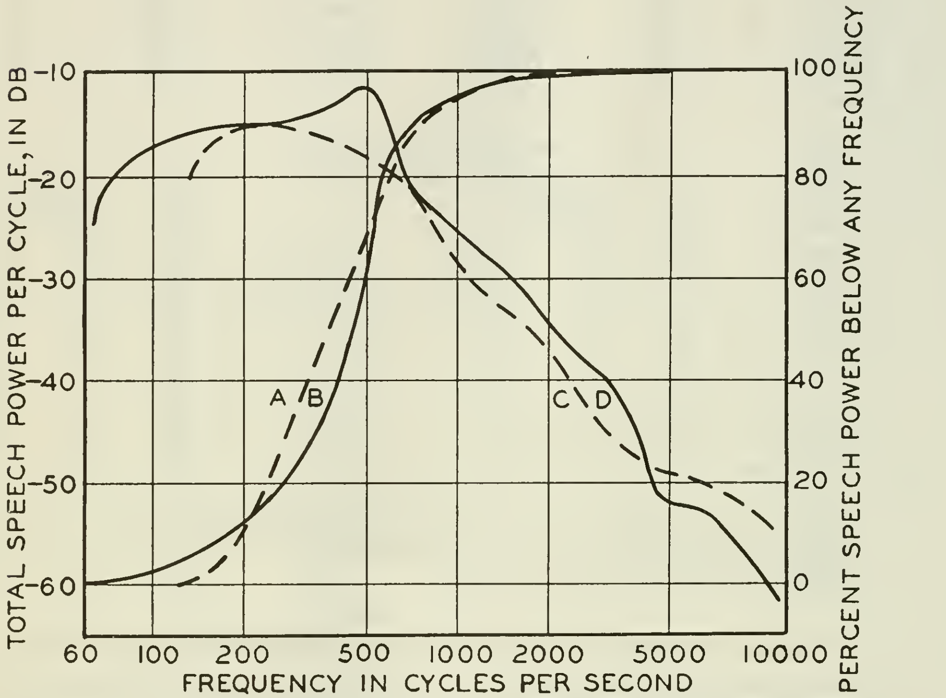

FIG. 1.—Speech power for men (continuous curves) and women (dotted curves) given in percentage power below any frequency. Curves A and B, power per cycle, curves C and D, O db = 1 microwatt.

[101] Dunn, H. K., and White, S. D., Journ. Accoust. Soc. Amer., vol. 11, p. 278, 1940.

TABLE 303.—PEAK POWER OF MUSICAL INSTRUMENTS[102]

	Watts		Watts		Watts
Orchestra, 75 pieces	70	Cymbals	10	Piccolo	.08
Bass drum, large	25	Trombone	6	Flute	.06
Pipe organ	13	Piano	.3	Clarinet	.05
Snare drum	12	Trumpet	.3	French horn	.05
		Bass viol	.2	Triangle	.05

[102] Sivian, L. J., Dunn, H. K., and White, S. D., Journ. Acoust. Soc. Amer., vol. 2, p. 330, 1931.

TABLE 304.—CHARACTERISTIC RESONANCE VALUES OF SPOKEN VOWELS[103]

The "pitch" of one's voice, i.e., his fundamental frequency, fluctuates considerably during conversational speech, and there is a great deal of variation from individual to individual. The average fundamental frequency for the average male voice in conversational English speech is in the neighborhood of 130 cps, while the corresponding value for the female voice is 230 cps.

The vocal cords, housed in the larynx, emit a pressure wave that is essentially "sawtooth" in character. The numerous harmonics that result from this complex wave form are selectively transmitted to the open air. The throat, mouth, nose, and constrictions formed by the tongue and lips are most important in determining the frequency characteristics of the transmission system. The pressure spectrum of speech has many peaks. Apparently vowel sounds are distinguished by the position of these resonant peaks. The following table gives representative frequencies of the first two principal resonant peaks for different vowel sounds spoken by the average male adult:

Vowel indicated by italics in the words	Frequency of 1st principal resonant peak cps	Frequency of 2d principal resonant peak cps	Vowel indicated by italics in the words	Frequency of 1st principal resonant peak cps	Frequency of 2d principal resonant peak cps
s*ee*	290	2375	s*aw*	600	900
s*i*t	440	2050	f*oo*t	500	1050
l*e*t	585	1875	s*oo*n	330	900
s*a*t	725	1675	s*u*n	650	1225
f*a*ther	780	1125	s*i*r	475	1375

[103] Potter, R. K., and Peterson, G. E., Journ. Acoust. Soc. Amer., vol. 20, p. 528, 1948.

TABLE 305.—APPROXIMATE RANGE OF FUNDAMENTAL FREQUENCY ON ORCHESTRAL INSTRUMENTS

The values given are for average instruments in tune with A440 cps. The lower frequency limits of some special instruments are indicated in brackets.

Instrument	Frequency range in cps: Lower limit	Upper limit	Instrument	Frequency range in cps: Lower limit	Upper limit
Violin	195	2093	B♭ tenor saxophone	103	623
Viola	131	1318	E♭ baritone saxophone	69	416
Cello	65	880	Trumpet	164	1047
Bass (32)	41	262	French horn	61	699
Piccolo	587	4186	Trombone (51)	82	524
Flute	261	2043	Bass tuba	41	234
Oboe	233	1397	Piano	27	4186
English horn	164	934	Organ (16)	32	4186
Clarinet (138)	146	1568	Harp	32	3136
Bass clarinet (65)	73	467	Soprano voice	261	1568
Bassoon	58	623	Tenor voice	123	1174
Contra bassoon	30	175	Alto voice	174	933
E♭ alto saxophone	138	831	Baritone voice	98	416
			Bass voice	65	294

The following definitions and Tables 307 and 308 are taken from the American Standard Acoustical Terminology Z24.1, 1949.

Just scale.—A just scale is a musical scale such that the frequency intervals are represented by the ratios of small integers.

Equally tempered scale.—An equally tempered scale is a series of notes selected from a division of the octave (usually) into 12 equal intervals.

Equally tempered semitone (half-step).—An equally tempered semitone is the interval between two sounds whose basic frequency ratio is the twelfth root of two.

NOTE.—The interval, in semitones, between any two frequencies is 12 times the logarithm on the base 2 of the frequency ratio.

Cent.—A cent is the interval between two sounds whose basic frequency ratio is the twelve-hundredth root of two.

NOTE.—The interval, in cents, between any two frequencies is 1200 times the logarithm on the base 2 of the frequency ratio. Thus, 1200 cents = 12 semitones = 1 octave.

TABLE 306.—FREQUENCY RATIOS AND INTERVALS FOR JUST AND EQUALLY TEMPERED SCALES

	Just temperament		Equal temperament	
Interval from starting point	Frequency ratio from starting point	Cents from starting point	Frequency ratio from starting point	Cents from starting point
Unison	1:1	0	1:1	0
Minor second or semitone	16:15	111.731	1.059463:1	100
Minor tone	10:9	182.404	—	—
Major second or whole tone	9:8	203.910	1.122462:1	200
Minor third	6:5	315.641	1.189207:1	300
Major third	5:4	386.314	1.259921:1	400
Perfect fourth	4:3	398.045	1.334840:1	500
Augmented fourth	45:32	590.224	1.414214:1	600
Diminished fifth	64:45	609.777	1.414214:1	600
Perfect fifth	3:2	701.955	1.498397:1	700
Minor sixth	8:5	813.687	1.587401:1	800
Major sixth	5:3	884.359	1.681793:1	900
Harmonic minor seventh	7:4	968.826	—	—
Grave minor seventh	16:9	996.091	—	—
Minor seventh	9:5	1017.597	1.781797:1	1000
Major seventh	15:8	1088.269	1.887749:1	1100
Octave	2:1	1200.000	2:1	1200

TABLE 307.—FREQUENCIES OF THE TONES OF THE USUAL EQUALLY TEMPERED SCALE, ARRANGED BY CORRESPONDING PIANO KEY NUMBERS, AND CALCULATED ACCORDING TO AMERICAN STANDARD PITCH

Note name	Key No.	Freq. cps	Key No.	Freq. cps	Key No.	Freq. cps	Key No.	Freq. cps	Key No.	Freq. cps	Key No.	Freq. cps	Key No.	Freq. cps	Key No.	Freq. cps	Note name
A	1	27.500	13	55.000	25	110.000	37	220.000	49	440.000	61	880.000	73	1760.000	85	3520.000	A
A♯–B♭	2	29.135	14	58.270	26	116.541	38	233.082	50	466.164	62	932.328	74	1864.655	86	3729.310	A♯–B♭
B	3	30.868	15	61.735	27	123.471	39	246.942	51	493.883	63	987.767	75	1975.533	87	3951.066	B
C	4	32.703	16	65.406	28	130.813	40	261.626	52	523.251	64	1046.502	76	2093.005	88	4186.009	C
C♯–D♭	5	34.648	17	69.296	29	138.591	41	277.183	53	554.365	65	1108.731	77	2217.461			C♯–D♭
D	6	36.708	18	73.416	30	146.832	42	293.665	54	587.330	66	1174.659	78	2349.318			D
D♯–E♭	7	38.891	19	77.782	31	155.563	43	311.127	55	622.254	67	1244.508	79	2489.016			D♯–E♭
E	8	41.203	20	82.407	32	164.814	44	329.628	56	659.255	68	1318.510	80	2637.021			E
F	9	43.654	21	87.307	33	174.614	45	349.228	57	698.456	69	1396.913	81	2793.826			F
F♯–G♭	10	46.249	22	92.499	34	184.997	46	369.994	58	739.989	70	1479.978	82	2959.955			F♯–G♭
G	11	48.999	23	97.999	35	195.998	47	391.995	59	783.991	71	1567.982	83	3135.964			G
G♯–A♭	12	51.913	24	103.826	36	207.652	48	415.305	60	830.609	72	1661.219	84	3322.438			G♯–A♭

TABLE 308.—PRESSURE FIELD AROUND THE HUMAN HEAD DURING SPEECH[104]

The following data describe the pressure field around the head of a speaker at a radius of 30 cm from the speaker's lips. The sound-pressure level is given for 13 frequency bands, and for all the bands, i.e., "whole speech," in db above the sound-pressure level in the same bands at the point (30 cm, O, O). These data give the pressure distribution in the horizontal plane $\phi = 0$, and the relative pressures overhead.

Azimuth θ (Degrees)	Altitude ϕ (Degrees)	Whole-speech	Band No. 2 62.5-125	Band No. 3 125-250	Band No. 4 250-500	Band No. 5 500-700	Band No. 6 700-1000	Band No. 7 1000-1400	Band No. 8 1400-2000	Band No. 9 2000-2800	Band No. 10 2800-4000	Band No. 11 4000-5600	Band No. 12 5600-8000	Band No. 13 8000-12000
0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
45	0	− .1	− .1	+ .6	+ .1	.0	.0	−1.2	− .8	− 2.5	+ .6	− 2.9	+ .5	− 2.4
90	0	− .4	− .2	− .3	−1.2	+ .3	+1.4	−3.7	− 4.1	− 7.9	− 2.5	− 5.2	− 3.5	− 4.9
135	0	−3.0	− .2	−2.5	−3.6	−1.5	−1.7	−4.3	− 5.4	− 9.1	−12.6	−14.9	−12.7	−14.6
180	0	−4.9	− .6	−4.6	−5.3	−3.3	−3.8	−5.1	−12.4	−14.8	−17.2	−18.6	−21.3	−16.1
—	+90	−2.6	−1.6	−1.9	−2.4	−2.4	−2.3	−3.0	− 4.5	− 3.2	− 2.0	− 7.7	− 5.2	− .9

[104] Dunn, H. K., and Farnsworth, D. W., Journ. Acoust. Soc. Amer., vol. 10, p. 184, 1939.

The minimum effective sound pressure of a specified signal that is capable of evoking an auditory sensation is called the threshold of audibility for that signal. The characteristics of the signal, the manner in which it is presented to the listener, and the point at which the sound pressure is measured must be specified. Two classes of ear-sensitivity determinations are shown in figure 2. M.A.P. is just-audible sound pressure measured at the observer's ear drum. M.A.F. is the sound pressure level that is just audible to an observer in an acoustical field free of reflecting surfaces (the sound-pressure level is measured after the observer's head is withdrawn from the field); the observer faces the source of sound and listens binaurally. These curves were derived by Sivian and White from measurements on young adult observers all having very good hearing.[105] The average person cannot detect pressures as low as those given. He will have a threshold curve displaced upward on the chart. (See Table 309A for data on hearing losses.)

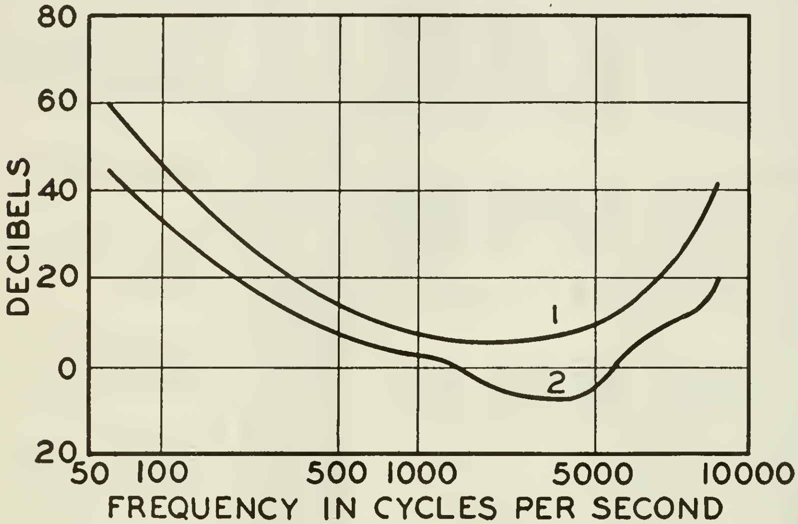

FIG. 2.—The variation of two classes of ear sensitivity. Curve 1, Monaural M.A.P. The ordinate for curve 1 is 20 $\log_{10} p/p_0$ where $p =$ M.A.P. at ear drum (dyne/cm^2) and $p_0 = 2 \times 10^{-4}$ (dyne/cm^2). Curve 2, Binaural M.A.F. Observer facing source. (0 db $= 10^{-16}$ watts/cm^2).

The term "differential sensitivity of frequency and intensity" refers to the smallest changes in frequency and intensity, respectively, that can be perceived by an observer with normal hearing. The values depend to some extent on the method of presentation of the test stimuli. For pure tones above 500 cps having levels greater than 40 db above threshold, the measurements of Shower and Biddulph indicate that the smallest perceptible difference in frequency has the approximate constant value of 0.3 percent. For levels greater than 40 db above threshold and for frequencies between 200 and 7000 cps, the measurements of Riesz and others indicate that the smallest perceptible difference in intensity varies from one-quarter to three-quarters of a decibel.

The range of frequency perceived by the average ear varies considerably; however, the figures of 20–20,000 cycles are frequently quoted as covering the range heard by the average of a group of young adults having no hearing impairments

[105] Sivian, L. J., and White, S. D., Journ. Acoust. Soc. Amer., vol. 4, p. 228, 1933.

TABLE 309A.—DISTRIBUTION OF LOSS OF HEARING ACUITY[106]

The following data are part of the results of the hearing tests conducted by the Bell System at the New York and San Francisco World's Fairs in 1939. The first four columns indicate the percentages of the population having hearing losses of 25 db or more at various frequencies. A person having a loss of 25 db at all frequencies below 2000 cps may experience difficulty in understanding unamplified speech, as in an auditorium or church. The second four columns indicate the corresponding percentages for losses of 45 db or more. A person having such a loss experiences difficulty in understanding ordinary conversational speech at distances greater than 2 or 3 feet.

	25-db loss Frequency in cps				45-db loss Frequency in cps		
Age group	440;880	1760	3520	7040	440;880	1760	3520
10–19 men	1.7	1.6	4.5	8.0	.6	.6	1.8
women	1.8	1.2	1.2	2.5	.6	.4	.3
20–29 men	1.1	1.2	7.0	9.5	.1	.3	2.7
women	1.8	1.6	2.2	3.5	.4	.3	.7
30–39 men	1.8	3.5	15.	19.	.3	.6	6.0
women	3.5	3.5	5.5	10.	1.2	.8	1.6
40–49 men	5.5	9.5	32.	39.	1.4	2.6	16.
women	7.0	7.0	11.	24.	2.1	1.5	3.
50–59 men	9.5	17.	48.	58.	2.6	6.0	27.
women	13.	14.	22.	43.	4.0	3.0	7.

[106] Steinberg, Montgomery, and Gardner, Journ. Acoust. Soc. Amer., vol. 12, p. 291, 1940.

TABLE 310.—ARCHITECTURAL ACOUSTICS[107]

Planning for good acoustics in a building requires careful consideration of noise control. This includes consideration of the selection of a site, the arrangement of the rooms within the building, the selection of the proper sound-insulation constructions, and the control of noise sources within the building. The design of a room where people gather to listen to speech or music should be such that its shape and size will ensure the most advantageous flow of properly diffused sound to all auditors. Absorptive and reflective materials and constructions should be selected and distributed to provide the optimum conditions for the growth, decay, and steady-state distribution of sound in the room. The reverberation characteristics of the room are controlled by the amount and placement of the absorptive material.

Reverberation time calculations.—Because of the importance of the proper control of reverberation in rooms, a standard of measure called reverberation time has been established. This is the time required for a specified sound to die away to one-thousandth of its initial pressure, which corresponds to a drop in sound-pressure level of 60 db. The reverberation time of a room is given by the following equation:

$$T = \frac{0.049V \quad 6}{-2.30\ S\ \log_{10}\ (1-\overline{\alpha}) + 4mV}$$

where V is the volume of the room, S is the total surface area in square feet, and $\overline{\alpha}$ is the average absorption coefficient for the room given by

$$\overline{\alpha} = \frac{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots\ldots}{S_1 + S_2 + S_3 + \ldots\ldots} = \frac{a}{S}$$

where α_1 is the absorption coefficient of the area S_1, etc.

The second term in the denominator, $4mV$, represents the effective absorption in the room contributed by the air. The attenuation coefficient m at each frequency depends upon the humidity and temperature of the air. Except in very large rooms the absorption in air can be neglected below about 2000 cps. The values of m for a temperature 68°F are given in figure 3 as a function of relative humidity for a number of frequencies.

[107] Taken from Acoustical designing in architecture, by V. O. Knudsen and C. M. Harris, John Wiley & Sons, 1949. Used by permission of the publishers.

(continued)

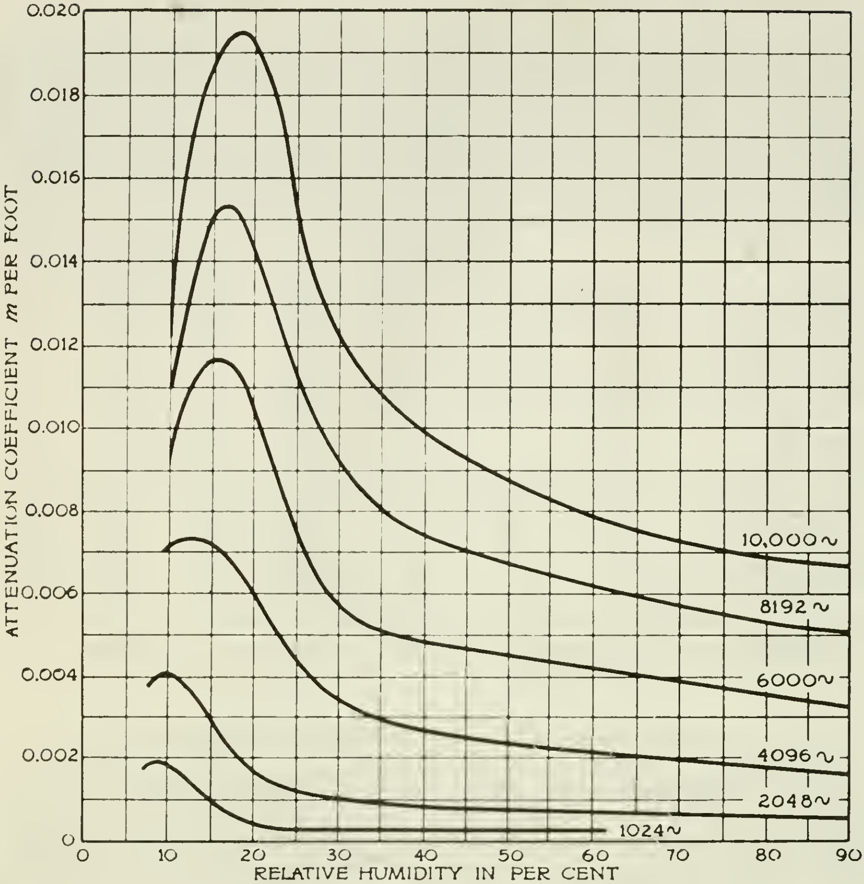

FIG. 3.—Attenuation coefficient *m* per foot as a function of humidity.

TABLE 310A.—OPTIMUM REVERBERATION TIME (FIGS. 4 AND 5)

The following figures give the recommendations of Knudsen and Harris for optimum reverberation time for different types of rooms as a function of room volume. The optimum times for speech rooms, motion-picture theaters, and school auditoriums are given by a single line; the optimum time for music by a broad band. The optimum reverberation time is not the same for all kinds of music. For example, slow organ and choral music require more reverberation than does a brilliant allegro composition played on woodwinds, piano, or harpsicord.

The optimum reverberation time vs. frequency characteristic for a room can be obtained from these charts in the following manner: After having specified the volume and purpose of the room, determine the optimum reverberation time at 512 cycles from the upper chart. Then, to obtain optimum reverberation time at any other frequencies multiply the 512-cycle value by the appropriate ratio R which is given in the lower chart. Note that R is unity for frequencies above 500 cycles, and is given by a band for frequencies below 500 cycles. The ratio R for large rooms may have any value within the indicated band; preferred ratios for small rooms are given by the lower part of the band.

(continued)

TABLE 310A.—OPTIMUM REVERBERATION TIME (FIGS. 4 AND 5) (concluded)

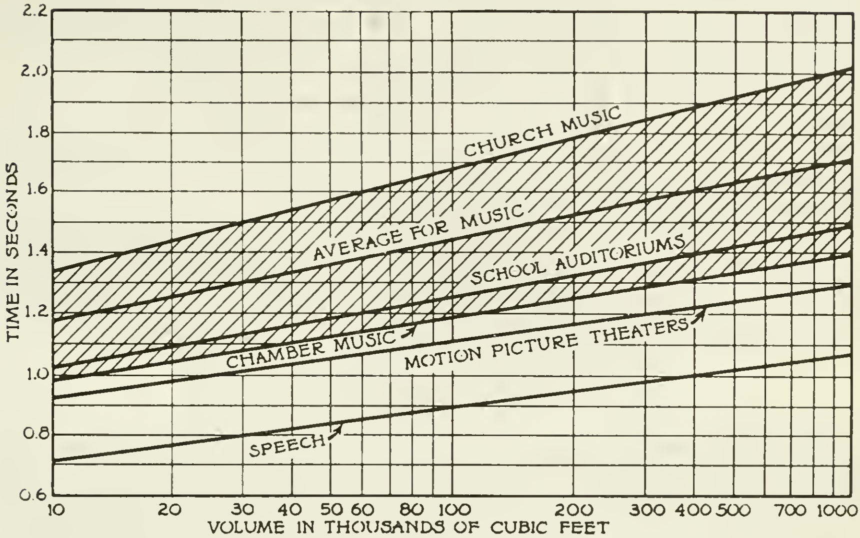

Fig. 4.—Optimum reverberation time as a function of volume of rooms for various types of sound for a frequency of about 512 cycles per second.

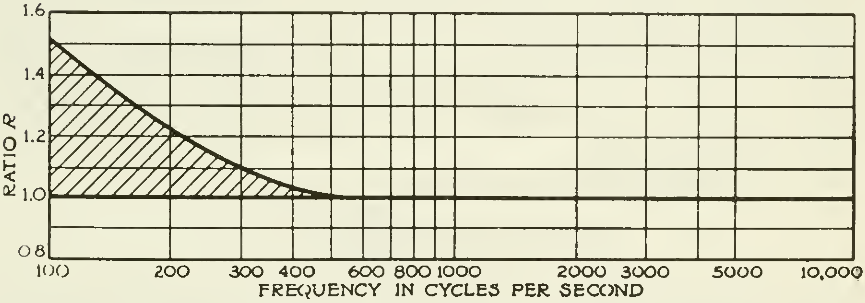

Fig. 5.—Ratio of the reverberation time for various frequencies as a function of the reverberation for 512 cycles per second.

TABLES 311-338.—VISCOSITY OF FLUIDS AND SOLIDS *

The coefficient of viscosity of a substance is the tangential force required to move a unit area of a plane surface with unit speed relative to another parallel plane surface from which it is separated by a layer of the substance a unit thick. Viscosity measures the temporary rigidity it gives to the substance.

Fluidity is the reciprocal of viscosity expressed in poises. Kinematic viscosity is absolute viscosity divided by density. Specific viscosity is viscosity relative to that of some standard substance, generally water at some definite temperature. The dimensions of viscosity are $ML^{-1}T^{-1}$. It is generally expressed in cgs units as dyne-second per cm^2 or poises.

The viscosity of fluids is generally measured by one of several methods depending on the magnitude of the viscosity value to be measured. For vapors and gases as well as for liquids of low viscosity, measurements of viscosity are made by the rate of flow of the fluid through a capillary tube whose length is great in comparison with its diameter. The equation generally used is

$$\eta\text{, the viscosity, } = \frac{\gamma \pi g d^4 t}{128 Q (l+\lambda)}\left(h - \frac{mv^2}{g}\right),$$

where γ is the density (g/cm^3), d and l are respectively the diameter and length in cm of the tube, Q the volume in cm^3 discharged in t sec, λ the Couette correction to the measured length of the tube, h the average head in cm, m the coefficient of kinetic energy correction, mv^2/g, necessary for the loss of energy due to turbulent, in distinction from viscous, flow, g being the acceleration of gravity (cm/sec^2), v the mean velocity in cm/sec. (See Herschel, Nat. Bur. Standards Techn. Pap. Nos. 100 and 112, 1917-1918, for discussion of this correction and λ.)

For liquids of medium and high values of viscosity measurements are made by Margule's method of observing the torque on the inner of two concentric cylinders while the outer is rotated with constant angular speed with the viscous liquid filling the space between, or by noting the rate of fall of a solid sphere through the liquid.

For the method of concentric cylinders the equation is

$$\eta\text{, the viscosity, } = \frac{K\theta(R_1^2 - R_2^2)}{4\pi\Omega R_1^2\, R_2^2\, L},$$

where K denotes the elastic constant of the torsion member supporting the inner cylinder of radius R_2 cm and length L cm, θ is the angular displacement of the inner cylinder from its position of equilibrium, Ω the angular speed of the outer rotating cylinder of radius R_1 cm in the corresponding units employed to measure θ. The necessary corrections due to end effects of cylinders of finite length are given in the reference.[108]

For the falling sphere method, the equation is that of Stokes law as modified by R. G. Hunter: [109]

$$\eta\text{, the viscosity, } = \frac{2}{9}\frac{R^2(d_1 - d_2)}{V}\,\frac{\left(1 - \frac{R^{2.25}}{\gamma}\right)}{\left(1 + 3.3\frac{R}{h}\right)},$$

where γ denotes the radius in cm of the crucible containing the liquid of density d_2 (g/cm^3), to a depth of h cm, R the radius in cm of the sphere of density d_1 (g/cm^3), and V the velocity (cm/sec) of the falling sphere.

* The data on viscosity were selected and arranged by George V. McCauley, Corning Glass Works.

[108] Lillie, H. R., Journ. Amer. Cer. Soc., vol. 12, p. 505, 1929.

[109] Hunter, R. G., Journ. Amer. Cer. Soc., vol. 17, p. 123, 1934; Ann. d. Phys., ser. 4, vol. 22, p. 287, 1907; vol. 23, p. 447, 1907.

For very viscous materials, measurements of viscosity are made by noting the rate of elongation of fibers under load or by observing the aperiodic motion of an elastic system displaced from its position of equilibrium and damped by the viscous material.

The formula for the rate of elongation of fibers as employed by H. R. Lillie [110] is

$$\eta \text{, the viscosity, } = \frac{L \times g \times k}{3\pi R^2 E},$$

where R is the radius in cm of the fiber of effective length, L (cm), g the mass in grams of the attached load, k the acceleration of gravity (cm/sec^2), and E the rate of elongation in cm/sec.

For the aperiodic motion of the system consisting of the suspended inner cylinder of Margule's apparatus described above, the formula is

$$\eta \text{, the viscosity, } = \frac{K(t_2 - t_1) \log e}{4\pi L \log_{10} \frac{\theta_1}{\theta_2}} \left(\frac{R_2^2 - R_1^2}{R_1^2 \, R_2^2} \right),$$

where t_2 and t_1 denote the times in seconds of angular positions θ_2 and θ_1 of the suspended system from its position of equilibrium. The other characters have the same significance as in the formula above for the rotating cylinder method of measuring viscosity. (For reference, see footnote 108.)

The viscosity of solids may be measured in relative terms by the damping of the oscillations of suspended wires (see Table 323). Ladenburg (1906) gives the viscosity of Venice turpentine at 18.3° as 1300 poises; Trouton and Andrews (1904) of pitch at 0°, 51×10^{10}, at 15°, 1.3×10^{10}; of shoemaker's wax at 8°, 4.7×10^6; of soda glass at 575°, 11×10^{12}; Deeley (1908) of glacier ice as 12×10^{13}.

[110] Lillie, H. R., Journ. Amer. Cer. Soc., vol. 14, p. 502, 1931.

TABLE 311.—VISCOSITY OF WATER IN CENTIPOISES

(Temperature variation)

Part 1.—Low temperature

°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp
0	1.7921	10	1.3077	20	1.0050	30	.8007	40	.6560	50	.5494	60	.4688
1	1.7313	11	1.2713	21	.9810	31	.7840	41	.6439	51	.5404	65	.4355
2	1.6728	12	1.2363	22	.9579	32	.7679	42	.6321	52	.5315	70	.4061
3	1.6191	13	1.2028	23	.9358	33	.7523	43	.6207	53	.5229	75	.3799
4	1.5674	14	1.1709	24	.9142	34	.7371	44	.6097	54	.5146	80	.3565
5	1.5188	15	1.1404	25	.8937	35	.7225	45	.5988	55	.5064	85	.3355
6	1.4728	16	1.1111	26	.8737	36	.7085	46	.5883	56	.4985	90	.3165
7	1.4284	17	1.0828	27	.8545	37	.6947	47	.5782	57	.4907	95	.2994
8	1.3860	18	1.0559	28	.8360	38	.6814	48	.5683	58	.4832	100	.2838
9	1.3462	19	1.0299	29	.8180	39	.6685	49	.5588	59	.4759	153	.181

(continued)

TABLE 311.—VISCOSITY OF WATER IN CENTIPOISES (concluded)

Part 2.—High temperature [111]

°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp
130	...	155	.184	180	.155	205	.136
135	...	160	.178	185	.151	210	.134
140	...	165	.173	190	.146	215	.131
145	.199	170	.166	195	.143	220	.129
150	.191	175	.160	200	.139	225	.128

[111] Based on measurements by Shugayev, V., Journ. Exp. and Theoret. Phys. (U.S.S.R.), vol. 4, p. 760, 1934.

Part 3.—Viscosity of heavy water in centipoises [112]

99.65% D_2O; $d_4^{20} = 1.10495$

°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp	°C	Viscosity cp
4	2.25	8	1.81	12	1.56	16	1.37
5	2.10	9	1.73	13	1.51	17	1.33
6	1.99	10	1.67	14	1.46	18	1.29
7	1.90	11	1.61	15	1.41	19	1.25

[112] Data by Lemond, Henri, Compt. Rend., vol. 212, p. 81, 1941.

TABLE 312.—VISCOSITY OF ALCOHOL-WATER MIXTURES IN CENTIPOISES

(Temperature variation)

°C	Percentage by weight of ethyl alcohol: 0	10	20	30	35	40	45	50	60	70	80	90	100
0	1.792	3.311	5.319	6.94	7.25	7.14	6.94	6.58	5.75	4.762	3.690	2.732	1.773
5	1.519	2.577	4.065	5.29	5.62	5.59	5.50	5.26	4.63	3.906	3.125	2.309	1.623
10	1.308	2.179	3.165	4.05	4.39	4.39	4.35	4.18	3.77	3.268	2.710	2.101	1.466
15	1.140	1.792	2.618	3.26	3.52	3.53	3.51	3.44	3.14	2.770	2.309	1.802	1.332
20	1.005	1.538	2.183	2.71	2.88	2.91	2.88	2.87	2.67	2.370	2.008	1.610	1.200
25	.894	1.323	1.815	2.18	2.35	2.35	2.39	2.40	2.24	2.037	1.748	1.424	1.096
30	.801	1.160	1.553	1.87	2.00	2.02	2.02	2.02	1.93	1.767	1.531	1.279	1.003
35	.722	1.006	1.332	1.58	1.71	1.72	1.73	1.72	1.66	1.529	1.355	1.147	.914
40	.656	.907	1.160	1.368	1.473	1.482	1.495	1.499	1.447	1.344	1.203	1.035	.834
45	.599	.812	1.015	1.189	1.284	1.289	1.307	1.294	1.271	1.189	1.081	.939	.764
50	.549	.734	.907	1.050	1.124	1.132	1.148	1.155	1.127	1.062	.968	.848	.702
60	.469	.609	.736	.834	.885	.893	.907	.913	.902	.856	.789	.704	.592
70	.406	.514	.608	.683	.725	.727	.740	.740	.729	.695	.650	.589	.504
80	.356	.430	.505	.567	.598	.601	.609	.612	.604	—	—	—	—

TABLE 313.—VISCOSITY OF GLUCOSE [113]

(Temperature variation)

Viscosity values given as $\log_{10} \eta$ (poises)

Temp. °C	$\log_{10} \eta$	Temp. °C	$\log_{10} \eta$	Temp. °C	$\log_{10} \eta$
22	13.96	50	7.48	100	2.40
24	13.41	55	6.67	105	2.15
26	12.86	60	5.97	110	1.90
28	12.34	65	5.35	115	1.70
30	11.82	70	4.80	120	1.50
32	11.32	75	4.29	125	1.32
34	10.83	80	3.82	130	1.16
36	10.35	85	3.40	135	1.01
40	9.44	90	3.02	140	.88
45	8.40	95	2.69	145	.75

As with other liquids in the temperature interval of high viscosities, measured values for glucose depend on the thermal treatment to which the sample is subjected prior to and during measurement. Prolonged holding at a given temperature followed by rapid cooling to a lower temperature at which viscosity is measured will result in increasing values with time. Decreasing viscosity values with time will result from the reverse temperature treatment. At temperatures of high viscosity, constant, or equilibrium, viscosity values will be found only after long holding at the given temperature or after slow and controlled cooling from conditions of low viscosity to the desired temperature.

[113] Barton, Spaght, and Richardson, Journ. Appl. Phys., vol. 5, p. 156, 1934.

TABLE 314.—VISCOSITY AND DENSITY OF GLYCEROL IN AQUEOUS SOLUTION AT 20°C *

% Glycerol	Density g/cm³	Viscosity in centipoises	Kinematic viscosity † in centistokes	% Glycerol	Density g/cm³	Viscosity in centipoises	Kinematic viscosity † in centistokes
5	1.0098	1.181	1.170	50	1.1258	5.908	5.248
10	1.0217	1.364	1.335	55	1.1393	7.664	6.727
15	1.0337	1.580	1.529	60	1.1528	10.31	8.943
20	1.0461	1.846	1.765	65	1.1662	14.51	12.44
25	1.0590	2.176	2.055	70	1.1797	21.49	18.22
30	1.0720	2.585	2.411	75	1.1932	33.71	28.25
35	1.0855	3.115	2.870	80	1.2066	55.34	45.86
40	1.0989	3.791	3.450	85	1.2201	102.5	84.01
45	1.1124	4.692	4.218	90	1.2335	207.6	168.3

* Tables 314 and 315 taken from Nat. Bur. Standards Techn. Pap. No. 112, 1918. Glycerol data, Table 314, from Archbutt, Deeley, and Gerlack; castor oil data, Table 315, from Kahlbaum and Raber. Archbutt and Deeley give for the density and viscosity of castor oil at 65.6°C, 0.9284 and 0.605, respectively; at 100°C, 0.9050 and 0.169.

† The kinematic viscosity is the ordinary viscosity in cgs units (poises) divided by the density in g/cm³. The cgs unit of kinematic viscosity is the stoke.

TABLE 315.—VISCOSITY AND DENSITY OF CASTOR OIL

(Temperature variation)

°C	Density g/cm³	Viscosity in poises	Kinematic viscosity in stokes	°C	Density g/cm³	Viscosity in poises	Kinematic viscosity in stokes
5	.9707	37.6	38.7	23	.9583	7.67	8.00
6	.9700	34.5	35.5	24	.9576	7.06	7.37
7	.9693	31.6	32.6	25	.9569	6.51	6.80
8	.9686	28.9	29.8	26	.9562	6.04	6.32
9	.9679	26.4	27.3	27	.9555	5.61	5.87
10	.9672	24.2	25.0	28	.9548	5.21	5.46
11	.9665	22.1	22.8	29	.9541	4.85	5.08
12	.9659	20.1	20.8	30	.9534	4.51	4.73
13	.9652	18.2	18.9	31	.9527	4.21	4.42
14	.9645	16.61	17.22	32	.9520	3.94	4.14
15	.9638	15.14	15.71	33	.9513	3.65	3.84
16	.9631	13.80	14.33	34	.9506	3.40	3.58
17	.9624	12.65	13.14	35	.9499	3.16	3.33
18	.9617	11.62	12.09	36	.9492	2.94	3.10
19	.9610	10.71	11.15	37	.9485	2.74	2.89
20	.9603	9.86	10.27	38	.9478	2.58	2.72
21	.9596	9.06	9.44	39	.9471	2.44	2.58
22	.9589	8.34	8.70	40	.9464	2.31	2.44

TABLE 316.—VISCOSITY OF GLYCERINE-WATER MIXTURES[114]

(Temperature variation)

Sp. gravity	% Glycerol	Viscosity in centipoises 20°C	25°C	30°C
1.00000	0	1.005	.893	.800
1.02370	10	1.311	1.153	1.024
1.04840	20	1.769	1.542	1.360
1.07395	30	2.501	2.157	1.876
1.10040	40	3.750	3.180	2.731
1.12720	50	6.050	5.041	4.247
1.15460	60	10.96	8.823	7.312
1.18210	70	22.94	17.96	14.32
1.20925	80	62.0	45.86	34.92
1.23585	90	234.6	163.6	115.3
1.26201	100	1499.	945.	624.

[114] Landolt and Börnstein, 1935. Data by Sheely, Ind. Eng. Chem., vol. 24, p. 1060, 1932.

TABLE 317.—VISCOSITY OF GASOLINE AND KEROSENE IN CENTIPOISES[115]

Gasoline No.	Sp. gr. 15.6°/15.6°	Temperature 5°C	15°C	25°C	35°C	45°C	55°C
1	.757	.690	.603	.518	.472	.426	.382
2	.748	.769	.663	.588	.516	.467	.412
3	.743	.775	.641	.541	.493	.441	. . .
4	.726	.495	.429	.379	.341	.309	.278
5	.722	.529	.457	.410	.360	.325	.293
6	.717	.568	.481	.418	.361	.339	. . .
7	.716	.508	.461	.391	.346	.312	.294
8	.708	.493	.435	.389	.336	.301	.278
9	.702	.429	.383	.338	.312	.279	.250
10	.701	.435	.382	.349	.300	.268	.251
11	.699	.429	.372	.327	.299	.269	.236
12	.694	.399	.350	.317	.283	.259	.234
13	.680	.347	.310	.274	.242	.227	.211
Kerosene	.813	2.57	2.13	1.64	1.41	1.19	. . .

[115] Herschel, Nat. Bur. Standards Techn. Pap. No. 125, 1919.

TABLE 318.—VISCOSITY OF ORGANIC LIQUIDS

(Temperature variation)

Compiled from Landolt and Börnstein, 1923. Based principally on work of Thorpe and Rogers, 1894–1897. Viscosity given in centipoises. One centipoise = 0.01 dyne-second per cm^2.

Liquid	Formula	Viscosity in centipoises							
		0°C	10°C	20°C	30°C	40°C	50°C	70°C	100°C
Acids:									
Formic	CH_2O_2	solid	2.247	1.784	1.460	1.219	1.036	.780	.549
Acetic	$C_2H_4O_2$	solid	solid	1.222	1.040	.905	.796	.631	.465
Acetic (anhydrous) ...	$C_2H_4O_2$	1.245	1.053	.907	.792	.699	.623	.507	.387
Propionic	$C_3H_6O_2$	1.521	1.289	1.102	.960	.845	.752	.607	.495
Propionic (anhydrous) ...	$C_3H_6O_2$	1.610	1.330	1.119	.961	.836	.735	.584	.438
Butyric	$C_4H_8O_2$	2.286	1.751	1.540	1.304	1.121	.975	.760	.551
i-Butyric	$C_4H_8O_2$	1.887	1.568	1.318	1.129	.980	.862	.683	.501
Alcohols:									
Methyl	CH_4O	.817	.690	.596	.520	.457	.403		
Ethyl	C_2H_6O	1.772	1.451	1.194	.992	.831	.701	.510	
Propyl	C_3H_8O	3.883	2.918	2.256	1.779	1.405	1.131	.761	
i-Propyl	C_3H_8O	4.565	3.246	2.370	1.757	1.331	1.029	.646	
Butyl	$C_4H_{10}O$	5.186	3.873	2.948	2.267	2.782	1.411	.930	.540
i-Butyl	$C_4H_{10}O$	8.038	5.548	3.907	2.864	2.122	1.611	.976	.527
Allyl	C_3H_6O	2.145	1.705	1.363	1.168	.914	.763	.553	
Aromatics:									
Benzene	C_6H_6	.906	.763	.654	.567	.498	.444	.359	
Toluene	C_7H_8	.772	.671	.590	.525	.471	.426	.354	.278
Orthoxylene	C_8H_{10}	1.105	.937	.810	.709	.627	.560	.458	.352
Metaxylene	C_8H_{10}	.806	.702	.620	.553	.497	.451	.375	.297
Paraxylene	C_8H_{10}	solid	.739	.648	.574	.513	.463	.383	.300
Ethyl Benzene ...	C_8H_{10}	.877	.761	.671	.595	.532	.481	.399	.311
Bromides:									
Ethyl	C_2H_5Br	.487	.441	.402	.368				
Propyl	C_3H_7Br	,651	.582	.524	.475	.433	.397	.338	
i-Propyl	C_3H_7Br	.611	.545	.489	.443	.403	.368		
i-Butyl	C_4H_9Br	.828	.726	.643	.575	.518	.470	.390	
Allyl	C_3H_5Br	.626	.560	.504	.458	.419	.384	.328	
Ethylene	C_2H_4Br	2.438	2.039	1.721	1.475	1.286	1.131	.903	.679
Bromine	Br	1.267	1.120	1.005	.911	.831	.761		
Chlorides:									
Propyl	C_3H_7Cl	.442	.396	.359	.326	.299			
i-Propyl	C_3H_7Cl	.408	.365	.329	.299				
i-Butyl	C_4H_9Cl	.568	.519	.462	.414	.373	.339		
Allyl	C_2H_3Cl	.413	.372	.337	.307	.283			
Methylene	CH_2Cl_2	.543	.488	.444	.406	.373			
Ethylene	$C_2H_4Cl_2$	1.132	.966	.839	.736	.652	.584	.479	
Chloroform	$CHCl_3$	.706	.633	.571	.519	.474	.435		
Carbon-tetra	CCl_4	1.351	1.138	.975	.848	.746	.662	.534	
Ethers:									
Diethyl	$C_4H_{10}O$	.295	.268	.245	.223				
Methyl-Propyl ...	$C_4H_{10}O$	.314	.285	.260	.237				
Ethyl-Propyl	$C_5H_{12}O$	.402	.360	.324	.294	.268	.245		
Methyl-iso-Butyl .	$C_5H_{12}O$	.387	.346	.313	.284	.260	.239		
Dipropyl	$C_6H_{14}O$	.544	.479	.425	.381	.344	.311	.260	
Ethyl-iso-Butyl ..	$C_6H_{14}O$	.487	.430	.384	.345	.311	.284	.237	

(*continued*)

(Temperature variation)

Liquid	Formula	0°C	10°C	20°C	30°C	40°C	50°C	70°C	100°C
		Viscosity in centipoises							
Esters:									
Methyl-formate ..	$C_2H_4O_2$	.436	.391	.355	.325				
Ethyl-formate	$C_3H_6O_2$	.510	.454	.409	.369	.336	.308		
Propyl-formate ...	$C_4H_8O_2$	.672	.589	.521	.465	.417	.378	.314	
Methyl-acetate ...	$C_3H_6O_2$	.484	.431	.388	.352	.320	.293		
Ethyl-acetate	$C_4H_8O_2$	.583	.512	.455	.407	.367	.333	.279	
Propyl-acetate ...	$C_5H_{10}O_2$	.773	.669	.585	.516	.460	.414	.341	.259
Methyl-propionate.	$C_4H_8O_2$	.587	.517	.460	.414	.375	.341	.286	
Ethyl-propionate .	$C_5H_{10}O_2$	.697	.608	.537	.477	.428	.387	.321	
Methyl-butyrate ..	$C_5H_{10}O_2$	.763	.661	.580	.513	.459	.413	.341	.265
Methyl-iso-butyrate	$C_5H_{10}O_2$	.676	.591	.523	.466	.419	.375	.315	
Iodides:									
Methyl	CH_3I	.606	.548	.500	.460	.424			
Ethyl	C_2H_5I	.727	.654	.593	.540	.495	.456	.391	
Propyl	C_3H_7I	.944	.833	.744	.669	.607	.552	.466	.371
i-Propyl	C_3H_7I	.884	.781	.697	.627	.568	.516	.435	
i-Butyl	C_4H_9I	1.166	1.001	.875	.777	.697	.629	.522	.406
Allyl	C_3H_5I	.936	.826	.734	.660	.597	.544	.459	.365
Paraffins: * [116]									
Pentane				.274	.227	vapor			
Octane				.707	.542	.429			
Hexane				.382	.308	.254			
Heptane				.521	.411	.333			
Sulfides:									
Methyl	C_2H_6S	.361	.329	.301	.277				
Ethyl	$C_4H_{10}S$	.563	.501	.450	.407	.369	.338	.287	
Carbon di	CS_2	.438	.405	.376	.352	.330			
Turpentine		2.248	1.783	1.487	1.272	1.071	.926	.728	

* Very pure.
[116] Geist, J. M., and Cannon, M. R., Ind. Eng. Chem., anal. ed., vol. 18, p. 611, 1946.

TABLE 319.—VISCOSITY OF SODIUM SILICATES [117]

(Temperature variation)

Wt. % Na_2O	900°C	1000°C	1100°C	1200°C	1300°C	1400°C
	Log₁₀ η (poises) at					
18.4				3.15	2.77	2.47
21.91	4.55	3.83	3.28	2.82	2.44	2.11
24.89	4.29	3.62	3.08	2.63	2.26	1.95
25.78	4.22	3.55	3.02	2.58	2.22	1.91
26.57	4.19	3.52	2.98	2.55	2.19	1.88
26.79	4.18	3.49	2.97	2.54	2.18	1.87
28.46	4.07	3.41	2.90	2.48	2.12	1.79
29.79	3.98	3.32	2.81	2.39	2.03	1.72
31.74	3.84	3.21	2.70	2.28	1.93	1.62
32.91	3.76	3.15	2.64	2.23	1.88	1.57
33.24	3.74	3.12	2.62	2.21	1.87	1.55
33.77	3.71	3.08	2.58	2.18	1.83	1.52
34.27	3.70	3.08	2.59	2.16	1.82	1.53
34.92	3.66	3.04	2.54	2.15	1.80	1.50
36.73	3.57	2.94	2.45	2.05	1.70	1.40
39.2	3.46	2.81	2.33	1.93	1.56	
39.74	3.34	2.74	2.25	1.86	1.51	1.20
52.1		1.66	1.21	.91	.66	.47

[117] Babcock, C. L., Journ. Amer. Cer. Soc., vol. 17, p. 319, 1934. Lillie, H. R., Journ. Amer. Cer. Soc., vol. 22, p. 367, 1939.

TABLE 320.—VISCOSITY OF DIMETHYSILOXANE POLYMERS

(Temperature variation)

Based on data by Dow Corning Corporation for DC 200 fluids.

Fluid designation (centistokes at 25° C)	Viscosity in poises						
	−25°C	0°C	25°C	50°C	75°C	100°C	150°C
1	.0163	.0118	.0083	.0064	.0052		
2	.0472	.0287	.0173	.0129	.0100	.0079	.0056
5	.145	.077	.0452	.0301	.0221	.0173	.0116
10	.323	.159	.090	.059	.043	.032	.026
20	.683	.328	.184	.105	.082	.062	.040
50	2.39	.820	.467	.298	.208	.153	.094
100	3.22	1.61	.94	.59	.398	.285	.172
200	6.70	3.40	1.92	1.19	.798	.580	.346
500	15.9	8.15	4.84	2.89	1.94	1.36	.82
1000	34.4	17.00	9.70	6.04	4.02	2.80	1.57
12500	368.5	183.7	119.3	73.9	53.0	39.7	24.3
30000	1035.	517.	291.5	186.2	126.4	90.2	50.7
200,000	5820.	3265.	1940.	1256.	839.	604.	345.

TABLE 321.—VISCOSITY IN THE SYSTEM ORTHOCLASE-ALBITE

(Temperature variation)

Values given as $\log_{10} \eta$, where η = viscosity in poises.

Wt. % Orthoclase	100	80	60	40	20	0
Wt. % Albite	0	20	40	60	80	100
1300°C						6.04
1350°C			6.30	6.18	6.00	5.63
1400°C	7.00	6.23	5.88	5.81	5.65	5.26
1450°C	6.00	5.85	5.51	5.40	5.26	

TABLE 322.—VISCOSITY OF SILICON DIOXIDE[118]

(Temperature variation)

Values given as $\log_{10} \eta$; η = viscosity in poises.

Temperature °C	1250	1300	1350	1400	1450	1500
$\log_{10} \eta$	13.40	12.19	11.46	10.69	10.02	9.42

[118] Volarovich, M. P., and Leontieva, A. A., Journ. Soc. Glass Techn., vol. 20, p. 139, 1936.

TABLE 323.—VISCOSITY OF MISCELLANEOUS MOLTEN OXIDES[119]

(Temperature variation)

Values given as $\log_{10} \eta$, where η = viscosity in poises.

Material	1100°C	1200°C	1300°C	1400°C	1500°C	1600°C
Silica (SiO_2)	15.57	13.68	12.06	10.66	9.20	...
Wollastonite ($CaSiO_3$)	...	...	...	...	.486	.387
Diopside ($CaMgSi_2O_6$)	...	...	1.52	1.43	.267	.079
Akermanite ($Ca_2MgSi_2O_7$)	...	...	1.48	.656	.362	.146
Monticellite ($CaMgSiO_4$)	...	...	...	...	.241	.053
Albite ($NaAlSi_3O_8$)	...	7.17	5.82 6.04	4.60 5.25	...	...
Orthoclase ($KAlSi_3O_8$)	...	...	...	7.0	6.2	...
Anorthite ($CaAl_2Si_2O_8$)	...	...	...	2.32	1.78	1.40
Gehlenite (Ca_2AlSiO_7)	...	...	...	...	.911	.549

[119] Birch, Handbook of physical constants, 1942. Measurements by: Volarovich and Leontieva, Trans. Soc. Glass Techn., vol. 20, p. 139, 1936. McCaffery, Trans. Amer. Inst. Min. and Met. Eng., vol. 100, pp. 64, 86, 122, 125, 1932. Bowen, Trans. Amer. Geophys. Union, pt. 1, p. 249, 1934. Kani, Proc. Imp. Acad. (Tokyo), vol. 11, p. 334, 1935. Kani and Kuzu, Proc. Imp. Acad. (Tokyo), vol. 11, p. 383, 1935.

TABLE 324.—VISCOSITY OF BORON TRIOXIDE[120]

(Temperature variation)

Temperature °C	$\log_{10} \eta$ (poises) *	†	‡	§	‖
300	...	9.64	...	...	...
400	...	6.20	...	...	6.30
500	4.59	...	4.40	...	4.47
600	3.68	...	...	...	3.49
700	2.93	...	...	2.90	2.89
800	2.42	...	...	2.53	2.49
900	2.08	...	...	2.27	2.19
1000	1.87	...	...	2.10	1.96
1100	1.63	...	...	1.92	1.78
1200	...	...	...	...	1.62

[120] Dane and Birch, Journ. Appl. Phys., vol. 9, p. 669, 1938, have shown that for pressures not in excess of 2000 kg/cm² the viscosity of boron trioxide is given for various pressures by the relation $\eta = \eta_0 e^{ap}$; and at 359°C, $a = 15.10^{-4}$ cm²/kg, and at 516°C, $a = 4.6 \times 10^{-4}$ cm²/kg. Data from Birch, Handbook of physical constants, 1942, and from unpublished measurements by H. R. Lillie.

Observers of data by columns:

* Arndt, Zeit. Elektrotechn., vol. 13, p. 578, 1907.
† Parks and Spaght, Physics, vol. 6, p. 67, 1935.
‡ Volarovich and Tolstoi, Trans. Soc. Glass Techn., vol. 18, p. 209, 1934.
§ Volarovich and Fridman, Acta Phys. (U.S.S.R.), vol. 6, p. 393, 1937.
‖ Lillie, unpublished data.

TABLE 325.—VISCOSITY IN THE SYSTEM DIOPSIDE-ALBITE-ANORTHITE *

(Temperature variation)

Values given as $\log_{10} \eta$, where η = viscosity in poises.

Wt. % diopside	100	80	60	40	20	0
Wt. % albite	0	20	40	60	80	100
1200°C				3.99	5.08	
1300°C			2.45	3.20	4.30	6.04
1400°C	1.60	1.93	2.04	2.64	3.63	5.26
Wt. % diopside	20	40	60	80		
Wt. % anorthite	80	60	40	20		
1300°C		3.77	2.18			
1400°C		2.00	1.96	1.92		
1500°C	2.04					
Wt. % albite	80	60	40	20	0	
Wt. % anorthite	20	40	60	80	100	
1300°C	5.51	4.67				
1400°C	4.63	3.89	3.40			
1500°C			2.66	2.28		
1555°C				2.11	2.04	
Wt. % diopside	60	40	40	20	20	20
Wt. % albite	20	40	20	60	40	20
Wt. % anorthite	20	20	40	20	40	60
1200°C		3.65		4.83		
1300°C	2.23	2.92	2.67	3.88	3.57	
1400°C	1.99	2.36	2.11	3.18	2.79	2.56

* For reference, see footnote 45, p. 136.

TABLE 326.—VISCOSITY OF MOLTEN METALS [121]

(Temperature variation)

Temp. °C	Lead	Tin *	Tin †	Temp. °C	Antimony
300	...	1.73	1.67	650	1.50
350	2.58	1.58	1.51	700	1.26
400	2.33	1.43	1.38	750	1.16
450	2.07	1.30	1.27	800	1.08
500	1.84	1.20	1.18	850	1.05
550	1.58	1.14	1.11		
600	1.38	1.08	1.05	Temp. °C	Copper
650	...	...	.99		
700	...	...	.94	1100	3.33
750	...	...	.91	1150	3.22
800	...	...	.87	1200	3.12

[121] Landolt and Börnstein, 1935. Based on data by Esser, Greis, and Brundgart, Arch. Eisenhütten, vol. 7, p. 385, 1934. Viscosity in centipoises. Data on tin by Stott, Proc. Phys. Soc., vol. 45, p. 530, 1933, included.
* Esser, Greis, and Brundgart. † Stott.

TABLE 327.—VISCOSITY OF MISCELLANEOUS LIQUIDS

Viscosities are given in cgs units, dyne-seconds per cm^2, or poises.

Liquid	°C	Viscosity	Liquid	°C	Viscosity
Acetaldehyde	0.	.00275	Oils:		
"	10.	.00252	* Filtered cylinder	37.8	2.406
"	20.	.00231	" "	100.0	.187
Air	—192.3	.00172	* Dark cylinder	37.8	4.224
Aniline	20.	.04467	" "	100.0	.240
"	60.	.0156	" "	37.8	7.324
Bismuth	285.	.0161	" "	100.0	.341
"	365.	.0146	*"Extra L. L."	37.8	11.156
Black treacle	12.3	.400	" " "	100.0	.451
Copal lac	22.	4.80	‡ Linseed .925	30.	.331
Hydrogen, liquid	—	.00011	" .922	50.	.176
Menthol, solid	14.9	2×10^{12}	" .914	90.	.071
" liquid	56.9	.069	Olive .9195	10.	1.38
Mercury	—20.	.0184	"	15.	1.075
"	0.	.01661	" .9130	20.	.840
"	20.	.01547	" .9065	30.	.540
"	34.	.01476	" .9000	40.	.363
"	98.	.01263	" .8935	50.	.258
"	193.	.01079	" .8800	70.	.124
"	299.	.00975	† Rape	15.6	1.118
Oils:			"	37.8	.422
‡ Dogfish-liver .923	30.	.414	"	100.0	.080
" " .918	50.	.211	" (another)	15.6	1.176
" " .908	90.	.080	" (another)	100.0	.085
Linseed .925	30.	.331	‡ Soya bean .919	30.0	.406
" .922	50.	.176	" " .915	50.0	.206
" .914	90.	.071	" " .906	90.0	.078
* Spindle oil .885	15.6	.453	† Sperm	15.6	.420
" "	37.8	.162	"	37.8	.185
" "	100.0	.033	"	100.0	.046
* Light machinery			Phenol	18.3	.1274
.907‡	15.6	1.138	"	90.0	.0126
* Light machinery	37.8	.342	Sulfur	170.	320.0
" "	100.0	.049	"	180.	550.0
*"Solar red" engine	15.6	1.915	"	187.	560.0
" " "	37.8	.496	"	200.	500.0
" " "	100.0	.058	"	250.	104.0
*"Bayonne" engine	15.6	2.172	"	300.	24.0
" "	37.8	.572	"	340.	6.2
" "	100.0	.063	"	380.	2.5
*"Queen's red" engine	15.6	2.995	"	420.	1.13
" " "	37.8	.711	"	448.	.80
" " "	100.0	.070	Sulfuric acid ($\rho = 1.03$)	25.	.00973
*"Galena" axle	15.6	4.366	† Tallow	66.	.176
" " "	37.8	.909	"	100.	.078
* Heavy machinery	15.6	6.606	Zinc	280.	.0168
" "	37.8	1.274	"	357.	.0142
			"	389.	.0131

* American mineral oils; based on water as .01028 at 20°C. † Based on water as per 1st footnote. ‡ Densities.

TABLE 328.—RATIO OF VISCOSITY AT HIGH TO THAT AT ATMOSPHERIC PRESSURE

Pressure tons/in²	Pressure kg/cm²	Bayonne oil (mineral)	FFF cylinder (mineral)	Trotter (animal)	Rape (vegetable)	Castor (vegetable)	Sperm (fish)
1	157.5	1.3	1.4	1.2	1.1	1.2	1.2
2	315.	2.0	2.0	1.6	1.4	1.6	1.5
4	630.	4.0	4.5	2.4	2.3	2.7	2.4
6	945.	7.8	8.9	3.5	3.5	4.2	3.5
8	1260.	16.1	—	5.0	—	5.8	—

TABLE 329.—VISCOSITY OF LIQUEFIED PURE GASES AND VAPORS[122]

Viscosities in millipoises.

(Temperature variation)

Temp. °K	C_2H_4	C_2H_6	C_3H_6	C_3H_8
85	...	...	...	118.5
90	...	...	125.5	74.2
95	...	...	72.5	52.5
100	...	9.15	45.5	38.3
105	6.60	7.48	31.1	29.0
110	5.60	6.37	22.3	22.3
115	4.86	5.66	17.0	18.2
120	4.24	5.06	13.3	15.2
125	3.73	4.52	11.1	13.2
130	3.32	4.00	9.4	11.6
135	2.96	3.58	8.2	10.3
140	2.66	3.23	7.2	9.3
145	2.43	2.92	6.2	8.2
150	2.22	2.66	5.6	7.3
155	2.03	2.44	5.0	6.5
160	1.86	2.27	4.5	5.5
165	1.71	2.12	4.0	5.0
170	1.58	2.00	3.5	4.5

Temp. °K	N_2
66	2.49
68	2.26
70	2.08
72	1.93
74	1.80
76	1.67
78	1.56
80	1.47

Temp. °K	CH_4
95	1.82
100	1.53
105	1.34
110	1.21

[122] Gerf, S. F., and Galkov, G. I., Journ. Techn. Phys. (U.S.S.R.), vol. 10, p. 725, 1940.

TABLE 330.—VISCOSITY OF PURE HYDROCARBONS[123]

Viscosities in centipoises; densities referred to water at 4°C.

Temp. °C	Propane, C_3H_8		n-Butane, C_4H_{10}		iso-Butane, C_4H_{10}	
	Density	Viscosity	Density	Viscosity	Density	Viscosity
−70	.614	.287	.671	.460	.657	.533
−60	.604	.253	.661	.403	.647	.455
−50	.592	.227	.652	.354	.637	.393
−40	.580	.205	.642	.314	.626	.343
−30	.568	.184	.632	.281	.615	.301
−20	.556	.168	.622	.253	.605	.267
−10	.543	.152	.611	.229	.593	.239
0	.531	.138	.601	.209	.582	.215
+10	.517	.126	.590	.191	.571	.195
+20	.502	.116	.579	.174	.559	.176
+30	.487	.108	.567	.159	.547	.160
+40	.471	.099	.555	.146	.534	.146

[123] Lipkin, M. R., Davison, J. A., and Kurtz, S. S., Ind. Eng. Chem., vol. 34, p. 976, 1942.

TABLE 331.—VISCOSITY OF GLASS[124]

(Temperature variation)

Part 1.

$Log_{10}\,\eta$ (poises) at

Glass	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C	1200°C	1300°C
1	13.76	9.85	7.03	5.42	4.37	3.52	2.93	2.47	2.09
2	...	...	...	5.84	4.79	3.99	3.41	2.93	2.50
3	...	...	...	5.38	4.29	3.52	2.94	2.48	2.08
4	...	...	...	5.74	4.48	3.60	2.96	2.47	2.03
5	15.20	12.35	9.82	7.87	6.48	5.52	4.77	4.16	3.67
6	13.82	10.85	8.55	6.81	5.68	4.88	4.20	3.65	3.22
7	...	...	...	...	1.55	1.24	1.00	.83	.69
8	...	...	...	...	2.17	1.81	1.55	1.33	1.16
9	...	...	...	...	...	4.20	3.54	3.02	...
10	...	...	...	...	...	4.00	3.37	2.85	...
11	...	...	...	...	4.71	3.85	3.24	2.74	...
12	...	...	...	...	...	3.89	3.34	2.91	...
13	...	...	...	...	...	4.06	3.47	3.01	2.67
14	...	...	...	6.02	5.79	3.97	3.35	2.89	2.31
15	...	9.49	7.30	5.70	4.48	3.70	3.08	2.60	2.40

Part 2.

Composition (weight percentages)

Glass	SiO_2	B_2O_3	Na_2O	K_2O	MgO	CaO	ZnO	PbO	Al_2O_3
1	69.73	...	20.96	trace	...	9.05	...	...	.18*
2	72.6	1.43	16.0	.68	1.7	6.40	...	...	1.0 *
3	70.12	...	21.1	trace	...	8.77	...	...	.02
4	67.3	2.00	14.0	...	...	7.0	7.0	...	2.50
5	81.0	13.00	4.00	...	...	...	...	...	2.0
6	75.0	15.00	5.0	...	...	...	...	5.0	...
7	65.0	...	7.5	7.5	...	...	...	20.0	...
8	60.0	...	5.0	5.0	...	...	...	30.0	...
9	73.97	...	15.30	...	3.57	5.69	...	...	.91*
10	74.35	...	15.30	...	.18	9.03	...	...	.85*
11	72.27	...	16.88	...	.35	8.79	...	...	1.72*
12	62.50	...	7.50	6.70	...	...	...	22.00	1.30*
13	75.0	10	10	...	...	...	...	...	5
14†	56	7.5	4	10	...	...	...	...	2.5
15	73.18	...	19.38	...	.21	6.26	...	...	1.19*

Part 3.—Commercial glass ‡

$Log_{10}\,\eta$ (poises) at

Glass designation	Manufacturer	700 °C	800 °C	900 °C	1000 °C	1100 °C	1200 °C	1300 °C	1400 °C
Code 0010-Potash soda lead.	Corning Glass Works ..	6.51	5.35	4.52	3.86	3.36	2.91	2.53	2.22
" 0120-Potash soda lead.	" " " ..	6.62	5.41	4.57	3.89	3.36	2.91	2.53	2.22
" 1710-Hard lime	" " " ..	...	10.45	7.95	6.28	4.93	3.92	3.22	2.62
" 7720-Borosilicate	" " " ..	...	6.80	5.66	4.82	4.16	3.65	3.20	2.86
" 7740-Pyrex	" " " ..	9.82	7.87	6.48	5.52	4.77	4.16	3.67	...
Plate glass	Blue Ridge Glass Corp..	...	...	5.00	4.03	3.41	2.87	2.46	2.07
Window glass	Libby-Owens-Ford	...	8.35	5.06	4.14	3.41	2.90	2.48	2.14

[124] Babcock, C. L., Journ. Amer. Cer. Soc., vol. 17, p. 329, 1934; English Journ. Soc. Glass Techn., vol. 7, p. 25, 1923; vol. 8, p. 205, 1924; vol. 9, p. 83, 1925; vol. 10, p. 52, 1926; Lillie, H. R., Journ. Amer. Cer. Soc., vol. 14, p. 502, 1931; Hunter, Journ. Amer. Cer. Soc., vol. 17, p. 121, 1934; Lillie, H. R., unpublished data.

* R_2O_3. Glasses 11 and 12 contained 0.50 and 0.34 percent BaO, respectively. † Glass 14 contains 20 percent BaO. ‡ Data by H. R. Lillie, Corning Glass Works Laboratory.

Variation of viscosity with pressure and temperature

According to the kinetic theory of gases the coefficient of viscosity $\eta = \frac{1}{3}(\rho \bar{c} l)$, ρ being the density, $\bar{c}$ the average velocity of the molecules, l the average path. Since l varies inversely as the number of molecules per unit volume, ρl is a constant and η should be independent of the density and pressure of a gas (Maxwell's law). This has been found true for ordinary pressures; below 1/60 atmosphere it may fail, and for certain gases it has been proved untrue for high pressures, e.g., CO_2 at 33° and above 50 atm. See Jeans, "Dynamical Theory of Gases."

If B is the amount of momentum transferred from a plane moving with velocity U and parallel to a stationary plane distant d, and s is a quantity (coefficient of slip) to allow for the slipping of the gas molecules over the plane, then $\eta = (B/U)\,(d+2s)$; s is of the same magnitude as l, probably between .7 (Timiriazeff) and .9 (Knudsen) of it; at low pressures d becomes negligible compared with $2s$ and the viscosity should vary inversely as the pressure.

$\bar{c}$ depends only on the temperature and the molecular weight. $\bar{c}$ varies as the $\sqrt{T}$, but η has been found to increase much more rapidly. Meyer's formula, $\eta_t = \eta_0(1 + at)$, where a is a constant and η_0 the viscosity at 0°C, is a convenient approximate relation. Sutherland's formula

$$\eta_t = \eta_0 \frac{273 + C}{T + C}\left(\frac{T}{273}\right)^{\frac{3}{2}}$$

is the most accurate formula in use, taking into account the effect of molecular forces. It holds for temperatures above the critical and for pressures following approximately Boyle's law. It may be thrown into the form $T = KT^{\frac{3}{2}}/\eta - C$ which is linear of T and $T^{\frac{3}{2}}/\eta$, with a slope equal to K and the ordinate intercept equal to $-C$. Onnes (see Jeans) shows that this formula does not represent helium at low temperatures with anything like the accuracy of the simpler formula $\eta = \eta_0(T/273.1)^n = AT^n$.

The following table [125] contains the constant a of Meyers formula, C and K of Sutherland's formula, n and A of the exponential formula, and the temperature range for which the constants of the latter two are applicable.

Gas	Temperature range °C	$a \times 10^3$	C	$K \times 10^6$	n	$A \times 10^6$
Air	23 to 750	2.90	117.9	14.82	.754	2.490
Ammonia	− 77 to 441	...	472	15.42	1.041	.274
Argon	−183 to 827	1.78	133	19.00	.766	2.782
Benzene	0 to 313	...	403	10.33	.974	.299
Carbon dioxide	− 98 to 1052	3.48	233	15.52	.868	1.057
Carbon monoxide	...	2.69	102	13.5	.74	...
Chloroform	...	...	454	15.9	...	...
Ethylene	...	3.50	226	10.6	...	...
Helium	−258 to 817	...	97.6	15.13	.653	4.894
Hydrogen	−258 to 825	...	70.6	6.48	.678	1.860
Krypton	...	...	188	...	...	...
Mercury	−218 to 610	...	996	63.00	1.082	.573
Methane	18 to 499	...	155	9.82	.770	1.360
Neon	...	...	252	...	...	...
Nitrogen	−191 to 825	2.69	102	13.85	.702	3.213
Nitrous oxide	...	3.45	313	17.2	.93	...
Oxygen	−191 to 829	...	110	16.49	.721	3.355
Water vapor	0 to 407	...	659	18.31	1.116	.170
Xenon	...	...	252	...	...	...

[125] Dushman, S., Vacuum technique, p. 37, John Wiley & Sons, New York, 1949; Banerjea, G. B., and Plattanaik, B., Zeit. Physik, vol. 110, p. 676, 1938; Partington, J. R., Phys. Zeit., vol. 34, p. 289, 1933; Fisher, Phys. Rev., vol. 24, 1907.

TABLE 333.—VISCOSITY OF GASES AND VAPORS

Part 1.—Viscosity of vapors

The values of η given in the table are 10^6 times the coefficients of viscosity in cgs units.

Substance	Temp. °C	η	Substance	Temp. °C	η
Acetone	18.0	78.	Ether	16.1	73.2
Alcohol, Methyl	66.8	135.	"	36.5	79.3
Alcohol, Ethyl	78.4	142.	Ethyl chloride	0.	93.5
Alcohol, Propyl, norm.	97.4	142.	Ethyl iodide	72.3	216.0
Alcohol, Isopropyl	82.8	162.	Ethylene	0.0	96.1
Alcohol, Butyl, norm.	116.9	143.	Mercury	270.0	489.
Alcohol, Isobutyl	108.4	144.	"	300.0	532.
Alcohol, Tert. butyl	82.9	160.	"	330.0	582.
Ammonia	20.0	108.	"	360.0	627.
Benzene	0.	70.	"	390.0	671.
"	19.0	79.	Methane	20.0	120.1
"	100.0	118.	Methyl chloride	0.0	98.8
Carbon bisulfide	16.9	92.4	" "	15.0	105.2
Carbon monoxide	20.0	184.0	" "	302.0	213.9
Chloroform	0.0	95.9	Methyl iodide	44.0	232.
"	17.4	102.9	Water vapor	0.0	90.4
"	61.2	189.0	" "	16.7	96.7
Ether	0.0	68.9	" "	100.0	132.0

Part 2.—Viscosity of gases and vapors[126]

(Temperature variation)

Temp. °C	Viscosity in millipoises								
	Air	Argon	Carbon dioxide	Chlorine	Helium	Hydrogen	Nitrogen	Oxygen	Xenon
—200	.053	...	...	...	...	.033	...	...	.222 (15°C)
—150	.081	...	...	...	...	.047	...	...	
—100	.111	...	.087	...	...	.061	...	...	Nitric oxide
— 50	.139	...	.112	...	...	.073	...	...	.179 (0°C)
0	.175	...	.135	...	...	.083	...	...	
50	.193	.241	.159	.147	.207	.093	.189	.217	Nitrous oxide
100	.216	.269	.181	.167	.228	.102	.207	.241	.138 (0°C)
150	.237	.297	.203	.189	.247	.111	.226	.264	
200	.256	.321	.225	.208	.267	.120	.245	.287	Krypton
250	.275	.346	.245	.228	.285	.129	.263	.309	.246 (15°C)
300	.293	.367	.262	...	.305	.137	.280	.330	
350	.310	.389	.280	...	.323	.145	.296	.349	Carbon monoxide
400	.327	.410	.299	...	.341	.153	.311	.368	.163 (0°C)
500	.357	.450	.331	...	.375	.167	.341	.403	
600	.384	.488	.362	...	.408	.181	.367	.435	Ammonia
700	.411	.521	.391	...	.438	.195	.391	.466	.096 (0°C)
800	.437	.554	.417	...	.467	.208	.414	.494	
900	.463	...	.421	...	...	...	...	...	
1000	.499	...	.465	...	...	...	...	...	
1100	.511	...	...	...	...	...	...	...	

[126] Based on data from Landolt and Börnstein, 3d supplementary vol., pt. 1, p. 184, 1935.

TABLE 334.—PRESSURE EFFECT ON VISCOSITY OF PURE LIQUIDS[127]

This table gives $\log_{10}$ of the relative viscosity as a function of pressure and density, the viscosity at 30°C and atmospheric pressure taken as unity. For each compound first line $\log \eta/\eta_0$ at 30°C, second line at 75°C, third line η_{30}/η_{75}.

Substance	Pressure kg/cm² 1	500	1000	2000	4000	6000	8000	10000	12000	η_{30}
Methyl alcohol	.000	.094	.167	.286	.471	.616	.750	.874	.998	
	9.769	9.862	9.933	.043	.208	.334	.448	.555	.655	.00520
	1.702	1.706	1.714	1.750	1.832	1.914	2.004	2.084	2.203	
Ethyl alcohol	.000	.107	.200	.363	.617	.829	1.023	1.211	1.390	
	9.657	9.772	9.873	.045	.289	.473	.634	.778	.919	.01003
	2.203	2.163	2.123	2.080	2.128	2.270	2.449	2.710	2.958	
n-Propyl alcohol	.000	.151	.283	.494	.836	1.131	1.402	1.667	1.915	
	9.598	9.754	9.880	.074	.368	.610	.827	1.033	1.223	.01779
	2.523	2.495	2.529	2.630	2.938	3.319	3.758	4.305	4.920	
n-Butyl alcohol	.000	.175	.321	.554	.934	1.289	1.609	1.912	2.208	
	9.548	9.724	9.867	.089	.312	.690	.941	1.172	1.396	.02237
	2.845	2.838	2.858	2.932	3.343	3.991	4.679	5.521	6.518	
n-Amyl alcohol	.000	.188	.341	.607	1.060	1.448	1.811	2.164	2.495	
	9.540	9.723	9.871	.105	.466	.772	1.049	1.313	1.562	
	2.884	2.917	2.951	3.177	3.926	4.742	5.781	7.096	8.570	
n-Pentane	.000	.181	.315	.524	.847	1.112	1.360	1.615	1.846	
	9.811	.014	.163	.380	.676	.908	1.119	1.313	1.493	.00220
	1.545	1.469	1.419	1.393	1.483	1.600	1.742	2.004	2.254	
n-Hexane	.000	.184	.332	.561	.914	1.224	1.514	1.803		
	9.803	.028	.171	.379	.701	.961	1.198	1.426	1.646	.00296
	1.574	1.432	1.449	1.521	1.633	1.832	2.070	2.382		
Ethyl chloride	.000	.134	.242	.405	.649	.837	1.008	1.172	1.323	
	9.850	.017	.131	.285	.514	.683	.834	.977	1.111	
	1.413	1.309	1.291	1.318	1.365	1.426	1.493	1.567	1.633	
Ethyl bromide	.000	.121	.222	.387	.631	.854	1.043	1.223	1.400	
	9.806	9.959	.072	.235	.472	.653	.816	.978	1.123	.00368
	1.567	1.452	1.413	1.419	1.442	1.589	1.687	1.758	1.892	
Ethyl iodide	.000	.115	.218	.385	.656	.888	1.108	1.330	1.549	
	9.837	9.954	.057	.227	.467	.672	.854	1.030	1.200	.00540
	1.455	1.449	1.445	1.439	1.545	1.644	1.795	1.995	2.234	
Acetone	.000	.135	.226	.373	.605	.804	.987	1.160		
	9.895	.017	.113	.245	.445	.610	.762	.898	1.031	.00285
	1.274	1.312	1.297	1.343	1.445	1.563	1.679	1.828		
Glycerine	.000	.134	.260	.497	.936	1.346	1.741	2.133		
	8.810	8.920	9.023	9.204	9.529	9.818	.094	.369	.628	3.8
	15.49	16.37	17.26	19.63	25.53	33.73	44.36	58.08		
CCl_4	.000	.190	.351	.493 (1500) kg/cm²						
	9.760	9.949	.100	.349	.542					.00845
	1.738	1.742	1.782							
Chloroform	.000	.110	.211	.386	.660	.884				
	9.858	9.985	.094	.251	.480	.691	.914	1.141		.00519
	1.387	1.334	1.309	1.365	1.514	1.560				
CS_2	.000	.090	.160	.307	.509	.674	.840	1.010	1.189	
	9.875	9.972	.051	.180	.372	.527	.671	.808	.946	.00352
	1.334	1.312	1.285	1.340	1.371	1.403	1.476	1.592	1.750	
Ether	.000	.189	.324	.514	.792	1.042	1.261	1.469	1.670	
	9.878	.024	.149	.344	.601	.806	.986	1.155	1.311	.00212
	1.324	1.462	1.496	1.479	1.552	1.722	1.884	2.061	2.286	
Benzene	.000	.173	.347							
	9.765	9.938	.081	.308	.498 (3000) kg/cm²					.00566
	1.718	1.718	1.845							
Toluene	.000	.145	.274	.497	.897	1.285	1.699	2.177		
	9.796	9.939	.065	.267	.597	.896	1.186	1.504	1.832	.00523
	1.600	1.607	1.618	1.698	1.995	2.449	3.258	4.710		
Eugenol	.000	.288	.541	1.081	2.273	3.007				
				1.652	(3000)	(5000)	kg/cm²			
	9.429	9.616	9.810	.143	.805	1.520	2.343			
	3.724	4.699	5.383	8.670	29.38					

[127] Bridgman, P. W., Proc. Acad. Arts and Sci., vol. 61, p. 59, 1926.

TABLE 335.—VISCOSITY OF OILS [128]

The SAE viscosity numbers constitute a classification of crankcase lubricating oils in terms of viscosity only. Other facts of oil quality or character are not considered.

Part 1.—Crankcase oil classification

SAE recommended practice

SAE viscosity number	Viscosity range, Saybolt univ., sec: At 130° F Min.	At 130° F Max.	At 210° F Min.	At 210° F Max
10	90	Less than 120	...	....
20	120	" " 185	...	....
30	185	" " 255	...	....
40	255	....	...	Less than 80
50	...	....	80	" " 105
60	...	....	105	" " 125
70	...	....	125	" " 150

Part 2.—Automotive Manufacturers' viscosity classification

SAE general information

Viscosity number	Viscosity range at 0°F, Saybolt univ., sec: Min.	Max.
10W	6,000	12,000
20W	12,000	48,000

[128] SAE Handbook, 1949 ed., p. 580, Soc. Automot. Eng., New York.

TABLE 336.—EFFECT OF PRESSURE UPON VISCOSITY [129]

Substance	Temperature °C	Absolute viscosity at 1 atm centipoises	Relative viscosity, Pressure in kg/cm²: 1	1000	4000	8000	12,000
i-Pentane	30	.198	1.0	2.208	7.834	26.98	88.51
	75	—	.662	1.560	5.188	15.10	38.55
Acetone	30	.285	1.0	1.683	4.027	9.705	—
	75	—	.785	1.297	2.786	5.781	10.74
CS_2	30	.352	1.0	1.445	3.228	6.918	15.45
	75	—	.750	1.125	2.355	4.688	8.83
Sulfuric ether	30	.212	1.0	2.109	6.194	18.24	46.77
	75	—	.755	1.409	3.990	9.683	20.46
Petroleum ether	30	—	1.0	1.995	8.51	38.9	151.4
	80	—	—	—	3.63	11.5	30.9
Kerosene	30	—	1.0	2.88	5.13	—	—
	80	—	—	—	8.13	75.9	631
Water	0	1.792	1.0	.921	1.111	freezes	—
	10.3	1.297	.779	.743	.842	1.152	—
	30	.801	.488	.514	.658	.923	1.206
	75	.380	.222	.239	.302	.445	—
	100	.284	—	—	—	—	—
Mercury	30	1.516	1.0	1.023	1.097	1.202	1.324
	75	1.340	.884	.883	.880	.877	.876

[129] Bridgman, P. W., The physics of high pressure. Macmillan, New York, 1931.

With very few exceptions present-day lubricants are petroleum products or blends of petroleum products with various compounding or addition agents such as fatty oils, diversified types of soap, and in rare instances solid materials such as graphite. Addition agents are more costly than petroleum derivatives; hence they are used as sparingly as possible. The addition agents are generally employed when conditions of use require greater "oiliness" (higher film strength) than is attainable with unblended petroleum oils. The latter usually deteriorate more slowly in service than blended products, which is an advantage supplementing that of low relative cost. There are a few jobs of lubrication for which fatty oils have never been entirely supplanted, as for example the use of porpoise-jaw oil in fine watches.

Lubricants for Cutting Tools[130]

Various types of oils have been used as lubricants for cutting tools. These are fatty oils, kerosene, turpentine, mineral oils and various blends of these oils. Sulfur has been combined with some of these oils to increase the film strength. Such mixtures and blends are furnished by the various manufacturers under their trade names such as Pennex, Dortan, Fanox, and Kutwell by the Standard Oil Co. of New Jersey.

Severity	Type of operation	Ferrous (more than 70%)	Ferrous (50-65%)	Ferrous (less than 40%)	Nonferrous (more than 100%)	Nonferrous (less than 100%)
1 (greatest)	Broaching, internal	Em Sulf	Sulf Em	Sulf Em	MO Em	Sulf ML
3	Tapping, plain	Sulf	Sulf	Sulf	Em Dry	Sulf ML
2	Threading, pipe	Sulf	Sulf ML	Sulf	—	Sulf
3	Threading, plain	Sulf	Sulf	Sulf	Em Sulf	Sulf
4	Gear shaving	Sulf L	Sulf L	Sulf L	—	—
4	Gear cutting	Sulf ML Em	Sulf	Sulf ML	—	Sulf ML
5	Drilling, deep	Em ML	Sulf Em	Sulf	MO ML Em	Sulf ML
7	Boring, multiple head	Sulf Em	Sulf Em	Sulf Em	K Dry Em	Sulf Em
8	High-speed, light-feed, automatic screw machines	Sulf Em ML	Sulf Em ML	Sulf ML Em	Em Dry ML	Sulf
9	Turning; single-point tool, form tools	Em Sulf ML	Em Sulf ML	Em Sulf ML	Em Dry ML	Em Sulf

[130] Metals Handbook, 1948 ed., p. 69, American Society for Metals, Cleveland.

Symbols: *Dry* = no cutting fluid, *Em* = soluble or emulsifiable oils and compounds, *K* = kerosene, *L* = lard oil, *ML* = mineral-lard oils, *MO* = mineral oils, *Sulf* = sulfurized oils.

The required force F necessary to just move an object along a horizontal plane $= fN$ where N is the normal pressure on the plane and f the "coefficient of friction." The angle of repose Φ ($\tan \Phi = F/N$) is the angle at which the plane must be tilted before the object will move from its own weight. The following table of coefficients was compiled by Rankine from the results of General Morin and other authorities and is sufficient for ordinary purposes.

Material	f	$1/f$	ϕ
Wood on wood, dry	.25–.50	4.00–2.00	14.0–26.5
" " " soapy	.20	5.00	11.5
Metals on oak, dry	.50–.60	2.00–1.67	26.5–31.0
" " " wet	.24–.26	4.17–3.85	13.5–14.5
" " " soapy	.20	5.00	11.5
" " elm, dry	.20–.25	5.00–4.00	11.5–14.0
Hemp on oak, dry	.53	1.89	28.0
" " " wet	.33	3.00	18.5
Leather on oak	.27–.38	3.70–2.86	15.0–19.5
" " metals, dry	.56	1.79	29.5
" " " wet	.36	2.78	20.0
" " " greasy	.23	4.35	13.0
" " " oily	.15	6.67	8.5
Metals on metals, dry	.15–.20	6.67–5.00	8.5–11.5
" " " wet	.3	3.33	16.5
Smooth surfaces, occasionally greased	.07–.08	14.3–12.50	4.0–4.5
" " continually greased	.05	20.00	3.0
" " best results	.03–.036	33.3–27.6	1.75–2.0
Steel on agate, dry	.20	5.00	11.5
" " " oiled	.107	9.35	6.1
Iron on stone	.30–.70	3.33–1.43	16.7–35.0
Wood on stone	About .40	2.50	22.0
Masonry on brick work, dry	.60–.70	1.67–1.43	33.0–35.0
" " " " damp mortar	.74	1.35	36.5
" " dry clay	.51	1.96	27.0
" " moist clay	.33	3.00	18.25
Earth on earth	.25–1.00	4.00–1.00	14.0–45.0
" " " dry sand, clay, and mixed earth	.38–.75	2.63–1.33	21.0–37.0
" " " damp clay	1.00	1.00	45.0
" " " wet clay	.31	3.23	17.0
" " " shingle and gravel	.81–1.11	1.23–.9	39.0–48.0

TABLE 339.—DYNAMIC PRESSURE AT DIFFERENT AIR SPEEDS

The force on a body moving through a fluid may be expressed in the form

$$F = C_F\, q\, A$$

where F is the force, C_F a nondimensional force coefficient, q the dynamic pressure ($q = \frac{1}{2}\rho V^2$, definition), and A an area. In general, the value of the coefficient C_F is dependent on several nondimensional parameters. When the medium is air, C_F depends on the Reynolds number $\frac{Vl\rho}{\eta}$, the Mach number $\frac{V}{a}$, the body shape and attitude to the relative wind, the relative surface roughness, and the degree of turbulence of the air stream. The quantity ρ denotes the fluid density, V the velocity of the body relative to the fluid, η the coefficient of fluid viscosity, l a linear dimension of the body fixing the scale, and a the speed of sound in the ambient fluid.

The table gives values of dynamic pressure q for a wide range of speeds. In conjunction with the values of the force coefficient in subsequent tables, this table can be used for computation of lift, drag, and moment under specified conditions. The values in the table are computed for standard air density: dry air, normal CO_2 content, 15°C, one atmosphere. Standard air density is $0.12497 \frac{\text{metric slugs}}{\text{m}^3}$ or $0.002378 \frac{\text{slugs}}{\text{ft}^3}$. For standard gravity, the weight of one metric slug (MKS) is 9.807 kilograms and the weight of one slug is 32.174 pounds. For other densities the values must be multiplied by the ratio of the actual density to the standard density.

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* Tables 339 to 346 and figures 6 to 15 were prepared under the direction of C. H. Helms, assistant director of aeronautical research, National Advisory Committee for Aeronautics.

(*continued*)

TABLE 339.—DYNAMIC PRESSURE AT DIFFERENT AIR SPEEDS (concluded)

Air speed m/sec	Dynamic pressure, q kg/m²	Air speed m/sec	Dynamic pressure, q kg/m²	Air speed m/sec	Dynamic pressure, q kg/m²	Air speed m/sec	Dynamic pressure, q kg/m²	Air speed m/sec	Dynamic pressure, q kg/m²
1	.0625	12	8.998	35	76.54	85	451.4	170	1806
2	.2499	14	12.25	4C	99.98	90	506.1	180	2024
3	.5624	16	16.00	45	126.5	95	563.9	190	2256
4	.9998	18	20.24	50	156.2	100	624.8	200	2499
5	1.562	20	24.99	55	189.0	110	756.1	250	3905
6	2.249	22	30.24	60	224.9	120	899.8	300	5624
7	3.062	24	35.99	65	264.0	130	1056.0	350	7654
8	3.999	26	42.24	70	306.2	140	1225	400	9998
9	5.061	28	48.99	75	351.5	150	1406	450	12653
10	6.248	30	56.24	80	399.9	160	1600	500	15621

Air speed ft/sec	Dynamic pressure, q lb/ft²	Air speed ft/sec	Dynamic pressure, q lb/ft²	Air speed ft/sec	Dynamic pressure, q lb/ft²	Air speed ft/sec	Dynamic pressure, q lb/ft²	Air speed ft/sec	Dynamic pressure, q lb/ft²
1	.0012	20	.4756	120	17.12	220	57.55	600	428.0
2	.0048	30	1.0701	130	20.09	230	62.90	650	502.4
3	.0107	40	1.902	140	23.30	240	68.49	700	582.6
4	.0190	50	2.972	150	26.75	250	74.31	750	668.8
5	.0297	60	4.280	160	30.44	300	107.01	800	761.0
6	.0428	70	5.826	170	34.36	350	145.6	850	859.0
7	.0583	80	7.610	180	38.52	400	190.2	900	963.1
8	.0761	90	9.631	190	42.92	450	240.8	950	1073
8	.0963	100	11.890	200	47.56	500	297.2	1000	1189
10	.1189	110	14.39	210	52.43	550	359.7	1500	2675

TABLE 340.—FORCES ON THIN FLAT PLATES AT ANGLES TO THE WIND (FIG. 6)

For plates at angles to the wind (angle of attack, α) the force is usually resolved into components at right angles and parallel to the direction of the relative wind. The components, termed the lift and drag, respectively, are expressed in the form of coefficients, the forces being divided by the product of the dynamic pressure and the area of the plate (not the projected area on a plane normal to the wind). The ratio of the distance between the leading edge and the center of pressure to the chord length is called the center of pressure coefficient, *CP*. The center of pressure is defined as the intersection of the line of action of the resultant force, *F*, with the plate. The forces on a plate vary with "aspect ratio," a term defined for a rectangular plate as the ratio of the span to the chord length.

The lift (C_L), drag (C_D), and center of pressure coefficients (CP) are given as functions of angle of attack α for thin plates of aspect ratio 1, 3, and 6.

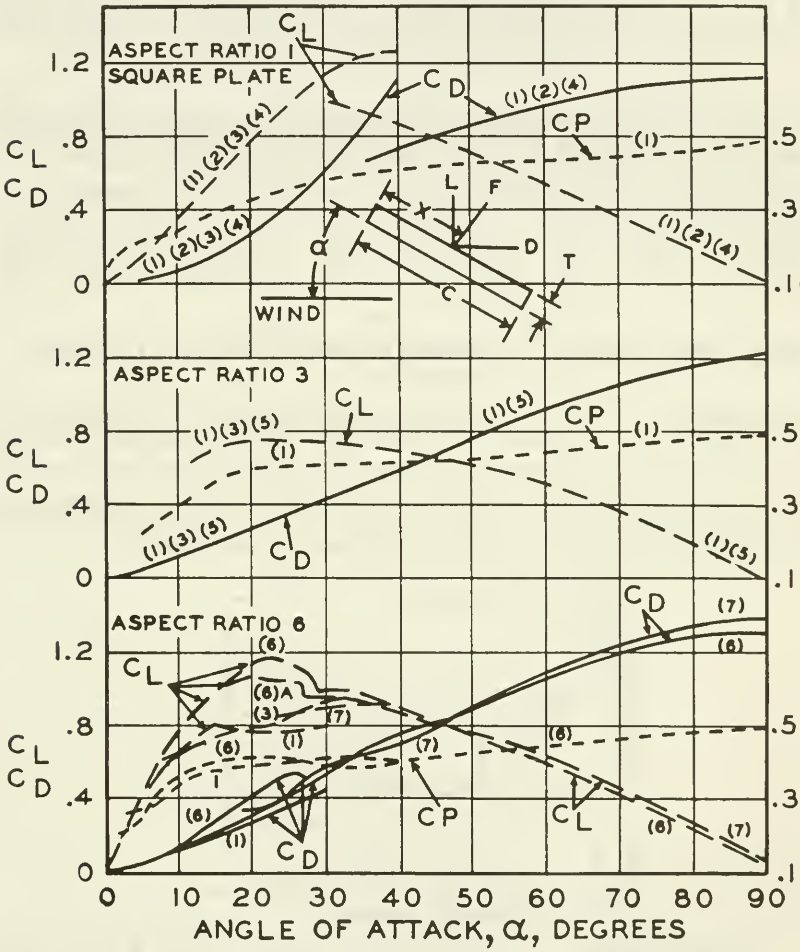

FIG. 6.—The lift coefficient (C_L), the drag coefficient (C_D), and the center of pressure (CP) for thin plates for aspect ratios 1, 3, and 6, as a function of the angle α with the wind. (See small figure in upper center.) $D = C_D A q$, $L = C_L A q$, $X = CP \times c$.

(continued)

TABLE 340.—FORCES ON THIN FLAT PLATES AT ANGLES TO THE WIND (FIG. 6) (concluded)

	Conditions of experiments											
	Aspect ratio 1				Aspect ratio 3				Aspect ratio 6			
Authority [131]	1	2	3	4	1	3	5	1	3	6	6a	7
Span, cm	25	30.5	12	12	45	7.6	36	90	.72	30.5	30.5	45.7 to 91.4
Chord, cm	25	30.5	12	12	15	2.5	12	15	12	5.08	5.08	7.6 to 15.2
Thickness, cm	.3	.32	.17	—	.3	.025	.17	.3	.17	.117	.129	—
Tunnel diam., cm	150	∿	200	120	150	60	200	150	200	137	137	152.4
Reynolds No. $\times 10^{-3}$	210	382	55	42	126	10	55	126	55	64	64	153

[131] Authorities: 1, Eiffel G., Resistance de l'air et l'aviation, 2d ed., p. 231, Dunod et Pinat, Paris. 2, Dines, Proc. Roy. Soc. London, A, Math. and Phys. Sci., vol. 48, p. 233, 1890. 3, Föppl, Jahrb. Motorluftschiff-Studiengesellsch., vol. 4, p. 51, 1910. 4, Riabouchinski, Bull. Inst. Aerodynam. de Koutchino, Petrograd, vol. 4, p. 113, 1912. 5, Stanton, T. E., Air resistance of plane surfaces, Minutes of Proc. Inst. Civil Eng., vol. 156, p. 78, 1903. 6 and 6a, National Bureau of Standards, private communication. 7, Knight, Montgomery, and Wenzinger, Carl J., Wind tunnel tests on a series of wing models through a large angle of attack range, Pt. 1, Force tests. NACA Rep. No. 317, 1929.

TABLE 340A.—VALUES OF DRAG COEFFICIENT C_D FOR FLAT PLATES OF DIFFERENT ASPECT RATIO NORMAL TO THE WIND ($\alpha = 90°$)

Values of C_D *for circular disks are practically the same as for a square plate.*

Aspect ratio	1	2	3	4	5	6	7	8	∞
C_D	1.12	1.18	1.22	1.24	1.26	1.28	1.30	1.32	2.00

TABLE 340B.—FORCES ON NONROTATING CIRCULAR CYLINDERS (FIG. 7) [132]

The drag coefficient C_D for cylinders whose axes are perpendicular to the relative wind, the area A being taken as the product of the length L and diameter d, depends to a marked degree on the aspect ratio $\frac{L}{d}$, the Reynolds number R, and the Mach number M. The figure shows the variation of the drag coefficient C_D with R for cylinders of infinite aspect ratio at very low Mach numbers. The drag coefficient C_D varies with Mach number in a manner quite similar to that of the sphere on Table 340C (figures 8 and 10).

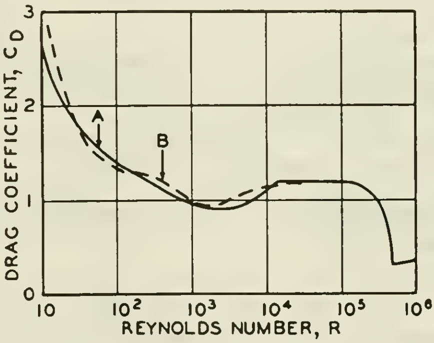

FIG. 7.—The drag coefficient C_D as a function of the Reynolds number R at low Mach numbers for cylinders of infinite aspect ratios with axes perpendicular to the wind.

Drag $= C_D A q$, Reynolds number, $R = \frac{Vd\rho}{\eta}$, Mach number, $M = \frac{V}{a}$. For q see Table 339, V = air speed, ρ = air density, η = coefficient of air viscosity.

[132] Wieselberger, C., New data on the laws of fluid resistance. NACA TN No. 84, 1922. Relf, E. F., Discussion of the results of measurements of the resistance of wires with some additional tests on the resistance of wires of small diameter. R. & M. No. 102, British ACA, March 1914. Wieselsberger, C., Further information on the laws of fluid resistance. NACA TN No. 121, December 1922.

(*continued*)

TABLE 340B.—FORCES ON NONROTATING CIRCULAR CYLINDERS (FIG. 7) (concluded)

The variation of C_D with aspect ratio for Reynolds number of 80,000 is as follows.

Aspect ratio $\frac{L}{d}$	1	2	3	5	10	20	40	∞
C_D	.63	.69	.75	.75	.83	.92	1.00	1.20

If the axis of the cylinder is inclined to the wind direction, the force remains approximately at right angles to the axis of the cylinder, its magnitude falling off approximately as the square of the sine of the angle of the axis to the wind.

TABLE 340C.—FORCES ON SPHERES (FIGS. 8-10)[133]

For spheres, the linear dimension l is taken as the diameter of the sphere d and the area A as $\frac{\pi d^2}{4}$. For values of Reynolds number between 80,000 and 400,000 at low values of Mach number the value of the drag coefficient C_D depends in large measure on the turbulence of the air stream. As the Reynolds number is increased in this range the drag coefficient of the sphere and the pressure coefficient at the rear of the sphere decrease rapidly. The pressure coefficient is equal to the ratio of the difference between free stream stagnation pressure and local static pressure to the dynamic pressure q. The Reynolds number at which the pressure coefficient at the rear of the sphere is 1.22 is defined as the critical Reynolds number, R_{cr}. This value of pressure coefficient corresponds very nearly to $C_D = .3$. The value of R_{cr} represented by point d in the figure is considered to be typical of turbulence-free air.

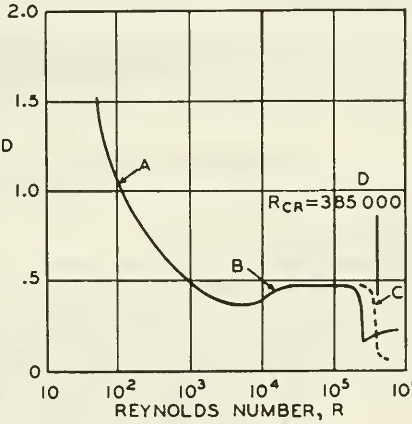

FIG. 8.—The drag coefficient C_D on spheres as a function of the Reynolds number.

$$\text{Drag, } D = C_D A q \quad R = \frac{V d \rho}{\eta}$$

Sphere tests in wind tunnels indicate different values of R_{cr} for different sphere sizes. Correlation of the data may be obtained if values of $\frac{\sqrt{\overline{u^2}}}{V}\left(\frac{d}{L}\right)^{\frac{1}{5}} = (K)$ are plotted as a function of R_{cr}. The value $\sqrt{\overline{u^2}}$ is the root-mean-square of the fluctuation velocity in the direction of the relative wind, V the velocity of the relative wind, d the sphere diameter, and L is the scale of the turbulence as defined in the reference. The figure shows a correlation (K) obtained with two sizes of spheres and several values of L.

[133] Allen, H. S., The motion of a sphere in a viscous fluid, Phil. Mag., vol. 50, p. 323, 1900. Wieselberger, C., Further information on the laws of fluid resistance, NACA TN No. 121, December 1922. Millikan, C. B., and Klein, A. L., The effect of turbulence, Aircraft Eng., vol. 5, p. 169, 1933. Platt, Robert C., Turbulence factors of NACA wind tunnels as determined by sphere tests, NACA Rep. No. 558, 1936. Dryden, Hugh L., Schubauer, G. B., Mock, W. C., Jr., and Skramstad, H. K., Measurements of intensity and scale of wind-tunnel turbulence and their relation to the critical Reynolds number of spheres, NACA Rep. No. 581, 1937. Ferri, Antonio, The influence of Reynolds numbers at high Mach numbers, Atti di Guidonia, n. 67/69, Mar. 10, 1942.

(*continued*)

TABLE 340C.—FORCES ON SPHERES (FIGS. 8-10) (concluded)

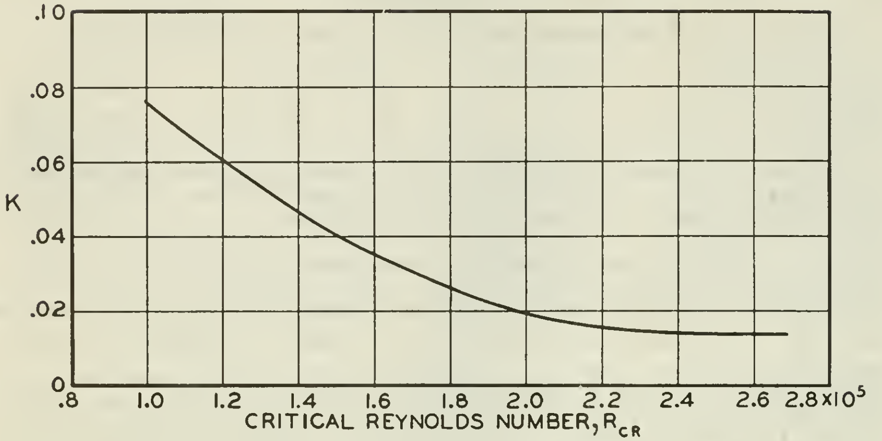

FIG. 9.—The value of $\frac{\sqrt{\bar{u}^2}}{V}\left(\frac{d}{L}\right)^{\frac{1}{5}} = K$ plotted as a function of the critical Reynolds number, R_{cr}.

At Mach numbers greater than about 0.3 the drag coefficient C_D depends on the values of both Reynolds number and Mach number.

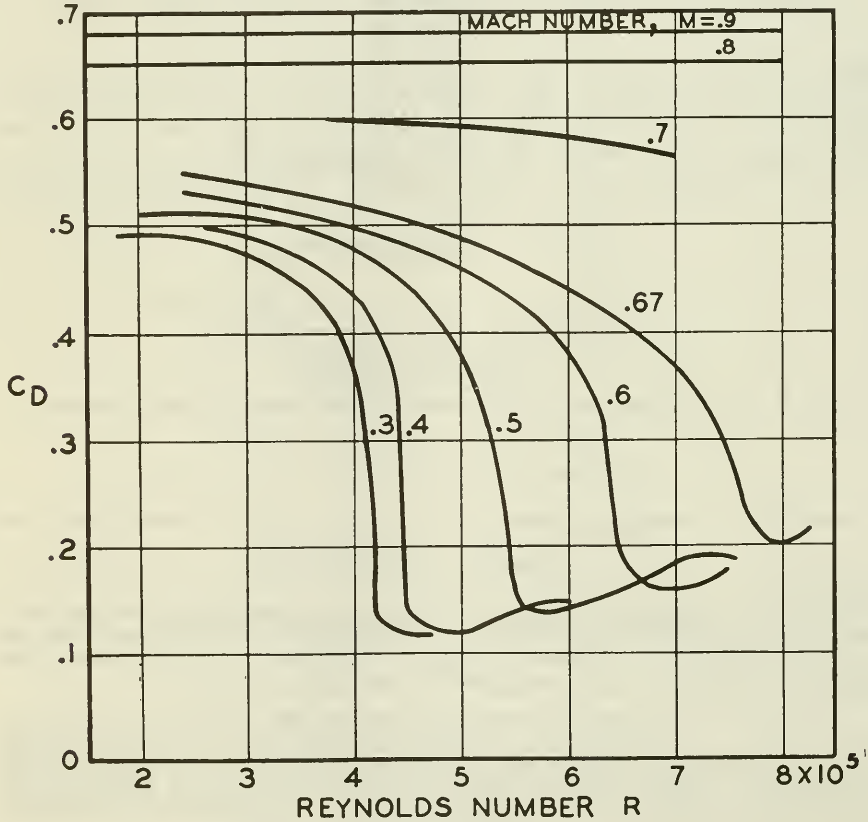

FIG. 10.—The drag coefficient for a sphere as a function of the Reynolds number for several Mach numbers.

The values of the drag coefficients in this table are based on the area of the projection of the body on a plane normal to the wind direction. Where this projection is a circle, the diameter is used as the linear dimension l in the Reynolds number. Where the projection is rectangular, the shortest side of the rectangle is taken as l.

Body	C_D	Reynolds number
Streamline bodies of revolution	.05– .06	3,000,000
Rectangular prism 1 × 1 × 5 normal to 1 × 5 face	1.56	180,000
Rectangular prism 1 × 1 × 5, long axis perpendicular to the relative wind and 1 × 5 face at 45°	.92	254,000
Automobile	.78	[about 300,000]
Cone, angle 60°, point to wind, solid	.51	[about 270,000]
Cone, angle 30°, point to wind, solid	.34	270,000
Hemispherical cup, open back	.41	100,000
Hemispherical cup, open front	1.40	100,000
Sphero-conic body, cone 20° point forward	.16	135,000
Sphero-conic body, cone 20° point to rear	.09	135,000
Cylinder 120 cm long, spherical ends with axis parallel to the relative wind	.19	100,000

TABLE 341A.—SKIN FRICTION ON FLAT PLATES (FIGS. 11, 12)[134]

If the flat plate is in a uniform stream of fluid and the flow is parallel to the plate the skin friction coefficient, C_f, is dependent mainly on the Reynolds number, $R = \frac{VL\rho}{\eta}$. The skin friction coefficient $C_f = \frac{D_f}{qL}$ where D_f is the friction drag per unit width of one side of the plate, q the dynamic pressure (see Table 339), and L the length from the leading edge of the plate.

For laminar flow

$$C_f = \frac{1.328}{\sqrt{R}} \qquad \text{(Blasius)}$$

For turbulent flow

$$C_f = \frac{0.455}{(\log_{10} R)^{2.58}} \qquad \text{(Schlichting)}$$

The Reynolds number for transition from laminar to turbulent flow depends on the roughness of the plate and the turbulence of the airstream.

The figure shows the variation of the skin friction (C_f) with R for laminar and turbulent flow.

[134] Tetervin, Neal, A method for the rapid estimation of turbulent boundary-layer thickness for calculating profile drag, NACA ACR No. L4G14, July 1944

(continued)

TABLE 341A.—SKIN FRICTION ON FLAT PLATES (FIGS. 11, 12) (continued)

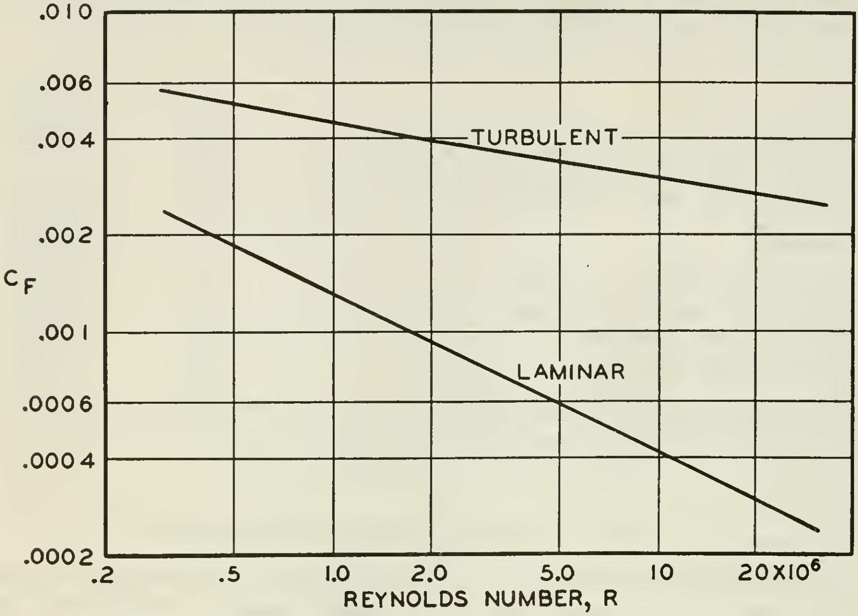

FIG. 11.—A log-log plot of the skin-friction coefficient C_f on a flat plate as a function of the Reynolds number for laminar and turbulent flow.

The local skin-friction coefficient $\frac{\tau_0}{2q}$ may be approximated by a power function of the Reynolds number based on the momentum thickness, $R_\Theta = \frac{V\Theta\rho}{\eta}$. When the boundary layer is laminar

$$\frac{\tau_0}{2q} = \frac{0.2205}{R_\Theta}$$

When the boundary layer is turbulent

$$\frac{\tau_0}{2q} = \frac{1}{\left[2.5 \log_e \frac{R_\Theta}{2.5(1-5\sqrt{\tau_0/2q})} + 5.5\right]^2},$$

The momentum thickness

$$\theta = \int_0^\delta \frac{u}{V}\left(1 - \frac{u}{V}\right) dy,$$

where u is the local velocity inside the boundary layer, V the local velocity outside the boundary layer, and δ the boundary-layer thickness. The local skin-friction coefficient is plotted against Reynolds number for the case of a turbulent boundary layer.

(continued)

TABLE 341A.—SKIN FRICTION ON FLAT PLATES (FIGS. 11, 12) (concluded)

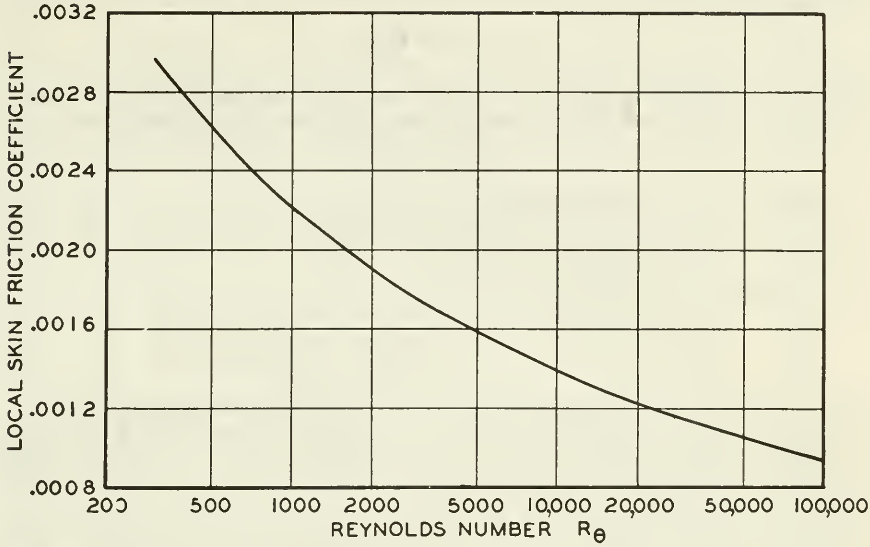

FIG. 12.—The local skin-friction coefficient on a flat plate plotted against the Reynolds number for a turbulent boundary layer.

TABLE 342.—STANDARD ATMOSPHERE [135]

Standard atmospheric values are given up to altitudes of 65,000 feet, and quantities that have been found to be of use in the interpretation of airspeed and related factors are included (Table 343). These quantities are the pressure p in pounds per square foot, the pressure p in inches of water, the speed of sound a, the coefficient of viscosity η, and the kinematic viscosity ν. The values for the coefficient of viscosity η and the kinematic viscosity ν are not standard values since a standardization of air viscosity has not been agreed upon as yet. The values listed for η and ν are believed to be sufficiently accurate, however, to be useful in calculations requiring viscosity of air. The coefficient of viscosity η was computed from the formula

$$\eta = \frac{2.318}{10^8}\frac{T^{3/2}}{T+216}.$$

The kinematic viscosity of air ν was obtained from the definition $\nu = \frac{\eta}{\rho}$. The quantity $1/\sqrt{\sigma}$ is given to facilitate the computation of the true airspeed V from the equivalent airspeed V_e.

$$V = \frac{1}{\sqrt{\sigma}} V_e$$

The speed of sound in miles per hour is computed from $a = 33.42\sqrt{T}$ where T is the temperature in degrees Fahrenheit absolute. A value of $\gamma = 1.4$ was assumed to hold throughout the temperature range.

The values of the standard atmosphere are based upon the following values:

Sea-level pressure $p_0 = 29.921$ inHg
$= 407.1$ inH_2O
$= 2116.2$ lb/ft^2
Sea-level temperature $t_0 = 59°$F
Sea-level absolute temperature $T_0 = 518.4°$F abs
Sea-level density $\rho_0 = 0.002378$ slug/ft^3
Gravity $g = 32.1740$ ft/sec^2
Temperature gradient $\frac{dT}{dh} = 0.00356617°$F/ft
The altitude of the lower limit of the isothermal atmosphere $= 35{,}332$ ft
Specific weight of mercury at 32°F $= 848.7149$ lb/ft^3
Specific weight of water at 59°F $= 62.3724$ lb/ft^3

[135] Aiken, William S., Jr., Standard nomenclature for airspeeds with tables and charts for use in calculation of airspeed, NACA Rep. No. 837, 1947. Warfield, Calvin N., Tentative tables for the properties of the upper atmosphere, NACA TN No. 1200, January 1947.

(*continued*)

Up to the lower limit of the isothermal atmosphere (—67°F corresponding to 35,332 ft) the temperature is assumed to decrease linearly according to the equation

$$T = T_0 - \frac{dT}{dh}\,h$$

Further, the atmosphere is assumed to be a dry perfect gas that obeys the laws of Charles and Boyle, so that the mass density corresponding to the pressure and temperature is

$$\rho = \rho_0 \frac{p}{p_0} \frac{T_0}{T}$$

The pressure and altitude are related by

$$h = \frac{p_0}{\rho_0 g} \frac{T_m}{T_0} \log_e \frac{p_0}{p} .$$

The harmonic mean temperature T_m is given by

$$T_m = \frac{\Sigma \Delta h}{\sum \frac{\Delta h}{T_{av}}} = \frac{\Delta h_1 + \Delta h_2 + \cdots}{\frac{\Delta h_1}{T_{av1}} + \frac{\Delta h_2}{T_{av2}} + \cdots}$$

where T_{av1}, T_{av2}, ... are the average temperatures for the altitude increments Δh_1, Δh_2, ...

The NACA Special Subcommittee on the Upper Atmosphere, at a meeting on June 24, 1946, resolved that a tentative extension of the standard atmosphere from 65,000 to 100,000 feet be based upon a constant composition of the atmosphere and an isothermal temperature which are the same as standard conditions at 65,000 feet. This tentative extended isothermal region (Table 344) ends at 32 kilometers (approximately 105,000 ft). It is possible that as results of higher altitude temperature soundings become available and the standard atmosphere is extended to very high altitudes the present recommendations may be modified.

The Subcommittee also recommended that the values of temperature given in the following table be considered as maximum and minimum values occurring for the given altitudes with the variations between the specified points to be linear:

Altitude (km)	Temperature (°C abs) Minimum	Maximum
20	180	250
25	—	250
45	200	380

A tentative extension of the standard atmosphere computed from the equations using the recommended isothermal temperature and constant gravity altitudes from 65,000 to 100,000 feet are included in the table. Calculations have been made[185] by assuming that the acceleration of gravity varies inversely as the square of the distance from the center of the earth. Up to 100,000 feet this assumption does not greatly affect the tabulated values.

Altitude, h ft	Pressure, p lb/ft²	Pressure, p inH₂O	Pressure, p inHg	Density ρ slugs/ft³	Density ratio $\sigma = \frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T °F abs	Speed of sound, a mi/hr	Coefficient of viscosity, η slugs/ft-sec	Kinematic viscosity, ν ft²/sec
0	2116	407.1	29.92	.002378	1.0000	1.000	518.4	760.9	3.725×10^{-7}	1.566×10^{-4}
2,000	1968	378.5	27.82	.002242	.9428	1.030	511.2	755.7	3.685	1.644
4,000	1828	351.6	25.84	.002112	.8881	1.061	504.1	750.4	3.644	1.725
6,000	1696	326.2	23.98	.001988	.8358	1.094	497.0	745.1	3.602	1.812
8,000	1572	302.4	22.22	.001869	.7859	1.128	489.9	739.7	3.561	1.905
10,000	1455	279.9	20.58	.001756	.7384	1.164	482.7	734.3	3.519	2.004
12,000	1346	258.9	19.03	.001648	.6931	1.201	475.6	728.8	3.476	2.109
14,000	1243	239.1	17.57	.001545	.6499	1.240	468.5	723.4	3.434	2.223
16,000	1146	220.6	16.21	.001448	.6088	1.282	461.3	718.7	3.391	2.342
18,000	1056	203.2	14.94	.001355	.5698	1.325	454.2	712.2	3.348	2.471
20,000	972.1	187.0	13.75	.001267	.5327	1.370	447.1	706.6	3.305	2.608
22,000	893.3	171.9	12.63	.001183	.4974	1.418	439.9	701.1	3.261	2.756
24,000	819.8	157.7	11.59	.001103	.4640	1.468	432.8	695.3	3.217	2.916
26,000	751.2	144.5	10.62	.001028	.4323	1.521	425.7	689.5	3.173	3.086
28,000	687.4	132.2	9.720	.000957	.4023	1.577	418.5	683.7	3.128	3.268
30,000	628.0	120.8	8.880	.000889	.3740	1.635	411.4	677.9	3.083	3.468
32,000	572.9	110.2	8.101	.000826	.3472	1.697	404.3	672.0	3.038	3.678
34,000	521.7	100.4	7.377	.000765	.3218	1.763	397.2	666.0	2.992	3.911
35,332	489.8	94.24	6.926	.000727	.3058	1.808	392.4	662.0	2.962	4.073
36,000	474.4	91.31	6.711	.000705	.2963	1.837	392.4	662.0	2.962	4.204
38,000	431.1	82.97	6.098	.000640	.2692	1.927	392.4	662.0	2.962	4.625
40,000	391.9	75.44	5.544	.000582	.2448	2.021	392.4	662.0	2.962	5.089
42,000	356.2	68.56	5.038	.000529	.2225	2.120	392.4	662.0	2.962	5.599
44,000	323.7	62.29	4.578	.000480	.2021	2.224	392.4	662.0	2.962	6.161
46,000	294.2	56.63	4.162	.000437	.1838	2.333	392.4	662.0	2.962	6.778
48,000	267.4	51.46	3.782	.000397	.1670	2.447	392.4	662.0	2.962	7.459
50,000	243.1	46.78	3.438	.000361	.1518	2.567	392.4	662.0	2.962	8.206
52,000	220.9	42.52	3.124	.000328	.1379	2.692	392.4	662.0	2.962	9.028
54,000	200.8	38.64	2.840	.000298	1.1254	2.824	392.4	662.0	2.962	9.933
56,000	182.5	35.12	2.581	.000271	.1140	2.962	392.4	662.0	2.962	10.93
58,000	165.9	31.92	2.346	.000246	.1036	3.107	392.4	662.0	2.962	12.02
60,000	150.8	29.01	2.132	.000224	.09415	3.259	392.4	662.0	2.962	13.23
62,000	137.1	26.37	1.938	.000203	.08557	3.419	392.4	662.0	2.962	14.56
64,000	124.6	23.96	1.761	.000185	.07777	3.586	392.4	662.0	2.962	16.02
65,000	118.7	22.85	1.679	.000176	.07414	3.672	392.4	662.0	2.962	16.80

* For metric values see Table 628.

TABLE 344.—PROPERTIES OF THE TENTATIVE STANDARD-ATMOSPHERE EXTENSION

Altitude h ft	Pressure, p lb/ft²	Pressure, p inH₂O	Pressure, p inHg	Density, ρ slugs/ft³	Density ratio, $\sigma = \frac{\rho}{\rho_0}$	$\frac{1}{\sqrt{\sigma}}$	Temperature, T °F abs	Speed of sound, a mi/hr	Coefficient of viscosity, η slugs/ft-sec	Kinematic viscosity, ν ft²/sec
65,000	118.7	22.85	1.679	.000176	.07414	3.672	392.4	662.0	2.962×10^{-7}	16.80×10^{-4}
70,000	93.53	17.99	1.322	.000139	.05839	4.138	392.4	662.0	2.962	21.33
75,000	73.66	14.17	1.042	.000109	.04599	4.663	392.4	662.0	2.962	27.09
80,000	58.01	11.16	.8202	.0000861	.03621	5.255	392.4	662.0	2.962	34.39
85,000	45.68	8.789	.6460	.0000678	.02852	5.921	392.4	662.0	2.962	43.67
90,000	35.97	6.921	.5086	.0000534	.02246	6.672	392.4	662.0	2.962	55.45
95,000	28.33	5.451	.4006	.0000421	.01769	7.519	392.4	662.0	2.962	70.41
100,000	22.31	4.293	.3156	.0000331	.01394	8.472	392.4	662.0	2.962	89.41

In high speed research, use is frequently made of the theoretical relationships existing between the Mach number and various flow parameters. Two types of flow are tabulated: isentropic flow and normal-shock flow. Isentropic flow is generally valid for a subsonic or supersonic expanding flow and may be used for subsonic compression flow. Normal-shock flow is valid for supersonic compression flow when the deviation of the flow through the shock is zero. Oblique-shock flow may be obtained from the normal-shock flow by superimposing a velocity tangential to the shock.

The assumption that air is a perfect gas with a value of γ of 1.400 is valid for the conditions usually encountered in the subsonic and lower supersonic regions for normal stagnation conditions. For Mach numbers greater than about 4.0 or for unusual stagnation conditions, however, the behavior of air will depart appreciably from that of a perfect gas if the liquefaction condition is approached, and caution should be used in applying the results in the table at the higher Mach numbers.

The formulas for isentropic flow are:

$$\frac{p_1}{p_0} = \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{\frac{\gamma}{1-\gamma}}$$

$$\frac{\rho_1}{\rho_0} = \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{\frac{1}{1-\gamma}}$$

$$\frac{T_1}{T_0} = \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{-1}$$

$$\frac{A_{cr}}{A_1} = M_1 \left(\frac{1 + \frac{\gamma - 1}{2}}{1 + \frac{\gamma - 1}{2} M_1^2}\right)^{\frac{\gamma + 1}{2(\gamma - 1)}}$$

$$\frac{a_1}{a_0} = \left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{-\frac{1}{2}}$$

$$V_1 = M_1 \left(\frac{a_1}{a_0}\right) a_0$$

$$F_c = \frac{2}{\gamma M_1^2}\left[\left(1 + \frac{\gamma - 1}{2} M_1^2\right)^{\frac{\gamma}{\gamma - 1}} - 1\right]$$

$$\phi = \sin^{-1}\left(\frac{1}{M_1}\right)$$

$$\nu = \left(\frac{\gamma + 1}{\gamma - 1}\right)^{\frac{1}{2}} \cos^{-1}\left[\frac{\gamma + 1}{2\left(1 + \frac{\gamma - 1}{2} M_1^2\right)}\right]^{\frac{1}{2}} + \phi - 90°,$$

and the formulas for normal-shock flow are:

$$\frac{p_2}{p_1} = \frac{2\gamma}{\gamma + 1} M_1^2 - \frac{\gamma - 1}{\gamma + 1}$$

$$\frac{p_2}{p_0} = \left(\frac{p_2}{p_1}\right)\left(\frac{p_1}{p_0}\right)$$

$$\frac{p_3}{p_2} = \left(\frac{\gamma - 1}{2} M_2^2 + 1\right)^{\frac{\gamma}{\gamma - 1}}$$

$$\frac{p_3}{p_0} = \left(\frac{p_3}{p_2}\right)\left(\frac{p_2}{p_0}\right)$$

$$M_2 = \left[\left(\frac{\gamma + 1}{2\gamma}\right)^2 \left(\frac{1}{M_1^2 - \frac{\gamma - 1}{2\gamma}}\right) + \frac{\gamma - 1}{2\gamma}\right]^{\frac{1}{2}}$$

[156] Burcher, Marie A., Compressible flow tables for air, NACA TN No. 1592, August 1948.

(*continued*)

TABLE 345.—COMPRESSIBLE FLOW TABLES FOR AIR (concluded)

$$\frac{\rho_2}{\rho_1} = \left(\frac{M_1}{M_2}\right)^2 \left(\frac{p_1}{p_2}\right)$$

$$\frac{V_2}{V_1} = \frac{\rho_1}{\rho_2}$$

where

$a =$ speed of sound in air.

$A =$ cross-sectional area of the stream tube.

$A_{cr} =$ cross-sectional area of the stream tube for $M_1 = 1.0$.

$F_c =$ compressibility factor, increase in pressure above the static pressure set up in a tube whose open end is pointed into the relative wind divided by the dynamic pressure.

$M =$ Mach number $\left(\frac{V}{a}\right)$.

$\phi =$ Mach angle, degrees.

$p =$ absolute pressure.

$T =$ temperature, °F absolute.

$V =$ airspeed, feet per second, computed for $T_0 = 520$°F absolute and $a_0 = 1117.372$ feet per second.

$\gamma =$ ratio of specific heats, taken as 1.400.

$\nu =$ expansion angle required to change Mach number from 1.0 to M_1, degrees.

$\rho =$ mass density of air.

Subscripts:

$0 =$ stagnation conditions before shock.

$1 =$ air stream conditions before shock.

$2 =$ air stream conditions behind shock.

$3 =$ stagnation conditions behind shock.

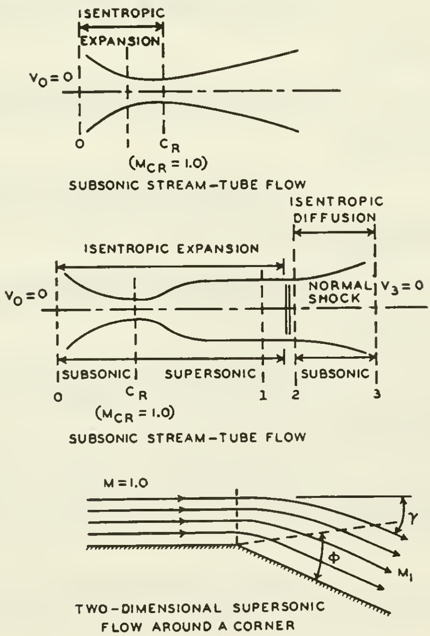

FIG. 13.—Illustrating three types of flow.

TABLE 346.—RELATION BETWEEN MACH NUMBER AND VARIOUS FLOW PARAMETERS

M_1	$\frac{p_1}{p_0}$	$\frac{\rho_1}{\rho_0}$	$\frac{T_1}{T_0}$	$\frac{A_{cr}}{A_1}$	$\frac{a_1}{a_0}$	V_1 ($T_0 = 520°$ F abs.)	F_c
0	1.000	1.000	1.000	0	1.000	0	1.000
.05	.9983	.9988	.9995	.0863	.9998	55.85	1.001
.10	.9930	.9950	.9980	.1718	.9990	111.6	1.003
.15	.9844	.9888	.9955	.2557	.9978	167.2	1.006
.20	.9725	.9803	.9921	.3374	.9960	222.6	1.010
.25	.9575	.9694	.9877	.4162	.9938	277.6	1.016
.30	.9395	.9564	.9823	.4914	.9911	332.2	1.023
.35	.9188	.9413	.9761	.5624	.9880	386.4	1.031
.40	.8956	.9243	.9690	.6288	.9844	440.0	1.041
.45	.8703	.9055	.9611	.6903	.9803	492.9	1.052
.50	.8430	.8852	.9524	.7464	.9759	545.2	1.064
.50	.8430	.8852	.9524	.7464	.9759	545.2	1.064
.55	.8142	.8634	.9430	.7969	.9711	596.8	1.078
.60	.7840	.8405	.9328	.8416	.9658	647.5	1.093
.65	.7528	.8164	.9221	.8806	.9603	697.4	1.110
.70	.7209	.7916	.9107	.9138	.9543	746.4	1.129
.75	.6886	.7660	.8989	.9413	.9481	794.5	1.149
.80	.6560	.7400	.8865	.9632	.9416	841.7	1.170
.85	.6235	.7136	.8737	.9797	.9347	887.8	1.194
.90	.5913	.6870	.8606	.9912	.9277	932.9	1.219
.95	.5595	.6604	.8471	.9979	.9204	977.0	1.246
1.00	.5283	.6339	.8333	1.0000	.9129	1020.0	1.276

M_1	$\frac{p_1}{p_0}$	$\frac{\rho_1}{\rho_0}$	$\frac{T_1}{T_0}$	$\frac{A_1}{A_{cr}}$	$\frac{a_1}{a_0}$	V_1 ($T_0 = 520°$ F abs.)	ϕ	γ	$\frac{p_2}{p_1}$	$\frac{p_2}{p_0}$	$\frac{p_3}{p_0}$	$\frac{\rho_2}{\rho_1}$	M_2	$\frac{V_2}{V_1}$
1.00	.5283	.6339	.8333	1.000	.9129	1020	90.00	0	1.000	.5283	1.000	1.000	1.000	1.000
1.10	.4684	.5817	.8052	1.008	.8973	1103	65.38	1.34	1.245	.5831	.9989	1.169	.9118	.8554
1.20	.4124	.5311	.7764	1.030	.8811	1181	56.44	3.56	1.513	.6241	.9928	1.342	.8422	.7454
1.30	.3609	.4829	.7474	1.065	.8645	1256	50.28	6.17	1.805	.6514	.9794	1.516	.7860	6598
1.40	.3142	.4374	.7184	1.115	.8476	1326	45.58	8.99	2.120	.6662	.9582	1.690	.7397	.5918
1.50	.2724	.3950	.6897	1.176	.8305	1392	41.81	11.91	2.458	.6697	.9298	1.862	.7011	.5370
1.60	.2353	.3557	.6614	1.250	.8133	1454	38.68	14.86	2.820	.6635	.8952	2.032	.6684	.4922
1.70	.2026	.3197	.6337	1.338	.7961	1512	36.03	17.81	3.205	.6493	.8557	2.198	.6405	.4550
1.80	.1740	.2868	.6068	1.439	.7790	1567	33.75	20.73	3.613	.6289	.8127	2.359	.6165	.4239
1.90	.1492	.2570	.5807	1.555	.7620	1618	31.76	23.59	4.045	.6037	.7674	2.516	.5956	.3975
2.00	.1278	.2300	.5556	1.688	.7454	1666	30.00	26.38	4.500	.5751	.7209	2.667	.5774	.3750
2.10	.1094	.2058	.5313	1.837	.7289	1710	28.44	29.10	4.978	.5444	.6742	2.812	.5613	.3556
2.20	.09352	.1841	.5081	2.005	.7128	1752	27.04	31.73	5.480	.5125	.6281	2.951	.5471	.3388
2.30	.07997	.1646	.4859	2.193	.6971	1791	25.77	34.28	6.005	.4802	.5833	3.085	.5344	.3242
2.40	.06840	.1472	.4647	2.403	.6817	1828	24.62	36.75	6.553	.4482	.5401	3.212	.5231	.3113
2.50	.05853	.1317	.4444	2.637	.6667	1862	23.58	39.12	7.125	.4170	.4990	3.333	.5130	.3000
2.60	.05012	.1179	.4252	2.896	.6521	1894	22.62	41.41	7.720	.3869	.4601	3.449	.5039	.2899
2.70	.04295	.1056	.4068	3.183	.6378	1924	21.74	43.62	8.338	.3581	.4236	3.559	.4956	.2810
2.80	.03685	.09463	.3894	3.500	.6240	1952	20.92	45.75	8.980	.3309	.3895	3.664	.4882	.2730
2.90	.03165	.08489	.3729	3.850	.6106	1979	20.17	47.79	9.645	.3053	.3577	3.763	.4814	.2658
3.00	.02722	.07623	.3571	4.235	.5976	2003	19.47	49.76	10.33	.2813	.3283	3.857	.4752	.2593
3.10	.02345	.06852	.3422	4.657	.5850	2026	18.82	51.65	11.05	.2590	.3012	3.947	.4695	.2534
3.20	.02023	.06165	.3281	5.121	.5728	2048	18.21	53.47	11.78	.2383	.2762	4.031	.4643	.2480
3.30	.01748	.05554	.3147	5.629	.5609	2068	17.64	55.22	12.54	.2191	.2533	4.112	.4596	.2432
3.40	.01512	.05009	.3019	6.184	.5495	2088	17.10	56.91	13.32	.2015	.2322	4.188	.4552	.2388

TABLE 346.—RELATION BETWEEN MACH NUMBERS AND VARIOUS FLOW PARAMETERS (concluded)

M_1	$\frac{p_1}{p_0}$	$\frac{\rho_1}{\rho_2}$	$\frac{T_1}{T_0}$	$\frac{A_1}{A_{cr}}$	$\frac{a_1}{a_0}$	V_1 ($T_0 = 520°$ F abs.)	ϕ	γ	$\frac{p_2}{p_1}$	$\frac{p_2}{p_0}$	$\frac{p_3}{p_0}$	$\frac{\rho_2}{\rho_1}$	M_2	$\frac{V_2}{V_1}$
3.50	.01311	.04523	.2899	6.790	.5384	2106	16.60	58.53	14.13	.1852	.2129	4.261	.4512	.2347
3.60	.01138	.04089	.2784	7.450	.5276	2122	16.13	60.09	14.95	.1702	.1953	4.330	.4474	.2310
3.70	.009903	.03702	.2675	8.169	.5172	2138	15.68	61.60	15.81	.1565	.1792	4.395	.4439	.2275
3.80	.008629	.03355	.2572	8.951	.5072	2153	15.26	63.04	16.68	.1439	.1645	4.457	.4407	.2244
3.90	.007532	.03044	.2474	9.799	.4974	2168	14.86	64.44	17.58	.1324	.1510	4.516	.4377	.2215
4.00	.006586	.02766	.2381	10.72	.4880	2181	14.48	65.78	18.50	.1218	.1388	4.571	.4350	.2188
4.20	.005062	.02292	.2208	12.79	.4699	2205	13.77	68.33	20.41	.1033	.1173	4.675	.4299	,2139
4.40	.003918	.01909	.2053	15.21	.4531	2227	13.14	70.71	22.42	.08783	.09948	4.768	.4255	.2097
4.60	.003053	.01597	.1911	18.02	.4372	2247	12.56	72.92	24.52	.07485	.08459	4.853	.4217	.2060
4.80	.002394	.01343	.1783	21.26	.4223	2265	12.02	74.99	26.71	.06396	.07214	4.930	.4183	.2028
5.00	.001890	.01134	.1667	25.00	.4082	2281	11.54	76.92	29.00	.05481	.06172	5.000	.4152	.2000
5.20	.001501	.009620	.1561	29.28	.3950	2295	11.09	78.73	31.38	.04711	.05297	5.064	.4125	.1975
5.40	.001200	.008197	.1464	34.17	.3826	2308	10.67	80.43	33.85	.04061	.04560	5.122	.4101	.1952
5.60	.0009643	.007012	.1375	39.74	.3708	2320	10.29	82.03	36.42	.03512	.03938	5.175	.4079	.1932
5.80	.0007794	.006023	.1294	46.05	.3597	2331	9.93	83.54	39.08	.03046	.03412	5.224	.4059	.1914
6.00	.0006334	.005194	.1220	53.18	.3492	2341	9.59	84.96	41.83	.02650	.02965	5.268	.4042	.1898
6.20	.0005173	.004495	.1151	61.21	.3393	2350	9.28	86.29	44.68	.02312	.02584	5.309	.4025	.1883
6.40	.0004247	.003904	.1088	70.23	.3298	2359	8.99	87.56	47.62	.02022	.02259	5.347	.4011	.1870
6.60	.0003503	.003402	.1030	80.32	.3209	2366	8.71	88.76	50.65	.01774	.01981	5.382	.3997	.1858
6.80	.0002902	.002974	.09758	91.59	.3124	2373	8.46	89.90	53.78	.01561	.01741	5.415	.3985	.1847
7.00	.0002416	.002609	.09259	104.1	.3043	2380	8.21	90.97	57.00	.01377	.01535	5.444	.3974	.1837
7.20	.0002019	.002295	.08797	118.1	.2966	2386	7.98	92.00	60.31	.01218	.01357	5.472	.3963	.1827
7.40	.0001694	.002025	.08367	133.5	.2893	2392	7.77	92.97	63.72	.01080	.01202	5.498	.3954	.1819
7.60	.0001427	.001792	.07967	150.6	.2823	2397	7.56	93.90	67.22	.009594	.01068	5.522	.3945	.1811
7.80	.0001207	.001589	.07594	169.4	.2756	2402	7.37	94.78	70.81	.008547	.009510	5.544	.3937	.1804
8.00	.0001024	.001414	.07246	190.1	.2692	2406	7.18	95.62	74.50	.007631	.008488	5.565	.3929	.1797
8.20	.00008723	.001260	.06921	212.8	.2631	2411	7.00	96.43	78.28	.006828	.007592	5.585	.3922	.1791
8.40	.00007454	.001126	.06617	237.8	.2572	2414	6.84	97.20	82.15	.006123	.006806	5.603	.3915	.1785
8.60	.00006390	.001009	.06332	265.0	.2516	2418	6.68	97.94	86.12	.005503	.006114	5.620	.3909	.1779
8.80	.00005494	.0009059	.06065	294.8	.2463	2422	6.53	98.64	90.18	.004955	.005504	5.636	.3903	.1774
9.00	.00004739	.0008150	.05814	327.2	.2411	2425	6.38	99.32	94.33	.004470	.004964	5.651	.3898	.1770
9.20	.00004099	.0007348	.05578	362.5	.2362	2428	6.24	99.97	98.58	.004040	.004486	5.665	.3893	.1765
9.40	.00003555	.0006638	.05356	400.8	.2314	2431	6.11	100.6	102.9	.003659	.004061	5.679	.3888	.1761
9.60	.00003092	.0006008	.05146	442.3	.2269	2433	5.98	101.2	107.4	.003319	.003683	5.691	.3884	.1757
9.80	.00002696	.0005447	.04949	487.3	.2225	2436	5.86	101.8	111.9	.003016	.003346	5.703	.3880	.1753
10.00	.00002356	.0004948	.04762	535.9	.2182	2438	5.74	102.3	116.5	.002745	.003045	5.714	.3876	.1750

TABLE 346A.—FORCES ON AIRFOILS AT ANGLES TO THE WIND (FIGS. 14, 15)[137]

By suitably proportioning the thickness distribution over the chord of a plate, an airfoil may be derived around which the flow will adhere even when the angle of attack is large. Because the flow remains attached to the airfoil, high lift coefficients may be obtained with low drag coefficients.

The flow around a particular airfoil at a given angle of attack depends on the Reynolds number, R, the Mach number, M, and the degree of surface roughness. The main effect of increasing the Reynolds number is to change the maximum-lift coefficient and the minimum-drag coefficient. When the surface of the airfoil is made rough, simulating the surface of an actual airplane wing, the flow breaks away from the upper surface of the airfoil at a smaller angle of attack and therefore results in a considerably smaller value of maximum-lift coefficient. A rough surface increases the percentage of the chord over which the flow is turbulent and tends to make the drag coefficient much higher (see figure 11). As the Mach number is increased the variation of the local velocity from the stream velocity is increased.

On figure 14 are shown the force coefficients for two symmetrical NACA airfoils of infinite aspect ratio plotted against angle of attack, α, for a Reynolds number of 6×10^6. Methods exist (see Method for calculating wing characteristics by lifting-line theory using nonlinear section lift data, by James C. Sivells and Robert H. Neely, NACA TN No. 1269, April 1947) for converting infinite aspect ratio data to finite wing characteristics. The force coefficients of a 21-percent thick airfoil in the smooth condition and a 12-percent thick airfoil in both the rough and smooth conditions are given.

Figure 15 shows the variation in the force coefficients with Mach number for a symmetrical 9-percent thick airfoil at an angle of attack of 2° and at Reynolds numbers from $.35 \times 10^6$ to $.75 \times 10^6$.

[137] Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr., Summary of airfoil data. NACA Rep. No. 824, 1945. Stack, John, and von Doenhoff, Albert E., Tests of 16 related airfoils at high speeds, NACA Rep. No. 492, 1934.

(*continued*)

TABLE 346A.—FORCES ON AIRFOILS AT ANGLES TO THE WIND (FIGS. 14, 15) (concluded)

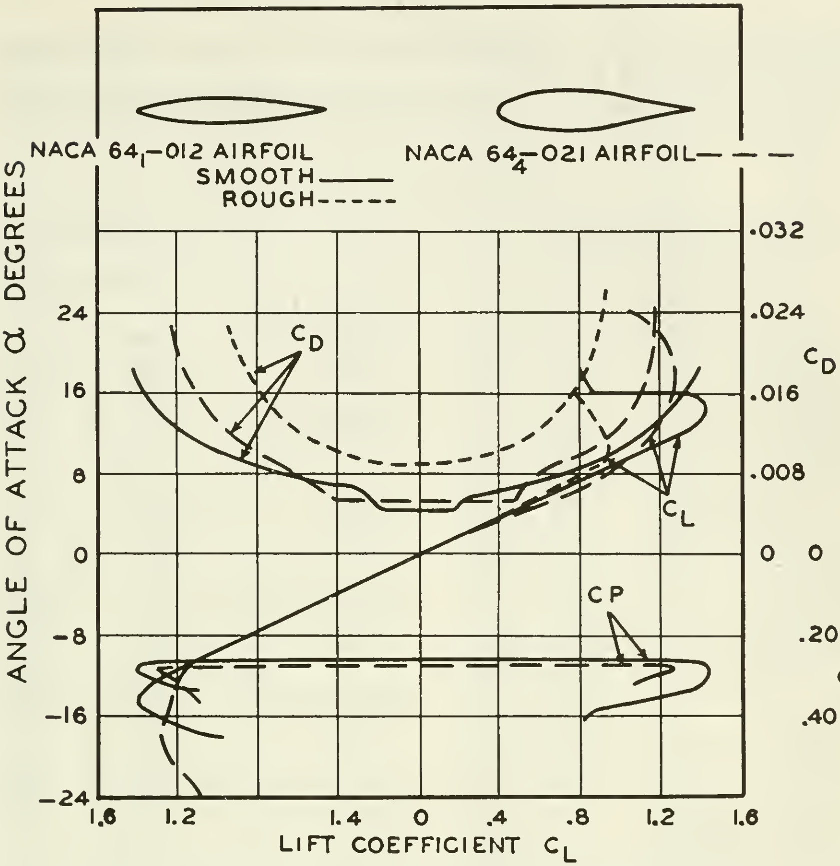

FIG. 14.—Force coefficients for two symmetrical airfoils of infinite aspect ratio plotted against angle of attack, α, for Reynolds number 6×10^6.

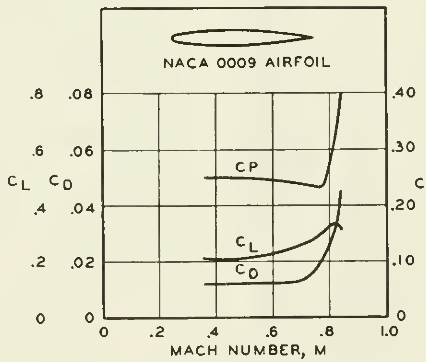

FIG. 15.—The force coefficients, C_L, C_D, and CP, plotted against Mach number for a 9-percent thick airfoil at an angle of attack of 2° and Reynolds number from $.35 \times 10^6$ to $.75 \times 10^6$.

TABLES 347-369.—DIFFFUSION, SOLUBILITY, SURFACE TENSION, AND VAPOR PRESSURE

TABLE 347.—DIFFUSION OF AN AQUEOUS SOLUTION INTO PURE WATER

If k is the coefficient of diffusion, dS the amount of the substance which passes in the time dt, at the place x, through q cm² of a diffusion cylinder under the influence of a drop of concentration dc/dx, then

$$dS = -kq \frac{dc}{dx} dt$$

k depends on the temperature and the concentration. c gives the gram-molecules per liter. The unit of time is a day.

Substance	c	t° °C	k
Bromine	.1	12.	.8
Chlorine	"	12.	1.22
Copper sulfate	"	17.	.39
Glycerine	"	10.14	.357
Hydrochloric acid	"	19.2	2.21
Iodine	"	12.	(.5)
Nitric acid	"	19.5	2.07
Potassium chloride	"	17.5	1.38
" hydroxide	"	13.5	1.72
Silver nitrate	"	12.	.985
Sodium chloride	"	15.0	.94
Urea	"	14.8	.97
Acetic acid	.2	13.5	.77
Barium chloride	"	8.	.66
Glycerine	"	10.1	3.55
Sodium acetate	"	12.	.67
" chloride	"	15.0	.94
Urea	"	14.8	.969
Acetic acid	1.0	12.	.74
Ammonia	"	15.23	1.54
Formic acid	"	12.	.97
Glycerine	"	10.14	.339
Hydrochloric acid	"	12.	2.09
Magnesium sulfate	"	7.	.30
Potassium bromide	"	10.	1.13
" hydroxide	"	12.	1.72
Sodium chloride	"	15.0	.94
" "	"	14.3	.964
" hydroxide	"	12.	1.11
" iodide	"	10.	.80
Sugar	"	12.	.254
Sulfuric acid	"	12.	1.12
Zinc sulfate	"	14.8	.236
Acetic acid	2.0	12.	.69
Calcium chloride	"	10.	.68
Cadmium sulfate	"	19.04	.246
Hydrochloric acid	"	12.	2.21
Sodium iodide	"	10.	.90
Sulfuric acid	"	12.	1.16
Zinc acetate	"	18.05	.210
" "	"	.04	.120
Acetic acid	3.0	12.	.68
Potassium carbonate	"	10.	.60
" hydroxide	"	12.	1.89
Acetic acid	4.0	12.	.66
Potassium chloride	"	10.	1.27

Substance	c	t° °C	k
Calcium chloride	.864	8.5	.70
" "	1.22	9.	.72
" "	.060	9.	.64
" "	.047	9.	.68
Copper sulfate	1.95	17.	.23
" "	.95	17.	.26
" "	.30	17.	.33
" "	.005	17.	.47
Glycerine	2/8	10.14	.354
"	6/8	10.14	.345
"	10/8	10.14	.329
"	14/8	10.14	.300
Hydrochloric acid	4.52	11.5	2.93
" "	3.16	11.	2.67
" "	.945	11.	2.12
" "	.387	11.	2.02
" "	.250	11.	1.84
Magnesium sulfate	2.18	5.5	.28
" "	.541	5.5	.32
" "	3.23	10.	.27
" "	.402	10.	.34
Potassium hydroxide	.75	12.	1.72
" "	.49	12.	1.70
" "	.375	12.	1.70
" nitrate	3.9	17.6	.89
" "	1.4	17.6	1.10
" "	.3	17.6	1.26
" "	.02	17.6	1.28
" sulfate	.95	19.6	.79
" "	.28	19.6	.86
" "	.05	19.6	.97
" "	.02	19.6	1.01
Silver nitrate	3.9	12.	.535
" "	.9	12.	.88
" "	.02	12.	1.035
Sodium chloride	2/8	14.33	1.013
" "	4/8	14.33	.996
" "	6/8	14.33	.980
" "	10/8	14.33	.948
" "	14/8	14.33	.917
Sulfuric acid	9.85	18.	2.36
" "	4.85	18.	1.90
" "	2.85	18.	1.60
" "	.85	18.	1.34
" "	.35	18.	1.32
" "	.005	18.	1.30

Coefficients of diffusion of vapors in cgs units. The coefficients are for the temperatures given in the table and a pressure of 76 cmHg.

Vapor	Temp. °C	k_t for vapor diffusing into hydrogen	k_t for vapor diffusing into air	k_t for vapor diffusing into carbon dioxide
Acids: Formic	.0	.5131	.1315	.0879
"	65.4	.7873	.2035	.1343
"	84.9	.8830	.2244	.1519
Acetic	.0	.4040	.1061	.0713
"	65.5	.6211	.1578	.1048
"	98.5	.7481	.1965	.1321
Isovaleric	.0	.2118	.0555	.0375
"	98.0	.3934	.1031	.0696
Alcohols: Methyl	.0	.5001	.1325	.0880
"	25.6	.6015	.1620	.1046
"	49.6	.6738	.1809	.1234
Ethyl	.0	.3806	.0994	.0693
"	40.4	.5030	.1372	.0898
"	66.9	.5430	.1475	.1026
Propyl	.9	.3153	.0803	.0577
"	66.9	.4832	.1237	.0901
"	83.5	.5434	.1379	.0976
Butyl	.0	.2716	.0681	.0476
"	99.0	.5045	.1265	.0884
Amyl	.0	.2351	.0589	.0422
"	99.1	.4362	.1094	.0784
Hexyl	.0	.1998	.0499	.0351
"	99.0	.3712	.0927	.0651
Benzene	.0	.2940	.0751	.0527
"	19.9	.3409	.0877	.0609
"	45.0	.3993	.1011	.0715
Carbon disulfide	.0	.3690	.0883	.0629
" "	19.9	.4255	.1015	.0726
" "	32.8	.4626	.1120	.0789
Esters: Methyl acetate	.0	.3277	.0840	.0557
" "	20.3	.3928	.1013	.0679
Ethyl "	.0	.2373	.0630	.0450
" "	46.1	.3729	.0970	.0666
Methyl butyrate	.0	.2422	.0640	.0438
" "	92.1	.4308	.1139	.0809
Ethyl "	.0	.2238	.0573	.0406
" "	96.5	.4112	.1064	.0756
" valerate	.0	.2050	.0505	.0366
" "	97.6	.3784	.0932	.0676
Ether	.0	.2960	.0775	.0552
"	19.9	.3410	.0893	.0636
Water	.0	.6870	.1980	.1310
"	49.5	1.0000	.2827	.1811
"	92.4	1.1794	.3451	.2384

TABLE 349.—COEFFICIENTS OF DIFFUSION FOR VARIOUS GASES AND VAPORS

Gas or vapor diffusing	Gas or vapor diffused into	Temp. °C	Coefficient of diffusion
Air	Hydrogen	0	.661
"	Oxygen	0	.1775
Carbon dioxide	Air	0	.1423
" "	"	0	.1360
" "	Carbon monoxide	0	.1405
" "	" "	0	.1314
" "	Hydrogen	0	.5437
" "	Methane	0	.1465
" "	Nitrous oxide	0	.0983
" "	Oxygen	0	.1802
Carbon disulfide	Air	0	.0995
Carbon monoxide	Carbon dioxide	0	.1314
" "	Ethylene	0	.101
" "	Hydrogen	0	.6422
" "	Oxygen	0	.1802
" "	"	0	.1872
Ether	Air	0	.0827
"	Hydrogen	0	.3054
Hydrogen	Air	0	.6340
"	Carbon dioxide	0	.5384
"	" monoxide	0	.6488
"	Ethane	0	.4593
"	Ethylene	0	.4863
"	Methane	0	.6254
"	Nitrous oxide	0	.5347
"	Oxygen	0	.6788
Nitrogen	"	0	.1787
Oxygen	Carbon dioxide	0	.1357
"	Hydrogen	0	.7217
"	Nitrogen	0	.1710
Sulfur dioxide	Hydrogen	0	.4828
Water	Air	8	.2390
"	"	18	.2475
"	Hydrogen	18	.8710

TABLE 350.—DIFFUSION OF METALS INTO METALS

$\frac{dv}{dt} = k\frac{d^2v}{dx^2}$; where x is the distance in direction of diffusion; v, the degree of concentration of the diffusing metal; t, the time; k, the diffusion constant = the quantity of metal in grams diffusing through a cm^2 in a day when unit difference of concentration (g/cm^3) is maintained between two sides of a layer one cm thick.

Diffusing metal	Dissolving metal	Temperature °C	k	Diffusing metal	Dissolving metal	Temperature °C	k
Gold	Lead	555	3.19	Platinum	Lead	492	1.69
"	"	492	3.00	Lead	Tin	555	3.18
"	"	251	.03	Rhodium	Lead	550	3.04
"	"	200	.008	Tin	Mercury	15	1.22
"	"	165	.004	Lead	"	15	1.0
"	"	100	.00002	Zinc	"	15	1.0
"	Bismuth	555	4.52	Sodium	"	15	.45
"	Tin	555	4.65	Potassium	"	15	.40
Silver	"	555	4.14	Gold	"	15	.72

(Temperature variation)

The numbers give the number of grams of the *anhydrous* salt soluble in 1000 g of water at the given temperatures.

Salt	Temperature °C										
	0	10	20	30	40	50	60	70	80	90	100
$AgNO_3$	1150	1600	2150	2700	3350	4000	4700	5500	6500	7600	9100
$Al_2(SO_4)_3$	313	335	362	404	457	521	591	662	731	808	891
$Al_2K_2(SO_4)_4$	30	—	—	84	—	—	248	—	—	—	1540
$Al_2(NH_4)_2(SO_4)_4$	26	45	66	91	124	159	211	270	352	—	—
B_2O_3	11	15	22	—	40	—	62	—	95	—	157
$BaCl_2$	316	333	357	382	408	436	464	494	524	556	588
$Ba(NO_3)_2$	50	70	92	116	142	171	203	236	270	306	342
$CaCl_2$	595	650	745	1010	1153	—	1368	1417	1470	1527	1590
$CoCl_2$	405	450	500	565	650	935	940	950	960	—	1030
$CsCl$	1614	1747	1865	1973	2080	2185	2290	2395	2500	2601	2705
$CsNO_3$	93	149	230	339	472	644	838	1070	1340	1630	1970
Cs_2SO_4	1671	1731	1787	1841	1899	1949	1999	2050	2103	2149	2203
$Cu(NO_3)_2$	818	—	1250	—	1598	—	1791	—	2078	—	—
$CuSO_4$	149	—	—	255	295	336	390	457	535	627	735
$FeCl_2$	—	—	685	—	—	820	—	—	1040	1050	1060
Fe_2Cl_6	744	819	918	—	—	3151	—	—	5258	—	5357
$FeSO_4$	156	208	264	330	402	486	550	560	506	430	—
$HgCl_2$	43	66	74	84	96	113	139	173	243	371	540
KBr	540	—	650	—	760	—	860	—	955	—	1050
K_2CO_3	1050	—	—	1140	1170	1210	1270	1330	1400	1470	1560
KCl	285	312	343	373	401	429	455	483	510	538	566
$KClO_3$	33	50	71	101	145	197	260	325	396	475	560
K_2CrO_4	589	609	629	650	670	690	710	730	751	771	791
$K_2Cr_2O_7$	50	85	131	—	292	—	505	—	730	—	1020
$KHCO_3$	225	277	332	390	453	522	600	—	—	—	—
KI	1279	1361	1442	1523	1600	1680	1760	1840	1920	2010	2090
KNO_3	133	209	316	458	639	855	1099	1380	1690	2040	2460
KOH	970	1030	1120	1260	1360	1400	1460	1510	1590	1680	1780
K_2PtCl_6	7	9	11	14	18	22	26	32	38	45	52
K_2SO_4	74	92	111	130	148	165	182	198	214	228	241
$LiOH$	127	127	128	129	130	133	138	144	153	—	175
$MgCl_2$	528	535	545	—	575	—	610	—	660	—	730
$MgSO_4$ ....(7aq)	260	309	356	409	456	—	—	—	—	—	—
" ....(6aq)	408	422	439	453	—	504	550	596	642	689	738
NH_4Cl	297	333	372	414	458	504	552	602	656	713	773
NH_4HCO_3	119	159	210	270	—	—	—	—	—	—	—
NH_4NO_3	1183	—	—	2418	2970	3540?	4300?	5130?	5800	7400	8710
$(NH_4)_2SO_4$	706	730	754	780	810	844	880	916	953	992	1033
$NaBr$	795	845	903	—	1058	1160	1170	—	1185	—	1205
$Na_2B_4O_7$	—	16	—	39	—	105	200	244	314	408	523
Na_2CO_3 ...(10aq)	71	126	214	409	—	—	—	—	—	—	—
" ....(7aq)	204	263	335	435	(1aq)	475	464	458	452	452	452
$NaCl$	356	357	358	360	363	367	371	375	380	385	391
$NaClO_3$	820	890	990	—	1235	—	1470	—	1750	—	2040
Na_2CrO_4	317	502	900	—	960	1050	1150	—	1240	—	1260
$Na_2Cr_2O_7$	1630	1700	1800	1970	2200	2480	2830	3230	3860	—	4330
$NaHCO_3$	69	82	96	111	127	145	164	—	—	—	—
Na_2HPO_4	25	39	93	241	639	—	—	949	—	—	988
NaI	1590	1690	1790	1900	2050	2280	2570	—	2950	—	3020
$NaNO_3$	730	805	880	962	1049	1140	1246	1360	1480	1610	1755

(*continued*)

TABLE 351.—SOLUBILITY OF INORGANIC SALTS IN WATER (concluded)

Salt	Temperature °C 0	10	20	30	40	50	60	70	80	90	100
NaOH	420	515	1090	1190	1290	1450	1740	—	3130	—	—
$Na_4P_2O_7$	32	39	62	99	135	174	220	255	300	—	—
Na_2SO_3	141	—	287	—	495	—	—	—	—	—	330
Na_2SO_4 ...(10aq)	50	90	194	400 }	482	468	455	445	437	429	427
" ....(7aq)	196	305	447	— }							
$Na_2S_2O_3$	525	610	700	847	1026	1697	2067	—	2488	2542	2660
$NiCl_2$	—	600	640	680	720	760	810	—	—	—	—
$NiSO_4$	272	—	—	425	—	502	548	594	632	688	776
$PbBr_2$	5	6	8	12	15	20	24	28	33	—	48
$Pb(NO_3)_2$	365	444	523	607	694	787	880	977	1076	1174	1270
RbCl	770	844	911	976	1035	1093	1155	1214	1272	1331	1389
$RbNO_3$	195	330	533	813	1167	1556	2000	2510	3090	3750	4520
Rb_2SO_4	364	426	482	535	585	631	674	714	750	787	818
$SrCl_2$	442	483	539	600	667	744	831	896	924	962	1019
SnI_2	—	—	10	12	14	17	21	25	30	34	40
$Sr(NO_3)_2$	395	549	708	876	913	926	940	956	972	990	1011
$Th(SO_4)_2$ ..(9aq)	7	10	14	20	30	51	—	—	—	—	—
" ..(4aq)	—	—	—	—	40	25	16	11	—	—	—
TlCl	2	2	3	5	6	8	10	13	16	20	—
$TlNO_3$	39	62	96	143	209	304	462	695	1110	2000	4140
Tl_2SO_4	27	37	49	62	76	92	109	127	146	165	—
$Yb_2(SO_4)_3$	442	—	—	—	—	—	104	72	69	58	47
$Zn(NO_3)_2$	948	—	—	—	2069	—	—	—	—	—	—
$ZnSO_4$	—	—	—	—	700	768	—	890	860	920	785

TABLE 352.—SOLUBILITY OF A FEW ORGANIC SALTS IN WATER

(Temperature variation °C)

Salt	0	10	20	30	40	50	60	70	80	90	100
$H_2(CO_2)_2$	36	53	102	159	228	321	445	635	978	1200	—
$H_2(CH_2{\cdot}CO_2)_2$	28	45	69	106	162	244	358	511	708	—	1209
Tartaric acid	1150	1260	1390	1560	1760	1950	2180	2440	2730	3070	3430
Racemic "	92	140	206	291	433	595	783	999	1250	1530	1850
$K(HCO_2)$	2900	—	3350	—	3810	—	4550	—	5750	—	7900
$KH(C_4H_4O_6)$	3	4	6	9	13	18	24	32	45	57	69

TABLE 353.—SOLUBILITY OF GASES IN WATER

(Temperature variation °C)

The table gives the weight in grams of the gas which will be absorbed in 1000 g of water when the partial pressure of the gas plus the vapor pressure of the liquid at the given temperature equals 760 mmHg.

Gas	0	10	20	30	40	50	60	70	80
O_2	.0705	.0551	.0443	.0368	.0311	.0263	.0221	.0181	.0135
H_2	.00192	.00174	.00160	.00147	.00138	.00129	.00118	.00102	.00079
N_2	.0293	.0230	.0189	.0161	.0139	.0121	.0105	.0089	.0069
Br_2	431.	248.	148.	94.	62.	40.	28.	18.	11.
Cl_2	—	9.97	7.29	5.72	4.59	3.93	3.30	2.79	2.23
CO_2	3.35	2.32	1.69	1.26	.97	.76	.58	—	—
H_2S	7.10	5.30	3.98	—	—	—	—	—	—
NH_3	987.	689.	535.	422.	—	—	—	—	—
SO_2	228.	162.	113.	78.	54.	—	—	—	—

TABLE 354.—CHANGE OF SOLUBILITY PRODUCED BY UNIFORM PRESSURE

	$CdSO_4 8/3H_2O$ at 25° C		$ZnSO_4.7H_2O$ at 25° C		Mannite at 24.05° C		NaCl at 24.05° C	
Pressure in atm	Conc. of satd. soln. g $CdSO_4$ per 100g H_2O	Percentage change	Conc. of satd. soln. g $ZnSO_4$ per 100g H_2O	Percentage change	Conc. of satd. soln. g mannite per 100g H_2O	Percentage change	Conc. of satd. soln. g NaCl per 100g H_2O	Percentage change
1	76.80	—	57.95	—	20.66	—	35.90	—
500	78.01	+1.57	57.87	—.14	21.14	+2.32	36.55	+1.81
1000	78.84	+2.68	57.65	—.52	21.40	+3.57	37.02	+3.12
1500	—	—	—	—	21.64	+4.72	37.36	+4.07

TABLE 355.—COMMONLY USED ORGANIC SOLVENTS *

Arranged in the order of their boiling points

Name	Boiling point °C	Name	Boiling point °C
Ethyl ether	34.54	Xylene (o)	144
Carbon disulfide	46.25	Amyl acetate	147.6
Acetone	56.08	Ethyl lactate	154
Methyl acetate	57.1	Cellosolve acetate	156
Chloroform	61.2	Cyclohexanone	156.7
Methyl alcohol	64.5	Furfural	158–162
Carbon tetrachloride	76.74	Butyl cellosolve	170.6
Ethyl acetate	77.15	Ethyl acetoacetate	180.0
Ethyl alcohol	78.32	Diethyl oxalate	186.1
Benzol	79.6	Ethylene glycol	197.2
Isopropyl alcohol	82.26	Carbitol	202
Ethylene dichloride	83.5	Benzyl alcohol	205.8
Trichlorethylene	87	Ethyl benzoate	213.2
Ethyl propionate	99.1	Butyl stearate	223 (25mm)
Toluene	110.7	Butyl carbitol	230
Butyl alcohol (n)	117.7	Diethylene glycol	245
Ethyl butyrate	121.3	Triphenyl phosphate	245 (11mm)
Methyl cellosolve	124.5	Triacetin	259
Diethyl carbonate	125.8	Diacetin	261
Butyl acetate	126.5	Dimethyl phthalate	282
Tetrachlorethane	130	Diethyl phthalate	296
Cellosolve	135.1	Dibutyl phthalate	340
Ethyl benzene	136.1	Diamyl phthalate	344
Amyl alcohol (n)	137.9		

* Table by J. W. H. Randall, reprinted with permission of Chemical Catalog Co.

TABLE 356.—ABSORPTION OF GASES AND VAPORS BY LIQUIDS *

Temperature °C	Absorption coefficient, *at*, for gases in water: Carbon dioxide CO_2	Carbon monoxide CO	Hydrogen H	Nitrogen N	Nitric oxide NO	Nitrous oxide N_2O	Oxygen O
0	1.797	.0354	.02110	.02399	.0738	1.048	.04925
5	1.450	.0315	.02022	.02134	.0646	.8778	.04335
10	1.185	.0282	.01944	.01918	.0571	.7377	.03852
15	1.002	.0254	.01875	.01742	.0515	.6294	.03456
20	.901	.0232	.01809	.01599	.0471	.5443	.03137
25	.772	.0214	.01745	.01481	.0432	—	.02874
30	—	.0200	.01690	.01370	.0400	—	.02646
40	.506	.0177	.01644	.01195	.0351	—	.02316
50	—	.0161	.01608	.01074	.0315	—	.02080
100	.244	.0141	.01600	.01011	.0263	—	.01690

Temperature °C	Air	Ammonia NH_3	Chlorine Cl	Ethylene C_2H_4	Methane CH_4	Hydrogen sulfide H_2S	Sulfur dioxide SO_2
0	.02471	1174.6	3.036	.2563	.05473	4.371	79.79
5	.02179	971.5	2.808	.2153	.04889	3.965	67.48
10	.01953	840.2	2.585	.1837	.04367	3.586	56.65
15	.01795	756.0	2.388	.1615	.03903	3.233	47.28
20	.01704	683.1	2.156	.1488	.03499	2.905	39.37
25	—	610.8	1.950	—	.02542	2.604	32.79

Temperature °C	Absorption coefficients, a_t, for gases in alcohol, C_2H_5OH: Carbon dioxide CO_2	Ethylene C_2H_4	Methane CH_4	Hydrogen H	Nitrogen N	Nitric oxide NO	Nitrous oxide N_2O	Hydrogen sulfide H_2S	Sulfur dioxide SO_2
0	4.329	3.595	.5226	.0692	.1263	.3161	4.190	17.89	328.6
5	3.891	3.323	.5086	.0685	.1241	.2998	3.838	14.78	251.7
10	3.514	3.086	.4953	.0679	.1228	.2861	5.525	11.99	190.3
15	3.199	2.882	.4828	.0673	.1214	.2748	3.215	9.54	144.5
20	2.946	2.713	.4710	.0667	.1204	.2659	3.015	7.41	114.5
25	2.756	2.578	.4598	.0662	.1196	.2595	2.819	5.62	99.8

* This table contains the volumes of different gases, supposed measured at 0°C and 76 cmHg pressure. which unit volume of the liquid named will absorb at atmospheric pressure and the temperature stated in the first column. The numbers tabulated are commonly called the absorption coefficient for the gases in water, or in alcohol, at the temperature *t* and under 1 atm of pressure.

TABLE 357.—VAPOR PRESSURE OF SOME ELEMENTS

(Over liquid unless otherwise noted.)

Hydrogen °K	mmHg	Helium °K	mmHg	Neon °K	atm	Argon °K	mmHg	Krypton °K	mmHg	Xenon °K	mmHg	Ozone °K	mmHg
20.48	787	5.16	16680	41.38	17.43	90.35	1026	210.5	41240	287.7	44110	120	34
20.36	760	4.9	1329	36.27	7.97	87.31	746	201.5	31620	255.6	21970	162	760
19.65	611	4.20	758	31.32	2.98	83.93	512	170.9	11970	244.2	15870	89.94	.089
18.03	552	3.52	360	27.17	1.00	77.48	201	112.7	387	231.4	11130	86.01	.042
16.49	192	1.48	4.2	20.4	12.8 mm	69.43	48.0	88.6	17.4	237.4	13500	83.24	.0152
14.10	59.5	...	.....	15.6	2.4	65.49	22.0	84.2	9	183.2	2020	81.36	.0068

Radon °K	mmHg	Oxygen °K	mmHg	Nitrogen °K	mmHg	Chlorine °C	atm	Bromine °C	mmHg	Iodine °C	mmHg	Radon °C	mmHg
377.5	62	62.37	9.59	77.33	760	+100	41.7	+58.75	760	+55	3.084	—70.6	.66
364.4	53	68.57	36.1	76.65	700	+20	6.62	51.95	600	50	2.154	—60.8	1.05
321.7	26.4	71.71	64	74.03	500	0	3.66	40.45	400	45	1.498	+17.1	13.2
290.3	13.2	77.59	162.2	72.39	400	—33.6	760 mm	23.45	200	40	1.025	+91.2	52.8
262.8	6.6	86.18	493	70.42	300	—50	350 mm	8.20	100	35	.699		
212.4	1.05	90.13	760	67.80	200	—70	118 mm	—7.0	45	30	.469		
202.6	.66	90.47	786.6	63.65	100	—80	62 mm	—12.0	30	15	.131		
						—88	37 mm	—16.65	20	0	.030		

TABLE 358.—SURFACE TENSION OF LIQUIDS

Part 1.—Water and alcohol in contact with moist air

Values represent means. See I.C.T. and L. and B. for more elaborate tables. Tension (γ) in dynes/cm.

°C	H_2O	C_2H_5OH	°C	H_2O	C_2H_5OH	°C	H_2O
−5	76.4		35	70.3	21.0	75	64.3
0	75.6	24.0	40	69.5	20.6	80	62.5
5	74.8	23.5	45	68.7	20.2	85	61.6
10	74.2	23.1	50	67.9	19.8	90	60.7
15	73.4	22.7	55	67.0	19.4	95	59.8
20	72.7	22.3	60	66.1	19.0	100	58.8
25	71.9	21.8	65	65.7	18.6	...	...
30	71.1	21.4	70	64.3	18.2	...	...

Part 2.—Miscellaneous liquids in contact with air

Liquid	°C	γ Dynes per cm	Formula
Acetone	20	23.7	$(CH_3)_2CO$
Acetic acid	20	27.6	CH_3CO_2H
Amyl alcohol	20	24	$C_5H_{12}O$
Aniline	20	43	C_6H_7N
Benzene	0	27	C_6H_6
"	20	28.9	
Bromoform	20	41.5	$CHBr_3$
Butyric acid	15	26.7	$CH_3(CH_2)_2CO_2H$
Carbon disulfide	20	32.3	CS_2
Carbon tetrachloride	20	26.8	CCl_4
Chloroform	20	27.2	$CHCl_3$
Ether	20	17.01	$C_4H_{10}O$
Ethyl chloride	20	16.2	CH_3Cl
Glycerine	18	63	$C_3H_5(OH)_3$
Methyl alcohol	20	22.6	CH_3OH
Olive oil	18	33.1	...
Petroleum	25	26	...
Phenol	20	41.0	C_6H_6O
Propyl alcohol	20	23	$CH_3(CH_2)_1OH$
Silicon tetrachloride	19	17.0	$SiCl_4$
Toluene	20	28.4	C_7H_8
Turpentine	20	27	...

TABLE 359.—SURFACE TENSION OF SOLUTIONS OF SALTS IN WATER

Salt	% Salt	°C	Dynes per cm
$BaCl_2$	0	30	71.1
	24.6	30	75.6
$CaCl_2$	0	30	71.1
	12.3	30	75.7
	31.9	30	86.4
HCl	0	20	73.0
	15	20	72.0
	25	20	70.7
KCl	0	30	71.1
	23.3	30	76.8
	21.1	18	77.7
NaCl	0	18	72.4
	7.6	18	74.8
	13.7	18	76.9
NH_4Cl	0	18	72.5
	11	18	74.9
K_2CO_3	0	30	71.1
	39.4	30	89.4
	53.6	30	107.2
Na_2CO_3	0	30	71.1
	10.5	30	73.9
	24.4	30	76.5
	63.1	30	80.6
KNO_3	0	18	72.6
	15.2	18	74.5
	21.5	18	75.4
$NaNO_3$	0	30	71.1
	35.6	30	78.4
	50.9	30	82.8
$CuSO_4$	0	30	71.1
	25.4	30	74.1
H_2SO_4	0	18	72.8
	12.7	18	73.5
	47.6	18	76.7
	80.3	18	71.2
	90	18	63.6
K_2SO_4	0	18	72.7
	9.1	18	74.6
HNO_3	7.2	20	73.1
	50	20	65.4
	70	20	59.4
NaOH	0	20	72.8
	10	20	77.3
	20	20	85.8
	30	20	95.1
KOH	0	18	72.8
	3.8	18	74.1
	7.8	18	75.5

Liquid	Specific gravity	Surface tension in dynes per cm of liquid in contact with— Air	Water	Mercury
Water	1.0	75.0	.0	(392)
Mercury	13.595	513.0	392.0	0
Bisulfide of carbon	1.2687	30.5	41.7	(387)
Chloroform	1.498	(31.8)	26.8	(415)
Ethyl alcohol	.807	(24.1)	—	364
Olive oil	.918	34.6	18.6	317
Turpentine	.873	28.8	11.5	241
Petroleum	.870	29.7	(28.9)	271
Hydrochloric acid	1.10	(72.9)	—	(392)
Hyposulfite of soda solution	1.1248	69.9	—	429

TABLE 361.—SURFACE TENSION OF LIQUIDS AT SOLIDIFYING POINT

Substance	Temperature of solidification °C	Surface tension in dynes per cm	Substance	Temperature of solidification °C	Surface tension in dynes per cm
Platinum	2000	1691	Antimony	432	249
Gold	1200	1003	Borax	1000	216
Zinc	360	877	Carbonate of soda	1000	210
Tin	230	599	Chloride of sodium	—	116
Mercury	—40	588	Water	0	87.9
Lead	330	457	Selenium	217	71.8
Silver	1000	427	Sulfur	111	42.1
Bismuth	265	1390	Phosphorus	43	42.0
Potassium	58	371	Wax	68	34.1
Sodium	90	258			

TABLE 362.—VAPOR PRESSURE AND RATE OF EVAPORATION

°K	Mo mmHg	W mmHg	Evaporation rate g cm⁻² sec⁻¹ Mo	W	Platinum °K	mm	g cm⁻² sec⁻¹
1800	$.0_{8}643$	—	$.0_{10}863$	—	1000	$.0_{17}324$	$.0_{19}832$
2000	$.0_{6}789$	$.0_{11}645$	$.0_{7}100$	$.0_{12}114$	1200	$.0_{12}111$	$.0_{14}260$
2200	$.0_{4}396$	$.0_{9}849$	$.0_{6}480$	$.0_{10}144$	1400	$.0_{9}188$	.0[illegible]401
2400	$.0_{2}1027$	$.0_{7}492$	$.0_{4}120$	$.0_{9}798$	1600	$.0_{7}484$	$.0_{9}966$
2600	.0160	$.0_{5}151$	$.0_{3}179$	$.0_{7}236$	1800	$.0_{5}350$	$.0_{7}667$
2800	.1679	$.0_{4}286$	$.0_{2}181$	$.0_{6}429$	2000	$.0_{3}107$	$.0_{5}195$
3000	—	$.0_{3}362$	—	$.0_{5}523$	4180	760 mm	—
3200	3890° }	$.0_{2}333$	—	$.0_{4}467$			
3500	760 mm }	.0572	—	$.0_{3}769$			

$p = K.T^{-\frac{1}{2}}e^{-\lambda 0/RT}$ dynes/cm² (Egerton).
Zn, $\lambda_0 = 3.28 \times 10^4$; $K = 1.17 \times 10^{14}$; Cd, $\lambda_0 = 2.77 \times 10^4$; $K = 5.27 \times 10^{13}$;
Hg, $\lambda_0 = 1.60 \times 10^4$; $K = 3.72 \times 10^{13}$ (Knudsen).

For the range of pressures for which the corresponding values of t°C are given in the table (Part 2), the pressure as a function of $T(=t+273)$ may be represented to a satisfactory degree of approximation by the relation

$$\log p = A - B/T. \qquad (1)$$

Part 1 gives values of A and B used in calculating the values of t°C in Part 2, where p is expressed in microns of mercury. The symbols (s) and (l) refer to the solid and liquid states, respectively.

The rate of evaporation is given by the relation

$$\log W = \bar{5}.7660 + 0.5 \log M + \log p - 0.5 \log T \qquad (2)$$

$$= c + \log p - 0.5 \log T, \qquad (3)$$

where W is expressed in g cm^{-2} sec^{-1}, and p in microns.

Explanation of data in Part 2.—The first row for each metal, which is designated t, gives the temperatures in °C corresponding to the pressures in microns at the head of each column. These were calculated by means of equation 1. The second row, designated W, gives the rates of evaporation (in a good vacuum) in grams per square centimeter per second (g cm^{-2} sec^{-1}), at the values of t immediately above in the same column. These were calculated by means of equation 3.

In addition to the values of t given in the first row, which are to be regarded as, in the writer's opinion, the more reliable, there are also given, in the case of a number of the metals, a series of other values of t, which have been observed by some investigators; The fact that for the same value of the vapor pressure in microns two or more values of t are quoted by different authorities indicates the degree of uncertainty that exists for some of the data given in the tables. For metals for which the data are very questionable, it has not been considered worth while even to calculate values of W.

The column headed t_m gives the melting point in degrees C, and p_m gives the vapor pressure in microns at the melting point. For values of t below t_m, the metal is obviously in the solid state, and for values of t above t_m, the metal is in the liquid state.

* Prepared by Saul Dushman, General Electric Research Laboratory, Schenectady, N. Y.

Part 1.—Constants in relations for evaporation of metals

Metal	A	$10^{-3} \times B$	$c+4$	Metal	A	$10^{-3} \times B$	$c+4$
Li	10.50(l)	7.480	.1867	Si	13.20(s)	19.72	.4900
Na	10.71(l)	5.480	.4468		12.55(l)	18.55	.4900
K	10.36(l)	4.503	.5621	Ti	11.25(s)	18.64	.6061
Rb	10.42(l)	4.132	.7319		11.98(l)	20.11	...
	[10.53(l)	4.291]	...	Zr	12.38(s)	25.87	.7460
Cs	9.86(l)	3.774	.8278		13.04(l)	27.43	...
	[10.02(l)	3.883]	...	Th	12.52(l)	28.44	.9488
				Ge	10.94(l)	15.15	.6965
Cu	12.81(s)	18.06	.6678				
	11.72(l)	16.58	...	Sn	9.97(l)	13.11	.8032
Ag	12.28(s)	14.85	.7825	Pb	10.69(l)	9.60	.9242
	11.66(l)	14.09	...	V	13.32	26.62	.6195
Au	11.65(l)	18.52	.9135	Nb	14.37(s)	40.40	.7500
Be	12.99(s)	18.22	.2436	Ta	13.00(s)	40.21	.8947
	11.95(l)	16.59	...				
Mg	11.82(s)	7.741	.4590	Sb_2	11.42	9.913	.9592
				Bi	11.14(l)	9.824	.9260
Ca	11.30(s)	9.055	.5675	Cr	12.88(s)	17.56	.6240
Sr	11.13(s)	8.324	.7373	Mo	11.80(s)	30.31	.7570
Ba	10.88	8.908	.8349	W	12.24(s)	40.26	.8983
Zn	11.94(s)	6.744	.6737				
Cd	11.78(s)	5.798	.7914	U	12.88(l)	25.80	.9544
				Mn	12.25(s)	14.10	.6359
B	14.13(s)	21.37	.2831	Fe	12.63(s)	20.00	.6395
Al	11.99(l)	15.63	.4814		13.41(l)	21.40	
Sc	11.94	18.57	.5931	Co	12.43	21.96	.6512
Y	12.43	21.97	.7405	Ni	13.28(s)	21.84	.6503
La	11.88(l)	18.00	.8374		12.55(l)	20.60	
Ce	13.74(l)	20.10	.8392	Ru	13.50	33.80	.7696
Ga	10.79(l)	13.36	.6877	Rh	13.55	30.40	.7722
In	10.93(l)	12.15	.7959	Pd	11.46	19.23	.7801
Tl	11.15(l)	8.92	.9212	Os	13.59	37.00	.9056
C	14.06(s)	38.57	.3056	Ir	13.06	34.11	.9089
				Pt	12.633	27.50	.9112

(continued)

TABLE 363.—EVAPORATION OF METALS (continued)

Part 2.—Temperatures for given values p in microns of mercury and rates of evaporation (W, g cm^{-2} sec^{-1})

Metal	Ref.[138]	$p(\mu Hg)$	10^{-2}	10^{-1}	1	10	100	1000	t_m	p_m
Li	a	t°C:	325	377	439	514	607	725	179	9×10^{-7}
		W:	6.28×10^{-8}	6.03×10^{-7}	5.76×10^{-6}	5.48×10^{-5}	5.18×10^{-4}	4.87×10^{-3}		
	b	t°C:	353	406	467	541	632	745		
Na	a	t°C:	158	195	238	291	356	437	98	8.2×10^{-5}
		W:	1.35×10^{-7}	1.29×10^{-6}	1.24×10^{-5}	1.18×10^{-4}	1.12×10^{-3}	1.05×10^{-2}		
K	a	t°C:	91	123	161	207	265	338	64	9.8×10^{-4}
		W:	1.91×10^{-7}	1.83×10^{-6}	1.75×10^{-5}	1.67×10^{-4}	1.57×10^{-3}	1.48×10^{-2}		
Rb	d	t°C:	59.4	88.5	123	165	217	283	38.5	1.5×10^{-3}
		W:	2.96×10^{-7}	2.84×10^{-6}	2.71×10^{-5}	2.58×10^{-4}	2.43×10^{-3}	2.29×10^{-2}		
	c	t°C:	70	99	135	177	230	297		
Cs	e	t°C:	45	74	110	153	207	277	29	1.5×10^{-3}
		W:	3.77×10^{-7}	3.61×10^{-6}	3.44×10^{-5}	3.18×10^{-4}	3.07×10^{-3}	2.87×10^{-2}		
	c	t°C:	50	79	115	158	211	280		
Cu	f, c	t°C:	946	1035	1141	1273	1432	1628	1083	.31
		W:	1.33×10^{-7}	1.29×10^{-6}	1.24×10^{-5}	1.18×10^{-4}	1.13×10^{-3}	1.07×10^{-2}		
Ag	a	t°C:	767	848	936	1047	1184	1353	961	1.78
		W:	1.88×10^{-7}	1.81×10^{-6}	1.74×10^{-5}	1.67×10^{-4}	1.59×10^{-3}	1.50×10^{-2}		
Au	a	t°C:	1083	1190	1316	1465	1646	1867	1063	6×10^{-3}
		W:	2.22×10^{-7}	2.14×10^{-6}	2.05×10^{-5}	1.96×10^{-4}	1.87×10^{-3}	1.77×10^{-2}		
Be	c, g	t°C:	942	1029	1130	1246	1395	1582	1284	19.5
		W:	5.03×10^{-8}	4.86×10^{-7}	4.68×10^{-6}	4.49×10^{-5}				
Mg	a	t°C:	287	331	383	443	515	605	651	2.2×10^{3}
		W:	1.21×10^{-7}	1.17×10^{-6}	1.12×10^{-5}	1.08×10^{-4}	1.02×10^{-3}	9.71×10^{-3}		
Ca	a	t°C:	408	463	528	605	700	817	810	8.75×10^{2}
		W:	1.42×10^{-7}	1.37×10^{-6}	1.31×10^{-5}	1.25×10^{-4}	1.19×10^{-3}	1.12×10^{-2}		
	h	t°C:	462	523	594	680	784	. . .		
Sr	c	t°C:	361	413	475	549	639	750	771	1.44×10^{3}
		W:	2.17×10^{-7}	2.08×10^{-6}	2.00×10^{-5}	1.91×10^{-4}	1.81×10^{-3}	1.71×10^{-2}		

[138] For references, see p. 367.

(continued)

TABLE 363.—EVAPORATION OF METALS (continued)

Metal	Ref.	$p(\mu Hg)$	10^{-2}	10^{-1}	1	10	100	1000	t_m	p_m
Ba	c	t°C:	418	476	546	629	730	858	717	76.
		W:	2.60×10^{-7}	2.50×10^{-6}	2.39×10^{-5}	2.28×10^{-4}	2.16×10^{-3}	2.03×10^{-2}		
	i	t°C:	485	549	625	716	829	861		
	j	t°C:	476	544	626	726	851	...		
Zn	a	t°C:	211	248	292	343	405	...	419	1.6×10^{2}
		W:	2.15×10^{-7}	2.07×10^{-6}	1.98×10^{-5}	1.90×10^{-4}	1.81×10^{-3}	...		
Cd	a	t°C:	148	180	220	264	321	...	321	1.0×10^{2}
		W:	3.01×10^{-7}	2.91×10^{-6}	2.79×10^{-5}	2.67×10^{-4}	2.54×10^{-3}	...		
Hg	k	t°C:	—23.9	—5.5	18.0	48.0	82.0	126	—38.9	2.5×10^{-3}
		W:	5.23×10^{-7}	5.50×10^{-6}	4.84×10^{-5}	4.61×10^{-4}	4.39×10^{-3}	4.14×10^{-2}		
B	c	t°C:	1052	1140	1239	1355	1489	1648	2000–2080	...
		W:	5.27×10^{-8}	5.11×10^{-7}	4.94×10^{-6}	4.76×10^{-5}	4.57×10^{-4}	4.38×10^{-3}		
Al	a	t°C:	724	808	889	996	1123	1279	660	1.2×10^{-3}
		W:	9.60×10^{-8}	9.21×10^{-7}	8.88×10^{-6}	8.51×10^{-5}	8.11×10^{-4}	7.69×10^{-3}		
	c, l	t°C:	843	929	1030	1148	1291	1465	660	1.8×10^{-5}
		W:	9.07×10^{-8}	8.74×10^{-7}	8.40×10^{-6}	8.04×10^{-5}	7.66×10^{-4}	7.27×10^{-3}		
Sc	c	t°C:	1058	1161	1282	1423	1595	1804	1397	6.6
		W:	1.07×10^{-7}	1.04×10^{-6}	9.94×10^{-6}	9.51×10^{-5}	9.07×10^{-4}	8.40×10^{-3}		
Y	c	t°C:	1249	1362	1494	1649	1833	2056	1477	.76
		W:	1.41×10^{-7}	1.36×10^{-6}	1.31×10^{-5}	1.25×10^{-4}	1.20×10^{-3}	1.14×10^{-2}		
La	c	t°C:	1023	1125	1242	1381	1549	1754	887	2.3×10^{4}
		W:	1.91×10^{-7}	1.84×10^{-6}	1.77×10^{-5}	1.69×10^{-4}	1.61×10^{-3}	1.53×10^{-2}		
Ce	c	t°C:	1004	1091	1190	1305	1439	1599	785	5.5×10^{-6}
		W:	1.93×10^{-7}	1.87×10^{-6}	1.80×10^{-5}	1.74×10^{-4}	1.67×10^{-3}	1.60×10^{-2}		
Ga	c	t°C:	771	859	965	1093	1248	1443	30	0
		W:	1.51×10^{-7}	1.45×10^{-6}	1.38×10^{-5}	1.32×10^{-4}	1.25×10^{-3}	1.18×10^{-2}		
In	c, m	t°C:	667	746	840	952	1088	1260	157	0
		W:	2.04×10^{-7}	1.96×10^{-6}	1.87×10^{-5}	1.79×10^{-4}	1.69×10^{-3}	1.60×10^{-2}		
Tl	a	t°C:	405	461	527	606	702	821	304	5.0×10^{-5}
		W:	3.20×10^{-7}	3.08×10^{-6}	2.95×10^{-5}	2.81×10^{-4}	2.67×10^{-3}	2.52×10^{-2}		

(continued)

TABLE 363.—EVAPORATION OF METALS (continued)

Metal	Ref.	$p(\mu Hg)$	10^{-2}	10^{-1}	1	10	100	1000	t_m	p_m
C	c	t°C:	2129	2288	2471	2681	2926	3214		
		W:	4.13×10^{-8}	4.00×10^{-7}	3.86×10^{-6}	3.72×10^{-5}	3.58×10^{-4}	3.42×10^{-3}		
Si	c	t°C:	1024	1116	1223	1343	1485	1670	1410	31.6
		W:	8.58×10^{-8}	8.29×10^{-7}	7.99×10^{-6}	7.68×10^{-5}	7.37×10^{-4}	7.01×10^{-3}		
Ti	c	t°C:	1134	1249	1384	1546	1742	1965	1727	84.3
		W:	1.08×10^{-7}	1.04×10^{-6}	9.92×10^{-6}	9.47×10^{-5}	9.00×10^{-4}	8.53×10^{-3}		
Zr	c	t°C:	1527	1660	1816	2001	2212	2459	2127	40.7
		W:	1.31×10^{-7}	1.27×10^{-6}	1.22×10^{-5}	1.17×10^{-4}	1.12×10^{-3}	1.07×10^{-2}		
Th	c	t°C:	1686	1831	1999	2196	2431	2715	1827	9.3×10^{-2}
		W:	2.01×10^{-7}	1.94×10^{-6}	1.86×10^{-5}	1.79×10^{-4}	1.71×10^{-3}	1.63×10^{-2}		
Ge	c	t°C:	897	996	1112	1251	1421	1635	959	4.5×10^{-2}
		W:	1.45×10^{-7}	1.40×10^{-6}	1.34×10^{-5}	1.27×10^{-4}	1.21×10^{-3}	1.14×10^{-2}		
Sn	c	t°C:	823	922	1042	1189	1373	1609	232	0
		W:	1.92×10^{-7}	1.84×10^{-6}	1.75×10^{-5}	1.66×10^{-4}	1.57×10^{-3}	1.47×10^{-2}		
Pb	a	t°C:	483	548	625	718	832	975	328	5.4×10^{-6}
		W:	3.05×10^{-7}	2.93×10^{-6}	2.80×10^{-5}	2.67×10^{-4}	2.53×10^{-3}	2.38×10^{-2}		
V	c	t°C:	1465	1586	1725	1888	2079	2207	1697	.65
		W:	1.0×10^{-7}	9.6×10^{-7}	9.3×10^{-6}	8.9×10^{-5}	8.6×10^{-4}	8.2×10^{-3}		
Nb	n	t°C:	2194	2355	2539				2500	.6
		W:	1.16×10^{-7}	1.08×10^{-6}	1.06×10^{-5}					
Ta	o, p	t°C:	2407	2599	2820				2996	5.0
		W:	1.55×10^{-7}	1.48×10^{-6}	1.41×10^{-5}					
Sb_2	c	t°C:	466	525	595	678	779	904	630	2.82
		W:	3.35×10^{-7}	3.22×10^{-6}	3.09×10^{-5}	2.95×10^{-4}	2.81×10^{-3}	2.65×10^{-2}		
Bi	c	t°C:	474	536	609	698	802	934	271	1.20×10^{-7}
		W:	3.08×10^{-7}	2.96×10^{-6}	2.84×10^{-5}	2.71×10^{-4}	2.57×10^{-3}	2.43×10^{-2}		
Cr	c, 1	t°C:	907	992	1090	1205	1342	1504	1900	6.35×10^{4}
		W:	1.22×10^{-7}	1.18×10^{-6}	1.14×10^{-5}	1.09×10^{-4}	1.05×10^{-3}	1.00×10^{-2}		

(continued)

Metal	Ref.	p(μHg)	10^{-2}	10^{-1}	1	10	100	1000	t_m	p_m
Mo	r	t°C:	1923	2095	2295	2533			2622	22.0
		W:	1.29×10^{-7}	1.18×10^{-6}	1.12×10^{-5}	1.05×10^{-4}				
W	s	t°C:	2554	2767	3016	3309			3382	17.5
		W:	1.47×10^{-7}	1.46×10^{-6}	1.45×10^{-5}	1.43×10^{-4}				
U	c	t°C:	1461	1585	1730	1898	2098	2338	1132	3.24×10^{-6}
		W:	2.16×10^{-7}	2.09×10^{-6}	2.01×10^{-5}	1.93×10^{-4}	1.85×10^{-3}	1.76×10^{-2}		
Mn	c	t°C:	717	791	878	980	1103	1251	1244	9.04×10^{2}
		W:	1.38×10^{-7}	1.32×10^{-6}	1.27×10^{-5}	1.22×10^{-4}	1.17×10^{-3}	1.11×10^{-2}		
Fe	c, f	t°C:	1094	1195	1310	1447	1602	1783	1535	37.2
		W:	1.29×10^{-7}	1.20×10^{-6}	1.10×10^{-5}	1.02×10^{-4}	1.01×10^{-3}	9.6×10^{-2}		
Co	c	t°C:	1249	1362	1494	1649	1833	2056	1478	.76
		W:	1.15×10^{-7}	1.11×10^{-6}	1.06×10^{-5}	1.02×10^{-4}	9.76×10^{-4}	9.28×10^{-3}		
Ni	c, q	t°C:	1157	1257	1371	1510	1679	1884	1455	4.37
		W:	1.18×10^{-7}	1.14×10^{-6}	1.10×10^{-5}	1.06×10^{-4}	1.01×10^{-3}	9.62×10^{-3}		
Ru	c	t°C:	1913	2058	2230	2431	2666	2946	2427	9.8
		W:	1.26×10^{-7}	1.22×10^{-6}	1.18×10^{-5}	1.13×10^{-4}	1.08×10^{-3}	1.04×10^{-2}		
Rh	c	t°C:	1681	1815	1971	2149	2358	2607	1967	1.0
		W:	1.34×10^{-7}	1.29×10^{-6}	1.25×10^{-5}	1.20×10^{-4}	1.15×10^{-3}	1.10×10^{-2}		
Pd	c	t°C:	1156	1271	1405	1566	1759	2000	1555	8.71
		W:	1.59×10^{-7}	1.53×10^{-6}	1.47×10^{-5}	1.41×10^{-4}	1.34×10^{-3}	1.26×10^{-2}		
Os	c	t°C:	2101	2264	2451	2667	2920	3221	2697	13.5
		W:	1.65×10^{-7}	1.60×10^{-6}	1.54×10^{-5}	1.48×10^{-4}	1.42×10^{-3}	1.36×10^{-2}		
Ir	c	t°C:	1993	2154	2340	2556	2811	3118	2454	3.55
		W:	1.70×10^{-7}	1.65×10^{-6}	1.59×10^{-5}	1.52×10^{-4}	1.46×10^{-3}	1.39×10^{-2}		
Pt	c	t°C:	1606	1744	1904	2090	2313	2582	1774	.16
		W:	1.88×10^{-7}	1.81×10^{-6}	1.75×10^{-5}	1.68×10^{-4}	1.60×10^{-3}	1.52×10^{-2}		

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TABLE 364.—VAPOR PRESSURE OF ORGANIC LIQUIDS

The vapor pressures on this page are in mmHg over a liquid phase unless distinguished by the subscript $_s$. They are generally means from various determinations.

°C	Acetone C_3H_6O	Benzine C_3H_6	Camphor $C_{10}H_{16}O$	Carbon bisulfide CS_2	Carbon tetrachloride CCl_4	Chloroform $CHCl_3$	Ethane C_2H_6	Ethyl ether $C_4H_{10}O$	Ethyl bromide C_2H_5Br	Turpentine $C_{10}H_6$
−90	.02	...	...	...	−70° }	−60° }	−100° }	−101.3° }	...	...
−57	1.26	{ −50°	...	−80° }	.14 }	.8 }	390 }	.058 }	...	...
−40	...	.3 }	...	.6 }	−50° }	4.8	− 90° }	− 60° }	...	...
−30	...	.3	...	−25° }	.92 }	10	700 }	4 }	...	...
−20	...	...	...	.34 }	...	19	− 80° }	− 40° }	59	...
−10	...	14	...	80	...	...	1180 }	19 }	102	...
0	...	26.5	.06	127	33	61.0	− 75°	186.1	166	.2
+ 5	...	34	...	160	43	...	1500	...	207	...
10	116	45	.10	198	56	100	...	291.8	257	.3
15	...	59	...	244	71	...	...	...	317	.3
20	185	75	.15	298	90	160	...	442.4	386	.4
30	283	119	.26	433	141	247	...	648	564	.7
40	422	182	.60	617	213	370	...	921	802	1.1
50	612	269	1.30	855	315	540	...	1276	1113	1.7
60	860	390	2.6	1170	448	750	...	1728	1510	2.6
70	1190	548	4.6	1570	620	1025	...	2294	2015	4.1
80	1860	750	9.2	2040	843	1400	...	2991	2640	6.1
90	2140	1010	...	2620	1120	2130	...	3840	3400	9.0
100	2800	1340	26	3000	1460	2420	...	4860	4310	13.1
110	3590	1740	...	4160	1880	...	...	...	5390	18.6
120	4550	2200	...	5150	2390	3900	...	7500	6660	25.7
130	5670	2800	...	...	3000	4000	...	...	8120	34.9
140	6970	3500	...	...	3700	6000	...	11080	9780	...
150	...	4300	170	9100	4500	7300	...	160° } 15800 }	...	...
200	...	...	625	...	10900	...	...	180° } 21800 }	...	...

Ethylene C_2H_4 °C		Glycerine C_3H_8O °C		Methane CH_4 °C		Methyl ether $(CH_3)_2O$ °C			Naphthalene $C_{10}H_8$ °C		Ethyl chloride C_2H_5Cl °C	
−150	14.9	118	.24	−180	119	− 67	78		0	$.02_s$	−30	110
−190	45.6	161	6.5	−175	212	− 60	120		20	$.06_s$	−20	188
−145	26.7	175	13	−170	353	− 41.4	326		50	$.81_s$	−10	302
−135	74.4	190	32	−165	559	− 30.9	524		70	4.0_s	0	465
−130	117.2	220	100	−160	848	−241	782		80	10	10	691
−120	260	260	385	−155	1229	*0*	*2.52*	atm	90	13	20	1000
−110	519			−150	1720	*25.4*	*6.05*	"	100	20	30	1400
−103	792					*49.75*	*11.2*	"	110	29	50	2850
						80.1	*22.1*	"	120	43	75	4980
						99.9	*32.1*	"	150	119	100	8720
						125.9	*51*	"	200	490		

(continued)

°C	Ammonia NH_3 atm	Carbon dioxide CO_2 atm	Ethyl iodide C_2H_5I mm	Ethyl acetate mm	Hydrogen sulfide H_2S mm	Methyl chloride CH_3Cl mm	Naphthalin $C_{10}H_8$ mm	Sulfur dioxide SO_2 mm	Toluol $C_{10}H_8$ °C	Toluol $C_{10}H_8$ mm
−50	.403	6.74	...	...	1216	...	...	86	−91.9	.002
−30	1.180	14.10	...	...	2840	579	...	286	−81.7	.005
−25	1.496	16.61	...	...	...	718	...	379	−77.4	.007
−20	1.877	19.44	...	6.5	4100	883	...	474	−67.5	.020
−15	2.332	22.60	...	...	...	1079	...	...	−57.7	.060
−10	2.870	26.13	...	12.9	5720	1310	...	760	−38.0	.39
− 5	3.502	30.05	...	...	...	1579	...	...	−24.2	1.47
0	4.238	34.38	41.5	24.3	7750	1891	...	1155	− 2.9	5.72
+ 5	5.090	39.16	53.5	...	...	2250	...	...	0	6.86
10	6.068	44.41	68.6	42.7	10300	2660	...	1714	+15.0	16.8
15	7.188	50.17	...	...	...	3134	...	...	+25.8	28.7
20	8.458	56.50	108.5	72.8	14000	3667	...	2460	...	...
25	9.896	63.45	...	...	...	4267	...	...	...	...
30	11.512	71.4	167.6	119	17500	4940	...	3420	...	...
35	13.321	...	...	...	...	5700	...	...	...	...
40	15.339	(I.C.T.	250	186	22000	6650	...	4650		
45	17.580	1928)	...	...	...	...	...	...		
50	20.060	...	362	282	27500	8510	...	6210		
60	25.80	...	510	415	...	10900	...	8150		
70	32.69	...	...	596	40400	14300	...	10540		
80	40.90	...	...	833	...	16800	9.6	...		
90	50.56	...	...	1130	...	21000	13.0	...		
100	61.82	...	...	1515	...	25800	19.7	*27.8* atm		
	Cragoe 1920			{200° 15600		{141° 53600	{200° 490	{150° 71.4 "		

TABLE 365.—VAPOR PRESSURE AT LOW TEMPERATURES

Many of the following values are extrapolations made by Langmuir by means of plots of log p against $1/T$. 1 barye = 0.000000987 atm = 0.000750 mmHg.

Gas	°C	mmHg	Gas	°C	Baryes
O_2	−182.9	760	CO_2	−148	100
	−211.2	7.75		−168	1
N_2	−195.8	760		−182	.01
	−210.5	86		−193	.0001
CO	−190	863	Ice	− 60	9.6
	−200	249		− 75	1.0
CH_4	−185.8	79.8		− 89	.1
	−201.5	50.2		−100	.01
A	−186.2	760		−110	.001
	−194.2	300	Hg	+ 30	3.7
C_2H_4	−175.7	.76		+ 20	1.6
	−188	.076		+ 10	.65
	−197	.0076		0	.25
	−205	.00076		− 10	.087
C_2H_6	−150	7.6		− 20	.029
	−180	.076		− 40	.0023
	−190	.0076		− 78	4.3×10^{-6}
	−198	.00076		−180	2.3×10^{-24}

TABLE 366.—VAPOR PRESSURE OF ETHYL ALCOHOL

Temp. °C	0	1	2	3	4	5	6	7	8	9
	Vapor pressure in mmHg at 0°C									
0	12.24	13.18	14.15	15.16	16.21	17.31	18.46	19.68	20.98	22.34
10	23.78	25.31	27.94	28.67	30.50	32.44	34.49	36.67	38.97	41.40
20	44.00	46.66	49.47	52.44	55.56	58.86	62.33	65.97	69.80	73.83
30	78.06	82.50	87.17	92.07	97.21	102.60	108.24	114.15	120.35	126.86
40	133.70	140.75	148.10	155.80	163.80	172.20	181.00	190.10	199.65	209.60
50	220.00	230.80	242.50	253.80	265.90	278.60	291.85	305.65	319.95	334.85
60	350.30	366.40	383.10	400.40	418.35	437.00	456.45	476.45	497.25	518.85
70	541.20	564.35	588.35	613.20	638.95	665.55	693.10	721.55	751.00	781.45

From the formula $\log p = a + b\alpha^t + c\beta^t$ Ramsay and Young obtain the following numbers:

Temp. °C	0	10	20	30	40	50	60	70	80	90
	Vapor pressure in mmHg at 0°C									
0	12.24	23.73	43.97	78.11	133.42	219.82	350.21	540.91	811.81	1186.5
100	1692.3	2359.8	3223.0	4318.7	5686.6	7368.7	9409.9	11858.	14764.	18185.
200	22182.	26825.	32196.	38389.	45519.					

TABLE 367.—VAPOR PRESSURE OF METHYL ALCOHOL

Temp. °C	0	1	2	3	4	5	6	7	8	9
	Vapor pressure in mmHg at 0°C									
0	29.97	31.6	33.6	35.6	37.8	40.2	42.6	45.2	47.9	50.8
10	53.8	57.0	60.3	63.8	67.5	71.4	75.5	79.8	84.3	89.0
20	94.0	99.2	104.7	110.4	116.5	122.7	129.3	136.2	143.4	151.0
30	158.9	167.1	175.7	184.7	194.1	203.9	214.1	224.7	235.8	247.4
40	259.4	271.9	285.0	298.5	312.6	327.3	342.5	358.3	374.7	391.7
50	409.4	427.7	446.6	466.3	486.6	507.7	529.5	552.0	575.3	599.4
60	624.3	650.0	676.5	703.8	732.0	761.1	791.1	822.0	—	—

TABLE 368.—VAPOR PRESSURE OF A NUMBER OF LIQUIDS (mmHg)

Carbon disulfide, chlorobenzene, bromobenzene, and aniline

Temp. °C	0	1	2	3	4	5	6	7	8	9
					Carbon disulfide					
0	127.90	133.85	140.05	146.45	153.10	160.00	167.15	174.60	182.25	190.20
10	198.45	207.00	215.80	224.95	234.40	244.15	254.25	264.65	275.40	286.55
20	298.05	309.90	322.10	334.70	347.70	361.10	374.95	389.20	403.90	419.00
30	434.60	450.65	467.15	484.15	501.65	519.65	538.15	557.15	576.75	596.85
40	617.50	638.70	660.50	682.90	705.90	729.50	753.75	778.60	804.10	830.25
					Chlorobenzene					
20	8.65	9.14	9.66	10.21	10.79	11.40	12.04	12.71	13.42	14.17
30	14.95	15.77	16.63	17.53	18.47	19.45	20.48	21.56	22.69	23.87
40	25.10	26.38	27.72	29.12	30.58	32.10	33.69	35.35	37.08	38.88
50	40.75	42.69	44.72	46.84	49.05	51.35	53.74	56.22	58.79	61.45
60	64.20	67.06	70.03	73.11	76.30	79.60	83.02	86.56	90.22	94.00
70	97.90	101.95	106.10	110.41	114.85	119.45	124.20	129.10	134.15	139.40
80	144.80	150.30	156.05	161.95	168.00	174.25	181.70	187.30	194.10	201.15
90	208.35	215.80	223.45	231.30	239.35	247.70	256.20	265.00	274.00	283.25
100	292.75	302.50	312.50	322.80	333.35	344.15	355.15	366.65	378.30	390.25
110	402.55	415.10	427.95	441.15	454.65	468.50	482.65	497.20	512.05	527.25
120	542.80	558.70	575.05	591.70	608.75	626.15	643.95	662.15	680.75	699.65
130	718.95	738.65	758.80	—	—	—	—	—	—	—
					Bromobenzene					
40	—	—	—	—	—	12.40	13.06	13.75	14.47	15.22
50	16.00	16.82	17.68	18.58	19.52	20.50	21.52	22.59	23.71	24.88
60	26.10	27.36	28.68	30.06	31.50	33.00	34.56	36.18	37.86	39.60
70	41.40	43.28	45.24	47.28	49.40	51.60	53.88	56.25	58.71	61.26
80	63.90	66.64	69.48	72.42	75.46	78.60	81.84	85.20	88.68	92.28
90	96.00	99.84	103.80	107.88	112.08	116.40	120.86	125.46	130.20	135.08
100	140.10	145.26	150.57	156.03	161.64	167.40	173.32	179.41	185.67	192.10
110	198.70	205.48	212.44	219.58	226.90	234.40	242.10	250.00	258.10	266.40
120	274.90	283.65	292.60	301.75	311.15	320.80	330.70	340.80	351.15	361.80
130	372.65	383.75	395.10	406.70	418.60	430.75	443.20	455.90	468.90	482.20
140	495.80	509.70	523.90	538.40	553.20	568.35	583.85	599.65	615.75	632.25
150	649.05	666.25	683.80	701.65	719.95	738.55	757.55	776.95	796.70	816.90
					Aniline					
80	18.80	19.78	20.79	21.83	22.90	24.00	25.14	26.32	27.54	28.80
90	30.10	31.44	32.83	34.27	35.76	37.30	38.90	40.56	42.28	44.06
100	45.90	47.80	49.78	51.84	53.98	56.20	58.50	60.88	63.34	65.88
110	68.50	71.22	74.04	76.96	79.98	83.10	86.32	89.66	93.12	96.70
120	100.40	104.22	108.17	112.25	116.46	120.80	125.28	129.91	134.69	139.62
130	144.70	149.94	155.34	160.90	166.62	172.50	178.56	184.80	191.22	197.82
140	204.60	211.58	218.76	226.14	233.72	241.50	249.50	257.72	266.16	274.82
150	283.70	292.80	302.15	311.75	321.60	331.70	342.05	352.65	363.50	374.60
160	386.00	397.65	409.60	421.80	434.30	447.10	460.20	473.60	487.25	501.25
170	515.60	530.20	545.20	560.45	576.10	592.05	608.35	625.05	642.05	659.45
180	677.15	695.30	713.75	732.65	751.90	771.50	—	—	—	—

(*continued*)

TABLE 368.—VAPOR PRESSURE OF A NUMBER OF LIQUIDS (mmHg) (concluded)

Methyl salicylate, bromonaphthalene, and mercury

Temp. °C	0	1	2	3	4	5	6	7	8	9
					Methyl salicylate					
70	2.40	2.58	2.77	2.97	3.18	3.40	3.62	3.85	4.09	4.34
80	4.60	4.87	5.15	5.44	5.74	6.05	6.37	6.70	7.05	7.42
90	7.80	8.20	8.62	9.06	9.52	9.95	10.44	10.95	11.48	12.03
100	12.60	13.20	13.82	14.47	15.15	15.85	16.58	17.34	18.13	18.95
110	19.80	20.68	21.60	22.55	23.53	24.55	25.61	26.71	27.85	29.03
120	30.25	31.52	32.84	34.21	35.63	37.10	38.67	40.24	41.84	43.54
130	45.30	47.12	49.01	50.96	52.97	55.05	57.20	59.43	61.73	64.10
140	66.55	69.08	71.69	74.38	77.15	80.00	82.94	85.97	89.09	92.30
150	95.60	99.00	102.50	106.10	109.80	113.60	117.51	121.53	125.66	129.90
160	134.25	138.72	143.31	148.03	152.88	157.85	162.95	168.19	173.56	179.06
170	184.70	190.48	196.41	202.49	208.72	215.10	221.65	228.30	235.15	242.15
180	249.35	256.70	264.20	271.90	279.75	287.80	296.00	304.48	313.05	321.85
190	330.85	340.05	349.45	359.05	368.85	378.90	389.15	399.60	410.30	421.20
200	432.35	443.75	455.35	467.25	479.35	491.70	504.35	517.25	530.40	543.80
210	557.50	571.45	585.70	600.25	615 05	630.15	645.55	661.25	677.25	693.60
220	710.10	727.05	744.35	761.90	779.85	798.10				
					Bromonaphthalene					
110	3.60	3.74	3.89	4.05	4.22	4.40	4.59	4.79	5.00	5.22
120	5.45	5.70	5.96	6.23	6.51	6.80	7.10	7.42	7.76	8.12
130	8.50	8.89	9.29	9.71	10.15	10.60	11.07	11.56	12.07	12.60
140	13.15	13.72	14.31	14.92	15.55	16.20	16.87	17.56	18.28	19.03
150	19.80	20.59	21.41	22.25	23.11	24.00	24.92	25.86	26.83	27.83
160	28.85	29.90	30.98	32.09	33.23	34.40	35.60	36.83	38.10	39.41
170	40.75	42.12	43.53	44.99	46.50	48.05	49.64	51.28	52.96	54.68
180	56.45	58.27	60.14	62.04	64.06	66.10	68.19	70.34	72.55	74.82
190	77.15	79.54	81.99	84.51	87.10	89.75	92.47	95.26	98.12	101.05
200	104.05	107.12	110.27	113.50	116.81	120.20	123.67	127.22	130.86	134.59
210	138.40	142.30	146.29	150.38	154.57	158.85	163.25	167.70	172.30	176.95
220	181.75	186.65	191.65	196.75	202.00	207.35	212.80	218.40	224.15	230.00
230	235.95	242.05	248.30	254.65	261.20	267.85	274.65	281.60	288.70	295.95
240	303.35	310.90	318.65	326.50	334.55	342.75	351.10	359.65	368.40	377.30
250	386.35	395.60	405.05	414.65	424.45	434.45	444.65	455.00	465.60	476.35
260	487.35	498.55	509.90	521.50	533.35	545.35	557.60	570.05	582.70	595.60
270	608.75	622.10	635.70	649.50	663.55	677.85	692.40	707.15	722.15	737.45
					Mercury					
270	123.92	126.97	130.08	133.26	136.50	139.81	143.18	146.61	150.12	153.70
280	157.35	161.07	164.86	168.73	172.67	176.79	180.88	185.05	189.30	193.63
290	198.04	202.53	207.10	211.76	216.50	221.33	226.25	231.25	236.34	241.53
300	246.81	252.18	257.65	263.21	268.87	274.63	280.48	286.43	292.49	298.66
310	304.93	311.30	317.78	324.37	331.08	337.89	344.81	351.85	359.00	366.28
320	373.67	381.18	388.81	396.56	404.43	412.44	420.58	428.83	437.22	445.75
330	454.41	463.20	472.12	481.19	490.40	499.74	509.22	518.85	528 63	538.56
340	548.64	558.87	569.25	579.78	590.48	601.33	612.34	623.51	634.85	646.36
350	658.03	669.86	681.86	694.04	706.40	718.94	731.65	744.54	757.61	770.87
360	784.31									

TABLE 369.—VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER

The first column gives the chemical formula of the salt. The headings of the other columns give the number of gram-molecules of the salt in a liter of water. The numbers in these columns give the lowering of the vapor pressure produced by the salt at the temperature of boiling water under 76 cmHg.

Substance	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
$Al_2(SO_4)_3$	12.8	36.5							
$AlCl_3$	22.5	61.0	179.0	318.0					
BaS_2O_6	6.6	15.4	34.4						
$Ba(OH)_2$	12.3	22.5	39.0						
$Ba(NO_3)_2$	13.5	27.0							
$Ba(ClO_3)_2$	15.8	33.3	70.5	108.2					
$BaCl_2$	16.4	36.7	77.6						
$BaBr_2$	16.8	38.8	91.4	150.0	204.7				
CaS_2O_3	9.9	23.0	56.0	106.0					
$Ca(NO_3)_2$	16.4	34.8	74.6	139.3	161.7	205.4			
$CaCl_2$	17.0	39.8	95.3	166.6	241.5	319.5			
$CaBr_2$	17.7	44.2	105.8	191.0	283.3	368.5			
$CdSO_4$	4.1	8.9	18.1						
CdI_2	7.6	14.8	33.5	52.7					
$CdBr_2$	8.6	17.8	36.7	55.7	80.0				
$CdCl_2$	9.6	18.8	36.7	57.0	77.3	99.0			
$Cd(NO_3)_2$	15.9	36.1	78.0	122.2					
$Cd(ClO_3)_2$	17.5								
$CoSO_4$	5.5	10.7	22.9	45.5					
$CoCl_2$	15.0	34.8	83.0	136.0	186.4				
$Co(NO_3)_2$	17.3	39.2	89.0	152.0	218.7	282.0	332.0		
$FeSO_4$	5.8	10.7	24.0	42.4					
H_3BO_3	6.0	12.3	25.1	38.0	51.0				
H_3PO_4	6.6	14.0	28.6	45.2	62.0	81.5	103.0	146.9	189.5
H_3AsO_4	7.3	15.0	30.2	46.4	64.9				
H_2SO_4	12.9	26.5	62.8	104.0	148.0	198.4	247.0	343.2	
KH_2PO_4	10.2	19.5	33.3	47.8	60.5	73.1	85.2		
KNO_3	10.3	21.1	40.1	57.6	74.5	88.2	102.1	126.3	148.0
$KClO_3$	10.6	21.6	42.8	62.1	80.0				
$KBrO_3$	10.9	22.4	45.0						
$KHSO_4$	10.9	21.9	43.3	65.3	85.5	107.8	129.2	170.0	
KNO_2	11.1	22.8	44.8	67.0	90.0	110.5	130.7	167.0	198.8
$KClO_4$	11.5	22.3							
KCl	12.2	24.4	48.8	74.1	100.9	128.5	152.2		
$KHCO_3$	11.6	23.6	59.0	77.6	104.2	132.0	160.0	210.0	255.0
KI	12.5	25.3	52.2	82.6	112.2	141.5	171.8	225.5	278.5
$K_2C_2O_4$	13.9	28.3	59.8	94.2	131.0				
K_2WO_4	13.9	33.0	75.0	123.8	175.4	226.4			
K_2CO_3	14.4	31.0	68.3	105.5	152.0	209.0	258.8	350.0	
KOH	15.0	29.5	64.0	99.2	140.0	181.8	223.0	309.5	387.8
K_2CrO_4	16.2	29.5	60.0						
$LiNO_3$	12.2	25.9	55.7	88.9	122.2	155.1	188.0	253.4	309.2
$LiCl$	12.1	25.5	57.1	95.0	132.5	175.5	219.5	311.5	393.5
$LiBr$	12.2	26.2	60.0	97.0	140.0	186.3	241.5	341.5	438.0
Li_2SO_4	13.3	28.1	56.8	89.0					
$LiHSO_4$	12.8	27.0	57.0	93.0	130.0	168.0			
LiI	13.6	28.6	64.7	105.2	154.5	206.0	264.0	357.0	445.0
Li_2SiF_6	15.4	34.0	70.0	106.0					
$LiOH$	15.9	37.4	78.1						
Li_2CrO_4	16.4	32.6	74.0	120.0	171.0				

(continued)

TABLE 369.—VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER (concluded)

Substance	0.5	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0
$MgSO_4$	6.5	12.0	24.5	47.5					
$MgCl_2$	16.8	39.0	100.5	183.3	277.0	377.0			
$Mg(NO_3)_2$	17.6	42.0	101.0	174.8					
$MgBr_2$	17.9	44.0	115.8	205.3	298.5				
$MgH_2(SO_4)_2$	18.3	46.0	116.0						
$MnSO_4$	6.0	10.5	21.0						
$MnCl_2$	15.0	34.0	76.0	122.3	167.0	209.0			
NaH_2PO_4	10.5	20.0	36.5	51.7	66.8	82.0	96.5	126.7	157.1
$NaHSO_4$	10.9	22.1	47.3	75.0	100.2	126.1	148.5	189.7	231.4
$NaNO_3$	10.6	22.5	46.2	68.1	90.3	111.5	131.7	167.8	198.8
$NaClO_3$	10.5	23.0	48.4	73.5	98.5	123.3	147.5	196.5	223.5
$(NaPO_3)_6$	11.6								
$NaOH$	11.8	22.8	48.2	77.3	107.5	139.1	172.5	243.3	314.0
$NaNO_2$	11.6	24.4	50.0	75.0	98.2	122.5	146.5	189.0	226.2
Na_2HPO_4	12.1	23.5	43.0	60.0	78.7	99.8	122.1		
$NaHCO_3$	12.9	24.1	48.2	77.6	102.2	127.8	152.0	198.0	239.4
Na_2SO_4	12.6	25.0	48.9	74.2					
$NaCl$	12.3	25.2	52.1	80.0	111.0	143.0	176.5		
$NaBrO_3$	12.1	25.0	54.1	81.3	108.8	136.0			
$NaBr$	12.6	25.9	57.0	89.2	124.2	159.5	197.5	268.0	
NaI	12.1	25.6	60.2	99.5	136.7	177.5	221.0	301.5	370.0
$Na_4P_2O_7$	13.2	22.0							
Na_2CO_3	14.3	27.3	53.5	80.2	111.0				
$Na_2C_2O_4$	14.5	30.0	65.8	105.8	146.0				
Na_2WO_4	14.8	33.6	71.6	115.7	162.6				
Na_3PO_4	16.5	30.0	52.5						
$(NaPO_3)_3$	17.1	36.5							
NH_4NO_3	12.8	22.0	42.1	62.7	82.9	103.8	121.0	152.2	180.0
$(NH_4)_2SiF_6$	11.5	25.0	44.5						
NH_4Cl	12.0	23.7	45.1	69.3	94.2	118.5	138.2	179.0	213.8
NH_4HSO_4	11.5	22.0	46.8	71.0	94.5	118.	139.0	181.2	218.0
$(NH_4)_2SO_4$	11.0	24.0	46.5	69.5	93.0	117.0	141.8		
NH_4Br	11.9	23.9	48.8	74.1	99.4	121.5	145.5	190.2	228.5
NH_4I	12.9	25.1	49.8	78.5	104.5	132.3	156.0	200.0	243.5
$NiSO_4$	5.0	10.2	21.5						
$NiCl_2$	16.1	37.0	86.7	147.0	212.8				
$Ni(NO_3)_2$	16.1	37.3	91.3	156.2	235.0				
$Pb(NO_3)_2$	12.3	23.5	45.0	63.0					
$Sr(SO_3)_2$	7.2	20.3	47.0						
$Sr(NO_3)_2$	15.8	31.0	64.0	97.4	131.4				
$SrCl_2$	16.8	38.8	91.4	156.8	223.3	281.5			
$SrBr_2$	17.8	42.0	101.1	179.0	267.0				
$ZnSO_4$	4.9	10.4	21.5	42.1	66.2				
$ZnCl_2$	9.2	18.7	46.2	75.0	107.0	153.0	195.0		
$Zn(NO_3)_2$	16.6	39.0	93.5	157.5	223.8				

TABLES 370-406.—VARIOUS ELECTRICAL CHARACTERISTICS OF MATERIALS

The fundamental electrical and magnetic definitions and the values of the practical units of current, voltage, and other electrical quantities, have been given (Tables 2-5). Some data will now be presented on electrical characteristics of various materials.

TABLE 370.—THE EFFECT OF ELECTRIC CURRENT ON THE HUMAN BODY [138a]

Some thought must be given to the electrical characteristics of the human body, since careless handling of electric circuits is very dangerous. The regular 120-volt circuit is dangerous, and any voltage above this increases the hazard. No bare contacts should be permitted where anyone might come in contact with them.

	AC (60 cycles)	DC
Threshold of perception	1 ma	5 ma
muscular decontrol	15	<70
danger to life	20	80
fibrillation (almost certain death)	100	..

Since the resistance of the human body for direct current (hand to foot or hand to hand), neglecting the contact resistance, is 5,000-10,000 ohms, good contact with electric circuits must be avoided. For alternating current the resistance is much lower.

[138a] Cromwell, J. C., Origins and prevention of laboratory accidents, 1950; Bell Laboratories Rec., p. 318, June 1936; Johns Hopkins University, Report of Electrician, November 1934; Journ. Franklin Inst., vol. 215, p. 1, 1933.

TABLE 371.—TRIBOELECTRICITY

Part 1.—The tribo-electric series

The following table is so arranged that any material in the list becomes positively electrified when rubbed by one lower in the list. The phenomenom depends upon surface conditions and circumstances may alter the relative positions in the list.

1 Asbestos (sheet).
2 Rabbit's fur, hair (Hg).
3 Glass (combn. tubing).
4 Vitreous silica, oppossum's fur.
5 Glass (fusn.).
6 Mica.
7 Wool.
8 Glass (pol.), quartz (pol.), glazed porcelain.
9 Glass (broken edge), ivory.
10 Calcite.
11 Cat's fur.
12 Ca, Mg, Pb, fluorspar, borax.
13 Silk.
14 Al, Mn, Zn, Cd, Cr, felt, hand, wash-leather.
15 Filter paper.
16 Vulcanized fiber.
17 Cotton.
18 Magnalium
19 K-alum, rock-salt, satin spar.
20 Woods, Fe.
21 Unglazed porcelain, sal-ammoniac.
22 K-bichromate, paraffin, tinned-Fe.
23 Cork, ebony.
24 Amber.
25 Slate, chrome-alum.
26 Shellac, resin, sealing-wax.
27 Ebonite.
28 Co, Ni, Sn, Cu, As, Bi, Sb, Ag, Pd, C, Te, Eureka, straw, copper sulfate, brass.
29 Para rubber, iron alum.
30 Guttapercha.
31 Sulfur.
32 Pt, Ag, Au.
33 Celluloid.
34 Indiarubber.

Part 2.—Triboelectric series in voltage of a number of metals as compared with silica (as O) [139]

Au	+17	Ni	+ 7.8	Silica	0.
Pt	+15	Pb	+ 7	Al	— .1
Ag	+14	Fe	+ 4.8	Sb	— .6
Cd	+10	Cr	+ 3.3	Zn	— 2
Cu	+ 9.3	Co	+ 1.4	Sn	— 7.3
Bi	+ 8.5	Tl	+ .6	Se	— 7.7

[139] Shaw, P. E., and Leavey, E. W. L., Proc. Roy. Soc., vol. 138, p. 506, 1932.

TABLE 372.—CONTACT DIFFERENCE OF POTENTIAL IN VOLTS *

Solids with liquids and liquids with liquids in air

Temperature of substances during experiment about 16°C

	C	Cu	Fe	Pb	Pt	Sn	Zn	Amalg. Zn	Brass	Distilled water
H_2O	.01 to .17	.269 to .100	.148	.171	.285 to .345	.177	−.105 to +.156	.100	.231	...
Alum. sat.sol.	...	−.127	−.653	−.139	.246	−.225	−.536	...	.014	...
$CuSO_4$ sol. sp.gr. 1.087	...	.103	...	...	...	...	...	...	...	...
$CuSO_4$ sat.sol.	...	.070	...	...	...	...	...	...	...	...
Sea salt sol. 1.18 at 20°C	...	−.475	−.605	...	−.856	−.334	−.565	...	−.435	...
NH_4Cl, sat.sol.	...	−.396	−.652	−.189	.059	−.364	−.637	...	−.348	—
$ZnSO_4$ sol. 1.125 at 4°C	...	...	...	...	...	...	−.238	...	...	...
$ZnSO_4$ sat.sol.	...	...	...	...	. .	..	−.430	−.284	...	−.200
One part H_2O + 3, sat. $ZnSO_4$	...	...	...	...	...	...	−.444	...	...	...
Strong H_2SO_4 in water:										
1 to 20 by wt.	...	...	...	...	...	...	−.344	...	...	...
1 to 10 by vol.	about −.035	...	...	...	...	...	...	−.358	...	...
1 to 5 by wt.	...	...	...	...	...	...	...	.429	...	...
5 to 1 by wt.	.01 to 3.0	...	...	−.120	...	−.25	...	...	−.016	...
Con. H_2SO_4	.55 to .85	1.113	...	.72 to 1.252	1.3 to 1.6	...	...	.848	...	1.298
Con. HNO_3	...	...	...	...	.672	...	...	...	...	...

Mercurous sulfate paste, Hg, + .475. Sat.$CuSO_4$sol., H_2O, — .043; sat.$ZnSO_4$sol., + .095; 1 pt. H_2O, 3 pt. $ZnSO_4$ + .102.

Concentrated H_2SO_4, H_2O, + 1.298; sat.alum.sol., + 1.456; $CnSO_4$sat. + 1.269; $ZnSO_4$sat.sol., + 1.699.

* Everett, Units and physical constants: Table of Ayrton and Perry's results, prepared by Ayrton.

TABLE 373.—THERMAL ELECTROMOTIVE FORCE OF ALUMINUM VERSUS PLATINUM [140]

Temperature versus emf

°C	mv	°C	mv	°C	mv
0	.000	240	1.374	480	3.703
20	+.062	260	1.538	500	3.931
40	.135	280	1.708	520	4.164
60	.218	300	1.884	540	4.403
80	.312	320	2.065	560	4.647
100	.416	340	2.252	580	4.896
120	.529	360	2.444	600	5.150
140	.651	380	2.641	620	5.409
160	.781	400	2.843	640	5.673
180	.919	420	3.050	660	5.942
200	1.064	440	3.262		
220	1.216	460	3.480		

[140] Nat. Bur. Standards Circ. 346, 1927.

TABLE 374.—COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS

The electromotive forces given in this table approximately represent what may be expected from a cell in good working order, but, with the exception of the standard cells, all of them are subject to considerable variation.

Part 1.—Double fluid cells

Name of cell	Negative pole	Solution	Positive pole	Solution	emf in volts
Bunsen	Amalg. Zn	$1,H_2SO_4;12,H_2O$	C	Fuming HNO_3	1.94
"	" "	"	"	HNO_3; dens. 1.38	1.86
Chromate	" "	$12,K_2Cr_2O_7$; $25,H_2SO_4$; $100,H_2O$	"	$1,H_2SO_4$; $12,H_2O$	2.00
"	" "	$1,H_2SO_4$; $12,H_2O$	"	$12,K_2Cr_2O_7$; $100,H_2O$	2.03
Daniell	" "	$1,H_2SO_4$; $4,H_2O$	Cu	Sat.sol.$CuSO_4$;$5,H_2O$	1.06
"	" "	$1,H_2SO_4$; $12,H_2O$	"	"	1.09
"	" "	5% sol.$ZnSO_4$;$6H_2O$	"	"	1.08
"	" "	1NaCl; 4 parts H_2O	"	"	1.05
Grove	" "	$1H_2SO_4$; $12H_2O$	Pt	Fuming HNO_3	1.93
"	" "	Sol.$ZnSO_4$	"	HNO_3; dens. 1.33	1.66
"	" "	H_2SO_4 sol.; dens. 1.136	"	Concent. HNO_3	1.93
"	" "	H_2SO_4; dens. 1.136	"	HNO_3; dens. 1.33	1.79
"	" "	H_2SO_4 sol.; dens. 1.14	"	HNO_3; dens. 1.19	1.66
"	" "	H_2SO_4 sol.; dens. 1.06	"	" " "	1.61
"	" "	NaCl sol.	"	" " 1.33	1.88
Partz	" "	Sol.$MgSO_4$	"	Sol.$K_2Cr_2O_7$	2.06

Part 2.—Single fluid cells

Name of cell	Negative pole	Solution	Positive pole	emf in volts
Leclanche	Amalg. Zn	Sol.NH_4Cl	Carbon *	1.46
Chaperon	" "	Sol.KOH	Copper †	.98
Edison-Lelande	" "	"	"	.70
AgCl	Zn	23% sol.NH_4Cl	Silver ‡	1.02
Law	"	15% " "	Carbon	1.37
Dry cell	"	1 pt. ZnO, 1 pt. NH_4Cl, 3 pts. plaster of paris, 2 pts. $ZnCl_2$, and water to make a paste	"	1.3
Poggendorff	Amalg. Zn	Sol.$K_2Cr_2O_7$	"	1.08
"	"	$12K_2Cr_2O_7$; $25H_2SO_4$; $100,H_2O$	"	2.01
Regnault	" "	$1H_2SO_4$; $12H_2O$; $1CaSO_4$	Cd	.34
Volta couple	Zn	H_2O	Cu	.98

* Depolarizer: Manganese peroxide with powdered carbon. † Depolarizer: CuO. ‡ Depolarizer: Silver chloride.

Part 3.—Secondary cells

Name of cell	Negative pole	Solution	Positive pole	emf in volts
Pb accumulator	Pb	H_2SO_4 sol. of density 1.1	PbO_2	2.2§
Regnier (1)	Cu	$CuSO_4$; H_2SO_4	"	1.68 to .85
" (2)	Amalg. Zn	$ZnSO_4$ sol.	" in H_2SO_3	2.36
Main	" "	H_2SO_4; dens. about 1.1	" "	2.50
Edison	Fe	KOH 20% sol.	A nickel oxide	1.1 mean

§ F. Streintz gives the following value of the temperature variations $\frac{dE}{dt}$ at different stages of charge:

emf	1.9223	1.9828	2.0031	2.0084	2.0105	2.0779	2.2070
$dE/dt \times 10^6$	140	228	335	285	255	130	73

Dolezalek gives the following relation between emf and acid concentration:

Percent H_2SO_4	64.5	52.2	35.3	21.4	5.2
emf °C	2.37	2.25	2.10	2.00	1.89

(continued)

TABLE 374.—COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS (concluded)

Part 4.—Standard cells

Clark	Zn + Hg	$ZnSO_4$	Paste H_2SO_4+Hg	1.434
Weston ‖	Cd + Hg	$CdSO_4$	Paste $CdSO_4$+Hg	1.0185

‖ Very low temperature coefficient.

TABLE 375.—DIFFERENCE OF POTENTIAL BETWEEN METALS IN SOLUTIONS OF SALTS

The following numbers are given by G. Magnanini for the difference of potential in hundredths of a volt between zinc in a normal solution of sulfuric acid and the metals named at the head of the different columns when placed in the solution named in the first column. The solutions were contained in a U-tube, and the sign of the difference of potential is such that the current will flow from the more positive to the less positive through the external circuit.

Strength of the solution in gram molecules per liter: No. of molecules	Salt	Zinc *	Cadmium *	Lead	Tin	Copper	Silver
		Difference of potential in centivolts					
.5	H_2SO_4	.0	36.6	51.3	51.3	100.7	121.3
1.0	NaOH	—32.1	19.5	31.8	.2	80.2	95.8
1.0	KOH	—42.5	15.5	32.0	—1.2	77.0	104.0
.5	Na_2SO_4	1.4	35.6	50.8	51.4	101.3	120.9
1.0	$Na_2S_2O_3$	— 5.9	24.1	45.3	45.7	38.8	64.8
1.0	KNO_3	11.8†	31.9	42.6	31.1	81.2	105.7
1.0	$NaNO_3$	11.5	32.3	51.0	40.9	95.7	114.8
.5	K_2CrO_4	23.9†	42.8	41.2	40.9	94.6	121.0
.5	$K_2Cr_2O_7$	72.8	61.1	78.4	68.1	123.6	132.4
.5	K_2SO_4	1.8	34.7	51.0	40.9	95.7	114.8
.5	$(NH_4)_2SO_4$	— .5	37.1	53.2	57.6†	101.5	125.7
.25	$K_4FeC_6N_6$	— 6.1	33.6	50.7	41.2	—†	87.8
.167	$K_6Fe_2(CN)_{12}$	41.0‡	80.8	81.2	130.9	110.7	124.9
1.0	KCNS	— 1.2	32.5	52.8	52.7	52.5	72.5
1.0	$NaNO_3$	4.5	35.2	50.2	49.0	103.6	104.6 §
.5	$Sr(NO_3)_2$	14.8	38.3	50.6	48.7	103.0	119.3
.125	$Ba(NO_3)_2$	21.9	39.3	51.7	52.8	109.6	121.5
1.0	KNO_3	—†	35.6	47.5	49.9	104.8	115.0
.2	$KClO_3$	15–10†	39.9	53.8	57.7	105.3	120.9
.167	$KBrO_3$	13–20†	40.7	51.3	50.9	111.3	120.8
1.0	NH_4Cl	2.9	32.4	51.3	50.9	81.2	101.7
1.0	KF	2.8	22.5	41.1	50.8	61.3	61.5
1.0	NaCl	—	31.9	51.2	50.3	80.9	101.3
1.0	KBr	2.3	31.7	47.2	52.5	73.6	82.4
1.0	KCl	—	32.1	51.6	52.6	81.6	107.6
.5	Na_2SO_3	— 8.2	28.7	41.0	31.0	68.7	103.7
—§	NaOBr	18.4	41.6	73.1	70.6†	89.9	99.7
1.0	$C_4H_6O_6$	5.5	39.7	61.3	54.4‡	104.6	123.4
.5	$C_4H_6O_6$	4.1	41.3	61.6	57.6	110.9	125.7
.5	$C_4H_4KNaO_6$	— 7.9	31.5	51.5	42–47	100.8	119.7

* Amalgamated. † Not constant. ‡ After some time. § A quantity of bromine was used corresponding to NaOH = 1.

TABLE 376.—THERMOELECTRIC EFFECT OF ALLOYS

The thermoelectric effect of a number of alloys is given in this table, the authority being Ed. Becquerel. They are relative to lead, and for a mean temperature of 50°C. In reducing the results from copper as a reference metal, the thermoelectric effect of lead to copper was taken as —1.9.

Substance	Relative quantity	Thermoelectric effect in microvolts
Antimony	806	227
Cadmium	696	
Antimony	4	146
Cadmium	2	
Zinc	1	
Antimony	806	137
Cadmium	696	
Bismuth	121	
Antimony	806	95
Zinc	406	
Antimony	806	8.1
Zinc	406	
Bismuth	121	
Antimony	4	76
Cadmium	2	
Lead	1	
Zinc	1	
Antimony	4	46
Cadmium	2	
Zinc	1	
Tin	1	

Substance	Relative quantity	Thermoelectric effect in microvolts
Antimony	2	43
Zinc	1	
Tin	1	
Antimony	12	35
Cadmium	10	
Zinc	3	
Antimony	10	10.2
Tellurium	1	
Antimony	10	8.8
Bismuth	1	
Antimony	4	2.5
Iron	1	
Antimony	8	1.4
Magnesium	1	
Antimony	8	— .4
Lead	1	
Bismuth	-	—43.8
Bismuth	2	—33.4
Antimony	1	

Substance	Relative quantity	Thermoelectric effect in microvolts
Bismuth	4	—51.4
Antimony	1	
Bismuth	8	—63.2
Antimony	1	
Bismuth	10	—68.2
Antimony	1	
Bismuth	12	—66.9
Antimony	1	
Bismuth	2	60
Tin	1	
Bismuth	10	—24.5
Selenium	1	
Bismuth	12	—31.1
Zinc	1	
Bismuth	12	—46.0
Arsenic	1	
Bismuth	1	68.1
Bismuth sulfide	1	

TABLE 377.—THERMOELECTRIC EFFECT

A measure of the thermoelectric effect of a circuit of two metals is the electromotive force produced by 1°C difference of temperature between the junctions. The thermoelectric effect varies with the temperature, thus: thermoelectric effect $= Q = dE/dt = A + Bt$, where A is the thermoelectric effect at 0°C, B is a constant, and t is the mean temperature of the junctions. The neutral point is the temperature at which $dE/dt = 0$, and its value is $-A/B$. When a current is caused to flow in a circuit of two metals originally at a uniform temperature, heat is liberated at one of the junctions and absorbed at the other. The rate of production or liberation of heat at each junction, or Peltier effect, is given in calories per second, by multiplying the current by the coefficient of the Peltier effect. This coefficient in calories per coulomb $= QT/J$, in which Q is in volts per degree C, T is the absolute temperature of the junction, and $J = 4.19$. Heat is also liberated or absorbed in each of the metals as the current flows through portions of varying temperature. The rate of production or liberation of heat in each metal, or the Thomson effect, is given in calories per second by multiplying the current by the coefficient of the Thomson effect. This coefficient, in calories per coulomb $= BT\theta/J$, in which B is in volts per degree C, T is the mean absolute temperature of the junctions, and θ is the difference of temperature of the junctions. (BT) is Sir W. Thomson's "Specific Heat of Electricity," The algebraic signs are so chosen in the following table that when A is positive, the current flows in the metal considered from the hot junction to the cold. When B is positive, Q increases (algebraically) with the temperature. The values of A, B, and thermoelectric effect in the following table are *with respect to lead* as the other metal of the thermoelectric circuit. The thermoelectric effect of a couple composed of two metals, 1 and 2, is given by subtracting the value for 2 from that for 1; when this difference is positive, the current flows from the hot junction to the cold in 1. In the following table, A is given in microvolts per degree, B in microvolts per degree per degree, and the neutral point in degrees.

The table has been compiled from the results of Becquerel, Matthiessen and Tait; in reducing the results, the electromotive force of the Grove and Daniell cells has been taken as 1.95 and 1.07 volts. The value of constantan was reduced from results given in Landolt-Börnstein's tables.

(*continued*)

Substance	A Microvolts	B Microvolts	Thermoelectric effect at mean temp. of junctions (microvolts) 20°C	50°C	Neutral point $-\frac{A}{B}$
Aluminum	− .76	+.0039	− .68	− .56	+ 195
Antimony, comm'l pressed wire	—	—	+ 6.0	—	—
" axial	—	—	+ 22.6	—	—
" equatorial	—	—	+ 26.4	—	—
Argentan	−11.94	−.0506	− 12.95	−14.47	− 236
"	—	—	—	−12.7	—
Arsenic	—	—	− 13.56	—	—
Bismuth, comm'l pressed wire	—	—	− 97.0	—	—
" pure " "	—	—	− 89.0	—	—
" crystal, axial	—	—	− 65.0	—	—
" " equatorial	—	—	− 45.0	—	—
Cadmium	+ 2.63	−.0424	+ 3.48	+ 4.75	− 62
" fused	—	—	—	+ 2.45	—
Calcium	—	—	—	+ 8.9	—
Cobalt	—	—	− 22	—	—
Constantan	—	—	—	−19.3	—
Copper	+ 1.34	+.0094	+ 1.52	+ 1.81	− 143
" commercial	—	—	+ .10	—	—
" galvanoplastic	—	—	+ 3.8	—	—
Gallium	—	—	− .2	—	—
Gold	+ 2.80	+.0101	+ 3.0	+ 3.30	[− 277]
Iron	+17.15	−.0482	+ 16.2	+14.74	+ 356
" pianoforte wire	—	—	+ 17.5	—	—
" commercial	—	—	—	+12.10	—
" "	—	—	—	+ 9.10	—
Lead	—	.0000	+ .00	.00	—
Magnesium	+ 2.22	−.0094	+ 2.03	+ 1.75	+ 236
Molybdenum	—	—	+ 5.9	—	—
Mercury	—	—	− .413	− 3.30	—
Nickel	—	—	—	−15.50	—
" (−18° to 175°)	−21.8	−.0506	− 22.8	−24.33	[− 431]
" (250°–300°)	−83.57	+.2384	—	—	—
" (above 340°)	− 3.04	−.0506	—	—	—
Palladium	− 6.18	−.0355	− 6.9	− 7.96	− 174
Phosphorus (red)	—	—	+ 29.9	—	—
Platinum	—	—	+ .9	—	—
" (hardened)	+ 2.57	−.0074	+ 2.42	+ 2.20	347
" (malleable)	− .60	−.0109	− .818	− 1.15	− 55
" wire	—	—	—	+ .94	—
" another specimen	—	—	—	− 2.14	—
Platinum-iridium alloys:					
85% Pt + 15% Ir	7.90	+.0062	+ 8.03	+ 8.21	[−1274]
90% Pt + 10% Ir	+ 5.90	−.0133	+ 5.63	+ 5.23	444
95% Pt + 5% Ir	+ 6.15	+.0055	+ 6.26	+ 6.42	[−1118]
Selenium	—	—	+807.	—	—
Silver	+ 2.12	+.0147	+ 2.41	+ 2.86	− 144
" (pure hard)	—	—	+ 3.00	—	—
" wire	—	—	—	+ 2.18	—
Steel	+11.27	−.0325	+ 10.62	+ 9.65	347
Tantalum	—	—	− 2.6	—	—
Tellurium * β	—	—	+500.	—	—
" α	—	—	+160.	—	—
Thallium	—	—	+ .8	—	—
Tin (commercial)	—	—	—	+ .33	—
"	—	—	+ .1	—	—
"	− .43	+.0055	− .33	− .16	78
Tungsten	—	—	− 2.0	—	—
Zinc	+ 2.32	+.0238	+ 2.79	+ 3.51	− 98
" pure pressed	—	—	+ 3.7	—	—

* Electrical conductivity of $Te_\beta = 0.04$, $Te_\alpha = 1.7$ emu.

TABLE 378.—THERMAL ELECTROMOTIVE FORCE OF METALS AND ALLOYS VERSUS PLATINUM

(millivolts)

One junction is supposed to be at 0°C; + indicates that the current flows from the 0° junction into the platinum. The rhodium and iridium were rolled, the other metals drawn.

Temperature, °C	Au	Ag	90%Pt+10%Pd	10%Pt+90%Pd	Pd	90%Pt+10%Rh	90% Pt+10%Ru	Ir	Rh
−185	− .15	− .16	− .11	+ .24	+ .77	—	− .53	− .28	− .24
− 80	− .31	− .30	− .09	+ .15	+ .39	—	− .39	− .32	− .31
+100	+ .74	+ .72	+ .26	− .19	− .56	—	+ .73	+ .65	+ .65
+200	+1.8	+1.7	+ .62	− .31	−1.20	—	+1.6	+1.5	+1.5
+300	+3.0	+3.0	+1.0	− .37	−2.0	+2.3	+2.6	+2.5	+2.6
+400	+4.5	+4.5	+1.5	− .35	−2.8	+3.2	+3.6	+3.6	+3.7
+500	+6.1	+6.2	+1.9	− .18	−3.8	+4.1	+4.6	+4.8	+5.1
+600	+7.9	+8.2	+2.4	+ .12	−4.9	+5.1	+5.7	+6.1	+6.5
+700	+9.9	+10.6	+2.9	+ .61	−6.3	+6.2	+6.9	+7.6	+8.1
+800	+12.0	+13.2	+3.4	+1.2	−7.9	+7.2	+8.0	−9.1	+9.9
+900	+14.3	+16.0	+3.8	+2.1	−9.6	+8.3	+9.2	+10.8	+11.7
+1000	+16.8	—	+4.3	+3.1	−11.5	+9.5	+10.4	+12.6	+13.7
+1100	—	—	+4.8	+4.2	−13.5	+10.6	+11.6	+14.5	+15.8
+(1300)	—	—	—	—	—	+13.1	+14.2	+18.6	+20.4
+(1500)	—	—	—	—	—	+15.6	+16.9	+23.1	+25.6

TABLE 379.—THERMOELECTRIC PROPERTIES AT LOW TEMPERATURES [141]

Thermoelectric emf per °K against silver alloy

°C	Cu	Ag	Au	Pd	Pt	Fe	Pb
−255	+.07	−.10	−1.20	+ .75	+1.54	+.05	−1.06
−240	.45	+.37	− .05	2.10	3.60	1.40	−1.19
−220	.90	.39	+ .24	3.40	5.24	4.80	−1.25
−200	.89	.31	.30	3.48	5.40	8.45	−1.29
−180	.72	.25	.30	2.14	4.36	11.5	−1.33
−160	.61	.22	.33	.54	3.02	14.0	−1.42
−140	.52	.21	.37	−1.06	1.72	15.8	−1.54
−120	.47	.20	.40	−2.52	.50	16.9	−1.67
−100	.44	.20	.44	−3.92	− .70	17.5	−1.79
− 80	.45	.20	.47	−5.27	−1.76	17.5	−1.92
− 60	.47	.20	.51	−6.52	−2.80	17.3	−2.05
− 40	.49	.20	.55	−7.80	−3.80	16.9	−2.17
− 20	.51	.20.	.58	−9.05	−4.72	16.2	−2.29
0	.53	.21	.62	−10.32	−5.62	15.8	−2.42
+ 20	.56	.22	.65	−11.6	−6.56	15.3	−2.54

[141] Borelius, Keesom, Johansson, Linde, Com. Phys. Lab. Leiden, No. 206, 1930.

TABLE 380.—PELTIER EFFECT, FE-CONSTANTAN, NI-CU, 0° —560°C

Temperature	0°	20°	130°	240°	320°	560°C	
Fe-Constantan	3.1	3.6	4.5	6.2	8.2	12.5	g cal $\times 10^{-3}$ per coulomb
NiCu	1.92	2.15	2.45	2.06	1.91	2.38	

 TABLE 381.—THOMSON EFFECT IN MICROVOLTS PER DEGREE

°K	Cu	Ag	Au	Pd	Pt	Fe	Ni	Co	Pb
20	+ .59	+1.40	+2.83	+1.9	+3.2	+1.3	...	...	...
25	1.04	1.23	2.09	2.6	3.6	2.7	...	...	...
30	1.22	.85	1.58	3.1	3.9	4.1	—4 5	— .2	.00
40	1.03	.24	.88	3.2	3.8	6.7	—5.4	— .3	—.04
50	.67	— .02	.45	2.5	2.7	9.0	—5.0	— .8	—.06
60	.18	— .17	.19	1.0	1.0	10.8	—4.5	—2.0	—.09
70	— .29	— .24	.07	—1.5	—1.1	11.9	—4.1	—3.7	—.12
80	— .46	— .25	.05	—4.6	—3.3	12.6	—4.0	—5.5	—.15
90	— .48	— .17	.17	—6.6	—5.1	12.9	—4.0	—7.0	—.18
100	— .45	— .03	.32	—7.8	—6.5	13.0	—4.5	—8.4	—.20
110	— .37	+ .12	.45	—8.7	—7.5	13.0	—5.3	—9.8	—.23
120	— .26	.25	.56	—9.3	—8.0	12.8	—6.4	—11.1	—.26
130	— .13	.35	.66	—9.7	—8.2	12.2	—7.4	—12.4	—.29
140	+ .02	.44	.75	—10.1	—8.2	11.0	—8.3	—13.5	—.32
150	.17	.52	.83	—10.3	—8.3	8.9	—9.0	—14.6	—.34
160	.31	.59	.91	—10.6	—8.4	6.1	—9.7	—15.7	—.37
170	.46	.66	.99	—10.9	—8.5	2.6	—10.3	—16.7	—.40
180	.59	.72	1.06	—11.2	—8.7	— .2	—10.9	—17.6	—.42
200	.79	.84	1.19	—12.1	—9.1	—3.5	—12.1	—19.6	—.46
220	.96	.96	1.31	—13.3	—9.8	—4.5	—13.3	—21.5	—.49
240	1.10	1.08	1.43	—14 6	—10.6	—4.8	—14.5	—23.4	—.52
260	1.24	1.20	1.54	—15.8	—11.4	—5.2	—15.7	—25.4	—.54
280	1.38	1.32	1.66	—17.0	—12.3	—5 6	...	...	—.55
300	+1.52	+1.44	+1.77	—18.2	—13.2	—5.9	...	...	—.57

TABLE 382.—THERMOELECTRIC EFFECTS; PRESSURE EFFECTS

The following values of the thermoelectric effects under various pressures are taken from Bridgman. A positive emf means that the current at the hot junction flows from the uncompressed to the compressed metal. The cold junction is always at 0°C. The last two columns give the constants in the equation $E =$ thermoelectric force against lead (0° to 100°C) $= (At + Bt^2) \times 10^{-8}$ volts; at atmospheric pressure, a positive emf meaning that the current flows from lead to the metal under consideration at the hot junction.

	Thermal emf, volts × 10^9 Pressure, kg/cm²										
	2000		4000		8000		12,000				
	Temperature, °C									Formula coefficients	
Metal	50°	100°	50°	100°	50°	100°	20°	50°	100°	A	B
Bi	53,000	85,000	110,000	185,000	255,000	425,000	185,000	452,000	710,000	—74.42	+.0160
Zn	6,200	14,100	13,000	28,500	26,100	58,100	14,400	38,500	87,400	+3.047	—.00495
Tl	4,930	10,870	9,380	20,290	17,170	37,630	8,780	23,750	52,460	+1.659	—.00134[a]
Cd	2,040	7,120	4,620	14,380	10,960	28,740	6,680	19,180	45,560	+12.002	+.1619
Constantan ..	2.850	5,950	5,800	11,810	11,530	23,790	6,750	17,200	35,470	—34.76	—.0397
Pd	2,190	4,380	4,400	8,800	8,630	17,690	5,090	12,970	26,520	—5.496	—.01760
Pt	1,180	3,600	3,600	7,310	7,370	14,350	3,880	11,030	21,570	—3.092	—.01334
W	1,190	2,530	2,360	4,990	4,690	10,120	2,700	7,050	15,140	+1.594	+.01705
Ni	700	1,680	1,500	3,400	3,230	7,190	1,880	5,140	11,440	—17.61	—.0178
Ag	840	1,870	1,720	3,720	3,350	7,190	+1,900	4,950	10,560	+2.556	+.00432[b]
Fe	390	1,670	590	3,250	5,300	5,820	—990	220	7,680	+16.18	—.0089[b]
Pb	460	1,050	920	2,120	1,860	4,210	+880	281	6,330	—	—
Au	456	1,052	905	2,051	1,791	3,974	+990	2,627	5,760	+2.899	+.00467[c]
Cu	+292	584	+580	1,216	1,124	2,420	+596	1,616	3,546	+2.777	+.00483
Al	—70	101	—91	294	32	929	—68	312	1,962	—.416	+.00008[d]
Mo	+93	140	+187	278	375	555	+146	562	833	+5.892	+.02167[e]
Sn	+38	+87	+58	+165	+70	+292	—182	+10	+390	+.230	—.00067
Manganin ...	—123	—232	—242	—452	—489	—894	—308	—719	—1,314	+1.366	+.000414[f]
Mg	—84	—167	—181	—362	—395	—791	—259	—648	—1,296	—.095	+.00004
Co	—156	—348	—316	—692	—630	—1,360	—352	—937	—2,061	—17.32	—.0390

a, $-.0_5 56t^3$; b, $-.0_4 86t^3$, annealed ingot iron; c, $-.0_6 166t^3$; d, $-.0_4 1t^3$; e, $-.0_4 25t^3$; f, $-.0_4 112t^3$.

The following data indicate the magnitude of the effect of pressure on the Peltier and Thomson heats. They refer to the same samples as for the last table. The Peltier heat is considered positive if heat is absorbed by the positive current from the surroundings on flowing from uncompressed to compressed metal. A positive d^2E/dt^2 means a larger Thomson heat in the compressed metal, and the Thomson heat is itself considered positive if heat is absorbed by the positive current in flowing from cold to hot metal. Same reference as footnote 141, and notes as for preceding table.

Metal	Peltier heat, $10^6 \times$ Joules/coulomb; Pressure kg/cm² 6000; Temperature °C 0°	50°	100°	Peltier 12,000; 0°	50°	100°	Thomson heat, $10^8 \times J \times coulomb^{-1}$ °C^{-1}; Pressure kg/cm² 6000; Temperature °C 0°	50°	100°	Thomson 12,000; 0°	50°	100°
Bi	+1070	+1210	—	+2580	+2810	—	+1150	+650	—	−520	−405	—
Zn	+98	+140	+190	+190	+278	+412	+41	+48	+56	+63	+133	+220
Tl	+66	+95	+124	+112	+171	+229	+38	+28	+26	+79	+63	+50
Cd	+19	+71	+118	+81	+148	+221	+109	+74	+63	+105	+92	+93
Constantan	+46	+57	+70	+90	+114	+140	+5	+6	+6	+13	+14	+17
Pd	+35	+43	+52	+68	+86	+103	+3	+4	+4	+9	+9	+8
Pt	+23	+37	+35	+45	+76	+65	+49	−6	−18	+96	+17	+59
W	+17	+25	+32	+36	+49	+65	+8	+7	+6	+9	+14	+20
Ni	+11	+17	+23	+24	+37	+50	+9	+7	+8	+16	+15	+10
Ag	+13	+17	+23	+25	+34	+44	+4	+5	+6	+7	+8	+10
Fe	−11	+18	+15	−38	+38	+36	+79	+58	−121	−347	+120	−194
Pb	+7	+10	+16	+14	+20	+30	+2	+6	+10	+6	+8	+20
Au	+6	+10	+14	+13	+18	+25	+4	+4	+5	+6	+6	+7
Cu	+4	+6	+8	+8	+11	+16	+4	+1	+4	+6	+3	+8
Al	−2	+2	+8	−3	+7	+17	+6	+9	+11	+21	+16	+20
Mo	+1	+2	+0	+2	+4	+1	+1	−5	−1	+2	−11	−2
Sn	−1	+1	+1	−5	+2	+2	+6	+0	−1	+29	+2	−5
Manganin	−2	−2	−2	−4	−4	−4	+1	+1	+0	+2	+1	+1
Mg	−16	−18	−21	−35	−42	−48	0	0	0	0	0	0
Co	−23	−33	−44	−46	−67	−90	−14	−11	−10	−20	−24	−28

TABLE 384.—THERMAL ELECTROMOTIVE FORCE OF CADMIUM VERSUS PLATINUM

Temperature versus emf

°C	mv	°C	mv	°C	mv
0	.000	125	1.211	250	3.255
25	+.171	150	1.559	275	3.740
50	.378	175	1.940	300	4.238
75	.620	200	2.351	315	4.539
100	.898	225	2.790		

TABLE 385.—PELTIER EFFECT

The coefficient of Peltier effect may be calculated from the constants A and B of Table 377, as there shown. With Q (see Table 377) in microvolts per °C and T = absolute temperature (K), the coefficient of Peltier effect $= \frac{QT}{42}$ cal per coulomb $= 0.00086\ QT$ cal per ampere-hour $= QT/1000$ millivolts (= millijoules per coulomb). Experimental results, expressed in slightly different units are here given. The figures are for the heat production at a junction of copper and the metal named in calories per ampere-hour. The current flowing from copper to the metal named, a positive sign indicates a warming of the junction.

Sb *	Sb commercial †	Bi pure	Bi †	Cd	German silver	Fe	Ni	Pt	Ag	Zn
Calories per ampere-hour										
—	—	—	—	−.62	—	−3.61	4.36	.32	−.41	−.58
13.02	4.8	19.1	25.8	.46	2.47	2.5	—	—	—	.39

* Becquerel's antimony is 806 parts Sb + 406 parts Zn + 121 parts Bi.
† Becquerel's bismuth is 10 parts Bi + 1 part Sb.

TABLE 386.—RESISTIVITY OF METALS AND SOME ALLOYS

The resistivities are the values of ρ in the equation $R = \rho l/s$, where R is the resistance in microhms of a length l cm of uniform cross section s cm². The temperature coefficient is a_s in the formula $R_t = R_s[1 + a_s(t - t_s)]$. The information of column 2 does not necessarily apply to the temperature coefficient.

Substance	Remarks	Temperature °C	Microhm-cm	Temperature coefficient t_s	Temperature coefficient a_s
Advance	see constantan	—	—	—	—
Aluminum	—	20	2.828	18°	+.0039
"	c. p.	−189	.64	25	+.0034
"	"	−100	1.53	100	+.0040
"	"	0	2.62	500	+.0050
"	"	+100	3.86	—	—
"	"	400	8.0	—	—
Antimony	—	0	39.1	20	+.0036
"	—	−190	10.5	—	—
"	liquid	+860	120	—	—
Arsenic	—	0	35	—	—
Beryllium	—	20	10.1	—	—
Bismuth	—	18	119.0	20	+.004
"	—	100	160.2	—	—
Brass	—	20	7	20	+.002
Cadmium	drawn	−160	2.72	20	+.0038
"	"	18	7.54	—	—
"	"	100	9.82	—	—
"	liquid	318	34.1	—	—
Calcium	99.57 pure	20	4.59	—	+.0036
Calido	see nichrome	—	—	—	—
Cesium	—	−187	5.25	—	—
"	—	0	19	—	—
"	solid }	27	22.2	—	—
"	liquid }	30	36.6	—	—
Chromium	—	0	13	—	—
Climax	—	20	87	20	+.0007
Cobalt	99.8 pure	20	9.7	—	—
Constantan	60% Cu. 40% Ni	20	49	12	+.000008
"	—	—	—	25	+.000002
"	—	—	—	100	−.000033
"	—	—	—	200	−.000020
"	—	—	—	500	+.000027
Copper	annealed	20	1.724	20 see col. 2	+.00393
"	hard-drawn	20	1.77	" " " "	+.00382
"	electrolytic	−206	.144	100	+.0038
"	"	+205	2.92	400	+.0042
"	pure	400	4.10	1000	+.0062
"	very pure, ann'ld	20	1.692	—	—
Eureka	see constantan	—	—	—	—
Excello	—	20	92	20	+.00016
Gallium	—	0	53	—	—
German silver	18% Ni	20	33	20	+.0004
Germanium	—	0	89000.	—	—
Gold	99.9 pure	−183	.68	20	+.0034
"	—	0	2.22	100 ann'ld	+.0025
"	pure, drawn	20	2.44	500 "	+.0035
"	99.9 pure	194.5	3.77	1000 "	+.0049
Ia Ia	see constantan	—	—	—	—
Ideal	" "	—	—	—	—
Indium	—	0	8.37	—	—
Iridium	—	−186	1.92	—	—
"	—	0	6.10	—	—
"	—	+100	8.3	—	—
Iron	99.98% pure	20	10	20	+.0050
"	pure, soft	−205.3	.652	0	+.0062
"	" "	− 78	5.32	25	+.0052
"	" "	0	8.85	100	+.0068

(continued)

Substance	Remarks	Temperature °C	Microhm-cm	Temperature coefficient t_s	a_s
Iron	pure, soft	+ 98.5	17.8	500	+.0147
"	" "	196.1	21.5	1000	+.0050
"	" "	400	43.3	—	—
"	electrolytic	0	10.0	—	—
"	"	100	14.41	—	—
Lead	—	20	22	20	+.0039
"	cold pressed	−183	6.02	18	+.0043
"	" "	− 78	14.1	—	—
"	" "	0	19.8	—	—
"	" "	+ 90.4	28	—	—
"	" "	196.1	36.9	—	—
"	—	318	94	—	—
Lithium	solid	−187	1.34	—	—
"	"	0	8.55	—	—
"	"	99.3	12.7	—	—
"	liquid	230	45.2	—	—
Magnesium	—	20	4.6	20	+.004
"	free from Zn	−183	1.00	0	+.0038
"	" " "	− 78	2.97	25	+.0050
"	" " "	0	4.35	100	+.0045
"	" " "	+ 98.5	5.99	500	+.0036
"	pure	400	11.9	600	+.0100
Manganese	—	—	5.0±	—	—
Manganin	84 Cu, 12 Mn, 4 Ni	20	44	12	+.000006
"	—	—	—	25	.000000
"	—	—	—	100	−.000042
"	—	—	—	250	−.000052
"	—	—	—	475	−.000000
"	—	—	—	500	−.00011
Mercury	—	20	95.783	20	+.00089
"	solid	−183.5	6.97	0	+.00088
"	"	−102.9	15.04	—	—
"	"	− 50.3	21.3	$R_t = R_0(1 +$	—
"	"	− 39.2	25.5	$.00089t +$	—
"	liquid	− 36.1	80.6	$.000001t^2)$	—
"	"	0	94.07	—	—
"	"	50	98.50	—	—
"	"	100	103.25	—	—
"	"	200	114.27	—	—
"	"	350	135.5	—	—
Molybdenum	very pure	0	5.14	25	+.0033
"	—	—	—	100	+.0034
"	—	—	—	1000	+.0048
Monel metal	—	20	42	20	+.0020
Nichrome	—	20	100	20	+.0004
Nickel	—	20	7.8	20	+.006
"	very pure	20	7.236	—	—
"	pure	−182.5	1.44	0	+.0062
"	"	− 78.2	4.31	25	+.0043
"	"	0	6.93	100	+.0043
"	"	94.9	11.1	500	+.0030
"	—	—	—	1000	+.0037
Osmium	—	20	9.5	—	—
Palladium	—	20	11	20	+.0033
"	very pure	−183	2.78	0	+.0035
"	" "	− 78	7.17	—	—
"	" "	0	10.21	—	—
"	" "	98.5	13.79	—	—
Platinum	—	0	9.83	20	+.003
"	wire	−203.1	2.44	0	+.0037
"	"	− 97.5	6.87	—	—
"	"	0	10.96	—	—
"	"	100	14.85	—	—
"	—	400	26	—	—

(continued)

TABLE 386.—RESISTIVITY OF METALS AND SOME ALLOYS (continued)

Substance	Remarks	Temperature °C	Microhm-cm	Temperature coefficient t_s	a_s
Potassium	—	— 75	4	0	+.0057
"	—	0	6.1	—	—
"	—	55	8.4	—	—
Rhodium	—	—186	.70	—	—
"	—	— 78.3	3.09	—	—
"	—	0	5.11	0	+.0043
"	—	100	6.60	—	—
Rubidium	solid	—190	2.5	—	—
"	"	0	11.6	—	—
"	"	35	13.4	—	—
"	liquid	40	19.6	—	—
Silicium	—	20	58±	—	—
Silver	99.98 pure	18	1.629	20	+.0038
"	electrolytic	—183	.390	25	+.0030
"	"	— 78	1.021	100	+.0036
"	"	0	1.468	500	+.0044
"	"	98.15	2.062	—	—
"	"	192.1	2.608	—	—
"	"	400	3.77	—	—
Sodium	solid	—180	1.0	—	—
"	"	— 75	2.8	—	—
"	"	0	4.3	0	+.0054
"	"	55	5.4	—	—
"	liquid	116	10.2	—	—
Steel	E. B. B.	20	10.4	20 see col. 2	+.005
"	B. B.	20	11.9	" " " "	+.004
"	Siemens-Martin	20	18	" " " "	+.003
"	manganese	20	70	" " " "	+.001
"	35%Ni, "invar."	20	81	—	—
"	piano wire	0	11.8	0 see col. 2	+.0032
"	temp. glass, hard	0	45.7	" " " "	+.0016
"	" , yellow	0	27	—	—
"	" , blue	0	20.5	0 see col. 2	+.0033
"	" , soft	0	15.9	—	—
Strontium	—	20	24.8	—	—
Tantalum	—	20	15.5	20	+.0031
Tellurium*	—	19.6	200,000	—	—
Thallium	pure	—183	4.08	—	—
"	"	— 78	11.8	—	—
"	"	0	17.60	—	—
"	"	98.5	24.7	—	—
Tin	—	20	11.5	20	+.0042
"	—	—184	3.40	—	—
"	—	— 78	8.8	—	—
"	—	0	13	—	—
"	—	91.45	18.2	—	—
Titanium	—	—	55	—	—
Tungsten	—	20	5.51	18	+.0045
"	1000°K	727	25.3	500	+.0057
"	1500°K	1227	41.4	1000	+.0089
"	2000°K	1727	59.4	—	—
"	3000°K	2727	98.9	—	—
"	3500°K	3227	118	—	—
Zinc	trace Fe	—183	1.62	20	+.0037
"	" "	— 78	3.34	—	—
"	" "	0	5.75	—	—
"	" "	92.45	8	—	—
"	" "	191.5	10.37	—	—
"	liquid	440	37.2	—	—

* See note to Table 377.

TABLE 386.—RESISTIVITY OF METALS AND SOME ALLOYS (concluded)

Resistance temperature coefficient for a number of metals and alloys of high purity.

Metal	$(R_{100}-R_0)/100R_0$	Alloy	$(R_{100}-R_0)/100R_0$
Ni	.00667	95 Pt— 5 Rh	.00215
Zn	.00419	90 Pt—10 Rh	.00169
Cd	.00423	80 Pt—20 Rh	.00140
Pt	.003925	60 Pt—40 Rh	.00144
Rh	.00436	40 Pt—60 Rh	.00194
		20 Pt—80 Rh	.00260

TABLE 387.—SOME ELEMENTS ARRANGED IN ORDER OF INCREASING RESISTIVITY (ohm-cm$\times 10^{-6}$, 20°C)

Ag	1.468	Mn	5.±	Pd	10.21	Ga	53
Cu	1.59	Mo	(5.3)	Pt	10.96	Os	56
Au	2.22	Zn	5.75	Rb	13	Hg	94.07
Al	2.6	Ir	6.10	Sn	13	Bi	110
Cr	2.6	K	6.1	Ta	14.6	Graphite	8×10^2
Ti	3.2	Ni	6.93	Tl	17.6	Carbon	3×10^3
Na	4.3	Cd	7.04	Cs	19	Te	2×10^5
Ca	4.3	In	8.37	Pb	20.4	P	10^{12}
Mg	4.35	Li	8.55	Sr	(23.5)	B	8×10^{12}
Rh	4.69	Fe	8.8	As	35	Se	10^{13}
W	5	Co	9	Sb	39	S	10^{17}

TABLE 388.—THERMAL ELECTROMOTIVE FORCE OF PLATINUM-RHODIUM ALLOYS VERSUS PLATINUM

emf (mv)

Percent rhodium

Temp. °C	.5	1.0	5.0	10.0	20.0	40.0	80.0	100.0
0	.00	.00	.00	.00	.00	.00	.00	.00
100	+.10	+.18	+.54	+.64	+.63	+.65	+.62	+.70
200	.20	.37	1.16	1.43	1.44	1.52	1.49	1.61
300	.29	.57	1.82	2.32	2.40	2.55	2.55	2.68
400	.39	.76	2.49	3.25	3.47	3.70	3.77	3.91
500	.48	.94	3.17	4.22	4.63	4.97	5.12	5.28
600	.58	1.12	3.86	5.22	5.87	6.36	6.60	6.77
700	.67	1.30	4.55	6.26	7.20	7.85	8.20	8.40
800	.76	1.48	5.25	7.33	8.59	9.45	9.92	10.16
900	.85	1.66	5.96	8.43	10.06	11.16	11.76	12.04
1000	.94	1.84	6.68	9.57	11.58	12.98	13.73	14.05
1100	1.03	2.02	7.42	10.74	13.17	14.90	15.81	16.18
1200	1.13	2.20	8.16	11.93	14.84	16.91	17.99	18.42

TABLE 389.—EFFECT OF TENSION ON THE RESISTANCE OF METALS

	Li	Ca	Sr	Sb	Bi	Manganin	Co
Recip. Young's mod. $\times 10^6$	20	4.75	7.5	1.25	4.2	.72	.5
Poisson ratio	.42	.30	.36	.30?	.37	.33	.30
Tens. coef. spec. resist. $\times 10^6$	+11	+.8	—21.2	+3.0	—3.65	—.60	+.19

TABLE 390.—VARIATION OF THE ELECTRICAL RESISTANCE WITH PRESSURE FOR TWO TEMPERATURES OF A NUMBER OF METALS[142]

Pressure kg/cm²	Copper—ΔR/R₀ 30°C	Copper 75°C	Silver—ΔR/R₀ 30°C	Silver 75°C	Gold—ΔR/R₀ 30°C	Gold 75°C	Iron—ΔR/R₀ 30°C	Iron 75°C	Lead—ΔR/R₀ 30°C	Lead 75°C
5,000	.0096	.0094	.0174	.0176	.0151	.0154	.0121	.0118	.0686	.0691
10,000	.0186	.0185	.0338	.0341	.0293	.0299	.0234	.0232	.1266	.1277
15,000	.0271	.0271	.0492	.0497	.0429	.0437	.0341	.0341	.1770	.1791
20,000	.0354	.0354	.0637	.0644	.0559	.0570	.0444	.0447	.2214	.2242
25,000	.0434	.0435	.0774	.0784	.0684	.0698	.0542	.0548	.2611	.2643
30,000	.0513	.0514	.0904	.0916	.0806	.0824	.0637	.0646	.2959	.2998

[142] Bridgman, Proc. Amer. Acad. Arts and Sci., vol. 72, p. 174, 1938.

TABLE 391.—RELATIVE ELECTRICAL RESISTANCE WITH PRESSURE FOR TWO TEMPERATURES OF A NUMBER OF METALS *

Pressure kg/cm²	Lithium R/R (0, 30°) 30°C	Lithium R/R (0, 75°) 75°C	Calcium R/R(0, 30°) 30°C	Calcium 75°C	Strontium R/R(0, 30°) 30°C	Strontium 75°C	Barium R/R(0, 30°) 30°C	Barium 75°C	Zinc, Axis 87° to length R/R (0, 30°) 30°C	Zinc, Axis 87° 75°C	Zinc, Axis 17° to length R/R (0, 30°) 30°C	Zinc, Axis 17° 75°C
0	—	—	1.0000	1.1688	1.0000	1.0974	1.0000	1.156	1.0000	1.1627	1.0000	1.1650
2,500	1.0175	1.0172	1.0237	1.1922	1.1141	1.2140	.982	1.130	.9868	1.1488	.9758	1.1352
5,000	1.0354	1.0351	1.0490	1.2187	1.2448	1.3451	.971	1.114	.9744	1.1355	.9525	1.1062
7,500	1.0539	1.0537	1.0764	1.2485	1.3922	1.4908	.967	1.107	.9628	1.1228	.9300	1.0809
10,000	1.0727	1.0730	1.1069	1.2816	1.5562	1.6510	.970	1.106	.9518	1.1107	.9081	1.0562
12,500	1.0920	1.0928	1.1407	1.3178	1.7364	1.8258	.976	1.108	.9416	1.0991	.8882	1.0325
15,000	1.1117	1.1131	1.1772	1.3571	1.9333	2.0153	.984	1.113	.9321	1.0880	.8686	1.0103
17,500	1.1318	1.1339	1.2164	1.3998	2.1467	2.2195	.995	1.123	.9233	1.0776	.8500	.9890
20,000	1.1524	1.1553	1.2582	1.4460	2.3767	2.4377	1.008	1.140	.9150	1.0677	.8321	.9687
22,500	1.1735	1.1770	1.3025	1.4959	2.6273	2.6703	1.025	1.161	.9072	1.0582	.8153	.9495
25,000	1.1949	1.1992	1.3491	1.5485	2.8905	2.9187	1.044	1.184	.8998	1.0498	.7990	.9310
27,500	1.2169	1.2221	1.3983	1.6033	3.1695	3.1805	1.066	1.211	.8926	1.0420	.7835	.9129
30,000	1.2394	1.2453	1.4500	1.6603	3.4665	3.4585	1.092	1.241	.8855	—	.7687	.8959

Pressure kg/cm²	Potassium R/R(0, 30°) 30°	Potassium 75°	Cesium R/R(0, 30°) 30°	Cesium 75°	Sodium R/R(0, 30°)	Rubidium R/R(0, 30°)
0	1.0000	—	1.0000	—	1.0000	1.0000
2,500	.664	—	.807	—	.8529	.615
5,000	.491	.615	.812	1.046	.7537	.471
7,500	.378	.467	.884	1.117	.6762	.407
10,000	.303	.372	1.005	1.260	.6171	.371
12,500	.253	.310	1.169	1.450	.5708	.354
15,000	.219	.269	1.376	1.685	.5341	.350
17,500	.197	.242	1.624	1.984	.5049	.358
20,000	.1821	.224	1.917	2.369	.4813	.376
22,500	—	—	2.492	3.068	.4619	.404
25,000	.1719	.216	2.836	3.491	.4456	.447
27,500	—	—	3.239	3.972	.4324	.504
30,000	.1778	—	—	4.509	.4223	.576

* For reference, see footnote 142, above.

TABLE 392.—THERMAL ELECTROMOTIVE FORCE OF NICKEL VERSUS PLATINUM[143]

Temperature versus emf

°C	mv	°C	mv	°C	mv
0	.000	400	5.450	800	9.350
25	−.350	425	5.580	825	9.675
50	.710	450	5.745	850	10.010
75	1.090	475	5.960	875	10.350
100	1.485	500	6.165	900	10.695
125	1.880	525	6.360	925	11.045
150	2.285	550	6.585	950	11.400
175	2.695	575	6.800	975	11.765
200	3.105	600	7.040	1000	12.130
225	3.505	625	7.290	1025	12.500
250	3.890	650	7.550	1050	12.875
275	4.255	675	7.825	1075	13.250
300	4.590	700	8.105	1100	13.625
325	4.880	725	8.415		
350	5.110	750	8.720		
375	5.290	775	9.030		

[143] Nat. Bur. Standards Journ. Res., vol. 5, p. 1291, 1930.

TABLE 393.—AVERAGE PRESSURE COEFFICIENTS* OF ELECTRICAL RESISTANCE UP TO 7000 kg/cm² AS A FUNCTION OF TEMPERATURE[144]

Metal	Temperatures −182.0°C	−78.4°C	0°C	30°C	75°C
Lead	−12.76	−12.88	−12.99	−9.3	−9.2
Magnesium	−5.89	−4.49	−4.39		
Aluminum	−9.16	−4.71	−4.28		
Silver	−4.09	−3.46	−3.45	−3.0	−3.0
Gold	−3.27†	−2.97	−2.94	−2.6	−2.7
Copper	−3.09	−2.14	−1.88	−1.7	−1.7
Nickel	−1.88	−2.00	−1.85		
Iron	−2.44	−2.27	−2.34		
Palladium	−2.82	−2.32	−2.13		
Niobium	− .80	− .98	−1.18		
Platinum	−2.34	−1.97	−1.93		
Rhodium	−2.26	−1.86	−1.64‡		
Molybdenum	−1.91	−1.29	−1.30		
Tantalum	−1.17	−1.42	−1.45		
Tungsten	−1.36	−1.42	−1.37		

* $\times 10^6$
[144] Bridgman, P. W., Proc. Amer. Acad. Arts and Sci., vol. 67, p. 342, 1932.
† Maximum pressure 4300.
‡ On a less pure sample.

TABLE 394.—RESISTIVITY OF MERCURY AND MANGANIN UNDER PRESSURE

Pressure, kg/cm²	—	500	1000	1500	2000	2500	3000	4000	5000	6000	6500
$R(p, -75°)$ Hg	.9186	.9055	.8930	.8818	.8714	.8582	.8478	.8268	.8076	.7896	.7807
$R(p, 25°)$ Hg	1.0000	.9836	.9682	.9535	.9394	.9258	.9128	.8882	.8652	.8438	.8335
* Hg	1.0000	.9854	.9716	.9588	.9462	.9342	.9228	.9010	.8806	.8616	.8527
$R(p, 125°)$ Hg	1.0970	1.0770	1.0580	1.0400	1.0230	1.0070	.9908	.9614	.9342	.9086	.8966

* This line gives the specific mass resistance at 25°, the other lines, the specific volume resistance.

The use of mercury as above has the advantage of being perfectly reproducible so that at any time a pressure can be measured without recourse to a fundamental standard. However, at 0°C mercury freezes at 7500 kg/cm². Manganin is suitable over a much wider range. Over a temperature range 0 to 50°C the pressure resistance relation is linear within 1/10 percent of the change of resistance up to 13,000 kg/cm². The coefficient varies slightly with the sample. Bridgman's samples (German) had values of $(\Delta R/pR_0) \times 10^9$ from 2295 to 2325. These are + instead of −, as with most of the above metals.

TABLE 395.—THERMAL ELECTROMOTIVE FORCE OF ZINC VERSUS PLATINUM

Temperature versus emf

°C	mv	°C	mv	°C	mv
0	.000	150	1.276	300	3.417
25	+.153	175	1.572	325	3.853
50	.331	200	1.894	350	4.310
75	.533	225	2.240	375	4.786
100	.758	250	2.610	400	5.290
125	1.005	275	3.002	415	5.604

TABLE 396.—CONDUCTIVITY AND RESISTIVITY OF MISCELLANEOUS ALLOYS

Temperature coefficients

Conductivity in mhos or $\frac{1}{\text{ohms-cm}} = \gamma^t = \gamma^0(1 - at + bt^2)$ and resistivity in microhm — cm $= \rho^t = \rho^0(1 + at - bt^2)$.

Metals and alloys	Composition by weight	$\frac{\gamma^0}{10^4}$	$a \times 10^6$	ρ^0
Gold-copper-silver	58.3 Au + 16.5 Cu + 15.2 Ag	7.58	574*	13.2
" " "	66.5 Au + 15.4 Cu + 18.1 Ag	6.83	529†	14.6
" " "	7.4 Au + 78.3 Cu + 14.3 Ag	28.06	1830‡	3.6
Invar	....	1.33	2000	75
Welding iron	0.05% Cu	6.25	6000	18
Woods metal	56 Bi, 17 Cd, 14 Pb, 13 Sn	1.93	2900	52
Brass	Various	12.2–15.6	$1\text{–}2+10^3$	6.4–8.4
" hard drawn	70.2 Cu+ +29.8 Zn	12.16	—	8.2
" annealed	" "	14.35	—	7.0
German silver	Various	3–5	—	20–33
" "	60.16 Cu + 25.37 Zn + 14.03 Ni + .30 Fe with trace of cobalt and manganese	3.33	360	30
Aluminum bronze	....	7.5–8.5	600	12–13
Phosphor bronze	....	10–20	—	5–10
Silicium bronze	....	41	—	2.4
Manganese-copper	30 Mn + 70 Cu	1.00	40	100
Nickel-manganese-copper	3 Ni + 24 Mn + 73 Cu	2.10	—30	48
Nickelin	18.46 Ni + 61.63 Cu + 19.67 Zn + 0.24 Fe + 0.19 Co + 0.18 Mn	3.01	300	33
Patent nickel	25.1 Ni + 74.41 Cu + 0.42 Fe + 0.23 Zn + 0.13 Mn + trace of cobalt	2.92	190	34
Rheotan	53.28 Cu + 25.31 Ni + 16.89 Zn + 4.46 Fe + 0.37 Mn	1.90	410	53
Rheotan	53 Cu, 25 Ni, 17 Zn, 5 Fe	2.24	280	45
Copper-manganese-iron	91 Cu + 7.1 Mn + 1.9 Fe	4.98	120	20
Copper-manganese-iron	70.6 Cu + 23.2 Mn + 6.2 Fe	1.30	22	77
Copper-manganese-iron	69.7 Cu + 29.9 Ni + 0.3 Fe	2.60	120	38
Therlo	85 Cu, 13 Mn, 2 Al	2.24	10	46.5
Manganin	84 Cu + 12 Mn + 4 Ni	2.3	6	44
Constantan	60 Cu + 40 Ni	2.04	8	49

* $b \times 10^9 = 924$. † $b \times 10^9 = 93$. ‡ $b \times 10^9 = 7280$.

This table shows the conductivity of alloys and the variation of the conductivity with temperature. The conductivity is given as $C_t = C_0 (1 - at + bt^2)$, and the range of temperature was from 0° to 100°C.

The table is arranged in three groups to show (1) that certain metals when melted together produce a solution which has a conductivity equal to the mean of the conductivities of the components, (2) the behavior of those metals alloyed with others, and (3) the behavior of the metals alloyed together.

Part 1

Alloys	Weight % of first named	Volume % of first named	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$
Sn_6Pb	77.04	83.96	7.57	3890	8670
Sn_4Cd	82.41	83.10	9.18	4080	11870
SnZn	78.06	77.71	10.56	3880	8720
PbSn	64.13	53.41	6.40	3780	8420
$ZnCd_2$	24.76	26.06	16.16	3780	8000
$SnCd_4$	23.05	23.50	13.67	3850	9410
$CdPb_6$	7.37	10.57	5.78	3500	7270

Part 2

Alloys	Volume % of first named	Weight % of first named	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$
Lead-silver ($Pb_{20}Ag$)	95.05	94.64	5.60	3630	7960
Lead-silver (PbAg)	48.97	46.90	8.03	1960	3100
Lead-silver ($PbAg_2$)	32.44	30.64	13.80	1990	2600
Tin-gold ($Sn_{12}Au$)	77.94	90.32	5.20	3080	6640
" " (Sn_6Au)	59.54	79.54	3.03	2920	6300
Tin-copper	92.24	93.57	7.59	3680	8130
" "	80.58	83.60	8.05	3330	6840
" "	12.49	14.91	5.57	547	294
" "	10.30	12.35	6.41	666	1185
" "	9.67	11.61	7.64	691	304
" "	4.96	6.02	12.44	995	705
" "	1.15	1.41	39.41	2670	5070
Tin-silver	91.30	96.52	7.81	3820	8190
" "	53.85	75.51	8.65	3770	8550
Zinc-copper	36.70	42.06	13.75	1370	1340
" "	25.00	29.45	13.70	1270	1240
" "	16.53	23.61	13.44	1880	1800
" "	8.89	10.88	29.61	2040	3030
" "	4.06	5.03	38.09	2470	4100

NOTE.—Barus has pointed out that the temperature variation of platinum alloys containing less than 10% of the other metal can be nearly expressed by an equation $y = \frac{n}{x} - m$, where y is the temperature coefficient and x the specific resistance, m and n being constants. If a be the temperature coefficient at 0°C and s the corresponding specific resistance, $s(a + m) = n$

For platinum alloys Barus's experiments gave $m = -.000194$ and $n = .0378$.

For steel $m = -.000303$ and $n = .0620$.

Matthiessen's experiments reduced by Barus gave for

Gold alloys $m = -.000045$, $n = .00721$.
Silver " $m = -.000112$, $n = .00538$.
Copper " $m = -.000386$, $n = .00055$.

(continued)

TABLE 397.—ELECTRICAL CONDUCTIVITY OF ALLOYS (concluded)

Part 3

Alloys	Weight % of first named	Volume % of first named	$\frac{C_0}{10^4}$	$a \times 10^6$	$b \times 10^9$
Gold-copper	99.23	98.36	35.42	2650	4650
" "	90.55	81.66	10.16	749	81
Gold-silver	87.95	79.86	13.46	1090	793
" "	87.95	79.86	13.61	1140	1160
" "	64.80	52.08	9.48	673	246
" "	64.80	52.08	9.51	721	495
" "	31.33	19.86	13.69	885	531
" "	31.33	19.86	13.73	908	641
Gold-copper	34.83	19.17	12.94	864	570
" "	1.52	.71	53.02	3320	7300
Platinum-silver	33.33	19.65	4.22	330	208
" "	9.81	5.05	11.38	774	656
" "	5.00	2.51	19.96	1240	1150
Palladium-silver	25.00	23.28	5.38	324	154
Copper-silver	98.08	98.35	56.49	3450	7990
" "	94.40	95.17	51.93	3250	6940
" "	76.74	77.64	44.06	3030	6070
" "	42.75	46.67	47.29	2870	5280
" "	7.14	8.25	50.65	2750	4360
" "	1.31	1.53	50.30	4120	8740
Iron-gold	13.59	27.93	1.73	3490	7010
" "	9.80	21.18	1.26	2970	1220
" "	4.76	10.96	1.46	487	103
Iron-copper	.40	.46	24.51	1550	2090
Phosphorus-copper	2.50	—	4.62	476	145
" "	.95	—	14.91	1320	1640
Arsenic-copper	5.40	—	3.97	516	989
" "	2.80	—	8.12	736	446
" "	trace	—	38.52	2640	4830

The electrical resistivity (ρ, ohm-cm) of good conductors depends greatly on chemical purity, Slight contamination even with metals of lower ρ may greatly increase ρ. Solid solutions of good conductors generally have higher ρ than components. Reverse is true of bad conductors. In solid state allotropic and crystalline forms greatly modify ρ. For liquid metals this last cause of variability disappears. The + temperature coefficients of pure metals is of the same order as the coefficients of expansion of gases. For temperature resistance (t, ρ) plot at low temperatures the graph is convex toward the axis of t and probably approaches tangency to it. However for extremely low temperatures Onnes finds very sudden and great drops in ρ, e.g., for mercury, $\rho_{3.6K} < 4 \times 10^{-10} \rho_0$ and for Sn, $\rho_{3.5K} < 10^{-7} \rho_0$. The t, ρ graph for an alloy may be nearly parallel to the t axis, cf. constantan; for poor conductors ρ may decrease with increasing t. At the melting-points there are three types of behavior of good conductors; those about doubling ρ and then possessing nearly linear t, ρ graphs (Al, Cu, Sn, Au, Ag, Pb); those where ρ suddenly increases and then the + temp. coefficient is only approximately constant (Hg, Na, K); those about doubling ρ then having a —, slowly changing to a + temp. coef. (Zn, Cd); those where ρ suddenly decreases and thereafter steadily increases (Sb, Bi). The values from different authorities do not necessarily fit because of different samples of metals. Resistivities are in microhm-cm unless otherwise stated. Italicized figures indicate liquid state.

Gold

°C	ρ_t	ρ_t/ρ_0
—252.8	.018	.0081
—200.	.601	.267
—192.5	.520	.231
—150.	.997	.444
—100.	1.400	.623
— 77.6	1.564	.696
— 50.	1.813	.806
0.	2.247	1.00
100.	2.97	1.32
200.	3.83	1.70
500.	6.62	2.94
750.	9.35	4.16
1000.	12.54	5.58
1063.	13.50	6.01
1063.	*30.82*	*13.7*
1200.	*32.8*	*14.6*
1400.	*35.6*	*15.8*
1500.	*37.0*	*16.5*

Copper

°C	ρ_t	ρ_t/ρ_0
—258.6	.014	.0091
—252.8	.016	.0103
—251.1	.028	.0178
—206.6	.163	.1035
—192.9	.249	.1580
—150.	.567	.359
—100.	.904	.573
— 50.	1.240	.786
0.	1.578	1.00
100.	2.28	1.44
200.	2.96	1.88
500.	5.08	3.22
750.	7.03	4.46
1000.	9.42	5.97
1083.	10.20	6.47
1083.	*21.30*	*13.5*
1200.	*22.30*	*14.1*
1400.	*23.86*	*15.1*
1500.	*24.62*	*15.6*

Silver

°C	ρ_t	ρ_t/ρ_0
—258.6	.009	.0057
—252.8	.014	.0090
—189.5	.334	.222
—200.	.357	.237
—150.	.638	.424
—100.	.916	.608
— 76.8	1.040	.690
— 50.	1.212	.805
0.	1.506	1.00
100.	2.15	1.43
200.	2.80	1.86
400.	3.46	2.30
750.	6.65	4.42
960.	8.4	5.58
960.	*16.6*	*11.0*
1000.	*17.01*	*11.3*
1200.	*19.36*	*12.9*
1400.	*21.72*	*14.4*
1500.	*23.0*	*15.3*

Zinc

°C	ρ_t	ρ_t/ρ_0
—252.9	.0511	.0089
—200.	1.39	.242
—191.1	1.23	.214
—150.	2.00	.348
—100.	2.90	.504
— 77.8	3.97	.691
— 50.	4.04	.703
0.	5.75	1.00
100.	7.95	1.38
300.	13.25	2.30
415.	17.00	2.96
427.	*37.30*	*6.49*
450.	*37.08*	*6.46*
500.	*36.60*	*6.36*
600.	*35.90*	*6.25*
700.	*35.60*	*6.19*
800.	*35.60*	*6.19*
850.	*35.74*	*6.21*

Mercury

°C	ρ_t	ρ_t/ρ_0
—200.	5.38	.057
—150.	10.30	.109
—100.	15.42	.164
— 50.	21.4	.227
— 30.	*91.7*	*.975*
0.	*94.1*	*1.000*
50.	*98.3*	*1.045*
100.	*103.1*	*1.096*
200.	*114.0*	*1.212*
300.	*127.0*	*1.350*

Potassium

°C	ρ_t	ρ_t/ρ_0
—200.	1.720	.246
—150.	2.654	.379
—100.	3.724	.532
— 50.	5.124	.732
0.	7.000	1.00
20.	7.116	1.016
60.	8.790	1.256
65.	*13.40*	*1.914*
100.	*15.31*	*2.187*
120.	*16.70*	*2.386*

Sodium

°C	ρ_t	ρ_t/ρ_0
—200.	.605	.137
—150.	1.455	.330
—100.	2.380	.541
— 50.	3.365	.764
0.	4.40	1.000
20.	4.873	1.107
93.5	6.290	1.429
100.	*9.220*	*2.095*
120.	*9.724*	*2.209*
140.	*10.34*	*2.349*

Iron

°C	ρ_t	ρ_t/ρ_0
—252.7	.011	.0010
—200.	.57	.053
—192.5	.844	.079
—100.	5.92	.554
— 75.1	6.43	.602
— 50.	8.15	.763
— 0.	10.68	1.00
100.	16.61	1.554
200.	24.50	2.293
400.	43.29	4.052

Manganin

°C	ρ_t	ρ_t/ρ_0
—200.	37.8	.974
—150.	38.2	.985
—100.	38.5	.992
— 50.	38.7	.997
0.	38.8	1.000
100.	38.9	1.003
400.	38.3	.987

German silver

°C	ρ_t	ρ_t/ρ_0
—200.	27.9	.930
—150.	28.7	.957
—100.	29.3	.977
— 50.	29.7	.990
0.	30.0	1.000
100.	33.1	1.103

Constantan

°C	ρ_t	ρ_t/ρ_0
—200.	42.4	.961
—150.	43.0	.975
—100.	43.5	.986
— 50.	43.9	.995
0.	44.1	1.000
100.	44.6	1.012
400.	44.8	1.016

90% Pt 10% Rh

°C	ρ_t	ρ_t/ρ_0
—200.	14.49	.685
—150.	16.29	.770
—100.	18.05	.854
— 50.	19.66	.930
0.	21.14	1.000
100.	24.20	1.145

(*continued*)

TABLE 398.—RESISTIVITIES AT HIGH AND LOW TEMPERATURES (concluded)

(Ohm-cm unless stated otherwise.)

Platinum			Lead			Bismuth			Cadmium		
°C	ρ_t	ρ_t/ρ_0	°C	ρ_t	ρ_t/ρ_0	°C	ρ_t	ρ_t/ρ_0	°C	ρ_t	ρ_t/ρ_0
—265.	.10	.0092	—252.9	.59	.0298	—200.	34.8	.314	—252.9	.17	.0218
—253.	.15	.014	—203.	4.42	.223	—150.	55.3	.499	—200.	1.66	.214
—233.	.54	.049	—192.8	5.22	.264	—100.	75.6	.683	—190.2	2.00	2.58
—153.	4.18	.378	—103.	11.8	.598	— 50.	94.3	.852	—183.1	2.22	.286
— 73.	7.82	.708	— 75.8	13.95	.705	0.	110.7	1.00	—139.2	3.60	.464
0.	11.05	1.00	— 53.	15.7	.792	17.	120.0	1.083	—100.	4.80	.619
100.	14.1	1.28	0.	19.8	1.00	100.	156.5	1.413	0.	7.75	1.00
200.	17.9	1.62	100.	27.8	1.403	200.	214.5	1.937	300.	16.50	2.13
400.	25.4	2.30	200.	38.0	1.919	259.	267.0	2.411	325.	*33.76*	*4.35*
800.	40.3	3.65	319.	50.0	2.52	263.	*127.5*	*1.150*	350.	*33.60*	*4.33*
1000.	47.0	4.25	333.	*95.0*	*4.80*	300.	*128.9*	*1.164*	400.	*33.70*	*4.35*
1200.	52.7	4.77	400.	*98.3*	*4.96*	500.	*139.9*	*1.263*	500.	*35.12*	*4.40*
1400.	58.0	5.25	600.	*107.2*	*5.41*	700.	*150.8*	*1.361*	700.	*35.78*	*4.62*
1600.	63.0	5.70	800.	*116.2*	*5.86*	750.	*153.5*	*1.386*			

Tin			Carbon, graphite *			Fused silica		Alundum cement	
°C	ρ_t	ρ_t/ρ_0	°C	ρ in ohms-cm: Carbon	Graphite	°C	ρ = megohms-cm	°C	ρ in ohms-cm
—200.	2.60	.199	0.	.0035	.00080	15.	>200,000,000.	20.	$>9\times10^9$
—100.	7.57	.580	500.	.0027	.00083	230.	20,000,000.	800.	30800.
0.	13.05	1.00	1000.	.0021	.00087	300.	200,000.	900.	13600.
200.	20.30	1.55	1500.	.0015	.00090	350.	30,000.	1000.	7600.
225.	22.00	1.69	*2000.*	.0011	.00100	450.	800.	1100.	6500.
235.	*47.60*	*3.65*	2500.	.0009	.0011	700.	30.	1200.	2300.
750.	*61.22*	*4.69*				850.	about 20.	1600.	190.

* Diamond 1030°C, $\rho > 10^7$; 1380°, 7.5×10^5.

TABLE 399.—SUPERCONDUCTIVITY OF SOME METALS[145]

Metal	T°K	Metal	T°K	Metal	T°K
Nb	9.22	In	3.38	U	.75
Pb	7.2	Re	2.57*	Os	.71
La	5.2	Tl	2.4	Zr	.54*
Ta	4.4	Th	1.32	Cd	.54
V	4.3	Al	1.15	Ti	.53†
Hg	4.15	Ga	1.12	Ru	.47
Sn	3.71	Zn	.95†	Hf	.35

[145] Smith, Thomas S., Ohio State University, private communication.
* Daunt, J. G., and Smith, T. S. † Daunt, J. G., and Heer, C. V., Phys. Rev., vol. 76, pp. 719 and 1324, 1948.

TABLE 400.—SUPERCONDUCTIVITY OF SOME ALLOYS AND COMPOUNDS[146]

NbC	10.1°K	Pb–As alloy	8.4°K	PbS	4.1°K	W_2C	2.05°K
TaC	9.2	MoC	7.7	Hg_5Tl_7	3.8	Au_2Bi	1.84
Pb–As–Bi	9.0	N_2Pb_5	7.2	ZrB	2.82	CuS	1.6
Pb–Bi–Sb	8.9	Bi_6Tl_3	6.5	WC	2.8	TiN	1.4
Pb–Sn–Bi	8.5	Sb_2Tl_7	5.5	Mo_2C	2.4	VN	1.3
		TaSi	4.2			TiC	1.1

[146] Smith, G. H., and Wilhelm, J. O., Rev. Mod. Phys., vol. 7, p. 240, 1935.

TABLE 401.—VOLUME AND SURFACE RESISTANCE OF SOLID DIELECTRICS

The resistance between two conductors insulated by a solid dielectric depends both upon the surface resistance and the volume resistance of the insulator. The volume resistivity, ρ, is the resistance between two opposite faces of a centimeter cube. The surface resistivity, σ, is the resistance between two opposite edges of a centimeter square of the surface. The surface resistivity usually varies through a wide range with the humidity.

Material	σ; megohms 50% humidity	σ; megohms 70% humidity	σ; megohms 90% humidity	ρ Megohm-cm
Amber	6×10^{8}	2×10^{8}	1×10^{5}	5×10^{10}
Beeswax, yellow	6×10^{8}	6×10^{8}	5×10^{8}	2×10^{9}
Celluloid	5×10^{4}	2×10^{4}	2×10^{3}	2×10^{4}
Fiber, red	2×10^{4}	3×10^{3}	2×10^{2}	5×10^{3}
Glass, plate	5×10^{4}	6×10	2×10	2×10^{7}
" Kavalier	4×10^{6}	4×10^{3}	1×10^{3}	8×10^{9}
Hard rubber, new	3×10^{9}	1×10^{8}	2×10^{3}	1×10^{12}
Ivory	5×10^{3}	1×10^{3}	3×10	2×10^{2}
Khotinsky cement	7×10^{8}	3×10^{8}	5×10^{5}	2×10^{9}
Marble, Italian	3×10^{3}	2×10^{2}	2×10	1×10^{5}
Mica, colorless	2×10^{7}	4×10^{5}	8×10^{3}	2×10^{11}
Paraffin (parowax)	9×10^{9}	7×10^{9}	6×10^{9}	1×10^{10}
Porcelain, unglazed	6×10^{5}	7×10^{3}	5×10	3×10^{8}
Quartz, fused	3×10^{9}	2×10^{3}	2×10^{2}	5×10^{12}
Rosin	6×10^{5}	3×10^{8}	2×10^{8}	5×10^{10}
Sealing wax	2×10^{9}	6×10^{8}	9×10^{7}	8×10^{9}
Shellac	6×10^{7}	3×10^{6}	7×10^{3}	1×10^{10}
Slate	9×10	3×10	1×10	1×10^{2}
Sulfur	7×10^{9}	4×10^{9}	1×10^{8}	1×10^{11}
Wood, paraffined mahogany	4×10^{6}	5×10^{5}	7×10^{3}	4×10^{7}

TABLE 402.—ELECTRICAL RESISTIVITY OF SOME OXIDES AND MISCELLANEOUS MINERALS *

Material	Resistivity ohm-cm	Material	Resistivity ohm-cm
Graphite, commercial electrodes (density = 1.5)	.001–.0013	Sulfur	$>10^{14}$
Hematite, Fe_2O_3, mineral	.35–.7	PbO_2, synthetic	.000092
Iron, metallic, meteoric	$2.4\text{–}3.2\times6^{-8}$?	MnO_2, synthetic	6
Rock salt, pure	10^{6}–10^{7}	W_2O_5	.00045
impure	10^{6}	WO_3	2×10^{5}

* For reference, see footnote 45, p. 136.

TABLE 403.—ELECTRICAL RESISTIVITY OF ROCKS AND SOILS *

Igneous rocks	Resistivity ohm-cm	Sedimentary rocks	Resistivity ohm-cm
Granite	10^{7}–10^{9}	Limestone	10^{4}
Lava flow (basic)	10^{6}–10^{7}	Limestone, Cambrian	10^{4}–10^{5}
Lava, fresh	3×10^{5}–10^{6}	Sandstone, eastern	3×10^{3}–10^{4}
Quartz vein, massive	$>10^{9}$	Sandstone	10^{5}
		Limestone	10^{5}
Metamorphic rocks	**Resistivity ohm-cm**	**Unconsolidated materials**	**Resistivity ohm-cm**
Marble, white	10^{10}	Clay, blue	2×10^{4}
Marble	4×10^{8}	Clayey earth	10^{4}–4×10^{4}
Marble, yellow	10^{10}	Clay, fire	2×10^{5}
Schist, mica	10^{7}	Gravel	10^{5}
Shale, Nonesuch	10^{4}	Sand, dry	10^{5}–10^{6}
Shale, bed	10^{6}	Sand, moist	10^{5}–10^{6}

* For reference, see footnote 45, p. 136.

TABLE 404.—RESISTIVITY OF SOILS AND SEA WATER MEASURED WITH HIGH-FREQUENCY ALTERNATING CURRENT *

Material	Frequency kilocycles/sec	Resistivity ohm/cm	Material	Frequency kilocycles/sec	Resistivity ohm/cm
Soil, very dry ..	1 to 10,000	10^7	Clay, dry	37,000	60,000
Topsoil, dry	37,000	7,000	Chalk		
			(moisture, 24%)	100	33,000
				1,200	22,000
				10,000	14,000
Loam, dark			Sea water	100	21
(moisture, 60%)	100	2,600		1,200	21
	1,200	2,300		10,000	16.5
	10,000	1,500			

* For reference, see footnote 45, p. 136.

TABLE 405.—ELECTRICAL RESISTIVITY OF NATURAL WATERS *

Material	Resistivity ohm-cm	Material	Resistivity ohm-cm
Very fresh distilled waters	2×10^7	Potable ground waters	10^3–10^5
Mine waters	500	Surface waters	10^5

* For reference, see footnote 45, p. 136.

TABLE 406.—RESISTIVITY OF SOME GLASSES AT THREE TEMPERATURES [147]

Glass	Principal use	Density	Log 10 Volume resistivity (ohm-cm) 25°C	250°C	350°C
Potash soda lead	Lamp tubing	2.85	17.+	8.9	7.0
Soda lime	Lamp bulbs	2.47	12.4	6.4	5.1
Potash soda lead	Lamp tubing	3.05	17.+	10.1	8.0
Hard Lime	Cooking utensils	2.53	17.+	11.4	9.4
Borosilicate	Kovar sealing	2.28	17.	9.2	7.4
Borosilicate	Low loss electrical	2.13	17.+	11.2	9.1
Borosilicate	Baking ware	2.24	15.	8.2	6.7
Pyrex	General	2.23	15.	8.1	6.6
Vycor	Low expansion ultra-violet transmission	2.18	17.+	11.2	9.2
Fused quartz		2.20			10.48

[147] Corning Glass Co. publication, Properties of selected commercial glasses, 1949. General Electric Co. publication, Fused quartz, 1947.

TABLE 407.—CONDUCTIVITY OF ELECTROLYTIC SOLUTIONS

In these tables m represents the number of gram molecules to the liter of water in the solution for which the conductivities are tabulated. The conductivities were obtained by measuring the resistance of a cell filled with the solution by means of a Wheatstone bridge alternating current and telephone arrangement. The results are for 18°C, and relative to mercury at 0° C, the cell having been standardized by filling with mercury and measuring the resistance. They are supposed to be accurate to within one percent of the true value.

The tabular numbers were obtained from the measurements in the following manner:

Let K_{18} = conductivity of the solution at 18°C relative to mercury at 0°C.

K^{w}_{18} = conductivity of the solvent water at 18°C relative to mercury at 0°C.

Then $K_{18} - K^{w}_{18} = k_{18}$ = conductivity of the electrolyte in the solution measured.

$\frac{k_{18}}{m} = \mu$ = conductivity of the electrolyte in the solution per molecule, or the "specific molecular conductivity."

Part 1.—Value of k_{18} for a few electrolytes

This short table illustrates the apparent law that the conductivity in very dilute solutions is proportional to the amount of salt dissolved.

m	KCl	NaCl	$AgNO_3$	$KC_2H_3O_2$	K_2SO_4	$MgSO_4$
.00001	1.216	1.024	1.080	.939	1.275	1.056
.00002	2.434	2.056	2.146	1.886	2.532	2.104
.00006	7.272	6.162	6.462	5.610	7.524	6.216
.0001	12.09	10.29	10.78	9.34	12.49	10.34

Part 2.—Electrochemical equivalents and normal solutions

The following table of the electrochemical equivalent numbers and the densities of approximately normal solutions of the salts quoted in Table 409 may be convenient. They represent g per cm³ of the solution at the temperature given.

Salt dissolved	g per l	m	Temp. °C	Density	Salt dissolved	g per l	m	Temp. °C	Density
KCl	74.59	1.0	15.2	1.0457	$\frac{1}{2}K_2SO_4$	87.16	1.0	18.9	1.0658
NH_4Cl	53.55	1.0009	18.6	1.0152	$\frac{1}{2}Na_2SO_4$	71.09	1.0003	18.6	1.0602
NaCl	58.50	1.0	18.4	1.0391	$\frac{1}{2}Li_2SO_4$	55.09	1.0007	18 6	1.0445
LiCl	42.48	1.0	18.4	1.0227	$\frac{1}{2}MgSO_4$	60.17	1.0023	18 6	1.0573
$\frac{1}{2}BaCl_2$	104.0	1.0	18.6	1.0888	$\frac{1}{2}ZnSO_4$	80.58	1.0	5.3	1.0794
$\frac{1}{2}ZnCl_2$	68.0	1.012	15.0	1.0592	$\frac{1}{2}CuSO_4$	79.9	1.001	18.2	1.0776
KI	165.9	1.0	18.6	1.1183	$\frac{1}{2}K_2CO_3$	69.17	1.0006	18.3	1.0576
KNO_3	101.17	1.0	18.6	1.0601	$\frac{1}{2}Na_2CO_3$	53.04	1.0	17.9	1.0517
$NaNO_3$	85.08	1.0	18.7	1.0542	KOH	56.27	1.0025	18.8	1.0477
$AgNO_3$	169.9	1.0	—	—	HCl	36.51	1.0041	18.6	1.0161
$\frac{1}{2}Ba(NO_3)_2$	65.28	.5	—	—	HNO_3	63 13	1.0014	18.6	1.0318
$KClO_3$	61.29	.5	18.3	1.0367	$\frac{1}{2}H_2SO_4$	49.06	1.0006	18.9	1.0300
$KC_2H_3O_2$	98.18	1.0005	18.6	1.0467					

TABLE 408.—TEMPERATURE COEFFICIENTS OF CONDUCTIVITY

The temperature coefficient in general diminishes with dilution, and for very dilute solutions appears to approach a common value. The following table gives the temperature coefficient for solutions containing 0.01 gram molecule of the salt.

Salt	Temp. coeff.	Salt	Temp. coeff.	Salt	Temp. coeff.	Salt	Temp. coeff.
KCl	.0221	KI	.0219	$\frac{1}{2}K_2SO_4$	.0223	$\frac{1}{2}K_2CO_3$	.0249
NH_4Cl	.0226	KNO_3	.0216	$\frac{1}{2}Na_2SO_4$	.0240	$\frac{1}{2}Na_2CO_3$	.0265
NaCl	.0238	$NaNO_3$	.0226	$\frac{1}{2}Li_2SO_4$	.0242	KOH	.0194
LiCl	.0232	$AgNO_3$	.0221	$\frac{1}{2}MgSO_4$	.0236	HCl	.0159
$\frac{1}{2}BaCl_2$	.0234	$\frac{1}{2}Ba(NO_3)_2$	.0224	$\frac{1}{2}ZnSO_4$	.0234	HNO_3	.0162
$\frac{1}{2}ZnCl_2$	.0239	$KClO_3$	.0219	$\frac{1}{2}CuSO_4$	.0229	$\frac{1}{2}H_2SO_4$	.0125
$\frac{1}{2}MgCl_2$	.0241	$KC_2H_3O_2$	.0229	—	—	$\frac{1}{2}H_2SO_4$ for m = .001	.0159

TABLE 409.—SPECIFIC MOLECULAR CONDUCTIVITY OF SOLUTIONS

Mercury = 10^8/(ohm-cm)

Salt dissolved	m = 10	5	3	1	.5	.1	.05	.03	.01
$\frac{1}{2}K_2SO_4$	—	—	—	—	672	736	897	959	1098
KCl	—	—	827	919	958	1047	1083	1107	1147
KI	—	770	900	968	997	1069	1102	1123	1161
NH_4Cl	—	752	825	907	948	1035	1078	1101	1142
KNO_3	—	—	572	752	839	983	1037	1067	1122
$\frac{1}{2}BaCl_2$	—	—	487	658	725	861	904	939	1006
$KClO_3$	—	—	—	—	799	927	(976)	1006	1053
$\frac{1}{2}BaN_2O_6$	—	—	—	—	531	755	828	(870)	951
$\frac{1}{2}CuSO_4$	—	—	150	241	288	424	479	537	675
$AgNO_3$	—	351	448	635	728	886	936	(966)	1017
$\frac{1}{2}ZnSO_4$	—	82	146	249	302	431	500	556	685
$\frac{1}{2}MgSO_4$	—	82	151	270	330	474	532	587	715
$\frac{1}{2}Na_2SO_4$	—	—	—	475	559	734	784	828	906
$\frac{1}{2}ZnCl_2$	60	180	280	514	601	768	817	851	915
$NaCl$	—	398	528	695	757	865	897	(920)	962
$NaNO_3$	—	—	430	617	694	817	855	877	907
$KC_2H_3O_2$	30	240	381	594	671	784	820	841	879
$\frac{1}{2}Na_2CO_3$	—	—	254	427	510	682	751	799	899
$\frac{1}{2}H_2SO_4$	660	1270	1560	1820	1899	2084	2343	2515	2855
C_2H_4O	.5	2.6	5.2	12	19	43	62	79	132
HCl	600	1420	2010	2780	3017	3244	3330	3369	3416
HNO_3	610	1470	2070	2770	2991	3225	3289	3328	3395
$\frac{1}{3}H_3PO_4$	148	160	170	200	250	430	540	620	790
KOH	423	990	1314	1718	1841	1986	2045	2078	2124
NH_3	.5	2.4	3.3	8.4	12	31	43	50	92

Salt dissolved	.006	.002	.001	.0006	.0002	.0001	.00006	.00002	.00001
$\frac{1}{2}K_2SO_4$	1130	1181	1207	1220	1241	1249	1254	1266	1275
KCl	1162	1185	1193	1199	1209	1209	1212	1217	1216
KI	1176	1197	1203	1209	1214	1216	1216	1216	1207
NH_4Cl	1157	1180	1190	1197	1204	1209	1215	1209	1205
KNO_3	1140	1173	1180	1190	1199	1207	1220	1198	1215
$\frac{1}{2}BaCl_2$	1031	1074	1092	1102	1118	1126	1133	1144	1142
$KClO_3$	1068	1091	1101	1109	1119	1122	1126	1135	1141
$\frac{1}{2}BaN_2O_6$	982	1033	1054	1066	1084	1096	1100	1114	1114
$\frac{1}{2}CuSO_4$	740	873	950	987	1039	1062	1074	1084	1086
$AgNO_3$	1033	1057	1068	1069	1077	1078	1077	1073	1080
$\frac{1}{2}ZnSO_4$	744	861	919	953	1001	1023	1032	1047	1060
$\frac{1}{2}MgSO_4$	773	881	935	967	1015	1034	1036	1052	1056
$\frac{1}{2}Na_2SO_4$	933	980	998	1009	1026	1034	1038	1056	1054
$\frac{1}{2}ZnCl_2$	939	979	994	1004	1020	1029	1031	1035	1036
$NaCl$	976	998	1008	1014	1018	1029	1027	1028	1024
$NaNO_3$	921	942	952	956	966	975	970	972	975
$KC_2H_3O_2$	891	913	919	923	933	934	935	943	939
$\frac{1}{2}Na_2CO_3$	956	1010	1037	1046	988	874	790	715	697*
$\frac{1}{2}H_2SO_4$	3001	3240	3316	3342	3280	3118	2927	2077	1413*
C_2H_4O	170	283	380	470	796	995	1133	1328	1304*
HCl	3438	3455	3455	3440	3340	3170	2968	2057	1254*
HNO_3	3421	3448	3427	3408	3285	3088	2863	1904	1144*
$\frac{1}{3}H_3PO_4$	858	945	968	977	920	837	746	497	402*
KOH	2141	2140	2110	2074	1892	1689	1474	845	747*
NH_3	116	190	260	330	500	610	690	700	560*

* Acids and alkaline salts show peculiar irregularities.

TABLE 410.—LIMITING VALUES OF μ, THE SPECIFIC MOLECULAR CONDUCTIVITY

This table shows limiting values of $\mu = \frac{k}{m} .10^8$ for infinite dilution for neutral salts, calculated from Table 409.

Salt	μ	Salt	μ	Salt	μ	Salt	μ
$\frac{1}{2}K_2SO_4$	1280	$\frac{1}{2}BaCl_2$	1150	$\frac{1}{2}MgSO_4$	1080	$\frac{1}{2}H_2SO_4$	3700
KCl	1220	$\frac{1}{2}KClO_3$	1150	$\frac{1}{2}Na_2SO_4$	1060	HCl	3500
KI	1220	$\frac{1}{2}BaN_2O_6$	1120	$\frac{1}{2}ZnCl_2$	1040	HNO_3	3500
NH_4Cl	1210	$\frac{1}{2}CuSO_4$	1100	$NaCl$	1030	$\frac{1}{3}H_3PO_4$	1100
KNO_3	1210	$AgNO_3$	1090	$NaNO_3$	980	KOH	2200
—	—	$\frac{1}{2}ZnSO_4$	1080	$K_2C_2H_3O_2$	940	$\frac{1}{2}Na_2CO_3$	1400

TABLE 411.—THE EQUIVALENT CONDUCTIVITY OF THE SEPARATE IONS

Ion	0°C	18°	25°	50°	75°	100°	128°	156°
K	40.4	64.6	74.5	115	159	206	263	317
Na	26	43.5	50.9	82	116	155	203	249
NH_4	40.2	64.5	74.5	115	159	207	264	319
Ag	32.9	54.3	63.5	101	143	188	245	299
$\frac{1}{2}$Ba	33	55[2]	65	104	149	200	262	322
$\frac{1}{2}$Ca	30	51[2]	60	98	142	191	252	312
$\frac{1}{3}$La	35	61	72	119	173	235	312	388
Cl	41.1	65.5	75.5	116	160	207	264	318
NO_3	40.4	61.7	70.6	104	140	178	222	263
$C_2H_3O_2$	20.3	34.6	40.8	67	96	130	171	211
$\frac{1}{2}SO_4$	41	68[2]	79	125	177	234	303	370
$\frac{1}{2}C_2O_4$	39	63[2]	73	115	163	213	275	336
$\frac{1}{3}C_6H_5O_7$	36	60	70	113	161	214		
$\frac{1}{4}Fe(CN)_6$	58	95	111	173	244	321		
H	240	314	350	465	565	644	722	777
OH	105	172	192	284	360	439	525	592

TABLE 412.—HYDROLYSIS OF AMMONIUM ACETATE AND IONIZATION OF WATER

Temperature	Percentage hydrolysis	Ionization constant of water	Hydrogen-ion concentration in pure water Equivalents per liter	Temperature	Percentage hydrolysis	Ionization constant of water	Hydrogen-ion concentration in pure water Equivalents per liter
t	100_h	$K_W \times 10^{14}$	$C_H \times 10^7$	t	100_h	$K_W \times 10^{14}$	$C_H \times 10^7$
0°C	—	.089	.30	100°C	4.8	48.	6.9
18	(.35)	.45	.68	156	18.6	223.	14.9
25	—	.82	.91	218	52.7	461.	21.5
				306	91.5	168.	13.0

TABLE 413.—THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS, AND BASES IN AQUEOUS SOLUTIONS

In the following table the equivalent conductance is expressed in reciprocal ohms. The concentration is expressed in milli-equivalents of solute per liter of solution at the temperature to which the conductance refers. (In the cases of potassium hydrogen sulfate and phosphoric acid the concentration is expressed in milli-formula-weights of solute, $KHSO_4$ or H_3PO_4, per liter of solution, and the values are correspondingly the modal, or "formal," conductances.) Except in the cases of the strong acids the conductance of the water was substracted, and for sodium acetate, ammonium acetate and ammonium chloride the values have been corrected for the hydrolysis of the salts.

$$\text{Concentration in } \frac{\text{g equivalents}}{1000\text{ l}}.$$

$$\text{Equivalent conductance in } \frac{\text{reciprocal ohm-cm}}{\text{g equivalents per cm}^3}.$$

Substance	Concentration	Equivalent conductance at the following °C temperatures: 18°	25°	50°	75°	100°	128°	156°	218°	281°	306°
Potassium chloride...	0	130.1	(152.1)	(232.5)	(321.5)	414	(519)	625	825	1005	1120
" " ...	2	126.3	146.4	—	—	393	—	588	779	930	1008
" " ...	10	122.4	141.5	215.2	295.2	377	470	560	741	874	910
" " ...	80	113.5	—	—	—	342	—	498	638	723	720
" " ...	100	112.0	129.0	194.5	264.6	336	415	490			
Sodium chloride.....	0	109.0	—	—	—	362	—	555	760	970	1080
" "	2	105.6	—	—	—	349	—	534	722	895	955
" "	10	102.0	—	—	—	336	—	511	685	820	860
" "	80	93.5	—	—	—	301	—	450	500	674	680
" "	100	92.0	—	—	—	296	—	442			
Silver nitrate........	0	115.8	—	—	—	367	—	570	780	965	1065
" "	2	112.2	—	—	—	353	—	539	727	877	935
" "	10	108.0	—	—	—	337	—	507	673	790	818
" "	20	105.1	—	—	—	326	—	488	639		
" "	40	101.3	—	—	—	312	—	462	599	680	680
" "	80	96.5	—	—	—	294	—	432	552	614	604
" "	100	94.6	—	—	—	289					
Sodium acetate......	0	78.1	—	—	—	285	—	450	660	—	924
" "	2	74.5	—	—	—	268	—	421	578	—	801
" "	10	71.2	—	—	—	253	—	396	542	—	702
" "	80	63.4	—	—	—	221	—	340	452		
Magnesium sulfate...	0	114.1	—	—	—	426	—	690	1080		
" " ...	2	94.3	—	—	—	302	—	377	260		
" " ...	10	76.1	—	—	—	234	—	241	143		
" " ...	20	67.5	—	—	—	190	—	195	110		
" " ...	40	59.3	—	—	—	160	—	158	88		
" " ...	80	52.0	—	—	—	136	—	133	75		
" " ...	100	49.8	—	—	—	130	—	126			
" " ...	200	43.1	—	—	—	110	—	109			
Ammonium chloride..	0	131.1	152.0	—	—	(415)	—	(628)	(841)	—	(1176)
" " ..	2	126.5	146.5	—	—	399	—	601	801	—	1031
" " ..	10	122.5	141.7	—	—	382	—	573	758	—	925
" " ..	30	118.1	—	—	—	—	—	—	—	—	828
Ammonium acetate...	0	(99.8)	—	—	—	(338)	—	(523)			
" " ...	10	91.7	—	—	—	300	—	456			
" " ...	25	88.2	—	—	—	286	—	426			
Barium nitrate.......	0	116.9	—	—	—	385	—	600	840	1120	1300
" "	2	109.7	—	—	—	352	—	536	715	828	824
" "	10	101.0	—	—	—	322	—	481	618	658	615
" "	40	88.7	—	—	—	280	—	412	507	503	448
" "	80	81.6	—	—	—	258	—	372	449	430	
" "	100	79.1	—	—	—	249					

(*continued*)

TABLE 413.—THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS, AND BASES IN AQUEOUS SOLUTIONS (concluded)

Substance	Concentration	Equivalent conductance at the following °C temperatures 18°	25°	50°	75°	100°	128°	156°	218°	281°	306°
Potassium sulfate	0	132.8	—	—	—	455	—	715	1065	1460	1725
" "	2	124.8	—	—	—	402	—	605	806	893	867
" "	10	115.7	—	—	—	365	—	537	672	687	637
" "	40	104.2	—	—	—	320	—	455	545	519	466
" "	80	97.2	—	—	—	294	—	415	482	448	396
" "	100	95.0	—	—	—	286					
Hydrochloric acid	0	379.0	—	—	—	850	—	1085	1265	1380	1424
" "	2	373.6	—	—	—	826	—	1048	1217	1332	1337
" "	10	368.1	—	—	—	807	—	1016	1168	1226	1162
" "	80	353.0	—	—	—	762	—	946	1044	1046	862
" "	100	350.6	—	—	—	754	—	929	1006		
Nitric acid	0	377.0	421.0	570	706	826	945	1047	(1230)	—	(1380
" "	2	371.2	413.7	559	690	806	919	1012	1166	—	1156
" "	10	365.0	406.0	548	676	786	893	978			
" "	50	353.7	393.3	528	649	750	845	917			
" "	100	346.4	385.0	516	632	728	817	880	—	—	454*
Sulfuric acid	0	383.0	(429)	(591)	(746)	891	(1041)	1176	1505	—	(2030)
" "	2	353.9	390.8	501	561	571	551	536	563	—	637
" "	10	309.0	337.0	406	435	446	460	481	533		
" "	50	253.5	273.0	323	356	384	417	448	502		
" "	100	233.3	251.2	300	336	369	404	435	483	—	474*
Postassium hydrogen sulfate	2	455.3	506.0	661.0	754	784	773	754			
	50	295.5	318.3	374.4	403	422	446	477			
	100	263.7	283.1	329.1	354	375	402	435			
Phosphoric acid	0	338.3	376	510	631	730	839	930			
" "	2	283.1	311.9	401	464	498	508	489			
" "	10	203.0	222.0	273	300	308	298	274			
" "	50	122.7	132.6	157.8	168.6	168	158	142			
" "	100	96.5	104.0	122.7	129.9	128	120	108			
Acetic acid	0	(347.0)	—	—	—	(773)	—	(980)	(1165)	—	(1268)
" "	10	14.50	—	—	—	25.1	—	22.2	14.7		
" "	30	8.50	—	—	—	14.7	—	13.0	8.65		
" "	80	5.22	—	—	—	9.05	—	8.00	5.34		
" "	100	4.67	—	—	—	8.10	—	—	4.82	—	1.57
Sodium hydroxide	0	216.5	—	—	—	594	—	835	1060		
" "	2	212.1	—	—	—	582	—	814			
" "	20	205.8	—	—	—	559	—	771	930		
" "	50	200.6	—	—	—	540	—	738	873		
Barium hydroxide	0	222	256	389	(520)	645	(760)	847			
" "	2	215	—	359	4	591					
" "	10	207	235	342	449	548	664	722			
" "	50	191.1	215.1	308	399	478	549	593			
" "	100	180.1	204.2	291	373	443	503	531			
Ammonium hydroxide	0	(238)	(271)	(404)	(526)	(647)	(764)	(908)	(1141)	—	(1406)
	10	9.66	—	—	—	23.2	—	22.3	15.6		
	30	5.66	—	—	—	13.6	—	13.0			
	100	3.10	3.62	5.35	6.70	7.47	—	7.17	4.82	—	1.33

* These values are at the concentration 80.0.

TABLE 414.—THE EQUIVALENT CONDUCTIVITY OF SOME ADDITIONAL SALTS IN AQUEOUS SOLUTION

Substance	Concentration	Equivalent conductance at the following °C temperature							
		0°	18°	25°	50°	75°	100°	128°	156°
Potassium nitrate.......	0	80.8	126.3	145.1	219	299	384	485	580
" "	2	78.6	122.5	140.7	212.7	289.9	370.3	460.7	551
" "	12.5	75.3	117.2	134.9	202.9	276.4	351.5	435.4	520.4
" "	50	70.7	109.7	126.3	189.5	257.4	326.1	402.9	476.1
" "	100	67.2	104.5	120.3	180.2	244.1	308.5	379.5	447.3
Potassium oxalate......	0	79.4	127.6	147.5	230	322	419	538	653
" "	2	74.9	119.9	139.2	215.9	300.2	389.3	489.1	587
" "	12.5	69.3	111.1	129.2	199,1	275.1	354.1	438.8	524.3
" "	50	63	101	116.5	178.6	244.9	312.2	383.8	449.5
" "	100	59.3	94.6	109.5	167	227.5	288.9	353.2	409.7
" "	200	55.8	88.4	102.3	155	210.9	265.1	321.9	372.1
Calcium nitrate	0	70.4	112.7	130.6	202	282	369	474	575
" "	2	66.5	107.1	123.7	191.9	266.7	346.5	438.4	529.8
" "	12.5	61.6	98.6	114.5	176.2	244	314.6	394.5	473.7
" "	50	55.6	88.6	102.6	157.2	216.2	276.8	343	405.1
" "	100	51.9	82.6	95.8	146.1	199.9	255.5	315.1	369.1
" "	200	48.3	76.7	88.8	135.4	184.7	234.4	288	334.7
Potassium ferrocyanide .	0	98.4	159.6	185.5	288	403	527		
" " .	.5	91.6	——	171.1					
" " .	2	84.8	137	158.9	243.8	335.2	427.6		
" " .	12.5	71	113.4	131.6	200.3	271	340		
" " .	50	58.2	93.7	108.6	163.3	219.5	272.4		
" " .	100	53	84.9	98.4	148.1	198.1	245		
" " .	200	48.8	77.8	90.1	135.7	180.6	222.3		
" " .	400	45.4	72.1	83.3	124.8	165.7	203.1		
Barium ferrocyanide	0	91	150	176	277	393	521		
" "	2	46.9	75	86.2	127.5	166.2	202.3		
" "	12.5	30.4	48.8	56.5	83.1	107	129.8		
Calcium ferrocyanide ...	0	88	146	171	271	386	512		
" " ...	2	47.1	75.5	86.2	130				
" " ...	12.5	31.2	49.9	57.4					
" " ...	50	24.1	38.5	44.4	64.6	81.9			
" " ...	100	21.9	35.1	40.2	58.4	73.7	84.3		
" " ...	200	20.6	32.9	37.8	55	68.7	77.5		
" " ...	400	20.2	32.2	37.1	54	67.5	76.2		
Potassium citrate	0	76.4	124.6	144.5	228	320	420		
" "	0.5	——	120.1	139.4					
" "	2	71	115.4	134.5	210.1	293.8	381.2		
" "	5	67.6	109.9	128.2	198.7	276.5	357.2		
" "	12.5	62.9	101.8	118.7	183.6	254.2	326		
" "	50	54.4	87.8	102.1	157.5	215.5	273		
" "	100	50.2	80.8	93.9	143.7	196.5	247.5		
" "	300	43.5	69.8	81	123.5	167	209.5		
Lanthanum nitrate	0	75.4	122.7	142.6	223	313	413	534	651
" "	2	68.9	110.8	128.9	200.5	279.8	363.5	457.5	549
" "	12.5	61.4	98.5	114.4	176.7	243.4	311.2	383.4	447.8
" "	50	54	86.1	99.7	152.5	207.6	261.4	315.8	357.7
" "	100	49.9	79.4	91.8	139.5	189.1	236.7	282.5	316.3
" "	200	46	72.1	83.5	126.4	170.2	210.8	249.6	276.2

Every gram-atom involved in an electrolytic change requires the same number of coulombs, or ampere-hours of electricity, per unit change of valency. This constant is 96487.7 coulomb/g-atom, or 26.801 ampere-hours per g-atom hour, corresponding to an electrochemical equivalent of silver of 0.0011810 g $sec^{-1}amp^{-1}$. It is to be noted that the change of valence of the element from its state before to that after the electrolytic action should be considered. The valence of a free, uncombined element is to be considered as 0. The same current will electrolyze "chemically equivalent" quantities per unit time. The valence is then included in the "chemically equivalent" quantity.

Element	Change of valency	Mg per coulomb	Coulombs per mg	G per amp hour
Al	3	.09317	10.733	.3354
Cl	1	.36749	2.7212	1.3230
"	3	.12250	8.1633	.4410
"	5	.07350	13.605	.2646
"	7	.05250	19.048	.1890
Cu	1	.6585	1.5186	2.3706
"	2	.3293	3.0367	1.1855
Au	1	2.044	.4892	7.358
"	3	.6813	1.468	2.453
H	1	.0104472	95.719	.0376099
Pb	1	2.1476	.46564	7.7314
"	2	1.07379	.93128	3.8656
"	4	.53690	1.8625	1.9328
Hg	1	2.0792	.48095	7.4851
"	2	1.0396	.961908	3.7426
Ni	1	.60828	1.6440	2.1898
"	2	.3041	3.2884	1.0948
"	3	.20276	4.9319	.7299
O	2	.082914	12.0607	.298490
"	4	.041457	24.1214	.14945
Pt	2	1.01171	.98843	3.6422
"	4	.50585	1.97687	1.82107
"	6	.33724	2.9652	1.2140
K	1	.4052	2.4679	1.4587
Ag	1	1.11810	.894374	4.02516
Na	1	.23835	4.1955	.85806
Sn	2	.61512	1.6257	2.2144
"	4	.30756	3.2514	1.1072
Zn	2	.33881	2.9515	1.21972

The electrochemical equivalent for silver is 0.00111810 g sec^{-1} amp^{-1}. For other elements the electrochemical equivalent = (atomic weight divided by change of valency) and this divided by 96487.7 coulomb/g-atom.

TABLE 416.—INTRODUCTION TO WIRE TABLES; MASS AND VOLUME RESISTIVITY OF COPPER AND ALUMINUM

The following wire tables are abridged from those prepared by the Bureau of Standards at the request and with the cooperation of the Standards Committee of the American Institute of Electrical Engineers. The standard of copper resistance used is "The International Annealed Copper Standard" as adopted September 5, 1913, by the International Electrotechnical Commission and represents the average commercial high-conductivity copper for the purpose of electric conductors. This standard corresponds to a conductivity of 58×10^{-5} emu, and a density of 8.89, at 20°C. In the various units of mass resistivity and volume resistivity this may be stated as

0.15328 ohm (m, g) at 20°C
875.20 ohms (mi, lb) at 20°C
1.7241 microhm-cm at 20°C
0.67879 microhm-in. at 20°C
10.371 ohms (mil, ft) at 20°C

The temperature coefficient for this particular resistivity is $\alpha_{20} = 0.00393$, or $\alpha_0 = 0.00427$. The temperature coefficient of copper is proportional to the conductivity, so that where the conductivity is known the temperature coefficient may be calculated, and vice versa. Thus the next table shows the temperature coefficients of copper having various percentages of the standard conductivity. A consequence of this relation is that the change of *resistivity* per degree is constant, independent of the sample of copper and independent of the temperature of reference. This resistivity-temperature constant, for volume resistivity and Centigrade degrees, is 0.00681 microhm-cm, and for mass resistivity is 0.000597 ohm (m, g).

The density of 8.89 g per cm³ at 20°C, is equivalent to 0.32117 lb per in.³

The values in the following tables are for annealed copper of standard resistivity. The user of the tables must apply the proper correction for copper of other resistivity. Hard-drawn copper may be taken as about 2.7 percent higher resistivity than annealed copper.

The following is a fair average of the chemical content of commercial high conductivity copper:

Copper	99.91%	Sulfur	.002%
Silver	.03	Iron	.002
Oxygen	.052	Nickel	trace
Arsenic	.002	Lead	"
Antimony	.002	Zinc	"

The following values are consistent with the data above:

Conductivity at 0°C, in emu	62.969×10^{-5}
Resistivity at 0°C, in microhm-cm	1.5881
Density at 0°C	8.90
Coefficient of linear expansion per degree C	.000017
"Constant mass" temperature coefficient of resistance at 0°C	.00427

The aluminum tables are based on a figure for the conductivity published by the National Bureau of Standards, which is the result of many thousands of determinations by the Aluminum Co. of America. A volume resistivity of 2.828 microhm-cm and a density of 2.70 may be considered to be good average values for commercial hard-drawn aluminum. These values give:

Conductivity at 0°C in emu	38.36×10^{-5}
Mass resistivity, in ohms (m, g) at 20°C	.0764
" " " " (mi, lb) at 20°C	436.
Mass percent conductivity relative to copper	200.7%
Volume resistivity, in microhm-cm at 20°C	2.828
" " in microhm-in. at 20°C	1.113
Volume percent conductivity relative to copper	61.0%
Density, in g/cm³	2.70
Density, in lb/in.³	.0975

The average chemical content of commercial aluminum wire is

Aluminum	99.57%
Silicon	.29
Iron	.14

Gage No.	American wire gage (B. & S.) mils *	American wire gage (B. & S.) mm *	Steel wire gage † mils	Steel wire gage † mm	Stubs' steel wire gage mils	(British) standard wire gage mils	Birmingham wire gage (Stubs') mils	Gage No.
7–0			490.0	12.4		500.		7–0
6–0			461.5	11.7		464.		6–0
5–0			430.5	10.9		432.		5–0
4–0	460.	11.7	393.8	10.0		400.	454.	4–0
3–0	410.	10.4	362.5	9.2		372.	425.	3–0
2–0	365.	9.3	331.0	8.4		348.	380.	2–0
0	325.	8.3	306.5	7.8		324.	340.	0
1	289.	7.3	283.0	7.2	227.	300.	300.	1
2	258.	6.5	262.5	6.7	219.	276.	284.	2
3	229.	5.8	243.7	6.2	212.	252.	259.	3
4	204.	5.2	225.3	5.7	207.	232.	238.	4
5	182.	4.6	207.0	5.3	204.	212.	220.	5
6	162.	4.1	192.0	4.9	201.	192.	203.	6
7	144.	3.7	177.0	4.5	199.	176.	180.	7
8	128.	3.3	162.0	4.1	197.	160.	165.	8
9	114.	2.91	148.3	3.77	194.	144.	148.	9
10	102.	2.59	135.0	3.43	191.	128.	134.	10
11	91.	2.30	120.5	3.06	188.	116.	120.	11
12	81.	2.05	105.5	2.68	185.	104.	109.	12
13	72.	1.83	91.5	2.32	182.	92.	95.	13
14	64.	1.63	80.0	2.03	180.	80.	83.	14
15	57.	1.45	72.0	1.83	178.	72.	72.	15
16	51.	1.29	62.5	1.59	175.	64.	65.	16
17	45.	1.15	54.0	1.37	172.	56.	58.	17
18	40.	1.02	47.5	1.21	168.	48.	49.	18
19	36.	.91	41.0	1.04	164.	40.	42.	19
20	32.	.81	34.8	.88	161.	36.	35.	20
21	28.5	.72	31.7	.81	157.	32.	32.	21
22	25.3	.62	28.6	.73	155.	28.	28.	22
23	22.6	.57	25.8	.66	153.	24.	25.	23
24	20.1	.51	23.0	.58	151.	22.	22.	24
25	17.9	.45	20.4	.52	148.	20.	20.	25
26	15.9	.40	18.1	.46	146.	18.	18.	26
27	14.2	.36	17.3	.439	143.	16.4	16.	27
28	12.6	.32	16.2	.411	139.	14.8	14.	28
29	11.3	.29	15.0	.381	134.	13.6	13.	29
30	10.0	.25	14.0	.356	127.	12.4	12.	30
31	8.9	.227	13.2	.335	120.	11.6	10.	31
32	8.0	.202	12.8	.325	115.	10.8	9.	32
33	7.1	.180	11.8	.300	112.	10.0	8.	33
34	6.3	.160	10.4	.264	110.	9.2	7.	34
35	5.6	.143	9.5	.241	108.	8.4	5.	35
36	5.0	.127	9.0	.229	106.	7.6	4.	36
37	4.5	.113	8.5	.216	103.	6.8		37
38	4.0	.101	8.0	.203	101.	6.0		38

* The American wire gage sizes have been rounded off to the usual limits of commercial accuracy. They are given to four significant figures in Tables 420 to 423. They can be calculated with any desired accuracy, being based upon a simple mathematical law. The diameter of No. 0000 is defined as 0.4600 inch and of No. 36 as 0.0050 inch. The ratio of any diameter to the diameter of the next greater number $\sqrt[39]{\frac{.4600}{.0050}} = 1.1229322$.

† The steel wire gage is the same gage that has been known by the various names: "Washburn and Moen," "Roebling," "American Steel and Wire Co.'s." Its abbreviation should be written "Stl. W. G." to distinguish it from "S. W. G.," the usual abbreviation for the (British) Standard Wire Gage.

(continued)

TABLE 417.—TABULAR COMPARISON OF WIRE GAGES (concluded)

Gage No.	American wire gage (B. & S.) mils *	American wire gage (B. & S.) mm *	Steel wire gage † mils	Steel wire gage † mm	Stubs' steel wire gage mils	(British) standard wire gage mils	Birmingham wire gage (Stubs') mils	Gage No.
39	3.5	.090	7.5	.191	99.	5.2		39
40	3.1	.080	7.0	.178	97.	4.8		40
41			6.6	.168	95.	4.4		41
42			6.2	.157	92.	4.0		42
43			6.0	.152	88.	3.6		43
44			5.8	.147	85.	3.2		44
45			5.5	.140	81.	2.8		45
46			5.2	.132	79.	2.4		46
47			5.0	.127	77.	2.0		47
48			4.8	.122	75.	1.6		48
49			4.6	.117	72.	1.2		49
50			4.4	.112	69.	1.0		50

TABLE 418.—TEMPERATURE COEFFICIENTS OF COPPER FOR DIFFERENT INITIAL TEMPERATURES (CENTIGRADE) AND DIFFERENT CONDUCTIVITIES

Ohms (m, g) at 20°C	Percent conductivity	a_0	a_{15}	a_{20}	a_{25}	a_{30}	a_{50}
.161 34	95%	.004 03	.003 80	.003 73	.003 67	.003 60	.003 36
.159 66	96%	.004 08	.003 85	.003 77	.003 70	.003 64	.003 39
.158 02	97%	.004 13	.003 89	.003 81	.003 74	.003 67	.003 42
.157 53	97.3%	.004 14	.003 90	.003 82	.003 75	.003 68	.003 43
.156 40	98%	.004 17	.003 93	.003 85	.003 78	.003 71	.003 45
.154 82	99%	.004 22	.003 97	.003 89	.003 82	.003 74	.003 48
.153 28	100%	.044 27	.004 01	**.003 93**	.003 85	.003 78	.003 52
.151 76	101%	.004 31	.004 05	.003 97	.003 89	.003 82	.003 55

NOTE.—The fundamental relation between resistance and temperature is the following:

$$R_t = R_{t_1}(1 + a_{t_1}[t - t_1]),$$

where a_{t_1} is the "temperature coefficient," and t_1 is the "initial temperature" or "temperature of reference."

The values of a in the above table exhibit the fact that the temperature coefficient of copper is proportional to the conductivity. The table was calculated by means of the following formula, which holds for any percent conductivity, n, within commercial ranges, and for centigrade temperatures. (n is considered to be expressed decimally: e.g., if percent conductivity = 99 percent, $n = 0.99$.)

$$a_{t_1} = \frac{1}{\frac{1}{n(0.00393)} + (t_1 - 20)}.$$

TABLE 419.—REDUCTION OF OBSERVATIONS TO STANDARD TEMPERATURE (Copper)

Temperature, °C	Corrections to reduce resistivity to 20°C: Ohm (m, g)	Microhm—cm	Ohm (mi, lb)	Microhm—in.	Factors to reduce resistance to 20°C: For 96 percent conductivity	For 98 percent conductivity	For 100 percent conductivity	Temperature, °C
0	+.011 94	+.1361	+ 68.20	+.053 58	1.0816	1.0834	1.0853	0
5	+.008 96	+.1021	+ 51.15	+.040 18	1.0600	1.0613	1.0626	5
10	+.005 97	+.0681	+ 34.10	+.026 79	1.0392	1.0401	1.0409	10
11	+.005 37	+.0612	+ 30.69	+.024 11	1.0352	1.0359	1.0367	11
12	+.004 78	+.0544	+ 27.28	+.021 43	1.0311	1.0318	1.0325	12
13	+.004 18	+.0476	+ 23.87	+.018 75	1.0271	1.0277	1.0283	13
14	+.003 58	+.0408	+ 20.46	+.016 07	1.0232	1.0237	1.0242	14
15	+.002 99	+.0340	+ 17.05	+.013 40	1.0192	1.0196	1.0200	15
16	+.002 39	+.0272	+ 13.64	+.010 72	1.0153	1.0156	1.0160	16
17	+.001 79	+.0204	+ 10.23	+.008 04	1.0114	1.0117	1.0119	17
18	+.001 19	+.0136	+ 6.82	+.005 36	1.0076	1.0078	1.0079	18
19	+.000 60	+.0068	+ 3.41	+.002 68	1.0038	1.0039	1.0039	19
20	0	0	0	0	1.0000	1.0000	1.0000	20
21	—.000 60	—.0068	— 3.41	—.002 68	.9962	.9962	.9961	21
22	—.001 19	—.0136	— 6.82	—.005 36	.9925	.9924	.9922	22
23	—.001 79	—.0204	— 10.23	—.008 04	.9888	.9886	.9883	23
24	—.002 39	—.0272	— 13.64	—.010 72	.9851	.9848	.9845	24
25	—.002 99	—.0340	— 17.05	—.013 40	.9815	.9811	.9807	25
26	—.003 58	—.0408	— 20.46	—.016 07	.9779	.9774	.9770	26
27	—.004 18	—.0476	— 23.87	—.018 75	.9743	.9737	.9732	27
28	—.004 78	—.0544	— 27.28	—.021 43	.9707	.9701	.9695	28
29	—.005 37	—.0612	— 30.69	—.024 11	.9672	.9665	.9658	29
30	—.005 97	—.0681	— 34.10	—.026 79	.9636	.9629	.9622	30
35	—.008 96	—.1021	— 51.15	—.040 18	.9464	.9454	.9443	35
40	—.011 94	—.1361	— 68.20	—.053 58	.9298	.9285	.9271	40
45	—.014 93	—.1701	— 85.25	—.066 98	.9138	.9122	.9105	45
50	—.017 92	—.2042	—102.30	—.080 37	.8983	.8964	.8945	50
55	—.020 90	—.2382	—119.35	—.093 76	.8833	.8812	.8791	55
60	—.023 89	—.2722	—136.40	—.107 16	.8689	.8665	.8642	60
65	—.026 87	—.3062	—153.45	—.120 56	.8549	.8523	.8497	65
70	—.029 86	—.3403	—170.50	—.133 95	.8413	.8385	.8358	70
75	—.032 85	—.3743	—187.55	—.147 34	.8281	.8252	.8223	75

TABLE 420.—WIRE TABLE, STANDARD ANNEALED COPPER

American wire gage (B. & S.)

Gage No.	Diameter in mils, at 20°C	Cross section at 20°C		Ohms per 1000 ft			
		Circular mils	in.²	0°C (= 32°F)	20°C (=68°F)	50°C (= 122°F)	75°C (= 167°F)
0000	460.0	211 600.	.1662	.045 16	.049 01	.054 79	.059 61
000	409.6	167 800.	.1318	.056 95	.061 80	.069 09	.075 16
00	364.8	133 100.	.1045	.071 81	.077 93	.087 12	.094 78
0	324.9	105 500.	.082 89	.090 55	.098 27	.1099	.1195
1	289.3	83 690.	.065 73	.1142	.1239	.1385	.1507
2	257.6	66 370.	.052 13	.1440	.1563	.1747	.1900
3	229.4	52 640.	.041 34	.1816	.1970	.2203	.2396
4	204.3	41 740.	.032 78	.2289	.2485	.2778	.3022
5	181.9	33 100.	.026 00	.2887	.3133	.3502	.3810
6	162.0	26 250.	.020 62	.3640	.3951	.4416	.4805
7	144.3	20 820.	.016 35	.4590	.4982	.5569	.6059
8	128.5	16 510.	.012 97	.5788	.6282	.7023	.7640
9	114.4	13 090.	.010 28	.7299	.7921	.8855	.9633
10	101.9	10 380.	.008 155	.9203	.9989	1.117	1.215
11	90.74	8234.	.006 467	1.161	1.260	1.408	1.532
12	80.81	6530.	.005 129	1.463	1.588	1.775	1.931
13	71.96	5178.	.004 067	1.845	2.003	2.239	2.436
14	64.08	4107.	.003 225	2.327	2.525	2.823	3.071
15	57.07	3257.	.002 558	2.934	3.184	3.560	3.873
16	50.82	2583.	.002 028	3.700	4.016	4.489	4.884
17	45.26	2048.	.001 609	4.666	5.064	5.660	6.158
18	40.30	1624.	.001 276	5.883	6.385	7.138	7.765
19	35.89	1288.	.001 012	7.418	8.051	9.001	9.702
20	31.96	1022.	.000 802 3	9.355	10.15	11.35	12.35
21	28.45	810.1	.000 636 3	11.80	12.80	14.31	15.57
22	25.35	642.4	.000 504 6	14.87	16.14	18.05	19.63
23	22.57	509.5	.000 400 2	18.76	20.36	22.76	24.76
24	20.10	404.0	.000 317 3	23.65	25.67	28.70	31.22
25	17.90	320.4	.000 251 7	29.82	32.37	36.18	39.36
26	15.94	254.1	.000 199 6	37.61	40.81	45.63	49.64
27	14.20	201.5	.000 158 3	47.42	51.47	57.53	62.59
28	12.64	159.8	.000 125 5	59.80	64.90	72.55	78.93
29	11.26	126.7	.000 099 53	75.40	81.83	91.48	99.52
30	10.03	100.5	.000 078 94	95.08	103.2	115.4	125.5
31	8.928	79.70	.000 062 60	119.9	130.1	145.5	158.2
32	7.950	63.21	.000 049 64	151.2	164.1	183.4	199.5
33	7.080	50.13	.000 039 37	190.6	206.9	231.3	251.6
34	6.305	39.75	.000 031 22	240.4	260.9	291.7	317.3
35	5.615	31.52	.000 024 76	303.1	329.0	367.8	400.1
36	5.000	25.00	.000 019 64	382.2	414.8	463.7	504.5
37	4.453	19.83	.000 015 57	482.0	523.1	584.8	636.2
38	3.965	15.72	.000 012 35	607.8	659.6	737.4	802.2
39	3.531	12.47	.000 009 793	766.4	831.8	929.8	1012.
40	3.145	9.888	.000 007 766	966.5	1049.	1173.	1276.

(*continued*)

TABLE 420.—WIRE TABLE, STANDARD ANNEALED COPPER (continued)

American wire gage (B. & S.)

Gage No.	Diameter in mils. at 20°C	lb/(1000 ft)	ft/lb	ft/ohm 0°C (= 32°F)	ft/ohm 20°C (= 68°F)	ft/ohm 50°C (= 122°F)	ft/ohm 75°C (= 167°F)
0000	460.0	640.5	1.561	22 140.	20 400.	18 250.	16 780.
000	409.6	507.9	1.968	17 560.	16 180.	14 470.	13 300.
00	364.8	402.8	2.482	13 930.	12 830.	11 480.	10 550.
0	324.9	319.5	3.130	11 040.	10 180.	9103.	8367.
1	289.3	253.3	3.947	8758.	8070.	7219.	6636.
2	257.6	200.9	4.977	6946.	6400.	5725.	5262.
3	229.4	159.3	6.276	5508.	5075.	4540.	4173.
4	204.3	126.4	7.914	4368.	4025.	3600.	3309.
5	181.9	100.2	9.980	3464.	3192.	2855.	2625.
6	162.0	79.46	12.58	2747.	2531.	2264.	2081.
7	144.3	63.02	15.87	2179.	2007.	1796.	1651.
8	128.5	49.98	20.01	1728.	1592.	1424.	1309.
9	114.4	39.63	25.23	1370.	1262.	1129.	1038.
10	101.9	31.43	31.82	1087.	1001.	895.6	823.2
11	90.74	24.92	40.12	861.7	794.0	710.2	652.8
12	80.81	19.77	50.59	683.3	629.6	563.2	517.7
13	71.96	15.68	63.80	541.9	499.3	446.7	410.6
14	64.08	12.43	80.44	429.8	396.0	354.2	325.6
15	57.07	9.858	101.4	340.8	314.0	280.9	258.2
16	50.82	7.818	127.9	270.3	249.0	222.8	204.8
17	45.26	6.200	161.3	214.3	197.5	176.7	162.4
18	40.30	4.917	203.4	170.0	156.6	140.1	128.8
19	35.89	3.899	256.5	134.8	124.2	111.1	102.1
20	31.96	3.092	323.4	106.9	98.50	88.11	80.99
21	28.46	2.452	407.8	84.78	78.11	69.87	64.23
22	25.35	1.945	514.2	67.23	61.95	55.41	50.94
23	22.57	1.542	648.4	53.32	49.13	43.94	40.39
24	20.10	1.223	817.7	42.28	38.96	34.85	32.03
25	17.90	.9699	1031.	33.53	30.90	27.64	25.40
26	15.94	.7692	1300.	26.59	24.50	21.92	20.15
27	14.20	.6100	1639.	21.09	19.43	17.38	15.98
28	12.64	.4837	2067.	16.72	15.41	13.78	12.67
29	11.26	.3836	2607.	13.26	12.22	10.93	10.05
30	10.03	.3042	3287.	10.52	9.691	8.669	7.968
31	8.928	.2413	4145.	8.341	7.685	6.875	6.319
32	7.950	.1913	5227.	6.614	6.095	5.452	5.011
33	7.080	.1517	6591.	5.245	4.833	4.323	3.974
34	6.305	.1203	8310	4.160	3.833	3.429	3.152
35	5.615	.095 42	10 480.	3.299	3.040	2.719	2.499
36	5.000	.075 68	13 210.	2.616	2.411	2.156	1.982
37	4.453	.060 01	16 660.	2.075	1.912	1.710	1.572
38	3.965	.047 59	21 010.	1.645	1.516	1.356	1.247
39	3.531	.037 74	26 500.	1.305	1.202	1.075	.9886
40	3.145	.029 93	33 410.	1.035	.9534	.8529	.7840

(*continued*)

TABLE 420.—WIRE TABLE, STANDARD ANNEALED COPPER (concluded)

American wire gage (B. & S.). English units

Gage No.	Diameter in mils. at 20°C	ohm/lb 0°C (= 32°F)	ohm/lb 20°C (= 68°F)	ohm/lb 50°C (= 122°F)	lb/ohm 20°C (= 68°F)
0000	460.0	.000 070 51	.000 076 52	.000 085 54	13 070.
000	409.6	.000 1121	.000 1217	.000 1360	8219.
00	364.8	.000 1783	.000 1935	.000 2163	5169.
0	324.9	.000 2835	.000 3076	.000 3439	3251.
1	289.3	.000 4507	.000 4891	.000 5468	2044.
2	257.6	.000 7166	.000 7778	.000 8695	1286.
3	229.4	.001 140	.001 237	.001 383	808.6
4	204.3	.001 812	.001 966	.002 198	508.5
5	181.9	.002 881	.003 127	.003 495	319.8
6	162.0	.004 581	.004 972	.005 558	201.1
7	144.3	.007 284	.007 905	.008 838	126.5
8	128.5	.011 58	.012 57	.014 05	79.55
9	114.4	.018 42	.019 99	.022 34	50.03
10	101.9	.029 28	.031 78	.035 53	31.47
11	90.74	.046 56	.050 53	.056 49	19.79
12	80.81	.074 04	.080 35	.089 83	12.45
13	71.96	.1177	.1278	.1428	7.827
14	64.08	.1872	.2032	.2271	4.922
15	57.07	.2976	.3230	.3611	3.096
16	50.82	.4733	.5136	.5742	1.947
17	45.26	.7525	.8167	.9130	1.224
18	40.30	1.197	1.299	1.452	.7700
19	35.89	1.903	2.065	2.308	.4843
20	31.96	3.025	3.283	3.670	.3046
21	28.46	4.810	5.221	5.836	.1915
22	25.35	7.649	8.301	9.280	.1205
23	22.57	12.16	13.20	14.76	.075 76
24	20.10	19.34	20.99	23.46	.047 65
25	17.90	30.75	33.37	37.31	.029 97
26	15.94	48.89	53.06	59.32	.018 85
27	14.20	77.74	84.37	94.32	.011 85
28	12.64	123.6	134.2	150.0	.007 454
29	11.26	196.6	213.3	238.5	.004 688
30	10.03	312.5	339.2	379.2	.002 948
31	8.928	497.0	539.3	602.9	.001 854
32	7.950	790.2	857.6	958.7	.001 166
33	7.080	1256.	1364.	1524.	.000 7333
34	6.305	1998.	2168.	2424.	.000 4612
35	5.615	3177.	3448.	3854.	.000 2901
36	5.000	5051.	5482.	6128.	.000 1824
37	4.453	8032.	8717.	9744.	.000 1147
38	3.965	12 770.	13 860.	15 490.	.000 072 15
39	3.531	20 310.	22 040.	24 640.	.000 045 38
40	3.145	32 290.	35 040.	39 170.	.000 028 54

American wire gage (B. & S.). Metric units

Gage No.	Diameter in mm at 20°C	Cross section in mm² at 20°C	ohm/km 0°C	ohm/km 20°C	ohm/km 50°C	ohm/km 75°C
0000	11.68	107.2	.1482	.1608	.1798	.1956
000	10.40	85.03	.1868	.2028	.2267	.2466
00	9.266	67.43	.2356	.2557	.2858	.3110
0	8.252	53.48	.2971	.3224	.3604	.3921
1	7.348	42.41	.3746	.4066	.4545	.4944
2	6.544	33.63	.4724	.5127	.5731	.6235
3	5.827	26.67	.5956	.6465	.7227	.7862
4	5.189	21.15	.7511	.8152	.9113	.9914
5	4.621	16.77	.9471	1.028	1.149	1.250
6	4.115	13.30	1.194	1.296	1.449	1.576
7	3.665	10.55	1.506	1.634	1.827	1.988
8	3.264	8.366	1.899	2.061	2.304	2.506
9	2.906	6.634	2.395	2.599	2.905	3.161
10	2.588	5.261	3.020	3.277	3.663	3.985
11	2.305	4.172	3.807	4.132	4.619	5.025
12	2.053	3.309	4.801	5.211	5.825	6.337
13	1.828	2.624	6.054	6.571	7.345	7.991
14	1.628	2.081	7.634	8.285	9.262	10.08
15	1.450	1.650	9.627	10.45	11.68	12.71
16	1.291	1.309	12.14	13.17	14.73	16.02
17	1.150	1.038	15.31	16.61	18.57	20.20
18	1.024	.8231	19.30	20.95	23.42	25.48
19	.9116	.6527	24.34	26.42	29.53	32.12
20	.8118	.5176	30.69	33.31	37.24	40.51
21	.7230	.4105	38.70	42.00	46.95	51.08
22	.6438	.3255	48.80	52.96	59.21	64.41
23	.5733	.2582	61.54	66.79	74.66	81.22
24	.5106	.2047	77.60	84.21	94.14	102.4
25	.4547	.1624	97.85	106.2	118.7	129.1
26	.4049	.1288	123.4	133.9	149.7	162.9
27	.3606	.1021	155.6	168.9	188.8	205.4
28	.3211	.080 98	196.2	212.9	238.0	258.9
29	.2859	.064 22	247.4	268.5	300.1	326.5
30	.2546	.050 93	311.9	338.6	378.5	411.7
31	.2268	.040 39	393.4	426.9	477.2	519.2
32	.2019	.032 03	496.0	538.3	601.8	654.7
33	.1798	.025 40	625.5	678.8	758.8	825.5
34	.1601	.020 14	788.7	856.0	956.9	1041.
35	.1426	.015 97	994.5	1079.	1207.	1313.
36	.1270	.012 67	1254.	1361.	1522.	1655.
37	.1131	.010 05	1581.	1716.	1919.	2087.
38	.1007	.007 967	1994.	2164.	2419.	2632.
39	.089 69	.006 318	2514.	2729.	3051.	3319.
40	.079 87	.005 010	3171.	3441.	3847.	4185.

(*continued*)

TABLE 421.—WIRE TABLE, STANDARD ANNEALED COPPER (continued)

American wire gage (B. & S.). Metric units

Gage No.	Diameter in mm at 20°C	kg/km	m/g	m/ohm 0°C	20°C	50°C	75°C
0000	11.68	953.2	.001 049	6749.	6219.	5563.	5113.
000	10.40	755.9	.001 323	5352.	4932.	4412.	4055.
00	9.266	599.5	.001 668	4245.	3911.	3499.	3216.
0	8.252	475.4	.002 103	3366.	3102.	2774.	2550.
1	7.348	377.0	.002 652	2669.	2460.	2200.	2022.
2	6.544	299.0	.003 345	2117.	1951.	1745.	1604.
3	5.827	237.1	.004 217	1679.	1547.	1384.	1272.
4	5.189	188.0	.005 318	1331.	1227.	1097.	1009.
5	4.621	149.1	.006 706	1056.	972.9	870.2	799.9
6	4.114	118.2	.008 457	837.3	771.5	690.1	634.4
7	3.665	93.78	.010 66	664.0	611.8	547.3	503.1
8	3.264	74.37	.013 45	526.6	485.2	434.0	399.0
9	2.906	58.98	.016 96	417.6	384.8	344.2	316.4
10	2.588	46.77	.021 38	331.2	305.1	273.0	250.9
11	2.305	37.09	.026 96	262.6	242.0	216.5	199.0
12	2.053	29.42	.034 00	208.3	191.9	171.7	157.8
13	1.828	23.33	.042 87	165.2	152.2	136.1	125.1
14	1.628	18.50	.054 06	131.0	120.7	108.0	99.24
15	1.450	14.67	.068 16	103.9	95.71	85.62	78.70
16	1.291	11.63	.085 95	82.38	75.90	67.90	62.41
17	1.150	9.226	.1084	65.33	60.20	53.85	49.50
18	1.024	7.317	.1367	51.81	47.74	42.70	39.25
19	.9116	5.803	.1723	41.09	37.86	33.86	31.13
20	.8118	4.602	.2173	32.58	30.02	26.86	24.69
21	.7230	3.649	.2740	25.84	23.81	21.30	19.58
22	.6438	2.894	.3455	20.49	18.88	16.89	15.53
23	.5733	2.295	.4357	16.25	14.97	13.39	12.31
24	.5106	1.820	.5494	12.89	11.87	10.62	9.764
25	.4547	1.443	.6928	10.22	9.417	8.424	7.743
26	.4049	1.145	.8736	8.105	7.468	6.680	6.141
27	.3606	.9078	1.102	6.428	5.922	5.298	4.870
28	.3211	.7199	1.389	5.097	4.697	4.201	3.862
29	.2859	.5709	1.752	4.042	3.725	3.332	3.063
30	.2546	.4527	2.209	3.206	2.954	2.642	2.429
31	.2268	.3590	2.785	2.542	2.342	2.095	1.926
32	.2019	.2847	3.512	2.016	1.858	1.662	1.527
33	.1798	.2258	4.429	1.599	1.473	1.318	1.211
34	.1601	.1791	5.584	1.268	1.168	1.045	.9606
35	.1426	.1420	7.042	1.006	.9265	.8288	.7618
36	.1270	.1126	8.879	.7974	.7347	.6572	.6041
37	.1131	.089 31	11.20	.6324	.5827	.5212	.4791
38	.1007	.070 83	14.12	.5015	.4621	.4133	.3799
39	.089 69	.056 17	17.80	.3977	.3664	.3278	.3013
40	.079 87	.044 54	22.45	.3154	.2906	.2600	.2390

(continued)

TABLE 421.—WIRE TABLE, STANDARD ANNEALED COPPER (concluded)

American wire gage (B. & S.). Metric units

Gage No.	Diameter in mm at 20°C	ohm/kg 0°C	ohm/kg 20°C	ohm/kg 50°C	g/ohm 20°C
0000	11.68	.000 155 4	.000 168 7	.000 188 6	5 928 000.
000	10.40	.000 247 2	.000 268 2	.000 299 9	3 728 000.
00	9.266	.000 393 0	.000 426 5	.000 476 8	2 344 000.
0	8.252	.000 624 9	.000 678 2	.000 758 2	1 474 000.
1	7.348	.000 993 6	.001 078	.001 206	927 300.
2	6.544	.001 580	.001 715	.001 917	583 200.
3	5.827	.002 512	.002 726	.003 048	366 800.
4	5.189	.003 995	.004 335	.004 846	230 700.
5	4.621	.006 352	.006 893	.007 706	145 100.
6	4.115	.010 10	.010 96	.012 25	91 230.
7	3.665	.016 06	.017 43	.019 48	57 380.
8	3.264	.025 53	.027 71	.030 98	36 080.
9	2.906	.040 60	.044 06	.049 26	22 690.
10	2.588	.064 56	.070 07	.078 33	14 270.
11	2.305	.1026	.1114	.1245	8976.
12	2.053	.1632	.1771	.1980	5645.
13	1.828	.2595	.2817	.3149	3550.
14	1.628	.4127	.4479	.5007	2233.
15	1.450	.6562	.7122	.7961	1404.
16	1.291	1.043	1.132	1.266	883.1
17	1.150	1.659	1.801	2.013	555.4
18	1.024	2.638	2.863	3.201	349.3
19	.9116	4.194	4.552	5.089	219.7
20	.8118	6.670	7.238	8.092	138.2
21	.7230	10.60	11.51	12.87	86.88
22	.6438	16.86	18.30	20.46	54.64
23	.5733	26.81	29.10	32.53	34.36
24	.5106	42.63	46.27	51.73	21.61
25	.4547	67.79	73.57	82.25	13.59
26	.4049	107.8	117.0	130.8	8.548
27	.3606	171.4	186.0	207.9	5.376
28	.3211	272.5	295.8	330.6	3.381
29	.2859	433.3	470.3	525.7	2.126
30	.2546	689.0	747.8	836.0	1.337
31	.2268	1096.	1189.	1329.	.8410
32	.2019	1742.	1891.	2114.	.5289
33	.1798	2770.	3006.	3361.	.3326
34	.1601	4404.	4780.	5344.	.2092
35	.1426	7003.	7601.	8497.	.1316
36	.1270	11140.	12090.	13510.	.082 74
37	.1131	17710.	19220.	21480.	.052 04
38	.1007	28150.	30560.	34160.	.032 73
39	.089 69	44770.	48590.	54310.	.020 58
40	.079 87	71180.	77260.	86360.	.012 94

TABLE 422.—WIRE TABLE, ALUMINUM

Hard-drawn aluminum wire at 20°C (68°F)

American wire gage (B. & S.). English units

Gage No.	Diameter in mils	Cross section: Circular mils	Cross section: in.²	ohm / 1000 ft	lb / 1000 ft	lb/ohm	ft/ohm
0000	460.	212 000.	.166	.0804	195.	2420.	12 400.
000	410.	168 000.	.132	.101	154.	1520.	9860.
00	365.	133 000.	.105	.128	122.	957.	7820.
0	325.	106 000.	.0829	.161	97.0	602.	6200.
1	289.	83 700.	.0657	.203	76.9	379.	4920.
2	258.	66 400.	.0521	.256	61.0	238.	3900.
3	229.	52 600.	.0413	.323	48.4	150.	3090.
4	204.	41 700.	.0328	.408	38.4	94.2	2450.
5	182.	33 100.	.0260	.514	30.4	59.2	1950.
6	162.	26 300.	.0206	.648	24.1	37.2	1540.
7	144.	20 800.	.0164	.817	19.1	23.4	1220.
8	128.	16 500.	.0130	1.03	15.2	14.7	970.
9	114.	13 100.	.0103	1.30	12.0	9.26	770.
10	102.	10 400.	.008 15	1.64	9.55	5.83	610.
11	91.	8230.	.006 47	2.07	7.57	3.66	484.
12	81.	6530.	.005 13	2.61	6.00	2.30	384.
13	72.	5180.	.004 07	3.29	4.76	1.45	304.
14	64.	4110.	.003 23	4.14	3.78	.911	241.
15	57.	3260.	.002 56	5.22	2.99	.573	191.
16	51.	2580.	.002 03	6.59	2.37	.360	152.
17	45.	2050.	.001 61	8.31	1.88	.227	120.
18	40.	1620.	.001 28	10.5	1.49	.143	95.5
19	36.	1290.	.001 01	13.2	1.18	.0897	75.7
20	32.	1020.	.000 802	16.7	.939	.0564	60.0
21	28.5	810.	.000 636	21.0	.745	.0355	47.6
22	25.3	642.	.000 505	26.5	.591	.0223	37.8
23	22.6	509.	.000 400	33.4	.468	.0140	29.9
24	20.1	404.	.000 317	42.1	.371	.008 82	23.7
25	17.9	320.	.000 252	53.1	.295	.005 55	18.8
26	15.9	254.	.000 200	67.0	.234	.003 49	14.9
27	14.2	202.	.000 158	84.4	.185	.002 19	11.8
28	12.6	160.	.000 126	106.	.147	.001 38	9.39
29	11.3	127.	.000 099 5	134.	.117	.000 868	7.45
30	10.0	101.	.000 078 9	169.	.0924	.000 546	5.91
31	8.9	79.7	.000 062 6	213.	.0733	.000 343	4.68
32	8.0	63.2	.000 049 6	269.	.0581	.000 216	3.72
33	7.1	50.1	.000 039 4	339.	.0461	.000 136	2.95
34	6.3	39.8	.000 031 2	428.	.0365	.000 085 4	2.34
35	5.6	31.5	.000 024 8	540.	.0290	.000 053 7	1.85
36	5.0	25.0	.000 019 6	681.	.0230	.000 033 8	1.47
37	4.5	19.8	.000 015 6	858.	.0182	.000 021 2	1.17
38	4.0	15.7	.000 012 3	1080.	.0145	.000 013 4	.924
39	3.5	12.5	.000 009 79	1360.	.0115	.000 008 40	.733
40	3.1	9.9	.000 007 77	1720.	.0091	.000 005 28	.581

TABLE 423.—WIRE TABLE, ALUMINUM

Hard-drawn aluminum wire at 20°C (68°F)

American wire gage (B. & S.). Metric units

Gage No.	Diameter in mm	Cross section in mm²	ohm/km	kg/km	g/ohm	m/ohm
0000	11.7	107.	.264	289.	1 100 000.	3790.
000	10.4	85.0	.333	230.	690 000.	3010.
00	9.3	67.4	.419	182.	434 000.	2380.
0	8.3	53.5	.529	144.	273 000.	1890.
1	7.3	42.4	.667	114.	172 000.	1500.
2	6.5	33.6	.841	90.8	108 000.	1190.
3	5.8	26.7	1.06	72.0	67 900.	943.
4	5.2	21.2	1.34	57.1	42 700.	748.
5	4.6	16.8	1.69	45.3	26 900.	593.
6	4.1	13.3	2.13	35.9	16 900.	470.
7	3.7	10.5	2.68	28.5	10 600.	373.
8	3.3	8.37	3.38	22.6	6680.	296.
9	2.91	6.63	4.26	17.9	4200.	235.
10	2.59	5.26	5.38	14.2	2640.	186.
11	2.30	4.17	6.78	11.3	1660.	148.
12	2.05	3.31	8.55	8.93	1050.	117.
13	1.83	2.62	10.8	7.08	657.	92.8
14	1.63	2.08	13.6	5.62	413.	73.6
15	1.45	1.65	17.1	4.46	260.	58.4
16	1.29	1.31	21.6	3.53	164.	46.3
17	1.15	1.04	27.3	2.80	103.	36.7
18	1.02	.823	34.4	2.22	64.7	29.1
19	.91	.653	43.3	1.76	40.7	23.1
20	.81	.518	54.6	1.40	25.6	18.3
21	.72	.411	68.9	1.11	16.1	14.5
22	.64	.326	86.9	.879	10.1	11.5
23	.57	.258	110.	.697	6.36	9.13
24	.51	.205	138.	.553	4.00	7.24
25	.45	.162	174.	.438	2.52	5.74
26	.40	.129	220.	.348	1.58	4.55
27	.36	.102	277.	.276	.995	3.61
28	.32	.0810	349.	.219	.626	2.86
29	.29	.0642	440.	.173	.394	2.27
30	.25	.0509	555.	.138	.248	1.80
31	.227	.0404	700.	.109	.156	1.43
32	.202	.0320	883.	.0865	.0979	1.13
33	.180	.0254	1110.	.0686	.0616	.899
34	.160	.0201	1400.	.0544	.0387	.712
35	.143	.0160	1770.	.0431	.0244	.565
36	.127	.0127	2230.	.0342	.0153	.448
37	.113	.0100	2820.	.0271	.009 63	.355
38	.101	.0080	3550.	.0215	.006 06	.282
39	.090	.0063	4480.	.0171	.003 81	.223
40	.080	.0050	5640.	.0135	.002 40	.177

TABLE 424.—AUXILIARY TABLE FOR COMPUTING WIRE RESISTANCES

For computing resistances in ohms per meter from resistivity, ρ, in microhm-cm (see Table 386, etc.). e.g., to compute for No. 23 copper wire when $\rho = 1.724$: 1 m $= 0.0387 + .0271 + .0008 + .0002 = 0.0668$ ohms; for No. 11 lead wire when $\rho = 20.4$: 1 m $= 0.0479 + .0010 = 0.0489$ ohms. The following relation allows computation for wires of other gage numbers: resistance in ohms per m of No. n wire $= 2 \times$ resistance of wire No. $(n - 3)$ within 1 percent: e.g., resistance of m of No. 18 $= 2 \times$ No. 15.

Gage No.	Diam. in mm	Section mm²	ρ in microhm-cm: 1	2	3	4	5	6	7	8	9	10
			Resistance of wire 1 m long in ohms									
0000	11.7	107.2	$.0_4933$	$.0_3187$	$.0_3280$	$.0_3373$	$.0_3466$	$.0_3560$	$.0_3653$	$.0_3746$	$.0_3840$	$.0_3933$
00	9.27	67.43	$.0_3148$	$.0_3297$	$.0_3445$	$.0_3593$	$.0_3742$	$.0_3890$	$.0_2104$	$.0_2119$	$.0_2133$	$.0_2148$
1	7.35	42.41	$.0_3236$	$.0_3472$	$.0_3707$	$.0_3943$	$.0_2118$	$.0_2141$	$.0_2165$	$.0_2189$	$.0_2212$	$.0_2236$
3	5.83	26.67	$.0_3375$	$.0_3750$	$.0_2112$	$.0_2150$	$.0_2187$	$.0_2225$	$.0_2262$	$.0_2300$	$.0_2337$	$.0_2375$
5	4.62	16.77	$.0_3596$	$.0_2119$	$.0_2179$	$.0_2239$	$.0_2298$	$.0_2358$	$.0_2417$	$.0_2477$	$.0_2537$	$.0_2596$
7	3.66	10.55	$.0_3948$	$.0_2190$	$.0_2284$	$.0_2379$	$.0_2474$	$.0_2569$	$.0_2664$	$.0_2758$	$.0_2853$	$.0_2948$
9	2.91	6.634	$.0_2151$	$.0_2301$	$.0_2452$	$.0_2603$	$.0_2754$	$.0_2904$	.0106	.0121	.0136	.0151
11	2.30	4.172	$.0_2240$	$.0_2479$	$.0_2719$	$.0_2959$	.0120	.0144	.0168	.0192	.0216	.0240
13	1.83	2.624	$.0_2381$	$.0_2762$	.0114	.0152	.0191	.0229	.0267	.0305	.0343	.0381
15	1.45	1.650	$.0_2606$	.0121	.0182	.0242	.0303	.0364	.0424	.0485	.0545	.0606
17	1.15	1.038	$.0_2963$	.0193	.0289	.0385	.0482	.0578	.0674	.0771	.0867	.0963
19	.912	.6527	.0153	.0306	.0460	.0613	.0766	.0919	.1072	.1226	.1379	.1532
21	.723	.4105	.0244	.0487	.0731	.0974	.1218	.1462	.1705	.1949	.2192	.2436
23	.573	.2582	.0387	.0775	.1162	.1549	.1936	.2324	.2711	.3098	.3486	.3873
25	.455	.1624	.0616	.1232	.1847	.2463	.3079	.3695	.4310	.4926	.5542	.6158
27	.361	.1021	.0979	.1959	.2938	.3918	.4897	.5877	.6856	.7835	.8815	.9794
29	.286	.0642	.1557	.3114	.4671	.6228	.7786	.9343	1.090	1.246	1.401	1.557
31	.227	.0404	.2476	.4952	.7428	.9904	1.238	1.486	1.733	1.981	2.228	2.476
33	.180	.0254	.3937	.7874	1.181	1.575	1.968	2.362	2.756	3.150	3.543	3.937
35	.143	.0160	.6262	1.252	1.879	2.505	3.131	3.757	4.383	5.009	5.636	6.262
37	.113	.0100	.9950	1.990	2.985	3.980	4.975	5.970	6.965	7.960	8.955	9.950
39	.090	.0063	1.583	3.166	4.748	6.331	7.914	9.497	11.08	12.66	14.25	15.83
40	.080	.0050	1.996	3.992	5.988	7.984	9.980	11.98	13.97	15.97	17.96	19.96

TABLE 425.—SAFE CURRENT-CARRYING CAPACITY OF COPPER WIRE, FOR DIFFERENT CONDITIONS, IN AMPERES PER CONDUCTOR *

Wire size AWG	Varnish cambric insulators: Single wire in free air	Not more than three conductors in raceway or cable	Rubber insulators in enclosed and exposed conduit: Single conductor	Three conductor	Impregnated paper insulation: Single conductor cable in air	Three conductor cable in underground duct
14	30	23	23	19		
10	54	38	40	33		
6	99	68	71	57	98	78
3	155	104				
2	179	118	127	101	173	134
0	245	157	167	133	234	177
0000	383	237	256	203	352	264

* These values are for voltages in the range up to 5,000 or 7,000 and for 75 to 100 percent time load, ambient temperature 30°C and copper temperature 75-80°C. Adapted from Publication No. P-29-226 of the Insulated Power and Cable Engineers' Association. For other values see these tables.

TABLE 426.—THE CALCULATION OF THE HIGH-FREQUENCY RESISTANCE OF CONDUCTORS *

The resistance of a conductor to high-frequency alternating currents is not the same as it offers to direct or low-frequency currents. The linkages of flux with the inner portions of the conductor are more numerous than with the outer portions. That is, the reactances of the inner filaments are greater than those of the outer filaments. Consequently, the current density decreases from the outside toward the center of the conductor.

This tendency of the current to crowd toward the outer portions of the cross section becomes more pronounced the higher the frequency, and at very high frequencies the current density is sensibly zero everywhere except in the surface layer of the conductor. This phenomenon is called the "skin effect." It causes an increase in the effective resistance of the conductor over its resistance to a direct current.

What is of interest in the calculation of the high-frequency resistance is the *resistance ratio,* the quotient of the resistance at the given frequency by the direct-current resistance. The resistance ratio depends upon the distribution of current density in the cross section, and this is a function of the frequency and the shape of the cross section. In general, however, the resistance ratio is a function of the parameter $\sqrt{\frac{f}{R_0}}$, in which f is the frequency, and R_0 is the direct-current resistance per unit length. In what follows R_0 will be taken as the direct-current resistance per 1000 ft of conductor.

The distribution of current in the cross section is affected by a neighboring conductor carrying high-frequency currents. This *proximity effect* finds an explanation in that the value of the mutual inductance of any filament A of one conductor on a filament B of the other conductor depends upon the positions of A and B in their respective cross sections. The proximity effect may be very appreciable for conductors nearly in contact; falling off rapidly as their distance increased, it is negligible for moderate ratios of distance apart to cross sectional dimensions. In such cases the resistance is sensibly the same as for an *isolated* conductor.

Besides the spacing factor of the conductors, the proximity effect depends upon the frequency, and in lesser degree upon the shape of the cross sections. Quantitatively, the proximity effect may be expressed by the *proximity factor,* which is the quotient of actual resistance of the conductor by the resistance which it would have if removed to a great distance from the disturbing conductor, both values of resistance being referred to the same frequency.

That is, if

R_0 = the direct current resistance
R_1 = the resistance of the conductor when isolated, frequency f
R_2 = the resistance in the presence of the disturbing conductor at frequency f

then the proximity factor is $P = \frac{R_2}{R_1}$, and the resistance ratio $\frac{R_2}{R_0}$, in the presence of the disturbing conductor, is obtained from the resistance ratio $\frac{R_1}{R_0}$ when isolated by the relation $\frac{R_2}{R_0} = P\,\frac{R_1}{R_0}\cdot$ Resistance ratio may be obtained in any case if the resistance ratio when isolated is known, together with the value of the proximity factor.

Formulas for the high-frequency resistance ratio have been developed in only a few simple (but important) cases, and even then very complicated formulas result. For practical work, tables are necessary for simplifying the calculations. The following tables cover the most important cases.

Formulas have been derived for the high-frequency resistance ratio of single-layer coils wound with round wire. Generally, these differ from one another and from measured values, because simplifying assumptions are made which are not sufficiently realized in practice. No tables of values for coils such as are met in practical radio work are available As a rough guide, the high-frequency resistance ratio for a single-layer coil is often from two to five times as great as the resistance ratio of the same wire stretched out straight and carrying current of the given frequency. The experimental work available indicates that this factor is due to the coiling of the wire, that is, the total proximity effect of the turns of the coil is largely dependent upon the frequency and the ratio of wire diameter to pitch of winding, and in lesser degree to the ratio of length to diameter.

* Prepared by F. W. Grover, Nat. Bur. Standards.

(*continued*)

TABLE 426.—THE CALCULATION OF THE HIGH-FREQUENCY RESISTANCE OF CONDUCTORS (continued)

Part 1.—Resistance ratio "F" for isolated round wires

Resistance ratio F of isolated round wire, as a function of the square root of the frequency divided by the direct current resistance per 1000 ft of conductor.

$\sqrt{f/R_0}$	0	10	20	30	40	50	60	70	80	90	100
F	1.000	1.000	1.0005	1.0025	1.008	1.019	1.038	1.069	1.114	1.173	1.247
$\sqrt{f/R_0}$	100	120	140	160	180	200	250	300	350	400	500
F	1.247	1.427	1.631	1.836	2.036	2.231	2.715	3.201	3.688	4.176	5.152

Part 2.—Values of resistance ratio for isolated tubular conductors

t, thickness of wall of tube; d, outer diameter of tube

$\sqrt{\frac{f}{R_0}}$	$\frac{t}{d}$ = 0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001
100	1.001	1.001	1.002	1.002	1.004	1.008	1.007	1.009	...	1.014
150	1.001	1.003	1.006	1.011	1.017	1.024	1.033	1.044	1.056	1.070
200	1.002	1.008	1.019	1.034	1.053	1.076	1.104	1.134	1.167	1.204
250	1.005	1.020	1.046	1.081	1.125	1.176	1.233	1.296	1.365	1.440
300	1.011	1.042	1.095	1.163	1.25	1.34	1.44	1.55	1.65	1.75
350	1.020	1.076	1.167	1.285	1.42	1.56	1.70	1.83	1.97	2.09
400	1.032	1.127	1.27	1.44	1.66	1.81	1.99	2.13	2.28	2.42
450	1.051	1.198	1.41	1.63	1.87	2.08	2.28	2.44	2.60	2.74
500	1.079	1.30	1.57	1.86	2.14	2.34	2.56	2.73	2.88	3.03

$\sqrt{\frac{f}{R_0}}$	$\frac{t}{d}$ = 0.10	0.12	0.15	0.20	0.25	0.30	0.35	0.40	0.45	Solid 0.50
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
50	1.001	1.001	1.002	1.004	1.006	1.008	1.012	1.015	1.017	1.019
100	1.014	1.021	1.032	1.063	1.094	1.132	1.175	1.202	1.224	1.247
150	1.070	1.102	1.155	1.266	1.39	1.51	1.60	1.68	1.71	1.733
200	1.204	1.294	1.42	1.65	1.845	1.995	2.095	2.15	2.20	2.231
250	1.44	1.585	1.79	2.11	2.32	2.45	2.536	2.64	2.68	2.715
300	1.75	1.94	2.19	2.51	2.735	2.90	3.03	3.12	3.17	3.201
350	2.09	2.33	2.57	2.90	3.15	3.35	3.495	3.59	3.66	3.688
400	2.42	2.66	2.92	3.27	3.58	3.80	3.96	4.07	4.14	4.176
450	2.74	3.00	3.27	3.66	4.00	4.25	4.43	4.55	4.63	4.664
500	3.03	3.33	3.62	4.07	4.42	4.69	4.90	5.03	5.12	5.152

(*continued*)

TABLE 426.—THE CALCULATION OF THE HIGH-FREQUENCY RESISTANCE OF CONDUCTORS (concluded)

Part 3.—Coefficients in formula for proximity factor of equal parallel round wires

The proximity factor of two equal parallel conductors may be calculated by the formula

$$P = 1 + [G \cdot d^2/s^2]/[F(1 - Hd^2/s^2)]$$

in which the coefficient F is to be obtained from Part 1 for the given value of $\sqrt{f/R_0}$ and the coefficients G and H are to be taken from the table below for the given value of $\sqrt{f/R_0}$. In the table below the values of H apply to currents in the same direction; in the case of currents in opposite directions H' is to be used. In the above formula d is the diameter of the wires and s their axial spacing. The proximity factor for two equal parallel tubular conductors does not differ much from the value for two solid wires with the same axial spacing and a value of $\sqrt{f/R_0}$ one-half the value for two solid wires of the same diameter, except for conductors very close together.

$\sqrt{f/R_0}$	G	H	H'	$\sqrt{f/R_0}$	G	H	H'
0	0	+.0417	+.0417	200	.8491	—.1904	.5530
25	.0036	.0395	.0443	250	1.0959	—.2017	.5932
50	.0519	+.0109	.0798	300	1.340	—.2093	.6200
75	.1903	—.0659	.1838	350	1.585	—.2149	.6389
100	.3562	—.1379	.3112	400	1.830	—.2191	.6530
125	.4914	—.1685	.4114	450	2.073	—.2224	.6639
150	.6096	—.1776	.4787	500	2.319	—.2231	.6722
175	.7277	—.1839	.5228				

TABLE 427.—RATIO OF ALTERNATING TO DIRECT CURRENT RESISTANCES FOR COPPER WIRES

This table gives the ratio of the resistance of straight copper wires with alternating currents of different frequencies to the value of the resistance with direct currents.

Diameter of wire in mm	Frequency $f =$					
	60	100	1000	10,000	100,000	1,000,000
.05	—	—	—	—	—	*1.001
.1	—	—	—	—	*1.001	1.008
.25	—	—	—	—	1.003	1.247
.5	—	—	—	*1.001	1.047	2.240
1.0	—	—	—	1.008	1.503	4.19
2.0	—	—	1.001	1.120	2.756	8.10
3.	—	—	1.006	1.437	4.00	12.0
4.	—	—	1.021	1.842	5.24	17.4
5.	—	*1.001	1.047	2.240	6.49	19.7
7.5	1.001	1.002	1.210	3.22	7.50	29.7
10.	1.003	1.008	1.503	4.19	12.7	39.1
15.	1.016	1.038	2.136	6.14	18.8	—
20.	1.044	1.120	2.756	8.10	25.2	—
25.	1.105	1.247	3.38	10.1	28.3	—
40.	1.474	1.842	5.24	17.4	—	—
100.	3.31	4.19	13.7	39.1	—	—

Values between 1.000 and 1.001 are indicated by *1.001.

The values are for wires having an assumed conductivity of 1.60 microhm-cm; for copper wires at room temperatures the values are slightly less than as given in table.

The change of resistance of wire other than copper (iron wires excepted) may be calculated from the above table by taking it as proportional to $d\sqrt{f/\rho}$ where d = diameter, f the frequency (cycles/sec) and ρ the resistivity.

If a given wire be wound into a solenoid, its resistance, at a given frequency, will be greater than the values in the table, which apply to straight wires only. The resistance in this case is a complicated function of the pitch and radius of the winding, the frequency, and the diameter of the wire, and is found by experiment to be sometimes as much as twice the value for a straight wire.

TABLE 428.—MAXIMUM DIAMETER OF WIRES FOR HIGH-FREQUENCY RESISTANCE RATIO OF 1.01

Frequency ÷ 10^6	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.5	2.0	3.0
Wavelength, m	3000	1500	750	500	375	300	250	200	150	100
Material	Diameter in cm									
Copper	.0356	.0251	.0177	.0145	.0125	.0112	.0102	.0092	.0079	.0065
Silver	.0345	.0244	.0172	.0141	.0122	.0109	.0099	.0089	.0077	.0063
Gold	.0420	.0297	.0210	.0172	.0149	.0133	.0121	.0108	.0094	.0077
Platinum	.1120	.0793	.0560	.0457	.0396	.0354	.0323	.0290	.0250	.0205
Mercury	.264	.187	.132	.1080	.0936	.0836	.0763	.0683	.0591	.0483
Manganin	.1784	.1261	.0892	.0729	.0631	.0564	.0515	.0461	.0399	.0325
Constantan	.1892	.1337	.0946	.0772	.0664	.0598	.0546	.0488	.0423	.0345
German silver	.1942	.1372	.0970	.0792	.0692	.0614	.0560	.0500	.0434	.0354
Graphite	.765	.541	.383	.312	.271	.242	.221	.197	.171	.140
Carbon	1.60	1.13	.801	.654	.566	.506	.462	.414	.358	.292
Iron $\mu = 1000$	.00263	.00186	.00131	.00108	.00094	.00083	.00076	.00068	.00059	.00048
$\mu = 500$	.00373	.00264	.00187	.00152	.00132	.00118	.00108	.00096	.00084	.00068
$\mu = 100$	.00838	.00590	.00418	.00340	.00295	.00264	.00241	.00215	.00186	.00152

TABLES 429-452.—SOME CHARACTERISTICS OF DIELECTRICS

TABLE 429.—STEADY POTENTIAL DIFFERENCE IN VOLTS REQUIRED TO PRODUCE A SPARK IN AIR WITH BALL ELECTRODES (RADIUS R)

Spark length, cm	$R=0$ Points	$R=0.25$ cm	$R=0.5$ cm	$R=1$ cm	$R=2$ cm	$R=3$ cm	$R=\infty$ Plates
.02	—	—	1560	1530			
.04	—	—	2460	2430	2340		
.06	—	—	3300	3240	3060		
.08	—	—	4050	3990	3810		
.1	3720	5010	4740	4560	4560	4500	4350
.2	4680	8610	8490	8490	8370	7770	7590
.3	5310	11140	11460	11340	11190	10560	10650
.4	5970	14040	14310	14340	14250	13140	13560
.5	6300	15990	16950	17220	16650	16470	16320
.6	6840	17130	19740	20070	20070	19380	19110
.8	8070	18960	23790	24780	25830	26220	24960
1.0	8670	20670	26190	27810	29850	32760	30840
1.5	9960	22770	29970	37260			
2.0	10140	24570	33060	45480			
3.0	11250	28380					
4.0	12210	29580					
5.0	13050						

TABLE 430.—ALTERNATING-CURRENT POTENTIAL REQUIRED TO PRODUCE A SPARK IN AIR WITH VARIOUS BALL ELECTRODES

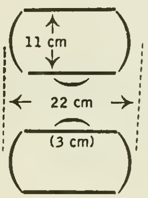
The potentials given are the maxima of the alternating waves used. Frequency, 33 cycles per second.

Spark length cm	$R=1$ cm	$R=1.92$	$R=5$	$R=7.5$	$R=10$	$R=15$
.08	3770					
.10	4400	4380	4330	4290	4245	4230
.15	5990	5940	5830	5790	5800	5780
.20	7510	7440	7340	7250	7320	7330
.25	9045	8970	8850	8710	8760	8760
.30	10480	10400	10270	10130	10180	10150
.35	11980	11890	11670	11570	11610	11590
.40	13360	13300	13100	12930	12980	12970
.45	14770	14700	14400	14290	14330	14320
.50	16140	16070	15890	15640	15690	15690
.6	18700	18730	18550	18300	18350	18400
.7	21350	21380	21140	20980	20990	21000
.8	23820	24070	23740	23490	23540	23550
.9	26190	26640	26400	26130	26110	26090
1.0	28380	29170	28950	28770	28680	28610
1.2	32400	34100	33790	33660	33640	33620
1.4	35850	38850	38850	38580	38620	38580
1.6	38750	43400	43570	43250	43520	
1.8	40900	—	48300	47900		
2.0	42950	—	—	52400		

TABLE 431.—POTENTIAL NECESSARY TO PRODUCE A SPARK IN AIR BETWEEN MORE WIDELY SEPARATED ELECTRODES

Spark length, cm	Dull points. Alternating current	Steady potentials: Ball electrodes $R=$ 1 cm	Steady potentials: Ball electrodes $R=$ 2.5 cm	Steady potentials: Cup electrodes, Projection 4.5 mm	Steady potentials: Cup electrodes, Projection 1.5 mm
.3	—	—	—	—	11280
.5	—	17610	17620	—	17420
.7	—	—	23050	—	22950
1.0	12000	30240	31390	31400	31260
1.2	—	33800	36810	—	36700
1.5	—	37930	44310	—	44510
2.0	29200	42320	56000	56500	56530
2.5	—	45000	65180	—	68720
3.0	40000	46710	71200	80400	81140
3.5	—	—	75300	—	92400
4.0	48500	49100	78600	101700	103800
4.5	—	—	81540	—	114600
5.0	56500	50310	83800	—	126500
5.5	—	—	—	—	135700

Spark length, cm	Dull points. Alternating current	Steady potentials: Ball electrodes $R=$ 1 cm	Steady potentials: Ball electrodes $R=$ 2.5 cm
6.0	61000	—	86830
7.0	—	52000	—
8.0	67000	52400	90200
10.0	73000	74300	91930
12.0	82600	—	93300
14.0	92000	—	94400
15.0	—	—	94700
16.0	101000	—	101000
20.0	119000		
25.0	140600		
30.0	165700		
35.0	190900		



The specially constructed electrodes for the columns headed "cup electrodes" had the form of a projecting knob 3 cm in diameter and having a height of 4.5 mm and 1.5 mm respectively, attached to the plane face of the electrodes. These electrodes give a very satisfactory linear relation between the spark lengths and the voltage throughout the range studied.

TABLE 432.—EFFECT OF THE PRESSURE OF THE AIR ON THE DIELECTRIC STRENGTH

Voltages are given for different spark lengths l.

Pressure, cmHg	$l=0.04$	$l=0.06$	$l=0.08$	$l=0.10$	$l=0.20$	$l=0.30$	$l=0.40$	$l=0.50$
2	—	—	—	—	744	939	1110	1266
4	—	483	567	648	1015	1350	1645	1915
6	—	582	690	795	1290	1740	2140	2505
10	—	771	933	1090	1840	2450	3015	3580
15	—	1060	1280	1490	2460	3300	4080	4850
25	1110	1420	1725	2040	3500	4800	6000	7120
35	1375	1820	2220	2615	4505	6270	7870	9340
45	1640	2150	2660	3120	5475	7650	9620	11420
55	1820	2420	3025	3610	6375	8950	11290	13455
65	2040	2720	3400	4060	7245	10210	12950	15470
75	2255	3035	3805	4565	8200	11570	14650	17450

TABLE 433.—POTENTIALS IN VOLTS TO PRODUCE A SPARK IN KEROSENE

Spark length cm	Electrodes balls of diam. d: 0.5 cm	1 cm	2 cm	3 cm	Spark length cm	Electrodes balls of diam. d: 0.5 cm	1 cm	2 cm	3 cm
.1	3800	3400	2750	2200	.5	13050	12400	11000	6900
.2	7500	6450	4800	3500	.6	14000	13550	12250	8250
.3	10250	9450	7450	4600	.8	15500	15100	13850	10450
.4	11750	10750	9100	5600	1.0	16750	16400	15250	12350

TABLE 434.—DIELECTRIC STRENGTH OF MATERIALS

Potential necessary for puncture expressed in kilovolts per centimeter thickness of the dielectric

Substance	Thickness	Kilovolts per cm
Ebonite		300–1100
Empire cloth		80–300
" paper		450
Fiber		20
Fuller board		200–300
Glass		300–1500
Granite (fused)		90
Guttapercha		80–200
Impregnated jute		20
Leatheroid		30–60
Linen, varnished		100–200
Liquid air		40–90
Mica:		
Madras	.1 mm	1600
"	1.0 "	300
Bengal	.1 "	2200
"	1.0 "	700
Canada	.1 "	1500
"	1.0 "	500
South America		1500
Micanite		400

Substance	Thickness	Kilovolts per cm
Oils:		
Castor	.2 mm	190
"	1.0 "	130
Cottonseed		70
Lard	.2 "	140
"	1.0 "	40
Linseed, raw	.2 "	185
" "	1.0 "	90
" boiled	.2 "	190
" "	1.0 "	80
Lubricating		50
Neatsfoot	.2 "	200
"	1.0 "	90
Olive	.2 "	170
"	1.0 "	75
Paraffin	.2 "	215
"	1.0 "	160
Sperm, mineral	.2 "	180
" "	1.0 "	85
" natural	.2 "	195
" "	1.0 "	90
Turpentine	.2 "	160
"	1.0 "	110

Substance	Melt. point / Thickness	Kilovolts per cm
Papers:		
Beeswaxed		770
Blotting		150
Manilla		25
Paraffined		500
Varnished		100–250
Paraffin:		
Melted		75
Solid	43°	350
"	47°	400
"	52°	230
"	70°	450
Presspaper		45–75
Rubber		160–500
Vaseline		90–130
Xylene	.2 mm	140
"	1.0 "	80

TABLE 435.—DIELECTRIC CONSTANT (SPECIFIC INDUCTIVE CAPACITY) OF GASES

Atmospheric pressure

Wavelengths of the measuring current greater than 10000 cm

Gas	°C	Dielectric constant: Vacuum = 1	Dielectric constant: Air = 1	Gas	°C	Dielectric constant: Vacuum = 1	Dielectric constant: Air = 1
Air	0	1.000588	1.000000	HCl	100	1.00258	1.00199
NH_3	20	1.00718	1.00659	H_2	0	1.000264	.999676
CS_2	0	1.00290	1.00231	CH_4	0	1.000948	1.000360
"	100	1.00239	1.00180	N_2O	0	1.00108	1.00050
CO_2	0	1.000966	1.000377	SO_2	0	1.00993	1.00934
CO	0	1.000692	1.000104	H_2O, 4 atm	145	1.00705	1.00646
C_2H_4	0	1.00138	1.00079				

TABLE 436.—VARIATION OF THE DIELECTRIC CONSTANT WITH THE TEMPERATURE

If K_0 = the dielectric constant at the temperature θ°C of the above table, K_t at the temperature t°C, and α and β are quantities in the following table, then $K_t = K_\theta - \alpha (t - \theta) + \beta (t - \theta)^2$.

Ammonia	$\alpha = 5.45 \times 10^{-5}$	$\beta = 2.59 \times 10^{-7}$	Range, 15–110°C
Sulfur dioxide	6.19×10^{-5}	1.86×10^{-7}	0–110
Water vapor	1.4×10^{-4}	....	145

The dielectric constant of air at 76 cmHg and varying temperature may be calculated since K — 1 is approximately proportional to the density. See Table 437.

TABLE 437.—VARIATION OF THE DIELECTRIC CONSTANT OF GASES WITH THE PRESSURE

	°C	Pressure atm			°C	Pressure atm	
Air	19	20	1.0108	Air	11	120	1.0579
"	"	40	1.0218	"	"	140	1.0674
"	"	60	1.0330	"	"	160	1.0760
"	"	80	1.0439	"	"	180	1.0845
"	"	100	1.0548	CO_2	15	10	1.008
"	11	20	1.0101	"	"	20	1.020
"	"	40	1.0196	"	"	40	1.060
"	"	60	1.0294	N_2O	15	10	1.010
"	"	80	1.0387	"	"	20	1.025
"	"	100	1.0482	"	"	40	1.070

TABLE 438.—DIELECTRIC CONSTANT OF LIQUIDS (K). PRESSURE EFFECT[148]

	P	30°C		75°C	
	atm	K	Density	K	Density
C_5H_{12}	1	1.82	.613	...	...
Pentane	1000	1.96	.701	1.92	...
	4000	2.12	.796	2.11	...
	8000	2.24	.865	2.22	...
	12000	2.33	.907	2.31	...
CS_2	1	2.61	1.241	...	...
Carbon	1000	2.82	1.332	2.69	1.29
bisulfide	4000	3.11	1.487	3.02	1.46
	8000	3.33	1.601	3.28	1.58
	12000	3.52	1.689	3.45	1.66
$(C_2H_5)_2O$	1	4.15	.720	...	...
Ethyl	1000	4.88	.801	4.08	.74
ether	4000	6.05	.911	5.17	.87
	8000	6.93	.988	6.00	.94
	12000	7.68	1.047	6.94	1.00
C_6H_5Br	1	5.22	1.465	4.87	1.40
Bromo-	500	5.36	1.525	5.05	1.46
benzene	1000	5.47	1.558	5.16	1.50
	4000	5.88	1.705	5.62	1.65
	8000	...	...	5.95	1.76
C_6H_5Cl	1	5.41	1.004	4.90	.96
Chloro-	500	5.59	1.038	5.12	1.00
benzene	1000	5.75	1.065	5.28	1.03
	4000	6.33	1.152	5.88	1.13
	8000	...	...	6.29	1.20
$C_6H_{13}OH$	1	12.90	.812	8.55	.78
Hexyl	1000	13.54	.861	9.32	.84
alcohol	4000	15.06	.937	10.42	.92
	8000	...	...	11.15	.99

	P	0°		30°C	
	atm	K	Density	K	Density
C_2H_5OH	1	27.8	.806	23.2	.781
Ethyl	1000	29.4	.864	25.3	.844
alcohol	8000	35.3	1.031	31.7	1.019
	12000	57.6	1.082	33.7	1.073
C_4H_9OH	1	21.1	.819	17.3	.806
i-butyl	1000	22.9	.877	18.7	.856
alcohol	8000	26.8	1.031	22.8	1.018
	12000	28.2	1.080	23.9	1.069
$C_3H_8O_3$	1	49.9	1.272	42.8	1.254
Glycerine	1000	51.9	1.305	44.8	1.287
	4000	56.4	1.367	49.1	1.349
	8000	61.1	1.429	53.8	1.410

Anomalous dispersion 247000 cycles

Isobutyl-alcohol: 0°C

p:	1	2900	5810	9680	10830	12130
K:	21.1	24.4	25.9	27.4	27.2	26.4
Glycerine . P		1	1940	4290	6330	8490
0°C . . . . . K		49.9	53.4	55.6	52.2	40.1
Eugenol . . P		1	2960	5081	5680	6300
30°C . . . . K		9.42	10.79	11.09	10.57	6.05

[148] Danforth, Phys. Rev., vol. 38, p. 1224, 1931.

A wavelength greater than 10000 cm is designated by ∞.

Substance	Temp. °C	Wave-length, cm	Dielectric constant
Alcohol:			
Amyl	frozen	∞	2.4
"	−100	"	30.1
"	−50	"	23.0
"	0	"	17.4
"	+20	"	16.0
"	18	200	10.8
"	18	73	4.7
Ethyl	frozen	∞	2.7
"	−120	"	54.6
"	−80	"	44.3
"	−40	"	35.3
"	0	"	28.4
"	+20	"	25.8
"	17	200	24.4
"	"	75	23.0
"	"	53	20.6
"	"	4	8.8
"	"	.4	5.0
Methyl	frozen	∞	3.07
"	−100	"	58.0
"	−50	∞	45.3
"	0	"	35.0
"	+20	"	31.2
"	17	75	33.2
Propyl	−120	∞	46.2
"	−60	"	33.7
"	0	"	24.8
"	+20	"	22.2
"	15	75	12.3
Acetone	−80	∞	33.8
"	0	"	26.6
"	15	1200	21.85
"	17	73	20.7
Acetic acid	18	∞	9.7
" "	15	1200	10.3
" "	17	200	7.07
" "	19	75	6.29
Amyl acetate	19	∞	4.81
Amylene	16	"	2.20
Aniline	18	∞	7.316
Benzol (benzene)	18	"	2.288
" "	19	73	2.26
Bromine	23	84	3.18
Carbon bisulfide	20	∞	2.626
" "	17	73	2.64
Chloroform	18	∞	5.2
"	17	73	4.95
Decane	14	∞	1.97
Decylene	17	"	2.24
Ethyl ether	−80	∞	7.05
" "	−40	"	5.67
" "	0	"	4.68
" "	18	"	4.368
" "	20	"	4.30
" "	60	"	3.65

Substance	Temp. °C	Wave-length, cm	Dielectric constant
Ethyl ether	100	"	3.12
" "	140	"	2.66
" "	180	"	2.12
" "	Crit. temp. 192	"	1.53
" "	18	83	4.35
Formic acid	+2	73	19.0
" "	(frozen) 15	1200	62.0
" "	16	73	58.5
Glycerine	15	1200	56.2
"	15	200	39.1
"	15	75	25.4
"	—	8.5	4.4
"	—	.4	2.6
Hexane	17	∞	1.880
Hydrogen peroxide 46% in H_2O	18	75	84.7
Kerosene	—	—	.2
Meta-xylene	18	∞	2 37
" "	17	73	2.37
Nitrobenzol	(frozen) −10	∞	9.9
"	−5	"	42.0
"	0	"	41.0
"	+15	"	37.8
"	30	"	35.1
"	18	"	36.45
"	17	73	34.0
Octane	17	∞	1.949
Oils:			
Almond	20	∞	2.83
Castor	11	"	4.67
Colza	20	"	3.11
Cottonseed	14	"	3.10
Lemon	21	"	2.25
Linseed	13	"	3.35
Neatsfoot	—	"	3.02
Olive	20	"	3.11
Peanut	11.4	"	3.03
Petroleum	—	2000	2.13
Petroleum ether	20	∞	1.92
Rape seed	16	"	2.85
Sesame	13.4	"	3.02
Sperm	20	"	3.17
Turpentine	20	"	2.23
Vaseline	—	"	2.17
Phenol	48	73	9.68
Toluene	−83	∞	2.51
"	+16	"	2.33
"	19	73	2.31
Water	18	∞	81.07
(for temp. coeff.	17	200	80.6
see Table 440.)	17	74	81.7
	17	38	83.6

TABLE 440.—DIELECTRIC CONSTANT OF LIQUIDS

Temperature coefficients of the formula: $K_\theta = K_t[1 - a(t-\theta) + \beta(t-\theta)^2]$

Substance	a	β	Temp. range, °C
Amyl acetate	.0024	—	—
Aniline	.00351	—	—
Benzene	.00106	.0000087	10–40
Carbon bisulfide	.000966	—	—
" "	.000922	.00000060	20–181
Chloroform	.00410	.000015	22–181
Ethyl ether	.00459	—	—
Methyl alcohol	.0057	—	—
Oils: Almond	.00163	.000026	—
Castor	.01067	—	—
Olive	.00364	—	—
Paraffin	.000738	.0000072	
Toluene	.000921	—	0–13
"	.000977	.00000046	20–181
Water	.004474	—	5–20
"	.004583	.0000117	0–76
"	.00436	—	4–25
Meta-xylene	.000817	—	20–181

TABLE 441.—DIELECTRIC CONSTANT OF LIQUEFIED GASES

A wavelength greater than 10000 cm is designated by ∞.

Substance	Temp. °C	Wave-length, cm	Dielectric constant	Substance	Temp. °C	Wave-length, cm	Dielectric constant
Air	−191	∞	1.43_2				
"	"	75	1.47–1.50	Nitrous oxide			
Ammonia	−34	75	21–23	N_2O	−88	∞	1.93_3
"	14	130	16.2	" "	−5	"	1.63_0
Carbon dioxide	−5	∞	1.60_8	" "	+5	"	1.57_3
" "	0	"	1.58_3	" "	+15	"	1.52_0
" "	+10	"	1.54_0	Oxygen	−182	"	1.49_1
" "	+15	"	1.52_6	"	"	"	1.46_5
Chlorine	−60	"	2.15_0	Sulfur dioxide	14.5	120	13.75
"	−20	"	2.03_0	" "	20	∞	14.0
"	0	"	1.97_0	" "	40	"	12.5
"	+10	"	1.94_0	" "	60	"	10.8
"	0	"	2.08	" "	80	"	9.2
"	+14	100	1.88	" "	100	"	7.8
Cyanogen	23	84	2.52	" "	120	"	6.4
Hydrocyanic acid	21	"	about 95	" "	140	"	4.8
Hydrogen sulfide	10	∞	5.93	Critical	154.2	"	2.1
" "	50	"	4.92				
" "	90	"	3.76				

TABLE 442.—DIELECTRIC CONSTANT OF ROCKS *

Material	Wave-length, cm	Dielectric constant, range	Material	Wave-length, cm	Dielectric constant, range
Chalk, middle Devonian	...	8.0–9.0	Limestone	...	8.0–12.0
Coral dolomite	...	8.0–9.0	Marmorized limestone	3×10^4	15.2
Granite	...	7.0–9.0	Mica schist	...	16.0–17.0
			Sandstone, variegated	...	9.0–11.0

* For reference, see footnote 45, p. 136.

Substance	Condition	Wave-length, cm	Dielectric constant
Asphalt	—	∞	2.68
Barium sulfate	—	75	10.2
Caoutchouc	—	∞	2.22
Diamond	—	"	16.5
"	—	75	5.50
Ebonite	—	∞	2.72
"	—	"	2.86
"	—	1000	2.55
Glass	Density		
Flint (extra heavy)	4.5	∞	9.90
Flint (very light)	2.87	"	6.61
Hard crown	2.48	"	6.96
Mirror	—	"	6.44–7.46
"	—	"	5.37–5.90
"	—	600	5.42–6.20
Lead (Powell)	3.0–3.5	∞	5.4–8.0
Jena			
Boron	—	"	5.5–8.1
Barium	—	"	7.8–8.5
Borosilicate	—	"	6.4–7.7
Gutta percha	—	—	3.3–4.9
	Temp. °C		
Ice	−5	1200	2.85
"	−18	5000	3.16
"	−190	75	1.76–1.88
Iodine (cryst.)	23	75	4.00
Lead chloride (powder)	—	"	42
" nitrate	—	"	16
" sulfate	—	"	28
" molybdenate	—	"	24
Marble (Carrara)	—	"	8.3
Mica	—	∞	5.66–5.97
"	—	"	5.80–6.62
Madras, brown	—	"	2.5–3.4
" green	—	"	3.9–5.5
" ruby	—	"	4.4
Bengal, yellow	—	"	2.8
" white	—	"	4.2
" ruby	—	"	4.2–4.7
Canadian amber	—	"	3.0
South America	—	"	5.9
Ozokerite (raw)	—	"	2.21

Substance	Condition	Wave-length, cm	Dielectric constant
	Temp. °C		
Paper (telephone)	—	"	2.0
" (cable)	—	"	2.0–2.5
Paraffin		"	2.46
"	Melting point	"	2.32
"	44–46	"	2.10
"	54–56	"	2.14
"	74–76	"	2.16
"	47.6°C	61	2.16
"	56.2	61	2.25
Phosphorus:			
Yellow	—	75	3.60
Solid	—	80	4.1
Liquid	—	80	3.85
Porcelain:			
Hard (Royal B'l'n)	—	∞	5.73
Seger " "	—	"	6.61
Figure " "	—	"	6.84
Selenium	—	"	7.44
"	—	75	6.60
"	—	∞	6.13
"	—	1000	6.14
Shellac	—	∞	3.10
"	—	"	2.95–3.73
"	—	"	3.67
Amber	—	—	2.86
Sulfur			
Amorphous	—	∞	3.98
"	—	75	3.80
Cast, fresh	—	∞	4.22
" "	—	"	4.05
" "	—	75	3.95
Cast, old	—	∞	3.60
" "	—	75	3.90
Liquid	near melting-point	∞	3.42
Strontium sulfate	—	75	11.3
Thallium carbonate	—	75	17
" nitrate	—	75	16.5
Wood		dried	
Red beech	∥ fibers	∞	4.83–2.51
" "	⊥ "	"	7.73–3.63
Oak	∥ "	"	4.22–2.46
"	⊥ "	"	6.84–3.64

TABLE 444.—ELECTROSTRICTION *

Electrostriction is a change in the dimensions of a dielectric proportional to the square of an applied electric field. The effect is very small except for bodies of very high dielectric constant or high mechanical compliance.[n, e]

Typical values for—

Glasses	Rubber	Barium titanate polycrystalline
0.1 to 0.7×10^{-12} transverse	7×10^{-9} longitudinal	100×10^{-9} cm²/statvolt longitudinal

* Prepared by Hans Jaffe, Brush Development Co., Cleveland, Ohio.
[n, e] Letters refer to references, p. 431.

TABLE 445.—STANDARD SOLUTIONS FOR THE CALIBRATION OF APPARATUS FOR THE MEASURING OF DIELECTRIC CONSTANT

Substance	Diel. const. at 18°C $\lambda = \infty$	Acetone in benzene at 19°C $\lambda = 75$ cm: Percent by weight	Density 16°C	Dielectric constant	Temp. coefficient	Ethyl alcohol in water at 19.5°C $\lambda = \infty$: Per-cent by weight	Dielec-tric constant
Benzene	2.288	0	.885	2.26	.1%	100	26.0
Meta-xylene	2.376	20	.866	5.10	.3	90	29.3
Ethyl ether	4.36[7]	40	.847	8.43	.4	80	33.5
Aniline	7.29[8]	60	.830	12.1	.5	70	38.0
Ethyl chloride	10.90	80	.813	16.2	.5	60	43.1
O-nitro toluene	27.71	100	.797	20.5	.6		
Nitrobenzene	36.45						
Water (conduct. 10^{-6})	81.07						
		Water in acetone at 19°C $\lambda = 75$ cm					
		0	.797	20.5	.6%		
		20	.856	31.5	.5		
		40	.903	43.5	.5		
		60	.940	57.0	.5		
		80	.973	70.6	.5		
		100	.999	80.9	.4		

TABLE 446.—DIELECTRIC CONSTANT OF MINERALS *

Material	Wavelength, cm	Range	Dielectric constant ⊥ axis	Dielectric constant ‖ axis
Asphalt	...	2.7	...	...
Beryl	∞	...	7.85	6.05
Coal, anthracite	...	5.6–6.3	...	...
Fluorite	...	6.8	...	...
Glass, flint ex. heavy	...	9.9	...	...
Glass, hard crown	...	7.0	...	...
Glass, Jena barium	...	7.8–8.5	...	...
Glass, lead (Powell)	...	5.4–8.0	...	...
Gypsum	...	6.3	...	...
Ice (—2°C)	...	93.9	...	...
Iceland spar	75	...	8.50	8.00
Quartz, fused	...	3.5–3.6	...	...
Sulfur, amorphous	...	3.9	...	...

* For reference, see footnote 45, p. 136.

TABLE 447.—THE DIELECTRIC PROPERTIES OF NONCONDUCTORS

Results of tests at unit area and unit thickness of dielectric

At 1000 cycles	Mica	Paper	Celluloid	Ice
Max. breakdown volts per cm	1.06×10^{6}	$.71 \times 10^{6}$	1.05×10^{6}	$.001 \times 10^{6}$
Specific induc. capacity	4.00	4.90	13.26	86.40
Max. absorbable energy, watts-sec/cm^3	.198	.108	.640	.00040
90°-angle of lead	0° 57′	2° 10′	3° 40′	13° 39′
Equiv. resistance (ohm-cm) $\times 10^{11}$	3.91	9.84	48.3	1400
Conductivity, 1/(ohm-cm) $\times 10^{-10}$	2.56	1.02	.207	.00722
Percent change in cap. per cycle $\times 10^{4}$	2.18	14.31	30.7	70.0
Percent change in resistance per cycle	.258	.146	.106	.127
At 15 cycles				
Specific inductive capacity	4.09	5.77	18.60	429.0
Max. absorbable energy, watt-sec/cm^3	.203	.126	.90	.002
Percent change in capacity per cycle	.00	.306	1.74	1.59
On direct current				
Conductivity, 1/(ohm-cm)	2.42×10^{-17}	2.27×10^{-14}	71.5×10^{-14}	163.10^{-11}

TABLE 448.—VALUES OF DIELECTRIC CONSTANT FOR SEVERAL ELECTRIC INSULATING MATERIALS AT RADIO FREQUENCIES

Material	Frequency kc	Dielectric constant
Glass	30	5.1–7.9
cobalt	500	7.3
crown	230	6.3
	800	6.2
flint	500	7.0
	890	7.0
photographic	100	7.5
	1700	7.4
plate	500	6.8–7.6
Pyrex	30	4.8
	500	4.9–5.8
Marble	44	8.4
	80–650	9.2–11.7*
	1400	7.3
Mica	100–1000	5.8–8.7
Phenolic insulation:		
laminated	190	5.0–7.4
	1000	4.7–7.0
molded	190	4.3–7.6
	1000	4.9–7.0
Rubber, hard	135	3.7
	210	3.0
	1126	3.0–3.7
Wood:		
bay	870	3.8
birch	500	5.2
maple	500	4.4
oak	300	3.1†–6.7
	425	3.3
	635	3.0†–6.5
	1060	3.3

* Range of 10 samples of various kinds of marble.   † After drying sample for 48 hours at 80°C.

TABLE 449.—COMPARISON OF ELECTRICAL PROPERTIES OF INSULATING MATERIALS AT ROOM TEMPERATURE **

Material	Intrinsic dielectric strength: Thickness (mm)	Intrinsic dielectric strength: (Kv/cm)	Dielectric constant	Volume resistivity (ohm-cm)
Cellulose acetate	.025–.12	2300†	5.5	10^{12}
Glass:				
borosilicate No. 7740 (Pyrex)	.10	4800*	4.8	10^{16}
soda lead	.10	3100*	8.2	10^{14}
soda lime	.10	4500*	7.0	10^{12}
Mica, muscovite clear ruby	.020–.10	3000–8200†	7.3	10^{17}
Phenolic resin	.012–.04	2600–3300†	7.5	10^{11}
Porcelain, electrical	—	380†	4.4–6.8	10^{14}
Porcelain, steatite—low loss	—	500†	6.0–6.5	10^{15}
Silica, fused	—	5000*	3.5	10^{18}
Rubber, hard	.10–.30	2150†	2.8	10^{18}

** Table from Corning Glass Works publication on Properties of Selected Commercial Glasses (B-83).
* Values of P. H. Moon and A. S. Norcross, Trans. Amer. Inst. Electr. Engr., vol. 49, p. 775 (1930).
† Values of S. Whitehead. World Power, p. 72, September 1936.

Intrinsic dielectric strength can be realized only under test conditions and is very much higher than the working dielectric strength attainable in ordinary service. These data are listed for purposes of comparison.

cgs system, $K_{vacuum} = 1$

The dielectric constants,† K, given here have usually been determined at low field strength (order of 1 volt/cm). Unless specifically noted, the frequency is between 60 cycles/sec and 5 megacycles/sec. Homogeneous crystals show little dispersion in this frequency range unless they are strongly piezoelectric or have very high dielectric constant. For some strongly piezoelectric crystals, the notation "free" appears in the frequency column. Dielectric constants so noted hold for the mechanically unconstrained condition which is usually fulfilled for frequencies below the principal mechanical resonances of the test body. The dielectric constants for the "clamped" crystal are smaller than for the "free" crystal. The difference does not exceed 10 percent except for K_a of Rochelle salt (see fig. 16) and $K\|$ of barium titanate.

K_a, K_b, and K_c for orthorhombic crystals refer to electric field parallel to the crystallographic a, b, and c axes.

For monoclinic crystals, K_b refers to electric field parallel to the b axis which is the symmetry axis; K_c to field parallel to the c axis accepted by crystallographic convention; and K_a to an electric field perpendicular to the b and c axes.

* Tables 444, 450, and 451 prepared by Hans Jaffe, Brush Development Co., Cleveland, Ohio. † All data refer to room temperature unless otherwise noted.

Cubic crystals

Name	Composition	K	Authority[149]	Name	Composition	K	Authority
Silver chloride	$AgCl$	12.3	g	Sphalerite	ZnS	8.8	e
Silver bromide	$AgBr$	13.1	g	Sodium chlorate	$NaClO_3$	5.7	h
Lithium fluoride	LiF	9.00	f	Sodium bromate	$NaBrO_3$	5.7	h
Sodium chloride	$NaCl$	5.90	f	Magnesium oxide	MgO	9.65	f
Potassium chloride	KCl	4.68	g	Potassium bromide	KBr	4.90	f
Barium oxide	BaO	34.	o	Thallium chloride	$TlCl$	31.1	g

Uniaxial crystals

Name	Composition	$K\perp$	$K\|$	Frequency	Authority
Quartz	SiO_2	4.5	4.6	...	b
Calcite	$CaCO_3$	8.78	8.29	...	g
Sapphire	Al_2O_3‡	8.6	10.5	10^2—10^7	f
Rutile	TiO_2‡	86	170	10^5—10^6	f
Barium titanate	$BaTiO_3$	4400	200	?—10^7	i
Tourmaline	...	8.2	7.5	...	h
Magnesite	$MgCO_3$	6.91	8.1	...	g
Dihydrogen phosphates and arsenates:					
"ADP"	$NH_4H_2PO_4$	56	15.4	free	d
"KDP"	KH_2PO_4	46	22	free	h
"ADA"	$NH_4H_2AsO_4$	75	14	free	d
"KDA"	KH_2AsO_4	52	22	free	d

Orthorhombic crystals

Name	Composition	K_a	K_b	K_c	Frequency	Authority
Sulfur	S	3.75	3.95	4.45	$10^2 \times 10^8$	f
Celestite	$SrSO_4$	7.7	18.5	8.3	4×10^8	g
Barite	$BaSO_4$	7.65	12.2	7.7	4×10^8	g
Anglesite	$PbSO_4$	27.5	54.6	27.3	5×10^2—10^6	g
Epsomite	$MgSO_4 \cdot 7H_2O$	6.5	7.9	6.9	...	k
Ammonium oxalate	$(NH_4)_2C_2O_4 \cdot H_2O$	8.2	5.5	6.0	free	k
Potassium pentaborate	$KB_5O_8 \cdot 4H_2O$	4.6	5.5	4.5	free	d
Iodic acid	HIO_3	7.5	12.4	8.1	free	h

149 For authorities, see references, p. 431.
‡ Synthetic, Linde Air Products Company.

(*continued*)

TABLE 450.—DIELECTRIC CONSTANT OF CRYSTALS (concluded)

Name	Composition	K_a	K_b	K_c	Frequency	Authority
Tartrates:						
Rochelle salt	$NaKC_4H_4O_6 \cdot 4H_2O$	8.0	...	...	2.5×10^{10}	h
" " 30°C §..	...	300	9.4	9.6	free	c, j
	$NaNH_4C_4H_4O_6 \cdot 4H_2O$	9.0	8.9	10.0	free	h
	$LiKC_4H_4O_6 \cdot H_2O$	5.84	7.32	7.4	free	h
	$LiNH_4C_4H_4O_6 \cdot H_2O$	7.2	8.0	6.9	free	h
Monoclinic crystals						
Lithium sulfate	$Li_2SO_4 \cdot H_2O$	5.6	10.3	6.5	free	h
Tartaric acid	$C_4H_6O_6$	4.3	4.3	4.5	free	h
Potassium tartrate	$K_2C_4H_4O_6 \cdot \frac{1}{2}H_2O$	6.44	5.80	6.49	free	h
Ammonium tartrate ...	$(NH_4)_2C_4H_4O_6$	6.45	8.2	6.0	free	h
Ethylene diamine tartrate (EDT)	$C_2N_2H_8 \cdot C_4H_6O_6$	5.0	8.22	6.0	free	h

§ See also figure 16.

REFERENCES: a, Bechmann, R., and Lynch, A. C., Nature, vol. 163, p. 915, 1949. b, Cady, W. G., Piezoelectricity, McGraw-Hill, New York, 1946. c, Hablützel, J., Helvet. Phys. Acta, vol. 12, p. 489, 1939. d, Jaffe, H., The Brush Development Co. Report to U.S. Signal Corps on synthetic water-soluble piezoelectric crystals, April 1, 1948. e, Jaffe, H., personal communication. f, Laboratory for Insulation Research, Massachusetts Inst. Techn. Tables of Dielectric Materials III, 1948; and personal communication. g, Landolt Börnstein Tables, 5th ed. h, Mason, W. P., Piezoelectric crystals and their application to ultrasonics, Van Nostrand Co., New York, 1950. i, Merz, W. J., Phys. Rev., vol. 75, p. 687, 1949. j, Mueller, H., Phys. Rev., vol. 47, p. 175, 1935; vol. 58, p. 565, 1940. k, Naval Research Laboratory, Crystal Section. l, Spitzer, F., Dissertation, Göttingen, 1938. m, Standards on piezoelectric crystals, Proc. Inst. Radio Eng., vol. 37, p. 1378, 1949. n, International Critical Tables, vol. 6. o, Bever and Sproul, Phys. Rev., vol. 53, p. 801, 1951.

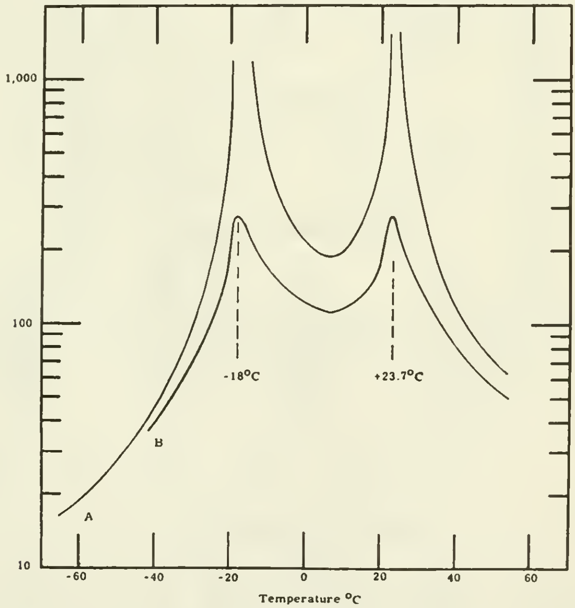


FIG. 16.—Dielectric constant K_a of Rochelle salt. Curve A: free condition (audio frequency); curve B: clamped condition (radio frequency).

TABLE 451.—PIEZOELECTRICITY

In this table are listed piezoelectric strain coefficients * d_{nm} which are ratios of piezoelectric polarization components to components of applied stress at constant electric field (direct piezoelectric effect) and also ratios between piezoelectric strain components to applied electric field components at constant mechanical stress (converse effect). The subscripts n = 1 to 3 indicate electric field components, m = 1 to 6 mechanical stress or strain components. These components are referred to orthogonal coordinate axes. For correlation of these to crystallographic axes, we follow Standards on Piezoelectric Crystals.[m]

In the monoclinic system, indices 2 and 5 refer to the symmetry (*b*) axis, in distinction from the older convention [b] relating indices 3 and 6 to the symmetry axis. Crystal classes are designated by international (Hermann-Mauguin) symbols. A dot in place of a coefficient indicates that it is equal by symmetry from another listed coefficient; a blank space indicates that the coefficient is zero by symmetry. If the sign of a coefficient is not given it is unknown, not necessarily positive.

$$\text{Unit for } d_{nm} = 10^{-8} \text{ statcoulomb/dyne} = \frac{1}{3} \times 10^{-12} \text{ coulomb/newton}$$

$$= 10^{-8} \text{ cm/statvolt} = \frac{1}{3} \times 10^{-12} \text{ meter/volt}$$

* The coefficient d_{14} of Rochelle salt is extremely dependent on temperature and on amplitude. The ratio of d_{14} to dielectric constant K (for the latter see figure 16) is, however, nearly constant; $4\pi d_{14}/K = g_{14} = 6.4 \times 10^{-7}$ statvolt cm/dyne.

m Letters refer to references, p. 431.

Cubic and tetragonal crystals

Name	Composition	Class	d_{14}	d_{36}	Authority[149]
Sphalerite	ZnS	43m	9.7	·	b
Sodium chlorate	$NaClO_3$	23	5.2	·	l
Sodium bromate	$NaBrO_3$	23	7.3	·	l
"ADP"	NH_4H_2PO	$\bar{4}2m$	− 1.5	+48.0	d
"KDP"	KH_2PO_4	$\bar{4}2m$	+ 1.3	+21	e
"ADA"	$NH_4H_2AsO_4$	$\bar{4}2m$	+41	+31	d
"KDA"	KH_2AsO_4	$\bar{4}2m$	+23.5	+22	d

Trigonal crystals

Name	Class	d_{11}	d_{14}	d_{15}	d_{22}	d_{31}	d_{33}	Authority
Quartz	32	+6.9	−2.0					b
Tourmaline	3m			+11.0	−.94	+.96	+5.4	b

Orthorhombic crystals

Substance	Class	d_{14}	d_{25}	d_{36}	Authority
Epsomite	222	−6.2	−8.2	−11.5	l
Iodic acid	222	57	46	70	h
Rochelle salt (30°C)	222	+1500*	−160	+35	b
$NaNH_4$ tartrate	222	+56	−150	+28	b
LiK tartrate	222	9.6	33.6	22.8	h
$LiNH_4$ tartrate	222	13.2	19.6	14.8	h
$(NH_4)_2$ oxalate	222	50	11	25	e

Substance	Class	d_{15}	d_{24}	d_{31}	d_{32}	d_{33}	Authority
K pentaborate	mm	9.5	1.7	−5.4	0	+5.6	d

Monoclinic crystals (Class 2)

Substance	d_{14}	d_{16}	d_{21}	d_{22}	d_{23}	d_{26}	d_{34}	d_{36}	Authority
Lithium sulfate	+14.0	−12.5	+11.6	−45.0	−5.5	+16.5	−26.4	+10.0	h
Tartaric acid	+24.0	+15.8	−2.3	−6.5	−6.3	+1.1	−32.4	+35.0	h
K_2 tartrate (DKT)	−25	+6.5	−2.2	+8.5	−10.4	−22.5	+29.4	−66.0	h
$(NH_4)_2$ tartrate	+9.3	−8.5	+17.6	−26.2	+1.8	−5.9	−14.0	+5.6	l
EDT (Ethylene diamine tartrate)	−31.1	−36.5	+30.6	+6.6	−33.8	−54.3	−51	−56.9	a
Cane sugar	−3.7	−7.2	+4.4	−10	+2.2	−2.6	−1.3	+1.3	b

(*continued*)

Polarized polycrystalline substance

	d_{15}	d_{31}	d_{33}	Authority
Barium titanate ceramic .... K = 1700	750	−235	+570	e

TABLE 452.—VALUES FOR POWER FACTOR IN PERCENT FOR SEVERAL ELECTRICAL INSULATING MATERIALS AT RADIO FREQUENCIES

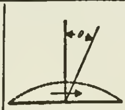
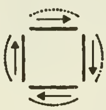
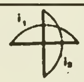
From the range of values given, an approximate figure can be taken for a particular material and its relative position with respect to other materials seen. Data of this kind are much affected by the condition and past treatment of the samples and by the conditions of the tests. The power factor and dielectric constant of dry air may be taken as 0 and 1.00. Fused quartz has the lowest power factor among the solid insulating materials, and is used for supporting the insulated plates of standard air condensers.

Material	Frequency kc	Power factor
Amber	187.5	.459
	300	.476
	600	.495
	1000	.514
Glass	30	.35 – 2.98*
	600	.040– .653†
cobalt	500	.70
flint	500	.42
	890	.40
photographic	100	.95
	235	.86
	1700	.77
plate	14	.97
	100	.77 – .93
	500	.66 – .70
	635	.82
	1000	.62
Pyrex	14	.88
	30	.26 – .56
	100	.58 – .74
	420	.50
	500	.42 – .67
	750	.68
Marble	80–650	.35 – 4.72‡
Mica	600	.007– .93§
Paraffin	14	.042
	100	.017– .031
	500	.026
	1070	.034
Phenolic insulation:		
laminated ‖ .	190	2.62 – 8.0
	1000	3.85 – 6.65
molded ‖ ...	190	1.64 –10.9
	1000	1.56 – 8.4
Rubber, hard ..	135	.68
	315	.70
	600	.62
	625	.70
	710	.88
	1000	.68
	1085	.74
	1126	1.05
Wood:		
bay	870	3.76
birch	500	6.48
maple	500	3.33 – 3.63
oak	300	2.94¶–13.8
	635	3.24¶–10.1
	1060	4.20

* Range of 9 samples. † Range of 27 samples. ‡ Range of 10 samples. § Range of a number of samples from different localities. ‖ Range of several samples. ¶ After drying 48 hours at 80°C.

Antenna arrays (figs. 17-19).—The basis for all directivity control in antenna arrays is wave interference. By providing a large number of sources of radiation, it is possible with a fixed amount of power greatly to reinforce radiation in a desired direction by suppressing the radiation in undesired directions. The individual sources may be any type of antenna.

The radiation patterns of several common types of individual elements are shown in figure 17. The expressions hold for linear radiators, rhombics, vees, horn radiators, or other complex antennas when combined into arrays, provided a suitable expression is used for A, the radiation pattern of the individual

type of radiator	current distribution	directivity horizontal $F(\theta)$	directivity vertical $F(\beta)$
Half-wave dipole		$F(\theta) = K\dfrac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta} \cong K\cos\theta$	$F(\beta) = K(1)$
Shortened dipole		$F(\theta) \cong K\cos\theta$	$F(\beta) = K(1)$
Lengthened dipole		$F(\theta) = K\left[\dfrac{\cos\left(\frac{\pi l}{\lambda}\sin\theta\right) - \cos\frac{\pi l}{\lambda}}{\cos\theta}\right]$	$F(\beta) = K(1)$
Horizontal loop		$F(\theta) \cong K(1)$	$F(\beta) = K\cos\beta$
Horizontal turnstile	 i_1 and i_2 phased 90°	$F(\theta) \cong K'(1)$	$F(\beta) \cong K'(1)$

θ = horizontal angle measured from perpendicular bisecting plane

β = vertical angle measured from horizon

K and K' are constants and $K' \cong 0.7K$

FIG. 17.—Radiation patterns of several common types of antennas.

antenna. The array expressions are multiplying factors. Starting with an individual antenna having a radiation pattern given by A, the result of combining it with similar antennas is obtained by multiplying A by a suitable array factor, thus obtaining an A' for the group. The group may then be treated as a single source of radiation. The result of combining the group with similar groups, or, for instance, of placing the group above ground, is obtained by multiplying A' by another of the array factors given.

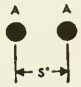
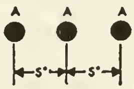
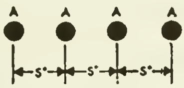
The expressions given here assume negligible mutual coupling between individual antennas. When coupling is not negligible, the expressions apply only if the feeding is adjusted to overcome the coupling and thus produce resultant currents that are of the amplitude and relative phases indicated.

* Data arranged by Newbern Smith and Marcella Phillips, Central Radio Propagation Laboratory, National Bureau of Standards.

(*continued*)

One of the most important arrays is the linear multielement array where a large number of equally spaced antenna elements are fed equal currents in phase to obtain maximum directivity in the forward direction. Figure 18 gives expressions for the radiation pattern of several particular cases and the general case of any number of broadside elements.

In this type of array a great deal of directivity may be obtained. A large number of minor lobes, however, are apt to be present, and they may be undesirable under some conditions, in which case a type called the binomial array may be used. Here again all the radiators are fed in phase but the current is not distributed equally among the array elements, the center radiators in the array

configuration of array	expression for intensity $F(\theta)$
	A[1]
	$2A\left[\cos\left(\frac{s^\circ}{2}\sin\theta\right)\right]$
	$A + 2A\,[\cos(s^\circ\sin\theta)]$
	$4A\left[\cos(s^\circ\sin\theta)\cos\left(\frac{s^\circ}{2}\sin\theta\right)\right]$
m radiators (general case)	$A\dfrac{\sin\left(m\frac{s^\circ}{2}\sin\theta\right)}{\sin\left(\frac{s^\circ}{2}\sin\theta\right)}$

$A = 1$ for horizontal loop, vertical dipole

$A = \dfrac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta}$ for horizontal dipole

s° = spacing of successive elements in degrees

FIG. 18.—Linear multielement array broadside directivity.

being fed more current than the outer ones. Figure 19 shows the configuration and general expression for such an array. In this case the configuration is made for a vertical stack of loop antennas in order to obtain single-lobe directivity in the vertical plane. If such an array were desired in the horizontal plane, say n dipoles end to end, with the specified current distribution the expression would be

$$F(\theta) = 2^{n-1}\left[\frac{\cos \pi/2 \sin\theta}{\cos\theta}\right]\cos^{n-1}(1/2\ S^\circ \sin\theta)$$

The term binomial results from the fact that the current intensity in the successive array elements is in accordance with the binomial expansion $(1+1)^{n-1}$, where n is the number of elements.

(continued)

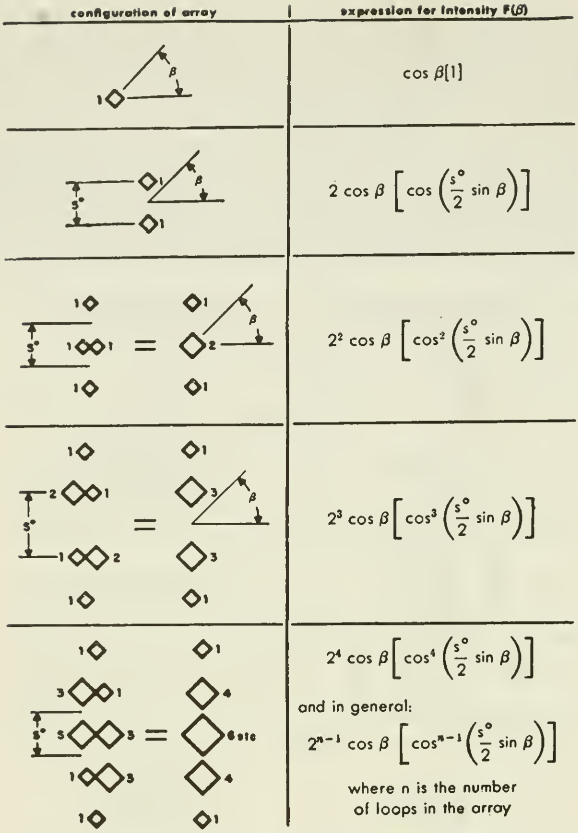


FIG. 19.—Development of binomial array.

TABLE 453.—DIELECTRIC CONSTANT OF NONPOLAR GASES[160]

at 0°C and 76cmHg

Gas	$(K-1)\times10^6$	Gas	$(K-1)\times10^6$	Gas	$(K-1)\times10^6$
Helium	69.2	Hydrogen	272	Carbon dioxide	988
Neon	134.1	Oxygen	532.5	Air (CO_2 free)	570
Argon	554.2	Nitrogen	580		

[160] Jelatis, J. G., Journ. Appl. Phys., vol. 19, p. 419, 1948; Hecter, L. G., and Woernley, D. C., Phys. Rev., vol. 69, p. 101, 1946.

TABLE 454.—DIELECTRIC CONSTANT AND LOSS TANGENT OF DIELECTRIC MATERIALS[151]

The following table presents values of dielectric constant,[a] ϵ' (relative to that vacuum ϵ_0) and loss tangent, tan δ, for various substances at the frequencies and temperatures indicated. The loss tangent, tan δ, is identical with the power factor, cos θ (or sin δ), for low loss substances. The table shows it multiplied by 10^4.

Part 1.—Solids

Materials	Temp. °C		Frequency, cycles per second 1×10^2	1×10^3	1×10^6	1×10^8	1×10^{10}
A. Inorganic							
1. *Crystals*							
Ice[1]*	−12	ϵ'/ϵ_0			4.15		3.17
		tan δ			1200		7
Sodium chloride[2]	25	ϵ'/ϵ_0	5.90	5.90	5.90		5.90
		tan δ	<1	<1	<2		5
2. *Ceramics*							
a. Steatite bodies							
AlSiMag 211[3]	25	ϵ'/ϵ_0	6.00	5.98	5.97	5.96	5.90
		tan δ	92	34	5	4	14
b. Miscellaneous							
Ruby mica[4]	26	ϵ'/ϵ_0	5.4	5.4	5.4	5.4	
		tan δ	25	6	3	2	
Mycalex K 10[5]	24	ϵ'/ϵ_0	9.5	9.3	9.0		11.3**
		tan δ	170	125	26		40
Porcelain, dry process[6]	25	ϵ'/ϵ_0	5.50	5.36	5.08	5.04	4.74
		tan δ	220	140	75	78	156
3. *Glasses*							
Corning No. 790[7]	20	ϵ'/ϵ_0	3.85	3.85	3.85		3.82
		tan δ	6	6	6		9.4
Corning No. 1990[8]	24	ϵ'/ϵ_0	8.40	8.38	8.30	8.20	7.94
		tan δ	4	4	5	9	42
Foamglas[9]	23	ϵ'/ϵ_0	90.0	82.5	17.5		5.49
		tan δ	1500	1600	3180		455
Fused quartz[10]	25	ϵ'/ϵ_0	3.78	3.78	3.78	3.78	3.78
		tan δ	8.5	7.5	2	1	1
B. Organic, with or without inorganic components							
1. *Crystals*							
Naphthalene[11]	25	ϵ'/ϵ_0		2.85	2.85		
		tan δ		19	3		
2. *Plastics*							
a. Phenol-formaldehyde							
Bakelite BM-16981[12]	25	ϵ'/ϵ_0	5.05	4.87	4.72	4.62	4.52
(powder preheated)		tan δ	190	160	72	56	82
Formica XX[13]	26	ϵ'/ϵ_0	5.23	5.15	4.60	4.04	3.55†
(field ⊥ to laminate)		tan δ	230	165	340	570	700†
b. Phenol-aniline-formaldehyde							
Resinox 7013[14]	25	ϵ'/ϵ_0	4.64	4.55	4.37	4.30	4.25
(preformed and preheated)		tan δ	160	137	62	77	124
c. Melamine-formaldehyde							
Formica grade FF-41[15] (sheet stock)	26	ϵ'/ϵ_0	6.15	6.00	5.75	5.5	
		tan δ	400	119	115	200	
Melmac resin 592[16]	27	ϵ'/ϵ_0	6.70	6.25	5.20	4.70	4.59
		tan δ	590	470	347	360	434
d. Urea-formaldehyde							
Plaskon urea, natural[17]	24	ϵ'/ϵ_0	7.1	6.7	6.0	5.2	4.65
		tan δ	380	280	310	500	782
e. Hexamethylene-adipamide							
Nylon 610[18]	25	ϵ'/ϵ_0	3.60	3.50	3.14	3.0	
		tan δ	155	186	218	200	
Nylon 610[18]	25	ϵ'/ϵ_0	4.5	4.2	3.2	3.0	
90% humidity		tan δ	650	640	380	220	

[151] These data were selected from Tables of Dielectric Materials, volume 3, Laboratory of Insulation Research, Massachusetts Institute of Technology, Cambridge, Mass., June 1948.
[a] ϵ is used for dielectric constant in this table in the place of K.
* Numbers refer to notes at end of table.
** Not corrected for variations of density.
† Rod stock in H_{11} (TE_{11}) made of circular wave guide.

(*continued*)

TABLE 454.—DIELECTRIC CONSTANT AND LOSS TANGENT OF DIELECTRIC MATERIALS (continued)

Materials	Temp. °C		Frequency, cycles per second 1×10^2	1×10^3	1×10^6	1×10^8	1×10^{10}
f. Cellulose derivatives							
(1) Acetates							
Tenite II 205A H_2[19]..							
(cellulose acetate)	26	ϵ'/ϵ_0	3 54	3.50	3.28	3.05	
(butyrate)		tan δ	78	107	178	190	
(2) Nitrate							
Pyralin[20]	27	ϵ'/ϵ_0	10.8	8.4	6.6	5.2	3 32
		tan δ	6400	1000	640	1030	1310
(3) Ethyl cellulose							
Ethocel No. 2840[21] ..	25	ϵ'/ϵ_0	3.90	3.80	3.40	3.20	
		tan δ	75	210	275	240	
g. Silicone resins							
DC 2101[22]	25	ϵ'/ϵ_0	2.9	2.9	2.9	2.9	
		tan δ	70	56	45	45	
h. Polyvinyl resins							
Polyethylene DE-3401[23] ...	25	ϵ'/ϵ_0	2.26	2.26	2.26		2.26
		tan δ	<2	<2	<2		3.6
Vinylite QYNA[24]	20	ϵ'/ϵ_0	3.18	3.10	2.88	2.85	
		tan δ	130	185	160	81	
Saran B-115[25]	23	ϵ'/ϵ_0	4.88	4.65	3.18	2.82	2.70
		tan δ	800	630	570	180	51
Lucite HM-119[26]	23	ϵ'/ϵ_0	3.20	2.84	2.63	2.58	2.57
		tan δ	620	440	145	67	49
Polystyrene[27]	25	ϵ'/ϵ_0	2.56	2.56	2.56	2.55	2.54
(commercially molded)		tan δ	<.5	<.5	.7	<1	4.3
Sheet stock							
3. *Elastomers*							
Hevea rubber[28]	25	ϵ'/ϵ_0	2.4	2.4	2.4	2.4	
		tan δ	28	18	18	50	
Gutta-percha[29]	25	ϵ'/ϵ_0	2.61	2.60	2.53	2.47	2.38
		tan δ	5	4	42	120	50
GR-S (Buna S)[30]	26	ϵ'/ϵ_0	2.66	2.66	2.56	2.52	2.44
compound		tan δ	7	9	120	95	50
GR-I (Butyl rubber)[31]	25	ϵ'/ϵ_0	2.39	2.38	2.35	2.35	2.35
		tan δ	34	35	10	10	8
Neoprene GR-M[32]	26	ϵ'/ϵ_0	7.5	6.5	5.7	3.4	
		tan δ	8000	860	950	1600	
4. *Natural resins*							
Amber[33]	25	ϵ'/ϵ_0	2.7	2.7	2.65		
		tan δ	12.5	18	56		
Shellac, natural XL[34]	28	ϵ'/ϵ_0	3.86	3.81	3.47	3.10	
		tan δ	65	74	310	300	
5. *Asphalts and Cement*							
Plicene cement[35]	25	ϵ'/ϵ_0	2.48	2.48	2.48	2.47	2.35
		tan δ	43.9	35.5	25.5	15	6.8
6. *Waxes*							
Apiezon wax "W"[36]	22	ϵ'/ϵ_0	2.75	2.69	2.63		
		tan δ	186	120	25		
Beeswax, white[37]	23	ϵ'/ϵ_0	2.65	2.63	2.43	2.39	2.35
		tan δ	140	118	84	60	48
Ceresin, white[38]	25	ϵ'/ϵ_0	2.3	2.3	2.3	2.3	2.24
		tan δ	8	6	4	4	6.5
Paraffin wax[39]	25	ϵ'/ϵ_0	2.25	2.25	2.25	2.25	2.24
132° ASTM		tan δ	<2	<2	<2	<2	2.1
Sealing wax[40]	25	ϵ'/ϵ_0	3.68	3.52	3.29	3.2	
Red express		tan δ	249	150	80	120	
7. *Woods*							
Balsa	26	ϵ'/ϵ_0	1.4	1.4	1.37	1.30	1.20
		tan δ	50	40	120	135	83
Fir, Douglas, plywood ‡	25	ϵ'/ϵ_0	2.1	2.1	1.90		
		tan δ	115	105	230		
Mahogany ‡	25	ϵ'/ϵ_0	2.42	2.40	2.25	2.07	1.7
		tan δ	86	120	250	320	210

‡ Field ⊥ to grain.

(*continued*)

TABLE 454.—DIELECTRIC CONSTANT AND LOSS TANGENT OF DIELECTRIC MATERIALS (continued)

Part 2.—Liquids

Materials	Temp. °C		Frequency, cycles per second				
A. Inorganic			1×10^5	1×10^6	3×10^8	3×10^9	1×10^{10}
Water, conductivity[41]	1.5	ϵ'/ϵ_0	87.0	87.0	86.5	80.5	38
		$\tan\delta$	1,900	190	320	3,100	10,300
	25	ϵ'/ϵ_0	78.2	78.2	77.5	76.7	55
		$\tan\delta$	4,000	400	160	1,570	5,400
	45	ϵ'/ϵ_0		71.5	71.0	70.7	59
		$\tan\delta$		590	105	1,060	4,000
	65	ϵ'/ϵ_0		64.8	64.5	64.0	59
		$\tan\delta$		865	84	765	3,200
	85	ϵ'/ϵ_0	58	58	57	56.5	54
		$\tan\delta$	12,400	1.240	73	547	2,600
B. Organic							
1. *Aliphatic*			1×10^2	1×10^3	1×10^6	1×10^8	
Methyl alcohol[42]	25	ϵ'/ϵ_0			31	31	8.9
		$\tan\delta$			2,000	380	8,100
Ethyl alcohol[43]	25	ϵ'/ϵ_0			24.5	23.7	1.7
		$\tan\delta$			900	620	680
n-Propyl alcohol[44]	25	ϵ'/ϵ_0			20.1	19.0	2.3
		$\tan\delta$			180	2000	900
Carbon tetrachloride[45]	25	ϵ'/ϵ_0	2.17	2.17	2.17	2.17	2.17
		$\tan\delta$	60	8	<.4	<2	16
2. *Aromatic*							
Nitrobenzene[45]	25	ϵ'/ϵ_0			36		
		$\tan\delta$			80		
Styrene N-100[46]	22	ϵ'/ϵ_0	2.40	2.40	2.40		2.36
		$\tan\delta$	38	5	<3		58
3. *Insulating oils*							
Bayol[47]	24	ϵ'/ϵ_0	2.14	2.14			2.14
		$\tan\delta$	12.6	2			18
Fractol[48]	26	ϵ'/ϵ_0	2.17	2.17			2.16
		$\tan\delta$	<1	<1			11.3
Marcol[49]	24	ϵ'/ϵ_0	2.14	2.14	2.14		2.14
		$\tan\delta$	1	<1	<2		11.2
Primol-D[50]	24	ϵ'/ϵ_0	2.17	2.17	2.17		2.16
		$\tan\delta$	<1	<1	<2		10.6
Cable oil 5314[51]	25	ϵ'/ϵ_0	2.25	2.25			2.22
		$\tan\delta$	3	<.4			22
	80	ϵ'/ϵ_0	2.18	2.18			
		$\tan\delta$	38	4			
Pyranol 1467[52]	25	ϵ'/ϵ_0	4.40	4.40	4.40	4.04	2.65
		$\tan\delta$	36	3	190	1300	750
Halowax oil 1000[53]	25	ϵ'/ϵ_0	4.80	4.77	4.77		2.99
		$\tan\delta$	490	50	<2		1850
4. *Lubricants*							
Vaseline	25	ϵ'/ϵ_0	2.16	2.16	2.16	2.16	2.16
		$\tan\delta$	3	2	<1	<4	10
Silicone fluid No. 500,[54]	22	ϵ'/ϵ_0	2.76	2.76			2.72
100 cs. at 25°C		$\tan\delta$	.4	<.4			240
Silicone fluid No. 200,[54]	23	ϵ'/ϵ_0	2.76	2.76			2.70
100 cs. at 25°C		$\tan\delta$	.8	.4			320

NOTES: 1, From conductivity water. 2, Fresh crystals (Harshaw). Audio frequency loss decreases with time. For a discussion of low-frequency dispersion in ionic crystals see R. G. Breckenridge, Bull. Amer. Phys. Soc., vol. 23, p. 33, 1948. 3, Magnesium silicate (American Lava). 4, Muscovite. 5, Mica, glass, TiO_2 (Mycalex). 6, Knox. 7, 96% SiO_2. 8, Iron sealing glass. 9, Soda-lime (Pittsburgh-Corning). 10, SiO_2 (General Electric). 11, Eastman Kodak; recryst. and resubl. Lab. Ins. Res. 12, Mica-filled (Bakelite). 13, 50% paper laminate (Formica). 14, 58% mica, 2% misc. (Monsanto). 15, 55% filler (Formica). 16, Mineral filler (American Cyanamid). 17, α-cellulose (Libbey-Owens-Ford). 18, DuPont. 19, 5-15% plasticizer, pigments, dyes (Tennessee Eastman). 20, 25% camphor (DuPont). 21, 2.73 ethoxy groups/glucose, plast. (Dow). 2, Cross-linked organo siloxane polymer (Dow Corning). 23.

(*continued*)

TABLE 454.—DIELECTRIC CONSTANT AND LOSS TANGENT OF DIELECTRIC MATERIALS (concluded)

1% antioxidant (Bakelite). 24, 100% polyvinyl chloride (Bakelite). 25, Polyvinylidene and vinyl chlorides (Dow). 26, Polymethyl methacrylate (DuPont). 27, For sheet stock, various samples used for different frequencies; for rod stock, ϵ'/ϵ_0 is the same as for sheet stock. (Plax). 28, Pale crepe (Rubber Research Corp.). 29, Palaquium Oblongifolium (Hermann Weber). 30, 100 pts GR-S, 1 pt stearic acid, 5 pts Kadox, 5 pts Captax, 3 pts sulfur (Rubber Research Corp). 31, Copolymer of 98-99% isobutylene, 1-2% isoprene (Rubber Research Corp.). 32, Poly-2-chlorobutadiene-1, 3 stabilized with Methyl Tuads (DuPont). 33, Fossil resin (Amber Mines). 34, Contains ca. 3.5% wax (Zinsser). 35, Central Scientific. 36, Shell Oil. 37, Bromund. 38, Vegetable and mineral waxes (Kuhne-Libby). 39, Mainly C_{22} to C_{29} aliphatic, saturated hydrocarbons (Standard Oil New Jersey). 40, Dennison. 41, Research Laboratory of Physical Chemistry, Massachusetts Inst. Techn. 42, Absolute, Analytical Grade (Mallinckrodt). 43, Absolute (U. S. Industrial Chemicals). 44, Eastman Kodak. Dried and refractionated, Lab. Ins. Res. 45, Purified Lab. Ins. Res. 46, Dow. 47, 72.0% paraffins, 28.0% naphthenes (Stanco). 48, 57.4% paraffins, 42.6% naphthenes (Stanco). 49, 72.4% paraffins, 27.6% naphthenes (Stanco). 50, 49.4% paraffins, 50.6% naphthenes (Stanco). 51, Aliphatic and aromatic hydrocarbons (General Electric). 52, Chlorinated benzenes and diphenyls (General Electric). 53, 60% mono-, 40% di- and trichloronaphthalenes (Bakelite). 54, Methyl or ethyl siloxane polymer (Dow Corning).

cs., centistoke.

TABLE 455.—DIELECTRIC CONSTANT AND CONDUCTIVITY OF SOILS[152]

Measurements of samples of soil taken from different depths at various sites in England

Geological classification	Depth ft	Description of sample	Moisture content % by weight	Conductivity (in esu) at 20°C: 1 kc	100 kc	1.2 Mc	10 Mc	Dielectric constant: 1.2 Mc	10 Mc
Lower lias	Surface	Dark fibrous loam	60	3.0×10^8	3.4×10^8	3.9×10^8	6.0×10^8	100	55
	1	Loam and clay	33	6.5	7.0	7.0	9.0	95	43
	2	Clay and sand	26	7.5	8.0	8.0	12.0	105	48
	3	Blue clay	25	8.0	9.0	9.5	11.0	95	46
Chalk	Surface	Fibrous loam	21	.85	.90	.95	1.4	39	23
	1	Chalky loam	21	.55	.55	.85	.95	41	25
	2	Chalk	24	.28	.26	.38	.61	28	21
Upper greensand	Surface	Fibrous loam	37	2.7	3.4	4.0	5.0	80	49
	1	Brown, sandy clay	19	2.2	2.4	2.4	3.8	39	19
	2	Brown sand	15	1.8	2.0	2.1	3.3	33	19
Upper lias	Surface	Fibrous loam	28	.85	.95	1.1	1.6	48	30
	1	Sandy loam	16	.34	.34	.40	.61	20	17
	2	Brown sand	14	.29	.29	.33	.46	20	14
	5	Sand and sandstone	8.5	.075	.090	.12	.22	14	9
Red marls	Surface	Reddish-brown loam	23	1.5	1.7	1.8	2.3	46	32
	1	Reddish-brown clay	20	1.5	1.7	1.8	2.5	50	33
	2	Reddish-brown clay	18	2.6	2.8	3.1	3.6	80	45
Devonian	Surface	Black fibrous loam	21	1.3	1.5	1.8	2.5	90	65
	1	Loam and slate	9.0	.026	.030	.040	.060	12	10
	10	Slate	—	.00026	.0025	.0092	.046	9.5	8.0
Granite	1	Gritty loam	18	.12	.12	.16	.18	22	15
	3 to 10	Granite	—	.00090	.0070	.028	.11	12	8.5
	3 to 10	Granite	—	.00070	.0050	.019	.095	10.0	7.5
Boulder clay	Surface	Fibrous loam	38	.55	.65	.75	1.1	50	20
	2	Clay and loam	19	1.1	1.1	1.2	1.7	60	21
	3	Dark grit and clay	18	.60	.70	.80	1.2	50	19

[152] Smith-Rose, Journ. Inst. Electr. Eng., London, vol. 75, p. 221, 1934.

The dipole moments are given in Debye units (1 Debye unit $= 1 \times 10^{-18}$ esu). The moments listed were obtained from gaseous measurements. The data are taken from Tables of Electric Dipole Moments, April 1947, compiled by L. G. Wesson, Laboratory for Insulation Research, Massachusetts Inst. Techn., Cambridge, Mass. Where several sources were given, a study was made to select the best value. Reference to original sources can be made from the above tables.

Part 1.—Inorganic substances

Substance	Electric dipole moment 1×10^{-18} esu	Substance	Electric dipole moment 1×10^{-18} esu
Ammonia	1.46	Nitric oxide	.1
Argon	.0	Nitrogen	.0
Arsine	.16	Nitrogen dioxide	.3
Boron fluoride	.0	Oxygen	.0
Deuterium chloride	1.089	Phosphine	.55
Helium	.0	Potassium chloride	6.3
Hydrogen	.0	Silane, SiH_4	.0
Hydrogen fluoride	1.91	Sodium iodide	4.9
Hydrogen iodide	.38	Sulfur dioxide	1.7
Krypton	.0	Water	1.84
Neon	.0	Xenon	.0

Part 2.—Organic substances

Substance	Electric dipole moment 1×10^{-18} esu	Substance	Electric dipole moment 1×10^{-18} esu
Phosgene CCl_2O (carbonyl chloride)	1.18	Ethyl chloride C_2H_5Cl	2.00
Thiophosgene CCl_2S	.28	Ethyl fluoride C_2H_5F	1.92
Carbon tetrachloride CCl_4	.0	Ethyl iodide C_2H_5I	1.87
Chloroform $CHCl_3$	1.02	Nitroethane $C2H_5NO_2$	3.70
Hydrogen cyanide CHN	2.94	Ethane C_2H_6	.0
Formaldehyde CH_2O	2.27	Ethyl alcohol C_2H_6O	1.68
Formic acid CH_2O_2	1.51	Methyl sulfone $C_2H_6O_2S$	4.41
Methyl bromide CH_3Br	1.79	Dimethylamine C_2H_7N	.99
Methyl chloride CH_3Cl	1.86	Cyanogen C_2N_2	.0
Methyl iodide CH_3I	1.64	Propene (propylene) C_3H_6	.35
Formamide CH_3NO	3.22	Acetone C_3H_6O	2.85
Nitromethane CH_3NO_2	3.49	Methyl acetate $C_3H_6O_2$	1.67
Methane CH_4	.0	Ethyl ether $C_4H_{10}O$	1.14
Methyl alcohol CH_4O	1.69	Ethyl sulfide $C_4H_{10}S$	1.51
Carbon monoxide CO	.11	Diethyl carbonate $C_5H_{10}O_3$	1.06
Carbon dioxide CO_2	.0	Bromobenzene C_6H_5Br	1.74
Carbon disulfide CS_2	.0	Chlorobenzene C_6H_5Cl	1.69
Acetylene C_2H_2	.0	Fluorobenzene C_6H_5F	1.57
Ethylene C_2H_4	.0	Nitrobenzene $C_6H_5NO_2$	4.23
Acetaldehyde C_2H_4O	2.71	Benzene C_6H_6	.0
Acetic acid $C_2H_4O_2$	1.73	Phenol C_6H_6O	1.40
Ethyl bromide C_2H_5Br	1.96	Aniline C_6H_7N	1.48
		Toluene C_7H_8	.37

TABLE 457A.—ATTENUATION COEFFICIENTS FOR VERY LOW FREQUENCY RADIO PROPAGATION

For very low frequencies (100 kc and under), an empirical transmission formula of the form

$$F = \frac{377\ h\ I}{\lambda\ d} \sqrt{\frac{\theta}{\sin\theta}} \times e^{\frac{-\alpha d}{\lambda^x}}$$

has been found useful (Austin-Cohen; Austin; Espenschied, Anderson, and Bailey), where

F = received field intensity, in $\mu\ v/m$
h = effective height of transmitting antenna, in km
I = transmitting antenna current, in amp
θ = transmission distance, in radians
d = transmission distance, in km
λ = wavelength, in km

Values of α and x were found to vary somewhat.

Since theoretical justification for the Austin-Cohen value of $x = \frac{1}{2}$ has been given by Watson (Proc. Roy. Soc. London, A, vol. 95, p. 546, 1919), data furnished by the above observers have been reevaluated, assuming validity of the relationship

$$F = \frac{377\ h\ I}{\lambda\ d} \sqrt{\frac{\theta}{\sin\theta}} \times e^{\frac{-\alpha d}{\sqrt{\lambda}}},$$

and the resulting values of α presented in the accompanying table, together with their relative weights estimated from the number of observations used in their determination.

α varies notably with frequency, time of day, and the type of ground along the transmission path, and less definitely with season, solar activity, and the location of the transmission path. The values presented here are for conditions where the entire transmission path, at the height of the ionospheric reflecting layer, lies in daylight or in darkness. For conditions of sunrise or sunset on the transmission path, α has generally been found to lie between day and night values, but under certain circumstances, to far exceed these values.

					Transmission path			
f, kc	α	Day weight	α	Night weight	Ground	Transmitter location	Receiver location	Observations by
12.8	$.59\times10^{-3}$	97			Sea water	Bordeaux, France	Washington, D. C.	Austin
17.13	.66	112	$.32\times10^{-3}$	48	"	Rocky Point, N. Y.	New Southport, England	Espenchied, Anderson, Bailey
22.9	1.49	59			Land	San Diego, Calif.	Washington, D. C.	Austin
23.4	1.01	97			Sea water	Nauen, Germany	Washington, D. C.	Austin
24.05	.61	93	.25	7	"	Leafield, England	Belfast, Maine	Espenchied, Anderson, Bailey
24.05	.80	42	.46	2	"	"	Riverhead, L. I., N. Y.	"
24.05	.81	52	.44	1	"	"	Greenharbor, Mass.	"
25.7	.76	104	.29	42	"	Marion, Mass.	New Southgate, England	"
52	1.45	29	.60	15	"	Northolt, England	Riverhead, L. I., N. Y.	"
52	1.40	75	.84	21	"	"	Belfast, Maine	"
54.5	1.49	45	.89	30	"	"	Green Harbor, Mass.	"
57	1.48	112	.55	48	"	Rocky Point, N. Y.	New Southgate, England	"

TABLE 457B.—ATTENUATION IN HIGH FREQUENCY PROPAGATION OVER LONG DISTANCES

At high frequencies and distances where the radiation is chiefly received by means of sky-wave transmission, reference is given to the methods for calculation of received field intensities presented in Chapter 7, National Bureau of Standards Circular 462, "Ionospheric Radio Propagation."

For long transmission paths (over 4000 km),

$$F = F_0 + \tfrac{1}{2}\log P - S_0 J Q \overline{K} d$$

where F = log of the received field intensity, in $\frac{\mu v}{m}$

F_0 = log of the ionospherically unabsorbed field intensity, in $\frac{\mu v}{m}$, for 1 kw effective radiated power

$= 1.6 - 1.44\ [\log d - 3.60]$

d = transmission distance, in units of 1000 km

P = effective radiated power, in kw

$\log S_0 = 0.502 - 1.916\ (\log f - 0.477)$

f = frequency, in Mc

$Q = 1 + 0.005\ R$

R = sunspot number

$\overline{K}$ = average K for the transmission path

$K = 0.142 + 0.858 \cos \psi$

ψ = solar zenith angle

$$\overline{K}d = 0.142\ D' + (K_1 + K_2 - 0.284) \tan \frac{D'}{2R}$$

where D' = the length of the path in the region where K is not equal to zero, in units of 1000 km

K_1 and K_2 = values of K at transmitting and receiving stations

R = radius of the earth in units of 1000 km

J = seasonal variation factor. J has the values 1.0, 1.3, 1.15, respectively, if both terminals of the transmission path lie in summer, winter, or equinoctial regions. If one terminal lies in a summer region, the other in winter, $J = 1.15$.

TABLE 458.—E-LAYER MAXIMUM USABLE FREQUENCIES IN Mc FOR 2,000-km TRANSMISSION DISTANCE

	June *						Equinox					
Local time of day:	00	04	08	12	16	20	00	04	08	12	16	20
	Sunspot number = 0						Sunspot number = 0					
Latitude												
N. 80°	7.5	9.7	11.3	11.8	11.3	9.7			8.2	10.0	8.6	
40			13.6	16.2	13.6				11.7	14.4	12.2	
0			12.3	15.6	12.3				13.2	16.8	13.0	
40			8.3	12.0	8.3				11.4	14.2	11.9	
S. 80									7.3	8.7	7.5	
	Sunspot number = 125						Sunspot number = 125					
N. 80°	9.8	11.2	13.4	14.0	13.4	11.2			8.9	10.3	8.7	
40			17.4	20.2	17.4				15.1	18.6	14.7	
0			16.3	20.8	16.3				17.0	21.3	16.4	
40			10.7	15.4	10.7				13.5	16.8	13.3	
S. 80									8.3	9.6	8.1	

* For December, use reversed latitudes.

Norton calculated from Van der Pol's and Bremmer's theory and checked at broadcast frequencies the following results for vertically polarized ground-wave propagation. In many cases ionospheric waves will be much stronger than is indicated for ground-wave propagation in these tables. Some indication of when ionospheric waves may be expected is given.

Factor A for transmission over sea water

$\epsilon = 80$, ($\sigma = 5 \times$ mhos/m)

Freq. Mc	50 km	100 km	150 km
.5	1.0	.96	.90
2	1.0	.77	.72
10	.71	.46	.33
50	.025	.0050	.0016
200	.00075	—	—

Factor A for transmission over good ground

$\epsilon = 15$, $\sigma = 10^{-2}$ mhos/m

Freq. Mc	5 km	10 km	15 km	25 km	50 km	100 km	150 km
.1	1.00	1.00	1.0	1.0	1.0	.90	.87
.5	.98	.93	.90	.73	.68	.48	.35
2.0	.50	.30	.21	.095	.049	.018	.0092
10	.026	.011	.0072	.0036	.0018	.00054	.00020
50	.0030	.0015	.0096	.00040	.00017	—	—
300	.00046	.00021	.00013				

Factor A for transmission over poor ground

$\epsilon = 5$, $\sigma = 10^{-3}$ mhos/m

Freq. Mc	5 km	10 km	15 km	25 km	50 km	100 km	150 km
.1	1.0	.99	.95	.92	.85	.73	.64
.5	.64	.45	.35	.22	.096	.038	.022
2.0	.056	.027	.018	.010	.0050	.0018	.00093
10	.0059	.0030	.0019	.0011	.00048	.00013	—
50	.0012	.00055	.00036	.00022	—	—	—
100	.00080	.00026	.00016	—	—	—	—

CRITICAL FREQUENCIES AND MAXIMUM USABLE FREQUENCIES FOR RADIO TRANSMISSION BY REFLECTION FROM THE E AND F_2 LAYERS OF THE IONOSPHERE

Values of ionospheric critical frequencies and virtual reflection heights for all ionospheric layers (E, F_1, F_2, E_s) observed at a large number of stations are regularly distributed by the Central Radio Propagation Laboratory of the National Bureau of Standards to laboratories cooperating in ionospheric research. The values presented in Tables 458 and 461 are synthesized from the trends of these data. Values are not given here for the F_1 and E_s layers since their trends are much less accurately established than those of the E and F_2 layers.

Table 458 presents E-layer maximum usable frequencies for a transmission distance of 2,000 km, the maximum practical distance for 1-hop transmission by means of E-layer reflection.

Table 461 presents F_2-layer ordinary-wave critical frequencies, and maximum usable frequencies for a transmission distance of 4,000 km, the maximum practical distance for 1-hop transmission by means of F_2-layer reflection.

[153] Norton, K. A., The calculation of ground wave field intensity over a finitely conducting spherical earth, Proc. Inst. Radio Eng., December 1941; Van der Pol, Balth, and Bremmer, H., Philos. Mag., vol. 24, p. 141, 1937; vol. 24, p. 825, supplement, November 1937.

(*continued*)

Latitudes and local times are those of the ionospheric reflection points. The F_2-layer zones (*W*, *I*, and *E*) are those chosen for practical description of longitude effect by the International Radio Conference of April-May 1944. The *W* and *E* zones are centered on 70°W. and 110°E. longitude, respectively; the two *I* zones are intermediate between these.

Values are presented for sunspot numbers of 0 and 125. Since both critical frequencies and maximum usable frequencies show approximately linear variation with sunspot number, values for any other sunspot number, *X*, may be obtained by interpolation.

[World-wide charts of predicted *MUF*, three months in advance, for both *E* and F_2 layers, are regularly published in Central Radio Propagation Laboratory Series D reports, "Basic Radio Propagation Prediction."]

E-Layer ordinary-wave critical frequencies.—These may be obtained by dividing the *E*-layer 2,000 km *MUF* by 4.78, since the minimum virtual height of reflection is nearly constant for this layer.

Extraordinary-wave critical frequencies, f^x (or zero-distance *MUF*).—The ordinary-wave critical frequency f°, the extraordinary-wave critical frequency f^x, and the gyrofrequency f_h are related by the equation

$$(f^\circ)^2 = (f^x \pm f_h)\, f^x$$

The gyrofrequency, f_h, varies with the intensity of the earth's magnetic field, *H*, and is given by

$$f_h = \frac{e\,H}{2\pi m\,c},$$

where *e* and *m* are, respectively, the electronic (or ionic) charge and mass, *c* the velocity of light in free space, and *H* is given in gauss.

Ion density.—The number of ions per cm³ at the reflection point may be obtained from the value of the ordinary-wave critical frequency, f°, by the equation

$$N = \frac{\pi m}{e^2\ (f^\circ)^2},$$

where *m* and *e* are, respectively, the ionic mass and charge.

Minimum virtual heights of reflection.—The maximum usable frequency at any transmission (except for those nearly equal to zero) is equal to

$$MUF = f^\circ \sec \phi$$

where ϕ is the angle of incidence of the wave upon the ionospheric reflecting layer.

ϕ is approximately given by

$$\phi = \tan^{-1} \frac{\sin \frac{1}{2}\theta}{1 + (h/R) - \cos \frac{1}{2}\theta},$$

where θ is the angular distance of the transmission path, *h* the virtual height of reflection, and *R* the radius of the earth. (Cf. Smith, N., Proc. Inst. Radio Eng., May 1939, p. 232.)

Maximum usable frequencies for other transmission distances.—These may be obtained from the *MUF* of Table 461 by using the factors and procedure presented in Table 462.

Skip distances.—The *MUF* for a given distance is the frequency for which that distance is the skip distance.

TABLE 460.—ATTENUATION OF MICROWAVES BY WATER VAPOR IN THE ATMOSPHERE (in db/km)[154]

Measured at 45°C at atmospheric pressure

Wavelength (cm)	.75 cm	.96	1.16	1.28	1.37	1.69
Frequency (kmc)	40.2	31.2	25.8	23.5	21.9	17.8
Water vapor density (g/m³)						
10	.103 db/km	.081	.149	.230	.224	.049
30	.408	.321	.495	.69	.672	.18
50	.84	.665	.90	1.15	1.12	.355

[154] Adapted from Becker and Autler, Phys. Rev., vol. 70, p. 303, September 1946.

TABLE 461.—F_2-LAYER CRITICAL FREQUENCIES AND MAXIMUM USABLE FREQUENCIES FOR 4,000-km TRANSMISSION DISTANCE IN Mc

E zone

Latitude	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF
Local time of day: 00			Sunspot number = 0				Time: 12			Sunspot number = 0		
N. 80°	4.1	14.2	3.9	13.9	3.4	12.6	4.2	13.9	4.4	15.4	3.7	13.4
40	4.18	13.9	3.8	12.9	2.9	9.6	5.8	19.0	6.1	21.4	6.8	24.7
0	3.5	11.4	4.0	14.7	4.9	16.5	9.0	25.6	8.6	24.7	8.2	24.5
40	2.7	9.2	3.0	10.3	4.3	14.7	5.0	18.8	5.6	19.5	5.9	19.4
S. 80	2.4	8.8	2.8	9.9	3.9	13.5	3.3	11.9	3.6	12.9	4.5	14.9
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.2	16.3	6.1	18.8	5.6	17.8	5.4	16.0	6.7	21.2	5.4	17.6
40	8.6	24.9	7.0	21.3	3.5	10.8	9.0	25.6	11.4	35.3	11.1	36.4
0	8.8	27.0	10.9	38.8	8.2	25.9	14.0	32.7	15.5	38.8	12.7	30.2
40	4.1	12.8	5.9	18.2	8.2	24.7	10.8	36.4	10.5	34.1	8.3	22.7
S. 80	4.4	13.8	5.4	17.5	5.4	16.5	6.0	19.8	6.2	19.8	6.2	17.6
Local time of day: 04			Sunspot number = 0				Time: 16			Sunspot number = 0		
N. 80°	3.9	13.0	3.6	12.9	3.0	10.8	4.5	14.8	4.5	15.9	3.9	14.2
40	3.7	11.8	3.7	12.3	2.9	9.9	5.6	18.2	5.6	20.0	5.0	18.3
0	2.3	8.1	2.3	8.5	3.0	9.9	8.4	24.2	9.0	27.0	8.6	28.1
40	2.9	10.1	2.0	6.9	2.6	8.9	5.0	18.2	5.1	18.3	5.9	19.9
S. 80	2.4	8.5	2.5	8.7	3.8	13.3	3.0	10.9	3.7	12.7	4.3	14.3
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.2	15.4	5.5	17.5	4.4	14.0	5.6	16.3	6.5	20.0	5.4	17.3
40	8.0	23.3	6.3	18.8	3.6	10.9	9.0	26.5	10.9	33.2	8.8	28.8
0	4.9	15.3	7.2	23.5	6.2	20.0	14.0	34.0	16.2	41.2	12.2	29.6
40	4.1	12.8	4.6	14.1	6.0	17.8	10.4	35.3	9.8	32.3	8.2	25.9
S. 80	4.1	12.9	5.2	16.5	5.6	16.5	5.4	17.4	6.7	21.9	6.0	17.3
Local time of day: 08			Sunspot number = 0				Time: 20			Sunspot number = 0		
N. 80°	4.0	13.0	4.0	14.3	3.4	12.5	4.2	14.3	4.4	15.8	3.7	13.3
40	5.8	19.4	5.7	20.9	5.2	19.4	5.5	18.8	5.1	18.2	2.7	9.6
0	7.4	22.5	7.8	25.3	6.7	20.6	4.5	14.7	8.2	25.9	7.2	23.5
40	3.9	14.1	4.3	15.9	5.0	17.4	2.7	9.6	4.0	13.9	5.4	19.4
S. 80	2.4	8.8	3.4	11.8	4.3	14.7	2.5	9.3	3.3	11.4	4.4	14.9
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.3	15.4	6.7	21.2	5.0	15.8	5.5	16.7	6.6	20.8	5.2	16.7
40	9.4	28.2	10.0	33.2	8.2	29.4	8.6	26.0	8.0	25.9	4.3	14.1
0	12.7	35.5	13.5	38.2	12.0	34.7	11.0	28.2	14.0	34.2	10.0	25.9
40	7.5	26.0	8.1	28.1	7.4	21.4	5.5	17.6	7.9	24.7	8.4	25.9
S. 80	4.3	13.6	5.9	19.3	6.2	17.6	4.4	13.9	6.3	20.6	6.0	17.6

I zone

Latitude	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF
Local time of day: 00			Sunspot number = 0				Time: 12			Sunspot number = 0		
N. 80°	3.9	13.6	3.6	12.9	2.7	9.8	4.0	13.5	3.7	13.2	3.4	12.5
40	3.8	12.9	3.0	10.1	3.0	9.8	5.2	17.2	5.5	19.4	6.8	25.9
0	5.2	16.9	6.3	23.3	5.0	16.5	6.2	17.6	6.5	18.8	7.8	22.9
40	2.9	9.8	2.6	8.9	5.4	17.9	4.7	17.9	5.2	18.3	6.6	21.9
S. 80	2.4	8.8	2.8	9.9	3.9	13.5	3.3	11.9	3.6	12.9	4.5	14.9
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.2	16.9	5.8	18.2	4.8	15.3	5.3	15.6	5.9	18.7	5.4	17.3
40	6.4	18.6	5.0	15.3	3.3	10.3	7.9	21.9	10.2	31.9	11.0	37.7
0	9.0	28.2	10.0	32.8	10.0	31.8	10.4	24.8	11.0	28.6	10.9	25.6
40	4.1	12.7	5.8	18.2	8.4	24.7	11.5	38.7	10.8	34.7	9.4	26.5
S. 80	4.4	13.8	5.4	17.5	5.4	16.5	6.0	19.8	6.2	19.8	6.2	17.6

(*continued*)

TABLE 461.—F_2-LAYER CRITICAL FREQUENCIES AND MAXIMUM USABLE FREQUENCIES FOR 4,000-km TRANSMISSION DISTANCE IN Mc (continued)

Latitude	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF
Local time of day: 04			Sunspot number = 0				Time: 16		Sunspot number = 0			
N. 80°	3.7	12.8	3.4	12.2	2.7	9.9	4.0	13.2	3.6	12.6	3.4	12.1
40	3.1	10.7	2.9	9.9	2.9	10.0	5.2	17.0	5.5	19.8	5.6	20.6
0	3.2	11.0	3.0	11.6	3.3	10.3	6.8	19.8	8.2	24.6	9.4	30.0
40	2.8	9.6	2.2	7.5	3.5	11.9	4.6	17.2	4.8	17.0	6.4	21.8
S. 80	2.4	8.5	2.5.	8.7	3.8	13.3	3.0	10.9	3.7	12.7	4.3	14.3
			Sunspot number = 125						Sunspot number = 125			
N. 80°	4.8	15.4	5.7	17.4	3.9	12.2	5.2	15.6	5.9	18.8	5.2	16.6
40	5.3	15.3	4.6	14.2	3.4	10.6	7.8	22.6	9.7	30.6	9.8	33.9
0	6.9	21.8	5.4	17.6	7.2	22.9	10.8	26.8	12.5	31.8	12.4	35.0
40	4.0	12.5	4.2	12.6	6.2	18.5	10.0	33.5	10.4	33.5	9.2	27.3
S. 80	4.1	12.9	5.2	16.5	5.6	16.5	5.4	17.4	6.7	21.9	6.0	17.3
Local time of day: 08			Sunspot number = 0				Time: 20		Sunspot number = 0			
N. 80°	3.9	12.8	3.6	13.2	3.0	10.9	3.8	13.2	3.6	12.8	3.1	11.5
40	4.8	16.5	5.0	18.8	5.0	18.8	5.2	17.9	3.6	12.9	2.7	8.8
0	6.2	18.6	5.6	17.9	7.4	22.9	6.0	20.8	7.0	21.6	7.6	24.9
40	3.5	12.9	4.3	15.9	5.6	19.4	2.7	9.5	3.4	11.8	6.7	22.2
S. 80	2.4	8.8	3.4	11.8	4.3	14.7	2.5	9.3	3.3	11.4	4.4	14.9
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.1	15.0	5.9	18.8	4.3	13.5	5.1	16.0	5.8	18.3	4.9	15.5
40	7.6	21.2	8.6	28.8	7.8	29.4	7.5	21.4	6.7	21.6	3.7	12.7
0	8.9	24.9	11.6	33.0	10.3	29.3	9.4	23.4	10.2	25.9	10.5	27.0
40	7.7	26.5	8.6	29.4	8.8	25.6	5.4	17.6	7.4	24.3	9.2	26.8
S. 80	4.3	13.6	5.9	19.3	6.2	17.6	4.4	13.9	6.3	20.6	6.0	17.6
						W zone						
Local time of day: 00			Sunspot number = 0				Time: 12		Sunspot number = 0			
N. 80°	3.9	13.6	3.6	12.9	2.7	9.8	4.0	13.5	3.7	13.2	3.4	12.5
40	3.0	10.5	2.0	6.8	2.3	7.8	5.2	16.8	5.2	18.6	6.5	24.5
0	4.4	14.6	5.5	20.6	3.6	12.0	7.6	21.8	10.6	30.3	8.6	26.5
40	2.3	7.9	3.4	11.8	5.0	16.5	5.0	18.9	6.7	24.1	8.4	28.1
S. 80	3.0	10.8	3.2	11.3	4.2	14.8	3.4	12.5	3.6	12.8	4.6	15.0
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.2	16.9	5.8	18.2	4.8	15.3	5.3	15.6	5.9	18.7	5.4	17.3
40	6.6	20.6	5.6	17.0	4.6	14.5	7.1	20.8	9.3	29.3	12.3	40.3
0	10.5	31.8	12.2	39.2	9.0	28.3	11.7	28.2	14.9	37.0	14.1	33.3
40	3.4	10.6	7.2	22.6	9.9	29.3	11.0	37.6	13.9	44.7	12.1	33.9
S. 80	5.1	16.3	6.2	20.0	5.9	17.5	5.7	18.3	7.6	24.7	7.0	19.8
Local time of day: 04			Sunspot number = 0				Time: 16		Sunspot number = 0			
N. 80°	3.7	12.8	3.4	12.2	2.7	9.9	4.0	13.2	3.6	12.6	3.4	12.1
40	2.1	6.8	1.7	5.8	2.6	8.9	5.2	17.2	5.3	19.0	5.7	21.0
0	3.2	11.0	3.5	12.8	2.3	7.8	9.2	26.9	10.2	31.5	8.6	27.3
40	2.0	6.8	2.9	10.0	4.7	15.9	4.4	16.5	5.0	18.5	7.2	24.5
S. 80	2.9	10.5	2.5	8.9	4.2	14.6	3.2	11.8	3.8	13.3	4.5	14.9
			Sunspot number = 125						Sunspot number = 125			
N. 80°	4.8	15.4	5.7	17.4	3.9	12.2	5.2	15.6	5.9	18.8	5.2	16.6
40	4.9	15.6	4.1	12.5	4.4	13.6	7.4	21.8	9.3	28.8	11.2	36.3
0	7.0	22.1	6.2	21.5	4.9	14.5	11.8	29.4	14.0	37.5	13.8	34.3
40	3.2	9.9	5.8	17.6	9.4	27.6	8.5	30.0	11.4	37.4	11.0	32.9
S. 80	4.6	14.7	5.2	16.7	5.6	16.7	5.2	16.6	6.9	22.2	6.5	18.7

(continued)

TABLE 461.—F_2-LAYER CRITICAL FREQUENCIES AND MAXIMUM USABLE FREQUENCIES FOR 4,000-km TRANSMISSION DISTANCE IN Mc (concluded)

Latitude	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF	June $f°F_2$	June F_2-4000 MUF	Sept. $f°F_2$	Sept. F_2-4000 MUF	Dec. $f°F_2$	Dec. F_2-4000 MUF
Local time of day: 08			Sunspot number = 0				Time: 20		Sunspot number = 0			
N. 80°	3.9	12.8	3.6	13.2	3.0	10.9	3.8	13.2	3.6	12.8	3.1	11.5
40	4.8	16.2	4.6	17.4	4.5	17.6	5.4	18.7	4.0	14.5	2.6	9.0
0	5.8	17.4	7.5	24.1	7.6	22.9	6.8	22.3	8.4	26.0	5.7	19.0
40	4.4	15.9	5.9	21.8	6.6	22.9	2.2	7.8	2.9	10.1	6.4	21.6
S. 80	3.1	11.3	3.0	11.0	4.5	15.3	2.9	10.6	3.5	12.2	4.5	15.5
			Sunspot number = 125						Sunspot number = 125			
N. 80°	5.1	15.0	5.9	18.8	4.3	13.5	5.1	16.0	5.8	18.3	4.9	15.5
40	6.4	20.2	8.3	27.0	8.5	29.4	7.6	23.5	7.4	23.5	6.7	21.2
0	9.4	27.0	11.3	34.1	14.5	42.4	10.7	27.6	13.5	34.0	11.9	30.1
40	8.1	27.6	10.6	36.4	11.0	31.8	3.8	12.9	7.8	25.6	10.7	32.8
S. 80	5.0	15.9	6.8	22.1	6.7	18.9	4.9	15.8	6.5	20.6	6.5	19.3

TABLE 462.—FACTORS FOR OBTAINING F_2-LAYER MUF, AND COMBINED E, F_1-LAYER MUF AT OTHER DISTANCES, FROM F_2-4,000 km MUF AND E-2,000 km MUF

The accompanying table presents (a) factors, $F_{2000}{}^{E-E,F_1}$, by which the 2,000 E-layer maximum usable frequencies may be multiplied in order to obtain values of maximum usable frequencies by combined E- and F_1-layer transmission for other distances, and (b) factors, $F_{4000}{}^{F_2-F_2}$, by which 4,000-km F_2-layer maximum usable frequencies may be multiplied in order to obtain values of F_2-layer maximum usable frequencies at other transmission distances. These factors become less accurate with decreasing transmission distance.

For obtaining the maximum usable frequency for practical radio transmission, the following procedures may be used:

1. *One-hop transmission:*—Obtain both the combined E-, F_1-layer, and F_2-layer maximum usable frequencies pertinent to the midpoint of the transmission path. The higher of the two will be the *MUF* for the path, neglecting possible transmission by sporadic-E ionization.

2. *Long-path transmission:*—For transmission paths exceeding 4,000 km, the following procedure generally affords a sufficiently good value for practical use:

(a) Determine the 2,000-km E-layer *MUF* for a point 1,000 km along the transmission path from the transmitting station. Determine the 4,000-km F_2-layer *MUF* for a point 2,000 km along the transmission path from the transmitting station. Select the higher of two values, for comparison with a value to be later obtained in procedure (b).

(b) Determine the 2,000-km E-layer *MUF* for a point 1,000 km along the transmission path from the receiving station. Determine the 4,000-km F_2-layer *MUF* for a point 2,000 km along the transmission path from the receiving station. Select the higher of these two values, for comparison with the value obtained in procedure (a).

(c) Compare the values obtained in procedures (a) and (b) above. The lower of the two will be the *MUF* for the transmission path, neglecting possible transmission by sporadic-E ionization.

For more detailed and accurate procedures, and for inclusion of sporadic-E layer effects, reference is given to National Bureau of Standards Circular 462, "Ionospheric Radio Propagation," and to reports of the Central Radio Propagation Laboratory, Series D, "Basic Radio Propagation Prediction."

Distance km	$F_{2000}{}^{E-E,F_1}$	$F_{4000}{}^{F_2-F_2}$	Distance km	$F_{2000}{}^{E-E,F_1}$	$F_{4000}{}^{F_2-F_2}$
200	.25	.35	2200	...	.79
400	.36	.36	2400	...	.83
600	.48	.38	2600	...	.86
800	.62	.41	2800	...	.90
1000	.72	.46	3000	...	.92
1200	.82	.51	3200	...	.95
1400	.88	.57	3400	...	.97
1600	.95	.63	3600	...	.98
1800	.98	.69	3800	...	.99
2000	1.00	.74	4000	...	1.00

TABLE 463.—CALCULATED ATTENUATION OF MICROWAVES BY RAIN (db/km)[155]

Rate of rainfall (mm/hr)	Wavelength (cm) 1.25	3	5	10
2.46	.193 db/km	.049	.004	.0007
6.0 (moderate)	.615	.192	.012	.0017
22.6 (heavy)	2.40	.728	.053	.0070
43.1 (cloudburst)	6.17	1.64	.165	.016

[155] Adapted from article by L. Goldstein in Summary Technical Report of the National Defense Research Committee, Committee on Propagation, vol. 2, p. 164, published by Academic Press.

TABLE 464.—ATTENUATION OF MILLIMETER WAVES BY ATMOSPHERIC OXYGEN (db/km)[156]

Wave-length (mm)	Attenuation coefficient (db/km)	Wave-length (mm)	Attenuation coefficient (db/km)	Wave-length (mm)	Attenuation coefficient (db/km)	Wave-length (mm)	Attenuation coefficient (db/km)	Wave-length (mm)	Attenuation coefficient (db/km)
6.34	.05	5.60	1.8	5.19	12.7	5.10	13.9	4.96	14.7
5.76	1.0	5.28	10.2	5.13	15.7	5.04	14.5	4.48	.4

[156] Lamont, H. R., Proc. Phys. Soc. London, vol. 61, p. 562, 1948.

TABLE 465.—EXTRATERRESTRIAL RADIO FREQUENCY RADIATION *

Part 1.—Discrete sources

Source	α	δ	Reported by [157]	Remarks
Cygnus	20^h00^m	+43°	Hey, Parsons, Phillips [e]	Approx. position; λ ≈ 5m.
Cygnus A	19 59	+41°41′	Bolton [a]	Uncertainty of position about 1°. Observed on 100 Mc/s.
Cygnus	$19^h58^m47^s \pm 10^s$	+41°41′±7′	Bolton and Stanley [f]	Observed on 100, 60, 85, 200 Mc/s.
Cygnus	$19^h56^m.5$	+39°50′	Ryle and Smith [d]	Observed on 80 Mc/s.
Cygnus	20 30	+38°	Hey, Parsons, Phillips [g]	Observed on 64 Mc/s; position very uncertain.
Ursa Major	12 18.2	+58°00	Ryle and Smith [d]	Observed on 80 Mc/s.
Taurus A	5 13	+28°	Bolton [a]	Angular width < 30°; uncertainty of position about 1°. Observed on 100 Mc/s.
Taurus A	$5^h31^m00^s \pm 30^s$	+22°01′	Bolton, Stanley, Slee [b]	Intensity measured at 100 Mc/s.
Taurus A	5 31 20 ±30	+22°02′±8′	Bolton, Stanley [h]	Observed on 100 Mc/s.
Cassiopeia	$23^h17^m.5$	+58°10′	Ryle and Smith [d]	Observed on 80 Mc/s.
Possible sources ..	$18^h59^m.1$	+46°11′	Ryle [c]	Obsered on 80 Mc/s.
	13 55 .3	+57 14	Ryle [c]	
	12 20	+48	Ryle [c]	
	18 51	+24	Ryle [c]	
	19 15	0	Ryle [c]	
Coma Berenices A.	12 04	+20°30′	Bolton [a]	Angular width < 15′; uncertainty of position about 1°. Observed on 100 Mc/s.
Hercules A	16 21	+15	Bolton [a]	Angular width < 1°; uncertainty of position about 1°. Observed on 100 Mc/s.
Virgo A	$12^h28^m06^s \pm 37^s$	+12°41′±10′	Bolton, Stanley, Slee [b]	Intensity measured at 100 Mc/s.
Centaurus A	13 22 20 ±60	−42°37′±8′	Bolton, Stanley, Slee [b]	Intensity measured at 100 Mc/s.

* Prepared by C. R. Burrows.
[157] For references, see p. 450.

(continued)

TABLE 465.—EXTRATERRESTRIAL RADIO FREQUENCY RADIATION (concluded)

Part 2.—Galactic noise from direction of Sagittarius [i]

Observer	Frequency, Mc/s	Wavelength, cm	Equivalent monochromatic radiation temp. (°K)	Approx. resolving power (°)	Observer	Frequency, Mc/s	Wavelength, cm	Equivalent monochromatic radiation temp. (°K)	Approx. resolving power (°)
Moxon	40	750.0	30,000	35×70	Reber	480	62.5	230	2×3
Hey, Parsons, and Phillips	65	462.5	10,500	12×30	Reber	900	33.3		
Moxon	90	333.3	3,000	35×35	Southworth	3000	10.0	Negative results but due to low sensitivity can only say $T_v << 20{,}000$.	
Reber	160	187.5	5,300	6×8	Reber	3300	9.1		
Moxon	200	150.0	300	...	Southworth	30,000	1.0		

Part 3.—Constant component of solar noise [j]

Observer	Frequency, Mc/s	Wavelength cm	T_R (°K) equivalent blackbody	Observer	Frequency, Mc/s	Wavelength cm	T_R (°K) equivalent blackbody
Piddington and Minnett	24,000	1.25	$1.0\times10^4\pm10\%$	Lehany and Yabsley	600	50.	$.5\times10^6\pm20\%$
Dicke and Beringer	24,000	1.25	1.0×10^4	Reber	480	62.5	1.0×10^6
Southworth	10,000	3	1.8×10^4	McCready, Pawsey and Payne-Scott	200	150.	1.2×10^6
Sander	9,375	3.2	2.2×10^4	Pawsey and Yabsley	200	150.	$.7\times10^6$
Southworth	3,000	10	1.8×10^4	Lehany and Yabsley	200	150.	1.0×10^6
Covington	2,804	10.7	5.6×10^4	Ryle and Vonberg	175.4	171.	$.6\times10^6$
Covington	2,804	10.7	6.5×10^4	Reber	160	187.	1.8×10^6
Lehany and Yabsley	1,200	25	$1.0\times10^5\pm20\%$	Ryle and Vonberg	80	375.	1.3×10^6

REFERENCES: a, Bolton, J. G., Nature, vol. 162, p. 141, 1948; b, Bolton, J. G., Stanley, G. J., and Slee, O. B., Nature, vol. 164, p. 101, 1949; c, Unpublished; d, Ryle, M., and Smith, F. G., Nature, vol. 162, p. 462, 1948; e, Hey, J. S., Parsons, S. J., and Phillips, J. W., Nature, vol. 158, p. 234, 1946; f, Bolton, J. G., and Stanley, G. J., Nature, vol. 161, p. 312, 1948; g, Hey, J. S., Parsons, S. J., and Phillips, J. W., Proc. Roy. Soc. London, vol. 192, p. 425, 1948; h, Bolton, J. G., and Stanley, G. J., Australian Journ. Sci. Res., vol. 2, p. 139, 1949; i, Williamson, R. E., Journ. Roy. Astron. Soc. Canada, vol. 42, p. 9, 1948; j, Pawsey, J L., and Yabsley, D. E., Australian Journ. Sci. Res., vol. 2, p. 198, 1949.

TABLES 466-494.—MAGNETIC PROPERTIES OF MATERIALS

TABLE 466.—DEFINITIONS *, BASIC EQUATIONS, AND GENERAL DISCUSSION

B, flux density (magnetic) induction, $= \phi/A = 4\pi I + H$; unit the gauss, maxwell per cm.

Diamagnetic substances, $\mu < 1$, κ negative. Most diamagnetic substance known is Bi, $\mu = .9998$ $\kappa = -14 \times 10^{-6}$.

Ferromagnetic substances, μ very large, κ very large: Fe, Ni, Co, Heusler's alloy (see Table 476), magnetite and a few alloys of Mn. μ for Heusler's alloy, 90 to 100 for $B =$ 2,200; for Si sheet steel 350 to 5,300.

H, field strength, = No. of lines of force crossing unit area in normal direction; unit = gauss = one line per unit area.

Hall effect (galvanomagnetic difference of potential), Ettinghausen effect (galvanomagnetic difference of temperature), Nernst effect (thermomagnetic difference of potential) and the Leduc effect (thermomagnetic difference of temperature), see Tables 519 and 521.

Hysteresis is work done in taking a cm³ of the magnetic material through a magnetic cycle $= \int H\,dI = (1/4\pi)\int H\,dB$. Steinmetz's empirical formula gives a close approximation to the hysteresis loss; it is $aB^{1.6}$ where B is the max. induction and a is a constant (see Table 482). The retentivity (B_r) is the value of B when the magnetizing force is reduced to zero. The reversed field necessary to reduce the magnetism to zero is called the coercive force (H_c).

I, intensity of magnetization or pole strength per unit area, $= \mathsf{M}/V = m/A$ where A is cross section of uniformly magnetized pole face, and V is the volume of the magnet. $4\pi m/A = 4\pi I =$ No. of lines of force leaving unit area of pole.

J, specific intensity of magnetism, $= I/\rho$ where $\rho =$ density, g/cm³.

J_A, J_M, similarly atomic and molecular intensity of magnetization.

κ, susceptibility; permeability relates to effect of iron core on magnetic field strength of coil; if effect be considered on iron core, which becomes a magnet of pole strength m and intensity of magnetism I, then the ratio $I/H = (\mu - 1)/4\pi$ is the magnetic susceptibility per unit volume and is a measure of the magnetizing effect of a magnetic field on the material placed in the field. $\mu = 4\pi\kappa + 1$.

M, magnetic moment $= ml$, where l is length between poles of magnet.

Magneto-strictive phenomena:

Joule effect: Mechanical change in length when specimen is subjected to a magnetic field. With increasing field strength, iron and some iron alloys show first a small increment $\Delta l/l = (7 \text{ to } 35) \times 10^{-7}$, then a decrement, and for $H = 1600$. $\Delta l/l$ may amount to $-(6 \text{ to } 8) \times 10^{-6}$. Cast cobalt with increasing field first decreases, $\Delta l/l = -8 \times 10^{-6}$, $H =$ 150, then increases in length, $\Delta l/l = +5 \times 10^{-6}$, $H = 2{,}000$; annealed cobalt steadily contracts, $\Delta l/l = -25 \times 10^{-6}$, $H = 2000$. Ni rapidly then slowly contracts, $\Delta l/l = -30 \times 10^{-6}$, $H = 100$; -35×10^{-6}, $H = 300$; -36×10^{-6}, $H = 2{,}000$. A transverse field generally gives a reciprocal effect.

Villari effect; really a reciprocal Joule effect. The susceptibility of an iron wire is increased by stretching when the magnetism is below a certain value, but diminished when above that value.

Wiedemann effect: The lower end of a vertical wire, magnetized longitudinally, when a current is passed through it, if free, twists in a certain direction, depending upon circumstances. A reciprocal effect is observed in that when a rod of soft iron, exposed to longitudinal magnetizing force, is twisted, its magnetism is reduced.

μ, magnetic permeability, $= B/H$. Strength of field in air-filled solenoid $= H = (4\pi/10)$ ni in gausses, i in amperes, n, number of turns per cm length. If iron filled, induction increased, i.e., No. of lines of force per unit area, B, passing through coil is greater than H; $\mu = B/H$.

Paramagnetic substances, $\mu > 1$, very small but positive, $\kappa = 10^{-3}$ to 10^{-6}: oxygen, especially at low temperatures, salts of Fe, Ni, Mn, many metallic elements. (See Table 486.)

Paramagnetic substances show no retentivity or hysteresis effect. Susceptibility independent of field strength. The specific susceptibility for both para- and diamagnetic substances is independent of field strength.

ϕ, magnetic flux, $= 4\pi m + HA$ for magnet placed in field of strength H (axis parallel to field). Unit, the maxwell.

Unit pole is of such strength that it will repel another unit pole with a force of one dyne; at unit distance in free space, 4π lines of force radiate from it. m, pole strength; $4\pi m$ lines of force radiate from pole of strength m.

χ, specific susceptibility (per unit mass) $= \kappa/\rho = J/H$.

χ_A, atomic susceptibility, $= \chi \times$ (atomic weight); $\chi_M =$ molecular susceptibility.

* See pages 16-18.

TABLE 467.—MAGNETIC PROPERTIES OF VARIOUS TYPES OF IRON AND STEEL

From tests made at the National Bureau of Standards. *B* and *H* are measured in cgs units.

Values of *B*		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
Annealed Norway iron	H	**.81**	**1.15**	**1.60**	**2.18**	**3.06**	**4.45**	**7.25**	**23.5**	**116.**	—
	μ	2470	3480	3750	3670	3270	2700	1930	680	150	—
Cast semi-steel	H	**2.00**	**2.90**	**4.30**	**6.46**	**9.82**	**15.1**	**24.9**	**50.5**	**135.**	**325.**
	μ	1000	1380	1400	1240	1020	795	563	317	133	62.
Machinery steel	H	**5.0**	**8.8**	**13.1**	**18.6**	**25.8**	**35.8**	**50.5**	**76.0**	**142.**	—
	μ	400	455	460	430	390	340	280	210	127	—
Very pure iron as received	H	**3.30**	**4.48**	**6.35**	**9.10**	**13.0**	**18.9**	**28.8**	**47.0**	**103.**	**240.**
	μ	606	893	945	880	770	635	486	340	175	83
Annealed in vacuo from 900°C	H	**.46**	**.60**	**.80**	**1.02**	**1.38**	**2.00**	**3.20**	**11.3**	**72.0**	**194.**
	μ	4350	6670	7500	7840	7250	6000	4380	1420	250	103

As received. . . . . H_{max} 150, B_{max} 18,900, B_r 7,650, H_c 2.8.
After annealing. . . . . H_{max} 150, B_{max} 19,500, H_c .53.

TABLE 468.—MAGNETIC PROPERTIES OF ELECTRICAL SHEETS

From tests made at the National Bureau of Standards. *B* and *H* are measured in cgs units.

Values of *B*		2000	4000	6000	8000	10,000	12,000	14,000	16,000	18,000	20,000
Dynamo steel	H	**1.00**	**1.10**	**1.43**	**2.00**	**3.10**	**4.95**	**9.20**	**34.0**	**114.**	—
	μ	2000	3640	4200	4000	3220	2420	1520	470	158	—
Ordinary transformer steel	H	**.60**	**.87**	**1.10**	**1.48**	**2.28**	**3.85**	**10.9**	**43.0**	**149.**	—
	μ	3340	4600	5450	5400	4380	3120	1280	372	121	—
High silicon transformer steel	H	**.50**	**.70**	**.90**	**1.28**	**1.99**	**3.60**	**9.80**	**47.4**	**165.**	—
	μ	4000	5720	6670	6250	5020	3340	1430	338	109	—

TABLE 469.—MAGNETIC PROPERTIES OF IRON IN VERY WEAK FIELDS

The effect of very small magnetizing forces has been studied by C. Baur and by Lord Rayleigh. The following short table is taken from Baur's paper, and is taken by him to indicate that the susceptibility is finite for zero values of *H* and for a finite range increases in simple proportion to *H*. He gives the formula $k = 15 + 100H$, or $I = 15H + 100H^2$. The experiments were made on an annealed ring of round bar 1.013 cm radius, the ring having a radius of 9.432 cm. Lord Rayleigh's results for an iron wire not annealed give $k = 6.4 + 5.1H$, or $I = 6.4H + 5.1H^2$. The forces were reduced as low as 0.00004 cgs, the relation of *k* to *H* remaining constant.

First experiment			Second experiment	
H	*k*	*I*	*H*	*k*
.01580	16.46	2.63	.0130	15.50
.03081	17.65	5.47	.0847	18.38
.07083	23.00	16.33	.0946	20.49
.13188	28.90	38.15	.1864	25.07
.23011	39.81	91.56	.2903	32.40
.38422	58.56	224.87	.3397	35.20

TABLE 470.—TYPICAL DATA FOR MAGNETIC MATERIALS [157a]

Part 1.—High-permeability materials

Material	Form	Approximate percent composition: Fe	Ni	Co	Mo	Other	Typical heat treatment °C	Permeability at $B = 20$ gausses	Maximum permeability	Saturation flux density B_s gausses	Hysteresis ‡ loss, W_h ergs/cm³	Coercive ‡ force H_c oersteds	Resistivity Microhm-cm	Density, g/cm³
Cold rolled steel	Sheet	98.5	—	—	—	—	950 Anneal	180	2,000	21,000	—	1.8	10	7.88
Iron	Sheet	99.91	—	—	—	—	950 Anneal	200	5,000	21,500	5,000	1.0	10	7.88
Purified iron	Sheet	99.95	—	—	—	—	1480 H_2 + 880	5,000	180,000	21,500	300	.05	10	7.88
4% Silicon-iron	Sheet	96	—	—	—	4 Si	800 Anneal	500	7,000	19,700	3,500	.5	60	7.65
Grain oriented*	Sheet	97	—	—	—	3 Si	800 Anneal	1,500	30,000	20,000	—	.15	47	7.67
45 Permalloy	Sheet	54.7	45	—	—	.3 Mn	1050 Anneal	2,500	25,000	16,000	1,200	.3	45	8.17
45 Permalloy†	Sheet	54.7	45	—	—	.3 Mn	1200 H_2 Anneal	4,000	50,000	16,000	—	.07	45	8.17
Hipernik	Sheet	50	50	—	—	—	1200 H_2 Anneal	4,500	70,000	16,000	220	.05	50	8.25
Monimax	Sheet	—	—	—	—	—	1125 H_2 Anneal	2,000	35,000	15,000	—	.1	80	8.27
Sinimax	Sheet	—	—	—	—	—	1125 H_2 Anneal	3,000	35,000	11,000	—	—	90	—
78 Permalloy	Sheet	21.2	78.5	—	—	.3 Mn	1050 + 600 Q**	8,000	100,000	10,700	200	.05	16	8.60
4–79 Permalloy	Sheet	16.7	79	—	4	.3 Mn	1100 + Q	20,000	100,000	8,700	200	.05	55	8.72
Mu metal	Sheet	18	75	—	—	2 Cr, 5 Cu	1175 H_2	20,000	100,000	6,500	—	.05	62	8.58
Supermalloy	Sheet	15.7	79	—	5	.3 Mn	1300 H_2 + Q	100,000	800,000	8,000	—	.002	60	8.77
Permendur	Sheet	49.7	—	50	—	.3 Mn	800 Anneal	800	5,000	24,500	12,000	2.0	7	8.3
2V Permendur	Sheet	49	—	49	—	2 V	800 Anneal	800	4,500	24,000	6,000	2.0	26	8.2
Hiperco	Sheet	64	—	34	—	Cr	850 Anneal	650	10,000	24,200	—	1.0	25	8.0
2–81 Permalloy	Insulated powder	17	81	—	2	—	650 Anneal	125	130	8,000	—	<1.0	10^6	7.8
Carbonyl iron	Insulated powder	99.9	—	—	—	—	— —	55	132	—	—	—	—	7.86
Ferroxcube III	Sintered powder	$MnFe_2O_4 + ZnFe_2O_4$					— —	1,000	1,500	2,500	—	.1	10^8	5.0

[157a] Compiled by R. A. Chegwidden, Bell Telephone System Monogr. B-1605, Metal Progress, vol. 54, p. 705, 1948.
* Properties in direction of rolling. † Similar properties for Nicaloi, 4750 alloy, Carpenter 49, Armco 48. ‡ At saturation. ** Q, quench or controlled cooling.

(continued)

TABLE 470.—TYPICAL DATA FOR MAGNETIC MATERIALS (concluded)

Part 2.—Permanent magnet alloys

Material	Percent composition (remainder Fe)	Heat treatment * (temperature, °C)	Magnetizing force $H_{max.}$ oersteds	Coercive force H_c oersteds	Residual induction B_r gausses	Energy product $BH_{max.}$ $\times 10^{-6}$	Method of fabrication †	Mechanical Properties ‡	Weight lb/in.³
Carbon steel	1 Mn, 0.9 C	Q 800	300	50	10,000	.20	HR, M, P	H, S	.280
Tungsten steel	5 W, 0.3 Mn, 0.7 C	Q 850	300	70	10,300	.32	HR, M, P	H, S	.292
Chromium steel	3.5 Cr, 0.9 C, 0.3 Mn	Q 830	300	65	9,700	.30	HR, M, P	H, S	.280
17% Cobalt steel	17 Co, 0.75 C, 2.5 Cr, 8 W	—	1,000	150	9,500	.65	HR, M, P	H, S	—
36% Cobalt steel	36 Co, 0.7 C, 4 Cr, 5 W	Q 950	1,000	240	9,500	.97	HR, M, P	H, S	.296
Remalloy or Comol	17 Mo, 12 Co	Q 1200, B 700	1,000	250	10,500	1.1	HR, M, P	H	.295
Indalloy (sintered)	— Mo, — Co	— —	1,000	240	9,000	.9	HR, M, P	H	.290
Alnico I	12 Al, 20 Ni, 5 Co	A 1200, B 700	2,000	440	7,200	1.4	C, G	H, B	.249
Alnico II	10 Al, 17 Ni, 2.5 Co, 6 Cu	A 1200, B 600	2,000	550	7,200	1.6	C, G	H, B	.256
Alnico II (sintered)	10 Al, 17 Ni, 2.5 Co, 6 Cu	A 1300	2,000	520	6,900	1.4	Sn, G	H	.249
Alnico IV	12 Al, 28 Ni, 5 Co	Q 1200, B 650	3,000	700	5,500	1.3	Sn, C, G	H	.253
Alnico V	8 Al, 14 Ni, 24 Co, 3 Cu	AF 1300, B 600	2,000	550	12,500	4.5	C, G	H, B	.264
Alnico VI	8 Al, 15 Ni, 24 Co, 3 Cu, 1 Ti	— —	3,000	750	10,000	3.5	C, G	H, B	.268
Alnico XII	6 Al, 18 Ni, 35 Co, 8 Ti	— —	3,000	950	5,800	1.5	C, G	H, B	.26
Vicalloy I	52 Co, 10 V	B 600	1,000	300	8,800	1.0	C, CR, M, P	D	.295
Vicalloy II (wire)	52 Co, 14 V	CW + B 600	2,000	510	10,000	3.5	C, CR, M, P	D	.292
Cunife (wire)	60 Cu, 20 Ni	CW + B 600	2,400	550	5,400	1.5	C, CR, M, P	D, M	.311
Cunico	50 Cu, 21 Ni, 29 Co	— —	3,200	660	3,400	.80	C, CR, M, P	D, M	.300
Vectolite	30 Fe_2O_3, 44 Fe_3O_4, 26 C_2O_3	— —	3,000	1,000	1,600	.60	Sn, G	W	.113
Silmanal	86.8 Ag, 8.8 Mn, 4.4 Al	— —	20,000	6,000[a]	550	.075	C, CR, M, P	D, M	.325
Platinum-cobalt	77 Pt, 23 Co	Q 1200, B 650	15,000	3,600	5,900	6.5	C, CR, M	D	—
Hyflux	Fine powder	— —	2,000	390	6,600	.97	—	—	.176

[a] Value given is intrinsic H_c. * Q-Quenched in oil or water. A-Air cooled. B-Baked. F-Cooled in magnetic field. CW-Cold worked. † HR-Hot rolled or forged. CR-Cold rolled or drawn. M-Machined. G-Must be ground. P-Punched. C-Cast. Sn-Sintered. ‡ M-Hard. B-Brittle. S-Strong. D-Ductile. M-Malleable. W-Weak.

TABLE 471.—MAGNETIC PROPERTIES OF SOME ALLOYS *
B & H MEASURED IN cgs UNITS

		Induction data								
Values of B		2000	4000	6000	8000	10000	12000	14000	16000	18000
Carbon steel	H	33	50	61	72	93	155	290	600	—
.9 C, .5 Mn, .2 Si, Bal Fe	μ	60	80	98	111	108	77	48	27	
Chrome	H	32	48	61	75	100	175	—	—	—
Bar, 3.5 Cr, 0.9 C	μ	63	83	98	107	100	69	—	—	—
Chrome	H	30	44	52.5	62	75	155	235	—	—
Sheet, 5.75 Cr, 1.25 C	μ	67	91	114	129	133	104	60	—	—
Chrome	H	36	47.5	64	80	122	—	—	—	—
Sheet, 5.75 Cr, 10 C	μ	56	84	94	100	82	—	—	—	—
Tungsten steel	H	35	52.5	63	70	81.5	115	195	195	500
0.6 C, 5 W, 0.5 Mn, 0.2 Si	μ	57	76	95	114	123	104	72	72	32
Cobalt	H	140	203	240	269	313	413	649	—	—
Bar, 36 Co, 3.5 Cr, 3.0 W	μ	14	20	25	30	32	29	22	—	—
Comal 1	H	134	201	237	258	290	369	651	1355	2571
12 Co, 17 Mo, Bal Fe	μ	14.9	19.9	25.3	31	34.5	32.5	21.5	11.8	7
Alnico 1	H	280	400	478	582	910	1820	—	—	—
12 Al, 20 Ni, 5 Co, Bal Fe	μ	7.1	10.0	12.6	13.8	11.0	6.6	—	—	—
Alnico 2	H	360	560	668	785	1020	1680	—	—	—
Cast, 10 Al, 17 Ni, 12.5 Co	μ	5.6	7.1	9.0	10.2	9.8	7.1	—	—	—
Alnico 2	H	340	515	605	760	1200	1800	—	—	—
Sintered, 10 Al, 17 Ni	μ	5.9	7.8	9.9	10.5	8.3	6.7	—	—	—
Alnico 3	H	305	473	565	698	1035	2000	—	—	—
12 Al, 2.5 Ni, Bal Fe Up to 5/8x5/8" cross section	μ	6.6	8.5	10.6	11.5	9.7	6.0	—	—	—
Alnico 3	H	279	395	478	575	940	1910	—	—	—
Cast, 12 Al, 25 Ni, Bal Fe 5/8x5/8" cross section and over	μ	7.2	10.1	12.5	13.9	10.6	6.3	—	—	—
Alnico 4	H	500	850	1075	1350	1890	—	—	—	—
Cast, and sintered 12 Al, 28 Ni, 5 Co, Bal Fe	μ	4.0	4.7	5.6	5.9	5.3	—	—	—	—
Alnico 5	H	468	560	580	580	598	640	945	—	—
Cast, 8 Al, 14 Ni, 24 Co, 3 Cu, Bal Fe	μ	4.3	7.1	10.3	13.8	16.7	18.8	148	—	—
Alnico 6	H	430	675	770	845	940	1110	1700	—	—
Cast, 8 Al, 15 Ni, 24 Co, 3Cu, 1.25 Ti, Bal Fe	μ	4.7	5.9	7.8	9.5	10.6	10.8	8.2	—	—
Alnico 12	H	610	1000	1300	1600	2000	3000	—	—	—
Cast, 6 Al, 18 Ni, 35 Co, 8 Ti, Bal Fe	μ	3.3	4.0	4.6	5.0	5.0	4.8	—	—	—
Cunife	H	530	645	845	—	—	—	—	—	—
Under .155" dia. 60 Cu, 20 Ni, Bal Fe	μ	3.8	6.2	7.1	—	—	—	—	—	—
Cunico	H	590	1000	1630	3200	—	—	—	—	—
50 Cu, 21 Ni, 29 Co	μ	3.4	4.0	3.7	2.5	—	—	—	—	—
Vectolite	H	1110	2050	3700	—	—	—	—	—	—
30 Fe_2O_3, 44 Fe_3O_4, 26 Co_2O_3	μ	1.8	2.0	1.7	—	—	—	—	—	—
Silmanal					Maximum μ 1.111					

* Much of the data on magnetism was corrected by W. E. Ruder, of the General Electric Co.

TABLE 472.—SPECIAL TRANSFORMER SHEET

Low induction values

Special Hi silicon steel, (4½% Si), .014″ sheet
H_2 annealed 875°C

Values of H	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B			3.0	5.0	7.0	10.0	13.0	16.0	21.0	24.0
Values of μ			750	833	875	1000	1083	1143	1167	1200

Nickel-iron alloy 48% Ni, 52% Fe, .014″ sheet
Allegheny electrical alloy 4750
Treatment 1100°C 6 hr p.d. H_2 cooled to room temp. 5 hr

Values of H	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B	7.0	15.0	32.0	49.0	67.0	88.0	108.0	132.0	185.0	215.0
Values of μ	7000	7500	8000	8165	8375	8800	9000	9430	10280	10750

Permalloy strip, 79% Ni, 21% Fe
Treatment H_2 1100°C 4 hr f. c. 625°C in air

Values of H	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B	15.0	30.0	67.0	115.0	180.0	260.0	365.0	458.0	683.0	805.0
Values of μ	15000	15000	16750	19160	22500	26000	30420	32710	37940	40250

Monimax 47% Ni, 3%Mo bal Fe, strip .004″
Treatment annealed 2 hr 1150°C p.d. H_2

Values of H	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B	—	—	—	—	—	21	26	32	42	50
Values of μ	—	—	—	—	—	2100	2160	2290	2340	2500

Mumetal strip .014″, 77.2 Ni, 4.8 Cu, 1.5 Cr, 14.9 Fe
Treatment annealed in p.d. H_2 at 1100°C 4 hr f. c.

Values of H	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B	20.0	50.0	158.0	300.0	443.0	600.0	758.0	923.0	1253.0	1420.0
Values of μ	20000	25000	39500	50000	55375	60000	63160	65930	69610	71000

Cold rolled 3% Si, strip (oriented) .014″
Annealed in H_2 980°C

Values of H	0.001	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.018	0.020
Values of B	—	7	15	24	33	42	52	63	85	100
Values of μ	—	3500	3750	4000	4100	4200	4300	4500	4700	5000

TABLE 473.—MAXIMUM CORE LOSSES IN ELECTRICAL STEEL SHEETS

	Watts per lb for 60 cycles							
Designation Thickness, in.:	.0140	.0155	.0170	.0185	.0220	.0250	.0280	.0310
	At 10,000 gausses							
Armature AISI M-43........	1.30	1.38	1.46	1.55	1.75	1.98	2.23	2.50
Electrical AISI M-36........	1.17	1.23	1.29	1.35	1.50	1.70	1.94	2.17
Motor AISI M-27...........	1.01	1.05	1.09	1.14	1.22	1.30	1.44	1.60
Dynamo AISI M-22.........	.82	.86	.90	.94	1.02	1.10		
Transformer 72 AISI M-19..	.72	.76	.80	.83	.90	.97		
Transformer 65 AISI M-17..	.65	.68	.72	.75				
Transformer 58 AISI M-15..	.58	.61	.65	.68				
Transformer 52 AISI M-14..	.52							
Transformer 100 AISI M-10..								
Transformer 90 AISI M-9...								
	At 15,000 gausses							
Armature AISI M-43........	4.30	4.37	4.44	4.50	4.80	5.30	5.85	6.50
Electrical AISI M-36........	3.60	3.67	3.74	3.80	4.10	4.40	4.95	5.50
Motor AISI M-27...........	2.65	2.75	2.85	2.95	3.20	3.40	3.70	4.10
Dynamo AISI M-22.........	1.85	2.23	2.31	2.40	2.60	2.80		
Transformer 72 AISI M-19..	1.65	1.93	2.02	2.10	2.25	2.40		
Transformer 65 AISI M-17..	1.50	1.72	1.80	1.88				
Transformer 58 AISI M-15..	1.40	1.57	1.65	1.73				
Transformer 52 AISI M-14..	1.00							
Transformer 100 AISI M-10..	.90							
Transformer 90 AISI M-9...	.80							

Nickel at 0° and 100°C

H	S	I	B	μ
100	35.0	309	3980	39.8
200	43.0	380	4966	24.8
300	46.0	406	5399	18.0
500	50.0	441	6043	12.1
700	51.5	454	6409	9.1
1000	53.0	468	6875	6.9
1500	56.0	494	7707	5.1
2500	58.4	515	8973	3.6
4000	59.0	520	10540	2.6
6000	59.2	522	12561	2.1
9000	59.4	524	15585	1.7
12000	59.6	526	18606	1.5
At 0°C this specimen gave the following results:				
12300	67.5	595	19782	1.6

Cobalt at 0° and 100°C

H	S	I	B	μ
200	106	848	10850	54.2
300	116	928	11960	39.9
500	127	1016	13260	26.5
700	131	1048	13870	19.8
1000	134	1076	14520	14.5
1500	138	1104	15380	10.3
2500	143	1144	16870	6.7
4000	145	1164	18630	4.7
6000	147	1176	20780	3.5
9000	149	1192	23980	2.6
At 0°C this specimen gave the following results:				
7900	154	1232	23380	3.0

Magnetite *

H	I	B	μ
500	325	4580	9.16
1000	345	5340	5.34
2000	350	6400	3.20
12000	350	16400	1.37

* These results are given by Du Bois for a specimen of magnetite.
S = Magnetic moment per gram. I = Magnetic moment per cm³.

Professor Ewing has investigated the effects of very intense fields on the induction in iron and others metals. The results show that the intensity of magnetization does not increase much in iron after the field has reached an intensity of 1000 cgs units, the increase of induction above this being almost the same as if the iron were not there, that is to say, dB/dH is practically unity. For hard steels, and particularly manganese steels, much higher forces are required to produce saturation. Hadfield's manganese steel seems to have nearly constant susceptibility up to a magnetizing force of 10,000. The following tables, taken from Ewing's papers, illustrate the effects of strong fields on iron and steel. The results for nickel and cobalt do not differ greatly from those given above.

Lowmoor wrought iron

H	I	B	μ
3080	1680	24130	7.83
6450	1740	28300	4.39
10450	1730	32250	3.09
13600	1720	35200	2.59
16390	1630	36810	2.25
18760	1680	39900	2.13
18980	1730	40730	2.15

Vicker's tool steel

H	I	B	μ
6210	1530	25480	4.10
9970	1570	29650	2.97
12120	1550	31620	2.60
14660	1580	34550	2.36
15530	1610	35820	2.31

Hadfield's manganese steel

H	I	B	μ
1930	55	2620	1.36
2380	84	3430	1.44
3350	84	4400	1.31
5920	111	7310	1.24
6620	187	8970	1.35
7890	191	10290	1.30
8390	263	11690	1.39
9810	396	14790	1.51

TABLE 475.—EFFECT OF TEMPERATURE ON PERMEABILITY OF NICKEL-IRON ALLOY (47-50 Ni)[158]

Test Temp. °F	B (gausses) at 30 H (oersteds)	Maximum permeability (B/H)	B (gausses) at maximum permeability (B/H)	Permeability (B/H) at 100 gausses
390	11500	79000	4600	8000
190	11850	59000	4400	7000
80	12000	49000	4700	6100
32	12000	44000	5200	5600
− 42	12200	34000	6000	4500
−100	12300	30000	7000	4200

[158] Hicks, Laurence C., Nickel-iron alloys for magnetic circuits, Electrical Manufacturing, January 1946.

TABLE 476.—HEUSLER MAGNETIC ALLOYS

Several alloys have been experimented with that, although all the constitutents are nonmagnetic or very weakly magnetic materials, have quite definite magnetic properties. Among these are Nos. 1-3 below, Heusler magnetic alloys. Some alloys made up for the most part of magnetic elements are nonmagnetic or very weakly magnetic, i.e., No. 4 below.

1. 61 Cu, 25 Mg, 14 Al
   magnetic with a permeability μ of 33.
2. 75.6 Cu, Mn 14.3, Al 10.1, Pb
   magnetic $B_r = 480$, $H_c = 3.8$, μ max $= 80$.
3. Cu 61.5, Mn 23.5, Al 15
   $B_r = 2550$, $H_c = 7.3$, μ max $=$ 236.
4. Cu 78, Fe 12, Mg
   nonmagnetic.

TABLE 477.—PERMEABILITY OF SOME SPECIMENS OF IRON AND STEEL

This table gives the induction and the permeability for different values of the magnetizing force of some of the specimens in Table 493. The specimen numbers refer to the same table. The numbers have been taken from the curves given by Hopkinson and may therefore be slightly in error; they are the mean values for rising and falling magnetizations.

Magnetizing force	Specimen 1 (iron)		Specimen 8 (annealed steel)		Specimen 9 (same as 8 tempered)		Specimen 3 (cast iron)	
H	B	μ	B	μ	B	μ	B	μ
1	—	—	—	—	—	—	265	265
2	200	100	—	—	—	—	700	350
3	—	—	—	—	—	—	1625	542
5	10050	2010	1525	300	750	150	3000	600
10	12550	1255	9000	900	1650	165	5000	500
20	14550	727	11500	575	5875	294	6000	300
30	15200	507	12650	422	9875	329	6500	217
40	15800	395	13300	332	11600	290	7100	177
50	16000	320	13800	276	12000	240	7350	149
70	16360	234	14350	205	13400	191	7900	113
100	16800	168	14900	149	14500	145	8500	85
150	17400	116	15700	105	15800	105	9500	63
200	17950	90	16100	80	16100	80	10190	51

Magnetizing force	ASTM 20 medium (as cast)		ASTM 30 medium (as cast)		ASTM 40 electric furnace (as cast)	
H	B	μ	B	μ	B	μ
5	1300	260	600	120	1750	350
10	3400	340	2550	255	4100	410
20	5250	262	4450	222	5950	297
30	6200	206	5450	181	6950	231
40	6950	173	6100	152	7600	190
50	7500	150	6700	134	8250	165
70	8300	118	7600	108	9100	130
100	9100	91	8600	86	10050	100
150	10150	67	9800	65	11100	74
200	11050	55	10650	53	11900	59

TABLE 478.—MAGNETIC PROPERTIES OF SOFT IRON AT 0° and 100°C

Soft iron at 0°C					Soft iron at 100°C				
H	S*	I†	B	μ	H	S	I	B	μ
100	180.0	1408	17790	177.9	100	180.0	1402	17720	177.2
200	194.5	1521	19310	96.5	200	194.0	1511	19190	96.0
400	208.0	1627	20830	52.1	400	207.0	1613	20660	51.6
700	215.5	1685	21870	31.2	700	213.4	1663	21590	29.8
1000	218.0	1705	22420	22.4	1000	215.0	1674	22040	21.0
1200	218.5	1709	22670	18.9	1200	215.5	1679	22300	18.6

* Magnetic moment per grain. † Magnetic moment per cm^3.

TABLE 479.—MAGNETIC PROPERTIES OF STEEL AT 0° and 100°C

Steel at 0°C					Steel at 100°C				
H	S†	I‡	B	μ	H	S	I	B	μ
100	165.0	1283	16240	162.4	100	165.0	1278	16170	161.7
200	181.0	1408	17900	89.5	200	180.0	1395	17730	88.6
400	193.0	1500	19250	48.1	400	191.0	1480	19000	47.5
700	199.5	1552	20210	28.9	700	197.0	1527	19890	28.4
1000	203.5	1583	20900	20.9	1000	199.0	1543	20380	20.4
1200	205.0	1595	21240	17.7	1500	203.0	1573	21270	14.2
3750*	212.0	1650	24470	6.5	3000	205.0	1593	23020	7.7
					5000	208.0	1612	25260	5.1

* The results in this and other tables for forces above 1200 were obtained from a small piece of the metal provided with a polished mirror surface and placed, with its polished face normal to the lines of force, between the poles of a powerful electromagnet. The induction was then inferred from the rotation of the plane of a polarized ray of red light reflected normally from the surface. (See Kerr's Constants, Tables 516, 517, 520.)

† Magnetic moment per grain. ‡ Magnetic moment per cm^3.

TABLE 480.—ENERGY LOSSES IN TRANSFORMER STEELS

D. C. Hysteresis data

From $B_{max} = 10{,}000$ gausses

Grade	Thickness in.	H_c oersteds	B_r gausses	H_{max} oersteds	$H_c \times B_r$
Transformer 52	.0140	—.20	4800	2.03	960
Transformer 58	.0140	—.24	5050	1.94	1210
Transformer 65	.0140	—.31	5200	2.16	1610
Transformer 72	.0140	—.42	6200	2.19	2610
Transformer 72	.0185	—.43	5050	2.58	2170
Transformer 72	.0250	—.50	5300	2.72	2650
Dynamo	.0140	—.51	6650	2.30	3400
Dynamo	.0185	—.53	5500	2.85	2920
Dynamo	.0250	—.59	5750	2.87	3400
Motor	.0140	—.55	6350	3.33	3500
Motor	.0185	—.58	6700	2.80	3890
Motor	.0250	—.63	6900	2.99	4350
Electrical	.0140	—.62	7700	2.52	4770
Electrical	.0285	—.61	8100	2.16	4950
Electrical	.0250	—.68	8250	2.26	5610
Armature	.0140	—.64	8350	2.30	5350
Armature	.0185	—.68	8300	2.20	5650
Armature	.0250	—.72	8230	2.26	5940

TABLE 481.—ENERGY LOSSES IN TRANSFORMER STEELS

a c core losses

Watts/lb for 60 cycle at 10,000 gausses

Designation	Thickness in.	Gage	Eddy current loss	Hysteresis	Total
Transformer 52	.0134	29	.149	.345	494
Transformer 58	.0137	29	.163	.385	.548
Transformer 65	.0136	29	.193	.426	.619
Transformer 72	.0136	29	.205	.450	.675
Dynamo	.0137	29	.218	.572	.790
Motor	.0140	29	.245	.709	.954
Electrical	.0137	29	.262	.852	1.114
Armature	.0139	29	.486	.741	1.227
Oriented C. R. strip....	.0140	29	.164	.236	.40

TABLE 482.—DISSIPATION OF ENERGY IN THE CYCLIC MAGNETIZATION OF VARIOUS SUBSTANCES

C. P. Steinmetz concludes from his experiments that the dissipation of energy due to hysteresis in magnetic metals can be expressed by the formula $e = aB^{1.6}$, where e is the energy dissipated and a a constant. He also concludes that the dissipation is the same for the same range of induction, no matter what the absolute value of the terminal inductions may be. His experiments show this to be nearly true when the induction does not exceed ± 15000 cgs units per cm². It is possible that, if metallic induction only be taken, this may be true up to saturation; but it is not likely to be found to hold for total inductions much above the saturation value of the metal. The law of variation of dissipation with induction range in the cycle, stated in the above formula, is also subject to verification.

The following table gives the values of the constant a as found by Steinmetz for a number of different specimens. The data are taken from his second paper.

Kind of material	Description of specimen	Value of a
Iron	Norway iron	.00227
"	Wrought bar	.00326
"	Commercial ferrotype plate	.00548
"	Annealed " "	.00458
"	Thin tin plate	.00286
"	Medium-thickness tin plate	.00425
Steel	Soft galvanized wire	.00349
"	Annealed cast steel	.00848
"	Soft annealed cast steel	.00457
"	Very soft annealed cast steel	.00318
"	Same as 8 tempered in cold water	.02792
"	Tool steel glass hard-tempered in water	.07476
"	" " tempered in oil	.02670
"	" " annealed	.01899
"	Same as 12, 13, and 14, after having been subjected to an alternating m. m. f. of from 4000 to 6000 ampere turns for demagnetization	.06130
"		.02700
"		.01445
Cast iron	Gray cast iron	.01300
" "	" " " containing ⅛% aluminum	.01365
" "	" " " " ½% "	.01459
Magnetite	A square rod 6 cm² section and 6.5 cm long, from the Tilly Foster mines, Brewsters, Putnam County, New York, stated to be a very pure sample	.02348
Nickel	Soft wire	.0122
"	Annealed wire, calculated by Steinmetz from Ewing's experiments	.0156
"	Hardened, also from Ewing's experiments	.0385
Cobalt	Rod containing about 2% of iron, also calculated from Ewing's experiments by Steinmetz	.0120
Iron filings	Consisted of thin needle-like chips obtained by milling grooves about 8 mm wide across a pile of thin sheets clamped together. About 30% by volume of the specimen was iron. 1st experiment, continuous cyclic variation of m. m. f. 180 cycles per second	.0457
	2d experiment, 114 cycles per second	.0396
	3d " 79–91 cycles per second	.0373
Nickel alloy	Permalloy	.0001
	Hipernik	.00015
Electrical sheet	Silicon steel 4.5% Si	.00046
	Silicon steel 4.5% Si	.00051
	Silicon steel 4.4% Si	.00056
	Silicon steel 3.5% Si	.00065
	Silicon steel 2.5% Si	.00081
	Silicon steel 1.0% Si	.00088
	Silicon steel 0.5% Si	.001
	Low carbon sheet	.003
	Cast steel annealed	.005
	Cast iron annealed	.012

TABLE 483.—CURIE CONSTANT AND TEMPERATURE FOR PARAMAGNETIC SUBSTANCES

The relation deduced by Curie that $\chi = C/T$, where C is a constant and T the absolute temperature, holds for some paramagnetic substances over the ranges given in the following table. Many paramagnetic substances do not obey the law. See the following table.

Substance	$C \times 10^6$	Range °C	Substance	$C \times 10^6$	Range °C
Oxygen	33,700	20° to 450°C	Gadolinium sulfate	21,000	—259° to 17
Air	7,830	— — —	Ferrous sulfate	11,000	—259 " 17
Palladium	1,520	20 to 1370	Ferric sulfate	17,000	—208 " 17
Magnetite	28,000	850 " 1360	Manganese chloride	30,000	—258 " 17
Cast iron	38,500	850 " 1267			

TABLE 484.—TEMPERATURE EFFECT (°C) ON SUSCEPTIBILITY OF DIAMAGNETIC ELEMENTS *

No effect:

B	Cryst. 400 to 1200°	P	white	Se	—	Sb	—170 to 50°
C	Diamond, + 170 to 200°	S	Cryst.; ppt.	Br	—170 to 18°	Cs	and Au
C	"Sugar" carbon	Zn	—170 to 300°	Zr	Cryst. —170 to 500°	Hg	—39 to + 350°
Si	Cryst.	As	—	Cd	—170 to 300°	Pb	327 to 600°

Increase with rise in temperature:

Be	—	C	Diamond, 200 to 1200°	I	—170 to 114°
B	Cryst. + 170 to 400°	Ag	—	Hg	—170 to —30°

Decrease with rise in temperature:

C	Amorphous	Gd	—179 to 30°	In	—170 to 150°	Tl	—
C	Ceylon graphite	Ge	—170 to 900°	Sb	+ 50 to + 631°	Pb	—170 to 327°
Cu	—	Zr	500 to 1200°	Te	—	Bi	—170 to 268°
Zn	+ 300 to 700°	Cd	300 to 700°	I	+ 114 to + 200°		

* Tables 484 and 485 are from Honda and Owen.

TABLE 485.—TEMPERATURE EFFECT (°C) ON SUSCEPTIBILITY OF PARAMAGNETIC ELEMENTS

No effect:

Li	—	K	—170 to 150°	Cr	—170 to 500°	W	—
Na	—170 to 97°	Ca	—170 to 18°	Mn	—170 to 250°	Os	—
Al	657 to 1100°	V	—170 to 500°	Rb	—		

Increase with rise in temperature:

Ti	—40 to 1100°	Cr	500 to 1100°	Ru	+ 550 to 1200°	Ba	—170 to 18°
V	500 to 1100°	Mo	—170 to 1200°	Rh	—	Ir	and Th

Decrease with rise in temperature:

(O)	—	Ti	—180 to —40°	Ni	350 to 800°	Pd and Ta
As	—170 to 657°	Mn	250 to 1015°	Co	above 1150°	Pt and U
Mg	—	(Fe)	—	Nb	—170 to 400°	Rare earth metals

TABLE 486.—MAGNETIC SUSCEPTIBILITY OF SOME MATERIALS

If I is the intensity of magnetization produced in a substance by a field strength H then the magnetic susceptibility $\kappa = I/H$. This is generally referred to the unit mass; italicized figures refer to the unit volume. The susceptibility depends greatly upon the purity of the substance, especially its freedom from iron. The mass susceptibility of a solution containing p percent by weight of a water-free substance (susceptibility κ) is $\kappa_x = (p/100)\kappa + (1 - p/100)\kappa_0$. ($\kappa_0 =$ susceptibility of water.)

Substance	$\kappa \times 10^6$	Temp. °C	Remarks
Ag	−.19	18	
AgCl	−.28		
Air, 1 Atm.	*+.024*	15	
Al	+.65	18	
$Al_2K_2(SO_4)_4 24H_2O$	*−1.0*		Cryst.
A, 1 Atm.	*−.10*	0	
As	*−.3*	18	
Au	−.15	18	
B	−.71	18	
$BaCl_2$	−.36	20	
Be	+.79	75	Powd.
Bi	−1.4	18	
Br	−.38	18	
C, arc-carbon	−2.0	18	
C, diamond	−.49	18	
CH_4, 1 Atm.	*+.001*	16	
CO_2, 1 Atm.	*+.002*	16	
CS_2	*−.77*	18	
CaO	*−.27*	16	Powd.
$CaCl_2$	−.40	19	"
$CaCO_3$, marble	−.7		
Cd	−.17	18	
$CeBr_3$	+6.3	18	
Cl_2, 1 Atm.	−.59	16	
$CoCl_2$	+90.	18	Sol'n
$CoBr_2$	+47.	18	"
CoI_2	+33.	18	"
$CoSO_4$	+57.	19	"
$Co(NO_3)_2$	+57.	18	"
Cr	+3.7	18	
CsCl	−.28	18	Powd.
Cu	−.09	18	
$CuCl_2$	+12.	20	Sol'n
$CuSO_4$	+10.	20	Sol'n
CuS	+.16	17	Powd.
$FeCl_3$	+90.	18	Sol'n
$FeCl_2$	+90.	18	"
$FeSO_4$	+82.	20	"
$Fe_2(NO_3)_6$	+50.	18	"
He, 1 Atm.	*−.002*	0	
H_2, 1 Atm.	*.000*	16	
H_2, 40 Atm.	*.000*	16	
H_2O	−.79	20	
HCl	*−.80*	20	
H_2SO_4	*+.78*	20	
HNO_3	*−.70*	20	
Hg	−.19	20	
I	−.4	20	
In	.1±	18	
Ir	+.15	18	
K	+.40	20	
KCl	−.50	20	
KBr	−.40	20	
KI	−.38	20	
KOH	−.35	22	Sol'n
K_2SO_4	−.42	20	
$KMnO_4$	+2.0		
KNO_3	−.33	20	
K_2CO_3	−.50	20	Sol'n
Li	+.38		
Mo	+.04	18	
Mg	+.55	18	
$MgSO_4$	−.40		
Mn	+11.	18	
$MnCl_2$	+122.	18	Sol'n
$MnSO_4$	+100.	18	"
N_2, 1 Atm.	*.001*	16	
NH_3	−1.1		
Na	+.51	18	
NaCl	−.50	20	
Na_2CO_3	−.19	17	Powd.
$Na_2CO_3 \cdot 10\ H_2O$	−.46	17	"
Nb	+1.3	18	
$NiCl_2$	+40.	18	Sol'n
$NiSO_4$	+30.	20	"
O_2, 1 Atm.	+.120	20	
Os	+.04	20	
P, white	−.90	20	
P, red	−.50	20	
Pb	−.12	20	
$PbCl_2$	−.25	15	Powd.
Pd	+5.8	18	
$PrCl_3$	+13.	18	Sol'n
Pt	+1.1	18	
$PtCl_4$	.0	22	Sol'n
Rh	+1.1	18	
S	−.48	18	
SO_2 1 Atm.	−.30	16	
Sb	−.94	18	
Se	−.32	18	
Si	−.12	18	Cryst.
SoO_2, Quartz	−.44	20	
—Glass	−.5±		
Sn	+.03	20	
$SrCl_2$	−.42	20	Sol'n
Ta	+.93	18	
Te	−.32	20	
Th	+.18	18	
Ti	+3.1	18	
V	+1.5	18	
W	+.33	20	
Zn	−.15	18	
$ZnSO_4$	−.40		
Zr	−.45	18	
CH_3OH	−.73		
C_2H_5OH	−.80		
C_3H_7OH	−.80		
$C_2H_5OC_2H_5$	*−.60*	20	
$CHCl_3$	−.58		
C_6H_6	−.78		
Ebonite	*+1.1*		
Glycerine	−.64	22	
Sugar	−.57		
Paraffin	*−.58*		
Petroleum	−.91		
Toluene	−.77		
Wood	−.2–5		
Xylene	−.81		

TABLE 487.—TEMPERATURE VARIATION OF RESISTANCE OF BISMUTH IN TRANSVERSE MAGNETIC FIELD (°C)

Proportional values of resistance

H	−192°	−135°	−100°	−37°	0°	+18°	+60°	+100°	+183°
0	.40	.60	.70	.88	1.00	1.08	1.25	1.42	1.79
2000	1.16	.87	.86	.96	1.08	1.11	1.26	1.43	1.80
4000	2.32	1.35	1.20	1.10	1.18	1.21	1.31	1.46	1.82
6000	4.00	2.06	1.60	1.29	1.30	1.32	1.39	1.51	1.85
8000	5.90	2.88	2.00	1.50	1.43	1.42	1.46	1.57	1.87
10000	8.60	3.80	2.43	1.72	1.57	1.54	1.54	1.62	1.89
12000	10.8	4.76	2.93	1.94	1.71	1.67	1.62	1.67	1.92
14000	12.9	5.82	3.50	2.16	1.87	1.80	1.70	1.73	1.94
16000	15.2	6.95	4.11	2.38	2.02	1.93	1.79	1.80	1.96
18000	17.5	8.15	4.76	2.60	2.18	2.06	1.88	1.87	1.99
20000	19.8	9.50	5.40	2.81	2.33	2.20	1.97	1.95	2.03
25000	25.5	13.3	7.30	3.50	2.73	2.52	2.22	2.10	2.09
30000	30.7	18.2	9.8	4.20	3.17	2.86	2.46	2.28	2.17
35000	35.5	20.35	12.2	4.95	3.62	3.25	2.69	2.45	2.25

TABLE 488.—INCREASE OF RESISTANCE OF NICKEL DUE TO A TRANSVERSE MAGNETIC FIELD, EXPRESSED AS % OF RESISTANCE AT 0°C AND H = 0

H	−190°	−75°	0°	+18°	+100°	+182°
0	+0	0	0	0	0	0
1000	+.20	+.23	+ .07	+ .07	+ .96	+ .04
2000	+.17	+.16	+ .03	+ .03	+ .72	− .07
3000	.00	−.05	− .34	− .36	− .14	− .60
4000	−.17	−.15	− .60	− .72	− .70	−1.15
6000	−.19	−.20	− .70	− .83	−1.02	−1.53
8000	−.19	−.23	− 76	− .90	−1.15	−1.66
10000	−.18	−.27	− .82	− .95	−1.23	−1.76
12000	−.18	−.30	− .87	−1.00	−1.30	−1.85
14000	−.18	−.32	− .91	−1.04	−1.37	−1.95
16000	−.17	−.35	− .94	−1.09	−1.44	−2.05
18000	−.17	−.38	− .98	−1.13	−1.51	−2.15
20000	−.16	−.41	−1.03	−1.17	−1.59	−2.25
25000	−.14	−.49	−1.12	−1.29	−1.76	−2.50
30000	−.12	−.56	−1.22	−1.40	−1.95	−2.73
35000	−.10	−.63	−1.32	−1.50	−2.13	−2.98

TABLE 489.—CHANGE OF RESISTANCE OF VARIOUS METALS IN A TRANSVERSE MAGNETIC FIELD

(Room temperature)

Metal	Field strength in gausses	Percent increase	Metal	Field strength	Percent
Nickel	10000	−1.2	Lead	10000	+ .0004
"	"	−1.4	Tantalum	"	+ .0003
"	6000	−1.0	Magnesium ...	6000	+ .01
"	10000	−1.4	Manganin	"	+ .01
Cobalt	"	− .53	Tellurium	?	+ .02 to .34
Cadmium	"	+ .03	Antimony	?	+ .02 to .16
Zinc	"	+ .01			
Copper	"	+ .004	Iron	Different specimens show very diverse results, usually an increase in weak fields, a decrease in strong.	
Silver	"	+ .004			
Gold	"	+ .003			
Tin	"	+ .002			
Palladium	"	+ .001	Nickel steel ...	Alloys behave similarly to iron.	
Platinum	"	+ .0005			

		Electrolytic iron	Good cast steel	Poor cast steel	Steel	Cast iron	Electrical sheets: Ordinary	Electrical sheets: Silicon steel
Chemical composition in percent	C	.024	.044	.56	.99	3.11	.036	.036
	Si	.004	.004	.18	.10	3.27	.330	3.90
	Mn	.008	.40	.29	.40	.56	.260	.090
	P	.008	.044	.076	.04	1.05	.040	.009
	S	.001	.027	.035	.07	.06	.068	.006
Coercive force		2.83	1.51	7.1	16.7	11.4		
		[.36]	[.37]	(44.3)	(52.4)	[4.6]	[1.30]	[.77]
Residual B		11400	10600	10500	13000	5100		
		[10800]	[11000]	(10500)	(7500)	[5350]	[9400]	[9850]
Maximum permeability		1850	3550	700	375	240		
		[14400]	[14800]	(170)	(110)	[600]	[3270]	[6130]
B for H = 150		19200	18800	17400	16700	10400		
		[18900]	[19100]	(15400)	(11700)	[11000]	[18200]	[17550]
4πI for saturation		21620	21420	20600	19800	16400		
		[21630]	[21420]	(20200)	(18000)	[16800]	[20500]	[19260]

Brackets indicate annealing at 800°C in vacuum.
Parentheses indicate hardening by quenching from cherry-red.

TABLE 491.—CAST IRON IN INTENSE FIELDS

Soft cast iron				Hard cast iron			
H	*B*	*I*	*μ*	*H*	*B*	*I*	*μ*
114	9950	782	87.3	142	7860	614	55.4
172	10800	846	62.8	254	9700	752	38.2
433	13900	1070	32.1	339	10850	836	30.6
744	15750	1200	21.2	684	13050	983	19.1
1234	17300	1280	14.0	915	14050	1044	15.4
1820	18170	1300	10.0	1570	15900	1138	10.1
12700	31100	1465	2.5	2020	16800	1176	8.3
13550	32100	1475	2.4	10900	26540	1245	2.4
13800	32500	1488	2.4	13200	28600	1226	2.2
15100	33650	1472	2.2	14800	30200	1226	2.0

TABLE 492.—CORRECTIONS FOR RING SPECIMENS

In the case of ring specimens, the average magnetizing force is not the value at the mean radius, the ratio of the two being given in the table. The flux density consequently is not uniform, and the measured hysteresis is less than it would be for a uniform distribution. This ratio is also given for the case of constant permeability, the values being applicable for magnetizations in the neighborhood of the maximum permeability. For higher magnetizations the flux density is more uniform, for lower it is less, and the correction greater.

Ratio of radial width to diameter of rings	Ratio of average *H* to *H* at mean radius		Ratio of hysteresis for uniform distribution to actual hysteresis	
	Rectangular cross section	Circular cross section	Rectangular cross section	Circular cross section
1/2	1.0986	1.0718	1.112	1.084
1/3	1.0397	1.0294	1.045	1.033
1/4	1.0216	1.0162	1.024	1.018
1/5	1.0137	1.0102	1.015	1.011
1/6	1.0094	1.0070	1.010	1.008
1/7	1.0069	1.0052	1.008	1.006
1/8	1.0052	1.0040	1.006	1.004
1/10	1.0033	1.0025	1.003	1.002
1/19	1.0009	1.0007	1.001	1.001

TABLE 493.—COMPOSITION AND MAGNETIC PROPERTIES OF IRON AND STEEL

This table and Table 477 are from a paper by Dr. Hopkinson on the magnetic properties of iron and steel. The numbers in the columns headed "magnetic properties" give results for the highest magnetizing force used, which is stated in the paper to have been 240. The maximum magnetization is not tabulated; but as stated by Hopkinson it may be obtained by subtracting the magnetizing force (240) from the maximum induction and then dividing by 4π. "Coercive force" is the magnetizing force required to reduce the magnetization to zero. The "demagnetizing force" is the magnetization force which had to be applied in order to leave no residual magnetization after previous magnetization in the opposite direction to the "maximum induction" stated in the table. The "energy dissipated" was calculated from the formula: Energy dissipated = coercive force × maximum induction divided by π, which however, was only found to agree roughly with the the results of the experiment.

		Chemical analysis						Magnetic properties				
Description of specimen	Temper	Total carbon	Manganese	Sulfur	Silicon	Phosphorus	Specific electrical resistance × 10⁶	Maximum induction	Residual induction	Coercive force	Demagnetizing force	Energy dissipated per cycle ergs
Wrought iron	Annealed	—	—	—	—	—	13.78	18251	7248	2.30	—	13356
Malleable cast iron	"	—	—	—	—	—	32.54	12408	7479	8.80	—	34742
Gray cast iron	—	—	—	—	—	—	105.60	10783	3928	3.80	—	13037
Bessemer steel	—	.045	.200	.030	None	.040	10.50	18196	7860	2.96	—	17137
Whitworth mild steel	Annealed	.090	.153	.016	"	.042	10.80	19840	7080	1.63	—	10289
" " "	"	.320	.438	.017	.042	.035	14.46	18736	9840	6.73	—	40120
" " "	Oil-hardened	"	"	"	"	"	13.90	18796	11040	11.00	—	65786
" " "	Annealed	.890	.165	.005	.081	.019	15.59	16120	10740	8.26	—	42366
" " "	Oil-hardened	"	"	"	"	"	16.95	16120	8736	19.38	—	99401
Hadfield's manganese steel	—	1.005	12.360	.038	.204	.070	65.54	310	—	—		—
Manganese steel	As forged	.674	4.730	.023	.608	.078	53.68	4623	2202	23.50	37.13	34567
" "	Annealed	"	"	"	"	"	39.28	10578	5848	33.86	46.10	113963
" "	Oil-hardened	"	"	"	"	"	55.56	4769	2158	27.64	40.29	41941
" "	As forged	1.298	8.740	.024	.094	.072	69.93	747	—	—	—	—
" "	Annealed	"	"	"	"	"	63.16	1985	540	24.50	50.39	15474
" "	Oil-hardened	"	"	"	"	"	70.66	733	—	—	—	—
Silicon steel	As forged	.685	.694	"	3.438	.123	61.63	15148	11073	9.49	12.60	45740
" "	Annealed	"	"	"	"	"	61.85	14701	8149	7.80	10.74	36485

(continued)

TABLE 493.—COMPOSITION AND MAGNETIC PROPERTIES OF IRON AND STEEL (concluded)

Description of specimen	Temper.	Chemical analysis: Total carbon	Manganese	Sulphur	Silicon	Phosphorus	Specific electrical resistance × 10^6	Magnetic properties: Maximum induction	Residual induction	Coercive force	Demagnetizing force	Energy dissipated per cycle ergs
Silicon steel	Oil-hardened	.685	.694	.024	3.438	.123	61.95	14696	8084	12.75	17.14	59619
Chrome steel ... a	As forged	.532	.393	.020	.220	.041	20.16	15778	9318	12.24	13.87	61439
" " ... a	Annealed	"	"	"	"	"	19.42	14848	7570	8.98	12.24	42425
" " ... a	Oil-hardened	"	"	"	"		27.08	13960	8595	38.15	48.45	169455
" " ... b	As forged	.687	.028	"	.134	.043	17.91	14680	7568	18.40	22.03	85944
" " ... b	Annealed	"	"	"	"	"	18.49	13233	6489	15.40	19.79	64842
" " ... b	Oil-hardened	"	"	"	"	"	30.35	12868	7891	40.80	56.70	167050
Tungsten steel ... c	As forged	1.357	.036	None	.043	.047	22.49	15718	10144	15.71	17.75	78568
" " ... c	Annealed	"	"	"	"	"	22.50	16498	11008	15.30	16.93	80315
" " ... c	Hardened in cold water	"	"	"	"	"	22.74	—	—	—	—	—
" " ... c	Hardened in tepid water	"	"	"	"	"	22.49	15610	9482	30.10	34.70	149500
" " (French) .. d	Oil-hardened	.511	.625	None	.021	.028	36.04	14480	8643	47.07	64.46	216864
" " ... e	Very hard	.855	.312	—	.151	.089	44.27	12133	6818	51.20	70.69	197660
Gray cast iron ... f	—	3.455	.173	.042	2.044	.151	114.0	9148	3161	13.67	17.03	39789
Mottled cast iron ... g	—	2.581	.610	.105	1.476	.435	62.86	10546	5108	12.24	—	41072
White " " ...	—	2.036	.386	.467	.764	.458	56.61	9342	5554	12.24	20.40	36383
Spiegeleisen ...	—	4.510	7.970	Trace	.502	.128	105.20	385	77	—	—	—
Silicon steel ...	Annealed				4.5		65	10000	6500	3.5		
C. R. silicon steel (oriented).	Annealed	.03			3.25		50	15000	10750	2.9		
Ingot iron ... h	Hot rolled	.01				.01	15	19400	5500	2.9		
	H_2 annealed					.01	15	19400	10000	1.5		

Other substances present—a .621 Cr, b 1.195 Cr, c 4.649 W, d 3.444 W, e 2.353 W, f 2.064 graphetic carbon, g 1.447 graphetic carbon, h 99.75 Fe.

H = true intensity of magnetizing field, H' = intensity of applied field, I = intensity of magnetization, $H = H' - NI$.

Shuddemagen says: The demagnetizing factor is not a constant, falling for highest values of I to about 1/7 the value when unsaturated; for values of B $(= H + 4\pi I)$ less than 1000, N is approximately constant; using a solenoid wound on an insulating tube, or a tube of split brass, the reversal method gives values for N which are considerably lower than those given by the step-by-step method; if the solenoid is wound on a thick brass tube, the two methods practically agree.

Values of $K \times 10^4$ are given where B is determined by the step method and $H = H' - KB$.

Ratio of length to diameter	Values of $N \times 10^4$: Ellipsoid	Values of $N \times 10^4$: Cylinder: Uniform magnetization	Values of $N \times 10^4$: Cylinder: Magnetometric method (Mann)	Values of $N \times 10^4$: Cylinder: Ballistic step method: Dubois: Diameter 0.158 cm	Values of $N \times 10^4$: Cylinder: Ballistic step method: Shuddemagen for range of practical constancy: Diameter 0.3175 cm	Values of $N \times 10^4$: Cylinder: Ballistic step method: Shuddemagen for range of practical constancy: Diameter 1.111 cm	Values of $N \times 10^4$: Cylinder: Ballistic step method: Shuddemagen for range of practical constancy: Diameter 1.905 cm	Values of $K \times 10^4$: Diameter 0.3175 cm	Values of $K \times 10^4$: Diameter 1.1 to 2.0 cm
5	7015	—	6800						
10	2549	630	2550	2160	—	—	1960		
15	1350	280	1400	1206	—	—	1075	—	85.2
20	848	160	898	775	—	—	671	—	53.3
30	432	70	460	393	388	350	343	30.9	27.3
40	266	39	274	238	234	212	209	18.6	16.6
50	181	25	182	162	160	145	149	12.7	11.6
60	132	18	131	118	116	106	106	9.25	8.45
70	101	13	99	89	88			—	—
80	80	9.8	78	69	69	66	63	5.5	5.05
90	65	7.8	63	55	56			—	—
100	54	6.3	51.8	45	46	41	41	3.66	3.26
150	26	2.8	25.1	20	23	21	21	1.83	1.67
200	16	1.57	15.2	11	12.5	11	11		
300	7.5	.70	7.5	5.0					
400	4.5	.39	—	2.8					

TABLE 495.—ELEMENTS OF THE EARTH'S MAGNETIC FIELD

The elements commonly used to describe the natural geomagnetic field are:

Symbol	Name	Remarks
D	Magnetic declination	Bearing of magnetic north with respect to geographic north, counted positive from north around by east
I	Magnetic dip or inclination	Positive when Z has downward direction
H	Horizontal intensity	Positive regardless of direction
X	North intensity	Referred to geographic north
Y	East intensity	Referred to geographic east
Z	Vertical intensity	Positive when downward
F	Total intensity	Positive regardless of direction

For a given time and place, the field is completely described by specifying the values of three magnetic elements, provided they include one from the group D, X, Y, and one from the group, I, Z, F. The ways in which the magnetic elements are interrelated may be seen from figure 20 and the formulas below. The formulas in the right-hand group are obtained from the others by differentiation; they are useful when dealing with small increments, such as those which describe annual and daily changes and minor local anomalies of the geomagnetic field. The formulas pertaining to values of ΔD and ΔI are expressed in minutes of arc.

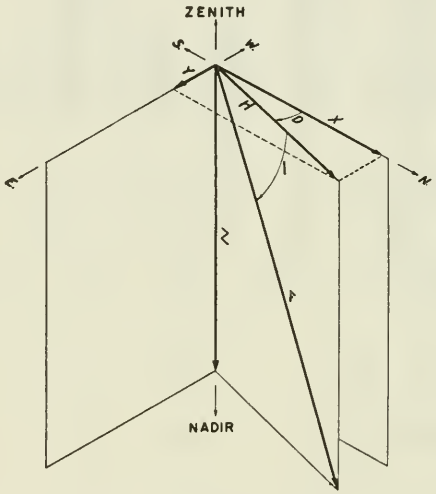


FIG. 20.—Interrelation of the magnetic elements.

$$X = H \cos D \qquad \Delta X = \cos D\ \Delta H - H \sin D \sin 1'\ \Delta D$$

$$Y = H \sin D \qquad \Delta Y = \sin D\ \Delta H + H \cos D \sin 1'\ \Delta D$$

$$Y = X \tan D \qquad \Delta F = \cos I\ \Delta H + \sin I\ \Delta Z$$

$$H = \sqrt{X^2 + Y^2} \qquad \Delta I = \frac{H\ \Delta Z - Z\ \Delta H}{H^2 \sec^2 I \sin 1'}$$

$$H = F \cos I \qquad \Delta I = \left(\frac{\Delta Z}{Z} - \frac{\Delta H}{H}\right) \frac{\sin 2I}{2 \sin 1'}$$

$$Z = H \tan I \qquad \Delta Z = \tan I\ \Delta H + \mathrm{H} \sec^2 I\ \Delta I \sin 1'$$

$$Z = F \sin I$$

$$F = \sqrt{H^2 + Z^2}$$

$$F = \sqrt{X^2 + Y^2 + Z^2}$$

* Prepared by E. H. Vestine, Carnegie Institution of Washington, and David G. Knapp, U. S. Coast and Geodetic Survey.

[159] For references, see bibliography following Table 511, p. 501.

(continued)

TABLE 495.—ELEMENTS OF THE EARTH'S MAGNETIC FIELD (concluded)

For purposes of mathematical analysis, it is convenient to recognize that the magnetic intensity or field strength (like other vector fields) is derivable from a scalar function or potential. If V be the potential corresponding to the geomagnetic field, we may write

$$F = -\,\mathrm{grad}\ V,$$

whence any of the magnetic elements may be expressed as functions of the potential.

In polar coordinates (r, θ, λ) with origin at the earth's center, we have

$$V = a \sum_{n=1}^{\infty} \left\{ (r/a)^n\ T_n{}^e + (a/r)^{n+1}\ T_n{}^i \right\} = V^e + V^i,$$

where a denotes the earth's mean radius (6.37×10^8 cm) (see Table 827).

$$T_n \equiv \sum_{m=0}^{m} (g_n{}^m \cos m\lambda + h_n{}^m \sin m\lambda)\ p_n{}^m\ (\theta).$$

Here θ is the colatitude and λ the east longitude, and the affixes e and i refer to portions respectively of external and internal origin. The function

$$P_n{}^m\ (\theta) = \left\{ 2\frac{(n-m)\,!}{(n+m)\,!} \right\}^{\frac{1}{2}} P_{n,m}\ (\theta) \text{ when } m > 0,$$

$$= P_{n,m}\ (\theta) \text{ when } m = 0,$$

where

$$P_{n,m}\ (\theta) = \frac{(2n)\,!}{2^n\ n\,!\ (n-m)\,!} \sin^m \theta \left\{ \cos^{n-m} \theta - \frac{(n-m)\ (n-m-1)}{2(2n-1)} \cos^{n-m-2} \theta + \ldots \right\}.$$

Magnetic surveys of portions of the earth have been made by means of observations at many thousands of stations, the elements usually observed being D, H, and I. Such surveys are repeated in part every few years in populated areas, and at intervals of one or more decades in most areas, because of a substantial and usually unpredictable change in the earth's field known as geomagnetic secular change. These changes are most accurately measured at fixed magnetic observatories to the number of about one hundred. The U. S. Coast and Geodetic Survey operates magnetic observatories at Cheltenham, Md.; Tucson, Ariz.; Sitka, Alaska; Honolulu, T. H.; and San Juan, P. R. Other nations conduct similar measurements.

Magnetic surveys by airplane will no doubt be commonplace in future years.

The part of the earth's field having external origin does not exceed a few percent, and its existence has never been indicated with much certainty by the spherical harmonic analyses. If the distinction between contributions of external and internal origin in the first formula is disregarded, the accompanying tables give the values of the principal harmonic terms at various epochs.

The magnetic moment of the earth as given by the centered dipole approximation for 1922 was 8.04×10^{25} cgs. The axis of this dipole intersects the earth's surface at points called the geomagnetic (axis) poles, located in 1922 at latitude 78°.5 N., and longitude 270°.0 E.; and at latitude 78°.5 S., and longitude 111° E. In comparison with these currently adopted values, the analysis of Vestine and Lange for 1945 shows only slight change that may have taken place since 1922.

The dipole part of the earth's field diminishes with height h approximately as $(1 - 3h/a)$. Values for 1945 have been estimated in tabulation to heights as great as $h = 5000$ km for spherical harmonic terms up to degree six.†

The magnetic north and south poles of popular interest are those defined by $H = 0$, or by $I = \pm 90°$. As H changes with time, owing to secular change, these poles must move with time, except in the unlikely event that the lines of zero change of X and Y both happen to pass through the poles. There are a principal north magnetic pole and a principal south magnetic pole, which undergo substantial change in position with time. In addition there are undoubtedly local (secondary) magnetic poles near each principal pole. These secondary poles occur only in pairs. Of each pair, one pole has the character of a potential focus (like the corresponding principal pole), while the other is a "false pole" or node of the equipotential lines. The secondary poles do not individually undergo large-scale migration, since they are associated with localized magnetic materials in the earth's crust. These occur when such materials succeed in reducing the changing value of H to zero, as the principal migrates.

The principal north and south magnetic poles are not diametrically opposite, each being about 2,300 km from the antipodes of the other.

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† See bibliography, reference g, p. 501.

TABLE 496.—THE FIRST EIGHT GAUSS COEFFICIENTS OF THE EARTH'S MAGNETIC POTENTIAL (V) EXPRESSED IN UNITS OF 10^{-4} cgs

Source	Epoch	g_1^0	g_1^1	h_1^1	g_2^0	g_2^1	h_2^1	g_2^2	h_2^2
Gauss	1835	−3235	−311	+625	+ 51	+292	+ 12	− 2	+157
Erman-Petersen	1829	−3201	−284	+601	− 8	+257	− 4	− 14	+146
Adams	1845	−3219	−278	+578	+ 9	+284	− 10	+ 4	+135
Adams	1880	−3168	−243	+603	− 49	+297	− 75	+ 61	+149
Fritsche	1885	−3164	−241	+591	− 35	+286	− 75	+ 68	+142
Schmidt	1885	−3168	−222	+595	− 50	+278	− 71	+ 65	+149
Dyson and Furner	1922	−3095	−226	+592	− 89	+299	−124	+144	+ 84
Afanasieva	1945	−3032	−229	+590	−125	+288	−146	+150	+ 48
Vestine and Lange	1945	−3057	−211	+581	−127	+296	−166	+164	+ 54

TABLE 497.—SPHERICAL HARMONIC COEFFICIENTS OF THE AVERAGE ANNUAL SECULAR VARIATION EXPRESSED IN UNITS OF 10^{-5} cgs

Source	Epoch	g_1^0	g_1^1	h_1^1	g_2^0	g_2^1	h_2^1	g_2^2	h_2^2
Dyson-Schmidt	1922–1885	+20	− 1	− 1	−10	+6	−14	+21	−18
Bartels	1920–1902	+42	− 9	+12	− 7	+8	−25	+13	− 8
Carlheim-Gyllensköld	1920–1902	0	+13	+ 4	0	−4	−12	+13	−17
Vestine and Lange	1912.5	+25	+ 1	− 7	− 7	−1	− 9	+24	−17
Vestine and Lange	1922.5	+28	+ 4	− 7	−10	+1	−14	+17	−17
Vestine and Lange	1932.5	+23	+ 1	− 5	−14	+1	−18	+10	−14
Vestine and Lange	1942.5	+ 9	+ 2	+ 1	−18	0	−20	+ 2	−14

The magnetic moment of the earth (epoch 1922) = 8.06×10^{25} cgs.

Geomagnetic north pole.......... Latitude 78.6 N. Longitude 289.9 E.

Geomagnetic south pole.......... Latitude 78.6 S. Longitude 109.9 E.

TABLE 498.—COORDINATES OF NORTH MAGNETIC POLE

Date or epoch	North latitude	West longitude	Observer	Authority *
	° ′	° ′		
1831.4	78 05.4	96 53.5	J. C. Ross	A. Nippoldt [m]
	°	°		
1904.5	70.5	96.5	R. Amundsen	Vestine et al.[f,n]
1912.5	70.9	96.8	....	Vestine et al.†
1922.5	71.4	97.2	....	Vestine et al.†
1932.5	71.9	97.6	....	Vestine et al.†
1942.5	72.6	97.9	....	Vestine et al.†
1948.0	73.0	100.0	P. H. Serson et al.	R. G. Madill, Arctic, vol. 1, p. 8, 1948.

* For authorities, see bibliography, p. 501.
† Based on the above position for 1904.5 with reduction for secular change.

TABLE 499.—COORDINATES OF SOUTH MAGNETIC POLE

Date or epoch	South latitude	East longitude	Observer	Authority *
	° ′	° ′		
1841.1	75 00	153 45	J. C. Ross	C. C. Farr °
1909.0	72 25	155 16	D. Mawson	C. C. Farr °
	°	°		
1912.5	71.2	150.7	E. N. Webb	Vestine et al.[f,o]
1922.5	70.2	149.2	....	Vestine et al.†
1932.5	69.0	148.1	....	Vestine et al.†
1942.5	68.3	146.2	....	Vestine et al.†
1945.0	68.2	145.4	....	Vestine et al.†

* For authorities, see bibliography, p. 501.
† Based on the above position for 1912.5 with reduction for secular change.

TABLE 500.—DIP OR INCLINATION, UNITED STATES

This table gives for the epoch January 1, 1950, smoothed values of the magnetic dip, I, corresponding to the longitudes, λ, west of Greenwich in the heading and the north latitudes, Φ, in the first column. The remarks about smoothing, in Table 502, apply to this table as well.

$\Phi \backslash \lambda$	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	...	...	54.7	...	...	...	...	...	...	...	...	...	...
23	...	...	57.0	56.3	55.0	54.1	52.7	51.4	50.1	...	...	...	...
25	...	...	59.2	58.5	57.6	56.6	55.2	53.9	52.6	51.4	50.3	...	...
27	...	...	61.1	60.8	59.9	58.8	57.6	56.3	55.0	53.7	52.6	51.6	...
29	...	62.9	63.0	62.8	62.0	61.0	59.8	58.5	57.2	56.0	54.8	53.8	...
31	...	64.5	64.8	64.7	63.9	63.0	61.8	60.6	59.4	58.2	57.0	55.9	...
33	...	66.2	66.5	66.5	65.9	64.9	63.8	62.6	61.5	60.4	59.0	58.0	...
35	...	67.8	68.2	68.2	67.7	66.8	65.8	64.7	63.6	62.4	61.1	60.0	...
37	...	69.4	69.9	69.9	69.5	68.6	67.6	66.6	65.5	64.4	63.0	61.8	...
39	...	70.7	71.3	71.4	71.1	70.4	69.4	68.5	67.4	66.2	64.9	63.6	62.7
41	...	72.0	72.6	72.8	72.6	72.0	71.2	70.2	69.2	68.0	66.7	65.4	64.3
43	72.3	73.2	73.9	74.2	74.0	73.6	72.5	71.9	70.9	69.6	68.4	67.1	65.9
45	73.4	74.4	75.2	75.6	75.5	75.0	74.4	73.6	72.6	71.3	70.0	68.8	67.5
47	74.4	75.6	76.3	76.8	76.9	76.6	75.9	75.1	74.1	72.8	71.6	70.4	69.2
49	75.5	76.6	77.4	78.0	78.4	78.1	77.3	76.5	75.5	74.4	73.0	71.9	70.7

TABLE 501.—SECULAR CHANGE OF DIP, UNITED STATES

Smoothed values of the magnetic dip for the indicated places for January 1 of the years stated. The degrees are given in the third column and in the succeeding column. The remarks about smoothing, in Table 502, apply to this table as well.

Lat.	Long.		1930	1935	1940	1945	1950	Lat.	Long.		1930	1935	1940	1945	1950
25°	80°	55′	179′	202′	214′	213′	210	43°	70°	73′	17′	19′	24′	19′	12′
25	90	53	188	210	218	216	215	43	80	73	76	80	85	80	74
25	100	51	162	176	178	176	173	43	90	73	39	43	46	40	33
31	80	62	137	154	166	164	161	43	100	71	67	69	70	63	56
31	90	60	163	178	185	181	178	43	110	69	50	50	51	45	39
31	100	58	153	162	165	161	157	43	120	67	20	16	18	14	7
31	110	57	72	77	77	75	71	47	70	75	49	46	49	44	36
37	80	68	102	113	122	118	114	47	80	76	61	60	62	57	50
37	90	67	92	101	108	102	97	49	90	78	23	22	21	15	7
37	100	65	98	104	107	101	96	49	100	76	46	45	43	37	31
37	110	63	89	91	93	88	82	49	110	74	35	32	31	26	21
37	120	61	61	59	62	57	51	49	120	71	68	62	62	58	53

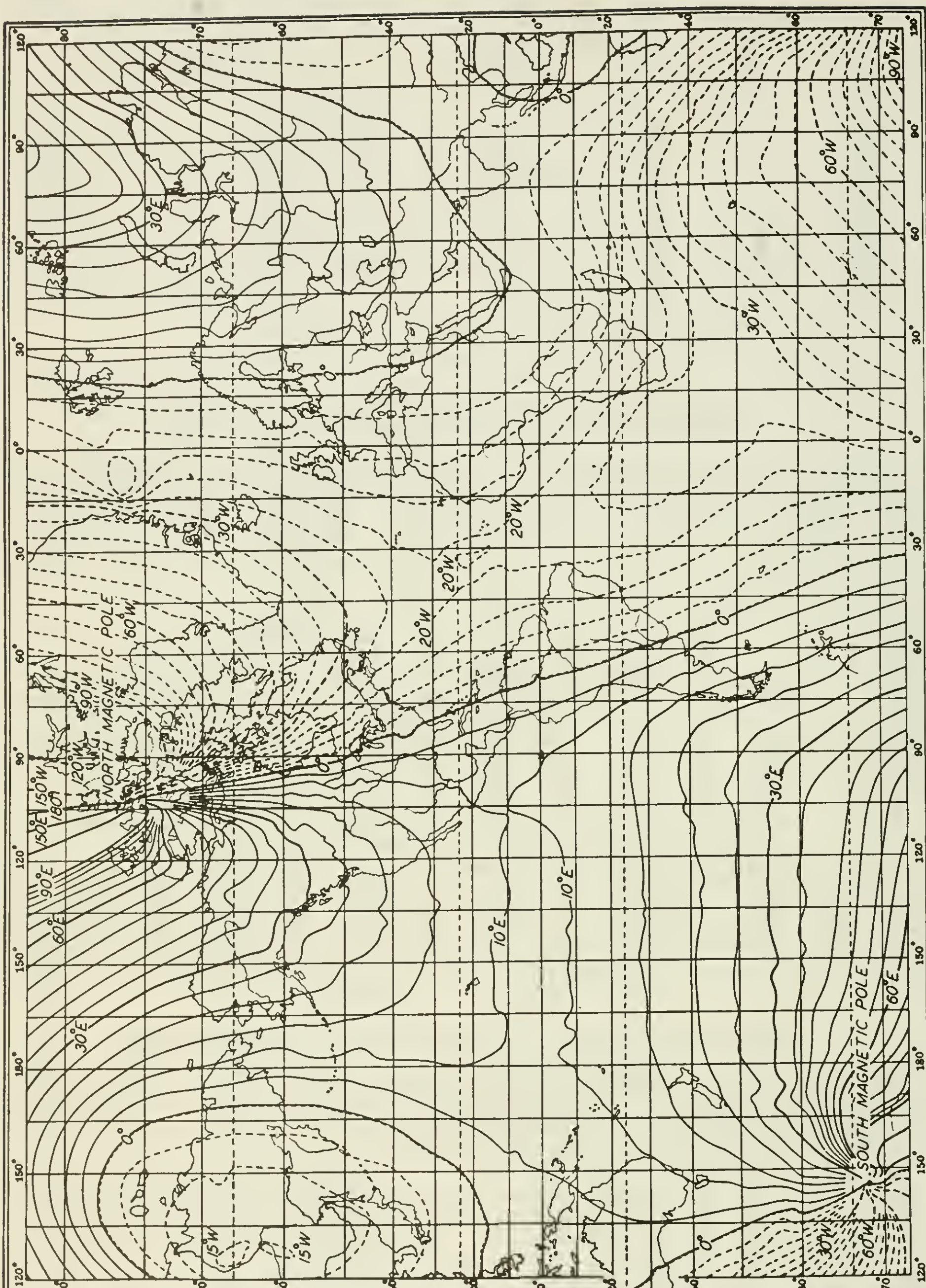

FIG. 21.—World isogonic lines, epoch 1945 (lines of equal declination, D, in degrees).

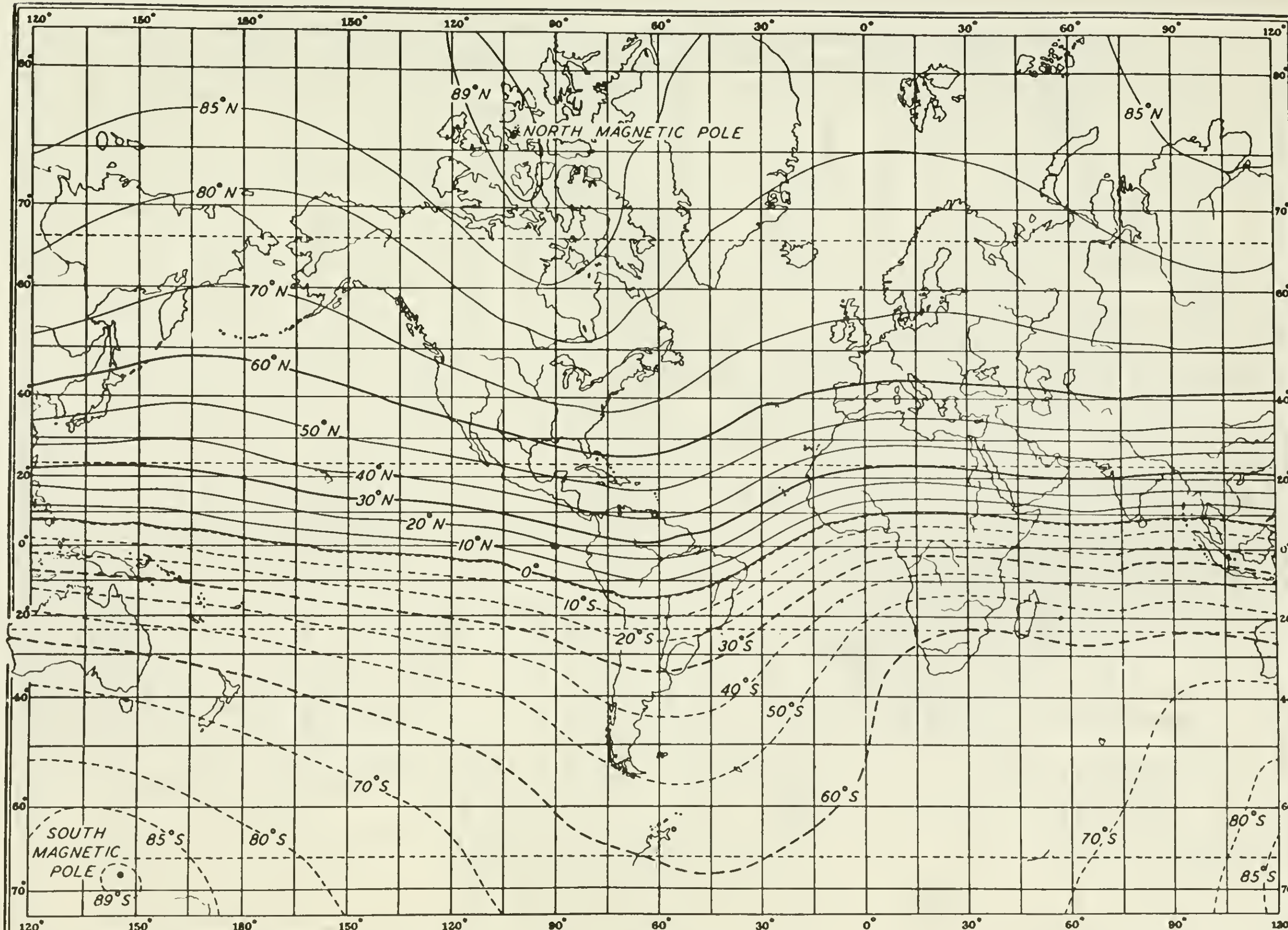

FIG. 22.—World isoclinic lines, epoch 1945 (lines of equal inclination, I, in degrees). Solid lines indicate north end dipping; broken lines, south end dipping.

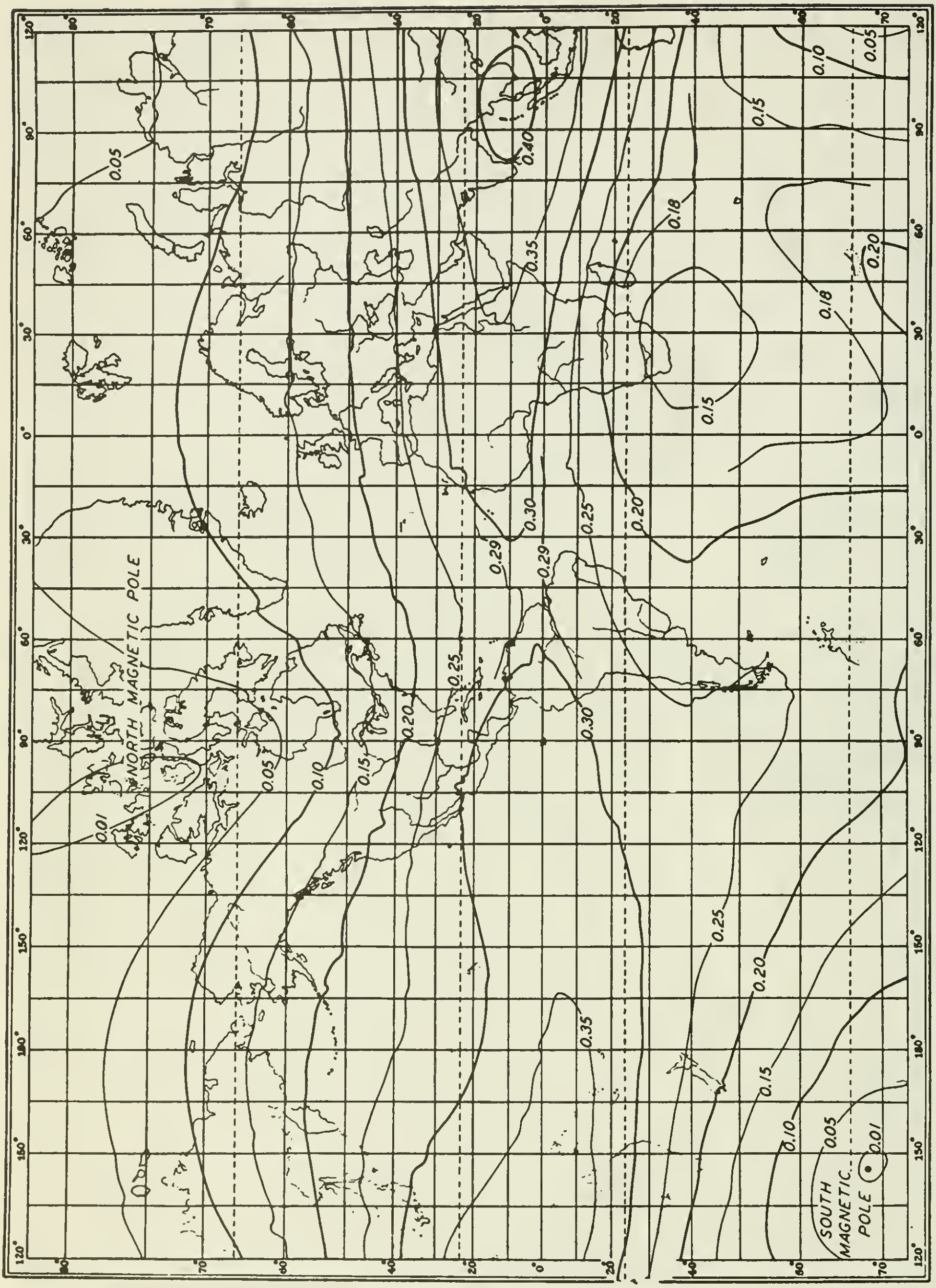

Fig. 23.—World isodynamic lines, epoch 1945 (lines of equal horizontal intensity, H, in cgs).

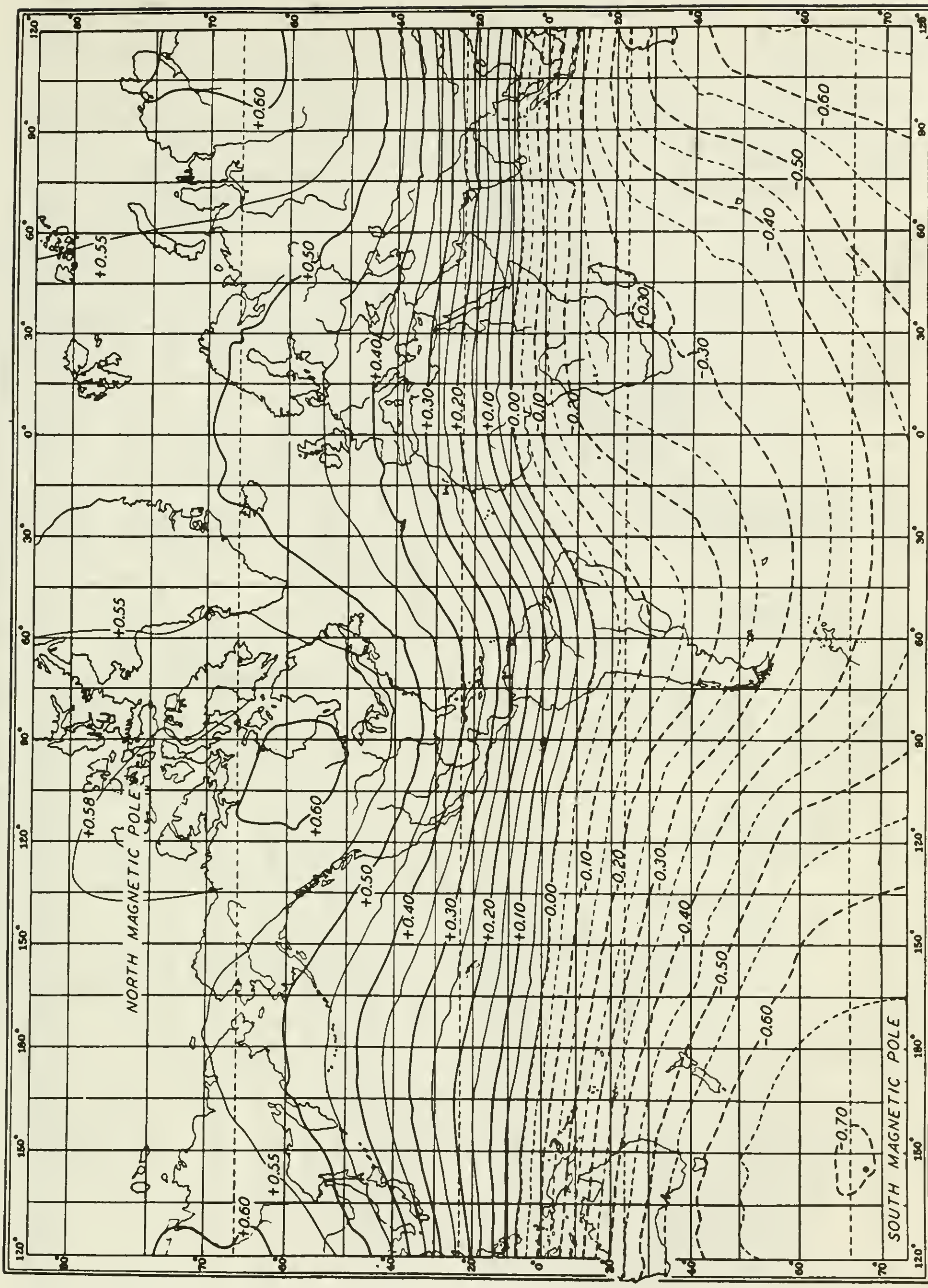

FIG. 24.—World isodynamic lines, epoch 1945 (lines of equal vertical intensity, Z, in cgs).

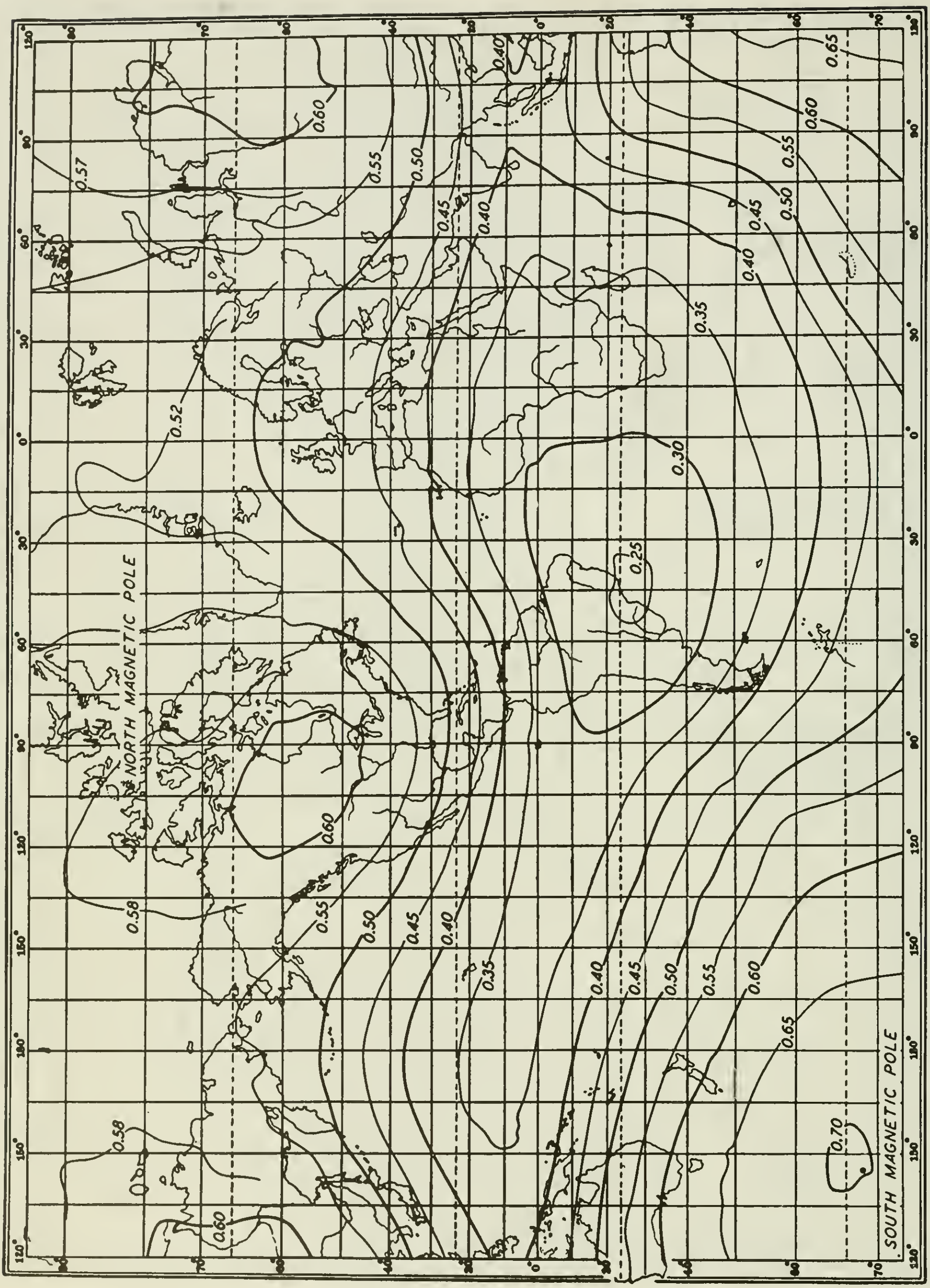

FIG. 25.—World isodynamic lines, epoch 1945 (lines of equal total intensity, F, in cgs).

TABLE 502.—SECULAR CHANGE OF MAGNETIC DECLINATION IN THE UNITED STATES

Smoothed values of the magnetic declination for the indicated places for January 1 of the years stated. The degrees are given in the fourth column, together with the indication E (east) or W (west); the minutes are given in the succeeding columns. The pattern depicted by this table for any date is highly smoothed and corresponds with that shown on "datum charts" discussed in current publications of the U. S. Coast and Geodetic Survey, such as those cited.** The latter contain more detailed secular-change tables, as well as current magnetic charts which may be consulted for values reflecting a greater amount of local information than it is possible to show in tabular form.

** See bibliography, references d, e, p. 501.

Locality	Lat.	Long.		1920	1930	1940	1950
At sea	44°	68°	13°W	319′	357′	377′	377′
Maine	46	68	16 W	269	299	312	307
Canada	48	68	19 W	241	263	269	258
At sea	40	72	6 W	311	356	382	387
Conn.	42	72	7 W	355	400	425	426
N. H.	44	72	9 W	349	392	413	410
Canada	46	72	11 W	357	393	409	401
At sea	34	76	0†	260	283	298	306
N. C.	36	76	0 W	324	351	366	372
Md.	38	76	1 W	333	367	382	385
Pa.	40	76	2 W	350	389	403	404
Pa.	42	76	3 W	376	420	434	432
N. Y.	44	76	5 W	357	402	415	409
At sea	26	80	0 E	72	77	75	59
At sea	28	80	0 E	39	40	37	25
At sea	30	80	0†	4*	0	3	11
At sea	32	80	0†	33	43	46	51
S. C.	34	80	0†	81	96	98	101
N. C.	36	80	0†	132	153	157	157
Va.	38	80	0†	191	218	221	219
Pa.	40	80	0†	255	289	293	288
Pa.	42	80	0 W	326	365	371	365
Canada	44	80	1 W	352	396	403	394
Fla.	30	84	2 E	28	31	39	35
Ga.	32	84	1 E	62	59	66	66
Ga.	34	84	1 E	32	23	30	32
Tenn.	36	84	0 E	59	44	50	54
Ky.	38	84	0†	18*	5	0	6*
Ohio	40	84	0†	24	55	52	44
Mich.	42	84	0†	77	114	113	105
Mich.	44	84	0†	141	183	187	178
Mich.	46	84	0†	212	260	270	263
Ala.	30	88	4 E	42	50	64	64
Ala.	32	88	4 E	28	30	42	44
Ala.	34	88	4 E	12	7	18	22
Tenn.	36	88	3 E	54	42	53	58
Ind.	38	88	3 E	34	14	23	29
Ill.	40	88	2 E	70	41	47	52
Ill.	42	88	2 E	41	6	8	12
Wis.	44	88	1 E	70	28	25	27
Mich.	46	88	0 E	87	37	28	26
Mich.	48	88	0†	35*	20	35	42
La.	30	92	6 E	47	57	74	74
La.	32	92	6 E	44	49	64	66
Ark.	34	92	6 E	39	37	51	55
Ark.	36	92	6 E	40	29	38	42
Mo.	38	92	6 E	39	20	27	29
Mo.	40	92	6 E	34	8	12	12
Iowa	42	92	5 E	87	52	50	49
Minn.	44	92	5 E	76	34	28	22
Minn.	46	92	4 E	128	79	64	53
Minn.	48	92	4 E	116	60	37	21
At sea	28	96	7 E	85	101	119	115
Tex.	30	96	7 E	96	107	123	121
Tex.	32	96	8 E	48	54	67	66
Okla.	34	96	8 E	61	61	70	69
Okla.	36	96	8 E	75	66	71	69
Kans.	38	96	9 E	27	10	12	9
Kans.	40	96	9 E	38	13	12	6
Iowa	42	96	9 E	48	16	11	2
Minn.	44	96	8 E	120	81	70	57
Minn.	46	96	8 E	134	88	69	50
Minn.	48	96	8 E	154	100	71	48

Locality	Lat.	Long.		1920	1930	1940	1950
Mexico	28°	100°	8 E	112′	127′	142′	135′
Tex.	30	100	9 E	75	85	98	92
Tex.	32	100	9 E	98	103	114	108
Tex.	34	100	10 E	63	63	69	63
Okla.	36	100	10 E	89	82	83	76
Kans.	38	100	11 E	52	38	35	25
Kans.	40	100	11 E	74	52	47	34
Nebr.	42	100	11 E	99	71	62	46
S. Dak.	44	100	11 E	129	94	79	59
N. Dak.	46	100	12 E	105	63	40	16
N. Dak.	48	100	12 E	143	94	64	34
Tex.	30	104	10 E	91	100	110	100
Tex.	32	104	11 E	65	69	76	66
N. Mex.	34	104	11 E	98	97	100	90
N. Mex.	36	104	12 E	72	66	65	52
Colo.	38	104	13 E	45	33	26	12
Colo.	40	104	13 E	78	60	49	31
Nebr.	42	104	13 E	118	94	79	58
S. Dak.	44	104	14 E	107	76	57	31
N. Dak.	46	104	15 E	98	61	37	6
N. Dak.	48	104	15 E	154	110	79	44
Mexico	30	108	11 E	95	100	108	95
N. Mex.	32	108	12 E	74	75	79	65
N. Mex.	34	108	12 E	111	109	109	95
N. Mex.	36	108	13 E	90	84	80	63
Colo.	38	108	14 E	69	59	51	32
Colo.	40	108	15 E	56	40	26	5
Wyo.	42	108	15 E	111	90	73	47
Wyo.	44	108	16 E	113	86	66	35
Mont.	46	108	17 E	114	81	56	21
Mont.	48	108	18 E	117	78	47	8
Ariz.	32	112	12 E	125	125	126	112
Ariz.	34	112	13 E	107	104	103	86
Ariz.	36	112	14 E	91	84	78	60
Utah	38	112	15 E	80	70	60	39
Utah	40	112	16 E	76	62	49	25
Utah	42	112	17 E	79	61	44	16
Idaho	44	112	18 E	84	61	41	9
Mont.	46	112	19 E	96	67	41	5
Mont.	48	112	19 E	163	129	99	59
Mexico	32	116	12 E	164	162	163	148
Calif.	34	116	13 E	151	146	144	128
Calif.	36	116	14 E	141	134	128	109
Nev.	38	116	15 E	137	127	118	97
Nev.	40	116	16 E	138	126	113	89
Nev.	42	116	17 E	140	124	109	81
Idaho	44	116	18 E	152	133	114	83
Idaho	46	116	19 E	168	143	120	85
Mont.	48	116	21 E	119	90	61	23
At sea	34	120	13 E	189	184	180	163
Calif.	36	120	14 E	184	177	171	152
Calif.	38	120	15 E	182	172	163	143
Calif.	40	120	16 E	180	168	156	132
Calif.	42	120	17 E	184	169	154	129
Oreg.	44	120	18 E	200	181	163	135
Wash	46	120	19 E	213	192	172	140
Wash.	48	120	21 E	168	142	116	80
At sea	38	124	15 E	212	202	194	175
Calif.	40	124	16 E	211	199	187	167
Calif.	42	124	17 E	215	201	187	164
Oreg.	44	124	18 E	229	212	194	170
Oreg.	46	124	19 E	241	222	203	175
Wash.	48	124	20 E	256	234	210	179

* East declination. † Values on this line are west, except those marked (*).

TABLE 503.—HOURLY DEPARTURE OF MAGNETIC DECLINATION FROM NORMAL *

The daily variation is not predictable in detail since it fluctuates in form and amplitude from day to day. However, the variations shown in this table appear with considerable regularity when the data are averaged over several months or years. Values are based on the 10 least-disturbed days of each month of the interval 1918-1928, using photographic registrations obtained at three of the magnetic observatories listed in Table 510. A plus sign signifies that east declination is greater, or west declination less, than the mean for the day.

	January, February, November, December			March, April, September, October			May, June, July, August		
Hour, local mean time	Sitka, Alaska	Chelten-ham, Md.	Tucson, Ariz.	Sitka, Alaska	Chelten-ham, Md.	Tucson, Ariz.	Sitka, Alaska	Chelten-ham, Md.	Tucson, Ariz.
2 a.m.	.0	− .2	− .3	.0	+ .4	+ .1	− .9	+ .3	+ .1
4 a.m.	+ .2	+ .2	− .2	+ .5	+1.0	+ .3	+ .6	+1.0	+ .6
6 a.m.	+ .7	+ .8	+ .2	+2.4	+2.3	+1.5	+4.9	+4.1	+2.6
8 a.m.	+1.8	+2.5	+1.9	+4.8	+4.7	+4.0	+7.7	+5.9	+4.7
10 a.m.	+1.7	+2.5	+2.3	+3.6	+2.2	+1.4	+4.8	+1.3	+ .4
Noon	− .2	−2.0	−1.1	− .6	−3.7	−2.3	−1.8	−4.7	−3.2
2 p.m.	−1.5	−3.2	−2.2	−2.9	−4.7	−2.8	−5.2	−5.4	−3.2
4 p.m.	−1.6	−1.5	−1.0	−3.2	−2.2	−1.4	−5.1	−2.5	−1.4
6 p.m.	− .9	− .2	.0	−2.3	− .6	− .6	−2.5	− .2	− .3
8 p.m.	− .3	+ .5	+ .3	−1.3	.0	− .2	−1.0	− .4	− .4
10 p.m.	.0	+ .6	+ .2	− .8	+ .3	− .1	−1.0	.0	− .2
Midnight	− .1	+ .2	− .1	− .3	+ .4	.0	−1.1	+ .2	− .1

* Expressed in minutes.

TABLE 504.—HORIZONTAL MAGNETIC INTENSITY, UNITED STATES

This table gives for the epoch January 1, 1950, the smoothed horizontal intensity, H, expressed in cgs units, corresponding to the longitudes west of Greenwich in the heading and the north latitudes in the first column. The remarks about smoothing, in Table 502, apply to this table as well.

$\Phi \backslash \lambda$	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
21°	...	...	.267	...	...	...	...	...	...	...	...	...	...
23	...	...	.262	.267	.274	.282	.288	.293	.296	...	...	...	...
25	...	...	.254	.259	.266	.273	.278	.284	.288	.290	.290	...	...
27	...	...	.246	.251	.257	.264	.270	.276	.280	.282	.282	282	...
29	...	.232	.236	.241	.247	.254	.260	.266	.271	.273	.274	.276	...
31	...	.222	.226	.231	.237	.244	.250	.257	.262	.265	.267	.269	...
33	...	.212	.215	.220	.225	.232	.239	.246	.252	.256	.259	.261	...
35	...	.202	.204	.208	.213	.220	.227	.234	.241	.246	.250	.253	...
37	...	.192	.193	.196	.201	.207	.214	.222	.229	.236	.240	.244	...
39	...	.181	.181	.184	.188	.194	.201	.210	.217	.224	.230	.234	.238
41	...	.171	.170	.171	.176	.181	.188	.196	.204	.212	.219	.224	.230
43	.165	.161	.160	.160	.162	.167	.174	.182	.191	.200	.207	.214	.219
45	.156	.151	.148	.148	.149	.153	.160	.168	.177	.186	.195	.202	.208
47	.145	.140	.137	.135	.135	.140	.146	.154	.164	.174	.182	.190	.197
49	.134	.129	.126	.123	.122	.126	.133	.140	.150	.160	.170	.178	.185

TABLE 505.—SECULAR CHANGE OF HORIZONTAL INTENSITY, UNITED STATES

Smoothed values of horizontal intensity in cgs units at the indicated places for January 1 of the years stated. The remarks about smoothing, in Table 502, apply to this table as well.

Lat.	Long.	1930	1935	1940	1945	1950	Lat.	Long.	1930	1935	1940	1945	1950
25°	80°	.2653	.2612	.2589	.2586	.2587	43°	70°	.1627	.1613	.1601	.1608	.1613
25	90	.2801	.2761	.2741	.2735	.2731	43	80	.1621	.1604	.1589	.1595	.1598
25	100	.2908	.2878	.2861	.2851	.2843	43	90	.1693	.1675	.1664	.1671	.1671
31	80	.2361	.2325	.2303	.2304	.2306	43	100	.1838	.1822	.1814	.1820	.1820
31	90	.2494	.2461	.2442	.2441	.2438	43	110	.2015	.2002	.1994	.1997	.1996
31	100	.2622	.2595	.2578	.2573	.2567	43	120	.2154	.2143	.2135	.2136	.2136
31	110	.2698	.2677	.2662	.2656	.2648	47	70	.1405	.1398	.1389	.1398	.1403
37	80	.2003	.1974	.1954	.1958	.1960	47	80	.1362	.1352	.1342	.1350	.1353
37	90	.2111	.2084	.2068	.2071	.2070	49	90	.1256	.1249	.1243	.1253	.1255
37	100	.2262	.2239	.2226	.2227	.2223	49	100	.1406	.1398	.1394	.1403	.1405
37	110	.2389	.2372	.2361	.2359	.2355	49	110	.1601	.1592	.1587	.1594	.1597
37	120	.2473	.2460	.2449	.2446	.2442	49	120	.1783	.1775	.1771	.1775	.1777

TABLE 506.—VERTICAL MAGNETIC INTENSITY, UNITED STATES

This table gives for the epoch January 1, 1950, the smoothed vertical intensity, Z, expressed in cgs units, corresponding to the longitudes west of Greenwich in the heading and the north latitudes in the first column. The remarks about smoothing, in Table 502, apply to this table as well.

$\phi \backslash \lambda$	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
21°	...	...	.378	...	...	...	...	...	...	...	...	...	...
23	...	...	.402	.399	.391	.389	.378	.367	.354	...	...	...	...
25	...	...	.425	.422	.419	.414	.401	.390	.376	.362	.348	...	...
27	...	...	.445	.448	.442	.435	.426	.413	.399	.383	.368	.356	...
29	...	.454	.463	.468	.465	.458	.447	.434	.421	.404	.389	.376	...
31	...	.465	.480	.488	.484	.478	.467	.456	.442	.427	.411	.398	...
33	...	.480	.494	.505	.503	.495	.487	.477	.464	.449	.432	.418	...
35	...	.493	.511	.552	.520	.513	.505	.505	.485	.471	.453	.437	...
37	...	.509	.526	.536	.536	.529	.521	.514	.502	.491	.473	.456	...
39	...	.518	.536	.545	.548	.545	.536	.531	.521	.509	.491	.473	.461
41	...	.527	.544	.557	.559	.558	.551	.546	.536	.524	.509	.490	.476
43	.517	.534	.554	.566	.569	.566	.563	.558	.551	.538	.523	.506	.490
45	.521	.541	.561	.573	.575	.576	.572	.571	.564	.550	.536	.521	.503
47	.521	.546	.563	.578	.583	.585	.583	.581	.576	.559	.548	.533	.518
49	.518	.542	.565	.581	.595	.596	.591	.586	.581	.570	.556	.543	.527

TABLE 507.—SECULAR CHANGE OF VERTICAL INTENSITY, UNITED STATES

Smoothed values of vertical intensity in cgs units at the indicated places for January 1 of the years stated. The remarks about smoothing, in Table 502, apply to this table as well.

Lat.	Long.	1930	1935	1940	1945	1950	Lat.	Long.	1930	1935	1940	1945	1950
25°	80°	.4243	.4240	.4236	.4228	.4222	43°	70°	.5417	.5382	.5370	.5365	.5343
25	90	.4174	.4171	.4162	.4148	.4139	43	80	.5754	.5719	.5698	.5687	.5660
25	100	.3959	.3952	.3933	.3914	.3896	43	90	.5771	.5734	.5715	.5702	.5659
31	80	.4902	.4889	.4887	.4881	.4875	43	100	.5696	.5658	.5639	.5618	.5579
31	90	.4835	.4823	.4810	.4794	.4778	43	110	.5486	.5451	.5434	.5413	.5381
31	100	.4644	.4624	.4603	.4582	.4559	43	120	.5158	.5115	.5104	.5085	.5061
31	110	.4351	.4332	.4307	.4292	.4268	47	70	.5559	.5511	.5496	.5498	.5464
37	80	.5415	.5389	.5378	.5370	.5356	47	80	.5907	.5856	.5828	.5824	.5784
37	90	.5368	.5341	.5332	.5312	.5287	49	90	.6110	.6067	.6029	.6024	.5964
37	100	.5236	.5207	.5189	.5167	.5137	49	100	.5979	.5937	.5905	.5897	.5860
37	110	.5005	.4977	.4961	.4938	.4908	49	110	.5806	.5754	.5729	.5722	.5701
37	120	.4654	.4623	.4612	.4591	.4564	49	120	.5531	.5474	.5461	.5452	.5431

TABLE 508.—TOTAL MAGNETIC INTENSITY, UNITED STATES

This table gives for the epoch January 1, 1950, the smoothed total intensity, F, expressed in cgs units, corresponding to the longitudes west of Greenwich in the heading and the north latitudes in the first column. The remarks about smoothing, in Table 502, apply to this table as well.

$\Phi \backslash \lambda$	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	120°	125°
21°	...	...	.463	...	...	...	...	...	...	...	...	...	...
23	...	...	.480	.480	.477	.481	.475	.469	.461	...	...	...	...
25	...	...	.495	.495	.496	.496	.489	.482	.473	.464	.453	...	...
27	...	...	.508	.514	.512	.509	.504	.497	.487	.476	.464	.454	...
29	...	.510	.520	.526	.526	.524	.518	.509	.501	.488	.476	.466	...
31	...	.515	.530	.539	.539	.536	.530	.523	.514	.502	.490	.480	...
33	...	.525	.539	.550	.552	.547	.543	.536	.528	.517	.503	.493	...
35	...	.533	.550	.562	.562	.558	.535	.549	.541	.531	.518	.505	...
37	...	.544	.561	.570	.572	.568	.564	.560	.552	.544	.530	.518	...
39	...	.549	.566	.575	.579	.578	.572	.571	.564	.556	.542	.528	.519
41	...	.554	.570	.582	.586	.586	.582	.580	.574	.566	.554	.539	.529
43	.543	.558	.576	.588	.591	.590	.589	.587	.583	.574	.563	.549	.537
45	.543	.562	.581	.592	.594	.596	.594	.595	.591	.581	.571	.559	.545
47	.541	.564	.580	.594	.599	.601	.601	.602	.599	.585	.577	.565	.554
49	.535	.557	.579	.594	.607	.609	.606	.603	.600	.592	.581	.572	.559

TABLE 509.—SECULAR CHANGE OF TOTAL INTENSITY, UNITED STATES

Smoothed values of total intensity in cgs units at the indicated places for January 1 of the years stated. The remarks about smoothing, in Table 502, apply to this table as well.

Lat.	Long.	1930	1935	1940	1945	1950	Lat.	Long.	1930	1935	1940	1945	1950
25°	80°	.5004	.4980	.4964	.4956	.4951	43°	70°	.5656	.5619	.5604	.5601	.5581
25	90	.5026	.5002	.4984	.4968	.4959	43	80	.5978	.5940	.5915	.5907	.5881
25	100	.4912	.4889	.4864	.4843	.4823	43	90	.6014	.5974	.5952	.5942	.5901
31	80	.5441	.5414	.5402	.5398	.5393	43	100	.5985	.5944	.5923	.5906	.5869
31	90	.5441	.5415	.5394	.5380	.5364	43	110	.5845	.5807	.5788	.5770	.5740
31	100	.5332	.5303	.5276	.5255	.5232	43	120	.5589	.5545	.5532	.5516	.5493
31	110	.5120	.5092	.5064	.5047	.5023	47	70	.5734	.5686	.5669	.5673	.5642
37	80	.5773	.5739	.5722	.5716	.5703	47	80	.6062	.6010	.5981	.5979	.5940
37	90	.5768	.5733	.5719	.5701	.5677	49	90	.6237	.6194	.6156	.6153	.6095
37	100	.5703	.5668	.5647	.5626	.5597	49	100	.6142	.6099	.6067	.6061	.6026
37	110	.5546	.5513	.5494	.5473	.5444	49	110	.6022	.5970	.5945	.5940	.5920
37	120	.5271	.5237	.5222	.5202	.5176	49	120	.5812	.5754	.5741	.5734	.5715

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES**

The usual conventions are followed as explained in connection with Table 502.

In addition to permanent geomagnetic observatories, there are given the numerous series of magnetic records obtained for the better part of a year by special expeditions, as, for example, those obtained during the two International Polar Years of 1882-83 and 1932-33; all are listed in decreasing order of north latitude.

Generally, values are from continuous magnetograph records for all days, and are for mean of year.

The many special notes applying to individual observatories have been omitted in the tabulation; these may be obtained from the references cited below if desired. However, the following general types of notes should be taken cognizance of:

* = Observatory so marked is in a region of local magnetic disturbance.

—— = A break occurred between the preceding and following years due to change in procedure, method, standard, or site.

a) = Means quoted here are for all days, and may differ slightly from previously published means for 10 quiet days, given in official publication of U. S. Coast and Geodetic Survey.

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ†	North X γ	East Y γ	Vertical Z γ	Total F γ
Teplitz Bay (Camp Abruzzi)	+81°48′	57°59′	1904	+22°42′.0	+83°12′.4	6766	6242	+2611	+56798	57200
Alger Island	+80 22	56 06	1905	+20 28.4	+82 45.8	7161	6709	+2505	+56395	56848
Bay Tikhaya (Calm Bay)	+80 20	52 48	1933	+21 07.3	+83 06.3	6605	6159	+2380	+54616	55000
			1941	+23 07.7	+83 22.4	6355	5844	+2496	+54699	55067
Refuge Harbor (Greenland)	+78 32	287 37	1923-1924	−99 49.5	+85 47.1	4136	706	−4075	+56118	56270
Cape Thordsen (Spitsbergen)	+78 28	15 42	1932-1933	− 5 54.6	+81 12.4	8187	8144	− 843	+52926	53555
Sveagruvan (Spitsbergen)	+77 54	16 45	1932-1933	− 4 53.7	+80 59.4	8328	8298	− 711	+52524	53180
Chelyuskin	+77 17	104 17	1935	+25 32.1	+86 00.4	4024	3631	+1734	+57649	57789
			1940	+24 57.5	+86 12.0	3850	3490	+1625	+57972	58100
Thule	+76 32	291 06	1933	−81 21.2	+85 18.9	4570	687	−4518	+55757	55944
Jekman Island	+76 26	95 08	1939	+29 14.2	+85 11.6	4799	4188	+2344	+57070	57271
Bear Island (Björnöya)	+74 29	19 14	1932-1933	− 1 53.9	+79 34.1	9498	9493	− 315	+51588	52455
Dickson	+73 30	80 25	1933	+28 31.6	+83 05.0	6971	6125	+3329	+57430	57852
			1941	+29 14.0	+83 24.5	6614	5772	+3230	+57229	57610
Matochkin Shar	+73 16	56 24	1938	+22 21.9	+80 39.6	8935	8263	+3400	+54325	55055
			1940	+22 41.1	+80 40.9	8902	8213	+3433	+54251	54977
Point Barrow	+71 23	203 43	1932-1933	+28 45	+80 41	9223	8086	+4436	+56219	56971

** For references, see bibliography, p. 501.

† $\gamma = 10^{-5}$ cgs.

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
						Components of intensity				
Jan Mayen	+70°59′	351°40′	1933	−21°43′.8	+76°53′.5	11726	10890	−4340	+50352	51699
Scoresby Sund (Greenland)	+70 29	338 02	1932 / 1933	−34 33.2	+78 17.9	10576	8710	−5998	+51063	52147
Tromsö	+69 40	18 57	1930	− 4 07.7	....	11567	11537	− 833	....	....
			1942	− 2 10.6	+77 25.8	11244	11236	− 427	+50424	51662
			1944	− 1 54.3	+77 28.4	11213	11207	− 373	+50647	51698
Petsamo	+69 32	31 15	1933	+ 5 46.2	+77 25.5	11341	11284	+1140	+50838	52088
Bodö	+69 18	14 25	1934	− 5 42	+76 08	12233	12172	−1215	+49555	51042
Godhavn	+69 14	306 29	1930	−57 41.1	+81 34.7	8227	4398	−6953	+55564	56170
			1938	−55 28.0	+81 34.5	8174	4634	−6734	+55193	55795
King Point	+69 07	221 52	1906	+42 25	+81 51.6	8448	6237	+5698	+59061	59662
Gjöhavn	+68 37	264 07	1905	− 6 06	+89 17.3	750	746	− 80	+60434	60439
Sodankylä	+67 22	26 39	1930	+ 2 36.5	+76 04.0	12207	12194	+ 556	+49202	50693
			1942	+ 4 25.1	+76 32.2	11882	11847	+ 915	+49630	51033
Kandalaksha	+67 09	32 26	1932 / 1933	+ 6 44.0	+76 11.7	12318	12233	+1444	+50118	51609
Wellen	+66 10	190 10	1939	+15 41.2	+75 37.2	13707	13196	+3706	+53460	55189
			1941	(+15 37.5	+75 36.7	13720	13213	+3695	+53478	55210)
Angmagssalik	+65 37	322 22	1933	−39 52.9	+78 18.1	10705	8215	−6864	+51699	52796
College	+64 52	212 10	1942	(+29 52.4	+77 11.2	12582	10910	+6267	+55323	56736)
			1944	(+29 46.1	+77 11.9	12587	10926	+6249	+55395	56807)
Bowdoin Harbor (Baffin Island)	+64 24	282 08	1921 / 1922	−52 12.1	+85 29.2	4722	2894	−3731	+59824	60010
Chesterfield Inlet	+63 20	269 18	1932 / 1933	−12 36.1	+86 23.4	3834	3742	− 836	+60762	60883
Fort Rae	+62 50	243 56	1932 / 1933	+37 30.7	+82 39.0	7734	6135	+4709	+59956	60453
Srednikan	+62 26	152 19	1939	− 9 04.1	+73 24.1	16147	15945	−2545	+54169	56524
			1945	(− 9 14.8	+73 09.9	16393	16180	−2634	+54179	56605)
Dombås	+62 05	9 06	1940	(− 7 08	+73 36.4	13900	13792	−1726	+47250	49252)
			1946	(− 6 16	+73 44.6	13837	13754	−1510	+47450	49426)
Yakutsk	+62 01	129 43	1940	−17 08.0	....	14500	13857	−4272	....	....
			1945	(−17 36.4	....	14524	13844	−4393	....	....
Julianehaab	+60 43	313 58	1933	−43 20.8	+77 38.1	11616	8447	−7973	+52989	54247

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Lerwick	+60°08′	358°49′	1930	−14°11′.2	+72°41′.6	14527	14084	−3561	+46624	48835
			1944	−11 39.3	+72 58.0	14381	14084	−2905	+46937	49091
			1946	−11 21.3	+73 00.2	14364	14083	−2828	+46990	49136
Oslo (Christiania)	+59 55	10 43	1929	− 8 07.0	....	15934	15774	−2250	....	....
			1930	− 7 58.9	....	15929	15775	−2212	....	....
Slutsk (Pavlovsk, succeed Leningrad)	+59 41	30 29	1939	+ 5 04.9	+72 14.1	15260	15200	+1352	+47631	50016
			1941	+ 5 16.8	+72 18.2	15228	15163	+1401	+47725	50096
Lovö	+59 21	17 50	1940	− 1 28.1	+71 52.6	15317	15312	− 393	+46979	49241
			1946	− 0 42.4	+72 03.2	15231	15230	− 188	+47024	49429
Sitka [a]	+57 03	224 40	1920	+30 28.5	+74 22.3	15568	13417	+7896	+55655	57791
			1930	+30 15.6	+74 22.8	15449	13344	+7785	+55256	57375
			1945	+29 30.2	+74 15.4	15513	13501	+7640	+55029	57174
			1947	(+29 22.6	+74 15.8	15503	13510	+7605	+55016	57159)
Sverdlovsk (Katharinenburg)	+56 50	60 38	1899	+ 9 59.6	+70 42.0	17795	17525	+3088	+50815	53840
			1929	+10 57.2	+72 20.3	16285	15988	+3094	+51145	53676
			1931	+10 54.6	+72 26.9	16200	15907	+3066	+51220	53721
Vyssokaya Dubrava (succeeding Sverdlovsk)	+56 44	61 04	1940	+12 57.2	+72 31.9	16085	15676	+3606	+51116	53587
			1944	+13 03.0	+72 40.0	16030	15616	+3620	+51360	52803
Rude Skov (succeeding Copenhagen)	+55 51	12 27	1930	− 6 00.4	+69 19.0	16893	16800	−1768	+44747	47829
			1944	− 3 51.0	+69 45.6	16710	16672	−1122	+45318	48301
			1946	− 3 34.8	+69 49.3	16680	16647	−1041	+45386	48354
Zaimishche (new site of Kasan)	+55 50	48 51	1940	+ 9 27.5	+71 10.5	16651	16425	+2736	+48441	51601
			1945	(+ 9 40.9	+71 21.7	16560	16324	+2785	+49096	51814)
Kasan	+55 47	49 08	1909	+ 8 05.1	+69 09.1	18118	17938	+2548	+47575	50908
			1913	+ 8 10.9	+69 18.2	17959	17776	+2556	+47535	50815
Kutchino	+55 46	37 58	1927	+ 6 36.1	+68 59.5	17875	17756	+2055	+46545	59859
Copenhagen	+55 41	12 34	1900	−10 12.2	+68 39.0	17513	17236	−3102	+44803	48104
Eskdalemuir	+55 19	356 48	1930	−14 47.1	+69 43.2	16585	16036	−4232	+44881	47847
			1946	−12 05.9	+69 54.0	16517	16150	−3462	+45134	48061
Gross Raum	+54 50	20 30	1925	− 2 18.3	+68 01.9	17771	17757	− 715	+44055	47504
			1935	− 0 43.1	+68 33.5	17530	17529	− 221	+44636	47955
Flensburg	+54 47	9 26	1903	−11 28.0	....	....	....	....	....	....

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Meanook	+54°37′	246°40′	1920	+27°38′.6	+77°53′.6	12923	11445	+5996	+60246	61617
			1942	+25 33.6	+77 51.8	12729	11482	+5492	+59188	60541
Hel	+54 36	18 48	1934	− 2 35.5	+68 25.2	17553	17535	− 794	+44384	47729
Neufahrwasser	+54 25	18 39	1903	− 7 13	....	....	....	....	....	....
Barth	+54 22	12 45	1903	− 9 52.9	+67 37.6	18261	17990	−3134	+44363	47974
Wustrow	+54 21	12 24	1903	−10 08	....	....	....	....	....	....
Rostock	+54 06	12 08	1903	−10 08	....	....	....	....	....	....
Stonyhurst	+53 51	357 32	1920	−15 52.9	+68 43.5	17303	16640	−4734	+44429	47679
			1943	−11 30.5	+68 54.5	17166	16820	−3425	+44504	47699
Wingst	+53 45	9 04	1939	− 5 59.1	+68 12.0	17636	17540	−1839	+44092	47488
			1946	− 4 59.7	+68 21.2	17601	17534	−1532	+44347	47712
Stettin-Zabelsdorf	+53 27	14 34	1901	− 8 43	....	....	....	....	....	....
Witteveen	+52 49	6 40	1940	− 7 09.2	+67 39.2	17959	17820	−2236	+43686	47233
			1946	− 6 14.7	+67 45.0	17946	17840	−1952	+43867	47396
Zuy (new site of Irkutsk)	+52 28	104 02	1899	+ 2 08.8	+70 27.8	19948	19934	+ 747	+56220	59654
			1930	(+ 0 17.7	+71 21.5	19019	19019	+ 98	+56380	59500)
			1945	(− 0 47.7	+71 34.4	19028	19026	− 264	+57109	60196)
Potsdam (succeeding Berlin)	+52 23	13 04	1899	−10 00.7	+66 25.7	18818	18531	−3271	+43133	47060
			1920	− 7 29.4	+66 33.5	18606	18447	−2425	+42912	46772
			1927	− 6 09.1	+66 44.0	18489	18383	−1981	+43002	46809

The Potsdam Observatory was set up in 1889 but electric-tram disturbances beginning in 1906 forced transfer of registration to Seddin, which, in turn, for the same reason had to be transferred in 1932 to Niemegk.

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Seddin	+52 17	13 01	1920	− 7 31.2	+66 30.6	18645	18485	−2440	+42899	46776
			1931	− 5 28.9	+66 49.8	18450	18365	−1762	+43106	46888
Irkutsk (old site)	+52 16	104 16	1910	+ 1 47.0	+70 36.0	19824	19814	+ 617	+56293	59682
			1920	+ 1 02.8	+70 51.9	19458	19455	+ 355	+56081	59360
Swider	+52 07	21 15	1930	− 1 57.3	+67 01.1	18476	18465	− 630	+43565	47310
			1943	− 0 16.7	....	....	....	....	....	....
De Bilt (succeeding Utrecht)	+52 06	5 11	1930	− 9 26.3	+67 00.4	18282	18034	−2998	+43084	46801
			1938	− 8 04.6	+67 09.3	18226	18045	−2561	+43263	46945
Niemegk (succeeding Seddin)	+52 04	12 40	1940	− 4 09.6	+67 00.1	18434	18386	−1337	+43431	47182
			1944	(− 3 38.1	....	18411	18374	−1167	....	....)

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Valencia Cahirciveen	+51°56′	349°45′	1930	−17°27′.6	+67°59′.8	17813	16992	−5345	+44081	47546
			1937	−16 11.7	+67 58.0	17802	17096	−4965	+43987	47453
Nizhnedevitsk	+51 31	38 22	1935	+ 5 33.6	+67 34.7	18588	18501	+1801	+45060	48743
			1940	+ 5 54.0	....	18472	18374	+1899	....	....
Bochum	+51 29	7 14	1934	− 7 52.4	....	....	....	....	....	....
Kew	+51 28	359 41	1910	−16 03.2	+66 58.7	18503	17781	−5117	+43546	47313
			1924	−13 45.1	+66 56.5	18392	17865	−4372	+43205	46957
Greenwich	+51 28	0 00	1920	−14 08.6	+66 53.6	18450	17890	−4510	+43250	47020
			1925	−13 09.9	+66 51.4	18410	17930	−4190	+43080	46850
Abinger (succeeding Greenwich)	+51 11	359 37	1940	−10 43.0	+66 43.9	18533	18210	−3446	+43099	46915
			1946	− 9 51.1	+66 45.4	18469	18295	−3177	+43235	47054
Uccle (Brussels)	+50 48	4 21	1910	−13 22.2	+66 00.8	19028	18512	−4400	+42764	46807
			1941	− 8 02.4	....	....	....	....	....	....
Hermsdorf	+50 46	16 14	1927	− 4 29.3	....	....	....	....	....	....
			1929	− 4 10.6	....	....	....	....	....	....
Tellnitz	+50 44	13 58	1934	− 4 42.5	....	....	....	....	....	....
Beuthen	+50 21	18 55	1911	− 5 48.0	....	....	....	....	....	....
Manhay (succeeding Uccle)	+50 18	5 41	1942	− 7 06.6	+65 54.6	19106	18959	−2365	+42733	46810
Beuthen-Miklow	+50 09	18 54	1932	− 2 28.0	....	....	....	....	....	....
Falmouth	+50 09	354 55	1899	−18 32.7	+66 48.7	18663	17694	−5936	+43569	47398
			1912	−17 24.2	+66 26.6	18799	17938	−5623	+43118	47038
Prague	+50 05	14 25	1899	− 9 11.9	....	19926	19670	−3185	....	....
			1926	− 5 27.7	....	....	....	....	....	....
Cracow	+50 94	19 58	1913	− 5 03.3	+64 18.4	....	....	....	....	....
Janów	+49 54	23 44	1933	+ 0 06.4	+64 50.9	20110	20110	+ 37	+42830	47316
St. Helier (Jersey)	+49 12	357 54	1899	−17 03.7	+65 49.4	....	....	....	....	....
			1907	+16 27.4	+65 34.5	....	....	....	....	....
Parc St. Muir (superseded by Val Joyeux)	+48 49	2 30	1900	−14 45.4	+64 53.5	19738	19087	−5028	+42120	46515
Val Joyeux (succeeding Parc St. Muir)	+49 49	2 01	1930	−10 59.3	+64 42.0	19631	19271	−3742	+41529	45936
			1936	− 9 56.7	+64 45.4	19647	19351	−3393	+41668	46067
Vienna (Auhof)	+48 13	16 14	1940	− 2 35.6	+63 48.9	20473	20452	− 926	+41634	46395
			1942	− 2 20.9	+63 52.5	20467	20450	− 839	+41732	46481

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Maisach	+48°12′	11°15′	1927	− 6°52′.5	+63°32′.5	20314	20168	−2432	+40813	45593
			1932	− 5 59.3	+63 39.8	20299	20188	−2118	+41005	45754
Fürstenfeldbruck	+48 10	11 17	1944	− 4 13.6	+63 57.7	20314	20259	−1497	+41578	46275
Munich	+48 09	11 36	1910	− 9 31.5	+63 08.4	20638	20353	−3415	+40750	45678
			1920	− 8 03.8	....	....	....	....	....	....
			1926	− 6 54.7	....	....	....	....	....	....
Kremsmünster	+48 03	14 08	1904	− 9 02.4	+63 02.3	20730	20475	−3257	+40752	45721
Chambon-la-Forêt (Succeeding Val Joyeux)	+48 01	2 16	1936	− 9 28.9	+64 11.3	20011	19737	−3296	+41374	45959
			1946	− 8 01.0	+64 15.6	20085	19889	−2801	+41658	46247
O'Gyalla (Pesth)	+47 52	18 12	1910	− 6 34.5	+62 31.2	21076	20937	−2413	+40521	45674
			1918	− 5 21.1	....	20917	20826	−1951	....	....
O'Gyalla (Stará Dăla)	+47 52	18 11	1937	(− 2 16.8)	....	....	....	....	....	....
Nantes	+47 15	358 27	1940	−10 26.2	+63 41.5	20299	19963	−3677	+41058	45802
			1947	− 9 25.3	+63 42.3	20383	20108	−3337	+41250	46011
Toyohara	+46 58	142 45	1940	− 9 18.2	+60 41.1	25067	24737	−4052	+44643	51199
Toyohara (new site)	+46 57	142 45	1944	− 9 29.5	+60 37.9	25191	24846	−4154	+44764	51365
Stepanovka (succeeding Odessa)	+46 47	30 53	1938	+ 0 35.4	+62 55.0	21413	21412	+ 220	+41875	47032
Otomari	+46 39	142 46	1941	− 9 03.6	....	....	....	....	....	....
Odessa	+46 26	30 46	1923	− 1 52.9	+63 11.9	21267	21256	− 698	+42098	47165
			1925	− 1 36.4	+63 18.9	21213	21205	− 595	+42206	47237
Pola	+44 52	13 51	1899	− 9 31.7	+60 22.5	22120	21815	−3662	+38899	44748
			1922	− 6 25.3	+60 19.3	22049	21911	−2466	+38690	44532
Castellaccio	+44 26	8 56	1940	− 6 07.2	+60 18.3	22137	22011	−2360	+38818	44686
			1943	− 5 43.2	....	22196	22086	−2212	....	....
Agincourt	+43 47	280 44	1940	− 7 32.3	+74 51.5	15290	15158	−2006	+56503	58535
			1942	− 7 31.4	+74 50.0	15303	15171	−2004	+56460	58497
Nice	+43 43	7 16	1899	−12 04.0	+60 11.7	22390	21895	−4681	+39087	45046
Toulouse	+43 37	1 28	1900	−14 17.7	+60 55.4	21913	21235	−5411	+39408	45091
			1905	−13 59.7	+60 52.1	22013	21360	−5324	+39498	45218
Mai-Tun (succeeding Vladivostok)	+43 15	132 20	1941	− 8 40.9	+58 57.7	26826	26519	−4049	+44579	52028
			1944	− 8 43.9	+58 55.6	16913	26601	−4086	+44662	52144
Perpignan	+42 42	2 53	1899	−13 42.5	+60 00.0	22418	21779	−5313	+38829	44836
			1910	−12 44.8	....	....	....	....	....	....

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Dusheti (succeeding Karsani).......	+42°05′	44°42′	1940	+ 4°56′.2	+59°21′.3	24142	24052	+2078	+40749	47364
			1945	(+ 5 00.8	+59 36.9	24135	24043	+2109	+41161	47715)
Karsani (succeeding Tiflis).........	+41 50	44 42	1934	+ 4 26.0	+58 41.2	24570	24496	+1899	+40390	47276
Tiflis (succeeded by Karsani).......	+41 43	44 48	1899	+ 2 11.0	+55 52.1	25614	25599	+ 976	+37785	45652
			1905	+ 2 41.6	+56 02.8	25451	25423	+1196	+37799	45569
Keles (succeeding Tashkent)........	+41 25	69 12	1936	+ 5 23.5	+60 11.9	25359	25247	+2383	+44276	51024
			1945	(+ 5 03.2	+60 20.7	25537	25438	+2249	+44854	51614)
Tashkent	+41 20	69 18	1900	+ 6 02.0	+57 34.0	26780	26632	+2815	+42171	49956
Capodimonte	+40 52	14 15	1899	− 9 15.8	+56 25.0	24105	23791	−3880	+36304	43578
			1921	....	+56 11.8	....	....	....	....	....
Tortosa (Ebro)	+40 49	0 30	1905	−13 56.9	+58 07.6	23230	22545	−5600	+37359	43993
			1947	(− 7 56.1	+57 14.8	23724	23497	−3275	+36879	43851)
Coimbra	+40 12	351 35	1899	−17 24.2	+59 28.9	22724	21684	−6797	+38549	44748
			1940	−12 34.0	+57 30.7	23368	22808	−5084	+36463	43308
			1944	−12 02.3	....	23449	22933	−4891	....	....
Baldwin	+38 47	264 50	1901	+ 8 21.9	+68 34.5	21931	21698	+3190	+55890	60038
			1909	+ 8 34.0	+68 50.2	21644	21403	+3224	+55908	59951
Cheltenham [a]	+38 44	283 10	1901	− 5 05.0	+70 21.6	20194	20115	−1789	+56586	60081
			1930	− 6 56.0	+71 08.4	18583	18447	−2243	+54402	57448
			1941	(− 7 04.8	+71 22.9	18176	18037	−2240	+53953	56932)
			1947	(− 7 04.3	+71 18.4	18221	18082	−2243	+53852	56851)
Lisbon	+38 43	350 51	1900	−17 17.5	+57 55.6	23518	22455	−6990	+37530	44290
Athens	+37 59	23 42	1900	− 5 42.3	+52 07.7	26063	25934	−2591	+33514	42455
			1908	− 4 53.0	+52 11.7	26197	26102	−2230	+33613	42616
San Miguel (Ponta Delgada).......	+37 46	334 21	1911	−19 56.0	+60 59.1	22993	21615	−7839	+41456	47405
			1947	−16 58.3	+58 47.4	23830	22792	−6956	+39333	45989
Zinsen	+37 30	126 38	1918	− 5 41.1	+53 16	29978	29831	−2970	+40170	50123
			1941	− 6 17.0	+53 11.0	30167	29986	−3302	+40301	50341
San Fernando	+36 28	353 48	1899	−16 02.8	+55 16.6	24594	23636	−6978	+35487	43176
			1930	−12 32.8	+53 29.9	25072	24473	−5447	+33881	42149
			1946	−10 30.4	+52 48.8	25525	25097	−4654	+33644	42231
Kakioka (succeeding Tokyo)........	+36 14	140 11	1913	− 5 10.1	+49 30.9	29749	29628	−2680	+34851	45822
			1947	− 6 13.0	+49 29.3	29916	29741	−3239	+35014	46054

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Tsingtao	+36°04′	120°19′	1908	− 3°43′.6	+52°21′.5	30766	30701	−2000	+39890	50376
			1930	− 4 32.8	+52 06.6	30868	30771	−2447	+39667	50262
			1936	(− 4 37.6	+52 06.1	30935	30834	−2495	+39741	50361)
Tokyo	+35 41	139 45	1899	− 4 33.7	+49 02.7	29856	29761	−2374	+34400	45549
			1912	− 5 03.4	+48 53.7	29996	29879	−2644	+34379	45625
Ksara	+33 49	35 53	1940	+ 1 59.9	+48 21.2	28668	28651	+1000	+32236	43139
			1945	+ 2 09.4	+48 36.1	28780	28760	+1083	+32646	43521
Tuscon [a]	+32 15	249 10	1920	+13 48.0	+59 27.9	26894	26117	+6416	+45594	52935
			1940	+13 48.2	(+59 40.6	26136	25381	+6236	+44684	51766)
			1947	(+13 35.3	+59 36.2	26034	25305	+6117	+44380	51452)
Lukiapang (succeeding Zikawei)	+31 19	121 02	1908	− 2 56.2	+45 35.2	33173	33129	−1700	+33879	47416
			1933	− 3 35.4	+45 23.7	33329	33263	−2087	+33791	47462
Zikawei	+31 12	121 26	1899	− 2 20.3	+45 47.6	32825	32798	−1339	+33747	47078
			1908	− 2 35.4	+45 35.4	33078	33044	−1495	+33766	47268
Zô-sè	+31 06	121 11	1920	− 3 10.7	+45 38.4	33066	33016	−1833	+33813	47293
			1940	− 3 25.7	+45 29.7	33372	33312	−1995	+33954	47609
			1947	(− 3 26.8	+45 27.3	33588	33527	−2019	+34125	47882)
Dehra Dun	+30 19	78 03	1910	+ 2 31.9	+43 54.8	33257	33225	+1469	+32019	46165
			1930	+ 1 11.9	+45 34.5	32963	32956	+ 689	+33631	47091
			1937	+ 0 51.6	+45 39.9	33223	33219	+ 499	+34003	47539
Helwan	+29 52	31 20	1920	− 1 23.7	+41 12.8	29956	29947	− 730	+26236	39821
			1930	− 0 14.0	+41 43.0	30078	30078	− 122	+26814	40295
			1940	+ 0 27.8	+42 09.5	30438	30438	+ 246	+27560	41061
			1944	+ 0 40.1	+42 20.2	30572	30570	+ 357	+27854	41358
Taihoku	+25 02	121 31	1940	− 2 09.4	....	....	....	....	....	....
Minamitori Shima	+24 17	153 58	1941	+ 0 15.3	....	....	....	....	....	....
Tamarasset	+22 48	5 32	1938	− 7 33.1	+29 31.8	31924	+31647	−4196	+18084	36690
			1940	− 7 21.5	+29 24.0	32013	+31749	−4100	+18039	36746
Barrackpore	+22 46	8 22	1910	+ 0 55.5	+30 42.2	37329	37324	+ 603	+22168	43415
			1914	+ 0 32.2	+30 58.9	37403	37401	+ 350	+22459	43628
Au Tau (succeeding Hongkong)	+22 27	114 03	1930	− 0 43.6	+30 37.3	37485	37482	− 475	+22187	43559
			1939	− 0 38.0	+30 24.8	37705	37703	− 417	+22133	43721
Hongkong (superseded by Au Tau)	+22 18	114 10	1900	+ 0 18.5	+31 24.7	36728	36727	+ 198	+22430	43036
			1928	− 0 33.3	+30 36.3	37319	37317	− 361	+22075	43359

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Honolulu [a]	+21°19′	201°56′	1902	+ 9°19′.1	+40°14′.5	29254	28868	+4737	+24758	38324
			1920	+ 9 53.2	+39 25.7	28838	28410	+4951	+23712	37335
			1940	(+10 21.5	+39 08.2	28459	27995	+5117	+23158	36691)
			1946	(+10 28.2	+39 14.0	28346	27874	+5151	+23146	36596)
Honolulu (new site)	+21 18	201 54	1947	(+11 35.3	+38 40.2	28659	28075	+5757	+22935	36706)
Teoloyucan	+19 45	260 49	1922	+ 9 09.9	+46 30.7	32160	31749	+5122	+33903	46730
			1940	+ 9 41.8	+47 09.3	30825	30385	+5192	+33235	45329
			1946	+ 9 37.0	+47 02.4	30622	30192	+5116	+32884	44934
Toungoo	+18 56	96 27	1905	+ 0 48.4	+22 58.3	38675	38671	+ 544	+16394	42006
			1923	− 0 31.9	+23 06.1	39207	39205	− 364	+16725	42625
Colaba (superseded Alibag)	+18 54	72 49	1899	+ 0 26.6	+21 14.8	37441	37440	+ 290	+14558	40172
			1906	+ 0 13.2	+22 03.4	37393	37393	+ 144	+15150	40345
Alibag (succeeding Colaba)	+18 38	72 52	1904	+ 1 09.4	+22 54.6	36861	36853	+ 744	+15578	40018
			1930	− 0 08.0	+25 30.6	37253	37253	− 87	+17777	41277
			1937	− 0 21.8	+25 26.0	37652	37651	− 239	+17906	41693
San Juan [a] (superseding Vieques)	+18 23	293 53	1930	(− 4 50.6)	+52 31.9	(27494	27398	−2321)	+35872	45197
			1945	− 6 10.6	+52 35.7	27397	27238	−2948	+35827	45102
			1947	(− 6 18.2	+52 28.0	27430	27264	−3012	+35704	45024)
Vieques [a] (succeeded San Juan)	+18 09	294 33	1910	− 2 20.6	+49 52.4	28828	28804	−1177	+34203	44731
			1924	− 4 15.0	+51 42.2	27566	27490	−2043	+34908	44480
Antipolo (superseding Manila)	+14 36	121 10	1930	+ 0 26.7	+15 47.0	38253	38252	+ 298	+10813	39752
			1938	+ 0 36.2	+15 47.2	38356	38354	+ 404	+10844	39859
Manila (succeeded by Antipolo)	+14 35	120 58	1900	+ 0 52.1	+16 15.9	38029	38025	+ 576	+11095	39614
			1904	+ 0 51.4	+16 00.2	38215	38211	+ 571	+10960	39756
Kodakanai	+10 14	77 28	1910	− 0 55.0	+ 3 45.2	37485	37480	− 600	+ 2459	37566
			1923	− 2 00.7	+ 4 41.3	37950	37927	−1332	+ 3112	38077
Palau (Parao)	+ 7 20	134 29	1941	+ 2 07.1	....	....	....	....	....	....
Yaluit	+ 5 55	169 39	1941	+ 7 54.0	....	....	....	....	....	....
Mogadiscio	+ 2 02	45 21	1932–1933	+ 9 55.8	−16 38.2	33142	33138	− 538	− 9904	34590

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Batavia-Buitenzorg	From magnetograph records at Buitenzorg (Latitude — 6°35′, longitude 106°47′) reduced to Batavia; recording at Batavia discontinued April 1, 1899, because of electric-car disturbances.									
	— 6°11′	106°49′	1902	+ 1°02′.4	—30°20′.2	36717	36711	+ 666	—21487	42542
			1926	+ 0 51.6	—32 09.6	36826	36822	+ 553	—23154	43500
Batavia-Kuyper	From magnetograph records at Kuyper (Latitude — 6°02′, longitude 106°44′) reduced to Batavia; in a letter dated November 15, 1941, the Director of the Observatory stated that the published values of 1928-35 (see Preface of "Report on magnetic observations in Batavia," 58B, 1935) are subject to correction because of previous errors in the scale-values and that revised values will be supplied later.									
	— 6 11	106 49	1940	+ 1 20.3	—32 32.0	37035	37025	+ 865	—23624	43928
			1944	(+ 1 31.1	—32 31.6	37145	37133	+ 984	—23689	44055)
Dar-es-Salaam	— 6 49	39 18	1898	— 8 18.1	—36 56.8	28966	28662	—4182	—21875	36244
St. Paul de Loanda	— 8 49	13 13	1910	—16 12.3	—35 32.2	20125	19325	—5616	—14374	24732
			1918	—15 03.5	—36 04.2	19917	....	....	....	....
Elisabethville	—11 40	27 28	1933	— 9 32.1	—46 01.3	23801	23472	—3943	—24665	34276
			1945	— 8 55.4	—46 53.9	23286	23004	—3612	—24883	34079
Huancayo	—12 03	284 40	1922	+ 8 07.6	+ 0 37.5	29735	29436	+4203	+ 324	29737
			1944	+ 6 34.8	+ 2 10.3	29367	29174	+3365	+ 1114	29388
			1946	+ 6 26.7	+ 2 06.6	29259	29074	+3284	+ 1078	29279
Samoa, Apia	—13 48	188 14	1930	+10 34.2	—30 07.9	35195	34598	+6456	—20428	40694
			1940	+10 54.5	—30 38.1	34868	34238	+6598	—20650	40524
			1946	+11 14.0	—30 38.5	34839	34172	+6787	—20683	40493
Tanarive	—18 55	47 32	1910	— 9 01.3	—53 58.9	22585	22306	—3542	—31065	38407
			1941	— 9 38.5	—53 54.3	21082	20784	—3531	—28916	35785
Mauritius*	—20 06	57 33	1899	— 9 32.9	—54 16.8	23854	23524	—3957	—33171	40857
			1930	—12 05.5	—52 39.6	22697	22193	—4753	—29750	37420
			1940	—13 58.9	—53 06.9	22419	21755	—5417	—29876	37352
			1945	—14 51.5	—53 23.1	22389	21640	—5741	—30131	37539
La Quiaca	—23 07	294 25	1920	+ 6 03.3	—12 39.6	26621	26472	+2808	— 5979	27284
			1933	+ 4 16.7	—12 21.2	26223	26150	+1956	— 5743	26845
Vassouras (succeeding Rio de Janeiro)	—22 24	316 21	1915	—10 28.1	—14 44.1	24700	24289	—4488	— 6496	25540
			1942	—13 58.8	—18 57.8	23683	22982	—5721	— 8138	25042
			1944	—14 12.7	—19 22.2	23563	22842	—5785	— 8284	24977

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (continued)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Rio de Janeiro (superseded by Vassouras)	−22°55′	316°49′	1900	− 7°55′.7	−13°17′.1	25040	24801	−3454	− 5912	25729
			1906	− 8 55.3	−13 57.2	24772	24472	−3842	− 6169	25529
Watheroo	−30 19	115 52	1919	− 4 22.8	−63 51.4	24925	24852	−1904	−50780	56567
			1930	− 4 08.0	−64 17.7	24623	24559	−1775	−51151	56769
			1945	− 2 57.9	−64 25.4	24767	24734	−1281	−51746	57368
Pilar	−31 40	296 07	1905	+ 9 51.7	−26 03.0	25894	25511	+4435	−12657	28822
			1940	+ 5 24.9	−26 30.0	24137	24029	+2278	−12034	26971
			1944	+ 4 59.3	−26 48.1	23884	23794	+2077	−12066	26759
Santiago (new station)	−33 27	289 18	1899	+14 59.5	....	....	....	....	....	....
			1909	+13 57.9	−29 57.2	....	....	....	....	....
Cape Town (superseded by Hermanus)	−33 57	18 28	1933	−24 39.9	−63 09.2	15050	13677	−6281	−29733	33325
			1941	−24 13.1	−63 42.6	14357	13094	−5889	−29061	32413
Hermanus (succeeding Cape Town)	−34 25	19 14	1940	−23 54.5	−63 59.0	14328	13098	−5807	−29352	32663
			1946	−23 46.4	−64 17.5	13875	12697	−5594	−28819	31985
Toolangi (succeeding Melbourne)	−37 32	145 28	1919	+ 8 12.7	−67 36.0	23071	22834	+3295	−55974	60542
			1930	+ 8 20.8	−67 51.5	22872	22630	+3320	−56208	60683
			1944	+ 9 07.4	−67 51.0	22884	22594	+3628	−56215	60694
Melbourne (superseded by Toolangi)	−37 50	144 58	1899	+ 8 25.1	−67 23.1	23323	23072	+3414	−55989	60653
			1920	+ 8 00.8	−67 55.1	22874	22651	+3189	−56384	60847
Amberley (succeeding Christchurch)	−43 10	172 44	1929	+17 45.0	−67 57.8	22365	21301	+6819	−55252	59607
			1940	+18 30.2	−68 03.4	22248	21098	+7060	−55220	59533
			1945	(+19 01.7	−68 04.8	22215	21001	+7243	−55203	59506)
Christchurch (superseded by Amberley)	−43 32	172 37	1902	+16 15.1	−67 40.8	22694	21787	+6351	−55277	59754
			1930	+17 48.3	−68 18.3	22108	21049	+6760	−55570	59806
Kerguelen	−49 25	69 53	1902	−36 58.0	−70 25.3	16243	12978	−9768	−45672	48474
New Year's Island (Staten Island)	−54 39	295 51	1902	+15 57.3	−50 13.8	27306	26254	+7505	−32808	43685
			1914	+15 10.3	−49 43.4	26878	25941	+7034	−31719	41575
			1916	+15 02.4	−49 39.4	26771	25854	+6947	−31520	41355
Laurie Island	−60 43	315 13	1905	+ 5 16.6	−54 31.0	25667	25558	+2360	....	....
			1932–1933	+ 3 07.8	....	23928	23892	+1307	....	....

(continued)

TABLE 510.—MEAN ANNUAL VALUES OF MAGNETIC ELEMENTS AT OBSERVATORIES (concluded)

Observatory	Latitude (+ = N, − = S)	Longitude east	Year	Declination D	Inclination I	Components of intensity: Horizontal H γ	North X γ	East Y γ	Vertical Z γ	Total F γ
Winter Station, Gauss	−66°02′	89°38′	1902	−62°22′.6	−77°07′.2	13309	6171	−11792	−58206	59708
Cape Denison	−67 00	142 40	1912	− 6 36.8	−87 21.3	3112	3091	− 358	−67349	67421
Cape Evans	−77 38	166 24	1911–1912	+154 46.4	−86 27.0	4227	−1802	+3824	−68146	68277
Little America (III)	−78 29	196 09	1940–1941	+104 54.0	−81 22.4	10038	−2581	+9700	−66166	66923
Little America (II)	−78 34	196 04	1934–1935	+106 34.7	−81 53.5	9445	−2695	+9053	−66296	66966
Little America (I)	−78 35	196 12	1929–1930	+106 49.1	−82 18.7	8983	−2599	+8599	−66541	67145

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS

Part 1.—Geomagnetic latitudes of points on the earth in various geographic latitudes and longitudes

Geographic latitude *	Geographic east longitude in degrees																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
+88°	79	79	78	78	78	77	77	77	77	77	77	76	77	77	77	77	77	77	78
+84	79	78	77	76	75	75	74	74	73	73	73	73	73	73	73	73	74	75	75
+80	78	76	75	74	73	71	71	70	69	69	69	69	69	69	70	70	70	71	72
+76	75	74	72	71	69	68	67	66	65	65	65	65	65	65	65	66	67	68	69
+72	73	71	69	67	66	64	63	62	62	61	61	61	61	61	61	62	63	64	65
+68	69	67	65	64	62	61	60	58	58	57	57	57	57	57	57	58	59	60	62
+64	66	64	62	60	58	57	56	55	54	53	53	53	53	53	54	54	55	57	58
+60	62	60	58	56	55	53	52	51	50	49	49	49	49	49	50	50	52	53	54
+56	58	56	55	53	51	49	48	47	46	45	45	45	45	45	46	47	48	49	51
+52	55	53	51	49	47	45	44	43	42	41	41	41	41	41	42	43	44	45	47
+48	51	49	47	45	43	42	40	39	38	37	37	37	37	37	38	39	40	41	43
+46	49	47	45	43	41	40	38	37	36	35	35	35	35	35	36	37	38	39	41
+44	47	45	43	41	39	38	36	35	34	33	33	33	33	33	34	35	36	37	39
+42	45	43	41	39	37	36	34	33	32	31	31	31	31	31	32	33	34	35	37
+40	43	41	39	37	35	34	32	31	30	29	29	29	29	29	30	31	32	33	35
+38	41	39	37	35	34	32	30	29	28	27	27	27	27	27	28	29	30	31	33
+36	39	37	35	33	32	30	28	27	26	25	25	25	25	25	26	27	28	30	31
+34	37	35	33	31	30	28	26	25	24	23	23	23	23	23	24	25	26	28	29
+32	35	33	31	30	28	26	24	23	22	21	21	21	21	21	22	23	24	26	27
+30	33	32	30	28	26	24	22	21	20	19	19	19	19	19	20	21	22	24	25
+28	32	30	28	26	24	22	20	19	18	17	17	17	17	17	18	19	20	22	23
+26	30	28	26	24	22	20	18	17	16	15	15	15	15	15	16	17	18	20	21
+24	28	26	24	22	20	18	17	15	14	13	13	13	13	13	14	15	16	18	19
+22	26	24	22	20	18	16	15	13	12	11	11	11	11	11	12	13	14	16	18
+20	24	22	20	18	16	14	13	11	10	9	9	9	9	9	10	11	12	14	16
+18	22	20	18	16	14	12	11	9	8	7	7	7	7	7	8	9	10	12	14
+16	20	18	16	14	12	10	9	7	6	5	5	5	5	5	6	7	8	10	12
+14	18	16	14	12	10	8	7	5	4	3	3	3	3	3	4	5	6	8	10
+12	16	14	12	10	8	6	5	3	2	1	1	1	1	1	2	3	4	6	8
+10	14	12	10	8	6	4	3	1	0	−1	−1	−1	−1	−1	0	1	2	4	6

* + = North latitude, − = south latitudes.

(*continued*)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Geographic latitude *	Geographic east longitude in degrees																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
+8°	12	10	8	6	4	2	1	−1	−2	−3	−3	−3	−3	−3	−2	−1	0	2	4
+6	10	8	6	4	2	0	−1	−3	−4	−5	−5	−5	−5	−5	−4	−3	−2	0	2
+4	8	6	4	2	0	−2	−3	−5	−6	−7	−7	−7	−7	−7	−6	−5	−4	−2	0
+2	6	5	2	0	−2	−4	−5	−7	−8	−9	−9	−9	−9	−9	−8	−7	−6	−4	−2
0	4	2	0	−2	−4	−6	−7	−9	−10	−11	−11	−11	−11	−11	−10	−9	−8	−6	−4
−2	2	0	−2	−4	−6	−8	−9	−11	−12	−13	−13	−13	−13	−13	−12	−11	−9	−8	−6
−4	0	−2	−4	−6	−8	−9	−11	−13	−14	−15	−15	−15	−15	−15	−14	−13	−11	−10	−8
−6	−2	−4	−6	−8	−10	−11	−13	−15	−16	−17	−17	−17	−17	−17	−16	−15	−13	−12	−10
−8	−4	−6	−8	−10	−12	−13	−15	−17	−18	−19	−19	−19	−19	−19	−18	−17	−15	−14	−12
−10	−6	−8	−10	−12	−14	−15	−17	−19	−20	−21	−21	−21	−21	−21	−20	−19	−17	−16	−14
−12	−8	−10	−12	−14	−15	−17	−19	−21	−22	−23	−23	−23	−23	−23	−22	−21	−19	−18	−16
−14	−10	−12	−14	−16	−17	−19	−21	−23	−24	−25	−25	−25	−25	−25	−24	−23	−21	−20	−18
−16	−12	−14	−15	−17	−19	−21	−23	−24	−26	−27	−27	−27	−27	−27	−26	−25	−23	−22	−20
−18	−14	−15	−17	−19	−21	−23	−25	−26	−28	−29	−29	−29	−29	−29	−28	−27	−25	−24	−22
−20	−16	−17	−19	−21	−23	−25	−27	−28	−30	−31	−31	−31	−31	−31	−30	−29	−27	−26	−24
−24	−19	−21	−23	−25	−27	−29	−31	−32	−34	−35	−35	−35	−35	−35	−34	−33	−31	−29	−28
−28	−23	−25	−27	−29	−31	−33	−35	−36	−38	−39	−39	−39	−39	−39	−38	−37	−35	−33	−32
−32	−27	−29	−31	−33	−35	−37	−39	−40	−42	−43	−43	−43	−43	−43	−42	−41	−39	−37	−35
−36	−31	−33	−35	−37	−39	−41	−43	−44	−46	−47	−47	−47	−47	−47	−46	−45	−43	−41	−39
−40	−35	−37	−39	−41	−43	−45	−47	−48	−50	−51	−51	−51	−51	−51	−50	−48	−47	−45	−43
−44	−39	−41	−43	−45	−47	−49	−50	−52	−53	−55	−55	−55	−55	−55	−54	−52	−51	−49	−47
−48	−43	−45	−47	−49	−50	−52	−54	−56	−57	−58	−59	−59	−59	−59	−58	−56	−55	−53	−51
−52	−47	−48	−50	−52	−54	−56	−58	−60	−61	−62	−63	−63	−63	−63	−62	−60	−58	−57	−55
−56	−51	−52	−54	−56	−58	−60	−62	−64	−65	−66	−67	−67	−67	−67	−65	−64	−62	−60	−58
−60	−54	−56	−58	−60	−62	−64	−66	−67	−69	−70	−71	−71	−71	−71	−69	−68	−66	−64	−62
−64	−58	−60	−62	−63	−65	−67	−69	−71	−73	−74	−75	−75	−75	−74	−73	−72	−70	−68	−66
−68	−62	−63	−65	−67	−69	−71	−73	−75	−77	−78	−79	−79	−79	−78	−77	−75	−73	−71	−69
−72	−65	−67	−69	−70	−72	−74	−76	−78	−80	−82	−83	−83	−83	−82	−80	−78	−76	−75	−73
−76	−69	−70	−72	−73	−75	−77	−79	−81	−83	−85	−86	−87	−87	−85	−83	−81	−79	−77	−75
−80	−72	−73	−75	−76	−77	−79	−81	−82	−84	−86	−87	−88	−88	−86	−84	−83	−81	−79	−78
−84	−75	−76	−77	−78	−79	−80	−81	−82	−83	−84	−84	−84	−84	−84	−83	−82	−81	−80	−79
−88	−78	−78	−78	−79	−79	−79	−80	−80	−80	−80	−80	−80	−80	−80	−80	−80	−80	−79	−79

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Geographic latitude *	Geographic east longitude in degrees																	
	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
+88°	78	78	79	79	79	80	80	80	80	80	80	80	80	80	80	80	79	79
+84	76	77	78	79	80	81	82	83	84	84	84	84	84	83	82	81	80	79
+80	73	75	76	77	79	81	82	84	86	87	88	88	86	85	83	81	79	78
+76	70	72	73	75	77	79	81	83	85	86	87	87	85	83	81	79	77	75
+72	67	69	70	72	74	76	79	80	82	83	83	83	82	80	78	76	75	73
+68	63	65	67	69	71	73	75	77	78	79	79	79	78	77	75	73	71	69
+64	60	62	63	65	67	69	71	73	74	75	75	75	74	73	72	70	68	66
+60	56	58	60	62	64	66	67	69	70	71	71	71	71	69	68	66	64	62
+56	52	54	56	58	60	62	64	65	66	67	67	67	67	65	64	62	60	58
+52	48	50	52	54	56	58	60	61	62	63	63	63	63	62	60	58	57	55
+48	45	47	49	50	52	54	56	57	58	59	59	59	59	58	56	55	53	51
+46	43	45	47	49	51	52	54	55	57	57	57	57	57	56	54	53	51	49
+44	41	43	45	47	49	50	52	53	55	55	55	55	55	54	52	51	49	47
+42	39	41	43	45	47	48	50	51	53	53	53	53	53	52	50	49	47	45
+40	37	39	41	43	45	47	48	50	51	51	51	51	51	50	48	47	45	43
+38	35	37	39	41	43	45	46	48	49	49	49	49	49	48	46	45	43	41
+36	33	35	37	39	41	43	44	46	47	47	47	47	47	46	45	43	41	39
+34	31	33	35	37	39	41	42	44	45	45	45	45	45	44	43	41	39	37
+32	29	31	33	35	37	39	40	42	43	43	43	43	43	42	41	39	37	35
+30	27	29	31	33	35	37	38	40	41	41	41	41	41	40	39	37	35	33
+28	25	27	29	31	33	35	36	38	39	39	39	39	39	38	37	35	33	32
+26	23	25	27	29	31	33	34	36	37	37	37	37	37	36	35	33	31	30
+24	21	23	25	27	29	31	32	34	35	35	35	35	35	34	33	31	29	28
+22	19	21	23	25	27	29	30	32	33	33	33	33	33	32	31	29	28	26
+20	17	19	21	23	25	27	28	30	31	31	31	31	31	30	29	27	26	24
+18	15	17	19	21	23	25	26	28	29	29	29	29	29	28	27	25	24	22
+16	14	15	17	19	21	23	24	26	27	27	27	27	27	26	25	23	22	20
+14	12	14	16	17	19	21	23	24	25	25	25	25	25	24	23	21	20	18
+12	10	12	14	15	17	19	21	22	23	23	23	23	23	22	21	19	18	16
+10	8	10	12	14	15	17	19	20	21	21	21	21	21	20	19	17	16	14

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Geographic latitude *	Geographic east longitude in degrees																	
	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
+ 8°	6	8	10	12	13	15	17	18	19	19	19	19	19	18	17	15	14	12
+ 6	4	6	8	10	11	13	15	16	17	17	17	17	17	16	15	13	12	10
+ 4	2	4	6	8	9	11	13	14	15	15	15	15	15	14	13	11	10	8
+ 2	0	2	4	6	8	9	11	12	13	13	13	13	13	12	11	9	8	6
0	− 2	0	2	4	6	7	9	10	11	11	11	11	11	10	9	8	6	4
− 2	− 4	− 2	0	2	4	5	7	8	9	9	9	9	9	8	7	6	4	2
− 4	− 6	− 4	− 2	0	2	3	5	6	7	7	7	7	7	6	5	4	2	0
− 6	− 8	− 6	− 4	− 2	0	1	3	4	5	5	5	5	5	4	3	2	0	− 2
− 8	−10	− 8	− 6	− 4	− 2	− 1	1	2	3	3	3	3	3	2	1	0	− 2	− 4
−10	−12	−10	− 8	− 6	− 4	− 3	− 1	0	1	1	1	1	1	0	− 1	− 2	− 4	− 6
−12	−14	−12	−10	− 8	− 7	− 5	− 3	− 2	− 1	− 1	− 1	− 1	− 1	− 2	− 3	− 4	− 6	− 8
−14	−16	−14	−12	−10	− 8	− 7	− 5	− 4	− 3	− 3	− 3	− 3	− 3	− 4	− 5	− 6	− 8	−10
−16	−18	−16	−14	−12	−10	− 9	− 7	− 6	− 5	− 5	− 5	− 5	− 5	− 6	− 7	− 8	−10	−12
−18	−20	−18	−16	−14	−12	−11	− 9	− 8	− 7	− 7	− 7	− 7	− 7	− 8	− 9	−10	−12	−14
−20	−22	−20	−18	−16	−14	−13	−11	−10	− 9	− 9	− 9	− 9	− 9	−10	−11	−12	−14	−16
−24	−26	−24	−22	−20	−18	−17	−15	−14	−13	−13	−13	−13	−13	−14	−15	−16	−18	−19
−28	−30	−28	−26	−24	−22	−20	−19	−18	−17	−17	−17	−17	−17	−18	−19	−20	−22	−23
−32	−33	−31	−30	−28	−26	−24	−23	−22	−21	−21	−21	−21	−21	−22	−23	−24	−26	−27
−36	−37	−35	−33	−32	−30	−28	−27	−26	−25	−25	−25	−25	−25	−26	−27	−28	−30	−31
−40	−41	−39	−37	−35	−34	−32	−31	−30	−29	−29	−29	−29	−29	−30	−31	−32	−33	−35
−44	−45	−43	−41	−39	−38	−36	−35	−34	−33	−33	−33	−33	−33	−34	−35	−36	−37	−39
−48	−49	−47	−45	−43	−42	−40	−39	−38	−37	−37	−37	−37	−37	−38	−39	−40	−41	−43
−52	−53	−51	−49	−47	−45	−44	−43	−42	−41	−41	−41	−41	−41	−42	−43	−44	−45	−47
−56	−56	−55	−53	−51	−49	−48	−47	−46	−45	−45	−45	−45	−45	−46	−47	−48	−49	−51
−60	−60	−58	−56	−55	−53	−52	−51	−50	−49	−49	−49	−49	−49	−50	−50	−52	−53	−54
−64	−64	−62	−60	−58	−57	−56	−55	−54	−53	−53	−53	−53	−53	−54	−54	−55	−57	−58
−68	−69	−67	−65	−64	−62	−61	−60	−58	−58	−57	−57	−57	−57	−57	−58	−59	−60	−62
−72	−71	−69	−67	−66	−64	−63	−62	−62	−61	−61	−61	−61	−61	−61	−62	−63	−64	−65
−76	−74	−72	−71	−69	−68	−67	−66	−65	−65	−65	−65	−65	−65	−65	−66	−67	−68	−69
−80	−76	−75	−74	−73	−71	−71	−70	−69	−69	−69	−69	−69	−69	−69	−70	−70	−71	−72
−84	−78	−77	−76	−75	−75	−74	−74	−73	−73	−73	−73	−73	−73	−73	−73	−74	−75	−75
−88	−79	−78	−78	−78	−77	−77	−77	−77	−77	−77	−76	−77	−77	−77	−77	−77	−77	−78

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Part 2.—Geomagnetic longitudes of points on the earth in various geographic latitudes and longitudes

Geographic latitude *	Geographic east longitude in degrees																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
+88°	170	170	170	170	171	172	173	174	175	177	178	180	181	183	184	186	187	188	
+84	149	150	152	154	157	160	163	166	169	173	176	180	183	187	190	193	197	200	
+80	130	134	138	142	147	151	156	161	165	170	175	180	184	189	194	198	203	208	
+76	116	122	128	134	140	146	151	157	163	168	174	179	185	191	196	202	208	213	
+72	106	113	121	128	135	141	148	154	160	167	173	179	186	192	198	205	211	217	
+68	99	107	116	123	131	138	145	152	159	166	173	179	186	193	200	207	214	221	
+64	93	103	111	120	128	135	143	150	158	165	172	179	186	194	201	208	216	223	
+60	89	99	108	117	125	133	141	149	157	164	172	179	187	194	202	210	217	225	
+56	87	96	106	115	123	131	140	148	156	164	171	179	187	195	203	211	219	227	
+52	84	94	103	112	121	130	138	147	155	163	171	179	187	195	204	212	220	:228	
+48	82	92	102	111	120	129	137	146	154	162	171	179	187	196	204	213	221	230	
+46	81	91	101	110	119	128	137	145	154	162	171	179	188	196	205	213	222	230	
+44	80	90	100	109	118	127	136	145	153	162	171	179	188	196	205	213	222	231	
+42	80	90	99	109	118	127	136	144	153	162	171	179	188	196	205	214	223	231	
+40	79	89	99	108	117	126	135	144	153	162	170	179	188	197	205	214	223	232	
+38	78	88	98	107	117	126	135	144	153	161	170	179	188	197	206	214	223	232	
+36	77	88	97	107	116	125	134	143	152	161	170	179	188	197	206	215	224	233	
+34	77	87	97	106	116	125	134	143	152	161	170	179	188	197	206	215	224	233	
+32	76	86	96	106	115	124	134	143	152	161	170	179	188	197	206	215	225	234	
+30	76	86	96	105	115	124	133	142	152	161	170	179	188	197	207	216	225	234	
+28	75	85	95	105	114	124	133	142	151	161	170	179	188	198	207	216	225	235	
+26	75	85	95	104	114	123	133	142	151	161	170	179	188	198	207	216	226	235	
+24	74	84	94	104	113	123	132	142	151	160	170	179	188	198	207	217	226	235	
+22	74	84	94	103	113	122	132	141	151	160	170	179	188	198	207	217	226	236	
+20	73	83	93	103	112	122	132	141	151	160	170	179	189	198	208	217	227	236	
+18	73	83	93	102	112	122	131	141	150	160	169	179	189	198	208	217	227	236	
+16	72	82	92	102	112	121	131	141	150	160	169	179	189	198	208	218	227	237	
+14	72	82	92	102	111	121	131	140	150	160	169	179	189	198	208	218	227	237	
+12	72	82	91	101	111	121	130	140	150	159	169	179	189	199	208	218	228	237	
+10	71	81	91	101	111	120	130	140	150	159	169	179	189	199	209	218	228	238	

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Geographic latitude *	Geographic east longitude in degrees																		
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
+8°	71	81	91	100	110	120	130	139	149	159	169	179	189	199	209	219	228	238	
+6	71	80	90	100	110	120	129	139	149	159	169	179	189	199	209	219	229	238	
+4	70	80	90	100	109	119	129	139	149	159	169	179	189	199	209	219	229	239	
+2	70	80	89	99	109	119	129	139	149	159	169	179	189	199	209	219	229	239	
0	69	79	89	99	109	119	128	138	148	159	169	179	189	199	210	220	230	240	
−2	69	79	89	98	108	118	128	138	148	158	169	179	189	199	210	220	230	240	
−4	69	78	88	98	108	118	128	138	148	158	169	179	189	200	210	220	230	240	
−6	68	78	88	98	107	117	128	138	148	158	169	179	189	200	210	220	230	241	
−8	68	78	87	97	107	117	127	137	148	158	168	179	189	200	210	221	231	241	
−10	68	77	87	97	107	117	127	137	147	158	168	179	190	200	211	221	231	241	
−12	67	77	87	96	106	116	126	137	147	158	168	179	190	200	211	221	231	242	
−14	67	76	86	96	106	116	126	136	147	157	168	179	190	200	211	221	232	242	
−16	66	76	86	96	105	116	126	136	147	157	168	179	190	201	211	222	232	242	
−18	66	76	85	95	105	115	125	136	146	157	168	179	190	201	211	222	232	243	
−20	66	75	85	95	105	115	125	135	146	157	168	179	190	201	212	222	233	243	
−24	65	74	84	94	104	114	124	135	146	156	168	179	190	201	212	223	234	244	
−28	64	73	83	93	103	113	123	134	145	156	167	179	190	202	213	224	235	245	
−32	63	72	82	92	102	112	122	133	144	156	167	179	191	202	213	225	235	246	
−36	62	71	81	91	100	111	121	132	143	155	167	179	191	203	214	226	237	247	
−40	61	70	80	89	99	109	120	131	143	154	167	179	191	203	215	227	238	248	
−44	60	69	78	88	98	108	119	130	142	154	166	179	191	204	216	228	239	250	
−48	58	67	77	86	96	106	117	128	140	153	166	179	192	205	217	229	241	252	
−52	57	66	74	84	94	104	115	126	139	151	165	179	192	206	219	231	243	254	
−56	55	64	73	82	92	102	112	124	137	150	164	179	193	207	221	233	245	256	
−60	53	62	70	79	88	99	109	121	134	148	163	178	194	209	223	236	248	259	
−64	51	59	67	76	85	95	105	117	130	145	161	178	196	212	227	241	253	263	
−68	48	55	63	71	80	89	99	111	124	140	158	178	198	217	233	247	259	270	
−72	44	51	58	65	73	81	90	101	114	130	151	177	204	226	243	256	268	277	
−76	39	45	51	57	63	70	77	84	95	108	131	175	223	249	263	273	281	289	
−80	32	37	41	45	49	53	56	59	61	59	49	7	316	302	299	300	303	306	
−84	23	25	28	30	31	32	31	30	26	20	12	1	350	341	335	331	329	328	
−88	9	9	10	10	10	9	9	8	6	4	2	0	358	356	354	353	352	351	

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Geographic latitude *	Geographic east longitude in degrees																		
	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
+88°	189	189	190	190	190	189	189	188	186	184	182	180	178	176	174	173	172	171	170
+84	203	205	208	210	211	212	211	210	206	200	192	181	170	161	155	151	149	148	149
+80	212	217	221	225	229	233	236	239	241	239	229	187	136	122	119	120	123	126	130
+76	219	225	231	237	243	250	257	264	275	288	311	355	43	69	83	93	101	109	116
+72	224	231	238	245	253	261	270	281	294	310	331	357	24	46	63	76	88	97	106
+68	228	235	243	251	260	269	279	291	304	320	338	358	18	37	53	67	79	89	99
+64	231	239	247	256	265	275	285	297	310	325	341	358	16	32	47	61	73	84	93
+60	233	242	250	259	268	279	289	301	314	328	343	358	14	29	43	56	68	79	89
+56	235	244	253	262	272	282	292	304	317	330	344	359	13	27	41	53	65	76	87
+52	237	246	254	264	274	284	295	306	319	331	345	359	12	26	39	51	63	74	84
+48	238	247	257	266	276	286	297	308	320	333	346	359	12	25	37	49	61	72	82
+46	239	248	258	267	277	287	298	309	321	333	346	359	11	24	37	49	60	71	81
+44	240	249	258	268	278	288	299	310	322	334	346	359	11	24	36	48	59	70	80
+42	240	250	259	269	278	289	299	311	322	334	346	359	11	24	36	47	58	69	80
+40	241	250	260	269	279	289	300	311	323	334	347	359	11	23	35	47	58	68	79
+38	242	251	260	270	280	290	301	312	323	335	347	359	11	23	35	46	57	68	78
+36	242	251	261	271	280	291	301	312	323	335	347	359	11	23	34	46	57	67	77
+34	243	252	261	271	281	291	302	313	324	335	347	359	11	22	34	45	56	67	77
+32	243	252	262	272	282	292	302	313	324	336	347	359	11	22	33	45	55	66	76
+30	243	253	263	272	282	292	303	314	325	336	347	359	10	22	33	44	55	66	76
+28	244	253	263	273	283	293	303	314	325	336	347	359	10	22	33	44	55	65	75
+26	244	254	263	273	283	293	304	314	325	336	348	359	10	21	33	43	54	65	75
+24	245	254	264	274	284	294	304	315	326	336	348	359	10	21	32	43	54	64	74
+22	245	255	264	274	284	294	305	315	326	337	348	359	10	21	32	43	53	64	74
+20	246	255	265	275	285	295	305	315	326	337	348	359	10	21	32	42	53	63	73
+18	246	256	265	275	285	295	305	316	326	337	348	359	10	21	31	42	53	63	73
+16	246	256	266	276	285	296	306	316	327	337	348	359	10	21	31	42	52	62	72
+14	247	256	266	276	286	296	306	316	327	337	348	359	10	20	31	41	52	62	72
+12	247	257	267	276	286	296	306	317	327	338	348	359	10	20	31	41	51	62	72
+10	248	257	267	277	287	297	307	317	327	338	348	359	10	20	31	41	51	61	71

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (continued)

Geographic latitude *	Geographic east longitude in degrees																		
	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
+8°	248	258	267	277	287	297	307	317	328	338	348	359	9	20	30	41	51	61	71
+6	248	258	268	278	287	297	308	318	328	338	349	359	9	20	30	40	50	61	71
+4	249	258	268	278	288	298	308	318	328	338	349	359	9	20	30	40	50	60	70
+2	249	259	269	278	288	298	308	318	328	338	349	359	9	19	30	40	50	60	70
0	249	259	269	279	289	299	308	318	328	339	349	359	9	19	30	40	50	60	69
−2	250	260	269	279	289	299	309	319	329	339	349	359	9	19	29	39	49	59	69
−4	250	260	270	280	289	299	309	319	329	339	349	359	9	19	29	39	49	59	69
−6	251	260	270	280	290	300	309	319	329	339	349	359	9	19	29	39	49	58	68
−8	251	261	271	280	290	300	310	319	329	339	349	359	9	19	29	39	48	58	68
−10	251	261	271	281	291	300	310	320	330	339	349	359	9	19	29	38	48	58	68
−12	252	262	271	281	291	301	310	320	330	339	349	359	9	19	28	38	48	57	67
−14	252	262	272	282	291	301	311	320	330	340	349	359	9	18	28	38	47	57	67
−16	252	262	272	282	292	301	311	321	330	340	349	359	9	18	28	38	47	57	66
−18	253	263	273	282	292	302	311	321	330	340	349	359	9	18	28	37	47	56	66
−20	253	263	273	283	292	302	312	321	331	340	350	359	9	18	28	37	47	56	66
−24	254	264	274	284	293	303	312	322	331	340	350	359	8	18	27	37	46	55	65
−28	255	265	275	285	294	304	313	322	331	341	350	359	8	18	27	36	45	55	64
−32	256	266	276	286	295	304	314	323	332	341	350	359	8	17	26	35	45	54	63
−36	257	268	277	287	296	305	314	323	332	341	350	359	8	17	26	35	44	53	62
−40	259	269	279	288	297	306	315	324	333	342	350	359	8	17	25	34	43	52	61
−44	260	270	280	289	298	307	316	325	333	342	351	359	8	16	25	33	42	51	60
−48	262	272	282	291	300	309	317	326	334	342	351	359	7	16	24	33	41	50	58
−52	264	274	283	292	301	310	318	327	335	343	351	359	7	15	24	32	40	48	57
−56	267	276	286	295	303	311	320	328	336	344	351	359	7	15	23	31	39	47	55
−60	269	279	288	297	305	313	321	329	337	344	352	359	7	14	22	30	37	45	53

(continued)

TABLE 511.—GEOMAGNETIC COORDINATES OF POSITION ON THE EARTH REFERRED TO THE GEOMAGNETIC AXIS POLE OF 1922, FOR POINTS IN VARIOUS GEOGRAPHICAL LOCATIONS (concluded)

Geographic latitude *	Geographic east longitude in degrees																		
	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
−64	273	283	291	300	308	315	323	330	338	345	352	359	6	14	21	28	36	43	51
−68	279	287	296	303	311	318	325	332	339	346	353	359	6	13	20	27	34	41	48
−72	286	293	301	308	315	321	328	334	340	347	353	359	6	12	18	25	31	37	44
−76	296	302	308	314	320	326	331	337	343	348	354	359	5	11	16	22	28	33	39
−80	310	314	318	322	327	331	336	341	345	350	355	360	4	9	14	18	23	28	32
−84	329	330	332	334	337	340	343	346	349	353	356	360	3	7	10	13	17	20	23
−88	350	350	350	350	351	352	353	354	355	357	358	360	1	3	4	6	7	8	9

Bibliography: a, Chapman, S., and Bartels, J., Geomagnetism, vols. 1 and 2, Oxford, 1940. b, Fleming, J. A., ed., Terrestrial magnetism and electricity, Physics of the earth series, vol. 8, McGraw-Hill, New York, 1939. c, Ludy, Albert K., and Herbert Howe, H., Magnetism of the earth, U.S. Coast and Geodetic Survey, Serial 663, Washington, 1945. d, Deel, Samuel A., Magnetic declination in the United States 1945, idem, Serial 664, 1946. e, Deel, Samuel A., and Herbert Howe, H., United States magnetic tables and magnetic charts for 1945, idem, Serial 667, 1948. f, Vestine, E. H., Laporte, L., Lange, I., Cooper, C., and Hendrix, W. C., Description of the earth's main magnetic field and its secular change 1905-1945, Carnegie Inst. Washington Publ. No. 578, 1947. g, Vestine, E. H., Lange, I., Laporte, L., and Scott, W. E., The geomagnetic field, its description and analysis, Carnegie Inst. Washington Publ. No. 580, 1947. h, Macht, H. G., Das erdmagnetisch Feld der Polargebiete, Zeitschr. Meteorol., vol. 1, pp. 289-297, 1947. i, Elsasser, W. M., Phys. Rev., vol. 60, p. 876, 1941; vol. 69, p. 106, 1946; vol. 70, p. 202, 1946. j, Bullard, E. C., The magnetic field within the earth, Proc. Roy. Soc. London, A, vol. 197, p. 433, 1949. k, Blackett, P. M. S., Nature, vol. 159, p. 658, 1947. (Gives recent review, theories of earth's field.) l, Journal of Geophysical Research, vol. 56, p. 283, 1951, Baltimore. m, Nippoldt, A., Prussia-Meteorologisches Institut, Bericht über die Tätigkeit des Preuss. Met. Inst. im Jahre 1929: Veröoffentlichungen Nr. 372, p. 137, 1930. n, Wasserfall, Terr. Mag., vol. 44, p. 263, 1939. o, Australian Antarctic Research (B.A.N.Z.A.R.) Expedition 1929-31 (D. Mawson, ed.), Reports, Ser. A, vol. 4, p. 1, Adelaide, 1944. p, Terr. Mag., vol. 48, pp. 97-108, 171-182, and 237-242, 1943; vol. 49, pp. 47-52, 109-118, 199-205, and 267-269, 1944; and vol. 53, pp. 199-240, 1948.

See (a) above for sunspot numbers and international character-figures C, 1890-1937; also (f) for C, 1905-1942; geomagnetic indices C and K for 1940-1947 are given in H. F. Johnston, W. E. Scott, and Ella Balsam, Internat. Union Geod. and Geophys., Terr. Mag. Electr., Bull. Nos. 12 and 12a, Washington, 1948. For current values, see (1), Forecasts of geomagnetic activity, National Bureau of Standards.

World isomagnetic charts are issued by U.S. Hydrographic Office; for the United States and possessions, by U.S. Coast and Geodetic Survey.

TABLE 512.—MAGNETIC AND ELECTRIC DATA FOR SUN AND EARTH

(Chapman, Cosmical magnetic phenomena, Nature, vol. 124, p. 19, 1929.)

Sun's magnetic field too small to be measured by direct effects on earth; measured by Zeeman effect on spectrum lines.

Earth's magnetic axis inclined 12° to rotation axis.

Earth's field rotates at same speed as nearly rigid earth.

Earth: Polar intensity of field $\frac{2}{3}$ gauss.

Sun: Intense local fields frequent, 3000 gauss. The magnetic field of spots reverses each cycle (Proc. Astron. Soc. Pacific, vol. 41, p. 136, 1929). The polarity of leading spot in a bipolar group in the Northern Hemisphere is opposite that in the Southern Hemisphere—relationship reverses each new sunspot cycle ∴ complete magnetic cycle is double sunspot cycle.

Specific resistances:	Earth		Sun	(Chapman, loc. cit.)
	Heaviside layer,	10^{10}	Reversing layer,	3×10^{10}
	Dry earth,	10^{15} to 10^{18}	Photosphere,	10^{8}, T, 10000°K.
	Sea water,	2×10^{10}	Center,	3×10^{3}, T, 4×10^{7}
	200-600 m deep,	3×10^{12}		

Further characteristics of spots: (Milne, Monthly Notices, Roy. Astron. Soc., vol. 90, p. 487, 1930.) Umbra (dark center), 800 (very small) to 80,000 km across: penumbra may reach 240,000 km. Generally short-lived. A few last several (3) rotations, very rarely 6; one in 1840, 18 months. Most occur in 2 belts 5° to 40° N. and S. latitudes, often occur in pairs (see above). Umbra temperature 4000° K. Evershed gives velocity of outburst from spot 2 km/sec.

Faraday discovered that, when a piece of heavy glass is placed in magnetic field and a beam of plane polarized light passed through it in a direction parallel to the lines of magnetic force, the plane of polarization of the beam is rotated. This was subsequently found to be the case with a large number of substances, but the amount of the rotation was found to depend on the kind of matter and its physical condition, and on the strength of the magnetic field and the wavelength of the polarized light. Verdet's experiments agree fairly well with the formula

$$\theta = clH\left(r - \lambda\frac{dr}{d\lambda}\right)\frac{r^2}{\lambda^2}$$

where c is a constant depending on the substance used, l the length of the path through the substance, H the intensity of the component of the magnetic field in the direction of the path of the beam, r the index of refraction, and λ the wavelength of the light in air. If H be different, at different parts of the path, lH is to be taken as the integral of the variation of magnetic potential between the two ends of the medium. Calling this difference of potential v, we may write $\theta = Av$, where A is constant for the same substance, kept under the same physical conditions, when the one kind of light is used. The constant A has been called "Verdet's constant," and a number of values of it are given in Tables 514-517. For variation with temperature the following formula is given by Bichat:

$$R = R_0\,(1 - 0.00104t - 0.000014t^2),$$

which has been used to reduce some of the results given in the table to the temperature corresponding to a given measured density. For change of wavelength the following approximate formula, given by Verdet and Becquerel, may be used:

$$\frac{\theta_1}{\theta_2} = \frac{\mu_1{}^2(\mu_1{}^2 - 1)\lambda_2{}^2}{\mu_2{}^2(\mu_2{}^2 - 1)\lambda_1{}^2},$$

where μ is index of refraction and λ wavelength of light.

A large number of measurements of what has been called molecular rotation have been made, particularly for organic substances. These numbers are not given in the table, but numbers proportional to molecular rotation may be derived from Verdet's constant by multiplying in the ratio of the molecular weight to the density. The densities and chemical formulas are given in the table. In the case of solutions, it has been usual to assume that the total rotation is simply the algebraic sum of the rotations which would be given by the solvent and dissolved substance, or substances, separately; and hence that determinations of the rotary power of the solvent medium and of the solution enable the rotary power of the dissolved substance to be calculated. Experiments by Quincke and others do not support this view, as very different results are obtained from different degrees of saturation and from different solvent media. No results thus calculated have been given in the table, but the qualitative result, as to the sign of the rotation produced by a salt, may be inferred from the table. For example, if a solution of a salt in water gives Verdet's constant less than 0.0130 at 20°C, Verdet's constant for the salt is negative.

As a basis for calculation, Verdet's constant for carbon disulfide and the sodium line D has been taken as 0.0130 at 20°C.

Wavelength	.5μ	1.0μ	1.5μ	2.0μ	2.5μ
Steel	−11′	−16′	−14′	−11′	−9′0
Cobalt	− 9.5	−11.5	− 9.5	−11.	−6.5
Nickel	− 5.5	− 4.0	0	+ 1.75	+3.0

Field intensity = 10,000 cgs units. (Intensity of magnetization = about 800 in steel, 700 to 800 in cobalt, about 400 in nickel.)

TABLE 514.—VERDET'S CONSTANT

Part 1.—Solids

Substance	Formula	Wavelength	Verdet's constant in min
		μ	
Amber		.589	.0095
Blende	ZnS	"	.2234
Diamond	C	"	.0127
Lead borate	PbB_2O_4	"	.0600
Selenium	Se	.687	.4625
Sodium borate	$Na_2B_4O_7$	.589	.0170
Ziqueline (Cuprite)	Cu_2O	.687	.5908
Fluorite	CaF_2	.2534	.05989
		.3655	.02526
		.4358	.01717
		.4916	.01329
		.589	.00897
		1.00	.00300
		2.50	.00049
		3.00	.00030
Glass:			
Jena, medium phosphate crn		.589	.0161
heavy crown, O1143		"	.0220
light flint, O451		"	.0317
heavy flint, O500		"	.0608
" " S163		"	.0888
Zeiss, ultraviolet		.313	.0674
"		.405	.0369
"		.436	.0311
Quartz, along axis, i.e., plate cut ⊥ to axis	SiO_2	.2194	.1587
		.2573	.1079
		.3609	.04617
		.4800	.02574
		.5892	.01664
		.6439	.01368
Rock salt	NaCl	.2599	.2708
		.3100	.1561
		.4046	.0775
		.4916	.0483
		.6708	.0245
		1.00	.01050
		2.00	.00262
		4.00	.00069
Sugar, cane: along axis IIA	$C_{12}H_{22}O_{11}$	.451	.0122
		.540	.0076
		.626	.0066
axis IIA[1]	–	.451	.0129
		.540	.0084
		.626	.0075
Sylvite	KCl	.4358	.0534
		.5461	.0316
		.6708	.02012
		.90	.01051
		1.20	.00608
		2.00	.00207
		4.00	.00054

(*continued*)

Part 2.—Liquids (for $\lambda = 0.589\ \mu$)

Substance	Chemical formula	Density in g per cm³	Verdet's constant in min	Temp. °C
Acetone	C_3H_6O	.7947	.0113	20°
Acids: Formic	CH_2O_2	1.2273	.0105	15
Acetic	$C_2H_4O_2$	1.0561	.0105	21
Hydrochloric	HCl	1.2072	.0224	15
Hydrobromic	HBr	1.7859	.0343	"
Hydroiodic	HI	1.9473	.0515	"
Nitric	HNO_3	1.5190	.0070	13
Alcohols: Methyl	CH_3OH	.7920	.0093	20
Ethyl	C_2H_5OH	.7900	.0112	"
Benzene	C_6H_6	.8786	.0297	"
Bromides: Methyl	CH_3Br	1.7331	.0205	0
Ethyl	C_2H_5Br	1.4486	.0183	15
Carbon bisulfide	CS_2	1.26	.0420	18
Chlorides: Carbon	CCl_4	1.60	.0321	15
Chloroform	$CHCl_3$	1.4823	.0164	20
Ethyl	C_2H_5Cl	.9169	.0138	6
Iodides: Methyl	CH_3I	2.2832	.0336	15
Ethyl	C_2H_5I	1.9417	.0296	"
Nitrates: Methyl	$CH_3O \cdot NO_2$	1.2157	.0078	"
Ethyl	$C_2H_5O \cdot NO_2$	1.1149	.0091	"
Paraffins: Pentane	C_5H_{12}	.6332	.0118	"
Hexane	C_6H_{14}	.6743	.0125	"
Toluene	C_7H_8	8581	.0269	28
Water = .2496μ	H_2O	....	.1042	..
.275	....	....	.0776	..
.4046	....	....	.0293	..
.589	....	....	.0131	..
1.000	....	....	.00410	..
1.300	....	....	.00264	..
Xylene	C_8H_{10}	.8746	.0263	27

TABLE 515.—VERDET'S CONSTANT FOR SOLUTIONS OF ACIDS AND SALTS IN WATER ($\lambda = 0.589\ \mu$)

Chemical formula	Density g per cm³	Verdet's constant in min	Temp. °C	Chemical formula	Density g per cm³	Verdet's constant in min	Temp. °C
HBr	1.3775	.0244	20°	Fe_2Cl_6	1.6933	—.2026	15°
HCl	1.1573	.0204	"	"	1.5315	—.1140	"
"	1.0762	.0168	"	"	1.1681	—.0015	"
HI	1.9057	.0499	"	"	1.0864	.0081	"
"	1.1760	.0205	"	"	1.0232	.0122	"
HNO_3	1.3560	.0105	"	$HgCl_2$	1.0381	.0137	16
NH_3	.8918	.0153	15	$NiCl_2$	1.4685	.0270	15
NH_4Br	1.2805	.0226	"	"	1.2432	.0196	"
$BaBr_2$	1.5399	.0215	20	KCl	1.6000	.0163	"
$CdBr_2$	1.3291	.0192	"	NaCl	1.0418	.0144	"
$CaBr_2$	1.2491	.0189	"	$SrCl_2$	1.1921	.0162	"
KBr	1.1424	.0163	"	$SnCl_2$	1.3280	.0266	"
"	1.0876	.0151	"	$ZnCl_2$	1.2851	.0196	"
NaBr	1.1351	.0165	"	NH_4I	1.5948	.0396	"
"	1.0824	.0152	"	"	1.2341	.0235	"
K_2CO_3	1.1906	.0140	"	KI	1.6743	.0338	"
Na_2CO_3	1.1006	.0140	"	"	1.1705	.0182	"
NH_4Cl	1.0718	.0178	15	KNO_3	1.0634	.0130	20
$BaCl_2$	1.2897	.0168	20	$NaNO_3$	1.1112	.0131	"
$CdCl_2$	1.3179	.0185	"	$U_2O_3N_2O_5$	2.0267	.0053	"
"	1.1732	.0160	"	"	1.1963	.0115	"
$CaCl_2$	1.1504	.0165	"	$BaSo_4$	1.1788	.0134	"
"	1.0832	.0152	"	K_2SO_4	1.0475	.0133	"
$FeCl_2$	1.4331	.0025	15	Na_2SO_4	1.0661	.0135	"
"	1.1093	.0118	"				

TABLE 516.—VERDET'S CONSTANT FOR SOME GASES

Du Bois shows that in the case of substances like iron, nickel, and cobalt which have a variable magnetic susceptibility the expression in Verdet's equation, which is constant for substances of constant susceptibility, requires to be divided by the susceptibility to obtain a constant. For this expression he proposes the name "Kundt's constant." These experiments of Kundt and Du Bois show that it is not the difference of magnetic potential between the two ends of the medium, but the product of the length of the medium and the induction per unit area, which controls the amount of rotation of the beam.

Some data on the Verdet constant of gases by Ingersol (*) and by de Mallemann (†) for wavelength 5780A, pressure 760 mmHg, and at temperature 0°C:

Substance	Verdet constant in min	Substance	Verdet constant in min	Substance	Verdet constant in min
Hydrogen † ...	6.29×10^{-6}	Helium *	$.51 \times 10^{-6}$	Methane †	17.4×10^{-6}
Hydrogen * ...	6.26	Oxygen *	5.55	Ethylene †	34.4
Deuterium * ...	6.21	Oxygen †	5.69	Ethylene *	34.6
Nitrogen *	6.30	Argon †	9.36	Carbon dioxide *	9.25

The de Mallemann values are from numerous papers in Comptes Rendus, 1929 to date (See in particular R. de Mallemann, F. Suhner, and J. Grange, C. R., vol. 232, p. 1094, 1915. See also P. Gabiano Ann. d. Physique, vol. 10, p. 68, 1933.). The Ingersoll values are from an ONR preliminary report (October 1952). The probable error of the de Mallemann and the Ingersoll values is of the order of 1 percent. The dispersion of the rotation for most gases, except oxygen, is roughly as the inverse square of the wavelength.

Substance	Pressure	Temp.	Verdet's constant in min
Atmospheric air	Atmospheric	Ordinary	6.83×10^{-6}
Carbon dioxide	"	"	13.00 "
Carbon disulfide	74 cmHg	70°C	23.49 "
Ethylene	Atmospheric	Ordinary	34.48 "
Nitrogen	"	"	6.92 "
Nitrous oxide	"	"	16.90 "
Oxygen	"	"	6.28 "
Sulfur dioxide	"	"	31.39 "
" "	246 cmHg	20°C	38.40 "

TABLE 517.—VERDET'S AND KUNDT'S CONSTANTS FOR SOME MATERIALS

The following short table is quoted from Du Bois's paper. The quantities are stated in cgs measure, circular measure (radians) being used in the expression of "Verdet's constant" and "Kundt's constant."

Name of substance	Magnetic susceptibility	Verdet's constant Number	Wavelength of light in cm	Knudt's constant
Cobalt	—	—	6.44×10^{-5}	3.99
Nickel	—	—	"	3.15
Iron	—	—	6.56 "	2.63
Oxygen: 1 atm......	$+.0126 \times 10^{-5}$	$.000179 \times 10^{-5}$	5.89 "	.014
Sulfur dioxide	−.0751 "	.302 "	"	− 4.00
Water	−.0694 "	.377 "	"	− 5.4
Nitric acid	−.0633 "	.356 "	"	− 5.6
Alcohol	−.0566 "	.330 "	"	− 5.8
Ether	−.0541 "	.315 "	"	− 5.8
Arsenic chloride	−.0876 "	1.222 "	"	−14.9
Carbon disulfide	−.0716 "	1.222 "	"	−17.1
Faraday's glass	−.0982 "	1.738 "	"	−17.7

TABLE 518.—VALUES OF KERR'S CONSTANT

Du Bois has shown that the rotation of the major axis of vibration of radiations normally reflected from a magnet is algebraically equal to the normal component of magnetization multiplied into a constant K. He calls this constant K, Kerr's constant for the magnetized substance forming the magnet.

Color of light	Spectrum line	Wave-length	Kerr's constant in minutes per cgs unit of magnetization			
			Cobalt	Nickel	Iron	Magnetite
Red	Li α	.677 μ	—.0208	—.0173	—.0154	+.0096
Red	—	.620	—.0198	—.0160	—.0138	+.0120
Yellow	D	.589	—.0193	—.0154	—.0130	+.0133
Green	*b*	.517	—.0179	—.0159	—.0111	+.0072
Blue	F	.486	—.0180	—.0163	—.0101	+.0026
Violet	G	.431	—.0182	—.0175	—.0089	—

TABLE 519.—TRANSVERSE GALVANOMAGNETIC AND THERMOMAGNETIC EFFECTS

Effects are considered positive when, the magnetic field being directed away from the observer, and the primary current of heat or electricity directed from left to right, the upper edge of the specimen has the higher potential or higher temperature.

E = difference of potential produced; T = difference of temperature produced; I = primary current; $\frac{dt}{dx}$ = primary temperature gradient; B = breadth, and D = thickness, of specimen; H = intensity of field, cgs units.

Hall effect (galvanomagnetic difference of potential), $E = R\frac{HI}{D}$

Ettingshausen effect (" " " temperature), $T = P\frac{HI}{D}$

Nernst effect (thermomagnetic " " potential), $E = QHB\frac{dt}{dx}$

Leduc effect (" " " temperature), $T = SHB\frac{dt}{dx}$

Substance	Values of R	$P \times 10^6$	$Q \times 10^6$	$S \times 10^8$
Tellurium	+ 400 to 800	+200	+360000	+400
Antimony	+.9 " .22	+2	+9000 to 18000	+200
Steel	+.012 " .033	—.07	—700 " 1700	+69
Heusler alloy	+.010 " .026	—	+1600 " 7000	
Iron	+.007 " .011	—.06	—1000 " 1500	+39
Cobalt	+.0016 " .0046	+.01	+1800 " 2240	+13
Zinc	—	—	—54 " 240	+13
Cadmium	+.00055			
Iridium	+.00040	—	up to —5 0	+ 5
Lead	+.00009	—	—5.0 (?)	
Tin	—.00003	—	—4.0 (?)	
Platinum	—.0002	—	—	— 2
Copper	—.00052	—	—90 to 270	—18
German silver	—.00054			
Gold	—.00057 to .00071			
Constantin	—.0009			
Manganese	—.00093			
Palladium	—.0007 to .0012	—	+50 to 130	— 3
Silver	—.0008 " .0015	—	—46 " 430	—41
Sodium	—.0023			
Magnesium	—.00094 to .0035			
Aluminum	—.00036 " .0037			
Nickel	—.0045 " .024	+.04 to .19	+2000 " 9000	—45
Carbon	—.017	+5.	+100	
Bismuth	— up to 16.	+3 to 40	+ up to 132000	—200

TABLE 520.—DISPERSION OF KERR EFFECT

Mirror	Field cgs	.41μ	.44μ	.48μ	.52μ	.56μ	.60μ	.64μ	.66μ
Iron	21,500	—.25	—.26	—.28	—.31	—.36	—.42	—.44	—.45
Cobalt	20,000	—.36	—.35	—.34	—.35	—.35	—.35	—.35	—.36
Nickel	19,000	—.16	—.15	—.13	—.13	—.14	—.14	—.14	—.14
Steel	19,200	—.27	—.28	—.31	—.35	—.38	—.40	—.44	—.45
Invar	19,800	—.22	—.23	—.24	—.23	—.23	—.22	—.23	—.23
Magnetite	16,400	—.07	—.02	+.04	+.06	+.08	+.06	+.04	+.03

TABLE 521.—VARIATION OF HALL CONSTANT WITH THE TEMPERATURE

Bismuth					
H	−182°C	−90°	−23°	+11.5°	+100°
1000	62.2	28.0	17.0	13.3	7.28
2000	55.0	25.0	16.0	12.7	7.17
3000	49.7	22.9	15.1	12.1	7.06
4000	45.8	21.5	14.3	11.5	6.95
5000	42.6	20.2	13.6	11.0	6.84
6000	40.1	18.9	12.9	10.6	6.72

Antimony				
H	−186°C	−79°	+21.5°	+58°
1750	.263	.249	.217	
3960	.252	.243	.211	
6160	.245	2 35	.209	.203

Bismuth									
H	+14.5°C	+104°	125°	189°	212°	239°	259°	269°	270°
890	5.28	2.57	2.12	1.42	1.24	1.11	.97	.83	.77*

* Melting point.

TABLES 522-555.—OPTICAL GLASS AND OPTICAL CRYSTALS

Optical glass and optical crystals are in general described by giving their indices of refraction for standard wavelengths, such as the *D, A, C, F,* etc., lines and their ν values $= (n_D - 1)/(n_F - n_C)$. Also, the spectral transmission and some other physical constants may be given. In addition, many crystals have different optical properties in different directions which require some consideration of their optical axes. For glasses used as filters the spectral transmission is an important item. A table of wavelength units and some data on various types of optical glass and crystals follow.

TABLE 522.—RADIATION WAVELENGTH UNITS

Radio	Radiation	Colorimetry	Spectroscopy	X-rays	γ rays
meter	micron	millimicron	angstrom	X-ray units	microangstrom

Units: Name	Symbol	Powers-of-10 equivalent of units listed in column 1: μ	$m\mu$	A	XU	μA	cgs unit cm	mm	m
Micron	μ	1	10^3	10^4	10^7	10^{10}	10^{-4}	10^{-3}	10^{-6}
Millimicron	$m\mu$	10^{-3}	1	10	10^4	10^7	10^{-7}	10^{-6}	10^{-9}
Angstrom	A	10^{-4}	10^{-1}	1	10^3	10^6	10^{-8}	10^{-7}	10^{-10}
X-ray unit	$X\mu$	10^{-7}	10^{-4}	10^{-3}	1	10^3	10^{-11}	10^{-10}	10^{-13}
Microangstrom	μA	10^{-10}	10^{-7}	10^{-6}	10^{-3}	1	10^{-14}	10^{-13}	10^{-16}

The X-ray unit as originally used referred to the measurement of x-wavelengths using a calcite crystal. Such results are in error by a factor of 1.00203.

OPTICAL GLASS

TABLE 523.—CHARACTERISTICS OF AMERICAN-MADE OPTICAL GLASSES[160]

Crown glasses—crown (CO), light barium crown (LBC), dense barium crown (DBC), extra dense barium crown (EDBC)

Name	*C—BL*	*LBC—BL*	*DBC—CG*	*DBC—CG*	*DBC—CG*	*EDBC—BL*
Type	518/596	573/568	612/595	620/603	638/555	617/539
n_D	1.51780	1.57250	1.61160	1.62030	1.63840	1.61700
n_G'	1.52886	1.58538	1.6246	1.6332	1.6532	1.63171
n_F	1.52393	1.57962	1.61880	1.62750	1.64650	1.62511
n_C	1.51524	1.56954	1.60852	1.61722	1.63500	1.61367
ν	59.6	56.8	59.5	60.3	55.5	53.9

Flint glasses—crown flint (CF), light flint (LF), short flint (SF), extra light flint (ELF), light barium flint (LBF), barium flint (BF), dense barium flint (DBF), dense flint (DF), extra dense flint (EDF)

Name	*CF—BL*	*LBF—BL*	*BF—BL*	*DBF—BL*	*DBF—CG*	*ELF—BL*
Type	526/546	548/537	570/481	617/385	670/472	541/475
n_D	1.52560	1.54770	1.57040	1.61700	1.66990	1.54140
n_G'	1.53793	1.56081	1.58575	1.63811	1.6882	1.55618
n_F	1.53239	1.55491	1.57880	1.62843	1.67990	1.54949
n_C	1.52277	1.54471	1.56695	1.61242	1.66572	1.53809
ν	54.6	53.7	48.1	38.5	47.2	47.5

Name	*ELF—BL*	*SF—CG*	*LF—BL*	*DF—BL*	*EDF—BL*
Type	559/455	613/442	575/429	596/397	751/277
n_D	1.55850	1.61300	1.57510	1.59560	1.75060
n_G'	1.57447	1.6308	1.59263	1.61538	1.78716
n_F	1.56722	1.62280	1.58464	1.60632	1.77009
n_C	1.55495	1.60893	1.57122	1.59130	1.74302
ν	45.5	44.2	42.9	39.7	27.7

[160] Adapted from data from Bausch & Lomb (BL) and Corning Glass Works (CG). F. A. Molby, West Virginia University, assisted in selecting and arranging these data. For reference see Molby, Journ. Opt. Soc. Amer., vol. 39, p. 600, 1949.

TABLE 524.—CHARACTERISTICS OF SOME OPTICAL GLASSES MADE AT THE NATIONAL BUREAU OF STANDARDS *

Name	*BSC* 511/635	*BSC* 517/645	*BSC* 536/645	*LC* 512/605	*LC* 523/586	*LC* 528/580	*BaC* 541/599	*BaC* 5725/574	*BaC* 574/577	*BaC* 6109/572	*BaC* 611/588	*BaC* 617/550	*BaC* 620/600	*CF* 529/516
Nominal														
n_D	1.511	1.517	1.536	1.5125	1.523	1.528	1.541	1.5725	1.574	1.6109	1.611	1.617	1.620	1.5286
ν	63.5	64.5	64.5	60.5	58.6	58.0	59.9	57.4	57.7	57.2	58.8	55.0	60.0	51.6
Typical glass														
n_D	1.51070	1.51728	1.53598	1.51310	1.52300	1.52882	1.54111	1.57283	1.57353	1.61118	1.61107	1.61727	1.61935	1.52900
$n_{G'}$	1.52086	1.52736	1.54645	1.52385	1.53433	1.54035	1.55259	1.58549	1.58623	1.62484	1.62425	1.63169	1.63257	1.54225
n_F	1.51635	1.52289	1.54182	1.51906	1.52928	1.53520	1.54747	1.57984	1.58055	1.61873	1.61837	1.62523	1.62667	1.53628
n_C	1.50829	1.51489	1.53349	1.51049	1.52037	1.52613	1.53843	1.56991	1.57060	1.60802	1.60801	1.61398	1.61626	1.52600
ν	63.4	64.7	64.4	60.6	58.7	58.3	59.9	57.7	57.6	57.0	59.0	54.9	59.5	51.4
Composition (batch)	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SiO_2	68.8	66.3	63.4	71.9	70.2	68.3	58.8	45.2	47.4	38.25	38.3	37.3	37.8	65.4
PbO										.2	.2	1.4		10.0
BaO							19.9	28.7	30.0	42.85	42.8	44.8	44.2	.2
B_2O_3	8.5	12.5	13.0	5.0	1.5	1.5	3.8	6.2	4.9	6.7	10.7	4.4	11.35	
Na_2O	7.8	7.5		14.7	14.0	14.0	2.8	1.4	.9			.2		13.2
K_2O	14.7	12.0	6.2	5.0	2.5	2.5	10.3	7.0	7.0			.4		5.6
As_2O_3	.2	.5	.4				.3	.3	.3	.4	.4	.3	.3	.2
Sb_2O_3				1.2	1.2	1.2		.7	.5	.2	.2	.7	.2	1.8
ZnO		1.2					4.1	7.5	7.5	4.2		5.6		3.6
BeO			2.0										2.3	
SrO			10.0											
Li_2O			5.0											
CaO				2.2	9.4	11.3				2.3	4.5		3.6	
Cl					.7	.7								
SO_3					.5	.5								
Al_2O_3								3.0		4.9	2.9	4.9		
ZrO_2													.25	

* Data furnished by L. W. Tilton, National Bureau of Standards.

(continued)

TABLE 524.—CHARACTERISTICS OF SOME OPTICAL GLASSES MADE AT THE NATIONAL BUREAU OF STANDARDS (concluded)

Name	*F* 572/425	*F* 5795/410	*F* 605/381	*F* 617/366	*F* 620/362	*F* 649/338	*F* 666/324	*F* 672/322	*F* 689/309	*F* 720/295	*F* 754/277	*BF* 584/460	*BF* 588/534	*BF* 604/435
Nominal														
n_D	1.5725	1.5795	1.605	1.617	1.620	1.649	1.666	1.6725	1.689	1.720	1.754	1.584	1.588	1.604
ν	42.5	41.0	38.1	36.6	36.2	33.8	32.4	32.2	30.9	29.5	27.7	46.0	53.4	43.5
Typical glass														
n_D	1.57184	1.57942	1.60490	1.61699	1.62042	1.64903	1.66600	1.67210	1.68884	1.72037	1.75410	1.58386	1.58835	1.60420
$n_{G'}$	1.58950	1.59800	1.62590	1.63936	1.64311	1.67470	1.69335	1.70003	1.71851	1.75349	1.79106	1.60030	1.60249	1.62240
n_F	1.58146	1.58951	1.61630	1.62907	1.63268	1.66285	1.68069	1.68710	1.70475	1.73808	1.77380	1.59283	1.59614	1.61410
n_C	1.56796	1.56536	1.60030	1.61217	1.61556	1.64356	1.66021	1.66619	1.68259	1.71345	1.74644	1.58019	1.58513	1.60020
ν	42.4	40.9	37.9	36.5	36.2	33.7	32.5	32.1	31.1	29.2	27.5	46.2	53.4	43.4
Composition (batch)	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SiO_2	55.1	53.1	47.6	45.6	45.6	41.2	39.3	38.8	37.0	34.1	31.2	49.8	45.8	45.7
PbO	31.7	35.5	40.9	43.2	45.2	51.1	54.4	55.4	58.1	62.4	66.2	18.8	10.0	23.3
BaO	1.0	.6										13.4	25.9	14.3
B_2O_3													8.8	
Na_2O	5.0	.4	2.2	4.6	3.0	.7						1.5	.8	
K_2O	6.9	9.6	8.8	6.1	5.7	6.5	6.0	5.5	4.6	3.2	2.3	8.2	6.7	8.2
As_2O_3	.3	.3	.5	.5	.5	.5	.3	.3	.3	.3	.3	.5	.5	.4
Sb_2O_3		.5												
ZnO												7.8		8.1
BeO														
SrO														
Li_2O														
CaO														
Cl														
SO_3														
Al_2O_3													1.5	
ZrO_2														

TABLE 525.—INDEX OF REFRACTION OF EASTMAN KODAK CO. NONSILICA GLASSES (1949)

Part 1

Type	*EK*—110 (*EK*—110 —5328)	*EK*—210	*EK*—310	*EK*—325 (*EK*—32 —2641)	*EK*—330 (*EK*—33 —2734*s*)	*EK*—450 (*EK*—45 —29)
Index						
n_h	1.71786	1.75861	1.77301	1.77288	1.78280	1.83767
n_g	1.71227	1.75201	1.76538	1.76518	1.77532	1.82832
n_F	1.70554	1.74413	1.75638	1.75607	1.76643	1.81738
n_D	1.69680	1.73400	1.74500	1.74450	1.75510	1.80370
	(1.6973)			(1.7442)	(1.7555)	(1.8016)
n_C	1.69313	1.72979	1.74033	1.73973	1.75043	1.79814
$n_{A'}$	1.68877	1.72484	1.73491	1.73417	1.74499	1.79180

Type numbers and n_D values in parentheses are 1947 descriptions of *EK* glasses for which expansion data appear in Table 550.

Part 2.—Dispersion of glasses

Index						
n_D	1.69680	1.73400	1.74500	1.74450	1.75510	1.80370
	(1.6973)			(1.7442)	(1.7555)	(1.8016)
$\nu = \frac{n_D - 1}{n_F - n_C}$	56.15	51.18	46.42	45.56	47.19	41.8
	(56.0)			(45.8)	(47.2)	(40.9)
$n_F - n_C$	.01241	.01434	.01605	.01634	.01600	.01924
	(.01246)			(.01624)	(.01602)	(.01959)
$n_F - n_D$	.00874	.01013	.01138	.01157	.01133	.01368
	(.00877)			(.01153)	(.01133)	(.01394)
$n_g - n_F$	.00673	.00788	.00900	.00911	.00889	.01094
	(.00677)			(.00913)	(.00890)	(.01118)
$n_h - n_g$	.00559	.00660	.00763	.00770	.00748	.00935
	(.00562)			(.00776)	(.00750)	(.00959)
$n_D - n_{A'}$	.00803	.00916	.01009	.01033	.01011	.01190
	(.00806)			(.01018)	(.01014)	(.0——)

TABLE 526.—TRANSMISSION OF OPTICAL GLASS

Thickness 10 mm, reflection deducted *

	BSC —1	*BSC* —2	*C* —1	*LBC* —2	*DBC* —1	*DBC* —3	*CF* —1	*BF* —1	*DF* —2	*EDF* —3
Cut-off in $m\mu$	300	296	301	306	328	320	310	316	326	350
T at 360 $m\mu$	90 0	76.0	84.0	47.5	22.0	82.5	97.0	94.0	72.5	6.5
380 $m\mu$	98.0	95.0	97.2	92.5	96.8	98.5	99.0	98.0	84.5	47.0
400 $m\mu$	99.5	99.5	99.3	99.5	99.5	99.4	99.5	99.5	90.5	70.0
460 $m\mu$	99.5	99.5	99.3	99.5	99.5	99.4	99.5	99.5	97.0	96.2
500 $m\mu$	99.5	99.5	99.3	99.5	99.5	99.4	99.5	99.5	98.9	99.3
800 $m\mu$	99.5	98.5	99.3	99.2	99.4	99.4	99.5	99.5	99.5	99.5
1000 $m\mu$	99.5	94.5	99.3	97.2	96.6	99.4	99.5	99.5	99.5	99.5
2000 $m\mu$	88.8	85.0	95.0	90.5	65.0	80.5	70.0	88.5	99.5	99.5
3000 $m\mu$	.5	.0	17.5	.6	.0	.0	.9	.9	6.0	3.0
Cut-off in $m\mu$	3200	3000	4000	3200	2900	2850	3350	3250	3500	4100

* Abbreviated from a list of results of measurements on freshly polished samples of Bausch & Lomb glasses. Data supplied by the Bausch & Lomb Optical Co.

TABLE 527.—CHANGES WITH TEMPERATURE IN ABSOLUTE INDEX OF REFRACTION (n) AT 20°C FOR A NUMBER OF GLASSES * †

n_D	Boro-silicate crown *BSC*—1	Crown *C*—1	Light barium crown *LBC*—2	Dense barium crown *DBC*—3	Crown flint *CF*—1	Barium flint *BF*—1	Dense flint *DF*—2
				Δn/°C			
4360A......	...	...	...	...	...	...	.586
4801A......	.101	.199	.085	.305	.261	.246	.492
5087A......	.087	.171	.072	.276	.244	.218	.450
5462A......	...	.159	...	...	...	...	.405
5894A......	.059	.150	.036	.256	.205	.162	.370
6440A......	.050	.131	.025	.237	.184	.140	.334

* For references, see footnote 160, p. 509.
† In units of the fifth decimal place.

TABLE 528.—INDEX OF REFRACTION OF GLASSES MADE BY SCHOTT AND GENOESSEN, JENA

The following constants are for glasses made by Schott and Genoessen, Jena: n_A, n_C, n_D, n_F, n_G, are the indices of refraction in air for $A = 0.7682\mu$, $C = 0.6563\mu$, $D = 0.5893$, $F = 0.4861$, $G' = 0.4341$, $\nu = (n_D - 1)/(n_F - n_C)$.

	Catalogue type =	O 546	O 381	O 184	O 102	O 165	S 57
	Designation =	Zinc-crown	Higher dispersion crown	Light silicate flint	Heavy silicate flint	Heavy silicate flint	Heaviest silicate flint
	Melting number =	1092	1151	451	469	500	163
	ν =	60.7	51.8	41.1	33.7	27.6	22.2
Kind of light and wavelength	Cd .2763μ	1.56759	—	—	—	—	—
	Cd .2837	1.56372	—	—	—	—	—
	Cd .2980	1.55723	1.57093	1.65397	—	—	—
	Cd .3403	1.54369	1.55262	1.63320	1.71968	1.85487	—
	Cd .3610	1.53897	1.54664	1.61388	1.70536	1.83263	—
	H .4340μ	1.52788	1.53312	1.59355	1.67561	1.78800	1.94493
	H .4861	1.52299	1.52715	1.58515	1.66367	1.77091	1.91890
	Na .5893	1.51698	1.52002	1.57524	1.64985	1.75130	1.88995
	H .6563	1.51446	1.51712	1.57119	1.64440	1.74368	1.87893
	K .7682	1.51143	1.51368	1.56669	1.63820	1.73530	1.86702
	.800μ	1.5103	1.5131	1.5659	1.6373	1.7338	1.8650
	1.200	1.5048	1.5069	1.5585	1.6277	1.7215	1.8481
	1.600	1.5008	1.5024	1.5535	1.6217	1.7151	1.8396
	2.000	1.4967	1.4973	1.5487	1.6171	1.7104	1.8316
	2.400	—	—	1.5440	1.6131	—	1.8286

Percentage composition of the above glasses:

O 546, SiO_2, 65.4; K_2O, 15.0; Na_2O, 5.0; BaO, 9.6; ZnO, 2.0; Mn_2O_3, 0.1; As_2O_3, 0.4; B_2O_3, 2.5.
O 381, SiO_2, 68.7; PbO, 13.3; Na_2O, 15.7; ZnO, 2.0; MnO_2, 0.1; As_2O_5, 0.2.
O 184, SiO_2, 53.7; PbO, 36.0; K_2O, 8.3; Na_2O, 1.0; Mn_2O_3, 0.06; As_2O_3, 0.3.
O 102, SiO_2, 40.0; PbO, 52.6; K_2O, 6.5; Na_2O, 0.5; Mn_2O_3, 0.09; As_2O_5, 0.3.
O 165, SiO_2, 29.26; PbO, 67.5; K_2O, 3.0; Mn_2O_3, 0.04; As_2O_3, 0.2.
S 57, SiO_2, 21.9; PbO, 78.0; As_2O_5, 0.1.

TABLE 529.—CHANGE OF INDICES OF REFRACTION FOR 1°C IN UNITS OF THE FIFTH DECIMAL PLACE

No. and designation	Mean temp	*C*	*D*	*F*	*G'*	$\frac{-\Delta n}{n} 100$
S 57 Heavy silicate flint......	58.8°	1.204	1.447	2.090	2.810	.0166
O 154 Light silicate flint.......	58.4	.225	.261	.334	.407	.0078
O 327 Baryt flint light.........	58.3	—.008	.014	.080	.137	.0079
O 225 Light phosphate crown...	58.1	—.202	—.190	—.168	—.142	.0049

TABLE 530.—TRANSMISSION OF RADIATION BY JENA GLASSES

Part 1

Coefficients, a, in the formula $I_t = I_0 a^t$, where I_0 is the intensity before, and I_t after, transmission through the thickness t.

Unit $t = 1$ dm	Coefficient of transmission, a .375μ	390μ	.400μ	.434μ	.436μ	.455μ	.477μ	.503μ	.580μ	.677μ
O 340, Ordinary light flint	.388	.456	.614	.569	.680	.834	.880	.880	.878	.939
O 102, Heavy silicate flint	—	.025	.463	.502	.566	.663	.700	.782	.828	.794
O 93, Ordinary " "	—	—	—	—	.714	.807	.899	.871	.903	.943
O 203, " " crown	.583	.583	.695	.667	.806	.822	.860	.872	.872	.903
O 598, (Crown)	—	—	—	—	.797	.770	.771	.776	.818	.860

Unit $t = 1$ cm	0.7μ	0.95μ	1.1μ	1.4μ	1.7μ	2.0μ	2.3μ	2.5μ	2.7μ	2.9μ	3.1μ
S 204, Borate crown	1.00	.99	.94	.90	.85	.81	.69	.43	.29	.18	—
S 179, Medium phosphate crown	—	.98	.95	.90	.84	.67	.49	.87	.18	—	—
O 1143, Dense borosilicate crown	.98	—	.97	—	.95	.93	.90	.84	.71	.47	.27
O 1092, Crown	.99	.96	.95	.99	.99	.91	.82	.71	.60	.48	.29
O 1151, "	.98	—	.99	.99	.98	.94	.90	.79	.75	.45	.32
O 451, Light flint	1.00	—	.99	—	.98	.95	.92	.84	.78	.54	.34
O 469, Heavy "	1.00	—	.98	—	.99	.98	.98	.97	.90	.66	.50
O 500, " "	1.00	—	1.00	—	1.00	—	1.00	.99	.92	.74	.53
S 163, " "	1.00	—	.98	—	.99	—	.99	--	.94	.78	.60

Part 2

R is reflection factor yellow light for two surfaces. Values of transmission are for 1 mm thickness. Ordinary figures refer to wavelengths in μ, .281 to .775, black-faced infrared.

Glass durability	Density R	.281 **.850**	.302 **.950**	.334 **1.15**	.366 **1.30**	.436 **1.60**	.480 **2.00**	.546 **2.20**	.578 **2.40**	.644 **2.60**	.700 **2.80**	.775 **3.00**
U G 1	2.77	.00	.17	.69	.85	.00	.00	.00	.00	.00	.01	.34
⅔	**.911**	**.22**	**.11**	**.05**	**.04**	**.03**	**.04**	**.06**	**.11**	**.15**	**.19**	**.17**
B G 1	2.50	.04	.40	.93	.97	.86	.44	.04	.05	.01	.51	.94
3	**.915**	**.97**	**.93**	**.76**	**.58**	**.40**	**.50**	**.59**	**.69**	**.74**	**.75**	**.55**
B G 4	2.41	.00	.00	.04	.74	.87	.53	.01	.01	.00	.07	.13
5	**.921**	**.12**	**.11**	**.13**	**.12**	**.14**	**.21**	**.45**	**.59**	**.63**	**.45**	**.40**
B G 10	2.60	.00	.00	.14	.64	.93	.95	.94	.88	.75	.62	.42
½	**.916**	**.31**	**.25**	**.26**	**.31**	**.47**	**.55**	**.56**	**.58**	**.55**	**.47**	**.46**
V G 1	2.93	.00	.00	.00	.00	.02	.47	.77	.56	.12	.06	.04
2	**.905**	**.05**	**.09**	**.18**	**.27**	**.47**	**.65**	**.71**	**.76**	**.77**	**.69**	**.55**
G G 2	2.58	.00	.00	.00	.64	.99	1.00	1.00	1.00	1.00	1.00	1.00
3	**.916**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**.99**	**.99**	**.98**	**.94**	**.84**	**.70**
G G 4	2.73	.00	.00	.03	.01	.67	.92	.97	.96	.94	.96	.99
2	**.913**	**.99**	**.99**	**.99**	**.99**	**.99**	**.99**	**.99**	**.98**	**.94**	**.85**	**.64**
G G 11	2.54	.00	.00	.00	.00	.01	.24	.99	.99	.99	.99	.98
2	**.913**	**.97**	**.96**	**.96**	**.99**	**.96**	**.97**	**.97**	**.95**	**.91**	**.82**	**.66**
R G 2	2.74	.00	.00	.00	.00	.00	.00	.00	.00	.92	.98	.98
2	**.913**	**.98**	**.98**	**.98**	**.98**	**.98**	**.98**	**.97**	**.95**	**.92**	**.81**	**.65**
R G 5	2.74	.00	.00	.00	.00	.00	.00	.00	.00	.02	.96	.98
2	**.913**	**.98**	**.98**	**.99**	**.99**	**.99**	**.99**	**.98**	**.97**	**.92**	**.79**	**.58**
N G 5	2.42	.00	.00	.00	.29	.59	.63	.66	.68	.70	.70	.65
1	**.919**	**.61**	**.59**	**.61**	**.65**	**.73**	**.78**	**.78**	**.76**	**.69**	**.58**	**.40**

U G 1 dark purple (uv., extreme red). B G 1 blue (uv.. extreme red). B G 4 blue (ir.). B G 10, light blue green, ir. absorption. V G 1 yellow-green. G G 2 colorless, uv. absorption. G G 4 almost colorless, strong uv. absorption. G G 11 dark yellow for contract filters. R G 2 pure red. R G 5 dark red. N G 5 light neutral.

OPTICAL CRYSTALS

Not so many years ago physicists had to depend upon natural crystals for their various optical instruments. Now, owing to a great deal of work in this field, it has been found possible to grow artificial crystals of various materials for this purpose. Data on some of these artificial crystals are given in the following tables and the spectral transmission of some of them is shown in figure 26.

TABLE 531.—SOME ARTIFICIAL OPTICAL CRYSTALS *

Part 1

Material	Type of crystal	Size grown: Diameter	Size grown: Length	Size grown: Weight	Transmission range	Uses	Reference [161]
Sodium chloride (NaCl)†	cubic	190 mm	125 mm	13 kg	.2 to 15μ, practical, 8.5 to 15μ	Ultraviolet, visible, and infrared spectroscopy, as lens elements for uv. and ir.	a, b
Potassium chloride (KCl)‡	cubic	190	125	16	.38 to 21μ	About the same as NaCl	c, d
Silver chloride (AgCl) (optical)§	cubic	95	125	4.5	Infrared to 30μ	Windows and prisms for uv. and ir. spectroscopy	e
Calcium fluoride (CaF_2)‖	cubic	125	100	5.0	.125 to 9.0μ	Windows and prisms uv., v., and ir. Lens parts	c, f
Potassium bromide (KBr)¶	cubic	190	125	16	Practical, 15 to 25μ	Prisms and lenses for far infrared	b, c, e
Potassium iodide (KI)¶	cubic	190	125	16	Long wavelength infrared, trans. 2 cm thickness, 50% at 32.8μ	Prisms and windows for far infrared	d, h
Lithium fluoride (LiF)¶	cubic	150	120	6	Practical, 1 to 5.0μ	Windows and prisms for uv. and ir., and as lens components	b, g
Thallium bromide-iodide (KRS-5)¶	cubic	125	87.5	6.8	20 to 37μ	Prisms and windows, ir., lens parts	e, i
Barium fluoride (BaF_2)	cubic	125	100	6.0	up to 12μ	Infrared windows, prisms	j
Cesium bromide (CsBr)	cubic	190	125	35	to 42μ	Windows, prisms	j
Potassium iodide (KI) (thallium activated)	cubic	190	126	16		Scintillation counters	j
Sodium iodide (Na I) (thallium activated)	cubic	190	125	16		Scintillation counters	j

* These crystals were grown by the Harshaw Chemical Company, Cleveland, Ohio, and the data were furnished by H. C. Kremers of that company. For index of refraction see: † Table 534. ‡ Table 536. § Table 538. ‖ Table 539. ¶ Part 2 of this table. ** KRS-5 consists of about 42 percent TlBr and 58 percent TlI.

[161] References: a, Gore, R. C., et al., Journ. Opt. Soc. Amer., vol. 37, p. 23, 1947. b, Kremers, H. C., Journ. Ind. Eng. Chem., vol. 32, p. 1478, 1940, and Journ. Opt. Soc. Amer., vol. 3, p. 337, 1947. c, Harrison, G. R., Lord, R. C., and Loofbourow, J. R., Practical spectroscopy, Prentice-Hall, Inc., New York, 1948. d, Sawyer, K. A., Experimental spectroscopy, Prentice-Hall, Inc., New York, 1944. e, Plyler, E. K., Nat. Bur. Standards Journ. Res., vol. 41, p. 125, 1948. f, Stockbarger, D. C., and Early, M., Artificial fluorite, Office of Scientific Research and Development Rep. No. 4690, 1944, and Journ. Opt. Soc. Amer., vol. 39, p. 731, 1949. g, Wright, N., Rev. Sci. Instr., vol. 15, p. 140, 1944. h, Strong, J., Phys. Rev., vol. 38, p. 1818, 1931. i, Tilton, L. W., Plyler, E. K., and Stephens, R. E., Nat. Bur. Standards Journ. Res., vol. 45, p. 81, 1949. j, Kremers, H. C., private communication.

(continued)

TABLE 531.—SOME ARTIFICIAL OPTICAL CRYSTALS (concluded)

Part 2

Material	Index of refraction λ	1st sample	2d sample	Reference
KBr	.486μ	1.57181	1.57194	c, b, e
	.589	1.55986	1.55997	
	.656	1.55503	1.55524	
	to infrared	(1–10μ)	1.54 to 1.53	
KI	n_F	n_D	n_D	d, h
	1.68755	1.6670	1.6588	
	to infrared	(1–20μ) 1.64,	1.62	
		n		
LiF	.4861	1.394810 ± 2 × 10^{-6}		b, g
	.5893	1.392057		
	.6563	1.390862		
Thallium bromide-iodide (KRS–5)**	Na_3, 2.629; 1μ, 2.45; 4μ, 2.4; 10μ, 2.39; 35μ, 2.30			i, e

TABLE 532.—n_D, DISPERSION AND DENSITY OF JENA GLASSES

No. and type of Jena glass	n_D for D	$n_F - n_C$	$\nu = \frac{n_D - 1}{n_F - n_C}$	$n_D - n_A$	$n_F - n_D$	$n_G' - n_F$	Specific gravity
O 225 Light phosphate crown	1.5159	.00737	70.0	.00485	.00515	.00407	2.58
O 802 Borosilicate crown	1.4967	0765	64.9	0504	0534	0423	2.38
UV 3109 Ultraviolet crown	1.5035	0781	64.4	0514	0546	0432	2.41
O 227 Barium-silicate crown	1.5399	0909	59.4	0582	0639	0514	2.73
O 114 Soft silicate crown	1.5151	0910	56.6	0577	0642	0521	2.55
O 608 High-dispersion crown	1.5149	0943	54.6	0595	0666	0543	2.60
UV 3248 Ultraviolet flint	1.5332	0964	55.4	0611	0680	0553	2.75
O 381 High-dispersion crown	1.5262	1026	51.3	0644	0727	0596	2.70
O 602 Baryt light flint	1.5676	1072	53.0	0675	0759	0618	3.12
S 389 Borate flint	1.5686	1102	51.6	0712	0775	0629	2.83
O 726 Extra light flint	1.5398	1142	47.3	0711	0810	0669	2.87
O 154 Ordinary light flint	1.5710	1327	43.0	0819	0943	0791	3.16
O 184 " " "	1.5900	1438	41.1	0882	1022	0861	3.28
O 748 Baryt flint	1.6235	1599	39.1	0965	1142	0965	3.67
O 102 Heavy flint	1.6489	1919	33.8	1152	1372	1180	3.87
O 41 " "	1.7174	2434	29.5	1439	1749	1521	4.49
O 165 " "	1.7541	2743	27.5	1607	1974	1730	4.78
S 386 Heavy flint	1.9170	4289	21.4	2451	3109	2808	6.01
S 57 Heaviest flint	1.9626	4882	19.7	2767	3547	3252	6.33

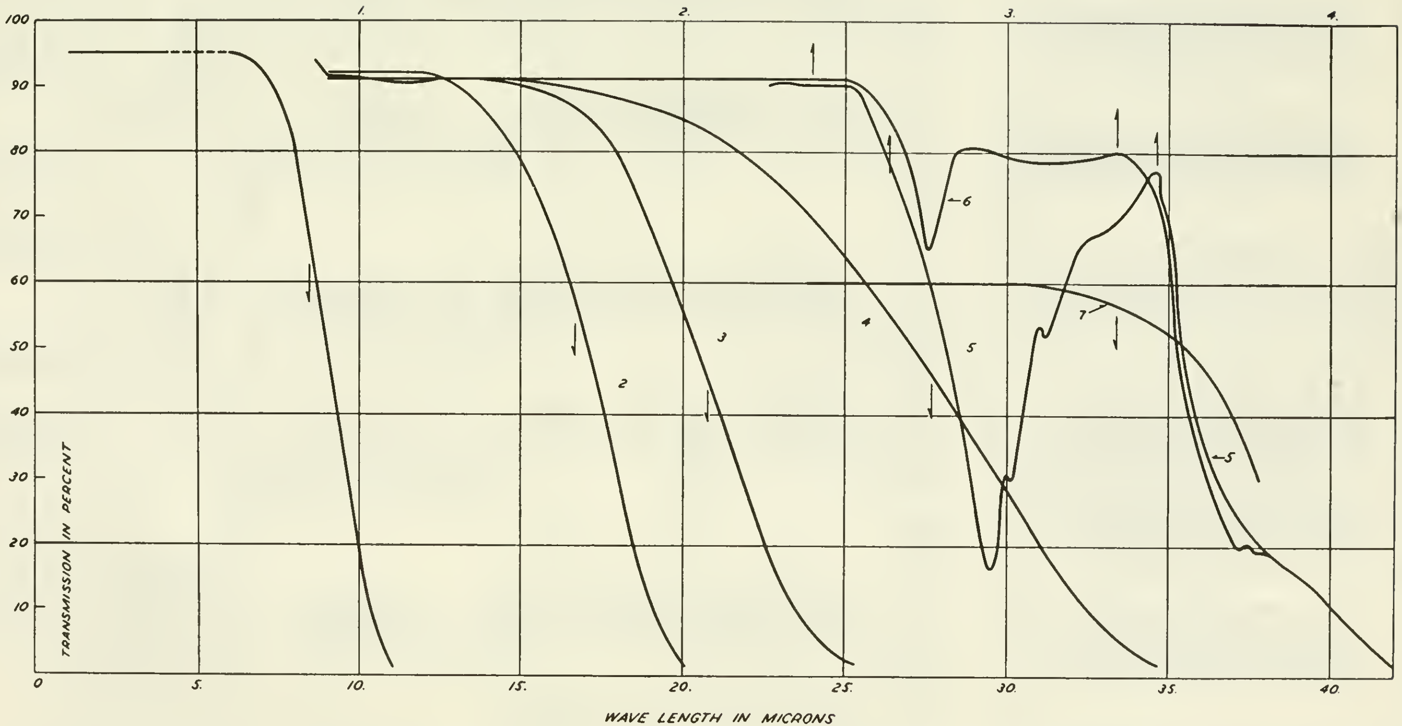

FIG. 26.—Spectral transmission of a number of infrared materials. Curves: 1, Fluorite, CaF_2, 1 cm thick. 2, Rocksalt, NaCl, 1 cm. 3, Silvite, KCl, 1 cm. 4, KBr, 1 cm. 5, Crystal quartz, SiO_2, 1 cm. 6, Fused SiO_2, 1 cm. 7, Thallium bromide, KRS–5, 4 mm thick. Taken from Baird Associates, Engineering Research Development Laboratories, Rep. W–44–009 Eng. 473, 1949.

TABLE 533.—INDEX OF REFRACTION OF QUARTZ (SiO_2), 15°C [161a]

Wavelength in air at 15° mμ	n_o Quartz	n_e Quartz	n Vitreous	Wavelength in air at 15° mμ	n_o Quartz	n_e Quartz	n Vitreous
185.467	1.67578	1.68997	1.57436	533.85	1.546799	1.555996	1.46067
193.583	1.65999	1.67343	1.55999	579.066	1.544667	1.553791	....
202.55	1.64557	1.65842	1.54727	589.29	1.544246	1.553355	1.45845
214.439	1.63039	1.64262	1.53386	643.847	1.542288	1.551332	1.45674
226.503	1.61818	1.62992	1.52308	667.815	1.541553	1.550573	....
250.329	1.60032	1.61139	1.50745	706.520	1.540488	1.549472	1.45517
274.867	1.58752	1.59813	1.49617	794.763	1.538478	1.547392	1.45340
303.412	1.576955	1.58720	1.48594	1000.00	1.53503	1.54381	....
340.365	1.56747	1.577385	1.47867	1200.00	1.53232	1.54098	....
396.848	1.55813	1.56772	1.47061	1400.00	1.52972	1.53826	....
434.047	1.553963	1.563405	1.46690	1600.00	1.52703	1.53545	....
467.815	1.551027	1.560368	1.46435	2058.20	1.51998	1.52814	....
508.582	1.548229	1.557475	1.46191	2500.00	1.51156	1.5195	....
				3000.00	1.49962	1.5070	....

[161a] Sosman, Robt. B., The properties of silica, p. 591, Chemical Catalog Co., NewYork, 1927.

TABLE 534.—INDEX OF REFRACTION OF ROCK SALT IN AIR

λ(μ)	n	λ(μ)	n	λ(μ)	n
.185409	1.89348	.88396	1.534011	5.8932	1.516014
.204470	1.76964	.972298	1.532532	"	1.515553
.291368	1.61325	.98220	1.532435	6.4825	1.513628
.358702	1.57932	1.036758	1.531762	"	1.513467
.441587	1.55962	1.1786	1.530372	7.0718	1.511062
.486149	1.55338	"	1.530374	7.6611	1.508318
"	1.553406	1.555137	1.528211	7.9558	1.506804
"	1.553399	1.7680	1.527440	8.8398	1.502035
.58902	1.544340	"	1.527441	10.0184	1.494722
.58932	1.544313	2.073516	1.526554	11.7864	1.481816
.656304	1.540672	2.35728	1.525863	12.9650	1.471720
"	1.540702	"	1.525849	14.1436	1.460547
.706548	1.538633	2.9466	1.524534	14.7330	1.454404
.766529	1.536712	3.5359	1.523173	15.3223	1.447494
.76824	1.53666	4.1252	1.521648	15.9116	1.441032
.78576	1.536138	"	1.521625	20.57	1.3735
.88396	1.534011	5.0092	1.518978	22.3	1.340

Talbot's bands (18°C) [162]

λ(μ)	n	λ(μ)	n	λ(μ)	n
18.1	1.413	21.3	1.352	25.8	1.229
18.7	1.403	22.8	1.318	26.6	1.203
19.4	1.394	23.6	1.299	27.3	1.175
20.0	1.381	24.2	1.278		
20.7	1.368	25.0	1.254		

$$n^2 = a^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} + \frac{M_2}{\lambda^2 - \lambda_2^2} - k\lambda^2 - h\lambda^4 \text{ or } = b^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} + \frac{M_2}{\lambda^2 - \lambda_2^2} - \frac{M_3}{\lambda_3^2 - \lambda^2}$$

where $a^2 = 2.330165$, $M_1 = .01278685$, $\lambda_1^2 = .0148500$, $M_2 = .005343924$,
$\lambda_2^2 = .02547414$, $k = .0009285837$, $h = .000000286086$,
$b^2 = 5.680137$, $M_3 = 12059.95$, $\lambda_3^2 = 3600.$

[162] Baird Associates, Infrared optical materials, Engineer Research and Development Laboratories, Fort Belvoir, Va.

TABLE 535.—INDEX OF REFRACTION OF SYLVITE (POTASSIUM CHLORIDE) IN AIR

$\lambda(\mu)$	n	$\lambda(\mu)$	n	$\lambda(\mu)$	n
.185409	1.82710	1.1786	1.478311	8.2505	1.462726
.200090	1.71870	"	1.47824	"	1.46276
.21946	1.64745	1.7680	1.475890	8.8398	1.460858
.257317	1.58125	"	1.47589	"	1.46092
.281640	1.55836	2.35728	1.474751	10.0184	1.45672
.308227	1.54136	2.9466	1.473834	"	1.45673
.358702	1.52115	"	1.47394	11.786	1.44919
.394415	1.51219	3.5359	1.473049	"	1.44941
.467832	1.50044	"	1.47304	12.965	1.44346
.508606	1.49620	4.7146	1.471122	"	1.44385
.58933	1.49044	"	1.47129	14.144	1.43722
.67082	1.48669	5.3039	1.470013	15.912	1.42617
.78576	1.483282	"	1.47001	17.680	1.41403
.88398	1.481422	5.8932	1.468804	20.60	1.3882
.98220	1.480084	"	1.46880	22.5	1.369

At 18°C [162]

$\lambda(\mu)$	n	$\lambda(\mu)$	n	$\lambda(\mu)$	n
18.2	1.409	22.2	1.374	26.7	1.300
18.8	1.401	23.1	1.363	27.2	1.275
19.7	1.398	24.1	1.352	28.2	1.254
20.4	1.389	24.9	1.336	28.8	1.226
21.1	1.379	25.7	1.317		

$$n^2 = a^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} + \frac{M_2}{\lambda^2 - \lambda_2^2} - k\lambda^2 - h\lambda^4 \text{ or } = b^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} + \frac{M_2}{\lambda^2 - \lambda_2^2} + \frac{M_3}{\lambda_3^2 - \lambda^2}$$

$a^2 = 2.174967$ $\lambda_2^2 = .0255550$ $b^2 = 3.866619$

$M_1 = .008344206$ $k = .000513495$ $M_3 = 5569.715$

$\lambda_1^2 = .0119082$ $h = .000000167587$ $\lambda_3^2 = 3292.47$

$M_2 = .00698382$

TABLE 536.—INDEX OF REFRACTION OF POTASSIUM BROMIDE * (22°C)

Wavelength	Index	Wavelength	Index	Wavelength	Index
.4047	1.589752	1.7011	1.53901	14.29	1.51505
.4358	1.581479	2.440	1.53733	14.98	1.51280
.4861	1.571789	2.730	1.53693	17.40	1.50390
.5086	1.568475	3.419	1.53614	18.16	1.50076
.5461	1.563928	4.258	1.53523	19.01	1.49705
.5876	1.559965	6.238	1.53288	19.91	1.49288
.6438	1.555858	6.692	1.53225	21.18	1.48655
.7065	1.552447	8.662	1.52903	21.83	1.48311
1.2140	1.54408	9.724	1.52695	23.86	1.47140
1.1287	1.54258	11.035	1.52404	25.14	1.46324
1.3621	1.54061	11.862	1.52200		

* Prepared by Stephens, Plyler, Rodney, and Spindler, National Bureau of Standards, March 1952.

TABLE 537.—INDEX OF REFRACTION OF NITROSO-DIMETHYL-ANILINE (WOOD)

λ	n	λ	n	λ	n	λ	n	λ	n
.497	2.140	.525	1.945	.584	1.815	.636	1.647	.713	1.718
.500	2.114	.536	1.909	.602	1.796	.647	1.758	.730	1.713
.506	2.074	.546	1.879	.611	1.783	.659	1.750	.749	1.709
.508	2.025	.557	1.857	.620	1.778	.669	1.743	.763	1.697
.516	1.985	.569	1.834	.627	1.769	.696	1.723		

Nitroso-dimethyl-aniline has enormous dispersion in yellow and green, metallic absorption in violet.

TABLE 538.—REFRACTIVE INDEX OF SILVER CHLORIDE (AgCl) AT 23.9°C *

Tenths of microns

Wave-length μ	0	1	2	3	4	5	6	7	8	9
0..	....	....	....	....	....	2.09648	2.06385	2.04590	2.03485	2.02752
1..	2.02239	2.01865	2.01582	2.01363	2.01189	2.01047	2.00931	2.00833	2.00750	2.00678
2..	2.00615	2.00559	2.00510	2.00465	2.00424	2.00386	2.00351	2.00318	2.00287	2.00258
3..	2.00230	2.00203	2.00177	2.00151	2.00126	2.00102	2.00078	2.00054	2.00030	2.00007

Wave-length μ	n	Wave-length μ	n	Wave-length μ	n	Wave-length μ	n
1	2.02239	6	1.99483	11	1.97556	16	1.94358
1.5	2.01047	6.5	1.99339	11.5	1.97297	16.5	1.93958
2	2.00615	7	1.99185	12	1.97026	17	1.93542
2.5	2.00386	7.5	1.99021	12.5	1.96742	17.5	1.93109
3	2.00230	8	1.98847	13	1.96444	18	1.92660
3.5	2.00102	8.5	1.98661	13.5	1.96133	18.5	1.92194
4	1.99983	9	1.98464	14	1.95807	19	1.91710
4.5	1.99866	9.5	1.98255	14.5	1.95467	19.5	1.91208
5	1.99745	10	1.98034	15	1.95113	20	1.90688
5.5	1.99618	10.5	1.97801	15.5	1.94743	20.5	1.90149

* Prepared by Leroy W. Tilton, Earle K. Plyler, and Robert E. Stephens, National Bureau of Standards.

TABLE 539.—INDEX OF REFRACTION OF FLUORITE (CaF_2) IN AIR

Part 1

λ(μ)	n	λ(μ)	n	λ(μ)	n	λ(μ)	n
.1856	1.50940	.76040	1.43101	2.2100	1.42288	5.0092	1.39898
.19881	1.49629	.8840	1.42982	2.3573	1.42199	5.3036	1.39529
.21441	1.48462	1.1786	1.42787	2.5537	1.42088	5.5985	1.39142
.22645	1.47762	1.3756	1.42690	2.6519	1.42016	5.8932	1.38719
.25713	1.46476	1.4733	1.42641	2.7502	1.41971	6.4825	1.37819
.32525	1.44987	1.5715	1.42596	2.9466	1.41826	7.0718	1.36805
.34555	1.44697	1.6206	1.42582	3.1430	1.41707	7.6612	1.35680
.39681	1.44214	1.7680	1.42507	3.2413	1.41612	8.2505	1.34444
.48607	1.43713	1.9153	1.42437	3.5359	1.41379	8.8398	1.33079
.58930	1.43393	1.9644	1.42413	3.8306	1.41120	9.4291	1.31612
.65618	1.43257	2.0626	1.42359	4.1252	1.40855	51.2	3.47
.68671	1.43200	2.1608	1.42308	4.4199	1.40559	61.1	2.66
.71836	1.43157			4.7146	1.40238	∞	2.63

Part 2 [163]

λ(μ)	n	λ(μ)	n	λ(μ)	n	λ(μ)	n
.404658	1.4415099	.508585	1.4361735	.770688	1.4308799	1.734047	1.4252000
.407785	1.4412890	.546077	1.4359584	.819115	1.4303704	1.767893	1.4250359
.435836	1.4394944	.579016	1.4341020	.961049	1.4291954	2.034339	1.4237262
.447150	1.4388656	.589298	1.4338304	1.092154	1.4283523	2.184308	1.4229318
.472219	1.4376377	.636238	1.4328439	1.156031	1.4279924	2.312063	1.4222226
.480525	1.4372742	.643850	1.4327050	1.178596	1.4278658	2.357191	1.4219705
.486138	1.4370381	.656286	1.4324825	1.441574	1.4265842	2.544951	1.4208398
.501570	1.4364325	.706523	1.4316947	1.638231	1.4256500	2.575402	1.4206797

$$n^2 = a^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} - e\lambda^2 - f\lambda^4 \text{ or } = b^2 + \frac{M_2}{\lambda^2 - \lambda_v^2} + \frac{M_3}{\lambda^2 - \lambda_r^2}$$

where $a^2 = 2.03882$, $M_1 = .0062183$, $\lambda_1^2 = .007706$, $e = .0031999$, $f = .000002916$, $b^2 = 6.09651$, $M_2 = .0061386$, $\lambda_v^2 = .00884$, $M_3 = 5114.65$, $\lambda_r^2 = 1260.56$, $\lambda_v = .0940\mu$, $\lambda_r = 35.5\mu$

Change of index of refraction of fluorite for 1°C in units of the 5th decimal place

C line, —1.220; D, —1.206; F, —1.170; G, —1.142.

[163] Schonrock, Zeitschr. Instrumentenkunde, vol. 40, p. 94, 1920; vol. 41, p. 104, 1921.

TABLE 540.—REFRACTIVE INDICES OF LITHIUM FLUORIDE AT 23.6°C *

Wave-length μ	Tenths of microns 0	1	2	3	4	5	6	7	8	9
0..	....	....	....	.....	....	1.39430	1.39181	1.39017	1.38896	1.38797
1..	1.38711	1.38631	1.38554	1.38477	1.38400	1.38320	1.38238	1.38153	1.38064	1.37971
2..	1.37875	1.37774	1.37669	1.37560	1.37446	1.37327	1.37203	1.37075	1.36942	1.36804
3..	1.36660	1.36512	1.36359	1.36201	1.36037	1.35868	1.35693	1.35514	1.35329	1.35138
4..	1.34942	1.34740	1.34533	1.34319	1.34100	1.33875	1.33645	1.33408	1.33165	1.32916
5..	1.32661	1.32399	1.32131	1.31856	1.31575	1.31287	1.30993	1.30692	1.30384	1.30068
6..	1.29745									

* Prepared by Leroy W. Tilton and Earle K. Plyler, National Bureau of Standards.

TABLE 541.—INDEX OF REFRACTION OF ICELAND SPAR ($CaCO_3$) IN AIR

λ (μ)	n_o	n_e	λ (μ)	n_o	n_e	λ (μ)	n_o	n_e
.198	—	1.5780	.508	1.6653	1.4896	.991	1.6438	1.4802
.200	1.9028	1.5765	.533	1.6628	1.4884	1.229	1.6393	1.4787
.208	1.8673	1.5664	.589	1.6584	1.4864	1.307	1.6379	1.4783
.226	1.8130	1.5492	.643	1.6550	1.4849	1.497	1.6346	1.4774
.298	1.7230	1.5151	.656	1.6544	1.4846	1.682	1.6313	—
.340	1.7008	1.5056	.670	1.6537	1.4843	1.749	—	1.4764
.361	1.6932	1.5022	.760	1.6500	1.4826	1.849	1.6280	—
.410	1.6802	1.4964	.768	1.6497	1.4826	1.908	—	1.4757
.434	1.6755	1.4943	.801	1.6487	1.4822	2.172	1.6210	—
.486	1.6678	1.4907	.905	1.6458	1.4810	2.324	—	1.4739

TABLE 542.—INDEX OF REFRACTION FOR VARIOUS ALUMS

R	Density	Temp C°	Index of refraction for the Fraunhofer lines a	B	c	D	E	b	F	G
			Aluminum alums $RAl(SO_4)_2 + 12H_2O$ *							
Na	1.667	17–28	1.43492	1.43563	1.43653	1.43884	1.44185	1.44231	1.44412	1.44804
$NH_3(CH_3)$	1.568	7–17	.45013	.45062	.45177	.45410	.45691	.45749	.45941	.46363
K	1.735	14–15	.45226	.45303	.45398	.45645	.45934	.45996	.46181	.46609
Rb	1.852	7–21	.45232	.45328	.45417	.45660	.45955	.45999	.46192	.46618
Cs	1.961	15–25	.45437	.45517	.45618	.45856	.46141	.46203	.46386	.46821
NH_4	1.631	15–20	.45509	.45599	.45693	.45939	.46234	.46288	.46481	.46923
Tl	2.329	10–23	.49226	.49317	.49443	.49748	.50128	.50209	.50463	.51076
			Chrome alums $RCr(SO_4)_2 + 12H_2O$ *							
Cs	2.043	6–12	1.47627	1.47732	1.47836	1.48100	1.48434	1.48491	1.48723	1.49280
K	1.817	6–17	.47642	.47738	.47865	.48137	.48459	.48513	.48753	.49309
Rb	1.946	12–17	.47660	.47756	.47868	.48151	.48486	.48522	.48775	.49323
NH_4	1.719	7–18	.47911	.48014	.48125	.48418	.48744	.48794	.49040	.49594
Tl	2.386	9–25	.51692	.51798	.51923	.52280	.52704	.52787	.53082	.53808
			Iron alums $RFe(SO_4)_2 + 12H_2O$ *							
K	1.806	7–11	1.47639	1.47706	1.47837	1.48169	1.48580	1.48670	1.48939	1.49605
Rb	1.916	7–20	.47700	.47770	.47894	.48234	.48654	.48712	.49003	.49700
Cs	2.061	20–24	.47825	.47921	.48042	.48378	.48797	.48867	.49136	.49838
NH_4	1.713	7–20	.47927	.48029	.48150	.48482	.48921	.48993	.49286	.49980
Tl	2.385	15–17	.51674	.51790	.51943	.52365	.52859	.52946	.53284	.54112

* *R* stands for the different bases given in the first column.
For other alums see references on Landolt-Börnstein-Roth Tabellen.

TABLE 543.—INDEX OF REFRACTION OF SELECTED MONOREFRINGENT OR ISOTROPIC MINERALS

The values are for the sodium *D* line unless otherwise stated and are arranged in the order of increasing indices. Selected by Edgar T. Wherry from a private compilation of E. S. Larsen, of the U. S. Geological Survey.

Mineral	Formula	Index of refraction $\lambda = 0.589\mu$
Villiaumite	NaF	1.328
Cryolithionite	$3NaF \cdot 3LiF \cdot 2AlF_3$	1.339
Opal	$SiO_2 \cdot nH_2O$	1.406
Fluorite	CaF_2	1.434
Alum	$K_2O \cdot Al_2O_3 \cdot 4SO_3 \cdot 24H_2O$	1.456
Sodalite	$3Na_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2NaCl$	1.483
Cristobalite	SiO_2	1.486
Analcite	$Na_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 2H_2O$	1.487
Sylvite	KCl	1.490
Noselite	$5Na_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2SO_3$	1.495
Hauynite	Like preceding + CaO	1.496
Lazurite	$4Na_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot Na_2S_6$	1.500±
Leucite	$K_2O \cdot Al_2O_3 \cdot 4SiO_2$	1.509
Pollucite	$2Cs_2O \cdot 2Al_2O_3 \cdot 9SiO_2 \cdot H_2O$	1.525
Halite	$NaCl$	1.544
Bauxite	$Al_2O_3 \cdot nH_2O$	1.570±
Pharmacosiderite	$3Fe_2O_3 \cdot 2As_2O_5 \cdot 3K_2O \cdot 5H_2O$	1.676
Spinel	$MgO \cdot Al_2O_3$	1.720±
Berzeliite	$3(Ca, Mg, Mn)O \cdot As_2O_5$	1.727
Periclasite	MgO	1.736
Grossularite	$3CaO \cdot Al_2O_3 \cdot 3SiO_2$	1.736
Helvite	$3(Mn, Fe)O \cdot 3BeO \cdot 3SiO_2 \cdot MnS$	1.739
Pyrope	$3MgO \cdot Al_2O_3 \cdot 3SiO_2$	1.745
Arsenolite	As_2O_3	1.754
Hessonite	$3CaO \cdot (Al, Fe)_2O_3 \cdot 3SiO_2$	1.763
Pleonaste	$(Mg, Fe)O \cdot Al_2O_3$	1.770±
Almandite	$3FeO \cdot Al_2O_3 \cdot 3SiO_2$	1.778
Hercynite	$FeO \cdot Al_2O_3$	1.800±
Gahnite	$ZnO \cdot Al_2O_3$	1.805±
Spessartite	$3MnO \cdot Al_2O_3 \cdot 3SiO_2$	1.811
Lime	CaO	1.838
Uvarovite	$3CaO \cdot Cr_2O_3 \cdot 3SiO_2$	1.838
Andradite	$3CaO \cdot Fe_2O_3 \cdot 3SiO_2$	1 857
Microlite	$6CaO \cdot 3Ta_2O_5 \cdot NbOF_3$	1.925
Nantokite	$CuCl$	1.930
Pyrochlore	Contains CaO, Ce_2O_3, TiO_2, etc.	1.960
Schorlomite	$3CaO \cdot (Fe, Ti)_2O_3 \cdot 3(Si, Ti)O_2$	1.980—
Percylite	$PbO \cdot CuCl_2 \cdot H_2O$	2.050
Picotite	$(Mg, Fe)O \cdot (Al, Cr)_2O_3$	2.050±
Eulytite	$2Bi_2O_3 \cdot 3SiO_2$	2.050
Cerargyrite	$AgCl$	2.061
Mosesite	Contains Hg, NH_4, Cl, etc.	2.065
Chromite	$FeO \cdot Cr_2O_3$	2.070
Senarmontite	Sb_2O_3	2.087
Embolite	$Ag(Br, Cl)$	2.150±
Manganosite	MnO	2.160
Bunsenite	NiO	2.18 *
Lewisite	$5CaO \cdot 2TiO_2 \cdot 3Sb_2O_5$	2.200
Miersite	$CuI \cdot 4AgI$	2.200
Bromyrite	$AgBr$	2.253
Dysanalite	Contains CaO, FeO, TiO_2, etc.	2.330
Marshite	CuI	2.346
Franklinite	$(Zn, Fe, Mn)O \cdot (Fe, Mn)_2O_3$	2.360*
Sphalerite	$(Zn, Fe)S$	2.370
Perovskite	$CaO \cdot TiO_2$	2.380
Diamond	C	2.419

(*continued*)

TABLE 543.—INDEX OF REFRACTION OF SELECTED MONOREFRINGENT OR ISOTROPIC MINERALS (concluded)

Mineral	Formula	Index of refraction $\lambda = 0.589\mu$
Eglestonite	$HgO \cdot 2HgCl$	2.490*
Hauerite	MnS_2	2.690*
Alabandite	MnS	2.700*
Cuprite	Cu_2O	2.849

* Li line.

TABLE 544.—INDEX OF REFRACTION OF MISCELLANEOUS MONOREFRINGENT OR ISOTROPIC SOLIDS

Substance	Spectrum line	Index of refraction
Albite glass	D	1.4890
Amber	D	1.546
Ammonium chloride	D	1.6422
Anorthite glass	D	1.5755
Asphalt	D	1.635
"	.670μ	1.621
Bell metal	D	1.0052
Boric acid, melted	C	1.4623
" " "	D	1.4637
" " "	F	1.4694
Borax, melted	C	1.4624
" "	D	1.4630
" "	F	1.4702
Camphor	D	1.532
"	D	1.5462
Canada balsam	D	1.530
Ebonite	red	1.66
Fuchsin	A	2.03
"	B	2.19
"	C	2.33
"	G	1.97
"	H	1.32
Gelatin, Nelson no. 1	D	1.530
" various	D	1.516–1.534
Gum Arabic	red	1.480
" "	red	1.514
Obsidian	D	1.482–1.496
Phosphorus	D	2.1442
Pitch	red	1.531
Potassium bromide	D	1.5593
" chlorstannate	D	1.6574
" iodide	D	1.6666
Resins: Aloes	red	1.619
Canada balsam	red	1.528
Colophony	red	1.548
Copal	red	1.528
Mastic	red	1.535
Peru balsam	D	1.593
Selenium	A	2.61
"	B	2.68
"	C	2.73
"	D	2.93
Sodium chlorate	D	1.5150
Strontium nitrate	D	1.5667

TABLE 545.—INDEX OF REFRACTION OF MISCELLANEOUS UNIAXIAL CRYSTALS

Crystal	Spectrum line	Index of refraction	
		Ordinary ray	Extraordinary ray
Ammonium arseniate $NH_4H_2AsO_4$	D	1.5766	1.5217
Benzil $(C_7H_5CO)_2$	D	1.6588	1.6784
Corundum, Al_2O_3, sapphire, ruby	D	1.769	1.760
Ice at −8°C	D	1.308	1.313
" " " "	Li	1.297	1.304
Ivory	D	1.539	1.541
Potassium arseniate KH_2AsO_4	F	1.5762	1.5252
" " "	D	1.5674	1.5179
" " "	C	1.5632	1.5146
Sodium arseniate $Na_3AsO_4 \cdot 12H_2O$	D	1.457	1.466
" nitrate $NaNO_3$	D	1.586	1.336
" phosphate $Na_3PO_4 \cdot 12H_2O$	D	1.447	1.453
Nickel sulfate $NiSO_4 \cdot 6H_2O$	F	1.5173	1.4930
" " "	D	1.5109	1.4873
" " "	C	1.5078	1.4844
Strychnine sulfate	D	1.614	1.599

TABLE 546.—INDEX OF REFRACTION OF SELECTED UNIAXIAL MINERALS

The values are arranged in the order of increasing indices for the ordinary ray and are for the sodium *D* line unless otherwise indicated. Selected by Edgar T. Wherry from a private compilation of Esper S. Larsen, of the U. S. Geological Survey.

Uniaxial positive minerals

Mineral	Formula	Index of refraction: Ordinary ray	Index of refraction: Extraordinary ray
Ice	H_2O	1.309	1.313
Sellaite	MgF_2	1.378	1.390
Chrysocolla	$CuO \cdot SiO_2 \cdot 2H_2O$	1.460±	1.570±
Laubanite	$2CaO \cdot Al_2O_3 \cdot 5SiO_2 \cdot 6H_2O$	1.475	1.486
Chabazite	$(Ca, Na_2)O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 6H_2O$	1.480±	1.482±
Douglasite	$2KCl \cdot FeCl_2 \cdot 2H_2O$	1.488	1.500
Hydronephelite	$2Na_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 7H_2O$	1.490	1.502
Apophyllite	$K_2O \cdot 8CaO \cdot 16SiO_2 \cdot 16H_2O$	1.535±	1.537±
Quartz	SiO_2	1.544	1.553
Coquimbite	$Fe_2O_3 \cdot 3SO_3 \cdot 9H_2O$	1.550	1.556
Brucite	$MgO \cdot H_2O$	1.559	1.580
Alunite	$K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$	1.572	1.592
Penninite	$5(Mg, Fe)O \cdot Al_2O_3 \cdot 3SiO_2 \cdot 4H_2O$	1.576	1.579
Cacoxenite	$2Fe_2O_3 \cdot P_2O_5 \cdot 12H_2O$	1.582	1.645
Eudialite	$6Na_2O \cdot 6(Ca, Fe)O \cdot 20(Si, Zr)O_2 \cdot NaCl$	1.606	1.611
Dioptase	$CuO \cdot SiO_2 \cdot H_2O$	1.654	1.707
Phenacite	$2BeO \cdot SiO_2$	1.654	1.670
Parisite	$2CeOF \cdot CaO \cdot 3CO_2$	1.676±	1.757
Willemite	$2ZnO \cdot SiO_2$	1.691	1.719
Vesuvianite	$2(Ca, Mn, Fe)O \cdot (Al, Fe)(OH, F)O \cdot 2SiO_2$	1.716±	1.721
Xenotime	$Y_2O_3 \cdot P_2O_5$	1.721	1.816
Connellite	$20CuO \cdot SO_3 \cdot 2CuCl_2 \cdot 20H_2O$	1.724	1.746
Benitoite	$BaO \cdot TiO_2 \cdot 3SiO_2$	1.757	1.804
Ganomalite	$6PbO \cdot 4(Ca, Mn)O \cdot 6SiO_2 \cdot H_2O$	1.910	1.945
Scheelite	$CaO \cdot WO_3$	1.918	1.934
Zircon	$ZrO_2 \cdot SiO_2$	1.923±	1.968±
Powellite	$CaO \cdot MoO_3$	1.974	1.978
Calomel	$HgCl$	1.973	2.650
Cassiterite	SnO_2	1.997	2.093
Zincite	ZnO	2.013	2.029
Phosgenite	$PbO \cdot PbCl_2 \cdot CO_2$	2.114	2.140
Penfieldite	$PbO \cdot PbCl_2$	2.130	2.210
Iodyrite	AgI	2.210	2.220
Tapiolite	$FeO \cdot (Ta, Nb)_2O_5$	2.270	2.420 (Li line)
Wurtzite	ZnS	2.356	2.378
Derbylite	$6FeO \cdot Sb_2O_3 \cdot 5TiO_2$	2.450	2.510 (Li line)
Greenockite	CdS	2.506	2.529
Rutile	TiO_2	2.616	2.903
Moissanite	CSi	2.654	2.697
Cinnabar	HgS	2.854	3.201

Uniaxial negative minerals

Mineral	Formula	Index of refraction: Ordinary ray	Index of refraction: Extraordinary ray
Chiolite	$2NaF \cdot AlF_3$	1.349	1.342
Hanksite	$11Na_2O \cdot 9SO_3 \cdot 2CO_2 \cdot KCl$	1.481	1.461
Thaumasite	$3CaO \cdot CO_2 \cdot SiO_2 \cdot SO_3 \cdot 15H_2O$	1.507	1.468
Hydrotalcite	$6MgO \cdot Al_2O_3 \cdot CO_2 \cdot 15H_2O$	1.512	1.498
Cancrinite	$4Na_2O \cdot CaO \cdot 4Al_2O_3 \cdot 2CO_2 \cdot 9SiO_2 \cdot 3H_2O$	1.524	1.496
Milarite	$K_2O \cdot 4CaO \cdot 2Al_2O_3 \cdot 24SiO_2 \cdot H_2O$	1.532	1.529
Kaliophilite	$K_2O \cdot Al_2O_3 \cdot 2SiO_2$	1.537	1.533
Mellite	$Al_2O_3 \cdot C_{12}O_9 \cdot 18H_2O$	1.539	1.511
Marialite	"Ma" $= 3Na_2O \cdot 3Al_2O_3 \cdot 18SiO_2 \cdot 2NaCl$	1.539	1.537
Nephelite	$Na_2O \cdot Al_2O_3 \cdot 2SiO_2$	1.542	1.538
Wernerite	$Me_1Ma_1 \pm$	1.578	1.551
Beryl	$3BeO \cdot Al_2O_3 \cdot 6SiO_2$	1.581±	1.575±
Torbernite	$CuO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$	1.592	1.582
Meionite	"Me" $= 4CaO \cdot 3Al_2O_3 \cdot 6SiO_2$	1.597	1.560
Melilite	Contains Na_2O, CaO, Al_2O_3, SiO_2, etc.	1.634	1.629

(continued)

TABLE 546.—INDEX OF REFRACTION OF SELECTED UNIAXIAL MINERALS (concluded)

Uniaxial negative minerals (*continued*)

Mineral	Formula	Index of refraction: Ordinary ray	Index of refraction: Extraordinary ray
Apatite	$9CaO \cdot 3P_2O_5 \cdot Ca(F, Cl)_2$	1.634	1.631
Calcite	$CaO \cdot CO_2$	1.658	1.486
Gehlenite	$2CaO \cdot Al_2O_3 \cdot SiO_2$	1.669	1.658
Tourmaline	Contains Na_2O, FeO, Al_2O_3, B_2O_3, SiO_2, etc.	1.669±	1.638±
Dolomite	$CaO \cdot MgO \cdot 2CO_2$	1.681	1.500
Magnesite	$MgO \cdot CO_2$	1.700	1.509
Pyrochroite	$MnO \cdot H_2O$	1.723	1.681
Corundum	Al_2O_3	1.768	1.760
Smithsonite	$ZnO \cdot CO_2$	1.818	1.618
Rhodochrosite	$MnO \cdot CO_2$	1.818	1.595
Jarosite	$K_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$	1.820	1.715
Siderite	$FeO \cdot CO_2$	1.875	1.635
Pyromorphite	$9PbO \cdot 3P_2O_5 \cdot PbCl_2$	2.050	2.042
Barysilite	$3PbO \cdot 2SiO_2$	2.070	2.050
Mimetite	$9PbO \cdot 3As_2O_5 \cdot PbCl_2$	2.135	2.118
Matlockite	$PbO \cdot PbCl_2$	2.150	2.040
Stolzite	$PbO \cdot WO_3$	2.269	2.182
Geikielite	$(Mg, Fe)O \cdot TiO_2$	2.310	1.950
Vanadinite	$9PbO \cdot 3V_2O_5 \cdot PbCl_2$	2.354	2.299
Wulfenite	$PbO \cdot MoO_3$	2.402	2.304 (Li line)
Octahedrite	TiO_2	2.554	2.493
Massicotite	PbO	2.665	2.535 (Li line)
Proustite	$3Ag_2S \cdot As_2S_3$	2.979	2.711 " "
Pryargyrite	$3Ag_2S \cdot Sb_2S_3$	3.084	2.881 " "
Hematite	Fe_2O_3	3.220	2.940 " "

TABLE 547.—INDEX OF REFRACTION OF MISCELLANEOUS LIQUIDS (see also Table 551), LIQUEFIED GASES, OILS, FATS, AND WAXES

Substance	Temp °C	Index for D 0.589μ	Substance	Temp °C	Index for D 0.589μ
Liquefied gases:			Oils:		
Br_2	15	1.659	Lavender	20	1.464 –1.466
Cl_2	14	1.367	Linseed	15	1.4820–1.4852
CO_2	15	1.195	Maize	15.5	1.4757–1.4768
C_2N_2	18	1.325	Mustard seed	15.5	1.4750–1.4762
C_2H_4	6	1.180	Neat's foot	15	1.4695–1.4708
H_2S	18.5	1.384	Olive	15.5	1.4703–1.4718
N_2	−190	1.205	Palm	60	1.4510
NH_3	16.5	1.325	Peanut	15.5	1.4723–1.4731
NO	− 90	1.330	Peppermint	20	1.464 –1.468
N_2O	15	1.194	Poppy	15.5	1.4770
O_2	−181	1.221	Porpoise	25	1.4677
SO_2	15	1.350	Rape (Colza)	15.5	1.4748–1.4752
HCl	16.5	1.252	Seal	25	1.4741
HBr	10	1.325	Sesame	15.5	1.4742
HI	16.5	1.466	Soya bean	15.5	1.4760–1.4775
Oils:			Sperm	15.5	1.4665–1.4672
Almond	15.5	1.4728–1.4753	Sunflower	15.5	1.4739
Castor	15	1.4799–1.4803	Tung	19	1.503
Citronella	20	1.47 –1.48	Whale	40	1.4649
Clove	20	1.5301–1.5360	Fats and Waxes:		
Cocoanut	15.5	1.4587	Beef tallow	40	1.4552–1.4587
Cod liver	15	1.4790–1.4833	Beeswax	75	1.4398–1.4451
Cotton seed	15.5	1.4737–1.4757	Carnauba wax	84	1.4520–1.4541
Croton	27	1.4757–1.4768	Cocoa butter	40	1.4560–1.4518
Eucalyptus	20	1.460 –1.467	Lard	40	1.4584–1.4601
Lard	15.5	1.4702–1.4720	Mutton tallow	60	1.4510

TABLE 548.—INDEX OF REFRACTION OF SELECTED BIAXIAL MINERALS

The values are arranged in the order of increasing β index of refraction and are for the sodium D line except where noted. Selected by Edgar T. Wherry from private compilation of Esper S. Larsen, of the U. S. Geological Survey.

Biaxial positive minerals

Mineral	Formula	Index of refraction n_α	n_β	n_γ
Stercorite	$Na_2O \cdot (NH_4)_2O \cdot P_2O_5 \cdot 9H_2O$	1.439	1.441	1.469
Aluminite	$Al_2O_3 \cdot SO_3 \cdot 9H_2O$	1.459	1.464	1.470
Tridymite	SiO_2	1.469	1.470	1.473
Thenardite	$Na_2O \cdot SO_3$	1.464	1.474	1.485
Carnallite	$KCl \cdot MgCl_2 \cdot 6H_2O$	1.466	1.475	1.494
Alunogen	$Al_2O_3 \cdot 3SO_3 \cdot 16H_2O$	1.474	1.476	1.483
Melanterite	$FeO \cdot SO_3 \cdot 7H_2O$	1.471	1.478	1.486
Natrolite	$Na_2O \cdot Al_2O_3 \cdot 3SiO_2 \cdot 2H_2O$	1.480	1.482	1.493
Arcanite	$K_2O \cdot SO_3$	1.494	1.495	1.497
Struvite	$(NH_4)_2O \cdot 2MgO \cdot P_2O_5 \cdot 12H_2O$	1.495	1.496	1.500
Heulandite	$CaO \cdot Al_2O_3 \cdot 6SiO_2 \cdot 3H_2O$	1.498	1.499	1.505
Thomsonite	$(Na_2, Ca)O \cdot Al_2O_3 \cdot 2SiO_2 \cdot 3H_2O$	1.497	1.503	1.525
Harmotome	$(K_2, Ba)O \cdot Al_2O_3 \cdot 5SiO_2 \cdot 5H_2O$	1.503	1.505	1.508
Petalite	$Li_2O \cdot Al_2O_3 \cdot 8SiO_2$	1.504	1.510	1.516
Monetite	$2CaO \cdot P_2O_5 \cdot H_2O$	1.515	1.518	1.525
Newberyite	$2MgO \cdot P_2O_5 \cdot 7H_2O$	1.514	1.519	1.533
Gypsum	$CaO \cdot SO_2 \cdot 2H_2O$	1.520	1.523	1.530
Mascagnite	$(NH_4)_2O \cdot SO_3$	1.521	1.523	1.533
Albite	"Ab" $= Na_2O \cdot Al_2O_3 \cdot 6SiO_2$	1.525	1.529	1.536
Hydromagnesite	$4MgO \cdot 3CO_2 \cdot 4H_2O$	1.527	1.530	1.540
Wavellite	$3Al_2O_3 \cdot 2P_2O_5 \cdot 12(H_2O, 2HF)$	1.525	1.534	1.552
Kieserite	$MgO \cdot SO_3 \cdot H_2O$	1.523	1.535	1.586
Copiapite	$2Fe_2O_3 \cdot 5SO_3 \cdot 18H_2O$	1.530	1.550	1.592
Whewellite	$CaO \cdot C_2O_3 \cdot H_2O$	1.491	1.555	1.650
Variscite	$Al_2O_3 \cdot P_2O_5 \cdot 4H_2O$	1.551	1.558	1.582
Labradorite	Ab_2An_3	1.559	1.563	1.568
Gibbsite	$Al_2O_3 \cdot 3H_2O$	1.566	1.566	1.587
Wagnerite	$3MgO \cdot P_2O_5 \cdot MgF_2$	1.569	1.570	1.582
Anhydrite	$CaO \cdot SO_3$	1.571	1.576	1.614
Colemanite	$2CaO \cdot 3B_2O_3 \cdot 5H_2O$	1.586	1.592	1.614
Fremontite	$Na_2O \cdot Al_2O_3 \cdot P_2O_5 \cdot (H_2O, 2HF)$	1.594	1.603	1.615
Vivianite	$3FeO \cdot P_2O_5 \cdot 8H_2O$	1.579	1.603	1.633
Pectolite	$Na_2O \cdot 4CaO \cdot 6SiO_2 \cdot H_2O$	1.595	1.604	1.633
Calamine	$2ZnO \cdot SiO_2 \cdot H_2O$	1.614	1.617	1.636
Chondrodite	$4MgO \cdot SiO_2 \cdot Mg(F, OH)_2$	1.604	1.617	1.636
Turquoise	$CuO \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 9H_2O$	1.610	1.620	1.650
Topaz	$2AlOF \cdot SiO_2$	1.619	1.620	1.627
Celestite	$SrO \cdot SO_3$	1.622	1.624	1.631
Prehnite	$2CaO \cdot Al_2O_2 \cdot 3SiO_2 \cdot H_2O$	1.616	1.626	1.649
Barite	$BaO \cdot SO_3$	1.636	1.637	1.648
Anthophyllite	$MgO \cdot SiO_2$	1.633	1.642	1.657
Sillimanite	$Al_2O_3 \cdot SiO_2$	1.638	1.642	1.653
Forsterite	$2MgO \cdot SiO_2$	1.635	1.651	1.669
Enstatite	$MgO \cdot SiO_2$	1.650	1.653	1.658
Euclase	$2BeO \cdot Al_2O_3 \cdot 2SiO_2 \cdot H_2O$	1.653	1.656	1.673
Triplite	$3MnO \cdot P_2O_5 \cdot MnF_2$	1.650	1.660	1.672
Spodumene	$Li_2O \cdot Al_2O_3 \cdot 4SiO_2$	1.660	1.666	1.676
Diopside	$CaO \cdot MgO \cdot 2SiO_2$	1.664	1.671	1.694
Olivine	$2(Mg, Fe)O \cdot SiO_2$	1.662	1.680	1.699
Triphylite	$Li_2O \cdot 2(Fe, Mn)O \cdot P_2O_5$	1.688	1.688	1.692
Zoisite	$4CaO \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot H_2O$	1.700	1.702	1.706
Strengite	$Fe_2O_3 \cdot P_2O_5 \cdot 4H_2O$	1.708	1.708	1.745
Diaspore	$Al_2O_3 \cdot H_2O$	1.702	1.722	1.750
Staurolite	$2FeO \cdot 5Al_2O_3 \cdot 4SiO_2 \cdot H_2O$	1.736	1.741	1.746
Chrysoberyl	$BeO \cdot Al_2O_3$	1.747	1.748	1.757
Azurite	$3CuO \cdot 2CO_2 \cdot H_2O$	1.730	1.758	1.838
Scorodite	$Fe_2O_3 \cdot As_2O_5 \cdot 4H_2O$	1.765	1.774	1.797

(continued)

TABLE 548.—INDEX OF REFRACTION OF SELECTED BIAXIAL MINERALS (continued)

Biaxial positive minerals (*continued*)

Mineral	Formula	Index of refraction n_α	n_β	n_γ
Olivenite	$4CuO \cdot As_2O_5 \cdot H_2O$	1.772	1.810	1.863
Anglesite	$PbO \cdot SO_3$	1.877	1.882	1.894
Titanite	$CaO \cdot TiO_2 \cdot SiO_2$	1.900	1.907	2.034
Claudetite	As_2O_3	1.871	1.920	2.010
Sulfur	S	1.950	2.043	2.240
Cotunnite	$PbCl_2$	2.200	2.217	2.260
Huebnerite	$MnO \cdot WO_3$	2.170	2.220	2.320
Manganite	$Mn_2O_3 \cdot H_2O$	2.240	2.240	2.530 (Li)
Raspite	$PbO \cdot WO_3$	2.270	2.270	2.300
Mendipite	$2PbO \cdot PbCl_2$	2.240	2.270	2.310
Tantalite	$(Fe, Mn)O \cdot Ta_2O_5$	2.260	2.320	2.430 (Li)
Wolframite	$(Fe, Mn)O \cdot WO_3$	2.310	2.360	2.460 (Li)
Crocoite	$PbO \cdot CrO_3$	2.310	2.370	2.660 (Li)
Pseudobrookite	$2Fe_2O_3 \cdot 3TiO_2$	2.380	2.390	2.420 (Li)
Stibiotantalite	$Sb_2O_3 \cdot Ta_2O_5$	2.374	2.404	2.457
Montroydite	HgO	2.370	2.500	2.650 (Li)
Brookite	TiO_2	2.583	2.586	2.741
Massicot	PbO	2.510	2.610	2.710

Biaxial negative minerals

Mineral	Formula	n_α	n_β	n_γ
Mirabilite	$Na_2O \cdot SO_3 \cdot 10H_2O$	1.394	1.396	1.398
Thomsenolite	$NaF \cdot CaF_2 \cdot AlF_3 \cdot H_2O$	1.407	1.414	1.415
Natron	$Na_2O \cdot CO_2 \cdot 10H_2O$	1.405	1.425	1.440
Kalinite	$K_2O \cdot Al_2O_3 \cdot 4SO_3 \cdot 24H_2O$	1.430	1.452	1.458
Epsomite	$MgO \cdot SO_3 \cdot 7H_2O$	1.433	1.455	1.461
Sassolite	$B_2O_3 \cdot H_2O$	1.340	1.456	1.459
Borax	$Na_2O \cdot 2B_2O_3 \cdot 10H_2O$	1.447	1.470	1.472
Goslarite	$ZnO \cdot SO_3 \cdot 7H_2O$	1.457	1.480	1.484
Pickeringite	$MgO \cdot Al_2O_3 \cdot 4SO_3 \cdot 22H_2O$	1.476	1.480	1.483
Bloedite	$Na_2O \cdot MgO \cdot 2SO_3 \cdot 4H_2O$	1.483	1.487	1.486
Trona	$3Na_2O \cdot 4CO_2 \cdot 5H_2O$	1.410	1.492	1.542
Thermonatrite	$Na_2O \cdot CO_2 \cdot H_2O$	1.420	1.495	1.518
Stilbite	$(Ca, Na_2)O \cdot Al_2O_3 \cdot 6SiO_2 \cdot 5H_2O$	1.494	1.498	1.500
Niter	$K_2O \cdot N_2O_5$	1.334	1.505	1.506
Kainite	$MgO \cdot SO_3 \cdot KCl \cdot 3H_2O$	1.494	1.505	1.516
Gaylussite	$Na_2O \cdot CaO \cdot 2CO_2 \cdot 5H_2O$	1.444	1.516	1.523
Scolecite	$CaO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 3H_2O$	1.512	1.519	1.519
Laumontite	$CaO \cdot Al_2O_3 \cdot 4SiO_2 \cdot H_2O$	1.513	1.524	1.525
Orthoclase	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	1.518	1.524	1.526
Microcline	Same as preceding	1.522	1.526	1.530
Anorthoclase	$(Na, K)_2O \cdot Al_2O_3 \cdot 6SiO_2$	1.523	1.529	1.531
Glauberite	$Na_2O \cdot CaO \cdot 2SO_3$	1.515	1.532	1.536
Cordierite	$4(Mg, Fe)O \cdot 4Al_2O_3 \cdot 10SiO_2 \cdot H_2O$	1.534	1.538	1.540
Chalcanthite	$CuO \cdot SO_3 \cdot 5H_2O$	1.516	1.539	1.546
Oligoclase	Ab_4An	1.539	1.543	1.547
Beryllonite	$Na_2O \cdot 2BeO \cdot P_2O_5$	1.552	1.558	1.561
Kaolinite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	1.561	1.563	1.565
Biotite	$K_2O \cdot 4(Mg, Fe)O \cdot 2Al_2O_3 \cdot 6SiO_2 \cdot H_2O$	1.541	1.574	1.574
Autunite	$CaO \cdot 2UO_3 \cdot P_2O_5 \cdot 8H_2O$	1.553	1.575	1.577
Anorthite	"An" $= CaO \cdot Al_2O_3 \cdot 2SiO_2$	1.576	1.584	1.588
Lanthanite	$La_2O_3 \cdot 3CO_2 \cdot 9H_2O$	1.520	1.587	1.613
Pyrophyllite	$Al_2O_3 \cdot 4SiO_2 \cdot H_2O$	1.552	1.588	1.600
Talc	$3MgO \cdot 4SiO_2 \cdot H_2O$	1.539	1.589	1.589
Hopeite	$3ZnO \cdot P_2O_5 \cdot 4H_2O$	1.572	1.590	1.590
Muscovite	$K_2O \cdot Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	1.561	1.590	1.594
Amblygonite	$Al_2O_3 \cdot P_2O_5 \cdot 2LiF$	1.579	1.593	1.597
Lepidolite	$Al_2O_3 \cdot 3SiO_2 \cdot 2(K, Li)F$	1.560	1.598	1.605
Phlogopite	$K_2O \cdot 6MgO \cdot Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	1.562	1.606	1.606
Tremolite	$CaO \cdot 3MgO \cdot 4SiO_2$	1.600	1.616	1.627

(*continued*)

TABLE 548.—INDEX OF REFRACTION OF SELECTED BIAXIAL MINERALS (concluded)

Biaxial negative minerals (*continued*)

Mineral	Formula	Index of refraction n_α	n_β	n_γ
Actinolite	$CaO \cdot 3(Mg, Fe)O \cdot 4SiO_2$	1.614	1.630	1.641
Wollastonite	$CaO \cdot SiO_2$	1.620	1.632	1.634
Lazulite	$(Fe, Mg)O \cdot Al_2O_3 \cdot P_2O_5 \cdot H_2O$	1.612	1.634	1.643
Danburite	$CaO \cdot B_2O_3 \cdot 2SiO_2$	1.632	1.634	1.636
Glaucophane	$Na_2O \cdot 2FeO \cdot Al_2O_3 \cdot 6SiO_2$	1.621	1.638	1.638
Andalusite	$Al_2O_3 \cdot SiO_2$	1.632	1.638	1.643
Hornblende	Contains Na_2O, MgO, FeO, SiO_2, etc.	1.634	1.647	1.652
Datolite	$2CaO \cdot 2SiO_2 \cdot B_2O_3 \cdot H_2O$	1.625	1.653	1.669
Erythrite	$3CoO \cdot As_2O_5 \cdot 8H_2O$	1.626	1.661	1.699
Monticellite	$CaO \cdot MgO \cdot SiO_2$	1.651	1.662	1.668
Strontianite	$SrO \cdot CO_2$	1.520	1.667	1.667
Witherite	$BaO \cdot CO_2$	1.529	1.676	1.677
Aragonite	$CaO \cdot CO_2$	1.531	1.682	1.686
Axinite	$6(Ca, Mn)O \cdot 2Al_2O_3 \cdot B_2O_3 \cdot 8SiO_2 \cdot H_2O$	1.678	1.685	1.688
Dumortierite	$8Al_2O_3 \cdot B_2O_3 \cdot 6SiO_2 \cdot H_2O$	1.678	1.686	1.689
Cyanite	$Al_2O_3 \cdot SiO_2$	1.712	1.720	1.728
Epidote	$4CaO \cdot 3(Al, Fe)_2O_3 \cdot 6SiO_2 \cdot H_2O$	1.729	1.763	1.780
Atacamite	$3CuO \cdot CuCl_2 \cdot 3H_2O$	1.831	1.861	1.880
Fayalite	$2FeO \cdot SiO_2$	1.824	1.864	1.874
Caledonite	$2(Pb, Cu)O \cdot SO_3 \cdot H_2O$	1.818	1.866	1.909
Malachite	$2CuO \cdot CO_2 \cdot H_2O$	1.655	1.875	1.909
Lanarkite	$2PbO \cdot SO_3$	1.930	1.990	2.020
Leadhillite	$4PbO \cdot SO_3 \cdot 2CO_2 \cdot H_2O$	1.870	2.000	2.010
Cerusite	$PbO \cdot CO_2$	1.804	2.076	2.078
Laurionite	$PbCl_2 \cdot PbO \cdot H_2O$	2.077	2.116	2.158
Matlockite	$PbO \cdot PbCl_2$	2.040	2.150	2.150
Baddeleyite	ZrO_2	2.130	2.190	2.200
Lepidocrocite	$Fe_2O_3 \cdot H_2O$	1.930	2.210	2.510
Limonite	$2Fe_2O_3 \cdot 3H_2O$ in part	2.170	2.290	2.310
Goethite	$Fe_2O_3 \cdot H_2O$	2.210	2.350	2.350 (Li)
Valentinite	Sb_2O_3	2.180	2.350	2.350
Turgite	$2Fe_2O_3 \cdot H_2O$ in part	2.450	2.550	2.550 (Li)
Realgar	AsS	2.460	2.590	2.610 (Li)
Terlinguaite	Hg_2OCl	2.350	2.640	2.660 (Li)
Hutchinsonite	$(Tl, Ag)_2S \cdot PbS \cdot 2As_2S_3$	3.078	3.176	3.188
Stibnite	Sb_2S_3	3.194	4.303	4.460

TABLE 549.—INDEX OF REFRACTION OF MISCELLANEOUS BIAXIAL CRYSTALS

Crystal	Spectrum line	Index of refraction n_α	n_β	n_γ
Ammonium oxalate, $(NH_4)_2C_2O_4 \cdot H_2O$	D	1.4381	1.5475	1.5950
Ammonium acid tartrate, $(NH_4)H(C_4H_4O_6)$	D	1.5188	1.5614	1.5910
Ammonium tartrate, $(NH_4)_2C_4H_4O_6$	D	—	1.581	—
Antipyrin, $CuH_{12}NO_2$	D	1.5697	1.6935	1.7324
Citric acid, $C_6H_8O_7 \cdot H_2O$	D	1.4932	1.4977	1.5089
Codein, $C_{18}H_{21}NO_3 \cdot H_2O$	D	1.5390	1.5435	—
Magnesium carbonate, $MgCO_3 \cdot 3H_2O$	D	1.495	1.501	1.526
" sulfate, $MgSO_4 \cdot 7H_2O$	D	1.432	1.455	1.461
" "	Cd, .226μ	1.4990	1.5266	1.5326
" "	H, .656μ	1.4307	1.4532	1.4584
Potassium bichromate, $K_2Cr_2O_7$	D	1.7202	1.7380	1.8197
" chromate, K_2CrO_4	D	—	1.7254	—
" "	red	1.6873	1.722	1.7305
" nitrate, KNO_3	D	1.3346	1.5056	1.5064
" sulfate, K_2SO_4	F	1.4976	1.4992	1.5029
" "	D	1.4932	1.4946	1.4980
" "	C	1.4911	1.4928	1.4959
Racemic acid, $C_4H_6O_6 \cdot H_2O$	yellow	—	1.526	—
Resorcin, $C_6H_6O_2$	D	—	1.555	—
Sodium bichromate, $Na_2Cr_2O_7 \cdot 2H_2O$	D	1.6610	1.6994	1.7510
" acid tartrate, $NaH(C_4H_4O_6) \cdot 2H_2O$	red	—	1.5332	—
Sugar (cane), $C_{12}H_{22}O_{11}$	Tl	1.5422	1.5685	1.5734
" "	D	1.5397	1.5667	1.5716
" "	Li	1.5379	1.5639	1.5693
Tartaric acid, $C_4H_6O_6$ (right-)	D	1.4953	1.5353	1.6046
Zinc sulfate, $ZnSO_4 \cdot 7H_2O$	F	1.4620	1.4860	1.4897
" "	D	1.4568	1.4801	1.4836
" "	C	1.4544	1.4776	1.4812

TABLE 550.—SPECIFIC GRAVITY, COEFFICIENT OF EXPANSION, AND STAIN CLASS OF OPTICAL GLASS *

Glass type	Specific gravity *BL*	*CG*	Cofficient of expansion mean values × 10^7 −40° to 0° *BL*	0° to 40° *BL*	0° to 100° *BL*	0° to 300° *CG*	Stain class for *BL*
511635	2.48	...	73.0	77.0	79.6	..	1
517645	2.53	2.53	62.0	65.2	67.5	80	1
523586	2.53	...	75.8	80.2	83.0	..	1
529516	2.73	...	70.2	73.0	74.5	..	1
573574	3.21	...	74.2	78.0	80.0	..	3
580410	3.27	3.21	...	...	...	99	1
584460	3.31	...	76.2	80.0	81.9	..	1
605381	3.49	3.47	...	...	...	86	1
611572	3.57	3.56	57.8	61.2	64.1	70	5
611588	3.58	3.40	60.8	64.0	66.9	71	5
617366	3.64	3.58	70.8	73.0	74.2	89	1
617550	3.66	3.50	...	...	...	72	5
620362	3.67	3.61	...	...	...	87	1
649338	3.91	3.89	...	...	...	85	2
720293	4.51	...	73.5	75.2	77.3	..	3
Melt No.							
EK-110-5328		4.1	58.0	61.2	63.5	...	
EK-32-2641		4.5	57.8	61.2	63.9	...	
EK-33-2734s		4.7	53.5	57.0	59.4	...	
EK-45-29		4.6	57.0	60.5	63.4	...	

BL, Bausch & Lomb Optical glass. *EK*, Eastman Kodak glass. *CG*, Corning glass.
The first 15 glass types in column 1 are described in Table 524 of NBS glasses.

* Types of glass in class 1 or 2 are not likely to stain even when used as exposed surfaces in tropical climates. Glasses in class 5 are liable to stain when exposed to rain, moisture condensation, or fingerprints in any climate. Other glasses are intermediate in stain resistance.

TABLE 551.—INDEX OF REFRACTION OF SOME LIQUIDS RELATIVE TO AIR

Substance	Density	Temp °C	Indices of refraction 0.397μ H	0.434μ G′	0.486μ F	0.589μ D	0.656μ C
Acetaldehyde, CH_3CHO	.780	20	—	1.3394	1.3359	1.3316	1.3298
Acetone, CH_3COCH_3	.791	20	—	1.3678	1.3639	1.3593	1.3573
Aniline, $C_6H_5\cdot NH_2$	1.022	20	—	1.6204	1.6041	1.5863	1.5793
Alcohol, methyl, $CH_3\cdot OH$	.794	20	1.3399	1.3362	1.3331	1.3290	1.3277
" ethyl, $C_2H_6\cdot OH$	.808	0	—	1.3773	1.3739	1.3695	1.3677
" "	.800	20	—	1.3700	1.3666	1.3618	1.3605
" " *dn/dt*	—	20	—	—.0004	—.0004	—.0004	—.0004
" n-propyl $C_3H_7\cdot OH$	.804	20	—	1.3938	1.3901	1.3854	1.3834
Benzene, C_6H_6	.880	20	—	1.5236	1.5132	1.5012	1.4965
" C_6H_6 *dn/dt*	—	20	—	—.0007	—.0006	—.0006	—.0006
Bromnaphthalene, $C_{10}H_7Br$	1.487	20	1.7289	1.7041	1.6819	1.6582	1.6495
Carbon disulfide, CS_2	1.293	0	1.7175	1.6920	1.6688	1.6433	1.6336
" "	1.263	20	1.6994	1.6748	1.6523	1.6276	1.6182
" tetrachloride, CCl_4	1.591	20	—	1.4729	1.4676	1.4607	1.4579
Chinolin, C_9H_7N	1.090	20	—	1.6679	1.6470	1.6245	1.6161
Chloral, $CCl_3\cdot CHO$	1.512	20	—	1.4679	1.4624	1.4557	1.4530
Chloroform, $CHCl_3$	1.489	20	1.463	1.458	1.4530	1.4467	1.4443
Decane, $C_{10}H_{22}$	.728	14.9	—	1.4200	1.4160	1.4108	1.4088
Ether, ethyl, $C_2H_5\cdot O\cdot C_2H_5$	.715	20	—	1.3607	1.3576	1.3538	1.3515
" " *dn/dt*	—	20	—	—.0006	—.0006	—.0006	—.0006
Ethyl nitrate, $C_2H_5\cdot O\cdot NO_3$	1.109	20	—	1.395	1.392	1.3853	1.3830
Formic acid, $H\cdot CO_2H$	1.219	20	—	1.3804	1.3764	1.3714	1.3693
Glycerine, $C_3H_8O_3$	1.260	20	—	1.4828	1.4784	1.4730	1.4706
Hexane, $CH_3(CH_2)_4CH_3$	.660	20	—	1.3836	1.3799	1.3754	1.3734
Hexylene, $CH_3(CH_2)_3CH\cdot CH_2$	.679	23.3	—	1.4059	1.4007	1.3945	1.3920
Methylene iodide CH_2I_2	3.318	20	1.8027	—	1.7692	1.7417	1.7320
" " *dn/dt*	—	20	—	—	—.0007	—.0007	—.0006
Naphthalene, $C_{10}H_8$	.962	98.4	—	—	1.6031	1.5823	1.5746
Nicotine, $C_{10}H_{14}N_2$	1.012	22.4	—	1.5439	—	1.5239	1.5198
Octane, $CH_3(CH_2)_6CH_3$	.707	15.1	—	1.4097	1.4046	1.4007	1.3987
Oil, almond	.92	0	—	—	1.4847	1.4782	1.4755
anise seed	.99	15.1	1.6084	—	1.5743	1.5572	1.5508
"	.99	21.4	—	—	1.5647	1.5475	1.5410
bitter almond	1.06	20	—	1.5775	1.5623	—	1.5391
cassia	—	10	1.7039	—	1.6389	1.6104	1.6007
"	—	22.5	1.6985	—	1.6314	1.6026	1.5930
cinnamon	1.05	23.5	—	—	1.6508	1.6188	1.6077
olive	.92	0	—	—	1.4825	1.4763	1.4738
rock	—	0	—	—	1.4644	1.4573	1.4545
turpentine	.87	10.6	1.4939	—	1.4817	1.4744	1.4715
"	.87	20.7	1.4913	—	1.4793	1.4721	1.4692
Pentane, $CH_3(CH_2)_3CH_3$	.625	15.7	—	1.3645	1.3610	1.3581	1.3570
Phenol, C_6H_5OH	1.060	40.6	—	1.5684	1.5558	1.5425	1.5369
"	1.021	82.7	—	—	1.5356	—	1.5174
Styrene, $C_6H_5CH\cdot CH_2$	.910	16.6	—	1.5816	1.5659	1.5485	1.5419
Thymol, $C_{10}H_{14}O$	.982	—	—	—	1.5386	—	1.5228
Toluene, $CH_3\cdot C_6H_5$	.86	20	—	1.5170	1.5070	1.4955	1.4911
Water, H_2O	—	20	1.3435	1.3404	1.3372	1.3330	1.3312
"	—	0	1.3444	1.3413	1.3380	1.3338	1.3319
"	—	40	1.3411	1.3380	1.3349	1.3307	1.3290
"	—	80	1.3332	1.3302	1.3270	1.3230	1.3213

TABLE 552.—INDICES OF REFRACTION FOR SOLUTIONS OF SALTS AND ACIDS RELATIVE TO AIR

Substance	Density	Temp °C	Indices of refraction for spectrum lines C	D	F	H_γ	H
Solutions in water							
Ammonium chloride	1.067	27.05	1.37703	1.37936	1.38473	—	1.39336
" "	.025	29.75	.34850	.35050	.35515	—	.36243
Calcium chloride	.398	25.65	.44000	.44279	.44938	—	.46001
" "	.215	22.9	.39411	.39652	.40206	—	.41078
" "	.143	25.8	.37152	.37369	.37876	—	.38666
Hydrochloric acid	1.166	20.75	1.40817	1.41109	1.41774	—	1.42816
Nitric acid	.359	18.75	.39893	.40181	.40857	—	.41961
Potash (caustic)	.416	11.0	.40052	.40281	.40808	—	.41637
Potassium chloride	normal solution		.34087	.34278	.34719	1.35049	—
" "	double normal		.34982	.35179	.35645	.35994	—
" "	triple normal		.35831	.36029	.36512	.36890	—
Soda (caustic)	1.376	21.6	1.41071	1.41334	1.41936	—	1.42872
Sodium chloride	.189	18.07	.37562	.37789	.38322	1.38746	—
" "	.109	18.07	.35751	.35959	.36442	.36823	—
" "	.035	18.07	.34000	.34191	.34628	.34969	—
Sodium nitrate	1.358	22.8	1.38283	1.38535	1.39134	—	1.40121
Sulfuric acid	.811	18.3	.43444	.43669	.44168	—	.44883
" "	.632	18.3	.42227	.42466	.42967	—	.43694
" "	.221	18.3	.36793	.37009	.37468	—	.38158
" "	.028	18.3	.33663	.33862	.34285	—	.34938
Zinc chloride	1.359	26.6	1.39977	1.40222	1.40797	—	1.41738
" "	.209	26.4	.37292	.37515	.38026	—	.38845
Solutions in ethyl alcohol							
Ethyl alcohol	.789	25.5	1.35971	1.35971	1.36395	—	1.37094
" "	.932	27.6	.35372	.35556	.35986	—	.36662
Fuchsin (nearly saturated)..	—	16.0	.3918	.398	.361	—	.3759
Cyanin (saturated)	—	16.0	.3831	—	.3705	—	.3821

NOTE.—Cyanin in chloroform also acts anomalously; for example, Sieben gives for a 4.5 percent solution $\mu_A = 1.4593$, $\mu_B = 1.4695$, μ_F (green) $= 1.4514$, μ_G (blue) $= 1.4554$. For a 9.9 percent solution he gives $\mu_A = 1.4902$, μ_F (green) $= 1.4497$, μ_G (blue) $= 1.4597$.

Solutions of potassium permanganate in water

Wavelength	Spectrum line	Index for 1% sol	Index for 2% sol	Index for 3% sol	Index for 4% sol	Wavelength	Spectrum line	Index for 1% sol	Index for 2% sol	Index for 3% sol	Index for 4% sol
.687μ	B	1.3328	1.3342	—	1.3382	.516μ	—	1.3368	1.3385	—	—
.656	C	.3335	.3348	1.3365	.3391	.500	—	.3374	.3383	1.3386	1.3404
.617	—	.3343	.3365	.3381	.3410	.486	F	.3377	—	—	.3408
.594	—	.3354	.3373	.3393	.3426	.480	—	.3381	.3395	.3398	.3413
.589	D	.3353	.3372	—	.3426	.464	—	.3397	.3402	.3414	.3423
.568	—	.3362	.3387	.3412	.3445	.447	—	.3407	.3421	.3426	.3439
.553	—	.3366	.3395	.3417	.3438	.434	—	.3417	—	—	.3452
.527	E	.3363	—	—	—	.423	—	.3431	.3442	.3457	.3468
.522	—	.3362	.3377	.3388	—	—	—	—	—	—	—

TABLE 553.—INDEX OF REFRACTION OF AIR (15°C, 76 cmHg)

Corrections for reducing wavelengths and frequencies in air (15°C, 76 cmHg) to vacuo

The indices were computed from the Cauchy formula $(n-1)10^7 = 2726.43 + 12.288/(\lambda^2 \times 10^{-8}) + 0.3555/(\lambda^4 \times 10^{-16})$. For 0°C and 76 cmHg the constants of the equation become 2875.66, 13.412 and 0.3777 respectively, and for 30°C and 76 cmHg 2589.72, 12.259 and 0.2576. Sellmeier's formula for but one absorption band closely fits the observations: $n^2 = 1 + 0.00057378\lambda^2/(\lambda^2 - 595260)$. If $n-1$ were strictly proportional to the density, then $(n-1)_0/(n-1)t$ would equal $1 + \alpha t$ where α should be 0.00367. The following values of α were found to hold:

λ	0.85μ	0.75μ	0.65μ	0.55μ	0.45μ	0.35μ	0.25μ
α	0.003672	0.003674	0.003678	0.003685	0.003700	0.003738	0.003872

The indices are for dry air (0.05 ± % CO_2). Corrections to reduce to dry air the indices for moist air may be made for any wavelength by Lorenz's formula, $+0.000041(m/760)$, where m is the vapor pressure in mm. The corresponding frequencies in waves per cm and the corrections to reduce wavelengths and frequencies in air at 15°C and 76 cmHg pressure to vacuo are given. E.g., a light wave of 5000 angstroms in dry air at 15°C, 76 cmHg becomes 5001.391 A in vacuo; a frequency of 20,000 waves per cm correspondingly becomes 19994.44.

Wave-length, λ ang-stroms	Dry air $(n-1) \times 10^7$ 15°C 76 cmHg	Vacuo correction for λ in air $(n\lambda - \lambda)$ add	Frequency waves per cm $\frac{1}{\lambda}$ in air	Vacuo correction for $\frac{1}{\lambda}$ in air $\left(\frac{1}{n\lambda} - \frac{1}{\lambda}\right)$ subtract
2000	3256	.651	50,000	16.27
2100	3188	.670	47,619	15.18
2200	3132	.689	45,454	14.23
2300	3086	.710	43,478	13.41
2400	3047	.731	41,666	12.69
2500	3014	.754	40,000	12.05
2600	2986	.776	38,461	11.48
2700	2962	.800	37,037	10.97
2800	2941	.824	35,714	10.50
2900	2923	.848	34,482	10.08
3000	2907	.872	33,333	9.69
3100	2893	.897	32,258	9.33
3200	2880	.922	31,250	9.00
3300	2869	.947	30,303	8.69
3400	2859	.972	29,411	8.41
3500	2850	.998	28,571	8.14
3600	2842	1.023	27,777	7.89
3700	2835	1.049	27,027	7.66
3800	2829	1.075	26,315	7.44
3900	2823	1.101	25,641	7.24
4000	2817	1.127	25,000	7.04
4100	2812	1.153	24,390	6.86
4200	2808	1.179	23,809	6.68
4300	2803	1.205	23,255	6.52
4400	2799	1.232	22,727	6.36
4500	2796	1.258	22,222	6.21
4600	2792	1.284	21,739	6.07
4700	2789	1.311	21,276	5.93
4800	2786	1.338	20,833	5.80
4900	2784	1.364	20,406	5.68
5000	2781	1.391	20,000	5.56
5100	2779	1.417	19,607	5.45
5200	2777	1.444	19,230	5.34
5300	2775	1.471	18,867	5.23
5400	2773	1.497	18,518	5.13
5500	2771	1.524	18,181	5.04
5600	2769	1.551	17,857	4.94
5700	2768	1.578	17,543	4.85
5800	2766	1.604	17,241	4.77
5900	2765	1.631	16,949	4.68
6000	2763	1.658	16,666	4.60
6100	2762	1.685	16,393	4.53
6200	2761	1.712	16,129	4.45
6300	2760	1.739	15,873	4.38
6400	2759	1.766	15,625	4.31
6500	2758	1.792	15,384	4.24
6600	2757	1.819	15,151	4.18
6700	2756	1.846	14,925	4.11
6800	2755	1.873	14,705	4.05
6900	2754	1.900	14,492	3.99
7000	2753	1.927	14,285	3.93
7100	2752	1.954	14,084	3.88
7200	2751	1.981	13,888	3.82
7300	2751	2.008	13,698	3.77
7400	2750	2.035	13,513	3.72
7500	2749	2.062	13,333	3.66
7600	2749	2.089	13,157	3.62
7700	2748	2.116	12,987	3.57
7800	2748	2.143	12,820	3.52
7900	2747	2.170	12,658	3.48
8000	2746	2.197	12,500	3.43
8100	2746	2.224	12,345	3.39
8250	2745	2.265	12,121	3.33
8500	2744	2.332	11,764	3.23
8750	2743	2.400	11,428	3.13
9000	2742	2.468	11,111	3.05
9250	2741	2.536	10,810	2.96
9500	2740	2.604	10,526	2.88
9750	2740	2.671	10,256	2.81
10000	2739	2.739	10,000	2.74

A formula was given by Biot and Arago expressing the dependence of the index of refraction of a gas on pressure and temperature. More recent experiments confirm their conclusions. The formula is $n_t - 1 = \frac{n_0 - 1}{1 + \alpha t} \cdot \frac{p}{760}$, where n_t is the index of refraction for temperature t, n_0 for temperature zero, α the coefficient of expansion of the gas with temperature, and p the pressure of the gas in millimeters of mercury. For air see Table 553.

Indices of refraction

Wave-length μ	$(n-1)\ 10^3$ Air	O	N	H	Wave-length μ	$(n-1)\ 10^3$ Air	O	N	H
.4861	.2951	.2734	.3012	.1406	.4360	.2971	.2743	CO_2	.1418
.5461	.2936	.2717	.2998	.1397	.5462	.2937	.2704	.4506	.1397
.5790	.2930	.2710	—	.1393	.6709	.2918	.2683	.4471	.1385
.6563	.2919	.2698	.2982	.1387	6.709	.2881	.2643	.4804	.1361
					8.678	.2888	.2650	.4579	.1361

The values are for 0°C and 760 mmHg

Substance	Kind of light	Indices of refraction	Substance	Kind of light	Indices of refraction
Acetone	D	1.001079–1.001100	Hydrogen	white	1.000138–1.000143
Ammonia	white	1.000381–1.000385	"	D	1.000132
"	D	1.000373–1.000379	Hydrogen sulfide	D	1.000644
Argon	D	1.000281	Hydrogen sulfide	D	1.000623
Benzene	D	1.001700–1.001823	Methane	white	1.000443
Bromine	D	1.001132	"	D	1.000444
Carbon dioxide ...	white	1.000449–1.000450	Methyl alcohol ...	D	1.000549–1.000623
" " ...	D	1.000448–1.000454	Methyl ether	D	1.000891
Carbon disulfide	white	1.001500	Nitric oxide	white	1.000303
Carbon disulfide	D	1.001478–1.001485	" "	D	1.000297
Carbon monoxide	white	1.000340	Nitrogen	white	1.000295–1.000300
Carbon monoxide	white	1.000335	"	D	1.000296–1.000298
Chlorine	white	1.000772	Nitrous oxide	white	1.000503–1.000507
"	D	1.000773	" "	D	1.000516
Chloroform	D	1.001436–1.001464	Oxygen	white	1.000272–1.000280
Cyanogen	white	1.000834	"	D	1.000271–1.000272
"	D	1.000784–1.000825	Pentane	D	1.001711
Ethyl alcohol	D	1.000871–1.000885	Sulfur dioxide ...	white	1.000665
Ethyl ether	D	1.001521–1.001544	" " ...	D	1.000686
Helium	D	1.000036	Water	white	1.000261
Hydrochloric acid	white	1.000449	"	D	1.000249–1.000259
Hydrochloric acid	D	1.000447			

TABLE 555.—PHYSICAL PROPERTIES OF SOME SPECIAL GLASSES

Glass	Composition *	Density g/cm³	Young's modulus kg/mm²	Coefficient of thermal expansion cgs	Thermal conductivity cal / cm sec °C	Specific heat	Softening points °C	Electric resistance †	Dielectric constant
Fused quartz	SiO_2	2.20	7100	5.5×10^{-7}	.0033	.18	1660	10.48	4.1
Pyrex (7740)	SiO_2, 80: B_2O_3, 14 Na_2O, 4: Al_2O_3, 2	2.35	6900	32×10^{-7}	.0027	.25	775	6.6	4.5
Vycor (7900)	SiO_2, 96: B_2O_3, 3: other oxides	2.18	6800	8×10^{-7}	.0022	...	1500	8.1	3.8
Lead glass	SiO_2, 68: PbO, 15: Na_2O_3, 10: K_2O, 6: CaO, 1	4.26	5400	91×10^{-7}	...	...	580	9.7	9.5
Soda lime glass	SiO_2, 72: Na_2O, 15: CaO, 9: MgO, 3: Al_2O_3, 1	2.47	6900	92×10^{-7}	...	...	695	5.1	7.2

units – dynes/cm²

Glass	Diameter μ	Breaking strength	Young's modulus	Torsion coefficient	$\Delta l/l$ for failure
Quartz fibers ‡	1.5	$.90 \times 10^{11}$	...	...	...
	3.0	.65	11.1×10^{11}	6.6×10^{11}	.059
	5.0	.48	9.8	5.8	.049
	10.0	.30	8.5	4.8	.035
	30.0	.145	7.1	3.5	.020

* Approximately. † Log *R* (microhm-cm) for 350°C. ‡ The tensile strength as measured from rods about 5 or 6 mm in diameter is about 5 kg/mm². For quartz fibers the tensile strength varies from 6-20 times these values.

TABLE 556.—COLOR SCREENS

Although only the potassium salt does not keep well, it is perhaps safer to use freshly prepared solutions.

Color	Thickness mm	Water solutions of	Grams of substance in 100 cm³	Optical center of band μ	Transmission
Red	20	Crystal-violet, 5BO	.005	.6659	begins about .718μ. ends sharp at .639μ.
"	20	Potassium monochromate	10.		
Yellow	20	Nickel sulfate, $NiSO_4 \cdot 7aq$	30.	.5919	.614–.574μ,
"	15	Potassium monochromate	10.		
"	15	Potassium permanganate	.025		
Green	20	Copper chloride, $CuCl_2 \cdot 2aq$	60.	.5330	.540–.505μ
"	20	Potassium monochromate	10.		
Bright blue	20	Double-green, SF	.02	.4885	.526–.494 and .494–.458μ
	20	Copper sulfate, $CuSO_4 \cdot 5aq$	15.		
Dark blue	20	Crystal-violet, 5BO	.005	.4482	.478–.410μ
	20	Copper sulfate, $CuSO_4 \cdot 5aq$	15.		

The following list is condensed from Wood's Physical Optics:

Methyl violet, 4*R*·(Berlin Anilin Fabrik) very dilute, and nitroso-dimethyl-aniline transmits 0.365μ. Methyl violet + chinin-sulfate (separate solutions), the violet solution made strong enough to blot out 0.4359μ, transmits 0.4047 and 0.4048, also faintly 0.3984.

Cobalt glass + aesculin solution transmits 0.4359μ.

Guinea green B extra (Berlin) + chinin sulfate transmits 0.4916μ.

Neptune green (Bayer, Elberfeld) + chrysoidine. Dilute the latter enough to just transmit 0.5790 and 0.5461; then add the Neptune green until the yellow lines disappear.

Chrysoidine + eosine transmits 0.5790μ. The former should be dilute and the eosine added until the green line disappears.

Silver chemically deposited on a quartz plate is practically opaque except to the ultraviolet region 0.3160–0.3260 where 90 percent of the energy passes through. The film should be of such thickness that a window backed by a brilliantly lighted sky is barely visible.

In the following those marked with a * are transparent to a more or less degree to the ultraviolet.

* Cobalt chloride: solution in water, absorbs 0.50–.53μ; addition of $CaCl_2$ widens the band to 0.47–.50. It is exceedingly transparent to the ultraviolet down to 0.20. If dissolved in methyl alcohol + water, absorbs 0.50–.53 and everything below 0.35. In methyl alcohol alone 0.485–0.555 and below 0.40μ.

Copper chloride: in ethyl alcohol absorbs above 0.585 and below 0.535; in alcohol + 50 percent water, above 0.595 and below 0.37μ.

Neodymium salts are useful combined with other media, sharpening the edges of the absorption bands. In solution with bichromate of potash, transmits 0.535–.565 and above 0.60μ, the bands very sharp (a useful screen for photographing with a visually corrected objective).

Praseodymium salts: three strong bands at 0.482, .468, .444. In strong solutions they fuse into a sharp band at 0.435–.485μ. Absorption below 0.34.

Picric acid absorbs 0.36–.42μ, depending on the concentration.

Potassium chromate absorbs 0.40–.35, 0.30–.24, transmits 0.23μ.

* Potassium permanganate: absorbs 0.555–.50, transmits all the ultraviolet.

Chromium chloride: absorbs above 0.57, between 0.50 and .39, and below 0.33μ. These limits vary with the concentration.

Aesculin: absorbs below 0.363μ, very useful for removing the ultraviolet.

* Nitroso-dimethyl-aniline: very dilute aqueous solution absorbs 0.49–.37 and transmits all the ultraviolet.

Very dense cobalt glass + dense ruby glass or a strong potassium bichromate solution cuts off everything below 0.70 and transmits freely the red.

Iodine: saturated solution in CS_2 is opaque to the visible and transparent to the infrared.

TABLE 557.—LIGHT FILTERS, NARROW SPECTRUM REGIONS[164]

Filters from the following components: Distilled H_2O; Aq. sol. $CuSO_4 \cdot 5H_2O$; $NiSO_4 \cdot 7H_2O$; Glasses, Corning G 986A, G 586, G 980A; dyed gelatin, Wratten filters 88A, 25, 61, 49.

Filter and absorbent	Solution: Concentration	Solution: Thickness	Wavelengths limits	Max	Transmission at max
88A	....	....	.720–1.400	...	.80
88A, H_2O	....	2 cm	.720–1.380	.800	.72
88A, G 986A *	....	....	.720–1.020	.770	.35
25, $CuSO_4 \cdot 5H_2O$	5%	2 cm	.590– .690	.630	.26
61, "	5%	2 cm	.490– .690	.530	.52
49, "	5%	2 cm	.380– .500	.460	.26
G 586,* "	10%	2 cm	.330– .430	.380	.69
G 986A, $NiSO_4 \cdot 7H_2O$	50%	1 cm	.260– .360	.310	.50

[164] Jones, L. A., Journ. Opt. Soc. Amer., vol. 16, p. 259, 1928.
* Thickness .32 cm.

TABLE 558.—NARROW BAND PASS FILTERS*

Filter	Thickness range	Wavelength limits	Max	Transmission at max
C.S. 5– 74	5. – 7.5 mm	.402–.480μ	.430μ	14.5 percent
5– 76	5. – 5.8	.400–.483	.430	27.5
5– 75	3.2– 5.7	.395–.495	.460	12.5
4–104	6. – 8.5	.467–.530	.485	5.3
4–117	7. –12.	.466–.580	.495	34.0
4–105	9. –12.5	.483–.570	.515	11.0
4–102	9. –13.5	.528–.573	.550	10.6
4–115 †	10. –14.	.530–.575	.555	35.5
3–110	5. – 9.	.561–.620	.580	3.0
3–120	6. –10.	.565–.670	.590	19.5
2– 77	6.5– 9.5	.585–.705	.610	11.5
2– 78	4. – 7.	.612–.760	.640	16.0
2– 79	8.8–12.	.665–.780	.715	9.5
7– 84	10. –13.	.710–.900	.750	15.0
7– 85 ‡	5. – 6.	.800–1.101	.960	25.0
7– 86	7. – 8.	1.200–2.800	2.100	45.0
4– 17	5.5–10.	1.700–2.800	2.400	21.0

* Corning Glass Works. † Second max at 2.55 with transmission at 5.0 percent. ‡ Second max at .605 with transmission at 1.0 percent.

TABLE 559.—TRANSPARENCY OF WATER[165]

Values of a in $I = I_0 e^{-at}$; t in cm; I_0, I, intensity before and after transmission through distilled water at 20°C; wavelength λ in μ.

b: λ	b: a	c: λ	c: a	d: λ	d: a	d: λ	d: a	e: λ	e: a
.1829	4.7	.20	.08	.40	.00080	.54	.00044	.70	.0058
.1854	1.11	.24	.0135	.42	.00061	.58	.00084	.75	.028
.1862	.86	.28	.0077	.44	.00046	.60	.00197	.80	.024
.1878	.48	.30	.0064	.48	.00037	.62	.00265	.85	.027
.1916	.20	.34	.0028	.50	.00038	.64	.00292	.90	.06
.1935	.12	.38	.0013	.52	.00040	.68	.00406	.95	.3

[165] b, Tsukamoto, K., Rev. d'Optique, vol. 7, p. 89, 1929. c, Dawson, L. H., and Hulburt, E. O., Journ. Opt. Soc. Amer., vol. 24, p. 175, 1934. d, Hulburt, E. O., Journ. Opt. Soc. Amer., vol. 35, p. 698, 1945. e, Collins, J. R., Phys. Rev., vol. 26, p. 771, 1925.

TABLE 560.—SOME BAUSCH & LOMB LIGHT FILTERS *

Percent transmission for a number of wavelengths. All values are for a thickness of 3.5 mm unless otherwise noted. The values given include surface reflection losses. All glasses except the sharp cutting reds and yellows will meet the standard value at 3.5 mm within a thickness range of 3.0 to 4.0 mm. The sharp cutting reds and yellows will meet the standard value at 3.5 within a thickness range of 2.0 to 6.0 mm.

Filter	.40μ	.45	.50	.55	.60	.65	.70	Remarks
N–1	80	64	69	69	68	68	79	
N–2	58	25	33	36	35	38	76	
N–3	36	7	12	13	12	13	52	
N–6 †	..	.02	.15	.11	.08	.16	..	0 at .43μ; 9.8 at .68μ
R–1	..	..	..	..	28	86	87	0 at .58μ
R–2	..	..	..	1	69	85	84	0 at .54μ; 35 at .59μ
R–5	..	..	..	..	2	87	89	0 at .59μ
R–6	..	..	..	..	84	86	83	54% at .58μ
R–7	..	..	..	..	..	..	81	44% at .67μ
Y–4	..	..	..	68	89	89	89	0 at .51μ
Y–9	27	56	74	82	84	85	86	
Y–10	..	1	73	87	90	89	87	0 at .44μ
G–1	..	3	7	1	..	..	..	0 at .41 and .56μ
G–9	..	1	23	54	22	6	8	0 at .43μ
BG–1	36	64	68	41	11	2	..	0 at .69μ
B–1	87	82	46	33	14	15	68	
B–2	82	59	7	2	..	..	39	0 at .58 and .66μ
B–4	42	11	..	..	..	..	..	0 at .48μ
B–8	91	86	63	53	35	38	81	
B–10	84	84	59	44	23	19	36	

* Adapted from data furnished by J. W. Forrest, Bausch & Lomb Optical Co.
† $t = 2.0$ mm.

TABLE 561.—SPECTRAL TRANSMISSION OF SOME RED PYROMETER GLASSES

Glass	Thickness mm	Wavelengths μ .60	.61	.62	.63	.64	.65	.66	.67	.68	.70	.72	.74	.76
Jena 4512	2.93	..	..	..	1.8	25.0	57.0	67.4	72.3	75.5	78.5	80.5	81.0	81.5
Jena 2745	3.2	..	.8	2.5	6.5	10.5	13.8	18.0	22.3	26.0	33.5	39.5	44.5	47.5
Corning high transmission red:														
150 percent	5	.1	4.7	38.5	64.3	72.2	76.5	79.3	80.8	87.5	80.8	78.5	77.0	75.0
50 percent	5	..	..	.1	5.5	44.5	66.5	74.2	76.5	77.8	77.5	76.3	75.5	74.1
28 percent	6	..	..	..	..	2.0	24.0	67.0	73.8	76.8	76.2	75.1	73.2	71.8

TABLE 562.—THE EFFECTIVE WAVELENGTH λ_e OF CORNING 50-PERCENT RED PYROMETER GLASS * 5 mm THICK FOR SOME TEMPERATURE INTERVALS [106]

Temperature interval	λ_e	Temperature interval	λ_e
1300–1700°K	.6602μ	1827–1300°K	.6601μ
1300–2100	.6599	1827–1500	.6598
1300–2500	.6596	1827–2100	.6593
1300–2900	.6594	1827–2500	.6589
1300–3300	.6592	1827–2900	.6587
2300–1300	.6596	1827–3300	.6585
2300–3300	.6581	1827–3600	.6584

* See Table 77.
[106] "Temperature, Its Measurement and Control," a symposium prepared by the American Institute of Physics, p. 1115, Reinhold Publishing Co.

TABLE 563.—ULTRAVIOLET TRANSPARENCY OF ATMOSPHERIC COMPONENTS

$I = I_0\, 10^{-ad}$, d in cm 0°C, 760 mmHg.

Oxygen		Oxygen		Ozone		Ozone			
.1900μ	a = .0014	.186μ	a = .0089	.2378μ	100.5	.230μ	50	.290μ	16.6
.1920	.0007	.193	.0015	.2482	141	.240	95	.300	4.6
.1929	.0022			.2537	148.8	.250	120	.310	1.23
.1947	.0007	O_2, air		.2652	123	.260	120	.320	.35
.1950	.0021			.2804	45.6	.270	91	.330	.093
.1955	.00075	Air		.2967	6.9	.280	46	.340	.024
.1962	.0020	.186μ	a = .0019	.3125	.96				
.1970	.0007			.3341	.07	Nitrogen			
.2000	.00043	Water				.186 = .000478			
.2050	.0003	.1875μ	a = .0055						
.2100	.0002	.1900	.0026						
		.1950	.0012						
		.2000	.0007						

Air at sea level (Washington), 400 m practically no absorption λ > .3μ; < .28μ about that due to molecular scattering. Air transmission reduced by 1/100: 22 km at .28μ; 5 at 25μ; 0.57 at .22μ; 20 km at .205μ.

Atmospheric transparency for ultraviolet

Wavelength, μ.......	.29	.30	.31	.32	.33	.34	.35	.37	.39	.41	.43	.45
Percent transmitted..	0	.9	9.	20.	27.	33.	38.	46.	51.	56.	60.	64.

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS *

The table gives the percentage transmittances (column 5) at various wavelengths, of the dye solutions, dissolved or buffered as indicated in the third column. All solutions are adjusted to that concentration which gives unit density (10-percent transmittance) at the wavelength of maximum absorption, except for those solutions (marked * in column 4) that have the maximum absorption in the ultraviolet range. The wavelength of maximum absorption is given in column 2. In column 3 is given the serial number of the dye as listed and described in the Colour Index of the British Society of Dyers and Colorists (1924). Dyes having no Colour Index number are listed by the "prototype number" (abbreviated Pr.) of the 1949 Technical Manual and Year Book of the American Association of Textile Chemists and Colorists, p. 147. The names assigned to the dyes are not the names used by the individual American manufacturers but are older names assigned by the Year Book to each Colour Index number, p. 237; or to the "foreign prototype," p. 261.

In column 4, A stands for acid buffer ($pH = 4.6$), K for alkaline buffer ($pH = 9.3$). In this column, E stands for ethanol (ethyl alcohol) used as solvent, and Bz for benzene. Where A or K are used, the solvent was water. N stands for "no buffer," with water as solvent.

In some cases two or more sets of transmissions correspond to a given Colour Index number and name. For example, C.I. No. 326 corresponds to 62 dyestuffs listed as on the American market in 1939, and these may be classified as of several distinct types of Benzo Fast Scarlets and Benzo Fast Oranges. In less striking cases, the different types result from uncontrollable variations in manufacture. In such cases, the transmissions should be considered as representative rather than as specifications of the dye. No manufacturer would guarantee the transmissions within a narrow range, though all data are accurate measurements on actual representatives of at least one manufacturer's products. Transmissions vary somewhat with the exact pH of the buffer and with the characteristics of the instrument used for measurement, especially with the slit width. The present data obtained with the General Electric recording spectrophotometer, which has a 10-micron slit width.

From the data of the table, approximate data for stronger solutions, whose transmission at the wavelength of maximum absorption is only 1 percent, may be readily obtained by means of a table of squares. Such solutions are twice as concentrated as those of the table. Their transmissions at any given wavelength are approximately the squares of the tabulated transmissions. These relations depend on the validity of Beer's Law for the solution in question.

* Data furnished by I. H. Godlove, General Aniline & Film Corporation.

(continued)

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS (continued)

Name	λ Max.	C.I. No. or Pr. No.	Buffer or solvent	Wavelength (microns) .40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
				Transmittances (percent)															
Primuline	343	812	N*	0	4	21	49	73	87	92	95	96	97	97	98	98	99	99	99
Celliton Fast Yellow G	356	Pr. 242	E*	3	7	15	36	70	90	96	98	99	99	99	100	100	100	100	100
Milling Yellow O	373	Pr. 139	A*	2	7	14	29	56	78	91	96	97	98	98	98	99	99	99	99
Amido Azo Toluol	379	17	Bz*	0	3	18	35	53	72	88	96	99	100	100	100	100	100	100	100
Milling Orange	380	274	A*	2	7	14	24	40	61	80	92	97	98	99	99	99	99	99	99
Diamine Green G	383 (615, 647)	594	K	4	8	12	18	29	40	44	39	29	19	12	10	10	12	29	65
Diamine Catechine G	389	Pr. 69	K*	6	8	13	20	30	41	51	60	68	76	84	89	93	95	96	97
Naphthol Yellow S	391 (418)	10	A*	11	10	12	30	70	94	99	100	100	100	100	100	100	100	100	100
Supramine Yellow 3GL	390	Pr. 474	A*	3	6	18	49	82	96	99	100	100	100	100	100	100	100	100	100
Mikado Yellow	392	622	K*	3	6	18	50	82	94	98	98	99	99	99	99	99	100	100	100
Chrysophenine	392	365	K*	5	8	12	20	37	62	79	86	89	89	89	89	89	89	89	88
Fastusol Yellow L5G	394	Pr. 99	K*	1	4	20	57	90	99	100	100	100	100	100	100	100	100	99	99
Mikado Yellow	397	622	K*	4	6	17	47	78	92	97	98	99	99	99	99	100	100	100	99
Diamine Fast Orange EG	408	Pr. 72	K	10	11	16	24	36	53	71	86	94	98	99	99	99	99	100	100
Benzo Chrome Brown G	408	Pr. 365	K	10	11	13	17	24	32	42	53	65	77	87	92	95	97	98	99
Thioflavine T	410	815	N	11	12	35	82	98	99	100	100	100	100	100	100	100	100	100	100
Sun Yellow	410	620	N	11	11	20	41	70	89	96	98	99	99	99	99	100	100	100	100
Sun Yellow	413	620	K	11	10	17	33	57	75	86	93	97	99	99	100	100	100	100	100
Sulphon Orange G	414	Pr. 186	A	11	10	13	16	15	17	24	40	74	94	99	100	100	100	100	100
Fastusol Orange LGGL	415	Pr. 276	K	11	10	13	19	29	46	68	86	95	98	98	99	99	99	99	99
Azosol Fast Yellow CGG	426	Pr. 215	E	17	10	12	30	69	95	99	99	100	100	100	100	100	100	100	100
Resorcin Brown	428	234	A	13	10	10	14	24	39	59	79	91	96	99	99	100	100	100	100
Benzo Fast Brown 3GL	430	Pr. 28	K	12	10	10	13	18	26	38	53	68	79	87	92	94	95	96	97
Auramine	431	655	A	29	12	12	35	80	97	99	100	100	100	100	100	100	100	100	100
Euchrysine 2G	434	797	A	30	14	11	28	72	94	98	99	99	99	100	100	100	100	100	100
Pryazol Orange	443	653	K	15	12	10	12	22	45	73	91	97	99	99	100	100	100	100	100
Celliton Fast Brown 3R	445	Pr. 230	E	23	13	10	11	16	24	37	55	72	85	93	97	99	99	99	100
Benzamine Brown 3GO	447	596	K	10	10	10	10	15	24	39	58	74	84	90	94	96	97	98	98
Trisulfon Brown B	450	561	K	12	11	10	10	11	13	17	22	28	32	38	46	56	68	78	86

(*continued*)

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS (continued)

Name	λ Max.	C.I. No. or Pr. No.	Buffer or solvent	Wavelength (microns) .40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
				Transmittances (percent)															
Bismarck Brown R...........	455	332	A	20	14	11	10	12	18	28	42	56	69	80	88	93	95	96	97
Congo Orange R..............	466 (<400)	459	K	13	16	13	10	10	13	21	46	79	94	98	99	99	99	99	100
Polar Orange R..............	475 (<400)	Pr. 152	A	27	23	14	10	10	13	21	45	77	93	98	100	100	100	100	100
Sudan I	478	24	Bz	23	17	16	12	10	14	29	85	98	99	99	99	100	100	100	100
Orange II	485	151	A	40	35	28	16	10	12	26	75	96	99	99	99	99	99	100	100
Celliton Scarlet B............	486	Pr. 244	E	58	37	21	13	10	11	19	38	66	86	95	99	99	100	100	100
Orange R	490	161	A	43	38	33	20	11	11	16	46	87	98	100	100	100	100	100	100
Supramine Red 2G............	490 (<400)	Pr. 194	A	50	48	32	18	11	11	18	44	83	96	98	99	99	99	99	99
Victoria Blue B Base.........	492 (418)	729	Bz	31	28	26	17	11	11	16	29	46	62	74	81	86	91	94	97
Celliton Fast Red GG.........	493	Pr. 236	E	66	43	24	15	11	10	14	27	50	75	91	97	99	99	99	100
Celliton Fast Rubine B........	494	Pr. 238	E	67	43	24	14	11	10	14	27	51	76	91	97	99	100	100	100
Congo Red	495	370	N	42	34	25	17	12	10	14	26	50	75	91	96	97	98	98	99
Palatine Fast Red RN.........	498	Pr. 327	N	45	40	30	19	12	10	13	21	41	73	91	96	97	98	98	98
Benzo Fast Scarlet (S).......	499	326	K	42	36	31	22	13	10	12	21	52	86	98	100	100	100	100	100
Paper Red A Extra...........	500	Pr. 148	A	43	46	43	26	14	10	13	26	62	90	98	99	100	100	100	100
Fast Red A..................	504	176	A	55	46	39	28	16	10	13	21	37	64	88	97	99	99	99	99
Cochineal Red A.............	506	185	*	61	53	45	49	15	10	12	22	53	88	98	100	100	100	100	100
Benzo Fast Scarlet (S).......	509	326	K	54	48	42	31	19	11	11	16	27	59	89	98	100	100	100	100
Crocein Scarlet 3BX..........	510	183	A	56	51	45	31	17	11	11	19	47	81	96	99	100	100	100	100
Azo Eosine G................	510 (<400)	114	A	57	65	59	48	20	12	10	13	35	80	96	98	99	100	100	100
Polar Red	511 (<400)	430	A	24	29	32	25	16	11	11	15	25	43	63	72	74	75	76	76
Anthralan Red B-CF.........	512	Pr. 210	A	50	47	40	29	17	11	11	18	38	70	90	97	99	100	100	100
Diamine Scarlet B............	512 (<400)	382	K	29	35	40	31	17	11	10	19	48	83	96	99	100	100	100	100
Guinea Fast Red BL..........	515	Pr. 101	A	61	59	49	34	20	12	10	15	40	81	96	99	100	100	100	100
Alizarine Rubinol 3G..........	515 (<400)	Pr. 361	A	84	78	60	38	21	12	10	15	42	81	96	98	99	99	99	99

(continued)

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS (continued)

Name	λ Max.	C.I. No. or Pr. No.	Buffer or solvent	Wavelength (microns) .40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
				Transmittances (percent)															
Eosine G	517	768	A	93	92	88	74	46	27	11	74	99	100	100	100	100	100	100	100
Fast Red B	518	88	A	61	59	53	39	22	13	10	15	26	46	74	92	98	100	100	100
Oxamine Brilliant Red B	518	Pr. 393	K	47	44	41	32	20	12	10	15	34	66	86	95	98	99	100	100
Sudan Red BB	519	Pr. 182	Bz	46	45	39	31	20	13	10	13	28	70	94	98	99	99	100	100
Diamine Scarlet B	522 (<400)	382	K	26	34	43	37	23	13	10	13	25	54	84	96	98	100	100	100
Amaranth	523	184	A	63	59	52	40	23	13	10	13	25	56	89	98	100	100	100	100
Supra Light Rubine BL	523 (<400)	Pr. 188	A	57	59	56	46	29	16	10	14	22	43	72	91	97	99	99	99
Erythrosine Bluish	527	773	A	92	90	88	79	57	36	13	28	80	97	99	99	99	99	99	99
Azosol Brilliant Red B	531 (492?)	Pr. 363	E	58	50	40	33	31	31	16	15	42	70	95	99	100	100	100	100
Celliton Fast Pink B	531 (565)	Pr. 234	E	88	83	71	51	33	20	12	12	15	29	79	96	98	99	99	99
Phloxine B	535	778	N	95	94	93	85	68	42	25	12	67	99	100	100	100	100	100	100
Palatine Fast Claret BN	535 (562)	Pr. 394	A	53	48	43	40	30	19	13	10	12	23	69	92	96	96	96	96
Fuchaine	538	677	A	92	83	65	47	34	28	18	10	35	78	94	98	99	99	99	99
Formyl Violet S4B	543	698	N	95	97	96	93	82	58	25	10	15	26	35	58	81	95	99	100
Brilliant Benzo Violet B	546 (<400)	Pr. 35	K	69	71	71	62	46	29	17	10	12	21	32	51	72	87	95	98
Rose Bengale B	548	779	A	93	91	90	84	69	45	28	14	30	93	100	100	100	100	100	100
Azosol Fast Red 3B	548 (<400)	Pr. 213	E	84	86	87	84	70	47	26	12	18	66	92	97	99	100	100	100
Methylene Violet	551	842	N	92	85	75	65	51	33	18	11	11	27	66	91	98	99	99	100
Anthraquinone Violet	551	1080	A	79	74	60	45	32	22	15	11	10	14	24	44	68	85	95	98
Rhodamine B	553 (<400)	749	A	92	93	96	95	84	63	40	19	15	75	98	99	99	100	100	100
Sulpho Rhodamine B	562 (<400)	748	A	92	93	96	94	84	66	40	24	10	41	93	99	100	100	100	100
Brilliant Sky Blue 5G	564 (<400)	710	A	82	85	84	77	62	41	23	13	10	11	16	26	38	51	63	72

(continued)

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS (continued)

Name	λ Max.	C.I. No. or Pr. No.	Buffer or solvent	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
				Wavelength (microns) — Transmittances (percent)															
Benzo Azurine G	565 (422)	502	K	69	67	69	64	53	38	24	14	10	12	19	28	37	53	70	84
New Blue R	566	909	A	70	64	60	57	46	31	19	13	10	12	20	30	56	85	95	97
Neolan Black WA	566 (<400)	Pr. 143	A	21	23	26	28	29	27	20	14	10	11	12	19	38	62	82	91
Benzo Blue RW	568	512	K	70	68	66	64	53	41	27	16	11	11	15	22	30	45	64	81
Sulphon Acid Blue R	570	208	A	81	80	73	63	52	39	25	15	11	11	16	29	51	72	87	94
Supramine Black BR	570 (<400)	Pr. 189	A	25	28	27	24	22	22	19	13	10	11	14	20	28	39	55	72
Benzo Fast Black L	574	Pr. 24	K	42	35	30	27	25	24	20	14	11	10	13	19	29	44	63	80
Methyl Violet B	583	680	A	98	97	92	83	67	48	30	20	15	10	17	55	86	95	98	99
Nigrosine P	583	865	A	35	34	33	29	25	20	16	13	11	10	11	13	16	21	26	32
Methyl Violet B	585	680	A	97	96	92	83	68	50	31	20	15	10	16	52	86	96	99	100
Diamine Fast Blue FFB	586 (<400)	Pr. 71	K	73	72	69	62	54	45	34	22	14	10	12	20	30	41	55	69
Benzo Blue BB	587	406	K	72	71	70	67	59	47	32	20	13	10	11	23	51	78	90	95
Crystal Violet	590	681	A	99	99	96	90	88	61	39	24	19	12	13	46	83	97	99	100
Ethyl Violet	592	682	A	98	97	96	93	84	66	43	23	16	13	11	36	75	92	98	99
Crystal Violet APX	592	681	A	98	97	95	89	78	60	39	24	19	13	13	44	82	95	99	100
Alizarine Sky Blue B	594	1088	A	50	65	82	85	75	61	44	28	18	11	10	11	15	31	61	84
Chlorazol Dark Green	600 (<400)	583	K	17	20	22	27	34	37	34	25	16	12	10	12	17	30	53	74
Victoria Blue B Base	602	729	E	88	95	95	94	91	84	70	47	24	13	10	12	20	44	72	89
Benzo Sky Blue	603	520	K	78	76	74	71	65	56	43	29	18	12	10	11	18	40	70	89
Fastusol Gray LVGL	605 (<400)	Pr. 379	K	41	41	37	35	31	26	22	18	14	11	10	11	14	19	26	34
Benzo Green 2B	607 (<400)	Pr. 29	K	21	24	28	32	36	42	42	36	25	15	10	11	15	24	42	68
Indigetin IA	608	1180	A	90	88	86	85	85	80	68	48	30	18	11	13	34	69	91	97
Palatine Fast Blue BN	612 (573, <400)	Pr. 318	A	43	51	55	54	53	47	34	23	13	11	11	11	31	66	88	95

(continued)

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS (continued)

Name	λ Max.	C.I. No. or Pr. No.	Buffer or solvent	Wavelength (microns) .40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
				Transmittances (percent)															
Setocyanine	613 (405)	663	A	75	82	95	96	93	88	78	63	45	30	14	12	45	84	97	100
Victoria Blue B	615 (<400)	729	A	86	95	94	91	84	73	57	38	24	16	12	10	24	55	79	91
Cyananthrol R	615 (582, <400)	1076	A	56	68	82	82	73	59	42	27	16	11	11	10	21	55	82	92
Naphthol Blue Black	617 (<400, 452)	246	A	59	62	60	60	60	56	48	35	23	14	11	10	20	54	84	95
Malachite Green	618 (428)	657	A	77	64	71	92	97	94	86	73	52	35	19	10	30	72	94	99
Celliton Fast Blue FR	619 (673, 580, <400)	Pr. 227	E	71	83	89	87	81	70	55	40	26	18	16	10	22	27	28	60
Diamine Green B	622 (<400)	593	K	27	31	35	36	39	44	45	40	30	20	13	10	11	15	27	52
Brilliant Green	624 (426)	662	A	77	66	74	93	97	95	90	79	59	41	24	10	22	63	91	98
Setoglaucine	630 (415)	658	A	77	75	87	94	93	91	86	76	60	41	28	13	14	49	85	96
Neeland Blue GG	635 (593, <400)	Pr. 144	A	48	58	67	67	65	62	54	39	28	17	14	13	11	34	77	94
Alizarine Supra Sky R	635 (595, <400)	Pr. 207	A	82	91	93	88	81	70	55	37	25	15	10	12	10	23	59	84
Xylene Blue AS	637 (412)	673	A	79	81	96	99	99	97	94	87	74	53	36	19	11	37	80	95

(continued)

TABLE 564.—TRANSMISSION OF DYESTUFF SOLUTIONS OF "ADJUSTED" CONCENTRATIONS (concluded)

Name	λ Max.	C.I. No. or Pr. No.	Buffer or solvent	Wavelength (microns) .40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70
				Transmittances (percent)															
Wool Green S	637 (<400, 443)	737	A	85	86	86	88	90	92	89	80	65	47	34	17	11	41	82	96
Xylene Blue VS	637 (414)	672	A	81	82	96	99	99	97	93	86	72	52	38	20	10	38	80	95
Nile Blue A	638 (605, 428)	913	A	87	86	87	89	91	87	76	57	36	18	10	11	10	18	52	78
Alizarine Cyanine Green	641 (610, 413)	1078	A	24	23	35	55	69	68	57	41	28	18	11	10	10	13	30	59
Alizarine Astrol B	642 (607, <400)	1075	A	51	56	74	87	86	75	61	42	28	17	11	11	10	17	43	75
Alkali Fast Green 10G	662 (437)	Pr. 13	A	72	64	60	74	89	93	92	86	76	61	42	26	15	10	15	38
Methylene Blue	664 (<400)	922	A	97	98	97	96	93	92	91	86	75	59	36	28	20	11	29	80
Naphthol Green B	723 (<400)	5	A	12	18	25	40	56	64	70	74	71	59	42	28	18	14	11	10

Alum: Ordinary alum (crystal) absorbs the infrared.
Metallic reflection at 9.05μ and 30 to 40μ.

Rock salt: Rubens and Trowbridge give the following transparencies for a 1 cm thick plate in percent:

λ	9	10	12	13	14	15	16	17	18	19	20.7	23.7μ
%	99.5	99.5	99.3	97.6	93.1	84.6	66.1	51.6	27.5	9.6	.6	0.

Pflüger gives the following for the ultraviolet, same thickness: 280$\mu\mu$, 95.5 percent; 231, 86 percent; 210, 77 percent; 186, 70 percent.
Metallic reflection at 0.110μ, 0.156, 51.2, and 87μ.

Sylvite: Transparency of a 1 cm thick plate:

λ	9	10	11	12	13	14	15	16	17	18	19	20.7	23.7μ
%	100.	98.8	99.0	99.5	99.5	97.5	95.4	93.6	92.	86.	76.	58.	15.

Metallic reflection at 0.114μ, 0.161, 61.1, 100.

Fluorite: Very transparent for the ultraviolet nearly to 0.1μ.
Rubens and Trowbridge give the following for a 1 cm plate:

λ	8μ	9	10	11	12μ
%	84.4	54.3	16.4	1.0	0

Metallic reflection at 24μ, 31.6, 40μ.

Iceland spar: Merritt gives the following values of k in the formula $i = i_0 e^{-kd}$ (d in cm):
For the ordinary ray:

λ	1.02	1.45	1.72	2.07	2.11	2.30	2.44	2.53	2.60	2.65	2.74μ
k	.0	.0	.03	.13	.74	1.92	3.00	1.92	1.21	1.74	2.36

λ	2.83	2.90	2.95	3.04	3.30	3.47	3.62	3.80	3.98	4.35	4.52	4.83μ
k	1.32	.70	1.80	4.71	22.7	19.4	9.6	18.6	∞	6.6	14.3	6.1

For the extraordinary ray:

λ	2.49	2.87	3.00	3.28	3.38	3.59	3.76	3.90	4.02	4.41	4.67μ
k	.14	.08	.43	1.32	.89	1.79	2.04	1.17	.89	1.07	2.40

λ	4.91	5.04	5.34	5.50μ
k	1.25	2.13	4.41	12.8

Quartz: Very transparent to the ultraviolet; Pflüger gets the following transmission values for a plate 1 cm thick: at 0.222μ, 94.2 percent; 0.214, 92; 0.203, 83.6; 0.186, 67.2 percent.
Merritt gives the following values for k (see formula under Iceland spar):
For the ordinary ray:

λ	2.72	2.83	2.95	3.07	3.17	3.38	3.67	3.82	3.96	4.12	4.50μ
k	.20	.47	.57	.31	.20	.15	1.26	1.61	2.04	3.41	7.30

For the extraordinary ray:

λ	2.74	2.89	3.00	3.08	3.26	3.43	3.52	3.59	3.64	3.74	3.91	4.19	4.36μ
k	.0	.11	.33	.26	.11	.51	.76	1.88	1.83	1.62	2.22	3.35	8.0

For $\lambda > 7\ \mu$, becomes opaque, metallic reflection at 8.50μ, 9.02, 20.75–24.4μ, then transparent again.

TABLE 566.—TRANSPARENCY OF WATER VAPOR (steam)

Wave-length	Steam	Absorption	Wave-length	Steam	Absorption	Wave-length	Steam	Absorption
.95μ	109 cm	7%	6.5μ	32.4 cm	80%	20μ	32.4	80%
1.13	"	14	11	104	15	22	"	22
1.36	"	75	13	104	35	26	"	30
1.84	"	84	15	104	55	30	"	50
2.64	"	100	18	32.4	55	34	"	80

TABLE 567.—TRANSMISSION OF RADIATION THROUGH MOIST AIR (percent)

The values of this table are of use for finding the transmission of energy through air containing a known amount of water vapor. An approximate value for the transmission may be had if the amount of energy from the source between the wavelengths of the first column is multiplied by the corresponding transmission coefficients of the subsequent columns. The values for the wavelengths greater than 18μ are tentative and doubtful.

Range of wavelengths μ	μ	Precipitable water in cm .001	.003	.006	.01	.03	.06	.10	.25	.50	1.0	2.0	6.0	10.0
.75 to	1.0	—	—	—	100	99	99	98	97	95	93	90	83	78
1.0	1.25	—	—	—	99	99	98	97	95	92	89	85	74	69
1.25	1.5	—	—	—	96	92	84	80	66	57	51	44	31	28
1.5	2.0	—	—	—	98	97	94	88	79	73	70	66	60	57
*2	3	96	92	87	84	77	70	64	—	—	—	—	—	—
3	4	95	88	84	78	72	66	63	—	—	—	—	—	—
*4	5	92	83	76	71	65	60	53	—	—	—	—	—	—
5	6	95	82	75	68	56	51	47	35	—	—	—	—	—
6	7	85	54	50	31	24	8	4	3	2	0	0	0	0
7	8	94	84	76	68	57	46	35	16	10	2	0	0	0
8	9	100	100	100	99	98	96	94	65	—	—	—	—	—
†9	10	100	100	100	100	100	100	100	100	100	100	100	—	—
†10	11	100	100	100	100	100	100	100	100	100	100	100	—	—
11	12	100	100	100	100	100	99	98	96	95	93	—	—	—
12	13	100	100	100	100	99	99	97	86	82	—	—	—	—
*13	14	100	100	100	99	97	94	90	80	60	—	—	—	—
*14	15	—	—	96	93	80	75	50	15	0	0	0	0	0
*15	16	—	—	—	—	70	55	40	0	0	0	0	0	0
16	17	—	—	—	—	—	50	20	0	0	0	0	0	0
17	18	—	—	—	—	—	25	10	0	0	0	0	0	0
18	∞	98	94	89	82	45	0	0	0	0	0	0	0	0

* These places require multiplication by the following factors to allow for losses in CO_2 gas. Under average sea-level outdoor conditions the CO_2 (partial pressure = 0.003 atm) amounts to about 0.6 g/cm³. Paschen gives 3 times as much for indoor conditions.

2μ to 3μ, for 2 g in m^2 path (95); for 140 g in m^2 path (93);
4 " 5 " " " " " " (93); " " " " " " (70); more CO_2 no further effect;
13 " 14, slight allowance to be made;
14 " 15, 80 g in m^2 path reduces energy to zero;
15 " 16, " " " " " " " " "

† These places require multiplication by 0.90 and 0.70 respectively for one air mass and 0.85 and 0.65 for two air masses to allow for ozone absorption when the radiation comes from a celestial body.

TABLE 568.—INFRARED TRANSMISSION OF VARIOUS SUBSTANCES (percent) [167]

		20μ	30	40	50	60	70	80	90	100	110	120	130μ
Fused quartz	.2 mm	0	0	2	20	35	51	53	52	..	..	..	..
" "	1.0 "	0	0	0	0	0	0	5	6	18	30	22	27
Crystal "	1.0 "	0	1	7	42	57	62	59	72	71	78	70	72
Sulfur, rhombic ..	.9 "	30	40	10	6	39	37	52	58	51	56	58	38
Paraffin	2.0 "	19	35	42	51	58	64	65	75	85	79	76	70
Mica	6μ	6	18	50	53	46	57	50	21	27	50	(55)	(55)
Cellophane	40μ	0	16	22	23	24	24	23	23	29	30	30	42
Celluloid	1μ	92	93	95	96	96	97	97	98	98	99	99	99
Black paper	.1 mm	..	..	..	2	5	13	19	22	23	26	28	30
Camphor soot	*	60	76	79	80	81	82	84	85	86	87	89	90
Pfund Bi black...	*	30	40	44	48	50	40	45	58	60	57	60	63
Lampblack, water glass	.8	0	(1)	(3)	7	12	21	20	26	30	25	30	30

[167] Barnes, Phys. Rev., vol. 39, p. 562, 1932.
* On celluloid 1μ thick.

TABLE 569.—INFRARED TRANSMISSION, IN PERCENT, OF A NUMBER OF MATERIALS [168]

Thickness in mm / λ (μ)	Lead chloride	Magnesium oxide	Potassium chloride	Silver chloride	Thallium bromide	Thallium bromide-iodide (58% I, 42% Br)	Thallium chloride	Sapphire	Cesium bromide
	6	.47	6	6	6	8	6	1.17	7
.40	..	..	..	..	..	..	..	..	71.5
.60	..	..	..	..	..	..	..	..	77.8
1	..	..	..	..	..	..	..	..	79.8
2	..	88	..	73	..	..	..	86.5	82.0
3	..	87	..	76	..	..	..	89.0	82.0
4	..	89	..	77	..	..	..	89.2	82.0
5	..	90	..	79	..	..	..	82.5	82.0
6	..	89	..	80	..	..	..	50.0	82.0
7	..	84	..	80	..	..	..	4.0	83.0
8	..	78	..	80	..	..	..		83.0
10	..	11	..	80	..	..	..	..	83.5
12	..	..	..	80	..	..	..	..	84.0
14	82	..	..	80	..	..	..	..	84.5
16	82	..	..	82	..	..	..	..	85.0
18	80	..	87	82	..	..	..	..	85.0
20	77	..	72	78	..	..	..	..	85.0
22	69	..	37	62	61	..	57	..	85.0
24	52	..	12	46	61	..	38	..	84.0
26	19	..	..	27	60	66	18	..	84.0
28	..	..	..	..	57	62	6	..	83.0
30	..	..	..	..	50	61	..	..	83.0
32	..	..	..	..	39	58	..	..	83.0
34	..	..	..	..	33	54	..	..	82.0
36	..	..	..	..	26	51	..	..	80.0
38	..	..	..	..	..	..	..	..	76.0

[168] Data from E. K. Plyler, Nat. Bur. Standards Journ. Res., vol. 41, p. 125, 1948, and E. K. Plyler, National Bureau of Standards, private communication. Cesium bromide data by E. K. Plyler and F. A. Phelps.

TABLE 570.—INFRARED TRANSMISSION OF GASES (percent) [169]

Length of cell, 4 inches.

Material	Pressure	6.7μ	8.7μ	20.75μ	22.9μ	27.3μ	29.4μ	32.8μ
NH_3	760 mmHg	24	26	79	93	83	82	62
C_2H_2	760	95	92	99	101	101	100	98
H_2S	760	97	98	98	97	92	90	83
SO_2	760	98	5	7	58	100	100	96
C_6H_6	96	65	97	102	99	100	98	95
CCl_4	114	95	99	97	99	99	99	91
CS_2	361	30	98	100	86	98	99	96
$CHCl_3$	200	93	90	99	98	98	97	97
$(C_2H_5)_2O$	526	17	6	61	45	69	71	61

[169] Strong, Phys. Rev., vol. 37, p. 1565, 1931, Restrahlung.

TABLE 571.—INFRARED TRANSMISSION OF SOLIDS (percent)

Material	Description	6.7μ	8.7μ	20.75μ	22.9μ	27.3μ	29.4μ	32.8μ
Lacquer film	±.55μ thickness	96	93	97	98	99	99	100
Mica	10μ thickness	83	22	19	00	35	42	44
Soot on lacquer	Opaque to visible	25	22	67	53	60	67	60
Quartz, fused	10μ thickness	86	02	01	03	51	55	68
Glass	3μ thickness	93	07	12	14	48	51	56
Cellophane	25μ thickness	33	04	04	01	20	25	26
MgO	Deposit from burning Mg ribbon	88	86	04	02	90	93	87
ZnO	Deposit from Zn arc	99	80	15	05	93	79	80

Description of reflector	22.9μ	32.8μ
Deposit of MgO from burning Mg ribbon	0	0
Reflection β-MgO	80	33
Mica	32	..
Paraffin	04	..
Pencil mark on paper	09	..
Silver covered with Soot coating	43	48
Silver covered with MgO coating	08	91
Silver covered with ZnO coating	01	52
Silver covered with Optical black	31	..
Gold foil blackened with bismuth	>19	..
$KBr + 1.5\mu\ CaF_2$ deposited by evaporation	10	..
$KI + 1.5\mu\ CaF_2$ deposited by evaporation	13	..

TABLE 573.—ABSORPTION OF VARIOUS MATERIALS USED FOR BLACKENING RECEIVERS FOR MEASURING RADIATION OF DIFFERENT WAVELENGTHS[170]

Soot from a candle, acetylene, or camphor flame has been used and was found by Pfund to be very good to wavelengths about 1.2μ; beyond this to longer wavelengths the soot becomes transparent until at about 11μ, for a film about as thick as will work satisfactorily, it transmits about 50 percent of the incident radiation.

Very finely powdered metal such as zinc (4 parts Zn and 1 part Sb) and platinum were found to be very good. Even for wavelengths of about 14μ the Zn powder absorbed over 98 percent of the radiation and out to 51μ the absorption was about 85 percent.

For longer wavelengths powdered NaCl, KBr, TlCs, and some other salts were found to be very good, as shown in the table.

The figures given in the table for radiation absorption are relative, those with the highest values being the blackest. For instance, India ink and tellurium powder are the best absorbers for radiation shorter than 5μ while for longer wavelengths than 50μ powdered glasses and $CuSO_4$ are probably the more nearly black.

The absorptive power is an integrated effect over the entire far infrared. Litharge, powdered glass, white lead, copper sulfide, celestite, and red phosphorus were the best absorbers beyond 50μ. A very thin coat of the absorbing material in most cases was an inefficient absorber of the extreme infrared waves. A very poor absorbing material in most cases such as copper or platinum will absorb if the surface is sufficiently rough.

For radiometers, the absorbing material is better when mixed with turpentine and alcohol and painted on the vanes. For thermocouples, the absorbing material is better if it is mixed with lacquer. Sixty-fold sensitiveness and better steadiness comes from evacuation.

The high absorption of glass in the near infrared suggests its use as a source of radiation. Two Pt wires separated by 4 mm and covered with glass were heated by an electric current; the hot portion of the glass between the wires served as a source of extreme infrared radiation. A convenient method of filtering out the near infrared is to grind the windows with emery so that the pits are about 4μ deep. The apparatus may be adjusted with visible light by covering the rough surface with turpentine.

Substance	Radiation absorbed for $\lambda < 5\mu$	$\lambda > 50\mu$
Litharge	10.8	4.3
Ground glass	11.9	4.7
Powdered glass	11.7	5.0
White lead 2 Pb $CO_3 \cdot Pb(OH)_2$	14.9	4.9
White lead in lacquer	14.3	4.4
Red phosphorus	18.3	5.0
Red phosphorus from a match box	17.7	5.1
Celestite, powdered $SrSO_4$	14.7	4.6
Brucite, powdered $Mg(OH)_2$	11.4	4.2
Angelsite, powdered $PbSO_4$	14.2	4.2
Copper sulfide	17.1	5.2
Copper oxide	13.8	4.4
Silver sulfide	12.8	4.4
Copper sulfate crystals from solution	15.0	4.1
Wellsbach mantle material	8.9	3 1
Platinum black	18.2	4.4
Tartaric acid and sugar	16.0	3.9
Talc	12.5	3.8
Water glass	12.1	3.7
Tellurium, powdered	19.2	3.3
India ink	18.8	3.8
Lacquer	8.6	3.0
Castor oil	8.8	2 8
Glycerine	11.2	3.1
Turpentine	8.1	.2
Clean receiver	2.9	.2

[170] Cartwright, Phys. Rev., vol. 35, p. 415, 1930; Pfund, Rev. Sci. Instr., vol. 1, p. 397, 1930, and Journ. Opt. Soc. Amer., vol. 23, p. 375, 1933.

TABLES 574-592.—REFLECTION AND ABSORPTION OF RADIATION

According to Fresnel, the amount of light reflected by the surface of a transparent medium $= \frac{1}{2}(A + B) = \frac{1}{2}\left\{\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right\}$; A is the amount polarized in the plane of incidence; B is that polarized perpendicular to this; i and r are the angles of incidence and refraction.

TABLE 574.—RADIATION REFLECTED WHEN $i = 0°$ OR INCIDENT LIGHT IS NORMAL TO SURFACE $= (n-1)^2/(n+1)^2$

(percent)

n	$\frac{1}{2}(A+B)$	n	$\frac{1}{2}(A+B)$	n	$\frac{1}{2}(A+B)$	n	$\frac{1}{2}(A+B)$
1.00	.00	1.4	2.78	2.0	11.11	5.	44.44
1.02	.01	1.5	4.00	2.25	14.06	5.83	50.00
1.05	.06	1.6	5.33	2.5	18.37	10.	66.67
1.1	.23	1.7	6.72	2.75	22.89	100.	96.08
1.2	.83	1.8	8.16	3.	25.00	∞	100.00
1.3	1.70	1.9	9.63	4.	36.00		

TABLE 575.—RADIATION REFLECTED WHEN $n = 1.55$

i °	r ° ′	A	B	dA †	dB †	$\frac{1}{2}(A+B)$	$\frac{A-B}{A+B}$ *
0	0 .0	4.65	4.65	.130	.130	4.65	.0
5	3 13.4	4.70	4.61	.131	.129	4.65	1.0
10	6 25.9	4.84	4.47	.135	.126	4.66	4.0
15	9 36.7	5.09	4.24	.141	.121	4.66	9.1
20	12 44.8	5.45	3.92	.150	.114	4.68	16.4
25	15 49.3	5.95	3.50	.161	.105	4.73	25.9
30	18 49.1	6.64	3.00	.175	.094	4.82	37.8
35	21 43.1	7.55	2.40	.191	.081	4.98	51.7
40	24 30.0	8.77	1.75	.210	.066	5.26	66.7
45	27 8.5	10.38	1.08	.233	.049	5.73	81.2
50	29 37.1	12.54	.46	.263	.027	6.50	92.9
55	31 54.2	15.43	.05	.303	.007	7.74	99.3
60	33 58.1	19.35	.12	.342	—.013	9.73	98.8
65	35 47.0	24.69	1.13	.375	—.032	12.91	91.2
70	37 19.1	31.99	4.00	.400	—.050	18.00	77.7
75	38 32.9	42.00	10.38	.410	—.060	26.19	61.8
80	39 26.8	55.74	23.34	.370	—.069	39.54	41.0
82 30	39 45.9	64.41	34.04	.320	—.067	49.22	30.8
85 0	39 59.6	74.52	49.03	.250	—.061	61.77	20.6
86 0	40 3.6	79.02	56.62	.209	—.055	67.82	16.5
87 0	40 6.7	83.80	65.32	.163	—.046	74.56	12.4
88 0	40 8.9	88.88	75.31	.118	—.036	82.10	8.3
89 0	40 10.2	94.28	86.79	.063	—.022	90.54	4.1
90 0	40 10.7	100.00	100.00	.000	—.000	100.00	.0

Angle of total polarization = 57° 10′.3, $A = 16.99$.

* This column gives the degree of polarization. † Columns 5 and 6 furnish a means of determining A and B for other values of n. They represent the change in these quantities for a change of n of 0.01.

TABLE 576.—REFLECTING FACTOR OF POWDERS (WHITE LIGHT)

(percent)

Various pure chemicals, very finely powdered and surface formed by pressing down with glass plate. White (noon sunlight) light. Reflection in percent.

Aluminum oxide	83.6	Rochelle salt	79.3
Barium sulfate	81.1	Salicylic acid	81.1
Borax	81.6	Sodium carbonate	81.8
Boric acid	83.2	Sodium chloride	78.1
Calcium carbonate	95†	Sodium sulfate	77.9
Citric acid	81.5	Starch	80.3
Magnesium carbonate	86.6	Sugar	87.8
" " (block)	94–97†	Tartaric acid	79.1
Magnesium oxide (6 mm. thick)	98*†		

* The smoke of magnesium turnings freely burning in air and deposited on a satisfactory base forms a uniform fine-grained diffusing surface of high reflectance. This oxide should be deposited so as not to be affected by the heat from the burning Mg. A satisfactory base may be Al, silver-plated Cu, block porcelain. The oxide adheres better to depolished surfaces. Surfaces of high and uniform reflectance throughout the spectrum are best. † Revised values.

TABLE 577.—VARIATION OF REFLECTING FACTOR OF SURFACES WITH ANGLE (RELATIVE VALUES)

Illumination at normal incidence, 1¼-watt tungsten lamp, reflection at angles indicated with normal.

Angle of observation	0°	1°	3°	5°	10°	15°	30°	45°	60°
Magnesium carbonate block	.88	—	—	.88	.88	.87	.83	.72	.68
Magnesium oxide	.80	—	—	.80	.80	.80	.77	.75	.66
Matt photographic paper	.78	—	—	.78	.78	.78	.78	.76	.72
White blotter	.76	—	—	.76	.76	.76	.73	.70	.67
Pot opal, ground	.69	.69	.69	.69	.69	.69	.68	.66	.64
Flashed opal, not ground	11.3	11.3	11.3	.31	.22	.21	.20	.20	.18
Glass, fine ground	.29	.29	.29	.29	.27	.20	.14	.13	.12
Glass, coarse ground	.23	.22	.21	.20	.19	.16	.11	.11	.12
Matt varnish on foil	.83	—	.78	.72	.62	.49	.28	.21	.16
Mirror with ground face	4.9	—	—	4.55	3.86	3.03	.78	.42	.35

The following figures, taken from Fowle, Smithsonian Misc. Coll., vol. 58, No. 8, indicate the amount of energy scattered on each side of the directly reflected beam from a silvered mirror; the energy at the center of the reflected beam was taken as 100,000, and the angle of incidence was about 3°.

Angle of reflection, 3° ±	0′	8′	10′	15′	20′	30′	45′	60′	100′
Energy	100,000	600	244	146	107	66	33	22	11

Wavelength of max. energy of Nernst lamp used as source about 2μ.

TABLE 578.—ULTRAVIOLET REFLECTING FACTOR OF SOME METALS[171]

	.250μ	.300	.350	.400	.450	.500	.550	.600
Aluminum, cast polished	.43	.45	.54	.62	.68	.72	.73	.74
" rolled	.21	.28	.34	.41	.46	.50	.53	.56
Rhodium	.30	.37	.44	.50	.53	.57	.58	.59
Tin, polished	.33	.38	.45	.52	.60	.67	.72	.73
Duralumin	.24	.31	.44	.46	.46	.46	.46	.46
" tarnished to	.20	.26	.32					

[171] Coblentz, Stair, Nat. Bur. Standards Journ. Res., vol. 4, p. 189, 1930.

TABLE 579.—PERCENTAGE REFLECTION FROM METALS, VIOLET END OF SPECTRUM [172]

Wavelength in μ	.05	.10	.15	.20	.25	.30	.35	.40	.50	.60
Ni electroplated	..	..	..	..	40	44	51	53	56	(60)
" vac. fused	..	..	..	..	48	42	45	52	62	64
Ag (min. 7%, 33μ)	..	..	..	..	30	16	71	88	92	(94)
Stellite (Co, Cr, Mo)	..	..	..	..	46	49	55	60	64	(68)
Stainless steel, 13% Cr	..	..	..	..	40	47	52	56	59	(60)
Cobalt	..	..	..	..	43	46	52	58	62	(67)
Speculum	..	..	..	..	31	41	50	56	60	(62)
Beryllium (98.7%)	46	53	67	79	84	87	..	..	..	..
Chromium on steel	69	63	65	71	78	82	86	88	..	..

[172] Coblentz, Stair, Nat. Bur. Standards Journ. Res., vol. 2, p. 343, 1929.

TABLE 580.—PERCENTAGE REFLECTING FACTOR OF DRY POWDERED PIGMENTS

The total reflecting power depends on the distribution of energy in the illuminant and is given in the last three columns for noon sun, blue sky, and for a 7.9 lumens/watt tungsten filament.

Spectrum color	Violet	Blue		Green			Yellow		Orange			Red			Noon sun	Sky light	Tungsten lamp
Wavelength in μ	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68	.70			
American vermilion	8	6	5	5	6	6	9	11	24	39	53	61	66	65	14	12	12
Venetian red	5	5	5	5	5	6	7	12	19	24	28	30	32	32	11	10	13
Tuscan red	7	7	7	8	8	8	8	12	16	18	20	22	23	24	11	10	12
Indian red	8	7	7	7	7	7	7	11	15	18	20	22	23	24	10	9	11
Burnt sienna	4	4	4	4	5	6	9	14	18	20	21	23	24	25	11	9	13
Raw sienna	12	13	13	13	18	26	35	43	46	46	45	44	45	43	33	30	37
Golden ochre	22	22	23	27	40	53	63	71	75	74	73	73	73	72	58	55	63
Chrome yellow ochre	8	9	7	7	10	19	30	46	60	62	66	82	81	80	33	29	40
Yellow ochre	20	20	21	24	32	42	53	63	64	61	60	59	59	59	49	46	53
Chrome yellow medium	5	5	6	8	18	48	66	75	78	79	81	81	81	81	54	50	63
Chrome yellow light	13	13	18	30	56	82	88	89	90	89	88	87	85	84	76	70	82
Chrome green light	10	10	14	23	26	23	20	17	14	11	9	8	7	6	19	19	18
Chrome green medium	7	7	10	21	21	17	13	11	9	7	6	6	6	5	14	14	12
Cobalt blue	59	58	49	35	23	15	11	10	10	10	11	15	20	25	16	18	13
Ultramarine blue	67	54	38	21	10	6	4	3	3	4	5	7	10	17	7	10	6

TABLE 581.—INFRARED DIFFUSE PERCENTAGE REFLECTING FACTORS OF DRY PIGMENTS

Wavelength in μ	Co_2O_3	CuO	Cr_2O_3	PbO	Fe_2O_3	Y_2O_3	$PbCrO_4$	Al_2O_3	ThO_2	ZnO	MgO	CaO	ZrO_2	$PbCO_3$	$MgCO_3$	White lead paint	Zn oxide paint
.60 *	3	—	27	52	26	74	70	84	86	82	86	85	86	88	85	76	68
.95 *	4	24	45	—	41	—	—	88	—	86	—	—	84	93	89	79	72
4.4	14	15	33	51	30	34	41	21	47	8	16	22	23	29	11	—	—
8.8	13	—	5	26	4	11	5	20	7	3	2	4	5	10	4	—	—
24.0	6	4	8	10	9	10	7	6	10	5	9	6	5	7	9	—	—

* Nonmonochromatic means from Coblentz.

A surface of plate glass, ground uniformly with the finest emery and then silvered, used at an angle of 75°, reflected 90 percent at 4μ, approached 100 for longer waves, only 10 at 1μ, less than 5 in the visible red and approached 0 for shorter waves. Similar results were obtained with a plate of rock salt for transmitted energy when roughened merely by breathing on it. In both cases the finer the surface, the more suddenly it cuts off the short waves.

TABLE 582.—REFLECTING FACTOR OF METALS

Perpendicular incidence and reflection (See also Tables 578, 579, 589)

The numbers give the percents of the incident radiation reflected.

Wavelength, μ	Silver-backed glass	Mercury-backed glass	Mach's magnalium 69Al + 31Mg	Brandes-Schünemann alloy 32Cu + 34Sn + 29Ni + 5Fe	Ross' speculum metal 68.2Cu + 31.8Sn	Nickel electrolytically deposited	Copper electrolytically deposited	Steel untempered	Copper commercially pure	Platinum electrolytically deposited	Gold electrolytically deposited	Brass (Trowbridge)	Silver chemically deposited
.251	—	—	67.0	35.8	29.9	37.8	—	32.9	25.9	33.8	38.8	—	34.1
.288	—	—	70.6	37.1	37.7	42.7	—	35.0	24.3	38.8	34.0	—	21.2
.305	—	—	72.2	37.2	41.7	44.2	—	37.2	25.3	39.8	31.8	—	9.1
.316	—	—	—	—	—	—	—	—	—	—	—	—	4.2
.326	—	—	75.5	39.3	—	45.2	—	40.3	24.9	41.4	28.6	—	14.6
.338	—	—	—	—	—	46.5	—	—	—	—	—	—	55.5
.357	—	—	81.2	43.3	51.0	48.8	—	45.0	27.3	43.4	27.9	—	74.5
.385	—	—	83.9	44.3	53.1	49.6	—	47.8	28.6	45.4	27.1	—	81.4
.420	—	—	83.3	47.2	56.4	56.6	—	51.9	32.7	51.8	29.3	—	86.6
.450	85.7	72.8	83.4	49.2	60.0	59.4	48.8	54.4	37.0	54.7	33.1	—	90.5
.500	86.6	70.9	83.3	49.3	63.2	60.8	53.3	54.8	43.7	58.4	47.0	—	91.3
.550	88.2	71.2	82.7	48.3	64.0	62.6	59.5	54.9	47.7	61.1	74.0	—	92.7
.600	88.1	69.9	83.0	47.5	64.3	64.9	83.5	55.4	71.8	64.2	84.4	—	92.6
.650	89.1	71.5	82.7	51.5	65.4	66.6	89.0	56.4	80.0	66.5	88.9	—	94.7
.700	89.6	72.8	83.3	54.9	66.8	68.8	90.7	57.6	83.1	69.0	92.3	—	95.4
.800	—	—	84.3	63.1	—	69.6	—	58.0	88.6	70.3	94.9	—	96.8
1.0	—	—	84.1	69.8	70.5	72.0	—	63.1	90.1	72.9	—	—	97.0
1.5	—	—	85.1	79.1	75.0	78.6	—	70.8	93.8	77.7	97.3	—	98.2
2.0	—	—	86.7	82.3	80.4	83.5	—	76.7	95.5	80.6	96.8	91.0	97.8
3.0	—	—	87.4	85.4	86.2	88.7	—	83.0	97.1	88.8	—	93.7	98.1
4.0	—	—	88.7	87.1	88.5	91.1	—	87.8	97.3	91.5	96.9	95.7	98.5
5.0	—	—	89.0	87.3	89.1	94.4	—	89.0	97.9	93.5	97.0	95.9	98.1
7.0	—	—	90.0	88.6	90.1	94.3	—	92.9	98.3	95.5	98.3	97.0	98.5
9.0	—	—	90.6	90.3	92.2	95.6	—	92.9	98.4	95.4	98.0	97.8	98.7
11.0	—	—	90.7	90.2	92.9	95.9	—	94.0	98.4	95.6	98.3	96.6	98.8
14.0	—	—	92.2	90.3	93.6	97.2	—	96.0	97.9	96.4	97.9	—	98.3

TABLE 583.—LONG-WAVE ABSORPTION BY GASES

Unless otherwise noted, gases were contained in a 20-cm long tube.

Gas	Pressure, cmHg	Percentage absorption				
					Long λ, Hg lamp	
		23μ	52μ	110μ		Filtered, 314μ
H_2	76	100	100	100	100	100
Cl_2	76	100	99.6	99.5	98.5	97.6
Br_2	20	100	100	100	100	100
SO_2	76	22.6	76.9	12.7	6	4.8
CO_2	76	100	100	100	100	100
CO	76	100	100	94.1	92.1	91.6
H_2S	76	99.6	11.6	5.4	10.3	21.4
N_2O	76	100	96.8	98.4	93.3	90.8
NO	76	—	94	99	87.3	85.5
$(CN)_2$	76	100	97.8	100	99.3	—

Gas	Pressure, cmHg	Percentage absorption				
					Long λ, Hg lamp	
		23μ	52μ	110μ		Filtered, 314μ
NH_3	76	83.1	.5	99.2	43.3	66.7
CH_4	76	91	94.3	99.2	100	100
C_2H_2	76	99.5	87.4	97.3	97.9	100
C_2H_4	76	99	96.4	92.8	100	100
CS_2	26	97.8	100	100	99.5	100
C_2H_6O	6	85.4	5.4	58	52.4	49.9
$C_4H_{10}O$	51	26.8	46	34	21.8	10.7
C_5H_{12}	46	66 †	44.5	88.8	87	84.2
CH_3Cl	14	98	100	100	95.4	94.7
H_2O *	76	39.6	.7	19.6	33.6	49.2

* Steam 100°C passed through tube 40 cm long, 150°C; 0.06 cm ppt. H_2O.
† Pentane vapor, pressure 36 cmHg.

The radiation used to measure the reflecting factors for the wavelengths given was obtained from the sun's radiation transmitted through selected filters. The radiation from a "pointalight" transmitted through a thin gold filter may be used in place of the sun.

Description	(1.78μ)	(.84μ)	(.61μ)	(.50μ)	Gold film	Computed
Magnesium carbonate	.63	.99	.98	.96	.96	..
Clay tiles						
Dutch: light red	.68	.66	.56	.21	.57	.52
Machine-made: red	.72	.42	.34	.11	.38	.38
red	.55	.38	.31	.11	.34	.33
lighter red	.52	.40	.32	.13	.34	.33
dark purple	.22	.22	.19	.13	.19	.18
Hand-made: red	.60	.47	.37	.12	.40	.39
red brown	.55	.33	.28	.13	.31	.31
Concrete tiles						
Uncolored	.37	.38	.36	.27	.35	.33
Brown	.13	.17	.15	.09	.15	.13
Brown: very rough	.08	.13	.13	.10	.12	.11
Black	.06	.09	.09	.09	.09	.08
Slates						
Dark gray: smooth	.09	.11	.11	.11	.11	.10
fairly rough	.10	.11	.10	.09	.10	.10
rough	.09	.10	.11	.11	.10	.10
Greenish gray: rough	.16	.11	.12	.13	.12	.13
Mauve	.14	.16	.13	.10	.14	.13
Blue gray	.20	.16	.13	.12	.13	.15
Silver gray (Norwegian)	.22	.21	.21	.19	.21	.20
Other roofing materials						
Asbestos cement: white	.35	.42	.41	.36	.41	.39
red	.33	.33	.29	.14	.31	.26
Enamelled steel: white	.35	.53	.53	.57	.52	.52
green	.26	.34	.17	.13	.24	.25
red	.24	.26	.18	.08	.19	.19
blue	.23	.27	.17	.18	.20	.23
Galvanized iron: new	.58	.30	.34	.34	.35	.35
very dirty	.10	.09	.09	.09	.09	.09
whitewashed	.63	.79	.79	.76	.78	.74
Special roofing sheet: brown	.20	.15	.12	.07	.13	.13
green	.13	.20	.12	.12	.14	.15
Bituminous felt	.10	.12	.11	.11	.12	.11
Aluminized felt	.67	.60	.61	.57	.62	.60
Weathered asphalt	.12	.12	.11	.09	.11	.11
Roofing lead: old	.46	.20	.19	.15	.21	.23
Bricks						
Gault: cream	.74	.69	.64	.43	.64	.61
Stock: light fawn	.56	.47	.38	.19	.44	.39
Fletton: light portion	.67	.61	.57	.35	.58	.52
dark portion	.54	.46	.37	.15	.41	.37
Wire cut: red	.56	.48	.41	.15	.44	.39
Sand-lime: red	.41	.37	.30	.11	.32	.30
Mottled purple	.33	.26	.22	.15	.23	.23
Stafford: blue	.21	.12	.11	.08	.11	.12
Lime-clay (French)	.57	.63	.52	.29	.54	.49

TABLE 585.—REFLECTION AND TRANSMISSION OF VARIOUS MATERIALS FOR VERY LONG WAVELENGTHS

With quartz, 1.7 cm thick: 60 to 80μ, absorption very great; 63μ, 99 percent; 82μ, 97.5; 97μ, 83.

Percentage reflection

Wavelength	Iceland spar	Marble	Rock salt	Sylvite	KBr	KI	Fluorite	Glass	Water	Alcohol
$\lambda = 82\mu$ *	—	—	25.8	36.0	82.6	29.6	19.7	—	9.6	—
$\lambda = 108\mu$ †	47.1	43.8	20.3	19.3	31.1	35.5	20.2	19.2	11.6	1.6

Percentage transparency
Uncorrected for reflections

Solid	Thickness	Transparency
Paraffin	3.03	57.0
Mica	.055	16.6
Hard rubber	.40	39.0
Quartz ‖ axis........	2.00	62.6
Quartz, amorph	3.85	0
Rock salt	.21	21.5
Fluorite	.59	5.3
Diamond	1.26	45.3
Quartz ⊥ axis.......	2.00	81.3
" " "	4.03	66.4
" " "	7.26	49.8
" " "	11.74	35.5
" " "	14.66	29.0

Liquid	Thickness	Thickness precipitable liquid	Transparency
Benzene	1.00	—	56.8
Ethyl alcohol ..	.158	—	7.9
Ethyl ether ...	.158	—	37.1
Water	.029	—	25.8
Water	.044	—	13.6
Vapors:			
Alcohol	2.00	.023	88
Ether	2.00	.350	33.5
Benzene	2.00	.063	100
Water	4.00	.21	19.6
CO_2	2.00	—	100

* Restrahlung from KBr. † Isolated with quartz lens.

TABLE 586.—TRANSPARENCY OF BLACK ABSORBERS

(percent)

Method and wavelength		Black silk paper, .025 mm thick	Opaque black paper, .11 mm thick	Black cardboard .4 mm thick	Candle lampblack, 10 cm² = 1.8 mg
Spectrometer	2μ	0	0	0	.5
	4	.9	0	0	8.6
	6	1.7	0	0	16.0
	12	8.2	1.4	0	37.6
Fluorite "reststrahlen" ...	26	24.2	3 2	0	76.7
Rock salt "reststrahlen" ..	52	46.0	15.1	0	91.3
Quartz lens isolation.....	108	61.5	33.5	1.6	91.5

TABLE 587.—RELATIVE REFLECTIVITY OF SNOW, SAND, AND OTHER MATERIALS[173]

	Maine sand *	Florida sand †	Crushed quartz	Snow	Plaster of paris	White paper	Sodium ‡ carbonate	Sodium chloride	White cotton cloth §
.3 to .4μ ...	8	15	40	35	40	8	14	38	26
.4 to .8μ ...	25	40	50	40	53	30	28	49	42
.8 to 2.6μ ...	33	50	53	15	60	30	35	54	40
2.6 to 7μ	31	30	28	18	63	15	18	55	20
7μ	48	..	..	26	..	..	..	..	..

[173] Hulburt, Journ. Opt. Soc. Amer., vol. 17, p. 23, 1928.
* Yellow-white grains of many kinds. † Very white. ‡ Anhydrous. § Handkerchief.

TABLE 588.—PERCENTAGE DIFFUSE REFLECTION FROM MISCELLANEOUS SUBSTANCES

Wave-length μ	Lamp-blacks: Paint	Lamp-blacks: Rosin	Lamp-blacks: Sperm candle	Lamp-blacks: Acetylene	Lamp-blacks: Camphor	Pt black electrol	Green leaves	Lead oxide	Al oxide	Zinc oxide	White paper	Lead carbonate	Asphalt	Black leaves	Black felt	Red brick
.60	3.2						25.	52.	84.	82.		89.	15.	1.8	14.	30.
.95	3.4	1.3	1.1	.6	1.3	1.1			88.	86.	75.	93.			21.	
4.4	3.2	1.3	.9	.8	1.2	1.4		51.	21.	8.	18.	29.		3.7		
8.8	3.8		1.3	1.2	1.6	2.1		26.	2.	3.	5.	11.		2.7		12.
24.0	4.4	3.0	4.0	2.1	5.7	4.2		10.	6.	5.		7.				

TABLE 589.—INFRARED REFLECTIVITY OF TUNGSTEN
(Temperature variation)

Three tungsten mirrors were used—a polished Coolidge X-ray target and two polished flattened wires mounted in evacuated soft-glass bulbs with terminals for heating electrically. Weniger and Pfund, Journ. Franklin Inst.

Wavelength in μ	Absolute reflectivity at room temperature in percent	Percent increase in reflectivity in going from room temperature to 1377°K	1628°K	1853°K	2056°K
.67	51	+6.0	+7.4	+ 8.7	+ 9.8
.80	55	—	—	—	+ 8.2
1.27	70	.0	.0	.0	.0
1.90	83	−6.6	−8.2	− 9.6	−11.0
2.00	85	−7.5	−9.3	−10.9	−12.3
2.90	92	−7.7	−9.4	−11.1	−12.5
4.00	93	—	—	—	−12.5

TABLE 590.—RESTRAHLUNG BANDS FROM VARIOUS MATERIALS[174]
(percent)

Number of reflections	Crystal mirrors	Filter (3 mm paraffin in each case)	Wavelength in μ	Frequency in ∼ /cm
4 ……	Quartz	1 cm KCl	20.7	483
3 ……	Fluorite	5 mm KCl	23	435
1 ……	Metal			
2 ……	Fluorite	3 mm KBr	27.3	366
4 ……	Calcite		29.4	340
3 ……	Fluorite	.4 mm quartz	32.8	305
1 ……	Metal	1.2 mm KBr		
3 ……	Aragonite	.4 mm quartz	41 *	244
1 ……	Metal			
4 ……	NaCl	2 mm quartz	52	192
4 ……	KCl	"	63	159
4 ……	KBr	"	83	120
4 ……	KI	"	94	106
4 ……	TlBr	"	117	85
4 ……	TlI	"	152	66
	Magnesium oxide	"	22.5	444

[174] Strong, Phys. Rev., vol. 38, p. 1818, 1931.
* The use of a paraffin window about 3 mm thick stops the short wavelength restrahlung of quartz at 8.7μ and of calcite at 6.7μ. Weak reflection at 41μ.

TABLE 591.—INFRARED REFLECTING FACTOR OF VARIOUS MATERIALS*

(percent)

	λ = 20μ	25	33⅓	50	66⅔	100	150μ
∼ /cm =	500	400	300	200	150	100	66⅔
Rough brass	67	70	78	83	92	96	100
" "	24	33	42	58	68	81	99
" "	12	14	17	21	25	40	82
Galena	31	30	21	51	73	76	76
Zincite	50	35	18	21	18	20	15
β magnesia, fused	80	60	34	30	30	30	30
Stibnite	21	20	4	39	48	52	39
Sphalerite	10	15	29	20	19	18	17
Corundum	(30)	41	26	31	29	24	22
Cuprite	45	47	47	42	41	42	46

* For reference, see footnote 174, p. 555.

TABLE 592.—INFRARED TRANSMISSION OF VARIOUS MATERIALS*

	λ = 20μ	25	33⅓	50	66⅔	100	150μ
∼ /cm =	500	400	300	200	150	100	66⅔
KBr	..	61	46	3	..	..	..
KI	..	83	76	12	..	..	..
Amorphous SiO_2	3	27	64	63	62	70	87
CCl_4 liquid	(57)	63	50	74	74	(72)	..
KCl	97	97	96	93	80	98	..

* For reference, see footnote 174, p. 555.

TABLES 593-597.—ROTATION OF PLANE OF POLARIZED LIGHT

TABLE 593.—TARTARIC ACID, CAMPHOR, SANTONIN, SANTONIC ACID, CANE SUGAR

A few examples are here given showing the effect of wavelength on the rotation of the plane of polarization. The rotations are for a thickness of one decimeter of the solution. The following symbols are used:

$p =$ number grams of the active substance in 100 g of the solution.
$c =$ " " solvent " " " "
$q =$ " " active " " cm³ "

Right-handed rotation is marked +, left-handed —.

Line of spectrum	Wavelength	Tartaric acid, $C_4H_6O_6$, dissolved in water. $q = 50$ to 95, temp = 24°C	Camphor, $C_{10}H_{16}O$, dissolved in alcohol. $q = 50$ to 95, temp = 22.9°C	Santonin, $C_{15}H_{18}O_3$, dissolved in chloroform $q = 75$ to 96.5, temp = 20°C
B	6867 A			—140°.1 + .2085 q
C	6562	+2°.748 + .09446 q	38°.549 — .0852 q	—149.3 + .1555 q
D	5892	+1.950 + .13030 q	51.945 — .0964 q	—202.7 + .3086 q
E	5269	+ .153 + .17514 q	74.331 — .1343 q	—285.6 + .5820 q
b₁	5183	.. ..	.. ..	—302.38 + .6557 q
b₂	5172	— .832 + .19147 q	79.348 — .1451 q	.. ..
F	4861	—3.598 + .23977 q	99.601 — .1912 q	—365.55 + .8284 q
e	4383	—9.657 + .31437 q	149.696 — .2346 q	—534.98 + 1.5240 q

			Santonin, $C_{15}H_{18}O_3$		
		Santonin, $C_{15}H_{18}O_3$, dissolved in alcohol. $c = 1.782$ temp = 20°C	dissolved in alcohol. $c = 4.046$ temp = 20°C	dissolved in chloroform. $c = 3.1$–30.5 temp = 20°C	Santonic acid, $C_{15}H_{20}O_4$, dissolved in chloroform. $c = 27.192$ temp = 20°C
B	6867	—110.4°	442°	484°	— 49°
C	6562	—118.8	504	549	— 57
D	5892	—161.0	693	754	— 74
E	5269	—222.6	991	1088	—105
b₁	5183	—237.1	1053	1148	—112
b₂	5172	—	—	—	—
F	4861	—261.7	1323	1444	—137
e	4383	—380.0	2011	2201	—197
G	4307	—	—	—	—
g	4226	—	2381	2610	—230

Values obtained at the National Bureau of Standards for the rotation of sucrose are given below.

Light source	Rot λ / Rot λ = 5461 A	$[\alpha]^{20}_{\lambda}$ *	Light source	Rot λ / Rot λ = 5461	$[\alpha]^{20}_{\lambda}$ *
Li 6708	.644	50.45	Cd 4678	1.403	109.9
Cd 6438	.711	55.70	Hg 4358	1.644	128.8
Na 5892.5	.84922	66.529	Ag 4208	1.786	139.9
Hg 5780	.8854	69.36	Hg 4047	1.95	152.8
Hg 5461	1.0000	78.342			
Ag 5209	1.108	86.80			
Cd 5086	1.167	91.43			
Cd 4800	1.323	103.65			

* Degrees per dm. The above values are for a near normal solution, i.e., approximately 26 g of sucrose per 100 cm³.

Sodium chlorate				Quartz					
Spectrum line	Wave-length	Temp °C	Rotation per mm	Spectrum line	Wave-length	Rotation per mm	Spectrum line	Wave-length	Rotation per mm
a	7164 A	15.0	2°068	A	7604	12°668	Cd_9	3609	63°628
B	6870	17.4	2.318	a	7164	14.304	N	3582	64.459
C	6563	20.6	2.599	B	6870	15.746	Cd_{10}	3465	69.454
D	5892	18.3	3.104				O	3441	70.587
E	5270	16.0	3.841	C	6563	17.318			
F	4861	11.9	4.587	D_1	5896	21.684	Cd_{11}	3401	72.448
G′	4340	10.1	5.331	D_2	5890	21.727	P	3360	74.571
G	4308	14.5	6.005				Q	3286	78.579
H	4101	13.3	6.754	E	5270	27.543	Cd_{12}	3247	80.459
L	3820	14.0	7.654	F	4862	32.773			
M	3728	10.7	8.100	G	4308	42.604	R	3180	84.972
N	3581	12.9	8.861				Cd_{17}	2747	121.052
P	3361	12.1	9.801	h	4102	47.481	Cd_{18}	2571	143.266
Q	3287	11.9	10.787	H	3969	51.193	Cd_{23}	2312	190.426
R	3180	13.1	11.921	K	3934	52.155			
T	3021	12.8	12.424				Cd_{24}	2264	201.824
Cd_{17}	2747	12.2	13.426	L	3820	55.625	Cd_{25}	2193	220.731
Cd_{18}	2571	11.6	14.965	M	3728	58.894	Cd_{26}	2143	235.972

TABLE 595.—REFLECTING FACTOR OF METALS (See Table 584)

Wave-length	Al	Sb	Cd	Co	Graphite	Ir	Mg	Mo	Pd	Rh	Si	Ta	Te	Sn	W	Va	Zn
μ								Percents									
.5	—	—	—	—	22	—	72	46	—	76	34	38	—	—	49	57	—
.6	—	53	—	—	24	—	73	48	—	77	32	45	49	—	51	58	—
.8	—	54	—	—	25	—	74	52	—	81	29	64	48	—	56	60	—
1.0	71	55	72	67	27	78	74	58	72	84	28	78	50	54	62	61	80
2.0	82	60	87	72	35	87	77	82	81	91	28	90	52	61	85	69	92
4.0	92	68	96	81	48	94	84	90	88	92	28	93	57	72	93	79	97
7.0	96	71	98	93	54	95	91	93	94	94	28	94	68	81	95	88	98
10.0	98	72	98	97	59	96	—	94	97	95	28	—	—	84	96	—	98
12.0	98	—	99	97	—	96	—	95	97	—	—	95	—	85	96	—	99

The surfaces of some of the samples were not perfect so that the corresponding values have less weight. The following more recent values are given for tungsten and stellite, an exceedingly hard and untarnishable alloy of Co, Cr, Mo, Mn, and Fe (C, Si, S, P).

Wavelength, μ,	.15	.20	.30	.50	.75	1.00	2.00	3.00	4.00	5.00	9.00
Tungsten,	—	—	—	.50	.52	.576	.900	.943	.948	.953	—
Stellite,	.32	.42	.50	.64	.67	.689	.747	.792	.825	.848	.880

TABLE 596.—OPTICAL CONSTANTS OF METALS

Two constants are required to characterize a metal optically, the refractive index, n, and the absorption index, k, the latter of which has the following significance: the amplitude of a wave after traveling one wavelength, λ^1 measured in the metal, is reduced in the ratio 1: $\exp(-2\pi k)$ * or for any distance d 1: $\exp(-2\pi dk/\lambda^1)$, for the same wavelength measured in air this ratio becomes 1: $\exp(-2\pi dnk/\lambda^1)$, nk is sometimes called the extinction coefficient. Plane polarized light reflected from a polished metal surface is in general elliptically polarized because of the relative change in phase between the two rectangular components vibrating in and perpendicular to the plane of incidence. For a certain angle, $\bar{\phi}$ (principal incidence) the change is 90° and if the plane polarized incident beam has a certain azimuth $\bar{\psi}$ (principal azimuth) circularly polarized light results.

$$k = \tan 2\bar{\psi}\,(1 - \cot^2\bar{\phi}) \text{ and } n = \frac{\sin\bar{\phi}\tan\bar{\phi}}{(1+k^2)^{\frac{1}{2}}}\left(1 + \tfrac{1}{2}\cot^2\bar{\phi}\right).$$

(continued)

For rougher approximations the factor in parentheses may be omitted. R = computed percentage reflection.

(The points have been so selected that a smooth curve drawn through them closely indicates the characteristics of the metal.)

Metal	λ	$\bar{\Phi}$	$\bar{\psi}$	Computed			
				n	k	nk	R
	μ						%
Cobalt	.231	64°31′	29°39	1.10	1.30	1.43	32.
	.275	70 22	29 59	1.41	1.52	2.14	46.
	.500	77 5	31 53	1.93	1.93	3.72	66.
	.650	79 0	31 25	2.35	1.87	4.40	69.
	1.00	81 45	29 6	3.63	1.58	5.73	73.
	1.50	83 21	26 18	5.22	1.29	6.73	75.
	2.25	83 48	26 5	5.65	1.27	7.18	76.
Copper	.231	65 57	26 14	1.39	1.05	1.45	29.
	.347	65 6	28 16	1.19	1.23	1.47	32.
	.500	70 44	33 46	1.10	2.13	2.34	56.
	.650	74 16	41 30	.44	7.4	3.26	86.
	.870	78 40	42 30	.35	11.0	3.85	91.
	1.75	84 4	42 30	.83	11.4	9.46	96.
	2.25	85 13	42 30	1.03	11.4	11.7	97.
	4.00	87 20	42 30	1.87	11.4	21.3	
	5.50	88 00	41 50	3.16	9.0	28.4	
Gold	1.00	81 45	44 00	.24	28.0	6.7	
	2.00	85 30	43 56	.47	26.7	12.5	
	3.00	87 05	43 50	.80	24.5	19.6	
	5.00	88 15	43 25	1.81	18.1	33.	
Iridium	1.00	82 10	29 20	3.6	1.60	5.8	
	2.00	84 40	28 10	6.0	1.48	8.9	
	3.00	85 40	26 40	8.0	1.37	11.0	
	5.00	87 20	24 00	12.5	1.13	14.1	
Nickel	.420	72 20	31 42	1.41	1.79	2.53	54.
	.589	76 1	31 41	1.79	1.86	3.33	62.
	.750	78 45	32 6	2.19	1.99	4.36	70.
	1.00	80 33	32 2	2.63	2.00	5.26	74.
	2.25	84 21	33 30	3.95	2.33	9.20	85.
Platinum	1.00	82 00	30 30	3.4	1.82	6.2	
	2.00	84 45	29 40	5.7	1.70	9.7	
	3.00	86 00	28 50	7.7	1.59	12.3	
	5.00	87 15	27 00	11.5	1.37	15.7	
Silver	.226	62 41	22 16	1.41	.75	1.11	18.
	.293	63 14	18 56	1.57	.62	.97	17.
	.316	52 28	15 38	1.13	.38	.43	4.
	.332	52 1	37 2	.41	1.61	.65	32.
	.395	66 36	43 6	.16	12.32	1.91	87.
	.500	72 31	43 29	.17	17.1	2.94	93.
	.589	75 35	43 47	.18	20.6	3.64	95.
	.750	79 26	44 6	.17	30.7	5.16	97.
	1.00	82 0	44 2	.24	29.0	6.96	98.
	1.50	84 42	43 48	.45	23.7	10.7	98.
	2.25	86 18	43 34	.77	19.9	15.4	99.
	3.00	87 10	42 40	1.65	12.2	20.1	
	4.50	88 20	41 10	4.49	7.42	33.3	
Steel	.226	66 51	28 17	1.30	1.26	1.64	35.
	.257	68 35	28 45	1.38	1.35	1.86	40.
	.325	69 57	30 9	1.37	1.53	2.09	45.
	.500	75 47	29 2	2.09	1.50	3.14	57.
	.650	77 48	27 9	2.70	1.33	3.59	59.
	1.50	81 48	28 51	3.71	1.55	5.75	73.
	2.25	83 22	30 36	4.14	1.79	7.41	80.

* See footnote 5, p. 7.

TABLE 597.—OPTICAL CONSTANTS OF METALS (additional data)

Metal	λ	n	k	R
	μ			
Al *	.589	1.44	5.32	83
Sb *	.589	3.04	4.94	70
Bi †‡	white	2.26	—	—
Cd *	.589	1.13	5.01	85
Cr *	.579	2.97	4.85	70
Nb *	.579	1.80	2.11	41
Au †	.257	.92	1.14	28
	.441	1.18	1.85	42
	.589	.47	2.83	82
I crys	.589	3.34	.57	30
Ir *	.579	2.13	4.87	75
Fe §	.257	1.01	.88	16
	.441	1.28	1.37	28
	.589	1.51	1.63	33
Pb *	.589	2.01	3.48	62
Mg *	.589	.37	4.42	93
Mn *	.579	2.49	3.89	64
Hg (liq)	.326	.68	2.26	66
	.441	1.01	3.42	74
	.589	1.62	4.41	75
	.668	1.72	4.70	77
Pd *	.579	1.62	3.41	65
Pt †	.257	1.17	1.65	37
	.441	1.94	3.16	58
	.589	2.63	3.54	59
	.668	2.91	3.66	59
Ni *	.275	1.09	1.16	24
	.441	1.16	1.23	25
	.589	1.30	1.97	43
Rh *	.579	1.54	4.67	78
Se ‡	.400	2.94	2.31	44
	.490	3.12	1.49	35
	.589	2.93	.45	25
	.760	2.60	.06	20
Si *	.589	4.18	.09	38
	1.25	3.67	.08	33
	2.25	3.53	.08	31
Na (liq)	.589	.004	2.61	99
Ta *	.579	2.05	2.31	44
Sn *	.589	1.48	5.25	82
W *	.579	2.76	2.71	49
V *	.579	3.03	3.51	58
Zn *	.257	.55	.61	20
	.441	.93	3.19	73
	.589	1.93	4.66	74
	.668	2.62	5.08	73

λ = wavelength, *n* = refraction index.
k = absorption index, *R* = reflection. Percent.

* Solid. † Electrolytic. ‡ Prism. § Deposited as film in vacuo.

TABLES 598-601.—MEDIA FOR DETERMINATIONS OF REFRACTIVE INDICES WITH THE MICROSCOPE

TABLE 598.—LIQUIDS, n_D (0.589μ) = 1.74 to 1.78

In 100 parts of methylene iodide at 20°C the number of parts of the various substances indicated in the following table form saturated solutions having the refractive indices specified. When ready for use the liquids can be mixed to give intermediate refractions. Commercial iodoform (CHI_3) powder is not suitable, but crystals from a solution of the powder in ether may be used, or the crystallized product may be bought. A fragment of tin in the liquids containing the SnI_4 will prevent discoloration.

CHI_3	SnI_4	AsI_3	SbI_3	S	n_{na} at 20°C
			12		1.764
	25				1.783
	25		12		1.806
	30			6	1.820
	27	13	7		1.826
40	27	16			1.842
	31	14	8	10	1.853
35	31	16	8	10	1.868

TABLE 599.—RESINLIKE SUBSTANCES, n_D (0.589μ) = 1.68 to 2.10

Piperine, an inexpensive alkaloid, comes in very pure straw-colored crystals. Melted, it dissolves the tri-iodides of Sb and As very freely. The solutions are fluid at slightly above 100° and when cold, resinlike. Three parts antimony iodide to one part of arsenic iodide with varying proportions of piperine are easier to manipulate than one containing either iodide alone. In preparing, the constituents, in powder of about 1 mm grain, should be weighed out and then fused *over*, not *in*, a low flame. Three-inch test tubes are suitable.

Percent iodides	00	10	20	30	40	50	60	70	80
Index of refraction......	1.683	1.700	1.725	1.756	1.794	1.840	1.897	1.968	2.050

TABLE 600.—PERMANENT STANDARD RESINOUS MEDIA, n_D (0.589μ) = 1.546 to 1.682

Any proportions of piperine rosin form a homogeneous fusion which cools to a transparent resinous mass. On account of the strong dispersion of piperine the refractive indices of minerals apparently matched with those of mixtures rich in this constituent are 0.005 to 0.01 too low. To correct this error a screen made of a thin film of 7 percent antimony iodide and 93 percent piperine should be used over the eyepiece. Any amber-colored rosin in lumps is suitable.

Percent rosin	00	10	20	30	40	50	60	70	80	90	100
Index of refraction	1.683	1.670	1.657	1.643	1.631	1.618	1.604	1.590	1.575	1.560	1.544

TABLE 601.—SUBSTANCES, n_D = 1.39 to 1.75

	n		n		n
n-Heptane	1.39	Eugenol	1.54	Quinaldine	1.61
Octylene	1.41	Nitrobenzene	1.55	Iodobenzene	1.62
Cyclohexane	1.44	Anethole	1.56	α-Chloronaphthalene	1.63
d-Limonene	1.47	o-Toluidine	1.57	α-Bromonaphthalene	1.66
p-Xylene	1.50	o-Bromophenol	1.58	α-Iodonaphthalene	1.69
Chlorobenzene	1.53	Bromoform	1.59	Methylene iodide	1.75

TABLE 602.—SENSITOMETRIC CONSTANTS OF TYPE PLATES AND FILMS, DEFINITIONS

Density (D).—Density is a measure of the degree of blackening of an exposed film or plate after development. Density is defined in general terms as the logarithm of the ratio of the radiant flux, P_0, incident on the sample to the radiant flux, P_t, transmitted by the sample.

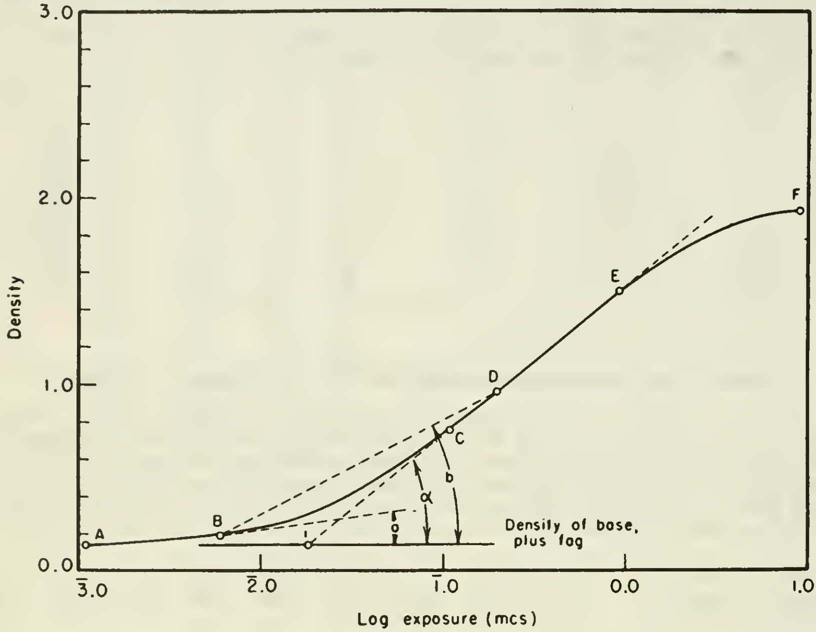

FIG. 27.—Typical characteristic curve. Ordinates are diffuse transmission density (D); abscissae, logs of exposure (log E). A-C = toe, C-E = straight line, E-F = shoulder, B = speed point, B-D = Δlog E = 1.50. Tan $\alpha = \gamma$, Tan $b = \beta$, Tan $a = 0.3\beta$.

$$D = \log\left(\frac{P_o}{P_t}\right)$$

Exposure (E).—$E = It$ (expressed in meter-candle seconds). I = illumination (meter-candles, mc) incident on the photographic material during exposure, t = exposure time in seconds.

Gamma (γ).—Gamma is defined as the tangent of the angle alpha (α) (fig. 27) which the straight-line part of the characteristic curve makes with the log-exposure axis.

Gamma infinity (γ_∞).—γ_∞ is defined as the limiting value to which gamma approaches as development time is increased.

Time of development for the half gamma infinity ($t_\gamma = \gamma_\infty/2$).—A convenient practical specification of development rate of significance in comparing developers.

Time of development for gamma of unity ($t_\gamma = 1.0$).—A convenient practical specification of development rate of significance in comparing photographic materials. Comparisons must be confined to materials in the same developer.

Inertia (i).—i = the value of exposure where the straight-line portion of the characteristic curve (fig. 27) extended cuts the log E axis.

Speed (S_e).—$S_e = 1/E$, where E is the exposure corresponding to point B on the D-log E curve in figure 27. This point is located in the following manner: A log exposure range of 1.50, represented in the figure by the distance along the log exposure axis between B and D, is selected in a region where the slope of the curve at the low end of the range is 0.30 of the average slope over the entire range. When the slope, or tangent of angle a, is 0.30 of the tangent of angle b, the point B, at the low end of the exposure range, represents the exposure value (E) from which the speed of the material is derived.

---

* The material on photography was prepared by L. A. Jones, of the Eastman Kodak Co.

In the determination of the values given in Table 604, developing solutions made up according to the following formulas were used (temperature, 20°C):

Developer A:

Monomethyl para-aminophenol sulfate *	2.0 grams
Sodium sulfite (anhydrous)	50.0 "
Hydroquinone	4.0 "
Sodium carbonate (anhydrous)	6.0 "
Potassium bromide	.75 "
Air-free distilled water to make	1.0 liter

Developer B:

Monomethyl para-aminophenol sulfate *	2.0 grams
Sodium sulfite (anhydrous)	80.0 "
Hydroquinone	4.0 "
Borax	4.0 "
Potassium bromide	.5 "
Air-free distilled water to make	1.0 liter

Developer C:

Water, about 125°F (50°C)	500.0 cc
Monomethyl para-aminophenol sulfate *	2.2 grams
Sodium sulfite (anhydrous)	96.0 "
Hydroquinone	8.8 "
Sodium carbonate, monohydrated	56.0 "
Potassium bromide	5.0 "
Air-free distilled water to make	1.0 liter

* Sold under such trade names as Metol, Elon, Rhodol, and Pictol.

TABLE 604.—SENSITOMETRIC CONSTANTS OF TYPE PLATES AND FILM

Material	Developer	γ_∞	$t_\gamma = \gamma_\infty/2$	$t_\gamma = 1.0$	Reciprocal inertia * (S_i)	Speed (S_c)
Motion-picture films						
Fast panchromatic	B	1.30	10.2	21.5	2300	400
Medium-speed panchromatic	B	1.70	9.8	13.0	1700	250
Fine-grain panchromatic	B	2.00	10.8	10.8	600	100
Positive (regular)	C	3.35	1.5	.9	25	...
Positive (fine-grain)	C	4.30	1.4	.7	5	...
Sheet films and plates						
Fast panchromatic	A	1.45	2.6	5.2	2500	500
Fast orthochromatic	A	1.50	2.0	4.2	1700	400
Medium-speed panchromatic	A	1.50	3.6	6.3	840	200
Medium-speed orthochromatic	A	1.25	2.7	9.9	850	200
Blue-sensitive	A	1.35	2.7	5.7	430	100
Amateur roll films						
Fast panchromatic	A	1.28	2.9	6.6	2500	400
Fast orthochromatic	A	1.25	2.2	5.7	1300	200
Fine-grain panchromatic	A	2.50	5.5	4.2	400	100
Process films and plates						
Panchromatic	C	6.90	3.3	.8	60	...
Orthochromatic	C	5.00	2.00	.7	60	...
Blue-sensitive	C	4.00	2.7	1.7	35	...

* $S_i = 10/i$, where i is the inertia value at $\gamma = 1.0$. Reciprocal inertia was originally proposed by Hurter and Driffield as a sensitometric measure of the speed of photographic materials. It bears no direct relation to their effective speed as determined by camera exposures, however. It is useful for comparing different types of materials which have no common basis of application in practice.

TABLE 605.—COMPARISON OF NUCLEAR AND OPTICAL EMULSIONS

Nuclear track plates differ markedly in physical composition and general characteristics from the ordinary photographic materials (optical type) as shown in the table, where a number of properties of optical and nuclear emulsions are compared.

Property	Optical type	Nuclear type
AgBr: gelatin (wt)	47:53	80:20
AgBr: gelatin (vol)	15:85	45:55
Grain diameter	.5 to 3μ	.1 to .4μ
Emulsion thickness	10μ	25 – 300μ
Emulsion wt mg/cm^2	2 – 4	10 – 80
Sensitivity to light	Very high	Low
Response to α-particles	High	Individual tracks
Response to β-particles	Moderate	Individual tracks
Response to γ-rays	Low	Very low

TABLE 606.—RESOLVING POWER AND EDGE GRADIENT VALUES[175]

Part 1.—Definitions

Resolving power (R).—The resolving power of a photographic material is broadly defined as the ability to record fine detail distinguishably. Any quantitative evaluation depends on the type of detail, and for convenience parallel lines separated by spaces whose width is equal to the common width of the lines are almost universally used.[176] Values are usually given as the number of lines per millimeter that can be resolved visually under adequate magnification.

Resolving power increases with increasing exposure to a maximum and then decreases, It is relatively unaffected by the type of developer, although developers that markedly reduce the grain size improve resolution. As the development time increases from zero, resolving power rises rapidly to a maximum, decreases slightly, and then remains sensibly constant for all practical development times. It increases in a roughly exponential manner as the contrast in the test object increases from zero, becoming substantially constant for contrasts exceeding about 100:1. Its dependence on wavelength is less well known, but in general it increases as wavelength decreases because of the increasing opacity of the emulsion. Although resolving power tends to increase as granularity decreases, this is by no means always the case. The values given in Table 608 apply when the ratio of brightness of the light to the dark lines is 1000: 1 and the test object is photographed with an especially well-corrected $f/5$ lens in tungsten light with the optimum exposure; the materials were developed for practical times in the developer for which the data are given in Table 604.

As thus specified, resolving power is a threshold phenomenon and is not a criterion of the clearness with which gross details will be reproduced. Furthermore, it is of questionable value when the image is to be scanned with a physical photometer because the effect of granularity depends upon the design of the instrument.

Edge gradient (G).—The appearance of sharpness produced by a photographic image probably depends, among other factors, upon the rate of change of density across the edge of the image with distance measured normal to the boundary. The curve of density vs distance resembles the H and D curve, and its gradient, called edge gradient to distinguish it from the gradient of the H and D curve, passes through a maximum with respect to distance. The values of this maximum for the respective materials in density units per micron are given in Table 608. These values were determined with a test object consisting of an extremely sharp, clear line in an opaque background on a high-resolution plate. This test object was pressed firmly against the sample with a contact liquid between and the combination was exposed to light from an $f/5$ lens. The resulting image was scanned with a physical microphotometer having a comparatively narrow slit.

The determinants of edge gradient have been less studied than have the determinants of resolving power, but it is known that the maximum gradient has a maximum with respect to exposure. It would be expected that the maximum gradient would increase in gamma, but present knowledge indicates that it increases less rapidly. The dependence on wavelength has not been studied with modern techniques, but older studies indicate that gradient increases with decreasing wavelength. The values in Table 608 are for $\gamma_\infty/2$ and tungsten light at the optimum exposure.

Both resolving power and edge gradient are inherent properties of the emulsion and are relatively inflexible. It is possible to improve them by bathing the material in dye that absorbs the light to which the emulsion is sensitive, but this is rarely practical because of the concomitant reduction in speed.

[175] Mees, C. E. K., The theory of the photographic process, chap. 21, Macmillan, 1942.
[176] Mees, C. E. K., Proc. Roy. Soc. London, vol. 83, p. 10, 1909.

(*continued*)

TABLE 606.—RESOLVING POWER AND EDGE GRADIENT VALUES (concluded)

Part 2.—Values

Material	Resolving power	Edge gradient ($\times 10^{-2}$)
Motion-picture films:		
Fast panchromatic	95	8
Medium-speed panchromatic	100	9
Fine-grain panchromatic	100	10
Positive (regular)	105	18
Positive (fine-grain)	130	22
Professional sheet films:		
Fast panchromatic	85	11
Fast orthochromatic	100	10
Medium-speed panchromatic	75	10
Medium-speed orthochromatic	75	11
Blue-sensitive	90	10
Amateur roll films:		
Fast panchromatic	95	10
Fast orthochromatic	100	11
Fine-grain panchromatic	105	12
Process films and plates:		
Panchromatic film	125	22
Orthochromate film	130	23
Blue-sensitive plates	110	18
High resolution plates:	approx. 2,500 *	

* This value was obtained by direct exposure to a line interference pattern. With conventional methods of measurement, the value is limited by the optical system rather than by the characteristics of the emulsion.

TABLE 607.—RELATIVE PHOTOGRAPHIC EFFICIENCY OF ILLUMINANTS

Source	Color temperature rating	Photographic efficiency, E_r* Blue sensitive	Ortho-chromatic	Panchromatic
Sun	....	100	100	100
Zenith blue sky	....	700	285	300
Carbon arc, white flame	....	440	220	230
Mercury arc, H-1	....	135	120	90
Mercury arc, H-4	....	225	175	130
Mercury arc, H-6	....	340	245	160
Fluorescent, standard warm white	....	70	70	75
Fluorescent, daylight	....	125	150	120
Incandescent tungsten	2848°	40	50	70
Argon glow lamp	....	21,000	60	35

* E_r = relative photographic efficiency of source evaluated on basis of equal visual intensities.

TABLE 608.—SPECTRAL SENSITIVITY OF PHOTOGRAPHIC MATERIALS

Spectral sensitivity is normally expressed in terms of the reciprocal of the energy (ergs/cm^2) at various wavelengths required to produce a given density under given conditions of development. The curves in figure 28 are shown for a scale of relative sensitivity values, with a value of 10 assigned to the point of maximum sensitivity. The curves should be regarded only as representative of the type of sensitizing for which they were determined and are not suitable for quantitative use. In figure 29 spectral sensitivity data are presented in a different form. Here the wavelengths to which classes of spectroscopic plates are sensitive are shown in a block diagram. No indications are given of the way in which sensitivity varies with wavelength. A solid portion of the block diagram indicates the spectral region for which the class is especially valuable, i.e., where the sensitizing is most effective.

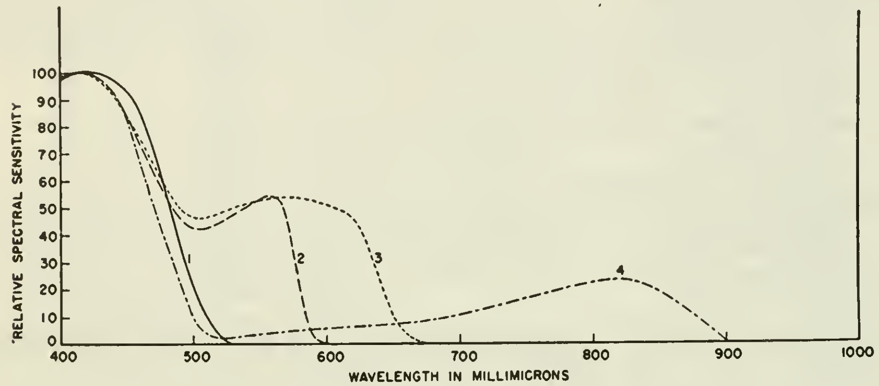

FIG. 28.—Spectral sensitivity curves for typical films: 1, blue sensitive; 2, orthochromatic; 3, panchromatic; 4, infrared sensitive.

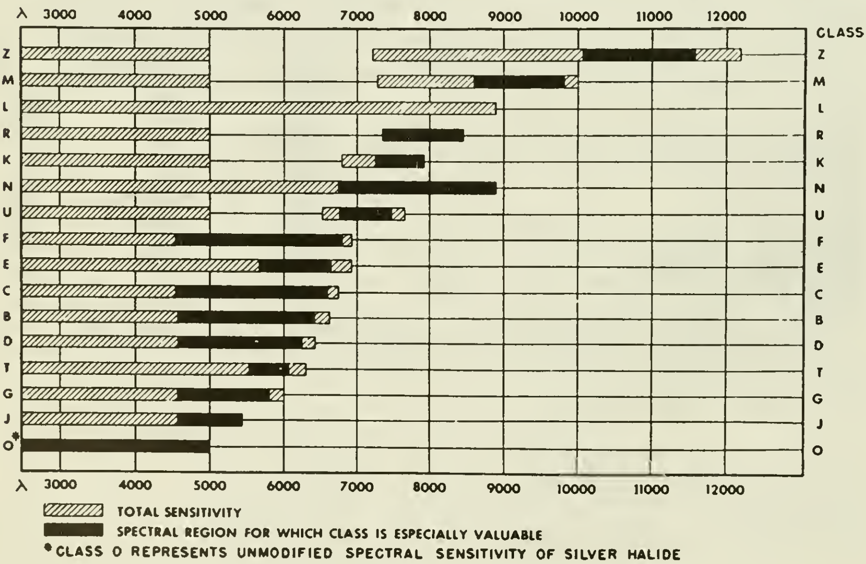

FIG. 29.—The range of spectral sensitivity of kodak spectroscopic plates.

TABLE 609.—NUCLEAR TRACK PLATE SPECIFICATIONS

Nuclear track plates are designed to register the paths of charged particles. The choice of plate depends upon the type of particle to be studied. Nuclear emulsions in general have about the same chemical composition and therefore have fairly uniform stopping power characteristics. The types of nuclear track plates can be divided broadly into four classes, depending upon the purposes for which they are to be used. A general classification of such emulsions for use in nuclear research is listed in the table. The emulsions are classified under the headings, *A*, *B*, *C*, and *D*, in terms of the maximum energy particle that they are capable of registering.

	A	*B*	*C* *	*D*
Nuclear particles recorded	α-particles 200 Mev Protons 10 Mev Deuterons 20 Mev	α-particles 400 Mev Protons 50 Mev Deuterons 100 Mev Electrons .05 Mev	α-particles of any energy Protons 750 Mev Deuterons 1500 Mev π mesons 110 Mev μ mesons 85 Mev Electrons .4 Mev	Nuclear fission fragments of high ionizing power
Sensitivity to light	Low	Moderate	High	Very low
Emulsion thicknesses available	25, 50, and 100μ	10, 50, 100, 150, and 200μ	10, 25, 50, 100, 150, and 200μ	20 and 50μ
Percent weight of AgBr in dry emulsion	81	81	81	65

* Specially fast batches of the general type of plate can be made that register singly charged particles at the minimum of the ionization curve and thus will register particles of any energy value whatsoever.

TABLES 610-625A.—STANDARD WAVELENGTHS [177-192] AND SERIES RELATIONS IN ATOMIC SPECTRA *

Primary standard of wavelength.—The red radiation, 6438.4696 *A,* emitted by a cadmium lamp of Michelson type was first chosen in 1907 by the International Union for Cooperation in Solar Research [177] as a primary standard of wavelength and definition of the angstrom as a unit of wavelength measurement. This primary standard was adopted in 1922 by the International Astronomical Union [178] and in 1927 by the International Committee on Weights and Measures [179] with the statement that the wavelength of this radiation is $6438.4696 \times 10^{-10}$ meters when the light is propagated in dry air at 15°C (hydrogen thermometer) at a pressure of 760 mmHg, gravity being 980.665 cm/sec^2.

Specifications for the standard cadmium lamp were last revised in 1935; [180] they designate that the lamp must be Michelson H-type with internal electrodes, excited with continuous or alternating current of industrial frequency, maintained at a temperature near 300°C (never exceeding 320°C) and contain air under a pressure between 0.7 and 1.0 mmHg at that temperature. The constriction must not be less than 2 mm diameter and the current must not exceed 7 $milliamps/mm^2$.

A summary of nine directly measured values of the wavelength of the red radiation of cadmium in terms of the meter has been given by H. Barrell [181] as in Table 612.

[177-192] For footnotes 177–192, see p. 578.

* Data furnished and arranged by W. F. Meggers, National Bureau of Standards.

TABLE 610.—PRELIMINARY VALUES OF Hg^{198} WAVELENGTHS IN ANGSTROMS

N.B.S. (U.S.A.)	N.P.L. (England)	I.B.W.M. (France)	Mean
5790.6628	5790.6628	5790.6630	5790.6629
5769.5983	5769.5985	5769.5986	5769.5985
5460.7532	5460.7531	5460.7533	5460.7532

International secondary standards of wavelength from neon, krypton, and iron spectra.—Spectroscopic secondary standards of wavelength are derived from the primary standard (Cd 6438.4696 A) by means of the Fabry-Perot interferometer. The existing international secondary standards represent the mean of three or more independent, concordant values adopted by the International Astronomical Union. All values of secondary standards of wavelength are valid for normal air (15°C and 760 mmHg). The most precisely determined secondary standards of wavelength have been obtained from discharge tubes of the Geissler type containing neon or krypton gas at a pressure not exceeding 15 mmHg. In 1935 the International Astronomical Union [183] adopted 8-figure values of 20 neon wavelengths with the reservation that they apply only to the conditions under which they were determined, viz, with interferometers of high resolving power but plate separations not exceeding 40 mm.

[183] For reference, see p. 578.

TABLE 611.—NEON SECONDARY STANDARD WAVELENGTHS IN ANGSTROMS

5852.4878	6074.3377	6266.4950	6532.8824
5881.8950	6096.1630	6304.7892	6598.9529
5944.8342	6143.0623	6334.4279	6678.2764
5975.5340	6163.5939	6382.9914	6717.0428
6029.9971	6217.2813	6506.5279	7032.4127

New values of 20 krypton lines as secondary standards of wavelength were adopted in 1935 by the International Astronomical Union.[184] See Table 614.

[184] For reference, see p. 578.

TABLE 612.—VALUES OF THE WAVELENGTH OF THE CADMIUM RED LINE IN TERMS OF THE INTERNATIONAL METER (Unit = 1×10^{-10} m)

Date of determination	Observers	Original values	Corrected and adjusted values in normal air	Differences from mean: 10^{-10} m	Differences from mean: Parts per 10^6
1892–93	Michelson and Benoît (B.I.P.M.)	6438.4722	6438.4691	—.0005	—.08
1905–06	Benoît, Fabry and Perot (B.I.P.M.)	6438.4696	6438.4703	+.0007	+.11
1927	Watanabe and Imaizumi (Tokyo)	6438.4685	6438.4682	—.0014	—.22
1933	Sears and Barrell (N.P.L.)	6438.4711	6438.4713	+.0017	+.26
1933	Kösters and Lampe (P.T.R.)	6438.4672	6438.4689	—.0007	—.11
1934–35	Sears and Barrell (N.P.L.)	6438.4709	6438.4709	+.0013	+.20
1934–35	Kösters and Lampe (P.T.R.)	6438.4685	6438.4690	—.0006	—.09
1937	Kösters and Lampe (P.T.R.)	6438.4700	6438.4700	+.0004	+.06
1940	Romanova, Varlich, Kartashev, and Batarchukova (Leningrad)	6438.4677	6438.4687	—.0009	—.14
		Mean	6438.4696	±.0009	±.14

The values originally reported (column 3) are corrected (column 4) to take account of subsequent conclusions (a) regarding the values to be attributed to the standards of length employed, and adjusted (b), so far as the available information permits, to uniform standard conditions of dry air at 15°C and 760 mmHg pressure, containing 0.03 percent CO_2. The statistical mean deviation associated with the average value of $6438.4696 \times 10^{-10}$ m derived from these nine determinations amounts to $\pm 0.0010 \times 10^{-10}$ m.

The recent production of purer monochromatic radiation (than the cadmium red line) suggests that eventually another wavelength from a single heavy isotype of even mass number may be adopted as the primary standard of length. Thus, since 1945 many milligrams of Hg^{198} have been made by transmutation of gold in chain-reacting uranium piles. Electrodeless lamps containing Hg^{198} have been made and distributed by the National Bureau of Standards. When excited by ultra-high frequency (> 100 megacycles) and water cooled these lamps emit with high intensity ideally sharp mercury lines. Preliminary measurements, relative to Cd 6438.4696 A, of the yellow and green lines of Hg^{198} have been reported [182] by the National Bureau of Standards, by the National Physical Laboratory, and by the International Bureau of Weights and Measures, as in Table 610.

182 For reference, see p. 578.

TABLE 613.—RESULTANT S VALUES AND TERM MULTIPLICITIES

Number of electrons	S	Term multiplicities
1	1/2	Doublets
2	0, 1	Singlets, triplets
3	1/2, 3/2	Doublets, quartets
4	0, 1, 2	Singlets, triplets, quintets
5	1/2, 3/2, 5/2	Doublets, quartets, sextets
6	0, 1, 2, 3	Singlets, triplets, quintets, septets
7	1/2, 3/2, 5/2, 7/2	Doublets, quartets, sextets, octets
etc.		

TABLE 614.—KRYPTON SECONDARY STANDARD WAVELENGTHS IN ANGSTROMS

4273.9700	4319.5797	4453.9179	5649.5629
4282.9683	4351.3607	4463.6902	5870.9158
4286.4873	4362.6423	4502.3547	5993.8503
4300.4877	4376.1220	5562.2257	6421.029
4318.5525	4399.9670	5570.2895	6456.291

Neon and krypton secondary standards are used extensively for interference measurements in metrology and spectroscopy, but their spectral range and distribution does not make them generally suitable for wavelength measurements by interpolation in prismatic or in grating spectra. For the latter purpose a system of secondary standards should consist of lines of comparable intensity distributed as uniformly as possible throughout the entire range of wavelengths commonly observed in optical spectra. An approach to such a system is found in the internationally adopted secondary standards derived from the spectrum of the iron arc. The source for iron secondary standards is specified[185] as the "Pfund arc operated between 110 and 250 volts, with 5 amperes or less, at a length of 12-15 millimeters used over a central zone at right angles to the axis of the arc, not to exceed 1.0-1.5 millimeters in width, and with an iron rod 6-7 millimeters diameter as the upper pole and a bead of oxide of iron as the lower pole. As the secondary standards to the red of 6000 A are all stable lines, and as the exposures with the above-mentioned arc may be rather long, it is recommended that the 6 mm, 6 ampere arc be retained for this region."

The list of iron secondary standards adopted by the International Astronomical Union[186] consists of 306 7-figure values ranging from 2447.708 to 6677.933 A, thus covering a little more than one octave.

Internal evidence from the combination principle as well as the agreement between independent observers indicates that the average probable error in these standards is ±0.001 A. Preliminary values of long-wave iron lines (6750.158 to 10216.351 A) have been suggested.[187]

Additional ultraviolet iron lines (2100.794 to 3383.980 A) have been suggested[188] and only one or two confirmatory observations are required to extend the secondary standards over a range of more than two octaves.

[185–188] For references, see p. 578.

TABLE 615.—J VALUES FOR LEVELS IN TERMS HAVING ODD AND EVEN MULTIPLICITIES

Terms	Values of J for —					
	Singlets	Doublets	Triplets	Quartets	Quintets	Sextets
S	0	1/2	1	3/2	2	5/2
P	1	1/2, 3/2	0 1 2	1/2, 3/2, 5/2	1 2 3	3/2, 5/2, 7/2
D	2	3/2, 5/2	1 2 3	1/2, 3/2, 5/2, 7/2	0 1 2 3 4	1/2, 3/2, 5/2, 7/2, 9/2
F	3	5/2, 7/2	2 3 4	3/2, 5/2, 7/2, 9/2	1 2 3 4 5	1/2, 3/2, 5/2, 7/2, 9/2, 11/2
G	4	7/2, 9/2	3 4 5	5/2, 7/2, 9/2, 11/2	2 3 4 5 6	3/2, 5/2, 7/2, 9/2, 11/2, 13/2
etc.						

TABLE 616.—TERMS FROM NONEQUIVALENT ELECTRONS

Electrons	Terms (omitting J values)
ss	$^1S, {}^3S$
sp	$^1P, {}^3P$
sd	$^1D, {}^3D$
pp	$^1S, {}^1P, {}^1D, {}^3S, {}^3P, {}^3D$
pd	$^1P, {}^1D, {}^1F, {}^3P, {}^3D, {}^3F$
dd	$^1S, {}^1P, {}^1D, {}^1F, {}^1G, {}^3S, {}^3P, {}^3D, {}^3F, {}^3G$
df	$^1P, {}^1D, {}^1F, {}^1G, {}^1H, {}^3P, {}^3D, {}^3F, {}^3G, {}^3H$
ff	$^1S, {}^1P, {}^1D, {}^1F, {}^1G, {}^1H, {}^1I, {}^3S, {}^3P, {}^3D, {}^3F, {}^3G, {}^3H, {}^3I$
etc.	

TABLE 617.—IRON SECONDARY STANDARDS OF WAVELENGTH IN ANGSTROMS

2447.708	3175.447	3565.381	3767.194	3922.914	4267.830	4647.437	5270.360
2584.536	3178.015	3576.760	3787.883	3927.922	4271.764	4667.459	5307.365
2635.808	3184.896	3581.195	3790.095	3930.299	4282.406	4678.852	5328.534
2679.062	3191.659	3584.663	3795.004	3935.815	4285.445	4691.414	5341.026
2689.212	3196.930	3585.320	3797.517	3940.882	4294.128	4707.281	5371.493
2699.107	3200.475	3586.114	3798.513	3942.443	4298.040	4710.286	5397.131
2723.577	3205.400	3589.107	3799.549	3948.779	4305.455	4733.596	5405.778
2735.475	3215.940	3608.861	3805.345	3956.681	4307.906	4641.533	5429.699
2767.523	3217.380	3617.788	3815.842	3966.066	4315.087	4745.806	5434.527
2778.221	3222.069	3618.769	3824.444	3967.423	4325.765	4772.817	5446.920
2804.521	3225.789	3621.463	3825.884	3969.261	4337.049	4786.810	5455.613
2813.288	3226.223	3631.464	3827.825	4005.246	4352.737	4789.654	5497.519
2823.276	3239.436	3647.844	3834.225	4014.534	4358.505	4859.748	5501.469
2832.436	3244.190	3649.508	3839.259	4045.815	4369.774	4878.218	5506.782
2838.120	3257.594	3651.469	3840.439	4063.597	4375.932	4903.317	5569.625
2851.798	3271.002	3669.523	3841.051	4066.979	4383.547	4918.999	5572.849
2869.308	3284.588	3676.314	3843.259	4067.275	4390.954	4924.776	5586.763
2912.158	3286.755	3677.630	3846.803	4071.740	4404.752	4939.690	5615.652
2929.008	3298.133	3679.915	3849.969	4107.492	4408.419	4966.096	5624.549
2941.343	3340.566	3687.458	3850.820	4114.449	4415.125	4994.133	5658.826
2953.940	3347.927	3695.054	3856.373	4118.549	4422.570	5001.871	5662.525
2957.365	3370.786	3704.463	3859.913	4121.806	4427.312	5012.071	6027.057
2965.255	3396.978	3705.567	3865.526	4127.612	4430.618	5041.759	6075.487
2981.446	3399.336	3719.935	3867.219	4132.060	4442.343	5049.825	6136.620
2987.292	3401.521	3722.564	3872.504	4134.681	4443.197	5051.636	6137.696
2999.512	3407.461	3724.380	3873.763	4143.871	4447.722	5083.342	6191.562
3037.388	3413.135	3727.621	3878.021	4147.673	4454.383	5110.414	6230.728
3047.605	3427.121	3732.399	3878.575	4156.803	4459.121	5123.723	6252.561
3057.446	3443.878	3733.319	3886.284	4170.906	4461.654	5127.363	6265.140
3059.086	3445.151	3734.867	3887.051	4175.640	4466.554	5150.843	6318.022
3067.244	3465.863	3737.133	3888.517	4184.895	4489.741	5167.491	6335.335
3075.721	3476.704	3738.308	3895.658	4202.031	4494.568	5168.901	5393.605
3083.742	3485.342	3748.264	3899.709	4203.987	4517.530	5171.599	6421.355
3091.578	3490.575	3749.487	3902.948	4213.650	4528.619	5198.714	6430.851
3116.633	3497.843	3758.235	3906.482	4216.186	4531.152	5202.339	6494.985
3134.111	3513.820	3760.052	3907.937	4219.364	4547.851	5216.278	6546.245
3157.040	3521.264	3763.790	3917.185	4250.790	4592.655	5227.192	6592.919
3160.658	3558.518	3765.542	3920.260	4260.479	4602.944	5242.495	6663.446
						5250.650	6677.933

Iron tertiary standards of wavelength.—The iron tertiary standards derived from diffraction-grating interpolation between secondary standards, and formerly adopted,[189] have all been superseded by interferometer, or grating interpolated, values published in the M.I.T. Wavelength Tables (John Wiley & Sons, New York, 1939).

Extreme ultraviolet standards of wavelength.—Provisional standards of wavelength in the extreme ultraviolet, measured relative to secondary and tertiary iron standards in overlapping spectral orders, have been published;[190] they include 57 carbon lines (1930.900 to 858.091 A), 23 nitrogen lines (1745.246 to 775.966 A), 25 oxygen lines (1306.038 to 580.974 A), and 10 argon lines (1066.660 to 871.099 A).

Standard solar wavelengths.—The International Astronomical Union[191] has adopted 7-figure standards of wavelength in the solar spectrum when two or more accordant values have been reported. These values have resulted mainly from interferometer measurements of solar-absorption wavelengths relative to neon or to iron secondary standards. The standards represent integrated solar light, are corrected for Doppler-Fizeau displacement, and are valid for standard air at 15°C and 760 mmHg pressure. In the long-wave region many of the solar spectrum standards originate in the terrestrial atmosphere as absorption by oxygen or water vapor.

In Table 618 the + sign following the symbol of an element indicates ionization; a symbol like Fe —, solar line too strong to be due to iron alone; Fe, Co, coincidences of like order; Fe Co, coincidence closer for preceding element; Fe — Co, Fe wavelength smaller, Co larger than solar line; an italicized element indicates a more prominent contribution and boldface a decidedly predominant element.

[189–191] For references, see p. 578.

TABLE 618.—STANDARD SOLAR WAVELENGTHS MEASURED IN AIR AT 15°C AND 1 ATMOSPHERE PRESSURE

λ Solar	Origin	Intensity	λ Solar	Origin	Intensity	λ Solar	Origin	Intensity
3592.027	V +	2	4348.947	Fe	2	4832.719	Ni — Fe	3
3635.469	Ti	4	4365.904	Fe	2	4839.551	Fe	3
3650.538		2	4389.253	Fe	2	4939.694	Fe	3
3672.712	Fe	3	4398.020	Y +	1	4983.260	Fe	3
3695.056	Fe	5	4416.828	Fe +	2	4994.138	Fe	4
3710.292	Y +	3	4425.444	Ca	4	5002.798	Fe	2
3725.496	Fe	3	4430.622	Fe	3	5014.951	Fe	3
3741.065	Ti	4	4439.888	Fe	1	5028.133	Fe	2
3752.418	Fe	3	4451.588	Mn	3	5079.745	Fe	4
3760.537	Fe	4	4454.388	Fe	3	5090.782	Fe	5
3769.994	Fe	4	4459.755	Cr — **V**	1	5109.657	Fe	2
3781.190	Fe	3	4470 485	Ni	2	5150.852	Fe	4
3793.876	Cr Fe	2	4481.616	Fe	1	5159.065	Fe	2
3804.015	Fe	3	4502.221	Mn	2	5198.718	Fe	3
3821.187	Fe	4	4508.289	Fe +	4	5225.534	Fe	2
3836.090	*Ti* + Cr V?	2	4512.741	Ti	3	5242.500	Fe	3
3843.264	Fe	4	4517.534	Fe	3	5253.468	Fe	2
3897.458	Fe —	4	4525.146	Fe	5	5273.389	Fe	3
3906.752	Fe	3	4531.631	Fe	2	5288.533	Fe	2
3916.737	Fe	4	4534.785	Ti	4	5300.751	Cr	2
3937.336	Fe	3	4541.523	Fe +	2	5307.369	Fe	3
3949.959	Fe	5	4547.853	**Fe** Ti	3	5322.049	Fe	3
3953.861	Fe —	3	4548.770	Ti	2	5332.908	Fe	4
3960.284	Fe —	3	4550.773	Fe	2	5348.326	Cr	4
3963.691	Cr	3	4563.766	Ti +	4	5365.407	Fe	4
3977.747	Fe	6	4571.102	Mg	5	5379.581	Fe	3
3991.121	*Cr* — Zr +	3	4571.982	Ti +	6	5389.486	Fe	3
4003.769	Fe — Ti	3	4576.339	Fe +	2	5398.287	Fe —	3
4016.423	Fe	2	4578.559	Ca	3	5409.799	Cr	5
4029.642	**Fe** — Zr +	5	4587.134	Fe	2	5415.210	Fe	5
4030.190	Fe	2	4589.953	Ti +	3	5432.955	Fe —	2
4037.121		2	4598.125	Fe	3	5445.053	Fe	4
4053.824	Ti + Fe	2	4602.008	Fe	3	5462.970	Fe	3
4062.447	Fe	5	4602.949	Fe	6	5473.910	Fe	3
4073.767	Fe	4	4607.654	Fe	4	5487.755	Fe	3
4079.843	Fe	3	4617.276	Ti	3	5501.477	Fe	5
4082.943	Mn	4	4625.052	Fe	5	5512.989	Ca	4
4091.557	Fe	3	4630.128	Fe	4	5525.552	Fe	2
4094.938	Ca	4	4635.853	Fe	2	5534.848	Fe +	2
4107.492	Fe	5	4637.510	Fe	5	5546.514	Fe	2
4120.212	Fe	4	4638 017	Fe	4	5590.126	Ca	3
4136.527	Fe	3	4643.470	Fe	4	5601.286	Ca	3
4139.936	Fe	4	4647.442	Fe	4	5624.558	**Fe** V	4
4154.814	Fe	4	4656.474	Ti	3	5641.448	Fe	2
4163.654	**Ti** + Cr — Fe	5	4664.794	*Cr* Na	3	5655.500	Fe	2
4168.620	Fe Fe + ?	2	4678.172		3 N	5667.524	Fe	2
4178.859	Fe +	3	4678.854	Fe	6	5679.032	Fe	3
4184.900	**Fe, Cr**	4	4683.567	Fe	3	5690.433	Si	3
4191.683	Fe	3	4690.144	Fe	4	5701.557	Fe	4
4198.638	Fe	3	4700.162	Fe	3	5731.772	Fe	4
4208.608	Fe	3	4704.954	Fe	3	5741.856	Fe	2
4220.347	Fe	3	4720.999	Fe	2	5752.042	Fe	4
4233.612	Fe	6	4728.552	Fe	4	5760.841	Ni	2
4241.123	Fe	2	4733.598	Fe	4	5805.226	Ni	4
4246.837	Sc +	5	4735.848	Fe	3	5809.224	Fe	4
4257.661	Mn	2	4736.783	Fe	6	5816.380	Fe	5
4266.968	Fe	3	4741.535	Fe	4	5853.688	Ba +	5
4276.680	**Fe** Ti	2	4745.807	Fe	4	5857.459	Ca	8
4282.412	Fe	5	4772.823	Fe	4	5859.596	Fe	5
4291.472	Fe	2	4788.765	Fe	3	5862.368	Fe	6
4318.659	*Ca* Ti	4	4789.658	Fe	3	5866.461	Ti	3
4331.651	Ni	2	4802.887	Fe	2	5867.572	Ca	2
4337.925	Ti +	4	4824.143	*Cr* + — Fe	3	5892.883	Ni	4

(*continued*)

TABLE 618.—STANDARD SOLAR WAVELENGTHS MEASURED IN AIR AT 15°C AND 1 ATMOSPHERE PRESSURE (continued)

λ Solar	Origin	Intensity	λ Solar	Origin	Intensity	λ Solar	Origin	Intensity
5898.166	Atm	4	6213.437	Fe	6	6455.605	Ca	2
5905.680	Fe	4	6215.149	Fe	3	6456.391	Fe +	3
5916.257	Fe —	3	6216.358	V	1	6471.668	Ca	5
5919.054	Atm	5	6219.287	Fe	6	6475.632	Fe	2
5919.644	Atm	7	6226.740	Fe	1	6482.809	Ni	1
5927.797	Fe	3	6229.232	Fe	1	6493.788	Ca	6
5930.191	Fe	6	6230.736	**Fe** — V	8	6494.994	Fe	8
5932.092	Atm	5	6232.648	Fe	4	6498.945	Fe	1
5934.665	Fe	5	6240.653	Fe	3	6499.654	Ca	4
5946.006	Atm	3	6244.476	Si	2	6516.083	Fe +	2
5952.726	Fe	4	6245.620	Sc +	1	6518.373	Fe	2
5956.706	Fe	4	6246.327	Fe	7	6569.224	Fe	4
5975.353	Fe	3	6247.562	Fe +	2	6592.926	Fe	6
5976.787	Fe	4	6252.565	Fe	7	6609.118	Fe	5
5983.688	Fe	5	6254.253	*Si*Fe	5	6643.638	Ni	6
5984.826	Fe	6	6256.367	FeNi	6	6677.997	Fe	8
6003.022	Fe	6	6258.110	Ti	3	6717.687	Ca	6
6008.566	Fe	6	6258.713	Ti	3	6810.267	Fe	2
6013.497	Mn	6	6265.141	Fe	5	6858.155	Fe	4
6016.647	Mn	6	6270.231	Fe	2	6870.946	Atm O	13
6024.068	Fe	7	6279.101	Atm O	3	6879.928	Atm O	10
6027.059	Fe	4	6279.896	Atm O	2	6918.122	Atm O	8
6042.104	Fe	3	6280.393	Atm O	2	6919.002	Atm O	8
6065.494	Fe	7	6280.622	Fe	3	6923.302	Atm O	6
6078.499	Fe	5	6281.178	Atm O	1	6924.172	Atm O	6
6079.016	Fe	3	6281.956	Atm O	2	6928.728	Atm O	5
6082.718	Fe	1	6283.796	Atm O	1	6934.422	Atm O	3
6085.257	Ti — Fe	2	6289.398	Atm O	1	6959.452	Atm	9
6086.288	Ni	2	6290.221	Atm O	2	6961.260	Atm	11
6089.574	Fe	2	6292.162	Atm O	2	6978.862	Fe	6
6090.216	V	2	6292.958	Atm O	3	6986.579	Atm	8
6093.649	Fe	2	6295.178	Atm O	3	6988.986	Atm	8
6096.671	Fe	3	6295.960	Atm O	3	7022.957	Fe	4
6102.183	Fe	6	6297.799	Fe	5	7023.504	Atm	5
6102.727	Ca	9	6299.228	Atm O	3	7027.478	Atm	5
6111.078	Ni	2	6301.508	Fe	7	7034.910	Si	5
6116.198	Ni	3	6302.499	Fe	5	7122.206	Ni	7
6122.226	Ca	10	6302.764	Atm O	2	7568.906	Fe	5
6127.912	Fe	3	6305.810	Atm O	2	7574.048	Ni	5
6128.984	Ni	1	6306.565	Atm O	2	7586.027	Fe	8
6136.624	Fe	8	6309.886	Atm O	2	7595.770	Atm O_2	12
6137.002	Fe	3	6315.314	Fe	3	7599.462	Atm O_2	0
6137.702	Fe	7	6315.814	Fe	2	7602.995	Atm O_2	0
6141.727	*Ba* + — Fe	7	6318.027	Fe	6	7611.194	Atm O_2	0
6145.020	Si	2	6322.694	Fe	5	7616.980	Ni	8
6149.249	Fe +	2	6327.604	Ni	2	7619.214	Ni	4
6151.623	Fe	4	6330.852	Fe	2	7621.802	Atm O_2	0
6154.230	Na	2	6335.337	Fe	7	7625.354	Atm O_2	1
6157.733	Fe	5	6336.830	Fe	7	7638.306	Atm O_2	3
6161.295	Ca	4	6344.155	Fe	4	7647.202	Atm O_2	1
6162.180	Ca	15	6355.035	Fe	4	7649.553	Atm O_2	—1
6165.363	Fe	2	6358.687	Fe	6	7651.963	Atm O_2	0
6166.440	Ca	5	6378.256	Ni	2	7657.606	Mg	9 N
6169.564	Ca	7	6380.750	Fe	4	7665.944	Atm O_2	10
6170.516	**Fe** — Ni	4	6393.612	Fe	7	7671.669	Atm O_2	10
6173.341	Fe	5	6400.009	Fe	8	7676.565	Atm O_2	9
6175.370	Ni	3	6400.323	Fe	2	7677.619	Atm O_2	9
6176.816	Ni	5	6408.026	Fe	5	7682.758	Atm O_2	8
6180.209	Fe	5	6411.658	Fe	7	7683.802	Atm O_2	8
5186.717	Ni	2	6419.956	Fe	4	7690.218	Atm O_2	6
6187.995	— Fe	4	6421.360	Fe	7	7695.838	Atm O_2	4
6191.571	Fe	9	6430.856	Fe	7	7696.869	Atm O_2	4
6200.321	Fe	6	6449.820	Ca	6	7714.310	Ni	6

(continued)

TABLE 618.—STANDARD SOLAR WAVELENGTHS MEASURED IN AIR AT 15°C AND 1 ATMOSPHERE PRESSURE (continued)

λ Solar	Origin	Intensity	λ Solar	Origin	Intensity	λ Solar	Origin	Intensity
7727.616	Ni	5	8259.692	Atm	8	9073.134	Atm	1
7748.284	Fe	6	8263.445	Atm	7	9074.306	Atm	7
7751.116	Fe	2	8272.042	Atm	8	9092.482	Atm	5
7780.568	Fe	8	8279.600	Atm	9	9105.399	Atm	7
7788.933	Ni	5	8300.408	Atm	10	9118.009	Atm	5
7797.588	Ni	5	8304.300	Atm	6	9132.443	Atm	3
7807.916	Fe? — Fe	4	8311.956	Atm	6	9140.457	Atm	1
7832.208	Fe	9	8316.224	Atm	5	9150.800	Atm	1
7836.130	Al	4 N	8327.061	Fe	10	9175.249	Atm	5
7864.437	Atm	2	8329.682	Atm	8	9178.534	Atm	3
7885.014	*Atm* Ti	1	8333.584	Atm	5	9181.203	Atm	3
7887.117	Atm	3	8342.290	Atm	3	9190.208	Atm	3
7893.512	Atm	4	8349.162	Atm	4	9192.568	Atm	5
7912.870	Fe	2	8357.040	Atm	6	9205.584	Atm	3
7915.634	Atm	3	8362.302	Atm	5	9225.006	Atm	6
7920.666	Atm	7	8367.331	Atm	6	9232.750	Atm	3
7928.618	Atm	7	8376.381	Atm	4	9251.100	Atm	6
7937.150	Fe	7	8394.020	Atm	3	9254.347	Atm	1
7941.096	Fe	2	8397.152	Atm	2	9275.072	Atm	2
7945.858	Fe	7	8426.514	Ti	2	9289.856	Atm	2
7958.492	Atm	7	8434.968	Ti	4	9301.910	Atm	5
7971.522	Atm	4	8439.581	Fe	5	9311.734	Atm	6
7984.342	Atm	4	8468.418	Fe	9	9314.006	Atm	4
7994.488	Fe	3	8471.744	Fe	2	9320.768	Atm	7
8000.300	Atm	6	8514.082	Fe	7	9321.650	Atm	0
8012.940	Atm	4	8515.122	Fe	5	9348.382	Atm	2
8036.460	Atm	3	8526.676	Fe	3	9361.227	Atm	6
8039.600	Atm	3	8556.797	Si	8 N	9363.334	Atm	3
8045.530	Atm	3	8571.807	Fe	2	9374.280	Atm	1
8046.058	Fe	8	8582.271	Fe	6	9400.094	Atm	7
8047.625	Fe	4	8595.968	Si	3 N	9406.904	Atm	6
8063.286	Atm	2	8598.836	Fe	3	9444.412	Atm	5
8075.158	Fe	2	8611.812	Fe	7	9463.992	Atm	3
8096.580	Atm	3	8613.946	Fe	1	9472.418	Atm	1
8103.165	Atm	1	8616.284	Fe	2	9476.754	Atm	4
8107.842	Atm	4	8648.472	Si	10 N	9478.884	Atm	0
8118.910	Atm	2	8674.756	Fe	7	9483.970	Atm	1
8125.445	Atm	3	8699.461	Fe	4	9486.042	Atm	7
8133.209	Atm	2	8713.208	Fe	3	9504.434	Atm	3
8139.718	Atm	3	8717.833	Mg?	7 N	9507.742	Atm	1
8146.213	Atm	5	8747.438	Fe	0	9512.630	Atm	5
8147.188	Atm	5	8773.906	Al	6	9533.411	Atm	4
8165.337	Atm	3	8784.444	Fe	1	9549.958	Atm	2
8169.386	Atm	6	8790.454	**Fe** Si	6	9550.962	Atm	2
8177.932	Atm	7	8793.350	Fe	6	9558.836	Atm	2
8178.491	Atm	4	8824.234	Fe	10	9575.680	Atm	3
8181.848	Atm	9	8866.943	Fe	9	9587.126	Atm	5
8194.836	Na	12 N	8868.444	Fe	3	9598.870	Atm	7
8200.694	Atm	6	8876.030	Fe	1	9601.170	Atm	3
8207.749	Fe	4	8879.316	Atm	4	9624.496	Atm	3
8212.132	Atm	5	8917.506	Atm	1	9629.997	Atm	1
8218.114	Atm	10	8927.392	Ca +	7	9643.105	Atm	3
8221.553	Atm	6	8930.270	Atm	4	9651.932	Atm	2
8225.688	Atm	5	8946.878	Atm	4	9664.646	Atm	6
8229.762	Atm	8	8950.744	Atm	1	9686.386	Atm	3
8233.906	Atm	8	8958.402	Atm	4	9694.588	Atm	0
8234.628	Atm	3	8963.492	Atm	4	9700.139	Atm	2
8237.341	Atm	5	8969.030	Atm	0	9708.922	Atm	6
8239.132	Fe	2	8976.424	Atm	1	9730.638	Atm	4
8239.924	Atm	4	8993.043	Atm	0	9755.979	Atm	0
8248.137	Fe	4	9047.412	Atm	2	9765.495	Atm	4
8248.802	⊙	4	9052.974	Atm	7	9768.637	Atm	2
8252.727	Atm	6	9060.434	Atm	6	9776.818	Atm	3

(*continued*)

TABLE 618.—STANDARD SOLAR WAVELENGTHS MEASURED IN AIR AT 15°C AND 1 ATMOSPHERE PRESSURE (concluded)

λ Solar	Origin	Intensity	λ Solar	Origin	Intensity	λ Solar	Origin	Intensity
9779.406	Atm	5	9803.241	Atm	3	9843.978	Atm	2
9787.146	Atm	3	9821.754	Atm	3	9850.524	Atm	—1
9791.006	Atm	7	9831.960	Atm — Ti	4	9873.638	Atm	4
9795.288	Atm	1	9835.758	Atm	1	9878.200	*Atm* Fe	1
9799.476	Atm	7	9840.092	Atm	—1	9889.050	Fe	5

Prominent lines in simple spectra of elements.—The more prominent lines, in simple spectra, easily excited with high intensity, are universally employed in spectroscopy, refractometry, polarimetry, spectrophotometry, interferometry, and metrology either to calibrate the wavelength scales of dispersing instruments or to make optical measurements at various wavelengths. A brief tabulation of the wavelengths most commonly used for these purposes is given in Table 619, where numerical values of wavelengths and approximate relative intensities by elements are followed by graphical presentation (fig. 30). The spectral range is restricted to that easily observed photographically in air (2000 to 10000 A). Values of wavelengths are quoted from the M.I.T. Wavelength Tables (John Wiley & Sons, New York, 1939) and relative intensities in individual spectra are estimated from arc spectrograms made at the National Bureau of Standards.

TABLE 619.—WAVELENGTHS (IN ANGSTROMS) AND RELATIVE INTENSITIES OF PROMINENT LINES IN SIMPLE SPECTRA

	Wavelength	Intensity		Wavelength	Intensity		Wavelength	Intensity
H	6562.849	200	Mg	5183.618	75	Cu	5782.132	30
	6562.725	100		5172.699	45		5218.202	100
	4861.327	40		5167.343	15		5153.235	30
	4340.465	15		3838.258	75		5105.541	15
	4101.735	5		3832.306	50		4651.134	10
	3970.074	1		3829.350	20		4586.954	8
				2852.129	500		4062.698	25
He	7065.188	40		2802.695	400		4022.657	20
	6678.149	75		2795.53	800		3273.962	400
	5875.618	500					3247.540	800
	5015.675	45	Al	3961.527	500		2961.165	4
	4921.929	25		3944.032	250		2824.369	8
	4713.143	25		3092.713	100		2766.371	15
	4471.477	40		3082.155	50		2618.366	30
	4026.189	20		2660.393	5		2492.146	5
	3888.646	500		2652.489	4		2406.665	5
	3203.14	25		2575.100	10		2392.627	20
	3187.743	50		2567.987	5		2293.842	15
	2945.104	25					2263.079	10
	2733.32	25	A	8521.441	200		2246.995	8
	2511.22	10		8424.647	250		2230.084	4
	2385.42	5		8408.208	300		2225.697	6
				8264.521	150		2199.583	5
Li	8126.52	30		8115.311	400		2192.260	4
	6707.844	900		8103.692	200		2135.976	4
	6103.642	60		8014.786	80			
	4971.990	5		8006.156	60	Zn	4810.534	100
	4602.863	10		7503.867	150		4722.159	60
	4132.29	3		7067.217	300		4680.138	20
	3232.61	4		6965.430	500		3345.572	15
	2741.31	2		6871.290	100		3345.020	80
				6752.832	100		3302.941	15
Na	8194.811	30		6677.282	80		3302.588	40
	8183.270	15		4200.675	50		3282.333	20
	5895.923	500		4158.590	50		3075.901	10
	5889.953	900		4044.418	20		2138.56	950
	5688.224	10		3948.979	20		2061.91	15
	5682.657	6					2025.51	30
	3302.988	10	Cu	8092.634	30			
	3302.323	20		7933.130	15			

(*continued*)

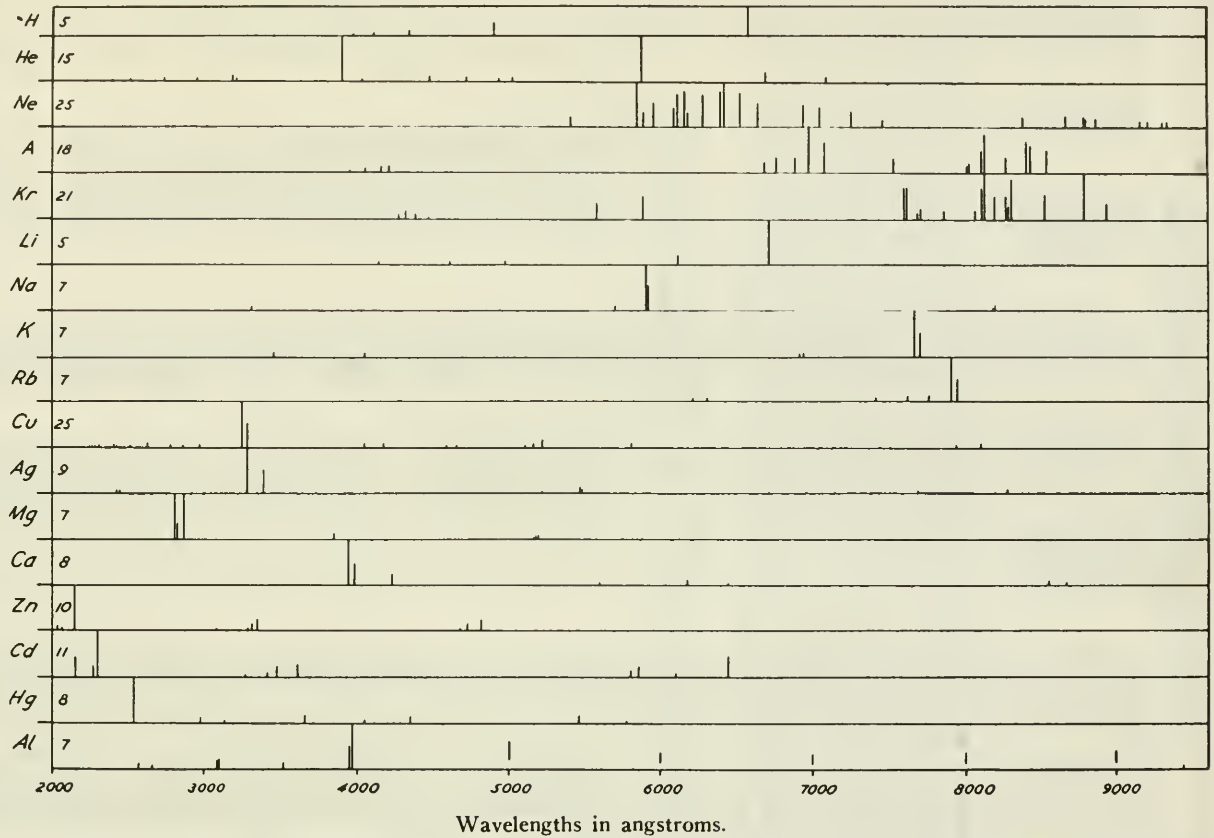

FIG. 30.—Spectra of the elements. Figure gives graphically the positions of some of the more prominent lines in the spectra of some of the elements. Flame spectra are indicated by lines in the lower parts of the panels; arc spectra in the upper parts.

TABLE 619.—WAVELENGTHS (IN ANGSTROMS) AND RELATIVE INTENSITIES OF PROMINENT LINES IN SIMPLE SPECTRA (concluded)

Element	Wavelength	Intensity
Ne	9665.424	100
	9326.52	60
	9300.85	60
	9201.76	60
	9148.68	60
	8853.866	80
	8783.755	100
	8780.622	120
	8654.383	150
	8377.607	80
	7438.899	80
	7245.167	200
	7032.4127	300
	6929.468	300
	6678.2764	400
	6506.5279	600
	6402.246	800
	6382.9914	500
	6266.4950	400
	6163.5939	250
	6143.0623	600
	6096.1630	400
	6074.3377	300
	5944.8342	400
	5881.8950	250
	5852.4878	800
	5400.562	50
Rb	7947.60	400
	7800.227	800
	7757.651	50
	7618.933	50
	7408.170	20
	6298.327	40
	6206.309	30
	6070.751	10
	5724.453	20
	4215.556	100
	4201.851	200
Ag	8273.519	30
	7687.779	15
	5471.551	50
	5465.487	100
	5209.067	50
	3382.891	400
	3280.683	800
	2437.791	4
	2413.184	2
K	7698.979	400
	7664.907	800
	6938.98	8
	6911.30	4
	4047.201	4
	4044.140	8
	3446.722	3
Ca	8662.140	40
	8542.089	80
	6439.073	40
	6162.172	60
	5588.748	50
	4226.728	200
	3968.468	400
	3933.666	800
Cd	6438.4696	200
	6099.18	50
	5085.824	100
	4799.918	60
	3612.875	20
	3610.510	100
	3467.656	20
	3466.201	55
	3403.653	25
	3261.057	20
	2288.018	900
	2265.017	100
	2144.382	200
Kr	9856.24	50
	9751.759	200
	8928.692	200
	8776.749	600
	8508.870	300
	8298.108	500
	8281.049	150
	8263.240	300
	8190.054	300
	8112.902	600
	8104.364	400
	8059.504	150
	7854.821	80
	7694.539	120
	7685.246	100
	7601.544	400
	7587.413	400
	5870.9158	300
	5570.2895	200
	4463.6902	20
	4376.1220	50
	4319.5797	80
	4318.5525	40
	4273.9700	40
Hg	5790.654	10
	5769.59	10
	5460.740	75
	4358.35	50
	4046.561	25
	3650.146	50
	3131.833	10
	3131.546	10
	3125.663	15
	2967.278	30
	2536.519	600

TABLE 620.—WAVELENGTHS OF FRAUNHOFER LINES

For convenience of reference the values of the wavelengths corresponding to the Fraunhofer lines usually designated by the letters in the column headed "Index letter," are here tabulated separately. The letters *x*, *y*, and *Z* were assigned by Abney.[102] Except for D_3, the rest have been taken from Higg's map of the normal solar spectrum. The data in columns 2, 3, and 4 are from the following sources:

For λ > 6600, Babcock, H. D., and Moore, C. E., Carnegie Inst. Washington Publ. 579, 1947.

For λ 3062–6600, Revised Rowland Table, St. John, C. E., et al., Carnegie Inst. Washington Publ. 396, 1928, with additions and corrections by C. E. Moore, unpublished (1949).

For λ < 3062, Babcock, H. D., Moore, C. E., and Coffeen, M. F., Astrophys. Journ., vol. 107, p. 287, 1948 (Mount Wilson Contr. No. 745).

[102] For reference, see p. 578.

(*continued*)

TABLE 620.—WAVELENGTHS OF FRAUNHOFER LINES (concluded)

Index letter	Identification	Solar wavelength	Solar intensity
y	Atm	8987.65	10
x_4	Mg	8806.775	14
x_3	Ca +	8662.170	23
x_2	Ca +	8542.144	25
x_1	Ca +	8498.062	20
Z	Atm	8226.962	(20)
A	Atm O_2	7593.695 *	10
a	Atm	7184.526	8
B	Atm O_2	6867.187 *	4
C	H_α	6562.808	40
α	Atm O_2	6276.607 *	2d
D_1	Na	5895.940	20
D_2	Na	5889.973	30
D_3	{He	5875.650 †	
	He	5875.618 †	
E	{Fe	5270.388	4
	Ca	5270.268	3
	Fe	5269.550	8D
b_1	Mg	5183.619	30
b_2	Mg	5172.698	20
b_3	{Fe +	5169.050	4
	Fe	5168.908	3
b_4	{Fe	5167.508	5
	Mg	5167.328	15
F	H_β	4861.342	30
g	H_γ	4340.475	20N

Index letter	Identification	Solar wavelength	Solar intensity
G	{*Fe* Ti +	4307.912	6
	Ca	4307.747	3
	Ca	4226.740 ‡	20d
h	H_δ	4101.748	40N
H	Ca +	3968.492	700
K	Ca +	3933.682	1000
L	Fe	3820.436	25
M	Fe	3727.634	4
N	Fe	3581.209	30
O	Fe	3441.019	15
P	Ti +	3361.193	8
Q	Fe	3286.772	7N
R	{Ca +	3181.276	3
	Ca +	3179.342	5d?
r	{Fe	3143.996	2
	Ti +	3143.764	4
S_1	{Ni	3101.895	3
	Ni	3101.574	4N
S_2	{Fe	3100.682	3
	Fe	3100.325	4N
	Fe	3099.987	3
	Fe	3099.896	3
s	Fe	3047.614	35
T	{Fe	3021.077	30
	Fe	3020.656	40
	Fe	3020.490	20
t	Fe Ni	2994.436	40

* Band lines due to molecular oxygen in the earth's atmosphere. The wavelength of the first line of the band is recorded here.
† Laboratory wavelengths listed. He lines are conspicuous in the spectrum of the chromosphere.
‡ Rowland assigns the index letter "*g*" to this line.

REFERENCES FOR STANDARD WAVELENGTHS

[177] Trans Int. Union Coop. Solar Res., vol. 2, p. 142, 1907.
[178] Trans. Int. Astron. Union, vol. 1, p. 35, 1922.
[179] Procès Verbaux Comité Int. Poids et Mesures, Ser. 2, vol. 12, p. 67, 1927.
[180] Ibid., vol. 17, p. 91, 1935.
[181] Proc. Roy. Soc. London, vol. A186, p. 164, 1946.
[182] Journ. Opt. Soc. Amer., vol. 38, p. 7, 1948; vol. 40, p. 545, 1950. Comptes Rendus, vol. 228, p. 964, 1949.
[183] Trans. Int. Astron. Union, vol. 5, p. 86, 1935.
[184] Ibid., vol. 5, p. 87, 1935.
[185] Ibid., vol. 1, p. 36, 1922.
[186] Ibid., vol. 3, p. 86, 1928; vol. 4, p. 234, 1932; vol. 6, p. 79, 1938.
[187] Ibid., vol. 5, p. 84, 1935; vol. 7, p. 146, 1949.
[188] Ibid., vol. 6, p. 80, 1938.
[189] Ibid., vol. 1, p. 41, 1922; vol. 2, p. 42, 1925.
[190] Phys. Rev., vol. 47, p. 653, 1935.
[191] Trans. Int. Astron. Union, vol. 3, p. 93, 1928; vol. 6, p. 90, 1938.
[192] Philos. Trans., vol. 177, p. 457, 1886.

Series relations in atomic spectra.—The analysis of atomic spectra began in 1889 when J. R. Rydberg first found that the wave number (number of waves per cm) of a spectral line could be represented as the difference between two numerical quantities that he called spectral terms. From the data of alkali and alkaline-earth spectra Rydberg sorted singlet, doublet, and triplet terms that formed sequences of the form $\frac{R}{(n+\mu)^2}$, where R is Rydberg's constant, n is an integer, and μ a fraction. Rydberg also distinguished between sharp, principal, and diffuse terms; the initial letters *s*, *p*, and *d* survive in spectroscopic notation today. To distinguish between successive terms of a series, cardinal numbers (n) were prefixed to the literal symbols, and to distinguish between the components of doublet and triplet terms numerical subscripts were arbitrarily attached.

Thus the wave numbers of the yellow doublet of sodium were represented symbolically: $\sigma = 1s - 2p_{1,2}$. More than 30 years passed before these arbitrary symbols could be given any atomic interpretation.

The concept of atomic energy levels was first clearly stated in 1913 by N. Bohr who postulated (1) that stationary atomic states exist, and (2) that the frequency of atomic radiation is proportional to the difference between two atomic energy states, $h\nu = (E_1 - E_2)$, the proportionality factor being Planck's constant, h. By 1919 the accumulation of singlet, doublet, and triplet terms found in arc and spark spectra barely sufficed to suggest two general laws of spectral structures: (1) the alternation law which states that even and odd multiplicities alternate in successive columns of the periodic chart of the atoms, and (2) the displacement law which states that the spectrum of an ionized atom resembles that of the preceding atom but the analogous lines are displaced toward higher frequencies. Term multiplicities of atoms or ions are thus determined solely by the number of electrons in the atoms, whereas the atomic charge controls the position of the spectrum. These two facts suggested that electrons and protons were involved in the exegesis of atomic spectra.

The more complex spectra resisted all attempts at interpretation until 1922 when M. A. Catalán deliberately set out to discover a new or more general principle in spectral structure. He found in the arc spectra of chromium and manganese terms having five or six levels which combined to produce groups of lines that he called multiplets. In a few years thousands of terms were found in atomic and ionic spectra, and contemporaneously the present quantum theory of atomic energy levels was developed. As a result of these developments the arbitrary symbols that empirical spectroscopy devised for the yellow doublet of sodium were replaced by the following:

$$\sigma = 3\ {}^2S_{1/2} - 3\ {}^2P^{\circ}_{1/2,\,1\,1/2}$$

Each and every item of this spectroscopic notation now has definite physical meaning in terms of a vector model of the Rutherford-Bohr atom which is assumed to consist of a minute but massive nucleus (composed of protons and neutrons) with one or more electrons circulating about it. The normal number of electrons in any atom is equal to the atomic number, Z: identical with the number of protons in its nucleus.

Spectral lines result from changes in atomic energies defined by the positions of one or more optical electrons in successive shells and by their orbital and axial momenta, each of which is associated with an appropriate quantum number. In general, the first large change in atomic energy occurs when an electron jumps from its normal shell, represented by the principal quantum number n, to another shell. These principal quantum numbers identify the successive shells of the periodic system and serve as coefficients to the spectral term symbols S, P, D, F, etc. If an electron is moved from its lowest value of n to $n = \infty$ the atom is ionized, and the voltage necessary to remove this electron is called the ionization potential. This ionization energy is expressed in wave number (cm^{-1}) or in electron volts (ev) as in Tables 623 and 624. Increasing atomic energies are exhibited in absorption spectra, decreasing energies in emission spectra.

After that due to a change in n, the next largest change in atomic energy is usually one associated with orbital angular momentum symbolized by an azimuthal quantum number l having integral values 0, 1, 2, 3, – – – corresponding respectively to the empirical term symbols S, P, D, F, – – –. Electrons with $l = 0$ are called s-electrons, those with $l = 1$, p-electrons, etc. These four l values and the first seven n values suffice to describe the normal electron configurations of all possible atoms and ions. When two or more optical electrons are present, their individual orbital momenta l_1. l_2 – – – are added vectorially to form a resultant L which is restricted by quantum theory to integral values ranging in the case of two electrons from $l_1 + l_2$ to $|l_1 - l_2|$. The types of spectral terms resulting from various simple configurations of electrons are shown in Table 621.

TABLE 621.—L VALUES AND SPECTRAL TERMS RESULTING FROM TWO ELECTRONS

Electrons	L	Terms
ss	0	*S*
sp	1	*P*
pp	0 1 2	*S P D*
pd	1 2 3	*P D F*
dd	0 1 2 3 4	*S P D F G*
df	1 2 3 4 5	*P D F G H*
ff	0 1 2 3 4 5 6	*S P D F G H I*

(*continued*)

TABLE 621.—L VALUES AND SPECTRAL TERMS RESULTING FROM TWO ELECTRONS (concluded)

A third contribution to the total energy of an atom or ion comes from the rotation of each electron about its own axis. This axial angular momentum is the same for all electrons; it is represented by the spin quantum number $s = \frac{1}{2}$. When two or more electrons are present the individual spin vectors s_1, s_2, – – – combine with each other to yield a resultant S, but (like L) the resultant spin S can take only certain discrete values, the maximum being obtained when all the individual spins are parallel, and the minimum being either one-half or zero according as the number of electrons is odd or even. Electron spins account for the splitting of most spectral terms into two or more components (called levels) and give a physical meaning to the subscripts attached to these levels. These subscripts are called inner quantum numbers; they are symbolized by J to represent the vector sum of L and S. The largest and smallest values of J result from simple addition and subtraction of L and S and all intermediate values of J that differ by integral amounts are allowed:

$$J = (L + S),\ (L + S - 1),$$

when $L > S$ the number of permitted J values is $2S + 1$, which fixes the term multiplicity R and underlies the alternation law, since the maximum multiplicity will be even or odd according as the number of electrons is odd or even. The S values and spectral-term multiplicities associated with numbers of optical electrons are displayed in Table 613.

Because $s = \frac{1}{2}$ for each electron the total angular momentum J of an atom or ion will have integral values for levels belonging to odd multiplicities, and half-integral values for levels if the term multiplicities are even, as shown in Table 615.

TABLE 622.—TERMS FROM EQUIVALENT ELECTRONS

Electrons	Terms (omitting J values)
s^2	^1S
p^2	$^1S, {}^1D, {}^3P$
p^3	$^2P, {}^2D, {}^4S$
d^2	$^1S, {}^1D, {}^1G, {}^3P, {}^3F$
d^3	$^2P, {}^2D, {}^2D, {}^2F, {}^2G, {}^2H, {}^4P, {}^4F$
f^2	$^1S, {}^1D, {}^1G, {}^1I, {}^3P, {}^3F, {}^3H$
etc.	

The actual types and multiplicities of terms arising from various configurations of optical electrons depend on whether the electrons are equivalent or nonequivalent, that is, have the same or different values of n and l. In any atom the maximum number of equivalent electrons is $2(2l + 1)$, and no shell can contain more than two s electrons (s^2), six p electrons (p^6), ten d electrons (d^{10}) or fourteen f electrons (f^{14}). In simple cases the spectral terms arising from nonequivalent electrons may be obtained from the L values of Table 621 and the S values of Table 613, as shown in Table 616.

When the optical electrons are equivalent, the Pauli exclusion principle introduces simplifications, some of which are evident by comparing Tables 616 and 622.

An important consequence of the Pauli principle is that closed shells, in which the maximum number of equivalent electrons is present, have $L = O$ and $S = O$ and therefore may be ignored in deriving the terms given by any electron configuration. Furthermore, any subgroup that lacks one or more electrons to fill the group behaves spectroscopically as if the lacking electrons were present, except that the terms are, in general, regular (smallest J level has least energy) when the group is less than half filled but inverted when more than half filled.

Each configuration (excluding single electrons and closed shells) yields many energy states, and the object of spectrum analysis is to determine (1) the numerical values of the energy levels, (2) the quantum numbers that characterize them, and (3) the electron configurations from which they arise. The wave number of each observed spectral line measures the energy difference between two quantized states of an atom or ion, but, because the same level can in general combine with many others, the number of levels is usually much smaller than the number of classified lines. The combining properties of atomic energy levels are governed by simple rules. Thus all terms or levels of a given atom fall into two groups of different parity called even and odd according as the arithmetical sum of the l values of the optical electrons is even or odd (distinguished by the sign ° and by level value in *italics*), and normally spectral lines are permitted only when terms of different parity combine. Furthermore, an overwhelming majority of the transitions between atomic energy levels obey the following rules:

$$\Delta R = 0$$
$$\Delta L = \pm 1$$
$$\Delta J = 0, \pm 1, \text{ excepting 0 to 0.}$$

In complex spectra, especially of heavy elements, intersystem combinations are observed for $\Delta R = \pm 2, \pm 4$. Likewise, transitions for $\Delta L = 0$ give strong multiplets, and transitions for which $\Delta L = \pm 2, \pm 3$ are observed but usually only faintly. Violations of the ΔJ rule are extremely rare. Assignment of L values and electron configurations to energy levels implicitly assumes that LS coupling or interaction exists among the individual vectors. This means that the individual l vectors are strongly coupled to produce resultant L values of different energies, and the individual s vectors are also strongly coupled to produce resultant S values. These L and S resultants are then less strongly coupled with each other to produce resultant J values. Other types of coupling such as JJ or JL are sometimes met with and in such cases L loses all or most of its significance. Also when the levels of two like-parity configurations overlap or dovetail, it is practically impossible to distinguish the two configurations or choose the levels that belong to each. However, because LS coupling holds for all the higher elements, predominates in many others, and is either accurately or approximately valid for the ground states of all atoms and ions, it is basic for the standardized notation for spectral terms. Thus, any atomic energy level or spectral term is symbolically represented by four quantities. (1) its principal quantum number n written as a coefficient of the term-type symbol; (2) its type—S, P, D, F, etc.—where the capital letters stand for azimuthal quantum numbers or orbital angular momenta $L = 0, 1, 2, 3$, etc., respectively; (3) its inner quantum number or total angular momentum $J = L + S$, written as a subscript to the term-type symbol; and (4) its multiplicity number, $R = 2S + 1$, written as a superior prefix to the term-type symbol. In addition the parity, if the sum of p and f electrons is odd, is indicated by the sign ° attached like an exponent to the term-type symbol.

For any given spectrum in which energy levels have been established, and in which LS coupling exists, it is possible to assign notation as well as electron configuration without ambiguity. Relative values of J are readily determined from the combining properties of the levels and the selection rule, $\Delta J = 0 \pm 1$. In terms of odd multiplicity the absolute value of J is fixed by the absence of the transition 0 to 0 which is forbidden. In other cases the absolute value of J can often be deduced from the sum rule (the sum of the intensities of all the lines of a multiplet that belong to the same initial or final state is proportional to the statistical weight $2J + 1$ of the initial or final state respectively), or from the interval rule (the interval between two successive components, J and $J + 1$, of a polyfold term is proportional to $J + 1$). The most decisive determination of J and L (excepting singlet terms) results from the observation of completely resolved Zeeman patterns since an external magnetic field causes each energy level to be split into $2J + 1$ sublevels and the splitting factors indicate L values.

It is a consequence of atomic structure that long series of spectral terms of the same parity, L, S, J, but increasing n, are observed only in one-electron spectra, as for example to $n = 79$ in the first spectrum of sodium. Five- six- or seven-electrons provide so many configurations and competing levels that it is often exceedingly difficult to detect the second or any higher members of a spectral series.

Quantum principles having thus specified the various spectral terms arising from certain electrons, it became possible in 1925 to determine from identified terms the electron configurations of all atoms and ions. By 1950 the ground states of 82 species of neutral atoms and 75 singly ionized atoms had been uniquely determined from spectral structure. Besides disclosing the ground level and normal electron configuration of each atom or ion, the discovery of series relations in atomic spectra has given exact values for many ionization potentials which measure the forces with which the optical electrons are bound to atoms and ions. Furthermore, since the most intense radiations are usually associated with the largest L and J values of low-lying levels, the analysis of spectra has aided in selecting the strongest spectral lines characteristic of atoms and ions. In general, the strongest lines result from $s \longleftrightarrow p$ electron transitions, but do not necessarily end on the ground state. Because these data are of great importance in spectroscopy, atomic physics, chemistry, and astrophysics, they are collected for neutral atoms in Table 623 and for singly ionized atoms in Table 624.[193]

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[193] For more detailed discussions of atomic spectra and complete compilations of atomic energy levels, see the list of references, page 585.

TABLE 623.—SPECTROSCOPIC PROPERTIES OF NEUTRAL ATOMS

The wavelengths of strongest lines exceeding 2000 A are valid for standard air, the remainder for vacuum.

Period n	Neutral atom	Normal electron configuration	Ground level	Spectral multiplicities	Ionization potential volts	Strongest line, A
1	1 H	$1s^1$	$^2S_{0½}$	2	13.595	1215.66
	2 He	$1s^2$	$^1S_0$	1, 3	24.580	584.33
2	3 Li	$2s^1$	$^2S_{0½}$	2	5.390	6707.85
	4 Be	$2s^2$	$^1S_0$	1, 3	9.320	2348.61
	5 B	$2s^2\,2p^1$	$^2P^\circ_{0½}$	2	8.296	2497.73
	6 C	$2s^2\,2p^2$	$^3P_0$	1, 3	11.264	1657.01
	7 N	$2s^2\,2p^3$	$^4S^\circ_{1½}$	2, 4	14.54	1134.98
	8 O	$2s^2\,2p^4$	$^3P_2$	1, 3, 5	13.614	1302.19
	9 F	$2s^2\,2p^5$	$^2P^\circ_{1½}$	2, 4	17.418	954.80
	10 Ne	$2s^2\,2p^6$	$^1S_0$	1, 3	21.559	735.89
3	11 Na	$3s^1$	$^2S_{0½}$	2	5.138	5889.95
	12 Mg	$3s^2$	$^1S_0$	1, 3	7.644	2852.13
	13 Al	$3s^2\,3p^1$	$^2P^\circ_{0½}$	2	5.984	3961.53
	14 Si	$3s^2\,3p^2$	$^3P_0$	1, 3	8.149	2516.12
	15 P	$3s^2\,3p^3$	$^4S^\circ_{1½}$	2, 4	10.55	1774.94
	16 S	$3s^2\,3p^4$	$^3P_2$	3, 5	10.357	1807.31
	17 Cl	$3s^2\,3p^5$	$^2P^\circ_{1½}$	2, 4	13.01	1347.2
	18 A	$3s^2\,3p^6$	$^1S_0$	1, 3	15.755	1048.22
4	19 K	$4s^1$	$^2S_{0½}$	2	4.339	7664.91
	20 Ca	$4s^2$	$^1S_0$	1, 3	6.111	4226.73
	21 Sc	$3d^1\,4s^2$	$^2D_{1½}$	2, 4	6.538	5671.80
	22 Ti	$3d^2\,4s^2$	$^3F_2$	1, 3, 5	6.818	4981.73
	23 V	$3d^3\,4s^2$	$^4F_{1½}$	2, 4, 6	6.743	4379.24
	24 Cr	$3d^5\,4s^1$	$^7S_3$	1, 3, 5, 7	6.74	4254.35
	25 Mn	$3d^5\,4s^2$	$^6S_{2½}$	2, 4, 6, 8	7.432	4030.76
	26 Fe	$3d^6\,4s^2$	$^5D_4$	1, 3, 5, 7	7.868	3581.20
	27 Co	$3d^7\,4s^2$	$^4F_{4½}$	2, 4, 6	7.862	3453.50
	28 Ni	$3d^8\,4s^2$	$^3F_4$	1, 3, 5	7.633	3414.76
	29 Cu	$3d^{10}4s^1$	$^2S^\circ_{0½}$	2, 4	7.724	3247.54
	30 Zn	$4s^2$	$^1S_0$	1, 3	9.931	2138.56
	31 Ga	$4s^2\,4p^1$	$^2P^\circ_{0½}$	2, 4	6.00	4172.06
	32 Ge	$4s^2\,4p^2$	$^3P_0$	1, 3	7.88	2651.18
	33 As	$4s^2\,4p^3$	$^4S^\circ_{1½}$	2, 4	9.81	1890.43
	34 Se	$4s^2\,4p^4$	$^3P_2$	3, 5	9.750	1960.91
	35 Br	$4s^2\,4p^5$	$^2P^\circ_{1½}$	2, 4	11.84	1488.4
	36 Kr	$4s^2\,4p^6$	$^1S_0$	1, 3	13.996	1235.82
5	37 Rb	$5s^1$	$^2S_{0½}$	2	4.176	7800.23
	38 Sr	$5s^2$	$^1S_0$	1, 3	5.692	4607.33
	39 Y	$4d^1\,5s^2$	$^2D_{1½}$	2, 4	6.377	5466.47
	40 Zr	$4d^2\,5s^2$	$^3F_2$	1, 3, 5	6.835	4687.80
	41 Nb	$4d^4\,5s^1$	$^6D_{0½}$	2, 4, 6	6.881	4058.94
	42 Mo	$4d^5\,5s^1$	$^7S_3$	3, 5, 7	7.131	3798.25
	43 Tc	$4d^5\,5s^2$	$^6S_{2½}$	4, 6, 8	7.23	3636.10
	44 Ru	$4d^7\,5s^1$	$^5F_5$	3, 5, 7	7.365	3498.94
	45 Rh	$4d^8\,5s^1$	$^4F_{4½}$	2, 4	7.461	3434.89
	46 Pd	$4d^{10}$	$^1S_0$	1, 3, 5	8.33	3404.58
	47 Ag	$5s^1$	$^2S_{0½}$	2, 4	7.574	3280.68
	48 Cd	$5s^2$	$^1S_0$	1, 3	8.991	2288.02

(continued)

TABLE 623.—SPECTROSCOPIC PROPERTIES OF NEUTRAL ATOMS (concluded)

Period n	Neutral atom	Normal electron configuration	Ground level	Spectral multiplicities	Ionization potential volts	Strongest line, A
	49 In	$5s^2\,5p^1$	$^2P^\circ_{0\frac{1}{2}}$	2, 4	5.785	4511.32
	50 Sn	$5s^2\,5p^2$	$^3P_0$	1, 3	7.332	3175.04
	51 Sb	$5s^2\,5p^3$	$^4S^\circ_{1\frac{1}{2}}$	2, 4	8.64	2068.38
	52 Te	$5s^2\,5p^4$	$^3P_2$	1, 3, 5	9.01	2142.75
	53 I	$5s^2\,5p^5$	$^2P^\circ_{1\frac{1}{2}}$	2, 4	10.44	1830.4
	54 Xe	$5s^2\,5p^6$	$^1S_0$	1, 3	12.127	1469.62
6	55 Cs	$6s^1$	$^2S_{0\frac{1}{2}}$	2	3.893	8521.10
	56 Ba	$6s^2$	$^1S_0$	1, 3	5.210	5535.55
	57 La	$5d^1\,6s^2$	$^2D_{1\frac{1}{2}}$	2, 4	5.61	6249.93
	58 Ce	...	...	...	...	5699.23
	59 Pr	$4f^3\,6s^2$	$^4I^\circ_{4\frac{1}{2}}$	4	...	4951.36
	60 Nd	$4f^4\,6s^2$	$^5I_4$	5	...	4924.53
	61 Pm	...	...	...	...	...
	62 Sm	$4f^6\,6s^2$	$^7F_4$	7, 9	5.6	4296.75
	63 Eu	$4f^7\,6s^2$	$^8S^\circ_{3\frac{1}{2}}$	6, 8, 10	5.67	4594.02
	64 Gd	$4f^7\,5d^1\,6s^2$	$^9D^\circ_2$	7, 9, 11	6.16	4225.85
	65 Tb	...	...	...	...	...
	66 Dy	...	...	...	...	...
	67 Ho	...	...	...	...	...
	68 Er	...	...	...	...	...
	69 Tm	$4f^{13}6s^2$	$^2F^\circ_{3\frac{1}{2}}$	2	...	5675.83
	70 Yb	$4f^{14}6s^2$	$^1S_0$	1, 3	6.2	3987.99
	71 Lu	$5d^1\,6s^2$	$^2D_{2\frac{1}{2}}$	2	5.0	4518.57
	72 Hf	$5d^2\,6s^2$	$^3F_2$	1, 3, 5	5.5	3682.24
	73 Ta	$5d^3\,6s^2$	$^4F_{1\frac{1}{2}}$	4, 6	7.7	2647.47
	74 W	$5d^4\,6s^2$	$^5D_0$	5, 7	7.98	4008.75
	75 Re	$5d^5\,6s^2$	$^6S_{2\frac{1}{2}}$	4, 6, 8	7.87	3460.47
	76 Os	$5d^6\,6s^2$	$^5D_4$	3, 5, 7	8.7	2909.06
	77 Ir	$5d^7\,6s^2$	$^4F_{1\frac{1}{2}}$	4, 6	9.2	2543.97
	78 Pt	$5d^9\,6s^1$	$^3D_3$	1, 3, 5	8.96	2659.44
	79 Au	$5d^{10}6s^1$	$^2S_{0\frac{1}{2}}$	2	9.223	2427.95
	80 Hg	$6s^2$	$^1S_0$	1, 3	10.434	1849.68
	81 Tl	$6s^2\,6p^1$	$^2P^\circ_{0\frac{1}{2}}$	2	6.106	5350.46
	82 Pb	$6s^2\,6p^2$	$^3P_0$	1, 3	7.415	4057.82
	83 Bi	$6s^2\,6p^3$	$^4S^\circ_{1\frac{1}{2}}$	2, 4	8 ±	3067.72
	84 Po	...	...	...	...	2449.99
	85 At	...	...	...	...	...
	86 Rn	$6s^2\,6p^6$	$^1S_0$	1, 3	10.745	1786.07
7	87 Fr	...	...	...	...	...
	88 Ra	$7s^2$	$^1S_0$	1, 3	5.277	4825.91
	89 Ac	$6d^1\,7s^2$	$^2D_{1\frac{1}{2}}$	2	...	...
	90 Th	$6d^2\,7s^2$	$^3F_2$	3, 5	...	...
	91 Pa	...	...	...	...	...
	92 U	$5f^3\,6d^1\,7s^2$	$^5L^\circ_6$	5, 7	4 ±	5915.40
	93 Np	...	...	...	...	...
	94 Pu	...	...	...	...	...
	95 Am	...	...	...	...	...
	96 Cm	...	...	...	...	...
	97 Bk	...	...	...	...	...
	98 Cf	...	...	...	...	...

TABLE 624.—SPECTROSCOPIC PROPERTIES OF SINGLY-IONIZED ATOMS

The wavelengths of strongest lines exceeding 2000 A are valid for standard air, the remainder for vacuum.

Period n	Ionized atom	Normal electron configuration	Ground level	Spectral multiplicities	Ionization potential volts	Strongest line, A
1	1 H^+	...	...	...	...	...
	2 He^+	$1s^1$	$^2S_{0\frac{1}{2}}$	2	54.403	303.78
2	3 Li^+	$1s^2$	$^1S_0$	1, 3	75.6193	1.99.26
	4 Be^+	$2s^1$	$^2S_{0\frac{1}{2}}$	2	18.206	3130.42
	5 B^+	$2s^2$	$^1S_0$	1, 3	25.149	1362.46
	6 C^+	$2s^2\ 2p^1$	$^2P^\circ_{0\frac{1}{2}}$	2, 4	24.376	1335.71
	7 N^+	$2s^2\ 2p^2$	$^3P_0$	1, 3, 5	29.605	1085.74
	8 O^+	$2s^2\ 2p^3$	$^4S^\circ_{1\frac{1}{2}}$	2, 4	35.146	834.47
	9 F^+	$2s^2\ 2p^4$	$^3P_2$	1, 3, 5	34.98	606.81
	10 Ne^+	$2s^2\ 2p^5$	$^2P^\circ_{1\frac{1}{2}}$	2, 4	41.07	460.73
3	11 Na^+	$2s^2\ 2p^6$	$^1S_0$	1, 3	47.29	372.07
	12 Mg^+	$3s^1$	$^2S_{0\frac{1}{2}}$	2	15.03	2795.53
	13 Al^+	$3s^2$	$^1S_0$	1, 3	18.823	1670.81
	14 Si^+	$3s^2\ 3p^1$	$^2P^\circ_{0\frac{1}{2}}$	2, 4	16.34	1817.0
	15 P^+	$3s^2\ 3p^2$	$^3P_0$	1, 3, 5	19.65	1542.32
	16 S^+	$3s^2\ 3p^3$	$^4S^\circ_{1\frac{1}{2}}$	2, 4	23.4	1259.53
	17 Cl^+	$3s^2\ 3p^4$	$^3P_2$	1, 3, 5	23.80	1071.05
	18 A^+	$3s^2\ 3p^5$	$^2P^\circ_{1\frac{1}{2}}$	2, 4	27.62	919.78
4	19 K^+	$3s^2\ 3p^6$	$^1S_0$	1, 3	31.81	600.77
	20 Ca^+	$4s^1$	$^2S_{0\frac{1}{2}}$	2	11.87	3933.67
	21 Sc^+	$3d^1\ 4s^1$	$^3D_1$	1, 3	12.80	3613.84
	22 Ti^+	$3d^2\ 4s^1$	$^4F_{1\frac{1}{2}}$	2, 4	13.57	3349.41
	23 V^+	$3d^4$	$^5D_0$	1, 3, 5	14.65	3093.11
	24 Cr^+	$3d^5$	$^6S_{2\frac{1}{2}}$	2, 4, 6	16.49	2835.63
	25 Mn^+	$3d^5\ 4s^1$	$^7S_3$	3, 5, 7	15.64	2576.10
	26 Fe^+	$3d^6\ 4s^1$	$^6D_{4\frac{1}{2}}$	2, 4, 6, 8	16.18	2382.04
	27 Co^+	$3d^8$	$^3F_4$	3, 5	17.05	2286.14
	28 Ni^+	$3d^9$	$^2D_{2\frac{1}{2}}$	2, 4	18.15	2216.47
	29 Cu^+	$3d^{10}$	$^1S_0$	1, 3, 5	20.29	2135.98
	30 Zn^+	$4s^1$	$^2S_{0\frac{1}{2}}$	2, 4	17.96	2025 51
	31 Ga^+	$4s^2$	$^1S_0$	1, 3	20.51	1414.44
	32 Ge^+	$4s^2\ 4p$	$^2P^\circ_{0\frac{1}{2}}$	2	15.93	1649.26
	33 As^+	$4s^2\ 4p^2$	$^3P_0$	1, 3	20.2	1266.36
	34 Se^+	$4s^2\ 4p^3$	$^4S^\circ_{1\frac{1}{2}}$	2, 4	21.5	1192.29
	35 Br^+	$4s^2\ 4p^4$	$^3P_2$	1, 3, 5	21.6	1015.42
	36 Kr^+	$4s^2\ 4p^5$	$^2P^\circ_{1\frac{1}{2}}$	2, 4	24.56	917.43
5	37 Rb^+	$4s^2\ 4p^6$	$^1S_0$	1, 3	27.5	741.4
	38 Sr^+	$5s^1$	$^2S_{0\frac{1}{2}}$	2	11.026	4077.71
	39 Y^+	$5s^2$	$^1S_0$	1, 3	12.233	3710.29
	40 Zr^+	$4d^2\ 5s^1$	$^4F_{1\frac{1}{2}}$	2, 4	12.916	3391.98
	41 Nb^+	$4d^4$	$^5D_0$	1, 3, 5	13.895	3094.18
	42 Mo^+	$4d^5$	$^6S_{2\frac{1}{2}}$	4, 6	...	2816.15
	43 Tc^+	$4d^5\ 5s^1$	$^7S_3$	5, 7	...	2543.24
	44 Ru^+	$4d^7$	$^4F_{4\frac{1}{2}}$	2, 4, 6	...	2402.72
	45 Rh^+	$4d^8$	$^3F_4$	3, 5	...	2334.77
	46 Pd^+	$4d^9$	$^2D_{2\frac{1}{2}}$	2, 4	19.9	2296.53
	47 Ag^+	$4d^{10}$	$^1S_0$	1, 3	21.5	2246.41
	48 Cd^+	$5s^1$	$^2S_{0\frac{1}{2}}$	2, 4	16.90	2144.38
	49 In^+	$5s^2$	$^1S_0$	1, 3	18.86	1586.4
	50 Sn^+	$5s^2\ 5p^1$	$^2P^\circ_{0\frac{1}{2}}$	2, 4	14.6	2152.22
	51 Sb^+	$5s^2\ 5p^2$	$^3P_0$	1, 3	19	1606.98
	52 Te^+	$5s^2\ 5p^1$	$^4S_{1\frac{1}{2}}$	2, 4	21.5	1161.52
	53 I^+	$5s^2\ 5p^4$	$^3P_2$	1, 3, 5	19.0	1233.97
	54 Xe^+	$5s^2\ 5p^5$	$^2P^\circ_{1\frac{1}{2}}$	2, 4	21.2	1100.42

(continued)

TABLE 624.—SPECTROSCOPIC PROPERTIES OF SINGLY-IONIZED ATOMS (concluded)

Period n	Ionized atom	Normal electron configuration	Ground level	Spectral multiplicities	Ionization potential volts	Strongest line, A
6	55 Cs^+	$5s^2\,5p^6$	$^1S_0$	1, 3	23.5	926.75
	56 Ba^+	$6s^1$	$^2S_{0\frac{1}{2}}$	2	10.00	4554.04
	57 La^+	$5d^2$	$^3F_2$	1, 3	11.43	3949.10
	58 Ce^+	$4f^2\,6s^1$	$^4H_{3\frac{1}{2}}$	2, 4	...	4186.60
	59 Pr^+	$4f^3\,6s^1$	$^6I^\circ_4$	3, 5	...	4179.42
	60 Nd^+	$4f^4\,6s^1$	$^6I_{3\frac{1}{2}}$	4, 6, 8	...	4303.57
	61 Pm^+	$4f^5\,6s^1$	...	...	...	...
	62 Sm^+	$4f^6\,6s^1$	$^8F_{0\frac{1}{2}}$	6, 8	11.2	3568.27
	63 Eu^+	$4f^7\,6s^1$	$^9S_4$	7, 9	11.24	4205.05
	64 Gd^+	$4f^7\,6s^1\,5d^1$	$^{10}D^\circ_{2\frac{1}{2}}$	6, 8, 10	12 ±	3422.47
	65 Tb^+	...	...	...	...	...
	66 Dy^+	...	...	...	...	...
	67 Ho^+	...	...	...	...	...
	68 Er^+	...	...	...	...	...
	69 Tm^+	$4f^{13}6s^1$	$^3F^\circ_4$	1, 3	...	3848.02
	70 Yb^+	$4f^{14}6s^1$	$^2S_{0\frac{1}{2}}$	2	12.10	3694.20
	71 Lu^+	$6s^2$	$^1S_0$	1, 3	14.7	2615.43
	72 Hf^+	$5d^1\,6s^2$	$^2D_{1\frac{1}{2}}$	2, 4	14.9	2641.41
	73 Ta^+	$5d^3\,6s^1$	$^5F_1$	1, 3, 5	...	2685.17
	74 W^+	$5d^4\,6s^1$	$^6D_{0\frac{1}{2}}$	4, 6	...	2204.49
	75 Re^+	$5d^5\,6s^1$	$^7S_3$	5, 7	...	...
	76 Os^+	...	...	...	...	...
	77 Ir^+	...	...	...	...	...
	78 Pt^+	$5d^9$	$^2D_{2\frac{1}{2}}$	2, 4	18.54	1777.09
	79 Au^+	$5d^{10}$	$^1S_0$	1	20.5	1740.47
	80 Hg^+	$6s^1$	$^2S_{0\frac{1}{2}}$	2, 4	18.751	1649.96
	81 Tl^+	$6s^2$	$^1S_0$	1, 3	20.42	1908.64
8	82 Pb^+	$6s^2\,6p^1$	$^2P^\circ_{0\frac{1}{2}}$	2, 4	15.03	1726.75
	83 Bi^+	$6s^2\,6p^2$	$^3P_0$	3	16.7	1902.41
	84 Po^+	...	...	...	...	...
	85 At^+	...	...	...	...	...
	86 Rn^+	...	...	...	...	...
	87 Fr^+	...	...	...	...	...
7	88 Ra^+	$7s^1$	$^2S_{0\frac{1}{2}}$	2	10.14	3814.42
	89 Ac^+	$7s^2$	$^1S_0$	1, 3	...	...
	90 Th^+	$6d^2\,7s^1$	$^4F_{1\frac{1}{2}}$	2, 4	...	4019.14
	91 Pa^+	...	...	...	...	...
	92 U^+	$5f^3\,7s^2$	$^4I^\circ_{4\frac{1}{2}}$	4, 6	...	3719.29
	93 Np^+	...	...	...	...	...
	94 Pu^+	...	...	...	...	...
	95 Am^+	...	...	...	...	...
	96 Cm^+	...	...	...	...	...
	97 Bk^+	...	...	...	...	...
	98 Cf	...	...	...	...	...

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TABLE 625.—MOLECULAR CONSTANTS OF DIATOMIC MOLECULES*

The energy, E, of a molecule is the sum of three contributions, the electronic energy, E_e, the vibrational energy, E_v, and the rotational energy, E_r, i.e.,

$$E = E_e + E_v + E_r \quad (1)$$

The electronic energy, E_e, gives the largest contribution and is entirely similar to the energy of atoms. Similar to S, P, D states of atoms, one distinguishes Σ, Π, Δ, . . . states of diatomic molecules depending on whether the electronic orbital angular momentum about the internuclear axis is 0, 1, 2 . . . in units of $h/2\pi$. Just as for atoms the resultant electron spin S determines the multiplicity $(2S+1)$ of the electronic state which is added to the term symbol as a left superscript. Σ states are designated Σ^+ or Σ^- depending on whether their eigenfunctions remain unchanged or change sign upon reflection at a plane through the internuclear axis. For molecules with identical nuclei (such as N_2, H_2, O_2, . . .) a subscript g or u indicates whether the eigenfunction upon reflection at the center remains unchanged or changes sign (e.g. ${}^1\Sigma_g^+$, ${}^1\Sigma_u^+$, ${}^1\Pi_g$, . . .).

In each electronic state the molecule may have various amounts of vibrational energy. Quantum mechanics shows that for diatomic molecules the vibrational energy is given by

$$\frac{E_v}{hc} = G(v) = \omega_e (v + \tfrac{1}{2}) - \omega_e x_e (v + \tfrac{1}{2})^2 + \ldots \quad (2)$$

where v is the vibrational quantum number which can assume the values 0, 1, 2, . . . and where ω_e is the (classical) vibrational frequency (in cm^{-1}) for infinitesimal amplitudes. The constant $\omega_e x_e$ is small compared to ω_e and is due to the anharmonicity of the vibration.

If the vibrational energy is increased more and more, a point is reached at which the two atoms fly apart, that is, the molecule is dissociated. The dissociation energy, D_0, corresponds to the maximum of the function $G(v)$ and can in many cases be determined from the spectrum.

In each vibrational level the molecule may have various amounts of rotational energy. For diatomic molecules, in the simplest case (${}^1\Sigma$ state), the rotational energy is given by

$$\frac{E_r}{hc} = F(J) = B_v J (J+1) - \ldots \quad (3)$$

where J is the rotational quantum number which may take the values 0, 1, 2, . . . and where B_v is the so-called rotational constant which is slightly different for different vibrational levels of a given electronic state: one has

$$B_v = B_e - \alpha_e (v + \tfrac{1}{2}) + \ldots \quad (4)$$

Here α_e is small compared to the rotational constant B_e which refers to the equilibrium position. For B_e one finds

$$B_e = \frac{h}{8\pi^2 c\mu r_e^2} \quad (5)$$

Here $\mu = \frac{m_1 m_2}{m_1 + m_2}$ is the reduced mass of the molecule with m_1 and m_2 the masses of the two atoms, and r_e is the internuclear distance in the equilibrium position. The product μr_e^2 is the moment of inertia of the molecule; in other words, B_e, apart from universal constants, is the reciprocal moment of inertia.

Each electronic state of a diatomic molecule is characterized by a certain set of values for the vibrational and rotational constants ω_e, $\omega_e x_e$, . . . , D_0, r_e, B_e, α_e, ... These constants have been determined for a large number of diatomic molecules in various electronic states from the analysis of band spectra. A comprehensive and up-to-date table may be found in "Molecular Spectra and Molecular Structure. I. Spectra of Diatomic Molecules," by G. Herzberg (Van Nostrand. New York, 1950). The following table is an excerpt from the compilation just mentioned, but brought up to date, 1953. Here only the constants ω_e, D_0^0, and r_e for the ground states are listed and the type of the ground state is given. From r_e the rotational constant B_e can be obtained according to the formula (5) given above. D_0^0 corresponds to dissociation into normal atoms. The values are given in ev (electron-volts) where 1 ev corresponds to 8068.3 cm^{-1}. The numbers on the element symbols give the mass numbers of the isotopic species to which the constants refer. When no mass number is given the data refer to the ordinary isotopic mixture. With the exception of the hydrogen molecule in each case only the data for one isotopic species are listed.

More detailed explanation of the underlying theory, the methods of determination of these constants and references for each individual molecule may be found in the book already quoted.

* Prepared by G. Herzberg, National Research Council of Canada.

TABLE 625A.—MOLECULAR CONSTANTS FOR THE GROUND STATES OF DIATOMIC MOLECULES

The following symbols are used: ( ) Constants and symbols in parentheses are uncertain or of low accuracy. [ ] Constants in brackets refer to the lowest vibrational levels rather than to the equilibrium position. Such a value under ω_e is the first vibrational quantum $\Delta G_{1/2} = G(1) - G(0) = \omega_e - 2\omega_e x_e + \ldots$; under r_e it is the effective value r_0 in the lowest vibrational level ($v = 0$), that is, it has been obtained from B_0 rather than B_e. * An asterisk in the column "Type of state" indicates that it is doubtful whether the state whose constants are given is the ground state of the molecule. † A dagger after a value under r_e indicates that it has been obtained from electron diffraction rather than from the spectrum of the molecule. { In a few cases several values of the dissociation energy are compatible with the available data. These values are grouped together by braces.

Molecule	Type of state	ω_e(cm^{-1})	D_0^0(ev)	r_e(Å)
$Ag^{109}Br^{81}$	$(^1\Sigma)$	247.72	2.6	
$Ag^{107}Cl^{35}$	$(^1\Sigma)$	343.6	3.1	
AgH^1	$^1\Sigma^+$	1760.0	2.5	1.617
$Ag^{107}I^{127}$	$(^1\Sigma)$	206.18	2.98	
AgO^{16}	$^2\Sigma^-$	493.2	(1.8)	
$Al^{27}Br^{79}$	$^1\Sigma^+$	378.0	(2.4)	2.295
$Al^{27}Cl^{35}$	$^1\Sigma^+$	481.30	(3.1)	2.14
$Al^{27}F^{19}$	$^1\Sigma^+$	814.5	(2.5)	
$Al^{27}H^1$	$^1\Sigma^+$	1682.57	<3.06	1.6459
$(Al^{27}H^1)^+$	$^2\Sigma^+$	(1610)		1.602
$Al^{27}I^{127}$	$^1\Sigma^+$	316.1	(2.9)	
$Al^{27}O^{16}$	$^2\Sigma^+$	978.2	(<3.75)	1.6176
As_2^{75}	$^1\Sigma_g^+$	429.44	≤ 3.96	
$(As_2^{75})^+$	$(^2\Sigma^+)$	314.8	(2.4)	
$As^{75}N^{14}$	$^1\Sigma^+$	1068.0	(6.5)	
$As^{75}O^{16}$	$^2\Pi$	967.4	≤ 5.0	
$Au^{197}Cl^{35}$	$(^1\Sigma^+)$	382.8	(3.5)	
$Au^{197}H^1$	$^1\Sigma^+$	2305.01	3.1	1.5237
B_2^{11}	$^3\Sigma_g^-$	1051.3	(3.6)	1.589
$BaBr^{79}$	$^2\Sigma^+$	193.8	(2.8)	
$Ba^{138}Cl^{35}$	$^2\Sigma$	279.3	(2.7)	
BaF^{19}	$^2\Sigma$	468.9	(3.8)	
BaH^1	$^2\Sigma^+$	1172	≤ 1.82	2.2318
BaO^{16}	$^1\Sigma$	669.8	4.7	1.940
BaS			(2.3)	
$B^{11}Br^{79}$	$^1\Sigma^+$	684.31	(4.1)	1.89
$B^{11}Cl^{35}$	$^1\Sigma^+$	839.12	(4.2)	1.716
Be^9Cl^{35}	$^2\Sigma^+$	846.58	(4.3)	(1.7)
Be^9F^{19}	$^2\Sigma^+$	1265.6	(5.4)	1.3614
Be^9H^1	$^2\Sigma^+$	2058.6	(2.2)	1.3431
$(Be^9H^1)^+$	$^1\Sigma^+$	2221.7	(3.2)	1.3122
Be^9O^{16}	$^1\Sigma^+$	1487.32	{ (3.7) (3.0)	1.3308
$B^{11}F^{19}$	$^1\Sigma^+$	1400.6	(4.3)	1.262
$B^{11}H^1$	$^1\Sigma^+$	(2366)	<3.51	1.2325
$(B^{11}H^1)^+$	$^2\Sigma^+$	(2435)		[1.2146]
Bi_2^{209}	$^1\Sigma_g^+$	172.71	1.70	
$Bi^{209}Br^{79}$		209.34	2.74	
$Bi^{209}Cl^{35}$		308.0	(3.0)	
$Bi^{209}F^{19}$		510.7	(3.2)	
$Bi^{209}H^1$	(0^+)	1698.9	(2.7)	1.809
$Bi^{209}I^{127}$		163.9	(2.7)	
$Bi^{209}O^{16}$		702.1	(2.9)	
$B^{11}N^{14}$	$^3\Pi$ *	1514.6	(5.0)	1.281
$B^{11}O^{16}$	$^2\Sigma^+$	1885.44	(9.1)	1.2049
$Br^{79}Br^{81}$	$^1\Sigma_g^+$	323.2	1.971	2.284
BrCl	$^1\Sigma^+$	[430]	2.138	
$Br^{79}F^{19}$	$^1\Sigma^+$	673	2.16	1.75555
BrO^{16}	*	713	(2.2)	
C_2^{12}	$^3\Pi_u$	1641.35	(3.6)	1.3117
$CaBr^{79}$	$^2\Sigma^+$	285.3	(2.9)	
$CaCl^{35}$	$^2\Sigma^+$	369.8	≤ 2.76	(1.86_6)
$Ca^{40}F^{19}$	$^2\Sigma^+$	587.1	≤ 3.15	([2.02])
$Ca^{40}H^1$	$^2\Sigma$	1299	≤ 1.70	2.0020

(continued)

TABLE 625A.—MOLECULAR CONSTANTS FOR THE GROUND STATES OF DIATOMIC MOLECULES (continued)

Molecule	Type of state	$\omega_e(\text{cm}^{-1})$	$D_0^0(\text{ev})$	$r_e(\text{Å})$
$(Ca^{40}H^{1})^{+}$				[1.73]
CaI^{127}	$(^2\Sigma)$	242.0	(2.8)	
$Ca^{40}O^{16}$	$^1\Sigma$ *	732.1	5.0	1.822
CaS			≦5.2	
$C^{12}Cl^{35}$	$^2\Pi$	846		
Cd_2			.087	
CdBr	*	230.0	(3.3)	
$CdCl^{35}$	$^2\Sigma$	330.5	(2.8)	
CdF^{19}	$(^2\Sigma)$	(535)		
CdH^{1}	$^2\Sigma^+$	1430.7	.678	1.762
$(CdH^{1})^{+}$	$^1\Sigma^+$	1775.4	(2.0)	1.667
CdI^{127}	$^2\Sigma$	178.5	(1.6)	
CdS			≦3.9	
CdSe			≦3.2	
CeO^{16}	*	865.0	(7.7)	
CF	$^2\Pi$	1308.4	(4.8)	1.27
$C^{12}H^{1}$	$^2\Pi$	2861.6	3.47	1.1198
$(C^{12}H^{1})^{+}$	$^1\Sigma^+$	[2739.54]	3.6	1.13083
Cl_2^{35}	$^1\Sigma_g^+$	564.9	2.475	1.988
$(Cl_2^{35})^{+}$	$^2\Pi$ *	645.3	(4.4)	1.891
$Cl^{35}F^{19}$	$^1\Sigma$	786.3	2.616	1.62813
ClO^{16}	*	(780)	1.9	
$C^{12}N^{14}$	$^2\Sigma^+$	2068.70		1.1718
$C^{12}O^{16}$	$^1\Sigma^+$	2170.21	{ 11.108 9.844 9.605	1.1282
$(C^{12}O^{16})^{+}$	$^2\Sigma^+$	2214.24	(9.9)	1.1151
CoCl	*	421.2		
CoH^{1}	$\Omega = 4$	(1890)		[1.542]
CoO^{16}	*	(850)		
$C^{12}P^{31}$	$^2\Sigma^+$	1239.67	(6.9)	1.562
CrO^{16}	*	898.8	4.4	
$C^{12}S^{32}$	$^1\Sigma^+$	1285.1	(7.8)	1.534
Cs_2^{133}	$^1\Sigma_g^+$	41.990	.45	
$Cs^{133}Br$	$^1\Sigma^+$	(194)	≧3.9	[3.14] †
$Cs^{133}Cl$	$^1\Sigma^+$	299		2.88
$C^{12}Se$	$^1\Sigma^+$	1036.0	(6.8)	
CsF^{19}	$^1\Sigma^+$	(270)	5.67	2.34
$Cs^{133}H^{1}$	$^1\Sigma^+$	890.7	(1.9)	2.494
$Cs^{133}I^{127}$	$^1\Sigma^+$	142	3.37_7	[3.41] †
CsRb		49.4		
Cu_2	$(^1\Sigma_g^+)$	160	(.17)	
$Cu^{63}Br^{79}$	$^1\Sigma^+$	314.10	(2.5)	
$Cu^{63}Cl^{35}$	$^1\Sigma^+$	416.9	(3.0)	
$Cu^{63}F^{19}$	$^1\Sigma^+$	622.7	(3.0)	1.743
$Cu^{63}H^{1}$	$^1\Sigma^+$	1940.4	<2.89	1.463
$(Cu^{63}H^{1})^{+}$	$^2\Sigma$	[1874]		[2.27]
$Cu^{63}I^{127}$	$^1\Sigma^+$	264.8	(3.0)	
CuO^{16}	$(^2\Sigma^+)$	628	4.9	
F_2^{19}	$^1\Sigma_g^+$	$[892._1]$	<1.63	1.418 †
$FeCl^{35}$	$^6\Sigma$ *	406.6		
FeO^{16}		880	≦4.24	
$Ga^{69}Br^{81}$	$^1\Sigma^+$	263.0	(2.7)	
$Ga^{69}Cl^{35}$	$^1\Sigma^+$	365.3	≦5.0	[2.21]
$Ga^{69}F^{19}$	$^1\Sigma^+$	623.2	(6.3)	
$Ga^{69}I^{127}$	$^1\Sigma^+$	216.4	≦2.88	
GaO^{16}	$^2\Sigma$	767.69	(2.9)	
GdO^{16}	*	841.0	(5.9)	
GeBr	$^2\Pi$	296.6	(3.0)	
$Ge^{74}Cl^{35}$	$^2\Pi$	406.6	(4.0)	
GeF^{19}	$^2\Pi$	$665._2$	(4.9)	
$Ge^{74}O^{16}$	$^1\Sigma^+$	985.7	(6.9)	1.651
$Ge^{74}S^{32}$	$^1\Sigma^+$	575.8	(5.6)	

(continued)

TABLE 625A.—MOLECULAR CONSTANTS FOR THE GROUND STATES OF DIATOMIC MOLECULES (continued)

Molecule	Type of state	ω_e(cm⁻¹)	D_0^0(ev)	r_e(Å)
$Ge^{74}Se^{80}$	$^1\Sigma^+$	406.8	(4.1)	
$Ge^{74}Te^{130}$	$^1\Sigma^+$	323.4	(3.2)	
H_2^1	$^1\Sigma_g^+$	4395.2	4.476	$.7416_6$
H^1H^2	$^1\Sigma_g^+$	3809.7	4.511	$.7414_9$
H^2H^3	$^1\Sigma_g^+$	2853.8	4.570	(0.7416_6)
H_2^2	$^1\Sigma_g^+$	3118.5	4.554	$(.7416_6)$
H^1H^3	$^1\Sigma_g^+$	3608.3	4.524	$(.7416_6)$
H_2^3	$^1\Sigma_g^+$	2553.8	4.588	$(.7416_6)$
$(H_2^1)^+$	$^2\Sigma_g^+$	2297	2.648	1.06
H^1Br	$^1\Sigma^+$	2649.67	3.75	1.414
$(H^1Br)^+$	$^2\Pi_i$		3.5	[1.459]
H^1Cl^{35}	$^1\Sigma^+$	2989.74	4.430	1.27460
$(H^1Cl^{35})^+$	$^2\Pi_i$	2675.4	4.48	1.3153
He_2^4	$^1\Sigma_g^+$	unstable		
$(He_2^4)^+$	$^2\Sigma_u^+$	[1627.2]	(3.1)	1.08
H^1F^{10}	$^1\Sigma^+$	4138.52	5.8	.9171
Hg_2	$^1\Sigma_g^+$	(36)	.060	3.3
$Hg^{202}Br^{81}$	$(^2\Sigma)$	186.2	.7	
$HgCl^{35}$	$^2\Sigma^+$	292.61	1.0	[2.23] †
HgF^{19}	$(^2\Sigma)$	490.8	(1.8)	
HgH^1	$^2\Sigma^+$	1387.09	.376	1.7404
$(HgH^1)^+$	$^1\Sigma^+$	2033.87	(2.3)	1.594
HgI^{127}	$(^2\Sigma)$	125.6	.36	
HgS			≤2.8	
HgSe			≤2.7	
HgTl		26.9	(.031)	
H^1I^{127}	$^1\Sigma^+$	2309.5	3.056	1.604
$(H^1I^{127})^+$			3.11	
H^1S^{32}	$^2\Pi_i$		<3.8	[1.35]
I_2^{127}	$^1\Sigma_g^+$	214.25	1.5417	2.667
$I^{127}Br^{79}$	$^1\Sigma^+$	268.4	1.817	
$I^{127}Cl^{25}$	$^1\Sigma^+$	384.18	2.152	2.32070
$I^{127}F^{10}$	$^1\Sigma^+$	610	1.98	
$In^{115}Br^{81}$	$^1\Sigma^+$	221.0	≤3.3	[2.57] †
$In^{115}Cl^{35}$	$^1\Sigma^+$	317.4	≤4.54	2.32
$In^{115}F^{19}$	$^1\Sigma^+$	534.7	(5.7)	
$In^{115}H^1$	$^1\Sigma^+$	1474.7	≤2.48	1.8376
$In^{115}I^{127}$	$^1\Sigma^+$	177.1	≤2.7	[2.86] †
InO^{16}	$(^2\Sigma)$ *	703.09	(1.3)	
$I^{127}O^{16}$	*	687	(1.9)	
K_2^{39}	$^1\Sigma_g^+$	92.64	.514	3.923
KBr	$^1\Sigma^+$	231	3.96	[2.94] †
KCl	$^1\Sigma^+$	280	4.42	[2.79] †
KF^{19}	$^1\Sigma^+$	(390)	≤5.9	[2.55]
$K^{39}H^1$	$^1\Sigma^+$	985.0	1.8_6	2.244
KI^{127}	$^1\Sigma^+$	212	3.33	[3.23] †
$La^{139}O^{16}$	$^2\Sigma$	811.6	(9)	
Li_2^7	$^1\Sigma_g^+$	351.43	1.03	2 672
LiBr	$^1\Sigma^+$		4.5	
LiCl	$^1\Sigma^+$		5.1	
Li^7Cs^{133}	$^1\Sigma^+$	(167)		
LiF^{19}			≤6.6	
Li^7H^1	$^1\Sigma^+$	1405.65	(2.5)	1.5953
LiI^{127}	$^1\Sigma^+$	450	3.6	
LiK	$^1\Sigma^+$	(207)		
LiRb	$^1\Sigma^+$	(185)		
LuO^{16}		841.66	(5.3)	
$Mg^{24}Br^{79}$	$(^2\Sigma)$	373.8	≤3.35	
$Mg^{24}Cl^{35}$	$^2\Sigma^+$	465.4	(3.2)	
$Mg^{24}F^{19}$	$^2\Sigma^+$	717.6	(4.2)	[1.75]
$Mg^{24}H^1$	$^2\Sigma^+$	1495.7	≤2.49	1.7306
$(Mg^{24}H^1)^+$	$^1\Sigma^+$	1695.3	(2.1)	1.649
MgI^{127}	$(^2\Sigma^+)$	[312]		

(continued)

TABLE 625A.—MOLECULAR CONSTANTS FOR THE GROUND STATES OF DIATOMIC MOLECULES (continued)

Molecule	Type of state	$\omega_e(cm^{-1})$	D_0^0(ev)	$r_e(\AA)$
$Mg^{24}O^{16}$	$^1\Sigma$ *	785.1	5.2	1.749
MgS	*	525.2	(2.9)	
$Mn^{55}Br$	$^7\Sigma$	289.7	(2.9)	
$Mn^{55}Cl^{(35)}$	$(^7\Sigma)$	384.9	(3.3)	
$Mn^{55}F^{19}$	$(^7\Sigma)$	618.8	(3.9)	
$Mn^{55}H^1$	$^7\Sigma$	[1490.58]	<(2.4)	1.73075
$Mn^{55}I^{127}$	$(^7\Sigma)$	(240)		
$Mn^{55}O^{16}$	*	840.7	(4.4)	
N_2^{14}	$^1\Sigma_g^+$	2359.61	9.756	1.094
$(N_2^{14})^+$	$^2\Sigma_g^+$	2207.19	8.724	1.116
Na_2^{23}	$^1\Sigma_g^+$	159.23	.73	3.079
$Na^{23}Br$	$^1\Sigma^+$	315	3.85	[2.64] †
$Na^{23}Cl$	$^1\Sigma^+$	380	3.58	[2.51] †
$Na^{23}Cs^{133}$	$^1\Sigma^+$	(98)		
$Na^{23}F^{19}$			≤5.3	
$Na^{23}H^1$	$^1\Sigma^+$	1172.2	(2.2)	1.8873
$Na^{23}I^{127}$	$^1\Sigma^+$	286	3.16	[2.90] †
$Na^{23}K$	$^1\Sigma^+$	123.29	.62	
$Na^{23}Rb$	$^1\Sigma^+$	106.64	(.57)	
$N^{14}Br$	*	693	(3.0)	
$N^{14}H^1$	$^3\Sigma^-$	(3300)	(3.8)	1.038
NiBr	*	334		
NiCl	$(^2\Pi)$ *	419.2	(7.3)	
NiH^1	$^2\Delta_{5/2}$	[1926.6]	≤3.1	1.475
NiO^{16}	*	(615)	≤4.2_7	
$N^{14}O^{16}$	$^2\Pi$	1903.85	6.49	1.1508
$(N^{14}O^{16})^+$			10.6	
$N^{14}S^{32}$	$^2\Pi_r$	1220.0	(5.9)	
O_2^{16}	$^3\Sigma_g^-$	1580.36	5.080	1.20740
O_2^+	$^2\Pi_g$	1876.4	6.48	1.1227
$O^{16}H^1$	$^2\Pi_i$	3735.21	4.35	.9706
$(O^{16}H^1)^+$	$^3\Sigma^-$	[2955]	≥4.4	1.0289
P_2^{31}	$^1\Sigma_g^+$	780.43	5.031	1.894
Pb_2		256.5	(.7)	
$PbBr^{79}$	$(^2\Pi_{1/2})$	207.5	3.0	
$PbCl^{35}$	$(^2\Pi_{1/2})$	303.8	3.1	
PbF^{19}	$^2\Pi_{1/2}$	507.2	3.5	
PbH^1	$(^2\Pi_{1/2})$	1564.1	≤1.59	1.839
PbI^{127}	$(^2\Pi_{1/2})$	160.5	2.8	
PbO^{16}	$^1\Sigma^+$	721.8	(4.2)	1.922
$Pb^{208}S^{32}$	$^1\Sigma^+$	428.14	(4.7)	2.395
PbSe	$^1\Sigma^+$	277.6	(4.7)	
PbTe	$^1\Sigma$	211.8	(3.5)	
$P^{31}H^1$	$^3\Sigma^-$	(2380)		[1.433]
$P^{31}N^{14}$	$^1\Sigma^+$	1337.24	(6.3)	1.4910
$P^{31}O^{16}$	$^2\Pi_r$	1230.6	(6.2)	1.447
$Pr^{141}O^{16}$	*	818.9		
Rb_2^{85}	$^1\Sigma_g^+$	57.28	.49	
RbBr	$(^1\Sigma)$		3.9	
RbCl	$^1\Sigma$	(253)	>3.96	[2.89] †
$RbCs^{133}$	$^1\Sigma^+$	49.41		
RbF^{19}	$(^1\Sigma)$	340	5.4_8	
RbH^1	$^1\Sigma^+$	936.77	(1.9)	2.367
RbI^{127}	$^1\Sigma$		3.29	[3.26] †
S_2^{32}	$^3\Sigma_g^-$	725.68	≤4.4	1.889
Sb_2	$^1\Sigma_g^+$	269.85	(3.7)	
$SbBi^{209}$	$^1\Sigma^+$	220.0	(3.0)	
$SbCl^{35}$		369.0	(4.6)	
SbF^{19}		614.2	(4.2)	
SbN^{14}	$^1\Sigma$	942.0	(4.8)	
SbO^{16}	$^2\Pi$	817.2	(3.8)	
$Sc^{45}O^{16}$	$^2\Sigma$	971.55	(7)	

(continued)

TABLE 625A.—MOLECULAR CONSTANTS FOR THE GROUND STATES OF DIATOMIC MOLECULES (concluded)

Molecule	Type of state	ω_e(cm^{-1})	D_0^0(ev)	r_e(Å)
Se_2^{80}	($^1\Sigma_g^+$)	391.77	≦3.55	2.16
SeO^{16}		907.1	(5.4)	
Si_2	*	(750)		
SiBr	$^2\Pi$	425.4	(3.7)	
$Si^{28}Cl^{35}$	$^2\Pi_r$	535.4	(4.0)	
$Si^{28}F^{19}$	$^2\Pi_r$	856.7	(4.8)	[1.603]
$Si^{28}H^1$	$^2\Pi_r$	(2080)		1.520
$Si^{28}N^{14}$	$^2\Sigma^+$	1151.68	(4.5)	1.572
$Si^{28}O^{16}$	$^1\Sigma^+$	1242.03	7.2	1.510
$(Si^{28}O^{16})^+$	$^2\Sigma^+$	(851)		1.504
$Si^{28}S^{32}$	$^1\Sigma^+$	749.5	(6.6)	1.929
$Si^{28}Se$	$^1\Sigma^+$	580.0	(5.8)	
$Si^{28}Te$	$^1\Sigma^+$	481.2	(5.5)	
SnBr	$^2\Pi_r$	247.7	(3.0)	
$SnCl^{35}$	$^2\Pi_r$	352.5	(3.6)	
SnF^{19}	$^2\Pi_{1/2}$	582.9	(3.9)	
SnH^1	$^2\Pi_r$	(1580)	<3.2	[1.782]
SnO^{16}	$^1\Sigma^+$	822.4	5.7	1.838
SnS	$^1\Sigma^+$	487.68	≦3.0	(2.06)
SnSe	$^1\Sigma^+$	331.2	(4.6)	
SnTe	$^1\Sigma^+$	259.5	(4.2)	
$S^{32}O^{16}$	$^3\Sigma^-$	1123.7	{4.001 {5.146	1.4933
$SrBr^{79}$	$^2\Sigma^+$	216.5	(2.8)	
$SrCl^{35}$	$^2\Sigma^+$	302.3	(3.0)	
SrF^{19}	$^2\Sigma^+$	500.1	(3.5)	
SrH^1	$^2\Sigma^+$	1206.2	≦1.68	2.1455
SrI^{127}	($^2\Sigma$)	173.9	(2.2)	
SrO^{16}	$^1\Sigma$ *	653.5	(4.5)	1.921
SrS			≦2.7	
Te_2		251	≦3.18	[2.59] †
TeO^{16}		796.0	{2.728 {3.453	
$Ti^{48}Cl^{35}$	*	456.4	(1.0)	
$Ti^{48}O^{16}$	$^3\Pi_r$	1008.26	(6.9)	1.620
$TlBr^{81}$	$^1\Sigma^+$	192.1	≦3.19	[2.68] †
$TlCl^{35}$	$^1\Sigma^+$	287.47	3.75	[2.55] †
TlF^{19}	$^1\Sigma^+$	475.00	<4.72	
TlH^1	$^1\Sigma^+$	1390.7	≦2.18	1.870
TlI^{127}	$^1\Sigma^+$	150	≦2.64	[2.87] †
$V^{51}O^{16}$	($^2\Delta$) *	1012.7	(6.4)	1.890
YbCl	($^2\Sigma$) *	293.6	(1.2)	
$Y^{89}O^{16}$	$^2\Sigma$	852.5	(9)	
Zn_2	($^1\Sigma$)		(.25)	
ZnBr	($^2\Sigma$) *	(220)		
$ZnCl^{35}$	$^2\Sigma$	390.5	(3.0)	
ZnF^{19}	$^2\Sigma$	(630)		
ZnH^1	$^2\Sigma^+$	1607.6	.851	1.5945
$(ZnH^1)^+$	$^1\Sigma^+$	1916	(2.5)	1.515
$Zn^{64}I^{127}$	($^2\Sigma$) *	223.4	(2.0)	
ZnO			≦4.0	
ZnS			≦4.4	
ZnTe			≦2.2	
$Zr^{90}O^{16}$	$^3\Pi$	937.2	(7.8)	(1.416)

The atmosphere, with a total mass of about 5.3×10^{21} g (about one-millionth the mass of the earth), extends 7,000-60,000 miles above sea level (depending upon the definition of the top) and for purposes of discussion may be divided into several regions or layers. From sea level up to about 10-15 km (the troposphere), about the next 30 km above this (the stratosphere), and the entire region above this (i.e., above about 40 km) is spoken of as the upper atmosphere. At heights above 80 km in the upper atmosphere strong ionization is found and thus this region is called the ionosphere. Again the ionosphere may be divided into three or four layers; first, the E layer (about 100 km) moderately ionized; next the F_1 layer (at about 200 km) more strongly ionized; the F_2 layer (about 300 km) much more strongly ionized. Above this, there is some recent evidence indicating an additional ionized region, the G layer (400-700 km).

The following tables give some characteristics of the atmosphere as a function of the height above sea level.

TABLE 626.—COMPOSITION OF THE AIR NEAR GROUND LEVEL[194]

Gas	Molecular weight	Percent per volume	
Nitrogen	28	78.09	
Oxygen	32	20.95	
Argon	40	.93	100.00
Carbon dioxide	44	.02 — .04	
Neon	20.2	18×10^{-4}	
Helium	4	5.3×10^{-4}	
Krypton	83	1.1×10^{-4}	
Hydrogen	2	$.5 \times 10^{-4}$	
Xenon	130	$.08 \times 10^{-4}$	
Ozone	48	$.02 \times 10^{-4}$, increasing with altitude	
Radon	222	7×10^{-18}, decreasing with altitude	
Water vapor	18	.2 — 4, variable	

[194] Regener, E., The structure and composition of the stratosphere, No. 509, Headquarters Air Materiel Command, Wright Field, Dayton, Ohio, April 1946.

TABLE 627.—COMPOSITION OF THE ATMOSPHERE UP TO THE F_2 LAYER, LATITUDE 45°[195]

Altitude km	Composition, 1 percent volume	Molecular weight of mixture, M	Altitude km	Composition 1 percent volume	Molecular weight of mixture, M
0	21 O_2, 78 N_2, .93 A	28.9	120	30.5 O, 69.5 N_2	24.35
50	18 O_2, 82 N_2	28.66	300	30.5 O, 69.5 N_2	24.35
83	18 O_2, 82 N_2	28.66	(F_2 layer)		

[195] Grimminger, G., Analysis of temperature, pressure and density of the atmosphere extending to extreme altitudes, p. 18, Rand Corporation, November 1948.

TABLE 628.—STANDARD ATMOSPHERE

A standard atmosphere is defined by an altitude-temperature-pressure relation. It is an aeronautic necessity in valuating the performance of airplanes and for the calibration of instruments. The following standard has been officially adopted by the Army Air Corps, National Bureau of Standards, National Advisory Committee for Aeronautics, and the Weather Bureau. See Table 343.

Altitude Meters	Pressure		Density		Temperature °C
	mmHg	inHg	kg/m³	lb/ft³	
0	760.0	29.921	1.2255	.07650	15.0
1000	674.1	26.54	1.1120	.06942	8.5
2000	596.2	23.47	1.0068	.06286	+ 2.0
3000	525.8	20.70	.9094	.05678	− 4.5
4000	462.3	18.20	.8193	.05115	−11.0
5000	405.1	15.95	.7363	.04597	−17.5
6000	353.8	13.93	.6598	.04119	−24.0
7000	307.9	12.12	.5896	.03681	−30.5
8000	266.9	10.51	.5252	.03279	−37.0
9000	230.4	9.07	.4664	.02912	−43.5
10000	198.2	7.80	.4127	.02577	−50.0
11000	169.7	6.68	.3614	.02256	−55.0
12000	145.0	5.71	.3090	.01929	−55.0
13000	124.0	4.88	.2642	.01649	−55.0
14000	106.0	4.17	.2259	.01410	−55.0
15000	90.6	3.57	.1931	.01206	−55.0

TABLE 629.—VALUES OF ATMOSPHERIC TEMPERATURE, PRESSURE, AND DENSITY UP TO THE F_2 LAYER*

Latitude 45°, $p_a = 1014$ *mb*,† $\rho_a = 1.223 \times 10^{-3}$ g/cm³, d (diameter of particle) $= 3 \times 10^{-8}$ cm

Height, h km	Height, h mi	Apparent gravity, g' cm/sec²	Temp °K	Pressure, p millibars	Density, ρ g/cm³	Number density, n particles/cm³	Mean particle speed, v cm/sec	Mean free path, L cm	Mean collision freq, ν 1/sec	Speed of sound, c cm/sec
0	0	980.69	288.0	1014	1.223×10^{-3}	2.568×10^{19}	4.590×10^{4}	9.744×10^{-6}	4.712×10^{9}	3.410×10^{4}
1.524	.947	980.22	278.1	843.5	1.055×10^{-3}	2.213×10^{19}	4.511	1.130×10^{-5}	3.991×10^{9}	3.351
3.048	1.894	979.74	268.2	697.5	9.047×10^{-4}	1.898×10^{19}	4.432	1.318×10^{-5}	3.362×10^{9}	3.291
6.096	3.788	978.80	248.4	466.8	6.537×10^{-4}	1.371×10^{19}	4.264	1.825×10^{-5}	2.337×10^{9}	3.167
9.144	5.682	977.87	226.6	302.3	4.601×10^{-4}	9.652×10^{18}	4.090	2.592×10^{-5}	1.578×10^{9}	3.038
10.769	6.629	977.37	218.0	236.2	3.768×10^{-4}	7.905×10^{18}	3.996	3.165×10^{-5}	1.262×10^{9}	2.967
13.716	8.523	976.46	218.0	149.2	2.381×10^{-4}	4.995×10^{18}	3.996	5.010×10^{-5}	7.976×10^{8}	2.967
16.764	10.417	975.52	218.0	92.88	1.482×10^{-4}	3.109×10^{18}	3.996	8.048×10^{-5}	4.965×10^{8}	2.967
22.860	14.205	973.66	218.0	36.14	5.761×10^{-5}	1.210×10^{18}	3.996	2.069×10^{-4}	1.931×10^{8}	2.968
27.432	17.045	972.26	218.0	17.89	2.849×10^{-5}	5.989×10^{17}	3.999	4.178×10^{-4}	9.572×10^{7}	2.970
32.000	19.884	970.87	218.0	8.901	1.415×10^{-5}	2.979×10^{17}	4.002	8.399×10^{-4}	4.765×10^{7}	2.972
39.624	24.621	968.54	276.0	3.148	3.946×10^{-6}	8.323×10^{16}	4.508	3.006×10^{-3}	1.499×10^{7}	3.348
50.000	31.068	965.40	355.0	1.054	1.024×10^{-6}	2.166×10^{16}	5.118	1.155×10^{-2}	4.430×10^{6}	3.802
60.000	37.282	962.39	355.0	4.136×10^{-1}	4.019×10^{-7}	8.501×10^{15}	5.118	2.943×10^{-2}	1.739×10^{6}	3.802
68.581	42.614	959.81	300.2	1.740×10^{-1}	2.000×10^{-7}	4.230×10^{15}	4.706	5.915×10^{-2}	7.956×10^{5}	3.496
78.000	48.466	957.00	240.0	5.469×10^{-2}	7.860×10^{-8}	1.663×10^{15}	4.209	1.505×10^{-1}	2.797×10^{5}	3.126
83.000	51.573	955.51	240.0	2.752×10^{-2}	3.956×10^{-8}	8.367×10^{14}	4.209	2.990×10^{-1}	1.408×10^{5}	3.126
92.965	57.765	952.55	276.4	7.938×10^{-3}	9.507×10^{-9}	2.096×10^{14}	4.612	1.194	3.862×10^{4}	3.443
100.58	62.500	950.30	304.2	3.526×10^{-3}	3.713×10^{-9}	8.459×10^{13}	4.916	2.958	1.662×10^{4}	3.686
120.00	74.564	944.60	375.0	6.677×10^{-4}	5.218×10^{-10}	1.299×10^{13}	5.708	1.926×10	2.964×10^{3}	4.322
152.40	94.697	935.20	505.5	8.67×10^{-5}	5.02×10^{-11}	1.25×10^{12}	6.63	2.00×10^{3}	3.32×10^{2}	5.02
213.36	132.58	917.88	751.0	5.99×10^{-6}	2.33×10^{-12}	5.83×10^{10}	8.07	4.29×10^{3}	1.88×10	....
259.08	160.98	905.21	935.2	1.40×10^{-6}	4.38×10^{-13}	1.09×10^{10}	9.01	2.29×10^{4}	3.93×10	....
300.00	186.41	894.09	1100	4.84×10^{-7}	1.29×10^{-13}	3.21×10^{9}	9.78	7.79×10^{4}	1.25×10	....

* For reference, see footnote 195, p. 592.
† 1 millibar (mb) = 10^3 dynes/cm² = 0.750 mmHg.

TABLE 630.—VALUES OF TEMPERATURE, PRESSURE, AND DENSITY ABOVE THE F_2 LAYER (CALCULATED) *

Latitude 45°, $p_a = 1014$ *mb*, $\rho_a = 1.223 \times 10^{-3}$ g/cm³

Height, *h*		Apparent gravity, *g'* cm/sec²	Temp °K	Percentage composition by mass				Mean mol wt *M*	Pressure, *p* millibars	Density, ρ g/cm³	Number density, *n* particles/cm³	*d* † = 2×10⁻⁸ cm		
km	mi			Atomic oxygen	Atomic nitrogen	Atomic helium	Atomic hydrogen					Mean particle speed *v* cm/sec	Mean free path, *L* cm	Mean collision freq, ν 1/sec
300	186.4	894.09	1100	....	....	....	....	24.35	4.84×10^{-7}	1.29×10^{-13}	3.21×10^{9}	9.78×10^{4}	1.76×10^{5}	5.56×10^{-1}
400	248.5	867.75	1500	22.22	77.78	1.39×10^{-4}	6.00×10^{-6}	14.40	9.70×10^{-8}	1.12×10^{-14}	4.72×10^{8}	1.48×10^{5}	1.20×10^{6}	1.24×10^{-1}
500	310.7	842.75	1900	20.20	79.80	2.62×10^{-4}	1.35×10^{-5}	14.36	4.06×10^{-8}	3.69×10^{-15}	1.56×10^{8}	1.67×10^{5}	3.63×10^{6}	4.62×10^{-2}
600	372.8	819.43	2300	18.70	81.30	4.29×10^{-4}	2.56×10^{-5}	14.33	2.05×10^{-8}	1.54×10^{-15}	6.49×10^{7}	1.84×10^{5}	8.69×10^{6}	2.12×10^{-2}
700	435.0	795.40	2500	17.53	82.47	6.53×10^{-4}	9.34×10^{-5}	14.31	1.16×10^{-8}	8.00×10^{-16}	3.39×10^{7}	1.92×10^{5}	1.66×10^{7}	1.16×10^{-2}
900	559.2	752.29	2500	15.48	84.52	1.41×10^{-3}	1.17×10^{-4}	14.28	4.01×10^{-9}	2.75×10^{-16}	1.17×10^{7}	1.93×10^{5}	4.81×10^{7}	4.00×10^{-3}
1000	621.4	732.04	2500	14.57	85.43	2.03×10^{-3}	1.88×10^{-4}	14.26	2.41×10^{-9}	1.65×10^{-16}	7.03×10^{6}	1.93×10^{5}	8.01×10^{7}	2.41×10^{-3}
1500	932.0	642.07	2500	10.92	89.06	1.10×10^{-2}	1.67×10^{-3}	14.19	2.31×10^{-10}	1.58×10^{-17}	6.73×10^{5}	1.93×10^{5}	8.36×10^{8}	2.31×10^{-4}
2000	1234	567.73	2500	8.397	91.54	4.84×10^{-2}	1.13×10^{-2}	14.11	2.96×10^{-11}	2.01×10^{-19}	8.62×10^{4}	1.94×10^{5}	6.52×10^{9}	2.97×10^{-5}
4000	2485	370.01	2500	3.392	89.32	3.887	3.402	9.14	9.75×10^{-14}	4.29×10^{-21}	2.84×10^{2}	2.41×10^{5}	1.98×10^{12}	1.22×10^{-7}
6000	3728	260.11	2500	.5616	26.86	23.13	49.44	1.76	2.58×10^{-14}	2.18×10^{-22}	7.52×10	5.48×10^{5}	7.49×10^{12}	7.32×10^{-8}
10,000	6214	148.58	2500	3.38×10^{-3}	.3451	13.12	86.53	1.12	1.58×10^{-14}	8.52×10^{-23}	4.61×10	6.87×10^{5}	1.22×10^{13}	5.62×10^{-8}
20,000	12,427	57.28	2500	4.85×10^{-8}	1.20×10^{-3}	3.847	96.23	1.04	9.82×10^{-15}	4.90×10^{-23}	2.86×10	7.14×10^{5}	1.96×10^{13}	3.64×10^{-8}
30,000	18,641	30.12	2500	2.47×10^{-7}	9.12×10^{-5}	2.152	97.85	1.02	7.90×10^{-15}	3.94×10^{-23}	2.33×10	7.19×10^{5}	2.41×10^{13}	2.98×10^{-8}
40,000	24,855	18.53	2500	4.52×10^{-8}	2.10×10^{-5}	1.541	98.46	1.02	7.11×10^{-15}	3.49×10^{-23}	2.08×10	7.20×10^{5}	2.71×10^{13}	2.66×10^{-8}
50,000	31,068	12.54	2500	1.51×10^{-8}	8.11×10^{-8}	1.241	98.76	1.02	6.60×10^{-15}	3.23×10^{-23}	1.93×10	7.21×10^{5}	2.92×10^{13}	2.47×10^{-8}
60,000	37,282	9.05	2500	7.02×10^{-9}	3.92×10^{-6}	1.067	98.93	1.02	6.27×10^{-15}	3.06×10^{-23}	1.83×10	7.22×10^{5}	3.08×10^{13}	2.34×10^{-8}
70,000	43,496	6.83	2500	3.99×10^{-9}	2.56×10^{-6}	.9536	99.05	1.02	6.03×10^{-15}	2.94×10^{-23}	1.76×10	7.22×10^{5}	3.20×10^{13}	2.26×10^{-8}

* For reference, see footnote 195, p. 592.
† *d* = diameter of particle.

TABLE 631.—RELATIVE DENSITY OF MOIST AIR FOR DIFFERENT PRESSURES AND HUMIDITIES

Part 1.—Values of $\frac{h}{760}$, from $h = 1$ to $h = 9$, for the computation of different values of the ratio of actual to normal barometric pressure

This gives the density of moist air at pressure h in terms of the same air at normal atmosphere pressure. When air contains moisture, as is usually the case with the atmosphere, we have the following equation for pressure term: $h = B - 0.378p$, where p is the vapor pressure, and B the corrected barometric pressure. When the necessary psychrometric observations are made the values of p may be taken from Table 640 and then $0.378p$ from Table 632, or the dew point may be found and the value of $0.378p$ taken from Table 632.

h	$\frac{h}{760}$
1	.0013158
2	.0026316
3	.0039474
4	.0052632
5	.0065789
6	.0078947
7	.0092105
8	.0105263
9	.0118421

Examples of use of the table

To find the value of $\frac{h}{760}$ when $h = 754.3$

$h = 700$	gives	.92105
50	"	.065789
4	"	.005263
.3	"	.000395
754.3		.992497

To find the value of $\frac{h}{760}$ when $h = 5.73$

$h = 5$	gives	.0065789
.7	"	.0009210
.03	"	.0000395
5.73		.0075394

Part 2.—Values of the logarithms of $\frac{h}{760}$ for values of h between 80 and 800

Values from 8 to 80 may be got by subtracting 1 from the characteristic, and from 0.8 to 8 by subtracting 2 from the characteristic, and so on.

	Values of log $\frac{h}{760}$									
h	0	1	2	3	4	5	6	7	8	9
80	$\bar{1}$.02228	$\bar{1}$.02767	$\bar{1}$.03300	$\bar{1}$.03826	$\bar{1}$.04347	$\bar{1}$.04861	$\bar{1}$.05368	$\bar{1}$.05871	$\bar{1}$.06367	$\bar{1}$.06858
90	.07343	.07823	.08297	.08767	.09231	.09691	.10146	.10596	.11041	.11482
100	$\bar{1}$.11919	$\bar{1}$.12351	$\bar{1}$.12779	$\bar{1}$.13202	$\bar{1}$.13622	$\bar{1}$.14038	$\bar{1}$.14449	$\bar{1}$.14857	$\bar{1}$.15261	$\bar{1}$.15661
110	.16058	.16451	.16840	.17226	.17609	.17988	.18364	.18737	.19107	.19473
120	.19837	.20197	.20555	.20909	.21261	.21611	.21956	.22299	.22640	.22978
130	.23313	.23646	.23976	.24304	.24629	.24952	.25273	.25591	.25907	.26220
140	.26531	.26841	.27147	.27452	.27755	.28055	.28354	.28650	.28945	.29237
150	$\bar{1}$.29528	$\bar{1}$.29816	$\bar{1}$.30103	$\bar{1}$.30388	$\bar{1}$.30671	$\bar{1}$.30952	$\bar{1}$.31231	$\bar{1}$.31509	$\bar{1}$.31784	$\bar{1}$.32058
160	.32331	.32601	.32870	.33137	.33403	.33667	.33929	.34190	.34450	.34707
170	.34964	.35218	.35471	.35723	.35974	.36222	.36470	.36716	.36961	.37204
180	.37446	.37686	.37926	.38164	.38400	.38636	.38870	.39128	.39334	.39565
190	.39794	.40022	.40249	.40474	.40699	.40922	.41144	.41365	.41585	.41804
200	$\bar{1}$.42022	$\bar{1}$.42238	$\bar{1}$.42454	$\bar{1}$.42668	$\bar{1}$.42882	$\bar{1}$.43094	$\bar{1}$.43305	$\bar{1}$.43516	$\bar{1}$.43725	$\bar{1}$.43933
210	.44141	.44347	.44552	.44757	.44960	.45162	.45364	.45565	.45764	.45963
220	.46161	.46358	.46554	.46749	.46943	.47137	.47329	.47521	.47712	.47902
230	.48091	.48280	.48467	.48654	.48840	.49025	.49210	.49393	.49576	.49758
240	.49940	.50120	.50300	.50479	.50658	.50835	.51012	.51188	.51364	.51539

[196] The tables on densities and humidities have been adapted from the sixth edition of the Smithsonian Meteorological Tables, which see for more extensive data.

(continued)

TABLE 631.—RELATIVE DENSITY OF MOIST AIR FOR DIFFERENT PRESSURES AND HUMIDITIES (continued)

Part 2.—Values of the logarithms of $\frac{h}{760}$ for values of h between 80 and 800 (continued)

	Values of log $\frac{h}{760}$									
h	0	1	2	3	4	5	6	7	8	9
250	$\bar{1}$.51713	$\bar{1}$.51886	$\bar{1}$.52059	$\bar{1}$.52231	$\bar{1}$.52402	$\bar{1}$.52573	$\bar{1}$.52743	$\bar{1}$.52912	$\bar{1}$.53081	$\bar{1}$.53249
260	.53416	.53583	.53749	.53914	.54079	.54243	.54407	.54570	.54732	.54894
270	.55055	.55216	.55376	.55535	.55694	.55852	.56010	.56167	.56323	.56479
280	.56634	.56789	.56944	.57097	.57250	.57403	.57555	.57707	.57858	.58008
290	.58158	.58308	.58457	.58605	.58753	.58901	.59048	.59194	.59340	.59486
300	$\bar{1}$.59631	$\bar{1}$.59775	$\bar{1}$.59919	$\bar{1}$.60063	$\bar{1}$.60206	$\bar{1}$.60349	$\bar{1}$.60491	$\bar{1}$.60632	$\bar{1}$.60774	$\bar{1}$.60914
310	.61055	.61195	.61334	.61473	.61611	.61750	.61887	.62025	.62161	.62298
320	,62434	.62569	.62704	.62839	.62973	.63107	.63240	.63373	.63506	.63638
330	.63770	.63901	.64032	.64163	.64293	.64423	.64553	.64682	.64810	.64939
340	.65067	.65194	.65321	.65448	.65574	.65701	.65826	.65952	.66077	.66201
350	$\bar{1}$.66325	$\bar{1}$.66449	$\bar{1}$.66573	$\bar{1}$.66696	$\bar{1}$.66819	$\bar{1}$.66941	$\bar{1}$.67064	$\bar{1}$.67185	$\bar{1}$.67307	$\bar{1}$.67428
360	.67549	.67669	.67790	.67909	.68029	.68148	.68267	.68385	.68503	.68621
370	.68739	.68856	.68973	.69090	.69206	.69322	.69437	.69553	.69668	.69783
380	.69897	.70011	.70125	.70239	.70352	.70465	.70577	.70690	.70802	.70914
390	.71025	.71136	.71247	.71358	.71468	.71578	.71688	.71798	.71907	.72016
400	$\bar{1}$.72125	$\bar{1}$.72233	$\bar{1}$.72341	$\bar{1}$.72449	$\bar{1}$.72557	$\bar{1}$.72664	$\bar{1}$.72771	$\bar{1}$.72878	$\bar{1}$.72985	$\bar{1}$.73091
410	.73197	.73303	.73408	.73514	.73619	.73723	.73828	.73932	.74036	.74140
420	.74244	.74347	.74450	.74553	.74655	.74758	.74860	.74961	.75063	.75164
430	.75265	.75366	.75467	.75567	.75668	.75768	.75867	.75967	.76066	.76165
440	.76264	.76362	.76461	.76559	.76657	.76755	.76852	.76949	.77046	.77143
450	$\bar{1}$.77240	$\bar{1}$.77336	$\bar{1}$.77432	$\bar{1}$.77528	$\bar{1}$.77624	$\bar{1}$.77720	$\bar{1}$.77815	$\bar{1}$.77910	$\bar{1}$.78005	$\bar{1}$.78100
460	.78194	.78289	.78383	.78477	.78570	.78664	.78757	.78850	.78943	.79036
470	.79128	.79221	.79313	.79405	.79496	.79588	.79679	.79770	.79861	.79952
480	.80043	.80133	.80223	.80313	.80403	.80493	.80582	.80672	.80761	.80850
490	.80938	.81027	.81115	.81203	.81291	.81379	.81467	.81554	.81642	.81729
500	$\bar{1}$.81816	$\bar{1}$.81902	$\bar{1}$.81989	$\bar{1}$.82075	$\bar{1}$.82162	$\bar{1}$.82248	$\bar{1}$.82334	$\bar{1}$.82419	$\bar{1}$.82505	$\bar{1}$.82590
510	.82676	.82761	.82846	.82930	.83015	.83099	.83184	.83268	.83352	.83435
520	.83519	.83602	.83686	.83769	.83852	.83935	.84017	.84100	.84182	.84264
530	.84346	.84428	.84510	.84591	.84673	.84754	.84835	.84916	.84997	.85076
540	.85158	.85238	.85319	.85399	.85479	.85558	.85638	.85717	.85797	.85876
550	$\bar{1}$.85955	$\bar{1}$.86034	$\bar{1}$.86113	$\bar{1}$.86191	$\bar{1}$.86270	$\bar{1}$.86348	$\bar{1}$.86426	$\bar{1}$.86504	$\bar{1}$.86582	$\bar{1}$.86660
560	.86737	.86815	.86892	.86969	.87047	.87123	.87200	.87277	.87353	.87430
570	.87506	.87582	.87658	.87734	.87810	.87885	.87961	.88036	.88111	.88186
580	.88261	.88336	.88411	.88486	.88560	.88634	.88708	.88782	.88856	.88930
590	.89004	.89077	.89151	.89224	.89297	.89370	.89443	.89516	.89589	.89661
600	$\bar{1}$ 89734	$\bar{1}$.89806	$\bar{1}$.89878	$\bar{1}$.89950	$\bar{1}$.90022	$\bar{1}$.90094	$\bar{1}$.90166	$\bar{1}$.90238	$\bar{1}$.90309	$\bar{1}$.90380
610	.90452	.90523	.90594	.90665	.90735	.90806	.90877	.90947	.91017	.91088
620	.91158	.91228	.91298	.91367	.91437	.91507	.91576	.91645	.91715	.91784
630	.91853	.91922	.91990	.92059	.92128	.92196	.92264	.92333	.92401	.92469
640	.92537	.92604	.92672	.92740	.92807	.92875	.92942	.93009	.93076	.93143
650	$\bar{1}$.93210	$\bar{1}$.93277	$\bar{1}$.93343	$\bar{1}$.93410	$\bar{1}$.93476	$\bar{1}$.93543	$\bar{1}$.93609	$\bar{1}$.93675	$\bar{1}$.93741	$\bar{1}$.93807
660	.93873	.93939	.94004	.94070	.94135	.94201	.94266	.94331	.94396	.94461
670	.94526	.94591	.94656	.94720	.94785	.94849	.94913	.94978	.95042	.95106
680	.95170	.95233	.95297	.95361	.95424	.95488	.95551	.95614	.95677	.95741
690	.95804	.95866	.95929	.95992	.96055	.96117	.96180	.96242	.96304	.96366
700	$\bar{1}$.96428	$\bar{1}$.96490	$\bar{1}$.96552	$\bar{1}$.96614	$\bar{1}$.96676	$\bar{1}$.96738	$\bar{1}$.96799	$\bar{1}$.96861	$\bar{1}$.96922	$\bar{1}$.96983
710	.97044	.97106	.97167	.97228	.97288	.97349	.97410	.97471	.97531	.97592
720	.97652	.97712	.97772	.97832	.97892	.97951	.98012	.98072	.98132	.98191
730	.98251	.98310	.98370	.98429	.98488	.98547	.98606	.98665	.98724	.98783
740	.98842	.98900	.98959	.99018	.99076	.99134	.99193	.99251	.99309	.99367

(continued)

TABLE 631.—RELATIVE DENSITY OF MOIST AIR FOR DIFFERENT PRESSURES AND HUMIDITIES (concluded)

Part 2.—Values of the logarithms of $\frac{h}{760}$ for values of h between 80 and 800 (concluded)

	Values of log $\frac{h}{760}$									
h	0	1	2	3	4	5	6	7	8	9
750	$\bar{1}$.99425	$\bar{1}$.99483	$\bar{1}$.99540	$\bar{1}$.99598	$\bar{1}$.99656	$\bar{1}$.99713	$\bar{1}$.99771	$\bar{1}$.99828	$\bar{1}$.99886	$\bar{1}$.99942
760	.00000	.00057	.00114	.00171	.00228	.00285	.00342	.00398	.00455	.00511
770	.00568	.00624	.00680	.00737	.00793	.00849	.00905	.00961	.01017	.01072
780	.01128	.01184	.01239	.01295	.01350	.01406	.01461	.01516	.01571	.01626
790	.01681	.01736	.01791	.01846	.01901	.01955	.02010	.02064	.02119	.02173

TABLE 632.—DENSITY OF MOIST AIR, VALUES OF 0.378p

This table gives the humidity term 0.378p, which occurs in the equation $\delta = \delta_0 \frac{h}{760} = \delta_0 \frac{B - 0.378p}{760}$ for the calculation of the density of air containing aqueous vapor at pressure p; δ_0 is the density of dry air at normal temperature and barometric pressure, B the observed barometric pressure, and $h = B - 0.378p$, the pressure corrected for humidity. For values of $\frac{h}{760}$, see Table 631. Temperatures are in degrees centigrade, and pressures in mmHg.

Dew point °C	p Vapor pressure (ice) mmHg	0.378p mmHg	Dew point °C	p Vapor pressure (water) mmHg	0.378p mmHg	Dew point °C	p Vapor pressure (water) mmHg	0.378p mmHg
—50	.029	.01	**0**	4.58	1.73	**30**	31.86	12.0
—45	.054	.02	1	4.92	1.86	31	33.74	12.8
—40	.096	.04	2	5.29	2.00	32	35.70	13.5
—35	.169	.06	3	5.68	2.15	33	37.78	14.3
—30	.288	.11	4	6.10	2.31	34	39.95	15.1
—25	.480	.18	**5**	6.54	2.47	**35**	42.23	16.0
24	.530	.20	6	7.01	2.66	36	44.62	16.9
23	.585	.22	7	7.51	2.84	37	47.13	17.8
22	.646	.24	8	8.04	3.04	38	49.76	18.8
21	.712	.27	9	8.61	3.25	39	52.51	19.8
—20	.783	.30	**10**	9.21	3 48	**40**	55.40	20.9
19	.862	.33	11	9.85	3.72	41	58.42	22.1
18	.947	.36	12	10.52	3.98	42	61.58	23.3
17	1.041	.39	13	11.24	4.25	43	64.89	24.5
16	1.142	.43	14	11.99	4.53	44	68.35	25.8
—15	1.252	.47	**15**	12.79	4.84	**45**	71.97	27.2
14	1.373	.52	16	13.64	5.16	46	75.75	28.6
13	1.503	.57	17	14.54	5.50	47	79.70	30.1
12	1.644	.62	18	15.49	5.85	48	83.83	31.7
11	1.798	.68	19	16.49	6.23	49	88.14	33.3
—10	1.964	.74	**20**	17.55	6.63	**50**	92.6	35.0
9	2.144	.81	21	18.66	7.06	51	97.3	36.8
8	2.340	.88	22	19.84	7.50	52	102.3	38.6
7	2.550	.96	23	21.09	7.97	53	107.3	40.6
6	2.778	1.05	24	22.40	8.47	54	112.7	42.6
— 5	3.025	1.14	**25**	23.78	8.99	**55**	118.2	44.7
4	3.291	1.24	26	25.24	9.54	56	124.0	46.9
3	3.578	1.35	27	26.77	10.12	57	130.0	49.1
2	3.887	1.47	28	28.38	10.73	58	136.3	51.5
1	4.220	1.60	29	30.08	11.37	59	142.8	54.0
0	4.580	1.73	**30**	31.86	12.04	**60**	149.6	56.5

TABLE 633.—MAINTENANCE OF AIR AT DEFINITE HUMIDITIES

The relative humidity and vapor pressure of aqueous vapor of moist air in equilibrium conditions above aqueous solutions of sulfuric acid are given below.

Density of acid sol	Relative humidity	Vapor pressure 20°C	Vapor pressure 30°C	Density of acid sol	Relative humidity	Vapor pressure 20°C	Vapor pressure 30°C
		mm	mm			mm	mm
1.00	100.0	17.4	31.6	1.30	58.3	10.1	18.4
1.05	97.5	17.0	30.7	1.35	47.2	8.3	15.0
1.10	93.9	16.3	29.6	1.40	37.1	6.5	11.9
1.15	88.8	15.4	28.0	1.50	18.8	3.3	6.0
1.20	80.5	14.0	25.4	1.60	8.5	1.5	2.7
1.25	70.4	12.2	22.2	1.70	3.2	.6	1.0

TABLE 634.—PRESSURE OF AQUEOUS VAPOR IN THE ATMOSPHERE

For various altitudes (barometric readings)

The amount of water vapor in the atmosphere may be determined by the use of the wet-bulb–dry-bulb hygrometer.

The first column gives the depression of the wet-bulb temperature t_1 below the air temperature t. The value corresponding to the barometric height at the altitude of observation is to be subtracted from the vapor pressure corresponding to the wet-bulb temperature taken from Part 3, Table 635. The temperature corresponding to this vapor pressure taken from Part 3, Table 635 is the dew point. The wet bulb should be ventilated about 3 meters per second. For sea-level use Table 640. Example: $t = 35°$, $t_1 = 30°$, barometer 74 cmHg. Then $31.83 - 2.46 = 29.37$ mm = aqueous vapor pressure; the dew point is 28.6°C.

$t - t_1$ °C	Barometric pressure in cmHg: 74	72	70	68	66	64	62	60	58	56	54	52	50	48
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1°	.50	.48	.47	.46	.44	.43	.42	.40	.39	.38	.36	.35	.34	.32
2	.98	.96	.93	.90	.88	.85	.82	.80	.77	.75	.72	.69	.67	.64
3	1.47	1.43	1.39	1.35	1.32	1.28	1.24	1.20	1.15	1.12	1.08	1.04	1.00	.96
4	1.97	1.91	1.86	1.81	1.75	1.70	1.65	1.60	1.54	1.49	1.44	1.38	1.33	1.28
5	2.46	2.39	2.32	2.26	2.19	2.13	2.06	1.99	1.93	1.86	1.80	1.73	1.66	1.60
6	2.95	2.87	2.79	2.71	2.63	2.55	2.47	2.39	2.32	2.24	2.16	2.08	2.00	1.92
7	3.45	3.36	3.26	3.17	3.08	2.99	2 89	2.80	2.71	2.61	2.52	2.43	2.33	2.24
8	3.95	3.84	3.73	3.63	3.53	3.42	3.31	3.20	3.10	2.99	2.88	2.78	2.67	2.56
9	4.44	4.32	4.21	4.09	3.97	3.85	3.73	3.61	3.49	3.37	3.25	3.13	3.00	2.88
10	4.94	4.81	4.68	4.54	4.41	4.28	4.14	4.01	3.88	3.74	3.61	3.48	3.34	3.21
11	5.44	5.30	5.15	5.00	4.86	4.71	4.56	4.42	4.27	4.12	3.97	3.83	3.68	3.53
12	5.94	5.78	5.62	5.46	5.30	5.14	4.98	4.82	4.66	4.50	4.34	4.18	4.02	3.85
13	6.45	6.27	6.10	5.92	5.75	5.57	5.40	5.23	5.05	4.88	4.70	4.53	4.36	4.18
14	6.95	6.76	6.58	6.39	6.20	6.01	5.83	5.64	5.45	5.26	5.07	4.88	4.70	4.51
15	7.46	7.26	7.06	6.85	6.65	6.45	6.25	6.05	5.85	5.64	5.44	5.24	5.04	4.84
16	7.96	7.75	7.54	7.32	7.11	6.89	6.68	6.46	6.24	6.03	5.81	5.60	5.38	5.17
17	8.47	8.24	8.02	7.79	7.56	7.33	7.10	6.87	6.64	6.41	6.18	5.95	5.72	5.50

TABLE 635.—PRESSURE OF SATURATED WATER VAPOR FOR VARIOUS CONDITIONS OF TEMPERATURE AND SURROUNDINGS

Pressure in mmHg, temperature in °C

Part 1.—At low temperatures over ice

Temp	0	1	2	3	4	5	6	7	8	9
—60	.0081	.0071	.0062	.0054	.0047	.0041	.0035	.0030	.0026	.0023
—50	.0295	.0261	.0222	.0203	.0178	.0157	.0138	.0121	.0106	.0094
—40	.0962	.0858	.0766	.0681	.0607	.0540	.0479	.0425	.0377	.0333
—30	.2855	.2560	.2308	.2075	.1865	.1675	.1502	.1337	.1205	.1078
—20	.7740	.7030	.6380	.5780	.5240	.4790	.4290	.3880	.3500	.3160
—10	1.945	1.782	1.630	1.486	1.359	1.239	1.130	1.029	.9360	.8510
0	4.580	4.219	3.880	3.565	3.280	3.010	2.765	2.531	2.322	2.128

Part 2.—At low temperatures over water

Temp	0	1	2	3	4	5	6	7	8	9
—10	2.148	1.983	1.832	1.690	1.556	1.434	1.319	1.215	1.109	1 025
0	4.580	4.260	3.968	3.672	3.410	3.160	2.930	2.712	2.510	2.321

Part 3.—For temperatures 0° to 374° over water

Temp	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	4.580	4.615	4.648	4.685	4.712	4.750	4.784	4.820	4.855	4.888
1	4.922	4.960	4.998	5.030	5.065	5.105	5.140	5.175	5.212	5.250
2	5.289	5.328	5.365	5.404	5.442	5.482	4.525	5.566	5.602	5.642
3	5.680	5.720	5.761	5.801	5.842	5.885	5.930	5.972	6.014	6.055
4	6.095	6.139	6.182	6.125	6.270	6.314	6.358	6.401	6.445	6.490
5	6.535	6.582	6.535	6.679	6.724	6.770	6.816	6.862	6.910	6.960
6	7.010	7.058	7.106	7.155	7.204	7.254	7.306	7.356	7.408	7.460
7	7.509	7.560	7.613	7.666	7.720	7.772	7.823	7.875	7.929	7.984
8	8.039	8.095	8.149	8.205	8.260	8.315	8.370	8.425	8.482	8.542
9	8.605	8.670	8.726	8.782	8.838	8.900	8.960	9.020	9.080	9.140
10	9.200	9.263	9.325	9.390	9.455	9.520	9.580	9.645	9.707	9.770
11	9.835	9.901	9.965	10.032	10.100	10.170	10.240	10.308	10.375	10.445
12	10.518	10.580	10.655	10.718	10.790	10.858	10.928	11.000	11.075	11.150
13	11.225	11.300	11.375	11.750	11.525	11.600	11.677	11.755	11.829	11.905
14	11.980	12.060	12.140	12.217	12.295	12.375	12.455	12.538	12.620	12.698
15	12.776	12.860	12.945	13.025	13.110	13.195	13.280	13.365	13.450	13.540
16	13.625	13.710	13.801	13.895	13.985	14.075	14.165	14.255	14.345	14.440
17	14.530	14.620	14.710	14.800	14.895	14.990	15.085	15.172	15.270	15.375
18	15.460	15.560	15.660	15.760	15.960	15.960	16.060	16.160	16.260	16.360
19	16.460	16.570	16.680	16.790	16.900	17.000	17.100	17.210	17.315	17.425
20	17.525	17.635	17.745	17.855	17.965	18.080	18.195	18.310	18.425	18.540
21	18.650	18.765	18.880	19.000	19.110	19.225	19.345	19.460	19.580	19.700
22	19.820	19.940	20.060	20.185	20.310	20.430	20.580	20.690	20.800	20.930
23	21.050	21.190	21.320	21.450	21.580	21.710	21.840	21.970	22.100	22.230
24	22.365	22.500	22.630	22.763	22.905	23.050	23.190	23.310	23.450	23.600
25	23.750	23.900	24.030	24.200	24.345	24.490	24.640	24.790	24.935	25.080

Temp	0	1	2	3	4	5	6	7	8	9
20	17.53	18.65	19.82	21.05	22.37	23.75	25.21	26.74	28.32	30.03
30	31.82	33.70	35.69	37.71	39.15	42.20	44.60	47.04	49.70	52.45
40	55.30	58.35	61.50	64.85	68.30	71.90	75.65	79.55	83:00	88.00
50	92.50	97.25	102.1	107.1	113.0	118.0	123.9	129.9	136.2	142.6
60	149.4	156.3	163.9	171.7	179.4	187.6	196.1	205.0	214.1	223.8
70	308.5	243.2	252.2	265.9	275.2	289.1	301.5	314.2	327.3	340.9
80	355.2	369.7	384.8	400.6	416.5	439.8	450.8	468.6	487.0	506.0
90	525.5	546.5	567.0	588.5	610.8	634.0	658.0	682.0	707.0	733.0
100	767.0	786.5	815.5	845.0	875.1	906.0	937.8	970.5	1004.2	1038.8

(continued)

TABLE 635.—PRESSURE OF SATURATED WATER VAPOR FOR VARIOUS CONDITIONS OF TEMPERATURE AND SURROUNDINGS (concluded)

Temp	0	1	2	3	4	5	6	7	8	9
110	1074	1111	1149	1187	1227	1268	1310	1353	1397	1442
120	1489	1536	1585	1636	1687	1740	1794	1850	1907	1965
130	2025	2086	2149	2214	2280	2347	2416	2487	2559	2633
140	2709	2786	2866	2947	3030	3115	3201	3290	3381	3473
150	3568	3665	3763	3864	3967	4072	4180	4290	4402	4516
160	4632	4751	4873	4997	5123	5252	5383	5518	5654	5794
170	5936	6080	6228	6378	6532	6688	6847	7009	7174	7342
180	7513	7688	7865	8046	8230	8417	8608	8802	8999	9200
190	9404	9612	9823	10040	10260	10480	10700	10940	11170	11410
200	11650	11890	12140	12400	12650	12920	13180	13450	13730	14010
210	14290	14580	14870	15160	15470	15770	16080	16400	16720	17040
220	17370	17710	18050	18390	18740	19100	19450	19820	20190	20560
230	20950	21330	21720	22120	22520	22930	23350	23770	24190	24620
240	25060	25500	25950	26410	26870	27340	27810	28290	28780	29270
250	29770	30280	30790	31310	31830	32360	32900	33450	34000	34560
260	35130	35700	36280	36870	37470	38070	38680	39300	39920	40560
270	41200	41840	42500	43160	43840	44520	45200	45900	46600	47320
280	48040	48760	49500	50250	51000	51770	52540	53320	54110	54910
290	55710	56530	57360	58190	59040	59890	60750	61620	62510	63400
300	64300	65210	66130	67060	68000	68960	69920	70890	71870	72860
310	73870	74880	75910	76940	77990	79050	80120	81200	82290	83390
320	84500	85630	86760	87910	89070	90250	91430	92630	93840	95060
330	96290	97530	98790	100060	101350	102640	103950	105280	106600	108000
340	109300	110700	112100	113500	114900	116300	117800	119200	120700	122200
350	123700	125200	126800	128300	129900	131400	133000	134600	136300	137900
360	139600	141200	142900	144600	146300	148100	149800	151600	153400	155200
370	157000	158800	160700	162600	164400	—	—	—	—	—

TABLE 636.—WEIGHT IN GRAMS OF A CUBIC METER OF SATURATED AQUEOUS VAPOR

Temp °C	0	1	2	3	4	5	6	7	8	9
−20	1.074	.988	.909	.836	.768	.705	.646	.592	.542	.496
−10	2.358	2.186	2.026	1.876	1.736	1.605	1.483	1.369	1.264	1.165
− 0	4.847	4.523	4.217	3.930	3.660	3.407	3.169	2.946	2.737	2.541
+ 0	4.847	5.192	5.559	5.947	6.360	6.797	7.260	7.750	8.270	8.819
+10	9.399	10.01	10.66	11.35	12.07	12.83	13.63	14.84	15.37	16.21
+20	17.30	18.34	19.43	20.58	21.78	23.05	24.38	25.78	27.24	28.78
+30	30.38	32.07	33.83	35.68	37.61	39.63	41.75	43.96	46.26	48.67

For higher temperatures see Table 166.

TABLE 637.—WEIGHT IN GRAINS OF A CUBIC FOOT OF SATURATED AQUEOUS VAPOR

Temp °F	0	1	2	3	4	5	6	7	8	9
−20	.219	.208	.198	.188	.179	.170	.161	.153	.146	.138
−10	.355	.339	.323	.308	.293	.280	.266	.254	.242	.230
− 0	.563	.540	.517	.492	.469	.448	.428	.408	.390	.372
+ 0	.563	.587	.614	.642	.671	.701	.732	.768	.799	.834
+10	.870	.908	.947	.988	1.030	1.074	1.119	1.166	1.215	1.265
+20	1.318	1.375	1.431	1.488	1.548	1.612	1.676	1.746	1.815	1.886
+30	1.961	2.038	2.118	2.200	2.285	2.375	2.466	2.558	2.656	2.755
+40	2.862	2.970	3.081	3.195	3.315	3.438	3.563	3.691	3.822	3.965
+50	4.105	4.256	4.410	4.565	4.722	4.890	5.060	5.235	5.420	5.608
+60	5.805	6.000	6.195	6.410	6.628	6.855	7.080	7.317	7.560	7.810
+70	8.060	8.325	8.600	8.880	9.165	9.460	9.765	10.075	10.390	10.720
+80	11.06	11.40	11.76	12.12	12.50	12.87	13.27	13.70	14.09	14.52
+90	14.96	15.41	15.98	16.34	16.84	17.32	17.82	18.34	18.90	19.39
+100	19.96	20.55	21.15	21.75	22.35	23.05	23.65	24.32	24.98	25.68
+110	26.35	27.12	27.90	28.62	29.40	30.20	31.00	31.85	32.68	33.55

TABLE 638.—RELATIVE HUMIDITY FOR VARIOUS PRESSURES AND DRY-BULB TEMPERATURES

Vertical argument is the observed vapor pressure which may be computed from the wet-bulb and dry-bulb readings through Tables 634 or 640. The horizontal argument is the observed air temperature (dry-bulb reading).

Vapor pressure mmHg	Air temperatures, dry bulb, °C																
	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10	−11	−12	−13	−14	−15	−20
.25	6	7	7	8	8	9	10	10	11	13	15	15	15	16	17	18	28
.50	12	13	14	15	16	17	18	19	21	23	26	28	29	31	34	37	55
.75	17	19	20	22	24	25	27	29	32	34	37	40	43	46	50	54	81
1.00	23	25	27	29	32	34	36	39	42	45	49	53	57	61	67	72	..
1.25	29	31	33	36	39	42	45	48	52	56	60	65	70	76	82	87	..
1.50	35	37	40	43	46	49	53	57	61	67	71	77	83	90	97	..	..
1.75	40	43	46	48	53	57	62	66	71	77	82	87	92	98	..	..	..
2.00	45	48	52	56	60	65	70	75	81	87	94	97	..	..	..	..	..
2.25	51	54	59	63	68	73	79	84	91	98	..	..	mmHg	0°	−1	−2	−3°
2.50	56	60	65	70	75	81	88	94	100	..	..	..	3.50	78	84	90	97
2.75	61	66	71	76	81	87	94	..	..	..	..	..	3.75	84	90	96	..
3.00	67	72	78	83	88	94	99	..	..	..	..	..	4.00	90	96	..	..
3.25	72	78	84	90	96	..	..	..	..	..	..	..	4.25	96	..	..	..
3.50	78	84	90	97	..	..	..	..	..	..	..	..	4.50	100	..	..	..

Vapor pressure mmHg	Air temperatures, dry bulb, °C																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
.5	12	11	11	10	9	9	8	8	7	7	6	6	6	5	5	5	4	4	4	3	3
1.0	24	23	21	20	18	17	16	15	14	13	13	12	11	10	10	9	9	8	8	7	7
1.5	35	33	31	29	27	25	23	21	20	19	18	17	16	15	14	13	12	11	11	10	10
2.0	46	43	40	37	35	32	30	28	27	25	23	22	21	20	18	17	16	15	14	13	12
2.5	56	52	48	45	42	39	36	34	32	30	28	26	25	23	22	21	19	18	17	16	15
3.0	67	63	58	54	50	47	44	41	38	36	34	32	30	28	26	25	23	22	20	19	18
3.5	78	73	68	63	59	55	52	48	45	43	40	38	35	33	31	29	28	26	24	23	22
4.0	91	85	79	74	69	65	61	57	53	50	47	44	41	39	37	35	32	30	29	27	25
4.5	99	93	87	81	76	71	67	62	58	55	52	49	46	43	40	38	36	33	31	29	28
5.0	..	..	95	89	83	78	73	68	64	60	56	53	50	47	44	41	39	36	34	32	31
5.5	..	..	..	96	91	86	81	75	70	66	62	58	55	51	48	45	42	40	37	35	33
6.0	..	..	..	..	100	94	88	82	76	72	68	64	60	56	53	50	46	43	40	38	36
6.5	..	..	..	..	..	99	93	89	83	78	72	68	64	60	56	52	49	46	44	41	39
7.0	..	..	..	..	..	..	100	94	88	82	77	72	68	64	60	56	52	49	47	44	42
7.5	..	..	..	..	..	..	..	100	94	88	83	77	73	68	65	61	57	54	51	48	46
8.0	..	..	..	..	..	..	..	..	100	94	88	83	77	73	68	65	61	57	54	51	48
8.5	..	..	..	..	..	..	..	..	..	98	92	86	81	76	72	68	63	60	57	53	51
9.0	..	..	..	..	..	..	..	..	..	..	97	91	86	81	76	72	67	64	60	56	53
9.5	..	..	..	..	..	..	..	..	..	..	..	97	91	85	80	75	71	67	63	59	56
10.0	..	..	..	..	..	..	..	..	..	..	..	..	95	89	84	79	74	70	66	62	59
11.0	..	..	..	..	..	..	..	..	..	..	..	..	..	96	92	87	82	77	72	67	64
12.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	94	89	84	79	74	70
13.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	96	90	85	80	76
14.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98	93	88	84
15.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	97	91	86
16.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	100	92
17.0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98

Vapor pressure mmHg	Air temperatures, dry bulb, °C																				
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	7	6	6	6	5	5	5	5	4	4	4	4	3	3	3	3	3	2	2	2	2
2	12	11	11	10	10	9	9	8	8	7	7	7	6	6	6	5	5	5	5	4	4
3	18	17	16	15	15	14	13	12	12	11	11	10	9	9	8	8	7	7	7	6	6
4	25	23	22	20	19	18	17	16	15	15	14	13	12	12	11	11	10	10	9	9	8
5	30	28	27	25	24	23	22	20	19	18	17	16	15	15	14	14	13	12	11	11	10
6	36	34	32	30	29	27	26	24	23	21	20	19	18	17	17	16	15	14	13	12	12
7	42	39	37	35	34	32	30	28	26	25	23	22	21	20	19	18	17	16	16	15	14
8	48	45	42	40	38	36	34	32	30	29	27	26	24	23	22	21	20	19	18	17	16

(continued)

TABLE 638.—RELATIVE HUMIDITY FOR VARIOUS PRESSURES AND DRY-BULB TEMPERATURES (continued)

Vapor pressure mmHg	Air temperatures, dry bulb, °C																				
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
9	53	50	47	44	41	39	37	35	33	31	29	27	26	25	24	23	22	21	20	19	18
10	59	56	52	50	47	44	42	40	37	35	34	32	30	28	27	26	24	23	22	21	20
11	64	61	57	53	50	48	45	43	41	38	36	35	33	31	29	28	26	25	24	23	22
12	70	66	62	59	56	53	50	47	44	42	40	38	36	34	32	31	29	28	26	25	24
13	75	71	67	63	60	57	53	50	48	45	43	41	38	36	35	33	32	30	28	27	26
14	81	76	72	68	64	61	57	54	51	49	46	44	41	39	37	35	33	32	30	29	27
15	86	82	77	72	68	65	61	56	54	52	49	46	44	42	40	38	36	34	32	31	29
16	92	87	82	77	73	69	65	62	58	55	52	49	47	45	42	40	38	36	34	33	31
17	100	92	86	82	77	73	69	65	62	58	55	52	49	47	45	42	40	38	36	34	33
18	..	100	91	86	82	77	73	69	65	62	58	55	52	50	47	45	42	40	38	36	35
19	..	..	99	93	86	81	77	73	69	65	61	58	55	52	50	47	45	42	40	38	36
20	..	..	..	96	90	85	80	76	72	68	65	61	58	55	52	50	47	45	42	40	38
21	..	..	..	99	94	89	84	79	75	72	68	64	61	58	55	52	49	47	44	42	40
22	..	..	..	..	98	93	88	83	79	75	71	67	63	60	57	54	51	49	46	44	42
23	..	..	..	..	..	97	92	87	82	78	74	70	66	62	59	57	54	51	48	46	44
24	..	..	..	..	..	..	96	90	85	81	77	73	69	65	62	59	56	53	50	48	46
25	..	..	..	..	..	..	100	94	89	84	79	75	71	68	64	61	58	55	51	50	48
26	..	..	..	..	..	..	..	97	92	87	83	78	74	70	67	63	60	57	54	52	49
27	..	..	..	..	..	..	..	..	96	91	86	82	78	73	69	65	62	59	56	53	51
28	..	..	..	..	..	..	..	..	99	94	89	85	82	77	71	68	64	61	58	55	53
29	..	..	..	..	..	..	..	..	..	97	92	87	83	78	74	70	67	63	60	57	54
30	..	..	..	..	..	..	..	..	..	..	95	90	85	81	77	73	70	66	62	59	56
31	..	..	..	..	..	..	..	..	..	..	98	93	88	83	79	75	71	68	64	61	58
32	..	..	..	..	..	..	..	..	..	..	..	95	90	86	81	77	73	69	66	63	60
33	..	..	..	..	..	..	..	..	..	..	..	98	95	89	85	80	76	72	69	65	62
34	..	..	..	..	..	..	..	..	..	..	..	..	98	93	88	84	79	75	72	68	65
35	..	..	..	..	..	..	..	..	..	..	..	..	100	95	89	85	81	77	73	69	66
36	..	..	..	..	..	..	..	..	..	..	..	..	..	97	91	86	82	78	74	70	67
37	..	..	..	..	..	..	..	..	..	..	..	..	..	98	94	89	84	80	76	72	69
38	..	..	..	..	..	..	..	..	..	..	..	..	..	..	96	91	86	82	78	74	70
39	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98	93	88	84	80	76	72
40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	100	95	90	86	82	78	74
41	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	97	92	88	83	80	76
42	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	100	94	90	85	81	77
43	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	97	92	87	83	79
44	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	99	94	90	85	81
45	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	96	91	86	82
46	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98	93	88	84
47	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	95	90	86
48	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	97	92	88
49	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	99	94	89
50	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	96	91
51	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98	92
52	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	99	94
53	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	97
54	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	98
55	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	100

Vapor pressure mmHg	Air temperatures, dry bulb, °C																				
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
5	10	10	9	9	8	8	8	7	7	7	6	6	6	6	5	5	5	5	5	4	4
10	20	19	18	17	16	15	14	14	13	13	12	12	11	11	10	10	9	9	8	8	7
15	29	28	26	25	24	23	22	21	20	19	18	17	16	16	15	14	14	13	12	12	11
20	38	37	35	33	31	30	29	27	26	25	24	23	22	20	19	18	18	17	16	15	15
25	47	45	43	41	39	37	35	33	32	31	29	28	27	25	24	23	22	21	20	19	19
30	56	53	51	49	46	44	42	40	38	36	35	33	32	30	29	28	27	25	24	22	21
35	66	62	59	57	53	51	48	46	44	42	40	38	37	35	33	32	30	29	28	26	24
40	74	70	67	64	60	58	55	52	50	48	45	43	41	39	38	36	35	33	32	30	28
45	82	78	75	71	68	65	61	58	56	53	51	48	46	44	42	40	39	37	35	34	32
50	91	87	82	79	75	71	68	65	62	59	56	53	51	49	47	45	43	41	39	37	35

(continued)

TABLE 638.—RELATIVE HUMIDITY FOR VARIOUS PRESSURES AND DRY-BULB TEMPERATURES (concluded)

Vapor pressure mmHg	Air temperatures, dry bulb, °C																				
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
55	100	95	90	86	82	78	74	71	68	65	62	59	56	54	51	49	47	45	43	41	39
60	..	..	97	93	88	84	80	77	73	70	67	64	61	58	55	53	51	49	47	45	43
65	..	..	..	..	96	91	87	83	79	75	72	69	65	62	60	57	55	52	50	48	46
70	..	..	..	..	..	98	93	89	85	81	77	74	70	67	64	61	59	56	54	52	49
75	..	..	..	..	..	..	100	95	91	86	83	79	75	72	69	66	63	60	58	55	53
80	..	..	..	..	..	..	..	..	96	91	87	83	80	76	73	69	66	63	61	58	56
85	..	..	..	..	..	..	..	..	..	97	92	88	84	81	77	74	70	67	64	62	59
90	..	..	..	..	..	..	..	..	..	..	96	92	89	85	81	78	74	71	68	65	62
95	..	mmHg	57°	58	59	60°	..	..	..	..	..	97	93	89	85	82	78	75	71	68	65
100	..	125	96	92	88	84	..	..	..	..	..	..	99	94	89	86	82	78	75	72	69
105	..	130	100	96	92	88	..	..	..	..	..	..	..	98	94	90	86	82	78	75	72
110	..	135	..	99	95	91	..	..	..	..	..	..	..	..	98	94	89	85	82	78	75
115	..	140	..	..	99	94	..	..	..	..	..	..	..	..	..	97	93	89	85	82	78
120	..	145	..	..	..	97	..	..	..	..	..	..	..	..	..	..	97	93	89	85	82
125	..	150	..	..	..	100	..	..	..	..	..	..	..	..	..	..	..	96	92	88	84

TABLE 639.—RELATIVE HUMIDITY, WET AND DRY THERMOMETERS

This table gives the relative humidity direct from the difference between the reading of the dry (t°C) and the wet (t_1°C) thermometer. It is computed for a barometer reading of 1000 mb. The wet thermometers should be ventilated about 3 meters per second. Changes due to different pressure can be calculated from the data given in Tables 634 and 640.

Temperatures of dry thermometer, $t°$

($t° - t_1°$)	−15	−10	−5	0	5
.2	92	94	95	96	97
.4	84	89	91	92	95
.5	80	86	89	91	93
.6	76	82	88	90	92
.8	68	77	83	87	89
1.0	60	71	78	83	86
1.2	52	65	74	80	84
1.4	43	59	72	76	81
1.5	39	56	67	74	80
1.6	35	53	65	73	78
1.8	27	49	61	69	75
2.0	18	41	56	65	73
2.5	..	27	46	58	66
3.0	..	10	35	50	60
3.5	..	..	24	41	53
4.0	..	..	12	33	47
4.5	..	..	..	25	40
5	..	..	..	16	34
6	..	..	..	..	21
7	..	..	..	..	8

($t° - t_1°$)	10	15	20	25	30	35	40
.5	94	95	96	96	97	97	97
1.0	89	90	92	93	93	94	94
1.5	83	86	88	89	90	91	91
2.0	77	81	83	85	86	88	89
2.5	72	76	80	82	83	85	86
3.0	67	72	75	78	80	82	83
3.5	61	67	72	75	77	79	81
4.0	56	63	68	71	74	76	78
4.5	51	58	64	68	71	73	76
5.0	46	54	60	65	68	71	73
6	36	46	53	58	62	65	68
7	26	38	46	52	57	60	63
8	15	29	39	46	51	55	59
9	5	21	32	40	46	51	54
10	..	13	25	34	41	46	50
11	..	5	19	30	36	42	46
12	..	..	13	23	31	37	43
13	..	..	..	18	28	33	38
14	..	..	..	13	25	29	34
15	..	..	..	8	19	25	31
16	..	..	..	..	13	21	28
17	..	..	..	..	9	18	24
18	..	..	..	..	5	14	21
19	..	..	..	..	3	10	18
20	..	..	..	..	2	7	14
22	..	..	..	..	..	..	11
24	..	..	..	..	..	..	9

TABLE 640.—PRESSURE OF AQUEOUS VAPOR IN THE ATMOSPHERE: SEA LEVEL

This table gives the vapor pressure corresponding to various values of the difference $t - t_1$ between the readings of dry-bulb and wet-bulb thermometers and the temperature t_1 of the wet-bulb thermometer. The difference $t - t_1$ is given by two-degree steps in the top line, and t_1 by degrees in the first column. Temperatures in Centigrade degrees, vapor pressures in millimeters of mercury are used throughout the table. The table was calculated for barometric pressure B equal to 76 cmHg. A correction is given for each centimeter at the top of the columns. Ventilating velocity of wet thermometer about 3 meters per second.

t_1	$t - t_1 = 0°$	2°	4°	6°	8°	10°	12°	14°	16°	18°	20°	Difference for 0.1° in $t - t_1$
Corrections for B per cmHg		.013	.026	.040	.053	.066	.079	.092	.106	.119	.132	
−10	1.96	.97	—	—	—							.050
− 9	2.14	1.15	.16	—	—							.050
− 8	2.34	1.35	.35	—	—							.050
− 7	2.55	1.56	.66	—	—							.050
− 6	2.78	1.78	.79	—	—							.050
− 5	3.02	2.03	1.03	.03	—							.050
− 4	3.29	2.29	1.29	.29	—							.050
− 3	3.58	2.58	1.58	.58	—							.050
− 2	3.89	2.89	1.89	.88	—	—	—	—	—	—	—	.050
− 1	4.22	3.22	2.22	1.21	.21	—	—	—	—	—	—	.050
0	4.58	3.58	2.57	1.57	.57	—	—	—	—	—	—	.050
1	4.92	3.92	2.92	1.91	.91	—	—	—	—	—	—	.050
2	5.29	4.29	3.28	2.27	1.27	.26	—	—	—	—	—	.050
3	5.68	4.68	3.67	2.66	1.66	.65	—	—	—	—	—	.050
4	6.10	5.09	4.08	3.07	2.07	1.06	.05	—	—	—	—	.050
5	6.54	5.53	4.52	3.51	2.51	1.50	.49	—	—	—	—	.050
6	7.01	6.00	4.99	3.98	2.97	1.96	.95	—	—	—	—	.050
7	7.51	6.50	5.49	4.48	3.47	2.46	1.45	.43	—	—	—	.050
8	8.04	7.03	6.02	5.01	4.00	2.98	1.97	.96	—	—	—	.050
9	8.61	7.60	6.58	5.57	4.56	3.54	2.53	1.52	.50	—	—	.050
10	9.21	8.20	7.18	6.17	5.15	4.14	3.12	2.11	1.09	.08	—	.050
11	9.85	8.83	7.81	6.80	5.78	4.77	3.75	2.73	1.72	.70	—	.051
12	10.52	9.50	8.49	7.47	6.45	5.44	4.42	3.40	2.38	1.37	.35	.051
13	11.24	10.22	9.20	8.18	7.16	6.14	5.13	4.11	3.09	2.07	1.05	.051
14	11.99	10.97	9.95	8.93	7.91	6.90	5.88	4.86	3.84	2.82	1.80	.051
15	12.79	11.77	10.75	9.73	8.71	7.69	6.67	5.65	4.63	3.61	2.59	.051
16	13.64	12.62	11.60	10.58	9.96	8.53	7.51	6.49	5.47	4.45	3.43	.051
17	14.54	13.52	12.49	11.47	10.45	9.42	8.40	7.38	6.36	5.33	4.31	.051
18	15.49	14.46	13.44	12.42	11.39	10.37	9.34	8.32	7.30	6.27	5.25	.051
19	16.49	15.46	14.44	13.41	12.39	11.36	10.34	9.31	8.29	7.26	6.24	.051
20	17.55	16.52	15.50	14.47	13.44	12.42	11.39	10.36	9.34	8.31	7.29	.051
21	18.66	17.64	16.61	15.58	14.56	13.53	12.50	11.47	10.45	9.42	8.39	.051
22	19.84	18.82	17.79	16.76	15.73	14.70	13.67	12.64	11.62	10.59	10.57	.051
23	21.09	20.06	19.03	18.00	16.97	15.94	14.91	13.88	12.85	11.82	10.79	.051
24	22.40	21.37	20.34	19.31	18.27	17.24	16.21	15.18	14.15	13.12	12.09	.051
25	23.78	22.75	21.71	20.68	19.65	18.62	17.59	16.56	15.52	14.49	13.46	.052
26	25.24	24.20	23.17	22.14	21.10	20.07	19.04	18.00	16.97	15.94	14.90	.052
27	26.77	25.73	24.70	23.66	22.63	21.60	20.56	19.53	18.49	17.46	16.42	.052
28	28.38	27.34	26.31	25.27	24.24	23.20	22.17	21.13	20.10	19.06	18.02	.052
29	30.08	29.04	28.00	26.97	25.93	24.89	23.86	22.82	21.78	20.75	19.71	.052
30	31.86	30.82	29.78	28.75	27.71	26.67	25.63	24.60	23.56	22.52	21.48	.052
31	33.74	32.70	31.66	30.62	29.58	28.54	27.50	26.46	25.42	24.38	23.34	.052
32	35.70	34.66	33.62	32.58	31.54	30.50	29.46	28.42	27.38	26.34	25.30	.052
33	37.78	36.73	35.69	34.65	33.61	32.57	31.53	30.49	29.44	28.40	27.36	.052
34	39.95	38.90	37.86	36.82	35.78	34.73	33.69	32.65	31.61	30.57	29.52	.052
35	42.23	41.18	40.14	39.10	38.05	37.01	35.97	34.92	33.88	32.83	31.79	.052
36	44.62	43.57	42.53	41.48	40.44	39.40	38.35	37.31	36.26	35.22	34.17	.052
37	47.13	46.08	45.04	43.99	42.94	41.90	40.85	39.81	38.76	37.71	36.67	.052
38	49.76	48.71	47.66	46.61	45.57	44.52	43.47	42.43	41.38	40.33	39.29	.052
39	52.51	51.46	50.41	49.37	48.32	47.27	46.22	45.17	44.12	43.08	42.03	.052
40	55.40	54.35	53.30	52.25	51.20	50.15	49.10	48.05	47.00	45.95	44.00	.052

Example

$t = 17.2$; $t_1 = 10.0$; $B = 74.5$ cmHg

$t - t_1 = 7.2$

From table: $6.17 - 12 \times 0.050 = 5.57$

For B, $1.5 \times .048 \quad = .07$

Hence $p \quad = 5.64$

TABLE 641.—PRESSURE OF COLUMNS OF MERCURY AND WATER

British and metric measures. Correct at 0°C for mercury and at 4°C for water.

Metric measure			British measure		
cmHg	Pressure g/cm²	Pressure lb/in.²	inHg	Pressure g/cm²	Pressure lb/in.²
1	13.5954	.193367	**1**	34.532	.491152
2	27.1908	.386734	2	69.065	.982304
3	40.7862	.580101	3	103.597	1.473457
4	54.3816	.773468	4	138.129	1.964609
5	67.9770	.966835	5	172.662	2.455761
6	81.5724	1.160204	**6**	207.194	2.946918
7	95.1678	1.353566	7	241.726	3.438058
8	108.7632	1.546936	8	276.259	3.929286
9	122.3586	1.740303	9	310.791	4.420370
10	135.9540	1.933670	10	345.323	4.911522
cm of H_2O	Pressure g/cm²	Pressure lb/in.²	Inches of H_2O	Pressure g/cm²	Pressure lb/in.²
1	1	.0142234	**1**	2.54	.036127
2	2	.0284468	2	5.08	.072255
3	3	.0426702	3	7.62	.108382
4	4	.0568936	4	10.16	.144510
5	5	.0711170	5	12.70	.180637
6	6	.0853404	**6**	15.24	.216764
7	7	.0995638	7	17.78	.252892
8	8	.1137872	8	20.32	.289019
9	9	.1280106	9	22.86	.325147
10	10	.1422340	10	25.40	.361274

[197] The tables on the barometer have been adapted from the Smithsonian Meteorological Tables, sixth edition.

TABLE 642.—CORRECTION OF THE BAROMETER FOR CAPILLARITY *

Metric measure

Diameter of tube in mm	Height of meniscus in millimeters							
	.4	.6	.8	1.0	1.2	1.4	1.6	1.8
4	1.1	1.7	2.1	2.4	2.6			
5	.73	1.06	1.34	1.55	1.76			
6	.47	.71	.91	1.08	1.21	1.30	1.37	1.43
7	.33	.48	.63	.76	.86	.96	1.03	1.08
8	.24	.35	.46	.55	.63	.70	.77	.82
9	.18	.27	.35	.41	.47	.53	.57	.61
10	.12	.18	.24	.30	.35	.40	.44	.47
12	.07	.10	.13	.16	.20	.22	.25	.27
14	.04	.06	.08	.10	.11	.13	.15	.17
16	.02	.04	.05	.06	.07	.09	.10	.11

* Corrections to be added in millimeters.

TABLE 643.—VOLUME OF MERCURY MENISCUS IN mm³

Height of meniscus	Diameter of tube in mm										
mm	14	15	16	17	18	19	20	21	22	23	24
1.6	157	185	214	245	280	318	356	398	444	492	541
1.8	181	211	244	281	320	362	407	455	507	560	616
2.0	206	240	278	319	362	409	460	513	571	631	694
2.2	233	271	313	358	406	459	515	574	637	704	776
2.4	262	303	350	400	454	511	573	639	708	781	859
2.6	291	338	388	444	503	565	633	706	782	862	948

TABLE 644.—CONSTANT *a* FOR REDUCTION OF BAROMETRIC HEIGHT TO STANDARD TEMPERATURE *

Brass scale and English measure		Brass scale and metric measure		Glass scale and metric measure	
Height of barometer in inches	*a* in inches for temp °F	Height of barometer in mmHg	*a* in mm for temp °C	Height of barometer in mmHg	*a* in mm for temp °C
15.0	.00135	**400**	.0651	**50**	.0086
16.0	.00145	410	.0668	100	.0172
17.0	.00154	420	.0684	150	.0258
17.5	.00158	430	.0700	200	.0345
18.0	.00163	440	.0716	250	.0431
18.5	.00167	450	.0732	300	.0517
19.0	.00172	460	.0749	350	.0603
19.5	.00176	470	.0765		
		480	.0781	**400**	.0689
20.0	.00181	490	.0797	450	.0775
20.5	.00185			500	.0861
21.0	.00190	**500**	.0813	520	.0895
21.5	.00194	510	.0830	540	.0930
22.0	.00199	520	.0846	560	.0965
22.5	.00203	530	.0862	580	.0999
23.0	.00208	540	.0878		
23.5	.00212	550	.0894	**600**	.1034
		560	.0911	610	.1051
24.0	.00217	570	.0927	620	.1068
24.5	.00221	580	.0943	630	.1085
25.0	.00226	590	.0959	640	.1103
25.5	.00231			650	.1120
26.0	.00236	**600**	.0975	660	.1137
26.5	.00240	610	.0992		
27.0	.00245	620	.1008	**670**	.1154
27.5	.00249	630	.1024	680	.1172
		640	.1040	690	.1189
28.0	.00254	650	.1056	700	.1206
28.5	.00258	660	.1073	710	.1223
29.0	.00263	670	.1089	720	.1240
29.2	.00265	680	.1105	730	.1258
29.4	.00267	690	.1121		
29.6	.00268			**740**	.1275
29.8	.00270	**700**	.1137	750	.1292
30.0	.00272	710	.1154	760	.1309
		720	.1170	770	.1327
30.2	.00274	730	.1186	780	.1344
30.4	.00276	740	.1202	790	.1361
30.6	.00277	750	.1218	800	.1378
30.8	.00279	760	.1235		
31.0	.00281	770	.1251	**850**	.1464
31.2	.00283	780	.1267	900	.1551
31.4	.00285	790	.1283	950	.1639
31.6	.00287	**800**	.1299	1000	.1723

* The height of the barometer is affected by the relative thermal expansion of the mercury and the glass, in the case of instruments graduated on the glass tube, and by the relative expansion of the mercury and the metallic enclosing case, usually of brass, in the case of instruments graduated on the brass case. This relative expansion is practically proportional to the first power of the temperature. The above tables of values of the coefficient of relative expansion will be found to give corrections almost identical with those given in the International Meteorological Tables. The numbers tabulated under *a* are the values of *a* in the equation $H_t = H_t' - a\,(t' - t)$ where H_t is the height at the standard temperature, H_t' the observed height at the temperature t', and $a\,(t' - t)$ the correction for temperature. The standard temperature is 0°C for the metric system and 28°.5 F for the English system. The English barometer is correct for the temperature of melting ice at a temperature of approximately 28°.5 F, because of the fact that the brass scale is graduated so as to be standard at 62°F, while mercury has the standard density at 32°F.

Example.—A barometer having a brass scale gave $H = 765$ mm at 25°C; required, the corresponding reading at 0°C. Here the value of *a* is the mean of .1235 and 1251, or .1243; ∴ $a\,(t' - t) = .1243 \times 25 = 3.11$. Hence $H_0 = 765 - 3.11 = 761.89$.

Note.—Although *a* is here given to three and sometimes to four significant figures, it is seldom worth while to use more than the nearest two-figure number. In fact, all barometers have not the same values for *a*, and when great accuracy is wanted the proper coefficients have to be determined by experiment.

TABLE 645.—REDUCTION OF BAROMETER TO STANDARD GRAVITY FOR DIFFERENT HEIGHTS

Free-air altitude term. Correction to be subtracted.

The correction to reduce the barometer to sea level is $[(g_1 - g)/g] \times B$ where B is the barometer reading and g and g_1 the value of gravity at sea level and the place of observation respectively. The following values were computed for free-air values of gravity g_1 (Table 802). It has been customary to assume for mountain stations that the value of $g_1 =$ say about $\frac{2}{3}$ the free-air value, but a comparison of modern determinations of g_1 in this country shows that little reliance can be placed on such an assumption. Where g_1 is known its value should be used in the above correction term. (See Tables 803-805.) Similarly for the latitude term, see succeeding tables; the true value of g should be used if known; the succeeding tables are based on the theoretical values, Table 802.)

Height above sea level meters	$g_1 - g$	Observed height of barometer in mmHg: 400	450	500	550	600	650	700	750	800		
100	.031	Correction in mmHg to be subtracted for height above sea level in first column and barometer reading in the top line.						.02	.02	.02	—	—
200	.062							.04	.05	.05	—	—
300	.093							.07	.07	.07	—	—
400	.123							.09	.10	.10	—	—
500	.154	—	—	—	—	—	—	.11	.12	.13	—	—
600	.185	—	—	—	—	—	.12	.13	.14	—	—	—
700	.216	—	—	—	—	—	.14	.15	.16	—	—	—
800	.247	—	—	—	—	—	.16	.18	.19	—	—	—
900	.278	—	—	—	—	—	.18	.20	.22	—	—	—
1000	.309	—	—	—	.18	.19	.20	.22	.24	—	—	—
1100	.339	—	—	—	.19	.21	.22	.24	—	—	—	—
1200	.370	—	—	—	.21	.23	.24	.26	—	—	—	—
1300	.401	—	—	—	.22	.24	.26	.29	—	—	—	—
1400	.432	—	—	—	.24	.26	.28	.31	—	—	—	—
1500	.463	—	—	.24	.26	.28	.30	.33	—	—	—	—
1600	.494	—	—	.25	.28	.30	.32	—	—	—	—	—
1700	.525	—	—	.27	.30	.32	.34	—	—	—	—	—
1800	.555	—	—	.28	.31	.34	.36	—	—	.020	.0463	15000
1900	.586	—	—	.30	.33	.36	.39	—	—	.019	.0447	14500
2000	.617	—	.28	.31	.34	.38	.41	—	.021	.019	.0432	14000
2100	.648	—	.30	.33	.36	.40	—	—	.021	.018	.0416	13500
2200	.679	—	.31	.35	.38	.41	—	—	.020	.017	.0401	13000
2300	.710	—	.32	.36	.40	.43	—	.021	.019	.017	.0386	12500
2400	.740	—	.34	.38	.42	.45	—	.021	.018	.016	.0370	12000
2500	.771	.31	.35	.39	.43	.47	—	.020	.018	.015	.0355	11500
2600	.802	.33	.37	.41	—	—	.021	.019	.017	.015	.0339	11000
2700	.833	.34	.38	.42	—	—	.020	.018	.016	.014	.0324	10500
2800	.864	.35	.40	.44	—	—	.019	.017	.015	.013	.0308	10000
2900	.895	.36	.41	.46	—	.020	.018	.016	.015	.013	.0293	9500
3000	.926	.38	.42	.47	—	.019	.017	.016	.014	.012	.0278	9000
3100	.957	.39	.44	—	—	.018	.016	.015	.013	—	.0262	8500
3200	.988	.40	.46	—	—	.017	.015	.014	.012	—	.0247	8000
3300	1.019	.42	.47	—	.017	.016	.014	.013	—	—	.0231	7500
3400	1.049	.43	.48	—	.016	.015	.013	.012	—	—	.0216	7000
3500	1.080	.44	.49	—	.015	.014	.012	.011	—	—	.0200	6500
3600	1.111	.45	—	—	.014	.013	.011	—	—	—	.0185	6000
3700	1.142	.46	—	—	.013	.012	.011	—	—	—	.0170	5500
3800	1.173	.48	—	.012	.011	.011	.010	—	—	—	.0154	5000
3900	1.204	.49	—	.011	.010	.010	—	—	—	—	.0139	4500
4000	1.235	.50	—	.010	.009	.009	—	—	—	—	.0123	4000
—	—	—	.008	.008	.007	.007	Corrections in in. to be subtracted for height above sea level in last column and barometer reading in bottom line.				.0092	3000
—	—	.006	.005	.005	.004	—					.0062	2000
—	—	.003	.003	.003	—	—					.0031	1000
		30	28	26	24	22	20	18	16	14	$g_1 - g$	Height above sea level feet
		Observed height of barometer in inches										

TABLE 646.—REDUCTION OF BAROMETER TO STANDARD GRAVITY *

METRIC MEASURES

From latitude 0° to 45°, the correction is to be added algebraically.

Latitude	520	540	560	580	600	620	640	660	680	700	720	740	760	780
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
0	−1.39	−1.45	−1.50	−1.55	−1.61	−1.66	−1.71	−1.77	−1.82	−1.87	−1.93	−1.98	−2.04	−2.09
5	−1.37	−1.42	−1.48	−1.53	−1.58	−1.64	−1.69	−1.74	−1.79	−1.85	−1.90	−1.95	−2.00	−2.06
6	1.36	1.42	1.47	1.52	1.57	1.63	1.68	1.73	1.78	1.83	1.89	1.94	1.99	2.04
7	1.35	1.40	1.46	1.51	1.56	1.61	1.66	1.72	1.77	1.82	1.87	1.92	1.98	2.03
8	1.34	1.39	1.44	1.49	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.91	1.96	2.01
9	1.33	1.38	1.43	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.84	1.89	1.94	1.99
10	−1.31	−1.36	−1.41	−1.46	−1.51	−1.56	−1.61	−1.66	−1.71	−1.76	−1.81	−1.86	−1.92	−1.97
11	1.29	1.34	1.39	1.44	1.49	1.54	1.59	1.64	1.69	1.74	1.79	1.84	1.89	1.94
12	1.27	1.32	1.37	1.42	1.47	1.52	1.57	1.62	1.67	1.72	1.76	1.81	1.86	1.91
13	1.25	1.30	1.35	1.40	1.45	1.50	1.54	1.59	1.64	1.69	1.74	1.78	1.83	1.88
14	1.23	1.28	1.33	1.38	1.42	1.47	1.52	1.56	1.61	1.66	1.71	1.75	1.80	1.85
15	−1.21	−1.26	−1.30	−1.35	−1.40	−1.44	−1.49	−1.54	−1.58	−1.63	−1.67	−1.72	−1.77	−1.81
16	1.19	1.23	1.28	1.32	1.37	1.41	1.46	1.50	1.55	1.60	1.64	1.69	1.73	1.78
17	1.16	1.20	1.25	1.29	1.34	1.38	1.43	1.47	1.52	1.56	1.60	1.65	1.69	1.74
18	1.13	1.18	1.22	1.26	1.31	1.35	1.39	1.44	1.48	1.52	1.57	1.61	1.65	1.70
19	1.10	1.15	1.19	1.23	1.27	1.32	1.36	1.40	1.44	1.48	1.53	1.57	1.61	1.65
20	−1.07	−1.11	−1.16	−1.20	−1.24	−1.28	−1.32	−1.36	−1.40	−1.44	−1.49	−1.53	−1.57	−1.61
21	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.48	1.52	1.56
22	1.01	1.05	1.09	1.13	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.48	1.51
23	.98	1.01	1.05	1.09	1.13	1.16	1.20	1.24	1.28	1.31	1.35	1.39	1.43	1.46
24	.94	.98	1.01	1.05	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34	1.37	1.41
25	− .90	− .94	− .97	−1.01	−1.04	−1.08	−1.11	−1.15	−1.18	−1.22	−1.25	−1.29	−1.32	−1.36
26	.87	.90	.93	.97	1.00	1.03	1.07	1.10	1.13	1.17	1.20	1.23	1.27	1.30
27	.83	.86	.89	.92	.96	.99	1.02	1.05	1.08	1.12	1.15	1.18	1.21	1.24
28	.79	.82	.85	.88	.91	.94	.97	1.00	1.03	1.06	1.09	1.12	1.15	1.18
29	.75	.78	.81	.84	.86	.89	.92	.95	.98	1.01	1.04	1.07	1.10	1.12
30	− .71	− .74	− .76	− .79	− .82	− .85	− .87	− .90	− .93	− .95	− .98	−1.01	−1.04	−1.06
31	.67	.69	.72	.74	.77	.80	.82	.85	.87	.90	.92	.95	.98	1.00
32	.62	.65	.67	.70	.72	.74	.77	.79	.82	.84	.86	.89	.91	.94
33	.58	.60	.63	.65	.67	.69	.72	.74	.76	.78	.80	.83	.85	.87
34	.54	.56	.58	.60	.62	.64	.66	.68	.70	.72	.74	.76	.79	.81
35	− .49	− .51	− .53	− .55	− .57	− .59	− .61	− .63	− .64	− .66	− .68	− .70	− .72	.74
36	.45	.46	.48	.50	.52	.53	.55	.57	.58	.60	.62	.64	.65	.67
37	.40	.42	.43	.45	.46	.48	.49	.51	.52	.54	.56	.57	.59	.60
38	.36	.37	.38	.40	.41	.42	.44	.45	.46	.48	.49	.51	.52	.53
39	.31	.32	.33	.34	.36	.37	.38	.39	.40	.42	.43	.44	.45	.46
40	− .26	− .27	− .28	− .29	− .30	− .31	− .32	− .33	− .34	− .35	− .36	− .37	− .38	− .39
41	.21	.22	.23	.24	.25	.26	.26	.27	.28	.29	.30	.30	.31	.32
42	.17	.17	.18	.19	.19	.20	.21	.21	.22	.22	.23	.24	.24	.25
43	.12	.12	.13	.13	.14	.14	.15	.15	.16	.16	.16	.17	.17	.18
44	.07	.07	.08	.08	.08	.08	.09	.09	.09	.10	.10	.10	.10	.11
45	− .02	− .02	− .03	− .03	− .03	− .03	− .03	− .03	− .03	− .03	− .03	− .03	− .03	− .04

* 980.665 cm sec^{-2}

(*continued*)

TABLE 646.—REDUCTION OF BAROMETER TO STANDARD GRAVITY (concluded)

METRIC MEASURES

From latitude 46° to 90°, the correction is to be added algebraically.

Latitude	520	540	560	580	600	620	640	660	680	700	720	740	760	780
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
45	−.02	−.02	−.03	−.03	−.03	−.03	−.03	−.03	−.03	−.03	−.03	−.03	−.03	−.04
46	+.02	+.03	+.03	+.03	+.03	+.03	+.03	+.03	+.03	+.03	+.03	+.03	+.04	+.04
47	.07	.08	.08	.08	.08	.09	.09	.09	.09	.10	.10	.10	.10	.11
48	.12	.12	.13	.13	.14	.14	.15	.15	.16	.16	.17	.17	.18	.18
49	.17	.17	.18	.19	.19	.20	.21	.21	.22	.23	.23	.24	.25	.25
50	.22	.22	.23	.24	.25	.26	.26	.27	.28	.29	.30	.31	.31	.32
51	+.26	+.27	+.28	+.29	+.30	+.31	+.32	+.33	+.34	+.35	+.36	+.37	+.38	+.39
52	.31	.32	.33	.34	.36	.37	.38	.39	.40	.42	.43	.44	.45	.46
53	.36	.37	.38	.40	.41	.42	.44	.45	.46	.48	.49	.51	.52	.53
54	.40	.42	.43	.45	.46	.48	.49	.51	.52	.54	.56	.57	.59	.60
55	.45	.46	.48	.50	.52	.53	.55	.57	.58	.60	.62	.64	.65	.67
56	+.49	+.51	+.53	+.55	+.57	+.59	+.60	+.62	+.64	+.66	+.68	+.70	+.72	+.74
57	.54	.56	.58	.60	.62	.64	.66	.68	.70	.72	.74	.76	.78	.80
58	.58	.60	.62	.65	.67	.69	.71	.74	.76	.78	.80	.82	.85	.87
59	.62	.65	.67	.69	.72	.74	.77	.79	.81	.84	.86	.89	.91	.93
60	.66	.69	.72	.74	.77	.79	.82	.84	.87	.89	.92	.94	.97	1.00
61	+.71	+.73	+.76	+.79	+.81	+.84	+.87	+.89	+.92	+.95	+.98	+1.00	+1.03	+1.06
62	.74	.77	.80	.83	.85	.88	.91	.94	.97	1.00	1.02	1.05	1.08	1.11
63	.78	.81	.85	.88	.91	.94	.97	1.00	1.03	1.06	1.09	1.12	1.15	1.18
64	.82	.85	.89	.92	.95	.98	1.01	1.04	1.08	1.11	1.14	1.17	1.20	1.23
65	.86	.89	.93	.96	.99	1.03	1.06	1.09	1.13	1.16	1.19	1.22	1.26	1.29
66	+.90	+.93	+.97	+1.00	+1.04	+1.07	+1.10	+1.14	+1.17	+1.21	+1.24	+1.28	+1.31	+1.35
67	.93	.97	1.00	1.04	1.08	1.11	1.15	1.18	1.22	1.25	1.29	1.33	1.36	1.40
68	.97	1.00	1.04	1.08	1.11	1.15	1.19	1.23	1.26	1.30	1.34	1.37	1.41	1.45
69	1.00	1.04	1.08	1.11	1.15	1.19	1.23	1.27	1.31	1.34	1.38	1.42	1.46	1.50
70	1.03	1.07	1.11	1.15	1.19	1.23	1.27	1.31	1.35	1.39	1.43	1.47	1.51	1.55
71	+1.06	+1.10	+1.14	+1.18	+1.22	+1.26	+1.31	+1.35	+1.39	+1.43	+1.47	+1.51	+1.55	+1.59
72	1.09	1.13	1.17	1.22	1.26	1.30	1.34	1.38	1.42	1.47	1.51	1.55	1.59	1.63
73	1.12	1.16	1.20	1.25	1.29	1.33	1.37	1.42	1.46	1.50	1.55	1.59	1.63	1.67
74	1.14	1.19	1.23	1.28	1.32	1.36	1.41	1.45	1.50	1.54	1.58	1.63	1.67	1.72
75	1.17	1.21	1.26	1.30	1.35	1.39	1.44	1.48	1.53	1.57	1.62	1.66	1.71	1.75
76	+1.19	+1.24	+1.28	+1.33	+1.37	+1.42	+1.47	+1.51	+1.56	+1.60	+1.65	+1.70	+1.74	+1.79
77	1.21	1.26	1.31	1.35	1.40	1.45	1.49	1.54	1.59	1.63	1.68	1.73	1.77	1.82
78	1.23	1.28	1.33	1.38	1.42	1.47	1.52	1.57	1.61	1.66	1.71	1.76	1.80	1.85
79	1.25	1.30	1.35	1.40	1.45	1.49	1.54	1.59	1.64	1.69	1.73	1.78	1.83	1.88
80	1.27	1.32	1.37	1.42	1.47	1.51	1.56	1.61	1.66	1.71	1.76	1.81	1.86	1.90
81	+1.29	+1.33	+1.38	+1.43	+1.48	+1.53	+1.58	+1.63	+1.68	+1.73	+1.78	+1.83	+1.88	+1.93
82	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95
83	1.31	1.36	1.41	1.46	1.51	1.56	1.61	1.67	1.72	1.77	1.82	1.87	1.92	1.97
84	1.32	1.37	1.42	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.93	1.98
85	1.33	1.38	1.43	1.49	1.54	1.59	1.64	1.69	1.74	1.79	1.84	1.90	1.95	2.00
90	+1.35	+1.41	+1.46	+1.51	+1.56	+1.61	+1.67	+1.72	+1.77	+1.82	+1.87	+1.93	+1.98	+2.03

TABLE 647.—REDUCTION OF BAROMETER TO STANDARD GRAVITY *

ENGLISH MEASURES

From latitude 0° to 45°, the correction is to be added algebraically.

Latitude	19	20	21	22	23	24	25	26	27	28	29	30
	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch
0	—.051	—.054	—.056	—.059	—.062	—.064	—.067	—.070	—.072	—.075	—.078	—.080
5	—.050	—.053	—.055	—.058	—.061	—.063	—.066	—.069	—.071	—.074	—.077	—.079
6	.050	.052	.055	.058	.060	.063	.066	.068	.071	.073	.076	.079
7	.049	.052	.055	.057	.060	.062	.065	.068	.070	.073	.075	.078
8	.049	.052	.054	.057	.059	.062	.064	.067	.070	.072	.075	.077
9	.048	.051	.054	.056	.059	.061	.064	.066	.069	.071	.074	.076
10	—.048	—.050	—.053	—.055	—.058	—.060	—.063	—.066	—.068	—.071	—.073	—.076
11	.047	.050	.052	.055	.057	.060	.062	.065	.067	.070	.072	.075
12	.047	.049	.051	.054	.056	.059	.061	.064	.066	.069	.071	.074
13	.046	.048	.051	.053	.055	.058	.060	.063	.065	.068	.070	.072
14	.045	.047	.050	.052	.055	.057	.059	.062	.064	.066	.069	.071
15	—.044	—.047	—.049	—.051	—.053	—.056	—.058	—.060	—.063	—.065	—.067	—.070
16	.043	.046	.048	.050	.052	.055	.057	.059	.062	.064	.066	.068
17	.042	.045	.047	.049	.051	.053	.056	.058	.060	.062	.065	.067
18	.041	.044	.046	.048	.050	.052	.054	.057	.059	.061	.063	.065
19	.040	.042	.045	.047	.049	.051	.053	.055	.057	.059	.062	.064
20	—.039	—.041	—.043	—.045	—.047	—.050	—.052	—.054	—.056	—.058	—.060	—.062
21	.038	.040	.042	.044	.046	.048	.050	.052	.054	.056	.058	.060
22	.037	.039	.041	.043	.045	.047	.049	.050	.052	.054	.056	.058
23	.036	.038	.039	.041	.043	.045	.047	.049	.051	.053	.054	.056
24	.034	.036	.038	.040	.042	.043	.045	.047	.049	.051	.052	.054
25	—.033	—.035	—.037	—.038	—.040	—.042	—.043	—.045	—.047	—.049	—.050	—.052
26	.032	.033	.035	.037	.038	.040	.042	.043	.045	.047	.048	.050
27	.030	.032	.033	.035	.037	.038	.040	.041	.043	.045	.046	.048
28	.029	.030	.032	.033	.035	.036	.038	.039	.041	.043	.044	.046
29	.027	.029	.030	.032	.033	.035	.036	.037	.039	.040	.042	.043
30	—.026	—.027	—.029	—.030	—.031	—.033	—.034	—.035	—.037	—.038	—.040	—.041
31	.024	.026	.027	.028	.030	.031	.032	.033	.035	.036	.037	.038
32	.023	.024	.025	.026	.028	.029	.030	.031	.032	.034	.035	.036
33	.021	.022	.023	.025	.026	.027	.028	.029	.030	.031	.032	.034
34	.020	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031
35	—.018	—.019	—.020	—.021	—.022	—.023	—.024	—.025	—.026	—.027	—.027	—.028
36	.016	.017	.018	.019	.020	.021	.022	.022	.023	.024	.025	.026
37	.015	.015	.016	.017	.018	.019	.019	.020	.021	.022	.022	.023
38	.013	.014	.014	.015	.016	.016	.017	.018	.018	.019	.020	.020
39	.011	.012	.012	.013	.014	.014	.015	.015	.016	.017	.017	.018
40	—.010	—.010	—.011	—.011	—.012	—.012	—.013	—.013	—.014	—.014	—.015	—.015
41	.008	.008	.009	.009	.009	.010	.010	.011	.011	.012	.012	.012
42	.006	.006	.007	.007	.007	.008	.008	.008	.009	.009	.009	.010
43	.004	.005	.005	.005	.005	.005	.006	.006	.006	.006	.007	.007
44	.003	.003	.003	.003	.003	.003	.003	.004	.004	.004	.004	.004
45	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001

* 32.17 in. sec^{-2}

(continued)

TABLE 647.—REDUCTION OF BAROMETER TO STANDARD GRAVITY (concluded)

ENGLISH MEASURES

From latitude 46° to 90°, the correction is to be added algebraically.

Latitude	19 Inch	20 Inch	21 Inch	22 Inch	23 Inch	24 Inch	25 Inch	26 Inch	27 Inch	28 Inch	29 Inch	30 Inch
45	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001
46	+.001	+.001	+.001	+.001	+.001	+.001	+.001	+.001	+.001	+.001	+.001	+.001
47	.003	.003	.003	.003	.003	.003	.003	.004	.004	.004	.004	.004
48	.004	.005	.005	.005	.005	.006	.006	.006	.006	.006	.007	.007
49	.006	.006	.007	.007	.007	.008	.008	.008	.009	.009	.009	.010
50	.008	.008	.009	.009	.010	.010	.010	.011	.012	.012	.012	.012
51	+.010	+.010	+.011	+.011	+.012	+.012	+.013	+.013	+.014	+.014	+.015	+.015
52	.011	.012	.012	.013	.014	.014	.015	.015	.016	.016	.017	.018
53	.013	.014	.014	.015	.016	.016	.017	.018	.018	.019	.020	.020
54	.015	.015	.016	.017	.018	.019	.019	.020	.021	.022	.022	.023
55	.016	.017	.018	.019	.020	.021	.021	.022	.023	.024	.025	.026
56	+.018	+.019	+.020	+.021	+.022	+.023	+.024	+.024	+.026	+.026	+.027	+.028
57	.020	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031
58	.021	.022	.023	.025	.026	.027	.028	.029	.030	.031	.032	.033
59	.023	.024	.025	.026	.028	.029	.030	.031	.032	.033	.035	.036
60	.024	.026	.027	.028	.029	.031	.032	.033	.034	.036	.037	.038
61	+.026	+.027	+.028	+.030	+.031	+.033	+.034	+.035	+.037	+.038	+.039	+.041
62	.027	.029	.030	.032	.033	.034	.036	.037	.039	.040	.042	.043
63	.029	.030	.032	.033	.035	.036	.038	.039	.041	.042	.044	.045
64	.030	.032	.033	.035	.036	.038	.040	.041	.043	.044	.046	.047
65	.031	.033	.035	.036	.038	.040	.041	.043	.045	.046	.048	.050
66	+.033	+.034	+.036	+.038	+.040	+.041	+.043	+.045	+.047	+.048	+.050	+.052
67	.034	.036	.038	.039	.041	.043	.045	.047	.048	.050	.052	.054
68	.035	.037	.039	.041	.043	.045	.046	.048	.050	.052	.054	.056
69	.036	.038	.040	.042	.044	.046	.048	.050	.052	.054	.056	.058
70	.038	.040	.042	.044	.046	.048	.050	.052	.053	.055	.057	.059
71	+.039	+.041	+.043	+.045	+.047	+.049	+.051	+.053	+.055	+.057	+.059	+.061
72	.040	.042	.044	.046	.048	.050	.052	.054	.057	.059	.061	.063
73	.041	.043	.045	.047	.049	.052	.054	.056	.058	.060	.062	.064
74	.042	.044	.046	.048	.051	.053	.055	.057	.059	.062	.064	.066
75	.043	.045	.047	.049	.052	.054	.056	.058	.061	.063	.065	.067
76	+.044	+.046	+.048	+.050	+.053	+.055	+.057	+.060	+.062	+.064	.066	.069
77	.044	.047	.049	.051	.054	.056	.058	.061	.063	.065	.068	.070
78	.045	.047	.050	.052	.055	.057	.059	.062	.064	.066	.069	.071
79	.046	.048	.051	.053	.055	.058	.060	.063	.065	.067	.070	.072
80	.046	.049	.051	.054	.056	.059	.061	.063	.066	.068	.071	.073
81	+.047	+.049	+.052	+.054	+.057	+.059	+.062	+.064	+.067	+.069	+.072	+.074
82	.047	.050	.052	.055	.057	.060	.062	.065	.067	.070	.072	.075
83	.048	.050	.053	.056	.058	.061	.063	.066	.068	.071	.073	.076
84	.048	.051	.053	.056	.059	.061	.064	.066	.069	.071	.074	.076
85	.049	.051	.054	.056	.059	.061	.064	.067	.069	.072	.074	.077
90	+.049	+.052	+.055	+.057	+.060	+.062	+.065	+.068	+.070	+.073	+.075	+.078

TABLE 648.—DETERMINATION OF HEIGHTS BY THE BAROMETER

Formula of Babinet: $Z = C \frac{B_0 - B}{B_0 + B}$

$$C \text{ (in feet)} = 52494 \left[1 + \frac{t_0 + t - 64}{900} \right] \text{ English measures.}$$

$$C \text{ (in meters)} = 16000 \left[1 + \frac{2 (t_0 + t)}{1000} \right] \text{ metric measures.}$$

In which Z = difference of height of two stations in feet or meters.

B_0, B = barometric readings at the lower and upper stations respectively, corrected for all sources of instrumental error.

t_0, t = air temperatures at the lower and upper stations respectively.

VALUES OF C

English measures			Metric measures		
½ $(t_0 + t)$ °F	C Feet	Log C	½ $(t_0 + t)$ °C	C Meters	Log C
10	49928	4.69834	**—10**	15360	4.18639
15	50511	.70339	— 8	15488	.19000
			— 6	15616	.19357
20	51094	4.70837	— 4	15744	.19712
25	51677	.71330	— 2	15872	.20063
30	52261	4.71818	**0**	16000	4.20412
35	52844	.72300	+ 2	16128	.20758
			4	16256	.21101
40	53428	4.72777	6	16384	.21442
45	54011	.73248	8	16512	.21780
50	54595	4.73715	**10**	16640	4.22115
55	55178	.74177	12	16768	.22448
			14	16896	.22778
60	55761	4.74633	16	17024	.23106
65	56344	.75085	18	17152	.23431
70	56927	4.75532	**20**	17280	4.23754
75	57511	.75975	22	17408	.24075
			24	17536	.24393
80	58094	4.76413	26	17664	.24709
85	58677	.76847	28	17792	.25022
90	59260	4.77276	**30**	17920	4.25334
95	59844	.77702	32	18048	.25643
			34	18176	.25950
100	60427	4.78123	36	18304	.26255

TABLE 649.—THUNDERSTORM ELECTRICITY[198]

(Lightning strokes consist of current peaks and continuing currents.)

	Maximum	Minimum	Average
Quantity discharged by single current peaks	5 coulombs		.2 coulombs
" " " total stroke	>300 coulombs		18 coulombs
Current amplitude in current peaks	2×10^5 amp		10^4 amp
" " " continuing current discharges	1000 amp		100 amp
Number of current peaks in strokes	42		2
Time interval between successive current peaks	.5 sec	3×10^{-4} sec	.04 sec
Variability in number of strokes (Empire State Bldg.)	50/yr	3/yr	21/yr
Number of strokes per square mile per year at an average isokeraunic level of 27			10 — 20
Wave shapes of current peaks:			
Fronts	10μ sec		1.5μ sec
Tail—time to half value	>120μ sec		38 μ sec
Effective rate of rise of current	4.5×10^4 amp/μ sec		1.2×10^4 amp/μ sec
Polarity of lightning strokes to ground from cloud (approximately)			95% —
Cloud potential (estimated)	20×10^6 volts to	10^9 volts	
Energy (depends on voltage and current in channel—estimated)			10^{17} ergs
Potential gradient at earth's surface beneath a thundercloud (estimated)	50 V/cm to	1000 V/cm	
Number of lightning discharges over entire earth each second		100	
Lightning channel:			
Current density during formation	3×10^4 amp/cm^2	1100 amp/cm^2	
Probable diameter	5 cm		

Cloud-to-ground stroke characteristics.—First discharge in a stroke progresses from cloud to ground as stepped leaders (average velocity, 1 foot per microsecond). After contacting earth a return stroke progresses toward the cloud (velocity, 65-450 feet/μ sec; average, 100 feet/μ sec). Subsequent discharges progress from the cloud as continuous leaders (average velocity, 10 feet/μ sec) and again a return stroke is formed.

In case of tall objects (skyscrapers) stroke leaders may start from the building toward the cloud. In such a case no thunder or very little thunder is heard unless initial discharge is followed by current peaks.

[198] McEachron, K. B., "Lightning and Lightning Protection," Encycl. Brit., vol. 14, June 1948. Used by permission.

TABLE 650.—ELEMENTS AND CONSTANTS OF ATMOSPHERIC ELECTRICITY *

The elements of atmospheric electricity show variations, both regular and irregular. Over land the irregular variations are very pronounced and the regular variations differ notably from place to place, in marked contrast to the corresponding characteristics over the ocean. Therefore, and because of the wider and more uniform geographical distribution of ocean observations, it seems best to give the greater weight to the ocean data when attempting to arrive at values characterizing world-wide conditions. Because of the wide variation from place to place in the means from land stations, due to local factors, a general mean of these is of questionable significance. Hence it seems better to indicate the extremes of station means in the case of elements for which the data are sufficiently abundant.

Certain disparities, which will be found between published tables of ocean data, arise largely from the inclusion of more recent data.

Of the atmospheric-electric elements the potential gradient has been the most extensively observed. The sign of the average gradient is everywhere such as to drive positive ions toward the earth. The periodic variations in this element are of great interest because of their apparent relation with cosmic phenomena. Thus the potential gradient apparently increases with increase in sunspot numbers and varies throughout the year. The maxima in monthly means occur everywhere, with few exceptions, at the time of northern winter, and the corresponding minima occur at the time of northern summer. The diurnal variation observed over the oceans is everywhere in phase when considered on a common-time basis, except for a minor phase-shift that depends upon the season. This diurnal variation derived from observatories made on the *Carnegie* during 1915 to 1921, given by the Fourier expression $\Delta P/P = 0.15 \sin(\theta + 186^\circ) + 0.03 \sin(2\theta + 237^\circ)$ where θ is reckoned at 15° per hour beginning at 0^h Greenwich mean civil time, is in close agreement with that obtained from 1928–1929 observations.

No general expression that will approximately characterize the diurnal variation over land can be given. These variations determined by local factors are apparently superimposed upon a variation of the same world-wide character as that found to prevail over the oceans.

* Tables 650-653 prepared by G. R. Wait, Department of Terrestrial Magnestism, Carnegie Institution of Washington.

TABLE 651.—IONIC EQUILIBRIUM IN THE ATMOSPHERE

Equilibrium for atmospheric ionization occurs when $q = \alpha n^2 + \eta_1 N_0 n + \eta_2 N n$, where n and N are the number of pairs of small and large ions of one sign and N_0 the number of uncharged nuclei; α, η_1, η_2, are coefficients of recombination of small ions with small ions, with uncharged nuclei, and with large ions. If for both small and large ions the positive and negative are equally abundant, then $N_0/N = \eta_2/\eta_1$. When $n/N \ll 2\eta_2/\alpha$, the equilibrium-condition is expressed by $q = \beta n$; β is designated the diminution-constant; $1/\beta = \Theta$ is the "average life" of a small ion in air which contains an abundance of large ions; Θ varies inversely as N.

α: 1.6×10^{-6} cm³/sec
η_1: 5×10^{-6} "
η_2: 6×10^{-6} "
Θ Over land,
  Average, 30 sec
  Extremes, 10 to 60 sec
 Over sea, 230 sec
N: Over land, 500 to 50,000 ions/cm³
Aitken nuclei, number per cm³:
 Over open country, up to 10^5
 Over midocean, about 800
 In free air,
  Altitude 1 km 6,000   5 km 50
  3 km 200   8.5 km about 5

TABLE 652.—CHARGE ON RAIN AND SNOW

Specific net charge on precipitation:

Average, 0.5 esu/g
Maximum observed, 20 esu/g

Specific charge on individual raindrops or snowflakes:

Rain, + 2.7 to — 3.2 esu/g
Snow, + 11.6 to — 8.1 esu/g

TABLE 653.—ATMOSPHERIC-ELECTRIC DATA

Element	Symbol	Means	Units	Variations
				Range — Percent of mean
Potential gradient.	P	Land: 64 to 317	volts/m	Annual 22 to 145
			"	Diurnal 35 to 120
		Sea: 128		Annual 13
				Diurnal 35
		Free air		Percentage of surface values at various altitudes: 0 km 100; 3 " 17; 6 km 8; 9 " 4
Air-conductivity total	$\lambda = \lambda_+ + \lambda_-$	Land: 1 to 5	esu $\times 10^{-4}$	Variations determined chiefly by local factors
		Sea: 2.6	" "	Variations small and chiefly irregular
		Free air		Ratio of value at various altitudes to that at surface: 0 km 1; 3 " 8; 6 km 20; 9 " 38
Ratio of positive to negative conductivity	λ_+/λ_-	Land: 1.12		
		Sea: 1.26		
Air-earth current density	$i = \lambda P/30000$	Land: 7.0	esu $\times 10^{-7}$	
		Sea: 11.0		
Density of small ions: Positive ..	n_+	Land: 750	ions/cm³	
		Sea: 600	"	
Negative .	n_-	Land: 650	"	
		Sea: 500	"	
	$(n_+ + n_-)/2$	Free air		Values at various altitudes: 2 km 1300; 4 " 1900; 5 " 2300
Ratio of positive to negative ionic density	$p = n_+/n_-$	Land: 1.23		
		Sea: 1.23		

(*continued*)

Element	Symbol	Means		Units
Space-charge, over land..	ρ	At surface:* — 2000 to + 1900		10^{-10} esu/cm^3
	$\rho = -\left(\frac{dP}{dh}/1.2\pi\right) \times 10^{-10}$	Free air:		
	(For h = height in km)		ρ	
		0 to 3 km	9.0	"
		3 to 6	0.9	"
		6 to 9	0.4	"
Mobility of small ions:	$k_+ = \lambda_+/300\ en_+$			
Positive	k_+	Land:	0.9	cm sec^{-1} $volt^{-1}$ cm^{-1}
		Sea:	1.6	"
Negative	k_-	Land:	1.0	"
		Sea:	1.7	"
Rate of formation of ion-pairs	q	Over land:		
		Ra and Th products in air		
		α rays	4.6	ions cm^{-3} sec^{-1}
		β rays	0.2	"
		γ rays	0.15	"
		Radioactive matter in the earth's crust		
		β rays	0.1	"
		γ rays	3.0	"
		Penetrating radiation	1.5	"
		Total	9.55	"
		At sea:		
		Penetrating radiation	1.5	"
		(?)	.07	"
		Total	2.2	"

* The sign and magnitude of surface values are exceedingly variable from place to place.

Just a few years ago it was held that the universe was made up of 92 elements and that probably these elements were made of two elementary particles. While most of these 92 elements had been identified and their properties studied, there were several that had not been identified and thus very little was known directly about their properties.

As a result of a great amount of study and investigation, during the past few years the number of known elementary particles has been extended to seven or eight (see Table 720), and all the elements missing from the periodic table (see Table 658) have been identified and some of their properties studied.[199] In addition to this, the number of elements has been extended to five or six beyond uranium and some of the properties of these elements have been studied. (See Table 658.)

It is now generally considered that the elements are made up of electrons, protons, and neutrons. Each element now has three designations: the name; the atomic number, Z, i.e., the charge on the atomic nucleus and the mass number, A, which is the number of protons and neutrons that make up the nucleus of the atom and extends from 1 for hydrogen (or the neutron) to 246 for the isotope of californium. This mass number is not too definite since, in many cases, several atoms have isotopes of the same mass number.

Atoms of number greater than 83 and certain isotopes of eight atoms of lower atomic number, are unstable in that they break down into other isotopes, i.e., they are radioactive. (See Table 732.) There are in all about 1,220 different isotopes[199] that have been identified and have had some of their properties studied. Of these only 274 are stable. A number of atoms[200] (Z = 43, 61, 85, 93, 94, 95, 96) are so unstable that they are not now found on the earth. Two of the isotopes, A = 5, and 8, have so short a life that it is almost impossible to detect them. A radioactive material with a life shorter than about 10^{-20} sec and longer than about 10^{14} years will be unobservable as such.

The values given for certain physical dimensions of molecules, atoms, or nuclei depend upon the definition of the particular dimension and the method used in its calculation. Diameters may be calculated from Van der Waal's equation, from viscosity, and from certain force relations. Some values are the results of assuming the atom or nucleus to be a sphere. While these various methods give results that do not differ too much, neither are the results in good enough agreement for one to feel that the answer is final. The following tables give some results of physical dimension obtained by various means of calculation.

[199] Seaborg and Perlman, Rev. Mod. Phys., vol. 20, p. 585, 1948.
[200] Bethe, H. A., Elementary nuclear theory, John Wiley & Sons, Inc., 1947. Reprinted by permission.

TABLE 654.—CONVERSION FACTORS FOR UNITS OF MOLECULAR ENERGY *

Units	Erg/molecule	Joule/mole	Cal/mole	Electron-volt/ molecule	Wave No † (cm^{-1})
1 erg/molecule =	1	6.02283×10^{16}	1.43491×10^{16}	6.2422×10^{11}	5.03581×10^{15}
1 joule/mole =	1.660349×10^{-17}	1	.239006	1.036427×10^{-5}	8.36121×10^{-2}
1 cal/mole =	6.94690×10^{-7}	4.1840	1	4.33641×10^{-5}	.349833
1 electron-volt/ molecule =	1.601992×10^{-12}	96.4853×10^{3}	2.30605×10^{4}	1	8.06734×10^{3}
1 wave No (cm^{-1}) =	1.985776×10^{-16}	11.95999	2.85851	1.239567×10^{-4}	1

* This table adapted from data furnished by the National Bureau of Standards. † This means $h\nu$/molecule where the values given are for ν = unity.

Element	Symbol	At No	Atomic weight *	Element	Symbol	At No	Atomic weight *
Actinium	Ac	89	227	Molybdenum	Mo	42	95.95
Aluminum	Al	13	26.98	Neodymium	Nd	60	144.27
Americium	Am	95	[243]	Neon	Ne	10	20.183
Antimony	Sb	51	121.76	Neptunium	Np	93	[237]
Argon	A	18	39.944	Nickel	Ni	28	58.69
Arsenic	As	33	74.91	Niobium	Nb	41	92.91
Astatine	At	85	[210]	Nitrogen	N	7	14.008
Barium	Ba	56	137.36	Osmium	Os	76	190.2
Berkelium	Br	97	[245]	Oxygen	O	8	16
Beryllium	Be	4	9.013	Palladium	Pd	46	106.7
Bismuth	Bi	83	209.00	Phosphorus	P	15	30.975
Boron	B	5	10.82	Platinum	Pt	78	195.23
Bromine	Br	35	79.916	Plutonium	Pu	94	[242]
Cadmium	Cd	48	112.41	Polonium	Po	84	210
Calcium	Ca	20	40.08	Potassium	K	19	39.100
Californium	Cf	98	[246]	Praseodymium	Pr	59	140.92
Carbon	C	6	12.010	Promethium	Pm	61	[145]
Cerium	Ce	58	140.13	Protactinium	Pa	91	231
Cesium	Cs	55	132.91	Radium	Ra	88	226.05
Chlorine	Cl	17	35.457	Radon	Rn	86	222
Chromium	Cr	24	52.01	Rhenium	Re	75	186.31
Cobalt	Co	27	58.94	Rhodium	Rh	45	102.91
Copper	Cu	29	63.54	Rubidium	Rb	37	85.48
Curium	Cm	96	[243]	Ruthenium	Ru	44	101.7
Dysprosium	Dy	66	162.46	Samarium	Sm	62	150.43
Erbium	Er	68	167.2	Scandium	Sc	21	44.96
Europium	Eu	63	152.0	Selenium	Se	34	78.96
Fluorine	F	9	19.00	Silicon	Si	14	28.06
Francium	Fr	87	[223]	Silver	Ag	47	107.880
Gadolinium	Gd	64	156.9	Sodium	Na	11	22.997
Gallium	Ga	31	69.72	Strontium	Sr	38	87.63
Germanium	Ge	32	72.60	Sulfur	S	16	32.066 †
Gold	Au	79	197.2	Tantalum	Ta	73	180.88
Hafnium	Hf	72	178.6	Technetium	Tc	43	[99]
Helium	He	2	4.003	Tellurium	Te	52	127.61
Holmium	Ho	67	164.94	Terbium	Tb	65	159.2
Hydrogen	H	1	1.0080	Thallium	Tl	81	204.39
Indium	In	49	114.76	Thorium	Th	90	232.12
Iodine	I	53	126.91	Thulium	Tm	69	169.4
Iridium	Ir	77	193.1	Tin	Sn	50	118.70
Iron	Fe	26	55.85	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.92
Lanthanum	La	57	138.92	Uranium	U	92	238.07
Lead	Pb	82	207.21	Vanadium	V	23	50.95
Lithium	Li	3	6.940	Xenon	Xe	54	131.3
Lutetium	Lu	71	174.99	Ytterbium	Yb	70	173.04
Magnesium	Mg	12	24.32	Yttrium	Y	39	88.92
Manganese	Mn	25	54.93	Zinc	Zn	30	65.38
Mercury	Hg	80	200.61	Zirconium	Zr	40	91.22

[201] Wichers, Edward, Journ. Amer. Chem. Soc., vol. 74, p. 2447, 1952.
* A value given in brackets denotes the mass number of the isotope of longest known half life.
† Because of natural variations in the relative abundance of the isotopes of sulfur, the atomic weight of this element has a range of ±.003.

1	Hydrogen	H	34	Selenium	Se	67	Holmium	Ho
2	Helium	He	35	Bromine	Br	68	Erbium	Er
3	Lithium	Li	36	Krypton	Kr	69	Thulium	Tm
4	Beryllium	Be	37	Rubidium	Rb	70	Ytterbium	Yb
5	Boron	B	38	Strontium	Sr	71	Lutetium	Lu
6	Carbon	C	39	Yttrium	Y	72	Hafnium	Hf
7	Nitrogen	N	40	Zirconium	Zr	73	Tantalum	Ta
8	Oxygen	O	41	Niobium	Nb	74	Tungsten	W
9	Fluorine	F	42	Molybdenum	Mo	75	Rhenium	Re
10	Neon	Ne	43	Technetium	Tc	76	Osmium	Os
11	Sodium	Na	44	Ruthenium	Ru	77	Iridium	Ir
12	Magnesium	Mg	45	Rhodium	Rh	78	Platinum	Pt
13	Aluminum	Al	46	Palladium	Pd	79	Gold	Au
14	Silicon	Si	47	Silver	Ag	80	Mercury	Hg
15	Phosphorus	P	48	Cadmium	Cd	81	Thallium	Tl
16	Sulfur	S	49	Indium	In	82	Lead	Pb
17	Chlorine	Cl	50	Tin	Sn	83	Bismuth	Bi
18	Argon	A	51	Antimony	Sb	84	Polonium	Po
19	Potassium	K	52	Tellurium	Te	85	Astatine	At
20	Calcium	Ca	53	Iodine	I	86	Radon	Rn
21	Scandium	Sc	54	Xenon	Xe	87	Francium	Fr
22	Titanium	Ti	55	Cesium	Cs	88	Radium	Ra
23	Vanadium	V	56	Barium	Ba	89	Actinium	Ac
24	Chromium	Cr	57	Lanthanum	La	90	Thorium	Th
25	Manganese	Mn	58	Cerium	Ce	91	Protactinium	Pa
26	Iron	Fe	59	Praesodymium	Pr	92	Uranium	U
27	Cobalt	Co	60	Neodymium	Nd	93	Neptunium	Np
28	Nickel	Ni	61	Promethium	Pm	94	Plutonium	Pu
29	Copper	Cu	62	Samarium	Sm	95	Americium	Am
30	Zinc	Zn	63	Europium	Eu	96	Curium	Cm
31	Gallium	Ga	64	Gadolinium	Gd	97	Berkelium	Bk
32	Germanium	Ge	65	Terbium	Tb	98	Californium	Cf
33	Arsenic	As	66	Dysprosium	Dy			

Given below by atomic numbers are some foreign or obsolete names for certain of the elements.

4	Glucinium, Gl	41	Columbium, Cb	61	Illinium, Il	80	Hydragyrum
11	Natrium	43	Masurium, Ma	71	Cassiopeium	82	Plumbum
13	Aluminium	47	Argentum	72	Celtium	85	Alabamine, Ab
19	Kalium	50	Stannum	75	Bohemium	86	Emanation, niton
26	Ferrum	51	Stibium	79	Aurum	87	Virginium, Vi

TABLE 657.—PERIODIC SYSTEM OF THE ELEMENTS[202]

	I a	I b	II a	II b	III a	III b	IV a	IV b	V a	V b	VI a	VI b	VII a	VII b	VIII a	VIII a	VIII a	VIII b
I	1 H 1.0080																	2 He 4.003
II	3 Li 6.940			4 Be 9.013		5 B 10.82		6 C 12.010		7 N 14.008		8 O 16		9 F 19.00				10 Ne 20.183
III	11 Na 22.997		12 Mg 24.32			13 Al 26.98		14 Si 28.06		15 P 30.975		16 S 32.066		17 Cl 35.457				18 A 39.944
IV	19 K 39.100		20 Ca 40.08		21 Sc 44.96		22 Ti 47.90		23 V 50.95		24 Cr 52.01		25 Mn 54.93		26 Fe 55.85	27 Co 58.94	28 Ni 58.69	
		29 Cu 63.54		30 Zn 65.38		31 Ga 69.72		32 Ge 72.60		33 As 74.91		34 Se 78.96		35 Br 79.916				36 Kr 83.80
V	37 Rb 85.48		38 Sr 87.63		39 Y 88.92		40 Zr 91.22		41 Nb 92.91		42 Mo 95.95		43 Tc [99]		44 Ru 101.7	45 Rh 102.91	46 Pd 106.7	
		47 Ag 107.880		48 Cd 112.41		49 In 114.76		50 Sn 118.70		51 Sb 121.61		52 Te 127.61		53 I 126.91				54 Xe 131.3
VI	55 Cs 132.91		56 Ba 137.36		57 La 138.92 58 to 71 Rare earths *		72 Hf 178.6		73 Ta 180.88		74 W 183.92		75 Re 186.31		76 Os 190.2	77 Ir 193.1	78 Pt 195.23	
		79 Au 197.2		80 Hg 200.61		81 Tl 204.39		82 Pb 207.21		83 Bi 209.00		84 Po 210		85 At [210]				86 Rn 222
VII	87 Fr 223		88 Ra 226.05		89 Ac 227 90-103 Actinide rare earths †													

[202] Meggers, W. F., Science, vol. 105, p. 514, 1947; G. T. Seaborg, private communication.

* Rare earths:

57 La 138.92	58 Ce 140.13	59 Pr 140.92	60 Nd 144.27	61 Pm [147]	62 Sm 150.43	63 Eu 152.0	64 Gd 156.9	65 Tb 159.2	66 Dy 162.46	67 Ho 164.94	68 Er 167.2	69 Tm 169.4	70 Yb 173.04	71 Lu 174.99

† Actinide rare earths:

90 Th 232.12	91 Pa 231	92 U 238.17	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf

TABLE 658.—ELECTRON CONFIGURATIONS OF THE ELEMENTS, NORMAL STATES *

	K	L		M			N			O
	1s	2s	2p	3s	3p	3d	4s	4p	4d	5s
1 H	1									
2 He	2									
3 Li	2	1								
4 Be	2	2								
5 B	2	2	1							
6 C	2	2	2							
7 N	2	2	3							
8 O	2	2	4							
9 F	2	2	5							
10 Ne	2	2	6							
11 Na	2	2	6	1						
12 Mg	2	2	6	2						
13 Al	2	2	6	2	1					
14 Si	2	2	6	2	2					
15 P	2	2	6	2	3					
16 S	2	2	6	2	4					
17 Cl	2	2	6	2	5					
18 A	2	2	6	2	6					
19 K	2	2	6	2	6		1			
20 Ca	2	2	6	2	6		2			
21 Sc	2	2	6	2	6	1	2			
22 Ti	2	2	6	2	6	2	2			
23 V	2	2	6	2	6	3	2			
24 Cr	2	2	6	2	6	5	1			
25 Mn	2	2	6	2	6	5	2			
26 Fe	2	2	6	2	6	6	2			
27 Co	2	2	6	2	6	7	2			
28 Ni	2	2	6	2	6	8	2			
29 Cu	2	2	6	2	6	10	1			
30 Zn	2	2	6	2	6	10	2			
31 Ga	2	2	6	2	6	10	2	1		
32 Ge	2	2	6	2	6	10	2	2		
33 As	2	2	6	2	6	10	2	3		
34 Se	2	2	6	2	6	10	2	4		
35 Br	2	2	6	2	6	10	2	5		
36 Kr	2	2	6	2	6	10	2	6		
37 Rb	2	2	6	2	6	10	2	6		1
38 Sr	2	2	6	2	6	10	2	6		2
39 Y	2	2	6	2	6	10	2	6	1	2
40 Zr	2	2	6	2	6	10	2	6	2	2
41 Nb	2	2	6	2	6	10	2	6	4	1
42 Mo	2	2	6	2	6	10	2	6	5	1
43 Tc	2	2	6	2	6	10	2	6	5	2
44 Ru	2	2	6	2	6	10	2	6	7	1
45 Rh	2	2	6	2	6	10	2	6	8	1
46 Pd	2	2	6	2	6	10	2	6	10	

* See column 3, Table 623. G. T. Seaborg, private communication.

(*continued*)

TABLE 658.—ELECTRON CONFIGURATIONS OF THE ELEMENTS, NORMAL STATES (concluded)

	K	*L*		*M*			*N*				*O*				*P*			
	1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*	4*d*	4*f*	5*s*	5*p*	5*d*	5*f*	6*s*	6*p*	6*d*	7*s*
47 Ag	2	2	6	2	6	10	2	6	10		1							
48 Cd	2	2	6	2	6	10	2	6	10		2							
49 In	2	2	6	2	6	10	2	6	10		2	1						
50 Sn	2	2	6	2	6	10	2	6	10		2	2						
51 Sb	2	2	6	2	6	10	2	6	10		2	3						
52 Te	2	2	6	2	6	10	2	6	10		2	4						
53 I	2	2	6	2	6	10	2	6	10		2	5						
54 Xe	2	2	6	2	6	10	2	6	10		2	6						
55 Cs	2	2	6	2	6	10	2	6	10		2	6			1			
56 Ba	2	2	6	2	6	10	2	6	10		2	6			2			
57 La	2	2	6	2	6	10	2	6	10		2	6	1		2			
58 Ce	2	2	6	2	6	10	2	6	10	2	2	6			2			
59 Pr	2	2	6	2	6	10	2	6	10	3	2	6			2			
60 Nd	2	2	6	2	6	10	2	6	10	4	2	6			2			
61 Pm	2	2	6	2	6	10	2	6	10	5	2	6			2			
62 Sm	2	2	6	2	6	10	2	6	10	6	2	6			2			
63 Eu	2	2	6	2	6	10	2	6	10	7	2	6			2			
64 Gd	2	2	6	2	6	10	2	6	10	7	2	6	1		2			
65 Tb	2	2	6	2	6	10	2	6	10	9	2	6			2			
66 Dy	2	2	6	2	6	10	2	6	10	10	2	6			2			
67 Ho	2	2	6	2	6	10	2	6	10	11	2	6			2			
68 Er	2	2	6	2	6	10	2	6	10	12	2	6			2			
69 Tm	2	2	6	2	6	10	2	6	10	13	2	6			2			
70 Yb	2	2	6	2	6	10	2	6	10	14	2	6			2			
71 Lu	2	2	6	2	6	10	2	6	10	14	2	6	1		2			
72 Hf	2	2	6	2	6	10	2	6	10	14	2	6	2		2			
73 Ta	2	2	6	2	6	10	2	6	10	14	2	6	3		2			
74 W	2	2	6	2	6	10	2	6	10	14	2	6	4		2			
75 Re	2	2	6	2	6	10	2	6	10	14	2	6	5		2			
76 Os	2	2	6	2	6	10	2	6	10	14	2	6	6		2			
77 Ir	2	2	6	2	6	10	2	6	10	14	2	6	7		2			
78 Pt	2	2	6	2	6	10	2	6	10	14	2	6	9		1			
79 Au	2	2	6	2	6	10	2	6	10	14	2	6	10		1			
80 Hg	2	2	6	2	6	10	2	6	10	14	2	6	10		2			
81 Tl	2	2	6	2	6	10	2	6	10	14	2	6	10		2	1		
82 Pb	2	2	6	2	6	10	2	6	10	14	2	6	10		2	2		
83 Bi	2	2	6	2	6	10	2	6	10	14	2	6	10		2	3		
84 Po	2	2	6	2	6	10	2	6	10	14	2	6	10		2	4		
85 At	2	2	6	2	6	10	2	6	10	14	2	6	10		2	5		
86 Rn	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		
87 Fr	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		1
88 Ra	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		2
89 Ac	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	1	2
90 Th	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	2	2
91 Pa	2	2	6	2	6	10	2	6	10	14	2	6	10	2	2	6	1	2
92 U	2	2	6	2	6	10	2	6	10	14	2	6	10	3	2	6	1	2
93 Np	2	2	6	2	6	10	2	6	10	14	2	6	10	4	2	6	1	2
94 Pu	2	2	6	2	6	10	2	6	10	14	2	6	10	5	2	6	1	2
95 Am	2	2	6	2	6	10	2	6	10	14	2	6	10	6	2	6	1	2
96 Cm	2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6	1	2
97 Bk	2	2	6	2	6	10	2	6	10	14	2	6	10	8	2	6	1	2
98 Cf	2	2	6	2	6	10	2	6	10	14	2	6	10	9	2	6	1	2

TABLE 659.—RADII, IN ANGSTROM UNITS, OF THE ELECTRONIC ORBITS OF LIGHTER ELEMENTS [208]

	K	L		M			N	
Element	1s	2s	2p	3s	3p	3d	4s	4p
H	.53							
He	.30							
Li	.20	1.50						
Be	.143	1.19						
B	.112	.88	.85					
C	.090	.67	.66					
N	.080	.56	.53					
O	.069	.48	.45					
F	.061	.41	.38					
Ne	.055	.37	.32					
Na	.050	.32	.28	1.55				
Mg	.046	.30	.25	1.32				
Al	.042	.27	.23	1.16	1.21			
Si	.040	.24	.21	.98	1.06			
P	.037	.23	.19	.88	.92			
S	.035	.21	.18	.78	.82			
Cl	.032	.20	.16	.72	.75			
A	.031	.19	.155	.66	.67			
K	.029	.18	.145	.60	.63		2.02	
Ca	.028	.16	.133	.55	.58		2.03	
Sc	.026	.16	.127	.52	.54	.61	1.80	
Ti	.025	.150	.122	.48	.50	.55	1.66	
V	.024	.143	.117	.46	.47	.49	1.52	
Cr	.023	.138	.112	.43	.44	.45	1.41	
Mn	.022	.133	.106	.40	.41	.42	1.31	
Fe	.021	.127	.101	.39	.39	.39	1.22	
Co	.020	.122	.096	.37	.37	.36	1.14	
Ni	.019	.117	.090	.35	.36	.34	1.07	
Cu	.019	.112	.085	.34	.34	.32	1.03	
Zn	.018	.106	.081	.32	.32	.30	.97	
Ga	.017	.103	.078	.31	.31	.28	.92	1.13
Ge	.017	.100	.076	.30	.30	.27	.88	1.06
As	.016	.097	.073	.29	.29	.25	.84	1.01
Se	.016	.095	.071	.28	.28	.24	.81	.95
Br	.015	.092	.069	.27	.27	.23	.76	.90
Kr	.015	.090	.067	.25	.25	.22	.74	.86

[208] Slater, J. C., Introduction to chemical physics, 1939. Courtesy of McGraw-Hill Book Co.

TABLE 660.—ELEMENTAL ABUNDANCES IN THE UNIVERSE [204]

(Atoms per 10,000 atoms of Si *)

Z	Element	Abundance	Source ‖	Z	Element	Abundance	Source	Z	Element	Abundance	Source
1	H †	3.5×10^8	S	29	Cu	4.6	M	58	Ce	.023	M
2	He †	3.5×10^7	S	30	Zn	1.6	M	59	Pr	.0096	M
3	Li	1		31	Ga	.65	M	60	Nd	.033	M
4	Be	.2		32	Ge	2.5	M	61	Pm	...	..
5	B	.2		33	As	4.8	M	62	Sm	.012	M
6	C	80,000	S	34	Se	.25	M	63	Eu	.0028	M
7	N	160,000	S	35	Br	.42	M	64	Gd	.017	M
8	O	220,000	S	36	Kr ‡	...	..	65	Tb	.0052	M
9	F	90	P	37	Rb	.071	M	66	Dy	.020	M
10	Ne ‡	9,000–24,000	P, Sc	38	Sr	.41	M	67	Ho	.0057	M
11	Na	462 ± 36	M	39	Y	.10	M	68	Er	.016	M
12	Mg	8,870 ± 250	M	40	Zr	1.5	M	69	Tm	.0029	M
13	Al	882 ± 81	M	41	Nb	.009	M	70	Yb	.015	M
14	Si	10,000	M	42	Mo	.19	M	71	Lu	.0048	M
15	P	130	M	43	Tc	...	..	72	Hf	.007	M
16	S	3500	S	44	Ru	.093	M	73	Ta	.0031	M
17	Cl	170	P	45	Rh	.035	M	74	W	.17	M
18	A ‡	130–2,200	P, Pe	46	Pd	.032	M	75	Re	.0041	M
19	K	69.3 ± 7.5	M	47	Ag	.027	M	76	Os	.035	M
20	Ca §	670 ± 74	M, S	48	Cd	.026	M	77	Ir	.014	M
21	Sc	.18	M	49	In	.01	M	78	Pt	.087	M
22	Ti	26.0 ± 9.0	M	50	Sn	.62	M	79	Au	.0082	M
23	V	2.5	M	51	Sb	.017	M	80	Hg	?	M
24	Cr	95	M	52	Te	?	..	81	Tl	?	M
25	Mn	77	M	53	I	.02	..	82	Pb	.27	M
26	Fe	18,300	M	54	Xe ‡	...	M	83	Bi	.0021	M
27	Co	99	M	55	Cs	.001	M	90	Th	.012	M
28	Ni	1,340	M	56	Ba	.039	M	92	U	.0026	M
				57	La	.021	M				

[204] Brown and Harrison, Rev. Mod. Phys., vol. 21, p. 625, 1949.
* Silicon is 12.3 percent by weight in meteorites. † The hydrogen-helium ratio and the ratio of hydrogen and helium to the "oxygen group" elements (C, N, O, Ne, Fe) are those computed by J. Greenstein and reported by M. Harrison, Astrophys. Journ., vol. 108, p. 310, 1940. ‡ See Table 663. § Stellar and meteoritic values have been combined by equalizing the calcium abundances. ‖ The letters S, P, Sc, Pe, and M designate the sources chosen (solar, planetary nebulae, τ-Scorpii, γ Pegasi, or meteoritic).

TABLE 661.—ABUNDANCE OF ELEMENTS IN OUR PLANET GIVEN IN PERCENTAGE BY WEIGHT *

Element	Earth crust	Earth	Lithosphere,† hydrosphere, atmosphere	Element	Earth crust	Earth	Lithosphere,† hydrosphere, atmosphere
O	46.6	24.4	49.38	P	...	.17	.12
Si	27.7	12.2	25.8	C	...	.07	.17
Al	8.1	1.0	7.5	Cl	...	.05	.19
Fe	5.0	45.6	4.66	H	...	.04	.87
Ca	3.63	1.2	3.34	Cu	...	.01	.01
Na	2.8	.47	2.55	Zn	...	.0005	.03
K	2.16	.12	2.38	As	...	.01	...
Mg	2.1	9.4	2.07	Ba	...	...	.04
Ti	.4	.06	.61	F	...	...	.04
Mn	.1	.19	.09	N	...	...	.03
Ni	...	3.41	.01	Zr	...	...	.02
S	...	1.08	.07	V	...	...	.02
Co	...	.26	.002	Sr	...	...	.02
Cr	...	.22	.03				

* This table was selected from several sources including the report by Brown (see footnote 204) and data furnished by Ingerson of the U. S. Geological Survey. † The lithosphere, 10 miles of earth crust, makes up 93 percent, the hydrosphere makes up 7 percent, and the atmosphere makes up 0.03 percent of the part of the earth considered. Proc. Nat. Acad. Sci., vol. 8, p. 114, 1922.

TABLE 662.—CHEMICAL COMPOSITION OF EARTH—METEORITES AND SOLAR ATMOSPHERE *[205]

The table gives log *NH*, where *NH* = the number of atoms, neutral and ionized, per cm³. Constants added to data of Russell and Brown to give order of magnitude agreement with Unsöld. : indicates less accuracy; ? origin doubtful.

H and He are about 97 percent of the total solar mass, the oxygen group 2.7 percent, the metals 0.3 percent; and by numbers of atoms 99 percent, 0.9 percent, and 0.1 percent respectively.

The level of ionization in the solar atmosphere is such that atoms of $IP = 8.33$ ev are 50 percent ionized; ionization temperature = 5676°K; electron pressure ≈ 32 bar; 85 percent of free electrons come from Mg, Si, Fe, according to Unsöld.

Element	Earth-meteorite †	Sun ‡	Sun §	Element	Earth-meteorite †	Sun ‡	Sun §
1 H	18.04	22.1	24.13	41 Nb	13.05	12.6:	....
2 He	....	20.6?	....	42 Mo	14.38	13.0	13.40
3 Li	14.91	13.6:	....	44 Ru	14.07	13.3	....
4 Be	14.23	13.4	....	45 Rh	13.64	12.1	....
5 B	14.72	16.6:	....	46 Pd	13.61	12.7	....
6 C	17.22	19.1	19.91	47 Ag	13.53	12.6	....
7 N	15.01	19.6:	20.23	48 Cd	13.52	13.8:	....
8 O	19.64	20.6	20.35	49 In	13.10	11.6:	....
9 F	15.48	17.6:	....	50 Sn	14.89	12.8?	....
10 Ne	....	...	....	51 Sb	13.33	12.4:	....
11 Na	17.76	18.8	17.90	53 I	13.35	...	....
12 Mg	19.05	18.9	19.13	55 Cs	12.10	?	....
13 Al	18.04	18.0	17.95	56 Ba	13.69	14.9	14.57
14 Si	19.10	19.1	18.91	57 La	13.42	13.4	....
15 P	17.21	15.6:	....	58 Ce	13.46	14.0	....
16 S	17.98	17.3:	18.54	59 Pr	13.08	12.2:	....
17 Cl	16.63	...	....	60 Nd	13.62	13.6	....
18 A	....	...	....	62 Sm	13.18	13.1	....
19 K	16.94	18.4:	16.82	63 Eu	12.55	13.0:	....
20 Ca	17.93	18.3	17.85	64 Gd	13.33	12.7:	....
21 Sc	14.36	15.2	14.95	65 Tb	12.82	...	....
22 Ti	16.52	16.8	16.58	66 Dy	13.40	13.2:	....
23 V	15.50	16.6	15.67	67 Ho	12.85	...	....
24 Cr	17.80	17.3	17.20	68 Er	13.30	11.7:	....
25 Mn	16.99	17.5	17.08	69 Tm	12.56	12.1:	....
26 Fe	19.37	18.8	19.34	70 Yb	13.28	12.6:	....
27 Co	17.10	17.2	16.65	71 Lu	12.78	12.6:	....
28 Ni	18.23	17.6	17.57	72 Hf	12.94	12.0	....
29 Cu	15.76	16.6	15.85	73 Ta	12.59	11.6:	....
30 Zn	15.30	16.5	16.40	74 W	14.33	11.8	....
31 Ga	14.91	13.6:	....	75 Re	12.71	...	....
32 Ge	15.50	14.6	....	76 Os	13.64	12.1:	....
33 As	15.78	...	....	77 Ir	13.25	11.4?	....
34 Se	14.50	...	....	78 Pt	14.04	13.2	....
35 Br	14.72	...	....	79 Au	13.01	...	....
37 Rb	13.95	13.3:	....	82 Pb	14.53	12.8	14.2
38 Sr	14.71	14.9	14.97	83 Bi	12.42	...	....
39 Y	14.10	14.2	14.83	90 Th	13.18	...	....
40 Zr	15.28	14.1	13.99	92 U	12.51	...	....

* Prepared by B. Bell.

[205] Brown, Rev. Mod. Phys., vol. 21, p. 625, 1949; Russell-Dugan-Stewart, Astronomy, vol. 2, p. 503, 1938: Unsöld, Zeitschr. f. Astrophys., vol. 24, p. 307, 1948.

† Brown. ‡ Russell. § Unsöld.

TABLE 663.—COSMIC ABUNDANCES OF THE RARE GASES *

As estimated by interpolation of the abundance curves (abundances in atoms per 10,000 atoms of silicon).

Gas	Isotope used for interpolation	Estimated abundance of isotope	Estimated abundance of element	Gas	Isotope used for interpolation	Estimated abundance of isotope	Estimated abundance of element
Ne	Ne^{21}	100	37,000	Kr	Kr^{83}	.1	.87
A	A^{36}	1000	1,000	Xe	Xe^{131}	.004	.015

* For reference, see footnote 204, p. 625.

Part 1.—Approximate counts of atomic lines identified in solar and sunspot spectra [206]

	Neutral atoms							Singly ionized atoms			
		Disk			Spot				Disk		
		No. lines **			No. lines				No. lines		
At No	Element	Unblended	Blended	Max int	Unblended	Blended	Max int	Element	Unblended	Blended	Max int
1	H †	9		40			25?				
2	He I †	1		5			5				
3	Li I	2		—3			3				
4	Be I	2		—3							
5	B ‡							Be II	2		1
6	C I	41	7	12			10				
7	N I	8	6	—1			—2				
8	O I	12	1	5			1				
9	F ‡										
11	Na I	21	6	30			70?				
12	Mg I	55	4	(200)			30	Mg II	12	2	(1000)
13	Al I	22	5	20			25				
14	Si I	156	29	(80)			12				
15	P I	6	1	1				Si II	4	2	2
16	S I	31	10	8			2				
19	K I	4	3	12			20				
20	Ca I	108	21	20			40				
21	Sc I	43	14	2	15	1	7	Ca II	25		1000
22	Ti I	687	264	7	134	2	10	Sc II	57	26	6
23	V I	272	133	4	53	2	8	Ti II	255	119	12
24	Cr I	776	305	10	23		12	V II	160	103	5
25	Mn I	185	73	7	1		12	Cr II	216	133	6
26	Fe I	4164	877	40	2		35	Mn II	16	11	6
27	Co I	501	209	6	7		6	Fe II	371	140	6
28	Ni I	617	180	25			9	Co II	6	7	0
29	Cu I	14	3	10			7	Ni II	13	8	3
30	Zn I	9	3	3			1				
31	Ga I	1	1	1			2				
32	Ge I	5		3							
37	Rb I	1		—3	1		4				
38	Sr I	13	2	1	6		3	Sr II	8	2	9
39	Y I	17	10	0	12	1	3	Y II	53	18	3
40	Zr I	59	41	0	41		3	Zr II	148	93	3
41	Nb I	4	2	—1				Nb II	13	8	—1
42	Mo I	8	6	—2				Mo II	7	5	0
44	Ru I	15	5	—1							
45	Rh I	8	3	—2				Rh II?	3	2	—2
46	Pd I	8	7	0							
47	Ag I	3		0							
48	Cd I	1		—1							
49	In I	1		—2			—1				
50	Sn I	2	2	—2							
51	Sb I	1	1	—3 N							
56	Ba I				1		1	Ba II	6	3	8

* Prepared by Charlotte E. Moore, National Bureau of Standards.

[206] The sources used are as follows:
2935A—3062A, Babcock, H. D., Moore, C. E., and Coffeen, M. F., Astrophys. Journ., vol. 107, p. 287, 1948 (Mount Wilson Contr. No. 745).
3062A—6600A, St. John, C. C., and others, Revised Rowland Table, Carnegie Inst. Washington Publ. 396, 1928, with unpublished corrections and revisions by C. E. Moore (September 1949).
6600A—13495A, Babcock, H. D., and Moore, C. E., Carnegie Inst. Washington Publ. 579, 1947.
The counts included also the *raie ultime* of Mg I (2852A); the ultimate lines of Mg II (2795A, 2802A) and the strong Si I line at 2881A. These lines, among others, have been identified in the ultraviolet solar spectrum photographed from a V-2 rocket. Intensities in parentheses are quoted from the paper on this subject by Durand, E., Oberly, J. J., and Tousey, R., Astrophys. Journ., vol. 109, p. 1, 1949. (See also Hopfield, J. J., and Clearman, H. E., Phys. Rev., vol. 73, p. 877, 1948.)
For lines of H and He see Menzel, D. H., Lick Obs. Publ. 17, p. 1, 1931; Mitchell, S. A., Astrophys. Journ., vol. 105, p. 1, 1947.

** These counts refer to lines not present in disk spectrum. † Lines of H and He are prominent in the spectrum of the chromosphere. ‡ B and F are identified only from their presence in compounds (see Part 2).

(continued)

TABLE 664.—66 KNOWN ELEMENTS IN THE SUN'S ATMOSPHERE (concluded)

	Neutral atoms							Singly ionized atoms			
		Disk			Spot				Disk		
		No. lines			No. lines				No. lines		
At No	Element	Unblended	Blended	Max int	Unblended	Blended	Max int	Element	Unblended	Blended	Max int
57	La I				1		—2 N	La II	44	20	1
58								Ce II	106	81	0
59								Pr II	11	16	—1
60								Nd II	74	72	1
62								Sm II	82	63	0
63	Eu I			2			—1	Eu II	10	4	1
64								Gd II	29	20	0
65								Tb II?	2	2	—1
66								Dy II	29	25	1
68								Er II	2		—1
69								Tm II?	6	5	—1
70	Yb I	2		0			1	Yb II		2	3?
71								Lu II?	1	4	—3
72	Hf I	1	1	—3				Hf II	13	5	—1
73	Ta I?	3		—2							
74	W I	13	8	—1			—1				
76	Os I	2	4?	0		1	—1				
77	Ir I	2	4	—2							
78	Pt I	3		2							
79	Au I	1		—3			—2				
82	Pb I	2		—2							
90	Th I	1		—1							

Part 2.—Molecules in the sun—18 present (either disk or spot spectrum, or both)[207]

OH	Mg H	Sc O	CH	Mg O	Y O
NH	C_2	Al O?	Cn	Ca H	Mg F
O_2	Ti O	Zr O	Si H	BH	Sr F

[207] Babcock, H. D., Astrophys. Journ., vol. 102, p. 154, 1945 (Mount Wilson Contr. No. 708).

TABLE 665.—ABUNDANCES OF LIGHT ELEMENTS IN EARLY TYPE STARS

The table gives the number of atoms per 1000 atoms oxygen for τ Scorpii, spectrum *dBo*,[208]; 10 Lacertae, *O*;[209]; γ Pegasi, *B*2.5 IV,[209]; mean for 8 *B*-stars, weighted mean by Aller,[209] the last 3 columns from letters to the editor, 1950. : less certain.

Element	τ Sco	10 Lac	γ Peg	8 *B*-stars	Mean
1 H	10×10^5	20×10^5	87×10^5	....	20×10^5
2 He	1.8×10^5	1.68×10^5	5.5×10^5:	....	1.7×10^5
6 C	170	200	120	150	160
7 N	380	220	200	230	250
8 O	1000	1000	1000	1000	1000
10 Ne	1100	880	....	....	1000
12 Mg	59	62	310	93	120
13 Al	3.7	....	11	4.2	6
14 Si	64	82	90	38	60
15 P	....	....	1.1	....	1.1
16 S	....	....	40	22	30
17 Cl	....	....	20:	....	20:
18 A	....	....	100:	....	100:

[208] Unsöld, Zeitschr. f. Astrophys., vol. 21, p. 1, 1941.
[209] Aller, Astrophys. Journ., vol. 104, p. 347, 1946.

TABLE 666.—GASES IN INTERSTELLAR SPACE * [210]

The gases that have been detected are listed together with the means of detection and approximate abundances. Both the observations and the application of ionization theory introduce considerable uncertainty in the determination of abundances. Values given are the best current estimates. In general, the composition of the interstellar gas appears to be the same as for the stars.

Gas	Density in clouds atoms/cm³	Detection	Gas	Density in clouds atoms/cm³	Detection
Hydrogen	10	Emission lines	Titanium	10^{-6} †	Absorption lines
Oxygen	.01	Emission lines	Nitrogen	...	N emission, CN absorption lines
Carbon	.003	Molecular absorption lines	Potassium	10^{-5} †	Absorption lines
Calcium	2×10^{-6}	Absorption lines	Sulfur	...	Emission lines
Sodium	4×10^{-5}	Absorption lines	CH	10^{-6} †	Absorption lines
Iron	...	Absorption lines	CN	10^{-6} †	Absorption lines
		Mean gas density......3×10^{-24} g/cm³			

The interstellar gas is strongly concentrated in clouds as evidenced by the multiplicity of interstellar absorption lines. Stromgren suggests density between clouds is about 1% of that in clouds.

* Prepared by B. Donn.

[210] Adams, Astrophys. Journ., vol. 109, 1949; Publ. Astron. Soc. Pacific, vol. 60, p. 354, 1948; Dunham, Proc. Amer. Philos. Soc., vol. 81, p. 277, 1939. Ledoux, Pop. Astr., vol. 49, p. 513, 1941. Stromgren, Astrophys. Journ., vol. 108, p. 242, 1948. Struve, Journ. Washington Acad. Sci., vol. 31, p. 217, 1941; Astrophys. Journ., vol. 89, p. 517, 1939.

† Values for apparently abnormally dense cloud.

TABLE 667.—THE ABUNDANCE OF CERTAIN ELEMENTS IN THE NEBULAE [211]

(Given as the exponent of 10)

Element	Abundance	Element	Abundance	Element	Abundance	Element	Abundance	Element	Abundance
H	11−	C	9	Na	≤7+	S	8	Sc	<6+
He	10	N	9−	Mg	7+	Cl	7+	Ti	<7−
Li	<8−	O	9	Al	<8−	A	7	V	<8
Be	<8−	F	6	Si	≤9	K	6+	Cr	<7
B	<9	Ne	8	P	<8−	Ca	7−	Mn	<7
								Fe	7+

[211] Bowen and Wyse, Lick Obs. Bull., vol. 19, p. 1, 1939.

TABLE 668.—MATTER IN INTERSTELLAR SPACE * [212]

The interpretation of the interstellar absorption curve and of absorption by dark clouds requires the presence of small grains with radii ranging around 10^{-5} cm. Polarization of starlight indicates that some, if not all, grains are elongated. Composition, from absorption curve and scattering appears to be mainly dielectric.

Density of matter

Solid grains:	
Uniform region, abs 0.5 m/kpc	10^{-26} g/cm³
Large cloud, abs 1 mag (10 m/kpc)	10^{-25} g/cm³
Dense condensation, abs 5–10 m (1000 m/kpc)	10^{-23} g/cm³
Mean density, gas and grains	3×10^{-24} g/cm³
Oort limit (Max density, stars plus diffuse matter)	6×10^{-24} g/cm³
Mean space density of stellar matter	3×10^{-24} g/cm³

* Prepared by B. Donn.

[212] Greenstein, Harvard Circ. 422, 1938. Spitzer, Astrophys. Journ., vol. 93, p. 369, 1941. Van de Hulst, Rech. Astron. de l'Obs. d'Utrecht, vol. 11, pt. 1, 1946, pt. 2, 1949. Schalen, Publ. of Uppsala Observatory, 1930 on. Oort, Astron. Inst. Netherlands Bull. No. 283, 1932.

Colloidal science originally dealt with that large field of small particles, but now it has been extended to cover also those materials that are small in one or two of the three dimensions. Thus, this field now includes chain molecules and films as well as the fine particles.

The diameters of atoms range from 2 to 3 *A* (angstroms) while diameters of ordinary inorganic molecules extend from about 7 to 10 *A*. Organic molecules are much larger and their dimensions may extend to 20 *A* or larger. It is sometimes stated that colloid particles range in diameter from 20 *A* to a much larger value but it must be remembered that it is difficult to fix such dimensions.

Many of the properties of colloids are due to their relatively very great surface as compared with their volumes. Some of the newer experimental tools, i.e., ultracentrifuges, X-rays, and the electron microscopes, have been a great help in studying these particles and their reactions. Several tables follow that give properties and characteristics of colloids and colloidal particles.

TABLE 669.—BROWNIAN MOVEMENT

The Brownian movement is a microscopically observed agitation of colloidal particles. It is caused by the bombardment of them by the molecules of the medium and may be used to determine the value of Avogadro's number. Perrin, Chaudesaignes, Ehrenhaft, and De Broglie found, respectively, 70, 64, 63 and 64 $\times 10^{22}$ as the value of this constant. The following table indicates the size and the dependence of this movement on the magnitude of the particles.

Material	Diameter $\times 10^5$ cm	Medium	Temp °C	Velocity $\times 10^5$ cm/sec
Dust particles	2.0	Water	—	none
Gold	.35	"	20?	200.
Gold	.1	"	"	280.
Gold	.06	"	"	700.
Platinum	.4 to .5	Acetone	18	3900.
Platinum	.4 to .5	Water	20	3200.
Rubber emulsion	10.	"	17	124.
Mastic	10.	"	20?	1.55
Gamboge	4.5	"	20	2.4
"	2.13	"	"	3.4

The movement varies inversely as the size of the particles; in water, particles of diameter greater than 4μ show no perceptible movement; when smaller than $.1\mu$, lively movement begins, while at $10m\mu$ the trajectories amount to up to $20m\mu$.

TABLE 670.—PARTICLE SIZES OF SOME INDIVIDUAL DUSTS[212a]

Dust	Diameter, cm
Milk powder (by evaporation of fine spray)	1.4×10^{-2}— $.7\times10^{-2}$
Fine powder (300 mesh) e.g., cement	1×10^{-2}— $.7\times10^{-2}$
Smelter fumes	1×10^{-2}— 1×10^{-5}
Atmosphere, fog particles	1.4×10^{-3}—3.5×10^{-3}
Cement kiln flue dust	6×10^{-3}— $.8\times10^{-3}$
H_2SO_4 mist from concentrators	1.1×10^{-3}—1.6×10^{-4}
NH_4Cl fumes	1×10^{-4}— 1×10^{-5}
Oil smoke	1×10^{-4}— 5×10^{-6}
Resin smoke	1×10^{-4}— 1×10^{-6}
Tobacco smoke	1.5×10^{-5}— 1×10^{-6}

[212a] Alexander, J., Colloid chemistry, vol. 2, Chemical Publishing Co. Used by permission.

TABLE 671.—PROTEIN MOLECULES[213]

M, molecular weight; f/f_0, dissymmetry constant; a, short diameter; b, long diameter.

Substance	M	f/f_0	b/a	a (A)	b (A)
Zein	35000	2.0	20.1	16	322
Cytochromec C	15600	1.3	5.8	18	98
Gliadin	26000	1.6	11.1	18	196
Hordein	27500	1.6	11.1	18	196
Erythrocruorin (*chironimus*)	31400	1.6	11.1	19	208
Serum albumin, urea denatured	67100	1.98	19.4	20	356
Lactalbumin α	17500	1.2	4.3	21	91
Erythrocruorin (*lampetra*)	17100	1.2	4.3	22	94
Bence-Jones β	37700	1.3	5.8	25	144
Myoglobin	17200	1.1	2.9	24	70
Crotoxin	30000	1.2	4.3	25	109
Concanavalin B	42000	1.3	5.8	26	149
Tuberculin protein	32000	1.2	4.3	26	112
Lactoglobulin	41800	1.2	4.3	28	122
Pepsin	35500	1.08	2.7	31	84
Insulin	40900	1.13	3.3	31	102
Egg albumin	40500	1.1	2.9	32	91
Hemoglobin (horse)	69000	1.24	4.8	32	155
Serum albumin (horse)	67100	1.2	4.3	34	145
Yellow ferment	82800	1.2	4.3	36	152
Canavalin	113000	1.3	5.8	36	207
Serum globulin	167000	1.4	7.5	37	280
Diphtheria toxin	72000	1.2	4.3	34	145
Antipneumococcus serum globulin (rabbit)	157000	1.4	7.5	37	274
Antipneumococcus serum globulin (man)	195000	1.5	9.2	37	338
Concanavalin A	96000	1.1	2.9	43	124
Erythrocruorin (*arc a*)	33600	1.0	1.	43	43
Bence-Jones α	35000	1.0	1.	43	43
Catalase	248000	1.3	5.8	46	297
Antipneumococcus serum globulin (horse)	920000	2.0	20.1	47	950
Phycoerythrin (*seramium*)	290000	1.2	4.3	54	232
Amandin	329000	1.3	5.8	51	291
Tyroglobulin	628000	1.5	9.2	54	498
Edestin	309000	1.2	4.3	55	237
Excelsin	294000	1.1	2.9	62	179
Urease	483000	1.2	4.3	64	274
Hemocyanin (*palinurus*)	446000	1.2	4.3	62	268
Tobacco mosaic virus	60000000	3.0			
Legumin	208000	1.02			

[213] Neurath, Journ. Amer. Chem. Soc., vol. 61, p. 1841, 1939.

TABLE 672.—INFLUENCE OF PARTICLE SIZE UPON SOLUBILITY[214]

Material	Size of particles μ	Solubility at 25°C
$CaSO_4$	2.0	2.085 g per liter *
	.3	2.476 g per liter
$BaSO_4$	1.8	2.29 mg per liter *
	.1	4.15 mg per liter
HgO	Coarse red powder	50 mg per liter *
	Very fine yellowish powder	150 mg per liter

[214] Thomas, Arthur W., Colloid chemistry, McGraw-Hill Book Co., 1934. Used by permission of the author.

* These are the permanent saturated solutions. The more concentrated solutions, obtained from contact with the more finely ground particles, slowly revert to the normally saturated solutions and the particles grow to 2 μ in size.

TABLE 673.—HEAT OF SORPTION *

(In small calories)

Substance	Fuller's earth	Bone charcoal	Kaolin	Dispersive power percent
Amylene	57.1	...	78.8	1.54
Water	30.2	18.5	...	2.82
Acetone	27.3	19.3	...	1.72
Methyl alcohol	21.8	17.6	27.6	1.60
Ethyl acetate	18.5	16.5	...	1.05
Ethyl alcohol	17.2	16.5	24.5	...
Aniline	13.4	...	...	...
Amyl alcohol	10.9	10.6	20.4	...
Ethyl ether	10.5	...	...	.90
Chloroform	8.4	14.0	15.7	.86
Benzene	4.6	11.1	9.9	.39
Carbon disulfide	4.6	8.4	9.9	...
Carbon tetrachloride	4.2	13.9	9.4	.27
Hexane	3.9	8.9	7.2	.22

* For reference, see footnote 214, p. 631.

TABLE 674.—EFFECT OF ACTIVATION ON THE ADSORBING POWER OF CHARCOAL[215]

Substance tested	Adsorption mg CCl_4/(g C)	Granular density	Physical character
Ironwood	22	.96	Fibrous, hard
Primary ironwood charcoal	30	.89	Hard
Activated ironwood charcoal	1160	.72	Hard, friable, granular
Commercial wood charcoal	11	.46	Firm, fibrous
Highest activated wood charcoal *	1480	.30	Soft, friable
Cocoanut shell	18	1.20	Hard
Primary cocoanut charcoal	47	.96	Hard
Activated cocoanut charcoal	630	.84	Hard
Lignite semi-coke	30	1.09	Firm
Good activated lignite charcoal	640	.89	Firm
Highest activated lignite charcoal *	2715	.31	Friable, granular

[215] Weiser, H. B., Colloid chemistry, 2d ed., John Wiley & Sons, Inc., 1949. Reprinted by permission.
* Further activation reduces the granules to a fine powder.

TABLE 675.—HEATS OF ADSORPTION OF VAPORS ON CHARCOAL *

Vapor	Integral heat of adsorption, h cal/mole	Heat of liquefaction, Q cal/mole	Net heat of adsorption, h-Q cal/mole	h-Q/ml cal/mole
C_2H_5Cl	12330	6220	6110	86.4
CS_2	12630	6830	5800	99.1
CH_3OH	12950	9330	3620	90.8
C_2H_5Br	14330	6850	7480	102.0
C_2H_5I	14250	7810	6440	81.5
$CHCl_3$	14930	8000	6930	87.5
$HCOOC_2H_5$	15420	8380	7040	90.1
C_6H_6	15170	7810	7360	85.0
C_2H_5OH	14980	10650	4330	76.8
CCl_4	16090	8000	8090	85.6
$(C_2H_5)_2O$	16090	6900	9190	80.3

* For reference, see footnote 215, above.

TABLE 676.—SPREADING COEFFICIENTS, *S*, OF ORGANIC LIQUIDS ON WATER AT 20°C *

Spreading liquids	$S = W_a - W_c$ †	Spreading liquids	$S = W_a - W_c$
Butyric acid	45.66	Heptane	22.40
Ethyl ether	45.50	Ethyl bromide	17.44
Isoamyl chloride	33.88	Chloroform	13.04
Heptaldehyde	32.22	Anisole	11.76
Nitromethane	26.32	Phenetole	10.66
Mercaptan	24.86	p-Cymene	10.10
Oleic acid	24.62	Isopentane	9.44

Liquids which form lenses	$S = W_a - W_c$
Ethylene dibromide	—3.19
Carbon disulfide	—6.94
Monoiodobenzene	—8.74
Bromoform	—9.58
Liquid petrolatum	—13.64

* For reference, see footnote 215, p. 632. † W_a, work adhesion; W_c, work of cohesion.

TABLE 677.—HEATS OF ADSORPTION OF GASES BY CHARCOAL[216]

Gas	Heat of adsorption g cal/mol	Heat of vaporization	Heat of sublimation	Gas	Heat of adsorption g cal/mol	Heat of vaporization	Heat of sublimation
Argon	3636	1504	4180	Carbon dioxide	7300	2540	6100
Nitrogen	3686	1250	....	Ammonia	7200	5000	7120
Carbon monoxide	3416	1410	3715				

[216] Lewis, Squires, and Broughton, Industrial chemistry of colloidal and amorphous materials, Macmillan Co., 1942. Used by permission of the publishers.

TABLE 678.—BOND ENERGIES * IN KILOCALORIES PER MOL[217]

Covalent bonds		Intermolecular cohesion		Covalent bonds		Intermolecular cohesion	
—C ≡ C—	123	>C=O ·· H—N<	10–16	→C—N<	59	—COOR:ROOC—	6
>C = C<	100	>C=O ·· H—O—	7–10	→C—S—	54	—HC=O:O=CH—	5
		→COH ·· HOC←	14				
→C — C←	59	H_2O ·· H—O—H	5	—S—S—	64	—Cl:Cl—	3
→C — O—	70	$—NO_2:O_2N—$	7	→Si—Si←	42	$—CH_3:H_3C—$	2

Covalent bonds		Intermolecular cohesion	
→Si—O—	90	$O_2:O_2$	2
Ionic bonds		—O—:—O—	1.6
Na^+, Cl^- (dry)	128	$—CH_2—:—CH_2—$	1.0
$—NH_3^+, —COO^-$ in water	4.5	$H_2:H_2$	.25

* For the energy per atom, divide these values by the Avogadro number, 6.023×10^{23}.
[217] Pauling, Linus, The nature of the chemical bond. Used by permission of the author.

TABLE 679.—IGNITION AND PROPAGATION TEMPERATURES OF DUSTS IN AIR *

Degrees Centigrade

Dust	Ignition temperature	Propagation temperature	Dust	Ignition temperature	Propagation temperature
Sugar	540	805	Cork	630	1000
Dextrin	540	940	Rice	630	970
Starch	640	1035	Mustard	680	1050
Cocoa	620	970	Wheat elevator	...	(1295)
		995	Oat and corn elevator	...	(995)
Flour	630	(1265)	Oat hull	...	(1020)

* For reference, see footnote 214, p. 631.

TABLE 680.—LOWER EXPLOSIVE LIMITS *

Milligrams per liter of air

Dust	Glowing Pt wire	Arc	Induction spark	Dust	Glowing Pt wire	Arc	Induction spark
Starch	7.0	10.3	13.7	Sugar	10.3	17.2	34.4
Corn elevator	10.3	10.3	13.7	Aluminum	7.0	7.0	13.7
Wheat elevator	10.3	10.3	...	Coal	17.2	24.1	No ignition
Sulfur	7.0	13.7	13.7				

* For reference, see footnote 214, p. 631.

TABLE 681.—SOME MEASUREMENTS OF EXPLOSION PRESSURES *

Dust	Pressure generated, lb/in.^{2}	Dust	Pressure generated, lb/in.^{2}	Dust	Pressure generated, lb/in.^{2}
Lycopodium	17.5	Cornstarch	12.7	Cocoa	9.9
Dextrin	14.6	Wheat elevator	12.5	Sulfur flour	8.8
Wheat starch	14.0	Sugar	12.2	Rice-bran dust	8.7
Tanbark dust	13.3	Linseed meal	11.7	Ground-cork dust	7.4
Wood dust	12.8	Pittsburgh coal	10.1		

* For reference, see footnote 214, p. 631.

TABLE 682.—*pH* STABILITY RANGE OF SOME PROTEINS *

Protein	Source	Stable in the *pH* range of
Amandin	Almonds	4.3 to 10.0
Bence-Jones	Pathological urine	3.5 to 7.5
Edestin	Hempseed	5.5 to 9.7
Egg albumin	Hens' eggs	4.0 to 9.0
Erythrocruorin	Blood of *Arenicola marina*	2.6 to 8.0
Erythrocruorin	Blood of *Lumbricus terrestris*	2.6 to 10.0
Excelsin	Brazil nuts	5.5 to 10.0
Hemocyanin	Blood of *Helix pomatia*	4.5 to 7.4
CO-hemoglobin	Horse blood hemoglobin plus CO	6.0 to 9.05
Insulin	Beef pancreas	4.5 to 7.0
Legumin	Vetch	5.0 to 9.0
Phycocyan	*Ceramium rubrum*	1.5 to 8.0
Serum albumin	Horse blood	4.0 to 9.0
Serum globulin	Horse blood	4.0 to 8.0

* For reference, see footnote 214, p 631.

TABLE 683.—ELECTRON EMISSION FOR HOT SOLIDS

The electron emission from a solid varies with the temperature T (°K) in accordance with the Richardson-Laue-Dushman equation

$$I = AT^2 [\exp(-b_o/T)] \quad (1)$$

where I = current in amps cm^{-2}, and A and b_o are constants, characteristic of the material. The constant b_o is ordinarily expressed in terms of electron volts (Φ_o) where

$$\Phi_o = 8.620 \times 10^{-5} b_o$$

or

$$b_o = 1.160 \times 10^4 \theta_o \quad (2)$$

The values of A and b_o (or Φ_o) are customarily derived from a plot of log (I/T^2) versus $1/T$, where

$$\log I = \log A + 2 \log T - \frac{b_o}{2.303T} \quad (3)$$

and log = log to base 10.

Hence,

$$\Phi_o = 1.986 \times 10^{-4} (b_o/2.303) \quad (4)$$

Theoretically, Φ_o, as determined from thermionic emission data, should be identical with Φ_e, the "work function" from contact potential measurements, and Φ_e, the work function determined by means of Einstein's equation

$$Ve = h\nu - \Phi_e$$

where ν = frequency for photoelectric emission, V = retarding potential, e = charge on the electron, and h = quantum constant.

* Prepared by Saul Dushman, General Electric Research Laboratory, Schenectady, N. Y.

TABLE 684.—ELECTRON EMISSION CONSTANTS FOR METALS AND CARBON

The table gives emission constants (see preceding equations) for metals and carbon. For other values and comprehensive data on this topic see references in footnote 218.

Element	A	$10^{-4}b_o$	ϕ_o	I_T	T°K	ϕ_e
Barium	60	2.47	2.10	1.5×10^{-8}	800	2.48–2.51
Calcium	60	2.60	2.24	2.9×10^{-7}	800	2.71
Carbon	30	5.03	4.34	1.4×10^{-3}	2000	4.82
Cesium	162	2.10	1.81	2.5×10^{-11}	500	1.91
Chromium	48	5.34	4.60	3.8×10^{-8}	1500	4.37
Cobalt	41	5.12	4.41	1.3×10^{-7}	1500	...
Copper	65	5.08	4.38	5.6×10^{-15}	1000	4.46
Hafnium	15	4.10	3.53	2.8×10^{-4}	1600	...
Iron	26	5.20	4.48	6.8×10^{-16}	1000	4.63
Molybdenum	60	5.07	4.37	2.4×10^{-3}	2000	4.12
Nickel	30	5.35	4.61	2.2×10^{-8}	1500	
Niobium	37	4.65	4.01	1.2×10^{-3}	2000	
Palladium	60	5.79	4.99	3.0×10^{-8}	1600	4.92
Platinum	32	6.17	5.32	1.8×10^{-9}	1600	
Rhenium	200	5.92	5.1	1.0×10^{-4}	2000	
Rhodium	33	5.57	4.80	1.1×10^{-4}	2000	4.92
Tantalum	55	4.86	4.19	6.2×10^{-3}	2000	4.05
Thorium	60	3.89	3.35	4.3×10^{-3}	1600	3.3–3.6
Tungsten	60	5.24	4.52	1.00×10^{-3}	2000	4.3–4.5
Zirconium	330	4.79	4.13	8.5×10^{-5}	1600	

218 Herring, C., and Nichols, M. H., Rev. Mod. Phys., vol. 21, p. 185, 1949. Reimann, A. L., Thermionic emission, John Wiley & Sons, Inc., 1934. Dushman, S., Rev. Mod. Phys., vol. 2, p. 381, 1930.

TABLE 685.—ELECTRON EMISSION (I = amp/cm²) AND (W = watts/cm²) FOR A NUMBER OF MATERIALS[219]

The table gives emission data for a range of temperature, for the most frequently used metals and for thoriated tungsten (ThW). Values of A and b_o used in calculation of I (amp/cm²) are those given in Table 684. For ThW, the values used are $A = 3.0$ and $\phi_o = 2.72$, $b_o = 3.15 \times 10^4$.

	Tungsten		Molybdenum		Tantalum		Niobium		ThW *
T°K	I	W	I	W	I	W	I	W	I
1000	...	...	...	...	...	...	...	...	1.73×10^{-7}
1200	...	...	...	...	...	...	...	...	3.95×10^{-5}
1400	...	...	...	...	...	...	...	...	2.03×10^{-3}
1600	9.27×10^{-7}	7.74	2.39×10^{-6}	6.30	9.1×10^{-6}	7.36	2.19×10^{-5}	6.40	4.06×10^{-2}
1800	4.47×10^{-5}	14.2	1.05×10^{-4}	11.3	3.32×10^{-4}	13.3	6.95×10^{-4}	11.4	.428
2000	1.00×10^{-3}	24.0	2.15×10^{-3}	19.2	6.21×10^{-3}	21.6	1.16×10^{-2}	18.5	2.864
2200	1.33×10^{-2}	38.2	2.59×10^{-2}	30.7	6.78×10^{-2}	34.2	.115	29.9	
2400	.116	57.7	.215	47.0	.509	51.3	.800	45.3	
2600	.716	83.8	1.29	69.5	2.25	75.4	5.20	67.0	
2800	3.54	117.6	6.04	98.0	12.53	105.5	60.67	130.6	
3000	14.15	160.5	23.28	116.0	45.60	144.4			

[219] Dushman, Saul, The scientific foundations of vacuum technique, John Wiley & Sons, Inc., 1949. Reprinted by permission.
* Layer of thorium on tungsten.

TABLE 686.—PHOTOELECTRIC EFFECT

A negative charged body loses its charge under the influence of ultraviolet radiation because of the escape of negative electrons freed by the absorption of the energy of the radiation. The radiation must have a wavelength shorter than some limiting value λ_o characteristic of the metal. The emission of these electrons, unlike that from hot bodies, is independent of the temperature. The relation between the maximum velocity v of the expelled electron and the frequency ν of the radiation is $(\frac{1}{2})mv^2 = h\nu - P$ (Einstein's equation) where h is Planck's constant (6.62×10^{-27} erg sec), $h\nu$, the energy of a "quanta," P, the work which must be done by the electron in overcoming surface forces. $(\frac{1}{2})mv^2$ is the maximum kinetic energy the electron may have after escape. Richardson identifies the P of Einstein's formula with the ϕ_e of electron emission of Table 683. The minimum frequency ν_0 (corresponding to maximum wavelength λ_0) at which the photoelectric effect can be observed is determined by $h\nu = P$. P applies to a single electron, whereas w applies to 96,500 coulombs (6.02×10^{23} electrons); therefore $w = NP = .00399\nu_0$ ergs. $\phi = (12.4 \times 10^{-5})\lambda_0$ volts.

TABLE 687.—THE ELECTRON AFFINITY OF THE ELEMENTS, IN VOLTS

Metal	Contact (Henning)	Thermionic (Langmuir)	Photo-electric and contact (Millikan)	Photo-electric (Richardson)	Miscel-laneous	Single-line spectra	Adjusted mean
Tungsten	—	4.52	—	—	—	—	4.52
Platinum	—	—	—	4.3	4.45	—	4.4?
Tantalum	—	4.31	—	—	—	—	4.3
Molybdenum	—	4.31	—	—	—	—	4.3
Carbon	—	4.14	—	—	—	—	4.1
Silver	4.05	—	—	—	—	—	4.1
Copper	(4.0)	—	—	4.1	—	—	4.0
Bismuth	—	—	—	3.7	—	—	3.7
Tin	3.78	—	—	3.5	—	—	3.8
Iron	3.86	3.2?	—	—	—	—	3.7
Zinc	3.46	—	—	3.4	—	4.04	3.4
Thorium	—	3.36	—	—	—	—	3.4
Aluminum	3.06	—	—	2.8	—	—	3.0
Magnesium	2.63	—	—	3.2	—	4.35	2.7
Titanium	—	2.4?	—	—	—	—	2.4
Lithium	—	—	2.35	—	—	1.85	2.35
Sodium	—	—	1.82	2.1	—	2.11	1.82

TABLE 688.—CONTACT (VOLTA) POTENTIALS

There has been considerable controversy over the reality and nature of the contact differences of potential between two metals. At present, owing to the studies of Langmuir, there is a decided tendency to believe that this Volta difference of potential is an intrinsic property of metals closely allied to the phenomena given in Tables 684 to 688 and that the discrepancies among different observers have been caused by the same disturbing surface conditions. The values are for freshly cut surfaces in vacuo. Freshly cut surfaces are more electropositive and grow more electronegative with age. That the observed initial velocities of emission of electrons from freshly cut surfaces are nearly the same for all metals suggests that the more electropositive a metal is the greater the actual velocity of emission of electrons from its surface.

	Ag	Cu	Fe	Brass	Sn	Zn	Al	Mg
Contact potential with Ag.....	0	.05	.19	.21	.27	.59	.99	1.42
Relative photosensitiveness	50	60	65	45	70	80	500	1000

	Pt	Fe	Cu	Au	Ag	Al	Mg	Zn	Pb	Sn
SiO_2	+2.22	+1.99	+1.60	+1.60	+1.42	+.93	+.93	+.45	+.16	— .30
Glass	+1.15	+1.15	+ .58	+ .58	+ .58	+.14	+.14	—.29	—.60	—1.14

	Cu	Cr	Ta	Mo	Ni
W	+.08	+.11	—.38	—.21	—.17

From the equation $w = RT \log (N_A/N_B)$, where w is the work necessary per gram-molecule when electrons pass through a surface barrier separating concentrations N_A and N_B of electrons, it can be shown that the Volta potential difference between two metals should be

$$v_1 - v_2 = \frac{1}{F}\{w_2 - w_1 + RT \log(N_A/N_B)\} = \frac{w_2 - w_1}{F} = \phi_2 - \phi_1$$

(see Table 686 for significance of symbols), since the number of free electrons in different metals per unit volume is so nearly the same that $RT \log (N_A/N_B)$ may be neglected. The contact potentials may thus be calculated from photoelectric phenomena. They are independent of the temperature. The following table gives a summary of values of ϕ in volts obtained from the various phenomena where an electron is torn from the attraction of some surface. In the case of ionization potentials the work necessary to take an electron from an atom of metal vapor is only approximately equal to that needed to separate it from a solid metal surface.

TABLE 689.—ELECTRODE POTENTIALS

It should not be assumed that all the emf of an electrolytic cell is contact emf. Its emf varies with the electrolyte, whereas the contact emf is an intrinsic property of a metal. There must be an emf between the two electrodes of such a cell dependent upon the concentration of the electrolyte used. The following table gives in its first line the electrode potential e_h of the corresponding metals (in solutions of their salts containing normal ion concentration) on assumption of no contact emf at the junction of the metals. The second line, $\phi - e_h - 3.7$ volts, gives an idea of the electrode potentials (arbitrary zero) exclusive of contact emf.

Metal	Ag	Cu	Bi	Sn	Fe	Zn	Mg	Li	Na
e_h	+.80	+.34	+.20	—.10	—.43	—.76	—1.55	—3.03	—2.73
$\phi - e_h - 3.7$	—.40	+.04	+.20	—.20	—.43	—.46	— .55	—1.65	— .85

TABLE 690.—PRESSURE AND NUMBER OF MOLECULES

1. Units of Pressure

A_n = normal atmosphere
= 760 mmHg at 0°C and 45° latitude
= 1.01325×10^6 microbars
1 dyne cm^{-2} = 1 microbar = 0.75 micron
1 micron = 10^{-3} mmHg = 1.333 microbars
= 1μ
P_{mm} = pressure in mmHg
$P\mu$ = pressure in microns = 10^{-3} P_{mm}
$P\mu b$ = pressure in microbars = 1.333×10^{-3} P_{mm}

2. Number of molecules per unit volume

For ideal gas,

$PV = R_o T$
Where V = volume per gram-molecular weight
P = pressure
T = absolute temperature in degrees Absolute (°K)
= degrees Centigrade + 273.16

For ideal gas at 0°C and $A_n = 1$,

$V = V_o = 22{,}414.6$ cm³
Hence R_o = 62.364 mm liter, deg^{-1} K g $mole^{-1}$
= 8.3146×10^7 erg deg^{-1} K g $mole^{-1}$
ρ = density of gas/g/cm³
= $1.2027 \times 10^{-8}\, MP\mu b/T^{-1}$ g cm^{-3}
= $1.6035 \times 10^{-5}\, MP_{mm}/T^{-1}$ g cm^{-3}
Where M = molecular weight in grams
n = number of molecules per cm³
= $7.244 \times 10^{15}\, P\mu b/T$
= $9.656 \times 10^{18}\, P_{mm}/T$

3. The number of molecules per cm³ for different temperatures and pressures

T(°K)	$P_{\mu b}$	P_{mm}	n	T°	$P_{\mu b}$	P_{mm}	n
273.16	1.0133×10^6	760	2.687×10^{19}	298.16	1.333×10^3	1	3.240×10^{16}
298.16	"	"	2.462×10^{19}	273.16	1.000	7.50×10^{-4}	2.653×10^{13}
273.16	1.333×10^3	1	3.536×10^{16}	298.16	"	"	2.430×10^{13}

* Prepared by Saul Dushman, General Electric Co. The formulae and calculations in this section are based on a more comprehensive discussion in chapter 1 of his "Scientific Foundations of Vacuum Technique" (John Wiley & Sons, New York, 1949).

TABLE 691.—MEAN FREE PATHS, L, MOLECULAR DIAMETERS, δ, AND RELATED DATA FOR WATER AND MERCURY VAPORS *

	t°C	P_{mm}**	$10^5\eta_0$	$10^3 L_t{}^1$	$L_t{}^P$	$10^8\delta_t$	$10^{-14}N_s$ †
H_2O	0	4.58	8.69	2.90	6.34×10^{-4}	4.68	5.27
	15	12.79	9.26	...	....	...	...
•	25	23.76	9.64	3.37	1.42×10^{-4}	...	...
Hg	219.4	31.57	46.66	6.28	1.99×10^{-4}	4.27	6.32
	150 0	2.807	39.04	4.87	1.74×10^{-3}	4.50	5.70
	100.0	.2729	33.56	3.93	1.44×10^{-2}	4.70	5.22
	25.0	.0018	25.40	2.66	1.45	5.11	4.42
	.0	....	16.2(J)	...	....	6.26(J)	...

* For reference, see footnote 219, p. 636.
** P_{mm} = vapor pressure at t°C. † N_s = number of molecules/cm² for monomolecular layer.
In the case of H_2O, for which the values of L (path length) and δ (diameter) for a series of temperatures are given in the table, the Sutherland relation was used with $C = 650$ and $\eta_{15} = 926\times10^{-6}$ cgs units.
In the case of Hg the values of η (viscosity) used are based on $t = 219.4$°C. Values at other temperatures were derived by means of Sutherland's relations, with $C = 942.2$

Part 1.—Discussion

Let a denote the *most probable* velocity, v_a, the *average* velocity and v_r, the *mean* velocity (the square root of the mean square). Then

$$a = \sqrt{2R_oT/M} = 12{,}895\sqrt{T/M}\ \text{cm sec}^{-1}$$
$$v_a = (2/\sqrt{\pi})\,a = 1.1284\,a = 14{,}551\sqrt{T/M}\ \text{cm sec}^{-1}$$
$$v_r = \sqrt{3/2}\,a = 1.225\,a = 15{,}794\sqrt{T/M}\ \text{cm sec}^{-1}$$

The probability of a random velocity $v = ca$ is

$$f_c = (r/\sqrt{\pi})c^2\,[\exp - c^2]$$

The fraction of the total number of molecules, N, which have a random velocity *equal to or less than* $v = ca$ is

$$y = \frac{N_c}{N} = \int_0^c f_c dc$$

Part 2 of this table gives values of f_c and of y for a series of values of c. The third column gives values of Δy, which is the fraction of the total number that have values of c between that given in the same horizontal row and that in the preceding row.

From the relation for f_c we obtain the relation for the probability that a molecule possesses the translational energy E. Let $x = E/(kT)$ where x is a dimensionless quantity. Then

$$f_x = 2\sqrt{x/\pi}\,(\exp - x)$$

and the average kinetic energy is $E_{av} = (3/2)kT$

where k = Boltzmann constant
$= 1.3805 \times 10^{-16}$ erg deg^{-1} K

The last two columns in Part 2, below, give values of f_x for a series of values of x.

Part 2.—Values of functions for application of distribution laws

c	f_c	y	Δy	x	f_x
0	0	0		0	
.2	.0867	.0059	.0059	.1	.3229
.3	.1856	.0193	.0134	.2	.4131
.5	.4393	.0812	.0619	.5	.4839
.7	.6775	.1939	.1127	.7	.4688
1.0	.8302	.4276	.2337	1.0	.4152
1.3	.7036	.6634	.2358	1.4	.3294
1.6	.4464	.8369	.1735	1.8	.2502
1.8	.2862	.9096	.0727	2.2	.1855
2.0	.1652	.9540	.0444	2.5	.1464
2.2	.0867	.9784	.0244	3.0	.0973
2.5	.0275	.9941	.0157	3.5	.0637
3.0	.0025	$1 - 4.2\times10^{-4}$		4.0	.0413
4.0	4.1×10^{-6}	$1 - 5.1\times10^{-7}$		5.0	.0170
5.0	7.8×10^{-10}	$1 - 7.9\times10^{-11}$		6.0	.0069

Part 3.—Rates of incidence and of evaporation of molecules

The rate at which molecules strike a surface is given by

$$\nu = (1/4)n\dot{v}_a\ \text{cm}^{-2}\,\text{sec}^{-1}$$
$$= 2.635 \times 10^{19}\,(P_{\mu b})/(\sqrt{MT})\ \text{cm}^{-2}\,\text{sec}^{-1}$$
$$= 3.513 \times 10^{22}\,P_{mm}/\sqrt{MT}\ \text{cm}^{-2}\,\text{sec}^{-1}$$
$$G = \textit{mass}\ \text{of gas of molecular wt, } M,$$
$$= 1.6604 \times 10^{-24}\,M\nu$$
$$= 4.375 \times 10^{-5}\,(P_{\mu b})(\sqrt{M/T})\ \text{g cm}^{-2}\,\text{sec}^{-1}$$
$$= 5.833 \times 10^{-2}\,(P_{mm})(\sqrt{M/T})\ \text{g cm}^{-2}\,\text{sec}^{-1}$$

If we assume that the accommodation coefficient for condensation is unity, then the rate of evaporation is equal to the rate of condensation and the *vapor pressure*, P_{mm}, is given by the relation

$$P_{mm} = 17.14G\sqrt{T/M}$$

TABLE 693.—MASSES, VELOCITIES, AND RATES OF INCIDENCE OF MOLECULES *

ν_1 = rate of incidence of molecules per cm^2 per sec, at 0°C and 1 microbar.
$\nu_{1'}$ = rate of incidence of molecules per cm^2 per sec, at 0°C and 1 mm.
G_1 = mass of gas corresponding to ν_1 (g cm^{-2} sec^{-1}).
$G_{1'}$ = mass of gas corresponding to $\nu_{1'}$ (g cm^{-2} sec^{-1}).
m = mass of molecule in grams = $1.66035 \times 10^{-24} M$; M = molecular weight; $\rho_1{}^0$ = density (g cm^{-3}) of gas at 0°C and 1 microbar.
v_a = average velocity (cm sec^{-1}).

Gas or vapor	M	$10^{23}m$	$10^{10}\rho_{10}$	$10^{-4} \times v_a$ 0°C	$10^{-4} \times v_a$ 25°C	$10^{-17}\nu_1$	$10^{-20}\nu_1'$	$10^5 G_1$	$10^2 G_1'$
H_2	2.016	.3347	.8878	16.93	17.70	11.23	14.97	.3759	.5012
He	4.003	.6646	1.7631	12.01	12.56	7.969	10.63	.5297	.7062
CH_4	16.04	2.663	7.063	6.005	6.273	3.981	5.308	1.060	1.414
NH_3	17.03	2.827	7.498	5.829	6.089	3.865	5.152	1.092	1.456
H_2O	18.02	2.992	7.936	5.665	5.919	3.756	5.007	1.124	1.498
Ne	20.18	3.351	8.886	5.355	5.594	3.550	4.733	1.190	1.586
CO	28.01	4.651	12.34	4.543	4.746	3.012	4.016	1.402	1.868
N_2	28.02	4.652	12.34	4.542	4.745	3.011	4.015	1.402	1.868
Air	28.98**	4.811	12.77	4.468	4.668	2.962	3.950	1.425	1.900
O_2	32.00	5.313	14.09	4.252	4.442	2.819	3.758	1.497	1.996
A	39.94	6.631	17.59	3.805	3.976	2.523	3.363	1.675	2.230
CO_2	44.01	7.308	19.38	3.624	3.787	2.403	3.204	1.756	2.342
CH_3Cl	50.49	8.383	22.23	3.385	3.356	2.244	2.991	1.881	2.508
SO_2	64.06	10.64	28.21	3.004	3.139	1.992	2.656	2.118	2.825
Cl_2	70.91	11.77	31.23	2.856	2.984	1.893	2.524	2.229	2.973
Kr	83.7	13.90	36.85	2.629	2.747	1.743	2.324	2.422	3.229
C_7H_{16}	100.2	16.63	44.12	2.403	2.510	1.593	2.123	2.650	3.533
Xe	131.3	21.80	57.82	2.099	2.193	1.392	1.856	3.034	4.044
CCl_4	153.8	25.54	67.72	1.939	2.026	1.286	1.714	3.283	4.377
Hg †	200.6	33.31	(88.33)	1.698	1.774	(1.126	1.501	3.750	4.998)

* For reference, see footnote 219, p. 636.
** Calculated from the value ρ (density) = 1.293×10^{-3} at 0°C and 760 mmHg.
† Since the vapor pressure of mercury at 0°C is 1.85×10^{-4} mmHg (=0.247μb), the values given in parentheses have no physical significance. Actual values at 0°C, corresponding to saturation pressure, are as follows: $\rho = 21.79 \times 10^{-10}$; $\nu = 2.777 \times 10^{16}$; $G = 9.249 \times 10^{-6}$.

TABLE 694.—MOLECULAR VELOCITIES [220]

Gas	C Root mean square velocities, NTP	c Average velocities, NTP
Hydrogen	18.38×10^4 cm/sec	16.93×10^4 cm/sec
Helium	13.11	12.08
Water vapor	6.15	5.65
Neon	5.84	5.38
Carbon monoxide	4.93	4.54
Nitrogen	4.93	4.54
Ethylene	4.93	4.54
Nitric oxide	4.76	4.38
Oxygen	4.61	4.25
Argon	4.13	3.80
Carbon dioxide	3.93	3.62
Nitrous oxide	3.93	3.62
Krypton	2.86	2.63
Xenon	2.28	2.10
Mercury vapor	1.84	1.70
Air	4.85	4.47
Ammonia	6.33	5.82

[220] Newman and Searle, The general properties of matter, Edward Arnold & Co., London.

Let L = mean free path, δ = molecular diameter. Then

$$L = \frac{1}{\sqrt{2}\pi n\delta^2} \qquad (1)$$

and $$\eta = 0.499\rho v_o L \qquad (2)$$

when η = coefficient of viscosity

ρ = density of gas at given pressure and temperature

Unit of η is the *poise* = g cm^{-1} sec^{-1}

Hence $$L = 1.1451 \times 10^4 \frac{\eta}{P_{\mu b}} \sqrt{\frac{T}{M}} \text{ cm} \qquad (3)$$

$$= 8.589 \frac{\eta}{P_{mm}} \sqrt{\frac{T}{M}} \text{ cm} \qquad (4)$$

and $$\delta^2 = \frac{2.714 \times 10^{-21}}{\eta} \sqrt{MT} \text{ cm}^2 \qquad (5)$$

η, as a function of T, is given by the relation

$$\eta_T = \left(\frac{T}{T_o}\right)^{3/2} \left(\frac{C + T_o}{C + T}\right) \qquad (6)$$

where η_o = value at T_o, η = value at T and C is known as the Sutherland constant. For short ranges of temperature, the *exponential* relation is used, of the form

$$(\eta_T/\eta_o) = (T/T_o)^x \qquad (7)$$

In Tables 691 and 696, which give values of L, δ and related data for a number of gases and vapors,

η_{15} = coefficient of viscosity at 15°C

η_0 = " " " " 0°C

and η_{25} = " " " " 25°C

x = value of exponent in equation (7)

L_o^1 = value of mean free path (in cm) at 0°C and 1 mmHg

L_o^{760} = value of mean free path (in cm) at 0°C and 760 mmHg

L_{25}^1 = value of mean free path (in cm) at 25°C and 1 mmHg

L_{25}^{760} = value of mean free path (in cm) at 25°C and 760 mmHg

δ = value of molecular diameter (in cm) at 0°C

$N_s = 1.154/\delta^2$ = of molecules per cm^2 to form a monolayer (assuming that the spacing is that of close-packed or face-centered lattice)

ω = collision-frequency at 25°C and 760 mmHg
$= v_a/L_{25}^{760}$

For the vapors of H_2O and Hg (Table 691), P = vapor pressure in mmHg at the temperature t, and L_t and δ_t denote the values of the mean free path and diameter, respectively, at this temperature. For H_2O vapor, $C = 650$ and $\eta_{15} = 9.26 \times 10^{-5}$. For Hg, C = 942.2 and value of η at $t = 219.4$°C was used. The values of η_o and δ_o for Hg at 0°C are those given by Jeans.

TABLE 696.—VISCOSITY, η, MEAN FREE PATHS, L, MOLECULAR DIAMETERS, δ, AND RELATED DATA FOR A NUMBER OF GASES *

Gas: Characteristic	H_2	He	Ne	Air	O_2	A	CO_2	Kr	Xe
x **	.69	.64	.67	.79	.81	.86	.95	.85	.92
$10^7 \times \eta_{15^\circ}$ †	871	1943	3095	1796	2003	2196	1448	2431	2236
$10^7 \times \eta_{0^\circ}$	839	1878	2986	1722	1918	2097	1377	2372	2129
$10^7 \times \eta_{25^\circ}$	892	1986	3166	1845	2059	2261	1496	2502	2308
$10^3 \times L_{0^\circ}{}^1$ ‡	8.39	13.32	9.44	4.54	4.81	4.71	2.95	3.69	2.64
$10^6 \times L_{0^\circ}{}^{760}$	11.04	17.53	12.42	5.98	6.33	6.20	3.88	4.85	3.47
$10^3 \times L_{25^\circ}{}^1$	9.31	14.72	10.45	5.09	5.40	5.31	3.34	4.06	2.98
$10^6 \times L_{25^\circ}{}^{760}$	12.26	19.36	13.75	6.69	7.10	6.67	4.40	5.34	3.93
$10^8 \times \delta$	2.75	2.18	2.60	3.74	3.64	3.67	4.65	4.15	4.91
C	84.4	80	56	112	125	142	254	188	252
$10^{-14} \times N_s$ §	15.22	24.16	17.12	8.24	8.71	8.54	5.34	6.69	4.78
$10^{-9} \times \omega$ ¶	14.45	7.16	1.68	6.98	6.26	5.70	8.61	6.48	5.71

* For reference, see footnote 219, p. 636.
** x from relations $\eta_T = aT^x$. † C = a measure of strength of the attraction forces (in dynes) between molecules. ‡ $L_{0^\circ}{}^1$ = mean free path at 0°C and 1 mmHg, etc. § N_s = number of molecules/cm² for monomolecular layer. ¶ ω = collision frequency (sec^{-1}) at 25°C and 760 mmHg.

TABLES 697-712.—ATOMIC AND MOLECULAR DIMENSIONS

TABLE 697.—EFFECTIVE ATOMIC RADII

Goldschmidt, on the basis of reasonable though empirical assumptions, has calculated effective radii of atoms in various charged conditions; Pauling, on the basis of wave mechanics, has presented theoretical values for most of the elements, the two series agreeing well in many cases. The latter values are printed in boldface type; the values considered nontypical are in parentheses; e.g., for silicon we have: Si^{+4} (0.22—) 0.39–**0.41**, Si° (1.12—) 1.18, Si^{-4} (1.98); **2.71**, signifying silicon, carrying 4 + charges, has apparent radius between 0.22 and 0.41; but the lower values relate to compounds where the atoms appear to be deformed; so Goldschmidt gives 0.39 as most significant. Wave mechanics yields **0.41.** Neutral, the radius ranges from 1.2, in abnormal compounds, to 1.18 in those typical; when carrying 4 — charges, the value is 1.98, according to calculations deemed faulty, **2.71** according to theory.

In applying the data to replacements, halides and oxides are usually ionized, and the values in the outer columns apply. Thus in fluorite the value for Ca^{+2} should be added to that for F^{-1}, giving between 2.32 and 2.42, or 2.37 as a mean; and the observed Ca-F distance in the crystal is 2.36 angstrom units. In the remaining types of compounds the atoms appear to be largely neutral and the first column should be used.

Atomic No; element	Radius neutral atom angstroms	Charge	Radius positively charged ion angstroms
1 H			
2 He	(.93)		
3 Li	(1.50—)1.56	1	**.60**– .78(— .82)
4 Be	1.05(—1.15)	2	**.31**– .34
5 B		3	**.20**
6 C	(.45—) .77	4	**.15**
7 N	(.65—) .71	5	**.11**
8 O	.60(— .65)	6	**.09**
9 F	.67	7	**.07**
10 Ne	(1.12)		
11 Na	(1.77—)1.86	1	**.95**– .98(—1.09)
12 Mg	(1.42—)1.62	2	**.65**– .78(— .85)
13 Al	(1.16—)1.43	3	**.50**– .57(— .66)
14 Si	(1.12—)1.18	4	(.22—) .39– **.41**
15 P	.93	5	**.34**
16 S	1.02–1.04	6	**.29**– .34
17 Cl	1.05–1.07	7	**.26**
18 A	(1.54)		
19 K	(2.07—)2.23	1	1.33(—1.84)
20 Ca	(1.70—)1.97	2	.99–1.66(—1.50)
21 Sc	1.51	3	**.81**– .83
22 Tl	(1.40—)1.49(—1.53)	4	(.58—) .64– **.68**
23 V	1.32(—1.43)	5	**.59**
V		4	**.59**– .61
24 Cr	(1.17—)1.25(—1.54)	6	**.52**– .65
25 Mn	(1.17—)1.29(—1.59)	7	**.46**
Mn		4	**.50**– .52
Mn		2	**.80**– .91
26 Fe	(1.21—)1.26(—1.45)	3	(.49—) .67
Fe		2	**.75**– .83
27 Co	1.26(—1.39)	3	.29– .47
Co		2	**.72**– .82
28 Ni	1.24(—1.39)	3	.35
Ni		2	**.69**– .78
29 Cu	(1.22—)1.27(—1.37)	2	.70
Cu		1	(.58—) **.96**
30 Zn	1.31–1.34	2	**.74**– .83
31 Ga	(1.28—)1.33(—1.45)	3	**.62**
32 Ge	1.22	4	.44– **.53**
33 As	(1.04—)1.16(—1.26)	5	**.47**
As		3	.69
34 Se	1.13–1.17	6	**.42**
35 Br	1.19	7	**.39**
36 Kr	(1.69)		
37 Rb	(2.25—)2.36	1	**1.48**–1.49(—1.88)
38 Sr	1.95	2	**1.13**–1.27(—1.45)
39 Y		3	**.93**–1.06
40 Zr	1.60–1.62	4	(.68—) **.80**– .89
41 Nb	1.43(—1.50)	5	.69– **.70**
Nb		4	**.67**– .69
42 Mo	1.36	6	**.62**
Mo		4	**.66**(— .83)
44 Ru	1.27–1.34	4	**.63**– .65
45 Rh	1.34–1.35	3	.69
46 Pd	1.37		
47 Ag	(1.17—)1.44	1	(.79—)1.13–**1.26**
48 Cd	(1.47—)1.49(—1.60)	2	(.78—) **.97**–1.03
49 In	1.45–1.62	3	**.81**– .92
50 Sn	(1.27—)1.40	4	(.64—) **.71**(—.81)
51 Sb	(1.22—)1.34(—1.44)	5	**.62**
Sb		3	.90
52 Te	1.33–1.43	6	**.56**
Te		4	**.81**– .89
53 I	1.36–1.40	7	**.50**
I		5	.94
54 Xe	(1.90)		
55 Cs	(2.37—)2.55	1	1.65–**1.69**(—1.75)
56 Ba	2.10	2	1.35–1.43(—1.49)
57 La		3	**1.15**–1.22
58 Ce	1.82–1.83	4	**1.01**–1.02
Ce		3	1.18
59 Pr		4	**.92**–1.00
Pr		3	1.16
60 Nd		3	1.15
62 Sm		3	1.13
63 Eu		3	1.13
64 Cd		3	1.11
65 Tb		3	1.09
66 Dy		3	1.07
67 Ho		3	1.05
68 Er		3	1.04
69 Tm		3	1.04
70 Yb		3	1.00
72 Hf	1.66		
73 Ta	1.42–1.44		
74 W	1.37	6	.88
W		4	**.66**– .68
76 Os	1.30–1.34	4	**.65**– .67
77 Ir	1.35	4	**.64**– .66
78 Pt	1.38(—1.43)		
79 Au	1.40–1.44	1	**1.37**
80 Hg	1.46–1.49	2	**1.10**–1.12
81 Tl	(1.71—)1.99(—2.25)	3	**.95**–1.05
Tl		1	1.44–1.51
82 Pb	1.74(—1.90)	4	**.84**
Pb		2	(.98—)**1.21**–1.32
83 Bi	(1.34—)1.46(—1.55)	5	**.74**
90 Th	1.80–1.82	4	**1.02**–1.10
92 U		4	**.97**–1.05
—NH_4		1	**1.42**–1.59

Element	Charge	Radius negative ion
1 H	—1	(1.27); **2.08**
6 C	—4	**2.60**
7 N	—3	1.71
8 O	—2	1.32–**1.40**
9 F	—1	1.33–**1.36**
14 Si	—4	(1.98); **2.71**
15 P	—3	**2.12**
16 S	—2	1.74–**1.84**
17 Cl	—1	**1.81**
32 Ge	—4	**2.72**
33 As	—3	**2.22**
34 Se	—2	1.91–**1.98**
35 Br	—1	**1.95**–1.96
50 Sn	—4	(2.15); **2.94**
51 Sb	—3	**2.45**
52 Te	—2	2.03–**2.21**
53 I	—1	**2.16**–2.20
82 Pb	—4	**2.15**

TABLE 698*.—DIFFUSION COEFFICIENTS OF GASEOUS IONS AT *NTP* [221]

Gas	Dry gas D^+	Dry gas D^-	Moist gas D^+	Moist gas D^-
Air	.028	.043	.032	.035
Oxygen	.025	.0396	.0288	.0358
Carbon dioxide	.023	.026	.0245	.0255
Nitrogen	.029	.0414	...	...
Hydrogen	.123	.190	.128	.142

* Tables 698-700 and 702 prepared by J. D. Cobine, General Electric Co., Schenectady, N. Y.
[221] Cobine, J. D., Gaseous conductors, 2d ed., McGraw-Hill Book Co. Used by permission of the publishers.

TABLE 699.—DIFFUSION COEFFICIENTS OF NEUTRAL GASES AT 0°C AND 760 mmHg *

Gases	D **	m †	Gases	D **	m †
A — He	.706	...	H_2 — CO	.651	1.75
Air — CO_2	.134	...	H_2 — CO_2	.534	1.75
Air — O_2	.178	...	H_2 — N_2	.674	1.75
CO — CO_2	.136	2.00	H_2 — N_2O	.535	1.75
CO — H_2O	.642	...	H_2 — O_2	.679	1.75
CO — O_2	.183	1.75	H_2O — Air	.220	1.75
CO_2 — Air	.134	...	Hg — Air	.112	...
CO_2 — H_2O	.528	...	O_2 — Air	.178	1.75
He — A	.641	1.75	O_2 — H_2	.722	...
H_2 — Air	.661	1.75	O_2 — CO	.185	1.75
			O_2 — CO_2	.136	2.00

* For reference, see footnote 221, above.
** D in cm²/sec. † $D = D_o(T/T_o)^m(p_o/p)$, where D_o is the value of D in the table, $T_o = 0°C$, $p_o = 1$ atm.

TABLE 700.—MOBILITIES OF POSITIVE IONS IN NOBLE GASES AT 760 mmHg AND 0°C *

(cm/sec per volt/cm)

Ion	He	Ne	A	Kr	Xe
Gas †	20.1	5.85	1.81	.88	.61
Li	24.2	11.87	4.68	3.72	2.84
Na	22.7	8.16	3.03	2.20	1.69
K	21.5	7.51	2.64	1.86	1.35
Rb	20.1	6.75	2.24	1.49	1.03
Cs	18.4	6.10	2.10	1.33	.91

* For reference, see footnote 221, above.
† Ions same as gas.

TABLE 701.—MOLECULAR DIAMETERS, δ, FOR ATTRACTIVE SPHERES *

Gas	From η †	From b ‡	Gas	From η †	From b ‡
Argon	2.87×10^{-8} cm	2.87×10^{-8} cm	Hydrogen	2.38×10^{-8} cm	2.53×10^{-8} cm
Krypton	3.15	3.16	Nitrogen	3.13	3.56–3.10
Xenon	3.50	3.45	Air	3.11	3.32
Helium	1.91	1.97	Carbon dioxide	3.23	3.22
Oxygen	2.96	2.91	..	3.30	3.42

* For reference, see footnote 220, p. 640.
† Viscosity. ‡ Van der Waal's equation.

TABLE 702.—MOBILITY * OF SINGLY-CHARGED GASEOUS IONS AT 760 mmHg AND 0°C **

(cm/sec per volt/cm)

Gas	$(\epsilon - 1)$ †	K_o^-	K_o^+
Air (dry)	.000585	2.2	1.6
A (pure)	.00056	206.0	1.81
Cl_2	....	.74	.74
CCl_4	.0030	.31	.30
CO	.00070	1.14	1.10
CO_2 (dry)	.00098	.98	.84
H_2	.00028	8.15	5.9
H_2 (pure)	....	7900.0	13.8
HCl	.0046	.62	.53
H_2O (at 100°C)	....	.95	1.1
H_2S	.0040	.56	.62
He	.000074	6.3	5.09
He (pure)	....	500.0	21.4
Hg in He	....	...	13.4
Hg in N_2	....	...	2.02
Kr	.0007685	...	.94
N_2	.00058	1.84	1.27
N_2 (pure)	....	145.0	2.51
NH_3	.0072	.66	.56
NH_3 in N_2	....	...	3.06
N_2O	.00113	.90	.82
Ne	.0001231	...	5.64
O_2	.00051	1.8	1.31
SO_2	.0095	.41	.41

* $K = K_o \rho_o / \rho$, where ρ_o is the gas density at NTP and ρ is the density at which K is desired.

$$K = \frac{0.235\left(\frac{m_1 + m_2}{m_1}\right)^{\frac{1}{2}}}{(\rho/\rho_o)(\epsilon - 1)_o M_o}.$$

where m_1 = mass of ion, m_2 = mass of gas particle, ϵ = dielectric constant, $(\epsilon - 1)_o$ is calculated for NTP. M_o = molecular weight of gas. Values of mobility in this table may not be absolute, but are of orienting value.

** For reference, see footnote 221, p. 644.

† International Critical Tables; Tables Annuelles Internationales de Constants.

TABLE 703.—MOLECULAR DIAMETER (BRAGG) *

Gas	From crystal measured in $2d$	From viscosity η	Ratio, $2d/\eta$
Neon	1.30×10^{-8} cm	2.35×10^{-8} cm	.553
Argon	2.05	2.87	.714
Krypton	2.35	3.15	.746
Xenon	2.70	3.50	.771

* For reference, see footnote 220, p. 640.

TABLE 704.—NUMBER OF MOLECULES (PER cm² AT 0°C) OF MONOLAYER AND EQUIVALENT VOLUME (cm³) *

Gas	No molecules $\times 10^{-14}$	Vol gas at 760 mmHg and 20°C $\times 10^5$	Gas	No molecules $\times 10^{-14}$	Vol gas at 760 mmHg and 20°C $\times 10^5$
H_2	15.22	6.08	CO	8.07	3.23
He	24.16	9.65	CO_2	5.34	2.13
A	8.54	3.41	CH_4	5.23	2.09
N_2	8.10	3.24	NH_3	4.56	1.82
O_2	8.71	3.48	H_2O	5.27	2.11

* For reference, see footnote 219, p. 636.

TABLE 705.—CROSS SECTION AND LENGTHS OF SOME ORGANIC MOLECULES

According to Langmuir, in solids and liquids every atom is chemically combined to adjacent atoms. In most inorganic substances the identity of the molecule is generally lost, but in organic compounds a more permanent existence of the molecule probably occurs. When oil spreads over water evidence points to a layer a molecule thick and that the molecules are not spheres. Were they spheres and an attraction existed between them and the water, they would be dissolved instead of spreading over the surface. The presence of the —COOH, —CO or —OH groups generally renders an organic substance soluble in water, whereas the hydrocarbon chain decreases the solubility. When an oil is placed on water the —COOH groups are attracted to the water and the hydrocarbon chains repelled but attracted to each other. The process leads the oil over the surface until all the —COOH groups are in contact if possible. Pure hydrocarbon oils will not spread over water. Benzene will not mix with water. When a limited amount of oil is present the spreading ceases when all the water-attracted groups are in contact with water. If weight w of oil spreads over water surface A, the area covered by each molecule is AM/wN where M is the molecular weight of the oil ($O = 16$), N, Avogadro's constant. The vertical length of a molecule $l = M/a\rho N = W/\rho A$ where ρ is the oil density and a the horizontal area of the molecule.

Substance	Cross section in $cm^2 \times 10^{16}$	l in cm (length) $\times 10^8$
Palmitic acid $C_{15}H_{31}COOH$	24	19.6
Stearic acid $C_{17}H_{35}COOH$	24	21.8
Cerotic acid $C_{25}H_{51}COOH$	25	29.0
Oleic acid $C_{17}H_{33}COOH$	48	10.8
Linoleic acid $C_{17}H_{31}COOH$	47	10.7
Linolenic acid $C_{17}H_{29}COOH$	66	7.6
Ricinoleic acid $C_{17}H_{32}(OH)COOH$	90	5.8
Cetyl alcohol $C_{16}H_{33}OH$	21	21.9
Myricyl alcohol $C_{30}H_{61}OH$	29	35.2
Cetyl palmitate $C_{15}H_{31}COOC_{16}H_{33}$	21	44.0
Tristearin $(C_{18}H_{35}O_2)_3C_3H_5$	69	23.7
Trielaidin $(C_{18}H_{33}O_2)_3C_3H_5$	137	11.9
Triolein $(C_{18}H_{33}O_2)_3C_3H_5$	145	11.2
Castor oil $(C_{17}H_{32}(OH)COO)_3C_3H_5$	280	5.7
Linseed oil $(C_{17}H_{31}COO)_3C_3H_5$	143	11.0

TABLE 706.—VOLUMES OF INERT GAS ATOMS *

Gas	Volume from ionic radius	b	$\frac{b}{\text{volume}}$	Volume of liquid
Neon	3.33	17.1	5.1	16.7
Argon	8.6	32.2	3.8	28.1
Krypton	12.5	39.7	3.2	38.9
Xenon	18.8	50.8	2.7	47.5

* For reference, see footnote 203, p. 624.

TABLE 707.—LATTICE SPACINGS OF IONIC CRYSTALS *

Material	r_0 observed A	r_0 calculated A	Melting point, °C	Material	r_0 observed A	r_0 calculated A	Melting point, °C
			Sodium chloride structure				
LiF	2.01	2.10	870	NH_4I	3.62	3.65	
LiCl	2.57	2.60	613	AgF	2.46	2.30	435
LiBr	2.75	2.75	547	AgCl	2.77	2.80	455
LiI	3.00	3.00	446	AgBr	2.88	2.95	434
NaF	2.31	2.35	980	MgO	2.10	2.15	2800
NaCl	2.81	2.85	804	MgS	2.60	2.60	
NaBr	2.98	3.00	755	MgSe	2.73	2.70	
NaI	3.23	3.25	651	CaO	2.40	2.40	2572
KF	2.67	2.65	880	CaS	2.84	2.85	
KCl	3.14	3.15	776	CaSe	2.96	2.95	
KBr	3.29	3.30	730	CaTe	2.97	3.15	
KI	3.53	3.55	773	SrO	2.58	2.60	2430
RbF	2.82	2.80	760	SrS	3.01	3.05	882
RbCl	3.27	3.30	715	SrSe	3.12	3.15	
RbBr	3.43	3.45	682	SrTe	3.33	3.35	
RbI	3.66	3.70	642	BaO	2.77	2.75	1923
CsF	3.00	3.05	684	BaS	3.19	3.20	
NH_4Cl	3.27	3.25		BaSe	3.30	3.30	
NH_4Br	3.45	3.40		BaTe	3.50	3.50	
			Cesium chloride structure				
CsCl	3.56	3.55	646	NH_4Br	3.51	3.40	
CsBr	3.71	3.70	636	NH_4I	3.78	3.65	
CsI	3.95	3.95	621	TlCl	3.33		430
NH_4Cl	3.34	3.25		TlBr	3.44		460
			Zincblende structure				
CuCl	2.34	2.30	422	ZnTe	2.64	2.65	
CuBr	2.46	2.45	504	CdS	2.52	2.50	1750
CuI	2.62	2.70	605	CdSe	2.62	2.60	
BeS	2.10	2.10		CdTe	2.80	2.80	
BeSe	2.18	2.20		HgS	2.53	2.50	
BeTe	2.43	2.40		HgSe	2.62	2.60	
ZnS	2.35	2.35	1800	HgTe	2.79	2.80	
ZnSe	2.45	2.45					
			Wurtzite structure (first distance is that to neighbor along axis, second to three neighbors in same layer)				
NH_4F	2.63, 2.76	2.75		ZnS	2.36, 2.36	2.35	1850
BeO	1.64, 1.60	1.65	2570	CdS	2.52, 2.56	2.50	1750
ZnO	1.94, 2.04	1.90		CdSe	2.63, 2.64	2.60	

* For reference, see footnote 203, p. 624.

TABLE 708.—IONIC RADII *

(Angstroms)

Be^{++} .20	Li^{+} .80				
Mg^{++} .70	Na^{+} 1.05	F^{-} 1.30	O^{--} 1.45		
Ca^{++} .95	K^{+} 1.35	Cl^{-} 1.80	S^{--} 1.90	Zn^{++} .45	Cu^{+} .50
Sr^{++} 1.15	Rb^{+} 1.50	Br^{-} 1.95	Se^{--} 2.00	Cd^{++} .60	Ag^{+} 1.00
Ba^{++} 1.30	Cs^{+} 1.75	I^{-} 2.20	Te^{--} 2.20	Hg^{++} .60	
	NH_4^{+} 1.45				

* For reference, see footnote 203, p. 624.

TABLE 703.—CRYSTAL STRUCTURE AND INTERATOMIC DISTANCES FOR METALS (Angstroms) **

Abbreviations: b.c., body-centered cubic; f.c., face-centered cubic; hex, hexagonal; di, diamond; *, other structures.

Li b.c. 3.03	Na b.c. 3.72	K b.c. 4.50	Rb b.c. 4.86	Cs b.c. 5.25
Be hex 2.28 2.24	Mg hex 3.20 3.19	Ca f.c. 3.93	Sr f.c. 4.29	Ba b.c. 4.35
B	Al f.c. 2.85	Sc	Y 3.58	La hex, f.c. 3.72, 3.73
		Ti hex 2.95 2.90	Zr hex 3.23 3.18	Hf hex 3.32 3.33
		V b.c. 2.63	Nb	Ta b.c. 2.88
		Cr b.c. 2.49	Mo b.c. 2.72	W b.c. 2.73
		Mn * 2.50		
		Fe f.c. 2.57, 2.48	Ru hex 2.69 2.65	Os hex 2.71 2.67
		Co hex, f.c. 2.71	Rh f.c. 2.69	Ir f.c. 2.70
		Ni f.c. 2.49	Pd f.c. 2.74	Pt f.c. 2.76
		Cu f.c. 2.55	Ag f.c. 2.88	Au f.c. 2.87
		Zn hex 2.65 2.94	Cd hex 2.97 3.30	Hg * 2.99
		Ga * 2.56	In * 3.24, 3.33	Tl hex, f.c. 3.45, 3.43
	Si di 2.35	Ge di 2.43	Sn di 2.80	Pb f.c. 3.49
		As * 2.50	Sb * 2.88	Bi * 3.10
		Se * 2.32	Te * 2.88	

** For reference, see footnote 203, p. 624.

TABLE 710.—GREATEST BINDING ENERGY OF AN ELECTRON—NEUTRAL ATOMS[222] *

The binding energy has been calculated by multiplying the absolute value of the appropriate energy level (in cm^{-1}), referred to its proper limit, by the factor 0.00012395, to express it in electron volts. A dash indicates that no such term exists. Brackets denote an estimated value.

Element	1s	2s	2p	3s	3p	3d		4s		4p		4d		5s		5p		5d	
H I	13.59	3.40	3.40	1.51	1.51	1.51		.85		.85		.85		.54		.54		.54	
He I	24.58	4.77	3.62	1.87	1.58	1.51		.99		.88		.85		.62		.56		.54	
Li I	...	5.39	3.54	2.02	1.56	1.51		1.05		.87		.85		.64		.55		.54	
Be I	...	9.32	6.60	2.86	2.03	1.63		1.32		[1.15]		.90		.77		[.69]		.57	
B I	...	...	8.30	3.33		1.51		1.48				.86		.84				.55	
C I	...	...	11.26	3.79	2.73	1.64		1.58		1.33		.91		.87		.75		.58	
N I	...	...	11.54	4.22	2.95	1.58		1.70		1.35		.89		.93				.57	
O I	...	...	13.61	4.47	2.88	1.54		1.78		1.33		.86		.96		.74		.55	
F I	...	...	17.42[a]	4.72	3.05	1.54		1.85		1.38		.87		.98		.78		.55	
Ne I	...	...	21.56	4.94	3.18	1.54		1.90		1.41		.86		1.00		.80		.55	
Na I	...	...	...	5.14	3.04	1.52		1.95		1.39		.86		1.02		.79		.55	
Mg I	...	...	...	7.64	4.94	1.89		2.54		1.71		1.06		1.21		.92		.66	
Al I	...	...	...	...	5.98	1.96		2.84		1.90		1.16		1.31		.99		.75	
Si I	...	...	...	...	8.15	2.28		3.23		2.29		1.43		1.43		1.15		.83	
P I	...	...	...	...	[10.55][b]	1.83		3.62		2.45									
S I	...	...	...	...	10.36	1.94		3.83		2.49		1.06		[1.59]		1.20		.66	
Cl I	...	...	...	...	13.01			4.09		2.74		1.15				1.30		.72	
A I	...	...	...	...	15.76	1.91		4.21		2.85		1.07		1.69		1.30		.66	
						A †	B ‡	A	B	A	B	A	B	A	B	A	B	A	B
K I	...	...	...	...	...	1.67	—	4.34	—	2.73	—	.94	—	1.73	—	1.28	—	.60	—
Ca I	...	...	...	...	...		3.59	5.28	6.11	3.37	4.23	1.44	1.49	1.92	2.20	1.45	1.58	.81	.81
Sc I	...	...	...	...	...	2.97	5.13	5.73	6.56	3.56	4.62		1.96	1.96	2.30				
Ti I	...	...	...	...	...	3.38	6.02	6.13	6.83	3.66	4.87	1.51	1.73	2.10	2.38		1.65		.90
V I	...	...	...	...	...	4.23	6.80	6.48	7.06	3.68	5.03	1.53	1.65	2.14	2.43				.90
Cr I	...	...	...	...	...	2.38	8.25	6.76	7.29	3.87	5.15	1.53	1.66	2.19	2.49	1.53		.85	
Mn I	...	...	...	...	...		5.32	7.09	7.43	4.03	5.15	1.55	1.64	2.24	2.54		1.73		.90
Fe I	...	...	...	...	...	4.05	7.04	7.27	7.90	4.03	5.50	1.55	1.66	2.30	2.59				
Co I	...	...	...	...	...	4.45	7.85	7.43	8.28	3.89	5.35	1.54	1.65	2.31	2.62				
Ni I	...	...	...	...	...	5.81	8.65	7.61	8.67	4.09	5.48	1.56	1.65	2.35	2.67	1.59		.87	.89
Cu I	...	...	...	...	...	—	10.44	7.72	9.05	3.94	5.61	1.53	1.66	2.38	2.71	1.60	1.73	.86	.92
Zn I	...	...	...	...	...	—		—	9.39	—	5.39	—	1.65	—	2.74	—	1.80	—	.92
Ga I	...	...	...	...	...	...		...		6.00		1.69		2.92				.94	
Ge I	...	...	...	...	...	...		...		7.88		1.87		3.24		2.09		1.02	
As I	...	...	...	...	...	...		...		9.81		2.03		3.53		2.28			
Se I	...	...	...	...	...	...		...		9.75		1.89		3.78		2.41		1.03	
Br I	...	...	...	...	...	...		...		11.84				3.98		2.59			
Kr I	...	...	...	...	...	...		...		14.00		2.00		4.08		2.70		1.13	
												A	B	A	B	A	B	A	B
Rb I	...	...	...	...	...	...		...		...		1.78	—	4.18	—	2.62	—	.99	—
Sr I	...	...	...	...	...	...		...		...			3.44		5.69	3.37	3.92		1.39
Y I	...	...	...	...	...	...		...		...		3.89	5.27	6.16	6.63	3.96	4.78		1.86
Zr I	...	...	...	...	...	...		...		...		4.58	6.35	6.67	6 95	4.34	5.12		2.00
Nb I	...	...	...	...	...	...		...		...		5.36		6.77	6.92	4.04	4.99		

[222] Moore, Charlotte E., and Russell, Henry Norris, Nat. Bur. Standards Journ. Res., vol. 48, p. 61, 1952.

* *A*, Lidén, K., Ark. f. Fys. (Stockholm), vol. 1, p. 260, 1949. *B*, Finkelnburg, W., and Stern, F., Phys. Rev., vol. 77, p. 303, 1950.

† *A*, limit is lowest level of configuration $3d^{n-1}$ (K I — Cu I), $4d^{n-1}$ (Rb I — Nb I) in the singly ionized atom. See column 6, Table 623. ‡ *B*, limit is lowest of configuration $3d^{n-2}\,4s$ (K I — Cu I), $4d^{n-2}\,5s$ (Rb I — Nb I) in the singly ionized atom.

TABLE 711.—GREATEST BINDING ENERGY OF AN ELECTRON— SINGLY-IONIZED ATOMS * †

Element	1s	2s	2p	3s	3p	3d	4s	4p	4d	5s	5p	5d
He II	54.40	13.60	13.60	6.04	6.04	6.04	3.40	3.40	3.40	2.18	2.18	2.18
Li II	75.62	16.61	14.35	6.86	6.27	6.05	3.73	3.49	3.40	2.34	2.22	2.18
Be II	....	18.21	14.25	7.27	6.25	6.05	3.89	3.49	3.40	2.42	2.22	2.18
B II	....	25.15	20.52	9.06	7.30	6.48	4.53	3.89	3.57	2.73		2.26
C II	....	....	24.38	9.93	8.05	6.33	4.89	4.23	3.54	2.89	2.65	2.25
N II	....	....	29.61	11.15	9.20	6.49	5.24	4.55	3.62	3.05		2.25
O II	....	....	35.15	12.19	9.87	6.48	5.57	4.68	3.60	3.20	2.80	2.27
F II	....	....	34.98	13.08	9.86	6.33	5.81	4.40	3.49			
Ne II	....	....	41.07	13.91	10.55	6.47	6.12		3.60			
Na II	....	....	47.29	14.45	10.95	6.32	6.20		3.47	3.50		
Mg II	....	....	....	15.03	10.61	6.17	6.38	5.04	3.47	3.53	2.95	2.21
Al II	....	....	....	18.82	14.19	6.98	7.51	5.76	3.77	3.94	3.24	2.36
Si II	....	....	....	....	16.34	6.51	8.22	6.28	3.82	4.20	3.47	2.41
P II	....	....	....	....	19.65	6.81	8.92	6.86	4.16	4.36		2.41
S II	....	....	....	....	23.4	9.75	9.82	7.85	4.57	4.78	3.06	
Cl II	....	....	....	....	23.80	10.13	10.43	7.86	4.63	4.93		2.75
A II	....	....	....	....	27.62	11.22	10.98	8.40	4.85	5.11	4.05	2.28
K II	....	....	....	....	31.81	11.55	11.67	9.10	5.11	5.46		
Ca II	....	....	....	....	....	10.18	11.87	8.75	4.82	5.40	4.36	2.85
Sc II	....	....	....	....	....	12.20	12.80	9.56	5.42	5.66		
Ti II	....	....	....	....	....	13.46	13.57	9.91	5.53	5.87		
V II	....	....	....	....	....	14.65	14.33	10.36	5.67			
Cr II	....	....	....	....	....	16.49	15.01	10.69	5.76	6.24		
Mn II	....	....	....	....	....	13.86	15.64	10.88	5.78	6.39	4.99?	3.25
Fe II	....	....	....	....	....	15.95	16.18	11.41	5.91	6.53	5.35	
Co II	....	....	....	....	....	17.05	16.64	11.45		6.64		
Ni II	....	....	....	....	....	18.15	17.11	11.76		6.77		
Cu II	....	....	....	....	....	20.29	17.57	12.05	6.09	6.90	5.40	3.39
Zn II	....	....	....	....	....	....	17.96	11.95	5.95	7.00	5.39	3.34
Ga II	....	....	....	....	....	....	20.51	14.64	7.16	7.75	5.83	3.51
Ge II	....	....	....	....	....	....	....	15.93	5.91	8.20	6.14	3.52
As II	....	....	....	....	....	....	....	20.2	9.2	10.4	8.4	
Se II	....	....	....	....	....	....	....	21.5		9.70	7.50	4.36
Br II	....	....	....	....	....	....	....	21.6	7.65	9.94	7.37	4.32
Kr II	....	....	....	....	....	....	....	24.56	8.95	10.58	7.96	4.63
Rb II	....	....	....	....	....	....	....	27.50		10.97	8.38	4.67
Sr II	....	....	....	....	....	....	....	....	9.22	11.03	8.09	4.42
Y II	....	....	....	....	....	....	....	....	11.40	12.29	9.15	5.14
Zr II	....	....	....	....	....	....	....	....	13.71	14.03	10.56	4.87
Nb II	....	....	....	....	....	....	....	....	....	....	....	....

* See column 6, Table 623.
† For reference, see footnote 222, p. 649.

TABLE 712.—CONSTANTS OF DIATOMIC MOLECULES *

The attractive force between atoms varies with the distance between centers. When this distance $= r_e$, the sum of the two radii, the force changes from an attraction to a repulsion. The force, D, at this distance, r_e, is thus the force necessary to pull the two atoms apart. The energy of separation is generally given.

Substance	D kgcal mole	D electron volts	r_e A	Substance	D kgcal mole	D electron volts	r_e A
H_2	103	4.454	.75	CO	223	9.6	1.13
CH	81	3.5	1.12	C_2	128	5.6	1.31
NH	97	4.2	1.08	Cl_2	57	2.47	1.98
OH	102	4.4	.96	Br_2	46	1.96	2.28
HCl	102	4.40	1.27	I_2	36	1.53	2.66
NO	123	5.3	1.15	Li_2	26	1.14	2.67
O_2	117	5.09	1.20	Na_2	18	.76	3.07
N_2	170	7.35	1.09	K_2	12	.51	3.91

* For reference, see footnote 203, p. 624.

Nuclear physics may be divided into three fields: radioactivity, cosmic rays, and artificial disintegration. The third division—artificial disintegration—is today the most active single experimental (and theoretical) problem of the physicist. This new branch of physics has introduced a number of terms, some of which are defined in Table 716. There is hardly a major physical laboratory that does not have at least one of the devices listed in Table 718 for producing high-energy particles of one kind or another.

The study of nuclear physics started more than 50 years ago with the discovery of radioactivity. This was a study of natural disintegration up to about 1919 when Rutherford produced and studied artificial disintegration by bombarding nitrogen with swift α-particles from RaC′. However, he had to depend upon nature for the high-speed particles that he used. The value of the speed and energy of the α-rays from natural radioactive materials (Table 732) shows the nature of the particles then available. It was not until about 10 years later that a start was made on the development of the various devices for producing the regulated high-speed and high-energy particles listed in Table 718.

By bombarding different materials with one of the high-speed particles produced by various devices it has been found possible to produce one or more radioactive isotopes of each of the 92 elements and, in addition, to produce 6 elements beyond uranium—each with a number of isotopes.* There are now 9 or 10 known fundamental particles (Table 720), 5 or 6 of which are used in the bombardment of isotopes for the production of new reactions. Some examples of reactions thus brought about by the use of different ones of these high-speed particles together with the minimum energy of the particles necessary to produce the reactions are given in Table 726.

The relative masses of the isotopes vary from 1.0081374 for H^1 to about 242.14152 for Cm^{242}. The actual mass in grams for H^1 is 1.67339×10^{-24} grams, and thus the mass, in grams, of any atom may be determined from its atomic weight. The mass of the neutron is 1.67473×10^{-24} g. The radius of a nucleus, r, is given approximately by $1.4 \times 10^{-13} A^{1/3}$ cm, A being the atomic mass number. These values give for the density of the nucleus about 10^{14} g/cm^3 (see Table 872). The atomic weight, the magnetic moment, and the spin of a number of isotopes are given in Table 719.

* For reference, see footnote 199, p. 618.

TABLE 713.—MASS, ENERGY, AND VELOCITY RELATIONS FOR THE ELECTRON

Energy Mev	Electron mass * g	Electron mass * m_0	β	Velocity cm/sec
very small	9.1066×10^{-28}			
.018	9.42×10^{-28}	1.035	.25	$.75 \times 10^{10}$
.05	10.00×10^{-28}	1.10	.42	1.26×10^{10}
.1	10.90×10^{-28}	1.20	.548	1.65×10^{10}
.5	18.02×10^{-28}	1.98	.863	2.585×10^{10}
1	26.93×10^{-28}	2.96	.94	2.818×10^{10}
5	98.24×10^{-28}	10.8	.996	2.985×10^{10}
7	133.89×10^{-28}	14.7	.9976	2.990×10^{10}
10	187.38×10^{-28}	20.6	.9988	2.994×10^{10}
20	365.64×10^{-28}	40.1	.9992	near the velocity of light
100	1791.8×10^{-28}	196.6	.9998	near the velocity of light
1000	17839×10^{-28}	1960	.999999	" " " " "
10000	178160×10^{-28}	19580	.9999999	" " " " "

* See Tables 27, 28, and 714.

The neutrons and protons are held together in a nucleus by attractive forces (nuclear force) which have a range of only about 2×10^{-13} cm but are stronger than the electric Coulomb forces at distances less than this range. The energy which would be required to separate a nucleus into its constituent protons and neutrons (collectively denoted by nucleons) is called the nuclear binding energy. According to Einstein's mass-energy relation this binding energy is equal to c^2 times the difference between the nuclear mass and the mass in the free state of the nucleons contained in the nucleus. The binding energy per nucleon is of the order of magnitude of a few Mev, its actual amount depending on various factors. Starting at about 1 Mev for the deuteron (nucleus of heavy hydrogen) the binding energy per nucleon increases on the average with increasing atomic weight A reaching a maximum of about 10 Mev for A about 50; as A increases further the Coulomb repulsion between the constituent protons becomes more and more important and the binding energy per particle decreases again. In addition to this general trend there are individual variations in stability, a notable example being the great stability of the α-particle (nucleus of He^4) with a binding energy of more than 7 Mev per nucleon.

The theory of relativity shows that energy and mass are related and that mass may be converted into energy, giving an amount of energy in ergs = mc^2, where c is the velocity of light expressed in cm/sec and m the mass in grams. This theory also shows that the velocity of light is the upper limit for the velocity for any particle. It is to be noted that this theory tells us nothing as to the method of converting mass to energy!

The mass m of a fast-moving particle depends upon its velocity v, thus, m (at velocity v) $= \dfrac{m_o}{\sqrt{1-\beta^2}}$ where $\beta = v/c$. The kinetic energy of a particle moving with a velocity near that of light

$$KE \doteq m_o c^2 \left(\frac{1}{\sqrt{1-\beta^2}} - 1 \right)$$

or

$$m \doteq m_o + \frac{KE}{c^2}$$

Some calculated results of the above relations are shown in Table 713. This theory, together with nuclear physics, shows that each moving particle has a wavelength that is given thus: the wavelength, $\lambda = h/mv$ for a particle of mass m with a velocity v. (See Table 722.)

TABLE 715.—TWO INTERESTING RESULTS OF ARTIFICIAL DISINTEGRATION *

Different results from the same material	Different ways of producing the same materials
${}_{13}Al^{27} + {}_{2}He^{4} \rightarrow {}_{15}P^{30} + {}_{0}n^{1}$	${}_{12}Mg^{25} + {}_{2}He^{4} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}$
${}_{13}Al^{27} + {}_{2}He^{4} \rightarrow {}_{14}Si^{30} + {}_{1}H^{1}$	${}_{13}Al^{27} + {}_{1}H^{2} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}$
${}_{13}Al^{27} + {}_{1}H^{2} \rightarrow {}_{12}Mg^{25} + {}_{2}He^{4}$	${}_{13}Al^{27} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + h\nu$
${}_{13}Al^{27} + {}_{1}H^{2} \rightarrow {}_{13}Al^{24} + {}_{1}H^{2}$	${}_{14}Si^{28} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + {}_{1}H^{1}$
${}_{13}Al^{27} + {}_{1}H^{1} \rightarrow {}_{14}Si^{27} + {}_{0}n^{1}$	${}_{15}P^{31} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + {}_{2}He^{4}$
${}_{13}Al^{27} + {}_{0}n^{1} \rightarrow {}_{13}Al^{28} + h\nu$	
${}_{13}Al^{27} + {}_{0}n^{1} \rightarrow {}_{12}Mg^{27} + {}_{1}H^{1}$	
${}_{13}Al^{27} + {}_{0}n^{1} \rightarrow {}_{11}Na^{24} + {}_{2}He^{4}$	

* For reference, see footnote 224, p. 665.

TABLE 716.—DEFINITIONS OF SOME TERMS USED IN NUCLEAR PHYSICS

Alpha-particle.—A helium atom, stripped of its outer electrons, that is expelled from a radioactive material.

Artificial disintegration.—Breaking down of an atom by a controlled experiment.

Atom.—The smallest particle of any material substance that can exist as such.

Atomic bomb.—A bomb depending upon atomic energy. (U or Pu fission.)

Atomic energy.—Energy due to some breaking down of an atom.

Atomic mass unit, amu.—(1) The mass of a unit atomic weight (see Dalton). (2) An energy unit equal to the mass energy (mc^2) of a unit atomic mass (1/16 mass 0^{16}) $= 1.4921 \times 10^{-4}$ ergs $= 931.3$ Mev.

Atomic number.—The value of the positive charge of the atom. This determines the chemical properties.

Atomic weight.—Chemical: The relative weight of an atom taking the oxygen atom, found in nature, as having a weight of 16. Physical: The relative weight of an atom taking the oxygen isotope 16 as having a weight of 16. This makes the ratio of physical to chemical scale $= 1.000272 \pm .000005$.

Barn.—Unit area cross section of nucleus $= 10^{-24}$ cm^2.

Baryton.—See Table 720. See meson.

Beta-ray.—An electron expelled from a radioactive material.

Betatron.—See Table 718.

Binding energy.—The energy due to the packing of an element assuming that the element is made up of protons, electrons, and neutrons.

Bursts (cosmic ray).—A very great output of particles due to a cosmic-ray encounter with an atom.

Cathode rays.—Electrons that are driven from the negative electrode (the cathode) of a discharge tube. (See Table 758.)

Chain reaction.—A reaction in which one or more of the products of the reaction keeps it going, i.e., such as the fission of 92 U^{235}.

Compton effect.—The change in wavelength due to the scattering of radiation by a material substance.

Cosmic rays.—A radiation that falls upon the outer atmosphere, generally thought to come from outer space. (See page 710.)

Cosmos.—The entire universe.

Cross section, σ.—The proportionality constant between the beam intensity and the number of particles, considered, that strike a target. It has the dimension of an area. See Barn.

Cyclotron.—See Table 718.

De Broglie wavelength.—For a particle of mass m and velocity v, the De Broglie wavelength $\lambda = h/mv$.

Delta-rays.—Electrons that are emitted from certain materials due to α-ray bombardment.

Deuterium.—See deuteron.

Deuteron.—This isotope of hydrogen that has twice the atomic weight of the proton.

Electron ±.—The smallest particle of electricity that can exist.
- Positron, + electron. (Charge $+ 4.8025 \times 10^{-10}$ esu.)
- Negatron, − electron. (Charge $- 4.8025 \times 10^{-10}$ esu.)

Electron shell.—The shell that is used to describe the location of the outer electrons of an atom. These are K, L, M, N, O. (See Table 658.)

Energy units.—See Table 654. Erg:
- ev—The energy equal to that of an electron moving under an emf of 1 volt $= 1.602 \times 10^{-12}$ ergs.
- Mev—The energy equal to that of an electron moving under an emf of 10^6 volts.
- amu—The mass-energy of a unit mass of atomic weight $= 1.492 \times 10^{-3}$ ergs.
- Mass unit—Energy value of one gram $= 8.987 \times 10^{20}$ ergs.

Fission.—The breaking down of a heavy atom into two parts of about equal mass. (See page 706.)

Gamma-rays.—Radiation of very short wavelength that results from some radioactive breakdown. (See Tables 747-752.)

H-rays.—Hydrogen atoms that are emitted from certain materials due to α-ray bombardment.

h.—Planck constant. See quantum.

ℏ or ℏ $= h/2\pi$.

Isobar.—One of two or more nuclei that have the same weight but different atomic numbers.

(continued)

TABLE 716.—DEFINITIONS OF SOME TERMS USED IN NUCLEAR PHYSICS (concluded)

Isomer.—As applied to an isotope, it is one of two or more that have the same atomic number and weight but different radioactive properties.

Isotope.—One of two or more atomic nuclei that differ in weight but have the same atomic number, thus the same chemical characteristics.

Magnetic moment.—Nuclear unit of $= \frac{e\,h}{4\pi Mc} = 5.05 \times 10^{-24}$ erg/oersted where $M =$ mass of proton.

Magneton (Bohr).—The magnetic moment of the electron $= \frac{e\,h}{M_e 2\pi c} = 9.27 \times 10^{-21}$ erg/oersted.

Mass-energy ratio.—The relativistic relation between mass and energy, i.e., $E = mc^2$.

Mass, rest.—The mass of a particle M_o when at rest. See Table 714.

Mass-velocity ratio.—The variation of mass with velocity. $v =$ velocity, then $M_v = \frac{M_o}{\sqrt{1 - \frac{v^2}{c^2}}}$, $c =$ velocity of light. (See Table 714.)

Meson (Mesotron).—See Table 720.

Maximum velocity.—The highest velocity for any material substance, i.e., the velocity of light.

Mev.—A unit of energy; an electron moving under an emf of 10^6 v. (1.603×10^{-6} ergs). See energy units (Table 654).

Molecule.—An aggregate of two or more atoms of a substance that exists as a unit.

Momentum, angular of nucleus, measured in units $\hbar = \hbar = h/2\pi$.

Negatron.—See negative electron. (Sometimes spelled negaton.)

Neutrino.—See Table 720.

Neutron.—A neutral particle with a mass about the same as the proton. See Table 720.

Nucleon.—General name for protons and neutrons.

Nucleus.—The central part of an atom, i.e., what is left of an atom after all the outer electrons are stripped off.

Packing fraction.—Related to the mass lost when the atom was formed $= \frac{M_1 - A}{A}$ where M is the atomic weight of the atom and A the atomic number.

Photon.—The quantum of radiation $= h\nu$.

Proton.—The nucleus of the smallest unit mass, the smallest isotope of the hydrogen atom.

Positron.—See electron. (Sometimes written positon.)

Quantum $= h\nu$, a so-called atom of energy. $h =$ Planck constant. See photon.

Radioactivity.—Natural breakdown of atoms. (See page 672.)

Range of a particle.—The distance it can move through different media.

Rest mass.—The mass of any particle at rest.

Shower.—(Cosmic rays.) See Bursts. Showers may extend a very great distance, i.e., several hundred meters, and have about 10^{15} ev energy.

Spin.—Unit of nuclear spin $= \hbar = \hbar = h/2\pi$.

Synchrotron.—See Table 718.

Tritium.—See Triton.

Triton.—The isotpe of hydrogen that has three times the atomic weight of the proton.

Ultimate particle.—See Table 720.

Valence electrons.—The electrons of an atom, in the outer shell that determines its chemical valency.

Van de Graaff generator.—See Table 718.

Volt-electron, ve.—A unit of energy equal to that of an electron moving under an emf of 1 volt $= 1.602 \times 10^{-12}$ ergs.

X-rays.—A radiation of very short wavelengths that results when an electron is stopped (or started) very quickly, as when striking a metal target. (See page 692.)

Atomic number Z	Element	Isotopes (total number)	Naturally radioactive isotopes (number)	Artificially radioactive isotopes (number)	Relative abundance of natural isotopes
1	Hydrogen	3		1	H^1 †: $H^2 = 99.9844 : .0156$
2	Helium	3		1	$He^3 : He^4 = 1.3\times10^{-4} : 99.9999$
3	Lithium	3		1	$Li^6 : Li^7 = 7.39 : 92.61$
4	Beryllium	4		3	$Be^9 = 100.00$
5	Boron	3		1	$B^{10} : B^{11} = 18.83 : 81.17$
6	Carbon	5		3	$C^{12} : C^{13} = 98.9 : 1.1$
7	Nitrogen	5		3	$N^{14} : N^{15} = 99.62 : .38$
8	Oxygen	6		3	$O^{16} : O^{17} : O^{18} = 99.757 : .039 : .204$
9	Fluorine	4		3	$F^{19} = 100.00$
10	Neon	5		2	$Ne^{20} : Ne^{21} : Ne^{22} = 90.51 : .28 : 9.21$
11	Sodium	5		4	$Na^{23} = 100.00$
12	Magnesium	5		2	$Mg^{24} : Mg^{25} : Mg^{26} = 78.60 : 10.11 : 11.29$
13	Aluminum	5		4	$Al^{27} = 100.00$
14	Silicon	5		2	$Si^{28} : Si^{29} : Si^{30} = 92.28 : 4.67 : 3.05$
15	Phosphorus	5		4	$P^{31} = 100.00$
16	Sulfur	7		3	$S^{32} : S^{33} : S^{34} : S^{36} = 95.06 : .74 : 4.18 : .016$
17	Chlorine	7		5	$Cl^{35} : Cl^{37} = 75.4 : 24.6$
18	Argon	7		4	$A^{36} : A^{38} : A^{40} = .307 : .060 : 99.633$
19	Potassium	9	K^{40}	6	$K^{39} : K^{40} : K^{41} = 93.3 : .011 : 6.7$
20	Calcium	10		4	$Ca^{40} : Ca^{42} : Ca^{43} : Ca^{44} : Ca^{46} : Ca^{48} = 96.96 : .64 : .15 : 2.06 : .0033 : .19$
21	Scandium	10		9	$Sc^{45} = 100.00$
22	Titanium	9		4	$Ti^{46} : Ti^{47} : Ti^{48} : Ti^{49} : Ti^{50} = 7.95 : 7.75 : 73.45 : 5.51 : 5.34$
23	Vanadium	5		4	$V^{51} = 100.00$
24	Chromium	7		3	$Cr^{50} : Cr^{52} : Cr^{53} : Cr^{54} = 4.49 : 83.78 : 9.43 : 2.30$
25	Manganese	6		5	$Mn^{55} = 100.00$
26	Iron	8		4	$Fe^{54} : Fe^{56} : Fe^{57} : Fe^{58} = 5.81 : 91.64 : 2.21 : .34$
27	Cobalt	9		8	$Co^{59} = 100.00$
28	Nickel	10		5	$Ni^{58} : Ni^{60} : Ni^{61} : Ni^{62} : Ni^{64} = 67.76 : 26.16 : 1.25 : 3.66 : 1.16$
29	Copper	10		8	$Cu^{63} : Cu^{65} = 69.09 : 30.91$
30	Zinc	12		7	$Zn^{64} : Zn^{66} : Zn^{67} : Zn^{68} : Zn^{70} = 48.89 : 27.81 : 4.07 : 18.61 : .620$
31	Gallium	10		8	$Ga^{69} : Ga^{71} = 60.2 : 39.8$
32	Germanium	14		9	$Ge^{70} : Ge^{72} : Ge^{73} : Ge^{74} : Ge^{76} = 20.55 : 27.37 : 7.61 : 36.74 : 7.67$
33	Arsenic	9		8	$As^{75} = 100.00$
34	Selenium	16		10	$Se^{74 : 76 : 77 : 78 : 80 : 82} = .87 : 9.02 : 7.58 : 23.52 : 49.82 : 9.19$
35	Bromine	14		12	$Br^{79} : Br^{81} = 50.5 : 49.5$
36	Krypton	22		16	$Kr^{78 : 80 : 82 : 83 : 84 : 86} = .342 : 2.223 : 11.50 : 11.48 : 57.02 : 17.43$
37	Rubidium	16	Rb^{87}	14	$Rb^{85} : Rb^{87} = 72.8 : 27.2$
38	Strontium	14		10	$Sr^{84 : 86 : 87 : 88} = .56 : 9.86 : 7.02 : 82.56$
39	Yttrium	11		10	$Y^{89} = 100.00$
40	Zirconium	12		7	$Zr^{90 : 91 : 92 : 94 : 96} = 51.46 : 11.23 : 17.11 : 17.40 : 2.80$
41	Niobium	15		14	$Nb^{93} = 100.00$

* For reference, see footnote 199, p. 618.
† Numbers following symbol indicate names of isotopes of that element.

(continued)

Atomic number Z	Element	Isotopes (total number)	Naturally radioactive isotopes (number)	Artificially radioactive isotopes (number)	Relative abundance of natural isotopes
42	Molybdenum	12		5	$Mo^{92:94:95:96:97:98:100}$ = 15.86 : 9.12 : 15.7 : 16.5 : 9.45 : 23.75 : 9.62
43	Technetium	19		19	....
44	Ruthenium	13		6	$Ru^{96:98:99:100:101:102:104}$ = 5.68 : 2.22 : 12.81 : 12.70 : 16.98 : 31.34 : 18.27
45	Rhodium	11		10	Rh^{103} = 100.00
46	Palladium	12		6	$Pd^{102:104:105:106:108:110}$ = .8 : 9.3 : 22.6 : 27.2 : 26.8 : 13.5
47	Silver	14		12	Ag^{107} : Ag^{109} = 51.35 : 48.65
48	Cadmium	16		8	$Cd^{106:108:110:111:112:113:114:116}$ = 1.215 : .875 : 12.39 : 12.75 : 24.07 : 12.26 : 28.86 : 7.58
49	Indium	15		13	In^{113} : In^{115} = 4.23 : 95.77
50	Tin	27		17	$Sn^{112:114:115:116:117:118:119:120:122:124}$ = .90 : .61 : .35 : 14.07 : 7.54 : 23.98 : 8.62 : 33.03 : 4.78 : 6.11
51	Antimony	19		17	Sb^{121} : Sb^{123} = 57.25 : 42.75
52	Tellurium	26		18	$Te^{120:122:123:124:125:126:128:130}$ = .091 : 2.49 : .89 : 4.63 : 7.01 : 18.72 : 31.72 : 34.46
53	Iodine	17		16	I^{127} = 100.00
54	Xenon	22		13	$Xe^{124:126:128:129:130:131:132:134:136}$ = .094 : .088 : 1.90 : 26.23 : 4.07 : 21.17 : 26.96 : 10.54 : 8.95
55	Cesium	16		15	Cs^{133} = 100.00
56	Barium	19		12	$Ba^{130:132:134:135:136:137:138}$ = .101 : .097 : 2.42 : 6.59 : 7.81 : 11.32 : 71.66
57	Lanthanum	12		10	La^{138} : La^{139} = .089 : 99.911
58	Cerium	12		8	$Ce^{136:138:140:142}$ = .193 : .250 : 88.48 : 11.07
59	Praseodymium	7		6	Pr^{141} = 100.00
60	Neodymium	12	Nd^{150}	4	$Nd^{142:143:144:145:146:148:150}$ = 27.13 : 12.20 : 23.87 : 8.30 : 17.18 : 5.72 : 5.60
61	Promethium	8		8	....
62	Samarium	13	Sm^{152}	6	$Sm^{144:147:148:149:150:152:154}$ = 3.16 : 15.07 : 11.27 : 13.84 : 7.47 : 26.63 : 22.53
63	Europium	11		9	Eu^{151} : Eu^{153} = 47.77 : 52.23
64	Gadolinium	11		4	$Gd^{152:154:155:156:157:158:160}$ = .20 : 2.15 : 14.78 : 20.59 : 15.71 : 24.78 : 21.79
65	Terbium	7		6	Tb^{159} = 100.00
66	Dysprosium	10		3	$Dy^{156:158:160:161:162:163:164}$ = .0524 : .0902 : 2.294 : 18.88 : 25.53 : 24.97 : 28.18
67	Holmium	7		6	Ho^{165} = 100.00
68	Erbium	10		4	$Er^{162:164:166:167:168:170}$ = .1 : 1.5 : 32.9 : 24.4 : 26.9 : 14.2
69	Thulium	8		7	Tm^{169} = 100.00
70	Ytterbium	10		3	$Yb^{168:170:171:172:173:174:176}$ = .06 : 4.21 : 14.26 : 21.49 : 17.02 : 29.58 : 13.38
71	Lutetium	7	Lu^{176}	5	Lu^{175} : Lu^{176} = 97.5 : 2.5
72	Hafnium	9		3	$Hf^{174:176:177:178:179:180}$ = .18 : 5.30 : 18.47 : 27.10 : 13.84 : 35.11
73	Tantalum	9		8	Ta^{181} = 100.00

(*continued*)

Atomic number Z	Element	Isotopes (total number)	Naturally radioactive isotopes (number)	Artificially radioactive isotopes (number)	Relative abundance of natural isotopes
74	Tungsten	10		5	$W^{180}:^{182}:^{183}:^{184}:^{186}$ = .122 : 25.77 : 14.24 : 30.68 : 29.17
75	Rhenium	11	Re^{187}	9	$Re^{185}:Re^{187}$ = 37.07 : 62.93
76	Osmium	10		3	$Os^{184}:^{186}:^{187}:^{188}:^{189}:^{190}:^{192}$ = .018 : 1.59 : 1.64 : 13.3 : 16.1 : 26.4 : 41.0
77	Iridium	6		4	$Ir^{191}:Ir^{193}$ = 38.5 : 61.5
78	Platinum	11		6	$Pt^{192}:^{194}:^{195}:^{196}:^{198}$ = .78 : 32.8 : 33.7 : 25.4 : 7.23
79	Gold	13		12	Au^{197} = 100.00
80	Mercury	13		6	$Hg^{196}:^{198}:^{199}:^{200}:^{201}:^{202}:^{204}$ = .15 : 10.1 : 17.0 : 23.3 : 13.2 : 29.6 : 6.7
81	Thallium	15	Tl^{207}(AcC") Tl^{208}(ThC") Tl^{210}(RaC")	10	$Tl^{203}:Tl^{205}$ = 29.1 : 70.9
82	Lead	14	Pb^{210}(RaD) Pb^{211}(AcB) Pb^{212}(ThB) Pb^{214}(RaB)	6	$Pb^{204}:^{206}:^{207}:^{208}$ = 1.5 : 23.6 : 22.6 : 52.3
83	Bismuth	13	Bi^{210}(RaE) Bi^{211}(AcC) Bi^{212}(ThC) Bi^{214}(RaC)	8	Bi^{209} = 100.00

TABLE 718.—DEVICES FOR PRODUCING HIGH-ENERGY PARTICLES * † ‡

Impulse generator.

Transformer rectifier.—Max about 2 Mev.

Electrostatic generator, belt type.—Originated by R. J. Van de Graaff at M.I.T. Developed for use in nuclear physics at M.I.T. by Van de Graaff and at Carnegie Institution in Washington by M. A. Tuve. About 1-3 Mev. Performance improved at Wisconsin, by enclosing equipment in pressure chamber (with freon added to air), up to 4-5 Mev (under pressure) 100 lb/in.^{2} This device can accelerate any kind of charged particle. Under construction (M.I.T., Los Alamos) 12 Mev.

Cyclotron.—Originated at Berkeley by E. O. Lawrence. For accelerating any heavy charged particles (not electrons). 44 Mev alpha-particles, 22 Mev deuterons, 9.5 Mev protons.

Betatron.—Originated at Illinois by D. W. Kerst. For accelerating electrons. 300 Mev, Illinois; 100 Mev, General Electric Co.

Synchro-cyclotron.—Developed at Berkeley. 390 Mev alpha-particles, 400 Mev protons, 195 Mev deuterons.

Synchrotron (electron).—Berkeley, 335 Mev electrons; General Electric Co., Cornell, Michigan, Perdue, Berkeley, about 300 Mev; Harvard, 125 Mev.

Linear accelerator.—Berkeley, 32 Mev protons; Stanford, 5.7 Mev electrons (under construction, 1000 Mev); M.I.T., 20-30 Mev electrons.

Proton synchrotron.—Berkeley, 3-6 Mev (under construction); Brookhaven, 3 Mev (under construction).

Some of the smaller cyclotrons at various laboratories have been converted to F. M. cyclotrons. There are now in use, or under construction in this country, over 100 devices for producing particles of over 1 Mev energy.

* This list was prepared by R. G. Herb, University of Wisconsin, and W. W. Brobeck, University of California. See Brookhaven National Laboratory Publication BNL-L-101, Particle accelerators, 1948.

† High-speed neutrons cannot, of course, be produced directly by any of these devices. Neutrons are produced by bombarding certain materials with one of the high-speed particles produced by these devices. If beryllium, boron, or lithium are bombarded by α-particles neutrons are produced thus:

$${}_4Be^9 + 2\,He^4 \rightarrow {}_6C^{12} + {}_0n^1$$
$${}_5B^{11} + 2\,He^4 \rightarrow {}_7N^{14} + {}_0n^1$$
$${}_1H^2 + h\nu \rightarrow {}_1H^1 + {}_0n^1$$

‡ Machines up to about 6 Mev now produced commercially.

TABLE 719.—ATOMIC WEIGHTS AND OTHER CHARACTERISTICS OF ISOTOPES [223]

Part 1.—The neutron to fluorine [a]

Z	Element	Isotope	Atomic mass	Spin [g]	Magnetic moment [g]	Quadrupole moment ** (10^{-24} cm^2) [g]
0	n	1	1.008977	1/2	−1.91280 ±9	......
1	H	1	1.0081374	1/2	+2.79254 ±0	......
		2	2.014719	1	+ .857352±9	+.002766±25
		3	3.016971	1/2	+2.978624±28	......
2	He	3	3.016951	1/2	(−)2.127414±3	......
		4	4.003910	0	......	......
3	Li	6	6.017043	1	+ .82189 ±4	$\|<9\times10^{-4}\|$
		7	7.018242	3/2	+3.25586 ±11	+(.02)±2
		8	8.025031	...	......	......
4	Be	7	7.019169	...	......	......
		8	8.007916	...	......	......
		9	9.015098	3/2	(−).7849×I*±5	......
		10	10.016774	...	......	......
5	B	9	9.016246	...	......	......
		10	10.016173	3	+1.8004 ±7	+.06±4
		11	......	3/2	+2.68858 ±28	+.03±2
6	C	12	12.003900	0	......	......
		13	13.007554	1/2	+ .70225 ±14	......
		14	14.007733	0	......	......
7	N	13	13.009941	...	......	......
		14	14.007565	1	+ .40365 ±3	+.02
		15	......	1/2	− .28299 ±3	......
8	O	16	......	0	......	......
		17	17.004515	(1/2)	......	$\|<.02\|$
		18	......	(0)	......	$\|<4\times10^{-8}\|$
9	F	19	19.004486	1/2	+2.6285 ±7	......

[223] References and other footnotes at end of table, p. 663. Superior letters ([a], [b], etc) refer to authorities cited in footnote.

Part 2.—Fluorine to thallium [b]

Z	Element	Isotope	Atomic mass	Spin [g]	Magnetic moment [g]	Quadrupole moment † [g]
10	Ne	18	(18.0114)	...	.....	....
		19	19.00781	...	.....	....
		20	19.99877	(0)	~0	....
		21	20.99963	3/2 (>3/2?)	<0	....
		22	21.99844	(0)	~0	....
		23	23.0013	...	.....	....
11	Na	21	21.0035	...	.....	....
		22	21.9999	3	+1.74582	....
		23	22.99618	3/2	+2.21711±25	≠0
		24	24.9975	...	.....	....
		25	24.9967	...	.....	....
12	Mg	22	22.0062	...	.....	....
		23	23.0002	...	.....	....
		24	23.9925	(0)	~0	....
		25	24.9938	(5/2)	− .96±7	....
		26	25.9898	(0)	~0	....
		27	26.9928	...	.....	....
13	Al	25	24.9981	...	.....	....
		26	25.9929	...	.....	....
		27	26.9899	5/2	+3.6408±4	+ .156±3
		28	27.9903	...	.....	....
		29	28.9893	...	.....	....
		30	(29.9954)	...	.....	....
14	Si	27	26.9949	...	.....	....
		28	27.9866	(0)	.....	~0
		29	28.9866	1/2	.....	~0

(continued)

TABLE 719.—ATOMIC WEIGHTS AND OTHER CHARACTERISTICS OF ISOTOPES (continued)

Z	Element	Isotope	Atomic mass	Spin [g]	Magnetic moment [g]	Quadrupole moment † [g]
		30	29.9832	(0)	.....	~0
		31	30.9862	...	.....	....
		32	(31.9849)	...	.....	....
15	P	29	28.9919	...	.....	....
		30	29.9873	...	.....	....
		31	30.9843	1/2	+1.13165±20	....
		32	31.9827	...	.....	....
		33	32.9826	...	.....	....
		34	33.9826	...	.....	....
16	S	31	30.9899	...	.....	....
		32	31.98089	0	.....	....
		33	32.9800	3/2	(+)(.3±.2, .9)	— .08
		34	33.97710	(0)	.....	$\lvert<2\times10^{-3}\rvert$
		35	34.9788	3/2	.....	+ .06
		36	35.978	(0)	.....	< .01
		37	36.982	...	.....	....
17	Cl	33	32.9860	...	.....	....
		34	33.9801	...	.....	....
		35	34.97867	3/2	+ .82191±22	— .0795±5
		36	35.9788	2	.....	— .0172±4
		37	36.97750	3/2	+ .68414±24	— .0621±5
		38	37.981	...	.....	....
		39	(38.9794)	...	.....	....
18	A	35	34.9850	...	.....	....
		36	35.98780	(0)	~0	....
		37	36.9777	...	.....	....
		38	38.974	...	.....	....
		39	(38.9755)	...	.....	....
		40	39.9756	(0)	~0	....
		41	40.9770	...	.....	....
19	K	37	(36.9830)	...	.....	....
		38	37.9795	...	.....	....
		39	38.9747	3/2	.391±1	....
		40 ‡	39.9760	4	—1.291±4	....
		41	40.974	3/2	— .215±1	....
20	Ca	40	39.97530	(0)	~0	....
		42	41.9711	...	.....	....
		43	42.9723	...	.....	....
21	Sc	45	44.9669	7/2	—4.7556±10	....
22	Ti	46	45.9661	...	.....	....
		47	46.9647	...	.....	....
		48	47.9631	...	.....	....
		49	48.9646	...	.....	....
		50	49.9621	...	.....	....
		51	50.5887	...	.....	....
23	V	51	50.9577	7/2	(+)5.1478±5	....
24	Cr	51	50.958	...	.....	....
		52	51.956	...	.....	....
		53	52.956	...	.....	....
25	Mn	55	54.957	5/2	+3.4677±4	....
26	Fe	54	53.957	...	.....	....
		56	55.9568	...	.....	....
		57	56.957	...	~0	....
27	Co	59	58.94	7/2	+4.6482	....
28	Ni	58	57.9594	...	.....	....
		60	59.9495	...	.....	....
		61	60.9537	...	~0	....
		62	61.9493	...	.....	....
		64	63.9471	...	.....	....
29	Cu	63	62.957	3/2	+2.22617±36	— .26±10
		65	64.955	3/2	+2.3845±4	— .14±10
30	Zn	64	63.955	(0)	~0	....

(continued)

TABLE 719.—ATOMIC WEIGHTS AND OTHER CHARACTERISTICS OF ISOTOPES (continued)

Z	Element	Isotope	Atomic mass	Spin g	Magnetic moment g	Quadrupole moment † g
		66	65.954	(0)	~0	....
		67	66.954	5/2	+ .9	....
		68	67.955	(0)	~0	....
		70	69.954	...	.....	....
31	Ga	69	68.952	3/2	+2.0167±11	+ .2318±23
		71	70.952	3/2	+2.5614±10	+ .1461±15
32	Ge	70	.....	(0)	.....	$\|<7\times10^{-3}\|$
		72	.....	(0)	.....	$\|<7\times10^{-3}\|$
		73	.....	9/2,> 9/2	.....	− .21±10
		74	.....	(0)	.....	$\|<7\times10^{-3}\|$
		76	.....	(0)	.....	$\|<7\times10^{-3}\|$
33	As	75	74.91	3/2	+1.4	+ .3±2
34	Se	74	.....	(0)	.....	....
		76	.....	(0)	~0	$\|<2\times10^{-3}\|$
		77	.....	7/2±1,(1/2)	.....	$\|<2\times10^{-3}\|$
		78	.....	(0)	~0	$\|<2\times10^{-3}\|$
		80	.....	0	.....	$\|<2\times10^{-3}\|$
		82	.....	(0)	~0	....
35	Br	79	.....	3/2	+2.10576±37	+ .26±8
		81	.....	3/2	+2.2696±5	+ .21+7
36	Kr	82	.....	(0)	~0	....
		83	.....	9/2	− .9704	+ .15
		84	.....	(0)	~0	....
		86	.....	(0)	~0	....
37	Rb	85	.....	5/2	+1.3532±4	....
		87‡	.....	3/2	+2.7501±5	....
38	Sr	86	.....	(0)	.....	....
		87	.....	9/2	−1.1	....
		88	.....	(0)	~0	....
39	Y	89	.....	1/2	− .14	....
40	Zr	91	.....	5/2	.....	....
41	Nb	93	.....	9/2	+6.165±32	~0
42	Mo	92	.....	(0)	~0	....
		94	93.945	(0)	~0	....
		95	94.946	(5/2)	.....	....
		96	95.944	(0)	~0	....
		97	96.945	(5/2)	.....	....
		98	97.943	(0)	~0	....
43	Tc					
44	Ru	96	95.945	...	.....	....
		98	97.943	...	.....	....
		99	98.944	...	.....	....
		100	99.942	...	.....	....
		101	100.946	...	.....	....
		102	101.941	...	.....	....
45	Rh	102	102.941	...	.....	....
		103	.....	>(1/2?)	<0	....
46	Pd	102	101.941	...	.....	....
		104	103.941	...	.....	....
		105	104.942	...	.....	....
		106	105.941	...	.....	....
		108	107.941	...	.....	....
		110	109.941	...	.....	....
47	Ag	107	106.945	1/2	− .086	....
		109	108.944	1/2	− .160	....
48	Cd	110	.....	(0)	~0	....
		111	.....	1/2	− .59492±8	....
		112	.....	(0)	~0	....
		113	.....	1/2	− .62238±8	....
		114	.....	(0)	~0	....
		116	.....	(0)	~0	....
49	In	113	.....	9/2	+5.486±3	1.144
		115	.....	9/2	+5.500±3	1.161
50	Sn	115	114.940	1/2	− .9177±2	....

(continued)

TABLE 719.—ATOMIC WEIGHTS AND OTHER CHARACTERISTICS OF ISOTOPES (continued)

Z	Element	Isotope	Atomic mass	Spin ᵍ	Magnetic moment ᵍ	Quadrupole moment † ᵍ
		116	115.939	(0)	~0	....
		117	116.937	1/2	− .9997±2	....
		118	117.937	(0)	~0	....
		119	118.938	1/2	−1.0459±2	....
		120	119.937	(0)	~0	....
		122	121.945	...	.....	....
		124	123.944	...	.....	....
51	Sb	121	.....	5/2	+3.3591±5	− .3±2
		123	.....	7/2	+2.5465±5	−1.2±2
52	Te	123	.....	1/2	.....	....
		125	.....	1/2	.....	....
		126	.....	(0)	~0	....
		128	.....	(0)	~0	....
		130	.....	(0)	~0	....
53	I	127	126.92	5/2	+2.8086±8	− .59±20
		129	.....	7/2	(+)2.74±14h	− .43±15
54	Xe	129	.....	1/2	− .7766±1	....
		131	.....	3/2	+ .7	|< .1|
		132	.....	(0)	~0	....
		134	.....	(0)	~0	....
		136	.....	(0)	~0	....
55	Cs	133	132 91	7/2	+2.5771±9	|⩽ .3|
		135	.....	7/2	+2.7271±33	....
		137	.....	7/2	+2.8397±30	....
56	Ba	134	.....	(0)	~0	....
		135	.....	3/2	+ .8346±25	....
		136	.....	(0)	~0	....
		137	.....	3/2	+ .9351±27	....
		138	.....	(0)	~0	....
57	La	139	138.953	7/2	+2.7769±28	≠0
58	Ce					
59	Pr	141	140.95	5/2	+4.5938	....
60	Nd	145	144.962	...	.....	....
		146	145.962	...	.....	....
		148	147.962	...	.....	....
		150 ‡	149.964	...	.....	....
61	Pr					
62	Sm	147	.....	(>1/2)	.....	....
		149	.....	(>1/2)	.....	....
63	Eu	151	.....	5/2	+3.4	+1.2
		153	.....	5/2	+1.5	+2.5
64	Gd	154	153.971	...	.....	....
		155	154.971	...	.....	....
		156	155.972	...	.....	....
		157	156.973	...	.....	....
		158	157.973	...	.....	....
		160	159.974	...	.....	....
65	Tb	159	159.2	3/2	.....	....
66	Dy					
67	Ho	165	164.94	7/2	.....	....
68	Er					
69	Tm	169	169.4	1/2	.....	....
70	Yb	171	.....	1/2	+ .45	....
		173	.....	5/2	− .65	+3.9±4
71	Lu	175	.....	7/2	+2.6	+5.9
		176 ‡	.....	⩾7	+3.8	+7±1
72	Hf	177	.....	(1/2, 3/2)	.....	....
		178	.....	(0)	~0	....
		179	.....	(1/2, 3/2)	.....	....
		180	.....	(0)	~0	....
73	Ta	181	180.88	7/2	+2.1	+6
74	W	182	.....	(0)	.....	....
		183	.....	1/2	.....	....

(continued)

TABLE 719.—ATOMIC WEIGHTS AND OTHER CHARACTERISTICS OF ISOTOPES (continued)

Z	Element	Isotope	Atomic mass	Spin [g]	Magnetic moment [g]	Quadrupole moment † [g]
		184	.....	(0)	.....	....
		186	.....	(0)	.....	....
75	Re	185	.....	5/2	+3.3	(+2.8)
		186	.....	5/2	.....	....
		187‡	.....	5/2	+3.3	+2.6
76	Os	189	189.04	1/2	.....	....
		190	190.03	...	.....	....
		192	192.04	...	.....	....
77	Ir	191	191.04	(>1/2)	.....	....
		193	193.04	(3/2)	.....	....
78	Pt	194	194.039	(0)	~0	....
		195	195.039	1/2	— .60592±8	....
		196	196.039	(0)	~0	....
		198	198.05	...	.....	....
79	Au	197	197.04	3/2	+ .20	....
80	Hg	198	.....	(0)	~0	....
		199	.....	1/2	.50413±13	....
		200	.....	(0)	~0	....
		201	.....	3/2	+ .5590±1	+ .5
		202	.....	(0)	~0	....
		204	.....	(0)	~0	....

Part 3.—Thallium to curium (1950) §

The masses have been derived as outlined by Stern.[d] The mass of the α-particle is assumed to be 4.00389 mass units and the mass of Pb^{206} is 206.04519 mass units. The masses of thallium, lead, and bismuth isotopes are determined from the following neutron binding energies (in Mev):

Tl^{204} ..... 6.52±0.03	Pb^{206} .... 8.15 ±0.05	Pb^{209} .... 3.87±0.05
Tl^{206} ..... 7.48±0.15	Pb^{207} .... 6.719±0.016	Bi^{209} ..... 7.44±0.05
Tl^{208} ..... 6.30±0.03	Pb^{208} .... 7.38 ±0.008	Bi^{210} ..... 4.62±0.015

The decay energies are taken from a paper by Wapstra[e] except for two corrections. The decay energy of Ra^{223} is taken to be 170 Kev higher than that given by Wapstra as was assumed by Stern. Also, it is assumed that the decay of Ra^{225} is 700 Kev, and the masses based on this assumption are in parentheses. A few other disintegration energies not given by Wapstra were taken from Perlman, et al.[f]

Z		A	M-A	Spin [g]	Nuclear magnetons [g]	Z		A	M-A	Spin [g]	Nuclear magnetons [g]
81	Tl	203	.04187	1/2	+1.6114±3	83	Bi	211	.05968‡	...	....
		204	.04385	...	....			212	.06394‡	...	....
		205	.04480	1/2	+1.6272±3			213	.06720	...	....
		206	.04702	...	....			214	.07252‡	...	....
		207	.04854‡	...	....	84	Po	208	.05244	...	....
		208	.05339‡	...	....			209	.05425	...	....
		209	.05690	...	....			210	.05488‡	...	....
		210	.06261‡	...	....			211	.05899‡	...	....
82	Pb	204	.04291	(0)	~0			212	.06152‡	...	....
		205	.04496	...	....			213	.06586	...	....
		206	.04519	(0)	~0			214	.06848‡	...	....
		207	.04696	1/2	+ .5894±1			215	.07312‡	...	....
		208	.04802	(0)	~0			216	.07587‡	...	....
		209	.05285	...	....			218	.08398‡	...	....
		210	.05619‡	...	....	85	At	212	.06138	...	....
		211	.06117‡	...	....			214	.06964	...	....
		212	.06457‡	...	....			215	.07232‡	...	....
		214	.07353‡	...	....			216	.07636‡	...	....
83	Bi	208	.05114	...	....			217	.07877	...	....
		209**	.05213	9/2	+4.0801±5			218	.08365‡	...	....
		210	.05614	...	....	86	Rn	216	.07424	...	....

(continued)

TABLE 719.—ATOMIC WEIGHTS AND OTHER CHARACTERISTICS OF ISOTOPES (concluded)

Z		A	M-A	Spin [g]	Nuclear magnetons [g]
86	Rn	216	.07424	...	....
		217	.07822	...	....
		218	.08015	...	....
		219	.08447‡	...	....
		220	.08663‡	...	....
		222	.09387‡	...	....
87	Fr	218	.08211	...	....
		219	.08420	...	....
		220	.08756	...	....
		221	.08955	...	....
		223	.09608‡	...	....
88	Ra	220	.08632	...	....
		221	.08944	...	....
		222	.09116	...	....
		223	.09479‡	...	....
		224	.09673‡	...	....
		225	(.10053)	...	....
		226	.10300‡	...	....
		228	.10928‡	...	....
89	Ac	222	.09361	...	....
		223	.09535	...	....
		224	.09819	...	....
		225	.09978	...	....
		227	.10539‡	...	....
		228	.10926‡	...	....
90	Th	224	.09808	...	....
		225	.10051	...	....
		226	.10193	...	....
		227	.10528‡	...	....
		228	.10655‡	...	....
		229	(.10992)	...	....
		230	.11201‡	...	....
		231	.11505	...	....
		232	.11751‡	...	....
		233	(.12095)	...	....
		234	.12381‡	...	....

Z		A	M-A	Spin [g]	Nuclear magnetons [g]
91	Pa	226	.10494	...	....
		227	.10631	...	....
		228	.10874	...	....
		229	.10988	...	....
		231‡	.11479	3/2	....
		232	.11767	...	....
		233	(.11966)	...	....
		234‡	.12317	...	....
92	U	228	.10931	...	....
		229	.11142	...	....
		230	.11222	...	....
		232	.11624	...	....
		233	(.11908)	...	....
		234‡	.12110	...	....
		235‡	.12392	(5/2,7/2)	....
		237	(.12927)	...	....
		238‡	.13226	...	....
		239	.13606	...	....
93	Np	231	.11696	...	....
		233	.11985	...	....
		235	.12421	...	....
		237	(.12874)	5/2	....
		238	.13248	...	....
		239	.13470	...	....
94	Pu	232	.12039	...	....
		234	.12283	...	....
		236	.12641	...	....
		238	.13099	...	....
		239	.13343	...	....
		241	(.13864)	...	....
95	Am	239	.13440	...	....
		241	(.13862)	....	....
		242	.14206	...	....
96	Cm	238	.13382	...	....
		240	.13713	...	....
		242	.14152	...	....

[223] References: a, Tollestrup, Fowler, and Lauritsen, Phys. Rev., vol. 78, p. 372, 1950. b, Bethe, H. A. Elementary nuclear theory, John Wiley & Sons, Inc., 1947; Rasetti, F., Elements of nuclear physics. Prentice-Hall, Inc., 1936; Poss, H. L., Phys. Rev., vol. 75, p. 600, 1949. c, Harvey, J. A., Bull. Amer. Phys. Soc., vol. 25, p. U4, 1950. d, Stern, M. O., Rev. Mod. Phys., April 1949. e, Wapstra, A. H., Physica, vol. 16, p. 33, 1950. f, Perlman, I., Ghiorso, A., and Seaborg, G. T., Phys. Rev., vol. 77, p. 26, 1950; Kinsey, B. B., et al., Phys. Rev., vol. 78, p. 77, 1950; also private communications; Hanson, et al., Phys. Rev., vol. 76, p. 578, 1949. g, Ramsey, Norman, Experimental nuclear physics (forthcoming), John Wiley & Sons, Inc.

Note added in proof, 1953.—Because of recent mass measurements, the mass of Pb^{206} should be taken as 206.03859. All mass values should be lowered 0.00660 mass units. See Stone, Martin O., Rep. Univ. California Radiation Lab., April 1952.

* I = spin. **Quadrupole moment = —0.4. † (10^{-24} cm^2). ‡ Radioactive series. § Prepared by J. A. Harvey, Massachusetts Institute of Technology (see footnote 223, above, reference c).

TABLE 720.—SOME FUNDAMENTAL PARTICLES OF MODERN PHYSICS *

Electron.—A negatively charged stable particle. The negative charge surrounding the nuclei in all neutral atoms consists entirely of electrons.

Positron.—A particle of the same mass, M_e, as an ordinary electron. It has a positive electrical charge of exactly the same amount as that of an ordinary electron (which is sometimes called negatron). Positrons are created either by the radioactive decay of certain unstable nuclei or, together with a negatron, in a collision between an energetic (more than one Mev) photon and an electrically charged particle (or another photon). A positron does not decay spontaneously but on passing through matter it sooner or later collides with an ordinary electron and in this collision the positron-negatron pair is annihilated. The rest energy of the two particles, which is given by Einstein's relation $E = mc^2$ and amounts to 1.0216 Mev altogether, is converted into electromagnetic radiation in the form of one or more photons.

Proton.—This is the nucleus of an ordinary hydrogen atom. It has a positive charge of exactly the same amount as that of an electron and a mass M_P which is 1837 times larger than M_e and is a stable particle. No experimental evidence of negative protons has been found as yet.

Neutron.—An electrically neutral particle of mass only very slightly greater (by a factor of 1.0013) than that of the proton. Neutrons are produced in various nuclear reactions. In the free state a neutron is unstable, decaying spontaneously with a half-life of about 10 minutes into a proton, and electron and (presumably) a neutrino. When passing through matter a neutron can also be captured by atomic nuclei.

Deuteron.†—Nucleus of H^2.

α-particle.†—Nucleus of He^4.

Meson.—Two types of particles of mass intermediate between that of the electron and proton have been discovered in cosmic radiation and in the laboratory. The one particle with mass about 215 m_e is called μ-meson, the other with about 280 m_e π-meson. Mesons of both positive and negative charge have been found and there is now reasonably good evidence for neutral mesons. Both types of mesons decay spontaneously. Some evidence exists for a meson of mass about 1000 m_e.

Neutrino.—An electrically neutral particle of mass very much smaller than that of the electron and possibly zero. There exists as yet no direct experimental evidence for the existence of neutrinos since they interact extremely weakly with matter (e.g., only a small fraction of neutrinos passing through a body of solar mass would be absorbed). There exist, however, extensive measurements on the momentum and energy of the parent and daughter nucleus and of the emitted β-particle in a β-decay process. These measurements show that energy and momentum (as well as spin and charge) in such a process can be conserved if, and only if, a light neutral particle such as the neutrino is emitted together with the β-particle.

Photon.—A photon (or γ-ray) is a quantum of electromagnetic radiation which has zero rest mass and an energy of h (Planck's constant) times the frequency of the radiation. Photons are generated in collisions between nuclei or electrons and in any other process in which an electrically charged particle changes its momentum. Conversely photons can be absorbed (i.e., annihilated) by any charged particle.

There have been some reports of other particles than those listed above.

	Mass (g)	Spin ($\hbar$)	Charge (esu)	Magnetic moment (nuclear magnetons)
Electron, negative (negatron) e^-	9.1066×10^{-28}	1/2	-4.8025×10^{-10}	....
Electron, positive (positron) e^+	9.1066×10^{-28}	...	$+4.8025 \times 10^{-10}$	....
Proton, p	1.6725×10^{-24}	1/2	$+4.8025 \times 10^{-10}$	2.7926
Neutron, n	1.6747×10^{-24}	1/2	none	−1.9135
Deuteron, d	3.34486×10^{-24}	1	$+4.8025 \times 10^{-10}$	.8565
α-particle	6.6442×10^{-24}	none	$+9.6050 \times 10^{-10}$	0

Name	Symbol	Rest mass (electron mass)	Spin ($\hbar$)	Charge esu	Mean life (sec)	Mode of decay	Mode of capture
μ^+—meson	μ^+	209	1/2	$+4.8025 \times 10^{-10}$	2.15×10^{-6}	$\mu^+ \rightarrow e^+ + 2\nu$	......
μ^-—meson	μ^-	209	1/2	-4.8025×10^{-10}	2.15×10^{-6}	$\mu^- \rightarrow e^- + 2\nu$	$\mu^- + p \rightarrow n + \nu$
π^+—meson	π^+	275	0 or 1	$+4.8025 \times 10^{-10}$	2.96×10^{-8}	$\pi^+ \rightarrow \mu^+ + \nu$	......
π^-—meson	π^-	275	0 or 1	-4.8025×10^{-10}	2.96×10^{-8}	$\pi^- \rightarrow \mu^- + \nu$	$\pi^- + p \rightarrow n$
π°—meson	π°	265	0	0	$<5 \times 10^{-14}$	$\pi^\circ \rightarrow 2\gamma$	......
photon ‡	γ	0	integral	0	......	......	......
neutrino	ν	<.005	1/2	0	......	......	......

* Prepared by E. E. Salpeter and W. K. H. Wolfgang. † Not fundamental. ‡ The photon (radiation quantum), $h\nu$: γ; value ($\lambda = .6\mu$) $= 3.310 \times 10^{-12}$ ergs.

If a neutron or proton (or a light nucleus) approaches a nucleus at a distance less than the range of nuclear forces it may interact with the nucleus in various ways. If the kinetic energy of the incident particle is not more than a few Mev it is usually first captured by the nucleus, forming a compound nucleus. This compound nucleus is in an excited state (having an excess energy due to the extra binding energy of the additional particle as well as its initial kinetic energy) and in a short time either (a) makes a transition to its ground-state releasing the excess energy in the form of photons, (b) re-emits the incident particle returning to the ground-state or an excited state of the original nucleus (elastic or inelastic scattering), or (c) emits some other particle (neutron, proton, deuteron or α-particle usually).

A neutron does not experience any Coulomb repulsion on approaching a nucleus and hence can react with a nucleus however low its kinetic energy. However, if the incident particle is a proton or deuteron (and even more so if it is an α-particle) it has to overcome an energy barrier due to the electrostatic Coulomb repulsion of the nucleus. For a proton incident on a light nucleus (small Z) this barrier is a few hundred Kev and increases almost proportionately with Z. If the kinetic energy of an incident proton is larger than this barrier it can react about as easily as a neutron. If its energy is lower it can still react due to a purely quantum phenomenon called barrier penetration, but the probability of such a reaction's taking place decreases extremely rapidly as the kinetic energy is decreased relative to the barrier.

Nuclear processes in stars.—There are no free neutrons in stellar interiors (any produced are quickly captured by nuclei), but there is a large proportion of ionized hydrogen and helium (protons and α-particles). At a stellar temperature of, say, 2×10^7 °C the mean thermal kinetic energy of a proton is less than 2 Kev which is appreciably less than the Coulomb barrier of even light nuclei. This means that the reaction rate for protons being captured by a nucleus in stars is in general low and decreases very rapidly with increasing charge Z of the nucleus, reactions with nuclei of Z greater than 8 (oxygen) being negligible for practical purposes in stars.

Two different cycles (the carbon and proton-proton cycle respectively) are of importance in connection with nuclear energy production in stars. In each of these cycles four protons are captured, separately, by certain light nuclei, two of the compound nuclei thus formed, beta-decay, emitting a positron and neutrino. Each positron subsequently finds an electron and the pair is annihilated, accompanied by the emission of photons. The net effect in each of these cycles is that four protons and two electrons have disappeared, an α-particle has appeared in their place and two neutrinos have been emitted. The energy generated is the total binding energy of an α-particle plus the rest-energy of two electrons which amounts to about 29 Mev per cycle. About 7 percent of this energy is lost in the form of kinetic energy of neutrinos, which escape without interacting any further. The remaining 93 percent of the energy is converted into thermal kinetic energy and radiation. The photons created in the original nuclear processes are absorbed after traversing only a short distance in the star and a larger number of photons of lower frequency are emitted, etc., so that the radiation finally leaving the star has approximately the spectral distribution of black-body radiation. The rate at which these cycles take place and hence the rate of energy-production increases very much for even a small increase in the stellar temperature.

* Prepared by E. E. Salpeter.

TABLE 722.—THE THEORETICAL DE BROGLIE WAVELENGTHS ASSOCIATED WITH VARIOUS PARTICLES AND BODIES OF GROSS MATTER [224]

$(\lambda = h/(m v))$

Particle	Mass in g	Velocity cm/sec	Energy ergs	De Broglie wavelengths A
Slow electron	9.1×10^{-28}	1	4.5×10^{-28}	7.3×10^{8}
1-volt-electron	9.1×10^{-28}	5.9×10^{7}	1.6×10^{-12}	12.
100-volt-electron	9.1×10^{-28}	5.9×10^{8}	1.6×10^{-10}	1.2
10,000-volt-electron	9.2×10^{-28}	5.0×10^{9}	1.6×10^{-8}	.12
H_2 molecule at 200°C	3.3×10^{-24}	2.4×10^{5}	9.5×10^{-14}	.82
100-volt proton	1.67×10^{-24}	1.38×10^{7}	1.6×10^{-9}	.029
100-volt α-particle	5.6×10^{-24}	6.94×10^{6}	1.6×10^{-12}	.0143
α-particle from radium	6.6×10^{-24}	2.1×10^{9}	1.45×10^{-5}	6.6×10^{-5}
22 rifle bullet	1.9	32,000	9.5×10^{8}	1.1×10^{-23}
Golf ball	45	3,000	2.0×10^{8}	4.9×10^{-24}
Baseball	140	2,500	4.4×10^{8}	1.9×10^{-24}

[224] Stranathan, J. D., The particles of modern physics, Blakiston Co., 1942. Used by permission of the publishers.

TABLE 723.—RATES OF NUCLEAR REACTIONS IN STARS AND OF ENERGY PRODUCTION AT VARIOUS TEMPERATURES * [225]

Reaction / Temperature:	10×10^6	15×10^6	17.5×10^6	20×10^6	25×10^6	30×10^6
$H^1+H^1 \rightarrow H^2+e^+$	6×10^{10} yr	1.2×10^{10} yr	6×10^9 yr	4×10^9 yr	2×10^9 yr	1×10^9 yr
$H^2+H^1 \rightarrow He^3+\gamma$	15 sec	2 sec	1 sec	.5 sec	.2 sec	.1 sec
$He^3+He^4 \rightarrow Be^7+\gamma$	2×10^{12} yr	1.5×10^9 yr	1.2×10^8 yr	1.5×10^7 yr	5×10^5 yr	5×10^4 yr
$Be^7 \rightarrow Li^7-e^-$	70 days	70 days	70 days	70 days	70 days	70 days
$Li^7+H^1 \rightarrow He^4+He^4$	10 hr	50 min	50 sec	15 sec	2 sec	.4 sec
Mean life of hydrogen	6×10^{10} yr	3×10^9 yr	1.5×10^9 yr	1×10^9 yr	5×10^8 yr	3×10^8 yr
Energy production in ergs/(g sec)	.75	40	80	120	250	400

Part 2.—Carbon cycle, temperatures in °K

Reaction / Temperature:	10×10^6	15×10^6	17.5×10^6	20×10^6	25×10^6	30×10^6
$C^{12}+H^1 \rightarrow N^{13}+\gamma$	2×10^9 yr	1×10^6 yr	6×10^4 yr	7×10^3 yr	200 yr	15 yr
$N^{13} \rightarrow C^{13}+e^+$	10 min	10 min	10 min	10 min	10 min	10 min
$C^{13}+H^1 \rightarrow N^{14}+\gamma$	$\lesssim 5\times10^8$ yr	$\lesssim 2.5\times10^5$ yr	$\lesssim 1.5\times10^4$ yr	$\lesssim 1.5\times10^3$ yr	$\lesssim 50$ yr	$\lesssim 3$ yr
$N^{14}+H^1 \rightarrow O^{15}+\gamma$	2×10^{11} yr	4×10^7 yr	1.7×10^6 yr	1.5×10^5 yr	3×10^3 yr	150 yr
$O^{15} \rightarrow N^{15}+e^+$	2 min	2 min	2 min	2 min	2 min	2 min
$N^{15}+H^1 \rightarrow C^{12}+He^4$	4×10^7 yr	8×10^3 yr	300 yr	30 yr	.6 yr	.1 yr
Mean life of hydrogen	5×10^{13} yr	1×10^{10} yr	4×10^8 yr	4×10^7 yr	7×10^5 yr	3×10^4 yr
Energy production in ergs/(g sec)	.0025	12	300	3,000	200,000	4,000,000

Relative abundances of N^{14}: C^{12}: C^{13}: N^{15} at a temperature of 17.5×10^6 °K are in the approximate ratios of 5,000: 200: 50: 1.

Note that the energy-production for the carbon cycle increases much more rapidly with temperature than for the proton-proton cycle. At very "low" temperatures ($\lesssim 10^7$ °K) the proton-proton reactions are the only ones of importance. The net result at these temperatures is the formation of He^3 and a positron out of three H^1 nuclei, since the reaction between He^3 and He^4 is then too slow to be important. In Table 724 the reaction times of a few other nuclear reactions are given merely to show the rapid increase of the reaction time with increasing charge of the interacting nuclei especially at lower temperatures. None of the reactions listed in Table 724 are of importance as sources of stellar energy.

* Tables 723 and 724 prepared by E. E. Salpeter.

[225] Bethe, Phys. Rev., vol. 55, p. 434, 1939; Astrophys. Journ., vol. 92, p. 118, 1940. Gamow and Critchfield, Theory of atomc nucleus and nuclear energy sources, Oxford Univ. Press, 1940. Fowler, W. A., and Hall, R. N., Phys. Rev., vol. 77, p. 197, 1950, and private communication. Christy, R. F., and O'Reilly, J., unpublished work.

TABLE 724.—TIMES REQUIRED FOR SOME OTHER REACTIONS

Reaction / Temperature:	15×10^6 °K	20×10^6 °K	30×10^6 °K
$F^{19}+H^1 \rightarrow O^{16}+He^4$	5×10^9 yr	1×10^7 yr	5×10^8 yr
$N^{15}+H^1 \rightarrow O^{16}+\gamma$	1×10^8 yr	5×10^6 yr	5×10^8 yr
$O^{16}+H^1 \rightarrow F^{17}+\gamma$	5×10^{18} yr	2×10^{11} yr	1×10^8 yr
$Ne^{22}+H^1 \rightarrow Na^{23}+\gamma$	5×10^{15} yr	5×10^{12} yr	5×10^8 yr
$Li^7+He^4 \rightarrow B^{11}+\gamma$	2×10^{17} yr	2×10^{14} yr	2×10^{10} yr
$Be^7+He^4 \rightarrow C^{11}+\gamma$	5×10^{23} yr	1×10^{20} yr	2×10^{15} yr

All mean reaction times are proportional to the density ρ of the stellar material and to C_H, the percentage by weight of hydrogen (except the reactions in which one of the colliding nuclei is He^4 instead of H^1 in which case C_{He} replaces C_H). The figures in the above tables are for $C_H = 67$ percent, $C_{He} = 30$ percent, and for $\rho = 160$ g/cm^3. The calculations of Christy and O'Reilly* for the interior of the sun give these values for C_H, C_{He} and ρ as well as a concentration of 1.5 percent for carbon, nitrogen, and oxygen combined and of 1.5 percent for all other elements combined. Their calculations predict a temperature of about 17×10^6 °K in the interior of the sun. The mean life of all the hydrogen now present and the total energy production due to the proton-proton cycle and the carbon cycle are also given in Table 723. For the carbon cycle the mean life of hydrogen and the energy production depend on the concentration of the isotopes of carbon and nitrogen. These elements play the role of a "catalyst" controlling the speed of the reaction and are reproduced at the end of each cycle. The figures in Part 2 of Table 723 are for a concentration of 1 percent by weight for N^{14}.

* For reference, see footnote 225 above.

TABLE 725.—SLOW NEUTRON PRODUCED RADIOACTIVITIES OF LONG HALF-LIFE * [220]

Radioactive isotope	Half-life	Max energy β-particles emitted Mev	Max energy γ-rays emitted Mev	Thermal neutron cross section in barns	Percent abundance of parent nucleus
${}_{1}H^{3}$	12.1 yr	.0179	none	6.5×10^{-4}	.016
${}_{1}H^{3}$	12.1 yr	.0179	none	860 (n,a)	7.5
${}_{1}H^{3}$	12.1 yr	.0179	none	5000 (n,p)	1.2×10^{-4}
${}_{4}Be^{10}$	2.7×10^{6} yr	.6	none	.0085	100.
${}_{6}C^{14}$	5700 yr	.156	none	1.7 (n,p)	99.6
${}_{6}C^{14}$	5700 yr	.156	none	.1	1.12
${}_{11}Na^{24}$	14.8 hr	1.39	2.76	.4	100.
${}_{14}Si^{31}$	170 min	1.8	none	.11	3.05
${}_{15}P^{32}$	14.3 d	1.72	none	.23	100.
${}_{16}S^{35}$	87.1 d	.169	none	.26	4.15
${}_{17}Cl^{36}$	2×10^{6} yr	.64	none	53.	75.4
${}_{17}Cl^{38}$	37.5 min	4.94	2.15	.6	24.6
${}_{18}A^{41}$	1.83 hr	2.55	1.37	1.2	99.6
${}_{19}K^{42}$	12.4 hr	3.5	1.5	1.0	6.6
${}_{20}Ca^{45}$	152 d	.260	none	.63	2.06
${}_{20}Ca^{49}$	2.5 hr	2.3	.8	.2	.19
${}_{21}Sc^{46}$	85 d	1.49	1.12	22.	100.
${}_{22}Ti^{51}$	72 d	.36	1.0	.04	5.34
${}_{24}Cr^{51}$	26.5 d	K capture	.32	16.2	4.49
${}_{25}Mn^{56}$	2.59 hr	2.81	2.06	12.8	100.
${}_{26}Fe^{55}$	4 yr	K capture	.07	2.1	5.8
${}_{26}Fe^{59}$	47 d	.46	1.30	.32	.28
${}_{27}Co^{60}$	5.3 yr	.3	1.3	22.5	100.
${}_{28}Ni^{65}$	2.6 hr	1.9	1.1	2.6	.88
${}_{29}Cu^{64}$	12.8 hr	.66	1.35	4.3	69.1
${}_{30}Zn^{65}$	250 d	.4	1.14	.51	50.9
${}_{30}Zn^{69}$	13.8 hr	I.T.	.44	.09	17.4
${}_{30}Zn^{69}$	57 min	1.0	none	.9	17.4
${}_{31}Ga^{72}$	14.1 hr	3.17	2.5	3.4	39.8
${}_{32}Ge^{71}$(?)	40 hr	1.2	....	.073	21.2
${}_{32}Ge^{71}$	11.4 d	K capture	.32	.45	21.2
${}_{32}Ge^{75}$	89 min	1.2	....	.60	36.7
${}_{32}Ge^{77}$	12 hr	2.0	....	.085	7.7
${}_{33}As^{76}$	26.8 hr	3.0	1.2	4.6	100.
${}_{34}Se^{75}$	127 d	K capture	.5	24.	.87
${}_{34}Se^{81}$	58 min	I.T.	.10	.03	49.8
${}_{35}Br^{80}$	4.4 hr	I.T.	.049	3.0	50.6
${}_{35}Br^{82}$	34 hr	.47	1.35	2.25	49.4
${}_{36}Kr^{79}$	34 hr	.9	.2	.27	.34
${}_{36}Kr^{85}$	4.5 hr	.94	.37	.96	57.
${}_{36}Kr^{85}$	9.4 yr	.74	none	.06	57.
${}_{36}Kr^{87}$	74 min	4.	....	.06	17.4
${}_{37}Rb^{86}$	19.5 d	1.8	1.08	.72	72.8
${}_{38}Sr^{87}$	2.7 hr	I.T.	.386	1.3	9.9
${}_{38}Sr^{89}$	55 d	1.5	none	.005	82.6
${}_{39}Y^{90}$	62 hr	2.35	none	1.2	100.
${}_{40}Zr^{95}$	65 d	1.0	.92	.1	17.
${}_{40}Zr^{97}$	17 hr	2.1	.8	.29	2.8
${}_{42}Mo^{98}$	6.7 hr	3.7	1.6	.2	15.9
${}_{42}Mo^{99}$	67 hr	1.5	.75	.37	24.
${}_{43}Tc^{99}$	6.6 hr	I.T.	.136	from Mo^{99} decay	
${}_{44}Ru^{97}$	2.8 d	K capture	.23	.01	5.7
${}_{44}Ru^{103}$	41 d	.67	.55	1.2	31.3
${}_{44}Ru^{105}$	4 hr	1.35	.76	.67	18.3
${}_{45}Rh^{105}$	35 hr	.78	.3	from Ru^{105} decay	
${}_{46}Pd^{109}$	13 hr	1.1	none	12.1	27.
${}_{46}Pd^{111}$	26 min	3.5	....	.39	13.5
${}_{47}Ag^{110}$	225 d	.59	1.40	2.3	48.7
${}_{47}Ag^{111}$	7.5 d	1.0	none	from Pd^{111} decay	
${}_{48}Cd^{111}$	48.6 min	I.T.	.247	.2	12.8

* Revised by Jacob L. Rhodes, University of Pennsylvania.

[220] Stephens, W. E., (editor), Nuclear fission and atomic energy, Science Press. Used by permission of the editor.

(continued)

TABLE 725.—SLOW NEUTRON PRODUCED RADIOACTIVITIES OF LONG HALF-LIFE (concluded)

Radioactive isotope	Half-life	Max energy β-particles emitted Mev	Max energy γ-rays emitted Mev	Thermal neutron cross section in barns	Percent abundance of parent nucleus
${}_{48}Cd^{115}$	43 d	1.7	.5	.14	28.
${}_{48}Cd^{115}$	2.33 d	1.13	.55	1.1	28.
${}_{48}Cd^{117}$	2.8 hr	1.7	....	1.4	7.3
${}_{49}In^{114}$	48 d	I.T.	.19	61.	4.5
${}_{49}In^{116}$	53.9 min	.85	2.32	56.	95.77
${}_{50}Sn^{113}$	105 d	.080	.085	1.1	1.1
${}_{51}Sb^{122}$	2.8 d	1.94	.57	6.8	57.
${}_{51}Sb^{124}$	60 d	2.37	2.06	2.5	44.
${}_{52}Te^{127}$	9.3 hr	.70	none	.78	18.7
${}_{52}Te^{129}$	72 min	1.8	.8	.13	31.8
${}_{53}I^{128}$	25 min	2.02	.428	6.8	100.
${}_{53}I^{131}$	8 d	.687	.37	from Te^{131} decay	
${}_{54}Xe^{133}$	5.27 d	.35	.085	.2	26.9
${}_{55}Cs^{134}$	3.1 hr	2.4	.7	.016	100.
${}_{55}Cs^{134}$	2.3 yr	.66	1.40	26.	100.
${}_{56}Ba^{131}$	11.7 d	K capture	1.2	24.	.09
${}_{56}Ba^{139}$	85 min	2.27	.163	.5	71.7
${}_{57}La^{140}$	40 hr	2.12	2.3	9.	99.9
${}_{58}Ce^{141}$	30 d	.6	.2	.95	88.5
${}_{58}Ce^{143}$	33 hr	1.35	.5	.31	11.1
${}_{59}Pr^{142}$	19.3 hr	2.14	1.9	11.	100.
${}_{60}Nd^{147}$	11.0 d	.90	.58	1.5	16.5
${}_{60}Nd^{149}$	1.7 hr	1.5	....	2.4	6.8
${}_{62}Sm^{153}$	47 hr	.78	.61	280.	26.6
${}_{62}Sm^{155}$	25 min	1.9	.3	6.	22.5
${}_{63}Eu^{152}$	9.2 hr	1.88	.725	1530.	49.1
${}_{63}Eu^{154}$	7 yr	.9	1.2	1000.	52.2
${}_{64}Gd^{159}$	18 hr	.95	.38	1.1	24.8
${}_{65}Tb^{160}$	3.9 hr	....	....	11.	100.
${}_{65}Tb^{160}$	75 d	.88	1.15	22.	100.
${}_{66}Dy^{165}$	2.5 hr	1.2	.8	2700.	27.3
${}_{67}Ho^{166}$	27.2 hr	1.6	....	67.	100.
${}_{68}Er^{169}$	9.4 d	.33	none	....	27.1
${}_{68}Er^{171}$	7.5 hr	1.5	.81	7.	14.9
${}_{69}Tm^{170}$	127 d	.98	.83(?)	118.	100.
${}_{70}Yb^{169}$	33 d	K capture	.4	18,000.	.14
${}_{70}Yb^{175}$	4.1 d	.50	.35	50.	31.8
${}_{70}Yb^{177}$	2.1 hr	1.2	....	5.	12.7
${}_{71}Lu^{176}$	3.7 hr	1.15	none	30.	97.5
${}_{71}Lu^{177}$	6.6 d	.47	.2	3200.	2.5
${}_{72}Hf^{181}$	46 d	.46	.47	10.	35.1
${}_{73}Ta^{182}$	120 d	.53	1.22	20.6	100.
${}_{74}W^{185}$	73 d	.43	none	2.1	30.7
${}_{74}W^{187}$	24.1 hr	1.33	.69	37.2	29.2
${}_{75}Re^{186}$	90 hr	1.05	none	101.	38.2
${}_{75}Re^{188}$	18 hr	2.05	1.43	75.	61.8
${}_{76}Os^{191}$	15 d	.142	.129	3.4	26.4
${}_{76}Os^{193}$	32 hr	1.2	1.58	3.9	41.0
${}_{77}Ir^{192}$	70 d	.67	.607	740.	38.5
${}_{77}Ir^{194}$	19 hr	2.2	1.4	130.	61.5
${}_{78}Pt^{197}$	3.3 d	....	....	4.5	25.4
${}_{78}Pt^{197}$	18 hr	.7	....	1.1	25.4
${}_{78}Pt^{199}$	31 min	1.8	....	3.9	7.2
${}_{79}Au^{198}$	2.7 d	.96	.411	96.	100.
${}_{80}Hg^{203}$	51.5 d	.21	.3	2.4	29.6
${}_{81}Tl^{204}$	3.5 yr	.87	none	7.5	29.2
${}_{82}Pb^{209}$	3.32 yr	.68	none	.00045	52.3
${}_{83}Bi^{210}$	5.0 d	1.17	none	.015	100.
${}_{84}Po^{210}$	138 d	....	from Bi^{210} decay		
${}_{90}Th^{233}$	23.5 min	1.6	none	....	100.
${}_{91}Pa^{233}$	25 d	.23	.30	from Th^{233} decay	
${}_{92}U^{239}$	23.5 min	1.20	.076	....	99.
${}_{93}Np^{239}$	2.3 d	1.18	.27	from U^{239} decay	

When various materials are bombarded with the high-speed particles produced by one of the devices given in Table 718, disintegrations, or the building up of elements higher in the atomic table, result. Some examples of these reactions are given in the table.

Part 1.—Some values of the energy of artificial disintegration for different isotopes and for different reactions [227]

Neutron bombardment

$H^1(n,\gamma)H^2$	— 2.320 Mev	$B^{11}(n,H^3)Be^9$	— 9.57 Mev	$N^{14}(n,\alpha)B^{11}$	— .28 Mev
$He^3(n,p)H^3$	.764	$B^{11}(n,\gamma)B^{12}$	2.6	$N^{14}(n,p)C^{14}$	.60
$Li^6(n,p)He^6$	— 2.9	$Be^9(n,\gamma)Be^{10}$	6.69	$O^{16}(n,2n)O^{15}$	—15.6
$Li^6(n,\alpha)H^3$	4.785	$Be^9(n,\alpha)He^6$	— .80	$O^{16}(n,\alpha)C^{13}$	— 2.31
$Li^7(n,\gamma)Li^8$	1.98	$Be^9(n,2n)Be^8$	— 1.63	$O^{17}(n,\alpha)C^{14}$	1.73
$B^{10}(n,\alpha)Li^7$	2.79	$C^{12}(n,n)3\alpha$	— 7.43	$N^{14}(n,H^3)C^{12}$	— 4.10
$B^{10}(n,H^3)Be^8$	.22	$C^{12}(n,2n)C^{11}$	—18.68	$N^{14}(n,p)C^{14}$	.626
$B^{10}(n,p)Be^{10}$	.20	$C^{13}(n,\alpha)B^{10}$	— 3.94	$N^{14}(n,H^3)3\alpha$	—11.43
$B^{11}(n,\alpha)Li^8$	— 6.66			$N^{15}(n,H^3)C^{13}$	— 9.97

Proton bombardment

$Li^6(p,\gamma)Be^7$	5.53 Mev	$Be^9(p,d)Be^8$	.558	$N^{14}(p,\alpha)C^{11}$	— 3.00
$Li^6(p,\alpha)He^3$	4.021	$B^{10}(p,\gamma)C^{11}$	8.70	$N^{15}(p,\alpha)C^{12}$	4.92
$Li^7(p,n)Be^7$	— 1.645	$B^{10}(p,n)C^{10}$	— 5.2	$C^{12}(p,\gamma)N^{13}$	1.92
$Li^7(p,\gamma)Be^8,Be^{8*}$	17.21	$B^{10}(p,\alpha)Be^7$	1.146	$C^{13}(p,\gamma)N^{14},N^{14*}$	7.56
$Li^7(p,\alpha)He^4$	17.28	$B^{11}(p,\alpha)Be^8$	8.57	$C^{13}(p,n)N^{13}$	2.96
$Be^9(p,d)Be^8$	.559	$B^{11}(p,n)C^{11}$	— 2.762	$F^{19}(p,\alpha)O^{16}$	8.113
$Be^9(p,\gamma)B^{10},B^{10*}$	6.49	$B^{11}(p,\gamma)C^{12},C^{12*}$	15.96	$F^{19}(p,n)Ne^{19}$	— 3.84
$Be^9(p,n)B^9$	— 1.84			$O^{18}(p,n)F^{18}$	— 2.455
$Be^9(p,\alpha)Li^6$	2.125 Mev				

Deuteron bombardment

$Li^6(d,\alpha)He^4$	22.23 Mev	$B^{11}(d,\alpha)Be^9$	8.03 Mev	$C^{13}(d,p)C^{14}$	5.99 Mev
$Li^6(d,n)Be^8$	3.54	$B^{11}(d,n)C^{12},C^{12*}$	13.78	$N^{14}(d,\alpha)C^{12}$	13.50
$Li^6(d,p)Li^7$	5.012	$B^{11}(d,p)B^{12}$	.4	$N^{14}(d,p)N^{15}$	8.57
$Li^6(d,n)Be^7$	3.34	$Be^9(d,\alpha)Li^7,Li^{7*}$	7.09	$N^{14}(d,n)O^{15}$	5.1
$Li^6(d,\alpha)He^4$	22.29	$Be^9(d,H^3)Be^8$	4.53	$N^{14}(d,H^3)N^{13}$	— 4.36
$Li^7(d,p)Li^8$	— .193	$Be^9(d,p)Be^{10}$	4.52	$N^{14}(d,\alpha)3\alpha$	6.16
$Li^7(d,\alpha)He^5$	14.3	$C^{12}(d,p)C^{13}$	2.726	$N^{15}(d,\alpha)C^{13}$	7.62
$B^{10}(d,\alpha)Be^8,Be^{8*}$	17.81	$C^{12}(d,n)N^{13}$	— .279	$O^{16}(d,\alpha)N^{14}$	3.07
$B^{10}(d,p)B^{11},B^{11*}$	9.24	$C^{13}(d,\alpha)B^{11}$	5.10		
$B^{10}(d,n)C^{11}$	6.53				

α-ray bombardment

$Be^9(\alpha,\alpha')Be^8+n$	— 1.63 Mev	$Li^7(\alpha,n)B^{10},B^{10*}$	— 2.78 Mev	$Be^9(\alpha,\alpha')Be^{9*}$	— 1.63 Mev
$Be^9(\alpha,\alpha')Be^{8*}$	— 1.63	$B^{10}(\alpha,d)C^{12}$	1.44	$B^{11}(\alpha,n)N^{14}$	.28
$Be^9(\alpha,\alpha')He^5+\alpha$	— 2.4	$B^{10}(\alpha,p)C^{13},C^{13*}$	4.14	$B^{11}(\alpha,p)C^{14}$	.88
$Be^9(\alpha,\alpha')2\alpha+n$	— 1.58	$B^{10}(\alpha,n)N^{13}$	1.18	$C^{12}(\alpha,n)O^{15}$	— 8.4
$Li^6(\alpha,p)Be^9$	— 2.12	$Be^9(\alpha,n)C^{12},C^{12*}$	5.75		

[227] Hornyak, W. F., and Lauritsen, T., Rev. Mod. Phys., vol. 20, p. 191, 1948; Phys. Rev., vol. 78, p. 372, 1950.

Part 2.—Photo-nuclear reactions, threshold values [228]

$H^2(\gamma,n)H^1$	2.20 ± .05 Mev	$Ca^{40}(\gamma,n)Ca^{39}$	15.9 ± .4 Mev	$Cd^{113}(\gamma,n)Cd^{112}$	6.44 ± .15 Mev
$Be^9(\gamma,n)Be^8$	1.63 ± .3	$Fe^{54}(\gamma,n)Fe^{53}$	13.8 ± .2	$Sn^{119}(\gamma,n)Sn^{118}$	6.51 ± .15
$Li^7(\gamma,p)He^6$	9.8 ± .5	$Mn^{55}(\gamma,n)Mn^{54}$	10.15 ± .20	$Sn^{124}(\gamma,n)Sn^{123}$	8.50 ± .15
$C^{12}(\gamma,n)C^{11}$	18.7 ± 1.0	$Cu^{63}(\gamma,n)Cu^{62}$	10.9 ± .2	$Sb^{121}(\gamma,n)Sb^{120}$	9.25 ± .2
$N^{14}(\gamma,n)N^{13}$	10.65 ± .2	$Cu^{65}(\gamma,n)Cu^{64}$	10.2 ± .2	$I^{127}(\gamma,n)I^{126}$	9.3 ± .2
$Mg^{24}(\gamma,n)Mg^{23}$	16.2 ± .3	$Zn^{64}(\gamma,n)Zn^{63}$	11.80 ± .20	$Pr^{141}(\gamma,n)Pr^{140}$	9.40 ± .10
$Mg^{25}(\gamma,p)Na^{24}$	11.5 ± 1.0	$Zn^{70*}(\gamma,n)Zn^{69}$	9.20 ± .20	$Nd^{150}(\gamma,n)Nd^{149}$	7.40 ± .20
$Mg^{26}(\gamma,p)Na^{25}$	14.0 ± 1.0	$Br^{79}(\gamma,n)Br^{78}$	10.7 ± .20	$Ta^{181}(\gamma,n)Ta^{180}$	7.7 ± .2
$Al^{27}(\gamma,n)Al^{26}$	14.0 ± .4	$Br^{81}(\gamma,n)Br^{80}$	10.2 ± .20	$Au^{197}(\gamma,n)Au^{196}$	8.00 ± .15
$Si^{28}(\gamma,n)Si^{27}$	16.8 ± .4	$Zr^{90}(\gamma,n)Zr^{89}$	12.48 ± .15	$Hg^{201}(\gamma,n)Hg^{200}$	6.25 ± .20
$P^{31}(\gamma,n)P^{30}$	12.35 ± .2	$Zr^{91}(\gamma,n)Zr^{90}$	7.20 ± .40	$Tl^{205}(\gamma,n)Tl^{204}$	7.38 ± .15
$S^{32}(\gamma,n)S^{31}$	14.8 ± .4	$Mo^{92}(\gamma,n)Mo^{91}$	13.28 ± .15	$Pb^{207}(\gamma,n)Pb^{206}$	6.85 ± .20
$K^{39}(\gamma,n)K^{38}$	13.2 ± .2	$Mo^{97}(\gamma,n)Mo^{96}$	7.10 ± .30	$Bi^{209}(\gamma,n)Bi^{208}$	7.45 ± .2

[228] McElhinney, J., Hanson, A. O., Becker, R. A., Duffield, R. B., and Diven, B. C., Phys. Rev., vol. 75, p. 542, 1949.

TABLE 727.—METHODS OF PRODUCING ELEMENTS BEYOND URANIUM [229]

The heavier elements, Np, Pu, Am, Cm, Bk, and Cf may be produced by artificial transformation of U, followed by radioactive breakdown. A few examples follow:

$$_{92}U^{238} + {_0n^1} \rightarrow {_{92}U^{239}} + \gamma$$
$$_{92}U^{239} \rightarrow {_{93}Np^{239}} + \beta^-(23 \text{ min})$$
$$_{93}Np^{239} \rightarrow \underline{_{94}Pu^{239}} + \beta^-(2.3 \text{ days})$$
$$_{92}U^{238} + {_0n^1} \rightarrow {_{92}U^{237}} + {_0n^1} + {_0n^1}$$
$$_{92}U^{237} \rightarrow \underline{_{93}Np^{237}} + \beta^-(6.8 \text{ d})$$
$$_{92}U^{238} + {_1H^2} \rightarrow {_{93}Np^{238}} + {_0n^1} + {_0n^1}$$
$$_{93}Np^{238} \rightarrow \underline{_{94}Pu^{238}} + \beta^-(2.0 \text{ d})$$
$$_{92}U^{238} + {_2He^4} \rightarrow {_{94}Pu^{241}} + {_0n^1}$$
$$_{94}Pu^{241} \rightarrow \underline{_{95}Am^{241}} + \beta^-(\sim 10 \text{ yr})$$

For quantity production:

$$_{94}Pu^{239} + {_0n^1} \rightarrow {_{94}Pu^{240}} + \gamma$$
$$_{94}Pu^{240} + {_0n^1} \rightarrow {_{94}Pu^{241}} + \gamma$$
$$_{94}Pu^{241} \rightarrow \underline{_{95}Am^{241}} + \beta^-$$
$$_{94}Pu^{239} + {_2He^4} \rightarrow \underline{_{96}Cm^{242}} + {_0n^1}$$
$$\text{or } \underline{_{96}Cm^{240}} + {_0n^1} + {_0n^1} + {_0n^1}$$

For quantity production:

$$_{95}Am^{241} + {_0n^1} \rightarrow {_{95}Am^{242}} + \gamma$$
$$_{95}Am^{242}\,* \rightarrow \underline{_{96}Cm^{242}} + \beta^-$$
$$_{95}Am^{241} + {_2He^4} \rightarrow \underline{_{97}Bk^{243}} + {_0n^1} + {_0n^1}$$
$$_{96}Cm^{242} + {_2He^4} \rightarrow \underline{_{98}Cf^{244}} + {_0n^1} + {_0n^1}$$

[229] G. T. Seaborg, private communication.
* Sixteen-hour + 100-year isomers.

TABLE 728.—PILE YIELDS OF SOME ISOTOPES *

Calculated for 10 liters of material exposed to 10^{10} neutrons cm^{-3} sec^{-1}

Radioactive isotope	Cross section in units of 10^{-24} cm² times relative isotope abundance	Density of material g/cm³	Half-life in hours	Atomic weight of material	Mean free path cm	Yields mc/hr
H^3	10^{-7}	1	1.1×10^5	9	7×10^7	10^{-7}
Be^{10}	.0086	1.85	2.4×10^{10}	9	570	7×10^{-8}
C^{14}	1.7	1.6	4×10^7	30	12	2×10^{-3}
Na^{24}	.4	.97	14.8	23	60	1100
P^{32}	.23	2.2	343	31	60	45
K^{42}	.066	.86	12.4	39	680	120
Ca^{45}	.012	1.54	3650	40	2220	.12
Fe^{59}	.001	4.86	1110	56	7000	.1
Zn^{65}	.26	7.14	6000	65	65	4.5
As^{76}	4.6	5.7	26.8	75	2.86	1300
Br^{82}	1.12	3.12	34	80	22.8	1300
Rb^{86}	.52	1.53	469	85	106	20
Sr^{89}	.0041	2.6	1770	88	8000	.1
Ag^{110}	1.1	10.5	5400	108	.41	200
In^{114m}	2.74	7.3	1150	115	5.7	150
Ta^{182}	20.6	16.6	2800	181	.48	680
Bi^{210}	.015	9.8	120	209	1420	6

* Revised by J. L. Rhodes. For reference, see footnote 226, p. 667.

TABLE 729.—COMPARATIVE PROPERTIES OF ORDINARY AND HEAVY WATER *

Property	H_2O	$H_2{}^2O$
Specific gravity at 25°C relative to ordinary water at 25°C	1.0000	1.1079
Temperature of maximum density	4.0°C	11.6°C
Dielectric constant	81.5	80.7
Surface tension	72.75 dynes/cm	67.8
Viscosity at 10°C	13.10 millipoises	16.85
Melting point	.000°C	3.802°C
Boiling point (76 cmHg pressure)	100.00°C	101.42°C
Heat of fusion	1436 cal/mole	1510
Heat of vaporization at 25°C	10484 cal/mole	10743
Refractive index at 20°C for NaD line	1.33300	1.32828

* For reference, see footnote 224, p. 665.

TABLE 730.—THE MECHANICAL EFFECTS OF RADIATION [230]

Wavelengths, cm	Nature of radiation	Effect on atom	Temperature, °K	Where found
7500×10^{-8} to 3750×10^{-8}	Visible radiation	Disturbs outermost electrons	3880 to 7700	Stellar atmosphere
250×10^{-8} to 10^{-8}	X-rays	Disturb inner electrons	115,000 to 29,000,000	Stellar interiors
5×10^{-9} to 10^{-9}	Soft γ-rays	Strip off all or nearly all electrons	58,000,000 to 290,000,000	Central regions of dense stars
4×10^{-10}	γ-rays of *RaB*	Disturb nuclear arrangements	720,000,000	?
5×10^{-11}	Hardest γ-rays	......	58×10^{8}	
4.5×10^{-12}	?	Building of He atom out of H	64×10^{9}	
2×10^{-12}	Highly penetrating	Disintegrates nuclei	15×10^{10}	
1.3×10^{-13}	?	Annihilation or creation of proton and accompanying electron	22×10^{11}	

[230] Nat. Res. Council Bull. 80, 1931.

A number of elements (12; 43 isotopes) of high atomic weight, now found in the earth, and one of the isotopes of each of six lighter elements (Table 732) are unstable in that they spontaneously break down into other elements, emitting α, β or γ rays. The study of artificial radioactivity shows some other types of breakdown. Some of the artificial radioactive nuclei break down by the emission of positive electrons or of neutrons; a K electron may be captured (designated by K); some internal conversion of electrons may take place (e^-) or there may be some isomeric transition of the nucleus (I.T.).

The characteristics of the three rays—α, β, and γ—are quite different. A 3 Mev α-particle has a velocity of about 1/25 that of light, a range in air of 1.7 cm, and produces some 4,000 ion pairs per mm in air at 760 mmHg at 15°C. A 3 Mev β-ray has a velocity of nearly 99 percent of that of light and a range in air of about 13 meters, and produces only about 4 ion pairs per mm in air. The energy of a γ-ray, which is very short-wavelength radiant energy, is $E = h\nu$, and it has the velocity of light. Thus a 3 Mev γ-ray has a wavelength of 4.1 XU. However, the γ-rays given by the natural radioactive materials have much less energy than this (4 Mev), generally about 1 Mev. [Some artificial radioactive materials emit γ-rays with very high energy (See Tables 750-752.).] The wavelengths of the γ-rays from natural radioactivity particles range from about 4.5 to about 4,000 XU. γ-rays have a very long range. A γ-ray produces directly no ions along its path but spends almost its entire energy in producing a photoelectron. Rutherford [230a] says that the β-rays are about 100 times as penetrating as the α-rays, and the γ-rays 10 to 100 times as penetrating as the β-rays.

Today it should be stated that, in general, the radioactive isotopes (about 43 in number) of these 12 elements change into other isotopes, either smaller or of the same weight, depending upon the type of breakdown. The nucleus of the resulting isotope may be smaller in weight by about four units and have a charge two units smaller than the parent due to the emission of an α-particle, or it may be of almost the same weight and have a charge one unit greater due to the emission of a β-ray. There are several changes in both the weight and charge that may take place for some of the artificial radioactive nuclei.

The character of these changes varies with the element and seems to be determined by some probability law. It does not seem possible, by any ordinary physical or chemical means, to change these characteristics. (See artificial disintegration, Table 726.)

* For reference, see footnote 199, p. 618.

[230a] Rutherford, E., Chadwick, J., and Ellis, C. D., Radiation from radioactive substances, Cambridge Univ. Press, 1930.

TABLE 731.—UNITS FOR THE RATE OF RADIOACTIVE DISINTEGRATION

The curie, the adopted unit of the rate of radioactive decay, is defined as the number of disintegrations of 1 gram of radium (3.61×10^{10}) in 1 second. As a working value for the curie the National Bureau of Standards some years ago adopted the value 3.700×10^{10} disintegrations per second.

The rutherford (abbreviated *rd*) $= 10^6$ disintegrations per second, has been suggested as a smaller working standard. Then, 1 millirutherford (*mrd*) $= 10^3$ disintegrations per second and 1 microrutherford (μrd) $= 1$ disintegration per second.

The rate of disintegration of an isotope that emits gamma-rays may be determined by a measure of the γ-ray emission in roentgens.

A committee of the National Research Council [231] recommended that the curie be defined as 3.70×10^{10} disintegrations per second; the rutherford (*rd*) as just given. For quantitative comparison of radioactive sources emitting gamma-rays, for which disintegration rates cannot be determined, the roentgen per hour at 1 meter (*rhm*) is recommended.

[231] Physics Today, vol. 3, p. 5, 1950.

TABLE 732.—NATURAL RADIOACTIVE MATERIALS

Atomic number	Material	Isotope	Radioactive name *	Half-life	Decay constant	Radiation	Energy of radiation in Mev: α or β	Energy of radiation in Mev: γ	End product
92	Uranium	234	Uranium II	2.5×10^5 yr	2.8×10^{-6} yr^{-1}	α	4.76	. . .	90 Io 230
92	Uranium	235	Actinouranium	8.9×10^8 yr	7.8×10^{-10} yr^{-1}	$\alpha;\gamma$	4.5	.17	90 UY 231
92	Uranium	238	Uranium I	4.5×10^9 yr	1.54×10^{-10} yr^{-1}	α	4.2	. . .	90 UX_1 234
91	Protactinium	231	Protactinium	3.3×10^4 yr	2.1×10^{-5} yr^{-1}	$\alpha;\gamma$	5.0	.25	89 Ac 227
91	Protactinium	234	Uranium Z	6.7 hr	.103 hr^{-1}	$\beta^-;\gamma$	1.2	.70	92 U_{II} 234
91	Protactinium	234m	Uranium X_2	1.1 min	.63 min^{-1}	$\beta^-;\gamma$	2.3	.80	92 U_{II} 234
				1.2 min	.58 min^{-1}	I.T.			92 UZ 234
90	Thorium	227	Radioactinium	18.7 d	3.710^{-2} d^{-1}	$\alpha;\gamma$	5.8	. . .	88 AcX 223
90	Thorium	228	Radiothorium	1.90 yr	.36 yr^{-1}	$\alpha;\gamma$	5.3	. . .	88 ThX 224
90	Thorium	230	Ionium	8.1×10^4 yr	8.510^{-6} yr^{-1}	$\alpha;\gamma$	4.7	. . .	88 Ra 226
90	Thorium	231	Uranium Y	25.6 hr	2.710^{-2} hr^{-1}	$\beta^-;\gamma;e^-$	.2	.04	91 Pa 231
90	Thorium	232	Thorium	1.39×10^{10} yr	5.0×10^{-11} yr^{-1}	α	4.0	. . .	88 $MsTh_1$ 228
90	Thorium	234	Uranium X_1	24.1 d	2.9×10^{-2} d^{-1}	$\beta^-;\gamma$	.2	.09	91 UX_2 234m
89	Actinium	227	Actinium	21.7 yr	3.2×10^{-2} yr^{-1}	$\alpha;\gamma$	4.9	.03	87 AcK 223
						β^-			90 RaAc 227
89	Actinium	228	Mesothorium 2	6.1 hr	.11 hr^{-1}	$\beta^-;\gamma$	1.5	. . .	90 RaTh 228
88	Radium	223	Actinium X	11.2 d	6.2×10^{-2} d^{-1}	$\alpha;\gamma$	5.7	. . .	86 An 219
88	Radium	224	Thorium X	3.6 d	.19 d^{-1}	α	5.6	. . .	86 Tn 220
88	Radium	226	Radium	1620 yr	4.3×10^{-4} yr^{-1}	$\alpha;\gamma$	4.8	.19	86 Rn 222
88	Radium	228	Mesothorium 1	6.7 yr	8.101 yr^{-1}	β^-	.5	. . .	89 $MsTh_2$ 228
87	Francium	223	Actinium K	21 min	3.3×10^{-2} min^{-1}	$\beta^-;\gamma$	1.2	.09	88 AcX 223
86	Radon	219	Actinon	3.9 sec	.18 sec^{-1}	α	6.8	. . .	84 AcA 215
86	Radon	220	Thoron	54.5 sec	1.28×10^{-2} sec^{-1}	α	6.3	. . .	84 ThaA 216
86	Radon	222	Radon	3.83 d	.181 d^{-1}	α	5.5	. . .	84 RaA 218
85	Astatine	215	Astatine	$\sim10^{-4}$ sec	7×10^3 sec^{-1}	α	8.0	. . .	83 AcC 211
85	Astatine	216	"	3×10^{-4} sec	2.3×10^3 sec^{-1}	α	7.7	. . .	83 ThC 212
85	Astatine	218	"	several sec	. . . .	α	6.7	. . .	83 RaC 214
84	Polonium	210	Radium F	139 d	5.0×10^{-3} d^{-1}	$\alpha;\gamma$	5.3	.75	82 Pb 206
84	Polonium	211	Actinium C′	5×10^{-3} sec	1.4×10^2 sec^{-1}	α	7.4	. . .	82 AcD 207
84	Polonium	212	Thorium C′	3.2×10^{-7} sec	2.2×10^6 sec^{-1}	α	8.8	. . .	82 ThD 208
84	Polonium	214	Radium C′	1.5×10^{-4} sec	4.6×10^3 sec^{-1}	α	7.7	. . .	82 RaD 210
84	Polonium	215	Actinium A	1.8×10^{-3} sec	3.9×10^2 sec^{-1}	α	7.4	. . .	82 At 211
						β^-			85 AcB 215
84	Polonium	216	Thorium A	.16 sec	4.3 sec^{-1}	α	6.7	. . .	82 ThB 212
						β^-			85 At 216

* Many of these radioactive isotopes were known as radioactive decay products before it was known that they were isotopes of other elements.

(continued)

TABLE 732.—NATURAL RADIOACTIVE MATERIALS (concluded)

Atomic number	Material	Isotope	Radioactive name *	Half-life	Decay constant	Radiation	Energy of radiation in Mev: α or β	Energy of radiation in Mev: γ	End product
84	Polonium	218	Radium A	3.1 min	.22 min^{-1}	α	6.0	...	82 RaB 214
						β^-			85 At 218
83	Bismuth	210	Radium E	5 d	.14 d^{-1}	β^-	1.2	...	84 Po 210
						α	4.8	...	81 Tl 206
83	Bismuth	211	Actinium C	2.16 min	.32 min^{-1}	α	6.6	...	81 AcC″ 207
						β^-			84 AcC′ 211
83	Bismuth	212	Thorium C	60.5 min	1.14×10^{-2} min^{-1}	α	6.1	...	81 ThC″ 208
						β^-			84 ThC′ 212
83	Bismuth	214	Radium C	19.7 min	3.5×10^{-2} min^{-1}	α	5.5	1.8	81 RaC″ 210
						β^-	3.1	...	84 RaC′ 214
82	Lead	210	Radium D	22 yr	3.2×10^{-2} yr^{-1}	$\beta^-;\gamma$	.026	.045	83 RaE 210
82	Lead	211	Actinium B	36.1 min	1.92×10^{-2} min^{-1}	$\beta^-;\gamma$	1.0	.8	83 AcC 211
82	Lead	212	Thorium B	10.6 hr	6.5×10^{-2} hr^{-1}	$\beta^-;\gamma$	.36	...	83 ThC 212
82	Lead	214	Radium B	26.8 min	2.59×10^{-2} min^{-1}	$\beta^-;\gamma$	.65	...	83 RaC 214
81	Thallium	207	Actinium C″	4.76 min	.145 min^{-1}	$\beta^-;\gamma$	1.5	...	82 Pb 207
81	Thallium	208	Thorium C″	3.1 min	.22 min^{-1}	$\beta^-;\gamma$	1.75	2.6	82 Pb 208
81	Thallium	210	Radium C″	1.32 min	.52 min^{-1}	β^-	1.8	...	82 RaD 210
75	Rhenium	187	Rhenium	4×10^{12} yr	1.7×10^{-13} yr^{-1}	β^-	.04	...	76 Os 187
71	Lutetium	176	Lutetium	7.3×10^{10} yr	9.5×10^{-12} yr^{-1}	$\beta^-;\gamma$	.21	.26	72 Hf 176
62	Samarium	152	Samarium	1.0×10^{12} yr	6.9×10^{-13} yr^{-1}	α	2.1	...	60 Nd 148
60	Neodymium	150	Neodymium	$\sim5\times10^{10}$ yr	1.4×10^{-11} yr^{-1}	β^-	.01	...	61 Pm 150
37	Rubidium	87	Rubidium	6.3×10^{10} yr	1.1×10^{-11} yr^{-1}	$\beta^-;\gamma;e^-$	.15	.1	38 Sr 87
19	Potassium	40	Potassium	1.6×10^{9} yr	4.3×10^{-10} yr^{-1}	$\beta^-;\gamma$	1.7	1.5	20 Ca 40

TABLE 733.—THE ORIGINAL NAMES OF CERTAIN RADIOACTIVE MATERIALS *

Radioactive name	Element and isotope	Radioactive name	Element and isotope
Actinium	89 Actinium 227	" D	82 Lead 210
Actinium A	84 Polonium 215	Radium E	83 Bismuth 210
" B	82 Lead 211	" F	84 Polonium 210
" C	83 Bismuth 211	" G	82 Lead 206
" C′	84 Polonium 211	Radon †	86 Radon 222
" C″	81 Thallium 207	Actinon	86 Radon 219
" D	82 Lead 207	Emanation	86 Radon 222
" K	87 Francium 223	Niton	86 Radon 222
" X	88 Radium 223	Thoron	86 Radon 220
Actinouranium	92 Uranium 235	Thorium	90 Thorium 232
Brevium (see Uranium X_2)	91 Protactinium 234m	Thorium A	84 Polonium 216
		" B	82 Lead 212
Emanation	86 Radon 222	" C′	84 Polonium 212
Mesothorium I	88 Radium 228	" C″	81 Thallium 208
" II	89 Actinium 228	" D	82 Lead 208
Niton	86 Radon 222	" X	88 Radium 224
Radioactinium	90 Thorium 227	Thoron	86 Radon 220
Radiothorium	90 Thorium 228	Uranium I	92 Uranium 238
Radium	88 Radium 226	" II	92 Uranium 234
Radium A	84 Polonium 218	" X_1	90 Thorium 234
" B	82 Lead 214	" X_2	91 Protactinium 234m
" C	83 Bismuth 214	" Y	90 Thorium 231
" C′	84 Polonium 214	" Z	91 Protactinium 234
" C″	81 Thallium 210	Uranium lead	82 Lead 206

* At times the prefix *eca* was used to designate the element following certain elements either in the periodic table or in radioactive series. † At one time all these materials were called Emanation, i.e., RaEm, AcEm, ThEm.

TABLE 734.—THE FOUR RADIOACTIVE FAMILIES

The radioactive isotopes of the heavy materials arrange themselves into four families, or series, that are known either by the parent of the family or by the member of the series with the longest life. Before the various isotopes had been established some of the different members of the families had special names. (See Table 733.) These families or series are also designated by the numerical relation of the particular isotopes of the family involved and the number 4. Thus the four families or series are: (1) Thorium, or $4n$ series; (2) Neptunium,* or $4n+1$; (3) Uranium, or $4n+2$; (4) Actinium, or $4n+3$.

Generally, tables of these families show the type of radiation emitted, the energy of the radiation, the end product, and two or three factors that describe the time characteristics of the disintegrations; i.e., T the half-life (that is, the time it takes for one-half of the given material to disintegrate, which can be accurately measured T_a, the average life, and λ, the decay constant. From the law of disintegration which radioactive materials have been found to follow, the three constants are shown to be related as follows: $\lambda = \frac{0.693}{T}$ and $T_a = \frac{1}{\lambda}$.

There are a number of isomers [232] in the series as shown in Table 742, as for instance, see Uranium X_1, Radium C, Actinium, etc. As a result of recent work on the artificial production of radioactive isotopes many more isomers could be given. Also, the first member of some of the series might be different. Thus, the $4n+3$ series (the Actinium group) might start in this manner:

Element	Rays and end products	T (half-period)	Decay constant sec^{-1}
92 Uranium 239	β^-, Np^{239}	23.5 min	4.9×10^{-8}
93 Neptunium 239	β^-, Pu^{239}	2.3 days	3.5×10^{-7}
94 Plutonium 239	α, U^{235}	2.4×10^{4} yr	9.2×10^{-13}

To be sure, any trace of such members of this family would no longer be found in the earth.

* Almost all the isotopes of this family are artificial products and are not now found in the earth.
[232] Sergè, Emilio, and Helmholtz, A. C., Rev. Mod. Phys., vol. 21, p. 271, 1949.

(*continued*)

TABLE 734.—THE FOUR RADIOACTIVE FAMILIES (continued)

Part 1.—Thorium series (4 *n*)

Atomic number	Element	Isotope	Radioactive name	Rays	End product	*T* (half period)	Decay constant λ sec⁻¹	Energy of radiation in Mev: α or β	Energy of radiation in Mev: γ
90	Thorium	232	Thorium	α	MsTh 1	1.39×10^{10} yr	1.58×10^{-18}	4.0	—
88	Radium	228	Mesothorium 1	β^-	MsTh 2	6.7 yr	3.28×10^{-9}	.05	—
89	Actinium	228	Mesothorium 2	β^-, γ	RaTh	6.13 hr	3.14×10^{-5}	1.5	—
90	Thorium	228	Radiothorium	α, γ	ThX	1.90 yr	1.16×10^{-8}	5.4	—
88	Radium	224	Thorium X	α	Tn	3.64 days	2.20×10^{-6}	5.7	—
86	Radon	220	Thoron	α	ThA	54.5 sec	1.27×10^{-2}	6.3	—
84	Polonium	216	Thorium A	α	ThB	.158 sec	4.4	6.8	—
82	Lead	212	Thorium B	β^-, γ	ThC	10.6 hr	1.8×10^{-5}	.36	—
83	Bismuth	212	Thorium C	α	ThC″	60.5 min	1.91×10^{-3}	6.1	—
				β^-, γ	ThC′				
84	Polonium	212	Thorium C′	α	ThD	3×10^{-7} sec	2.3×10^{-8}	8.8	—
81	Thallium	208	Thorium C″	β^-, γ	ThD	3.10 min	3.72×10^{-3}	1.7	2.6
82	Lead	208	Thorium D		Stable				

Part 2.—Neptunium series (4 *n* + 1)

Atomic number	Element	Isotope	Rays	End product	*T* (half period)	Decay constant λ sec⁻¹	Energy of radiation in Mev: α or β	Energy of radiation in Mev: γ
94	Plutonium †	241	β^-	Am	~10 yr	2.2×10^{-9}	.01–.02	—
			α	U				
95	Americium	241	α, γ	Np	500 yr	4.40×10^{-11}	5.46	.06
92	Uranium	237	β^-, e^-, γ	Np	6.7 days	1.20×10^{-6}	.23	.2
93	Neptunium	237	α	Pa	2.6×10^{6} yr	8.4×10^{-14}	4.7	—
91	Protactinium	233	β^-, γ, e^-	U	27.4 days	2.93×10^{-7}	.4	.3
92	Uranium	233	α, γ, e^-	Th	1.63×10^{5} yr	1.34×10^{-13}	4.8	.3
90	Thorium	229	α	Ra	7000 yr	3.1×10^{-12}	5.	—
88	Radium	225	β^-	Ac	14.8 days	5.4×10^{-7}	.2	—
89	Actinium	225	α	Fr	10 days	8.0×10^{-7}	5.8	—

† Not isolated from ores, artificially produced by bombarding uranium with α-particles.

(continued)

TABLE 734.—THE FOUR RADIOACTIVE FAMILIES (continued)

Atomic number	Element	Isotope	Rays	End product	T (half period)	Decay constant λ sec⁻¹	Energy of radiation in Mev: α or β	γ
87	Francium	221	α	At	5 min	2.3×10^{-3}	6.31	—
85	Astatine	217	α	Bi	.021 sec	33.	7.0	—
83	Bismuth	213	β^-	Po	46 min	2.5×10^{-4}	1.3	—
			α	Tl			5.8	—
84	Polonium	213	α	Pb	4.2×10^{-6} sec	1.6×10^{5}	8.4	—
81	Thallium	209	β^-	Pb	2.2 min	5.2×10^{-3}	1.8	—
82	Lead	209	β^-	Bi	3.3 hr	5.8×10^{-5}	.70	—
83	Bismuth	209		Stable				

Part 3.—Uranium series ($4n+2$)

Atomic number	Element	Isotope	Radioactive name	Rays	End product	T (half period)	Decay constant λ sec⁻¹	Energy of radiation in Mev: α or β	γ
92	Uranium	238	Uranium I	α	UX 1	4.5×10^{9} yr	4.9×10^{-18}	4.2	—
90	Thorium	234	Uranium X_1	β^-, γ	UX 2	24.1 days	3.3×10^{-7}	.15	.09
				I.T.	UZ				
91	Protactinium	234 m	Uranium X_2	β^-, γ	U II	1.14 min	1.01×10^{-2}	2.0	.8
91	"	234	Uranium Z	β^-, γ	U II	6.7 hr	2.9×10^{-5}	1.0	.70
92	Uranium	234	Uranium II	α	Io	2.5×10^{5} yr	8.8×10^{-14}	4.7	—
90	Thorium	230	Ionium	α, γ	Ra	8.0×10^{4} yr	3.1×10^{-13}	4.7	—
88	Radium	226	Radium	α, γ	Rn	1620 yr	1.355×10^{-11}	4.8	.19
86	Radon	222	Emanation	α	RaA	3.825 days	2.10×10^{-6}	5.5	—
84	Polonium	218	Radium A	α	RaB	3.05 min	3.85×10^{-3}	6.0	—
				β^-	Ac			.65	—
82	Lead	214	Radium B	β^-	RaC	26.8 min	4.3×10^{-4}	5.4	1.8
83	Bismuth	214	Radium C	α, γ	RaC″	19.7 min	5.85×10^{-4}	3.1	—
				β^-	RaC′				
84	Polonium	214	Radium C′	α	RaD	1.5×10^{-4} sec	4.5×10^{3}	7.7	—
81	Thallium	210	Radium C″	β^-	RaD	1.32 min	9.8×10^{-3}	1.80	—
82	Lead	210	Radium D	β^-, γ	RaE	22 yr	1.0×10^{-9}	.025	.05
83	Bismuth	210	Radium E	β^-	RaF	5.0 days	1.6×10^{-6}	1.17	—
84	Polonium	210	Radium F	α, γ	RaG	138 days	5.35×10^{-8}	5.3	.77
82	Lead	206	Radium G (uranium lead)		Stable				

(continued)

TABLE 734.—THE FOUR RADIOACTIVE FAMILIES (concluded)

Part 4.—Actinium series ($4n+3$)

Atomic number	Element	Isotope	Radioactive name	Rays and end product		T (half period)	Decay constant λ sec^{-1}	Energy of radiation in Mev: α or β	γ
92	Uranium	235	Actinouranium	α, γ	UY	8×10^{8} yr	3.1×10^{-17}	4.6	.16
90	Thorium	231	Uranium Y	β^-, γ, c^-	Pa	25.6 hr	7.52×10^{-5}	.2	.04
91	Protactinium	231	Protactinium	α, γ	Ac	3.4×10^{4} yr	6.5×10^{-13}	5.0	.3
89	Actinium	227	Actinium	β^-	RdAc			4.9	.04
				α	AcK	21.7 yr	1.01×10^{-9}		
90	Thorium	227	Radioactinium	α, γ	AcX	18.6 days	4.3×10^{-7}	6.0	—
87	Francium	223	Actinium K	β^-, γ	AcX	21 min	5.5×10^{-4}	1.2	.1
88	Radium	223	Actinium X	α, γ	An	11.2 days	7.2×10^{-7}	5.7	—
86	Radon	219	Actinon	α	AcA	3.9 sec	.178	6.8	—
84	Polonium	215	Actinium A	α	AcB	1.8×10^{-3} sec	3.9×10^{2}	7.4	—
				β^-	At				
85	Astatine	215	Astatine	α	AcC	10^{-4} sec	6.9×10^{3}	8.	—
82	Lead	211	Actinium B	β^-, γ	AcC	36 min	3.2×10^{-4}	1.5	.8
83	Bismuth	211	Actinium C	β^-, γ	AcC′	2.2 min	5.2×10^{-3}	6.6	—
				α	AcC″				
84	Polonium	211	Actinium C′	α	AcD	5×10^{-3} sec	1.4×10^{2}	7.4	—
81	Thallium	207	Actinium C″	β^-, γ	AcD	4.8 min	2.4×10^{-3}	1.5	—
82	Lead	207	Actinium D		Stable				

TABLE 735.—VARIATIONS IN THE ISOTOPIC COMPOSITION OF COMMON LEAD *

Source of lead	Locality	Geological age	Relative isotope abundances 204	206	207	208
Galena	Great Bear Lake, Canada	Pre-Cambrian	1.000	15.93	15.30	35.3
Galena	Broken Hill, N.S.W.	Pre-Cambrian	1.000	16.07	15.40	35.5
Cerussite	Broken Hill, N.S.W.	Pre-Cambrian	1.000	15.92	15.30	35.3
			1.000	15.93	15.28	35.2
Galena	Yancey Co., N. C	Late pre-Cambrian	1.000	18.43	15.61	38.2
Galena	Nassau, Germany	Carboniferous	1.000	18.10	15.57	37.85
Cerussite	Eifel, Germany	Carboniferous	1.000	18.20	15.46	37.7
Galena I	Joplin, Mo.	Late Carboniferous	1.000	21.65	15.88	40.8
Galena II	Joplin, Mo.	Late Carboniferous	1.000	21.60	15.73	40.3
			1.000	21.65	15.75	40.45
Galena	Metalline Falls, Wash.	Late Cretaceous	1.000	19.30	15.73	39.5
Cerussite	Wallace, Idaho	Late Cretaceous	1.000	15.98	15.08	35.07
			1.000	16.10	15.13	35.45
Wulfenite and Vanadinite	Tucson Mts., Arizona	Miocene	1.000	18.40	15.53	38.1
Galena	Saxony, Germany		1.000	17.34	15.47	37.45
			1.000	17.38	15.44	37.3

* For reference, see footnote 45, p. 136.

TABLE 736.—LEAD RATIOS OF SELECTED RADIOACTIVE MINERALS *

Mineral	Locality	Geologic age	Age ratio in 10^6 years
Samarskite	Glastonbury, Conn.	Pre-Triassic	270
Pitchblende	Jachymov, Bohemia	Late-Paleozoic	220
Thorite	Brevig, Norway	Permian (?)	230
Kolm	Güllhögen, Sweden	Latest Cambrian	400
Bröggerite	Karlhus, Raade, Norway	Pre-Cambrian	900
Cleveite	Aust-agder, Arendal, Norway	Pre-Cambrian	1000
Uraninite	Keystone, S. Dak.	Pre-Cambrian	1500
Uraninite	Sinyaya, Pala, Carelia, Russia	Pre-Cambrian	1850

* For reference, see footnote 45, p. 136.

TABLE 737.—ANALYSIS OF THORIUM C″ (THALLIUM 208) BETA-RAY SPECTRUM [233]

Number of line	Intensity	Origin	Energy of β-ray line + absorption energy in Mev	Energy of γ-ray Mev	Number of line	Intensity	Origin	Energy of β-ray line + absorption energy in Mev	Energy of γ-ray Mev
1	v.s.	L_I	.0252+.0158	.0410	23	m.	L_I	.2446+.0158	.2604
2	s.	L_{II}	.0259+.0152	.0411	18	v.s.	K	.1915+.0875	.2790
3	m.	L_{III}	.0278+.0133	.0411	25	m.s.	L_I	.2640+.0158	.2798
4	v.s.	M_I	.0369+.0038	.0407	20	s.	K	.2042+.0875	.2917
5	m.	M_V	.0380+.0025	.0406	26	m.s.	L_I	.2756+ 0158	.2914
6	s.	N_I	.0398+.0009	.0407	29	v.s.	K	.4281+.0875	.5156
7	m.	N_I or O	.0404+.0001	.0405	30	v.s.	L_I	.5025+.0158	.5183
8	f.	K	.0577+.0875	.1452	31	m.f.	M_I	.5150+.0038	.5188
13	f.	L_I	.1283+.0158	.1441	30	v.s.	K	.5025+.0875	.5900
12	m.s.	K	.1231+.0875	.2106	33	m.s.	L_I	.5729+.0158	.5887
19	m.f.	L_I	.1954+.0158	.2112	35	m.f.	K	.6990+.0875	.786
14	m.s.	K	.1458+.0875	.2333	36	f.	L_I	.770 +.0158	.786
21	m.f.	L_I	.2165+.0158	.2323	40	s.	K	2.558 +.0875	2.646
16	m.s.	K	.1661+.0875	.2536	41	m.	L_I	2.635 +.0158	2.651
22	f.	L_I	.2369+.0158	.2527	42	f.	M_I	2.646 +.0034	2.649
17	m.	K	.1706+.0875	.2581					

[233] Rutherford, E., Chadwick, J., and Ellis, C. D., Radiation from radioactive substances, Cambridge University Press, 1930.

TABLE 738.—ALPHA-RAY SPECTRA OF SOME NATURAL RADIOACTIVE MATERIALS

It is sometimes stated that all alpha-particles from any one source are emitted with the same energy or velocity. This is in the main true for most of the particles but careful measurements have shown that this is not always the case. For some time it was known that occasionally an alpha-particle had a range much longer than average, which, of course, means a high initial velocity.

Atomic No.	Element and isotope	α-ray	Mean range in air, cm	Velocity (cm/sec) $\times 10^{-9}$	α-ray energy Mev	Disintegration energy Mev	Energy differences from main group Mev	Relative number of particles
92	Uranium 238		2.92	1.420	4.20	4.28	....	....
	(Uranium I)							
	Uranium 234		3.5	1.515	4.76	4.85	....	....
	(Uranium II)							
91	Protactinium 231		3.8	1.553	5.01	5.11	....	....
90	Thorium 232		2.90	1.390	4.00	4.75	....	....
	Thorium 230		3	1.500	4.66	4.67	....	....
	(Ionium)							
	Thorium 228	α_0	....	1.6150	5.418	5.517	0	5
	(Radiothorium)	α_1	....	1.6020	5.335	5.431	.086	1
	Thorium 227	α_0	....	1.7063	6.049	6.159	0	80
	(Radioactinium)	α_1	....	1.7021	6.019	6.127	.32	15
		α_2	....	1.6979	5.990	6.097	.62	100
		α_3	....	1.6948	5.986	6.075	.84	15
		α_4	....	1.6885	5.924	6.030	1.29	5
		α_5	....	1.6806	5.870	5.975	1.84	10
		α_6	....	1.6729	5.817	5.921	2.38	5
		α_7	....	1.6558	5.766	5.869	.290	80
		α_8	....	1.6627	5.744	5.847	.312	15
		α_9	....	1.6589	5.719	5.822	.337	60
		α_{10}	....	1.6524	5.674	5.776	.383	10
88	Radium 226	α_0	3.5	1.520	4.793	4.879	0	....
		α_1	3.4	1.492	4.612	4.695	.184	....
	Radium 224		....	1.653	5.681	5.786	....	....
	(Thorium X)							
	Radium 223	α_0	....	1.6589	5.719	5.823	0	6
	(Actinium X)	α_1	....	1.6424	5.607	5.709	.114	4
		α_2	....	1.6316	5.533	5.634	.186	1
86	Radon 222		4.3	1.626	5.486	5.58867	....	....
	(Emanation)							
	Radon 220		4.967	1.7387	6.2872	6.3995	....	....
	(Thoron)							
	Radon 219	α_0	5.655	1.8117	6.824	6.953	0	10
	(Actinon)	α_1	(5.308)	1.7763	6.561	6.683	.270	1
		α_2	5.147	1.7593	6.436	6.556	.397	1
84	Polonium 218		4.9	1.700	6.00024	6.11239	....	....
	(Radium A)							
	Polonium 216		5.601	1.8054	6.774	6.9038	....	....
	(Thorium A)							
	Polonium 215		6.420	1.8824	7.368	7.508	....	....
	(Actinium A)							
	Polonium 214		6.870	1.9220	7.68300	7.82934	0	10^6
	(Radium C′)		7.755	1.9550	8.280	8.437	.608	.43
			....	2.0729	8.941	9.112	1.283	(.45)
			9.00	2.0876	9.068	9.242	1.412	22
			....	2.1157	9.315	9.493	1.663	.38
			....	2.1356	9.492	9.673	1.844	1.35
			....	2.1543	9.660	9.844	2.015	.35
			....	2.1678	9.781	9.968	2.138	1.06
			....	2.1817	9.908	10.097	2.268	.36
			....	2.2001	10.077	10.269	2.439	1.67
			....	2.2079	10.149	10.342	2.513	.38
			....	2.2274	10.329	10.526	2.697	1.12
			11.47	2.2466	10.509	10.709	2.880	.23
	Polonium 213		3.805	1.59715	5.3006	5.4033	....	....

(continued)

TABLE 738.—ALPHA-RAY SPECTRA OF SOME NATURAL RADIOACTIVE MATERIALS (concluded)

Atomic No.	Element and isotope	α-ray	Mean range in air, cm	Velocity (cm/sec) × 10^{-9}	α-ray energy Mev	Disintegration energy Mev	Energy differences from main group Mev	Relative number of particles
	Polonium 212		8.533	2.05405	8.7783	8.9476	0	10^6
	(Thorium C′)		9.687	2.1354	9.4912	9.6736	.726	34
			11.543	2.2501	10.5418	10.7447	1.797	190
	Polonium 211 (Actinium C′)		6.518	1.8911	7.434	7.581	....	....
83	Bismuth 214	α_0	(4.039)	1.630	5.5068	5.6117	0	94
	(Radium C)	α_1	(3.969)	1.620	5.4458	5.5495	.062	113
	Bismuth 212	α_1	....	1.7108	6.081	6.20069	0	27.2
	(Thorium C)	α_2	....	1.7053	6.044	6.16069	.0400	69.8
		α_3	....	1.6651	5.762	5.8729	.3278	1.80
		α_4	....	1.6446	5.620	5.7283	.4724	.16
		α_5	....	1.6418	5.610	5.7089	.4918	1.10
	Bismuth 211	α_0	5.392	1.7832	6.619	6.739	0	100
	(Actinium C)	α_1	4.947	1.7356	6.262	6.383	.356	19

TABLE 739.—CHARACTERISTICS OF SOME HIGH-SPEED ALPHA-PARTICLES FROM NATURAL RADIOACTIVE SOURCES *

Atomic No.	Element	Isotope	Common name	Velocity	Energy Mev	Range † cm
92	Uranium	234	Uranium II	1.516×10^9	4.76	3.4
		235	Actinouranium	1.483	4.56	3.2
		238	Uranium I	1.43	4.18	2.9
91	Protactinium	231	....	1.555	5.01	3.7
90	Thorium	227	Radioactinium	....	6.05	4.8
		228	Radiothorium	1.616	5.42	4.1
		230	Ionium	1.500	4.66	3.3
		232	Thorium	1.498	3.98	2.7
89	Actinium	227	Actinium	1.537	4.94	3.6
88	Radium	223	Actinium X	1.660	5.72	4.4
		224	Thorium X	1.657	5.68	4.4
		226	Radium	1.520	4.79	3.5
86	Radon	219	Actinon	1.814	6.82	5.8
		220	Thoron	1.729	6.28	5.1
		222	Radon	1.628	5.49	4.2
85	Astatine	215	....	1.964	8.00	7.4
		216	....	1.937	7.79	7.1
		218	....	1.802	6.72	5.7
84	Polonium	210	Polonium	1.599	5.30	4.0
		211	Actinium C′	1.894	7.43	6.6
		212	Thorium C′	2.058	8.78	8.7
		214	Radium C′	1.925	7.68	7.0
		215	Actinium A	1.886	7.37	6.5
		216	Thorium A	1.805	6.77	5.8
		218	Radium A	1.701	6.00	4.8
83	Bismuth	211	Actinium C	1.787	6.62	5.6
		212	Thorium C	1.713	6.08	4.9
		214	Radium C	1.630	5.51	4.2

* For reference, see footnote 199, p. 618.
† Approximate range in air (from curve).

TABLE 740.—CHARACTERISTICS OF SOME HIGH-SPEED ALPHA-PARTICLES FROM ARTIFICIAL RADIOACTIVE SOURCES *

Atomic No.	Element	Isotope	Velocity cm/sec	Energy Mev	Range in air,† cm
96	Curium	238	1.77×10^9	6.50	5.4
		240	1.74	6.26	5.1
		241	1.71	6.08	4.9
		242	1.72	6.1	4.9
95	Americium	239	1.67	5.77	4.5
		241	1.62	5.48	4.2
94	Plutonium	232	1.78	6.6	5.5
		234	1.73	6.2	5.0
		236	1.66	5.75	4.5
		238	1.63	5.51	4.2
		239	1.57	5.15	3.8
		240	1.57	5.1	3.8
93	Neptunium	231	1.73	6.2	5.0
		235	1.56	5.06	3.8
		237	1.51	4.77	3.4
92	Uranium	228	1.80	6.72	5.7
		229	1.76	6.42	5.3
		230	1.68	5.85	4.6
91	Protactinium	226	1.81	6.81	5.8
		227	1.76	6.46	5.4
		228	1.71	6.09	4.9
		229	1.66	5.69	4.4
90	Thorium	224	1.86	7.20	6.3
		225	1.78	6.57	5.5
		226	1.74	6.30	5.1
		227	1.71	6.05	4.8
		229	1.56	5.02	3.7
89	Actinium	222	1.83	6.96	6.0
		223	1.79	6.64	5.6
		224	1.73	6.17	5.0
		225	1.67	5.80	4.5
88	Radium	220	1.90	7.49	6.7
		221	1.80	6.71	5.6
		222	1.77	6.51	5.4
		224	1.65	5.68	4.4
87	Francium	218	1.94	7.85	7.2
		219	1.88	7.30	6.4
		220	1.80	6.69	5.6
		221	1.74	6.30	5.2
86	Radon	216	1.97	8.07	7.6
		217	1.93	7.74	7.1
		218	1.85	7.12	6.2
85	Astatine	207	1.67	5.76	4.5
		208	1.65	5.66	4.4
		211	1.69	5.89	4.6
		214	2.06	8.78	8.4
		217	1.84	7.02	6.1
84	Polonium	208	1.57	5.14	3.8
		205	1.61	5.35	4.0
		206	1.58	5.2	3.9
		213	2.01	8.34	8.0
83	Bismuth	197	1.73	6.20	5.0
		198	1.68	5.83	4.6
		199	1.62	5.47	4.1
		200	1.58	5.15	3.8

* For reference, see footnote 199, p. 618.
† Approximately, from curve.

TABLE 741.—VAPOR PRESSURE OF THE RADIUM EMANATION IN cmHg

Temperature °C	−127	−101	−65	−56	−10	+17	+49	+73	+100	+104 (crit)
Vapor pressure	.9	5	76	100	500	1000	2000	3000	4500	4745

TABLE 742.—BETA-RAYS FROM RADIOACTIVE MATERIALS—BOTH NATURAL (MARKED WITH *) AND ARTIFICIAL

Atomic No.	Element	Isotope	Radioactive name	Energy in Mev
95	Americium	242 m	....	.8
93	Neptunium	239	....	.68
		238		1.39
92	Uranium	239	....	1.20
91	Protactinium	234 m*	Uranium X_2	2.32
		230	....	~1.1
90	Thorium	233	....	1.2
89	Actinium	228*	Mesothorium 2	1.55
87	Francium	223*	Actinium K	1.20
83	Bismuth	213	....	~1.3
		210*	Radium E	1.17
82	Lead	211*	Actinium B	1.40
		209	....	.7
81	Thallium	209	....	1.8
		208*	Thorium C″	1.82
		207*	Actinium C″	1.47
		206	....	1.70
		204	....	.8
80	Mercury	205	....	1.62
79	Gold	200–202	....	2.5
		198	....	.96
78	Platinum	199	....	1.8
		197	....	.65
77	Iridium	194	....	2.2
		192	....	.67

Atomic No.	Element	Isotope	Energy in Mev
76	Osmium	193	1.5
75	Rhenium	188	2.5
		186	1.07
74	Tungsten	187	.63
73	Tantalum	182	1.0
71	Lutetium	176 m	1.15
		170	1.7 β^+
70	Ytterbium	177	1.3
69	Thulium	170	1.0
68	Erbium	171	1.49
67	Holmium	166	1.8
		162–161	2.0 β^+
65	Terbium	154	2.6 β^+
64	Gadolinium	161	1.5
63	Europium	>154	~2.5
		157	~1.
		154	.9
		152	1.88
62	Samarium	155	1.9
		153	.78
61	Promethium	149	1.1
		148	2.5
			1.7
			2.0
60	Neodymium	149	1.6
		141	.78 β^+
59	Praseodymium	145	3.2
		144	3.0
		140	2.5 β^+
58	Cerium	143	1.36
57	Lanthanum	141	2.9
		<139	2.1
56	Barium	140	1.05
		139	2.27
55	Cesium	138	2.6

Atomic No.	Element	Isotope	Energy in Mev
54	Xenon	137	4.0
		135	.93
53	Iodine	136	6.5
		135	1.4
		133	1.4
		128	1.59
52	Tellurium	129	1.8
		127	.76
51	Antimony	126	2.8
		124 m	3.2
		124	2.37
		122	1.36
		120	1.53 β^+
		118	3.1 β^+
50	Tin	>120	1.8
		125	~2.2
		123	2.6
49	Indium	117	1.73
		116	2.8
		114	1.98
		112	1.5
			2.2 β^+
48	Cadmium	115 m	1.8
47	Silver	113	2.2
		112	3.6
		110	2.6
		108	2.8
		106	2.04 β^+
46	Palladium	111	3.5
		101	2.3 β^+
45	Rhodium	106	3.55
		104	2.3
44	Ruthenium	107	~4.
		105	1.4
		95	1.1 β^+

(continued)

TABLE 742.—BETA-RAYS FROM RADIOACTIVE MATERIALS—BOTH NATURAL (MARKED WITH *) AND ARTIFICIAL (concluded)

Atomic No.	Element	Isotope	Energy in Mev
43	Technetium	101	1.3
		100	2.3
		95	1.3
		94	2.47 β^+
		92	4.3 β^+
42	Molybdenum	101	2.0
		99	1.3
		93	2.65 β^+
41	Niobium	97	1.4
		96	1.8
		92	1.38
40	Zirconium	97	2.2
		89	1.07 β^+
39	Yttrium	93	3.1
		92	3.5
		91	1.5
		90	2.35
		88	.83 β^+
38	Strontium	91	1.3
		89	1.5
37	Rubidium	88	4.6
		86	1.8
		81	.9 β^+
36	Krypton	87	~4.
		85	1.0
35	Bromine	85	2.5
		84	5.3
		80	2.0
		78	2.3 β^+
		76	3.15 β^+
		75	1.6 β^+
34	Selenium	83	1.5
		83 m	3.4
		81	1.5
33	Arsenic	78	1.4
		74	1.3
		72	2.78 β^+
32	Germanium	77 m	2.8
		77	2.0
		71	1.2 β^+
31	Gallium	73	1.4
		70	1.68
		68	1.9 β^+
		66	3.1 β^+
30	Zinc	69	1.0
		63	2.3
29	Copper	66	2.9
		62	2.6 β^+
		61	1.2 β^+
		60	1.8 β^+
28	Nickel	65	1.9
		57	.67 β^+
27	Cobalt	62	2.5
		56	1.5 β^+
26	Iron	52	.55 β^+
25	Manganese	52 m	2.66 β^+
		51	2.0 β^+
24	Chromium	49	1.45 β^+
23	Vanadium	52	2.05
		47	1.9 β^+
22	Titanium	51 m	1.6
		45	1.2 β^+
21	Scandium	49	1.8
		44	1.5 β^+
		41	4.94 β^+
20	Calcium	49	2.3
19	Potassium	42	2.04
		40*	1.9
		38	2.5 β^+
18	Argon	41	1.18
		35	4.4 β^+
17	Chlorine	38	1.19
		34	2.5 β^+
		33	4.1 β^+
16	Sulfur	37	4.3
		31	3.85 β^+
15	Phosphorus	34	5.1
		32	1.7
		30	3.0 β^+
		29	3.6 β^+
14	Silicon	31	1.8
		27	3.74 β^+
13	Aluminum	29	2.5
		28	3.0
		26	3.0 β^+
12	Magnesium	23	2.82 β^+
11	Sodium	24	1.4
10	Neon	23	4.1
		19	2.2 β^+
9	Fluorine	20	5.0
		17	2.1 β^+
8	Oxygen	19	4.5
		14	1.8 β^+
7	Nitrogen	17	3.7
		16	3.5
		13	1.24 β^+
6	Carbon	~10	2 β^+
5	Boron	12	12
3	Lithium	8	12
2	Helium	6	3.7

TABLE 743.—RELATIVE STOPPING POWER OF SELECTED SUBSTANCES FOR α-PARTICLES [234]

Substance	Relative stopping power	Range in substance / Range in air
air	1	1
O_2	1.07	.93
H_2	.21	4.77
He	.17	5.88
Ne	.62	1.61
A	.98	1.02
Kr	1.52	.66
Xe	1.98	.50
Al	1700.00	5.8510^{-4}

[234] Rasetti, Franco, Elements of nuclear physics. Copyright 1936 by Prentice-Hall, Inc., New York.

TABLE 744.—ANALYSIS OF THE BETA-RAY SPECTRUM OF RADIOACTINIUM (THORIUM 227) *

Number of line	Intensity	Origin	Energy of β-ray line + absorption energy Mev	Energy of γ-ray Mev	Number of line	Intensity	Origin	Energy of β-ray line + absorption energy Mev	Energy of γ-ray Mev
1	20	L_I	.0125+.0192	.0317	26	40	L_I	.0813+.0192	.1005
3	20	L_{III}	.0160+.0154	.0314	29	30	M_I	.0965+.0048	.1013
6	15	M_I	.0262+.0048	.0310	30	30	N_I	.0990+.0012	.1002
7	10	M_{II}	.0271+.0044	.0315	18	100	K	.0454+.1035	.1489
9	15	M_V	.0290+.0031	.0321	35	80	L_I	.1305+.0192	.1497
10	30	N_I	.0299+.0012	.0311	36	30	M_I	.1445+.0048	.1493
11	20	N_{VI}	.0305+.0003	.0308	28	50	K	.0936+.1035	.1971
12	15	..	.0320	.0320	38	30	L_I	.1753+.0192	.1945
4	50	L_I	.0246+.0192	.0438	40	20	M_I	.1899+.0048	.1947
5	20	L_{II}	.0255+.0185	.0440	37	60	K	.1501+.1035	.2536
8	25	L_{III}	.0281+.0154	.0435	46	40	L_I	.2348+.0192	.2540
16	10	M_I	.0388+.0048	.0436	47	30	M_I	.2488+.0048	.2536
14	40	L_I	.0340+.0192	.0532	39	60	K	.1796+.1035	.2831
19	20	M_I	.0486+.0048	.0534	48	20	L_I	.2618+.0192	.2810
17	90	L_I	.0425+.0192	.0617	41	50	K	.1976+.1035	.3011
20	70	M_I	.0567+.0048	.0615	49	20	L_I	.2800+.0192	.2992
21	50	N_I	.0598+.0012	.0610					

* For reference, see footnote 233, p. 679.

TABLE 745.—ANALYSIS OF BETA-RAY SPECTRUM OF MESOTHORIUM 2 (ACTINIUM 228) *

Number of line	Intensity	Origin	Energy of β-ray line + absorption energy Mev	Energy of γ-ray Mev	Number of line	Intensity	Origin	Energy of β-ray line + absorption energy Mev	Energy of γ-ray Mev
1	100	L_I	.0381+.0204	.0585	18	6	M_I	.1782+.0052	.1834
2	85	L_{III}	.0416+.0162	.0578	16	18	K	.1406+.1092	.2498
3	65	M_I	.0523+.0052	.0584	20	8	L_I	.2291+.0204	.2495
4	45	N_I	.0566+.0013	.0579	19	16	K	.2099+.1092	.319
5	6	L_I	.0593+.0204	.0797	21	6	L_I	.299 +.0204	.319
6	4	L_{III}	.0631+.0162	.0793	22	2	N_I	.318 +.001	.319
The M and N lines would be masked exactly					23	8	K	.352 +.109	.461
by the intense lines 8 and 9.					24	4	L_I	.442 +.020	.462
11	35	L_I	.1093+.0204	.1297	25	2	M_I	.458 +.005	.463
12	25	L_{III}	.1129+.0162	.1291	26	6	K	.804 +.109	.913
13	22	M_I	.1245+.0052	.1297	28	2	L_I	.897 +.020	.917
14	6	N_I	.1279+.0013	.1292	27	3	K	.861 +.109	.970
8	50	K	.0749+.1092	.1841	29	2	L_I	.949 +.020	.969
17	20	L_I	.1644+.0204	.1848					

* For reference, see footnote 233, p. 679.

TABLE 746.—ANALYSIS OF THE BETA-RAY SPECTRUM OF PROTACTINIUM *

Number of line	Intensity	Origin	Energy of β-ray line + absorption energy Mev	Energy of γ-ray Mev	Number of line	Intensity	Origin	Energy of β-ray line + absorption energy Mev	Energy of γ-ray Mev
1	60	L_I	.0753+.0198	.0951	10	30	M_I	.2869+.0050	.2919
2	40	L_{III}	.0788+.0158	.0946	6	70	K	.2194+.1064	.3258
3	40	M_I	.0905+.0050	.0950	11	40	L_I	.3016+.0198	.3214
5	100	K	.1896+.1064	.2960	12	20	M_I	.3182+.0050	.3232
9	60	L_I	.2746+.0198	.2944					

* For reference, see footnote 233, p. 679.

TABLE 747.—GAMMA-RAY ENERGY OF SOME HEAVY ISOTOPES, NATURAL AND ARTIFICIAL

Atomic No.	Element	Isotope	γ-ray energy Mev	Atomic No.	Element	Isotope	γ-ray energy Mev
95	Americium	240	1.3	83	Bismuth	214	1.8
94	Plutonium	239	.42		(Radium C *)		
93	Neptunium	238	1.2			206	.74
		234	1.9	82	Lead	211	.8
92	Uranium	233	.31		(Actinium B *)		
91	Protactinium	234	.70			204 m	1.1
	(Uranium Z *)			81	Thallium	208	2.62
	(Uranium X_2*)	234 m	.81		(Thorium C″)		
		232	1.05			199	1.5
		230	.94			198	1.3
85	Astatine *	210	1.0	80	Mercury	198 m	.4
84	Polonium	210	.77				
	(Radium F)						
		207	1.3				
		206	.8				

* Natural radioactive source.

TABLE 748.—THE GAMMA-RAY SPECTRUM OF ThC″ *

These differences of energies, or velocities, of the α-ray from thorium C are sometimes explained on the energy-level basis of the nucleus. The agreement with the energies of the γ-rays emitted from ThC″, the daughter of ThC, and these apparent differences of disintegration energy of α-ray of ThC, given in the table show one agreement with this theory.

Transitions between levels	Apparent difference of disintegration energy of α-ray groups of ThC	Energy of observed γ-ray from ThC″	Transitions between levels	Apparent difference of disintegration energy of α-ray groups of ThC	Energy of observed γ-ray from ThC″
$L_2 - L_1$	.040	.040	$L_4 - L_2$	.433	.432
$L_3 - L_1$	.328	.327	$L_5 - L_2$	.452	.451
$L_4 - L_1$	.473	.471	$L_4 - L_3$	.145	...
$L_5 - L_1$	.492	...	$L_5 - L_3$	.164	...
$L_3 - L_2$	.288	.287	$L_5 - L_4$	.019	...

* For reference, see footnote 225, p. 666.

TABLE 749.—DANGER RANGES FOR PERSONS WHO ARE WORKING WITH RADIUM, FOR DIFFERENT AMOUNTS OF RADIUM, PROVIDING THE RADIUM IS ENCLOSED IN NOT LESS THAN 1 mm LEAD OR ITS EQUIVALENT

Amount of radium element milligrams	Daily exposure (in hours) 1	2	4	8	16
	Danger range (in meters)				
100	.9	1.3	1.8	2.5	3.6
200	1.3	1.8	2.6	3.6	5.1
400	1.8	2.5	3.5	5	7.1
1000	2.9	4	5.7	8	11.3

TABLE 750.—GAMMA-RAY ENERGY OF SOME ARTIFICIAL RADIOACTIVE ISOTOPES OF LOW ATOMIC WEIGHT

Atomic No.	Element	Isotope	γ-ray energy Mev	Atomic No.	Element	Isotope	γ-ray energy Mev
4	Beryllium	7	.49	40	Zirconium	95	.73
7	Nitrogen	15	6.7	41	Niobium	92	1.0
8	Oxygen	14	2.3			96	1.0
		19	1.6	42	Molybdenum	93	1.6
9	Fluorine	20	2.2	43	Technetium	92, 93	2.4
11	Sodium	22	1.3	45	Rhodium	100	1.2
		24	1.38			106	1.25
12	Magnesium	27	1.0	47	Silver	110	1.40
13	Aluminum	28	1.80	48	Cadmium	107	.84
16	Sulfur	37	2.6	49	Indium	116	2.32
17	Chlorine	34	3.4	50	Tin	126	1.2
		38	1.60	51	Antimony	118	1.5
18	Argon	41	1.37			124	2.04
19	Potassium *	38	2.15	52	Tellurium	119	1.4
		40	1.54	53	Iodine	135	1.6
		42	1.4			136	2.9
20	Calcium	47	1.3	54	Xenon	127	.9
		48	.8	55	Cesium	136	1.2
21	Scandium	43	1.65			138	1.2
		44	1.33	56	Barium	140	.53
		48	1.3	57	Lanthanum	140	1.63
22	Titanium	51	1.0	58	Cerium	139	1.8
23	Vanadium	52	1.46	59	Praseodymium	142	1.9
25	Manganese	52 m	1.46			146	1.4
		56	2.06	61	Promethium	143	.67
26	Iron	59	1.10	63	Europium	156	2.0
27	Cobalt	60	1.16	65	Terbium	154	1.4
		62	1.3	67	Holmium	162	1.1
28	Nickel	65	1.1	69	Thulium	166	1.5
29	Copper	60	1.5	71	Lutetium	170	1.5
		64	1.35	72	Hafnium	175	1.5
		66	1.32	73	Tantalum	176	1.7
30	Zinc	65	1.11			182	1.2
32	Germanium	75	1.1	75	Rhenium	182	1.5
33	Arsenic	72	2.4	76	Osmium	193	1.58
35	Bromine	76	2.0	77	Iridium	194	1.35
		82	1.35	78	Platinum	193	1.5
37	Rubidium	81	.8	79	Gold	192	2.3
		82	1.0	81	Thallium	198	1.3
		86	1.08	82	Lead	204 m	1.1
38	Strontium	91	1.3	83	Bismuth	206	.74
39	Yttrium	88	2.76				
		93	.7				

* Natural radioactive source.

TABLE 751.—TOTAL MASS ABSORPTION COEFFICIENT, μ/ρ, FOR γ-RAYS IN VARIOUS ELEMENTS (IN CM^2/G)

Wavelength A	C	Al	Cu	Ag	Pb
.1	.15	.16	.36	1.4	3.8
.2	.16	.28	1.5	5.6	4.9
.3	.19	.47	4.3	17.	14.
.4	.25	1.1	9.8	38.	31.
.5	.35	2.0	19.	71.	54.

TABLE 752.—GAMMA SPECTRUM FOR SOME RADIOACTIVE BREAKDOWNS *

$h\nu$ (Mev)	λA	Conversion observed
γ-rays of 89 Actinium 228→90 Thorium 228 (MsTh₂) (RaTh)		
.0581	.213	$L_IL_{III}M_IN_I$
.0795	.156	L_IM_{III}
.1294	.096	$L_IL_{III}M_IN_I$
.1841	.067	$K\ L_IM_I$
.2497	.050	$K\ L_I$
.319	.039	$K\ L_IN_I$
.338	.037	observed in external photoeffect
.408	.030	observed in external photoeffect
.462	.027	$K\ L_IM_I$
.915	.0135	$K\ L_I$
.970	.0128	$K\ L_I$
γ-rays of 90 Thorium 227→88 Radium 223 (RdAc) (AcX)		
.0315	.390	$L_IL_{III}M_IM_{II}N_{VI}$
.0437	.284	$L_IL_{II}L_{III}M_I$
.0533	.237	L_IM_I
.0614	.207	$L_IM_IN_I$
.1007	.123	$L_IM_IN_I$
.1493	.083	$K\ L_IM_I$
.1954	.063	$K\ L_IM_I$
.253	.049	$K\ L_IM_I$
.282	.044	$K\ L_I$
.300	.041	$K\ L_I$
γ-rays of 88 Radium 223→86 Radon 219 (AcX) (An)		
.1435	.086	$K\ L_IM_I$
.153	.081	$K\ L_IM_IN_I$
.157	.079	$K\ L_IM_I$
.200	.062	$K\ L_I$
.269	.046	$K\ L_I$
γ-rays of 90 Thorium 228→88 Radium 224 (RaTh) (ThX)		
.0848	.146	L_IM_I
.0881	.141	L_IM_I
γ-rays of 88 Radium 226→86 Radon 222		
.169	.066	$K\ L_IM_I$
γ-rays of 82 Lead 210→83 Bismuth 210 (RaD) (RaE)		
.0472	.026	$L_IL_{II}L_{III}M_IN_I$
γ-rays of 91 Protactinium 231→89 Actinium 227		
.0949	.0130	$L_IL_{III}M_I$
.294	.042	$K\ L_IM_I$
.323	.038	$K\ L_IM_I$
γ-rays of 82 Lead 214→83 Bismuth 214 (RaB) (RaC)		
.0529	.0235	$L_IL_{II}L_{III}M_IM_{II}M_{III}N_IO$
.2406	.052	$K\ C_{II}M_I$
.2571	.048	$K\ L_I$
.2937	.042	$K\ L_I$
.3499	.035	$K\ L_IM_IN_I$
γ-rays of 84 Polonium 210→82 Lead 206 (RaF) (RaG)		
.202	.062	K
.798	.0156	K
1.068	.0116	K
γ-rays of 83 Bismuth 211→81 Thallium 207 (AcC) (AcC″)		
γ-rays of 84 Polonium 211→82 Lead 207 (AcC′) (AcD)		
.354	.035	$K\ L_IM_I$
.460	.027	$K\ L_I$
.480	.026	$K\ L_I$
γ-rays of 83 Bismuth 214→84 Polonium 214 (RaC) (RaC′)		
.6067	.0205	$K\ L_IM_IN$
.766	.0162	K
.933	.0133	K
1.120	.0112	$K\ L_IM_I$
1.238	.0100	$K\ L_I$
1.379	.0090	K
1.414	.0088	$K\ L_IM_I$
1.761	.0071	$K\ L_I$
2.198	.0056	$K\ L$
γ-rays of 82 Lead 212→83 Bismuth 212 (ThB) (ThC)		
.1147	.0108	$L_IL_{II}M_IN_I$
.1757	.0071	K
.2379	.0052	$K\ L_IL_{II}L_{III}M_IN_I$
.2494	.0049	K
.2990	.0041	$K\ L_IM_I$
γ-rays of 83 Bismuth 212→84 Polonium 212 (TcC) (ThC′)		
.726	.0171	K
1.623	.0076	K
1.882	.0066	K
γ-rays of 83 Bismuth 212→81 Thallium 208 (ThC) (ThC″)		
.399	.0036	$L_IL_{II}L_{III}M_IM_{II}N_IO$
.287	.0043	$K\ L_I$
.298	.0042	K
.327	.0039	K
.432	.0287	K
.451	.0275	K
.471	.0263	K
.617	.0201	K
γ-rays of 84 Polonium 212→82 Lead 208 (ThC′) (ThD)		
.2765	.045	$K\ L_IL_{III}$
.5100	.0243	$K\ L_IM_I$
.5523	.0224	$K\ L_IM_I$
2.620	.0047	$K\ L_IM_I$

* For reference, see footnote 234, p. 684.

(continued)

TABLE 752.—GAMMA SPECTRUM FOR SOME RADIOACTIVE BREAKDOWNS (concluded)

γ-rays[235] from 82 Lead 210→83 Bismuth 210
(RaD) (RaE)

γ-ray line	E (kev)	γ-ray line	E (kev)
(X)	65 ± 5	D	32 ± 1
A	46.7 ± .1	E	23.2 ± .6
B	43 ± 1	F	7.3 ± .7
C	37 ± 1		

[235] San Tsiang Tsien, Phys. Rev., vol. 69, p. 38, 1946.

TABLE 753.—THE ENERGY RADIATED BY A NUMBER OF RADIOACTIVE MATERIALS *

Material	Half-life	Radiation	Energy of radiation in Mev: α or β	γ	Disintegrations No g^{-1} sec^{-1}	Radiation Mev g^{-1} sec^{-1}
92 Uranium 238 (Uranium I)	4.5×10^{9} yr	α	4.2	..	1.23×10^{4}	5.2×10^{4}
90 Thorium 232	1.39×10^{10} yr	α	4.1	..	4.1×10^{3}	1.70×10^{4}
88 Radium 226	1620 yr	α γ	4.79	.19	3.6×10^{10}	1.80×10^{11}
86 Radon 222	3.825 d	α	5.486	..	5.7×10^{15}	3.1×10^{16}
86 Radon 220 (Thoron)	54.5 sec	α	6.282	..	3.5×10^{19}	2.2×10^{20}
86 Radon 219 (Actinon)	3.92 sec	α	6.824	..	4.8×10^{20}	3.3×10^{21}
86 Radon 217	10^{-3} sec	α	7.74	..	1.93×10^{24}	1.50×10^{25}
84 Polonium 214 (Radium C′)	1.5×10^{-4} sec	α	7.680	..	1.30×10^{25}	1.0×10^{26}
84 Polonium 212 (Thorium C′)	3.1×10^{-7} sec	α	8.776	..	6.4×10^{27}	5.6×10^{28}
84 Polonium 211 (Actinium C′)	5×10^{-8} sec	α	7.434	..	3.9×10^{23}	2.9×10^{24}
84 Polonium 210	138 d	α γ	5.3	.77	1.57×10^{15}	1.2×10^{15}
83 Bismuth 214	19.7 min	α γ	5.5	1.8	1.65×10^{18}	3.0×10^{18}
81 Thallium 210 (Radium C″)	1.32 min	β^-	1.8	..	2.51×10^{19}	4.5×10^{19}
81 Thallium 208 (Thorium C″)	3.1 min	β^- γ	1.7	2.6	1.08×10^{19}	4.7×10^{19}
81 Thallium 207 (Actinium C″)	4.76 min	β^- γ	1.47	..	7.1×10^{18}	1.04×10^{19}
59 Praseodymium 142	19.3 hr	β^- γ	2.1	1.9	4.28×10^{17}	8×10^{17}
53 Iodine 136	1.8 min	β^- γ	6.5	2.9	2.85×10^{20}	8×10^{20}
19 Potassium 40 **	1.8×10^{9} yr	β^- γ	1.9	1.54	1.84×10^{5}	3.9×10^{5}

* For reference, see footnote 199, p. 618.
** The radiation from potassium may seem to be too intense as compared to that from thorium 232 or uranium 238 but it must be remembered that the active isotope of potassium constitutes only .01 percent of ordinary potassium while the active isotopes of uranium and thorium constitute about 100 percent of the material. It is also to be noted that the active isotope of potassium has more disintegration than either uranium or thorium, in part due to its greater number of atoms per gram.

TABLE 754.—SAFE WORKING DISTANCES FOR DIFFERENT EXPOSURE TIMES TO DIFFERENT AMOUNTS OF RADIUM

Daily exposure milligram-hr	Safe distance meters	Daily exposure milligram-hr	Safe distance meters
100	1	800	2½
200	1½	1600	3½
400	2	3200	5

TABLE 755.—COMBINATION OF LEAD SHIELD THICKNESS AND DISTANCE FOR ADEQUATE PROTECTION FOR EXPOSURES TO DIFFERENT AMOUNTS OF RADIUM, NOT EXCEEDING 8 HOURS PER DAY

Workers with radioactive materials must observe certain precautions to avoid being burned by the emitted radiations. Tables 749, 751, 754, 755, taken from the National Bureau of Standards Handbook H 23 on Radium Protection, give some of the necessary precautions. These precautions are for radium; if some other radioactive product is being worked with, care must be taken to increase these precautions if the materials are more active than radium. See Table 732.

The α-rays are much more easily stopped than the β- or γ-rays. The most energetic α-rays are stopped by an ordinary sheet of paper or a sheet of aluminum .06 mm thick. The β-rays are stopped by a few millimeters of aluminum, while many of the γ-rays will penetrate a block of lead a number of inches thick.

Amount of radium milligrams	Thickness of lead cm	Distance cm	Amount of radium milligrams	Thickness of lead cm	Distance cm
10	.5	70	1000	1	570
	1	60		3	340
	2	45		6	160
100	1	185	5000	4	550
	2	140		6	160
	3	105		10	220

TABLE 756.—CONSTANTS FOR CATHODE-RAY SPEEDS IN MATTER

Cathode rays whose direction of motion is perpendicular to the direction of a uniform magnetic field (H) describe a circular path of radius (r) according to the formula corrected for relativity change of mass of electron.

$$Hr = 1704\,[\beta\,(1-\beta^2)^{-1/2}]$$

where H is expressed in gauss and r in cm.

When cathode rays impinge on matter they are deflected from their original direction of motion. These deflections grade all the way from 180° "reflections" to the "diffusion" corresponding to deflections through very small angles. The large-angle deflections are ordinarily comparatively infrequent. However, when the substance struck by the cathode rays is crystalline, certain directions may be preferred by the deflections. Here the beam of cathode rays behaves as though it consisted of a train of waves of wavelength $\lambda_e = 0.02426/\beta$, where λ_e is in angstroms. The preferred directions for the "reflected" cathode-ray beams may be calculated from the Bragg formula (see Siegbahn's "X-ray Spectroscopy"). The simple Bragg formula is quite limited in application here, however, since refraction in the crystal is very appreciable for the cathode-ray beams. In general, the cathode rays which have been deflected bv matter will have lost speed, but the rays which have undergone these "preferred" deflections remain of the same speed as the primary cathode beam.

Cathode rays lose speed on penetrating matter. The losses of speed by individual cathode particles grade from complete stoppage to no loss of speed. The majority of the cathode particles, however, lose speed according to the relation (Thomas-Whiddington-Bohr law)

$$\beta_0^4 - \beta^4 = ax$$

where β_0 is the initial speed, and β the speed after traversing a path length x in the material (x to be measured in cm along the actual curved path), and a is a constant roughly equal to 6.5ρ where ρ is the density of the material in g/cm³. A convenient form for the expression is the following. Note that the two forms are not equivalent except at very low speeds (experiment has not yet decided between the two):

$$V_0^2 - V^2 = bx$$

where V_0 and V are the initial and final "equivalent voltages" (see above) of the cathode rays, in kv, and b is a constant roughly equal to $40 \times 10^4\rho$. A tabulation of experimental values of a and b for various materials follows:

Material	a	b
Beryllium	12.	$.75 \times 10^6$
Aluminum	17.	1.1 "
Copper	56.	3.6 "
Silver	66.	4.2 "
Gold	138.	9.0 "
Moist air, 76 cmHg 18° C	.0062	$.44 \times 10^3$

TABLE 757.—ENERGY IN CALORIES/HR DEVELOPED BY ONE GRAM OF RADIUM IN EQUILIBRIUM WITH ITS PRODUCTS*

Material	Radiation	Energy radiation in Mev α	β	γ
88 Radium 226	$\alpha\gamma$	17.32×10^{10}	....	$.69\times10^{10}$
86 Radon 222	α	19.80	....	....
84 Polonium 218 (Radium A)	α	21.64	....	....
82 Lead 214 (Radium B)	$\beta^-\gamma$	....	2.35×10^{10}	....
83 Bismuth 214 (Radium C)	$\alpha(.04\%)\beta^-\gamma$	....	11.46	6.50
84 Polonium 214 (Radium C′)	α	27.70	....	....
81 Thallium 210 (Radium C″)	β^-	....	6.50	....
82 Lead 210 (Radium D)	$\beta^-\gamma$	....	.09	.17
83 Bismuth 210 (Radium E)	β^-	....	4.22	....
84 Polonium 210 (Radium F)	$\alpha\gamma$	19.53	....	2.78
Radiation totals in Mev		105.99×10^{10}	24.62×10^{10}	10.14×10^{10}
Energy due to recoil of atom		3.71		
Alpha rays and recoil		109.70×10^{10}		

Total energy radiated (α, β^-, γ in Mev) $= 144.46\times10^{10} = 199$ cal/hr.
The total heating effect developed by one gram of radium in equilibrium with its products in 199 cal/hr.

* For reference, see footnote 199, p. 618.

TABLE 758.—CATHODE RAYS

Owing to the growth of the subject, electrons are treated under three separate headings; cathode rays, the swiftly moving electrons from the cathode in a discharge tube; beta rays, from radioactive breakdown; and the general field, electrons. The velocity of the cathode rays (electrons) depends upon the applied voltage. At comparatively low pressures the cathode rays have a nearly uniform velocity. Free electrons are emitted from hot bodies (Table 683-689), especially if the heated substance is coated with barium, calcium, or strontium oxide (Wehnelt cathode). These electrons can be given any desired speed, always less than that of light, if the heated substance (usually in the form of a wire) be enclosed in an evacuated tube and the difference of potential (V) applied between the wire (cathode) and another electrode (anode, anticathode, or target). The speed of the electron and also its kinetic energy is often designated by giving the applied voltage, i.e., a 10 kv electron has a speed of 10 kv, about .2 that of light, and an energy of 10,000 ev, or 1.602×10^{-8} ergs. (See Table 713.) The speed (v) of the cathode rays, expressed as a fractional part (β) of the speed of light ($\beta = v/c$, where c is the speed of light), when they have fallen through the entire potential difference, is given by the formula (which is corrected for the relativity change of mass)

$$V = 510.8\,[(1-\beta^2)^{-1/2}-1]$$

where V is in kilovolts.
A tabulation of the corresponding values of V (kilovolts) and β follows.

β	V(kv)	β	V(kv)	β	V(kv)
.01	.0255	.40	46.5	.90	661.
.02	.1022	.50	79.0	.942	1000.
.05	.639	.548	100.	.95	1085.
.10	2.574	.60	127.7	.98	2045.
.20	10.53	.80	340.4		

X-rays, which are short wavelength (.06 – 1020*A*) radiant energy, are, in general, generated whenever swiftly moving electrons are suddenly stopped by striking any material substance. The electrons may come from a cold cathode (gas-filled tube) and the current increased by ionization of the gas in the tube, or they may come from a hot cathode (Coolidge tube) in a tube of very low gas pressure. Soft and hard X-rays are terms applied to X-rays produced by low or high applied voltage respectively.

Two types of X-rays are generated when the electrons hit the target—continuous spectrum (over a limited wavelength) and the radiation that is characteristic of the material of which the anode is made. The continuous X-ray spectrum has a very definite short-wave limit that depends upon the voltage applied to the tube. Thus

$$V_0 e = h\nu_0 = hc/\lambda_0$$

If V_0 is given in volts, this wavelength λ_0 will be in angstroms if the other units are properly chosen.

$$\lambda_0 \text{ (in } A) = \frac{12395}{V_0}$$

The characteristic spectra are designated *K, L, M, N, O,* etc., where these letters refer to the various electron shells (Table 658).

X-rays, like any type of radiant energy, have two characteristics; intensity (i.e., the rate of energy transfer), and wavelength. These two quantities are connected thus: the energy $E = h\nu = hc/\lambda$.

This, of course, assumes monochromatic radiation or the energy for a narrow wavelength interval, which is not always the case; all electrons do not hit the anode with the same energy nor do all materials react alike to electron bombardment. Some of the characteristics of X-rays and the reaction of X-rays to various materials are given in the following tables.

TABLE 759.—X-RAY PRODUCTION[236]

Quantity of X-rays emitted by a tungsten-target tube per kilowatt of energy in cathode-ray beam.*

Operating potential kilovolts	Power in total X-rays from focal spot watts	Effective wavelength (unfiltered) angstrom units	Roentgens (*r*) per second at 1 meter from target (unfiltered)
50	2.5	.56	1.2
70	3.5	.40	.62
100	5.	.28	.34
200	10.	.14	.39
500	25.	.056	1.1
1000	48.	.028	2.1
2000	95.	.014	4.0

[236] Clark, George L., Applied X-rays, McGraw-Hill Book Company, Inc., 1940. Used by permission of the publishers.
* Compiled by A. H. Compton.

TABLE 760.—CRITICAL ABSORPTION WAVELENGTHS (A), *K* SERIES *

12 Mg	9.5112	35 Br	.9182	74 W	.17807
13 Al	7.9470	40 Zr	.6874	78 Pt	.1581
17 Cl	4.3938	42 Mo	.61842	79 Au	.1534
24 Cr	2.0663	47 Ag	.4852	82 Pb	.1410
26 Fe	1.7405	53 I	.3738	92 U	.1075
29 Cu	1.3780	56 Ba	.3308		

* For reference, see footnote 236, above.

TABLE 761.—RELATIVE IONIZATION PRODUCED IN VARIOUS GASES BY HETEROGENEOUS X-RAYS *

Gas or vapor	Density relative to air = 1	Ionization relative to air = 1	
		Soft X-rays	Hard X-rays
Hydrogen, H_2	.07	.01	.18
Carbon dioxide, CO_2	1.53	1.57	1.49
Ethyl chloride, C_2H_5Cl	2.24	18.0	17.3
Carbon tetrachloride, CCl_4	5.35	67	71
Nickel carbonyl, $Ni(CO)_4$	5.90	89	97
Ethyl bromide, C_2H_5Br	3.78	72	118
Methyl iodide, CH_3I	4.96	145	125
Mercury methyl, $Hg(CR_3)_2$	7.93	425	...

* For reference, see footnote 236, p. 692.

TABLE 762.—WAVELENGTHS OF FLUORESCENT RADIATION EXCITED BY X-RAYS *

Material	Region A	Position of maximum A
Fluorspar	3640–2400	2840
Fluorspar and iron spar	3900–2310	2800
Scheelite (Ca tungstate)	4800–3750	4330
Zinc sulfide	5090–4120	4500
K platinocyanide	4900–4120	4500
Ba platinocyanide	5090–4420	4800
Ca platinocyanide	5090–4550	4800
U NH_4 fluoride	4400–3800	4100
X-ray tube glass	5090–3000	3750

* For reference, see footnote 236, p. 692.

TABLE 763.—THE ABSORPTION OF X-RAYS

The absorption of X-rays by materials follows the same law as the absorption of radiant energy, i.e.,

$$I = I_0 \times e^{-\mu x}$$

where I_0 is the initial intensity and I the intensity after a distance x, and μ the absorption coefficient. μ/ρ is the mass absorption (ρ density) of the material. μ/ρ is really the sum of two coefficients—τ/ρ the true or fluorescent X-ray mass-absorption coefficient—and σ/ρ the mass-absorption due to scattering. For light elements σ/ρ has a practically constant value of 0.17 independent of the wavelength for intermediate ranges.

The following relations may be written

$$\mu/\rho = \tau/\rho + \sigma/\rho = K\,\lambda^3 + \sigma/\rho$$

The constants for this absorption equation for several materials follow: *

	Mo 42	Ag 47	Sn 50	W 74	Au 79	Pb 82
K_K	375	545	595	1870	2230	2570
K_L	50	70	90	330	395	476
K_K/K_L	7.5	7.8	6.6	5.65	5.65	5.40
$\tau A\ (10^{-21})$	13.3	11.0	8.90	3.19	2.57	2.37

* For reference, see footnote 236, p. 692.

TABLE 764.—APPROXIMATE LEAD THICKNESS REQUIRED TO REDUCE RADIATION DOSAGE RATE TO 5 PERCENT OF USEFUL BEAM [237]

Kilovolts	50	75	100	150	200	250	400	500	1000	2000
Lead thickness, mm	.1	.3	.4	.7	1.0	1.3	3.0	7	32	50

[237] National Bureau of Standards Handbook 41, Medical X-ray protection up to two million volts.

TABLE 765.—MASS-ABSORPTION COEFFICIENTS FOR A NUMBER OF MATERIALS FOR DIFFERENT WAVELENGTHS *

Wavelength angstroms	C	Al	Cu	Sn
.010	.061	.059	.056	.054
.015	.073	.070	.067	.067
.020	.081	.078	.076	.082
.025	.088	.085	.085	.102
.030	.097	.094	.097	.130
.040	.108	.104	.120	.204
.050	.117	.113	.150	.32
.064	.130	.130	.198	.49
.072	.136	.143	.232	.614
.098	.142	.156	.325	1.17
.130	.152	.186	.45	2.15
.175	.163	.228	1.12	4.50
.200	.175	.270	1.59	6.10
.280	.188	.402	3.25	12.8
.417	.256	1.18	11.4	45.5
.497	.315	1.90	18.9	11.8
.631	.474	3.73	37.2	23.0
.710	.605	5.22	51.0	34.0

* For reference, see footnote 236, p. 692.

TABLE 766.—EXPONENTIAL FORMULAE FOR THE TOTAL MASS-ABSORPTION VALUES, μ/ρ, FOR SEVERAL ELEMENTS *

Absorber	λ (*A*)	μ/ρ	Absorber	λ (*A*)	μ/ρ
Al	.1 to .4	$14.45 \times \lambda^3 + .15$	Mo	.1 to .35	$450 \times \lambda^3 + .4$
Al	.4 to .7	$14.30 \times \lambda^3 + .16$	Mn ...	$>\lambda_{K_{abs}}$	$51.5 \times \lambda^3 + 1.0$
Fe	.1 to .3	$110 \times \lambda^3 + .18$	Ag	.1 to .4	$603 \times \lambda^3 + .7$
Co	.1 to .3	$124 \times \lambda^3 + .18$	Ag	$>\lambda_{K_{abs}}$	$86 \times \lambda^3 + .6$
Ni	.1 to .3	$145 \times \lambda^3 + .20$	Pb	$>\lambda_{K_{abs}}$	$510 \times \lambda^3 + .75$
Cu	.1 to .6	$147 \times \lambda^3 + .5$			

* For reference, see footnote 236, p. 692.

TABLE 766A.—X-RAY DOSAGE UNITS

The international unit of quantity or dose of X-rays (and gamma-rays), one roentgen, *r*, is obtained from that X-ray (or gamma-ray) energy which, when the secondary electrons are fully utilized and secondary radiation from the walls of the chamber avoided, under standard conditions 0°C and 760 mmHg, produces in a cubic centimeter of atmospheric air such a degree of conductivity that the quantity of electricity, measured at saturation, equals 1 esu.

TABLE 767.—PROTECTIVE POWERS OF MATERIALS RELATIVE TO LEAD *

A lead screen is very effective in protecting against X-rays. The data in the table show the thickness of lead is as effective as 1 mm of certain other materials that are in common use for protection against X-rays generated by a 100,000-volt Coolidge tube.

Lead glass	.12 to .20	Woods	.001
Lead rubber	.25 to .45	Barium sulfate plaster......	.05 to .13
Bricks and concrete........	.01	Steel	.15

* For reference, see footnote 236, p. 692.

TABLE 768.—THE MINIMUM THICKNESS OF LEAD RECOMMENDED FOR PROTECTION FOR VARIOUS INTENSITIES OF X-RAYS

X-rays generated by peak voltage not in excess of (kilovolts):	Minimum equivalent thickness of lead millimeters	X-rays generated by peak voltage not in excess of (kilovolts):	Minimum equivalent thickness of lead millimeters
75	1.0	225	5.0
100	1.5	300	9.0
125	2.0	400	15.0
150	2.5	500	22.0
175	3.0	600	34.0
200	4.0		

The National Bureau of Standards Handbook 41 on X-ray protection gives as the permissible dosage rate 0.3 *r* per week. On the basis of a 48-hour week of uniform exposure the permissible dosage rate is 0.00625 *r* per hr (6.25 *mr* per hr).

This booklet also gives safety rules for operating X-ray equipment and the thickness of lead or concrete necessary for protection against X-ray tubes operated at various intensities.

TABLE 769.—DISTANCE PROTECTION *

Target current	Distance † for various applied voltages (kilovolts)									
	50	75	100	150	200	250	400	500	1000	2000
ma					feet					
.005	15	20	20	25	25	25	25	30	90	195
.05	40	50	60	60	65	70	70	75	220	400
.5	85	115	145	145	165	170	170	200	460	850
2.5	120	185	235	245	270	285	295	340	690	...
10	160	250	330	350	390	420	...	...	...	...
25	195	300	390	420	480	510	...	...	...	...

* For reference, see footnote 237, p. 693.

† These distances were computed by taking into account distance and air absorption. The air absorption was determined by assuming the radiation was monochromatic and of double the minimum wavelength of the polychromatic radiation given off by the tube at the indicated potential.

TABLE 770.—PRIMARY PROTECTIVE-BARRIER REQUIREMENTS FOR 10 MILLIAMPERES AT THE PULSATING POTENTIALS * AND DISTANCES INDICATED †

Target distance	Lead thickness with peak kilovolts of—					Target distance	Lead thickness with peak kilovolts of—				
	75	100	150	200	250		75	100	150	200	250
ft			mm			ft			mm		
2 (.61 m)	2.2	3.4	4.3	6.7	11.8	20 (6.1 m)	1.0	1.7	2.4	3.6	6.4
5 (1.52 m)	1.7	2.7	3.6	5.5	9.6	50 (15.2 m)	.5	1.1	1.7	2.4	4.3
10 (3.05 m)	1.3	2.2	3.0	4.5	8.1						

* Direct-current potentials require the order of 10 percent greater thickness than those given here for pulsating potential.

† For reference, see footnote 237, p. 693.

TABLE 771.—PRIMARY PROTECTIVE-BARRIER REQUIREMENTS FOR 400-KILOVOLTS PEAK PULSATING POTENTIAL WITH REFLECTION TARGET *

Target distance	Lead thickness with target current of—			Target distance	Lead thickness with target current of—		
	1 ma	3 ma	5 ma		1 ma	3 ma	5 ma
ft		mm		ft		mm	
5 (1.52 m)	16.5	20	22	20 (6.1 m)	9.5	11.5	13.0
10 (3.05 m)	12.5	15.5	17.0	50 (15.2 m)	5.5	8.0	9.0

* For reference, see footnote 237, p. 693.

TABLE 772.—PRIMARY PROTECTIVE-BARRIER REQUIREMENTS FOR 1000-KILOVOLT CONSTANT POTENTIAL WITH TRANSMISSION TARGET *

Target distance ft	Barrier thicknesses with target current of— 1 ma Lead mm	1 ma Concrete † in.	2 ma Lead mm	2 ma Concrete in.	3 ma Lead mm	3 ma Concrete in.
5 (1.52 m)	123	30.5	131	32.5	136	33.5
10 (3.05 m)	107	27.0	115	28.5	120	29.5
20 (6.1 m)	91	23.0	99	25.0	103	26.0
100 (30.5 m)	53	15.0	61	17.0	66	18.0

* For reference, see footnote 237, p. 693.
† These concrete thicknesses are for a concrete density of 147 pounds per cubic foot.

TABLE 773.—FILTERS FOR OBTAINING MONOCHROMATIC X-RAYS *

Target	Lowest approximate voltage for *K* series kilovolts	λ for *K α* doublet	Filter	Thickness, millimeters	g/cm²
Chromium	6	2.287	Vanadium	.0084	.0048
Iron	7	1.935	Manganese	.0075	.0055
Copper	9	1.539	Nickel	.0085	.0076
Molybdenum	20	.710	Zirconium	.037	.024
Silver	25	.560	Palladium	.03	.036

* For reference, see footnote 236, p. 692.

TABLE 774.—CRITICAL ABSORPTION WAVELENGTHS (A), *L* SERIES *

Element	L_I (L_{11})	L_{II} (L_{21})	L_{III} (L_{22})	Element	L_I (L_{11})	L_{II} (L_{21})	L_{III} (L_{22})
47 Ag	3.2474	3.5067	3.6908	78 Pt	.8921	.9321	1.0709
53 I	2.3839	2.5475	2.7139	82 Pb	.7806	.8136	.9500
56 Ba	2.0620	2.1993	2.3568	92 U	.5687	.5920	.7216
74 W	1.0205	1.0713	1.2116				

* For reference, see footnote 236, p. 692.

TABLE 775.—CRITICAL ABSORPTION WAVELENGTHS (A), *M* SERIES *

Element	M_I	M_{II}	M_{III}	M_{IV}	M_V	Element	M_I	M_{II}	M_{III}	M_{IV}	M_V
W	4.38	4.83	5.45	6.62	6.85	Th ...	2.338	2.571	3.058	3.552	3.721
Bi	3.100	3.342	3.889	4.574	4.763	U	2.228	2.385	2.873	3.326	3.491

* For reference, see footnote 236, p. 692.

TABLE 776.—CHARACTERISTIC EMISSION WAVELENGTHS (A). *K* SERIES *

Element	$\gamma(\beta_2)$	β_1	β_2	α_1	α_2
24 Cr	2.0667 (β_5)	2.0806	....	2.28503	2.28891
26 Fe	1.74080(β_5)	1.753013	1.75646	1.932076	1.936012
28 Ni	1.48561	1.49705	....	1.65450	1.65835
29 Cu	1.37824	1.38935	....	1.53739	1.54123
42 Mo	.619698	.630978	.631543	.707831	.712105
45 Rh	.53396	.54449	.54509	.61202	.61637
47 Ag	.486030	.496009	.49665	.55828	.56267
74 W	.17899 †	.18397	.18477	.20860	.21341
78 Pt	.15887	.16370	....	.18523	.19004

* For reference, see footnote 236, p. 692.
† $\delta = 0.17803$, $\delta_2 = 0.17917$ (Duane, 1933).

TABLE 777.—WAVELENGTHS IN ANGSTROMS OF *K*-SERIES LINES REPRESENTING TRANSITIONS IN THE ORDINARY X-RAY ENERGY LEVEL DIAGRAM * ALLOWED BY THE SELECTION PRINCIPLES [288]

Siegbahn Sommerfeld transition	$K\alpha_2$ $K\alpha'$ K-L_{II}	$K\alpha_1$ $K\alpha$ K-L_{III}	$K\beta$ $K\beta_3$ K-M_{II}	$K\beta_1$ $K\beta$ K-M_{III}	$K\beta_2$ $K\gamma$ K-$L_{II}N_{III}$
4 Be	115.7				
5 B	67.71				
6 C	44.54				
7 N	31.557				
8 O	23.567				
9 F	18.275				
11 Na	11.885		11.594		
12 Mg	9.869		9.539		
13 Al	8.3205		7.965		
14 Si	7.11106		6.7545		
15 P	6.1425		5.7921		
16 S	5.3637	5.3613	5.0211		
17 Cl	4.7212	4.7182	4.3942		
19 K	3.73707	3.73368	3.4468		
20 Ca	3.35495	3.35169	3.0834		
21 Sc	3.02840	3.02503	2.7739		
22 Ti	2.74681	2.74317	2.5090		
23 V	2.50213	2.49835	2.2797		
24 Cr	2.28891	2.28503	2.0806		
25 Mn	2.10149	2.09751	1.90620		
26 Fe	1.936012	1.932076	1.753013		
27 Co	1.78919	1.78529	1.61744		
28 Ni	1.65835	1.65450	1.47905		1.48561
29 Cu	1.541232	1.537395	1.38935		1.37824
30 Zn	1.43603	1.43217	1.29255		1.28107
31 Ga	1.34087	1.33715	1.20520		1.1938
32 Ge	1.25521	1.25130	1.12671		1.11459
33 As	1.17743	1.17344	1.05510		1.04281
34 Se	1.10652	1.10248	.99013		.97791
35 Br	1.04166	1.03759	.93087		.91853
36 Kr	.9821	.9781	.8767		.8643
37 Rb	.92776	.92364	.82749	.82696	.81476
38 Sr	.87761	.87345	.78183	.78130	.76921
39 Y	.83132	.82712	.73972	.73919	.72713
40 Zr	.78851	.78430	.70083	.70028	.68850
41 Nb	.74889	.74465	.66496	.66438	.65280
42 Mo	.712105	.707831	.631543	.630978	.619698
43 Tc	.675	.672	.601		
44 Ru	.64606	.64174	.57193	.57131	.56051
45 Rh	.61637	.61202	.54509	.54449	.53396
46 Pd	.58863	.58427	.52009	.51947	.50918
47 Ag	.56267	.55828	.49665	.49601	.48603
48 Cd	.53832	.53390	.47471	.47408	.46420
49 In	.51548	.51106	.45423	.45358	.44408
50 Sn	.49402	.48957	.43495	.43430	.42499
51 Sb	.47387	.46931	.41623		.40710
52 Te	.45491	.45037	.39926		.39037
53 I	.43703	.43249	.38292	.38315	.37471
54 Xe	.417		.360		
55 Cs	.40411	.39959	.35436	.35360	.34516
56 Ba	.38899	.38443	.34089	.34022	.33222
57 La	.37466	.37004	.32809	.32726	.31966
58 Ce	.36110	.35647	.31572	.31501	.30770
59 Pr	.34805	.34340	.30439	.30360	.29625
60 Nd	.33595	.33125	.29351	.29275	.28573
62 Sm	.31302	.30833	.27325	.27250	.26575
63 Eu	.30265	.29790	.26386	.26307	.25645

* This criterion cannot be strictly applied to the $K\alpha$ line from 4 Be to 9 F, nor to the $K\beta_1$ line from 11 Na to 29 Cu as reported in this table.

[288] Compton, A. H., and Allison, S. K., X-rays in theory and experiment, D. Van Nostrand Co., Inc., New York, 1935. Courtesy of the publishers.

(continued)

TABLE 777.—WAVELENGTHS IN ANGSTROMS OF *K*-SERIES LINES REPRESENTING TRANSITIONS IN THE ORDINARY X-RAY ENERGY LEVEL DIAGRAM ALLOWED BY THE SELECTION PRINCIPLES (concluded)

Siegbahn Sommerfeld transition	$K\ \alpha_2$ $K\ \alpha'$ $K\text{-}L_{II}$	$K\ \alpha_1$ $K\ \alpha$ $K\text{-}L_{III}$	$K\ \beta$ $K\ \beta_3$ $K\text{-}M_{II}$	$K\ \beta_1$ $K\ \beta$ $K\text{-}M_{III}$	$K\ \beta_2$ $K\ \gamma$ $K\text{-}L_{II}N_{III}$
64 Gd	.29261	.28782	.25471	.25394	.24762
65 Tb	.28286	.27820	.24629	.24551	.23912
66 Dy	.27375	.26903	.23787	.23710	.23128
67 Ho	.26499	.26030	....	....	....
68 Er	.25664	.25197	.22300	.22215	.21671
69 Tm	.24861	.24387	.21558	.21487	....
70 Yb	.24098	.23628	.20916	.20834	.20322
71 Lu	.23358	.2282	.20252	.20171	.19649
72 Hf	.22653	.22173	.19583	.19515	.19042
73 Ta	.21973	.21488	.18991		.18452
74 W	.21337	.20856	.18475	.18397	.17906
76 Os	.20131	.19645	.17361		.16875
77 Ir	.19550	.19065	.16850		.16376
78 Pt	.19004	.18223	.16370		.15887
79 Au	.18483	.17996	.15902		.15426
81 Tl	.17466	.16980	.15011		.14539
82 Pb	.17004	.16516	.14606		.14125
83 Bi	.16525	.16041	.14205		.13621
92 U	.13095	.12640	.11187		.10842

TABLE 778.—WAVELENGTHS, TUNGSTEN *L* SERIES *

γ_4	$L_{11} - O_{22}$	1.02647	β_7	$L_{22} - N_{43,\,44}$	1.2208
γ_9	$L_{11} - N_{33}$	1.0439	$\beta_{11,\,12}$	....	1.2354
γ_3	$L_{11} - N_{22}$	1.05965	β_2	$L_{22} - N_{32,\,33}$	1.24191
γ_2	$L_{11} - N_{21}$	1.06584	β_3	$L_{11} - M_{22}$	1.26000
γ_6	$L_{21} - O_{32}$	1.0720	β_1	$L_{21} - M_{32}$	1.27917
γ_8	$L_{21} - O_{11}$	1.079	β_6	$L_{22} - N_{11}$	1.2871
γ_1	$L_{21} - N_{32}$	1.09553	β_4	$L_{11} - M_{21}$	1.29874
γ_5	$L_{21} - N_{11}$	1.1292	β_{11}	$L_{11} - M_{11}$	1.3344
β_9	....	1.2021	η	$L_{21} - M_{11}$	1.4177
β_8	$L_{11} - M_{33}$	1.2034	α_1	$L_{22} - M_{33}$	1.47348
β_{10}	....	1.2094	α_2	$L_{22} - M_{32}$	1.48452
β_5	$L_{22} - O_{32,\,33}$	1.2125	l	$L_{22} - M_{11}$	1.67505

* For reference, see footnote 236, p. 692.

TABLE 779.—TYPICAL SAFE RATINGS OF DIAGNOSTIC X-RAY TUBES

General Electric Company Benson-type X-ray tube

Effective focal area	Full wave kv*	Full wave ma	Half wave kv*	Half wave ma	Self-rectified kv*	Self-rectified ma
Stationary target: 1 second						
1.5 mm²	110	20	110	15	...	...
3.7	110	60	95	50	...	...
5.2	90	150	100	100	78	100
1/60 second						
5.2	72	500	...	...	...	...
	104	350	...	...	...	...
Rotating target: 1 second						
	80	280	...	...	...	...
1/60 second						
	80	540	...	...	...	...

* Peak kilovolts.

Westinghouse Corporation WL-355 tube

Effective focal area	Full wave kv ma	Half wave kv ma	Self-rectified kv ma
Stationary target: 1 second			
1.5 mm²	2770	2025	1520
2.1	4830	3410	2570
2.6	6500	4730	3400
3.0	7680	5915	4150
4.2	11900	9650	6870
1/60 second			
4.2	25000	...	...

TABLE 780.—WAVELENGTHS OF THE MORE PROMINENT *L*-GROUP LINES IN ANGSTROMS *

Siegbahn Sommerfeld transition	α_2 α' L_{III}-M_{IV}	α_1 α L_{III}-M_V	β_1 β L_{II}-M_V	l ϵ L_{III}-M_I	η η L_{II}-M_I
16 S	....		....	83.75	
20 Ca	36.27		....	40.90	....
21 Sc	31.37		....	35.71	....
22 Ti	27.37		....	31.33	....
23 V	24.31		....	27.70	....
24 Cr	21.53		21.19	23.84	23.28
25 Mn	19.40		19.04	22.34	....
26 Fe	17.57		17.23	20.09	19.76
27 Co	15.93		15.63	18.25	17.86
28 Ni	14.53		14.25	16.66	16.28
29 Cu	13.306		13.027	15.26	14.87
30 Zn	12.229		11.960	13.97	13.61
31 Ga	11.27		11.01	12.89	12.56
32 Ge	10.415		10.153	11.922	11.587
33 As	9.652		9.395	11.048	10.711
34 Se	8.972		8.718	10.272	9.939
35 Br	8.358		8.109	9.564	9.235
37 Rb	7.3027		....	....	....
38 Sr	6.8486		6.610	7.822	7.506
39 Y	6.4357		6.2039	....	7.0310
				β_2 γ L_{III}-N_V	γ_1 δ L_{II}-N_{IV}
40 Zr	6.057		5.8236	5.5742	5.3738
41 Nb	5.718	5.7120	5.4803	5.2260	5.0248
42 Mo	5.401	5.3950	5.1665	4.9100	....
44 Ru	4.8437	4.8357	4.6110	4.3619	4.1728
45 Rh	4.5956	4.5878	4.3640	4.1221	3.9357
46 Pd	4.3666	4.3585	4.1373	3.9007	3.7164
47 Ag	4.1538	4.1456	3.9266	3.6938	3.5149
48 Cd	3.9564	3.9478	3.7301	3.5064	3.3280
49 In	3.7724	3.7637	3.5478	3.3312	3.1553
50 Sn	3.60151	3.59257	3.3779	3.16861	2.99494
51 Sb	3.4408	3.4318	3.2184	3.0166	2.8451
52 Te	3.2910	3.2820	3.0700	2.8761	2.7065
53 I	3.1509	3.1417	2.9309	2.7461	2.5775
55 Cs	2.8956	2.8861	2.6778	2.5064	2.3425
56 Ba	2.7790	2.7696	2.5622	2.3993	2.2366
57 La	2.6689	2.6597	2.4533	2.2980	2.1372
58 Ce	2.5651	2.5560	2.3510	2.2041	2.0443
59 Pr	2.4676	2.4577	2.2539	2.1148	1.9568
60 Nd	2.3756	2.3653	2.1622	2.0314	1.8738
62 Sm	2.2057	2.1950	1.9936	1.8781	1.7231
63 Eu	2.1273	2.1163	1.9163	1.8082	1.6543
64 Gd	2.0526	2.0419	1.8425	1.7419	1.5886
65 Tb	1.9823	1.9715	1.7727	1.6790	1.5266
66 Dy	1.9156	1.9046	1.7066	1.6198	1.4697
67 Ho	1.8521	1.8410	1.6435	1.5637	1.4142
68 Er	1.79202	1.78068	1.58409	1.51094	1.3611
69 Tm	1.7339	1.7228	1.5268	1.4602	1.3127
70 Yb	1.67942	1.66844	1.4725	1.41261	1.26512
71 Lu	1.6270	1.61617	1.42067	1.36731	1.21974
72 Hf	1.57704	1.56607	1.3711	1.3235	1.1765
73 Ta	1.52978	1.51885	1.32423	1.28190	1.13558
74 W	1.48438	1.47336	1.27917	1.24203	1.09630
75 Re	1.4410	1.42997	1.23603	1.2041	1.0587
76 Os	1.39866	1.38859	1.19490	1.16884	1.02296
77 Ir	1.3598	1.34847	1.15540	1.13297	.98876
78 Pt	1.32155	1.31033	1.11758	1.09974	.95599
79 Au	1.28502	1.27377	1.08128	1.06801	.92461

* For reference, see footnote 238, p. 697.

(*continued*)

TABLE 780.—WAVELENGTHS OF THE MORE PROMINENT *L*-GROUP LINES IN ANGSTROMS (concluded)

Siegbahn Sommerfeld transition	α_2 α' L_{III}-M_{IV}	α_1 α L_{III}-M_V	β_1 β L_{II}-M_V	β_2 γ L_{III}-N_V	γ_1 δ L_{II}-N_{IV}
80 Hg	1.24951	1.23863	1.04652	1.03770	.8946
81 Tl	1.21626	1.20493	1.01299	1.00822	.86571
82 Pb	1.18408	1.17258	.98083	.98083	.83801
83 Bi	1.15301	1.14150	.95002	.95324	.81143
90 Th	.96585	.95405	.76356	.79192	.65176
91 Pa	.9427	.9309	.7407	.7721	.6325
92 U	.92062	.90874	.71851	.75307	.61359

TABLE 781.—WAVELENGTHS OF *M*-SERIES LINES IN ANGSTROMS FROM 73 Ta TO 92 U *

Transition	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	81 Tl	82 Pb	83 Bi	90 Th	92 U
$M_{II}O_{IV}$	....	....	....	....	....	....	....	....	....	....	2.613	2.440
M_IN_{III}	....	5.163	....	....	....	4.451	4.291	4.005	3.864	3.732	2.938	2.745
$M_{II}N_{IV}$	5.558	5.342	....	4.944	4.770	4.590	4.424	4.110	3.964	3.829	3.006	2.813
$M_{III}O_V$	....	....	....	....	4.859	4.682	4.514	4.207	4.063	3.926	3.124	2.941
$M_{III}O_I$	....	5.620	....	....	....	....	....	....	4.235	4.096	....	3.114
$M_{II}N_I$	....	....	....	....	....	....	....	....	....	....	....	3.322
γ'	....	....	....	....	....	....	....	4.800	4.650	4.506	3.661	3.463
$M_{III}N_V$	6.299	6.076	5.875	5.670	5.490	5.309	5.135	4.815	4.665	4.522	3.672	3.473
$M_{III}N_{IV}$	6.340	6.121	5.919	5.712	5.529	5.346	5.175	4.855	4.705	4.560	3.710	3.514
$M_{IV}O_{II}$	7.083	6.794	....	....	....	....	....	....	....	4.813	3.804	3.570
β'	6.984	6.718	....	6.233	6.009	5.796	5.595	5.220	5.045	4.881	3.924	3.698
$M_{IV}N_{VI}$	7.008	6.743	6.491	6.254	6.025	5.8168	5.612	5.239	5.065	4.899	3.934	3.708
M_VO_{III}	....	....	....	....	....	5.975	5.755					
α''	7.201	6.932	....	6.440	6.215	5.997	5.794	5.416	5.239			
α'	7.219	6.948	....	6.459	6.231	6.011	5.811	5.433	5.256	5.087	4.112	3.886
M_VN_{VII}	7.237	6.969	6.715	6.477	6.249	6.034	5.828	5.450	5.274	5.108	4.130	3.902
M_VN_{VI}	....	....	....	....	6.262	6.045	5.842	5.461	5.288	5.119	4.143	3.916
$M_{III}N_I$	7.596	7.346	....	....	6.653	6.442	6.241	5.870	5.694	5.526	4.554	4.322
$M_{IV}N_{III}$	....	8.559	8.222	....	7.629	7.356	7.086	....	6.371	6.149	4.901	4.615
M_VN_{III}	9.297	8.943	8.612	8.293	8.002	7.722	7.451	6.960	6.726	6.508	5.229	4.937
$M_{IV}N_{II}$	9.311	8.977	8.646	8.344	8.048	7.774	7.507	7.017	6.788	6.571	5.329	5.040

* E. Lindberg, Dissertation, Uppsala (1931). In addition to the values listed here, measurements have been made in the range from Ce 58 to 72 Hf. The wavelengths may be found in the dissertation, or in Siegbahn, Spektroskopie der Röntgenstrahlen (1931). For reference, see footnote 238, p. 697.

TABLE 782.—X-RAY TERMS FOR VARIOUS ELEMENTS *

ν/R values; ν in cm^{-1}, $R = 109{,}737\ cm^{-1}$

Term	13 Al	20 Ca	29 Cu	42 Mo	47 Ag	74 W	92 U
K	10.71	297.4	661.6	1473.4	1880.9	5120.7	8474
L_I	....	....	81.0	211.3	282.7	890.8	1602.6
L_{II}	2.30	25.8	70.3	193.7	260.9	849.9	1542.7
L_{III}	2.30	25.5	68.9	186.0	248.6	751.3	1264.2
M_I	....	....	8.9	37.5	54.4	207.3	408.5
M_{II}	.63	1.9	5.7	30.5	46.7	189.3	381.5
M_{III}	.63	1.9	5.7	29.2	44.4	167.5	316.8
M_{IV}	....	.4	.4	17.3	29.2	137.5	274.2
M_V	....	.4	.4	17.1	28.8	132.9	261.2
N_I	....	....	....	5.1	8.7	43.3	106.0
N_{II}	....	....	....	2.9	6.5	36.0	93.5
N_{III}	....	....	....	2.9	6.5	31.0	76.6
N_{IV}	....	....	....	....	1.1	18.7	57.5
N_V	....	....	....	.4	2.0	17.6	54.3
N_{VI}	....	....	....	....	....	2.3	28.5
N_{VII}	....	....	....	....	....	2.0	27.6
O_I	....	....	....	....	....	5.4	23.7
O_{II}	....	....	....	....	....	2.9	18.3
O_{III}	....	....	....	....	....	2.9	13.9
$O_{IV}O_V$	....	....	....	....	....	....	7.0
$P_{II}P_{III}$	....	....	....	....	....	....	.8

* For reference, see footnote 238, p. 697.

TABLE 783.—CRITICAL ABSORPTION WAVELENGTHS IN ANGSTROMS *

	K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	M_{IV}	M_V	Longer wavelengths
1 H										
2 He	504.29									
3 Li										
4 Be	....	1329.89								
5 B	64.3									
6 C	43.5									
7 N	31.1									
8 O	23.5									
9 F	18.0									
10 Ne	....	255.77	572.4	574.9						
11 Na										
12 Mg	9.4962	....	....	....	1621.48					
13 Al	7.9356	....	181							
14 Si	6.7310	....	126							
15 P	5.7749	....	96.4							
16 S	5.0088	....	75.7							
17 Cl	4.3838	....	60.9							
18 A	3.8657	....	50.1		424.03	778.0	786.8			
19 K	3.4310									N_I
20 Ca	3.0643	....	35.63		....	....	....	....	....	2028.20
21 Sc	2.7517									
22 Ti	2.4912	....	27.29							
23 V	2.2630									
24 Cr	2.0659									
25 Mn	1.8916									
26 Fe	1.7394									
27 Co	1.6040									
28 Ni	1.4839									
29 Cu	1.3774	....	12.9	13.15						N_I
30 Zn	1.2805	....	....	....	....	....	....	708.18	722.08	1319.84
31 Ga	1.1902									
32 Ge	1.1164									
33 As	1.04263									
34 Se	.97773									

* For reference, see footnote 238, p. 697.

(continued)

TABLE 783.—CRITICAL ABSORPTION WAVELENGTHS IN ANGSTROMS (continued)

	K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	M_{IV}	M_V	Longer wavelengths		
35 Br	.91809									N_{II}	N_{III}	
36 Kr	.86372	....	....	....	....	....	....	....	....	845.42	855.63	
37 Rb	.81410	5.9854	....	6.8413						O_I		
38 Sr	.76837	5.5713	6.1621	6.3620	....	....	....	....	....	2177.46		
39 Y	.7255	5.2216	5.7373	5.9444								
40 Zr	.68738	4.8574	5.3659	5.5610								
41 Nb	.65158	4.5717	....	5.2121								
42 Mo	.61848	4.2897	4.7120	4.9042								
43 Tc												
44 Ru	.5584	....	4.1648	4.3577								
45 Rh	.53303	3.61860	3.9340	4.1212						N_{IV}	N_V	
46 Pd	.50795	3.4206	3.7512	3.9005	....	....	....	....	....	1412.92	1487.30	
47 Ag	.48448	3.2474	3.5067	3.6908	....	....	....	30.82	31.14	N_V	N_{VI}	O_I
48 Cd	.46313	3.0773	3.3192	3.4963	....	....	....	28.13		678.28	705.23	1378.57
49 In	.44298	2.9194	3.1395	3.3155								
50 Sn	.42394	2.7696	2.9723	3.1493	....	....	....	24.28				
51 Sb	.40609	2.6317	2.8219	2.9907								
52 Te	.38926	2.5039	2.6793	2.8457						$O_{II, III}$		
53 I	.37344	2.3839	2.5475	2.7139	....	....	....	19.66 {		1022.13		
54 Xe	.35777	2.2691	2.4241	2.5872	....	....	....	....	....			
55 Cs	.34404	2.1605	2.3073	2.4678						P_I		
56 Ba	.33070	2.0620	2.1993	2.3568	....	....	....	15.56	15.89	2379.29		
57 La	.31814	1.9689	2.0989	2.2537								
58 Ce	.30626	1.8856	2 0067	2.1579								
59 Pr	.2951	1.808	1.9197	2.0727								
60 Nd	.28458	1.7317	1.8391	1.9907								
61 Pm												
62 Sm	.2644	1.5954	1.6991	1.8408								
63 Eu	.2548	1.5333	1.6228	1.7717								
64 Gd	.2462	1.4740	1.5587	1.7062								
65 Tb	.2376	1.4181	1.4981	1.6453								
66 Dy	.2301	1.3648	1.4414	1.5870								
67 Ho	.22264	1.3146	1.3869	1.5322								
68 Er	....	1.2660	1.3349	1.4796								
69 Tm	.2085	1.2196	1.2849	1.4299								
70 Yb	.2016	1.1764	1.2381	1.38264								
71 Lu	.1951	1.1362	1.1945	1.3377								

(continued)

TABLE 783.—CRITICAL ABSORPTION WAVELENGTHS IN ANGSTROMS (concluded)

	K	L_{I}	L_{II}	L_{III}	M_{I}	M_{II}	M_{III}	M_{IV}	M_{V}	Longer wavelengths		
72 Hf	.1901	1.097	1.1515	1.2930								
73 Ta	.1836	1.057	1.1102	1.2517								
74 W	.17822	1.0205	1.0713	1.2116	4.365	4.800	5.427	6.487	6.702			
75 Re	.1735	.9873	1.0354	1.1755								
76 Os	.16755	.9558	.9998	1.1390	4.037	4.412	5.027	5.975	6.194			
77 Ir	.16209	.9223	.9654	1.1038	....	4.270	4.851	5.754	5.961			
78 Pt	.15770	.8914	.9321	1.0710	3.603	3.738	4.676	5.544	5.746			
79 Au	.15320	.8622	.9009	1.0382	3.742	4.085	4.508	5.330	5.529	O_{IV}	O_{V}	P_{I}
80 Hg	.14893	.8342	.8708	1.0075	....	....	4.340	5.139	5.331	742.22	835.47	1187.95
81 Tl	.14441	.8072	.8419	.9778	....	....	4.184	4.936	5.136			
82 Pb	.14049	.7812	.8143	.9492	....	....	4.034	4.747	4.945			
83 Bi	.13678	.7559	.7878	.9221	....	....	3.893	4.568	4.762			
84 Po												
85 At										$P_{II, III}$		
86 Rn	....	....	....	....	....	....	....	....	....	1153.52		
87 Fr												
88 Ra	....	....	.670	.802								
89 Ac												
90 Th	.11270	.6039	.6293	.7600	2.388	2.571	3.062	3.550	3.722			
91 Pa												
92 U	.10658	.5680	.5913	.7208	2.228	2.385	2.877	2.327	3.491			

TABLE 784.—CALCULATED MASS ABSORPTION COEFFICIENTS[239]

K series

Material	γ→ .010	.020	.040	.080	.15	.25	.40	.80	1.50	2.50	4.00	6.00
1 Hydrogen	.1134	.1577	.2083	.2628	.3081	.3366	.3559	.3854	.4318	.5916	1.2080	3.1420
2 Helium	.0571	.0794	.1049	.1325	.1553	.1702	.1841	.2171	.3687	.9970	3.4658	11.194
3 Lithium	.0494	.0687	.0910	.1147	.1347	.1489	.1660	.2417	.6731	2.4945	9.6441	31.927
4 Beryllium	.0506	.0705	.0933	.1176	.1389	.1560	.1838	.3552	1.3939	5.7894	22.972	76.193
5 Boron	.0528	.0734	.0973	.1228	.1455	.1662	.2061	.4864	2.2131	9.5170	37.995	125.84
6 Carbon	.0571	.0794	.1052	.1331	.1592	.1884	.2588	.8119	4.2565	18.768	74.928	246.27
7 Nitrogen	.0571	.0794	.1053	.1335	.1621	.2013	.3111	1.2266	6.9494	30.958	123.19	401.64
8 Oxygen	.0571	.0795	.1055	.1342	.1659	.2189	.3827	1.7915	10.591	47.288	186.85	601.92
9 Fluorine	.0541	.0753	.1000	.1278	.1619	.2292	.4513	2.3963	14.512	64.669	253.16	803.50
10 Neon	.0566	.0788	.1047	.1347	.1757	.2686	.5896	3.4280	21.036	93.298	361.06	1125.3
11 Sodium	.0546	.0760	.1012	.1312	.1771	.2938	.7092	4.4007	27.180	119.74	457.04	1393.5
12 Magnesium	.0563	.0784	.1046	.1367	.1920	.3461	.9060	5.8930	36.469	159.30	598.22	1775.8
13 Aluminum	.0551	.0767	.1024	.1353	.1985	.3882	1.0876	7.3182	45.240	195.61	720.70	2072.3
14 Silicon	.0570	.0794	.1062	.1417	.2167	.4532	1.3335	9.1794	56.745	244.02	889.43	2507.0
15 Phosphorus	.0553	.0771	.1034	.1399	.2255	.5096	1.5725	11.052	68.006	288.75	1037.1	2766.9
16 Sulfur	.0570	.0795	.1069	.1470	.2506	.6082	1.9568	13.914	85.069	355.96	1230.5	
17 Chlorine	.0548	.0765	.1031	.1442	.2607	.6754	2.2446	16.105	97.676	402.03	1343.4	
18 Argon	.0515	.0719	.0973	.1388	.2664	.7318	2.4967	18.014	108.25	437.17		
19 Potassium	.0555	.0776	.1054	.1537	.3131	.9065	3.1592	22.859	135.88	537.16		
20 Calcium	.0570	.0798	.1088	.1623	.3512	1.0651	3.7759	27.341	160.57	619.41		
22 Titanium	.0525	.0736	.1014	.1593	.3871	1.2683	4.6098	33.257	189.78	689.33		
24 Chromium	.0528	.0741	.1034	.1720	.4664	1.6220	5.9875	42.804	235.77			
26 Iron	.0533	.0750	.1061	.1880	.5634	2.0502	7.6376	53.860	284.05			
28 Nickel	.0546	.0771	.1110	.2101	.6888	2.5938	9.7060	67.243				
29 Copper	.0523	.0739	.1073	.2102	.7180	2.7412	10.265	70.389				
30 Zinc	.0526	.0745	.1092	.2215	.7862	3.0375	11.376	77.110	360.33			
32 Germanium	.0506	.0719	.1077	.2342	.8909	3.5078	13.113	86.581				
34 Selenium	.0494	.0706	.1082	.2527	1.0204	4.0731	15.161	97.059				
35 Bromine	.0503	.0721	.1118	.2703	1.1212	4.4985	16.696	105.02				
36 Krypton	.0494	.0710	.1116	.2794	1.1875	4.7850	17.698	109.22				
37 Rubidium	.0498	.0717	.1142	.2959	1.2866	5.2015	19.160	115.74				
38 Strontium	.0499	.0721	.1164	.3121	1.3820	5.6184	20.609	121.84				

[239] Private communication from John A. Victoreen, The Victoreen Instrument Co., Cleveland, Ohio.

(continued)

TABLE 784.—CALCULATED MASS ABSORPTION COEFFICIENTS (concluded)

K series

Material	.010	.020	.040	.080	.15	.25	.40	.80	1.50	2.50	4.00	6.00
42 Molybdenum	.0505	.0740	.1269	.3873	1.8412	7.4923	26.879					
46 Palladium	.0500	.0743	.1364	.4680	2.3331	9.4481	32.893					
47 Silver	.0505	.0755	.1411	.4971	2.5023	10.110	34.886					
50 Tin	.0490	.0743	.1466	.5581	2.8718	11.493	38.467					
52 Tellurium	.0475	.0728	.1492	.5950	3.0958	12.287	40.150					
53 Iodine	.0488	.0752	.1570	.6397	3.3434	13.207						
54 Xenon	.0481	.0746	.1587	.6606	3.4660	13.621						
56 Barium	.0478	.0750	.1661	.7190	3.7952	14.743						
58 Cerium	.0486	.0762	.1685	.7332	3.8080	14.536						
60 Neodymium	.0490	.0778	.1785	.7959	4.1654	15.620						
65 Terbium	.0485	.0798	.2013	.9689	5.0766							
73 Tantalum	.0488	.0858	.2508	1.3152	6.7235							
74 Tungsten	.0488	.0865	.2575	1.3614	6.9253							
78 Platinum	.0490	.0903	.2878	1.5647	7.7673							
79 Gold	.0493	.0917	.2973	1.6253	8.0105							
80 Mercury	.0493	.0925	.3049	1.6759	8.1957							
82 Lead	.0492	.0944	.3210	1.7806								
83 Bismuth	.0496	.0961	.3320	1.8491	8.5986							
90 Thorium	.0488	.0964	.3406	1.8609								
92 Uranium	.0490	.0992	.3612	1.9814								
Air	.0570	.0793	.1052	.1337	.1643	.2123	.3561	1.5759	9.1109	40.027	154.59	
Water	.0634	.0882	.1170	.1486	.1819	.2321	.3801	1.6341	9.4547	42.061	166.08	534.90
Nylon	.0624	.0869	.1151	.1457	.1747	.2084	.2921	.9573	5.0960	22.460	89.240	291.00
Polyethylene	.0651	.0906	.1201	.1517	.1806	.2097	.2733	.7506	3.7066	16.155	64.330	211.31
Polystyrene	.0614	.0854	.1133	.1431	.1708	.1999	.2666	.7788	3.9958	17.358	69.209	277.40

Artificial disintegration is generally considered in two parts: the first when the bombarded atom suffers a change not greater than the loss (or gain) of an alpha particle, and the second when the change in the bombarded atom is much greater—the bombarded atom being at times split into two nearly equal parts. This latter is called fission; the former, artificial disintegration. Fission was at first brought about by bombardment with neutrons but it can be caused by bombardment by almost any particle with the proper energy (see Table 726). This effect can be produced in a number of isotopes of the heavier atoms such as Np, U, Pa, Th, Pb, Sn, Eu, and Ni. Some other atoms such as Bi, Rb, Tl, Hg, Au, Pt, W, and many others show no fission; at least if such an effect exists it is less than 1/1000 that of Th. There are a great many products of fission as shown by a paper by scientists of the Plutonium Project.[240] One example of fission is

$$_{92}U^{235} + {_0n^1} \rightarrow {_{40}Zr^{97}} + {_{52}Te^{137}} + {_0n^1} + {_0n^1}$$

There is a considerable release of energy when fission takes place. Complete data are not available but such as are available give values of about 200 Mev per fission per atom of the heavier elements. (See Table 790.) It is also to be noted that there are two neutrons given as a result of the above reaction; thus, it is self-sustaining.

[240] Journ. Amer. Chem. Soc., vol. 68, p. 2411, 1946.

TABLE 785.—FISSION DATA *

Target substance	$_{92}U^{235}$	$_{93}Pu^{239}$	$_{90}Th^{232}$	$_{92}U^{238}$	$_{91}Pa^{231}$	$_{92}U^{233}$
Compound nucleus	$_{92}U^{236}$	$_{93}Pu^{240}$	$_{90}Th^{233}$	$_{92}U^{239}$	$_{91}Pa^{232}$	$_{92}U^{234}$
Threshold energy for fast neutron fission, in Mev	0	0	1.0 ± .1	1.1 ± .1	~1	0
Energy released per fission, in Mev	200	Estimated to be same as for $_{92}U^{235}$				
Energy of fission neutrons, in Mev	<3.5 (Ave ~ 1)					
Average number of neutrons released per fission	2.3 (2 to 3.5)					
Average number of neutrons released per thermal neutron absorbed, η	1.4					

* For reference, see footnote 226, p. 667.

TABLE 786.—FISSION THRESHOLDS *

Compound nucleus	Threshold energy for exciting fission	Cause of excitation	Target nucleus	Compound nucleus	Threshold energy for exciting fission	Cause of excitation	Target nucleus
$_{90}Th^{232}$	5.40±.22 Mev	γ	$_{90}Th^{232}$	$_{92}U^{238}$	5.08±.15 Mev	γ	$_{92}U^{238}$
$_{90}Th^{233}$	1.10±.05	*n*	$_{90}Th^{232}$	$_{92}U^{239}$	1.0 ±.1	*n*	$_{92}U^{238}$
$_{91}Pa^{232}$	~1	*n*	$_{91}Pa^{231}$	$_{93}Np^{238}$	<0	slow *n*	$_{93}Np^{237}$
$_{91}Pa^{233}$	<6.9	*p*	$_{90}Th^{232}$	$_{93}Np^{239}$	<6.9	*p*	$_{92}U^{238}$
$_{91}Pa^{234}$	~8	*d*	$_{90}Th^{232}$	$_{93}Np^{240}$	~8	*d*	$_{92}U^{238}$
$_{92}U^{233}$	5.18±.27	γ	$_{92}U^{233}$	$_{94}Pu^{239}$	5.31±.27	γ	$_{94}Pu^{239}$
$_{92}U^{235}$	5.31±.25	γ	$_{92}U^{235}$	$_{94}Pu^{240}$	<0	slow *n*	$_{94}Pu^{239}$
$_{92}U^{236}$	<0	slow *n*	$_{92}U^{235}$				

* Revised by J. L. Rhodes, University of Pennsylvania. For reference, see footnote 226, p. 667.

TABLE 787.—ESTIMATED VALUES OF THE NEUTRON BINDING ENERGY OF THE DIVIDING NUCLEUS *

Compound nucleus	Neutron binding energy	Compound nucleus	Neutron binding energy
$_{90}Th^{232}$	6.2 Mev	$_{92}U^{237}$	5.2 Mev
$_{90}Th^{233}$	5.2	$_{92}U^{238}$	6.1
$_{91}Pa^{231}$	6.4	$_{92}U^{239}$	5.1
$_{91}Pa^{232}$	5.4	$_{93}Np^{239}$	~6.3
$_{92}U^{234}$	6.5	$_{93}Np^{240}$	~5.3
$_{92}U^{235}$	5.4	$_{94}Pu^{239}$	~5.4
$_{92}U^{236}$	6.4	$_{94}Pu^{240}$	~6.4

* For reference, see footnote 226, p. 667.

TABLE 788.—THE CRITICAL ENERGY FOR FISSION *

The experimental values of the critical energy for fission of a number of isotopes have been determined by Koch, McElhinney, and Gasteiger [241] who give the following photofission threshold energies. (The work of Shoupp and Hill [242] on the fast neutron fission energies for Th^{232} and U^{238} was used for the values given for Th^{233} and U^{239}.)

Compound nucleus	E_c	Compound nucleus	E_c	Compound nucleus	E_c
$_{90}Th^{232}$	5.40±.22 Mev	$_{92}U^{235}$	5.31±.25 Mev	$_{92}U^{239}$	6.1 Mev
$_{90}Th^{233}$	6.3	$_{92}U^{238}$	5.08±.15	$_{94}Pu^{239}$	5.31±.27
$_{92}U^{233}$	5.18±.27				

* Prepared by J. L. Rhodes, University of Pennsylvania.
241 Phys. Rev., vol. 77, p. 329, 1950.
242 Phys. Rev., vol. 75, p. 785, 1949.

TABLE 789.—HALF-LIVES FOR SPONTANEOUS FISSION [243]

These half-lives are calculated on the basis of a half-life of 10^{15} years for U^{235}

Element Z A	Half-life	Element Z A	Half-life
$_{92}U^{235}$	10^{15} years	$_{94}Pu^{241}$	8.0×10^{13} years
$_{92}U^{233}$	1.4×10^{14}	$_{94}Pu^{230}$	1.3×10^{12}
$_{93}Np^{237}$	7.6×10^{13}	$_{94}Pu^{238}$	1.6×10^{11}
$_{94}Pu^{244}$	6.8×10^{16}	$_{95}Am^{243}$	6.6×10^{11}
$_{94}Pu^{242}$	7.7×10^{14}	$_{95}Am^{241}$	1.4×10^{10}

243 Turner, Rev. Mod. Phys., vol. 17, p. 292, 1945.

TABLE 790.—THE ENERGY RELEASED BY FISSION ON DIVISION OF SOME ATOMS INTO EQUAL PARTS *

Original	Two products	Energy released on division	Energy released in subsequent beta decay
$_{28}Ni^{61}$	$_{14}Si^{30, 31}$	−11 Mev	2 Mev
$_{50}Sn^{117}$	$_{25}Mn^{58, 59}$	10	12
$_{68}Er^{167}$	$_{34}Se^{83, 84}$	94	13
$_{82}Pb^{206}$	$_{41}Nb^{103, 104}$	120	32
$_{92}U^{239}$	$_{46}Pd^{110, 120}$	200	31

* For reference, see footnote 226, p. 667.

Radioactive isotope	Half-life	Maximum β-particle energy in Mev	Maximum γ-ray energy in Mev	Branching ratio in percent	Radioactive isotope	Half-life	Maximum β-particle energy in Mev	Maximum γ-ray energy in Mev	Branching ratio in percent
${}_{36}Kr^{85}$	9.4 yr	.74	none	.24	${}_{51}Sb^{127}$	93 hr	1.2	.72	...
${}_{37}Rb^{86}$	19 d	1.82	1.08	.00016	${}_{52}Te^{127}$	90 d	I.T.	...	.033
${}_{38}Sr^{89}$	55 d	1.5	none	4.6	${}_{52}Te^{129}$	32 d	I.T.	...	.19
${}_{38}Sr^{90}$	25 yr	.65	none	~5	${}_{52}Te^{132}$	77 hr	.28	.22	3.6
${}_{39}Y^{90}$	62 hr	2.35	none	...	${}_{53}I^{131}$	8 d	.687	.37	2.8
${}_{39}Y^{91}$	61 d	1.6	none	5.9	${}_{54}Xe^{133}$	5.3 d	.35	.085	6
${}_{40}Zr^{95}$	65 d	1.0	.92	6.4	${}_{55}Cs^{136}$	13 d	.28	1.2	.008
${}_{41}Nb^{95}$	35 d	.15	.77	...	${}_{55}Cs^{137}$	37 yr	.8	.75	~6
${}_{41}Nb^{95}$	90 hr	I.T.	...	...	${}_{56}Ba^{140}$	12.8 d	1.05	.53	6.1
${}_{42}Mo^{99}$	67 hr	1.5	.75	6.2	${}_{58}Ce^{141}$	30 d	.6	.2	5.7
${}_{44}Ru^{103}$	41 d	.67	.55	3.7	${}_{58}Ce^{144}$	275 d	.35	none	5.3
${}_{44}Ru^{106}$	1.0 yr	~.03	none	.5	${}_{59}Pr^{143}$	13.8 d	1.0	none	6
${}_{47}Ag^{111}$	7.5 d	1.0	none	.018	${}_{60}Nd^{147}$	11 d	.90	.58	2.6
${}_{48}Cd^{115}$	43 d	1.7	...	.0008	${}_{61}Pm^{147}$	3.7 yr	.23	none	2.6
${}_{48}Cd^{115}$	43 d	1.7	.5	.0008	${}_{63}Eu^{155}$	2 yr	.2	.084	.03
${}_{50}Sn^{123}$	130 d	1.3	.39	...	${}_{63}Eu^{156}$	15.4 d	2.4	2.0	.013
${}_{51}Sb^{125}$	2.7 yr	.7	.6	.02					

* Revised by J. L. Rhodes, University of Pennsylvania. For reference, see footnote 226, p. 667.

TABLE 792.—CROSS SECTIONS OF FISSIONABLE NUCLEI FOR NEUTRONS (IN UNITS OF 10^{-24} cm²) *

Target substance	Process	Cross section for energy ranges: Thermal	Resonance	Fast †
${}_{92}U^{235}$	fission	420±100	30	2.4
	scattering	17	17	6
${}_{92}U^{238}$	fission	0	0	.5
	scattering	17	17	6
	absorption (resonance)	3	5000 ‡	0
Ordinary uranium	fission	3 (ave)	.2 (ave)	.5
	scattering	17	17	6
	absorption (resonance)	3	5000 ‡	0
${}_{94}Pu^{239}$	fission	assumed same as for ${}_{92}U^{235}$		
${}_{92}U^{233}$	scattering	assumed same as for ${}_{92}U^{235}$		
${}_{90}Th^{232}$	fission	0	0	.1
	scattering	17	17	6
	absorption	8.3	..	..
${}_{91}Pa^{231}$	fission	0	0	3
	scattering	17	17	6
${}_{90}Th^{230}$	fission	0	0	.3
	scattering	17	17	6

* For reference, see footnote 226, p. 667.
† Most of the scattering of fast neutrons is inelastic scattering, resulting in large energy losses (as much as 90 percent). ‡ The resonance peak for U^{238} occurs at approximately 5 ev and is taken to have an effective width of 0.16.

TABLE 793.—CROSS SECTIONS OF SOME FISSION PRODUCTS FOR THERMAL NEUTRONS *

Atomic number	Element	"Average nucleus" Absorption σ_a	Total σ_t	Isotope (in units of 10^{-12} cm^2) Mass number	Absorption σ_a	Relative natural abundance
35	Br	7	9.5	79	12	50.6
				81	2.25	49.4
36	Kr	.1	27	78	.27	.34
				84	.16	57.0
				86	.061	17.4
37	Rb	.7	12	85	.724	72.8
				87	.135	27.2
38	Sr	1.5	11	86	1.3	9.8
				88	.005	82.56
39	Y	1.1	...	89	1.1	100
40	Zr	.4	15	90	.12	51.5
				91	1.54	11.2
				92	.27	17.1
				94	.53	17.4
				96	1.07	2.8
41	Nb	1.0	6.9	93	1.0	100
42	Mo	3.9	7.9	95	13	15.7
				97	2.3	9.5
				98	.37	24.1
				100	.23	9.25
51	Sb	4.7	9	121	6.8	56
				123	2.5	44
52	Te	5	10	126	.88	18.7
				128	.2	31.86
				130	.22	34.52
53	I	6.1	9.4	127	6.1	100
54	Xe	...	35	132	.2	26.9
				136	.15	8.9
56	Ba	1.25	9.25	138	.56	71.66
57	La	9	25	139	9	99.9
62	Sm	8000	...	149	53,000	15.5
63	Eu	2500	4500	151	5200	49.1
				153	240	50.9
64	Gd	38,000	...	155	50,000	14.8
				157	180,000	15.7

* Revised by J. L. Rhodes, University of Pennsylvania. For reference, see footnote 226, p. 667.

Cosmic rays are an ionizing radiation that has been discovered in the atmosphere of the earth. As generally discussed these rays are divided into primary and secondary cosmic rays, the primary rays being the high-energy particles that fall upon the outer atmosphere of the earth. In general, the intensity of cosmic radiation is given as the number of rays per cm^2 per second. The intensity (i.e., number of particles per cm^2) increases for about the first one-tenth of the atmosphere where it is about 5 times the initial intensity and from there down to sea level the intensity decreases. These primary rays appear to come from all directions from outer space and to consist almost entirely, if not altogether, of particles charged positively [245] (i.e., protons, alpha-particles, and probably other nuclei). Several theories have been advanced for the origin of this primary radiation: (1) Annihilation of matter; (2) speeding up of stripped atoms in outer space either by electrical fields or by changing magnetic fields; (3) from some activity in stars in distant space; or even (4) that it is radiation remaining from the original explosion some $10^9 - 10^{10}$ years ago when the present known universe was started. These assumptions are based upon the theory that this radiation comes from the cosmos or outer space. Some [246] present arguments for the sun as the source of the cosmic rays and argue that the magnetic field of the sun traps at least a part of the radiation from the sun, which give the results as now found on the earth. There are seemingly very great difficulties to explain away in establishing any one of these theories.

Owing to the effect of the earth's magnetic field there is less of this energy that reaches even the outer atmosphere at or near the magnetic equator than in higher latitudes, the lower-energy particles being screened off by the strong magnetic fields of the earth near the magnetic equator. The energy of the cosmic-ray particles that strike the upper atmosphere extends from about 10^9 to 10^{17} ev, or even higher, with a maximum number for about 6×10^9 ev. The average energy of all particles entering the atmosphere at the equator is about 3×10^{10} ev and for geomagnetic latitudes above about 40 the average is about 6×10^9 ev.

In Tables 794 and 797 are given some data on the primary radiation reaching the outer atmosphere for different geomagnetic latitudes.

[244] Rev. Mod. Phys., vol. 21, p. 1, 1949; Stranathan, The "particle" of modern physics, D. Blakiston Co.; Montgomery, D. J. X., Cosmic ray physics, Princeton University Press; Johnson, T. R., Rev. Mod. Phys., vol. 10, p. 193, 1938; Swann, W. F. G., Reports on progress in physics, vol. 10, p. 1, 1946.
[245] Korff, Physics Today, vol. 3, p. 9, 1950.
[246] Teller, Edward, Physics Today, vol. 2, p. 6, 1949.

TABLE 794.—PROBABLE CHARACTERISTICS OF COSMIC RAYS FALLING UPON THE TOP OF THE ATMOSPHERE AT VARIOUS MAGNETIC LATITUDES

All energies are given in electron volts.

	Geomagnetic latitude		
	3°	39°	52°
Energy falling per sec on each cm^2 of the atmosphere..	1×10^9	1.7×10^9	3.2×10^9
Total number of ions formed per sec below each cm^2 of the upper surface of the atmosphere............	3×10^7	5.4×10^7	7.4×10^7
Low energy limit of oncoming particles imposed by the earth's magnetic field..............................	15×10^9	8×10^9	2×10^9
Average energy per particle striking the atmosphere..	3×10^{10}	1.6×10^{10}	$.88\times10^{10}$
Probable number of particles striking each cm^2 of outer surface of the atmosphere per min.................	1.9	6.5	21.8

The secondary cosmic rays, which are due to the ionization and other actions of the high-energy particles of the primary cosmic rays, have been studied by various methods for various positions with respect to the geomagnetic latitude on the earth's surface and for different elevations up to such heights that only about 0.5 percent of the atmosphere, by weight, is above the measuring instrument. The secondary rays consist of all sorts of particles such as electrons, both positive and negative; protons, and other heavy particles; mesons; neutrons, traveling with various speeds, and radiant energy of very short wavelength.

At the surface of the earth (sea level) the cosmic rays are of such intensity that they produce 1.63 ion pair cm^{-3} sec^{-1}. The intensity is about constant, within a very few percent, for geomagnetic latitudes higher than above 40 and from this point to the equator the intensity drop-off is about 9 percent.

The ionization increases with altitude up to about 16,000 m for geomagnetic latitudes >40, where it is about 150-200 times as large as at sea level. Above this altitude the intensity of ionization drops off until, at an elevation where the amount of the atmosphere above the measuring instrument is only about 0.5 percent (35,300 m), the intensity is about 0.2 percent of that at the maximum, or about the same as that observed at 0.4 atmosphere above the earth. The variation with altitude is much less at the geomagnetic equator.

Cosmic rays react with the atoms of the atmosphere and produce a variety of effects; the production of a simple ion pair, the production of neutrons and electrons, the production of mesons, the production of extensive showers, where the released energy is so great that the cosmic ray must be only the cause of some explosion or some artificial disintegration. Mesons are particles that may have a unit positive or negative charge or they may be neutral as to charge. The mass of the meson is about 200 times that of an electron; it is very penetrating and is radioactive, with a life of about 2×10^{-6} sec. Some evidence exists for mesons with a mass of about 1000 m_e.

Thus, there are formed bursts, an extensive production of ionization, and stars when a group of particles have a common origin as shown by cloud-chamber pictures. Stars are probably so named because these pictures show a number of tracks that have a common origin. These tracks vary from 2 to 10 with an average of about 4. The number of stars increases with the elevation above sea level. At an elevation of about 4,500 m the average energy ionization star particle was about 12 Mev.

Cosmic-ray showers, extensive ionizations of exceedingly complex reactions taking place in the atmosphere, extend over distances up to several hundred meters. These showers contain millions of particles and represent a total of about 10^{15} ev.

These secondary rays may be roughly divided into a hard and a soft component. The separation is generally made by filtering out the soft component with about 10 to 12 cm of lead. The hard component consists of mesons, a small number of protons, possibly some fast-moving electrons, and short-wavelength photons. The soft component consists of electrons, photons, and some slow-moving mesons, protons, and neutrons. The number of rays of the hard component does not reach a maximum with height but seems to increase to as great a height as measurements have been made, i.e., up to a height where the pressure is above 0.8 mmHg, where it is about 15 times as intense as at sea level. The soft component increases in intensity down from the top of the atmosphere to a pressure of 75 mmHg, then decreases to sea level, where the intensity is about 1 percent of that at its maximum. At its maximum intensity the soft component is about 5 times that of the hard component, in the vertical direction. At the earth's surface this hard component makes up about 75 percent of the cosmic radiation and a much smaller part at high altitudes. This hard component is very penetrating, since it will pass through many meters of water or lead. Cosmic rays have been detected in a mine at a depth of 384 meters, and by tipping the apparatus, the thickness through which the cosmic rays passed was equivalent to 1,408 meters of water (about 124 meters of lead!). Another observer detected this radiation in a coal mine at a depth of 610 meters, which is equivalent to 1,600 meters of water! In this case, the intensity measured at the depth corresponding to 1,600 meters of water was only about 1/20000 of that at the surface! These highly penetrating rays are thought to be mesons, produced by the primary cosmic rays.

TABLE 796.—MEAN IONIZATION ENERGY OF γ-RAY NECESSARY TO PRODUCE AN ION PAIR *

(See Table 799.)

Gas	ev	Gas	ev	Gas	ev
H_2	33.0	N_2	35.0	Ne	27.4
He	27.8	O_2	32.3	A	25.4

* For reference, see footnote 203, p. 624.

TABLE 797.—THE CRITICAL ENERGY * AND THE TOTAL ENERGY OF COSMIC RAYS ENTERING THE ATMOSPHERE AT FOUR LOCATIONS

Location	Geomagnetic latitude	Eff crit energy Bev/particle	Total energy, E Bev cm^{-2} sec^{-1}	Location	Geomagnetic latitude	Eff crit energy Bev/particle	Total energy, E Bev cm^{-2} sec^{-1}
Saskatoon	60°	1.4	2.36	San Antonio ...	38°	6.7	1.81
Omaha	51°	2.9	2.25	Madras	3°	17.0	.94

* The energy of a cosmic ray which enables it to enter the earth's atmosphere.

TABLE 798.—ESTIMATED COSMIC RAY INTENSITIES AT 50° GEOMAGNETIC LATITUDE

In this table are given some data on cosmic rays for various altitudes for geomagnetic latitudes of 50°

Altitude		Total intensity			Hard component			Soft component		
		Omnidirectional	Vertical	Latitude effect	Omnidirectional	Vertical	Latitude effect	Omnidirectional	Vertical	Latitude effect
meters	atm	particle/sec cm^2	particle/sec cm^2 ω	per-cent	particle/sec cm^2	particle/sec cm^2 ω	per-cent	particle/sec cm^2	particle/sec cm^2 ω	per-cent
0	1.000	.020	.015	10	.013	.009	10	.007	.006	10
2,000	.784	.035	.025	15	.018	.012	15	.017	.013	15
4,500	.570	.10	.07	25	.03	.020	25	.07	.05	25
10,000	.261	.7	.3	45	.10	.05	30	.6	.25	30
16,100	.100	1.5	.5	75	.25	.08	?	1.25	.42	80
30,000	.0115	.5	.15	85	.4	.13	?	.06	.02	?
∞	0	.3	.1	90	?	?	?	?	?	?

ω = solid angle.

TABLE 799.—SOME COSMIC-RAY DATA

Total number of rays at top of the atmosphere..........	8×10^{17} sec^{-1}
Total energy carried to earth per second (outer atmosphere)	9×10^{18} Bev/sec, 1.4×10^{9} watts
If all particles are positively charged this stream gives a current of *	.13 amp
Average number of rays † at top of atmosphere..........	.16 cm^{-2} sec^{-1}
Average energy of all incident particles, latitude >40....	7 Bev
Average energy of all incident particles, all areas, about..	11 Bev
Cosmic energy reaching earth's outer atmosphere, high latitude	3.8×10^{-3} erg cm^{-2} sec^{-1}
Average energy of the cosmic rays entering the atmosphere is about..........	7×10^{9} ev
The spectrum extends from about..........	1×10^{9} to 10^{17} ev and probably higher
The energy required for the ionization found in a column 1 cm^2 in cross section extending to top of atmosphere at 60 N geomagnetic latitude..........	3.8×10^{-3} erg cm^{-2} sec^{-1}
Thus in this column there are formed about..........	7.4×10^{7} ion pairs
This means about..........	90 ion pair, cm^{-1} sec^{-1}
Total number of rays at sea level from all directions.....	1.2 ray min^{-1} cm^{-2}
Cosmic ray at sea level produces ‡..........	1.63 ion pair, cm^{-3} sec^{-1}
Total cosmic energy reaching earth per second at sea level.	40 joules
Radiant energy flux reaching earth from all stars.......	3.02×10^{-3} erg cm^{-2} sec^{-1}

* If there were no compensating effects the potential of the earth would increase about 180V/sec. † The number varies with the geomagnetic latitude, being about 0.33 particles cm^{-2} sec^{-1} at high latitudes (>40°) and about 0.032 particles cm^{-2} sec^{-1} at the equator. This data is based upon an energy of 32 ev necessary to produce one ion pair. ‡ Thus the average ray entering the cm^3 at sea level has an energy of about 10^8 ev.

TABLE 800.—RADIATION AT EARTH'S SURFACE, MASS AND RADIATION DENSITY IN OUR GALAXY, AND IN THE UNIVERSE

Our galaxy:	
Total number of stars	30×10^{9}
Average mass of stars	2×10^{33} g
Total mass of galaxy	3.27×10^{44} g
Total volume	10^{68} cm^{3}
Diameter (disk)	5×10^{22} cm
Average mass density	3×10^{-24} g cm^{-3}
Total mass energy	2.95×10^{65} ergs
Total kinetic energy	1.6×10^{60} ergs
Average mass-energy-density	3×10^{-3} erg cm^{-3}
Average kinetic energy-density	1.6×10^{-8} erg cm^{-3}
Universe:	
Mass density	3×10^{-30} g cm^{-3}
Mass-energy-density	3×10^{-9} erg cm^{-3}
Radiant-energy-density	6×10^{-16} erg cm^{-3}
Cosmic ray energy-density	1.7×10^{-11} erg cm^{-3}
At earth's surface (top of atmosphere):	
Total radiant energy from all stars	1.78×10^{-3} erg cm^{-2} sec^{-1}
Total radiant energy density (our galaxy)	5.8×10^{-14} erg cm^{-3}
Total radiant energy (sun directly overhead)*	1.2×10^{6} erg cm^{-2} sec^{-1}
Cosmic ray energy	3.8×10^{-3} erg cm^{-2} sec^{-1}
Cosmic ray energy-density	10^{-13} erg cm^{-3}

* Astrophysical data.

TABLE 801.—COMPOSITION OF COSMIC RADIATION AT GEOMAGNETIC LATITUDE 30° [247]

	Relative No. of particles				Relative No. of particles		
Nuclei	Sun	τ Sco	Cosmic rays	Nuclei	Sun	τ Sco	Cosmic rays
H	....	1.6×10^{6}	1.6×10^{6}	$11\leqslant Z\leqslant14$	157	215	~2600
He	....	2.9×10^{5}	4.0×10^{5}	$16\leqslant Z\leqslant20$	28	5	~1000
$6\leqslant Z\leqslant8$	3200	2500	14000	Fe	150	...	~ 400

[247] Bradt and Peters, Phys. Rev., vol. 77, p. 54, 1950.

TABLE 802.—ACCELERATION OF GRAVITY

For sea-level and different latitudes. Calculated from the International Gravity Formula:

$$g = 978.0490\ [1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi]$$

Latitude ϕ	g cm/sec²	log g	g ft/sec²	Latitude ϕ	g cm/sec²	log g	g ft/sec²
0°	978.0490	2.9903607	32.08	50°	981.0786	2.9917038	32.19
5	.0881	.9903780	.09	51	.1673	.9917431	.19
10	.2043	.9904296	.09	52	.2554	.9917821	.19
12	.2716	.9904594	.09	53	.3427	.9918207	.20
14	.3504	.9904944	.10	54	.4291	.9918589	.20
15	978.3940	.9905138	32.10	55	981.5146	.9918968	32.20
16	.4404	.9905344	.10	56	.5990	.9919341	.20
17	.4893	.9905561	.10	57	.6822	.9919709	.21
18	.5409	.9905790	.10	58	.7642	.9920072	.21
19	.5951	.9906031	.11	59	.8448	.9920428	.21
20	978.6517	.9906281	32.11	60	981.9239	.9920778	32.21
21	.7107	.9906543	.11	61	982.0015	.9921122	.22
22	.7721	.9906815	.11	62	.0773	.9921457	.22
23	.8357	.9907098	.11	63	.1515	.9921785	.22
24	.9015	.9907390	.12	64	.2238	.9922105	.22
25	978.9694	.9907691	32.12	65	982.2941	.9922415	32.23
26	979.0394	.9908001	.12	66	.3624	.9922718	.23
27	.1113	.9908321	.12	67	.4287	.9923010	.23
28	.1850	.9908648	.12	68	.4927	.9923293	.23
29	.2606	.9908983	.13	69	.5545	.9923567	.24
30	979.3378	.9909325	32.13	70	982.6139	.9923829	32.24
31	.4165	.9909674	.13	71	.6709	.9924081	.24
32	.4968	.9910030	.14	72	.7254	.9924322	.24
33	.5785	.9910392	.14	73	.7774	.9924552	.24
34	.6614	.9910760	.14	74	.8267	.9924769	.24
35	979.7455	.9911133	32.14	75	982.8734	.9924976	32.25
36	.8308	.9911511	.15	76	.9173	.9925170	.25
37	.9170	.9911893	.15	77	.9585	.9925351	.25
38	980.0041	.9912279	.15	78	.9968	.9925521	.25
39	.0919	.9912668	.15	79	983.0322	.9925678	.25
40	980.1805	.9913060	32.15	80	983.0647	.9925821	32.25
41	.2696	.9913455	.16	81	.0942	.9925951	.25
42	.3591	.9913852	.16	82	.1207	.9926068	.25
43	.4490	.9914250	.17	83	.1442	.9926172	.25
44	.5391	.9914649	.17	84	.1645	.9926262	.26
45	980.6294	.9915049	32.17	85	983.1818	.9926338	32.26
46	.7197	.9915449	.18	86	.1960	.9926402	.26
47	.8098	.9915848	.18	87	.2071	.9926450	.26
48	.8998	.9916246	.18	88	.2150	.9926485	.26
49	.9894	.9916643	.18	90	983.2213	.9926513	.26

TABLE 803.—FREE-AIR CORRECTION OF ACCELERATION OF GRAVITY FOR ALTITUDE

To reduce log g (cm per sec per sec) to log g (ft per sec per sec) add log 0.03280833 = 8.5159842 — 10.

The standard value of gravity, used in barometer reductions, etc., is 980.665. It was adopted by the International Committee on Weights and Measures in 1901. It corresponds nearly to latitude 45° sea-level.

—0.0003086 cm $sec^{-2}\ m^{-1}$ when altitude is in meters.
—0.000003086 ft $sec^{-2}\ ft^{-1}$ when altitude is in feet.

Altitude	Correction	Altitude	Correction
200 m	—.0617 cm/sec²	200 ft	—.000617 ft/sec²
300	.0926	300	.000926
400	.1234	400	.001234
500	.1543	500	.001543
600	.1852	600	.001852
700	.2160	700	.002160
800	.2469	800	.002469
900	.2777	900	.002777

* Prepared under the direction of K. T. Adams, U. S. Coast and Geodetic Survey.

TABLE 804.—ACCELERATION OF GRAVITY, VARIOUS WORLD STATIONS

Name	Latitude	Longitude	Elevation meters *	Gravity, cm/sec²	
				Observed	Reduced to sea level
Santiago, Chile	33°27′.1 S	70°39′.8 W	541.3	979.429	979.596
Rio, Brazil	22 53.7 S	43 13.4 W	29.0	978.805	978.814
Tacna, Peru	18 01.0 S	70 15.0 W	557.1	978.298	978.470
Chala, Peru	15 49.0 S	74 18.5 W	14.0	978.452	978.456
Lima, Peru	12 01.1 S	77 02.3 W	143.6	978.289	978.333
Minkindani, E. Africa	10 16.6 S	40 07.6 E	3	978.224	978.225
Timor Sea	9 36 S	128 07 E	− 340	978.233	978.233
Trujillo, Peru	8 07.0 S	79 02.3 W	29.4	978.095	978.104
Mafia, E. Africa	7 54.9 S	39 39.4 E	5	978.168	978.169
Indian Ocean	7 35 S	106 55 E	− 230	978.292	978.292
Kaliwa, E. Africa	5 04.2 S	31 47.5 E	1080	977.783	978.116
Banda Sea	1 45 S	126 57 E	−1390	978.058	978.058
Limuru, E. Africa	1 07 S	36 40 E	2193	977.412	978.089
Marigal, E. Africa	0 28 N	35 59 E	1036	977.664	977.984
Kanifuri, India	5 22.2 N	73 19.2 E	1	978.107	978.107
Indian Ocean	7 56 N	68 46 E	−4390	978.102	978.102
Punalur, India	9 01.0 N	76 55.8 E	34	978.107	978.117
Pacific Ocean	9 52 N	132 46 E	−6050	978.212	978.212
Pacific Ocean	13 35 N	95 27 W	−3870	978.360	978.360
Dharwar, India	15 27.6 N	75 00.2 E	728	978.183	978.407
Musmar, E. Africa	18 13.0 N	35 58 E	493	978.399	978.551
Tacubaya, Mexico	19 24.3 N	99 11.7 W	2299	977.941	978.650
Pacific Ocean	19 58 N	164 56 W	−4960	978.660	978.660
Atlantic Ocean	20 44 N	65 37 W	−5510	978.704	978.704
Santiago, Cuba	22 30.9 N	80 30.4 W	67	978.826	978.847
Atlantic Ocean	23 21 N	47 05 W	−3550	978.880	978.880
Key West, Fla.	24 33.6 N	81 48.4 W	1	978.973	978.973
Dholpur, India	26 42.0 N	77 54.8 E	176	978.999	979.054
Nagasaki, Japan	32 44.7 N	129 52.3 E	30	979.594	979.603
Mount Wilson, Calif.	34 13.4 N	118 03.4 W	1719.4	979.253	979.783
Batna, Algeria	35 33.0 N	6 10 E	1050	979.468	979.792
Atlantic Ocean	36 23 N	26 43 W	−3610	979.890	979.890
Sevilla, Spain	37 23.0 N	5 59.5 W	11	979.965	979.968
Denver, Colo.	39 40.6 N	104 57.1 W	1639.5	979.612	980.118
Buffalo, N. Y.	42 57.1 N	78 49.3 W	210	980.363	980.428
Atlantic Ocean	43 14 N	19 36 W	−4100	978.520	978.520
Ottawa, Ontario	45 23.6 N	75 43.0 W	83	980.622	980.648
Müchen, Germany	48 09 N	11 37 E	525	980.733	980.895
Greenwich, England	51 28.6 N	0 00.3 E	47	981.189	981.204
Saskatoon, Saskatchewan	52 07.8 N	106 38.1 W	497	981.138	981.291
Vladimirskaja, Siberia	54 57 N	85 59 E	265	981.424	981.506
Tomsk, Siberia	56 28 N	84 57 E	125	981.582	981.621
Oslo, Norway	59 54.7 N	10 43.5 E	28	981.927	981.936
St. Michael, Alaska	63 28.5 N	162 02.4 W	1	982.197	982.197
Arctic Red River, N. T.	67 26.6 N	133 44.3 W	41	982.438	982.451
Whales Point, Spitzbergen	77 30.4 N	20 58.8 E	458	982.897	983.038
Hellwald, Spitzbergen	78 44.1 N	20 50.2 E	660	982.871	983.075
Ile de Rosse	80 49.6 N	20 20.6 E	31	983.145	983.155
Arctic Ocean	81 48 N	19 25 E	−3402	983.096	983.096

* For sea stations, the depth is recorded in this column; the observations were made in submarines and reduced to sea level.

TABLE 805.—ACCELERATION OF GRAVITY (g) IN THE UNITED STATES

The following table is abridged from the table of Principal Facts in U. S. Coast and Geodetic Survey Special Publication No. 244, Pendulum Gravity Data in the United States. The observed values depend on relative determinations and on an adopted value of 980.118 for the Commerce Building Base in Washington, D. C.

There are also given two types of gravity anomalies. The free-air anomaly is the difference between the observed value of gravity and the theoretical values of gravity for the latitude of the station corrected for the elevation of the station. The isostatic anomaly is the difference between the observed values of gravity and the theoretical value of gravity for the latitude of the station corrected for the elevation of the station, topography and isostatic compensation in the earth's crust to a depth of 113.7 kilometers.

Station	Latitude	Longitude	Elevation *m*	Observed gravity gal	Free-air anomaly gal	Isostatic anomaly gal
Atlanta, Ga.	33°45′.3	84°23′.5	324.0	979.527	—.014	—.030
Austin, Tex. (university)	30 17.2	97 44.2	189	979.286	—.016	—.017
Baltimore, Md.	39 17.8	76 37.3	30.5	980.114	+.005	+.002
Beaufort, N. C.	34 43.1	76 39.8	1.5	979.732	+.011	—.026
Birmingham, Ala	33 30.8	86 48.8	179	979.539	—.027	—.038
Bismarck, N. Dak.	46 48.5	100 47.1	514.4	980.628	—.006	—.001
Boise, Idaho	43 37.2	116 12.3	822.0	980.215	—.036	+.010
Boston, Mass.	42 21.6	71 03.8	22	980.399	+.014	+.002
Burbank, Okla.	36 42.2	96 41.0	345	979.788	+.003	—.001
Calais, Maine	45 11.2	67 16.9	38	980.634	.000	—.008
Cambridge, Mass.	42 22.8	71 07.8	14	980.401	+.012	+.001
Charleston, S. C.	32 47.2	79 56.0	6.1	979.549	—.010	—.026
Charlottesville, Va.	38 02.0	78 30.3	166	979.941	—.015	—.017
Chicago, Ill.	41 47.4	87 35.9	182	980.281	—.003	—.004
Cincinnati, Ohio	39 08.3	84 25.3	245	980.007	—.022	—.024
Cleveland, Ohio	41 30.4	81 36.6	210	980.244	—.006	—.006
Cloudland, Tenn.	36 06.2	82 07.9	1890	979.386	+.129	—.001
Colorado Springs, Colo.	38 50.8	104 49.5	1841.8	979.493	—.017	—.008
Columbus, Ga.	32 27.0	84 57.6	73.5	979.526	+.015	+.014
Columbus, Ohio	39 57.8	82 59.4	231.0	980.092	—.014	—.014
Denver, Colo.	39 40.6	104 57.1	1639.5	979.612	—.034	—.016
Duluth, Minn.	46 47.0	92 06.4	215.8	980.761	+.037	+.048
Durham, N. C.	36 00.2	78 56	126	979.838	+.046	+.034
El Paso, Tex.	31 46.3	106 29.0	1146.0	979.127	+.002	+.009
Empire State Building, N. Y.	40 44.9	73 59.2	16.2	980.269	+.027	+.020
Eugene, Oreg.	44 02.7	123 05.6	129	980.493	—.010	+.005
Fort Dodge, Iowa	42 30.8	94 11.4	340.1	980.314	+.014	+.011
Grand Canyon, Ariz.	36 05.3	112 06.8	847.0	979.466	—.111	—.014
Grand Canyon, Wyo.	44 43.7	110 29.7	2386.0	979.902	+.033	—.002
Grand Rapids, Mich.	42 58.0	85 39.5	235.8	980.375	+.002	—.004
Green River, Utah	38 59.4	110 09.9	1243	979.639	—.068	—.025
Iowa City, Iowa	41 39.6	91 32.2	212.3	980.250	—.013	—.012
Ithaca, N. Y.	42 27.1	76 29.0	246.9	980.303	—.020	—.022
Key West, Fla.	24 33.6	81 48.4	1	978.973	+.034	—.011
Knoxville, Tenn.	35 57.7	83 55	280	979.715	—.027	—.026
Lancaster, N. H.	44 29.5	71 34.3	261.8	980.489	—.014	—.014
Las Vegas, N. Mex.	35 35.8	105 13.1	1959.6	979.207	+.015	—.003
Little Rock, Ark.	34 44.9	92 16.4	89.0	979.724	+.027	+.028
Madison, Wis.	43 04.6	89 24.0	270	980.368	—.005	—.008
Memphis, Tenn.	35 08.7	90 03.3	80.3	979.743	+.010	+.008
Miles City, Mont.	46 24.2	105 50	718	980.542	+.008	+.028
Minneapolis, Minn.	44 58.7	93 13.9	256.1	980.600	+.052	+.055
Mitchell, S. Dak.	43 41.8	98 01.8	408	980.378	—.003	—.002
Mount Hamilton, Calif.	37 20.4	121 38.6	1281.7	979.663	+.112	—.004
New Orleans, La.	29 56.9	90 04.3	2.4	979.326	—.007	—.020
New York, N. Y.	40 48.5	73 57.7	38.1	980.270	+.029	+.019
Oberlin, Ohio	41 17.5	82 13.2	248	980.208	—.011	—.013
Philadelphia, Pa.	39 57.1	75 11.7	15.8	980.199	+.028	+.018
Pike's Peak, Colo.	38 50.4	105 02.5	4293.1	978.957	+.203	+.018
Pittsburgh, Pa.	40 27.4	80 00.6	235	980.121	—.027	—.027
Prestonsburgh, Ky.	37 40.6	82 45.6	193	979.884	—.032	—.028
Princeton, N. J.	40 21.0	74 39.5	64.0	980.181	—.011	—.025

(*continued*)

TABLE 805.—ACCELERATION OF GRAVITY (g) IN THE UNITED STATES (concluded)

Station	Latitude	Longitude	Elevation m	Observed gravity gal	Free-air anomaly gal	Isostatic anomaly gal
Richmond, Va.	37°32ʹ.2	77°26ʹ.1	29.9	979.963	+.009	.000
St. Louis, Mo.	38 38.0	90 12.2	153.9	980.004	−.008	−.007
St. Petersburg, Fla.	27 48.9	82 40.2	15	979.191	+.025	+.006
Salt Lake City, Utah	40 46.1	111 53.8	1322	979.806	−.035	+.006
San Francisco, Calif.	37 37.5	122 25.7	114.3	979.968	+.018	−.022
Seattle, Wash. (university)	47 39.6	122 18.3	58	980.736	−.115	−.095
Sheridan, Wyo.	44 48.0	106 58.7	1149.9	980.244	−.012	+.010
Smith College, Mass.	42 19.0	72 38.2	54.6	980.376	+.005	+.006
State College, Pa.	40 47.9	77 51.8	357.8	980.127	−.014	−.014
Terre Haute, Ind.	39 28.7	87 23.8	150.9	980.075	−.013	−.011
Traverse City, Mich.	44 45.8	85 37.2	180.1	980.553	+.001	+.001
Wallace, Kans.	38 54.7	101 35.4	1005	979.758	−.016	−.016
Washington, D. C.:						
Geophysical Laboratory	38 56.6	77 03.4	88.1	980.104	+.044	+.036
National Bureau of Standards	38 56.5	77 03.9	95.1	980.100	+.042	+.034
Smithsonian Institution	38 53.3	77 01.5	10.4	980.118	+.039	+.038
Wheeling, W. Va.	40 04.0	80 43.3	205	980.088	−.035	−.032
Winnemucca, Nev.	40 58.4	117 43.8	1311	979.847	−.016	−.012
Worcester, Mass.	42 16.5	71 48.5	170.0	980.328	−.003	−.022
Wright Field, Ohio	39 46.6	84 05.9	247.8	980.094	+.010	+.008
Yuma, Ariz.	32 43.3	114 37.0	53.9	979.532	−.007	+.006

TABLE 806.—LENGTH OF SECONDS PENDULUM AT SEA LEVEL AND FOR DIFFERENT LATITUDES

Lat	Length cm	Log	Length in.	Log	Lat	Length cm	Log	Length in.	Log
0°	99.097	1.996061	39.014	1.591221	50°	99.404	1.997404	39.135	1.592565
5	99.101	1.996078	39.016	1.591243	55	99.449	1.997597	39.153	1.592765
10	99.113	1.996131	39.020	1.591287	60	99.490	1.99778	39.169	1.592943
15	99.132	1.996215	39.028	1.591376	65	99.527	1.997942	39.184	1.593109
20	99.158	1.996329	39.038	1.591488	70	99.560	1.998084	39.196	1.593242
25	99.190	1.996469	39.051	1.591632	75	99.586	1.998198	39.207	1.593364
30	99.228	1.996633	39.066	1.591799	80	99.605	1.998283	39.214	1.593441
35	99.269	1.996814	39.082	1.591977	85	99.618	1.998335	39.219	1.593497
40	99.313	1.997006	39.099	1.592166	90	99.622	1.998352	39.221	1.593519
45	99.359	1.997205	39.117	1.592366					

Calculated from Table 802 by the formula $l = g/\pi^2$. For each 100 ft of elevation subtract 0.000953 cm or 0.000375 in. or 0.0000313 ft. This table could also have been computed by either of the following formulas derived from the gravity formula at the top of Table 802.

$$l = 0.990961\ (1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi) \text{ meters.}$$
$$l = 0.990961 + .0052406 \sin^2 \phi - 0.0000058 \sin^2 2\phi, \text{ meters.}$$
$$l = 39.014135\ (1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi) \text{ inches.}$$
$$l = 39.014135 + 0.2063214 \sin^2 \phi - 0.0002302 \sin^2 2\phi, \text{ inches.}$$

TABLE 807.—SOME PLACES OF ANOMALOUS GRAVITY [248]

The departures are from values of gravity normally expected, from Table 802.

Latitude	Longitude	Elevation meters *	Gravity cm/sec²	Departure from values of table	Place
19°29'.8 N	155°34'.8 W	3970	978.096	+698	Mauna Loa
19 42.2 N	155 27.9 W	2030	978.504	+495	Kalaieha
19 25.4 N	155 15.7 W	1211	978.673	+428	Kilavea
23 47.0 N	166 12.5 W	2	979.201	+315	East Island
32 21 N	64 40 W	2	979.806	+282	St. Georges
37 30.0 N	2 45.0 W	858	979.669	+265	Baza
38 06.7 N	3 04.5 W	805	979.792	+248	Villacarrillo
42 55.8 N	0 08 E	2877	979.779	+224	Pic du Midi
37 11.0 N	3 36.0 W	669	979.669	+206	Granada
45 50 N	6 52 E	4807	979.401	+180	Mont Blanc
45 57.5 N	7 48.9 E	2797	980.019	+166	Bétempshütte
45 59.5 N	7 42.7 E	2582	980.080	+157	Schwarzsee
67 53.6 N	13 02.0 E	19	982.622	+142	Sörvaagen
33 48.5 N	74 33.3 E	3338	978.752	+133	Korag
51 48 N	10 37 E	1140	981.015	+129	Brocken
35 44.5 N	15 39.5 E	− 460	979.926	+118	Mediterranean Sea
40 38 N	17 57 E	16	980.337	+107	Brindisi
23 06.1 N	74 58.5 W	2	978.941	+100	Clarence Town
42 08 N	41 42 E	3	980.317	− 53	Poti
46 21.9 N	9 07.6 E	1030	980.374	− 61	Augio
56 08.0 N	91 18.0 E	339	981.435	− 70	Kosulka
8 14 S	30 35 E	783	977.835	− 78	Moliro
30 19.5 N	78 03.4 E	683	979.063	− 89	Dehra Dun
50 30.2 N	116 03.4 W	828	980.767	−100	Invermere
1 50 N	31 19 E	623	977.753	−109	Butiaba
7 50 S	120 48 E	−5140	978.024	−121	Java Sea
5 12 N	94 12 E	−2555	977.962	−129	Indian Ocean
40 26 N	50 00 E	57	980.065	−136	Surachany
8 48 S	128 26 E	−2120	978.019	−151	Timor Sea
26 41.8 N	88 24.8 E	118	978.887	−166	Siliguri
2 09 N	126 59 E	−2200	977.877	−179	Celebes Sea
10 17 N	126 41 E	−8740	978.013	−200	Philippine Sea
0 29 S	125 59 E	−2390	977.833	−216	Celebes Sea
5 36 S	131 08 E	−7330	977.843	−255	Banda Sea
19 32 N	66 46 W	−8040	978.284	−341	Atlantic Ocean

[248] Heiskanen, W., Catalogue of the isostatically reduced gravity stations, Helsinki, 1939.
* For sea stations, the depth is recorded in this column; the observations were made in submarines and reduced to sea level.

TABLE 808.—THE SOLAR CONSTANT

A long series of measurements has been made [249] at widely separated, selected stations by the astrophysicists of the Smithsonian Institution on both the total intensity of the solar radiation and the spectral distribution of this radiation. One result of these measurements is the value of the *solar constant*, that is, the total solar radiation (cal cm^{-2} min^{-1}) at normal incidence outside the atmosphere at the mean solar distance. As a result of the work up to 1913 the solar constant was found to be 1.9408 ly. min^{-1} (langley; see Table 2, Part 2). Later investigations [250] showed that the standard used in these measurements was somewhat in error. Observations showed that the correction employed for the unmeasured ultraviolet radiation was too low; also solar radiation in the infrared region beyond about 2.5 μ introduced some error. As a final result of all the corrections it was found that this 1913 value of the solar constant was very good. It should be pointed out that there is evidence [249] that the solar constant fluctuates as much as ± 1.5 percent. In addition, the varying distance between the sun and earth (see Table 827) produces a change in the actual solar radiation at the top of the atmosphere of about ± 3.5 percent from the mean value. Now in 1951 the value of the solar constant (amount of energy falling at normal incidence on one square centimeter per minute on body at earth's mean distance) = 1.946 calories = mean 6430 determinations 1924–47. Subject to variations, usually within the range of 2.8 percent, and occurring irregularly in periods of a week or 10 days. New data on the ultraviolet and infrared corrections to the solar constant given by F. S. Johnson (in press) indicate that the value 1.946 should be increased by 2.6 percent. Johnson's best value is 2.00 ± 2 percent.

Computed effective temperature of the sun: from form of blackbody curves, 6000° to 7000° Absolute; from $\lambda_{max} T = 2930$ and max = 0.470μ, 6230°; from total radiation, $J = 76.8 \times 10^{-12} \times T^4$, 5830°.

Sun radiates .... 3.8×10^{33} erg/sec
6.25×10^{10} erg sec^{-1} cm^{-2}
of this .... 1.72×10^{24} erg/sec strikes the earth.

* Prepared by L. B. Aldrich and W. H. Hoover, Astrophysical Observatory, Smithsonian Institution.
[249] Abbot, C. G., Solar radiation and weather studies, Smithsonian Misc. Coll., vol. 94, No. 10, 1935.
[250] Aldrich, L. B., and Abbot, C. G., Smithsonian pyrheliometry and the standard scale of solar radiation, Smithsonian Misc. Coll., vol. 110, No. 5, 1948. See also Annals, Smithsonian Astrophysical Observatory, vol. 7, ch. 3 (in press).

TABLE 809.—ATMOSPHERIC TRANSMISSION COEFFICIENTS

Wave-length μ	Montezuma, Chile		Table Mt., Calif.		Miami, Fla.	
	High	Low	High	Low	High	Low
.34	.620	.568	.605	.552	.512	.464
.35	.656	.600	.641	.585	.541	.492
.36	.687	.630	.672	.615	.567	.519
.37	.714	.657	.701	.643	.593	.545
.38	.738	.681	.726	.668	.617	.571
.39	.759	.703	.749	.692	.642	.595
.40	.778	.722	.769	.712	.662	.615
.45	.848	.792	.840	.783	.755	.709
.50	.890	.838	.883	.831	.818	.764
.55	.900	.849	.890	.838	.850	.788
.60	.913	.863	.905	.854	.873	.814
.65	.936	.884	.933	.880	.925	.872
.70	.963	.924	.961	.922	.935	.890
.75	.972	.936	.970	.934	.943	.902
.80	.980	.945	.978	.943	.949	.911
.85	.984	.952	.983	.950	.954	.917
.90	.985	.956	.984	.954	.957	.922
.95	.986	.957	.985	.956	.960	.925
1.00	.987	.958	.986	.957	.962	.928
1.25	.989	.960	.989	.959	.964	.933
1.50	.994	.965	.994	.968	.969	.942
1.75	.997	.970	.997	.970	.973	.946
2.00	.996	.975	.996	.974	.969	.945
2.25	.988	.970	.987	.965	.955	.930

High transmissions are for every clear day and low precipitable water, 2 mm for Montezuma and Table Mt., and 3.5 mm for Miami.
Low transmissions are for very hazy days and high precipitable water, 10 mm for Montezuma and Table Mt., and 25 mm for Miami.
Transmission coefficients in the range .70 — 2.25 λ are all smooth-curve values drawn over the tops of the water-vapor bands.
Unit air mass.

TABLE 810.—THE SOLAR CONSTANT, MONTHLY AND YEARLY MEANS*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly mean
1920										1.945	1.950	1.953	
21	1.957	1.955	1.949	1.947	1.950	1.939	1.950	1.943	1.950	55	57	52	1.950
22	47	46	36	30	30	18	14	21	17	25	26	24	28
23	42	29	32	31	36	28	36	34	53	45	44	43	38
24	44	41	47	42	50	52	51	46	47	52	53	50	48
25	46	55	50	50	48	48	49	47	49	48	46	48	49
26	45	38	40	38	40	41	42	46	43	38	36	37	40
27	39	39	40	44	43	46	44	43	48	42	46	44	43
28	41	42	46	44	48	49	43	42	42	43	46	47	44
29	48	41	41	43	43	37	41	39	40	39	43	46	42
1930	44	44	43	42	47	50	50	49	46	46	48	52	47
31	48	46	47	46	51	47	48	47	49	47	45	46	47
32	45	39	39	41	39	42	44	41	41	39	39	46	41
33	50	48	42	40	41	43	46	43	49	49	50	50	46
34	48	45	47	43	44	48	47	44	48	51	51	50	47
35	48	45	47	46	47	47	47	49	45	47	50	51	47
36	47	46	44	46	47	49	47	47	48	49	52	51	48
37	49	48	43	41	43	47	44	46	48	46	48	51	46
38	47	46	48	44	44	43	44	45	46	49	52	51	47
39	47	42	44	43	42	41	42	40	46	44	51	47	44
1940	47	45	43	48	48	48	49	47	49	46	45	49	47
41	48	48	50	47	51	48	52	50	48	50	49	51	49
42	49	48	43	45	47	48	48	45	44	44	48	44	46
43	42	44	43	45	46	51	48	49	47	46	43	48	46
44	48	52	44	44	46	44	45	43	40	43	46	46	45
45	39	46	44	48	47	44	47	41	42	42	47	43	44
46	46	39	38	46	53	52	51	48	50	48	53	54	48
47	53	49	45	49	50	51	47	49	47	52	53	54	50
48	51	53	49	51	52	56	57	53	56	52	56	55	53
49	55	56	47	49	51	44	49	49	47	50	52	54	50
1950	56	49	47	45	49	49	47	50	47	52	51	49	49
1951	50	52	55	43	40	44	46	48	47	47	42	46	46
1952	45	41	36	44	46	47	40	43	42	43	40	47	43

* Calories per cm per min.

TABLE 811.—AIR MASSES

The transmission, both total and spectral, of the atmosphere depends upon several varying factors besides the actual air masses, that is, the length of the path of the rays in the atmosphere; thus, corrections must always be determined for different tests.

Values of the transmission of the atmosphere for any position of the sun except when it is directly overhead are calculated from measurement when the sun is in the zenith, i.e., $e_m = e_0 a^m$ when e_m is the intensity of the radiation at air mass m, e_0 the intensity for the sun in the zenith, and a the transmission for unit air mass. m is unity when the sun is in the zenith and approximately equals the secant of the zenith distance for the other positions.

Besides values derived from the pure secant formula, the table contains those derived from various other more complex formulas, taking into account the curvature of the earth, refraction, etc. The most recent is that of Bemporad.

Zenith dist	0°	20°	40°	60°	70°	75°	80°	85°	88°
Secant	1.00	1.064	1.305	2.000	2.924	3.864	5.76	11.47	28.7
Forbes	1.00	1.065	1.306	1.995	2.902	3.809	5.57	10.22	18.9
Bouguer	1.00	1.064	1.305	1.990	2.900	3.805	5.56	10.20	19.0
Laplace	1.00	——	——	1.993	2.899	——	5.56	10.20	18.8
Bemporad	1.00	——	——	1.995	2.904	——	5.60	10.39	19.8

TABLE 812.—THE AMOUNT OF SOLAR RADIATION IN DIFFERENT SECTIONS OF THE SPECTRUM, ULTRAVIOLET, VISIBLE, AND INFRARED

Calories, $min^{-1}cm^{-2}$, Smithsonian scale of 1913

Wavelength μ	0	Miami, Fla. Air mass 1	2	3	4	5	Montezuma, Chile Air mass 1	2	3	4	5
.00 to .400	.151	.070	.036	.018	.010	.005	.094	.061	.041	.028	.019
.400 to .770	.925	.740	.591	.476	.386	.314	.813	.734	.664	.603	.549
.770 to ∞	.874	.606	.517	.450	.398	.359	.742	.695	.657	.630	.608
.00 to ∞	1.950	1.416	1.144	.944	.794	.678	1.649	1.490	1.362	1.261	1.176

Average clear day at Miami, Fla. (sea level) precipitable water about 2.00 cm.
Average clear day at Montezuma, Chile (altitude 9,000 feet) precipitable water 0.25 cm.

TABLE 813.—SPECTRAL DISTRIBUTION OF SOLAR RADIATION OUTSIDE THE ATMOSPHERE

On the bases of the Smithsonian and other observations, Moon[251] in 1940 proposed a spectral solar-radiation curve at normal incidence outside the atmosphere at the mean solar distance and also a like curve for solar radiation at the earth's surface for air mass 2 (Table 815). More recently a rocket observation[252] has given a direct measurement (at 55 km) of the ultraviolet spectrum of the sun at wavelengths below 0.34 μ. Since less than 1 percent of atmospheric ozone is above this level, this observation should be closely representative of ultraviolet solar radiation at wavelengths above 0.22 μ at the top of the atmosphere. Moon's values for wavelengths above 0.33μ and data from the rocket observation for wavelengths below 0.33μ were used in constructing the table.

Part 1.—Intensity of solar radiation outside the atmosphere

Wave-length μ	Intensity Relative units	Wave-length μ	Intensity Relative units	Wave-length μ	Intensity Relative units	Wave-length μ	Intensity Relative units
.220	14	.420	1766	.68	1473	2.5	50
.230	33	.424	1742	.69	1439	2.6	43
.240	40	.430	1788	.70	1405	2.7	38
.250	55	.44	1939	.71	1371	2.8	33
.260	126	.45	2036	.72	1337	2.9	30
.265	174	.46	2096	.73	1304	3.0	26
.270	162	.47	2119	.74	1270	3.1	23
.275	136	.48	2127	.75	1236	3.2	21
.280	145	.49	2103	.80	1097	3.3	19
.290	378	.50	2061	.85	976	3.4	17
.295	418	.51	2000	.90	871	3.5	15
.300	386	.52	1954	.95	781	3.6	14
.310	538	.53	1912	1.0	706	3.7	12
.320	621	.54	1894	1.1	590	3.8	11
.330	796	.55	1878	1.2	488	3.9	10
.335	826	.56	1861	1.3	395	4.0	9
.340	856	.57	1841	1.4	319	4.1	8
.345	886	.58	1819	1.5	260	4.2	8
.350	916	.59	1795	1.6	214	4.3	7
.360	976	.60	1762	1.7	177	4.4	6
.370	1046	.61	1727	1.8	148	4.5	6
.380	1121	.62	1690	1.9	124	4.6	5
.390	1202	.63	1653	2.0	105	4.7	5
.400	1304	.64	1616	2.1	89	4.8	5
.405	1427	.65	1579	2.2	76	4.9	4
.410	1728	.66	1543	2.3	66	5.0	4
.413	1803	.67	1508	2.4	57		

[251] Moon, P., Journ. Franklin Inst., vol. 230, p. 583, 1940.
[252] Hulbert, E. O., Journ. Opt. Soc. Amer., vol. 37, p. 405, 1947.

(continued)

TABLE 813.—SPECTRAL DISTRIBUTION OF SOLAR RADIATION OUTSIDE THE ATMOSPHERE (concluded)

Part 2.—Energy distribution of solar radiation outside the atmcsphere

Wavelength interval μ	Energy cal cm⁻² min⁻¹	Wavelength interval μ	Energy cal cm⁻² min⁻¹	Wavelength interval μ	Energy cal cm⁻² min⁻¹	Wavelength interval μ	Energy cal cm⁻² min⁻¹
.22—.23	.0004	.45—.46	.0303	.68—.69	.0213	.91—.92	.0123
.23—.24	.0006	.46—.47	.0309	.69—.70	.0208	.92—.93	.0121
.24—.25	.0010	.47—.48	.0312	.70—.71	.0203	.93—.94	.0118
.25—.26	.0011	.48—.49	.0311	.71—.72	.0198	.94—.95	.0116
.26—.27	.0025	.49—.50	.0306	.72—.73	.0194	.95—.96	.0113
.27—.28	.0021	.50—.51	.0299	.73—.74	.0189	.96—.97	.0111
.28—.29	.0029	.51—.52	.0290	.74—.75	.0183	.97—.98	.0109
.29—.30	.0059	.52—.53	.0283	.75—.76	.0179	.98—.99	.0107
.30—.31	.0067	.53—.54	.0279	.76—.77	.0175	.99—1.0	.0105
.31—.32	.0085	.54—.55	.0277	.77—.78	.0171	1.0—1.1	.0948
.32—.33	.0107	.55—.56	.0274	.78—.79	.0167	1.1—1.2	.0792
.33—.34	.0121	.56—.57	.0271	.79—.80	.0163	1.2—1.3	.0643
.34—.35	.0130	.57—.58	.0268	.80—.81	.0159	1.3—1.4	.0518
.35—.36	.0138	.58—.59	.0264	.81—.82	.0155	1.4—1.5	.0424
.36—.37	.0149	.59—.60	.0260	.82—.83	.0152	1.5—1.6	.0348
.37—.38	.0159	.60—.61	.0255	.83—.84	.0148	1.6—1.7	.0288
.38—.39	.0171	.61—.62	.0251	.84—.85	.0145	1.7—1.8	.0240
.39—.40	.0184	.62—.63	.0245	.85—.86	.0142	1.8—1.9	.0197
.40—.41	.0212	.63—.64	.0240	.86—.87	.0138	1.9—2.0	.0168
.41—.42	.0262	.64—.65	.0234	.87—.88	.0135	2.0—3.0	.0719
.42—.43	.0256	.65—.66	.0229	.88—.89	.0132	3.0—4.0	.0227
.43—.44	.0276	.66—.67	.0224	.89—.90	.0129	4.0—5.0	.0084
.44—.45	.0292	.67—.68	.0219	.90—.91	.0126		

TABLE 814.—DISTRIBUTION OF INTENSITY (RADIATION) OVER SOLAR DISC

Fraction of radius

Wave-length * μ	.00	.30	.50	.60	.70	.80	.90	.95	.975
.3149	1.000	.959	.857	.760	.721	.607	.446	.337	.251
.3518	1.000	.977	.895	.841	.785	.679	.524	.407	.328
.3665	1.000	.980	.881	.841	.787	.703	.546	.437	.359
.4030	1.000	.959	.877	.859	.767	.664	.533	.423	.346
.4487	1.000	.977	.912	.859	.804	.720	.594	.500	.389
.5186	1.000	.975	.929	.877	.832	.759	.644	.551	.466
.5485	1.000	.967	.919	.884	.832	.756	.650	.565	.487
.6151	1.000	.980	.936	.900	.853	.790	.687	.600	.528
.6980	1.000	.983	.946	.916	.872	.812	.722	.644	.574
.8384	1.000	.984	.952	.926	.893	.843	.766	.695	.640
.9920	1.000	.987	.957	.933	.903	.860	.788	.727	.670
1.1973	1.000	.988	.965	.944	.918	.880	.814	.758	.702
1.5397	1.000	.993	.973	.960	.940	.912	.863	.811	.763
1.7093	1.000	.994	.980	.967	.950	.925	.878	.832	.786
2.0664	1.000	.994	.980	.970	.955	.929	.888	.849	.811
2.2870	1.000	.995	.980	.968	.953	.931	.891	.850	.814
3.5	1.000	.996	.988	.980	.969	.952	.928	.902	.875
8.3	1.000	.998	.992	.990	.986	.977	.960	.942	.928
10.2	1.000	.998	.994	.991	.988	.982	.966	.953	.946

* Values .3149 through .4487 μ from Cavanaggia and Chalonge, Ann. d'Astrophys., vol. 9, p. 143, 1946; .5186 through 10.2 μ from Pierce, McMath, Goldberg, and Mohler, Astrophys. Journ., vol. 112, p. 289, 1950.

TABLE 815.—SOLAR IRRADIATION AT SEA LEVEL WITH SURFACE PERPENDICULAR TO SUN'S RAYS $m = 2$ *

(Watts per square meter per micron)

λ microns	J_λ	λ microns	J_λ	λ microns	J_λ	λ microns	J_λ
.295	2.09 [a]	.60	1167	1.15	216	1.65	173
.296	2.35 [a]	.61	1168	1.16	271	1.66	163
.297	2.87 [b]	.62	1165	1.17	328	1.67	159
.298	9.87 [b]	.63	1176	1.18	346	1.68	145
.299	.0346	.64	1175	1.19	344	1.69	139
.300	.0810	.65	1173	1.20	373	1.70	132
.301	.177	.66	1166	1.21	402	1.71	124
.302	.342	.67	1160	1.22	431	1.72	115
.303	.647	.68	1149	1.23	420	1.73	105
.304	1.16	.69	978	1.24	387	1.74	97.1
.305	1.91	.70	1108	1.25	328	1.75	80.2
.306	2.89	.71	1070	1.26	311	1.76	58.9
.307	4.15	.72	832	1.27	381	1.77	38.8
.308	6.11	.73	965	1.28	382	1.78	18.4
.309	8.38	.74	1041	1.29	346	1.79	5.70
.310	11.0	.75	867	1.30	264	1.80	,920
.311	13.9	.76	566	1.31	208	1.81	...
.312	17.2	.77	968	1.32	168	1.82	...
.313	21.0	.78	907	1.33	115	1.83	...
.314	25.4	.79	923	1.34	58.1	1.84	...
.315	30.0	.80	857	1.35	18.1	1.85	...
.316	34.8	.81	698	1.36	.660	1.86	...
.317	39.8	.82	801	1.37	...	1.87	...
.318	44.9	.83	863	1.38	...	1.88	...
.319	49.5	.84	858	1.39	...	1.89	...
.32	54.0	.85	839	1.40	...	1.90	...
		.86	813	1.41	1.91	1.91	.705
		.87	798	1.42	3.72	1.92	2.34
.33	101	.88	614	1.43	7.53	1.93	3.68
.34	151	.89	517	1.44	13.7	1.94	5.30
.35	188	.90	480	1.45	23.8	1.95	17.7
.36	233	.91	375	1.46	30.5	1.96	31.7
.37	279	.92	258	1.47	45.1	1.97	37.7
.38	336	.93	169	1.48	83.7	1.98	22.6
.39	397	.94	278	1.49	128	1.99	1.58
.40	470	.95	487	1.50	157	2.00	2.66
.41	672	.96	584	1.51	187	2.01	19.5
.42	733	.97	633	1.52	209	2.02	47.6
.43	787	.98	645	1.53	217	2.03	55.4
.44	911	.99	643	1.54	226	2.04	54.7
.45	1006	1.00	630	1.55	221	2.05	38.3
.46	1080	1.01	620	1.56	217	2.06	56.2
.47	1138	1.02	610	1.57	213	2.07	77.0
.48	1183	1.03	601	1.58	209	2.08	88.0
.49	1210	1.04	592	1.59	205	2.09	86.8
.50	1215	1.05	551	1.60	202	2.10	85.6
.51	1206	1.06	526	1.61	198	2.11	84.4
.52	1199	1.07	519	1.62	194	2.12	83.2
.53	1188	1.08	512	1.63	189	2.13	20.7
.54	1198	1.09	514	1.64	184	2.14	...
.55	1190	1.10	252				
.56	1182	1.11	126				
.57	1178	1.12	69.9				
.58	1168	1.13	98.3				
.59	1161	1.14	164				

* For reference, see footnote 251, p. 721.
[a] $\times 10^{-4}$ [b] $\times 10^{-8}$

TABLE 816.—THE BIOLOGICALLY EFFECTIVE COMPONENT OF ULTRAVIOLET, SOLAR, AND SKY RADIATION PER MONTH PER CM² (UVQ IN WATT MINUTES) AND THE TOTAL SOLAR AND SKY RADIATION (Q IN CALORIES PER MONTH PER CM²) INCIDENT IN WASHINGTON, D. C., 1941–1946, MONTHLY AVERAGE[253]

Month	*UVQ* watt min $month^{-1}$ cm^{-2}	*Q* cal $month^{-1}$ cm^{-2}	Month	*UVQ* watt min $month^{-1}$ cm^{-2}	*Q* cal $month^{-1}$ cm^{-2}
Jan.	.112	4,982	July	1.091	15,239
Feb.	.209	6,987	Aug.	1.012	14,470
Mar.	.466	10,847	Sept.	.721	11,158
Apr.	.692	12,916	Oct.	.406	8,767
May	.990	15,203	Nov.	.177	6,085
June	1.108	16,019	Dec.	.087	4,690

[253] Coblentz, W. W., Bull. Amer. Meteorol. Soc., vol. 28, p. 465, 1947.

TABLE 817.—DURATION OF SUNSHINE *

Approx declination of sun:	—23°27′	—15°	—10°	—5°	0°	+5°	+10°	+15°	+20°	+23°27′
Approx date:	Dec. 22	Feb. 9 Nov. 3	Feb. 23 Oct. 19	Mar. 8 Oct. 6	Mar. 21 Sept. 23	Apr. 3 Sept. 10	Apr. 16 Aug. 28	May 1 Aug. 13	May 20 July 24	June 21
Latitude	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
0°	12 07	12 07	12 07	12 07	12 07	12 07	12 06	12 06	12 07	12 07
10°	11 32	11 45	11 53	12 00	12 07	12 14	12 21	12 29	12 37	12 43
20°	10 55	11 23	11 38	11 52	12 07	12 22	12 37	12 53	13 08	13 21
30°	10 12	10 58	11 21	11 44	12 08	12 31	12 54	13 19	13 45	14 05
40°	9 20	10 26	11 01	11 35	12 09	12 43	13 16	13 53	14 32	15 01
50°	8 04	9 43	10 35	11 23	12 12	12 59	13 47	14 39	15 37	16 23
55°	7 10	9 15	10 16	11 14	12 12	13 11	14 08	15 11	16 24	17 23
60°	5 52	8 36	9 53	11 03	12 15	13 25	14 35	15 54	17 30	18 53
65°	3 34	7 42	9 21	10 50	12 17	13 45	15 14	16 58	19 16	22 03
70°		6 14	8 32	10 29	12 21	14 14	16 13	18 44		
80°			3 10	8 46	12 38	16 44				

* Prepared by G. M. Clemence, U. S. Naval Observatory. For more extensive tables, see "Tables of Sunrise, Sunset, and Twilight," Supplement to the American Ephemeris, 1946.

TABLE 818.—RELATIVE DISTRIBUTION IN NORMAL SPECTRUM OF SUNLIGHT AND SKY LIGHT AT MOUNT WILSON

Zenith distance about 50°

This table is abstracted in modified form from the Annals of the Smithsonian Astrophysical Observatory. The observations, which were visual, made on October 17, 1906, probably represent the most ideal sky conditions on Mount Wilson.

							C	*D*	*b*	*F*
Place in spectrum (μ)	.422	.457	.491	.566	.614	.660				
Intensity sunlight	186	232	227	211	191	166				
Intensity sky light	1194	986	701	395	231	174				
Ratio at Mount Wilson	642	425	309	187	121	105	102	143	246	316
Ratio computed by Rayleigh	—	—	—	—	—	—	102	164	258	328
Ratio observed by Rayleigh	—	—	—	—	—	—	102	168	291	369

TABLE 819.—ILLUMINATION DUE TO DIRECT SUNLIGHT, SKY LIGHT, AND TOTAL ON HORIZONTAL AND VERTICAL PLANES[254]

Solar altitude h	Air mass m	Direct sunlight I_{hd} (ft—c)	Direct sunlight I_{pd} (ft—c)	Skylight I_{hs} (ft—c)	Skylight I_{ps} (ft—c)	Total I_{ht} (ft—c)	Total I_{pt} (ft—c)
3	15.36	19.6	374	256	587	277	961
5	10.39	100	1150	325	746	425	1900
7	7.77	252	2050	395	848	647	2900
10	5.60	590	3350	491	953	1080	4300
15	3.82	1310	4910	629	1070	1940	5980
20	2.90	2130	5860	750	1140	2880	7000
25	2.36	2980	6390	856	1180	3840	7570
30	2.00	3820	6620	945	1210	4760	7830
35	1.74	4650	6640	1020	1220	5670	7860
40	1.55	5440	6490	1090	1220	6530	7710
45	1.41	6170	6170	1160	1220	7330	7390
50	1.30	6850	5750	1210	1200	8060	6950
55	1.22	7450	5220	1270	1180	8720	6400
60	1.15	8000	4620	1310	1150	9310	5770
65	1.10	8470	3950	1350	1090	9820	5040
70	1.06	8860	3230	1390	1020	10250	4250
75	1.04	9160	2450	1420	930	10580	3380
80	1.02	9380	1650	1440	834	10820	2480
85	1.01	9510	833	1460	728	10970	1560
90	1.00	9570	00	1480	615	11050	615

The solar altitude, h, is expressed in angular units, the illumination, I, in foot-candles. The subscripts p and h designate the evaluation of illumination on the perpendicular (facing the sun) and horizontal planes. The additional subscripts, d, s, and t, designate direct sunlight, sky light and total light (direct sunlight plus sky light).

[254] Jones, L. A., and Condit, H. R., Journ. Opt. Soc. Amer., vol. 38, p. 147, 1948.

TABLE 820.—MEAN INTENSITY J FOR 24 HOURS OF SOLAR RADIATION ON A HORIZONTAL SURFACE AT THE TOP OF THE ATMOSPHERE AND THE SOLAR RADIATION A, IN TERMS OF THE SOLAR RADIATION, A_0, AT EARTH'S MEAN DISTANCE FROM THE SUN

Date	Motion of the sun in longitude	Relative mean vertical intensity $\frac{J}{A_0}$, Latitude north 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	$\frac{A}{A_0}$
Jan. 1	0°.99	.303	.265	.220	.169	.117	.066	.018				1.0335
Feb. 1	31.54	.312	.282	.244	.200	.150	.100	.048	.006			1.0288
Mar. 1	59.14	.320	.303	.279	.245	.204	.158	.108	.056	.013		1.0173
Apr. 1	89.70	.317	.319	.312	.295	.269	.235	.195	.148	.101	.082	1.0009
May 1	119.29	.303	.318	.330	.329	.320	.302	.278	.253	.255	.259	.9841
June 1	149.82	.287	.315	.334	.345	.349	.345	.337	.344	.360	.366	.9714
July 1	179.39	.283	.312	.333	.347	.352	.351	.345	.356	.373	.379	.9666
Aug. 1	209.94	.294	.316	.330	.334	.330	.318	.300	.282	.295	.300	.9709
Sept. 1	240.50	.310	.318	.316	.305	.285	.256	.220	.180	.139	.140	.9828
Oct. 1	270.07	.317	.308	.289	.261	.225	.183	.135	.084	.065		.9995
Nov. 1	300.63	.312	.286	.251	.211	.164	.114	.063	.018			1.0164
Dec. 1	330.19	.304	.267	.224	.175	.124	.072	.024				1.0288
Year ..		.305	.301	.289	.268	.241	.209	.173	.144	.133	.126	

Average annual solar energy received per square dekameter of horizontal surface in kilowatt hours. U. S.: Lincoln, 160,906; Mount Weather, 148,824; Washington, 145,403; New York, 106,460; Chicago, 97,856. Other countries: Toronto, 139,523; Johannesburg, 175,696; Davos Platz, 174,043; South Kensington, 78,569; Stockholm, 79,267.

TABLE 821.—MEAN MONTHLY AND YEARLY TEMPERATURES, °C

Mean temperatures of a few selected American stations, also of one station of very high and two of very low temperature, and one of very great and one of very small range of temperature.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1	Hebron-Rama (Labr.)	−20.7	−20.9	−15.6	− 6.9	+ .2	+ 4.5	+ 7.6	+ 8.0	+ 4.5	− .8	− 6.2	−16.2	− 5.2
2	Winnipeg (Canada)	−21.6	−18.8	−11.0	+ 1.9	+10.9	+17.1	+18.9	+17.6	+11.6	+ 4.1	− 7.6	−15.7	+ .6
3	Montreal (Canada)	−10.9	− 9.1	− 4.3	+ 4.8	+12.6	+18.3	+20.5	+19.3	+14.7	+ 7.8	− .2	− 7.1	+ 5.5
4	Boston	− 2.8	− 2.2	+ 1.2	+ 7.3	+13.6	+19.1	+21.8	+20.6	+16.9	+11.1	+ 4.8	− .5	+ 9.2
5	Chicago	− 4.8	− 2.9	+ 1.2	+ 7.9	+13.4	+19.7	+22.2	+21.6	+17.9	+11.1	+ 3.6	− 1.5	+ 9.1
6	Denver	− 2.1	+ .1	+ 3.8	+ 8.3	+13.6	+19.1	+22.1	+21.2	+16.6	+10.3	+ 3.3	.0	+ 9.7
7	Washington	+ .7	+ 2.1	+ 5.2	+11.7	+17.7	+22.9	+24.9	+23.7	+19.9	+13.4	+ 6.9	+ 2.3	+12.6
8	Pikes Peak	−16.4	−15.6	−13.4	−10.4	− 5.3	+ .4	+ 4.5	+ 3.6	− .3	− 5.8	−11.8	−14.4	− 7.1
9	St. Louis	− .8	+ 1.7	+ 6.2	+13.4	+18.8	+24.0	+26.0	+24.9	+20.8	+14.2	+ 6.4	+ 2.0	+13.1
10	San Francisco	+10.1	+10.9	+12.0	+12.6	+13.7	+14.7	+14.6	+14.8	+15.8	+15.2	+13.5	+10.8	+13.2
11	Yuma	+12.3	+14.9	+18.1	+21.0	+25.1	+29.4	+33.1	+32.6	+29.1	+22.8	+16.6	+13.3	+22.3
12	New Orleans	+12.1	+14.5	+16.7	+20.6	+23.7	+26.8	+27.9	+27.5	+25.7	+21.0	+15.9	+13.1	+20.4
13	Massaua	+25.6	+26.0	+27.1	+29.0	+31.1	+33.5	+34.8	+34.7	+33.3	+31.7	+29.0	+27.0	+30.3
14	Ft. Conger (Greenl'd)	−39.0	−40.1	−33.5	−25.3	−10.0	+ .4	+ 2.8	+ 1.0	− 9.0	−22.7	−30.9	−33.4	−20.0
15	Verkhoyansk	−51.0	−45.3	−32.5	−13.7	+ 2.0	+12.3	+15.5	+10.1	+ 2.5	−15.0	−37.8	−47.0	−16.7
16	Batavia	+25.3	+25.4	+25.8	+26.3	+26.4	+26.0	+25.7	+25.9	+26.3	+26.4	+26.2	+25.6	+25.9

Lat., Long., Alt. respectively: (1) + 58°5, 63°0 W, —; (2) + 49.9, 97.1 W, 233m; (3) + 45.5, 73.6 W, 57m; (4) + 42.3, 71.1 W, 38m; (5) + 41.9, 87.6 W, 251m; (6) + 39.7, 105.0 W, 1613m; (7) + 38.9, 77.0 W, 34m; (8) + 38.8, 105.0 W, 4308m; (9) + 38.6, 90.2 W, 173m; (10) + 37.8, 122.5 W, 47m; (11) + 32.7, 114.6 W, 43m; (12) + 30.0, 90.1 W, 16m; (13) + 15.6, 37.5 E, 9m; (14) + 81.7, 64.7 W, —; (15) + 67.6, 133.8 E, 140m; (16) − 6.2, 106.8 E, 7m.

Note.—Highest recorded temperature in world = 57°C in Death Valley, California, July 10, 1913. Lowest recorded temperature in world = − 68°C at Verkhoyansk, Feb. 1892.

TABLE 822.—TEMPERATURE VARIATION OVER EARTH'S SURFACE (HANN)

Maximum values for month in italics.

Latitude	Temperatures °C						Mean ocean temp	Land surface %
	Jan.	Apr.	July	Oct.	Year	Range		
North pole	−41.0	−28.0	− 1.0	−24.0	−22.7	40.0	− 1.7	—
+80°	−32.2	−22.7	+ 2.0	−19.1	−17.1	34.2	− 1.7	20
70	−26.3	−14.0	7.3	− 9.3	−10.7	33.6	+ .7	53
60	−16.1	− 2.8	14.1	+ .3	− 1.1	30.2	4.8	61
50	− 7.2	+ 5.2	17.9	6.9	+ 5.8	25.1	7.9	58
40	+ 5.5	13.1	24.0	15.7	14.1	18.5	14.1	45
30	14.7	20.1	27.3	21.8	20.4	12.6	21.3	43.5
20	21.9	25.2	*28.0*	26.4	25.3	6.1	25.4	31.5
+10	25.8	*27.2*	27.0	*26.9*	*26.8*	1.4	27.2	24
Equator	*26.5*	26.6	25.7	26.5	26.3	.9	27.1	22
−10	26.4	25.9	23.0	25.7	25.5	3.4	25.8	20
20	25.3	24.0	19.8	22.8	23.0	5.5	24.0	24
30	21.6	18.7	14.5	18.0	18.4	7.1	19.5	20
40	15.4	12.5	8.8	11.7	11.9	6.6	13.3	4
50	8.4	5.4	3.0	4.8	5.4	5.4	+ 6.4	2
60	3.2	—	− 9.3	—	− 3.2	12.5	.0	0
70	− 1.2	—	−21.0	—	−12.0	19.8	− 1.3	71
80	(− 4.3)	—	(−28.7)	—	(−20.6)	(24.4)	—	100
South pole	(− 6.0)	—	(−33.0)	—	(−25.0)	(27.0)	—	(100)

TABLE 823.—TEMPERATURE VARIATION WITH DEPTH

Table illustrates temperature changes underground at moderate depths due to surface warming (read from plot for Tiflis, Lehrbuch der Meteorologie, Hann and Süring, 1915). Below 20–30 m (nearer the surface in Tropics) there is no annual variation. Increase downward at greater depths, 0.03 ± °C per m (1° per 35 m) l. c. At Pittsburgh, 1524 m, 49.4°, .0294 per m; Oberschlesien, 2003 m, 70°, .0294 per m; or West Virginia, 2200 m; 70°, .034° per m (Van Orstrand). Mean value outflow heat from earth's center, 0.00000172 g cal cm^{-2} sec^{-1}, or 54 g cal cm^{-2} yr^{-1} (39 Laby). Open ocean temperatures: Greatest mean annual range (Schott) 40° N., 4.2°C; 30° S., 5.1°; but 10° N., only 2.2°; 50° S., 2.9°. Mean surface temp. whole ocean (Krümmel) 17.4°; all depths, 3.9°. Below 1 km nearly isothermal with depth. In Tropics, surface 28°; at 183 m, 11°, 80 percent water less than 4.4°. Deep-sea (bottom) temps. range −0.5° to +2.6°. Soundings in South Atlantic: 0 km, 18.9°; .25 km. 15°; .5 km, 8.3°; 1 km, 3.3°; 3 km, 1.7°; 4.5 km, 0.6°.

Maximum values in boldface.

Depth, *m*	Temperature °C											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	*1*	4	10	14	21	29	**32**	32	24	16	9	4
.5	4	*4*	9	13	18	23	26	**28**	24	18	12	6
1.0	6	*6*	8	12	15	20	24	**26**	23	18	14	10
1.5	9	*8*	9	11	14	18	21	**23**	22	18	15	12
2.0	11	10	*10*	11	13	16	19	21	**21**	18	16	14
3.0	14	12	12	*11*	13	14	16	17	18	**18**	17	15
4.0	15	13	12	*12*	12	13	14	16	16	**17**	17	16
5.0	15	14	13	13	*13*	13	14	14	15	16	**16**	16
6.0	**15**	14	14	14	14	14	14	14	14	15	15	15

TABLE 824.—WOLF'S SUNSPOT NUMBERS, ANNUAL MEANS*[255]

Sunspot number = *k* (10 × number of groups and single spots observed + total number of spots in groups and single spots). *k* depends on observer and telescope, equaling unity for Wolf with 3-in. telescope and power of 64. Wolf's numbers are closely proportional to spotted area on sun, 100 corresponds to about 1/600 of visible disk covered (umbras and penumbras). Periodicity: successive outbursts about 11 years apart, extremes 7.3 years and 17.1 years. See references for daily and monthly values.

Smoothed monthly numbers are formed from monthly means of observed number by weighting the sixth months preceding and following 1, all 11 intervening months 2.

Smoothed monthly sunspot numbers, annual means

Maximum and minimum values for period in boldface

Year	0	1	2	3	4	5	6	7	8	9
1750	**83.1**	52.2	45.9	28.9	13.5	**9.3**	12.2	31.9	47.2	54.5
1760	64.7	**80.2**	60.1	48.5	36.7	21.4	**14.2**	35.9	66.8	**103.4**
1770	98.5	86.7	65.7	39.7	27.5	**8.8**	21.7	92.2	**151.3**	123.4
1780	89.2	66.5	38.7	22.5	**10.3**	26.7	81.2	128.2	**133.3**	117.0
1790	90.6	67.6	59.8	47.3	38.5	24.0	15.6	6.5	**4.6**	6.9
1800	15.0	33.7	44.1	43.0	**46.8**	42.5	27.3	11.6	7.6	3.1
1810	**.0**	1.7	4.5	12.1	15.5	35.1	**46.1**	39.8	30.0	23.4
1820	16.6	6.6	4.0	**2.6**	8.3	16.9	35.3	51.6	62.1	67.1
1830	**67.2**	50.5	26.3	**9.4**	13.3	59.1	121.1	**137.0**	103.4	83.4
1840	61.9	38.5	23.0	**13.2**	17.7	38.4	59.7	97.3	**125.0**	95.4
1850	69.8	63.2	52.8	38.6	21.0	7.7	**5.2**	23.0	56.3	90.3
1860	**94.8**	77.7	61.1	45.4	45.2	31.4	14.7	**8.8**	36.9	78.6
1870	**131.8**	113.8	99.7	67.9	43.1	18.9	11.7	11.0	**3.9**	7.7
1880	31.6	54.4	58.1	**65.4**	63.3	51.3	25.1	12.6	7.0	**6.3**
1890	8.4	37.7	70.0	**83.7**	79.1	61.5	43.1	28.1	24.6	13.8
1900	8.8	**3.4**	5.7	23.0	44.1	58.7	**60.3**	56.0	51.2	40.6
1910	21.0	6.5	3.4	**2.2**	11.8	46.4	59.1	**96.2**	83.1	65.5
1920	36.9	27.0	13.0	**6.3**	16.8	43.7	66.5	70.0	**74.5**	62.0
1930	38.8	21.1	12.1	**5.9**	9.4	36.5	79.6	**113.2**	103.9	89.6
1940	66.8	50.5	30.3	15.3	**11.1**	36.4	91.7	**145.6**	141.2	134.7
1950	83.9	69.4								

* Prepared by Allan F. Cook II.

[255] Astron. Mitt. Zürich, No. 145, 1945; Journ. Geophys. Res., vol. 54, p. 347, 1949; Waldmeier, M., Astron. Mitt Zürich; Terr. Mag.; Journ. Geophys. Res., Trans. Int. Astron. Union Quart. Bull. Solar Activity; American Sunspot Number Reductions, Central Radio Propagation Laboratory, National Bureau of Standards.

Astronomy, including astrophysics, is a study of the geometry and physics of the heavenly bodies and the material in the intervening space. This experimental science requires some very special apparatus—in general, used in connection with large telescopes. Table 825 gives a list of the larger telescopes that are now (1949) in active scientific use. Some definitions and standards and other data on astronomy follow.

* These tables were prepared under the supervision of D. H. Menzel, of Harvard University, and Edith Janssen Tebo, of Harvard College Observatory.

TABLE 825.—THE LARGEST TELESCOPES IN ACTIVE SCIENTIFIC USE (1949) †

Reflectors
(60-inch mirrors and larger)

Hale Telescope, Palomar Mountain, Calif., U. S. A.	200-inch
Hooker Telescope, Mount Wilson, Calif., U. S. A.	100-inch
MacDonald Observatory, Mount Locke, Tex., U. S. A.	82-inch
Radcliffe Observatory, Pretoria, South Africa	76-inch
David Dunlap Observatory, Richmond Hill, Ontario, Canada	74-inch
Dominion Astrophysical Observatory, Victoria, B. C., Canada	72-inch
Perkins Observatory, Delaware, Ohio, U. S. A.	69-inch
Wyeth Reflector, Harvard Observatory, Oak Ridge, Mass., U. S. A.	61-inch
Southern Station of the Harvard Observatory, Bloemfontein, South Africa	60-inch
Mount Wilson Observatory, Mount Wilson, Calif., U. S. A.	60-inch
Cordoba Observatory, Bosque Alegre, Argentina	60-inch

Refractors
(30-inch lenses and larger)

Yerkes Observatory, Williams Bay, Wis., U. S. A.	40-inch
Lick Observatory, Mount Hamilton, Calif., U. S. A.	36-inch
Astrophysical Section, Observatory of Paris, Mundon, France	33-inch
Allegheny Observatory, Pittsburgh, Pa., U. S. A.	30-inch
University of Paris Observatory, Nice, France	30-inch

Schmidt-type telescopes
(of large aperture)

48-inch correction plate, 72-inch mirror, Palomar Observatory, Calif., U. S. A.
24-inch correction plate, 36-inch mirror (Burrell Telescope), Warner & Swasey Observatory, Case Institute of Technology, Cleveland, Ohio, U. S. A.
24-inch correcting plate, 33-inch mirror (Jewett Telescope) Harvard Observatory, Oak Ridge, Mass., U. S. A.

† Prepared by J. J. Nassau, Case Institute of Technology.

TABLE 826.—APPROXIMATE EQUATION OF TIME **

The equation of time in this table is to be added algebraically to local apparent solar time to obtain *local* mean solar time.

Accurate values of the equation of time may be obtained from the American Ephemeris and Nautical Almanac.

	min		min		min		min
Jan. 1	+ 3	Apr. 1	+ 4	July 1	+ 4	Oct. 1	−10
11	+ 8	11	+ 1	11	+ 5	11	−13
21	+11	21	− 1	21	+ 6	21	−15
Feb. 1	+14	May 1	− 3	Aug. 1	+ 6	Nov. 1	−16
11	+14	11	− 4	11	+ 5	11	−16
21	+14	21	− 4	21	+ 3	21	−14
Mar. 1	+13	June 1	− 2	Sept. 1	0	Dec. 1	−11
11	+10	11	− 1	11	− 3	11	− 7
21	+ 8	21	+ 1	21	− 7	21	− 2

** Prepared by G. M. Clemence, U. S. Naval Observatory.

Aberration constant.—20″.47 (conventional value; work of Doolittle, Spencer Jones, and others, indicates a value of 20″.50).

Aphelion.—Point where earth is farthest from sun $= 1.520 \times 10^{13}$ cm.

Astronomical unit (A. U.)—Distance: mean distance earth to sun, 149,500,000 km. (Conventional value, solar parallax 8″.79 would give 149,700,000.) Mass: the combined mass of the sun and earth which means, practically, the sun's mass $= 1.987 \times 10^{33}$ g.

Color index.—Ordinary stellar magnitudes are supposed to correspond to observations with the normal eye. This is by no means easy to define, for the brightness of a red star compared with a white, appears greater when the amount of light entering the eye is increased for both in the same ratio (Purkinje effect) for low brightness.

Owing to differences in the actual distribution of the energy with wavelength, the relative brightness of stars of different temperatures and colors measured with receptors sensitive to different spectral regions vary greatly.

On ordinary photographs, red stars appear much fainter than to the eye. If the measures are calibrated so that the visual and photographic magnitudes average the same for spectral class A, the difference for any other group of stars is called *color index*. This ranges from about $-0^m.3$ to $+1.8$ for class M and reaches 5^m for the reddest stars of class N.

The difference in color index between the two standard types, e.g., AO and KO is called the *color-equation*. It varies over a wide range with the spectral sensitivity of the receiver, very large and positive for the violet and ultraviolet and negative for the red and infrared.

Photoelectric devices, combined with screens and measurable transmission have at last provided standard systems for stellar photometry of at least approximately definite physical significance for spectral regions ranging from the ultraviolet to the infrared. *Radiometric* magnitudes correspond to the measures of the whole observable energy radiation.

Bolometric magnitudes are supposed to represent the total energy radiation of all wavelengths, and must be found by calculation.

Date line.—Established by convention not far from the 180th meridian from Greenwich. Where the line runs across a group of islands, the change of the date line is diverted to one side so that the group has the same day. Ships crossing from the east, skip a day; going east, count the same day twice.

Day.—Mean solar day = 1,440 minutes = 86,400 seconds = 1.0027379 sidereal day. Sidereal day (ordinary, two successive transits of vernal equinox, might be called equinoctial day) = 86,164.09054 mean solar seconds = 23 hr, 56 min, 4.09054 sec mean solar time.

Two successive transits of same fixed star = 86,164.09967 mean solar seconds.

Declination.—If δ = declination, t, hour angle measured west from meridian, h, altitude, ϕ, latitude and A, azimuth measured from S. point through W. Then

$$\left.\begin{aligned} \sin h &= \sin\phi \sin\delta + \cos\phi \cos\delta \cos t \\ \cos h \cos A &= -\cos\phi \sin\delta + \sin\phi \cos\delta \cos t \\ \cos h \sin A &= \cos\delta \sin t \end{aligned}\right\} \text{given } \delta, t, \phi$$

$$\left.\begin{aligned} \sin\delta &= \sin\phi \sin h - \cos\phi \cos h \cos A \\ \cos\delta \cos t &= \cos\phi \sin h + \sin\phi \cos h \cos A \\ \cos\delta \sin t &= \cos h \sin A \end{aligned}\right\} \text{given } h, A, \phi$$

Delaunay's $\gamma = \sin 1/2\ I = 0.04488716$ (Brown).

Dip of horizon.—In minutes of arc $= \sqrt{\text{elevation in ft}}$ (approximately).

Earth.—Mean $r = 6.3712 \times 10^8$ cm. Equatorial diameter = 12,756.78km; polar diameter = 12,713.82 km. Area $= 5.101 \times 10^{18}$ cm². Angular velocity $= 72.9 \times 10^{-6}$ radians/sec. Volume $= 1.083 \times 10^{27}$ cm³. Mass $= 5.975 \times 10^{27}$ g. Density = 5.517 g/cm³. Mean distance to sun $= 1.495 \times 10^{13}$ cm. Distance to the moon $= 3.844 \times 10^{10}$ cm. Light traverses mean radius of earth's orbit in 498.6 sec. Semimajor axis orbit $= 1.4950 \times 10^{13}$ cm; semiminor axis $= 1.4948 \times 10^{13}$ cm. Viscosity $= 10.9 \times 10^{16}$ cgs. Velocity of equatorial point on earth, because of rotation: 1,050 mi/hr = 1,550 ft/sec = 1,650 km/hr = 460 m/sec. In orbit: 18/5 mi/sec = 30 km/sec. See Tables 831 and 833. Rotational energy $= 2.16 \times 10^{36}$ erg.

Earth's orbital velocity = 18.5 miles/second. 1,550 ft/sec (rotation at Equator).

Eccentricity of earth's orbit $= e = 0.01675104 - 4.180 \times 10^{-7} (t - 1900) - 1.26 \times 10^{-11} (t - 1900)^2$.

Eccentricity of moon's orbit $= e_2 = 0.05490056$ (Brown).

Gal.—Unit of gravity acceleration = 1 cm sec⁻².

General precession (westward movement of the equinoxes) = 50″.2564 + 0″.000222 $(t - 1900)$ per year (Newcomb). Probably requires correction of about +0″.01. See Table 838.

Gravitation constant $= (6.670 \pm 0.005) \times 10^{-8}$ dyne cm² g⁻² (Heyl, 1930).

Gravity, acceleration due to, $g = 978.0495$ cm sec^{-2} (conventional value at sea level at equator. See Table 802). Unit, gal = 1 cm sec^{-2}.

* Prepared by G. M. Clemence, U. S. Naval Observatory.

(continued)

TABLE 827.—MISCELLANEOUS ASTRONOMICAL DATA (continued)

Heat index.—Radiometric (heat or bolometric), zero taken to agree with Class *AO*, (radiometric — visual magnitude) = heat index, + for red stars.

Horizon.—Distance at sea is approximately, miles = $\sqrt{(3/2) \text{ height in feet}}$. Local refraction (mirage) may introduce large percentage changes in either direction for observations from altitudes of 30 feet or less.

Inclination of moon's orbit = $I = 5°8'43.5''$ (Brown).

Julian period, 1950 = 6663.—January 1, 1950, Julian-day number = 2433283.

Latitude variation.—The direction of the axis of the earth in space changes approximately 20″.5 per year owing to precession. The change is roughly periodic in 25,800 years with an amplitude of 23°.5. This does not affect terrestrial latitudes, but a variation in them is caused by a shift of the earth's body about this axis. The two ascertained components of the polar motion have periods of 1.00 and nearly 1.20 years (the annual and Chandlerian components, respectively), so that the oscillations in *X* and *Y*, as well as the resultant total motion have variations in amplitude with a "beat period" of about 6 years. In contrast to the annual terms, Chandler's term shows striking variations in amplitude. There is, further, a variation in the period of the Chandlerian term (1.18, 1.20, 1.17, 1.15, 1.19 years) which appears nearly proportional to the corresponding amplitude variations according to the relation $P = 0.185\,A + 1.128$, where P is the period in years and A the amplitude in 0″.01 units. (See T. Nicolini, appendix to Commission 19 Report, Trans. Int. Astron. Union, Zurich, 1948.)

Light, velocity of.—(Mean value) in vacuo, 299773 ± 10 km sec^{-1} (Dorsey).
299792.5 ± 0.8 km sec^{-1} (Bearden).
299776 ± 0.00004 km sec^{-1} (Birge).

Light year.—The distance light travels in 1 year = 9.5×10^{12} kilometers = 5.9×10^{12} miles. Light traverses mean radius of earth's orbit in 498.6 sec.

Lunar inequality of earth = L = 6.454″.

Lunar node d = daily motion = — 0°.052954.

Lunar parallax = 3422.70″ (Brown).

Lunar perigee, daily motion = + 0°.111404.

Lunar-solar precession = p' = 50.3714″ per year (De Sitter, 1927). Of this 0.0191″, Einstein, orbital motion earth.

Magnitudes.—The observed intensity of light received on the earth from astronomical bodies ranges over a factor exceeding 10^{19}. It is therefore expressed on a logarithmic scale—the system of stellar magnitudes. This system, which was adopted by Hipparchus more than 2,000 years ago, is closely represented by the equation

$$m = 2.5 \log_{10} (l_0/l)$$

where l is the observed light and l_0 a standard value corresponding roughly to the light of Arcturus or Vega. Decrease of light by a factor of 100 increases the stellar magnitude by 5.00; hence the brightest objects have negative magnitudes. (Sun: — 26.8; mean full moon: — 12.5; Venus at brightest: — 4.3; Jupiter at opposition: — 2.3; Sirius: — 1.6; Vega: + 0.2; Polaris: + 2.1). The faintest stars visible to the naked eye on a clear dark night are of about the sixth magnitude (though on a perfectly black background the limit for a single luminous point approaches the eighth magnitude). The faintest stars visible with a telescope of aperture A (in inches) is one approximately of magnitude $9 + 5 \log_{10} A$. The magnitude of the faintest stars which can be photographed with the 200-inch telescope is about + 22.7. The apparent magnitude of a standard candle at a distance of 1 meter is — 14.2.

Absolute magnitude, M, is that which the body would exhibit if placed at a distance of 10 parsecs, and corresponds to its actual luminosity. For a star of magnitude m, and parallax p, in seconds of arc

$$M = m + 5 + 5 \log p$$

For the sun, $M = +4.7$. The brightest stars probably exceed $M = -7$ and the faintest observed value is $M = +18$, a range of 10^{10}. The full moon (could it be observed without interference from the standard distance) would have $M = +32$ and a standard candle + 72.8.

Mean distance earth to moon = 60.2678 terrestrial radii.
= 384,411 kilometers = 238,862 miles. (See Table 834.)

Mean distance earth to sun = 149,500,000 kilometers = 92,900.000 miles. (See Astronomical unit.) See Table 833.

Month.—Sidereal = 27.321661 days, synodical (ordinary) = 29.530588 days (Brown).

Nutation constant (periodic motion of celestial pole) = 9.21″, conventional value; 9.207″. Principal in long = $\Delta\phi = (-17.234'' - .017''\,T) \sin \Omega$; principal term in obliquity = $\Delta\epsilon = (+9.210 + .0009\,T) \cos \Omega$ (Newcomb). T centuries from 1900.

Obliquity of ecliptic = $23°27'8.26'' - 0.4684\,(t - 1900)''$ (Newcomb).

(continued)

TABLE 827.—MISCELLANEOUS ASTRONOMICAL DATA (concluded)

Parallactic inequality moon $= Q = 124.785''$ (Brown.)

Parsec.—Distance of star whose parallax is 1 sec $= 31 \times 10^{12}$ km $= 19.2 \times 10^{12}$ miles $= 3.263$ light years.

Perihelion.—Point where earth is nearest sun $= 1.4700 \times 10^{13}$ cm.

Planetary precession $= \lambda = 0.1247''$ (Newcomb).

Pole of Milky Way = R. A., 12 hr 48 min; Dec., $+27°$.

Refraction.—r in. $('') = [983 \times$ (barometer in in.)$/(460 + t°F)]$ tan Z, where $Z =$ zenith distance. Error $< 1''$, $Z < 75°$, ordinary t and pressure.

Solar diameter = 864,408 miles.

Solar parallax = 8.″80 (conventional value), 8.″79 (Newcomb, Spencer Jones).

Sun.—$r = 6.965 \times 10^{10}$ cm. Area $= 6.093 \times 10^{22}$ cm^2. Volume $= 1.412 \times 10^{33}$ cm^3. Mass $= 1.987 \times 10^{33}$ g. Density $= 1.41$ g/cm^3. Mean distance to earth 1.495×10^{13} cm. See Table 831.

Twilight.—There are three definitions of twilight: civil, nautical, and astronomical. Civil twilight lasts until the sun is about 6° below the horizon, after which motor-car lights must be turned on. Nautical twilight lasts until the sun is about 12° below the horizon. This is the limit for observations of stars with the sea horizon. Astronomical twilight is considered to end when the sky is dark in the zenith. It lasts until the sun is about 18° below the horizon. For latitudes $> 50°$ there is a faint twilight at midnight in midsummer.

Year.—Anomalistic (two successive passages of the perihelion) $= 365.25964134 + 3.04 \times 10^{-8} (t - 1900)$ days. Eclipse (time taken by sun to pass from a node of the moon's orbit to the same node) $= 346.620031 + 3.2 \times 10^{-7} (t - 1900)$ days. Sidereal (from given star to same star again) $= 365.25636042 + 1.1 \times 10^{-9} (t - 1900)$ days. Tropical (ordinary) (two successive passages of vernal equinox by sun) $= 365.24219879 - 6.14 \times 10^{-8} (t - 1900)$ days.

TABLE 828.—ELEMENTS OF SOLAR MOTION *

Because of the asymmetry in stellar motions (Table 876), determinations of the speed and direction of the sun's motion are very sensitive to the selection of stars to which it is referred. Ideally we wish to refer the sun's motion to the circular velocity with respect to the galactic center; this may be called the basic solar motion. It is possible to determine this basic solar motion from detailed studies of the distribution of motions among nearby stars and it is found that such a determination made from the giant K stars is in excellent agreement with an independent determination from the A stars (Janssen and Vyssotsky). This value is given in the last line of the table. The figures listed for the first five groups are smoothed values obtained from a combination of the best observational results.[256] The values for the next four groups come from investigations made at Leiden, Mount Wilson, and McCormick Observatories. The solar motion with respect to B stars, c-stars, and Cepheids is difficult to determine satisfactorily because of uneven distribution in space, very small proper motions, etc.

Stellar group of reference	Solar velocity	Coordinates of the apex			
		R A	Dec	Gal long	Gal lat
B8 to A3	16 km/sec	263°	+20°	11°	+24°
A5 to F2	17	266	+23	15	+22
F5 to G0	18	269	+26	18	+21
K0 to K2	20	273	+29	23	+19
gK5 to gM8	22	276	+31	27	+17
dK8 to dM5	23	275	+44	39	+22
Irregular var	35	265:	+38:	30:	+28:
Long-period var	54	295	+46	47	+10
Cluster-type var	130	297	+52	53	+12
Basic solar motion	15	260	+17	7	+25

* Prepared by A. N. Vyssotsky, University of Virginia.
[256] Astron. Journ., vol. 53, p. 87, 1948.

TABLE 829.—PERPETUAL CALENDAR *

This calendar gives the day of the week for any known date from the beginning of the Christian Era down to the year 2400.

Dominical letters

Year \ Century				Julian Calendar: 0, 700, 1400	100, 800, 1500 †	200, 900	300, 1000	400, 1100	500, 1200	600, 1300	Gregorian Calendar: 1500 ‡	1600, 2000	1700, 2100	1800, 2200	1900, 2300
0				DC	ED	FE	GF	AG	BA	CB	——	BA	C	E	G
1	29	57	85	B	C	D	E	F	G	A	F	G	B	D	F
2	30	58	86	A	B	C	D	E	F	G	E	F	A	C	E
3	31	59	87	G	A	B	C	D	E	F	D	E	G	B	D
4	32	60	88	FE	GF	AG	BA	CB	DC	ED	CB	DC	FE	AG	CB
5	33	61	89	D	E	F	G	A	B	C	A	B	D	F	A
6	34	62	90	C	D	E	F	G	A	B	G	A	C	E	G
7	35	63	91	B	C	D	E	F	G	A	F	G	B	D	F
8	36	64	92	AG	BA	CB	DC	ED	FE	GF	ED	FE	AG	CB	ED
9	37	65	93	F	G	A	B	C	D	E	C	D	F	A	C
10	38	66	94	E	F	G	A	B	C	D	B	C	E	G	B
11	39	67	95	D	E	F	G	A	B	C	A	B	D	F	A
12	40	68	96	CB	DC	ED	FE	GF	AG	BA	GF	AG	CB	ED	GF
13	41	69	97	A	B	C	D	E	F	G	E	F	A	C	E
14	42	70	98	G	A	B	C	D	E	F	D	E	G	B	D
15	43	71	99	F	G	A	B	C	D	E	C	D	F	A	C
16	44	72		ED	FE	GF	AG	BA	CB	DC	——	CB	ED	GF	BA
17	45	73		C	D	E	F	G	A	B	——	A	C	E	G
18	46	74		B	C	D	E	F	G	A	——	G	B	D	F
19	47	75		A	B	C	D	E	F	G	——	F	A	C	E
20	48	76		GF	AG	BA	CB	DC	ED	FE	——	ED	GF	BA	DC
21	49	77		E	F	G	A	B	C	D	——	C	E	G	B
22	50	78		D	E	F	G	A	B	C	——	B	D	F	A
23	51	79		C	D	E	F	G	A	B	——	A	C	E	G
24	52	80		BA	CB	DC	ED	FE	GF	AG	——	GF	BA	DC	FE
25	53	81		G	A	B	C	D	E	F	——	E	G	B	D
26	54	82		F	G	A	B	C	D	E	C	D	F	A	C
27	55	83		E	F	G	A	B	C	D	B	C	E	G	B
28	56	84		DC	ED	FE	GF	AG	BA	CB	AG	BA	DC	FE	AG

Month					Dominical letter						
Jan., Oct.					A	B	C	D	E	F	G
Feb., Mar., Nov.					D	E	F	G	A	B	C
Apr., July					G	A	B	C	D	E	F
May					B	C	D	E	F	G	A
June					E	F	G	A	B	C	D
Aug.					C	D	E	F	G	A	B
Sept., Dec.					F	G	A	B	C	D	E
1	8	15	22.	29	Sun.	Sat.	Fri.	Thurs.	Wed.	Tues.	Mon.
2	9	16	23	30	Mon.	Sun.	Sat.	Fri.	Thurs.	Wed.	Tues.
3	10	17	24	31	Tues.	Mon.	Sun.	Sat.	Fri.	Thurs.	Wed.
4	11	18	25		Wed.	Tues.	Mon.	Sun.	Sat.	Fri.	Thurs.
5	12	19	26		Thurs.	Wed.	Tues.	Mon.	Sun.	Sat.	Fri.
6	13	20	27		Fri.	Thurs.	Wed.	Tues.	Mon.	Sun.	Sat.
7	14	21	28		Sat.	Fri.	Thurs.	Wed.	Tues.	Mon.	Sun.

To find the calendar for any year of the Christian Era, first find the Dominical letter for the year in the upper section of the table. Two letters are given for leap years; the first is to be used for January and February, the second for the other months. In the lower section of the table, find the column in which the Dominical letter for the year is in the same line with the month for which the calendar is desired; this column gives the days of the week that are to be used with the month.

E.g., in the table of Dominical Letters we find that the letter for 1951 is G; in the line with July, this letter occurs in the first column; hence July 4, 1951, is Wednesday.

* Prepared by G. M. Clemence, U. S. Naval Observatory. † On and before 1582, Oct. 4 only. ‡ On and after 1582, Oct. 15 only.

Days are numbered consecutively, beginning with the number 0, from Greenwich mean noon on Jan. 1, 4713 B.C. The number of days since that time that have elapsed at Greenwich mean noon on any given date is the Julian Day Number of that day.

For A.D. 0 to A.D. 1580 inclusive, the Julian Day Numbers in this table are the days elapsed at Greenwich mean noon up to January 0 of the Julian Calendar in each leap year.

For 1584 to 2096 inclusive, the Julian Day Numbers are for January 0 of the Gregorian Calendar, except that in 1700, 1800, and 1900, which were not leap years, they are for January — 1.

A.D.	0	100	200	300	400	500	600	700	800	900
0	1721057	1757582	1794107	1830632	1867157	1903682	1940207	1976732	2013257	2049782
4	1722518	1759043	1795568	1832093	1868618	1905143	1941668	1978193	2014718	2051243
8	1723979	1760504	1797029	1833554	1870079	1906604	1943129	1979654	2016179	2052704
12	1725440	1761965	1798490	1835015	1871540	1908065	1944590	1981115	2017640	2054165
16	1726901	1763426	1799951	1836476	1873001	1909526	1946051	1982576	2019101	2055626
20	1728362	1764887	1801412	1837937	1874462	1910987	1947512	1984037	2020562	2057087
24	1729823	1766348	1802873	1839398	1875923	1912448	1948973	1985498	2022023	2058548
28	1731284	1767809	1804334	1840859	1877384	1913909	1950434	1986959	2023484	2060009
32	1732745	1769270	1805795	1842320	1878845	1015370	1951895	1988420	2024945	2061470
36	1734206	1770731	1807256	1843781	1880306	1916831	1953356	1989881	2026406	2062931
40	1735667	1772192	1808717	1845242	1881767	1918292	1954817	1991342	2027867	2064392
44	1737128	1773653	1810178	1846703	1883228	1919753	1956278	1992803	2029328	2065853
48	1738589	1775114	1811639	1848164	1884689	1921214	1957739	1994264	2030789	2067314
52	1740050	1776575	1813100	1849625	1886150	1922675	1959200	1995725	2032250	2068775
56	1741511	1778036	1814561	1851086	1887611	1924136	1960661	1997186	2033711	2070236
60	1742972	1779497	1816022	1852547	1889072	1925597	1962122	1998647	2035172	2071697
64	1744433	1780958	1817483	1854008	1890533	1927058	1963583	2000108	2036633	2073158
68	1745894	1782419	1818944	1855469	1891994	1928519	1965044	2001569	2038094	2074619
72	1747355	1783880	1820405	1856930	1893455	1929980	1966505	2003030	2039555	2076080
76	1748816	1785341	1821866	1858391	1894916	1931441	1967966	2004491	2041016	2077541
80	1750277	1786802	1823327	1859852	1896377	1932902	1969427	2005952	2042477	2079002
84	1751738	1788263	1824788	1861313	1897838	1934363	1970888	2007413	2043938	2080463
88	1753199	1789724	1826249	1862774	1899299	1935824	1972349	2008874	2045399	2081924
92	1754660	1791185	1827710	1864235	1900760	1937285	1973810	2010335	2046860	2083385
96	1756121	1792646	1829171	1865696	1902221	1938746	1975271	2011796	2048321	2084846

A.D.	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
0	2086307	2122832	2159357	2195882	2232407	2268932	2305447	2341971†	2378495†	2415019†
4	2087768	2124293	2160818	2197343	2233868	2270393	2306908	2343432	2379956	2416480
8	2089229	2125754	2162279	2198804	2235329	2271854	1308369	2344893	2381417	2417941
12	2090690	2127215	2163740	2200265	2236790	2273315	2309830	2346354	2382878	2419402
16	2092151	2128676	2165201	2201726	2238251	2274776	2311291	2347815	2384339	2420863
20	2093612	2130137	2166662	2203187	2239712	2276237	2312752	2349276	2385800	2422324
24	2095073	2131598	2168123	2204648	2241173	2277698	2314213	2350737	2387261	2423785
28	2096534	2133059	2169584	2206109	2242634	2279159	2315674	2352198	2388722	2425246
32	2097995	2134520	2171045	2207570	2244095	2280620	2317135	2353659	2390183	2426707
36	2099456	2135981	2172506	2209031	2245556	2282081	2318596	2355120	2391644	2428168
40	2100917	2137442	2173967	2210492	2247017	2283542	2320057	2356581	2393105	2429629
44	2102378	2138903	2175428	2211953	2248478	2285003	2321518	2358042	2394566	2431090
48	2103839	2140364	2176889	2213414	2249939	2286464	2322979	2359503	2396027	2432551
52	2105300	2141825	2178350	2214875	2251400	2287925	2324440	2360964	2397488	2434012
56	2106761	2143286	2179811	2216336	2252861	2289386	2325901	2362425	2398949	2435473
60	2108222	2144747	2181272	2217797	2254322	2290847	2327362	2363886	2400410	2436934
64	2109683	2146208	2182733	2219258	2255783	2292308	2328823	2365347	2401871	2438395
68	2111144	2147669	2184194	2220719	2257244	2293769	2330284	2366808	2403332	2439856
72	2112605	2149130	2185655	2222180	2258705	2295230	2331745	2368269	2404793	2441317
76	2114066	2150591	2187116	2223641	2260166	2296691	2333206	2369730	2406254	2442778
80	2115527	2152052	2188577	2225102	2261627	2298152‡	2334667	2371191	2407715	2444239
84	2116988	2153513	2190038	2226563	2263088	2299603§	2336128	2372652	2409176	2445700
88	2118449	2154974	2191499	2228024	2264549	2301064	2337589	2374113	2410637	2447161
92	2119910	2156435	2192960	2229485	2266010	2302525	2339050	2375574	2412098	2448622
96	2121371	2157896	2194421	2230946	2267471	2303986	2340511	2377035	2413559	2450083

2000	2451544	2020	2458849	2040	2466154	2060	2473459	2080	2480764
2004	2453005	2024	2460310	2044	2467615	2064	2474920	2084	2482225
2008	2454466	2028	2461771	2048	2469076	2068	2476381	2088	2483686
2012	2455927	2032	2463232	2052	2470537	2072	2477842	2092	2485147
2016	2457388	2036	2464693	2056	2471998	2076	2479303	2096	2486608

Days to be added to reduce to the beginning of each month: For dates from 1582 October 15 to 1583 December 31, inclusive, Gregorian Calendar, *diminish all numbers in this table by 10.* In 1700, 1800, and 1900, Gregorian Calendar, *for January 0 use the number 1* instead of the tabular value 0, and *for February 0 use 32* instead of 31.

Year	Jan. 0	Feb. 0	Mar. 0	Apr. 0	May 0	June 0	July 0	Aug. 0	Sept. 0	Oct. 0	Nov. 0	Dec. 0
0	0	31	60	91	121	152	182	213	244	274	305	335
1	366	397	425	456	486	517	547	578	609	639	670	700
2	731	762	790	821	851	882	912	943	974	1004	1035	1065
3	1096	1127	1155	1186	1216	1247	1277	1308	1339	1369	1400	1430

* Prepared by G. M. Clemence, U. S. Naval Observatory. † For January — 1. ‡ Julian Calendar. § Gregorian Calendar.

TABLE 831.—PHYSICAL DATA; PLANETS AND PRINCIPAL SATELLITES

(From unpublished compilation by G. P. Kuiper and D. L. Harris, Yerkes Observatory.)

Planet or satellite	Mass * (Earth = 1)	Mean diameter † ($E = 1$)	Mean density $H_2O = 1$	Surface gravity ($E = 1$)	Velocity of escape km/sec	Rotation period (days)
Mercury	.0543	.38	5.46	.38	4.3	88.0
Venus	.8136	.967	4.96	.87	10.4	15–30?
Earth	1.0000	1.000	5.52	1.00	11.3	1.00
Mars	.1069	.523	4.12	.39	5.1	1.03
Jupiter	318.35	10.97	1.33	2.65	61.0	.41
Saturn	95.3	9.03	.71	1.17	36.7	.43
Uranus	14.58	3.72	1.56	1.05	22.4	.45
Neptune	17.26	3.38	2.47	1.23	25.6	.66
Pluto	<.1?	.45	<5.5?	<.5?	<5.3?	?
Moon	.0123	.273	3.33	.16	2.4	27.3
Jupiter I	.0121	.255	4.03	.19	2.5	1.77
Jupiter II	.0079	.226	3.78	.16	2.1	3.55
Jupiter III	.0261	.394	2.35	.17	2.9	7.15
Jupiter IV	.0160	.350	2.06	.13	2.4	16.69
Titan	.0235	.371	2.54	.17	2.8	15.95
Triton	.022	.35?	2.8?	.18?	2.8?	5.88

* Mass of the Earth is 5.975×10^{27} grams; of the Sun 332,488 (1 ± 0.00013) $E = 1.987 \times 10^{33}$ grams; of the Moon (0.012289 ± 0.000004) $E = 7.343 \times 10^{25}$ grams. † Equatorial diameter of the Earth = 12,756.78 km; polar diameter 12,713.82 km; "mean diameter" 12,742.46 km. See Table 827

TABLE 832.—PLANETARY TEMPERATURES

	Measured	Calculated A	Calculated B
Mercury (sunlit side)	690° K	445° K	631° K
Venus (dark side)	250	—	—
(bright side)	330	327	464
Earth (mean)	287	277	392
Moon (center of illuminated hemisphere)	400	277	392
Mars (warmest portions)	285	222	316
Jupiter	135	122	273
Saturn	120	90	128
Uranus	less than 90	63	89
Neptune	—	51	72

All temperatures are given on the absolute scale. To change to centigrade, subtract 273. The column headed "measured" presents values determined by Coblentz and Lampland, and by Pettit and Nicholson. The column headed "*A*" gives black sphere temperatures; "*B*" gives these multiplied by $\sqrt{2}$ or the calculated maximum temperatures of the center of the illuminated hemisphere of atmosphereless black planets. The observed values lie, as expected, between *A* and *B* in nearly every case.

TABLE 833.—PLANETARY ORBITS * [257]

Body	Mean distance to Sun AU	Mean distance to Sun km	Sidereal period Mean days	Sidereal period Tropical years	Inclination	Eccentricity
Mercury	.387	57.9 †	87.97	.241	7°.004	.2056
Venus	.723	108.1	224.70	.615	3.394	.0068
Earth	1.000	149.5 ‡	365.26	1.000	.000	.0167
Mars	1.524	227.8	686.98	1.881	1.850	.0934
Jupiter	5.203	777.8	4332.58	11.862	1.306	.0484
Saturn	9.539	1426.1	10759.20	29.458	2.490	.0557
Uranus	19.191	2869.1	30685.91	84.015	.773	.0472
Neptune	30.071	4495.6	60187.60	164.788	1.774	.0086
Pluto	39.457	5898.9	90469.27	247.697	17°.143	.2485

* Prepared G. P. Kuiper, Yerkes Observatory.
[257] American Ephemeris and Nautical Almanac for 1950.
† $\times 10^6$. ‡ Mean distance in km computed from earth's equatorial radius (6378.388 km) and solar parallax of 8."80. Recent determinations by Spencer Jones (Monthly Notices, Roy. Astron. Soc., vol. 101, p. 356, 1941) and Rabe (Astron. Journ., vol. 55, p. 112, 1950) give $8."790 \pm 0."001$ and $8."7984 \pm 0."0004$, respectively.

TABLE 834.—SATELLITE ORBITS *

Body	Mean distance from planet (km)	Sidereal period (days)	Vis magnitude at mean opp	Direction of motion †
Earth				
Moon	384,400	27.322	−12.7	D
Mars				
Phobos	9,400	.319	11.5	D
Deimos	23,500	1.262	13.0	D
Jupiter				
V	181,200	.498	13.0	D
I Io	421,400	1.769	5.0	D
II Europa	670,500	3.551	5.3	D
III Ganymede	1,069,500	7.155	4.6	D
IV Callisto	1,881,200	16.689	5.6	D
VI	11,500,000	250.6	13 7	D
VII	11,750,000	259.6	16.	D
X	11,750,000	260.	17.8	D
VIII	23,500,000	739.	16.	R
IX	23,700,000	758.	17.6	R
XI	22,500,000	692.	17.4	R
Saturn				
Mimas	185,500	.942	12.1	D
Enceladus	238,000	1.370	11.6	D
Tethys	294,600	1.888	10.5	D
Dione	377,300	2.737	10.7	D
Rhea	526,900	4.518	9.7	D
Titan	1,220,800	15.945	8.2	D
Hyperion	1,482,000	21.277	13.0	D
Iapetus	3,558,000	79.330	10.1–11.8	D
Phoebe	12,950,000	550.48	16.	R
Uranus				
Miranda	129,700	1.413	16.8	D
Ariel	190,700	2.520	14.8	D
Umbriel	265,700	4.144	15.4	D
Titania	435,800	8.706	13.9	D
Oberon	582,800	13.463	14.3	D
Neptune				
Triton	353,700	5.877	13.5	R
Nereid	5,580,000	368.	18.5	?

* Compiled by D. L. Harris, Yerkes Observatory. † With respect to rotation of planet. *D* = direct motion, *R* = retrograde motion.

TABLE 835.—NUMBER OF STARS [$\phi(M)$] PER CUBIC PARSEC *NEAR THE SUN* WITH ABSOLUTE (PHOTOGRAPHIC AND VISUAL) MAGNITUDES $M - 1/2$ TO $M + 1/2$ * [258]

	log $\phi(M) + 10$			log $\phi(M) + 10$	
M	Phot	Visual	*M*	Phot	Visual
− 6.0	2.10	1.63	+ 5.0	7.35	7.40
− 5.0	3.07	2.77	+ 6.0	7.49	7.45
− 4.0	3.65	3.58	+ 7.0	7.53	7.45
− 3.0	4.25	4.12	+ 8.0	7.46	7.55
− 2.0	4.75	4.71	+ 9.0	7.49	7.75
− 1.0	5.07	5.32	+10.0	7.64	7.84
.0	5.68	5.98	+11.0	7.81	7.99
+ 1.0	6.34	6.59	+12.0	7.97	8.02
+ 2.0	6.77	6.71	+13.0	8.01	8.05
+ 3.0	6.86	6.98	+14.0	8.06	...
+ 4.0	7.19	7.29			

* Prepared by S. W. McCuskey, Case Institute of Technology.
[258] van Rhijn, Groningen Publ. No. 47, 1936.

TABLE 836.—LUNAR AND TERRESTRIAL CRATERS*

Relationship between diameter and depth of terrestrial explosion craters, terrestrial meteoritic craters and lunar craters. (All explosions occurred slightly below the surface.)

$$D = 0.1083\, d^2 + 0.6917\, d + 0.75$$

where

$D =$ log diameter (feet)

$d =$ log depth (feet)

Examples:

	Diameter	Observed depth	Calculated depth
Shell crater	10 ft	3 ft +	2.20 ft
Arizona meteorite crater	4150 ft	700 ft (originally)	732 ft
Lunar crater Moretus	77 mi	14,600 ft	16,900 ft

Relationship between diameter of crater and rim height above ground level for terrestrial explosion craters, terrestrial meteoritic craters, and lunar craters.

$$E = -0.097\, D^2 + 1.542\, D - 1.841$$

where

$E =$ log rim height (feet)

$D =$ log diameter (feet)

Examples:

	Diameter	Observed rim height	Calculated rim height
Shell crater	10 ft	.4 ft ±	.40 ft
Arizona meteorite crater	4150 ft	165 ft (past erosion neglected)	295 ft
Lunar crater Cleomedes	80 mi	5200 ft	5830 ft

Terrestrial meteoritic craters

	Diameter (ft)	Present depth (ft)	Original depth (ft)	Present rim height	Discovered
American craters:					
Arizona	4150	570	700	165	1891
Odessa 1, near Odessa, Tex.	550	14	130	12	1921
Odessa 2	70	shallow	17	0	1921
At least one other small crater identified nearby	...	...	...	...	...
Brenham crater (near Brenham, Kans., also called Haviland crater)	56×36	shallow	>10	0	1933
Chubb (Quebec)	2½ mi	filled—ice-covered lake		550	1950
South American craters:					
Campo del Cielo, Argentine; many craters	20 to 254	...	...	...	Pits known since 1576
Australian craters:					
Henbury 1, near Henbury cattle station	75	shallow	...	0	1930
2	90	shallow	...	0	1930
3	135	18	...	2	1930
4	135	18	...	2	1930
5	75	6	...	4	1930
6	240	25	...	12	1930
7 (probably double)	660×360	60	...	high	1930
8	175	15	...	high	1930
9	small	...	...	...	1930
10	60	shallow	...	low	1930
11	45	...	...	...	1930
12	60	...	...	12	1930
13	30	3	10	low	1930
Boxhole crater, 200 miles N. E. of Henbury	600	50	...	...	1937
Dalgaranga crater	230	16	...	prominent	1923

* Prepared by R. B. Baldwin, Oliver Machinery Co., Grand Rapids, Mich.

(*continued*)

	Diameter (ft)	Present depth (ft)	Original depth (ft)	Present rim height	Discovered
Wolf Creek	3700	200	...	100	1947
Eurasian craters:					
Kaalijärv, on Baltic Island of Oesel	300—360	50	...	25	1827
Oesel 2	120	...	...	...	1827
3	100	...	...	...	1827
4	65	...	...	...	1827
5	35	...	...	...	1827
6 (probably double)	120×175	...	...	...	1827
At least three small craters nearby					
Wabar 1 in Rubàlkhali of Arabia	328	40	...	high	1932
2	130×180	30	...	high	1932
At least two smaller craters nearby					1932
Great Siberian craters. About 200 in number	30—175	...	...	...	Formed June 30, 1908
Silkhote-Alinsk, U.S.S.R., about 100 craters	<100	...	...	...	Formed Feb. 12, 1947

The 1947 meteorite probably disintegrated high in the air. The 1908 meteorite exploded violently either just before striking the ground or immediately after a ricochet. All others seem to have struck the ground, penetrated a short distance, and then exploded.

It will be noticed that there is a tendency for several craters to be formed simultaneously as if the meteorites traveled in clusters.

Only authenticated craters are here listed. Possible or doubtful cases have been omitted.

TABLE 837.—ALBEDOS

Object	m	g	σ	p	q	Visual albedo	Color index	Photographic albedo
Moon	−12.66	+ .29	2″.40	.104	.694	.072	+ .75	.059
Mercury	− 2.20	− .14	3.34	.080	.72	.058	+1.00	.038
Venus	− 5.12	−4.41	8.50	.630	1.20	.76	+ .62	.70
Mars	− 1.88	−1.39	4.60	.133	1.11	.148	+1.00	.088
Jupiter	− 2.53	−9.23	95.19	.424	1.2:	.51	+ .67	.45
Saturn	+ .76	−8.80	78.95	.416	1.2:	.50	+ .90	.36
Uranus	+ 5.55	−7.17	32.4	.548	1.2:	.66	+ .42	.73
Neptune	+ 7.80	−6.91	29.7	.514	1.2:	.62	+ .42	.68
Pluto	+14.74	−1.17	4.0	.146	1.1:	.16	+ .67	.14

Table compiled by D. L. Harris on the basis of measures by G. Müller and E. S. King and reduced to the International Photovisual System. Long-period variations of the outer planets have been suspected by W. Becker [259] but are subject to confirmation.

The albedo, according to Bond, is defined as follows: "Let a sphere S be exposed to parallel light. Then its albedo is the ratio of the whole amount reflected from S to the whole amount of light incident on it." In the above table, m = the stellar magnitude at mean opposition; g = magnitude it would have at full phase and unit distance from earth and sun; σ = assumed mean semidiameter at unit distance; p = ratio of observed brightness at full phase to that of a flat disk of same size and same position, illuminated and viewed normally and reflecting all the incident light according to Lambert's law; q depends on law of variation of light with phase; albedo = pq.

Albedo of the earth: 0.39.[260]

[259] Becker, W., Astron. Nachs., vol. 277, p. 65, 1949.
[260] Danjon, Ann. Strasbourg, vol. 3, pt. 3, p. 168, 1937.

TABLE 838.—PRECESSION FOR 50 YEARS * [201]

R A h m	Prec in Dec ′	Precession in right ascension, δ = +85° m	+80° m	+75° m	+70° m	+60° m	+50° m	+40° m	+30° m	+20° m	+10° m	0° m	—10° m	—20° m	—30° m	Prec in Dec ′	R A h m
0 00	+16.7	+ 2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	—16.7	12 00
0 30	+16.6	+ 4.22	3.38	3.10	2.96	2.81	2.73	2.68	2.64	2.61	2.59	2.56	2.53	2.51	2.48	—16.6	11 30
1 00	+16.1	+ 5.85	4.19	3.64	3.36	3.06	2.90	2.80	2.73	2.67	2.61	2.56	2.51	2.45	2.39	—16.1	11 00
1 30	+15.4	+ 7.43	4.98	4.15	3.73	3.30	3.07	2.92	2.81	2.72	2.64	2.56	2.49	2.40	2.31	—15.4	10 30
2 00	+14.5	+ 8.92	5.72	4.64	4.09	3.52	3.22	3.03	2.88	2.76	2.66	2.56	2.46	2.36	2.24	—14.5	10 00
2 30	+13.2	+10.31	6.40	5.09	4.42	3.73	3.37	3.13	2.95	2.81	2.68	2.56	2.44	2.31	2.17	—13.2	9 30
3 00	+11.8	+11.56	7.02	5.50	4.73	3.92	3.50	3.22	3.02	2.85	2.70	2.56	2.42	2.27	2.11	—11.8	9 00
3 30	+10.2	+12.66	7.57	5.86	4.99	4.09	3.61	3.30	3.07	2.88	2.72	2.56	2.40	2.24	2.05	—10.2	8 30
4 00	+ 8.3	+13.58	8.03	6.16	5.21	4.23	3.71	3.37	3.12	2.91	2.73	2.56	2.39	2.21	2.00	— 8.3	8 00
4 30	+ 6.4	+14.32	8.40	6.40	5.39	4.34	3.79	3.42	3.16	2.93	2.74	2.56	2.38	2.19	1.97	— 6.4	7 30
5 00	+ 4.3	+14.85	8.66	6.58	5.52	4.42	3.84	3.46	3.18	2.95	2.75	2.56	2.37	2.17	1.94	— 4.3	7 00
5 30	+ 2.2	+15.18	8.82	6.68	5.60	4.47	3.88	3.49	3.20	2.96	2.75	2.56	2.37	2.16	1.92	— 2.2	6 30
6 00	.0	+15.29	8.88	6.72	5.62	4.49	3.89	3.50	3.20	2.97	2.76	2.56	2.36	2.16	1.92	.0	6 00
12 00	—16.7	+ 2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+2.56	+16.7	24 00
12 30	—16.6	+ .90	1.82	2.02	2.16	2.31	2.39	2.44	2.48	2.51	2.53	2.56	2.59	2.61	2.64	+16.6	23 30
13 00	—16.1	— .73	+ .93	1.48	1.77	2.06	2.22	2.32	2.39	2.45	2.51	2.56	2.61	2.67	2.73	+16.1	23 00
13 30	—15.4	— 2.31	+ .14	.97	1.39	1.82	2.05	2.20	2.31	2.40	2.49	2.56	2.64	2.72	2.81	+15.4	22 30
14 00	—14.5	— 3.80	— .60	+ .46	1.03	1.60	1.90	2.09	2.24	2.36	2.46	2.56	2.66	2.76	2.88	+14.5	22 00
14 30	—13.2	— 5.19	—1.28	+ .03	.70	1.39	1.75	1.99	2.17	2.31	2.44	2.56	2.68	2.81	2.95	+13.2	21 30
15 00	—11.8	— 6.44	—1.90	— .38	+ .40	1.20	1.62	1.90	2.11	2.27	2.42	2.56	2.70	2.85	3.02	+11.8	21 00
15 30	—10.2	— 7.54	—2.45	— .74	+ .13	1.03	1.51	1.81	2.05	2.24	2.40	2.56	2.72	2.88	3.07	+10.2	20 30
16 00	— 8.3	— 8.46	—2.91	—1.04	— .09	+ .89	1.41	1.75	2.00	2.21	2.39	2.56	2.73	2.91	3.12	+ 8.3	20 00
16 30	— 6.4	— 9.20	—3.27	—1.28	— .27	+ .78	1.33	1.70	1.97	2.19	2.38	2.56	2.74	2.93	3.16	+ 6.4	19 30
17 00	— 4.3	— 9.73	—3.54	—1.45	— .40	+ .70	1.28	1.66	1.94	2.17	2.37	2.56	2.75	2.95	3.18	+ 4.3	19 00
17 30	— 2.2	—10.06	—3.70	—1.56	— .47	+ .65	1.25	1.63	1.92	2.16	2.37	2.56	2.75	2.96	3.20	+ 2.2	18 30
18 00	.0	—10.17	—3.75	—1.60	— .50	+ .63	1.23	1.62	1.92	2.16	2.36	2.56	2.76	2.97	3.20	.0	18 00

* Selected by Edith J. Tebo, Harvard Observatory.
[201] The Observer's Handbook for 1949, Royal Astronomical Society of Canada.

Part 1.—Density and pressure

The density distribution in the earth's interior is obtained by a series of approximations made to conform with known data as boundary conditions. These known facts, with which any density distribution must harmonize, include the following:

(1) The average density is 5.522, obtained by comparing the attraction of the earth with that of a known mass. Dr. Heyl's value for the constant of gravitation is used, 6.664×10^{-8} dyne cm^2 g^{-2} (Table 27).

(2) The precession constant and other astronomic and geodetic data (Table 827) give the earth's moments in inertia. $I = 0.33344\, Er^2$ where I is the moment of inertia about the polar axis, r the equatorial radius, and E the mass of the earth; further

$$I = \frac{8\pi}{15}\int \rho d\,(ar^4)$$

where a is the polar semi-axis and $\rho = f(a, r)$, the density. If the earth were a homogeneous sphere its moment of inertia would be 0.4 Mr^2 and density 4.6.

(3) The known flattening of the earth from geodetic data is 1/297. If the earth were homogeneous the flattening would be larger. These should be sufficient to give a unique density distribution but, as Lambert of the Coast and Geodetic Survey pointed out, a distribution satisfying condition (2) also satisfies condition (3).

(4) The last boundary condition results by comparing the elastic behavior at various depths with the known elastic constants of rocks. Time-distance curves of earthquake impulses enable one to calculate the velocities of the compressional, V_p, and distortional, V_s, waves at various depths in the earth. Assuming isotropy there are simple relations between K, R, E (moduli of compression, rigidity, Young's respectively), σ (Poisson's ratio), V_p and V_s such that if the density and any two of them are known the others can be had. The variation in elastic constants for different rocks is small but sufficient to permit discrimination when compared with the elastic properties at different depths computed by means of the equations

$$V_s^2 = R/\rho, \quad V_p^2 - \tfrac{4}{3} V_s^2 = K/\rho, \quad (V_p/V_s)^2 = \frac{2(1-\sigma)}{1-2\sigma}$$

The uncertainties result from extrapolating low pressure and temperature laboratory data to high pressures and temperatures.

Whence we deduce: "granitic" material to a depth of 10 to 30 km; below this the rock is denser, about 3.0, and corresponds to a basalt or gabbro. At about 45 km depth a discontinuity occurs; the change in elastic properties corresponds with a transition to peridotite, density 3.4. From this depth to 1,600 km the variation is uniform, the density increasing slowly with pressure. From 1,600 to 2,900 km the earthquake velocities remain somewhat constant and could be accounted for by a slow addition of iron and nickel to the material, the density changing from 3.4 to 9.0. Below 2,900 km V_p begins to decrease slightly and the assumption is that this core consists of nickel-iron with a density at the center of about 10.7.

Depth	Density	Pressure	Rock type
0 km	2.7 g/cm^3		Granitic
10	2.7	.0027×10^6 kg/cm^2	
30	3.0	.0067	Basaltic
60	3.4	.0171	Peridotitic
120	3.5	.0381	
400	3.75	.131	
800	4.0	.30	
1200	4.25	.47	
1700	4.4	.68	..
2000	5.8	.84	
2450	7.25	1.135	
2900	9.0	1.5	Transition layer
3200	9.6	1.7	
4800	10.25	2.8	Ni-Fe core
6370	10.7	3.1	

* Compiled by R. W. Goranson.

(continued)

TABLE 839.—CHARACTERISTICS OF EARTH'S INTERIOR (concluded)

Part 2.—Elastic constants of earth's interior

Depth km	Bulk modulus $\times 10^{-12}$ dynes/cm²	Rigidity $\times 10^{-12}$ dynes/cm²	Depth km	Bulk modulus $\times 10^{-12}$ dynes/cm²	Rigidity $\times 10^{-12}$ dynes/cm²
0	.415	.26	1200	3.6 ± .3	2.2 ± .3
0–20	.5 ± .05	.3 ± .05	1700	4.2 ± .3	2.7 ± .3
20–45	.7 ± .1	.4 ± .1	2850	8 ± 2	4.0 ± 1.0
45–120	1.4 ± .2	.6 ± .1	2900	7 ± 1?	Smaller than at surface, perhaps zero.
120–400	1.6 ± .2	1.0 ± .2	6370	12 ± 10 ?	

Part 3.—Velocities of earthquake waves

V_p is the velocity in km/sec of the primary or condensational wave, V_s, of the secondary or distortional wave. Turner speaks of them as the *push* and *shake* waves.

Layer	V_p, km/sec	V_s, km/sec
0 to 20 ± 10 km depth, depending on locality	5.4 to 5.6, depending on locality. May reach 6.1	3.2 ± .3
20 ± 10 to 45 ± 10 km depth, depending on locality	6.25 to 6.75, depending on locality	3.5 ± .3
Between 45 ± 10 and 2900 km depth:		
45 ± 10	8.0 ± .1	4.4 ± .2
1300	12.5 ± .1	6.9 ± .2
2400	13.5 ± .1	7.5 ± .2
<2900	13.5 ± .1	7.4 ± .2
Core, 2700 to 6370 km (center):		
>2900	8.7 ± .2	7
6000	10.9 ± .2	?

TABLE 840.—BULK MODULI OF ROCK-FORMING MINERALS *

The bulk modulus, K, of a compact holocrystalline rock can be obtained with a fair degree of accuracy except for low pressures by adding the proportionate bulk moduli of the constituent minerals.

Pressure, P, and $K \times 10^{-6}$ are in bars.

Mineral	Pressure in bars: 1	2,000	10,000
Feldspar: Orthoclase	.527	.538	.603
Oligoclase, $Ab_{78}An_{22}$	.582	.592	.641
Labradorite, $Ab_{48}An_{52}$	.654	.671	.758
Pyroxene: Orthorhombic	1.00	1.00	1.00
Diopside	.935	.935	.935
Augite	.981	.981	.981
Hornblende: Actinolite	.769	.769	.769
Mica: Phlogopite	.431	.451	.516
Quartz	.373	.383	.437
Calcite	.736	.741	.758
Magnetite	1.818	1.852	
Corundum	2.44	—	—
Tourmaline	1.22	—	—
Rutile	1.72	—	—

* Compiled by R. W. Goranson.

TABLE 841.—ELASTIC CONSTANTS OF ROCK *

P (pressure), and K, R, E (bulk, rigidity, and Young's moduli resp), are given in bars (1 bar $= 10^6$ dynes/cm²). V_p and V_s (compressional and distortional wave velocities respectively), are in km/sec. σ is Poisson's ratio and ρ is the density. ρ is in g/cm³.

Dynamically determined elastic constants are surrounded by parentheses (single parenthesis represents seismic data); the others are static determinations. Italicized figures are calculated. In places where insufficient data were present to complete the calculations, figures in square brackets have been assumed. In the "P" column m.s. denotes mean stress.

The basis of this table includes data of L. H. Adams and Williamson, F. D. Adams and Coker, Bridgman and others.

Name	P	$K\times10^{-6}$	σ	$R\times10^{-6}$	$E\times10^{-6}$	ρ	V_p	V_s
Granite	1	(*.439*)	(*.32*)	(*.18*)	(*.46*)	2.62	(5.05)	(2.62)
	m.s. 350	*.303*	*.23*	*.20*	.50	—	—	—
	2000	.472	[.28]	*.26*	*.62*	2.62	*5.53*	*3.05*
	10000	.552	[.28]	*.29*	*.73*	*2.67*	*5.91*	*3.26*
Basalt	200	(*.476*)	(*.30*)	(*.22*)	(*.58*)	2.91	(5.06)	(2.72)
	2000	.538	[.28]	*.28*	*.71*	2.91	*5.59*	*3.08*
	10000	.654	[.28]	*.34*	*.86*	*2.95*	*6.11*	*3.38*
Gabbro, norite, diabase	1 {	.606	.24	.35	.84	2.85	—	—
		(*.641*)	(*.27*)	(*.35*)	(*.88*)	2.85	(6.22)	(3.49)
		—	—	—	((.911))	—	—	—
	600	.641	—	—	—	—	—	—
	2000	.700	[.27]	*.38*	*.97*	2.85	*6.50*	*3.65*
	10000	.714	[.27]	*.39*	*.99*	*2.89*	*6.54*	*3.67*
Olivine diabase, olivine gabbro	1 {	.736	.28	.38	1.01	3.00 }	*6.46*	*3.57*
		—	—	—	((.985))	— }		
	m.s. 350	.741	.28	*.37*	.95	3.00 }		
	600	.752	—	—	—	—	—	—
	2000	.806	[.28]	*.42*	*1.06*	*3.01*	*6.7*	*3.7*
	10000	.826	[.28]	*.43*	*1.09*	*3.08*	*6.7*	*3.7*
Peridotite dunite	1	1.064	[.27]	*.58*	*1.47*	3.28	*7.5*	*4.2*
	2000	1.191	[.27]	*.65*	*1.64*	*3.28*	*7.9*	*4.4*
	10000	1.265	[.27]	*.69*	*1.74*	*3.29*	*8.15*	*4.57*
Obsidian	1	.345	.17	—	((.682))	2.34	—	—
	2000	.352	—	—	—	2.35	—	—
Basalt glass	10000	.352	—	—	—	2.41	—	—
Cryst limestone, parallel bed	2000 }	.690	{ —	—	—	2.85	—	—
	10000 }		{ [.27]	*.37*	*.95*	2.89	*6.4*	*3.6*
	m.s. 350	.437	.26	.24	.61	—	—	—
	7000	*.715*	[.28]	*.37*	*.94*	*2.71*	*6.68*	*3.69*
	{ 1	(*.439*)	(*.29*)	(*.17*)	(.55)	2.71	(5.2)	(2.81)
	{ 1	*.402*	*.26*	*.23*	.57	2.69	—	—
Quartzitic sandstone	1	.374	*.21*	*.27*	.65	2.64	*5.3*	*1.9*
	2000	.383	—	—	—	—	—	—
	10000	.437	[.27]	*.24*	*.60*	2.70	*5.4*	*2.9*

* Compiled by R. W. Goranson.

TABLE 842.—AGE OF EARTH, MOON, AND STRATA

The age of the earth is probably from (1.3 to 3) $\times 10^9$ years (radioactive data). Its liquefaction was probably complete within 5,000 years, solidification within 15,000 years from start. The age of the earth's crust may be taken as roughly 2,000 million years.

Ages of geologic strata

Late Oligocene	37,000,000 yr	Late pre-Cambrian (?)	587,000,000 yr
" Cretaceous (?)	59,000,000 "	Upper pre-Cambrian	640,000,000 "
Permian-Carboniferous	204,000,000 "	Middle pre-Cambrian	987,000,000 to 1,087,000,000 yr
Permian to Devonian	239,000,000 to 374,000,000 yr	Lower pre-Cambrian	1,800,000,000 "

The diagram, figure 31, prepared by the U. S. Naval Observatory, shows the paths of total and total-annular eclipses in the United States during the twentieth century. The following data for total United States solar eclipses between 1950 and 2000 are taken from the complete table of eclipses from A.D. 1900–A.D. 2000, given by D. H. Menzel.[202]

Date	Beginning		"Noon"		End		Maximum duration
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	
June 30, 1954	+42°	+ 99°	+62°	+ 5°	+26°	−74°	2 m 40 s
October 2, 1959	+42	+ 72	+23	+ 6	+ 7	−56	3 ..
July 20, 1963	+43	−143	+62	+126	+33	+44	1 ..
March 7, 1970	− 2	+149	+25	+ 88	+55	+23	3 ..
February 26, 1979	+47	+140	+61	+ 77	+77	+34	3 ..

[202] Menzel, D. H., Our Sun, p. 260, Harvard Univ. Press, 1949. Used by permission.

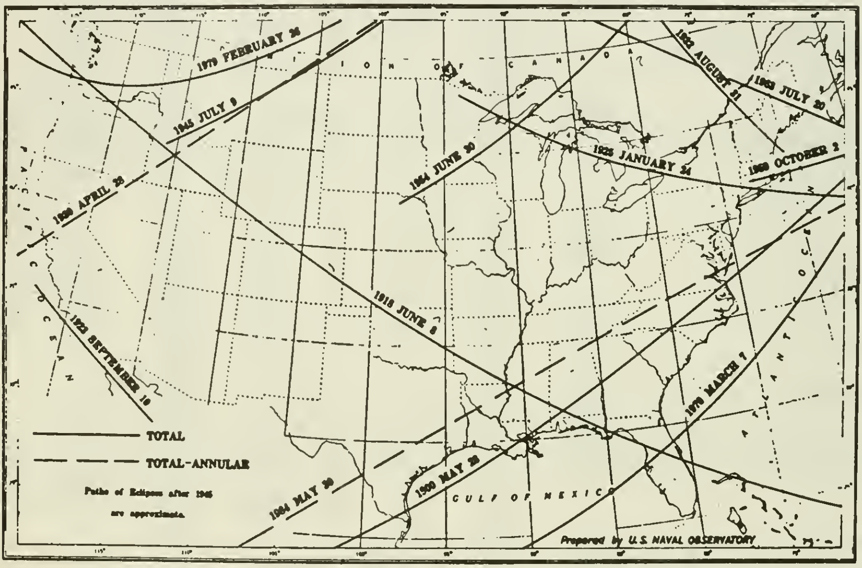

FIG. 31.—Curves showing the paths of solar eclipses during the twentieth century.

TABLE 843.—SPECTRUM CLASS AND PROPER MOTIONS *

Limits of p m	O	B	A	F	G	K	M	N
″00 to ″02	13	238	392	97	107	218	48	3
.02 to .04	6	164	533	115	91	327	54	4
.04 to .10	1	88	476	231	168	393	99	2
.10 to .20	..	..	160	245	70	242	27	1
.20 to .45	..	1	31	168	56	88	8	..
.45 to .80	..	..	1	46	20	23	1	..
.80 to 2.00	..	..	1	12	19	13	..	..
Over 2″00	..	..	..	1	6	6	..	..
Mean p m	″22	″03	″06	″17	″18	″12	″07	″04
Percentage of stars with $\mu >$ ″20	0	.2	5	25	18	10	4	0

* This table, after Boss, gives the number of stars in his catalog brighter than $6^m.5$ which have proper motions between given limits. For reference, see footnote 272, p. 746.

TABLE 844.—SOLAR FLARES *

Class	Mean area in 10^{-6} of sun's hemisphere	Mean duration	Class	Mean area in 10^{-6} of sun's hemisphere	Mean duration
1	217	17 min	3	1266	62 min
2	570	29 "	3+	2350	3 hr

The following paragraphs are reprinted from F. Hoyle, "Some Recent Researches in Solar Physics," p. 36, Cambridge University Press, 1949.†

Flares are a particular class of bright reversal characterized by sudden commencements. The properties of flares are:

(a) They are roughly classified in order of increasing importance as 1, 2, 3, and 3 +. The area of the flare, seen in projection against the solar disk, is, at present, used as the criterion of importance. Flares of class 3 + are rare, occurring on an average only once or twice per year. At the other extreme, flares of class 1 occur every few hours during periods of marked solar activity.

(b) The effective line width in $H\alpha$ at peak intensity varies between 1.75 A and 16 A. being approximately proportional to the importance of the flare. $H\beta$, $H\gamma$ show lesser widths, but the data for these are somewhat meager.

(c) The contour of the bright emission is *nearly* symmetrical about the normal position of $H\alpha$ and is independent of the position of the flare upon the disk (there is invariably a greater extension in the red wing than in the blue wing, which increases with the importance of the flare, reaching 0.7 A for those of the greatest intensity). Doppler displacements of the contour indicating large-scale turbulence of the emitting material in the line of sight have not been observed in excess of $\pm$ 10 km/sec.

(d) Flares are associated with sunspots, and in particular with complicated spot groups. The size of a sunspot, however, is not always a criterion of flare activity, some large spots being relatively inactive. The emitting material is mainly situated either in the reversing layer or the lower chromosphere, and the emission occurs in a region with fixed position relative to the position of the spot group. The areas of flares projected on the solar disk vary from a few hundred millionths up to the values exceeding 10,000 millionths of the area of the disk. The duration of a flare is usually of the order of an hour or less, but lifetimes > 5 hours occasionally occur.

(e) Flares are strongly correlated with a number of terrestrial effects. Radio fadeouts, due to increased ionization in the D-layer, occur simultaneously with the visible appearance of intense flares. Great magnetic storms are associated with flares of classes 3 and 3 +. The magnetic disturbances commence about 26 hours after the appearance of the flare, and are most marked when the flare is near the center of the disk. Finally, there is a growing body of evidence that the sun emits exceptionally high intensities in the radio meter wave-band during flares.

* Prepared by Edith J. Tebo, Harvard College Observatory. † Used with permission of the author.

TABLE 845.—CONSTELLATION ABBREVIATIONS (Astron. Union, 1922)

Andromeda	And	Circinus	Cir	Lacerta	Lac	Pisces Austr	PsA
Antlia	Ant	Columba	Col	Leo	Leo	Puppis	Pup
Apus	Aps	Coma Beren	Com	Leo Minor	LMi	Pyxis	Pyx
Aquarius	Aqr	Corona Aust	CrA	Lepus	Lep	Reticulum	Ret
Aquila	Aql	Corona Bor	CrB	Libra	Lib	Sagitta	Sge
Ara	Ara	Corvus	Crv	Lupus	Lup	Sagittarius	Sgr
Aries	Ari	Crater	Crt	Lynx	Lyn	Scorpius	Sco
Auriga	Aur	Crux	Cru	Lyra	Lyr	Sculptor	Scl
Boötes	Boo	Cygnus	Cyg	Mensa	Men	Scutum	Sct
Caelum	Cae	Delphinus	Del	Microscopium	Mic	Serpens	Ser
Camelopardalis	Cam	Dorado	Dor	Monoceros	Mon	Sextans	Sex
Cancer	Cnc	Draco	Dra	Musca	Mus	Taurus	Tau
Canes Venatici	CVn	Equuleus	Equ	Norma	Nor	Telescopium	Tel
Canis Major	CMa	Eridanus	Eri	Octans	Oct	Triangulum	Tri
" Minor	CMi	Fornax	For	Ophiuchus	Oph	" Austr	TrA
Capricornus	Cap	Gemini	Gem	Orion	Ori	Tucana	Tuc
Carina	Car	Grus	Gru	Pavo	Pav	Ursa Major	UMa
Cassiopeia	Cas	Hercules	Her	Pegasus	Peg	" Minor	UMi
Centaurus	Cen	Horologium	Hor	Perseus	Per	Vela	Vel
Cepheus	Cep	Hydra	Hya	Phoenix	Phe	Virgo	Vir
Cetus	Cet	Hydrus	Hyi	Pictor	Pic	Volans	Vol
Chamaeleon	Cha	Indus	Ind	Pisces	Psc	Vulpecula	Vul

TABLE 846.—EMISSION LINES IN THE SOLAR CORONA *

The following table was taken from Edlén's paper.[263] It summarizes the results of the identification of 19 of the coronal lines caused by forbidden transitions. Fe X, XI, XIII, XIV, XV; Ni XII, XIII, XV, XVI; Ca XII, XIII, XV; A X, XIV. Two of these identifications, namely λ 4359 attributed to A XIV and λ 5694 attributed to Ca XV, are somewhat questionable and therefore these two identifications are given with a (?) in the table. All these identified lines are caused by magnetic dipole radiation.

The first column gives the wavelengths of the coronal lines taken from Mitchell's compilation[264] and reduced values from later work by Lyot.[265] The second column gives the corresponding wave numbers. The third and fourth columns give the intensities as measured by Grotrian and Lyot respectively. The proposed identification is given in column five and the transition probabilities in column six. The seventh and eighth columns give the excitation potential and ionization potentials of the next preceding ionization stages.

λ	cm⁻¹	Intensity		Identification		A_m sec⁻¹	*EP*	*IP* †
3 328	30 039	1.0		Ca XII	$2s^2 2p^5\ ^2P_{1½} - ^2P_{1½}$	488	3.72	589
3 388.1	29 507	16		Fe XIII	$3s^2 3p^2\ ^1D_2 - ^3P_2$	87	5.96	325
3 454.1	28 943	2.3			....	...	...	...
3 601.0	27 762	2.1		Ni XVI	$3s^2 3p\ ^2P_{1½} - ^2P_{½}$	193	3.44	455
3 642.9	27 443	..		Ni XIII	$3s^2 3p^4\ ^1D_2 - ^3P_1$	18	5.82	350
3 800.8	26 303	..			....	...	...	...
3 986.9	25 075	.7		Fe XI	$3s^2 3p^4\ ^1D_2 - ^3P_1$	9.5	4.68	261
4 086.3	24 465	1.0		Ca XIII	$2s^2 2p^4\ ^3P_1 - ^3P_2$	319	3.03	655
4 231.4	23 626	2.6		Ni XII	$3s^2 3p^5\ ^2P_{½} - ^2P_{1½}$	237	2.93	318
4 311	23 190	..			....	...	...	...
4 359	22 935	..		? A XIV	$2s^2 2p\ ^2P_{1½} - ^2P_{½}$	108	2.84	682
4 567	21 890	1.1			....	...	...	...
5 116.03	19 541.0	4.3	2.2	Ni XIII	$3s^2 3p^4\ ^3P_1 - ^3P_2$	157	2.42	350
5 302.86	18 852.5	100	100	Fe XIV	$3s^2 3p\ ^2P_{1½} - ^2P_{½}$	60	2.34	355
5 536	18 059	..	..	A X	$2s^2 2p^5\ ^2P_{½} - ^2P_{1½}$	106	2.24	421
5 694.42	17 556.2	..	1.2	? Ca XV	$2s^2 2p^2\ ^3P_1 - ^3P_0$	95	2.18	814
6 374.51	15 683.2	8.1	18	Fe X	$3s^2 3p^5\ ^2P_{½} - ^2P_{1½}$	69	1.94	233
6 701.83	14 917.2	5.4	2.0	Ni XV	$3s^2 3p^2\ ^3P_1 - ^3P_0$	57	1.85	422
7 059.62	14 161.2		2.2	Fe XV	$3s\ 3p\ ^3P_2 - ^3P_1$	...	31.7	390
7 891.94	12 667.7		13	Fe XI	$3s^2 3p^4\ ^3P_1 - ^3P_2$	44	1.57	261
8 024.21	12 458.9		.5	Ni XV	$3s^2 3p^2\ ^3P_2 - ^3P_1$	22	3.39	422
10 746.80	9 302.5		55	Fe XIII	$3s^2 3p^2\ ^3P_1 - ^3P_0$	14	1.15	325
10 797.95	9 258.5		35	Fe XIII	$3s^2 3p^2\ ^3P_2 - ^3P_1$	9.7	2.30	325

* Prepared by Edith J. Tebo, Harvard College Observatory.
[263] Zeitschr. Astrophys., vol. 22, p. 30, 1943.
[264] Handbook d'Astrophys., vol. 4, p. 324, 1929; vol. 7, p. 401, 1936.
[265] Monthly Notices, Roy. Astron. Soc., vol. 99, p. 580, 1939.
† The ionization potential refers to the next lower stage.

TABLE 847.—THE CEPHEID PERIOD-LUMINOSITY CURVE *

Logarithm of period days	Mean spectrum [266]	Absolute photographic magnitude [267]	Absolute bolometric magnitude [268]	Logarithm of period days	Mean spectrum	Absolute photographic magnitude	Absolute bolometric magnitude
.0	*F* 2.5	— .31	— .85	1.2	*G* 6	—2.39	—3.77
.2	*F* 5.5	— .68	—1.26	1.4	*G* 8	—2.80	—4.31
.4	*F* 7.5	—1.01	—1.74	1.6	*K* .5	—3.25	—4.99
.6	*G* 0	—1.33	—2.25	1.8	*K* 2.5	—3.73	—5.87
.8	*G* 2	—1.66	—2.74	2.0	*M* 0	—4.24	—7.52
1.0	*G* 4	—2.02	—3.26				

* Prepared by H. Shapley, Harvard University.
[266] Shapley, Harvard Bull., vol. 861, 1928.
[267] Shapley, Proc. Nat. Acad. Sci., vol. 26, p. 544, 1940.
[268] Kuiper, Astrophys. Journ., vol. 88, p. 453, 1938.

λ	Classification	Excitation potential	Intensity 7027	Intensity 7662
H I				
4340.5	$2\,^2S, P - 5\,^2S, P, D$	13.0	39	40
4861.3	$2\,^2S, P - 4\,^2S, P, D$	12.7	100	100
6562.8	$2\,^2S, P - 3\,^2S, P, D$	12.0	580	500
He I				
3888.6	$2s\,^3S - 3p\,^3P$	22.9	<13	<25
4471.5	$2p\,^3P - 4d\,^3D$	23.6	6	5
5015.7	$2s\,^1S - 3p\,^1P$	23.0	5±	...
5875.6	$2p\,^3P - 3d\,^3D$	23.0	50	30
6678.1	$2p\,^1P - 3d\,^1D$	23.0	8	6
He II				
4541.6	$4\,^2S, P, D, F - 9\,^2S, P, D, F, G$	53.5	4	3
4685.8	$3\,^2S, P, D - 4\,^2S, P, D, F$	50.8	39	60
5411.6	$4\,^2S, P, D, F - 7\,^2S, P, D, F, G$	53.1	25	10
C II				
4267.2	$3d\,^2D - 4f\,^2F$	20.9	3	1
N II				
5755.0	$[2p^2\,^1D - 2p^2\,^1S]$	4.0	30	...
6548.4	$[2p^2\,^3P_1 - 2p^2\,^1D]$	1.9	150	5±
6583.9	$[2p^2\,^3P_2 - 2p^2\,^1D]$	1.9	260	10±
O I				
6300.2	$[2p^4\,^3P_2 - 2p^4\,^1D]$	2.0	50	1
O II				
3726.2	$[2p^3\,^4S - 2p^3\,^2D_{1½}]$	3.3	20	8
3729.1	$[2p^3\,^4S - 2p^3\,^2D_{2½}]$	3.3	11	5
7319.0	$[2p^3\,^2D_{2½} - 2p^3\,^2P]$	5.0	P	...
7330.4	$[2p^3\,^2D_{1½} - 2p^3\,^2P]$	5.0	P	...
O III				
4363.2	$[2p^2\,^1D - 2p^2\,^1S]$	5.3	23	19
4959.5	$[2p^2\,^3P_1 - 2p^2\,^1D]$	2.5	430	350
5007.6	$[2p^2\,^3P_2 - 2p^2\,^1D]$	2.5	1200	1000
Ne III				
3868.7	$[2p^4\,^3P_2 - 2p^4\,^1D]$	3.2	95	80
3967.5	$[2p^4\,^3P_1 - 2p^4\,^1D]$	3.2	24	<80
Ne IV				
4714.1	$[2p^3\,^2D_{2½} - 2p^3\,^2P]$	7.7	≪6	≪10
4719.7	$[2p^3\,^2D_{1½} - 2p^3\,^2P]$	7.7	...	...
Ne V				
3345.8	$[2p^2\,^3P_1 - 2p^2\,^1D]$	3.8	43	P
3425.8	$[2p^2\,^3P_2 - 2p^2\,^1D]$	3.8	109	P
S II				
4068.5	$[3p^3\,^4S - 3p^3\,^2P_{1½}]$	3.0	<8	<3
4076.5	$[3p^3\,^4S - 3p^3\,^2P_{½}]$	3.0	5	.5
6717.3	$[3p^3\,^4S - 3p^3\,^2D_{2½}]$	1.8	6 }	5
6731.5	$[3p^3\,^4S - 3p^3\,^2D_{1½}]$	1.8	12 }	
A IV				
4711.4	$[3p^3\,^4S - 3p^3\,^2D_{2½}]$	2.6	<6	<10
4740.3	$[3p^3\,^4S - 3p^3\,^2D_{1½}]$	2.6	10	10
Fe XI		4.7	≪95	≪80
3871.9	$[3p^4\,^3P_1 - 3p^4\,^1D]$			

The above table, containing most of the strongest and/or important lines under nebular conditions, is taken from a more complete list.[209] The brackets [ ] about a classification indicate a forbidden transition. These wavelengths are in all cases except Ne III and Ne V the values calculated from series analyses of the ions concerned. The last two columns give the observed intensities in the objects NGC 7027 and 7662. P indicates the line is present but out of the range covered by the observations and intensity estimates; < represents a blend with a line classified otherwise, transition indicated probably an appreciable contributor; ≪ is also a blend with a line classified otherwise, transition indicated probably is not an appreciable contributor.

* Prepared by Edith J. Tebo, Harvard College Observatory.
[209] Bowen, I. S., and Wyse, A. B., Lick Obs. Bull., vol. 19, p. 1, 1939.

The solar neighborhood distance of *50 light-years*, explored chiefly through the motions of nearby stars. A large majority are of less than solar luminosity, most below naked-eye visibility. Only 40 percent of the stars known to be nearer than 16 light-years are brighter than the sixth magnitude. Exploring the solar neighborhood therefore involves a search for telescopic dwarf stars. Any body 1/100 of sun's mass within 1,000 astronomical units (.015 light year) would be detected by its disturbance on Neptune and Uranus even if invisible (Russell). Nearest known star is 4 light-years distant (Proxima Centauri, $m = 11$, $M = 15.5$).

Region of brighter stars extending *500 light-years*. The great majority of naked-eye stars lie in this region, though some of unusually high intrinsic luminosity are farther away. It includes probably 500,000 telescopic stars. Studied by proper motions, trigonometric and spectroscopic parallaxes, and photometry.

The Milky Way with a radius of about *50,000 light-years*. The stars within 5,000 light-years of the sun are a trifling part of the galactic system outlined by the globular clusters and Milky Way clouds. The stars are so remote that proper motions and spectroscopic analyses hopelessly fail. Statistical counts are of some help in the nearer parts. But most of our knowledge comes from eclipsing binaries, long-period variables, and Cepheids. The period-luminosity relation for Cepheid variables is the key to practically all distances > a few 1,000 light-years.

The Clouds of Magellan, nearly *100,000 light-years* distant, nearest of all external galaxies and the most easily studied. Great advantage, all of its varied manifestations are seen at practically the same distance. These phenomena include gaseous nebulae, star clusters, giant and supergiant stars, some 1,500 known Cepheids in the Larger Cloud. In this cloud 750 stars brighter than — 5.0 abs mag and over 200,000 brighter than the 0.0 have been estimated.

The Supergalaxies, *1,000,000 to 500,000,000 light-years* distant. Composed of clusters of extragalactic nebulae. The relative diameters and brightnesses have been determined for some of the supergalaxies. The most conspicuous is the Coma-Virgo cloud *A*, a stream of several hundred bright spiral, spheroidal, and irregular galaxies, about 10^7 light-years distant; its greatest length about one-half this. One of the richest and most distinct supergalaxies is in Centaurus.

TABLE 850.—STELLAR SPECTRA AND RELATED CHARACTERISTICS *

The one-dimensional classification system.—The spectra of almost all the stars can be arranged in a continuous sequence, the various types connected in a series of imperceptible gradations. With two unimportant exceptions, the sequence is linear. According to the now generally accepted Harvard (or Draper) system of classification, certain principal types of spectrums are designated by letters—*P, W, O, B, A, F, G, K, M, R, N,* and *S*—and the intermediate types of suffixed numbers. A spectrum halfway between *B* and *A* is denoted by *B* 5 while those differing slightly from class *A* in the direction of Class *B* are called *B* 8 or *B* 9. Classes *R* and *N* apparently form one side chain, and class *S* another chain, both branching from the main series near class *K*.

The two-dimensional classification system.—In addition to the larger characteristics used to determine the spectral class (temperature differences) there are smaller luminosity effects that depend mainly on differences in densities in the atmospheres of the stars. Thus one can distinguish between dwarfs, giants, and supergiants. At Harvard, in 1897, Miss Maury was actually the first to denote certain stars by prefixing the letter "c" to the spectral class. These stars are now known to be supergiants. Mount Wilson observers still use this letter "c" to denote supergiants, "g" for giants, and "d" for dwarfs. This *dM* 5 denotes a dwarf star of spectral type *M* 5 (see Table 874). Morgan, Keenan, and Kellman have extended the classification even further.[270] Their luminosity classes include not only giants (III) and dwarfs (V) but subgiants (IV) and several classes of supergiants (I; Ia, and Ib) and intermediates (II).

Almost all the stars can be classified on the above system. In addition to individual peculiar stars there are, however, groups of stars that cannot be given specific classifications, such as the *A*-type spectrum variables[271] and the "metallic-line" stars.[272]

The colors of the stars, the degree to which they are concentrated into the region of the sky, including the Milky Way (Table 854), and the average magnitudes of their peculiar velocities in space (Tables 828 and 876) all show important correlations with spectral type. In the case of colors, the correlation is so close as to indicate that both spectrum and color depend almost entirely on the surface temperature of the stars. The correlation in the other two cases, though statistically important, is by no mean so close.

* Prepared by Edith J. Tebo, Harvard College Observatory.
[270] An Atlas of Stellar Spectra, University of Chicago Press, 1943.
[271] Deutsch, Astrophys. Journ., vol. 105, p. 283, 1947.
[272] Roman, Morgan, and Eggen, Astrophys. Journ., vol. 107, p. 107, 1948. Greenstein, Astrophys. Journ., vol. 107, p. 151, 1948; vol. 109, p. 121, 1949.

TABLE 851.—STELLAR SPECTRA *

Part 1.—The Harvard spectrum classification

Class	Principal spectral lines (absorption unless otherwise stated)	Example	Number brighter than 6.25, mag	Percent in galactic region
P	Gaseous nebulae. Emission lines and bands of H, He I and II, and O II.	....	....	....
W	Wolf-Rayet objects divided into two sequences: carbon, WC, have emission lines attributed to He I and II, C II, III, and IV, and O II, III, IV, V, and VI; nitrogen sequence, WN, have emission lines attributed to He I and II, and N III, IV, and V.	γ Velorum	5	100
O	Lines of H, He I and II, O II and III, and N II and III.	ζ Puppis	20	100
B	Neutral H and He, N II, and O II, and a few ionized lines of metals.	ϵ Orionis	696	82
A	H series at maximum, Ca II (H and K), and weak ionized metallic lines.	Sirius	1885	66
F	Ca II (H and K) strong, H lines fainter, metallic lines more abundant.	Canopus	720	57
G	H lines faint, Ca II (H and K) strong, many fine metallic lines.	The sun	609	58
K	Ca II (H and K) very strong, many neutral metallic lines. Spectrum faint in the violet.	Arcturus	1719	56
M	Molecular bands of TiO, lines of Ca I and II, and other metals. Long-period variables have emission H lines.	Antares	457	54
S	ZrO bands and metallic lines. Long-period variables have emission H lines.	π_1 Gruis	0	....
R	Bands of C_2, CN, and CH; many metallic lines.	B D —10°5057	0	63
N	Bands of C_2, CN, and CH; very little violet light.	19 Piscium	8	87
Q	Novae. Rapid spectral changes from early supergiant type near maximum, through nebular stage, and finally to a Wolf-Rayet type.	....	....	....

Part 2.—Prototypes for luminosity classification [273]

Class	Supergiants	Giants	Main sequence	Class	Supergiants	Giants	Main sequence
B 0	ϵ Ori	κ Ori	ζ Oph	*G* 5	9 Peg	γ Hya	κ Cet
B 5	67 Oph	δ Per	κ Hya	*K* 2	56 Ori	κ Oph	ϵ Eri
A 2	α Cyg	λ UMa	ζ Vir	*M* 1	α Sco	75 Cyg	*BD* + 42.2296
F 0	α Lep	ζ Leo	μ Cap	*M* 5	α Her	56 Leo	*BD* + 4.3561
F 8	γ Cyg	1 Com	β Vir				

For description of classification of Wolf-Rayet stars see reference, footnote 274. The "galactic region" here means the zone between galactic latitudes ± 30°, and including half the area of the heavens. 96 percent of the stars of known spectra belong to classes *A*, *F*, *G*, *K*, 99.7 percent including *B* and *M* (Innes, 1919). Henry Draper Catalog, 9 vols., 1918–24, and H. D. Extension, 2 vols., 1925–49, give positions, magnitudes, and spectra of nearly 360,000 stars. See also Yale Zone Catalogs, and the Bergedorf and Potsdam Spectral-Durchmusterungen.

* Prepared by M. W. Mayall, Harvard College Observatory.
[273] Trans. Int. Astron. Union, vol. 7, p. 408, 1950.
[274] Trans. Int. Astron. Union, vol. 6, p. 248, 1938.

TABLE 852.—PERCENTAGE OF STARS OF VARIOUS SPECTRAL CLASSES *

Visual magnitude	B (B 0 to B 5)	A (B 8 to A 3)	F (A 5 to F 2)	G (F 5 to G 0)	K (G 5 to K 2)	M (K 5 to M 8)
< 2.24	28	28	7	10	15	12
2.25 to 3.24	25	19	10	12	22	12
3.25 to 4.24	16	22	7	12	35	8
4.25 to 5.24	9	27	12	12	30	10
5.25 to 6.24	5	38	13	10	28	6
6.26 to 7.25	5	30	11	14	32	7
7.26 to 8.25	2	26	11	16	37	7
8.5 to 9.4	2	18	13	20	36	12
9.5 to 10.4	1	16	12	24	38	9
Photographic magnitude	(B 0 to B 5)	(B 6 to A 4)	(A 5 to F 4)	(F 5 to G 4)	(G 5 to K 4)	(K 5 to Mc)
8.5 to 9.5	2	31	16	24	24	3
9.5 to 10.5	1	24	16	31	26	3
10.5 to 11.5	1	17	13	40	27	3
11.5 to 12.5	0	10	13	47	26	3
12.5 to 13.5	0:	3:	10:	58:	26:	2:

The data are taken from the publications of the Harvard, McCormick, and Bergedorf Observatories. The discontinuity in trend appearing between the visual and photographic groupings is in the sense to be expected. Ninety-nine percent of the stars brighter than magnitude 8.5 belong to the six classes listed; less than one percent have spectra of classes *P*, *WR*, *O*, *R*, *N*, *S*, and Peculiar, and such stars are even more uncommon among the fainter groupings.

Among stars brighter than sixth magnitude the percentages of dwarfs are as follows (Öpik et al.):

F 5	F 8	G 0	G 5	K 0	K 2	K 5	M
75	60	50	15	5	3	2	0

A limited sampling in the Milky Way yields the following percentages of dwarfs among fainter stars (Nassau and McCrae):

Photographic magnitude	F 8 to G 2	G 5	G 8 to K 3
8 to 10	75	23	7
10 to 11	77	31	8
11 to 12	82	42	10

In higher galactic latitudes the percentages of dwarfs are higher; thus in latitudes 31° to 90° dwarfs constitute about 17 percent of the *K* 0 and *K* 2 stars of visual magnitude 10.4 (Janssen and Vyssotsky). Among the *M* 0 and *M* 8 stars of all latitudes between visual magnitudes 8.5 and 10.5 3 percent are dwarfs (Dyer and Vyssotsky).

* Prepared by A. N. Vyssotsky, University of Virginia.

TABLE 853.—THE LOCAL FAMILY OF GALAXIES[275]

Member	Type	Modulus † Obs	Modulus † Corr	Distance (corrected for lat effect)	M_{pg}	Diameter Apparent	Diameter Linear
Our galaxy	*Sb*						24 kpc
M 31	*Sb*	22.4	21.8	231 kpc	−17.9	3.2°	12.9
LMC	*I*	17.1	16.7	22	−15.9	12°	4.6
M 33	*Sc*	22.3	21.9	239	−14.9	62′	4.3
SMC	*I*	17.3	17.0	25	−14.5	8°	3.6
M 32	*E* 2	22.4	21.8	231	−12.9	...	...
Fornax system	*E*	21.0:	20.8:	142:	−11.9:	50′	2.1:
NGC 205	*E* 5*p*	22.4	21.8	231	−11.5	15′.8	1.1
NGC 6822	*I*	21.6	21.0	161	−10.8	20′	.94
IC 1613	*I*	22.0	21.8	225	−10.8	17′	1.1
Sculptor system	*E*	19.4	19.2	69	−10.6	45′	.90
NGC 185	*E*	22.4±	21.5±	204±	−10.6	14′.5	.86
NGC 147	*E*	22.4±	21.5±	204±	−10.3	14′.1	.83

[275] Baade, Walter, Astrophys. Journ., vol. 100, p. 150, 1944.
† Modulus in stellar magnitude is $m - M = 5 (\log d - 1)$, where d is distance in parsecs and M is absolute magnitude.

TABLE 854.—GALACTIC CONCENTRATION OF STARS OF VARIOUS SPECTRAL CLASSES *

Part 1.—Number of stars per 100 square degrees

Spectrum	B	A	F	G	K	M
Visual magnitude			Galactic latitude 0° to 5°			
< 6.0	4.5	6.0	1.7	2.1	3.5	1.3
6.0 to 7.0	6.3	15	3.4	3.0	12	2.6
7.0 to 8.25	19	76	14	21	54	14
8.5 to 9.4	46	190	85	96	200	57
9.5 to 10.4	82	610	240	310	490	150
Photographic magnitude						
9.5 to 10.5	38	510	150	220	180	19
10.5 to 11.5	87	970	430	720	460	42
11.5 to 12.5	100	1390	1200	1960	940	140
Visual magnitude			Galactic latitude 60° to 90°			
< 6.0	.2	2.6	.8	1.0	2.9	.7
6.0 to 7.0	0	3.8	1.8	2.4	7.5	.7
7.0 to 8.25	0	7.4	9.2	16	32	6.3
8.5 to 9.4	0	8	20	83	75	0
9.5 to 10.4	0	8	20	170	210	16
Photographic magnitude						
9.5 to 10.5	0	9	32	120	75	9
10.5 to 11.5	0	10	27	290	160	12
11.5 to 12.5	.9	14	34	680	270	26

The data are taken from the publications of the Harvard, McCormick, and Bergedorf Observatories. The spectral groupings are the same as in the preceding table. Absorption accounts for the apparent discrepancy in low latitudes between the numbers of early type stars in the last line of the visual magnitudes and those in the first line of the photographic magnitudes.

A measure of apparent galactic concentration may be found from the ratios of the star numbers in low latitudes to those in high latitudes. We obtain the figures given in Part 2:

Part 2.—Index of apparent galactic concentration

Visual magnitude	B	A	F	G	K	M
< 6.0	22	2.8	2.3	2.1	1.2	1.9
6.0 to 7.0	..	4.0	1.9	1.2	1.5	3.7
7.0 to 8.25	..	10	1.5	1.3	1.7	2.2
8.5 to 9.4	..	24	4.2	1.2	2.7	..
9.5 to 10.4	..	76	12	1.8	2.3	9
Photographic magnitude						
9.5 to 10.5	..	56	4.8	1.8	2.4	2.1
10.5 to 11.5	..	97	16	2.5	2.9	3.5
11.5 to 12.5	..	99	35	2.9	3.5	5.5

The irregularities here are attributable in part to inadequate sampling.

Among the stars of the main sequence the true concentration increases with the stellar mass; the true concentration of the red giants is relatively low. The *W*, *O*, and *N* stars show high apparent concentration to the Milky Way as do the Cepheids, and planetary nebulae; on the other hand, the long-period variables show little concentration and the cluster-type variables even less.

* Prepared by A. N. Vyssotsky, University of Virginia.

TABLE 855.—MEAN ANNUAL PARALLAX FOR STARS *

Part 1.—Stars of given visual magnitude and galactic latitude

Mag	0°—20°	20°—40°	40°—90°	Mag	0°—20°	20°—40°	40°—90°
3.0	″027	″036	″036	9.0	″0043	″0047	″0073
4.0	.020	.025	.027	10.0	.0032	.0037	.0057
5.0	.015	.017	.020	11.0	.0023	.0030	.0045
6.0	.011	.012	.015	12.0	.0018	.0024	.0034
7.0	.0080	.0086	.0117	13.0	.0014	.0020	.0027
8.0	.0059	.0062	.0092	14.0	.0011	.0016	.0021

These tabular values have been obtained by combining and smoothing the secular parallaxes derived at Groningen and McCormick together with mean parallaxes for fainter stars derived at Leiden. To obtain annual parallaxes from secular parallaxes a solar velocity of 19 kilometers per second has been assumed. Similarly the Leiden figures rest on certain assumptions as to the peculiar motions of faint stars. Recent studies of the space motions of stars more than 500 parsecs from the plane of the galaxy indicate that the annual parallaxes listed here may well be systematically too large for stars fainter than tenth magnitude in the higher latitudes.

Some idea of the dependence of the mean parallaxes on the spectral type may be gained from Part 2. Here the probable error of a secular parallax is approximately 0″001.

Part 2.—Mean parallaxes according to spectral class for stars of visual magnitude 10.0 (latitude 0° to 90°)

Spectral class	Secular parallax	Solar velocity	Annual parallax
B 8 to *A* 3	″007	16 km/sec	″0021
A 5 to *F* 2	.011	17	.0031
F 5 to *G* 0	.022	18	.0058
K 0 to *K* 2	.014	20	.0033
gM 0 to *gM* 8	.005	22	.0011

* Prepared by A. N. Vyssotsky, University of Virginia.

TABLE 856.—SPECTRUM CLASSES AND TEMPERATURES OF STARS *

Spectral type	Observed: Heat index Mag	Observed: Water-cell absorption Mag	Temperature by several methods, °K: Heat index λ 0.555 μ	Heat index λ 0.529 μ	Water-cell absorption	Color index [270]	Ionization
B 0	.05	.20				25000°	20000
B 5	.01	.23				15500	15000
A 0	.00	.26				10700	10000
A 5	.02	.30			7500°	8530	8400
F 0	.15	.36	6750°	7300°	6200	7500	7500
F 5	.30	.41	5760	6160	5450	6470	7000
dG 0	.32	.42	5700	6100	5350	6000	
dG 5	.39	.47	5350	5750	4920	5360	
DK 0	.55	.54	4820	5100	4460	4910	
dK 5	1.10	.76	3720	3980	3550	4150 †	
dM 0	1.40	.87	3400	3650	3260	3600 ‡	
dM 2	2.1	1.14	2870	3060	2780	3200	
gG 0	.47	.50	5000	5450	4700	5200	5600
gG 5	.65	.60	4550	4870	4140	4620	5000
gK 0	.90	.70	4020	4300	3750	4230	4000
gK 5	1.57	.93	3240	3480	3130	3580	3000
gM 0	1.86	1.01	3030	3250	2980	3400	3000
gM 2	2.2	1.14	2810	3000	2810	3200	
gM 4	3.1	1.30	2400	2590	2550	2930	
gM 6	4.2	1.46	2050	2200	2390	2750	
gM 8	5.2	1.62	1780	2000	2250		
Me Max	4.4	1.5	1990	2160	2350		
Me Min	8.9	2.2			1830		

* Prepared by S. B. Nicholson, Mount Wilson Observatory.
[270] Kuiper, G. P., Astrophys. Journ., vol. 88, p. 464, 1938.
† Payne, Stellar atmospheres, 1925. ‡ Interpolated.

TABLE 857.—STARS KNOWN TO BE WITHIN 5 PARSECS OF THE SUN *

	R A 1950 Dec h m	m_v	*Sp*	*p* ″	*M*	μ ″	θ	V_{rad}
α Cen A	14 36.2—60°38′	.3	*dG* 3	.755	4.7	3.68	281°	— 22
α Cen B	14 36.2—60 38	1.7	*dK* 2	.755	6.1	3.68	281	— 22
α Cen C	14 26.3—62 29	11.5	*dM* :	.778	16.0	3.85	282	....
+4:3561	17 55.4+ 4 33	9.4	*dM* 5	.544	13.1	10.26	356	—110
W 359	10 54.1+ 7 19	13.8	*dM* 6	.402	16.8	4.70	235	+ 13
L 726-8 A	1 36.4—18 13	12.4	*dM* 6*e*	.4: :	15.4	3.38	80	+ 30
L 726-8 B	1 36.4—18 13	12.9	*dM* 6*e*	.4: :	15.9	3.38	80	+ 30
+36:2147 A †	11 00.6+36 18	7.5	*dM* 2	.390	10.5	4.78	187	— 87
α CMa A	6 42.9—16 39	—1.6	*A* 0	.378	1 3	1.32	203	— 8
α CMa B	6 42.9—16 39	8.5	*F*	.378	11.4	1.32	203	— 8
R 154	18 46.7—23 54	10.5	*dM* 5	.354	13.2	.74	106	0
R 248	23 39.4+43 55	12.2	*dM* 6	.318	14.7	1.82	176	— 81
ε Eri	3 30.6— 9 38	3.8	*dK* 2	.301	6.2	.97	271	+ 15
61 Cyg A	21 04.7+38 30	5.6	*dK* 5	.298	8.0	5.21	52	— 64
61 Cyg B	21 04.7+38 30	6.3	*dK* 7	.298	8.7	5.21	52	— 64
τ Cet	1 41.7—16 12	3.6	*dG* 7	.298	6.0	1.92	296	— 16
α CMi A	7 36.7+ 5 21	.5	*dF* 4	.294	2.8	1.25	214	— 4
α CMi B	7 36.7+ 5 21	10.8	...	.294	13.1	1.25	214	— 4
L 789-6	22 35.7—15 36	12.3	*dM* 6	.293	14.6	3.27	46	— 60
ε Ind	21 59.6—57 00	4.7	*dK* 5	.288	7.0	4.69	123	— 40
R 128	11 45.1+ 1 07	11.0	*dM* 5	.288	13.3	1.39	153	— 12
+59:1914 A	18 42.2+59 33	8.9	*dM* 3	.285	11.2	2.28	324	+ 2
+59:1915 B	18 42.2+59 33	9.7	*dM* 4	.285	12.0	2.28	324	+ 2
+43:44 A †	0 15.4+43 44	8.1	*dM* 3	.279	10.3	2.90	82	+ 8
+43:44 B	0 15.4+43 44	10.8	*sdM* 4*e*	.279	13.0	2.90	82	+ 8
—36:9694	23 02.6—36 09	7.3	*dM* 1	.277	9.5	6.91	79	+ 10
—44:612	5:09.7—45:00	9.0	*sdM* 0	.262	11.1	8.74	131	+242
+ 5:1668	7 24.7+ 5 28	10.1	*dM* 5	.262	12.2	3.76	171	+ 27
—39:8920	21 14.3—39 04	6.6	*dM* 0	.257	8.8	3.46	251	+ 22
+56:2783 A	22 26.6+57 26	9.8	*dM* 4	.256	11.8	.86	246	— 24
+56:2783 B	22 26.6+57 26	11.2	*dM* 6	.256	13.2	.86	246	— 24
R 614 AB †	6 26.8— 2 46	11.6	*dM* 6*e*	.256	13.6	1.00	131	+ 25:
—12:4523	16 27.5—12 32	9.9	*dM* 4	.253	11.9	1.18	182	— 18
vMa 1	0 46.6+ 5 10	12.3	*DF*	.245	14.2	2.98	155	+238
W 424 A	12 30.8+ 9 18	12.7	*dM* 7	.225	14.5	1.80	279	— 5
W 424 B	12 30.8+ 9 18	12.7	*dM* 7	.225	14.5	1.80	279	— 5
Co—46:11540	17 24.9—46 51	9.7	*dM* 3	.224	11.5	1.04	147	....
—37:9435	0 02.5—37 36	8.5	*dM* 3	.222	10.2	6.07	113	+ 24
+68:946	17 36.7+68 23	9 2	*dM* 3	.218	10.8	1.31	197	— 17
+50:1725	10 08.3+49 42	6.7	*dK* 8	.218	8.4	1.45	249	— 27
—49:11439	21 30.3—49 14	9.0	*dM* 2	.212	10.6	.81	185	....
—15:6290	22 50.7—14 31	10.2	*dM* 5	.211	11.8	1.11	123	+ 10
CO—44:11909	17 33.4—44 16	10.5	*dM* 5	.210	12.1	1.15	217	....
α Aql	19 48.3+ 8 44	.9	*A* 4	.206	2.5	.66	55	— 26
L 145-141	11 42.7—64 34	12.1	*DA*	.204	13.6	2.68	97	....
+43:4305	22 44.7+44 05	10.1	*dM* 5	.203	11.6	.86	237	+ 2
o_2 Eri A	4 13.0— 7 44	4.5	*dK* 0	.200	6.0	4.08	213	— 42
o_2 Eri B	4 13.0— 7 44	9.4	*DA*	.200	10.9	4.08	213	— 42
c_2 Eri C	4 13.0— 7 44	11.1	*dM* 5*e*	.200	12.6	4.08	213	— 42
Grw+79:3888	11 45.4+78 58	11.0	*dM* 4	.200	12.5	.87	57	—120

The stars have been designated by their *B D* or *C P D* numbers and only if neither of these was available, by their Cordoba Durchmusterung numbers: for very faint stars the discoverer's numbers have had to be used. *p* = parallax, μ = proper motion, *m* = magnitude, *M* = absolute magnitude, V_{rad} = radial velocity, *Sp* = spectrum, θ = position angle.

* Prepared by W. Luyten, University of Minnesota. † These stars have invisible companions.

TABLE 858.—MASSES OF STARS FOR BINARIES WITHIN 10 PARSECS FROM THE SUN *

This table contains all visual binary stars within 10 parsecs for which the orbital elements and parallax are well determined.

The sum of the masses follows from the harmonic relation:

$$M_1 + M_2 = \frac{a^3}{P^2}$$

where a is the semimajor axis of the relative orbit, expressed in astronomical units, P the period in years; the masses are referred to the sun's mass as unit. For the majority of these binaries the mass-ratio is known, thus permitting a determination of the masses of the individual component.

Star	Parallax	a A U	P years	Sum of masses M_1+M_2	Separate masses M_1	M_2
η Cas	″184	67.9	526	1.13	.69	.44
p Eri	.161	52	251	2.22	..	..
o_2 Eri B, C	.202	34.1	248	.64	.44	.20
Sirius	.381	20.0	49.94	3.21	2.15	1.06
Procyon	.287	15.8	40.65	2.37	1.74	.63
ξ UMa	.129	19.7	59.86	2.13	.98	1.15
α Cen A, B	.756	23.2	80.09	1.92	1.06	.86
ξ Boo	.142	34.4	149.95	1.81	.96	.85
ζ Her	.102	13.24	34.42	1.96	1.12	.84
—8°4352	.148	1.28	1.72	.70	..	..
Fu 46	.155	4.58	13.12	.56	.31	.25
HR 6416	.132	37.4	242	.89	..	..
HR 6426	.147	12.5	42.2	1.09	..	..
μ Her B, C	.109	11.8	43.0	.87	..	..
7° Oph	.197	23.14	87.85	1.61	.89	.72
61 Cyg	.294	83.5	720	1.12	.69	.43
Krü 60	.256	9.23	44.52	.40	.26	.14

* Prepared by Peter van de Kamp, Swarthmore College.

TABLE 859.—THE FIRST-MAGNITUDE STARS ARRANGED IN ORDER OF BRIGHTNESS *

Name	R A 1950 h m	Dec	m_v m	Sp	μ	θ	V km/s	p	M_{abs}
Sirius †	6 42.9	−16°39′	−1.6	A 0	1″32	203°	− 8	″378	+1.3
Canopus	6 22.8	−52 40	− .9	cF 0	.02	47	+20	.012	−5.5
α Centauri † ‡	14 36.2	−60 38	.1	dG 3	3.68	281	−22	.755	+4.5
Vega §	18 35.2	+38 44	.1	A 0	.34	36	−14	.122	+ .5
Capella ‖	5 13.0	+45 57	.2	G 1	.44	168	+30	.073	− .5
Arcturus	14 13 4	+19 27	.2	K 0	2.28	209	− 5	.091	.0
Rigel † ‖	5 12.1	− 8 15	.3	cB 8	.00	...	+24	.002:	−8.:
Procyon †	7 36.7	+ 5 21	.5	dF 4	1.25	214	− 4	.294	+2.8
Achernar	1 35.9	−57 29	.6	B 7	.10	110	+19	.032	−1.9
β Centauri † ‖	14 00.3	−60 08	.9	B 3	.04	217	−12:	.036:	−1.3:
Altair §	19 48.3	+ 8 44	.9	A 4	.66	55	−26	.206	+2.5
Betelgeuse ‖ §	5 52.4	+ 7 24	.9:	M 2	.03	75	+21	.013	−3.5
Aldebaran ‡	4 33.0	+16 25	.8	K 5	.20	160	+54	.058	− .4
α Crucis † ‡ ‖	12 23.8	−62 49	1.1	B 1	.04	235	− 8:	.03:	−1.5
Spica ‖	13 22.6	−10 54	1.2	B 2	.06	230	+ 2:	.011:	−2.6:
Pollux §	7 42.3	+28 09	1.2	G 8	.62	265	+ 3	.100	+1.2
Antares †	16 26.3	−26 19	1.2	M 1	.03	200	− 3	.020:	−2.3:
Fomalhaut	22 54.9	−29 53	1.3	A 3	.37	116	+ 6	.145	+2.1
Deneb §	20 39.7	+45 06	1.3	cA 2	.C0	...	− 5:	.002:	−7.:
Regulus † ‡	10 05.7	+12 13	1.3	B 8	.25	270	+ 3:	.042	− .6
β Crucis ‖	12 44.8	−59 25	1.5	B 1	.05	235	+20	.006:	−4.4:

* Prepared by W. Luyten, University of Minnesota. † Visual binary. ‡ Has distant companion. § Has an optical companion. The magnitude shown is the combined visual magnitude. ‖ Spectroscopic binary. m = magnitude, Sp = spectrum, μ = proper motion, θ = position angle, V = radial velocity, p = parallax, M = absolute magnitude.

TABLE 860.—STELLAR TEMPERATURES AND DIAMETERS *

Main sequence	m_v	*Sp*	*p*	M_v	*T*	*R*	*d*	μ	ρ
β Centauri	.9	*B* 3	″036	—1.3	21,000°K	11	″001	(25)	.018
ν Scorpii	4.3	*B* 3	.009	— .8	21,000	3.2	.0003	(5.2)	.16
β Aurigae A	2.8	*A* 0	.034	.6	10,700	2.4	.0008	2.2	.13
α Lyrae	.1	*A* 0	.122	.5	10,700	2.4	.003	(3.0)	.11
α Can Maj A	—1.6	*A* 0	.378	1.3	10,700	1.8	.006	2.4	.42
α Aquilae	.9	*A* 4	.206	2.5	8,800	1.4	.003	(1.7)	.6
α Can Min	.5	*dF* 4	.294	2.8	6,100	1.9	.006	1.1	.16
α Centauri A	.1	*dG* 3	.755	4.5	5,850	1.0	.007	1.1	1.1
70 Ophiuchi A	4.3	*dK* 0	.192	5.7	5,740	1.0	.002	.9	.9
61 Cygni A	5.6	*dK* 5	.298	8.0	4,300	.7	.003	(.45)	1.3
Krüger 60 A	9.8	*dM* 4	.256	11.8	3,180	.34	.0008	.26	9.
Barnard's Star	9.4	*dM* 5	.544	13.1	3,020	.16	.0008	(.18)	45:
Giants									
α Aurigae A	.2	*gG* 1	.073	— .5	5,150	12	.007	4.2	.0024
α Boötis	.2	*gK* 0	.091	.0	4,620	30	.023	(8)	.0003
α Tauri	.8	*gK* 5	.058	— .4	3,940	70	.034	(5)	1.4×10^{-5}
β Pegasi	2.2	*gM* 3	.016	—1.0	3,390	160	.025	(6)	1.5×10^{-6}
α Orionis	.9	*cM* 2	.017	—4.0	3,060	480	.048	(35)	3×10^{-7}
α Scorpii A	1.2	*cM* 2	.0095	—3.5	3,060	380	.042	(22)	5×10^{-7}
White dwarfs									
α Can Maj B	8.5	*F*	.378	11.4	7,500	.034	.00012	.96	5×10^{4}
40 Eridani B	9.4	*A*	.200	10.9	11,000	.018	.00004	.44	7×10^{4}
van Maanen's Star	12.3	*F*	.245	14.2	7,500	.009:	.00002	(.14)	10^{5}—10^{6}

Many of the data were taken from the reference given in footnote 277. The spectra, magnitudes, radii, parallaxes, and densities have been revised for some of the stars. The letters *A* and *B* denote the brighter and fainter components, respectively, of binary stars.

Apparent (visual) magnitude is denoted by m_v, spectral class by *Sp*, parallax in seconds of arc, *p*, absolute (visual) magnitude by M_v, radius in terms of the sun by *R*, apparent diameter in seconds of arc by *d*, mass in terms of the sun by μ, and density by ρ (in g/cm³).

* Prepared by Edith J. Tebo, Harvard College Observatory.

[277] Russell, Dugan, and Stewart, Astronomy, p. 740, Ginn & Co., 1926. Used by permission.

TABLE 861.—SPECTRUM TYPE AND MEAN VISUAL ABSOLUTE MAGNITUDE *

Type	Main sequence	Super-giants	Type	Main sequence	Giants	Super-giants	Sub-giants
O	—3.8	..	*F* 5	+ 3.7	+1.2	—4.2	..
B 0	—3.1	—5.4	*F* 8	+ 4.1	+ .8	—4.0	..
B 1	—2.6	—5.4	*G* 0	+ 4.4	+ .6	—3.8	..
B 2	—2.2	—5.3	*G* 2	+ 4.7	+ .6	—3.6	..
B 3	—1.7	—5.3	*G* 5	+ 5.1	+ .5	—3.2	+3.0
B 5	— .8	—5.2	*G* 8	+ 5.5	+ .5	—2.8	..
B 8	+ .2	—5.0	*K* 0	+ 5.9	+ .5	—2.6	+3.0
B 9	+ .4	—5.0	*K* 2	+ 6.3	+ .5	—2.3	..
A 0	+ .7	—4.9	*K* 5	+ 7.1	+ .2	—2.0	..
A 2	+1.2	—4.8	*K* 8	+ 7.7	.0	..	..
A 3	+1.5	—4.8	*M* 0	+ 8.4	— .2	—4.5	..
A 5	+1.7	—4.7	*M* 1	+ 9.0	..	..	..
A 8	+2.3	—4.5	*M* 2	+ 9.6	..	..	..
F 0	+2.6	—4.4	*M* 3	+10.4	..	..	..
F 2	+3.1	—4.3	*M* 4	+11.5	..	..	..
			M 5	+13.6	..	..	..

For Type *R*, $\overline{M} = -0.5$; and for Type *N*, $\overline{M} = -2.0$.

* Prepared by R. E. Wilson, Mount Wilson Observatory.

TABLE 862.—REDUCTION OF VISUAL TO BOLOMETRIC MAGNITUDE *

The bolometric corrections (B C) given in the table are added algebraically to visual magnitudes. From tables by G. P. Kuiper,[278] slightly revised for *O* and *B* stars by same author. The (effective) temperature, Te, scale of the *O* and early *B* stars is still to be regarded as provisional. The corrections for $O_5 - F_0$ stars are based on the stellar temperature scale and on theoretical spectral-energy curves. For $F_0 - M_5$ stars they are based on radiometric observations by Pettit and Nicholson.

	Main seq			Main seq		Giants (M = 0)		Supergiants (M = —4)	
Type	B C	T_e	Type	B C	T_e	B C	T_e	B C	T_e
O 5	—5.3:	100,000:	*F* 0	.0	6500	.0	6500	.0	6500
O 6	—4.8	70,000:	*F* 2	— .04	6100	— .04	6100	— .04	6100
O 7	—4.3	50,000	*F* 5	— .04	6100	— .08	5850	— .12	5720
O 8	—3.9	41,600	*F* 8	— .05	6050	— .17	5500	— .28	5150
O 9	—3.5	35,000	*G* 0	— .06	6000	— .25	5240	— .42	4830
B 0	—3.0	28,500	*G* 2	— .07	5900	— .31	5070	— .52	4650
B 1	—2.8	26,300	*G* 5	— .10	5770	— .39	4880	— .65	4480
B 2	—2.5	23,000	*G* 8	— .10	5770	— .47	4720	— .80	4330
B 3	—2.3	21,000	*K* 0	— .11	5740	— .54	4620	— .93	4240
B 4	—2.1	19,300	*K* 2	— .15	5580	— .72	4420	—1.20	4060
B 5	—1.9	17,800	*K* 3	— .31	5070	— .89	4260	—1.35	3940
B 6	—1.6	15,600	*K* 4	— .55	4600	—1.11	4120	—1.56	3780
B 7	—1.4	14,300	*K* 5	— .85	4300	—1.35	3940	—1.86	3590
B 8	—1.2	13,100	*K* 6	—1.14	4100	....		....	
B 9	— .9	11,600	*M* 0	—1.43	3880	—1.55	3800	—2.2	3420
A 0	— .7	10,700	*M* 1	—1.70	3700	—1.72	3680	—2.6	3230
A 1	— .6	10,150	*M* 2	—2.03	3540	—1.95	3560	—3.0:	3060
A 2	— .5	9,600	*M* 3	—2.4:	3320	—2.26	3390	—3.6:	2840:
A 3	— .4	9,000	*M* 4	—2.7:	3180	—2.72	3160	....	
A 5	— .3	8,500	*M* 5	—3.1::	3020	—3.4:	2920:		
A 7	— .2	7,900							
F 0	— .0	6,500							

* Prepared by G. P. Kuiper, Yerkes Observatory.
[278] Astrophys. Journ., vol. 88, p. 446, 1938.

TABLE 862A.—RUSSELL-HERTZSPRUNG DIAGRAM *

Absolute magnitudes (ordinates) of 3,915 stars of different spectrum types (abscissae) determined by the spectroscopic method by W. S. Adams and his associates (courtesy of Mount Wilson Observatory, 1932). The diagram shows distinctly the division of types *G*, and later, into giants (high-luminosity stars) and dwarfs (low-luminosity) with few intermediate stars. The curve simulates the mirror image of the figure 7, and with the addition of much new material confirms fully that first drawn by Russell in 1913.

The majority of the stars may be divided into dwarfs, giants, and supergiants (a few stars do appear to have luminosities intermediate between these classifications). The luminosity of the dwarfs decreases regularly with advancing spectral type (reduced surface temperature); it drops abruptly for the coolest. Among the giants the luminosity decreases until about class *F* 5 and then increases with decreasing temperature at least as far as the early subdivisions of class *M*. For supergiants, the luminosity does not appear to change appreciably with spectral class.

In the diagram, the concentration into vertical columns is purely an effect of rough spectral classification. Most of the stars on this diagram belong to Population Type I (Table 874). The white dwarfs occupy the lower left corner (Table 872).

Kuiper [279] has more recently derived the empirical mass luminosity relation for (1) the visual binaries, (2) some selected spectroscopic binaries, and (3) Trumpler's massive stars in clusters. His diagram is reproduced in figure 33. Morgan, Keenan, and Kellman [280] have presented a preliminary calibration of their luminosity classes in terms of visual absolute magnitudes, which includes *B* stars as well as subclasses (intermediates between giants and dwarfs and between giants and supergiants).

* Prepared by Edith J. Tebo, Harvard College Observatory.
[279] Astrophys. Journ., vol. 88, p. 472, 1938.
[280] An atlas of stellar spectra, p. 34, University of Chicago Press, 1943.

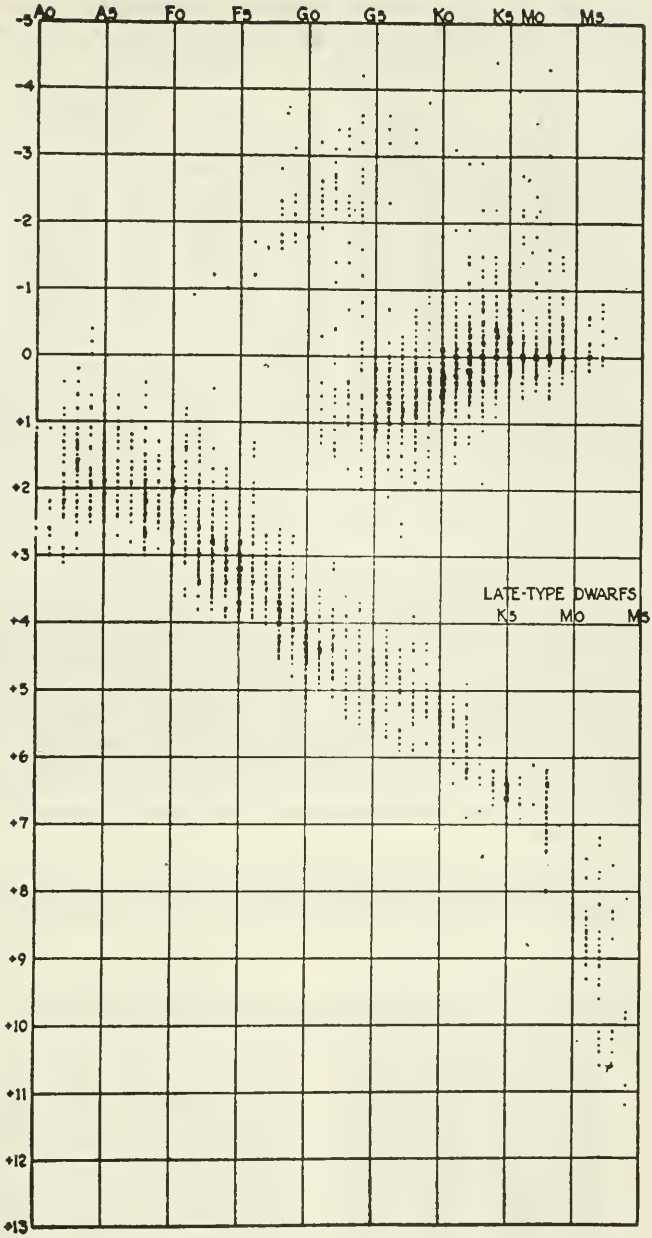

FIG. 32.—The Russell-Hertzsprung Diagram

TABLE 863.—LOG (NO. STARS)/(SQ. DEGREE) BRIGHTER THAN PHOTOGRAPHIC MAGNITUDE, *m*, AT STATED GALACTIC LATITUDES *

										Ratio Nos. successive magnitudes			Ratio Nos. at 0° ± 90°	
m	+90°	+40°	+20°	+10°	0°	−10°	−20°	−40°	−90°	+90°	0°	−90°	+90°	−90°
5.0	8.15	8.24	8.37	8.49	8.77	8.65	8.50	8.25	8.07				4.1	5.0
6.0	8.59	8.72	8.85	8.95	9.22	9.10	8.94	8.71	8.62	2.8	2.8	3.5	4.3	4.0
7.0	9.02	9.18	9.31	9.41	9.64	9.51	9.35	9.16	9.08	2.7	2.6	2.9	4.1	3.6
8.0	9.44	9.62	9.77	9.87	.09	9.93	9.79	9.60	9.50	2.6	2.8	2.6	4.5	3.9
9.0	9.86	.05	.21	.33	.55	.37	.23	.04	9.92	2.6	2.9	2.6	4.9	4.3
10.0	.25	.47	.65	.77	1.02	.82	.67	.47	.32	2.5	3.0	2.5	5.9	5.0
11.0	.63	.87	1.08	1.21	1.49	1.26	1.11	.89	.72	2.4	3.0	2.5	7.2	5.9
12.0	1.01	1.26	1.50	1.64	1.95	1.70	1.54	1.29	1.12	2.4	2.9	2.5	8.7	6.8
13.0	1.38	1.63	1.90	2.05	2.39	2.14	1.95	1.68	1.48	2.3	2.8	2.3	10	8.1
14.0	1.70	1.97	2.28	2.45	2.82	2.57	2.34	2.03	1.78	2.1	2.7	2.0	13	11
15.0	1.98	2.30	2.66	2.85	3.22	2.99	2.72	2.34	2.02	1.9	2.5	1.7	17	16
16.0	2.26	2.61	3.02	3.25	3.60	3.39	3.07	2.64	2.26	1.9	2.4	1.7	22	22
17.0	2.53	2.90	3.36	3.64	3.96	3.76	3.40	2.92	2.48	1.9	2.3	1.7	27	30
18.0	2.79	3.15	3.67	3.97	4.32	4.10	3.68	3.18	2.70	1.8	2.3	1.7	34	42
19.0										1.6	2.0			
20.0									Seares....	1.5	1.9			
21.0										1.4	1.9			

(Characteristic *8.* or *9.* means, of course, *—2.* or *—1.*)

For values averaged over all galactic longitudes see reference, footnote 281. An excess of stars, relative to the averages, between longitudes 230° and 50°, and a deficit elsewhere, reflect the eccentric position of the sun within the stellar system, which, in a first approximation, may be regarded as a greatly flattened spheroid. For more detailed values for both longitude and latitude see references, footnote 282. The Groningen numbers are generally larger than the Mount Wilson values, notably so in low galactic latitudes. This defference arises partly from the irregular influence of the highly complex structure of the stellar system and especially of the obscuring dust clouds in and near the Milky Way. Mount Wilson results were derived from counts of stars in small areas at and north of declination —15°; Groningen results from sample counts over the whole sky. The Groningen magnitude scale for faint stars south of declination —15° is, however, somewhat in doubt and may also affect the totals.

* Prepared by F. H. Seares, Mount Wilson Observatory.
[281] van Rhijn, Groningen Publ. No. 43, Table 6, 1929.
[282] van Rhijn, Groningen Publ. No. 43, Table 10; Seares and Joyner, Mount Wilson Contributions Nos. 346, 347; Astrophys. Journ., vol. 67, p. 24, 123, 1928; Publ. Astron. Soc. Pacific, vol. 40, p. 303, 1928.

TABLE 864.—STARS OF LARGE PROPER MOTION *

Star	*m*	*Sp*	*μ*	*θ*	Star	*m*	*Sp*	*μ*	*θ*
+ 4 : 3561	9.4	*dM* 5	10″.26	356°	W 489	14.8	*DC*	3″.92	252°
—44 : 612	9.0	*sdM* 0	8.74	131	Proxima Cen ...	11.5	*dM* :	3.85	282
+38 : 2285	6.4	*dG* 6	7.04	145	+ 5 : 1668	10.1	*dM* 5	3.76	171
—36 : 9694	7.3	*dM* 1	6.91	79	μ Cassiopeiae ..	5.3	*dG* 5	3.75	115
—37 : 9435	8.5	*dM* 3	6.07	113	α Centauri	.3	*dG* 3	3.68	281
R 619	12.6	*dM* 6	5.40	167	—15 : 4041/2 ...	9.3	*sdG* 6	3.68	235
61 Cygni	5.6	*dK* 5	5.21	52	—39 : 8920	6.6	*dM* 0	3.46	251
+36 : 2147	7.5	*dM* 2	4.78	187	L 726–8	12.4	*dM* 6*e*	3.38	80
W 359	13.8	*dM* 6	4.70	235	L 789–6	12.3	*dM* 6	3.27	46
ε Indi	4.7	*dK* 5	4.69	123	R 451	12.7	*sdK* 8	3.20	174
+44 : 2051	8.7	*dM* 1	4.49	282	—43 : 354	4.3	*dG* 5	3.15	76
o_2 Eridani	4.5	*dK* 0	4.08	213	R 578	14.1	*sdM* 2	3.06	152

m = magnitude, *Sp* = spectrum, *μ* = proper motion, *θ* = position angle.

Stars have been identified with their B.D. or C.P.D. numbers. In case of multiple stars the magnitudes and spectra of the brightest component are given. For further information on stars possessing large proper motions see references, footnote 283.

* Prepared by W. Luyten, University of Minnesota.
[283] Lick Obs. Bull. No. 344; Harvard Circ. 283; Publ. Cincinnati Obs. LO 18; Publ. Astronomical Obs. Univ. Minnesota, vol. 3, No. 1.

TABLE 865.—NUMBERS AND EQUIVALENT LIGHT OF THE STARS *

Photographic magnitude *m*	Number of stars	Equivalent no. 1st mag stars (photogr)	Totals to mag *m*	Photographic magnitude *m*	Number of stars	Equivalent no. 1st mag stars (photogr)	Totals to mag *m*
—1.6	Sirius	11	11	8.0— 9.0	40,600	40	258
— .9	α Carinae	6	17	9.0—10.0	116,000	46	304
.0	α Centauri	2	19	10.0—11.0	304,000	48	352
.0— 1.0	8	14	33	11.0—12.0	789,000	50	402
1.0— 2.0	24	15	48	12.0—13.0	2,000,000	50	452
2.0— 3.0	66	17	65	13.0—14.0	4,950,000	50	502
3.0— 4.0	188	19	84	14.0—15.0	11,500,000	46	548
4.0— 5.0	767	31	115	15.0—16.0	25,400,000	40	588
5.0— 6.0	2,000	32	147	16.0—17.0	56,000,000	35	623
6.0— 7.0	5,360	34	181	17.0—18.0	115,000,000	29	652
7.0— 8.0	14,800	37	218	18.0—∞	......	48	700

This table derived from van Rhijn's counts (Table 7 of reference 281) shows that to photographic magnitude 18.0 the total of starlight received is equivalent to 652 stars of photographic magnitude 1.0. If all the remaining stars are included, the equivalent addition is only 48 1st-magnitude stars, giving a total of 700, equal to about a hundredth part of full moonlight. The corresponding total of stars of visual magnitude 1.0 would be about 1,320, which agrees reasonably well with the equivalent total of 1,440 stars (zenith) found by van Rhijn from direct measurement of the visual brightness of the sky; or 1,674 stars outside the earth's atmosphere. Density of stellar radiation $= 0.8 \times 10^{-13}$ erg/cm³. Cosmic radiation density $= 1.3 \times 10^{-13}$ erg/cm³ (near the earth).

The number of stars in each magnitude interval is still increasing rapidly at $m = 18$, but the run in the numbers in the second column of the table indicates that somewhere about $m = 30$ the numbers begin to decrease and eventually to approach zero as the limit of the stellar system is reached. The extrapolated total number of stars in the system given by different investigations ranges from 30 to 100 billion. The great inherent uncertainty of this total is further increased by the unknown influence of interstellar absorption.

Practically all the stars visible to the naked eye lie within 1,000 parsecs of the sun, and most of them are more than 100 parsecs distant. In the vicinity of the sun, the majority of the stars lie within 200 or 300 parsecs of the galactic plane; but along this plane the star-filled region extends far beyond 1,000 parsecs in all directions, and may reach 30,000 parsecs in the great southern star clouds (Shapley).

* Prepared by F. H. Seares, Mount Wilson Observatory.

TABLE 866.—BRIGHT OR WELL-OBSERVED NOVAE *

Nova and year		Apparent magnitudes Max	Min	Duration 3 mags decline days	Distance parsecs	Absolute magnitudes Max	Min	Nebula radial expansion per year	Expansion velocities in km/sec (absorption lines) Principal	Diffuse enhanced	Orion
Aquilae	1918	—1.1	10.8v	8	430	—9.3	+2.6	1″0	+1500 [a]	—2200	—4000
T Aurigae	1891	3.8	14.8	100	800	—5.3	+5.7	.12	— 400	— 870	—1200
Carinae	1843	— .8	7.9	6000:	170 [b]	—7:‡	+1.7:	..	....	....	....
T Coronae B	1946 [c]	3.0	11:v	9	850	—7.0	+1:	..	—1100	—4360	....
Cygni	1920	2.0	15.5	16	1470	—8.9	+4.6	.09	— 725	—1400	—2500
Geminorum	1912	3.5	14.7	37	790 [d]	—6.4	+4.8	..	— 800	—1400	—2100
DQ Herculis	1934	1.4	15:v	100	230	—5.5	+7.5	.27	— 318	— 800	—1100
CP Lacertae	1936	2.1	15.3	9	1350	—8.6	+4.6	.25	—1500†	—3200	—3800
RS Ophiuchi	1933 [c]	4.3	11.0v	9	1150 [b]	—8.0‡	—1.3	..	Note	....	....
Persei	1901	.2	13:v	13	470	—8.4	+4:v	.4	—1300	—3500	—3700
RR Pictoris	1925	1.2	12.7	150	500	—7.3	+4.2	.17	— 320	— 750	—1500
CP Puppis	1942	.4	[17	7	500: [d]	—8:	[+8.5	..	—1000	....	....
RT Serpentis	1909 [e]	10.5	[16	8000:	3300 [b]	+3.6 [b]	..	..	small	....	....
T Pyxidis	1944 [c]	6.4	13.6	130	1370 [b]	—5.4 [b]	+1.6	..	— 940	—1800	—1900
Tauri	1054 [f]	—5:	15.9	...	1180	—16	+4.3	.20	—1100	....	....

* Prepared by D. B. McLaughlin, University of Michigan. a, Absorption velocities increased with time: N Aql, to —1700 km/sec; CP Lac, to —2500 km/sec. b, Absolute magnitude assumed; distance based on assumed absolute magnitude. c, Recurrent novae: T CrB; RS Oph, 1898; T Pyx, 1890, 1902, 1920. T CrB: distance based on spectroscopic parallax of class *M* companion. d, Nova Gem and CP Pup; distances based on strength of interstellar calcium lines. e, RT Serpentis reached maximum in 1919. f, Nova Tauri 1054; a super nova; now the Crab Nebula. Note on velocity of RS Ophiuchi: there was no system of absorption lines at the short-wavelength edge of the emissions as in other novae.

TABLE 866A.—MASS LUMINOSITY RELATION *

The mass-luminosity relation is shown in figure 33, which is based on data by G. P. Kuiper.[284] Dots and open circles represent visual and spectroscopic binaries, each component being shown separately. Crosses represent several visual binaries in the cluster of the Hyades. Squares represent the white dwarfs. The symbol ⊙ stands for the sun.

* Prepared by O. Struve, University of California, Berkeley.
[284] Astrophys. Journ., vol. 88, p. 472, 1938.

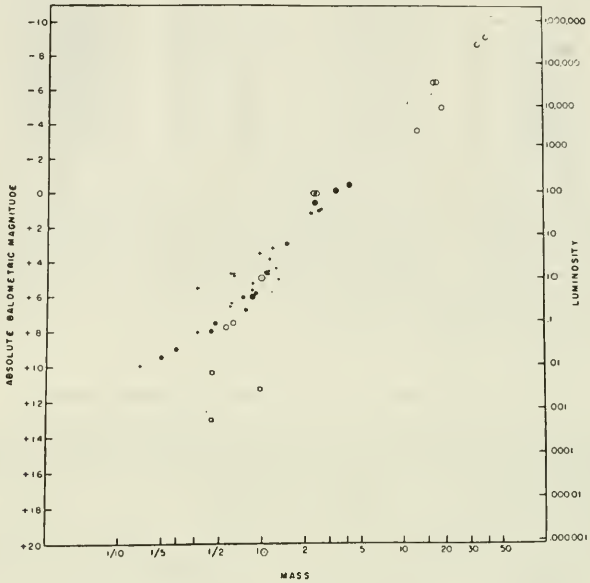

Fig. 33.—The mass luminosity relation for stars.

TABLE 867.—CLASSIFICATION OF NEBULAE

		Symbol	e. g.
I Galactic nebulae—	A Planetaries	P	N.G.C. 7662
	B Diffuse	D	
	(1) Predominantly luminous.	DL	N.G.C. 6618
	(2) " obscure .	DO	Barnard 92
	(3) Conspicuously mixed ...	DLO	N.G.C. 7023
II Extragalactic nebulae—	A Regular		
	(1) Elliptical .... 1 to 7 shows ellipticity	E_n	N.G.C. 3379 *E* 0 " 221 *E* 2 " 4611 *E* 5 " 2117 *E* 7
	(2) Spirals		
	(a) Normal spirals	S	
	(1) Early	Sa	N.G.C. 4594
	(2) Intermediate ...	Sb	" 2841
	(3) Late	Sc	" 5457
	(b) Barred spirals	SB	
	(1) Early	SBa	N.G.C. 2859
	(2) Intermediate ...	SBc	" 3351
	(3) Late	SBc	" 7479
	B Irregular	Irr	N.G.C. 4449

Extragalactic nebulae too faint to be classified, "*Q*"

Radiometric magnitude of any star = visual (or photographic) magnitude of a spectral class A^0 star giving the same radiometric deflection. If m_r, m_{pv}, and m_{pg} are, respectively, radiometric, photovisual, and photographic magnitude, then Color Index, $CI = (m_{pg} - m_{pv})$; heat index, $HI_{pv} = m_{pv} - m_r$; $HI_{pg} = m_{pg} - m_r$. Spectral class: Henry Draper, revised by D. Hoffleit (DH); by W. W. Morgan (WWM). All measures reduced to zenith at Mount Wilson; two reflections from fresh silver; zinc-antimony black thermojunction; rock salt window. Stars of known or suspected variability are rejected from this list.

All the stars were in both the Mount Wilson and Harvard observing programs.[285]

The reduction of the Mount Wilson and Harvard data to a common basis has been rather difficult. The following are the principal factors that differ between the Mount Wilson and Harvard observations.

(1) The Atmosphere.—There was more water vapor over Oak Ridge than Mount Wilson; hence, early-type stars would be too faint at Oak Ridge.

(2) The thermocouple blacking.—Probably the surfaces were equally "black" in the ultraviolet and visible regions; the Harvard surfaces were blacker in the infrared; hence, late-type stars would be too faint at Mount Wilson.

(3) The cell window.—Rock salt was used at Mount Wilson; fluorite was used at Harvard. These are equally good throughout the ultraviolet, visible, and infrared to the region of 6 to 8 microns. For longer wavelengths, rock salt is better. The effect of this difference is in the opposite direction to the thermocouple blacking in (2) above. However, the very small percentage of stellar energy beyond 8 microns and absorption bands in the earth's atmosphere means that the difference in the cell windows has a very much smaller effect than the thermocouple blacking and, therefore, (2) above dominates.

A systematic difference exists between the Mount Wilson and Harvard observations which follows a pattern predicted in accordance with factors (1) and (2) above. Therefore, corrections which are usually less than 0.1 magnitudes have been applied. The largest, 0.16 magnitudes, is for 51 Gem. This correction brings the two sets of data into better agreement but there remains an apparent difference in zero-point of about 0.13 magnitudes. Since it is impossible to determine which of these two sets of observations is in error, the mean of the Mount Wilson and Harvard data has been taken, corrected as indicated for factors (1) and (2) above. These mean values are the data given in the m_r column.

Star	Magnitude			Spectral class		Star	Magnitude			Spectral class	
	m_{pv}	m_{pg}	m_r	DH	WWM		m_{pv}	m_{pg}	m_r	DH	WWM
α And	2.11	2.08	2.12	B_9	....	51 Gem	4.85	...	2.17	M_6	....
β Cas	2.34	2.82	2.11	F_3	F_2 III	α CMi	.40	.83	.10	F_5	F_4 V
γ Peg	3.00	2.67	2.83	B_2	....	β Gem	1.13	2.31	.37	K_0	K_0 III
β And	2.07	3.94	.28	K_6	K_5 III	ε Leo	2.96	...	2.44	G_0	G_1 II
α Cet	2.54	4.47	.53	M_0	M_0 III	π Leo	4.52	...	2.77	M_2	....
α Per	1.78	2.43	1.47	F_3	F_5 I	β UMa	2.34	2.40	2.50	A_1	....
η Tau	2.90	2.92	2.86	B_5:	....	α UMa	1.70	3.09	1.02	G_7	K_0 III
α Tau	.77	2.70	—.80	K_5	K_5 III	α Cyg	1.24	1.40	1.17	A_{2p}	....
α Aur	.14	1.03	—.53	G_2	G_2 I	β Peg	2.25	4.39	.11	M_3	....
β Tau	1.68	1.52	1.66	B_8	....	α Peg	2.56	2.53	2.59	A_1	....

* Prepared by R. M. Emberson, Research and Development Board, Washington, D. C.

[285] Pettit and Nicholson, Astrophys. Journ., vol. 56, p. 295, 1922; vol. 68, p. 279, 1928; vol. 78, p. 320, 1933. Stern and Emberson, Astrophys. Journ., vol. 94, p. 412, 1941.

TABLE 869.—NONGALACTIC NEBULAE

Some 400 considered. Distribution of magnitudes appears uniform throughout sequence. For each stage in the sequence the total magnitude (M_T) is related to the max diameter (d) by the formula: $M_T = C\text{-}5 \log d$. When minor diameter is used, C approx constant throughout sequence ($C = 10.1$). Mean absolute visual magnitude —15.2. The statistical expression for distance in parsecs is $\log D = 4.04 + 0.2\, M_T$. *Masses* appear to be of the order of $2.6 \times 10^8 \times$ our sun's. Apparently nebulae as far as measured are distributed uniformly in space, one to 10^{17} parsecs^3 or 1.5×10^{-31} in cgs units.

Corresponding radius of curvature of the finite universe of general relativity is of order of 2.7×10^{10} parsecs, about 600 times the distance at which normal nebulae can be detected with the Mount Wilson 100-inch reflector.

TABLE 870.—VARIABLE STARS, GENERAL CHARACTERISTICS * [286]

The task of cataloging and naming variable stars was delegated in 1946 by the International Astronomical Union to the Sternberg Astronomical Institute in Moscow. The 1948 General Catalogue lists 10,912 variable stars; a supplement lists 265 additional variables discovered in 1948. Several thousands of variable stars in globular clusters, in the Magellanic Clouds, and in the nearest galaxies are not included in this catalog, nor are thousands of stars whose variability has been announced, but which are not officially recognized pending confirmation. The total number of variable-star discoveries announced until 1950 probably amount to 20,000.

Classification.—Variable stars, with the exception of eclipsing binaries (see Table 879), can be divided roughly into three major groups: (1) *Pulsating stars.* The variables of this group are all giants, located above the main sequence in the Russell diagram. (2) *Explosive stars.* The variables of this group are, as far as is known, dwarfish; located below the main sequence in the Russell diagram. (3) *Erratic variables,* whose light, fluctuations, mostly of an erratic nature, are produced by external causes (nebulosity) or by peculiar phenomena in their atmospheres.

Pulsating stars.—*Cepheids.* Usually divided into cluster-type variables, with periods shorter than one day, and classical Cepheids, with periods longer than one day, although at least five subgroups are indicated.

Cluster-type variables belong to Population II, have spectra ranging from *A* to *F*, absolute magnitudes close to zero; most variables found in globular clusters belong to this group. Periods range from $0^d.061$ (CY Aquarii) to $1^d.35$ (a star in the ω Centauri cluster), with the greatest concentration around $0^d.53$. Typical variable: RR Lyrae ($7^m.1 - 8^m.0$; period $0^d.57$; spectrum $A\,2 - F\,0$). About 1,700 galactic objects and 600 stars in globular clusters are known to belong to this group.

Classical Cepheids belong to Population I, have spectra ranging from *F* to *K*, with marked dependence on period, and intrinsic luminosities increasing with the period (period-luminosity law) from $-0^M.5$ to -3^M (absolute visual magnitudes). Periods range from $1^d.13$ (BQ Coronae Austrinae) to $45^d.2$ (SV Vulpeculae), with the greatest concentration around $2^d.7$. Typical variable: δ Cephei ($3^m.8 - 4^m.6$, period $5^d.37$, spectrum $F\,5 - G\,2$). About 500 galactic stars and 2,500 stars in the Magellanic Clouds and other extragalactic systems are known to belong to this group.

For both cluster-type and classical Cepheids the shape of the light curve is a function of the period; the rise to maximum is always faster than the decline. Average visual amplitude $0^m.75$; photographic amplitudes 50 percent larger. Radial-velocity curves are in phase with light curves (maximum approach at maximum light); Average amplitude 30–40 km/sec.

Long-period variables. Typical variable: *o* (Mira) Ceti ($2^m.0 - 10^m.1$; period 331^d; spectrum *M 6e*). Characterized by very large amplitudes (from 4 to 10 magnitudes, visual), late spectra (*M, S, R, N*) with bright hydrogen emission lines near maximum light, unstable light curves and periods ranging from 120^d (W Puppis) to 1379^d (BX Monocerotis). Greatest concentration of periods around 275^d. Long-period variables seem to fall into two major groups, whose periods overlap to a great extent. Stars of the first group have nearly symmetrical light curves with moderate amplitudes and periods ranging from 120^d to 450^d; they seem to belong to Population II. Stars of the second group have strongly asymmetrical light curve (rise faster than decline), large amplitudes and periods upward of 200^d; they seem to belong to Population I.

The enormous visual (and photographic) amplitudes are accounted for by a shift in the effective wavelength of the radiation with phase and by the formation of strong absorption bands at minimum light in the visual region of the spectrum. The total (bolometric) radiation has an amplitude of only one magnitude. Absolute bolometric magnitudes near —4. About 2,600 stars are known to belong to this group.

Semiregular red variables. Typical variables: Af Cygni ($6^m.3 - 8^m.0$; period 89^d; spectrum *M* 6). Spectra similar to those of long-period variables, except for much weaker, or entirely absent, hydrogen emission lines. Amplitude mostly comprised between 1 and 3 magnitudes (both visual and photographic). Light curves very irregular, often erratic; periods ranging from 42^d (TX Tauri) to 810^d (S Persei), but mostly comprised between 100^d and 200^d; several unrelated periods often occur in the same star and for many variables periods have only a statistical significance. Then mean brightness often changes slowly, with cycles of 1,000–2,000 days. Absolute visual magnitudes high, between 0 and —4. Their galactic distribution suggests Population II. Total number of recognized variables 600.

RV Tauri stars. Typical variable: RV Tauri ($8^m.7 - 11^m.8$; period $39^d.3$; spectrum *K* IV). Spectra Cepheid-like, but light curves similar to those of the preceding group. Deep and shallow minima often alternate. Periods (intervals between two successive

* Prepared by L. Jacchia, Massachusetts Institute of Technology.
[286] Kukarkin, B. V., and Parenago, P. P., Fizičeskie Peremennye Zvjozdy, 1937; Gaposchkin, C. P., and Gaposchkin, S., Variable stars, 1938; Campbell, L., and Jacchia, L., The story of variable stars, 1941.

(*continued*)

TABLE 870.—VARIABLE STARS, GENERAL CHARACTERISTICS (concluded)

minima, irrespective of principal and secondary) range from $16^d.5$ (SX Centauri) to 73^d (R Scuti). Galactic distribution suggests Population I. Only 60 stars can be safely assigned to this group.

Explosive stars.—*U Geminorum stars.* Typical variable: U Geminorum ($8^m.8$ — $14^m.0$; average cycle 97^d). Characterized by long permanence at minimum light, interrupted by brief, sudden explosions which bring the star almost always to the same maximum magnitude; the time between explosions might vary as from 1 to 4 for an individual star, but the average length of cycles over long periods of time are constant for each star. Average cycle length ranges from 13^d (AB Draconis) to 340^d (AW Geminorum). A few stars undergo temporary spells of continuous, irregular fluctuations. The amplitude increases from 3 magnitudes for short-cycle stars to 5 magnitudes for long-cycle stars. Spectra are of early type and peculiar; hydrogen lines in emission at minimum in absorption at maximum galactic concentration low for short-cycle variables, greater for long-cycle ones. Group numbers about 70 stars.

Z Camelopardalis stars. Typical variable: Z Camelopardalis ($10^m.5$ — $13^m.3$; average cycle $22^d.1$). Similar to the preceding, but with shorter minima and smaller amplitudes; erratic variation is the rule rather than the exception: Less than a dozen stars are known of this type.

Novae, repeating novae, and novaelike stars. Novae are stars that suddenly blaze up with startling rapidity and then gradually fade out again. For data on bright or well-observed novae see Table 866. A repeating (or recurrent) nova, such as T Pyx, has several outbursts, any one of which would have identified it as a nova. A novalike star, e.g., Z Andromeda, from time to time shows novalike characteristics with the formation of a shell spectrum and displaced absorption lines and later emission lines. Nebular lines are often associated with these objects.

Erratic variables.—*R Coronae Borealis stars.* Supergiants with *G* and *R* spectra and an abnormal abundance of carbon in their atmospheres. For long periods of time (often years) the light remains constant at maximum. At entirely irregular intervals the light is dimmed, probably by a carbon veil, with resulting fluctuations which may reach 9 or 10 magnitudes. Typical stars: R Coronae Borealis (variable from $5^m.8$ to $15^m.0$), RY Sagittarii (variable from $5^m.9$ to $15^m.0$ and probably fainter). Only 23 stars are known to belong to this type.

Variables associated with nebulosities. Stars in gaseous nebulae of the diffuse or of the cometary type, or even in dark nebulae, often show erratic variations with various amplitudes and speeds. At least three subtypes are indicated, typified by the following stars: T Orionis ($9^m.6$ — $11^m.9$; rapid; often constant at maximum); R Monocerotis (10^m — 14^m; slow); RW Aurigae ($9^m.0$ — $13^m.5$; very rapid, no constant light at any time). About 200 stars can be attributed to one or the other of these groups.

P Cygni and Be Stars. These early-type giants are normally quiescent, but occasionally some of them undergo slow fluctuations of moderate amplitude (1^m — 4^m) which last over a series of years. Typical: P Cygni (3^m — 6^m), active in the 17th century; γ Cassiopeiae ($1^m.6$ — $3^m.0$), active after 1936.

TABLE 871.—VISUAL BINARY STARS *

A. Visual binary stars are *cataloged* as follows:

1. "New General Catalog of Double Stars within 120° of the North Pole" (abbreviated: *ADS* = Aitken Double Stars), by R. G. Aitken, Carnegie Inst. Washington Publ. 417, 1932 (2 vols.); contains 17,180 objects.
2. *ADS* is the successor to *BDS* = "A General Catalog of Double Stars within 121° of the North Pole," by S. W. Burnham, Carnegie Inst. Washington Publ. 5, 1906 (2 vols.); this catalog contains 13,665 pairs. About one-third of these (mostly wide objects) are not repeated in *ADS*.
3. *SDS* or "Southern Double Star Catalog," from —19° to —90° declination, by R. T. A. Innes, B. H. Dawson, and W. H. van den Bos, Union Observatory, Johannesburg, South Africa, 1927 (4 vols.).
4. Many *wide* double stars of interest are contained in "Measures of Proper Motion Stars," by S. W. Burnham, Carnegie Inst. Washington Publ. 168, 1913.

B. A full discussion of *mass determinations* of visual binary stars is found in "The Masses of the Stars with a General Catalog of Dynamical Parallaxes," by H. N. Russell and C. E. Moore, Univ. Chicago Press, 1940.

C. *Orbits* of visual binaries are listed in W. H. Finsen, "Second Catalog of Orbits of Visual Binary Stars," Union Obs. Circ. 100, 1938. Supplementary orbits are found in later Union Observatory Circulars and in the Astronomical Journal.

* Prepared by G. P. Kuiper, Yerkes Observatory.

Star	m_v	CI	Sp	μ	p	M_v	r ☉ = 1	ρ cgs
		m				m		
V Ma 1	12.3	+.69	DF	2″.98	″245	14.2	.009:	10^5—10^6
o_2 Eridani B	9.4	.0:	DA	4.08	.200	10.9	.018	7×10^4
Sirius B	8.5	..	DF	1.32	.378	11.4	.034	5×10^4
He 3	12.0	—.80	DB	.90	.066	11.1	.002:	10^6—10^7
LDS 275 A	14.7	+.15	DC	.35	...	...	.012:	10^5—10^6
LDS 275 B	15.0	+.15	DC	.35	...	...	.012:	10^5—10^6
L 39–44	17.2	+.2:	...	.57	...	...	.005:	10^6
W 489	14.8	+.77	DC	3.92	.129	15.4	.012:	10^5—10^6
LDS 678 A	12.0	—.14	DA	.20	...	...	.014	10^5

p = parallax, μ = proper motion, Sp = spectrum, m = magnitude, M = absolute magnitude.

A representative selection of white dwarfs is given above, including the two stars for which the masses are known (o_2 Eri B and Sirius B), the bluest white dwarf (He 3), the reddest degenerate star (W 489), the only known double white dwarf (LDS 275), the faintest known white dwarf (L 39-44) and a typical example of a white component of red-white dwarf double (LDS 678 which has a red component of 13.7 vis with a color index of +1.81).

The values given for the radii and the densities (ρ) are in most cases very uncertain estimates based on very approximate parallaxes and estimated masses.

* Prepared by W. Luyten, University of Minnesota.

TABLE 873.—LOW-DENSITY STARS, GIANTS *

Star	Type	Visual abs mag	Density sun = 1	Radius sun = 1	Mass sun = 1
α Orionis	cM 2	—4.0	3×10^{-7}	480	(35)
α Scorpii A	cM 2	—3.5	5×10^{-7}	380	(22)
β Pegasi	gM 3	—1.0	1.5×10^{-6}	160	(6)
α Tauri	gK 5	— .4	1.4×10^{-5}	70	(5)

* Prepared by W. S. Adams, Mount Wilson Observatory.

TABLE 874.—GIANT AND DWARF STARS *

The table gives a list of typical supergiants, giants, and main-sequence stars. The relations between the absolute magnitudes and spectral types of the stars are conspicuous and complicated. Along the main sequence M (visual) falls very rapidly from about —4 for class O to +14 for M 6. For identical spectra, the scatter about the mean is of the order of $\pm1^m$. The normal giants form a sequence with M ranging from about 0 for class G 2 to —1.5 for M 8 with a somewhat greater scatter. Supergiants, with M from —4 to —7, are found sparingly in all spectral classes. The white dwarfs, of which nearly 100 are now known, form a widely separated group with spectra from A (or perhaps B) to G and with M from +10 to +15. Subgiants, one or two magnitudes fainter than the normal giants, are recognizable and the existence of other sequences is indicated by recent precise work.

The above discussion applies to stars of Population Type I, which is found in many parts of the galaxy, the arms of spiral nebulae, and other regions where absorbing interstellar material is present. Population II, in regions far from such matter, includes no supergiants or bright blue stars and the relation of the sequences are different. This type is found in the globular clusters, the elliptical nebulae, and the central regions of spiral nebulae and the galaxy. Both types occur near the sun.

The majority of the stars visible to the naked eye are giants, since these, being brighter, can be seen at much greater distances. Classes F and G comprise the greatest percentage of dwarf stars among those visible to the eye. The dwarf stars of classes K and M are actually much more numerous per unit of volume, but are so faint that few of the former, and none of the latter, are visible to the naked eye.

* Prepared by R. E. Wilson, Mount Wilson Observatory, and E. M. Janssen, Harvard College Observatory.

(*continued*)

Typical supergiants, giants, and main-sequence stars

Mount Wilson type	Star	Boss	Vis mag	1950 h m	1950
cB 0	ε Ori	1370	1.8	5 33.7	− 1°14′
gB 0	κ Ori	1435	2.2	5 45.4	− 9 41
dB 1	η Ori	1301	3.4	5 22.0	− 2 26
dB 3	η Aur	1204	3.3	5 03.0	+41 10
cB 5	η CMa	1934	2.4	7 22.7	−29 12
gB 5	δ Per	838	3.1	3 39.4	+47 38
dB 5	τ Her	4162	3.9	16 18.2	+46 26
cB 8	β Ori	1250	.3	5 12.8	− 8 15
gB 8	β Tau	1304	1.8	5 23.1	+28 34
dB 9	α Peg	5944	2.6	23 02.3	+14 56
gA 0	δ Cyg	5048	3.0	19 43.4	+45 00
dA 1	α Lyr	4722	.1	18 35.2	+38 44
cA 2	α Cyg	5320	1.3	20 39.7	+45 06
dA 2	α CMa	1732	1.6	6 42.9	−16 39
gA 5	β Tri	482	3.1	2 06.6	+34 45
dA 5	β Ari	428	2.7	1 51.9	+20 34
gA 7	γ Boo	3722	3.0	14 30.1	+38 42
dF 0	γ Vir	3307	2.9	12 39.1	− 1 11
gF 2	β Cas	12	2.4	0 06.5	+58 52
dF 3	α CMi	2008	.5	7 36.7	+ 5 21
cF 5	α Per	772	1.9	3 20.7	+49 41
Df 5	γ Ser	4055	3.9	15 54.1	+15 49
cF 8	γ Cyg	5229	2.3	20 20.4	+40 06
gF 8	ε Hya	2354	3.5	8 44.1	+ 6 36
dF 8	β Vir	3105	3.8	11 48.1	+ 2 03
dG 0	δ Tri	514	5.4	2 14.0	+34 00
gG 1	α Aur	1246	.2	5 13.0	+45 57
cG 2	GC 10756	2099	4.4	7 54.7	−22 45
gG 5	γ Hya	3449	3.3	13 16.2	−22 55
dG 5	κ Cet	752	5.0	3 16.7	+ 3 11
cG 8	ε Gem	1717	3.3	6 40.8	+25 11
gK 0	α Boo	3662	.2	14 13.4	+19 27
dK 0	70 Oph	4571	4.3	18 02.9	+ 2 31
cK 5	ξ Cyg	5431	3.9	21 03.1	+43 44
gK 5	α Tau	1077	1.1	4 33.0	+16 25
dK 6	61 Cyg A	5433	5.6	20 04.7	+38 30
dM 0	61 Cyg B	5434	6.3	20· 04.7	+38 30
gM 0	β And	259	2.4	1 06.9	+35 21
cM 1	α Sco	4193	1.2	16 26.3	−26 19
cM 2	α Ori	1468	.9	5 52.5	+ 7 24
gM 2	α Cet	691	2.8	2 59.7	+ 3 54
dM 2	GC 15183	2935	7.6	11 .6	+36 18
cM 5	α Her	4373	3.6	17 12.4	+14 27
gM 5	56 Leo	2915	6.0	10 53.4	+ 6 27
dM 5	GC 923	....	9.2	15 16.9	− 7 32

TABLE 875.—TEMPERATURE IN INTERSTELLAR SPACE * [287]

Because interstellar matter is far from being in thermodynamic equilibrium, the temperature of space will depend on the measuring process used.

Temperature from energy density of starlight.........	3°K
Color temperature of starlight........................	10,000 — 15,000°K dilution factor 10^{-14}
Temperature of gas (kinetic)	
H I region (hydrogen neutral)	60°K
H II region (hydrogen ionized)	10,000°K
Temperature of grains (internal energy)	20°K

* Prepared by B. Donn, Harvard University.

[287] Dunham, Proc. Amer. Philos. Soc., vol. 81, p. 277, 1939; Eddington, Proc. Roy. Soc. London, vol. A 111, p. 424, 1926; Spitzer, Astrophys. Journ., vol. 107, p. 6, 1948; vol. 109, p. 337, 1949; vol. 111, p. 593, 1950; van de Hulst, Rech. Astron. Obs. Utrecht, vol. 11, pt. 1, 1946.

TABLE 876.—MOTIONS OF THE STARS *

The motions of the stars show various well-marked features, of which the ellipsoidal distribution and the asymmetry are a consequence of the rotation of the galaxy; the significance of certain other features is not yet fully understood. If we assume the circular velocity around the galactic center (Table 828) as our origin, and plot the individual motions of the stars of any group as vectors from this origin, the ends of these vectors do not form a spherical distribution (as they would if the motions of the stars were at random) but rather an elongated distribution which is more or less asymmetrical and in which the area of highest concentration of the vector points is centered about the origin. If for the moment we ignore the asymmetry, the distribution may be characterized as roughly ellipsoidal and the approximate extent and shape of the distribution may be inferred from the dispersions of the velocity components along each of the three principal axes, σ_a, σ_b, and σ_c, in km/sec.

Spectral group [288] (main sequence)	σ_a	σ_b (km/sec)	σ_c	$\overline{M}\sigma_c^2$
A 0 to *A* 9	17	12	8½	180
F 0 to *F* 9	24½	16	12½	250
F 5 to *G* 0	27	17	13½	240
G 0 to *K* 6	32	16	16½	270
K 8 to *M* 5	37	25	17	170
(Giant branch)				
K 0 to *K* 9	23½	17	20	1300
M 0 to *M* 9	27	19:	19:	1800:

The direction of the *a*-axis is called the direction of the preferential motion; the two opposite points on the sky at the extremities of this axis are called the vertices. The *a*-axis for any group of stars is always nearly parallel to the plane of the galaxy. In the case of most groups of stars fainter than eighth magnitude, it appears that the *a*-axis is directed approximately toward the galactic center at longitude 325°. Among stars brighter than sixth magnitude the direction deviates from the direction of the galactic center toward greater longitudes and the deviation is most marked in the case of the *A* stars, for which the longitude of the vertex is close to 350°. In every case the *c*-axis is directed toward some point close to the galactic pole. The asymmetry referred to above characterizes the distribution of the components parallel to the *b*-axis. It is relatively slight when the dispersions are small as with the *A* stars, but becomes very pronounced in the case of groups with large dispersions, there being practically no large motions in the direction of the galactic rotation (longitude 55°).

The last column in the table contains the product of the mean stellar mass (in terms of the sun's mass) and the square of the dispersion along the *c*-axis. This quantity (analogous to kinetic energy) is practically constant for the various groups of the main sequence but is much larger for the giant branch.

The dispersions of velocities for the *B* stars, the *c* stars, and the Cepheids are of the order of 10 km/sec and difficult to determine accurately. For long-period variables the dispersions average about 50 km/sec and for the cluster-type variables 90 km/sec.

A general card catalog of radial velocities is kept at Mount Wilson Observatory. It now contains approximately 14,000 entries and will be published in the near future. The proper motions of all stars brighter than magnitude 7.0 and of many fainter stars may be found in the Albany General Catalog. The Transactions of the Yale Observatory contain the proper motions of many thousands of stars down to magnitude 9.5 and north of declination —30° and two catalogs of the Cape Observatory contain 40,000 proper motions in the zone —40° to —52°.

* Prepared by A. N. Vyssotsky, University of Virginia.
[288] Astron. Journ., vol. 53, p. 94, 1948.

TABLE 877.—STARS WITH LARGE SPACE VELOCITY GREATER THAN 200 km/sec, BASED ON PARALLAXES ≥ ″.005 * [289]

Star	Vis mag	Spec	Par	Rad vel km/sec	Apex l_a	Apex b_a	Vel km/sec
20 C 1321	10.8	*dG* 1	″.005	−178	163°	−29°	699
20 C 879	10.2	*dG* 2	.008	−138	190	+13	546
HD 134439	9.4	*dG* 2	.040	+295	273	− 3	521
HD 104800	9.3	*dG* 0	.006	+ 11	286	−17	488
HD 111980	8.3	*dF* 6	.009	+144	296	−26	472
HD 177095	9.4	*dG* 3	.009	+ 78	246	− 6	433
HD 160693	8.4	*dF* 8	.011	+ 40	299	+18	432
HD 224618	9.0	*dG* 6	.014	− 44	178	− 4	388
18 C 560	8.9	*dA* 8	.007	+338	187	0	380
HD 179626	9.3	*dF* 4	.007	− 71	264	+10	358
HD 6755	7.8	*dG* 0	.018	−325	248	+ 7	352
HD 64090	8.2	*sdG* 0	.038	−242	294	−15	345
20 C 825	10.2	*sdA* 4*p*	.009	−164	289	−18	324
HD 230409	10.0	*dG* 4	.009	− 19	288	− 1	316
HD 222766	9.7	*dG* 4	.009	− 98	188	+ 1	307
18 C 3002	8.4	*dK* 0	.023	− 26	162	−10	304
HD 103095	6.5	*sdG* 5	.108	− 98	299	−12	296
18 C 2348	9.1	*dF* 1	.008	−240	231	+ 2	276
HD 113083	8.2	*dF* 4	.014	+227	242	+18	275
HD 33793	9.2	*sdK* 2	.262	+242	243	− 8	273
20 C 58	12.3	*sdF* 3	.243	+263	97	−66	264
HD 134113	8.7	*dF* 8	.009	− 60	197	+21	263
HD 193901	8.2	*dF* 5	.027	−179	341	−13	258
18 C 756	9.2	*dF* 8	.031	−191	307	+12	243
HD 5223	8.8	*R* 3	.019	−234	275	+41	235
HD 148816	7.4	*dF* 7	.029	− 52	256	−16	223
HD 219175	8.3	*dF* 5	.011	− 32	173	−13	223
HD 102158	8.0	*dG* 0	.014	+ 24	162	+21	221
HD 74000	9.4	*dF* 5	.005	+200	238	+13	215
HD 25329	8.6	*dK* 0	.047	− 30	229	+ 8	214
HD 140283	7.3	*sdA* 5*p*	.033	−170	179	− 5	214
HD 219962	6.4	*gK* 1	.006	+ 23	161	−10	210
HD 219617	9.0	*sdA* 8*p*	.030	+ 6	293	− 6	202

* Revised by R. E. Wilson, Mount Wilson Observatory.
[289] Miczaika, G., Astron. Nachs., vol. 271, p. 265, 1940.

TABLE 878.—STARS WITH RADIAL VELOCITIES GREATER THAN 200 km/sec *

Star	Mag	Spec	A (1950) h m	D	Proper motion	Radial velocities km/sec
CD −29°2277	11.5	*sdF* 6	5 26.9	−29°56′	″41	+540
VX Her	10.5v	*A* 6	16 28.5	+18 28	.05	−390
HD 209621	8.8	*R* 3	22 02.1	+20 48	.01	−381
TU Per	12.1v	*A* 5	3 05.4	+53 00	.05	−380
GC 24145	6.9	*A* 4	17 44.6	+25 46	.06	−362
GC 5108	9.1	*dA* 8	4 11.6	+22 14	.54	+338
AR Her	10.4v	*A* 5	15 59.0	+47 04	..	−335
SZ Gem	11.5v	*A* 6	7 50.8	+19 24	..	+330
HD 6755	7.8	*dF* 5	1 06.5	+61 17	.62	−325
AC +25°67928	10.6	*sdF* 0	20 22.6	+24 54	..	−319
GC 20393	9.9	*sdG* 9	15 07.5	−16 13	3.69	+306
20 C 993	11.5	*sdG* 1	16 26.8	+44 48	.74	−301
S Lib	8.5v	*M* 2*e*	15 18.5	−20 13	.05	+294
GC 20394	9.4	*sdG* 2	15 07.5	−16 08	3.68	+292
S Car	6.9v	*K* 9*e*	10 07.8	−61 18	.12	+289
BD +30°2611	8.8	*dG* 2	15 04.8	+30 13	.02	−279
20 C 491	11.4	*sdG* 6	8 47.8	+ 7 49	.67	+276
BD +72°94	10.1	*sdF* 2	1 42.9	+73 13	.25	−266
20 C 58	12.3	*sdF* 3	0 46.5	+ 5 10	2.98	+263
20 C 1263	13.4	*sdM* 1	21 07.1	+59 33	2.14	−260
AC +64°4188	12.8	*sdA* 8	13 17.7	+64 26	.33	+252
20 C 1206	8.5	*dF* 5	20 23.8	+ 9 18	.56	−247
Luy Ye 24	12.5	*dM* 0	21 26.7	+11 58	.57	−247
HD 6833	7.1	*dG* 5	1 06.8	+54 28	.05	−244
GC 6369	8.5	*dK* 2	5 09.7	−45 00	8.72	+242
HD 64090	8.2	*dF* 8	7 50.4	+30 46	1.98	−240
18 C 2348	9.1	*dF* 1	17 36.1	+18 35	1.35	−240
RZ Lyr	11.9v	*A* 2	18 41.8	+32 45	.03	−240
HD 5223	8.8	*R* 3	0 51.6	+23 48	.14	−234
BD −17°484	9.4	*F* 1	2 29.1	−17 13	.43	+233
GC 17670	8.2	*dF* 4	12 58.8	−27 06	.55	+226
LPM 661	11.0	*sdF* 8	17 53.2	−16 23	.60	−216
HD 26	8.2	*sgG* 2*p*	0 02.8	+ 8 30	.26	−213
HD 74000	9.4	*dA* 9	8 38.5	−16 09	.63	+204
R Pic	6.7v	*M* 0*e*	4 44.8	−49 20	.05	+204

* Prepared by R. E. Wilson, Mount Wilson Observatory.

Star	Period days	App bright m	*Sp* 1	*Sp* 2	Radius R_1 (in ☉)	Radius R_2 (in ☉)	Mass M_1 (in ☉)	Mass M_2 (in ☉)	Ref [290]
V 444 Cyg ...	4.212	8.4	*O* 6	*WN* 6	13	...	35	20	a
AO Cas	3 523	5.8	*O* 8.5	*O* 8.5	16	10	31	29	b
γ Cyg	2.996	7.0	*O* 9	*O* 9	5.9	5.9	17.4	17.2	c
SZ Cam	2.698	7.0	*B* 0	(*B* 2)	12.7	5.6	36	10.3	d
AH Cep	1.775	6.6	*B* 0	*B* 0	6.1	6.1	16.5	14.2	e
δ Ori	5.733	2.4	*B* 0	(*B* 2)	17	10	26	10	f
V 478 Cyg ...	2.881	8.9	*B* .5	*B* .5	7.1	7.1	15.4	15.2	g
VV Cep	7430	6.6	*B*	*cM* 2	13	1200	33	47	h
V Pup	1.454	4.5	*B* 1	*B* 3	6.1	5.5	16.6	9.8	i
V 470 Cyg ...	1.873	8.7	*B* 2	*B* 2	6.0	7.2	13	11	j
μ' Sco	1.446	3.0	*B* 3	*B* 6	5.2	5.7	14.0	9.2	k
TT Aur	1.333	8.1	*B* 3	...	3.8	3.4	6.7	5.3	l
EO Aur	4.066	7.6	*B* 3	(*B* 8)	13	16	27	27	m
υ Her	2.051	4.6	*B* 3	*B* 7	4.4	4.4	6.8	5.4	n
CW Cep	2.729	7.6	*B* 3	*B* 3	4.5	4.0	10.0	9.8	j
AG Per	2.029	6.5	*B* 3	*B* 4	2.7	2.6	5.0	4.4	o
SX Aur	1.210	8.2	*B* 3.5	*B* 3.5	5.1	4.4	10.7	5.6	i
ξ Aur	972.15	6.6	*B* 6	*cK* 4	2.8	200	10	22	p
U CrB	3.452	7.6	*B* 5	(*A* 2)	3.4	5.5	6.4	2.4	q
U Oph	1.677	5.8	*B* 5	*B* 5	3.1	3.0	5.3	4.6	r
V 599 Agl ...	1.849	6.5	*B* 5	*B* 8	7.8	4.4	12	6.4	s
Z Vul	2.455	7.0	*B* 3	...	4.6	4.3	5.3	2.4	t
6 Agl	1.950	5.0	*B* 8	*B* 8	3.6	3.6	6.8	5.4	u
TX UMa	3.063	6.8	*B* 8	*gF* 2	2.1	3.4	2.8	.9	v
β Per	2.867	2.2	*B* 8	(*G*)	2.7	2.8	2.3	.6	w
AR Aur	4.135	5.8	*B* 9	*A* 0	1.8	1.8	2.6	2.3	c
β Lyr	12.908	3.4	*cB* 9	...	47	31	52	43	w
U Sge	3.381	6.4	*B* 9	*G* 2	4.5	5.8	6.7	2.0	x
GO Cyg	.718	8.3	*B* 9	...	2.0	1.4	1.6	1.3	y
β Aur	3.960	2.1	*A* 0	*A* 0	2.6	2.6	2.4	2.4	z
TV Cas	1.813	7.3	*A* 0	...	2.4	2.5	1.7	1.0	a 1
RX Her	1.779	7.1	*A* 0	*A* 0	2.3	1.8	2.1	1.9	b 1
MR Cyg	1.677	8.5	*A* 0	(*A* 0)	3.2	3.6	3.0	2.6	c 1
WX Cep	3.378	9.1	*A* 2	(*A* 5)	3	3	1.0	1.0	d 1
TX Her	2.060	8.3	*A* 2	*A* 2	1.6	1.6	2.0	1.8	e 1
CM Lac	1.605	8.3	*A* 2	*A* 8	1.3	1.7	2.0	1.5	f 1
UX Mon	5.905	8.7	*A* 3	*G* 2	1.8	6.6	3.4	1.5	g 1
RX Gem	12.208	8.5	*A* 4	*K* 0	2.2	5.5	3.1	.6	h 1
WW Aur	2.525	5.7	*A* 7	*A* 7	2.2	2.2	2.2	1.9	r
S Aut	.648	8.8	*A* 8	*A* 8	1.4	1.1	1.0	.9	i 1
Z Her	3.993	7.2	*F* 2	(*F* 2)	1.5	3.1	1.5	1.3	q
RS CV	4.798	8.0	*F* 4	*G* 8	1.6	5.3	1.9	1.7	j 1
VZ Hya	2.904	9.2	*F* 5	*F* 5	1.3	1.0	1.2	1.1	k 1
WUMa	.334	8.3	*F* 8	*F* 8	.8	.6	1.0	.9	l 1
WZ Oph	4.183	9.7	*G* 0	*G* 0	1.3	1.2	1.4	1.3	m 1
UV Leo	.600	8.5	*G* 0	*G* 2	1.1	1.2	1.3	1.2	n 1
RT And	.629	9.0	*G* 0	*K* 1	.8	1.4	1.5	1.0	o 1
ι Boo	.268	6.6	*G* 2	*G* 2	.7	.6	1.0	.5	p 1
WW Dra	4.630	8.8	*gG* 2	*gK* 0	4.8	8.3	3.5	2.5	q 1
Ar Lac	1.983	7.3	*G* 5	*K* 0	1.8	3.0	1.4	1.4	k 1
RT Lac	5.074	8.8	*G* 9	*K* 1	4.9	4.9	1.0	1.9	r 1
AH Vir	.408	9.7	*K* 0	*K* 0	1.3	.8	1.4	.6	s 1
YY Gem	.814	8.6	*M* 1	*M* 1	.6	.6	1.0	.9	t 1

* Prepared by Z. Kopal, Harvard College Observatory.

[290] References: a, Keeping, Publ. Dominion Astrophys. Obs., vol. 7, p. 349, 1947. b, Wood, Astrophys. Journ., vol. 108, p. 28, 1948. c, Dugan, Princeton Contr., No. 12, 1931. d, Kopal (unpublished). e,

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Huffer and Eggen, Astrophys. Journ., vol. 106, p. 313, 1947. f, Luyten-Struve-Morgan, Yerkes Publ., vol. 7, pt. 4, 1939. g, McDonald, Publ. Dominion Astrophys. Obs., vol. 7, p. 135, 1949. h, Geodicke, Michigan Publ., vol. 8, No. 1, 1939. i, Popper, Astrophys. Journ., vol. 97, p. 394, 1943. j, Gaposchkin, Astron. Journ., vol. 53, p. 112, 1948. k, Stibbs, Monthly Notices, Roy. Astron. Soc., vol. 108, p. 398, 1948. l, Joy and Sitterly, Astrophys. Journ., vol. 73, p. 77, 1931. m, Gaposchkin, Publ. Astron. Soc. Pacific, vol. 55, p. 192, 1943. n, Baker, Lick Obs. Bull., vol. 12, p. 130, 1926. o, Eggen (private communication). p, Kopal, Astrophys. Journ., vol. 103, p. 310, 1946. q, Shapley, Princeton Contr., No. 3, 1915. r, Huffer and Kopal, Astrophys. Journ. (in press). s, Gaposchkin, Harvard Bull., No. 917, 1943. t, Baker, Laws Bull., No. 2, p. 173, 1916. u, Wylie, Astrophys. Journ., vol. 56, p. 232, 1922. v, Huffer and Eggen, Astrophys. Journ., vol. 105, p. 217, 1947. w, Kopal, Astrophys. Journ., vol. 93, p. 92, 1941. x, Joy, Astrophys. Journ., vol. 71, p. 336, 1930. y, Pierce, Astron. Journ., vol. 48, p. 113, 1939. z, Piotrowski, Astrophys. Journ., vol. 108, p. 510, 1948; Smith, Astrophys. Journ., vol. 108, p. 504, 1948. a 1, McDiarmid, Princeton Contr., No. 7, 1924. b 1, Wood, Astrophys. Journ., vol. 110, p. 465, 1949. c 1, Fracastaro, Arcetri Publ., vol. 55, p. 37, 1937. d 1, Sahade and Cesco, Astrophys. Journ., vol. 102, p. 128, 1945. e 1, Baker, Laws Bull., No. 31, 1921. f 1, Wachmann, Astron. Journ., vol. 259, p. 323, 1936. g 1, Struve, Astrophys. Journ., vol. 106, p. 255, 1947. h 1, Gaposchkin, Astrophys. Journ., vol. 104, p. 376, 1946. i 1, Joy, Astrophys. Journ., vol. 64, p. 293, 1926. j 1, Sitterly, Princeton Contr., No. 11, 1930. k 1, Wood, Princeton Contr., No. 21, 1946. l 1, Huffer, Astrophys. Journ., vol. 79, p. 369, 1934. m 1, Gaposchkin, Harvard Bull., No. 907, 1938. n 1, Gaposchkin, Astrophys. Journ., vol., 104, p. 370, 1946. p 1, Eggen, Astrophys. Journ., vol. 108, p. 15, 1948. q 1, Plant, Diss. Leiden, 1939. r 1, Fowler, Astrophys. Journ., vol. 52, p. 261, 1920. s 1, Chang, Astrophys. Journ., vol. 107, p. 96, 1948. t 1, Kuiper, Astrophys. Journ., vol. 88, p. 456, 1938.

TABLE 880.—SPECTROSCOPIC BINARY STARS *

These binary systems were discovered and investigated by measuring the Doppler displacements of the spectrum lines. All except the widest systems are too close to each other to be observed as double stars through the telescope. The data given are from J. H. Moore's "Fifth Catalogue of Spectroscopic Binaries."[201] In the table a designates the semimajor axis of the orbit in kilometers and refers to the center of gravity of the system; i is the inclination of the orbit plane to the plane of the sky; and m designates the mass of each component. When both components of a binary system are bright enough to record their spectral lines, individual mass functions can be derived and these are shown in column 8. When only the spectrum of one star is visible a more complicated mass function is obtained involving the total mass of the system and the mass ratio. Several systems in the table are eclipsing stars and for them the inclination is nearly 90°. Hence for them the quantity $\sin^3 i$ in columns 8 and 9 is nearly equal to 1.

Star	Mag	Class	Period days	Eccentricity	Orbital velocity	$a \sin i$ 10^6 km	$m_1 \sin^3 i$ $m_2 \sin^3 i$	$\frac{m_2{}^3 \sin^3 i}{(m_1+m_2)^2}$
13 Ceti A	5.6	*F* 7	2.08	.1	37	1.06	....	.01
13 Ceti AB	5.2	...	6.91 yr	.7	...	....	....	...
α Ursa Minoris	2.5	*F* 7	29.6 yr	.6	4	466	....	.04
ε Aurigae	3.1	*F* 2	27.1 yr	.3	16	2014	....	3.34
ζ Turigae	4.9	*K* 4+*B*	973	.4	24	294	....	1.03
α Aurigae	.2	*G* 1	104	.02	26 32	37 46	1.19 .94	... ...
VV Orionis ab	5.3	*B* 2	1.49	.00	132	2.7	....	.36
VV Orionis abc	..	...	120	.3	13	20.5	....	.02
β Aurigae	2.1	*A* 0	4.0	.00	109	5.9	....	2.21
29 Canis Majoris	4.5	*O* 7	4.39	.06	216	13.0	....	4.60
† α¹ Geminorum	2.8	*A* 8	2.93	.00	31.9	1.28	....	.010
† α² Geminorum	2.0	*A* 3	9.21	.50	12.9	1.42	....	...
† α¹ + α² Gem	..	...	340 yr	.43	...	....	....	...
† YY Gem	9.0	*M* 1	.81	.00	114 127	1.28 1.42	.63 .57	... ...
V Puppis	4.1	*B* 1	1.45	.00	199 342	3.98 6.84	15.12 8.80	... ...
W Ursae Majoris	8.3	*F* 8	.33	.00	134 188	.61 .86	.67 .48	... ...
α Virginis	1.2	*B* 2	4.01	.10	127 202	6.96 11.10	8.97 5.63	... ...
θ Aquilae	3.4	*B* 9	17.12	.61	51 64	9.5 11.9	.75 .60	... ...
Y Cygni	7.0	*O* 9	3.00	.14	244 241	10.0 9.9	17.2 17.4	... ...

* Prepared by O. Struve, University of California, Berkeley.
[201] Lick Obs. Bull. No. 521, 1949.
† System of Castor.

TABLE 881.—PROPERTIES AND CLASSIFICATION OF STAR CLUSTERS *

Star clusters fall into two distinctly different types:

Globular.—Typical, Messier 13; open, Messier 4; elongated, Messier 19. Have strong central condensations, rich in faint stars. Scattered widely in latitude, restricted in longitude. Many variables—nearly 1,300 in 62 clusters. Radial velocities > 100 km/sec. All more than 5,000, and one-third more than 50,000 light-years away. Very few new ones found—about 100 known. Very definitely part of galaxy. Although concentrated toward its plane, only 2 within 4° of it (obstruction by interstellar dust clouds). Diameters about 35 parsecs. Many stars, tens and hundreds of thousands. Many giants and supergiants with maximum luminosity about —2.5.

Galactic.—Very varied: rich, *M* 11; irregular, *M* 35; nebulous, Pleiades; accidental, *M* 103. Almost exclusively in Milky Way, all longitudes; apparently no variables. Radial velocities rarely > 40 km/sec, generally less. Almost all less than 4,000 light-years distant. Almost exclusively in galactic region devoid of globulars. Tens and hundreds, rarely thousands of stars. Hyades type, yellow stars as dominant as *A* type. Pleiades type, almost all *B*'s and *A*'s, on Russell's main sequence.

* Prepared by H. Shapley, Harvard University.

Part 1.—Globular star clusters

This table contains those with galactic latitudes ⋝ 20°, for which space absorption can be evaluated and distance correctly estimated (also the giant cluster Omega Centauri in lower latitude).[292]

NGC	RA (1900) h m	Dec	Galactic Long	Galactic Lat	Apparent magnitude	Distance (kiloparsecs)	Absolute magnitude	No. of variables
104 (47 Tuc)	0 19.6	—72°38′	272°	—45°	(4.5)	7.6	—10.2	8
288	0 47.8	—27 08	157	—88	8.96	14.5	— 6.8	2
362	0 58.9	—71 23	268	—47	8.0	10.0	— 7.3	14
1261	3 9.5	—55 36	237	—51.5	9.5	22	— 7.2	0
1851	5 10.8	—40 09	212	—34.5	7.72	14	— 8.1	3
2419	7 31.4	+39 06	148	+26	11.51	56.2	— 7.7	36
4147	12 5.0	+19 06	226	+79	11.01	20.0	— 5.5	4
4590 (M 68)	12 34.2	—26 12	269	+36	9.12	13.5	— 6.8	28
5024 (M 53)	13 8.0	+18 42	305	+79	8.68	20.2	— 7.8	42
5053	13 11.5	+18 13	310	+78	10.9	17.4	— 5.3	10
5139 (ω Cen)	13 20.8	—46 47	277	+15	(4.7:)	6.8	—10:	168
5272 (M 3)	13 37.6	+28 53	8	+78	7.21	12.2	— 8.2	186
5466	14 1.0	+29 00	8	+72.5	10.39	17.0	— 5.8	18
5634	14 24.4	— 5 32	310	+48.5	10.8	32	— 6.7	7
5694	14 33.8	—26 36	299	+29	10.87:	33.1	— 7.1:	0
5897	15 11.7	—20 39	312	+29	9.61	13.8	— 6.5	0
5904 (M 5)	15 13.5	+ 2 27	332	+46	7.04	10.1	— 8.0	97
6205 (M 13)	16 38.1	+36 39	27	+40	6.78	9.5	— 8.1	15
6218 (M 12)	16 42.0	— 1 46	344	+25	7.95	8.3	— 7.3	1
6229	16 44.2	+47 42	40	+40	10.26	30	— 7.1	21
6254 (M 10)	16 51.9	— 3 57	343	+22	7.64	8.3	— 7.6	2
6341 (M 92)	17 14.1	+43 15	36	+35	7.30	10.3	— 7.8	16
6752	19 2.0	—60 48	303	—26.5	7.2:	5.8	— 7.4:	1
6809 (M 55)	19 33.7	—31 10	336	—25	7.08	5.8	— 7.7	2
6864 (M 75)	20 .2	—22 12	347	—27	9.50	42	— 8.9:	11
6934	20 29.3	+ 7 04	20	—20	10.01	18	— 7.0	51
6981 (M 72)	20 48.0	—12 55	3	—34	10.24	16.6	— 6.6	31
7006	20 56.8	+15 48	32	—21	11.45	44	— 7.3	20
7078 (M 15)	21 25.2	+11 44	33	—28	7.33	11.5	— 8.3	66
7089 (M 2)	21 28.3	— 1 16	21	—36	7.30	13.8	— 8.5	17
7492	23 3.1	—16 10	22	—64	12.33	25.1	— 4.7	9

[292] Shapley, Proc. Nat. Acad. Sci., vol. 30, p. 63, 1944; Pop. Astron., vol. 57, p. 9, 1949. For number of variables see Sawyer, Helen B., Publ. David Dunlap Obs., vol. 1, p. 388, 1947.

(continued)

TABLE 881.—PROPERTIES AND CLASSIFICATION OF STAR CLUSTERS (concluded)

Part 2.—Galactic star clusters

Columns 2 through 6 from Shapley.[203] Distances from R. J. Trumpler, unpublished. Linear diameters computed on basis of revised distances. 1 kiloparsec = 31×10^{15} km = 3×10^{3} light-years.

NGC	RA (1900) h m	Dec	Galactic Long	Galactic Lat	Diameter Ang ′	Diameter Linear pc	No. stars	Distance (kiloparsecs)
663	1 39.2	+60°44′	98°	.4°	11	5.8	80	1.8
869	2 12	+56 41	102.5	− 3.1	36	15.7	...	1.5
884	2 15.4	+56 39	103	− 3.1	36	15.7	...	1.5
Pleiades ...	3 41	+23 48	134.5	−22.3	..	..	...	.15
Hyades	4 14	+15 23	147	−22.6	..	..	...	.04
1960	5 29.5	+34 04	143	+ 2.4	12	3.5	60	1.0
2099	5 45.8	+32 31	145	+ 4.5	20	5.8	150	1.0
2632	8 34.3	+20 20	173.5	+34.0	..	..	...	.15
Mel III	12 20	+26 40	200	+85.4	..	..	...	.07
6705	18 45.7	− 6 23	355	− 4.2	10	3.8	200	1.30
7654	23 19.8	+61 03	80.5	+ .5	12	4.9	120	1.40

[203] Star clusters, p. 228, McGraw-Hill, 1930.

TABLE 882.—OUR GALAXY, ITS CENTER AND ROTATION *

The center of the galaxy apparently lies among the dense Milky Way clouds in Sagittarius, at a distance of about 9,000 to 10,000 parsecs from the sun. About this center the sun revolves with a period of some 200 million years at an orbital speed of nearly 300 km/sec. The amount of matter within the sun's orbit is probably more than 200 billion times the sun's mass. In the table, A is the differential orbital radial velocity per kiloparsec of distance from the sun, rA is the maximum group velocity for a distance r, and l_0 is the longitude of the galactic center. The sun is about 33 parsecs above the galactic plane.[204]

Stars	No.	Vis mag limit	Distance kpc	Max $\bar{r}A$ km/sec	A km sec⁻¹ kpc⁻¹	l_0	Dist to center kpc	Source [205]
O–M	210	8.0	.2— 1.1	35	19.0	324	6.3	a
O–B 7	849	7.5	.2— 1.4	22.2	15.0	324.4	10.0	b
Interstellar	261	8.6	.4— 1.2	13.5	16.6	331.7	..	c
B–K	3786	..	...	...	15.0	324	6.5	d
P G C and 18 C	4233	..	...	...	15.0	....	8.8	e
K	392	7.5	.2	...	17.0	17	..	f
Plan Neb	110	..	.5—12.0	264	14.0	333.0	9.4	g
Cepheids	156	14.1	.4— 2.3	39.4	20.9	325.3	10.0	h
O B, Ceph, c, gas....	...	..	.2—10.0	39.6	17.7	326.0	9.4	i
c	205	8.4	.2— 1.3	26.6	...	324.4	..	j
O 5–B 5	987	6.4	.3— 1.1	18.8	...	....	..	k
Irreg var	116	..	.5	9.5	...	325.7	..	l

* Prepared by A. H. Joy, Mount Wilson Observatory.

[204] Gerasimič, Luyten, Proc. Nat. Acad. Sci., vol. 13, p. 180, 1927.

[205] a, Oort, Bull. Astron. Inst. Netherlands, vol. 4, p. 80, 1927. b, Plaskett, Pearce, Publ. Dominion Astrophys. Obs., vol. 5, p. 241, 1936. c, Plaskett, Pearce, Publ. Dominion Astrophys. Obs., vol. 5, p. 167, 1933. d, Lindblad, Monthly Notices, Roy. Astron. Soc., vol. 90, p. 503, 1930. e, Wilson, R., Astron. Journ., vol. 40, p. 121, 1930. f, Redman, Publ. Dominion Astrophys. Obs., vol. 6, p. 27, 1931. g, Berman, Lick Obs. Bull., vol. 18, p. 57, 1937. h, Joy, Astrophys. Journ., vol. 89, p. 356, 1939. i, Wilson, Astrophys. Journ., vol. 93, p. 212, 1941. k, Wilson, Astrophys. Journ., vol. 94, p. 12, 1941. l, Wilson, Astrophys. Journ., vol. 96, p. 371, 1942.

TABLE 883.—ROTATION OF STARS *

The maximum component ($v \sin i$) along the line of sight of the equatorial velocity v of rotation is found from the distortion of an absorption line produced by differential Doppler effect across the observed hemisphere. For stars in the following groups, $v >$ 50 km/sec very rarely, and $v << 50$ km/sec usually: supergiants, giants; main-sequence stars later than *F* 5 and not close spectroscopic binaries. For main-sequence stars of early type, and not spectroscopic binaries or cluster members, the distribution function $f(v)$ is found to be well represented by the formula

$$f(v) = (j/\sqrt{\pi}) \{ \exp[-j^2 (v - v_1)^2] + \exp[-j (v + v_1)^2] \},$$

where the parameters j^{-1}, v_1, and $\bar{v}$ have the following values:

	Spectral type			
	Be	*O-B*	*A*	*F* 0-*F* 2
j^{-1} (km/sec)	70	63	107	90
v_1 (km/sec)	350	95	107	0
$\bar{v}$ (km/sec)	348	94	112	51

In an idealized Roche model, rotational instability sets in at $v = 560$ km/sec. The Be stars are surmised to be rotationally unstable *B*'s. Number of *B* 8's per *B* 8*e* = 123; number of (*B* 0-*B* 5)'s per (*B* 0*e*–*B* 5*e*) = 15. In the Pleiades and in *h* and χ Persei, v for *B*'s is $\sim 2 \times \bar{v}$ for noncluster *B*'s. For 13 Pleiades earlier than *B* 9, number of *B*'s per *Be* = 3. In many close spectroscopic binaries of both late and early types, the components rotate with the orbital period. In some eclipsing systems, the sense of rotation is found from the Doppler shift of an absorption line at partial phrase. The sense is always that of the orbital motion. For the sun, $v = 2.1$ km/sec.

* Prepared by A. J. Deutsch, Harvard University.

TABLE 884.—TRANSMISSION OF LIGHT THROUGH SPACE *

The obscuring matter in space is too irregularly distributed to be described by a mean extinction coefficient for the galaxy. For bright Milky Way regions a minimum value of 0.2 m/kpc has been found.[296]

Photoelectric measurements by Stebbins and Whitford[297] indicate that the wavelength dependence of the interstellar extinction is essentially the same throughout the galaxy. Their results are given with the table. See references to Oort[298] and Strohmeier[299] for possibility of variations in bright and obscured regions.

λ (*A*)	$\frac{1}{\lambda}(\mu^{-1})$	*m* (mag)	λ (*A*)	$\frac{1}{\lambda}(\mu^{-1})$	*m* (mag)
3200	3.12	1.30†	5700	1.75	.64
3550	2.83	1.18	7190	1.39	.35
4220	2.37	1.00	10300	.97	.00
4880	2.05	.81	21000	.48	—.25†

An unknown constant must be added to these values to give the actual extinction. The scale has been adjusted arbitrarily to give 1 mag differential extinction between λ 4200 and 10,300.

A value of 4 for the ratio of total photographic absorption to international color excess $[R = A_{4400}/(A_{4400} - A_{5400})]$ is obtained by extrapolation of the above table to $1/\lambda = 0$. Most observational determinations are between 3 and 5.[300]

Light from distant stars shows polarization up to 5 percent, approximately proportional to reddening. Plane of polarization variable but generally perpendicular to galactic plane.[301]

* Prepared by B. Donn, Harvard University. † Preliminary values, currently under investigation by Whitford.

[296] Stebbins, Huffer, and Whitford, Astrophys. Journ., vol. 96, p. 209, 1939; Bok, Pop. Astron., vol. 52, p. 261, 1944.

[297] Stebbins and Whitford, Astrophys. Journ., vol. 98, p. 323, 1943; Whitford, Astrophys. Journ., vol. 107, p. 102, 1948.

[298] Oort, Ann. d'Astrophys., vol. 1, p. 91, 1938.

[299] Strohmeier, Zeitschr. Astrophys., vol. 17, p. 83, 1939.

[300] Greenstein, Astrophys. Journ., vol. 87, p. 151, 1938; Oort, Bull. Astron. Inst. Netherlands, vol. 8, p. 308, 1938; Stebbins, Astrophys. Journ., vol. 90, p. 209, 1939; van Rhijn, Groningen Publ. 51, 1946; Weaver, Astrophys. Journ., vol. 110, p. 190, 1949.

[301] Hall, Science, vol. 109, p. 166, 1949; Hiltner, Science, vol. 109, p. 165, 1949, Astrophys. Journ., 1949.

TABLE 885.—SOME DATA ON THE EARTH AND ITS SURFACE

Part 1.—Dimensions

The earth is a great oblate spheroid with the oceans making up about 71 percent of the area. The dimensions of the earth are as follows:

Equatorial radius	6378.388 km
Polar radius	6356.912 km
Area of surface	510,100,934 km^2
Volume of geoid	1,083,319,780,000 km^3
The surface consists of:	
Oceans and seas	361.059×10^6 km^2 or 70.8 percent
Land	148.892×10^6 km^2 or 29.2 percent

The land surface is of various elevations above sea level, the mean being about 840 *m*, while the average depth of the three great oceans and adjacent seas is about 3800 *m* (Table 886). The highest elevation and the lowest elevation in each continent are given in Part 2.

Part 2.—Area and elevation of continents

	Area 10^6 km^2	Highest mountain	Height *m*	Lowest point	Depth *m*
Africa	29.8	Kibo	5970	Libian Desert	133
North America	21.5	McKinley	6150	Death Valley	85
South America	17.6	Aconcagua	6960	Sea level	...
Asia	44.0	Everest	8880	Dead Sea	392
Europe	9.7	Elbrus	5640	Caspian Sea	28
Australia	7.7	Korciusko	2230	Lake Eyre	12

TABLE 886.—SEA-WAVE HEIGHT IN FEET FOR VARIOUS WIND VELOCITIES AND DURATIONS

Wind duration in hours	Wind velocity in knots					
	10	20	30	40	50	60
6	2	5	10	14	20	25
12	2	7	13	20	30	35
24	2	9	17	30	40	55
48	2	10	22	35	45	70

Waves consistently higher than the values given are not found because stronger winds blow the tops of the waves off. Isolated waves up to 80 feet are due to the addition of two or more crests.

One of the longest swell periods recorded was 23 seconds. According to the relations given, its length in deep water would equal 2,650 feet, and its velocity 69 knots. A 28-second swell has been recorded near Cape of Good Hope. Its length must have been almost three-quarters of a mile and its speed 84 knots.

TABLE 887.—APPROXIMATE HEIGHT OF SWELL IN FEET AT VARIOUS DISTANCES FROM THE STORM AREA

Distance from storm area in nautical miles				
0	500	1000	2000	3000
40	25	20	12	8
30	19	14	8	5
20	12	8	5	3
15	8	5	3	2
10	5	3	2	1
5	2	1	.5	—

* Tables 888 to 894, and 897 prepared by R. H. Fleming, U. S. Hydrographic Office.

TABLE 888.—AREA, VOLUME, AND MEAN DEPTH OF OCEANS AND SEAS[302]

Body	Area 10^6 km²	Volume 10^6 km³	Mean depth m
Atlantic Ocean (excluding adjacent seas)	82.441	323.613	3,926
Pacific Ocean (excluding adjacent seas)	165.246	707.555	4,282
Indian Ocean (excluding adjacent seas)	73.443	291.030	3,963
All oceans (excluding adjacent seas)	321.130	1,322.198	4,117
Arctic Mediterranean	14.090	16.980	1,205
American Mediterranean	4.319	9.573	2,216
Mediterranean Sea and Black Sea	2.966	4.238	1,429
Asiatic Mediterranean	8.143	9.873	1,212
Large Mediterranean seas	29.518	40.664	1.378
Baltic Sea	.422	.023	55
Hudson Bay	1.232	.158	128
Red Sea	.438	.215	491
Persian Gulf	.239	.006	25
Small Mediterranean seas	2.331	.402	172
All Mediterranean seas	31.849	41.066	1,289
North Sea	.575	.054	94
English Channel	.075	.004	54
Irish Sea	.103	.006	60
Gulf of St. Lawrence	.238	.030	127
Andaman Sea	.798	.694	870
Bering Sea	2.268	3.259	1,437
Okhotsk Sea	1.528	1.279	838
Japan Sea	1.008	1.361	1,350
East China Sea	1.249	.235	188
Gulf of California	.162	.132	813
Bass Strait	.075	.005	70
Marginal seas	8.079	7.059	874
All adjacent seas	39.928	48.125	1,205
Atlantic Ocean (including adjacent seas)	106.463	354.679	3,332
Pacific Ocean (including adjacent seas)	179.679	723.699	4,028
Indian Ocean (including adjacent seas)	74.917	291.945	3,897
All oceans (including adjacent seas)	361.059	1,370.323	3,795

Mean elevation of land = 840 *m*
Mean depth of oceans = 3,800 *m*
Mean sphere depth = 2,440 *m*

Continental shelves extend out with small gradients to depths of about 100 to 150 *m*. Average width about 30 miles but varies from zero to several hundred. Continental slopes have about 2° to 3° inclination. Volcanic islands, fault scarps, etc., may have slopes as steep as similar features on land.

Greatest depths known are in the Pacific Ocean—10,800 *m*
Deepest sounding in the Atlantic Ocean is 9,200 *m*
Deepest sounding in the Indian Ocean is 7,450 *m*

Greatest depths occur in troughs or trenches paralleling mountainous coasts and insular arcs. These areas are centers of seismic and volcanic activity.

Topography of the ocean floor is in general similar to major features found on land. Submerged features such as the Mid-Atlantic Ridge are comparable in size and extent to the combined Rockies and Andes Mountains. In the Pacific are hundreds of isolated guyots, flat-topped seamounts rising thousands of feet from the ocean bed with minimum depths of 1,000–2,000 *m*. Many isolated seamounts rise more than 3,000 *m* from the sea floor. Continental and insular shelves and slopes are not regular but generally show topographic relief such as shoals, terraces, canyons and valleys. Certain areas such as the Mediterranean, Black Sea, Sea of Japan, Red Sea, etc., are isolated at depth by ridges separating the deep water from the adjacent sea or ocean.

[302] Reprinted by permission of the publishers from The oceans; their physics, chemistry, and general biology, by H. U. Sverdrup, Martin W. Johnson, and Richard H. Fleming. Copyright 1942 by Prentice-Hall, Inc.

TABLE 889.—PERCENTAGE AREA OF DEPTH ZONES IN THE OCEANS *

Depth interval (*m*)	Including adjacent seas			All oceans	Excluding adjacent seas			All oceans
	Atlantic	Pacific	Indian		Atlantic	Pacific	Indian	
0– 200	13.3	5.7	4.2	7.6	5.6	1.7	3.2	3.1
200–1000	7.1	3.1	3.1	4.3	4.0	2.2	2.7	2.8
1000–2000	5.3	3.9	3.4	4.2	3.6	3.4	3.1	3.4
2000–3000	8.8	5.2	7.4	6.8	7.6	5.0	7.4	6.2
3000–4000	18.5	18.5	24.0	19.6	19.4	19.1	24.4	20.4
4000–5000	25.8	35.2	38.1	33.0	32.4	37.7	38.9	36.6
5000–6000	20.6	26.6	19.4	23.3	26.6	28.8	19.9	26.2
6000–7000	.6	1.6	.4	1.1	.8	1.8	.4	1.2
>7000	...	.2	...	.1	...	.3	...	.1

* For reference, see footnote 302, p. 773.

TABLE 890.—PHYSICAL PROPERTIES OF SEA WATER (Fig. 34)

Temperatures in the sea range from —2° to 30°C. The lower limit is set by the formation of ice and the higher limit by the balance between incoming radiation, back radiation, and evaporation.

Pressures in the sea vary from zero at the sea surface to about 1,000 atm in the greatest depths (10,000 *m*). Standard unit is the bar $= 10^6$ dynes/cm². Approximately 10 *m* of sea water = 1 atm.

Concentration of the dissolved constituents varies from nearly zero in river mouths to 40°/₀₀ (parts per thousand) in isolated seas in arid regions. In most ocean waters the total solids are between 33 and 37°/₀₀. In addition, sea water contains dissolved gases, dissolved organic matter, and variable amounts of particulate material of biological or terrigenous origin.

Salinity is defined as the total amount of solid material in grams in one kg of sea water when all carbonates are converted to oxides, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized.

Chlorinity, determined by titration with $AgNO_3$, is essentially equal to the amount of chlorine in grams in one kg of sea water when all the bromine and iodine have been replaced by chlorine.

$$\text{Salinity} = 0.03 + 1.805 \times \text{Chlorinity } (°/_{oo})$$

Distribution of temperature and salinity is most variable in the surface layers. Low temperatures occur in high latitudes with relatively low salinities. In the Tropics surface temperatures and salinities are high. The great ocean basins are filled with high-density water produced in high latitudes during the winter when ice forms or when water of high salinity is cooled. Deep temperatures are therefore generally between 0° and 2°C. Convection and wind mixing produce a *surface layer* in which uniform conditions prevail. This may be as thick as several hundred meters. Immediately beneath this there is a rapid change in temperature called the *thermocline*. Diurnal variations of temperature at the surface rarely exceed 1°C. Annual variations of surface temperature are greatest in midlatitudes (about 10°C). Annual variations diminish with depth and rarely extend below 200 *m*.

Density of sea water is a function of salinity as well as temperature and pressure. The range in values is from 1.00 to about 1.04 g/cm³. Most of the other properties are functions of temperature, salinity, and pressure. The difference from the values for pure water depends then on the effects of the dissolved organic compounds. Light absorption and color will also be primarily determined by suspended or dissolved debris. Processes of heat conduction, diffusion, and transfer of momentum are dominated by turbulent water movements and consequently the laboratory coefficients of conductivity, diffusion, and viscosity have to be replaced by "eddy" coefficients of vastly greater magnitude.

Absorption of light.—Water is essentially opaque to electromagnetic radiation except in the visible spectrum. Below several hundred meters, even in the clearest water, all the solar radiation is absorbed. (See Table 891 and fig. 35.) In coastal waters that contain suspended debris, the radiation may be absorbed in only a few meters. The rapid absorption of radiation limits photosynthesis to the surface layers.

Evaporation.—The principal source of heat is radiation from sun and sky. The chief heat losses are due to long-wave radiation to space and evaporation. Evaporation is greatest when the air is dry and colder than the water. Regional variations are generally between 50 and 150 cm/year.

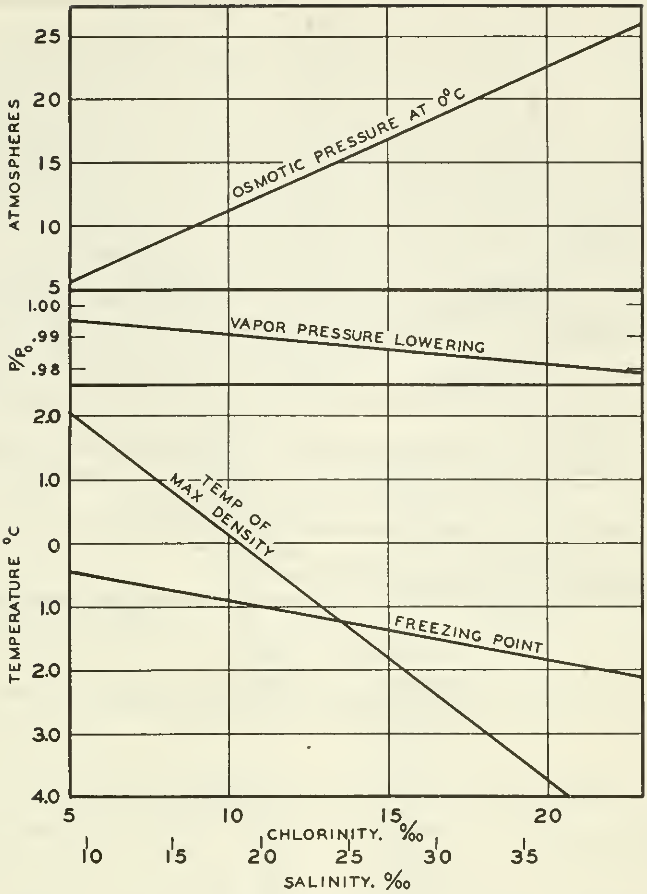
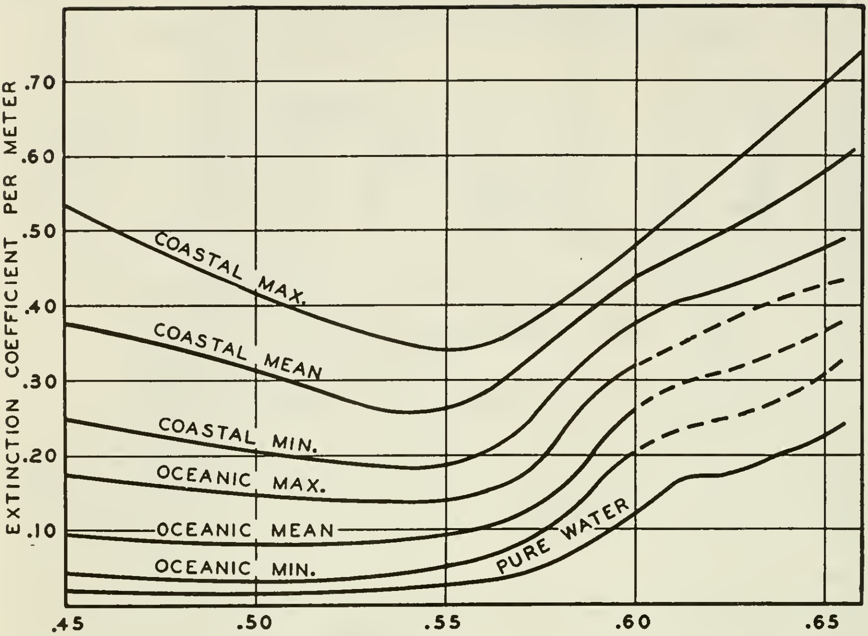


FIG. 34.—Osomotic pressure, vapor pressure, of sea water, relative to that of pure water, freezing point, and temperature of maximum density as functions of chlorinity and salinity.

TABLE 891.—PERCENTAGE OF RADIATION OF GIVEN WAVELENGTH TRANSMITTED BY 1 M OF WATER *

Type of water	Wavelength (μ) .46	.48	.515	.53	.565	.60	.66
Pure water	98.5	98.5	98.2	97.9	96.8	88.3	75.9
Oceanic water { highest	96.4	97.5	96.6	96.3	92.9	81.8	...
Oceanic water { highest	91.8	92.7	92.5	91.8	89.8	75.9	...
Oceanic water { average	85.1	85.7	86.7	86.9	84.5	71.6	...
Coastal water { average	80.0	79.4	82.6	84.5	...	68.7	62.0
Coastal water { lowest	69.7	71.6	75.9	76.4	...	64.6	53.6
Coastal water { lowest	60.0	63.5	67.1	70.6	...	61.4	46.7

* For reference, see footnote 302, p. 773.



Wavelengths in microns.

FIG. 35.—Extinction coefficients of radiation of different wavelengths in pure water and in different types of sea water.

TABLE 892.—COMPOSITION OF SEA WATER *

The major ions present (over 99.9 percent of dissolved solids) are given in the table for $Cl = 19.00$ °/oo.

Ion	°/oo	*Cl*-ratio	Equiv/kg	Ion	°/oo	*Cl*-ratio	Equiv/kg
Cl^-	18.9799	.99894	.5353	Na^+	10.5561	.5556	.4590
SO_4^-	2.6486	.1395	.0551	Mg^{++}	1.2720	.06695	.1046
HCO_3^{--} ..	.1397	.00735	.0023	Ca^{++}	.4001	.02106	.0200
Br^-	.0646	.00340	.0008	K^+	.3800	.02000	.0097
F^-	.0013	.00007	.0001	Sr^{++}	.0133	.00070	.0003
H_3BO_3	.0260	.00137	....				———
			———				.5936
			.5936				

Salinity = 34.325 °/oo. Total solids = 34.48 °/oo.

The *Cl*-ratios are constants for oceanic waters except for HCO_3^{--} and Ca^{++} which are affected by biological activity. Ratios are not valid in areas of river dilution.

* For reference, see footnote 302, p. 773.

TABLE 893.—GEOCHEMISTRY OF THE OCEANS

The oceans contain about 5×10^{16} metric tons of dissolved solids. The amount in tons of any element can be estimated by multiplying the values in Table 894 by 1.42×10^{12}. Rivers each year add about 2.7×10^{9} metric tons.

TABLE 894.—ELEMENTS PRESENT IN SOLUTION IN SEA WATER *

Elements present in solution in sea water in terms of $Cl = 19\,°/_{oo}$ are listed in order of abundance in the table. Adding the dissolved gases H_2, N_2, O_2, He, and A, a total of some 49 elements are known to occur.

Ranges are indicated for Si, N, P, As, Fe, Mn, and Cu. The distribution of these elements, present in small quantities, is affected by biological activity. Lower values are usually near surface.

All atmospheric gases are found in the sea. Their solubility decreases with increasing temperature and salinity. At 0°C, $Cl = 19\,°/_{oo}$, surface water contains 8.08 m *l/l* of O_2 and 14.40 *m l/l* of N_2. At 20°C corresponding values are 5.38 and 9.65. Distribution of dissolved N_2 is determined by temperatures and salinity. Oxygen at middepths is reduced, but only in the waters of isolated basins such as the Black Sea is there stagnation and H_2S present. Plant activity near the surface may increase O_2 above saturation values. Carbon dioxide is present in large quantities (about 50 *ml/l*) chiefly as HCO_3^- and CO_3^{--} balanced against basic cations. Strong acid must be added to drive off all CO_2. The *pH* in the sea varies between 7.4 and 8.4 depending upon the $O_2 \rightleftarrows CO_2$ changes due to respiration or photosynthesis.

(Dissolved gases not included)

Element	mg/kg $Cl = 19.00\,°/_{oo}$	Element	mg/kg $Cl = 19.00\,°/_{oo}$
Chlorine	18980	Copper	.001—.01
Sodium	10561	Zinc	.005
Magnesium	1272	Lead	.004
Sulfur	884	Selenium	.004
Calcium	400	Cesium	.002
Potassium	380	Uranium	.0015
Bromine	65	Molybdenum	.0005
Carbon	28	Thorium	.0005
Strontium	13	Cerium	.0004
Boron	4.6	Silver	.0003
Silicon	.02 —4.0	Vanadium	.0003
Fluorine	1.4	Lanthanum	.0003
Nitrogen †	.01 — .7	Yttrium	.0003
Aluminum	.5	Nickel	.0001
Rubidium	.2	Scandium	.00004
Lithium	.1	Mercury	.00003
Phosphorus	.001— .10	Gold	.000006
Barium	.05	Radium	$.2\text{—}3\times10^{-10}$
Iodine	.05	Cadmium	traces
Arsenic	.01 — .02	Chromium	traces
Iron	.002— .02	Cobalt	traces
Manganese	.001— .01	Tin	traces

* For reference, see footnote 302, p. 773.
† Computed.

TABLE 895.—WAVE VELOCITY IN VERY SHALLOW WATER

Depth of water feet	Speed of wave knots
15	13
10	11
5	8

TABLE 896.—VELOCITY OF EARTHQUAKE WAVES WITH DEPTH OF WATER

Depth in feet	500	1,000	2,000	5,000	10,000	15,000
Velocity in knots	70	100	150	240	340	420

If a large swell or an earthquake wave approaches a shoreline great damage may be done before the energy of the moving water is absorbed.

The permanent currents of the ocean are maintained by differential heat and cooling and by the indirect effects of the wind. They may extend to depths as great as 1,000 *m* and their speed is usually less than 50 cm/sec. In the Gulf Stream and Kuroshio, speeds may exceed 250 cm/sec. Volume transparents of the large current systems exceed 50 million tons/sec.

Wind-driven currents induced by the drag of the wind are generally shallow, less than 100 *m*, flow with speeds about 2 percent of wind, and deviate about 30° from the wind direction, to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Tidal currents follow elliptical orbits during each tidal cycle. Motion probably extends to the bottom. In restricted coastal channels the currents are reversing and sometimes exceed 250 cm/sec.

WAVES AT SEA *

Whenever the wind blows over the water, the surface is formed into waves which grow under the influence of the wind and form a most irregular surface known as a *sea*. Such waves traveling out from a storm area are called *swells*. As waves break near the shore *surfs* are formed.

Waves may also be formed by earthquakes, fault movements, submarine landslides, or volcanic eruptions beneath the sea.

The height of a wave, H, is the vertical distance from crest to trough. The length, L, is the horizontal distance between adjacent crests. The wave period, P, is the time interval between passage of successive crests at a fixed point. The velocity, V, of a wave is the speed with which the wave travels along the sea surface.

The following relations hold for depths greater than one-quarter wavelength with good approximation:

$$L = 5P^2, \quad V = 3P$$

where the wavelength, L, is in feet, the period, P, in seconds, and the velocity, V, in knots. The waves move along the surface of the water but the water, on the other hand, advances very little—about one percent only of the wave velocity.

The height of the *sea* is determined by three factors:

Wind velocity, average speed of wind over fetch.
Fetch, distance over wind blows.
Wind duration, how long the wind blows.

Tables 886 and 898 show the wave heights for some conditions.

* Abstracted from an article prepared for the Encyclopedia Britannica, by Walter Munk, Scripps Institute of Oceanography. Used by permission.

TABLE 898.—WAVE HEIGHT IN FEET FOR VARIOUS WIND VELOCITIES AND FETCHES

Fetch in nautical miles	Wind velocity in knots					
	10	20	30	40	50	60
10	2	3	5	7	9	10
20	2	4	7	9	12	14
50	2	6	10	14	18	22
100	2	7	13	17	25	30
500	2	10	20	31	45	55
1000	2	10	21	35	50	70

(See also Tables 886, 887, and 895.)

(Nat. Res. Council Bull. 78, 1931.)

Spring tides.—When moon (new or full) is in line with sun (large tide).

Neap tide.—When moon is in quadrature with sun (small tide).

Generally two high and two low each day. Variation in heights of two high and two low = "diurnal inequality."

River-type tide, steep short-period graph for flood, more inclined and longer for ebb. Extreme case = "bore," tide rises so rapidly it assumes form of wall several feet high. Most famous bores, Tsientang Kiang, China; Turnagain Arm, Alaska; Severn and the Wye, England; Seine in France; Hoogly, India; Petitcodiac, Canada.

Mean sea level (geodetic).—The equipotential surface which the oceans woud assume if undisturbed by the tides and effects of wind and weather. Starting with mean sea level at any given initial point the geodesist can determine by precise spirit leveling, the equipotential surface.

Mean sea level (geographic).—Determined by averaging actual tidal heights over a sufficient period. It is a local or geographic value. It is much disturbed by prevalent winds and local contours. Note difference between average of hourly readings (mean sea level) and half-tide point (because of the shape of the tide height as related to time). On Atlantic coast ½ tide level lies below mean by about 1/10 ft: on Pacific above by 1/20 ft. Mean tide near rivers varies with rainfall. Nineteen years' observation used for full tide cycle. A fundamental level net has been connected with mean sea level at Portland, Me., via Boston, Mass., Ft. Hamilton, N. Y., Sandy Hook and Atlantic City, N. J., Old Point Comfort and Norfolk, Va., Brunswick, Ga., Fernandina, St. Augustine, and Cedar Keys, Fla., Biloxi, Miss., Galveston, Tex., San Diego, San Pedro, San Francisco, Calif., Ft. Stevens, Oreg., and Seattle, Wash. The accuracy of high precision leveling is measured by the correction necessary to close circuits, about 0.00063 foot/mile. Mean sea level difference indicated by special adjustment of leveling network in 1929: Portland, Maine, 9 cm higher than Ft. Hamilton; Vancouver, 2 cm higher than Seattle; Galveston, 27 cm higher than St. Augustine; San Diego, 33 cm higher than Galveston; Fort Stevens, 26 cm higher than San Diego; Isthmus of Panama, Pacific coast, 20 cm higher than Atlantic; Death Valley, 280 ft (84.1) below sea level; Mount Whitney, 14,495 ft (4418.1 *m*) above.

TABLE 900.—THE EARTH'S ROTATION: ITS VARIATION [803]

From observations, Spencer Jones (Monthly Notices, Roy. Astron. Soc., vol. 99, p. 541, 1939) deduces as the best value of the apparent solar acceleration 2.5″/(century)^2. Lunar theory predicts 12.0″/(century)^2 leaving part attributable to tidal friction 10″/(century)^2.

Estimates of tidal friction losses (Jeffreys, Philos. Trans., A, vol. 221, p. 239, 1920):

Irish Sea	.6×10^{18} erg/sec	So. China Sea	—×10^{18} erg/sec	Hudson Str.	.2×10^{18} erg/sec
Eng. Channel	1.1 " "	Okhotsk Sea	.4 " "	Hudson Bay	— " "
North Sea	1.7 " "	Bering Sea	15.0 " "	Fox Strait	1.4 " "
Yellow Sea	1.1 " "	Malacca Str.	1.1 " "	Bay Fundy	.4 " "

Other contributions are small. Total for spring tides 22×10^{18} erg/sec. 1.1×10^{19} erg/sec average, corresponding to about 7″ secular acceleration per century per century. If Ω is earth's angular velocity of rotation, $d\Omega/dt = -2.5 \times 10^{-22}/\text{sec}^2$. $\Omega = 7.3 \times 10^{-5}$ rad./sec. Ω changes by 10^{-8} of its amount in 3×10^{12} sec or 10^5 years. The day *should* have lengthened by 1 sec in 120,000 years.

The fluctuations in the earth's rate of rotation indicated by astronomical evidence are of a quite greater order of magnitude. Moreover the changes vary in sign whereas frictional effects should not. The observations come from deviations of the sun and moon from their gravitational orbits, the transits of Mercury, and eclipses of Jupiter's satellites. Changes in the speed of rotation of the earth rotation seem the only explanation. This may be due to shifts of matter within or on the earth. The following figure by Brown indicates that in 1928 the earth was about 25 sec ahead of its average rotational motion during the last three centuries. The greatest apparent change in the loss or gain of one sec in a whole year. (1 part in 30,000,000.)

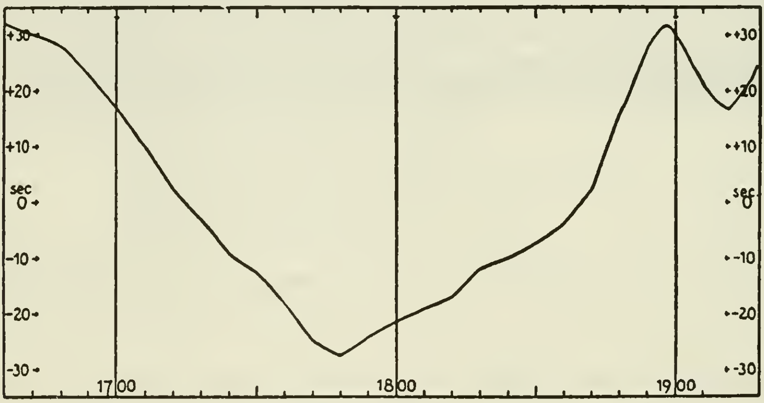


FIG. 36.—Irregularities in the earth's rotation derived from the moon's motions.

Tidal friction should make the earth rotate more slowly and the moon recede from the earth. The rate of dissipation of energy by friction is about 1.4×10^{19} erg/sec. The earth's rotation from this cause should have slowed by 4 hours during geologic time. The moon should continue to recede until its period of revolution and that of the earth's rotation are equal to 47 of our present days. The moon should then gradually approach the earth, ultimately coming within Roche's limit (about twice the earth's radius) breaking up possibly into a ring like Saturn's.

[803] Jeffreys, The earth, Macmillan, 1929; Innes, Changes in the length of the day, Scientia, vol. 42, p. 69, 1927; Brown, Nature, vol. 119, p. 200, 1927; Journ. Roy. Astron. Soc. Canada, vol. 24, p. 177, 1930. Revised by G. M. Clemence, U. S. Naval Observatory.

TABLE 901.—GENERAL CONVERSION FACTORS

Multiply	by	to obtain
Area (See Tables 31–33)		
acre	40.47	are
	1.60×10^2	rod^2
	4.356×10^4	ft^2
are	10^2	m^2
cir mils	5.067×10^{-6}	cm^2
ft^2	9.290×10^2	cm^2
in.^{3}	6.452	cm^2
Capacity units (See Tables 31–33)		
barrel	31.5	gal
bushel	1.244	ft^3
	2.1504×10^3	in.^{3}
	3.524×10^{-2}	m^3
	4	pecks
	64	pt (dry)
	32	qt (dry)
chaldrons (U.S., dry)	36	bu
firkin	9	gal
ft^3	7.48	gal
ft^3	28.32	liter
gallon	3.7854×10^3	cm^3
	.1337	ft^3
	2.31×10^2	in.^{3}
	3.7853	liter
	8	pt (liquid)
	4	qt (liquid)
hogsheads	8.423	ft^3
	63	gal
liter	1.000028×10^3	cm^3
lb of H_2O	1.602×10^{-2}	ft^3 of H_2O
	27.72	in.^{3} of H_2O
	.1200	gal
pt (liquid)	28.88	in.^{3}
qt (dry)	67.20	in.^{3}
qt (liquid)	57.75	in.^{3}
	1.164	qt (dry)

Multiply	by	to obtain
Density		
g/ft^3	35.31	g/m^3
g/liter	8.345×10^{-3}	lb/gal
g/cm^3	62.43	lb/ft^3
g/cm^3	1.94	slug/ft^3
lb/1000 ft^3	1.602	kg/100 m^3
lb/ft^3	1.602×10^{-2}	g/cm^3
lb/in.^{3}	27.68	g/cm^3
slug/ft^3	.5153	g/cm^2
	32.17	lb/ft^3
Electrical units (See Tables 6–8)		
amu	9.32×10^2	Mev
	1.492×10^{-3}	ergs
Energy units (See Tables 7, 654)		
cal	4.185×10^7	erg
erg	9.4801×10^{-11}	Btu *
	2.389×10^{-8}	cal *
	1.0197×10^{-3}	g-cm
	7.376×10^{-8}	ft-lbs
	2.373×10^{-6}	ft-poundals
	6.24×10^5	Mev
electron-volt	1.602×10^{-12}	erg
ft^3-atm	28.32	liter-atm
ft-lb	1.356×10^7	ergs
	3.766×10^{-7}	kw-hr
	.3238	cal
	32.17	ft-poundal
	1.285×10^{-3}	Btu
ft-poundal	4.214×10^5	ergs
	3.108×10^{-2}	ft-lb
g-cm	9.806×10^2	erg
hp-hr	2.684×10^6	joule
	2.545×10^3	Btu
	6.413×10^2	kg-cal
	.7457	kw-hrs

* In this table the calorie = 4.185 joules and the Btu = 252 calories (See Table 7).

(*continued*)

TABLE 901.—GENERAL CONVERSION FACTORS (continued)

Energy units (*continued*)

Multiply	by	to obtain
joule	10^7	ergs
	9.482×10^{-4}	Btu
	23.73	ft-poundals
	.7376	ft-lbs
	3.021×10^{18}	quanta ($\lambda = .6\,\mu$)
kg-cm	9.807×10^5	ergs
	7.233×10^{-2}	ft-lb
kw-hr	3.6×10^6	joule
	3.414×10^3	Btu
	8.602×10^5	cal
Mev	1.602×10^{-6}	ergs
pound-foot	1.3553×10^7	ergs
poundal-foot	4.2130×10^5	ergs
quantum ($\lambda = .6\,\mu$)	3.310×10^{-12}	ergs

Energy flow (See Tables 129–130)

Flow

Multiply	by	to obtain
ft^3/min	4.720×10^2	cm^3/sec
	.1247	gal/sec
	.4720	liter/sec
gal/min	2.228×10^{-3}	ft^3/sec
liter/min	5.885×10^{-4}	ft^3/sec
	4.403×10^{-3}	gal/sec

Force

Multiply	by	to obtain
dyne	7.233×10^{-5}	poundal
	2.248×10^{-6}	poundweight
	1.0197×10^{-6}	kg weight
newton †	10^5	dyne
pound (see lb)		
poundal	1.3827×10^4	dyne
pound (weight)	4.448×10^5	dyne
gram (weight)	9.81×10^2	dyne

Gravitational

Multiply	by	to obtain
grav (gal)	9.80665×10^2	cm/sec^2
	32.174	ft/sec^2

† The unit of force in the *MKS* system.

Heat flow units (See Tables 129–130)

Heat content (See thermal units)

Illumination (See Tables 71–72)

Multiply	by	to obtain
lu/ft^2	1	ft-candles

Linear units (See Tables 31–33, 522)

Multiply	by	to obtain
A	1×10^{-10}	m
	1×10^{-8}	cm
	1×10^{-4}	μ
barleycorns	1/3	in.
cubits	1.5	ft
ells	45	in.
	1.143×10^2	cm
ft	30.48	cm
	12	in.
ft	.3048	m
	1/3	yd
fathom	6	ft
furlong	.125	mile
	2.20×10^2	yds
hand	4	in.
league	1/3	nautical mile
light yrs	9.4602×10^{17}	cm
line	1/12	in.
m	39.37	in.
mil	10^{-3}	in.
mile (statute)	5.280×10^3	ft
mile (nautical)	6.0802×10^3	ft
micron (μ)	10^{-3}	mm
	10^{-4}	cm
parsec	3.1×10^{18}	cm
span	9	in.

Metric system prefixes (See Tables 31–33)

Multiply	by	to obtain
micro	.000001	
milli	.001	

(*continued*)

TABLE 901.—GENERAL CONVERSION FACTORS (continued)

Metric system prefixes (*continued*)

Multiply	by	to obtain
centi	.01	
deci	.1	
deka	10	
hecto	1.00×10^{2}	
kilo	1.00×10^{3}	
myra	1.00×10^{4}	
....	......	
mega	1.00×10^{6}	

Paper measure

Multiply	by	to obtain
reams	5.00×10^{2}	sheets

Photometric units (See Tables 66 and 69–74)

Power units

Multiply	by	to obtain
Btu/min	12.96	ft-lb/sec
	1.758×10^{-2}	kw
cal/min	5.145×10^{-2}	ft-lb/sec
	6.975×10^{-5}	kw
ft-lb/sec	1.82×10^{-3}	hp
hp	42.43	Btu/min
	.7457	kw
hp	5.50×10^{2}	ft-lb
	.7070	Btu/sec
	10.69	kg cal/min
	7.457×10^{2}	watts
kw	10^{3}	watts
	1.341	hp

Pressure units (See Table 260)

Multiply	by	to obtain
atm	1.033×10^{3}	g/cm²
	14.70	lb/in.²
	76	cmHg (0°C)
	7.60×10^{2}	Tor
	1.0332	kg/cm²
	29.921	in. Hg (0°C)
	1.01325×10^{6}	dynes/cm²
	1.01325	bar

Pressure units (*continued*)

Multiply	by	to obtain
atm	1.01325×10^{6}	barye
	33.90	ft water (4°C)
	1.0332×10^{3}	cm water (4°C)
	1.0332×10^{4}	kg/m²
	76×10^{-4}	μHg
	7.60×10^{2}	mmHg
	2.1168×10^{3}	lb/ft²
bar	.9869	atm
	7.501×10^{2}	mmHg
	1.0197×10^{3}	g/cm²
	1.0197×10^{4}	kg/m²
	10^{6}	dynes/cm²
	10^{6}	barye
	1.0197	kg/cm²
barye	1.00	dyne/cm²
	9.869×10^{-7}	atm
	7.50×10^{-4}	mmHg
cmHg	1.316×10^{-2}	atm
	.4461	ft of H_2O
	1.3596×10^{2}	kg/m²
	27.85	lb/ft²
	.1934	lb/in.²
	1.333×10^{4}	dynes
dynes/cm²	1.4505×10^{-5}	lb/in.²
	2.0888×10^{-3}	lb/ft²
	9.869×10^{-7}	atm
	10^{-6}	bar
	2.953×10^{-5}	in. Hg (0°C)
	1.0197×10^{-2}	kg/m²
	7.501×10^{-4}	mmHg
ft of water	2.950×10^{-2}	atm
	.8826	in. Hg
	3.048×10^{2}	kg/m²
	62.43	lb/ft²
	.4335	lb/in.²
in. Hg	3.342×10^{-2}	atm
	3.386×10^{4}	dynes

(*continued*)

TABLE 901.—GENERAL CONVERSION FACTORS (continued)

Pressure units (*continued*)

Multiply	by	to obtain
in. Hg	1.133	ft of water
	3.453×10^{2}	kg/m^2
	70.74	lb/ft^2
	.4913	$lb/in.^2$
in. of H_2O	2.458×10^{-3}	atm
	7.355×10^{-2}	in. Hg
	25.40	kg/m^2
	.5808	$oz/in.^2$
	5.203	lb/ft^2
	3.613×10^{-2}	$lb/in.^2$
kg/m^2	1.422×10^{-3}	$lb/in.^2$
kg/cm^2	.9681	atm
$kips/in.^2$	.7030	kg/mm^2
	10^{3}	$lb/in.^2$
lb/ft^2	4.725×10^{-4}	atm
$lb/in.^2$	6.803×10^{-2}	atm
	7.03×10^{-2}	kg/cm^2
	7.03×10^{-4}	kg/mm^2
	70.30	g/cm^2
mmHg	1.3332×10^{3}	dynes
	1.3158×10^{-3}	atm
	29.97	lb/m^2
	1.3595	g/cm^2
	1.3595×10^{-3}	kg/cm^2
	1	Tor
psi	1	$lb/in.^2$
Tor	1	mmHg
	1/760	atm

Resistivity

Multiply	by	to obtain
ohms-cm	6.016×10^{6}	ohms-mil-ft ‡

Speed

Multiply	by	to obtain
knot	1	nautical mile/hr
	1	6080.2 ft/hr

Temperature (See Table 1)

Multiply	by	to obtain
deg F/in.	.2187	°C/cm
deg C/cm	4.572	°F/in.

Thermal (heat) units (See Tables 1, 7)

Multiply	by	to obtain
Btu	2.52×10^{2}	cal
	7.782×10^{2}	ft-lb
	3.929×10^{-4}	hp-hrs
	2.929×10^{-4}	kw-hrs
	2.5026×10^{4}	ft-poundals
	1.0546×10^{3}	joules
	1.0754×10^{2}	kg-m
	10.41	liter-atm
Btu/lb	.5556	cal/g
Btu/ft^3	8.898×10^{-3}	cal/cm^3
	8.898	$kg\ cal/m^3$
Btu/(lb °F)	1	cal/(g °C)
cal	.4267	kg-m
	4.185	joule
	4.185×10^{7}	ergs
	4.130×10^{-2}	liter-atm
	3.968×10^{-3}	Btu
	3.088	ft-lb
	1.559×10^{-6}	hp-hrs
	1.163×10^{-6}	kw-hrs
	1.264×10^{19}	quanta ($\lambda = .6\ \mu$)
cal/g	1.8	Btu/lb
kg/cal	3.968	Btu
	10^{3}	cal
pyron	1	$cal\ cm^{-2}\ min^{-1}$
	1/60	$cal\ cm^{-2}\ sec^{-1}$
	6.97×10^{-2}	$watt/cm^2$

Time (See Tables 3, 729)

Multiply	by	to obtain
year §	3.155715×10^{7}	sec
day	8.64×10^{4}	sec

‡ This means the resistance of a wire 1 ft long and 1 mil in diameter.

§ Tropical year.

(continued)

TABLE 901.—GENERAL CONVERSION FACTORS (concluded)

Multiply	by	to obtain
Volume units (See Table 31)		
in.^{3}	16.387	cm^3
ft^3	2.8317×10^4	cm^3
Volume capacity		
ft^3/gal	7.482	m^3/kl
gal/(1000 ft^3)	13.37	1/100 m^3
g/100 kg	.02	lb/ton
g/m^3	.437	grains/ft^3
gal/ton	.4172	liter/(100 kg)
Weight (mass) units (See Table 31)		
carat (1877)	3.168	grains
	2.053×10^2	mg
carat (metric)	2.00×10^2	mg
drams (av)	1.772	g
	6.25×10^{-2}	oz
g	9.807×10^2	dynes

Multiply	by	to obtain
Weight (mass) units		
g	15.43	grains
	1×10^{-3}	kg
	10^3	mg
	3.527×10^{-2}	oz
	2.205×10^{-3}	lb
kips	10^3	lb
lb	7.00×10^3	grains
	4.536×10^2	g
	16	oz
lb (troy)	.8229	lb (av)
slug	1	gee lb
	32.17	lb
slug (metric)	9.80×10^2	g
Weight per volume		
ft^3 of gas/lb	6.243	m^3 of gas/100 kg
ft^3 of water (4°C)	62.43	lb.

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