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A STUDY OF THE RADIATION OF THE ATMOSPHERE

BASED UPON OBSERVATIONS OF THE NOCTURNAL RADIATION DURING EXPEDITIONS TO ALGERIA AND TO CALIFORNIA

BY
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PREFACE

The prosecution of the researches described in the following pages has been rendered possible by several grants from the Hodgkins Fund of the Smithsonian Institution, Washington, for which I here desire to express my deep gratitude.

I also stand indebted to various gentlemen for friendly help and encouragement.

In the first place, I wish to express my sincere thanks to my esteemed friend, Dr. C. G. Abbot, Director of the Astrophysical Observatory of the Smithsonian Institution, for the great interest he has shown in my researches. His aid and suggestions have ever been a source of stimulation and encouragement, while his criticisms of my work have never failed to be of the greatest assistance to me.

Other scholars, to whom it is largely due that the observations upon which this study is based have been so far brought to a successful termination that I have been able to draw from them certain conclusions of a general character, are Dr. E. H. Kennard, of Cornell University; Professor F. P. Brackett, Professor R. D. Williams, and Mr. W. Brewster, of Pomona College, California. To all these gentlemen I wish to express my sense of gratitude and my earnest thanks for the valuable assistance they have afforded me in my investigations during the expedition to California.

Ultimately, the value of the observations of nocturnal radiation here published will be greatly enhanced by the fact that the temperature, pressure, and humidity of the atmosphere, up to great elevations, were obtained experimentally by balloon observations made during the expedition from points at or near my observing stations. These observations, made by the United States Weather Bureau in cooperation with the Smithsonian Institution, are given in Appendix I.

It is also of advantage that observations of the solar constant of radiation, the atmospheric transparency for solar radiation, and the total quantity of water vapor in the atmosphere (as obtained by Fowle's spectroscopic method) were made at Mount Wilson during the stay of the expedition. A summary of these results forms Appendix II.

In the present discussion the results of the balloon flights and spectrobolometric work are not incorporated. A more detailed study of the atmospheric radiation, in which these valuable data would be indispensable, may be undertaken more profitably after a determination shall have been made of the individual atmospheric transmission coefficients throughout the spectrum of long wave rays as depending on humidity. This study is now in progress by Fowle and others, and the results of it doubtless will soon be available.

Anders Ångström.

Upsala, Sweden,
December, 1914.

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SUMMARY

The main results and conclusions that will be found in this paper are the following. They relate to the radiation emitted by the atmosphere to a radiating surface at a lower altitude, and to the loss of heat of a surface by radiation toward space and toward the atmosphere at higher altitudes.

I. The variations of the total temperature radiation of the atmosphere are at low altitudes (less than 4,500 m.) principally caused by variations in temperature and humidity.

II. The total radiation received from the atmosphere is very nearly proportional to the fourth power of the temperature at the place of observation.

III. The radiation is dependent on the humidity in such a way that an increase in the water-vapor content of the atmosphere will increase its radiation. The dependence of the radiation on the water content has been expressed by an exponential law.

IV. An increase in the water-vapor pressure will cause a decrease in the effective radiation from the earth to every point of the sky. The fractional decrease is much larger for large zenith angles than for small ones.

V. The total radiation which would be received from a perfectly dry atmosphere would be about $0.28 \frac{\text{cal.}}{\text{cm.}^2\ \text{min.}}$ with a temperature of 20°C. at the place of observation.

VI. The radiation of the upper, dry atmosphere would be about 50 per cent of that of a black body at the temperature of the place of observation.

VII. There is no evidence of maxima or minima of atmospheric radiation during the night that cannot be explained by the influence of temperature and humidity conditions.

VIII. There are indications that the radiation during the daytime is subject to the same laws that hold for the radiation during the night-time.

IX. An increase in altitude causes a decrease or an increase in the value of the effective radiation of a blackened body toward the sky, dependent upon the value of the temperature gradient and of the humidity gradient of the atmosphere. At about 3,000 meters altitude of the radiating body the effective radiation generally has a maximum. An increase of the humidity or a decrease of the temperature gradient of the atmosphere tends to shift this maximum to higher altitudes.

X. The effect of clouds is very variable. Low and dense cloud banks cut down the outgoing effective radiation of a blackened surface to about 0.015 calorie per $cm.^2$ per minute; in the case of high and thin clouds the radiation is reduced by only 10 to 20 per cent.

XI. The effect of haze upon the effective radiation to the sky is almost inappreciable when no clouds or real fog are formed. Observations in Algeria in 1912 and in California in 1913 show that the great atmospheric disturbance caused by the eruption of Mount Katmai in Alaska, in the former year, can only have reduced the nocturnal radiation by less than 3.0 per cent.

XII. Conclusions are drawn in regard to the radiation from large water surfaces, and the probability is indicated that this radiation is almost constant at different temperatures, and consequently in different latitudes also.

CHAPTER I

PROGRAM AND HISTORY OF THE EXPEDITIONS

It is appropriate to begin this paper with a survey of the external conditions under which the work upon which the study is based was done. Most of the observations here given and discussed were carried out during two expeditions, one to Algeria in 1912, the other to California in 1913. An account of these expeditions will give an idea of the geographical and meteorological conditions under which the observations are made, and it will at the same time indicate the program of the field work, a program that was suggested by the facts referred to in the historical survey of previous work and by the ideas advanced in the chapter on the theory of atmospheric radiation.

In 1912 I was invited to join the expedition of the Astrophysical Observatory of the Smithsonian Institution, led by its Director, Dr. C. G. Abbot, whose purpose it was to study simultaneously at Algeria and California the supposed variations of the radiation of the sun. In May of that year I met Dr. Abbot at Bassour, a little Arab village situated about 100 miles from Algiers, in the border region between the Atlas Mountains and the desert, lying at 1,100 meters above sea level. This place had been selected by Dr. Abbot for the purpose of his observations on the sun, and on the top of a hill, rising 60 meters above the village, his instruments were mounted under ideal conditions. The same place was found to be an excellent station for the author's observations of the nocturnal radiation. A little house was built of boards by Dr. Abbot and myself on the top of the hill. This house, about 2 meters in all three dimensions, was at the same time the living room and the observatory. The apparatus used for the nocturnal observations was of a type which will be described in a later chapter. Its principal parts consist of an actinometer, to be exposed to a sky with a free horizon, a galvanometer, and a milliammeter. At Bassour the actinometer was mounted on the roof of the little observatory, observations of the galvanometer and the ammeter being taken inside. The horizon was found to be almost entirely free. In the north some peaks of the Atlas Mountains rose to not more than half a degree over the horizon, and in the southeast some few sandy hills screened off with their flat wave-like tops a very narrow band of the sky.

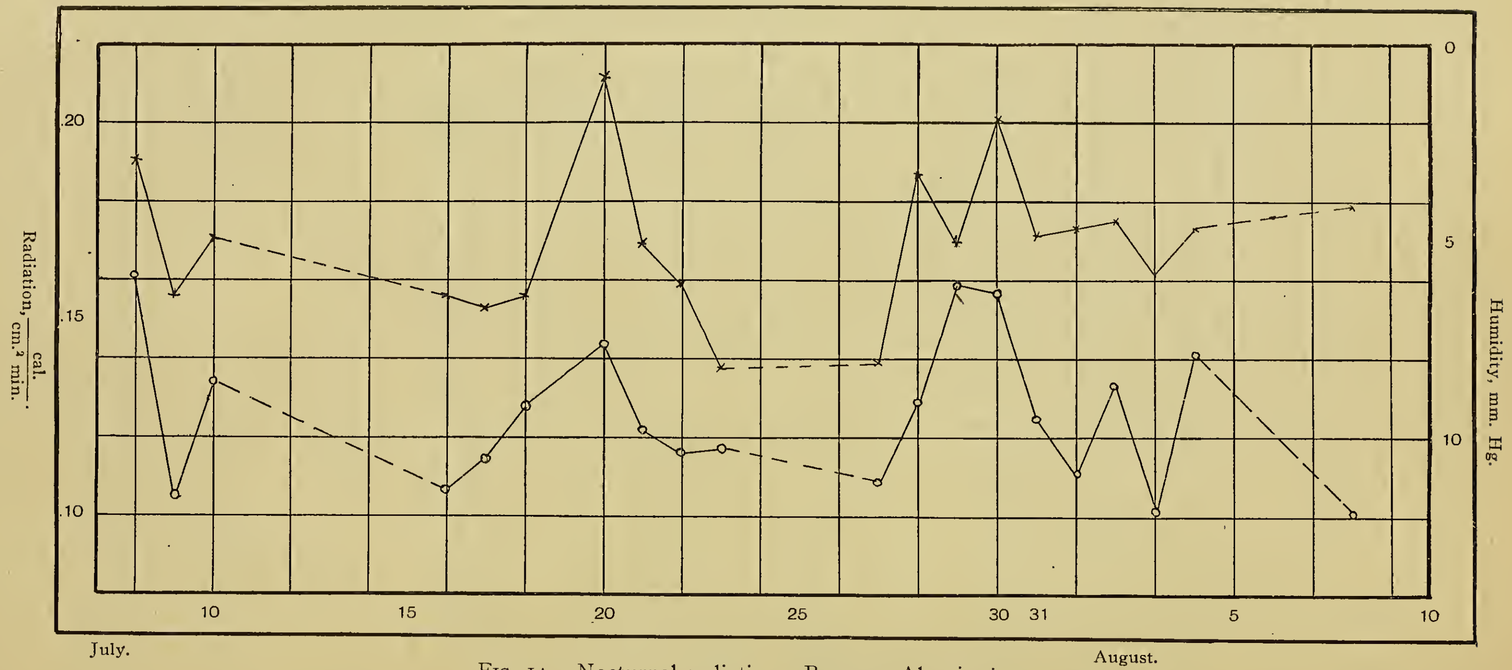

FIG. 1A.—Nocturnal radiation. Bassour, Algeria, 1912. Radiation, *x*; humidity, *o*.

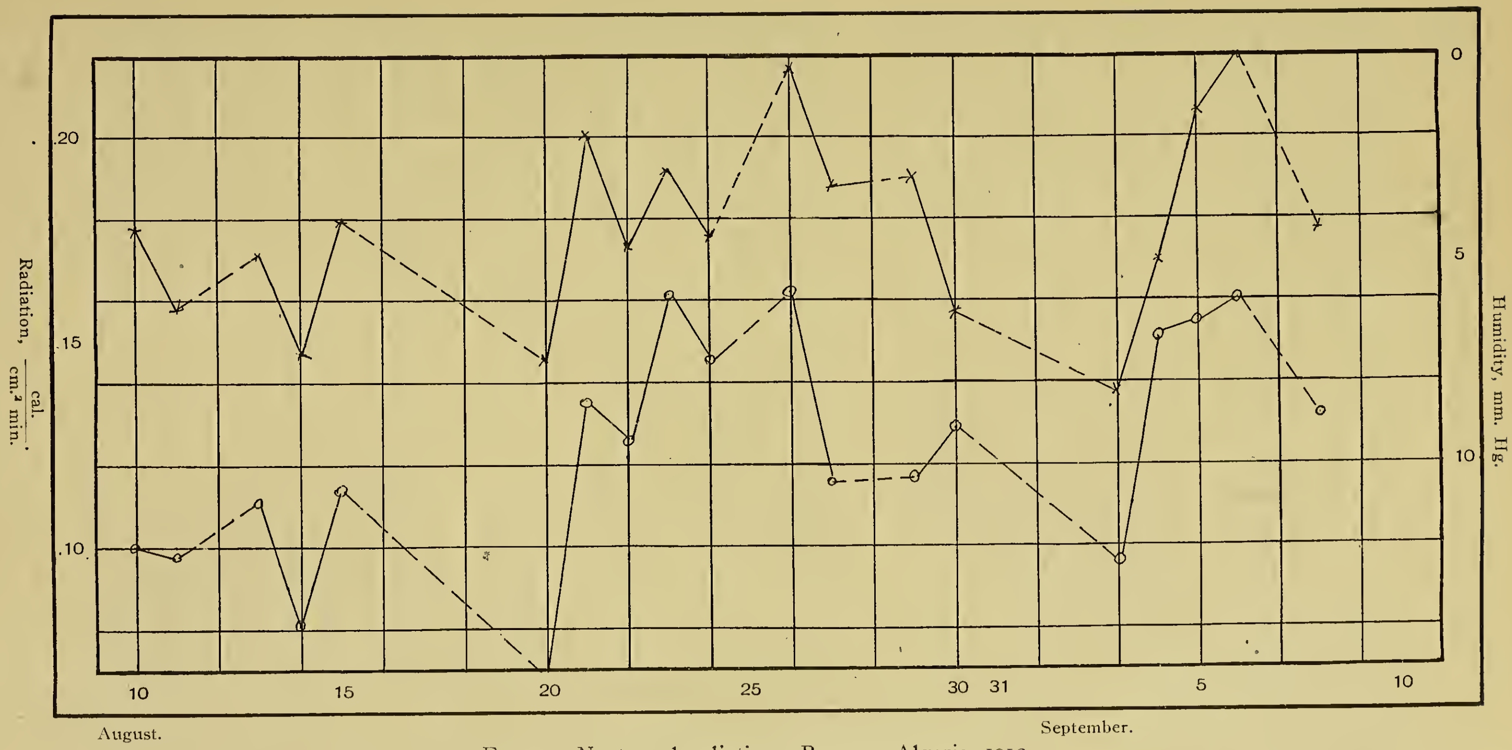

Fig. 1b.—Nocturnal radiation. Bassour, Algeria, 1912.
Radiation, *x*; humidity, *o*.

I was led by several circumstances to think that the nocturnal radiation to the sky would be found to be a function of the water-vapor content of the atmosphere and, as a consequence, observations were made with wet and dry thermometers simultaneously with the measurements of the radiation. In order not to introduce unnecessary influences that might modify this expected effect, it was considered important always to observe under a perfectly clear sky. It was found that a few scattered clouds, far from the zenith, seldom seemed to have any appreciable influence upon the radiation, but, in order not to introduce conditions of the effect of which one could not be quite sure, all the observations made at Bassour and used in this paper were made under a perfectly cloud-free sky. The climatic conditions were favorable for this program, and observations were taken almost every night under a clear sky. Observations were also made of the radiation to different parts of the sky, this study being considered as of special interest in connection with the general problem.

It was my purpose also to make an investigation of the influence of altitude upon the radiation to the sky, and in fact some preliminary measurements were carried out with a view to the investigation of that problem. Thus I made observations one night in the valley of Mouzaia les Mines, situated at the foot of the peak of Mouzaia among the Atlas Mountains, about 15 miles from Bassour. The height of the valley above sea level is 540 meters. Simultaneously Dr. Abbot observed at Bassour (1,160 m.) on this particular night, as well as during the following one, when I took measurements on the top of Mouzaia (1,610 m.). The result of these observations will be found among the investigations of the California expedition, one of the purposes of which was to consider more closely the problem of the influence of altitude upon the radiation of the atmosphere. For assistance with the practical arrangements in connection with the expedition to Mouzaia my hearty thanks are due to M. de Tonnac and M. Raymond, property owners.

As the most important result of the observations in Algeria it was found that the water vapor exerted a very marked influence upon the nocturnal radiation to the sky; a change in the water-vapor pressure from 12 to 4 mm., causing an increase in the nocturnal radiation amounting to about 35 per cent, other conditions being equal. From the observations it was possible to arrive at a logically founded mathematical expression for this influence.

A further investigation of the problem seemed, however, necessary. My special attention was directed to the influence of altitude and the influence of the temperature conditions of the instrument and of the atmosphere upon the radiation to the sky. For this purpose the climatic and geographic conditions of California were recommended as being suitable by Dr. Abbot.

There is probably no country in the world where such great differences in altitude are found so near one another as in California. Not far from Yosemite Valley, in the mountain range of Sierra Nevada, the highest peak in the United States, Mount Whitney, raises its ragged top to 4,420 meters, and from there one can look down into the lowest country in the world, the so-called Death Valley—200 meters below sea level. And further south, near the Mexican frontier, there is the desert of the Salton Sea, of which the lowest parts are below sea level; a desert guarded by mountain ranges whose highest peaks attain about 3,500 meters in altitude. In the summer the sky is almost always clear; a month and more may pass without a cloud being visible. It was evident that the geographical as well as the meteorological conditions of the country were very favorable for the investigations I contemplated.

On the advice of Dr. Abbot, I therefore drew up a detailed plan for an expedition to California, which was submitted to the Smithsonian Institution, together with an application for a grant from the Hodgkins Fund. The application was granted by the Institution, to whose distinguished secretary, Dr. Charles D. Walcott, I am much indebted for his great interest in the undertaking. The program for the expedition was as follows:

1. Preliminary observations at the top of Mount San Antonio (3,000 m.) and at Claremont (125 m.) simultaneously (3 nights).
2. Simultaneous observations at the top of Mount San Gorgonio (3,500 m.) and at Indio in the Salton Sea Desert (0 m.), (3 nights).
3. Expedition to Mount Whitney. Here the observations were to be extended to three stations at different altitudes, where simultaneous measurements should be made every clear night during a period of about two weeks. The stations proposed were: Lone Pine, at the foot of the mountain, at 1,200 m. altitude; the summit of Mount Whitney (4,420 m.); and an intermediate station on one of the lower ridges that project on the eastern side of the mountain. During this part of the expedition, as well as during the preliminary ones, the observations were to be made once an hour during the entire night, from 8 o'clock in the evening to 4 o'clock in the morn-

ing. It was proposed also to make pyrheliometric observations during the days on the top of Mount Whitney. These latter measurements, which are taken as a basis for determinations of the solar constant are given in an appendix written by Dr. Kennard and myself.[1]

The Mount Whitney part of the expedition was regarded as by far the most important, both on account of the higher altitude of the station, and because of the conveniences presented by the position on the top of the mountain, which made it possible to observe there during a considerable interval of time. Mount Whitney is too well known through the expedition of Langley (in 1881) and of Abbot (in 1909 and 1910) to need any description here. In the year 1909, the Smithsonian Institution erected—on the suggestion of Directors Campbell and Abbot—a small stone house on the summit as a shelter for future observers. Permission was given me by the Smithsonian Institution to use this shelter for the purposes of the expedition.

As the observations were to be made simultaneously in different places, several observers were needed. At this time (in the beginning of the year 1913) I was engaged in some investigations at the physical laboratory of Cornell University, Ithaca, N. Y., and from there I was enabled to secure the services of my friend, Dr. E. H. Kennard, as a companion and an able assistant in the work of the expedition. Further, Prof. F. P. Brackett, Director of the Astronomical Observatory of Pomona College, Claremont, California, promised his assistance, as also did Professor Williams and Mr. Brewster from the same college.

On the 8th of July, 1913, the author and Dr. Kennard arrived at Claremont, California, where Messrs. Brackett, Williams, and Brewster joined us. Through the kindness of Prof. Brackett the excellent little observatory of Pomona College was placed at my disposal as headquarters, and here the assistants were instructed, and the instruments—galvanometers, actinometers and ammeters—were tested.

On the 12th of July the first preliminary expedition was made, when the author and Mr. Brewster climbed to the summit of Mount San Antonio, the highest peak of the Sierra Madre Range (3,000 m.) and observed there during the two following nights. At the same time Prof. Brackett and Dr. Kennard observed at Claremont at the foot of the mountain, but unfortunately at the

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[1] This paper has also appeared in the Astrophysical Journal, Vol. 39, No. 4, May, 1914.

lower station the sky was cloudy almost the entire time, which condition, however, furnished an opportunity to demonstrate the effect of dense homogeneous cloud banks upon the nocturnal radiation.

The first simultaneous observations at different altitudes, favored by a clear sky at both stations, were obtained during a subsequent expedition, also of a preliminary nature, when the author and Mr. Brewster, proceeded to Indio in the Salton Sea Desert, and Prof. Brackett, Prof. Williams, and Dr. Kennard succeeded in climbing Mount San Gorgonio (3,500 m.), the highest peak of the San Bernardino range. Indio was chosen because of its low altitude (0 m.) and because of its meteorological conditions, the sky being almost always clear in this part of the desert. The horizon was almost perfectly free, the San Bernardino and San Jacinto mountains rising only to about 10° above the horizon. The temperature at the lower station, which is situated in one of the hottest regions of America, reached, in the middle of the day, a point between 40° and 46° C.; in the night-time it fell slowly from about 30° in the evening to about 20° in the morning. Here some interesting observations were obtained, showing the influence of temperature upon radiation to the sky. At the same time, the other party made observations on the top of Mount San Gorgonio (3,500 m.) situated about 40 miles farther north. The party climbed to the top in a heavy snowstorm, and during the two following, perfectly clear, nights, observations were taken, the temperature at the top being about 0° C. Thus simultaneous observations were obtained on two places differing in altitude by 3,500 meters.

The expedition to Mount Whitney, for which preparations were made immediately after the return of the parties to Claremont, was regarded as the most important part of the field work. On the proposal of Director Abbot, the U. S. Weather Bureau had resolved to cooperate with my expedition in this part of the undertaking. Under the direction of Mr. Gregg and Mr. Hathaway of that Bureau, the upper air was to be explored by means of captive balloons, carrying self-recording meteorological instruments. In this way the temperature and the humidity would be ascertained up to about 1,500 meters above the point from which the balloons were sent up. The ascents were to be made from Lone Pine (by Mr. Hathaway) and from the summit of Mount Whitney (by Mr. Gregg). The latter ascents are probably the first that have been carried on by means of captive balloons at altitudes exceeding 4,000 meters.

On July 29 the party, accompanied by Mr. Gregg and Mr. Hathaway of the Weather Bureau, left Los Angeles for Lone Pine, Inyo County, California. After arrival there in the morning a suitable place was found for the lower station, and final arrangements were made for the guide and pack train for the mountain party. The disposition of the observers was to be Ångström and Kennard at the upper station, Brewster and an assistant at the intermediate station, where observations were to be made only in the mornings and evenings, and, finally, Williams and Brackett at the lower station.

On Thursday, July 31, the mountain party set out from Lone Pine with Elder, the Mexican guide, a cook, a pack train of seven mules, and a light cart to convey the party up the incline to the foot of Lone Pine Canyon, whence the ascent would have to be made on foot or in the saddle. After some prospecting on the way, the intermediate station was located on a crag overlooking the canyon from a precipitous height of several hundred feet. Here Brewster was stationed and was later joined by a Mexican helper. Leaving Brewster, the party climbed that night to Elder's camp, at an elevation of nearly 3,000 meters. In spite of a storm which began with rain in the night and changed to snow, increasing in severity the next day, the summit was reached early in the afternoon. A thrilling electric storm raged for some time. Every point of rock and the tips of the nails and hair emitted electric discharges. But the little stone-and-iron building of the Smithsonian Institution furnished shelter. That the climbing of the mountain, with many instruments and a large pack train, succeeded without an accident, is largely due to the excellent work of Mr. G. F. Marsh, of Lone Pine, who had worked for weeks with a gang of 20 men to open up the trail, so that the ascent might be possible for men and pack animals carrying provisions, instruments, and fuel. Even so, in its upper reaches the trail passes over long slopes of ice and snow and clings to the face of naked and rugged steeps, where a false step would be fatal.

On the top of the mountain, a short distance from the house, is a little flat-roofed stone shelter about six feet square and eight feet high. In and upon this shed most of the instruments were set up.

On the whole, the weather upon the mountain was very favorable for the work of the expedition. Observations were made on seven nights out of a possible ten. Besides the hourly records of nocturnal radiation, the solar radiation was measured at suitable intervals throughout the day, and complete records were kept of the temperature, humidity, and pressure of the air at the summit. Strong winds interfered with the balloon ascents, but several of them were successful. During three nights records were obtained up to 400 to 1,000 meters above the station.

The observations at the lower stations have also proved to be very satisfactory. In the section on the experimental work the observations will be discussed in detail.

CHAPTER II

HISTORICAL SURVEY[1]

Insolation from the sun, on the one hand, and, on the other, radiation out to space, are the two principal factors that determine the temperature conditions of the earth, inclusive of the atmospheric envelope. If we do not consider the whole system, but only a volume element within the atmosphere (for instance, a part of the earth's surface) this element will gain heat: (I) through direct radiation from the sun; (II) from the portion of the solar radiation that is diffused by the atmosphere; (III) through the temperature radiation of the atmosphere. The element will lose heat through temperature radiation out to space, and it will lose or gain heat through convection and conduction. In addition to these processes, there will often occur the heat transference due to the change of state of water: evaporation, condensation, melting, and freezing. The temperature radiation from the element to space, diminished by the temperature radiation to it from the atmosphere, is often termed "nocturnal radiation," a name that is suggested by the fact that it has generally been observed at night, when the diffused skylight causes no complication. In this paper it will often be termed "effective radiation." The effective radiation out to the sky together with the processes of convection and conduction evidently under constant conditions must balance the incoming radiation from sun and sky. The problem of the radiation from earth to space is therefore comparable in importance to the insolation problem in determining the climatic conditions at a certain place.

The first observations relating to the problem of the earth's radiation to space are due to the investigations of Wilson,[2] Wells,[3] Six,[4] Pouillet,[5] and Melloni,[6] the observations having been made between the years 1780 and 1850. These observers have investigated the

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[1] Large parts of this chapter as well as of chapters III, IV and V: 1 have appeared in the Astrophysical Journal, Vol. 37, No. 5, June, 1913.

[2] Edinburgh Phil. Trans., Vol. 1, p. 153.

[3] Ann. de chimie et de physique, tome 5, p. 183, 1817.

[4] Six, Posthumous Works, Canterbury, 1794.

[5] Pouillet, Elément de physique, p. 610, 1844.

[6] Ann. de chimie et de physique, ser. 3, tome 22, pp. 129, 467, 1848. *Ibid.*, ser. 3, tome 21, p. 145, 1848.

nocturnal cooling of bodies exposed to the sky, a cooling that is evidently not only due to radiation but is also influenced by conduction and convection of heat through the surrounding medium. Melloni, making experiments in a valley called La Lava, situated between Naples and Palermo, found that a blackened thermometer exposed on clear nights showed a considerably lower value (3.6° C.) than an unblackened one under the same conditions. Melloni draws from his experiments the conclusion that this cooling is for the most part due to the *radiation* of heat to space. In fact, such a cooling of exposed bodies below the temperature of their surroundings was very early observed. Natives of India use it for making ice by exposing flat plates of water, on which dry grass and branches are floating, to the night-sky. The formation of ice, due to nocturnal radiation, has been systematically studied by Christiansen.

So far the observations have been qualitative rather than quantitative and the object of the observations not clearly defined. The first attempt to measure *the nocturnal radiation* was made by Maurer, the Swiss meteorologist. In the year 1886, Maurer published a paper dealing with the cooling and radiation of the atmosphere.[1] From thermometrical observations of the atmosphere's cooling he deduces a value $\delta = 0.007.10^{-4}$ (cm.^{3} min.) for the radiation coefficient of the air and from this a value for the radiation of the whole atmosphere: $0.39 \frac{\text{cal.}}{\text{cm.}^2 \text{ min.}}$ at 0°. This value is obtained on the assumption that the atmosphere is homogeneous, having a height of 8.10^5 cm. and by the employment of the formula

$$R = \frac{S}{a}\left[1 - e^{-ah}\right]$$

where S is the radiation, a the absorption coefficient and $h = 8.10^5$. Maurer's manner of proceeding in obtaining this value can scarcely be regarded as quite free from objection, and in the theoretical part of this paper I shall recur to that subject. But through his theory Maurer was led to consider the problem of the nocturnal radiation and to measure it.[2] His instrument consisted of a circular copper disk, fastened horizontally in a vertical cylinder with double walls, between which was running water to keep the cylinder at a constant temperature. The cover of the cylinder was provided with a circular diaphragm, which could be opened or shut. Opening and shutting this diaphragm at certain intervals of time, Maurer could,

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[1] Meteorologische Zeitschrift, 1887, p. 189.

[2] Sitzber. der Ak. der Wissensch. zu Berlin, 1887, p. 925.

from the temperature of the disk read on a thermometer, compute the radiation. He made his observations at Zürich during some clear nights in June and found a nocturnal radiation amounting to 0.13 cal. By this method, as well as by the similar method used by Pernter, certain corrections must be made for conduction and convection, and certain hypotheses must be made in order to compute the radiation to the whole sky from the radiation to a limited part of it given by the instrument.

The observations of Pernter[1] were made simultaneously on the top of Sonnblick (3,095 m.) and at Rauris (900 m.). He observed with an actinometer of the Violle type and found a radiation of 0.201 cal. (unless otherwise stated the radiation is always given as $\frac{\text{cal.}}{\text{cm.}^2\,\text{min.}}$ in this paper) at the higher station and 0.151 at the lower one.

Generally the methods for determining the effective radiation out to space have proceeded parallel—with a certain phase difference—with the development of the methods of pyrheliometry. In the year 1897, Homén[2] published an important paper bearing the title "Der tägliche Wärmeumsatz im Boden und die Wärmestrahlung zwischen Himmel und Erde." His method was an application of a method employed by K. Ångström for measuring sun radiation. The principal part of the instrument consists of two exactly equal copper plates. In the plates are introduced the junctions of a thermocouple. If now one of the plates is exposed to the radiation and the other covered, there will be a temperature difference between the disks growing with the time. If at a certain temperature difference, δ, the conditions are interchanged between the disks, they after a certain time, t, will get the same temperature. Then the intensity of the radiation is given by the simple formula:

$$Q = \frac{2W\delta}{t}$$

where W is the heat-capacity of the disks. By this method the effects of conduction and convection are eliminated. The weak point of the instrument, if applied to measurements of the nocturnal radiation, lies in the employment of a screen, which must itself radiate and cool, giving rise to a difference in the conditions of the two disks. Homén draws from his observations on the radiation between earth and sky the following conclusions:

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[1] Sitzber. der Ak. der Wissensch. zu Wien, 1888, p. 1562.

[2] Homén, Der tägliche Wärmeumsatz, etc., Leipzig, 1897.

(1) If the sky is clear, there will always be a positive radiation from earth to sky, even in the middle of the day.

(2) If the sky is cloudy, there will always, in the daytime, be a radiation from sky to earth.

(3) In the night-time the radiation for a clear as well as for a cloudy sky always has the direction from earth to sky.

Homén also made some measurements of the radiation to different parts of the sky and found that this radiation decreases rapidly when the zenith angle approaches the value 90°. His values of the nocturnal radiation vary between 0.13 and 0.22 for a clear sky.

When relatively large quantities of heat are to be measured under circumstances where the conduction and convection are subject to considerable variation, it is favorable if one can apply a zero method, where the instrument is kept the whole time at the temperature of its surroundings. As the first attempt to discover such a method may be regarded the experiment of Christiansen, who measured the thickness of ice formed on metal disks that were placed on a water-surface and exposed to the sky. In 1899 K. Ångström published a description of the compensation pyrheliometer and shortly afterward (1903) a modified type of this instrument was used by Exner[1] in order to measure the nocturnal radiation on the top of Sonnblick. In agreement with former investigations made by Maurer and Homén, Exner found the radiation to be relatively constant during the night. He points out that there are tendencies to a slight maximum of radiation in the morning, one to two hours before sunrise. To the method of Exner it can be objected that the radiation is only measured for a part of the sky. In order to obtain the radiation to the whole sky, Exner applied a correction with regard to the distribution of radiation to the different zones given by Homén. It will be shown in a later part of this paper that such a procedure is not entirely reliable.

In 1905 K. Ångström[2] gave a description of an instrument specially constructed for measuring the nocturnal radiation. The instrument is founded upon the principle of electric compensation, and, as it has been used in the work here published, I shall in a following chapter give a more detailed consideration of it. With this instrument Ångström measured the nocturnal radiation during several nights at Upsala and found values varying between 0.13 and

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[1] Met. Zt., 1903, p. 409.

[2] Nova Acta Reg. Soc., Sc. Upsal., Ser. 4, Vol. 1, No. 2.

0.18 cal. for a clear sky. With this type of instrument Lo Surdo[1] has made measurements at Naples. He observed the radiation during a clear and especially favorable night and found a pronounced maximum about two hours before sunrise. Contrary to Homén he finds a positive access of radiation from the sky even when the sky is clear. The following table gives a brief survey of the results obtained by different observers:

Observer	Date	Place	Temperature	Height	Mean Value
Maurer.....	June 13-18, 1887	Zürich	15°-18°	500	0.128
Pernter.....	Feb. 29, 1888	Sonnblick	—8°	3095	0.201
Pernter.....	Feb. 29, 1888	Rauris	......	900	0.151
Homén.....	Aug., 1896	Lojosee	......	....	0.17
Exner......	1902	Sonnblick	......	3106	0.19
Exner......	July 1, 1902	Sonnblick	......	3106	0.268 (max.)
K. Ångström	May-Nov., 1904	Upsala	0°-10°	200	0.155
Lo Surdo...	Sept. 5-6, 1908	Naples	20°-30°	30	0.182
A. Ångström	July 10-Sept. 10, 1912	Algeria	20°	1160	0.174

If we apply the constant of Kurlbaum $\sigma = 7.68.10^{-11}$, to the law of Stefan-Boltzmann for the radiation of a black surface, we shall find that such a surface at 15° C. temperature ought to radiate 0.526 cal. If the observed effective radiation does not amount to more, for instance, than 0.15 cal., this must depend upon the fact that 0.376 cal. is radiated to the surface from some other source of radiation. In the case of the earth this other source of radiation is probably to a large extent its own atmosphere, and in the following pages we shall often for the sake of convenience discuss this incoming radiation as if it were due to the atmosphere, ignoring the fact that a small fraction of it is due to the stars and planetary bodies.

Then the source of variations in the effective radiation to the sky is a double one. The variations depend upon the state of the radiating surface and also upon the state of the atmosphere. And the state of the atmosphere is dependent upon its temperature, its composition, density, the partial and total pressure of the components, and upon the presence of clouds, smoke, and dust from various sources.

The present paper is an attempt to show how the effective radiation, and consequently also what we have defined as the radiation of the atmosphere, is dependent upon various conditions of the atmosphere. It must be acknowledged that the conditions of the atmosphere are generally known only at the place of observation.

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[1] Nuovo Cimento, Ser. 5, Vol. 15, 1908.

But it has been shown by many elaborate investigations that, on an average, we are able, with a certain amount of accuracy, to draw conclusions about a large part of the atmosphere from observations on a limited part of it. This will be further discussed in a chapter on the distribution of water vapor and temperature conditions. The discussion of the observations will therefore be founded upon mean values, and will lead to a knowledge of average conditions.

CHAPTER III

A. THEORY OF THE RADIATION OF THE ATMOSPHERE

The outgoing effective radiation of a blackened body in the night must be regarded as the sum of several terms: (1) the radiation from the surface toward space (E_c) given, for a "black body," by Stefan's radiation law; (2) the radiation from the atmosphere to the surface (E_a), to which must be added the sum of the radiations from sidereal bodies (E_s), a radiation source that is indicated by Poisson by the term "sidereal heat." If J is the effective radiation, we shall evidently have:

$$J = E_c - E_a - E_s$$

For the special case where the temperature of the surface is constant and the same is assumed to be the case for the sidereal radiation, we can write:

$$J = K - E_a$$

K being a constant. Under these circumstances the variations in the effective radiation are dependent upon the atmospheric radiation only, and the problem is identical with the problem of the radiation from a gaseous body, which in this case is a mixture of several different components. As is well known from thorough investigations, a gaseous body has no continuous spectrum, but is characterized by a selective radiation that is relatively strong at certain points of the spectrum and often inappreciable at intermediate points. The law for the distribution of energy is generally very complicated and is different for different gases. The intensity is further dependent upon the thickness, density, and temperature of the radiating layer.

Let us consider the intensity of the radiation for a special wave length λ, from a uniform gaseous layer of a thickness R and a temperature T toward a small elementary surface $d\tau$. To begin with, we will consider only the radiation that comes in from an elementary radiation cone, perpendicular to $d\tau$, which at unit distance from $d\tau$ has a cross-section equal to $d\Omega$. One can easily deduce:

$$J_\lambda = \int_0^R \epsilon_\lambda e^{-a_\lambda r}\, dr\, d\Omega\, d\tau$$

which gives for unit surface:

$$J_\lambda = \frac{\epsilon_\lambda}{a_\lambda} \cdot d\Omega(1 - e^{-a_\lambda R}) \qquad (1)$$

where ϵ_λ is the emission coefficient and a_λ the absorption coefficient for the wave length λ.

Evidently:

$$\lim_{R=\infty} J_\lambda = \frac{\epsilon_\lambda}{a_\lambda} d\Omega = E_\lambda d\Omega \qquad (2)$$

where E_λ is the radiation from a black body for the wave length λ at the temperature T. It follows from this that, in all cases where one can assume a_λ to be independent of the temperature, ϵ_λ must be the same function of the temperature as E_λ multiplied by a constant. That means that the radiation law of Planck must always hold, as long as the absorption is constant:

$$\epsilon_\lambda = C\lambda^{-5} \frac{1}{e^{\frac{c_1}{\lambda T}} - 1}$$

If now the gas has many selective absorption bands we may write instead of (1):

$$J = \Sigma E_\lambda (1 - e^{-a_\lambda R}) d\Omega \qquad (3)$$

With the aid of (3) it is always possible to calculate the radiation for any temperature, if the absorption coefficient, which is assumed to be constant, is known.

If R is taken so great that the product $a_\lambda \cdot R$ has a very large value for all wave lengths, the expression (3) will become

$$\lim_{a_\lambda R=\infty} J = \Sigma E_\lambda = \sigma T^4 \qquad (4)$$

which is Stefan's radiation law for a black body.

If $a_\lambda R$ cannot be regarded as infinitely great for all wave lengths, the radiation, J, will be a more complicated function of T expressed by the general relation (3). The less the difference is between the radiation from the gas and the radiation from a black body at the same temperature, so much more accurately will the formula (4) express the relation between radiation and temperature.

Dr. Trabert[1] draws from observations on the nocturnal cooling of the atmosphere the conclusion that the radiation from unit mass of air is simply proportional to the absolute temperature. If this should be true, it can be explained only through a great variation of a_λ for a variation in the temperature. Later Paschen[2] and Very[3] measured in the laboratory the radiation from air-layers at different

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[1] Denkschriften der Wien. Akad., 59.

[2] Wied. Ann., 50, 1893.

[3] Very, Atmospheric Radiation, Washington, 1900.

temperatures and found a much more rapid increase with rising temperature than that indicated by Trabert.

From (3) we shall deduce some general laws for the radiation from gaseous layers. From such a layer the radiation will naturally come in from all sides, R being different for different angles of incidence. We may therefore write (3) in the form:

$$J=\overset{\gamma}{\Sigma}\overset{\lambda}{\Sigma}E_\lambda(1-e^{-a_\lambda\cdot\gamma R}) \qquad (5)$$

where γ is always a positive quantity. Now we have:

$$\frac{dJ}{dR}=\overset{\gamma}{\Sigma}\overset{\lambda}{\Sigma}E_\lambda a_\lambda\cdot\gamma\cdot e^{-a_\lambda\cdot\gamma R}$$

That is, we have the very evident result that the radiation of a gaseous layer increases with its thickness (or density). For very thick layers the increase is zero and the radiation constant.

By a second differentiation we get:

$$\frac{d^2J}{dR^2}=-\overset{\gamma}{\Sigma}\overset{\lambda}{\Sigma}(a_\lambda\cdot\gamma)^2e^{-a_\lambda\cdot\gamma R}$$

The second derivative is always negative, which shows that *the curve giving the relation between radiation and thickness is always concave toward the R-axis.*

We may now go a step further and imagine that on the top of the first layer is a new layer, which radiates in a certain way different from that of the first layer. A part of the radiation from the second layer will pass the first layer without being absorbed. That part we denote by H. Another fraction of the radiation will be absorbed, and it will be absorbed exactly at the wave lengths where the first layer is itself radiating. The sum of the radiations from the two layers can therefore be expressed by a generalization of (5)

$$\bar{J}=H+\overset{\gamma}{\Sigma}\overset{\lambda}{\Sigma}[E_\lambda-(E_\lambda-E'_\lambda)e^{-a_\lambda\cdot\gamma R}] \qquad (6)$$

where E'_λ is the radiation from the second layer at the wave length λ. If this layer has the same or a lower temperature than the first one, we evidently have:

$$E'_\lambda\leqq E_\lambda$$

In that case the laws given above in regard to the derivatives of J evidently hold, and we find here also that *the less the thickness of the layer is, so much more rapid is the increase of radiating power with increase in thickness.* This is true for a combination of several layers under the condition that the temperature is constant or is a decreasing function of the distance from the surface to which the radiation is measured. We shall make use of that fact in the experimental part of this paper, in order to calculate the maximum value of the radiation of the atmosphere when the density of one of its components approaches zero.

The relation

$$J = \Sigma E_\lambda (1 - e^{-a_\lambda \cdot R}) d\Omega$$

represents the general expression for the radiation within the radiation cone $d\Omega$ perpendicular to the unit of surface. Maurer bases his computation of the atmosphere's radiation upon the more simple expression

$$J = \frac{\epsilon}{a}(1 - e^{-aR})$$

where he puts R equal to the height of the reduced atmosphere and a equal to the absorption coefficient of unit volume. This is evidently an approximation that is open to criticism. In the first place it is not permissible to regard R as the height of the reduced atmosphere, and this for two reasons: first, because the radiation is chiefly due to the existence of water vapor and carbon dioxide in the atmosphere vapors, whose density decreases rapidly with increase in the altitude; and, secondly, because we have here to deal with a radiation that enters from all sides, R being variable with the zenith angle. But even if we assign to R a mean value with regard to these conditions, Maurer's formula will be true only for the case of one single emission band and is, for more complicated cases, incapable of representing the real conditions. I have referred to this case because it shows how extremely complicated are the conditions when all are taken into consideration.

If, with Maurer, we regard the atmosphere as homogeneous and of uniform temperature, having a certain height, h, we must, considering that R is a function of the zenith angle, write (1) in the following form:

$$J_\lambda = \frac{\epsilon_\lambda}{a_\lambda} \int d\Omega \left(1 - e^{-a_\lambda \cdot \frac{h}{\cos\Phi}}\right) \cos\Phi \qquad (7)$$

where the integration is to be taken over the hemisphere representing the space. Now we have

$$d\Omega = d\Phi d\psi \sin\Phi$$

and therefore

$$J_\lambda = \frac{\epsilon_\lambda}{a_\lambda} \int_0^{2\pi} d\psi \int_0^{\frac{\pi}{2}} \left(1 - e^{-a_\lambda \cdot \frac{h}{\cos\Phi}}\right) \sin\Phi \cos\Phi \, d\Phi \qquad (8)$$

This expression can easily be transformed into:

$$J_\lambda = \pi E_\lambda \left(1 - 2\rho^2 \int_\rho^\infty \frac{e^{-x}}{x^3}\,dx\right) \tag{9}$$

where $\rho = a_\lambda \cdot h$ and $x = a_\lambda \cdot \frac{h}{\cos\Phi}$. When $h \doteq 0$, this expression approaches zero; when $h \doteq \infty$, J_λ approaches the value πE_λ, which is equal to the radiation of a black body under the same conditions. We have, in fact:

$$\lim_{\rho=\infty} \rho^2 \int_\rho^\infty \frac{c^{-x}}{x^3}\,dx = \lim_{\rho=\infty} \frac{\frac{c^{-\rho}}{\rho^3}}{\frac{1}{2} \cdot \frac{1}{\rho^3}} = \lim_{\rho=\infty} \frac{c^{-\rho}}{2} = 0$$

and in a similar way:

$$\lim_{\rho=0} \rho^2 \int_\rho^\infty \frac{c^{-x}}{x^3}\,dx = \frac{1}{2}$$

We shall now consider in what respects these relations are likely to be true for the very complicated conditions prevailing in the atmosphere. The atmosphere, considered in regard to its radiating properties, consists of a *low radiating layer* up to about 10 km. made up of water vapor and carbon dioxide, and a *higher radiating layer* composed of carbon dioxide and ozone. These two layers naturally merge into one another, but it is convenient here to suppose a clear distinction, our surface of separation being at the altitude where the water vapor ceases to have any appreciable influence upon the radiation of the atmosphere.

The radiation of the lower layer is chiefly dependent upon the amount of water vapor contained in it, the strong radiation of the carbon dioxide being at wave lengths where the water vapor itself must radiate almost in the same way as a black body. At any rate, the *variations of the radiation* in that part of the atmosphere must depend almost entirely on the variations in the water-vapor element, the carbon-dioxide element being almost constant, as well in regard to time, as to place and to altitude. The probable slight influence of variations in the amount of ozone contained in the upper strata of the atmosphere, we may at present ignore. Including the constant radiation of the carbon dioxide in the radiation of the upper layer, we can apply the expression (5) and arrive at

$$J = H + \sum^{\gamma}\sum^{\lambda}\left[E_\lambda - (E_\lambda - E'_\lambda)\,e^{-a_\lambda \cdot \gamma R}\right] \tag{10}$$

where R can be put equal to the height of the reduced water-vapor atmosphere, or, what is the same, the amount of water vapor contained in a vertical cylinder of 1 cm.^{2} cross-section. Here a_λ has been considered as a constant. As has been shown by Miss von Bahr, the law of Beer does not, however, hold for vapors, absorption being variable with the total pressure to which the vapor is subjected. As will be seen in the experimental part of the paper, this circumstance has probably introduced a slight deviation from the conditions to be expected from the assumption of a constant value for a.

From (10) we draw a similar conclusion to the preceding: *with decreasing water-vapor content, the radiation of the atmosphere will also decrease and this decrease will be more rapid at a low water-vapor content than at a high one.*

The simplest form in which (10) can be written is obtained from the assumption that we can put:

$$H+\overset{\gamma\lambda}{\Sigma\Sigma}E_\lambda=K$$

and

$$\overset{\gamma\ \lambda}{\Sigma\Sigma}(E_\lambda-E'_\lambda)e^{-a_\lambda\gamma R}=Ce^{-a_m\gamma_m R}=Ce^{-\beta P}$$

where P is the height of the reduced water-vapor atmosphere. In such a case we shall obtain for the radiation of the atmosphere:

$$E_a=K-Ce^{-\beta P} \qquad (11)$$

and for the effective radiation:

$$J=E'+Ce^{-\beta P} \qquad (12)$$

We have heretofore supposed that the temperature of the radiating layer is constant. If that is not the case, it will introduce a new cause of variations. For every special wave length the radiation law of Planck will hold, but the integration will generally give a result different from the law of Stefan, dependent upon the different intensities of the various wave lengths relative to those of a black body. From the measurements of Rubens and Aschkinass on the transmission it can be seen, as will be shown later, that the radiation of the water vapor is very nearly proportional to the fourth power of the temperature, and as an approximation one may write:

$$E_a=\sigma T^4F(P)$$

or for the simple case (11):

$$E_a=cT^4(K''-e^{-\beta P})$$

Use will be made of these considerations in the treatment of the observations made.

B. DISTRIBUTION OF WATER VAPOR IN THE ATMOSPHERE[1]

In applying observations of the effective radiation toward the sky to determine a relation between the radiation of the atmosphere and its temperature and humidity, we are met by two great difficulties: First, the measurement of the total quantity of water contained in the atmosphere (I shall call this quantity hereafter the "integral water vapor" of the atmosphere); second, the determination of the effective atmospheric temperature.

There have been several elaborate investigations made of the water component of the atmosphere, by humidity measurements from balloons and on mountains, and indirectly by observations of the absorption, resulting from the water vapor, in the sun's radiation. Hann[2] has given the following formula, applicable to mountains, by which the water-vapor pressure at any altitude can be expressed as a function of the water-vapor pressure e observed at the ground. If e_0 is the observed water-vapor pressure in millimeters of mercury at a certain place, and h the altitude in meters above this place, the vapor pressure e_h at the height h meters is

$$e_h = e_0 e^{-\frac{h}{2730}} \tag{1}$$

In the free air the decrease of the pressure with altitude is more rapid, especially at high altitudes. From observations in balloons, Süring has given the formula:[3]

$$e_h = e_0 e^{-\frac{h}{2606}\left(1+\frac{h}{20}\right)} \tag{2}$$

If the atmosphere has the same temperature all through, the water element contained in a unit volume will be proportional to the vapor pressure. It is easy to see from the expression of Hann or of Süring that in such a case the integral water vapor will be proportional to the vapor pressure at the earth's surface. Through integration we shall get from Hann's formula:

$$F = 2.73 f_0 \cdot 10^3 \tag{3}$$

and from Süring's formula:

$$F = 2.13 f_0 \cdot 10^3 \tag{4}$$

where f_0 is the water content in grams per cm.^{3} at the earth's surface.

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[1] See the concluding part of the preface. The discussion here given is for the purpose of indicating how far observations of humidity and temperature at the earth's surface may take the place of detailed information obtainable only by balloon flights in the study of atmospheric radiation.

[2] Hann, Meteorologie, pp. 224-226.

[3] Arrhenius, Lehrbuch der Kosmischen Physik, p. 624.

When one wishes to compute the integral water vapor from the pressure, the fall of temperature will cause a complication. From (1) we get, instead of (3):

$$T_h \cdot f_h = T_0 f_0 e^{-\frac{h}{2730}}$$

where T_h denotes the absolute temperature at the altitude h meters. T_h is a function of the altitude. This function differs from time to time and can be known only by balloon observations, but for present purposes we may use an approximate formula for T_h. We may write, T_h is equal to T_0 when $h=0$ and T_h is equal to 0° at $h=\infty$. Also, we must have $\frac{dT}{dh}=0$ at $h=\infty$. Accordingly (as the temperature influence in the formula is not great) it may suffice to assume that *T on an average* can be expressed by an exponential function of the form:

$$T_h = T_0 e^{-ah} \qquad (6)$$

where a is to be determined by assuming that for $h=0$ $\frac{dT}{dh}$ is equal to the observed fall of temperature at the surface of the earth. For a fall of temperature of 0.7 degree per 100 m. one finds $a=0.03$. Introducing (3) into (1) we obtain the slightly different result for the integral water vapor:

$$F = 2.94 \cdot f_0 \cdot 10^3$$

and in a similar way from Süring's formula:

$$F = 2.30 \cdot f_0 \cdot 10^3$$

Hann's formula, which holds for mountain regions, indicates that here the element of water vapor contained in the atmosphere above a certain place is the absolute humidity at that place multiplied by a constant, the constant being independent of the altitude. This is not the case for the free air, if Süring's formula may be taken as a true expression of the conditions here prevailing. It is true that at a certain place we shall have $F=cf_0$, c being a constant, but this constant will differ at different altitudes. At an altitude of 4,400 m., we shall have

$$F = 1.8 \cdot f_{4,400} \quad \text{(free air)}$$

Fowle has made an interesting study of the absorption produced by water vapor in the sun's energy spectrum at Mount Wilson.[1] He also finds that the amount of water vapor contained in

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[1] Astrop. J., 37, N. 5, p. 359.

the air is proportional to f_0 under average conditions. Individual observations deviate, however, greatly from the computed value, which is to be expected in view of the variety of atmospheric conditions.

Briefly it may be said that the observations agree in showing that on an average the integral water vapor above a certain place is proportional to the absolute humidity at that place. The factor of proportionality is, however, in general a function of the altitude.

The application of these results to the present question means that we can replace the water content of the whole atmosphere (P) by the absolute humidity at the place of observation multiplied by a constant, the latter being a quantity it is possible to observe.

For the general case we thus obtain

$$E_a = \overset{\gamma}{\Sigma}(1 - e^{-\gamma f_0}) + H$$

or for the simplest possible case

$$E_a = K - Ce^{-\gamma f_0}$$

More difficult is the problem of assigning a mean value for the temperature of the radiating atmosphere. It is evident that this temperature is lower than the temperature at the place of observation, and it is evident that it must be a function of the radiating power of the atmosphere. The most logical way to solve the problem would be to write T as a function of the altitude and apply Planck's law to every single wave length. The radiation of the atmosphere would thus be obtained as a function of the humidity and the temperature; but even after many approximations the expression would be very complicated and difficult to test. The practical side of the question is to find out through observations how the radiation depends upon the *temperature at the place of observation.* Suppose this temperature to be T_0. We may consider a number of layers parallel with the surface of the earth, whose temperatures are T_1, T_2, T_3, etc. Suppose, that these layers radiate as the same function $cT_n{}^a$ of the temperature. Let us write: $T_1 = mT_0$; $T_2 = nT_0$; $T_3 = qT_0$. Then the radiation of all the layers will be:

$$J = cT_0{}^a \cdot [\alpha m^a + \beta n^a + \gamma q^a \dots .]$$

at another temperature t_0 the radiation will be:

$$i = ct_0{}^a \cdot [\alpha m_1{}^a + \beta n_1{}^a + \gamma q_1{}^a \dots .]$$

The condition that the whole layer shall radiate proportionally to this function cT_0^a, is evidently that we have:

$$m=m_1\,;\; n=n_1\,;\; q=q_1\ldots.$$

that is: *The temperature at every altitude ought to be proportional to the temperature at the zero surface.* This is approximately true for the atmosphere. In the above consideration of the question, the emissive powers, α, β, $\gamma\ldots.$, are assumed to be independent of temperature.

The discussion explains how it is to be expected that from the temperature at the earth's surface we can hope to draw conclusions about the temperature radiation of the whole atmosphere.

CHAPTER IV

A. INSTRUMENTS

For the following observations I used one or more nocturnal compensation instruments, *pyrgeometers* of the type described by K. Ångström in a paper in 1905.[1] Without going into details, for which I refer to the original paper, it may be of advantage to give here a short description of the instrument.

Founded on the same principle of electric compensation used in the Ångström pyrheliometer, the instrument has the general form indicated in figure 2. There are four thin manganine strips (M), of which two are blackened with platinum black, the other two gilded. On the backs of the metal strips are fastened the two contact points of a thermojunction, connected with a sensitive galvanometer G. If the strips are shaded by a screen of uniform temperature, the thermojunctions will have the same temperature, and we may read a certain zero position on the galvanometer. If the screen is removed and the strips are exposed to the sky, a radiation will take place, which is stronger for the black strips than for the bright ones, and there will be a deflection on the galvanometer due to the temperature difference between the strips. In order to regain the zero position of the galvanometer, we may restore the heat lost through radiation by sending an electric current through the black strips. Theoretical considerations, as well as experiments made, show that the radiation is proportional to the square of the current used, that is,

$$R = ki^2$$

where k is a constant that depends upon the dimensions, resistance, and radiating power of the strips. As the radiating power from the strips is difficult to compute, the constant k is determined from experiment with a known radiation. The strips are exposed to radiate to a black hemisphere of known temperature T_1, and the constant is determined by the relation:

$$ki^2 = \sigma(T^4 - T_1{}^4)$$

where T is the temperature of the strips. The advantage of this construction over the form used for instance by Exner and Homén, where the effects of conduction and convection are also eliminated,

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[1] Nova Acta Reg. Soc., Sc. Upsal., Ser. 4, Vol. 1, No. 2.

lies in the possibility of measuring the radiation to the whole sky and not only to a part of it, which is the case when one of the strips must be shaded. It must always be regarded as a dangerous approximation to compute the radiation to the whole sky from the radiation to a fraction of it, assuming a certain standard distribution of radiation to the different zones of the sky. The method of adding up

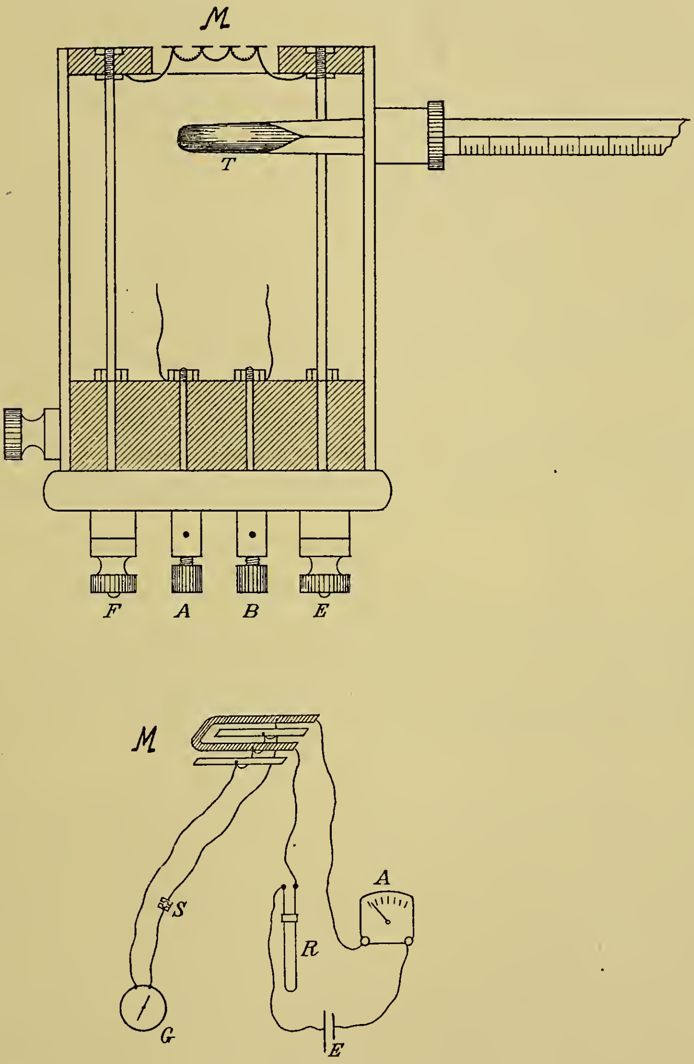

FIG. 2.—The Pyrgeometer.

different portions is too inconvenient and fails when the radiation is rapidly changing.

On the other hand, the value *k* is here dependent on the accuracy with which the radiation constant σ is determined. Further, since the emissive power of the strips, which is different for different wave lengths, enters into the constant *k*, this constant can be applied only for cases where the radiation is approximately of the same wave length as in the experiment from which *k* is computed. In the night-time this may be considered the case, the emissive power being the same for all heat waves longer than about 2 μ. But the instrument cannot, without further adjustment, be used for determining the radiation during the day, when the diffused radiation from the sky of short wave length enters as an important factor.

The constants of my three instruments, of which No. 17 and No. 18 were used at Bassour and California, and No. 22 in California, have been determined at the Physical Institute of Upsala on two occasions, before the expeditions by Dr. Lindholm of that Institute and after the expeditions by myself. The two determinations of the constants differ from one another only within the limits of probable error.

No.	Before	After	Mean
17	10.4	10.4	10.4
18	11.1	10.7	10.9
22	11.6	11.8	11.7

For the computations from the Algeria values the first values of the constants (for 17 and 18) have been used, for the California observations a mean value between them both. For the determination of the constants, Kurlbaum's value for σ has been used

$$\sigma = 7.68 \cdot 10^{-11}$$

not so much because this value is at present the most probable perhaps, as in order that observations with these instruments may be directly comparable with those of older ones. At any rate the relative values of the radiation must still be looked upon as the most important question.

The galvanometers that I have used were of the d'Arsonval type. They were perfectly aperiodic, and had a resistance of about 25 Ω and a sensitiveness of about $2 \cdot 10^{-8}$ amp. per mm. at meter distance. They generally showed a deflection of between 30 and 70 mm., when the strips were exposed to a clear sky. The galvanometers and the pyrgeometers were made by G. Rose, Upsala.

In the use of the compensation instrument one has to be careful that the instrument has had time to take the temperature of the surroundings before measurements are made. If the instrument is brought from a room out into the open air, one can be perfectly safe after ten minutes exposure. When measurements are made on the tops of mountains or at other places where the wind is liable to be strong, I have found it advantageous to place the galvanometer as near the ground as possible. By reading in a reclining posture one can very well employ the instrument box itself for the galvanometer support. Some heavy stones placed upon, at the sides, and at the back of the box will keep the whole arrangement as steady as in a good laboratory, even when the wind is blowing hard.

For the measurements of the current used for compensation milliammeters from Siemens and Halske were employed.

The measurements of the humidity, as well as of the temperature, were carried out with aid of sling psychrometers made by Green of Brooklyn. The thermometers were tested for zero, and agreed perfectly with one another.

In order to compute the humidity from the readings of the wet and dry thermometers I have used the tables given by Fowle in the Fifth Revised Edition of the " Smithsonian Physical Tables " 1910.[1]

B. ERRORS

The systematic error to which the constants of all the electric pyrgeometers are subject has already been discussed. There are however some sources of accidental errors in the observations, and I shall mention them briefly. The observer at the galvanometer will sometimes find—especially if there are strong and sudden wind gusts blowing upon the instrument—that the galvanometer does not keep quite steady at zero, but swings out from the zero position, to which it has been brought by compensation, and returns to it after some seconds. The reason for this is probably that the two strips are not quite at the temperature of the surroundings. From measurements on the reflection of gold, it appears that the bright strip must radiate about 3 per cent of the radiation of a black body, consequently it will remain at a temperature slightly lower than that of the surroundings, which will sometimes cause a slight disturbance due to convection, the convection being not perfectly equal for the two strips. Another cause of the same effect is the fact that the strips are covered

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[1] These tables are calculated from the formula

$$p = p_1 - 0.00066B\ (t - t_1)\ (1 + 0.00115t_1)$$

(Ferrel, Annual Report, U. S. Chief Signal Officer, 1886, App., 24).

by a diaphragm to about 1 mm. from the edges. On this part of its length the black strip will be heated but will not radiate, and the edges will therefore be slightly above the temperature of the surroundings. As I have made a detailed study of these edge-effects in the case of the pyrheliometer,[1] where I found that they affected the result only to about 1 per cent, I will not dwell upon them here. In the case of the pyrgeometer, the influence will result only in an unsteadiness of the zero, due to convection currents. The two mentioned effects will probably affect the result to not more than about ±2 per cent, even under unfavorable conditions.

Much larger are the accidental errors in the measurements of the humidity. The ventilated psychrometer, used in these measurements, has been subjected to several investigations and critical discussions and it is therefore unnecessary to go into details. It will be enough to state that the results are probably correct to within 5 per cent for temperatures above zero, and to within about 10 per cent for temperatures below 0°.

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[1] Met. Zeit., 8, 1914, p. 369.

CHAPTER V

1. OBSERVATIONS AT BASSOUR

The observations given in tables I and II were made at Bassour, Algeria, during the period July 10-September 10, 1912, at a height of 1,160 m. above sea level. In regard to the general meteorological and geographical conditions reference may be made to the introductory chapter. Every observation was taken under a perfectly cloudless sky, which in general appeared perfectly uniform. In regard to the uniformity of the sky, I may refer to chapter VI, where some observations are given that can be regarded as a test of the uniformity of the conditions.

Table I

Date	Time	*B*	Temperature	Δt	ρ	*R*
July 10	7:40	664.4	19.1	...	3.86	0.191
11	7:40	663.6	24.1	...	9.42	0.156
12	7:45	662.9	25.4	...	6.60	0.171
18	8:30	663.1	20.1	1.8	9.32	0.166
19	8:10	662.6	23.3	6.3	8.54	0.163
20	8:00	661.9	21.5	6.4	7.08	0.166
22	9:30	664.0	17.2	0.6	5.66	0.211
23	9:35	663.5	20.0	5.6	7.80	0.169
24	8:25	.....	19.5	5.7	8.36	0.159
25	8:35	664.9	18.8	—0.5	8.25	0.138
29	8:35	665.1	18.0	1.8	9.16	0.139
30	10:25	666.7	21.0	3.4	7.14	0.187
31	8:35	664.7	22.6	...	4.14	0.169
Aug. 1	9:45	662.3	23.8	4.2	4.40	0.201
2	8:55	662.9	20.3	2.4	7.54	0.171
3	9:05	.....	24.2	...	8.96	0.173
4	8:50	663.5	21.2	3.2	6.60	0.175
5	7:55	663.2	21.4	3.7	9.88	0.162
6	8:50	.....	23.6	3.3	5.89	0.173
10	8:50	665.7	25.0	3.3	9.98	0.178
11	8:20	666.9	22.8	2.7	10.20	0.158
13	9:00	662.7	19.5	1.5	8.86	0.171
14	10:00	662.6	18.6	0.0	11.90	0.147
15	8:30	665.4	20.6	—1.4	8.61	0.179
20	10:10	667.7	18.9	1.7	13.24	0.145
21	8:00	669.8	20.8	4.6	6.45	0.201
22	8:40	667.9	17.9	2.7	7.44	0.173
23	9:00	665.7	20.8	0.5	3.84	0.192
24	8:45	663.4	22.0	3.2	5.46	0.175
26	8:45	.....	21.5	...	3.80	0.217
27	9:05	.....	21.5	...	8.48	0.188
29	8:50	665.1	24.4	...	8.36	0.190
30	9:15	665.6	20.3	4.4	7.10	0.157
Sept. 3	8:35	664.3	13.8	4.2	10.40	0.138
4	8:05	666.7	11.1	...	4.98	0.169
5	9:50	664.0	20.8	2.1	4.57	0.205
6	9:30	661.5	20.0	2.4	3.99	0.220
8	9:00	666.7	15.7	—1.0	6.80	0.177

In table I are given: The date, the time of day, the barometric pressure *B*, the temperature of the air, the humidity (in mm. Hg.) ρ, and the effective radiation *R*. The temperature fall between the time of observation in the evening and the time of sunrise is indicated by Δt.

TABLE II

ρ	3.50–4.50			4.50–5.50			5.50–6.50		
	t	ρ	R	t	ρ	R	t	ρ	R
	19.1	3.86	0.191	22.0	5.46	0.175	17.2	5.66	0.211
	22.6	4.14	0.169	11.1	4.98	0.169	23.6	5.89	0.173
	23.8	4.40	0.201	20.8	4.57	0.205	20.8	6.45	0.201
	20.8	3.84	0.192	....	....	....	....	....	....
	21.5	3.80	0.217	....	....	....	....	....	....
	20.0	3.99	0.220	....	....	....	....	....	....
Means........	21.3	4.00	0.198	18.0	5.00	0.183	20.5	6.00	0.195
ρ	6.50–7.50			7.50–8.50			8.50–9.50		
	t	ρ	R	t	ρ	R	t	ρ	R
	25.4	6.60	0.171	20.0	7.80	0.169	24.1	9.42	0.156
	21.5	7.08	0.166	19.5	8.36	0.159	20.1	9.32	0.166
	21.0	7.14	0.187	18.8	8.25	0.138	23.3	8.54	0.163
	21.2	6.60	0.175	20.3	7.54	0.171	18.0	9.16	0.139
	17.9	7.44	0.173	21.5	8.48	0.188	24.2	8.96	0.173
	20.3	7.10	0.157	24.4	8.36	0.190	19.5	8.86	0.171
	15.7	6.80	0.177	....	....	....	20.6	8.61	0.179
Means........	20.4	6.98	0.173	20.7	8.13	0.169	21.4	8.98	0.164
ρ	9.50–10.50			11.90–13.24					
	t	ρ	R	t	ρ	R			
	21.4	9.88	0.162	18.6	11.90	0.147	....	....	....
	25.0	9.98	0.178	18.9	13.24	0.145	....	....	....
	22.8	10.20	0.158	....	....	....	....	....	....
	13.8	10.40	0.138	....	....	....	....	....	....
Means........	20.8	10.12	0.159	18.8	12.57	0.146	....	....	....

From figures 1a and 1b, where the radiation (crosses) and the humidity (circles) are given as functions of time, it is already evident that there must be a very close relationship between the two functions. In the figures the humidity values are plotted in the opposite direction to the radiation values. Plotting in this way we find that the maxima in the one curve correspond to the maxima in the other and minima to minima, which shows that low humidity and high effective radiation correspond and vice versa.

The observations of table I are now arranged in table II in such a way that all the radiation values that correspond to a water-vapor pressure falling between two given limits, are combined with one another in a special column. The mean values of humidity and radiation are calculated and plotted in a curve *aa*, figure 3, which gives the probable relation between water-vapor pressure and radiation. Tables I and II show that the temperature of the air, and consequently also that of the radiating surface, were almost constant for the different series and ought not, therefore, to have had any influence upon the form of the curve.

The smooth curve of figure 3 gives the relation between *effective radiation* and humidity. If we wish to know instead the relation between what we have defined as the radiation of the atmosphere and the humidity, we must subtract the value of the effective radiation from that of the radiation of a black body at a temperature of 20°. The curve indicates the fact, *that an increase in the water content of the atmosphere increases its radiation* and that *this increase will be slower with increasing vapor pressure.* It has been pointed out in the theoretical part that this is to be expected from the conditions of the atmosphere and from the laws of radiation. The relation between effective radiation and humidity can further be expressed by an exponential formula of the form:

$$R = 0.109 + 0.134 \cdot e^{-0.10p}$$

or

$$R = 0.109 + 0.134 \cdot 10^{(0.957-1) \cdot}$$

For the radiation of the atmosphere we get

$$E_a = 0.453 - 0.134 \cdot c^{-0.10p}$$

That the radiation of the atmosphere, as a function of the water-vapor pressure, can be given in this simple form is naturally due to the fact that several of the radiation terms given through the general expression (3), chapter III, have already reached their limiting values for relatively low values of the water-vapor density. These terms, therefore, appear practically as constants and are in the empirical expression included in the constant term.

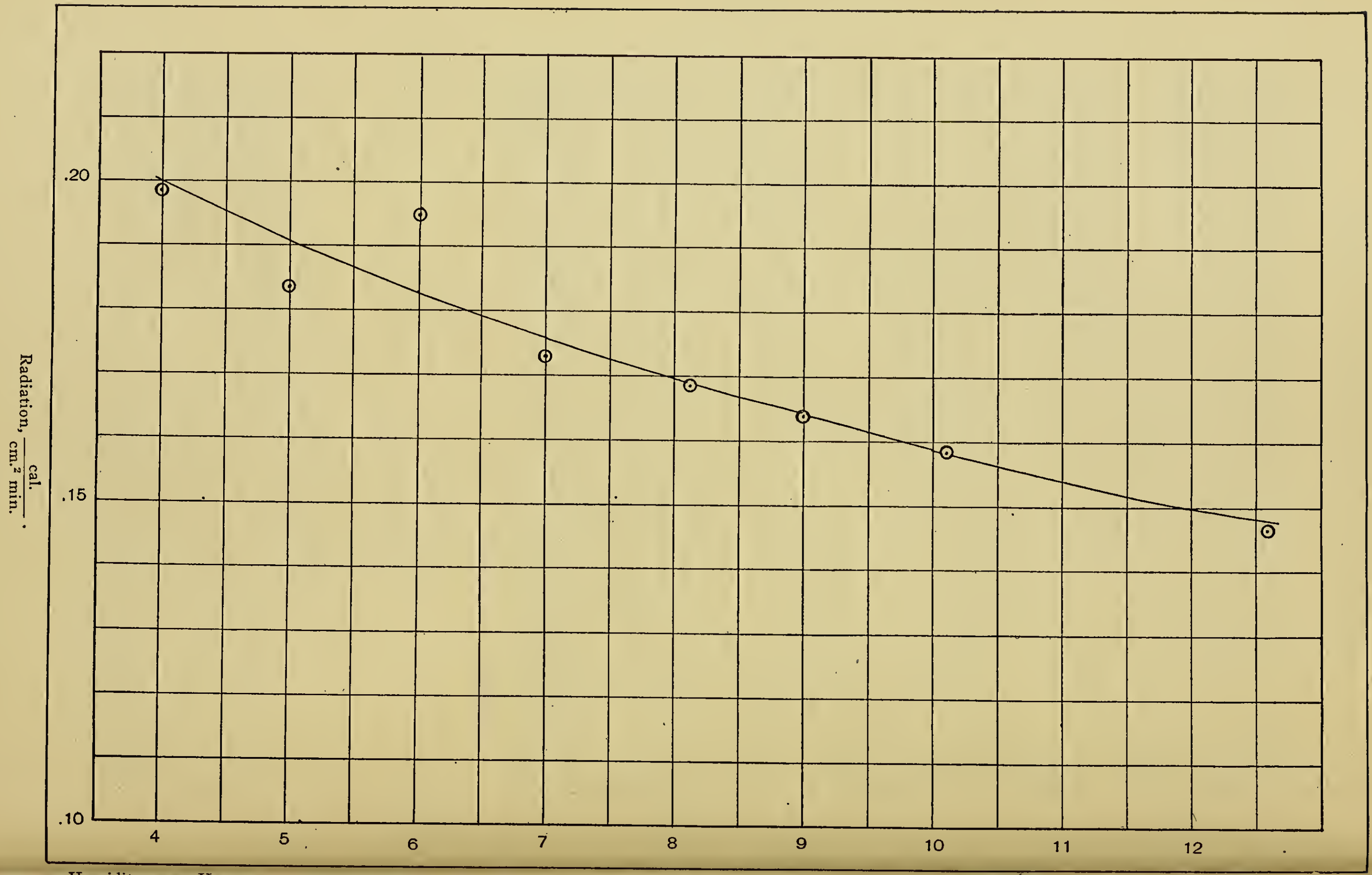

FIG. 3.—Nocturnal radiation and humidity, Bassour, 1912.

It is therefore evident that our formula can satisfy the conditions only between the limits within which the observations are made, and that in particular an extrapolation below 4 mm. water-vapor pressure is not admissible without further investigations. These conditions will be more closely considered in connection with the observations made on Mount Whitney, where the absolute humidity reached very low values.

For the case where ρ approaches very high values, the formula seems to indicate that the radiation approaches a value of about 0.11 cal., which may show that the water vapor, even in very thick layers, is *almost* perfectly transparent for certain wave lengths. This is probably only approximately true, and the apparent transparency would probably vanish totally if we could produce vapor layers great enough in density or thickness. In a subsequent chapter I shall discuss some observations that indicate that this is the case, and also that the formula given above must prove inadmissible for very great densities.

2. RESULTS OF THE CALIFORNIA EXPEDITION

The observations were taken simultaneously at different altitudes: (a) At Claremont (125 m.) and on the top of Mount San Antonio (3,000 m.); (b) at Indio in the Salton Sea Desert (0 m.) and on the top of Mount San Gorgonio (3,500 m.); and (c) at Lone Pine (1,150 m.), at Lone Pine Canyon (2,500 m.) and on the summit of Mount Whitney (4,420 m.).

A. INFLUENCE OF TEMPERATURE UPON ATMOSPHERIC RADIATION

Among the observations taken by this expedition I will first discuss some observations at Indio and Lone Pine separately, because they indicate in a very marked and evident way the effect upon the radiation of a very important variable, the temperature. The Indio observations of the effective radiation are given in table III and are graphically plotted in figures 17 and 18, where the radiation and the temperature during the night are plotted as functions of time. As will be seen from the tables, the humidity varied very little during these two nights.

As long as the temperature during the night is constant or almost constant, which is the case in mountain regions and at places near the sea, the effective radiation to the sky will not vary much, a fact that has been pointed out by several observers: Pernter, Exner, Homén, and others. But as soon as we have to deal with climatic conditions favorable for large temperature variations, the effective radiation to the sky must be subject to considerable changes also. Such conditions are generally characteristic of inland climates and are very marked in desert regions, where the humidity is low and the balancing influence of the neighborhood of the sea is absent. Indio is situated in a desert region. In the middle of the day the temperature reached a maximum value of 43° C. on the 23d and 46° C. on the 24th of July. In the evenings at about 8 o'clock the temperature was down to 30° C., falling continuously to values of 21° and 19° C., respectively, in the mornings at 4:30, when the observations ceased. From the curves it is obvious that there is a close relation between the radiation and the temperature. Every variation in the temperature conditions is accompanied by a similar change in the radiation. In fact *a decrease in the temperature of the surrounding air causes a decrease in the effective radiation to the sky.* This is even more obvious from the observations taken at Lone Pine on August 5 and August 10, when very irregular temperature variations took place during the nights. The humidity conditions appeared almost constant. From the curves (figs. 19 to 21) can be seen how a change in the one function is almost invariably attended by a change in the other.

In regard to the radiating surfaces of the instrument, one is pretty safe in assuming that the total radiation is proportional to the fourth power of the temperature, an assumption that is based upon the constancy of the reflective power of gold and of the absorption power of platinum-black soot within the critical interval. The radiation of these surfaces ought, therefore, to follow the Stefan-Boltzmann law of radiation. For the radiation of the atmosphere we thus get:

$$E_{at} = E_{st} - R_t$$

Knowing E_{st} and R_t, of which the first quantity is given by the radiation law of Stefan, to which I have here applied the constant of Kurlbaum ($\sigma = 7.68 \cdot 10^{-11}$), and the second quantity is the effective radiation measured, I can calculate the radiation of the atmosphere. We are led to try whether this radiation can be given as a function of temperature by an expression

$$E_{at} = C \cdot T^a \qquad (1)$$

similar in form to the Stefan-Boltzmann formula, and in which a is an exponent to be determined from the observations. From (1) we obtain:

$$\log E_{at} = \log C + a \log T$$

Now the observations of every night give us a series of corresponding values of E_{at} and T. For the test of the formula (1) I have chosen the observations at Indio during the nights of July 23 and 24, and at Lone Pine on August 5 and August 11. I have preferred these nights to the others because of the constancy of the humidity and the relatively great temperature difference between evening and morning values. By means of the formula connecting radiation and humidity obtained from the Algerian values at constant temperature, a small correction may be applied to these Californian observations, in order to reduce them to constant humidity. The logarithms of the radiation values thus obtained are calculated and also the logarithms of the corresponding temperatures, tables III and IV. If log E_{at} is plotted along the y-axis, log T along the x-axis, it ought to be possible to join the points thus obtained by a straight line, if the formula (2) is satisfied. The slope of this straight line ($\frac{dy}{dx}=$constant$=a$) ought in such a case to give us the value of a.

I have applied this procedure to the observations mentioned and found that within the investigated interval the logarithms of radiation and of temperature are connected to one another by a linear relation. Figure 4 gives the logarithm lines corresponding to the Indio observations. The deviations from the straight lines are somewhat larger for the Lone Pine values, but the discrepancies seem not to be systematic in their direction and I therefore think that one may regard the formula (1) as satisfied within the limits of the variation that can be expected as a result of the many atmospheric disturbances. The following table gives the values of a obtained from the observations on the four nights selected:

Place	Date	a	Weight
Indio	July 23	3.60	4
Indio	July 24	4.27	4
Lone Pine	August 5	4.4	1
Lone Pine	August 11	4.4	1

Weighted mean: $a=4.03$.

The table shows that the value of a is subject to considerable variations, which is a natural consequence of the great variations from the average conditions, to which the atmosphere is subject. In the following pages, when I have used the value 4.0 as an average value for a, in order to reduce the various observations to a constant temperature (20° C.), this procedure is held to be justified by the preceding discussion, as well as by the fact that, in applying this method of reduction, we obtain an almost constant value for the radiation during the night, if we reduce it to a constant humidity. For all other values of a, we shall get a systematic increase or de-

Table III—*Radiation and Temperature*

Indio, July 23, 1913

$273+t=T$	Log T	E_{at}	Log E_{at}
302.5	2.4807	0.447	0.6503—1
301.1	2.4787	0.435	0.6385—1
298.2	2.4745	0.421	0.6243—1
297.7	2.4738	0.419	0.6222—1
296.6	2.4722	0.423	0.6263—1
296.3	2.4717	0.415	0.6180—1
295.2	2.4701	0.409	0.6117—1
294.0	2.4683	0.402	0.6042—1

Indio, July 24, 1913

$273+t=T$	Log T	E_{at}	Log E_{at}
302.5	2.4807	0.461	0.6637—1
300.5	2.4778	0.446	0.6493—1
298.0	2.4742	0.435	0.6385—1
296.9	2.4726	0.424	0.6274—1
296.0	2.4713	0.418	0.6212—1
296.0	2.4713	0.418	0.6212—1
294.2	2.4686	0.405	0.6075—1
294.2	2.4686	0.405	0.6075—1
293.6	2.4678	0.405	0.6075—1
292.5	2.4661	0.407	0.6096—1

Table IV—*Radiation and Temperature*

Lone Pine, Aug. 5, 1913

$273+t=T$	Log T	E_{at}	Log E_{at}
297.6	2.4736	0.391	0.5922—1
296.0	2.4713	0.374	0.5729—1
290.1	2.4624	0.336	0.5263—1
294.4	2.4689	0.374	0.5729—1
288.6	2.4603	0.336	0.5263—1
285.4	2.4555	0.333	0.5224—1
287.8	2.4591	0.335	0.5250—1
287.4	2.4585	0.343	0.5353—1
287.4	2.4585	0.351	0.5453—1

Lone Pine, Aug. 11, 1913

$273+t=T$	Log T	E_{at}	Log E_{at}
293.5	2.4676	0.376	0.5752—1
297.6	2.4736	0.393	0.5944—1
296.2	2.4716	0.388	0.5888—1
293.7	2.4679	0.367	0.5647—1
291.9	2.4652	0.343	0.5353—1
287.3	2.4583	0.337	0.5276—1
285.0	2.4548	0.324	0.5105—1
284.8	2.4545	0.323	0.5092—1
282.8	2.4515	0.313	0.4955—1
283.0	2.4518	0.334	0.5237—1
281.9	2.4501	0.319	0.5038—1

crease in the radiation with the time owing to the fact that the temperature is always falling from evening to morning.

It is of interest to find that the value of a, thus determined, is in close agreement with the value deduced by Bigelow[1] from thermodynamic considerations of the heat processes to which the atmosphere is subject. Bigelow finds a to be equal to 3.82 and almost constant at various altitudes.

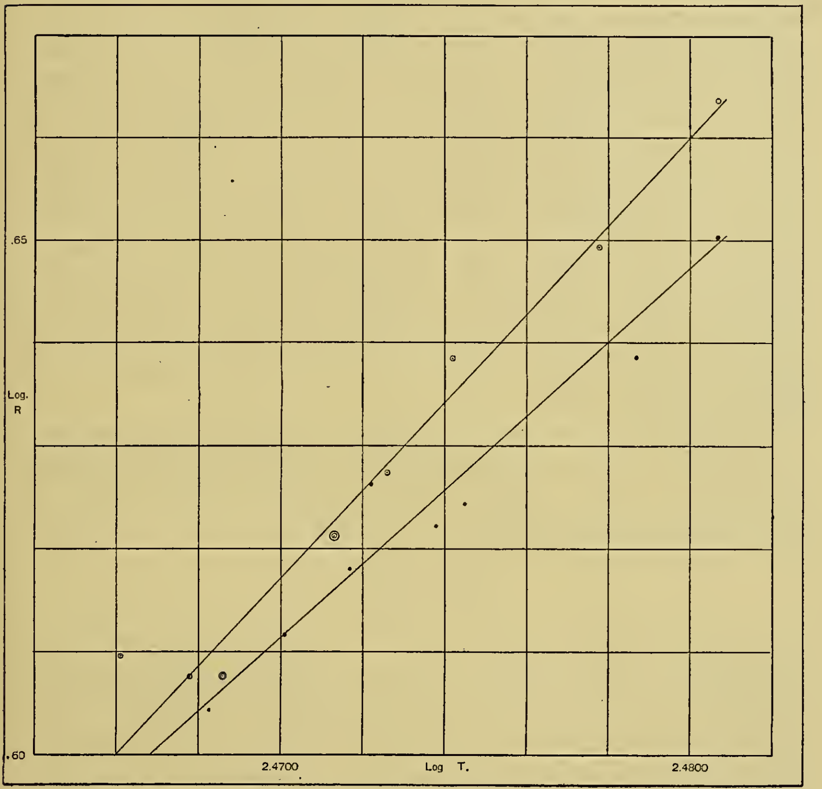

FIG. 4.—Atmospheric radiation and temperature. Indio, Cal., 1913.
Log E_{at} = Const. + a log T.

In regard to the connection that probably exists between the effective temperature of the air and the temperature at the earth's surface, I may refer to the theoretical treatment given in chapter III.

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[1] Boletín de la Oficina Meteorológica Argentina, Octubre, 1912, p. 15.

B. OBSERVATIONS ON THE SUMMITS OF MOUNT WHITNEY (4,420 M.), OF MOUNT SAN ANTONIO (3,000 M.), OF MOUNT SAN GORGONIO (3,500 M.), AND AT LONE PINE CANYON (2,500 M.).

These observations will be discussed further on in connection with the observations made simultaneously at lower altitudes. Here they will be considered separately in regard to the conditions of temperature and humidity prevailing at the high level stations. The problem to be investigated is this: Is the effective radiation, or the radiation of the atmosphere, at the high stations in any way different from the radiation found at lower altitudes, under the same conditions of temperature and humidity? Or is the average radiation of the atmosphere, at the altitudes here considered, a constant function of the temperature and the humidity? Will there not be other variables introduced when we move from one place to another at different altitudes? In the theoretical part I have pointed out some facts that ought to be considered in this connection and I then arrived at the conclusion that the effect on the radiation of temperature and humidity ought to prevail over other influences in the lower layers of the atmosphere.

The observations are given in tables 16 to 19. The tables also give the radiation of the atmosphere corresponding to each individual observation, as well as this radiation reduced to a temperature of 20° C. by means of the relation:

$$\frac{E_{\mathbf{a}t}}{E_{\mathbf{a}t_1}}=\left(\frac{T}{T_1}\right)^a$$

where a is assumed to have the same value as that obtained from our observations at Indio and at Lone Pine. The observations given in tables 16 to 19 are now arranged in tables V and VI in a way exactly similar to that which I have employed for the Algerian observations, except that in tables V and VI, I deal with the radiation of the atmosphere toward the instrument, instead of the reverse, as in table II. The relation of the two functions has been explained above.

From the tables it is seen that the Mount Whitney values, reduced in the way described, seem to fall to values a little lower than what would correspond to the form of the Algerian curve, as given above by the formula $E_{\mathbf{a}}=0.453-0.134\cdot e^{-0.10p}$. The reason for this discrepancy may be partly that the exponent a is not quite the same for thin as for thick radiating layers. This explanation is rendered unlikely by the calculations of Bigelow and the observations of Very and Paschen on radiating layers of moist air. But there are other

TABLE V—*Mt. Whitney and Mt. San Gorgonio*

p	0.5–1.0		1.5–2.0		2.0–2.5	
	p	E_a	p	E_a	p	E_a
	0.69	0.300	1.80	0.288	2.37	0.289
	0.69	0.303	1.91	0.295	2.37	0.316
	0.54	0.298	1.54	0.289	2.46	0.338
	0.54	0.297	1.88	0.274	2.46	0.337
			1.68	0.260	2.06	0.317
Means..........	0.62	0.299	1.70	0.339	2.06	0.334
			1.76	0.317	2.21	0.295
	1.0–1.5		1.76	0.306	2.21	0.267
			1.73	0.314	2.00	0.281
	p	R	1.81	0.312	2.00	0.262
			1.81	0.302	2.32	0.326
	1.17	0.300	1.86	0.318	2.32	0.319
	1.17	0.303	1.86	0.309	2.44	0.324
	1.02	0.325	1.90	0.304	2.44	0.327
	1.02	0.322	1.90	0.303	2.42	0.315
	1.12	0.316	1.83	0.308	2.42	0.315
	1.47	0.311	1.83	0.303	2.46	0.308
	1.47	0.393	1.93	0.298	2.46	0.314
	1.47	0.260	1.93	0.285	2.39	0.315
	1.32	0.323	1.52	0.335	2.39	0.309
	1.32	0.316	1.52	0.332	2.21	0.299
	1.40	0.316	....	.....	....	.....
	1.40	0.321	....	.....	....	.....
	1.14	0.276	....	.....	....	.....
Means..........	1.27	0.306	1.78	0.305	2.31	0.310

p	2.5–3.0		3.0–3.5		3.5–4.0	
	p	E_a	p	E_a	p	E_a
	2.95	0.300	3.07	0.351	3.80	0.277
	2.66	0.282	3.35	0.337	3.80	0.338
	2.61	0.288	3.35	0.345	3.75	0.306
	2.97	0.335	3.28	0.310	3.61	0.343
	2.90	0.344	3.28	0.304	3.79	0.345
	2.59	0.311	3.18	0.329	3.81	0.320
	2.59	0.308	3.15	0.350	3.70	0.302
	2.74	0.313	3.30	0.271	3.59	0.344
	2.74	0.302	3.23	0.327	3.59	0.330
	2.87	0.326	....	.....	3.51	0.356
	2.87	0.317	....	.....	3.51	0.351
	2.67	0.332	....	.....	....	.....
	2.67	0.317	....	.....	....	.....
Means..........	2.75	0.313	3.24	0.325	3.68	0.328

influences that are likely to produce a deviation of the same kind. Among these we will consider:

(1) The influence of the temperature gradient. It is evident that for a radiating atmosphere of low density, a larger part of the radiation reaching the surface of the earth must come from farther and therefore colder layers than for a dense atmosphere. From this it follows that a decrease in the density of the atmosphere must produce a decrease in its radiation in a twofold way: (A) in consequence of the diminished radiating power of the unit volume; and, (B) because of the simultaneous shifting of the effective radiating layer to higher altitudes.

(2) We must consider that the radiation is determined by the integral humidity, and that the water-vapor pressure comes into play only in so far as it gives a measure of this quantity. At a certain place we may obtain the integral humidity by multiplying the pressure by a certain constant; but this constant varies with the altitude. At sea level this constant has a value equal to 2.3 against 1.8 at the altitude of the summit of Mount Whitney; these values can be obtained from the formula of Süring, which has been discussed in a previous chapter.

This means that, in order to compare the integral humidities of two different localities as indicated by their absolute humidities, we should apply a reduction factor to the latter values. Thus, if the absolute humidity on the top of Mount Whitney is the same as at sea level (which naturally is unlikely to be the case at the same time), the integral humidity at the former place will be only $\frac{1.8}{2.4}$ of that at the latter.

(3) The coefficient of absorption, and consequently also that of the emission for a unit mass of water vapor, is a function of the total pressure to which it is subjected. This important fact has been revealed by the investigations of Eva von Bahr[1] who found that water vapor at a pressure of 450 mm. absorbs only about 77 per cent of what an identical quantity absorbs at 755 mm. pressure. The absorption coefficient will change in about the same proportion, and consequently the effective amount of water vapor (if we may use that term for the amount of water vapor that gives a constant radiation) will not be proportional to its mass but will be a function of the pressure, *i. e.,* a function also of the altitude. Miss v. Bahr's

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[1] Eva v. Bahr, Über die Einwirkung des Druckes auf die Absorption Ultraroter Strahlung durch Gase. Inaug. Diss., Upsala, 1908, p. 65.

measurements unfortunately do not proceed farther than to the water-vapor band at 2.7 μ and include therefore a part of the spectrum that is comparatively unimportant for the "cold radiation" with which we are dealing here. The maximum of radiation from a black body at 285 degrees absolute temperature occurs at about 10 μ, and

TABLE VI—*Mt. San Antonio and Lone Pine Canyon*

ρ	1.50–2.50		2.50–3.50		3.50–4.50	
	ρ	E_a	ρ	E_a	ρ	E_a
	2.27	0.310	2.54	0.363	3.63	0.348
	2.16	0.310	2.65	0.334	3.63	0.355
	1.63	0.309	3.24	0.340	3.91	0.357
	2.27	0.313	2.60	0.346	3.91	0.350
	1.99	0.324	3.23	0.357	3.53	0.361
	2.36	0.312	....	.....	4.23	0.334
	2.22	0.321	....	.....	4.07	0.345
	2.46	0.335	....	.....	3.75	0.334
	....	.....	....	.....	4.00	0.333
Means..........	2.17	0.317	2.85	0.348	3.85	0.346

ρ	4.50–5.50		5.50–6.50		6.50–7.50	
	ρ	E_a	ρ	E_a	ρ	E_a
	4.71	0.359	6.48	0.358	7.34	0.359
	5.27	0.346	6.35	0.362	6.53	0.367
	5.32	0.351	6.35	0.352		
	5.18	0.382	6.06	0.371	6.94	0.363
	5.04	0.375	5.93	0.378		
	5.04	0.397	5.88	0.374	7.50–8.50	
	....	.....	5.52	0.375		
	....	.....	6.09	0.391	ρ	E_a
	....	.....	5.98	0.383		
	....	.....	5.98	0.386	7.85	0.356
	....	.....	6.30	0.372	7.85	0.366
	....	.....	....	.....	7.63	0.376
Means..........	5.09	0.368	6.08	0.373	7.78	0.366

therefore we cannot apply the numerical results of Miss v. Bahr to the radiation of the atmosphere.

At any rate, the conclusion seems to be justified that if we take the absolute humidity at the place of observation as a measure for the radiating power of the integral water vapor, the result would be liable to give too high values at the higher altitude as compared with the lower one. This is actually the result of the observations. It therefore appears to me that the observations lend support to the view that the variations produced in the radiation of the lower atmosphere by a change of locality or by other influences are due to changes in the radiating power of the water vapor; changes that we are able to define, within certain limits, from observations of the temperature and the humidity at the surface of the earth.

I have now, without venturing to emphasize the absolute reliability of the procedure, applied a correction to the observed vapor pressure at different altitudes, in order that the pressure may give a true measure of the integral radiating power of the water vapor. Considering that at the altitude of Mount Whitney, the constant K in Süring's formula is 1.8, and that the total pressure there is only 44 cm., so that the absorption coefficient according to Miss v. Bahr's observations should be $\frac{16.5}{21.5}$ of the value corresponding to $p=66$ cm. (Lone Pine, Bassour), and finally that the pressure ought to be reduced to the temperature 20° C., I have used the reduction factor

$$\frac{1.8}{2.2}\cdot\frac{16.5}{21.5}\cdot\frac{273}{293}=0.68$$

for the humidity values taken at the summit of Mount Whitney (4,420 m.) and also for Mount San Gorgonio (3,500 m).

A similar consideration gives the reduction factor

$$\frac{2.0}{2.2}\cdot\frac{19.5}{21.5}\cdot\frac{288}{273}=0.84$$

for the measurements at Mount San Antonio (3,000 m.) and at Lone Pine Canyon (2,500 m.).

In this way the values plotted in figure 5 are obtained. We are now able to draw a continuous curve through the points given by the observations corresponding to various altitudes. With regard to the considerations that I have brought forward in the theoretical part, I have tried an expression of the form

$$E_a=K-Ce^{-\gamma p}$$

where

$$K=0.439,\ C=0.158,\ \text{and}\ \gamma=0.069.$$

This gives a fairly good idea of the relation between the radiation of the atmosphere at 20° C. and the humidity. The curve corresponding to this equation is given by a dotted line in figure 5. The expression adopted here does not fit the observations at high pressures so well as the expression given in connection with the discussion of the values obtained at Bassour, but it is better adapted to include in a general relation all the observations at different altitudes. As may be seen from the figure, the deviation from the curve is often considerable for single groups of values, but this can easily be explained as being due to deviations of the state of the atmosphere from its normal conditions and also to the fact that the mean value is often calculated from a few observations.

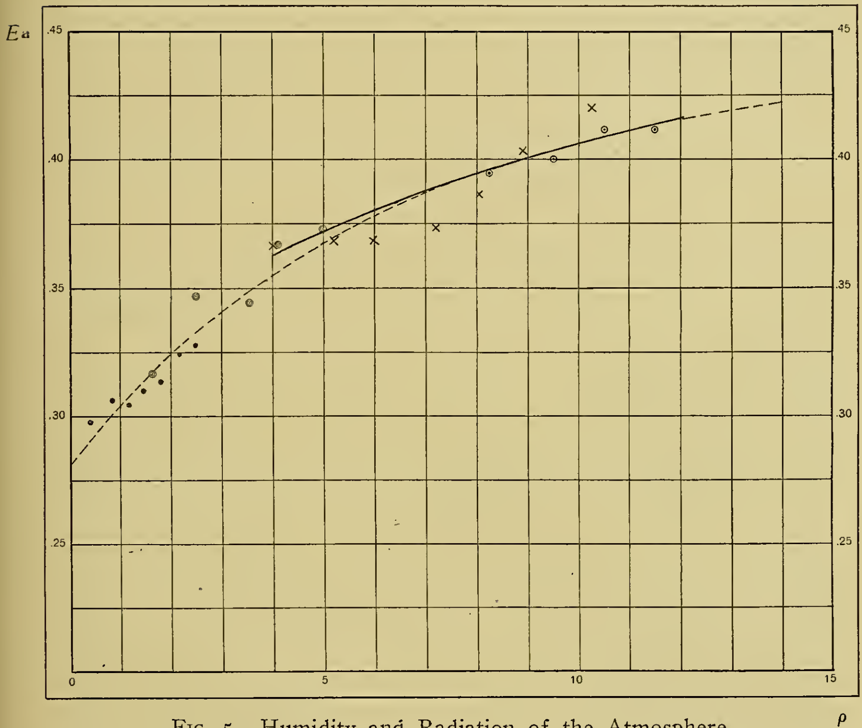

Fig. 5.—Humidity and Radiation of the Atmosphere.

Circles represent observations at Indio. Double circles represent observations at Mount San Antonio and at Lone Pine Canyon. Crosses represent observations at Lone Pine. Points represent observations at Mount San Gorgonio and at Mount Whitney.

It seems to me that the form of this curve enables us to draw some interesting conclusions about the radiation from the different constituents of the atmosphere. It must be admitted that the shape of the curve in the investigated interval does not allow of drawing any safe conclusions for points outside this interval, and particularly, as will be shown further on, the curve does not approach a limiting value of 0.439 cal. for very large values of ρ, as one would expect from the expression that has been adopted. On the other hand, the observations bring us very near the zero value of humidity and the question arises, whether we may not be entitled to attempt an extrapolation down to zero without causing too large an error in the limiting value. We wish to answer the question: how does the atmosphere radiate, if there is no water vapor in it? As I have pointed out previously, the possibility of an extrapolation to zero is doubtful, because in the non-homogeneous radiation of the water vapor there are certainly terms corresponding to wave lengths, where even very thin layers radiate almost to their full value. Consequently these have scarcely any influence upon the variations of the radiation from thicker layers. Will the curve that gives the relation between the radiation and the radiating mass of water vapor for values of the humidity lower than 0.4 show a rapid decline of which no indication is apparent in the investigated interval 0.4 – 12 mm.? For comparison I may refer to a curve drawn from a calculation by N. Ekholm[1] of the transmission of water vapor according to Langley and Rubens and Aschkinass. The curve represents the radiation from a black body at 15° temperature as transmitted through layers of water vapor of variable thickness. The same curve evidently also gives the radiation from the identical vapor layers, provided that the law of Kirchhoff holds, and that the water vapor itself is at 15°.

As far as the result may be depended upon, it apparently shows that laboratory measurements give no evidence whatever of a sudden drop in the radiation curve for very thin radiating layers. It would be rather interesting to investigate the radiation of the atmosphere compared with the radiation of the water vapor and of the carbon dioxide and possibly also that of the ozone contained in the upper layers, with proper regard to the temperature conditions and to careful laboratory measurements on the absorption and radiation of these gases. A first attempt in this direction is made by Ekholm. However, it appears to me that he does not give due attention to the fact that the magnitude of the effective radiation to space depends upon the capacity of the atmosphere to radiate back to the earth, and only indirectly upon the absorption capacity of the atmosphere. Quantitative calculations of the radiation processes within the atmosphere must necessarily take into consideration the temperature conditions in various atmospheric layers. The laboratory measurements upon which such a computation should be based are as yet very in-

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[1] Met. Zt., 1902, pp. 489-505.

complete and rather qualitative than quantitative, at least as regards water vapor. I have reason to believe that the careful observations of Fowle, of the Astrophysical Observatory of the Smithsonian Institution, will in the near future fill this gap.

From analogy with the absorbing qualities of water vapor, I think one may conclude that an extrapolation of the radiation curve (fig. 5) down to zero is liable to give an approximately correct result. The extrapolation for the radiation of a perfectly dry atmosphere at 20° C. gives a value of 0.281, which corresponds to a nocturnal radiation of 0.283 at the same temperature. At 0° C. the same quantities are 0.212 and 0.213 cal. and at $-8°$ they have the values 0.190 and 0.191, respectively. The latter value comes near the figure 0.201, obtained by Pernter on the top of Sonnblick at $-8°$ C. temperature.

These considerations have given a value of the radiation from a perfectly dry atmosphere, and at the same time they lead to an approximate estimate of the radiation of the upper atmosphere, which is probably chiefly due to carbon dioxide and a variable amount of ozone. The observations indicate a relatively high value for the radiation of the upper layers—almost 50 per cent of the radiation of a black body at the prevailing temperature of the place of observation. Hence the importance of the upper atmosphere for the heat-economy of the earth is obvious. The effect at places near the earth's surface is of an indirect character, as only a small fraction of the radiation from the upper strata reaches the earth's surface. But the importance of the upper layers for the protecting of the lower water-vapor atmosphere—the troposphere—against loss of heat, is entirely similar to the importance of the latter for the surface conditions of the earth. If we could suddenly make the upper atmosphere disappear, the effect would scarcely be appreciable at the earth's surface for the first moment. But the change would very soon make itself felt through a considerable increase in the temperature gradient. At places situated a few kilometers above the earth's surface, as, for instance, the summits of high mountains, the temperature would fall to very low values. As a consequence the conduction and convection of heat from the earth's surface would be considerably increased. Keeping these conditions in view, and in consideration of the high value of the radiation of the upper atmosphere—the stratosphere—indicated by the observations, I think it very probable that relatively small changes in the amount of carbon dioxide or ozone in the atmosphere, may have considerable effect on the temperature conditions of the earth. This hypothesis was first advanced by Arrhenius, that the glacial period may have been produced by a temporary decrease in the amount of carbon dioxide in the air. Even if this hypothesis was at first founded upon assumptions for the absorption of carbon dioxide which are not strictly correct, it is still an open question whether an examination of the " protecting " influence of the higher atmospheric layers upon lower ones may not show that a decrease of the carbon dioxide will have important consequences, owing to the resulting decrease in the radiation of the upper layers and the increased temperature gradient at the earth's surface. The problem is identical with that of finding the position of the effective layer in regard to the earth's radiation out to space. I propose to investigate this subject in a later paper, with the support of the laboratory measurements which will then be available.

C. OBSERVATIONS AT INDIO AND LONE PINE

Knowing the influence of temperature upon the radiation of the atmosphere, I can reduce the radiation values obtained at different places to a certain temperature. The function giving the relation between radiation and water-vapor content ought to be the same for every locality. Reducing the observations at Bassour, at Lone Pine, and at Indio (see tables VII and VIII) to 20° C., and plotting the mean values, we obtain a diagram of the aspect shown in figure 5. The values from Algeria are given by the smooth curve. The observations from Lone Pine (crosses) and the observations from Indio (circles) deviate more or less from the Algerian curve. Considering, however, that they are founded upon a very limited number of nights (Lone Pine 8, Indio 3), and that the mean deviation for all points is very inconsiderable, the result must be regarded as very satisfactory.

In regard to the general meteorological conditions at Lone Pine, it must be said that this place proved to be far from ideal for this kind of observation, the principal purpose here being, not to collect meteorological data, but to test a general law. The rapid changes in temperature and humidity during the nights must have had as a result that the atmosphere was often under very unstable conditions, widely differing from what may be regarded as the average. This is obvious also from the balloon observations of the U. S. Weather Bureau, made simultaneously with my observations during a couple of evenings at Lone Pine. These observations, made up to about 2,000 meters above the place of ascent, showed that there were often considerable deviations from the conditions defined by " the con-

TABLE VII—*Lone Pine*

ρ	3.50–4.50		4.50–5.50		5.50–6.50		6.50–7.50		7.50–8.50		8.50–9.50	
	ρ	E_a	ρ	E_a	ρ	E_a	ρ	E_a	ρ	E_a	ρ	E_a
	3.67	0.374	5.46	0.363	5.87	0.366	6.90	0.356	8.23	0.389	8.54	0.415
	3.67	0.382	4.71	0.381	5.79	0.358	6.99	0.397	8.05	0.387	8.99	0.419
	3.85	0.377	4.71	0.362	6.33	0.359	7.08	0.395	7.61	0.371	9.01	0.374
	3.85	0.346	5.30	0.369	5.97	0.360	7.07	0.385	8.39	0.411		
	4.49	0.368	5.30	0.371	5.96	0.379	7.47	0.399	8.11	0.407		
	4.49	0.357	5.08	0.363	6.40	0.377	7.48	0.359	8.13	0.406	8.85	0.403
	....	.....	5.08	0.352	6.12	0.381	7.48	0.369	8.03	0.408		
	....	.....	5.26	0.380	6.12	0.356	7.31	0.372	7.61	0.394		
	....	.....	5.26	0.389	5.78	0.371	7.31	0.369	8.29	0.394	9.50–11.50	
	....	.....	4.69	0.338	5.78	0.371	6.59	0.358	7.99	0.387		
	....	.....	5.37	0.365	5.78	0.363	6.59	0.522	7.38	0.360		
	....	.....	5.16	0.364	5.78	0.358	6.96	0.378	7.59	0.378	ρ	E_a
	....	.....	5.16	0.385	6.18	0.359	6.52	0.375	8.39	0.376		
	....	.....	5.36	0.349	6.18	0.372	7.18	0.394	8.43	0.395	10.01	0.407
	....	.....	5.36	0.356	5.78	0.351	7.18	0.374	8.29	0.402	10.24	0.419
	....	.....	5.42	0.405	5.78	0.365	7.25	0.360	8.47	0.379	10.50	0.423
	....	.....	....	.....	6.27	0.343	7.25	0.368	7.73	0.386	10.58	0.426
	....	.....	....	.....	6.27	0.384	7.38	0.373	8.28	0.389	10.20	0.420
	....	.....	....	.....	5.91	0.382	7.38	0.370	8.00	0.384	9.71	0.433
	....	.....	....	.....	5.91	0.397	7.48	0.359	8.44	0.389	10.11	0.415
	....	.....	....	.....	5.56	0.369	7.48	0.369	8.01	0.393	.....	.....
	....	.....	....	.....	5.56	0.367	....	.....	8.01	0.400	.....	.....
	....	.....	....	.....	....	.....	....	.....	8.23	0.393	.....	.....
	....	.....	....	.....	....	.....	....	.....	7.52	0.337	.....	.....
	....	.....	....	.....	....	.....	....	.....	7.52	0.347	.....	.....
	....	.....	....	.....	....	.....	....	.....	7.61	0.365	.....	.....
Means . .	4.00	0.367	5.17	0.368	5.96	0.368	7.16	0.373	8.02	0.386	10.19	0.420

stant temperature gradient" and by Süring's formula for the water-vapor pressure.

But the purpose of observations of the kind here described is a double one. In the first place, to find the general law for the average conditions, and in the second place to give an idea of the deviations likely to occur from these average conditions.

Table VIII—*Indio*

p	8.0–9.0		9.0–10.0			
	p	E_a	p	E_a		
	8.15	0.400	9.65	0.397	.....	.....
	8.43	0.393	9.37	0.398	.....	.....
	8.81	0.393	9.30	0.399	.....	.....
	....	.....	9.65	0.404	.....	.....
Means	8.46	0.395	9.49	0.400	.....	.....

p	10.0–11.0		11.0–12.0			
	p	E_a	p	E_a		
	10.31	0.402	11.86	0.436	.....	.....
	10.69	0.405	11.43	0.433	.....	.....
	10.97	0.410	11.13	0.438	.....	.....
	10.82	0.396	11.33	0.396	.....	.....
	10.52	0.395	11.30	0.391	.....	.....
	10.52	0.397	11.56	0.394	.....	.....
	10.47	0.402	11.41	0.396	.....	.....
	10.67	0.435	.....	.....	.....	.....
	10.77	0.440	.....	.....	.....	.....
	10.64	0.436	.....	.....	.....	.....
Means..........	10.64	0.412	11.43	0.412	.....	.....

D. THE EFFECTIVE RADIATION TO THE SKY AS A FUNCTION OF TIME

Exner[1] has made a comparison between the radiation values obtained at different hours of the night on the top of Sonnblick. He finds that there are indications of a maximum of radiation in the morning before sunrise.

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[1] Met. Zeitschrift (1903), 9, p. 409.

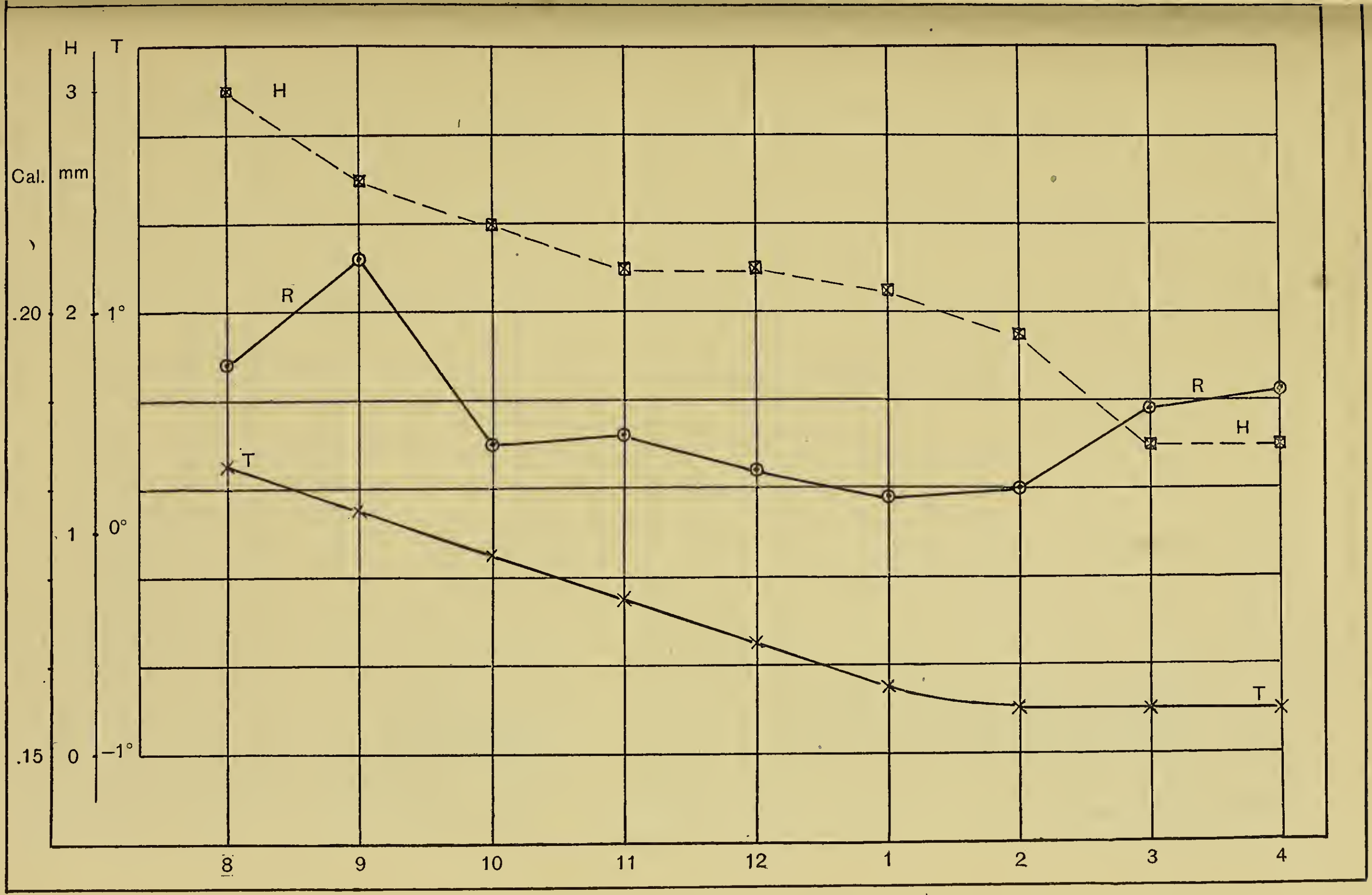

FIG. 6.—Mt. Whitney Night Observation of Humidity (*H*), Radiation (*R*), and Temperature (*T*).

From the observations on the nights of August 3, 4, 5, and 11 on the summit of Mount Whitney (during these nights the observations were carried on continuously from evening to morning), I have computed the means of the radiation, the temperature, and the humidity, corresponding to different hours. The result is given by figure 6, where the curve *RR* corresponds to the radiation; the curves *HH* and *TT* to the humidity and the temperature, respectively. The radiation decreases slowly from 9 o'clock in the evening to about 2 o'clock in the morning. At about 2:30 the radiation is subjected to a rapid increase; between 3 and 4 o'clock it keeps a somewhat higher value than during the rest of the night. The temperature, which shows a very continuous decrease from evening to morning, evidently cannot be regarded as a cause for these conditions. An examination of the humidity conditions shows however that the absolute humidity is subjected to a very marked decrease, which is perfectly simultaneous with the named increase in the effective radiation. Considering that the previous investigations, discussed in this paper, show that low humidity and high radiation correspond to one another, we must conclude that the maximum of radiation occurring in the morning before sunrise, is caused by a rapid decrease of the humidity at that time. It seems very probable to me that the maximum obtained by Exner from his observations on Sonnblick, may be explained in the same way.

E. INFLUENCE OF CLOUDS

The influence of clouds upon the radiation processes within the atmosphere is of very great importance for many meteorological questions. At the same time the problem is an immensely difficult one, because of the irregularities of the fundamental phenomenon itself. Take the question of the influence of the conditions of the atmosphere upon the amount of radiation reaching us from the sun. When the sky is clear, we can probably calculate from a single observation, or a couple of observations, together with one or two known facts, the whole access of radiation during the day to within perhaps 5 per cent. But as soon as clouds are present, we have to fall back upon continuous observations, the occurrence and density of the clouds, and the time of their appearance being subject to no known general law that holds for such small intervals of time as we wish to consider. Moreover the influence of clouds upon the solar radiation is very great, the radiation being reduced to a very small fraction of its former value by the interference of a cloud. Similar conditions hold in regard to the effective radiation to the sky. As this

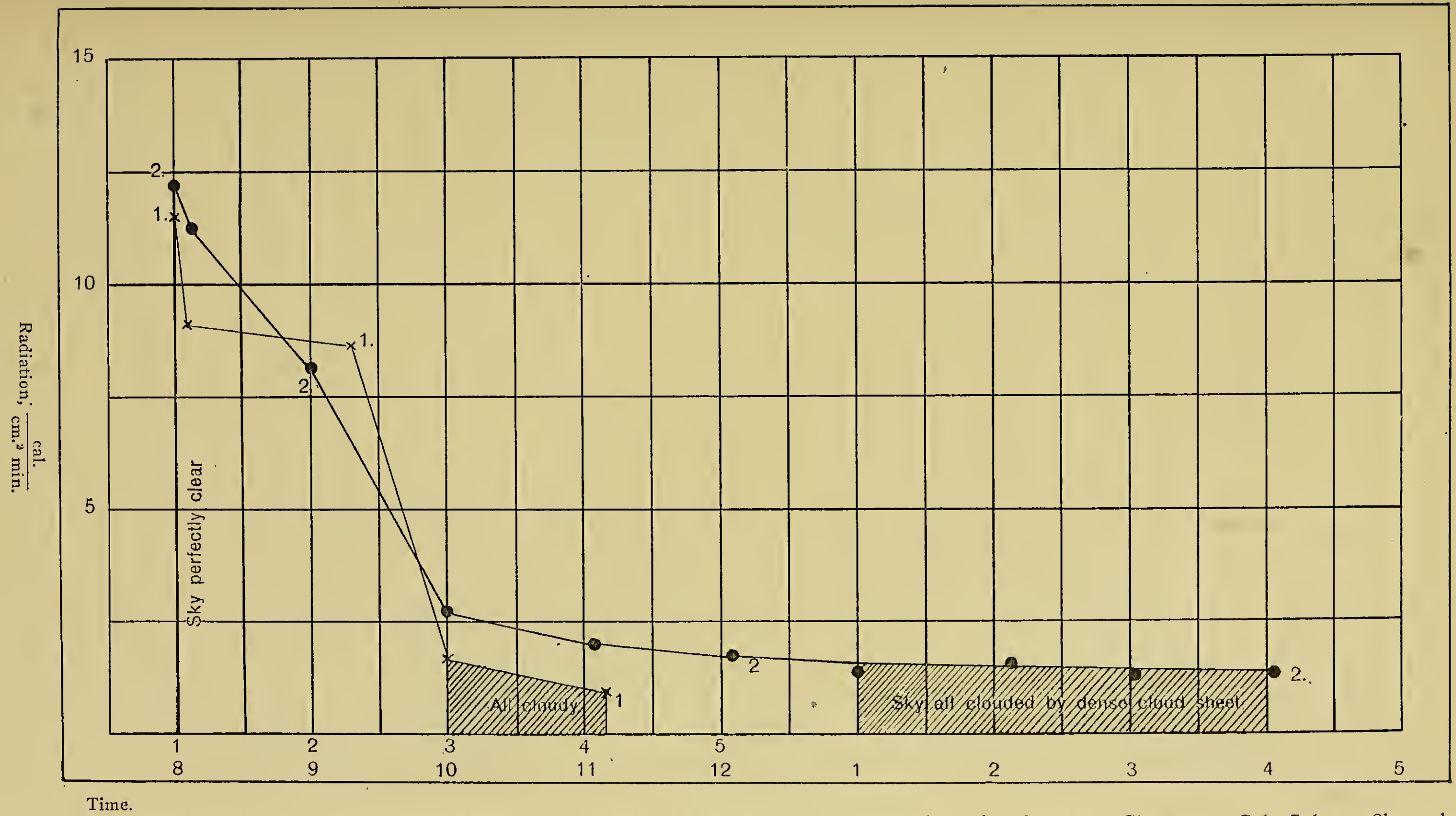

Fig. 7.—Effect of clouds on nocturnal radiation Curve 1: Claremont, Cal., July 12, 1^h to 5^h. Curve 2: Claremont, Cal., July 13, 8^h to 4^h

radiation goes out in all directions, the influence of a single cloud will be more continuous than is the case for the solar radiation. As soon as the cloud comes over the horizon it will begin to affect the radiation to the sky, its influence growing as it approaches the zenith. This will be rendered clearer, and details will be afforded, by the observations on the radiation to different parts of the sky, given in a later chapter.

It is evident that, when the sky is cloudy, we can distinguish between three radiation sources for the atmospheric radiation: First, the radiation from the parts of the atmosphere below the clouds; secondly, the part of the radiation from the clouds themselves, which is able to pass through the inferior layer, and, in the third place, the radiation from the layers above the clouds, of which probably, for an entirely overcast sky, only a very small fraction is able to penetrate the cloud-sheet and the lower atmosphere.

Some measurements were taken in the case of an entirely overcast sky. Figure 7 shows two curves drawn from observations at Claremont. In the beginning the sky was perfectly clear, at the end it was entirely covered by a low, dense cloud-sheet: cumulus or stratocumulus.

In general the following classification seems to be supported by the observations:

	Average radiation
Clear sky	0.14-0.20
Sky entirely overcast by:	
Cirrus, cirrostratus and stratus	0.08-0.16
Alto-cumulus and alto-stratus	0.04-0.08
Cumulus and strato-cumulus	0.01-0.04

Especially in the northern winter climate, the sky is very often overcast by more or less dense sheets of stratus clouds. They are very often not dense enough to prevent the brighter stars being very easily seen through them, and especially in the night it is therefore often difficult to tell whether the sky is perfectly clear or not. Dr. Kennard proposed to me that one should use the visibility of the stars (1st, 2d, 3d, and 4th magnitude, etc.) to define the sky, when it seemed to be overcast or very hazy. This may be of advantage, especially when observations are taken in the winter time or extended to hazy conditions.

CHAPTER VI

RADIATION TO DIFFERENT PARTS OF THE SKY[1]

In the foregoing chapters an account has been given of observations showing the influence of humidity and temperature conditions upon the effective radiation to the sky. There the total radiation to the sky was considered, independent of the fact that this radiation takes place in different directions. The thing measured represented an integral over the whole hemispherical space. About the different terms constituting the sum this integral gives us no idea.

In the historical survey I have referred to the interesting investigations of Homén, and mentioned his observations of the nocturnal radiation to *different parts of the sky*. Homén observed, with a somewhat modified Ångström pyrheliometer, of type 1905, where two metal disks were exposed to the sky alternately and their temperature difference at certain moments read off. In order to measure the radiation in various directions Homén used a screen arrangement, which screened off certain concentric zones of the sky. The chief objection to this method seems to me to be that the radiating power of the soot will be introduced as a variable with the direction, and as this quantity is not very well defined an error will probably be introduced, which, however, can scarcely amount to more than about 2 per cent. Homén found that the distribution of the radiation upon the different zones of the sky was almost constant for different values of the total radiation. As Homén's measurements have since been employed in extending, to represent the whole sky,[2] observations of the radiation toward a limited part of the sky, and as the question itself seems to be of interest for the knowledge of atmospheric radiation in its dependence upon other conditions, I have thought it valuable to investigate in what degree this distribution of radiation over the sky is subject to variations. For this purpose the arrangement shown schematically in figure 8 was found to be a satisfactory one.

To the electrical compensation instrument, which has been described, can be attached a hemispherical screen, *abcdef,* whose radius is 7.1 cm. From this screen can be removed a spherical cap *cd,* which

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[1] Large parts of this chapter were published in the Astrophysical Journal, Vol. 39, No. 1, January, 1914.

[2] Exner (1903), *loc. cit.*

leaves a hole of 32° plane angle open to the sky. The screen is brightly polished on the outside, but blackened on the inside, in order to avoid multiple reflections.

The instrument to which this arrangement was attached was pointed to different parts of the sky, and the zenith angle was read in a circular scale, as is shown in figure 8. The value of the radiation within the solid angle *csd* (32°) was obtained in the usual way by determining the compensation current through the black strip. This arrangement has two obvious advantages over a bolometer arranged in a similar way. In the first place, the instrument is very steady and quite independent of air current, because both strips are here exposed in exactly the same way. The readings must further be quite independent of the position of the strips, it being possible to turn the instrument over in different directions without change in the sensitiveness. Everyone who is familiar with bolometric work knows the difficulty that sometimes arises from the fact that the

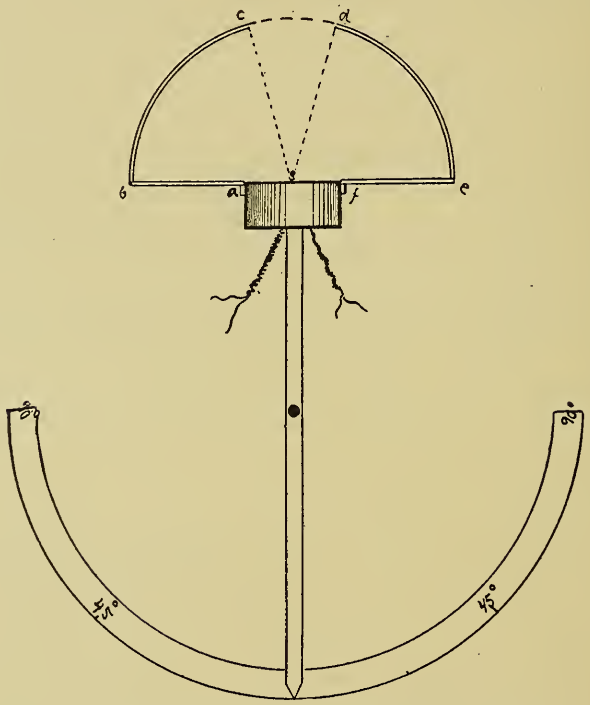

Fig. 8.—Apparatus used for determining the radiation to different parts of the sky.

sensitiveness of the bolometer changes with its position, the conductivity of heat from the strips through the air being different for vertical and horizontal positions. On the other hand, the sensitiveness of my apparatus, used in this way, was not very great. When the instrument was directed to points near the horizon the deflection of the galvanometer seldom amounted to more than about 2 mm., and for zenith position the deflection was about 6 mm. The probable error in every measurement is therefore about 5 per cent. In spite of this disadvantage, a comparison between the values of the total radiation observed and the total radiation computed from the observations of the radiation to the different zones shows a fairly close agreement.

If the dimensions of the strips can be regarded as negligible in comparison with the radius of the screen, we may assume the effective solid angle to be equal to the solid angle under which the central point of the instrument radiates to the hole. Now this is not exactly the case, and in computing the total radiation from the radiation to the limited parts of the sky, we must apply a correction with regard to the position of the strips. The mean solid angle is obtained through an easily effected but somewhat lengthy integration process given in the foot-note.[1] It is found to be 768.6°.

The correction term will make 1.5 per cent in the solid angle, a quantity that is not negligible when we wish to calculate the total radiation.

When the instrument is pointed in different directions, different parts of the strips will radiate to slightly different regions of the sky. In the process used for finding the distribution of radiation

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[1] Let us consider a circular hole of the radius ρ, radiating to a plane surface, parallel with the hole and at the vertical distance R from it. We wish to find the radiation T to a little elementary surface, $d\tau$, whose distance from the perpendicular from the central point of the hole, is l. Using cylindric coordinates, and defining the element of the hole (do), through the relation:

$$do = \rho_1 d\phi d\rho_1$$

we get:

$$dT = \frac{R^2 \rho_1 d\phi d\rho}{[R^2 + \rho_1^2 + l^2 - 2\rho_1 l \cos\phi]^2} \cdot d\tau$$

and for the radiation from the entire hole:

$$T = \int_0^a \int_0^{2\pi} \frac{a_1 da d\phi}{[1 + a_1^2 + \beta^2 - 2a_1\beta \cos\phi]^2} \cdot d\tau$$

where we have put:

$$a = \frac{\rho}{R}; \quad a_1 = \frac{\rho_1}{R}; \quad \beta = \frac{l}{R}$$

from the single measurements this would introduce a complication if the instrument were not always turned over so that the strips were parallel to the earth's surface. When this precaution is observed, we may regard the influence of the dimensions of the strips as negligible.

If α and β are not large, so that higher powers than the fourth may be neglected, the integration gives:

$$T = \pi\alpha^2(1 - \alpha^2 - 2\beta^2)\, d\tau \qquad (1)$$

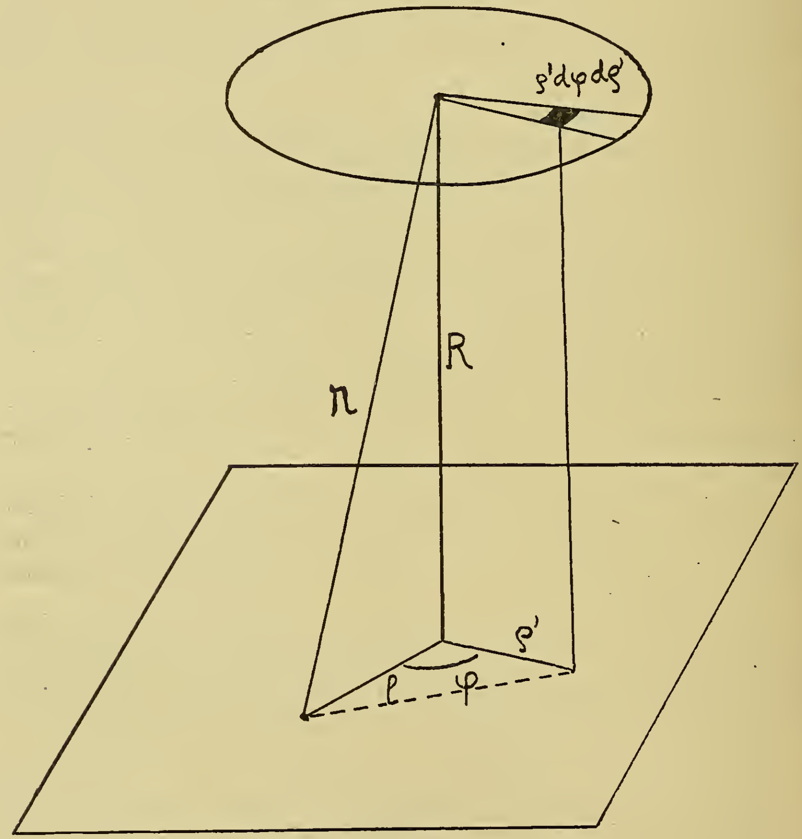

FIG. 9.

Now we proceed to consider the case, where the hole radiates to a strip of negligible width ds and of the length 2 m. The line is symmetrical in regard to the perpendicular from the central point of the hole. For the central point of the line we put: $l = n$. Then we have:

$$d\tau = dm'ds$$

$$\beta^2 = \frac{l^2}{R^2} = \frac{m'^2 + n^2}{R^2}$$

The results of these measurements for various conditions are given in table IX. Four series, representing different conditions in regard to the prevailing humidity, were taken at Bassour, Algeria, at a height of 1,160 m. above sea level. Two series were taken on

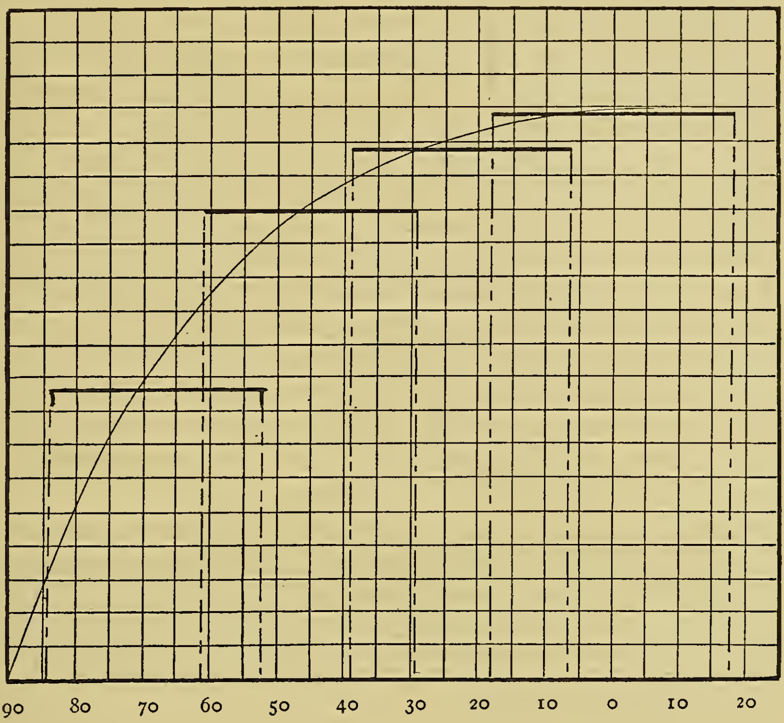

FIG. 10.

Introducing this in (1) and integrating between the limits *o* and *m*, we obtain for the radiation to the whole strip:

$$T' = \pi m a^2 \left[1 - a^2 - \frac{2\left(m^2 + \frac{n^2}{3}\right)}{R^2} \right] ds \qquad (2)$$

My instrument contained two radiating strips: For the one was: $m = 9.0$; $n = 2.0$. For the other one: $m = 9.0$ and $n = 6.0$. Further I had: $R = 68.3$; $\rho = 19.6$.

As my unit of radiation, I will now define the radiation from a surface equal to the surface of the strips within a solid angle whose cross-section is a square, and each side of which subtends one degree. Introducing the given values of a, m, n and R in (2), I then find that the mean radiation from the two strips is 768.6 times my unit of radiation.

top of Mount Whitney, 4,420 m. above sea level. In every instance the sky was perfectly clear and appeared perfectly uniform. It will be shown later on, that there is also strong experimental evidence for the perfect uniformity of the sky.

In order to obtain from the observations a more detailed idea of the effective radiation to different parts of the sky, I proceeded in the following way: In a system of coordinates, where the zenith angle is plotted along the x-axis, the magnitude of the radiation along the y-axis, every measurement with the instrument corresponds to an integral extending over 32° and limited by the x-axis and a certain curve—the distribution curve of radiation. If the measurements are plotted as rectangular surfaces, whose widths are 32° and whose heights are proportional to the magnitude of the radiation, we obtain from the observations a system of rectangles like those in figure 10. A curve drawn so that the integrals between the limits corresponding to the sides of the rectangles are equal to the areas of these rectangles will evidently be a curve representing the radiation as a function of the zenith angle.

(Note.—Against this procedure it can be objected that the observations do not really correspond to rectangular surfaces, the opening being circular and not square. The consequence will be that the real distribution curve will cut the rectangles in points lying nearer their central line than the section points defined by the procedure described. In fact this will alter the form of the curves very slightly; in drawing them the conditions just mentioned have been taken into consideration.)

In figures 11A and 11B the curves are shown. They indicate the fact—which has already been pointed out by Homén—that the effective radiation to a constant area of the sky decreases with an increase in the zenith distance. My observations indicate very strongly that the radiation approaches the zero value, when the zenith angle approaches 90°, which shows that the lower atmosphere, taken in very thick layers, radiates like a black body. If there were no radiating atmosphere at all, the distribution curve would be a straight line parallel to the x-axis.

A comparison between the different curves shows, further, that they differ in a very marked way from one another in regard to their form. It is also evident that this difference in form is very closely connected with the density conditions of the atmosphere and especially with its content of water vapor.

TABLE IX

Date	H	t	0°	½·45°	45°	³⁄₂·45°	Total Rad.	Computed	Diff.
1913 11:8[1]	1.47	—2°	0.0158 0.0155 } 0.0157	0.0158 0.0155 } 0.0157	0.0151 0.0147 } 0.0149	0.0129 0.0124 } 0.0127	0.194	0.197	+0.003
8:8[1]	3.6	—1°	0.0146 0.0144 } 0.0145	0.0147 0.0142 } 0.0145	0.0134 0.0138 } 0.0136	0.0111 0.0110 } 0.0111	0.168	0.176	+0.008
1912 23:8[2]	3.8	20.8°	0.0173	0.0167	0.0164	0.0120	0.192	0.197	+0.005
4:9[2]	5.0	11.1°	0.0168	0.0157	0.0140	0.0086	0.169	0.176	+0.007
30:8[2]	7.1	20.3°	0.0158	0.0147	0.0127	0.0062	0.157	0.150	—0.007
20:8[2]	13.2	18.9°	0.0153	0.0151	0.0126	0.0041	0.145	.....	.....
									+1.8%

[1] Mt. Whitney (altitude 4,420 m.).

[2] Bassour, Algeria (altitude 1,160 m.).

Together with the observations treated in the foregoing chapters, the present result gives us support for the following conclusions:

1. An increase in the water-vapor pressure will cause a decrease in the effective radiation to every point of the sky.

2. The fractional decrease is much larger for large zenith angles than for small ones.

If we regard the atmosphere as a plane parallel layer, having uniform density, ρ, and a temperature uniformly equal to the temperature at the earth's surface, the effective radiation of a certain wave length, λ, in different directions, may be expressed by

$$J_\lambda = Ce^{-\gamma \cdot \frac{\rho}{\cos\phi}} \tag{1}$$

where C and γ are constants and ϕ is the zenith angle. For another density, ρ', of the radiating atmosphere we have:

$$J'_\lambda = Ce^{-\gamma \frac{\rho'}{\cos\phi}} \tag{2}$$

and from (1) and (2):

$$\frac{J_\lambda}{J'_\lambda} = e^{-\gamma\left[\frac{\rho-\rho'}{\cos\phi}\right]} \tag{3}$$

If ρ is greater than ρ', J_λ will always be less than J'_λ. It is evident from the relation (3) that the ratio between J_λ and J'_λ diminishes as the zenith angle approaches 90°. The general behavior of the radiating atmosphere is therefore consistent with the case that only a single wave length is radiated and absorbed. But the detailed conditions are naturally very complicated through the lack of homogeneity of the radiation. Especially for the curves corresponding to high humidity the radiation falls off much quicker with the approach to the horizon than is to be expected from the dependence of the total radiation on the humidity. Especially is this the case after we have reached a value of the zenith angle of about 60 or 70 degrees. In part this is due to the increasing influence of the radiation of wave lengths whose radiation coefficients are small and can be neglected for smaller air masses, but which for the very large air masses that correspond to zenith angles not far from 90° must come into play and produce a rapid decrease of the effective radiation to points near the horizon. But here other influences are also to be considered. The observations of the total radiation, compared in regard to the diffusing power of the atmosphere for visible rays, show that the influence of diffusion can be neglected in comparison with the other more fundamental influences, as far as the total radiation is concerned. But in regard to the radiation to points near the horizon we must consider that the corresponding air masses become very large and that effects of dust and haze and other sources of lack of homogeneity in the air must be introduced in quite a marked way.

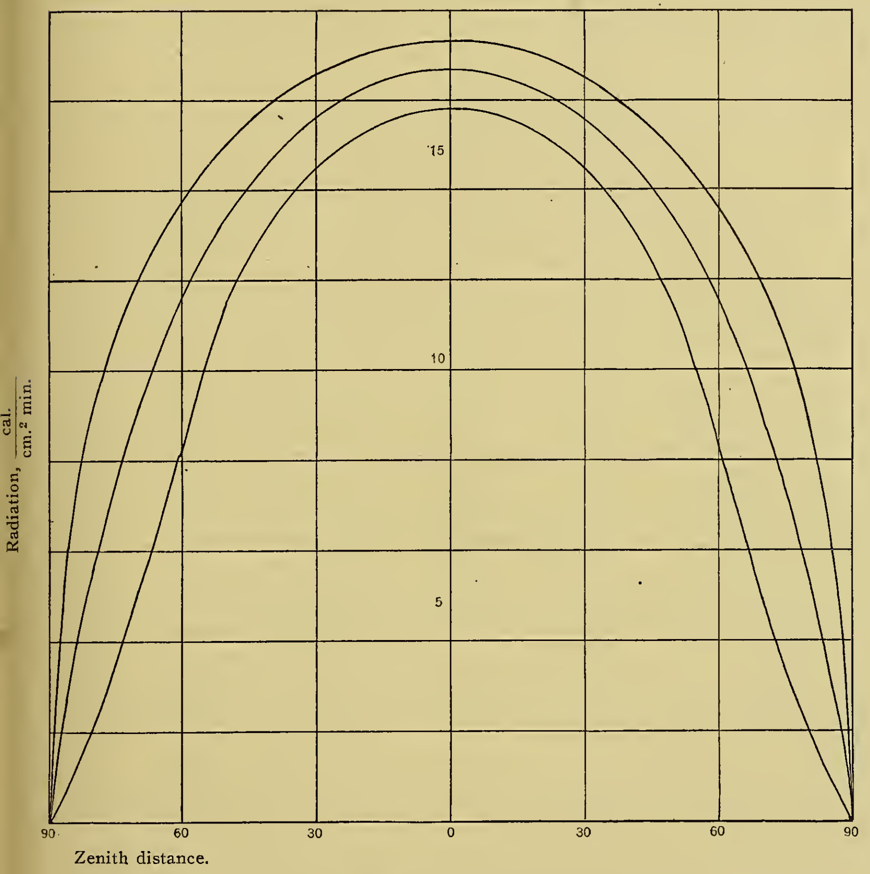

FIG. 11A.—Radiation to different parts of the sky. Bassour observations.

The curves in figures 11A and 11B represent the effective radiation within the unit of the solid angle in different directions from a surface perpendicular to the radiated beam. From these curves we can compute the radiation from a horizontal surface, like the earth's surface, to the different zones of the sky. If the radiation within a solid angle one degree square is R, the radiation (J) to the whole zone, whose width is one degree, is expressed by:

$$J = R \cos \phi \sin \phi \cdot 360 \qquad (1)$$

where ϕ is the zenith angle. For the radiation E to the whole sky, we consequently have:

$$E = 360\int_0^{\frac{\pi}{2}} J d\phi = 360\int_0^{\frac{\pi}{2}} R \cos\phi \sin\phi d\phi \qquad (2)$$

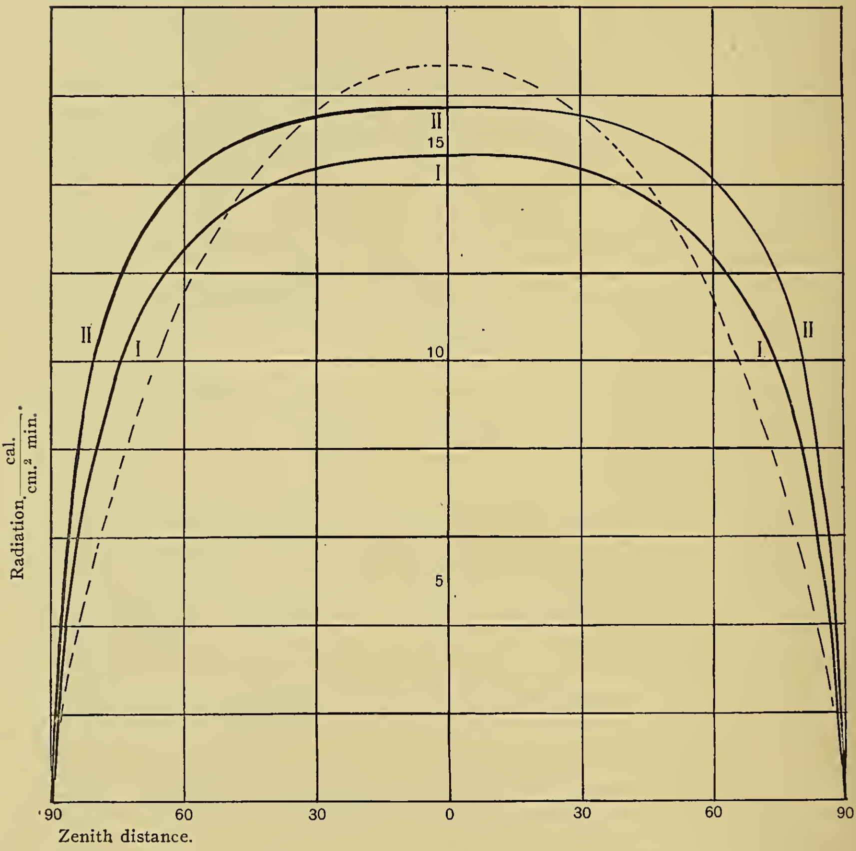

FIG. 11B.—Radiation to different parts of the sky. Curves I, II: Mt. Whitney, 1913. Water-vapor pressure; 3.6 and 1.5 mm. Hg. Curve dotted, Bassour, 1912. Water-vapor pressure; 5 mm. Hg. Temperature of instrument higher at Bassour. Compare table IX.

This integration can conveniently be effected in a mechanical way by measuring the areas given by (1). The curves that represent the radiation from a horizontal surface to different parts of the sky are shown in figure 12. The whole areas included between the curves and the x-axis must be proportional to the total radiation. In measuring the areas we must take into consideration the fact that the ordinates represent the radiation within a solid angle of 768.6° and consequently ought to be divided by the same number. The total radiation calculated in that way, is given in table IX, together with the total radiation observed under the same conditions. The mean difference between the two values is only 0.003, viz., less than 2 per cent. Considering the great difficulty of the observations upon which the computed value is based, the agreement must be regarded as very satisfactory. I therefore think we are justified in drawing therefrom the following conclusions:

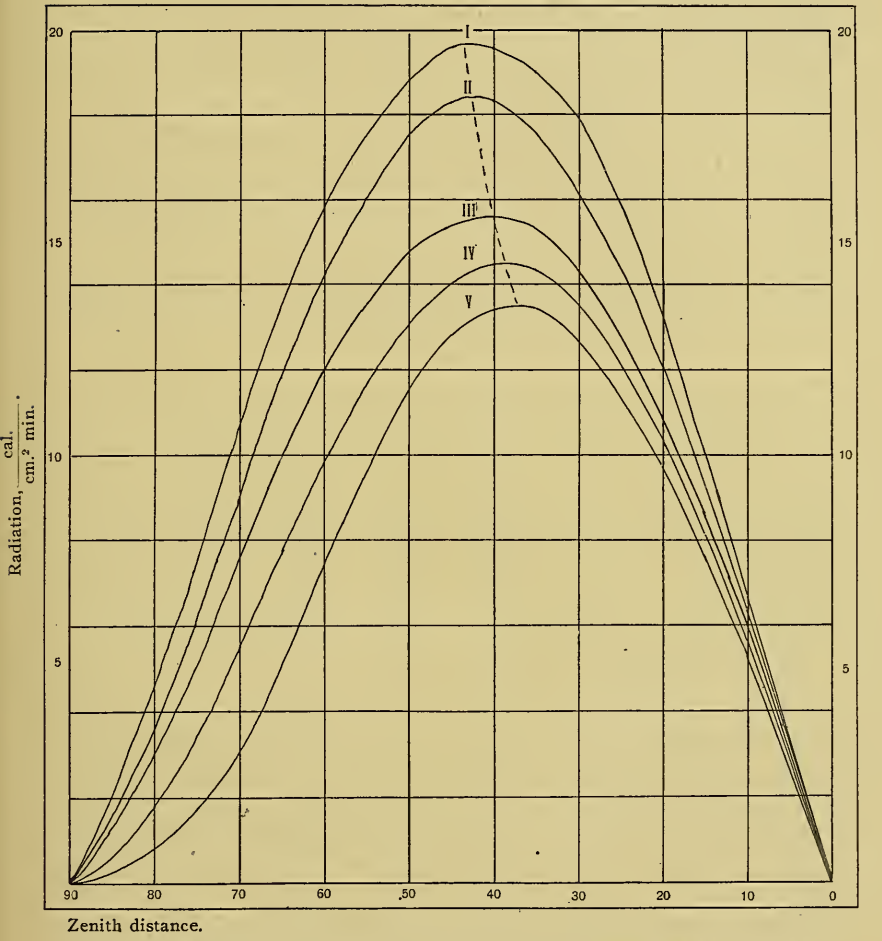

FIG. 12.—Radiation from horizontal surface to different parts of the sky.

I. That there is proportionality between the radiation and the energy of the current, used for compensation, down to very low values of both of them.

This is a very important point, as far as the utility of the instrument is concerned. The truth of the statement is clear from the fact that we can add up small portions observed and get a sum equal to the total quantity observed.

II. That the way in which the distribution curves have been extrapolated down to 90° zenith angle must be nearly correct.

III. That the sky must have been very uniform during the time of observation. If this had not been the case, it would not have been possible to calculate the total radiation from observations upon a single vertical circle.

From the diagrams it is to be concluded that the maximum of radiation from a horizontal surface toward rings of equal angular width takes place in a direction that makes an angle of between 35° and 45° with the zenith. An increase of the water-vapor density of the atmosphere shifts this maximum nearer the zenith; with decreasing density the maximum approaches a limiting position of 45°, which it would have if no absorbing and radiating atmosphere existed.

TABLE X

Observer	0°–22°30′	22°30′–45°	45°–67°30′	67°30′–90°	ρ
Homén	1.00	0.93	0.87	0.61	. . .
Ångström 1[1]	1.00	0.98	0.90	0.74	1.5
Ångström 2[1]	1.00	0.98	0.88	0.67	3.6
Ångström 3[2]	1.00	0.94	0.86	0.60	3.8
Ångström 4[2]	0.99	0.92	0.75	0.41	5.0
Ångström 5[2]	0.97	0.91	0.65	0.23	7.1

[1] Mt. Whitney (4,420 m.). [2] Bassour (1,160 m.).

In table X, which is obtained by measuring the corresponding areas in figure 12, the ratios are given between the values of the radiation within various zones, obtained from the observations, and the same values as calculated from the simple sine-cosine law, that is, for the case where a horizontal surface radiates directly to a non-absorbing space. Hereby the radiation is assumed to be unity for zenith angle 0°. Between 80° and 90° the radiation is only between 0.5 per cent and 2.0 per cent of the total radiation. The influence of mountain regions that do not rise higher than about 10 or 15 degrees above the horizon is therefore very small and can be neglected. In valley regions the effective radiation must be less than on a plane, owing to the shading influence of the mountains around. The conditions will, however, be slightly complicated through the superposed radiation from the surface of the mountains themselves, a radiation that is dependent upon the temperature of the heights and the properties of their surfaces (influence of snow).

CHAPTER VII

RADIATION BETWEEN THE SKY AND THE EARTH DURING THE DAYTIME

I must include here some observations which, in spite of their preliminary nature, yet may be of use in throwing a certain light upon questions nearly connected with the problem especially in view.

In the daytime, the radiation exchange between the sky and the earth is complicated by the diffuse sky radiation of short wave length that is present in addition to the temperature radiation of the sky. If this diffuse radiation is stronger than the effective temperature radiation to the sky, a black body like the instrument will receive heat. In the contrary case it will lose heat by radiation.

If one attempts to measure this positive (from sky to earth) or negative radiation with the instrument used in the present investigation, the sun itself being carefully screened off, such an attempt meets with the difficulty arising from the introduction of a systematic error. The bright metal strip has a smaller reflecting power for the diffuse radiation of short wave length than for the longer heat waves and we can no longer make use of the instrumental constant k, which holds only for long waves such as we have to deal with in the measurements of the nocturnal radiation. The reflecting power of the strips being about 97 per cent for waves longer than $2\,\mu$, and only about 70 per cent for waves of $0.5\,\mu$ length (a mean value of the wave length of the diffuse sky radiation), the introduction of the constant k into daylight measurements will evidently give a value of the sky radiation that is about 30 to 35 per cent too low.

On several occasions during the summer of 1912, I had the opportunity of making skylight measurements as well with my own instrument as with an instrument constructed on the same principle, but modified for the purpose of making day observations. This latter instrument is briefly described by Abbot and Fowle[1] in their interesting paper, "Volcanoes and Climate," where the effect of the diffusing power of the atmosphere on the climate is fully discussed. Both the strips employed in this instrument are blackened.

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[1] Smithsonian Miscellaneous Collections, Vol. 60, No. 29, 1913. (Reprinted in Annals of the Astrophysical Observatory of the Smithsonian Institution, Vol. 3.)

Instead of being side by side, the strips are here placed one above the other beneath a thin horizontal plate of brass. When the instrument was in use, a blackened screen was placed beneath it, so that the lower strip was exchanging radiation only with this screen, which subtended a hemisphere. The upper strip was exchanging radiation with the whole sky. The radiation was calculated from the current necessary to heat the upper strip to the same temperature as the lower one.

Even in the use of this instrument in its original form, it is difficult to avoid some systematic errors. One is due to the difficulty of protecting the screen with which the lower strip exchanges radiation, from absorbing a small fraction of the incoming radiation and in this way giving rise to a heating of the lower strip. And secondly the convection is apt to be different, the effect of rising air currents being greater for the upper strip than for the lower one. The error introduced by these causes may possibly amount to 10 or 15 per cent. In this instrument as well as in the original Ångström instrument, the error, when we attempt to measure the sky radiation during the day, tends to make this radiation appear weaker than it really is.

TABLE XI—*Radiation of the Sky*

	Sept. 5	Sept. 6	Sept. 7	Mean
Before sunrise	—0.169	—0.205	—0.208	—0.194
Noon	+0.062	+0.092	+0.047	+0.067
After sunset	—0.208	—0.225	—0.220	—0.218
Total sky radiation	+0.250	+0.307	+0.261	+0.273

Table XI gives some results of observations with the last named instrument, taken by Dr. Abbot and the author. My measurements of the nocturnal radiation during the preceding and following nights are given in the same place. The total diffuse sky radiation is calculated on the assumption that the effective temperature radiation during the daytime is a mean of the morning and evening values determined by the nocturnal apparatus. The sky was perfectly uniform during the observations but was overcast by a faint yellow-tinted haze, ascribed by Abbot to the eruption of Mount Katmai in Alaska. The energy of the direct solar beam at noon was, for all three days, 1.24 to 1.25 cal. The sun's zenith angle at noon was 32°. From the table it may be seen that there was always an access of radiation from the sky, indicating that the diffuse radiation from the sky was always stronger than the outgoing effective temperature radiation. The same was indicated by the nocturnal instrument, which, on two different occasions, showed, in one case no appreciable radiation in any direction, and in the other case a faint positive radiation from the sky. If we correct for the reflection of the bright strip the two instruments seem to be in general agreement with each other, showing the radiation from the sky to be *positive in the middle of the day,* under the conditions of the place. Lo Surdo found the same to be the case at Naples, where he observed during some summer days. On the other hand, Homén's observations at Lojosee in Finland, show that there the radiation during the daytime had the direction from earth to sky, and that consequently the effective temperature radiation was stronger (and very much stronger) than the incoming diffused light. The observations of the two observers are naturally in no way contradictory. The total radiation during the daytime is a function of many variables, which may differ largely from place to place. It is dependent on the effective temperature radiation to the sky. This radiation is probably about the same in different latitudes, a circumstance which will be discussed below; the effect of the higher temperature in low latitudes being counterbalanced by a high humidity. Thus we must seek the explanation in the behavior of the other important term, the scattered skylight. The strength of this light is dependent upon the diffusing power of the atmosphere: the molecular scattering and the scattering by dust, smoke, and other suspended particles in the air. For a not too low transmission of the air, the intensity of the skylight must increase with a decrease in the transmission power, so that the skylight is intense when the solar radiation is feeble, and vice versa.

There is nothing to indicate that the scattering power of the atmosphere is larger as a rule in low latitudes than at high ones, and I am therefore inclined to think that we ought not to ascribe the high intensity of the skylight in low latitudes to that cause. But the intensity of skylight is affected by another important factor—the height of the sun above the horizon. The nearer the sun approaches the zenith, the more intense must be the light reaching us from the diffusing atmosphere. The theory of scattered skylight, with due consideration of the so-called "self-illumination" of the sky, has been treated in a very interesting and remarkable paper by L. V. King.[1] In his paper King gives curves and equations representing

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[1] Phil. Trans. Roy. Soc. London, Ser. A, Vol. 212, pp. 375-433.

the intensity of the scattered skylight as a function of the attenuation of the solar radiation and of the zenith distance of the sun. The theoretical result is not in exact agreement with the few observations that have been made, for instance, by Abbot and Fowle, which may be partly due to the difficulties in this kind of observation; but the theoretical consideration proves that the intensity of the skylight must be a decreasing function of the sun's zenith distance. For the same transmission coefficient of the atmosphere, the skylight must therefore be stronger, on an average, in low latitudes than in high ones.

Systematic observations on the intensity of skylight in its dependence on other conditions are almost entirely lacking. This is one of the most important problems in atmospheric optics, whose consequences deeply affect the questions of climate and of the effects of dust and haze and volcanic eruptions upon the temperature conditions of the earth. The publications of Nichols, Dorno, and especially those of Abbot and Fowle contain important contributions to the problem. The outlines for further investigations of the subject seem to me to be given by the theoretical considerations of King.

A question of special interest for the problem I have dealt with in my investigation is this: Is the temperature radiation of the atmosphere during the day the same as during the night, when temperature and humidity conditions are assumed to be the same, or will the atmosphere under the direct influence of the solar radiation assume properties which will result in a deviation from the conditions prevailing in the night-time as far as the radiation is concerned? This question ought to be treated in a general way by methods allowing us to eliminate the short wave radiation and to observe the temperature radiation during different times of the day. Here I will only give a brief account of some observations made during the total eclipse of the sun in 1914 and of conclusions to be drawn from them in regard to the last named question. The observations were carried out at Åviken, a place situated on the Swedish coast, on the central line of the total eclipse, during the two nights preceding and one night following the total eclipse and also during the eclipse itself. As I myself was engaged in other observations I had availed myself of the able assistance of Dr. G. Witt and of Mr. E. Welander of the Institute of Engineering, Stockholm, for carrying out these observations.

In order to protect the instrument from the direct sunlight, a screen arrangement was used, where the screen, through a simple mechanical device, could be made to follow the changes in the position of the sun. The screen was blackened on the side turned towards the instrument and covered with white paper on the other side. The screen itself was to no appreciable degree heated by the sun radiation.

In figure 13 the observations are plotted as ordinates in a diagram where the time of the day is given by the abscissæ. The more the sunlight—and therefore also the scattered skylight—is cut off by the shadowing body of the moon, the more the effective radiation to the sky naturally increases. From what has been said above it is clear that we are right in comparing the radiation during the total phase only, with the values obtained during the night. The feeble radiation from the corona is perfectly negligible and causes no complications. The mean radiation during the totality is found to be 0.160. At the same time the temperature of the surrounding air was 13.6°, the humidity as given by the Assmann psychrometer, 7.7 mm. A comparison between the value of the effective radiation during the

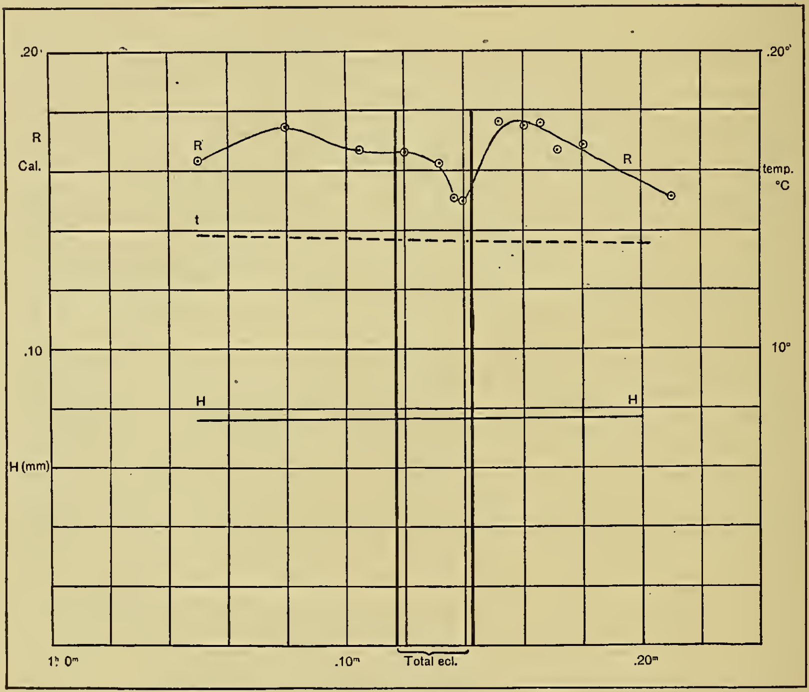

Fig. 13.—Radiation observed during total eclipse August 20, 1914.

eclipse and the value given by night observations under the same temperature and humidity conditions, displays a very slight difference. I therefore think that one may conclude that the effective temperature radiation during the day follows the same laws as hold for the nocturnal radiation. More extensive investigations are however needed before this conclusion can be regarded as definite.

It is of interest to notice that during the whole time preceding the eclipse, the instrument showed an outgoing radiation to the sky. From the intensity of this radiation it can be concluded that, at least before noon, the temperature radiation to the sky must have been stronger than the diffuse radiation from it. The same was found by Homén to be the case at Lojosee in Finland, as has been indicated in the discussion above.

CHAPTER VIII

APPLICATIONS TO SOME METEOROLOGICAL PROBLEMS

A. NOCTURNAL RADIATION AT VARIOUS ALTITUDES

The number of investigations contributing to our knowledge of this special question is not large. When we have mentioned the simultaneous observations of Pernter[1] at Rauris and on Sonnblick, and the observations of Lo Surdo[2] at Naples and Vesuvius we have exhausted the previous work on this subject. The observations that have been described above seem now to give a basis for forming a general view upon the question of the influence of altitude upon the effective radiation. In several cases observations have been carried out simultaneously at different altitudes, but before we enter upon a comparison between them, we shall treat the subject in a more general way. As has been emphasized on several occasions, our observations indicate that the atmospheric radiation in the lower layers of the atmosphere is dependent chiefly on two variables: temperature and humidity. Hence it is obvious that if we know the temperature and the integral humidity as functions of the altitude, we can calculate the radiation of the atmosphere at different altitudes, provided that the relation between radiation, temperature, and humidity is also known. It has been the object of my previous investigations to find this relation; hence, if the temperature and humidity at the earth's surface are known, together with the temperature gradient and the humidity gradient, I can from these data calculate the radiation at different altitudes. The radiation of the atmosphere will evidently always decrease with increasing altitude. But the effective radiation, which is dependent also on the temperature of the radiating surface, will behave very differently under different conditions. If no radiating atmosphere existed, the effective radiation would decrease with a rise in altitude owing to the decreasing temperature. If the temperature of the atmosphere were constant, the effective radiation would always increase, when we moved to higher levels, owing to the fact that the atmosphere (which is now assumed to radiate) gets thinner the higher the altitude.

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[1] *Loc. cit.* (Histor. Survey).

[2] Nuovo Cimento, 1900.

In order to get a general idea of the conditions, I will assume that Süring's formula:

$$e_h = e_0 \cdot e^{-\frac{h}{2606}\left(1+\frac{h}{20}\right)}$$

holds for the distribution of the humidity, and that the temperature gradient is constant up to an altitude of 5,000 m. I will consider the following special cases:

I The temperature gradient is 0.8° per 100 meters.
II " " " " 0.6° " " "

The pressure of the aqueous vapor at the earth's surface is: (a) 5 mm.; (b) 10 mm.; (c) 15 mm.

The effective radiation R_t at different altitudes can then be calculated according to the formula:

$$R_t = T^4 \cdot 0.170\,[1 + 1.26 \cdot e^{-0.069\rho}] \cdot 10^{-10}$$

where ρ can be obtained from Süring's formula, and where e_h has to be corrected for the conditions pointed out in chapter V, B, of this paper. In table XIIA are given, (1) the temperature (t), (2) the pressure of aqueous vapor (e_h), (3) the corrected pressure (ρ) and, finally, the effective radiation (R) at different altitudes. In table XIIB the same quantities are given for a temperature gradient of 0.6° per 100 meters. Figure 14 gives the curves, drawn from

TABLE XIIA—*Radiation at Different Altitudes*

Altitude	t	e_h'	e_h''	e_h'''	ρ'	ρ''	ρ'''	R'	R''	R'''
0	25°	5.0	10.0	15.0	5.5	11.0	16.6	0.205	0.164	0.146
1000	17°	3.35	6.7	10.0	3.4	6.8	10.1	0.208	0.171	0.150
2000	9°	2.15	4.3	6.45	2.05	4.1	6.1	0.205	0.177	0.167
3000	1°	1.35	2.7	4.05	1.3	2.4	3.6	0.195	0.178	0.165
4000	— 7°	0.77	1.55	2.3	0.7	1.2	1.8	0.182	0.175	0.166
5000	—15°	0.46	0.91	1.4	0.34	0.67	1.0	0.166	0.161	0.158

TABLE XIIB—*Radiation at Different Altitudes*

Altitude	t	e_h'	e_h''	e_h'''	ρ'	ρ''	ρ'''	R'	R''	R'''
0	25°	5.0	10.0	15.0	5.5	11.0	16.6	0.205	0.166	0.146
1000	19°	3.35	6.7	10.0	3.35	6.7	10.0	0.212	0.176	0.155
2000	13°	2.15	4.3	6.45	1.9	3.8	5.8	0.219	0.192	0.180
3000	7°	1.35	2.7	4.05	1.1	2.2	3.2	0.215	0.197	0.183
4000	1°	0.77	1.55	2.3	0.55	1.0	1.6	0.208	0.200	0.190
5000	—5°	0.46	0.91	1.4	0.28	0.55	0.8	0.194	0.190	0.185

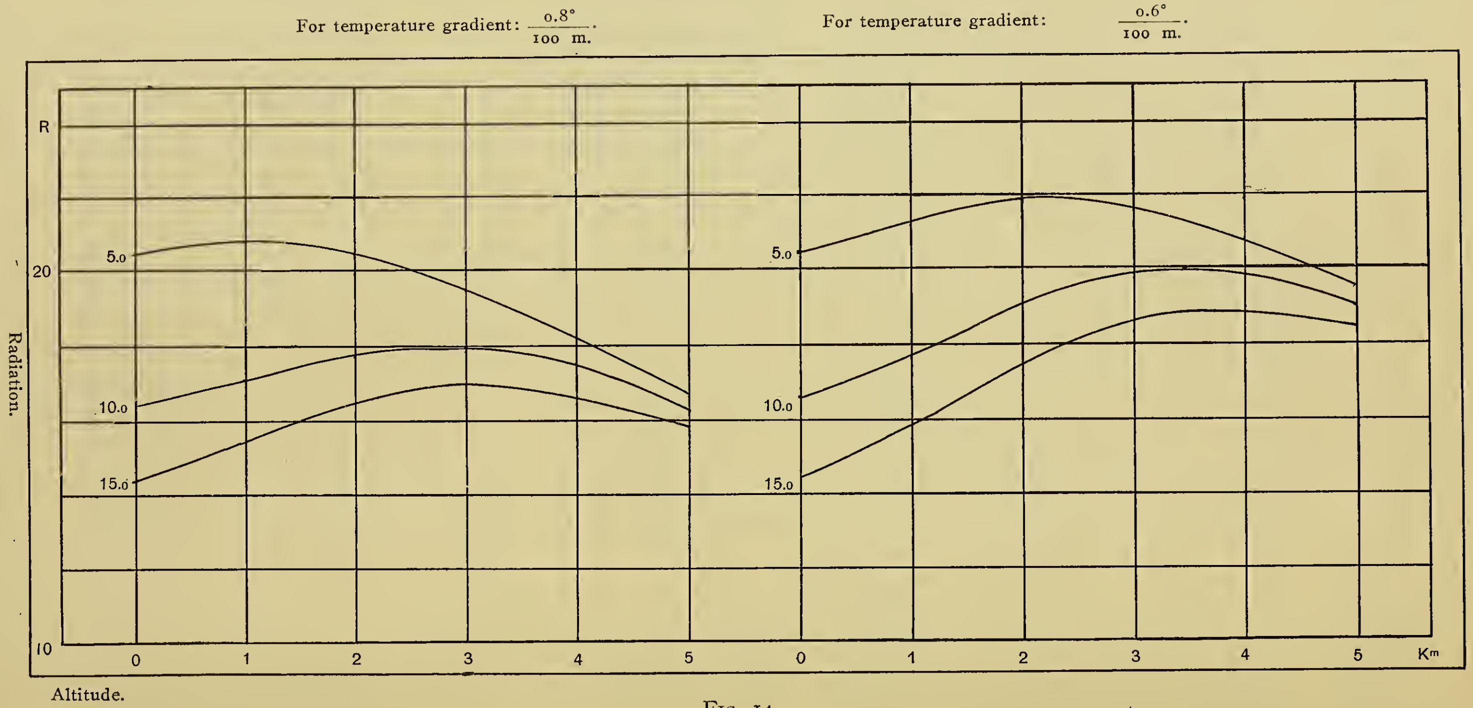
For temperature gradient: $\frac{0.8°}{100\ m.}$.
For temperature gradient: $\frac{0.6°}{100\ m.}$.
R
20
10
Radiation.
5.0
10.0
15.0
5.0
10.0
15.0
0
1
2
3
4
5
0
1
2
3
4
5
Km
Altitude.

FIG. 14.

the computed data, for the effective radiation as a function of the altitude. The curves bring out some interesting facts that deserve special consideration.

For ordinary values of the humidity, the effective radiation has a maximum at 1 to 4 km. altitude.

An increase of the humidity or a decrease of the temperature gradient shifts this maximum to higher altitudes.

The effective radiation gradient is consequently positive at low altitudes and negative at high altitudes.

An examination of the observations, made simultaneously at different altitudes, must naturally give a result that is in general accordance with these considerations, which are based upon the experimental investigations.

Table XIIIa

Date	Δt	Lone Pine			L. P. Canyon			Mt. Whitney		
		t	H	R	t	H	R	t	H	R
Aug. 2..........	0.61	18.3	10.0	0.141	....	...	.....	—1.3	3.2	0.182
3..........	0.57	17.6	8.0	0.166	....	...	.....	—0.7	2.7	0.182
4x	0.48	15.8	7.8	0.171	17.0	5.0	0.203	+0.6	2.4	0.196
5x	0.52	17.5	6.3	0.191	17.3	3.7	0.212	+1.0	2.1	0.188
8..........	....	....	....	.....	15.1	7.0	0.177	—1.4	3.5	0.166
9x	0.59	15.6	7.7	0.154	12.4	5.8	0.164	—3.4	3.0	0.154
10..........	....	18.7	7.7	0.185	11.4	6.1	0.168	.....	...	. .
11..........	0.58	15.9	5.9	0.189	....	...	.....	—2.5	1.2	0.191
12..........	0.71	21.2	5.1	0.198	....	...	.....	—1.4	1.2	0.193
General mean...	0.58	17.6	7.3	0.175	14.6	5.5	0.185	—1.1	2.4	0.182
Mean of (x)....	0.53	16.3	7.3	0.172	15.6	4.8	0.193	—0.6	2.5	0.179

Table XIIIb

Date	Δt	Indio [0 m.]			Mt. San Gorgonio [3,500]					
		t	H	R	t	H	R			
July 22	....	26.0	12.1	0.134	...	...	.....	...	...	...
23x........	0.69	24.7	11.0	0.181	0.7	2.5	0.208	...	...	...
24x........	0.61	23.5	9.6	0.172	2.1	1.6	0.217	...	...	...
Mean of (x)....	0.65	24.1	10.3	0.177	1.4	2.1	0.213	...	...	...

In table XIIIa I have collected the data, gained simultaneously at different altitudes during the Mount Whitney expedition. The values represent mean values during entire nights. They confirm the fact, already deduced from more general considerations, that the effective radiation has a maximum at an altitude of between 1,000 and 4,000 meters. Between 2,500 and 4,400 meters the mean gradient is generally negative; between 1,200 and 2,500 meters it generally has a positive sign. From the general discussion and the curves that represent ideal cases it is probable that the effective radiation always decreases with an increase in altitude, when about 3,000 meters is exceeded. Up to that altitude we shall generally find an increase of the effective radiation with the height. The latter conditions are demonstrated by my simultaneous observations at Indio and Mount San Gorgonio (table XIIIB), as well as by Pernter's[1] observations at Rauris and on the top of Sonnblick.

B. INFLUENCE OF HAZE AND ATMOSPHERIC DUST UPON THE NOCTURNAL RADIATION

From the observations made in Algeria, the conclusion was drawn[2] that a slight haziness, indicated by a decrease in the transmission by the atmosphere of visible rays (clouds not formed), had no appreciable influence upon the radiation of the atmosphere. In fact it was found from pyrheliometric measurements during the day that the transmission of the atmosphere generally kept a high or low or average value during periods of several days, the changes being slow and continuous from one extreme to the other. The assumption being made that the nights falling between days of a certain value of transmission can be classified as showing the same character as the days, it was found that the nocturnal mean radiation during nights belonging to a period of high transmission only differed within the limits of probable error from the mean value obtained during low transmission periods.[3]

The observations at Bassour, Algeria, were taken at a time when the volcanic dust from the eruption of Mt. Katmai at Alaska caused a considerable decrease in the sun radiation transmitted to the surface of the earth. Several observers, such as Hellmann,[4] Abbot and Fowle,[5] Kimball,[6] Jensen,[7] and others, all agree as regards the prob-

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[1] Pernter, *loc. cit.*

[2] A. Ångström: Studies in Nocturnal Radiation, I. Astroph. Journ., June, 1913.

[3] Abbot and Fowle: Volcanoes and Climate, l. c., p. 13.

[4] Zeitschrift für Meteorologie, Januari, 1913.

[5] Volcanoes and Climate. Smithsonian Misc. Collections, Vol. 60, No. 29.

[6] Bulletin of the Mount Weather Observatory, Vol. 3, Part 2.

[7] S. A. Mitt. d. Vereinigung von Freunden d. Astronomie und kosm. Physik, 1913.

able cause of this remarkable haziness. As regards the atmospheric conditions at Bassour, I may quote the description given by Abbot and Fowle in their interesting paper, Volcanoes and Climate: "On June 19 Mr. Abbot began to notice in Bassour streaks resembling smoke lying along the horizon, as if there were a forest fire in the neighborhood of the station. These streaks continued all summer, and were very marked before sunrise and after sunset, covering the sky towards the sun nearly to the zenith. After a few days the sky became mottled, especially near the sun. The appearance was like that of the so-called mackerel sky, although there were absolutely no clouds. In the months of July, August, and so long as the expedition remained in September, the sky was very hazy, and it was found that the intensity of the radiation of the sun was greatly decreased by uncommonly great haziness." Abbot and Dorno[1] both agree as to the average decrease per cent in the solar radiation caused by the dust; it was found to be about 20 per cent. "In the ultra-violet and visible spectrum the effect was almost uniform for all wave lengths, but was somewhat less in the infra-red." (Volcanoes and Climate.)

It is of very great interest to consider, in connection with the observations named, the effect of volcanic dust upon the *nocturnal radiation*. Unfortunately the observations at Algeria were not begun until after the haze had reached a considerable density, and therefore we cannot compare observations taken at the same place before and during the dust period. But the observations taken at Lone Pine during the California expedition may furnish a reliable basis for comparison, the two stations having almost exactly the same altitude. If we therefore consider the curve giving the relation between radiation and humidity at Lone Pine in comparison with the same curve obtained at Bassour, both curves reduced to the same temperature, we may from this draw some conclusions in regard to the effect of the volcanic haze. These curves are given in figure 5, and we can from the diagram read off the departures of the Lone Pine curve from the curve taken at Bassour. These departures are given in the following table, together with the mean departure, which is found to be +0.003 or just about 2 per cent of the mean radiation. The Lone Pine values are, on an average, a little less than 2 per cent higher than the values obtained at Bassour under identical conditions. If we compare the radiation values at Indio with those at Bassour in the same way, we shall find a departure of $+\frac{1}{2}$ per cent in favor of

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[1] Met. Zt., 29, 1912.

the Indio values. One may conclude from this that the volcanic dust, which causes a decrease of about 40 per cent (Dorno) in the ultra-violet radiation and about 20 per cent in the visible affects the rays that constitute the nocturnal radiation less than 2 per cent. As the nocturnal radiation has probably its maximum of energy in a region of wave lengths at about 8 μ, this is a fact that in itself is not very astonishing. Measurements in the sun's energy spectrum show that even for waves not longer than about 0.8 μ, the transmission of the atmosphere is very nearly equal to unity, the rays being very slightly affected by changes in the scattering power of the air. If we use the observations of Abbot or of Dorno in regard to the weakening of the ultra-violet and visible light, and apply the law of Rayleigh for the relation between scattering and wave length, we find from these data, applied to the average wave lengths of the regions concerned, that about 97 per cent of the radiation at 8 μ must pass undisturbed by the dust particles. There are several objections against a quantitative application of the theory of Rayleigh to the conditions here considered, but at least it shows that our result cannot be regarded as unexpected.

EFFECTIVE RADIATION

ρ mm.	Lone Pine–Bassour
4	— 0.004
5	+ 0.005
6	+ 0.012
7	+ 0.015
8	+ 0.009
9	— 0.003
10 11	— 0.013
Mean	+ 0.003

The fact that the nocturnal radiation has only decreased by about 2 per cent, when on the other hand the incoming solar radiation is reduced to about 80 per cent of its former value, explains the interesting relation between climate and volcanic eruptions pointed out by Abbot and Fowle in their paper already referred to. That the climatic effect is not larger, in spite of the great decrease in the insolation, may be due to the large number of processes at work—so to say—tending to balance or to weaken the consequences of a decrease in the incoming radiation. It has been shown here that this decrease is not to any appreciable amount counterbalanced by a decrease in the outgoing radiation from the *surface of earth.* But there are other means by which heat is carried away from the surface, evaporation, and especially convection, being factors that are not negligible. It is probable that if a part of the solar radiation is really absorbed by the volcanic dust, this will tend to diminish the temperature gradient between the sea level and the upper strata of the atmosphere, and consequently cause a decrease in the vertical heat convection from the lower stations. A second *access* of radiation is due to the scattered skylight, and Abbot as well as Dorno point out that the sum of skylight and direct solar radiation was subjected to only a relatively small change by the effect of the dust. One has naturally to expect that if a part of the direct solar radiation is uniformly scattered by the atmosphere, a part of the scattered radiation will reach the surface of the earth in the form of skylight, this part increasing with an increase in the scattering power. Part of the scattered radiation is reflected out to space. Similar conditions naturally hold for the nocturnal radiation, and it is evident that the quantity measured by the instrument will always be the outgoing heat radiation diminished by the part of this radiation that is reflected back by the diffusing atmosphere upon the radiating surface.

C. RADIATION FROM LARGE WATER SURFACES

The radiation from bodies with reflecting but not absorbing or diffusing surfaces depends upon their reflecting power and their temperature only. The emission of radiation in a direction that makes an angle ϕ with the normal to the surface at the point considered, is determined by the relation:

$$E_\phi = \epsilon_\phi (1 - R_\phi)$$

where ϵ_ϕ is the radiation of a black surface in the direction ϕ, and R_ϕ the reflected fraction of the light incident in the named direction. For the total radiation emitted we have

$$E_\phi = \int \epsilon_\phi (1 - R_\phi) \, d\Omega$$

where the integration is to be extended over the whole hemisphere.

In chapter VI, I have given an account of some observations that show in what way the radiation from a black surface to the sky is dependent on the direction. As a very large part of the earth's surface is covered with water, and therefore slightly different from the conditions defined by the "black surface," I have thought it to be of interest to give here a brief discussion of the case where we have, instead of the black surface, a plane water surface radiating out to space. The problem is important for the knowledge of the loss of heat from the oceans, and would probably be worth a special investigation in connection with an elaborate discussion of the quantity of heat absorbed from the incoming sun and sky radiation by water surfaces. Here I propose only to give a short preliminary survey of the question, giving at the same time the general outlines of the probable conditions.

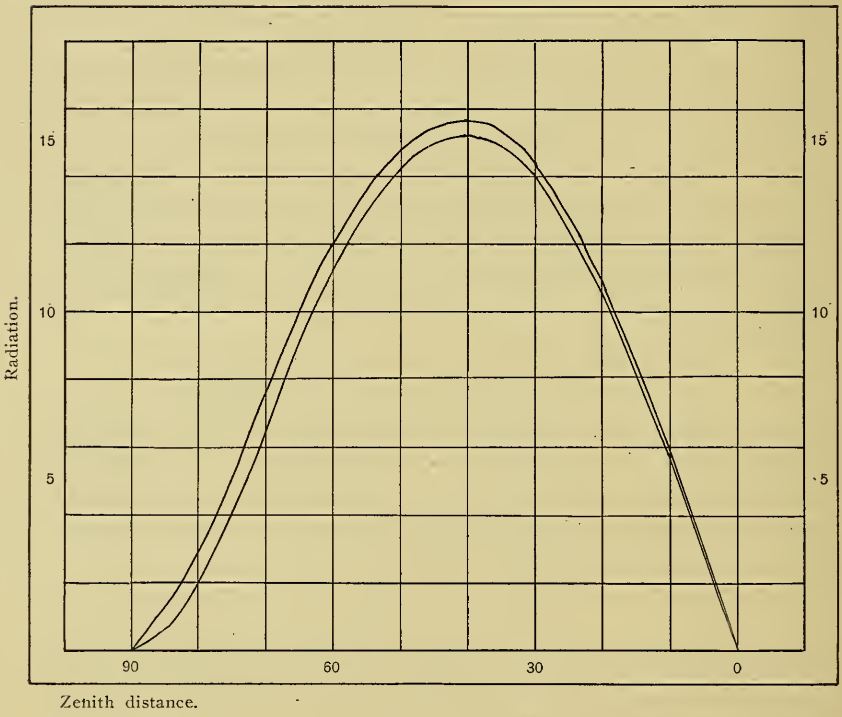

FIG. 15.—Radiation from water surface to sky. Lower curve for water surface. Upper curve for perfect radiator. From Bassour observations ($\rho = 5$ mm.). Ratio of areas 0.937.

In figure 12 I have given some curves representing the relative radiation from a black surface in various directions toward rings of equal angular width. The total energy emitted is represented by the areas of these curves. Now, if every ordinate is multiplied by the factor $(1 - R_\phi)$, where R_ϕ can be obtained from Fresnel's formulæ, if we know the index of refraction, the area included by the new curve will give us the radiation emitted by a water surface under the same conditions of temperature and water-vapor pressure. In figure 15 such curves are given. I have here assumed the mean refractive index for the long waves here considered to be 1.33, a value that is based upon measurements by Rubens and myself. The upper curve is taken from figure 12, curve IV. This same curve corresponds to a water-vapor pressure of 5 mm. The ratio between the areas is 0.937, *i. e.,* the water surface radiates under the given conditions 93.7 per cent of the radiation from a black body. A change in the water-vapor pressure will affect this ratio only to a small extent.

I will now assume that a black horizontal surface radiates to space, and that the vertical distribution of the water vapor over the surface satisfies the conditions for which our radiation formula holds (Chapter III (2)). Then the radiation can be computed provided the temperature is known. If the black surface is replaced by a water surface the radiation will be only 94 per cent of its former value. The latter radiation is given as a function of the temperature by figure 16, where I have applied the considerations made above to the interval between −10° C. and +20° C. From the figure may be seen how the radiation is kept almost constant through the increase with rising temperature of the water-vapor content of the atmosphere. There is only a slight *decrease* in the radiation *with rising temperature.*

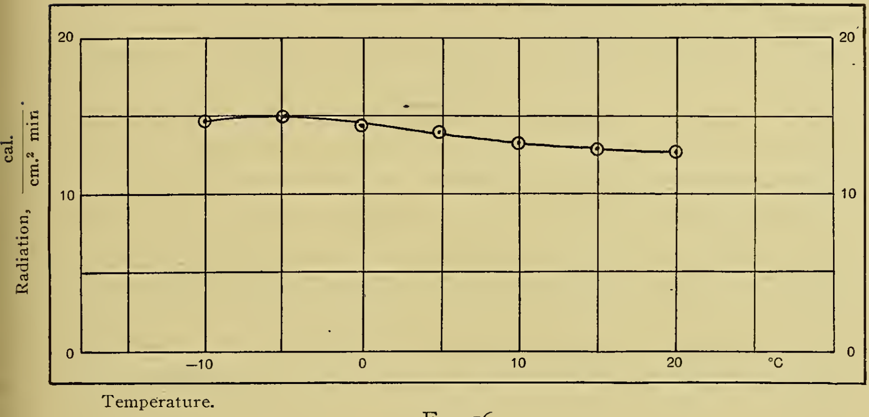

FIG. 16.

The ideal conditions here imagined are probably more or less inconsistent with the actual state of things. In the first place, the air immediately above the ocean is generally not saturated with water vapor, the relative humidity being rarely more than about 90 per cent. In the second place, it is not quite correct to assume that the average distribution of the water vapor over the ocean is the same as the average distribution over land. This will give a deviation from the assumed conditions and consequently a different absolute value to the radiation, but it will probably only to a small extent change the relative values and the general form of the curve.

Melloni[1] concludes his first memoir on the cooling of bodies exposed to the sky, published about 70 years ago, with the following remarkable statement, upon which he seems to lay a certain stress: " . . . . Un corps exposé pendant la nuit à l'action d'un ciel également pur et serein se refroidit toujours de la même quantité quelle que soit la température de l'air."

One may at first be inclined to attach very little importance to this statement. It seems in fact to be in contradiction with the most elementary laws of radiation. If we consider the temperature of the radiating surface as the only variable upon which the radiation depends, we would expect the cooling of the body below the temperature of the surroundings to be proportional to the fourth power of its absolute temperature. At 0° C. the cooling would for instance be only about three fourths as much as at 20° C.

Now the effect of temperature is generally a double one, as far as the radiation process is concerned. With a rise in temperature there generally follows an increase in the absolute humidity, which causes an increase in the radiating power of the atmosphere. The increase of the temperature radiation from the radiating surface is balanced by a corresponding increase in the radiation of the atmosphere; and the observed effective radiation is therefore only subjected to a small variation. The observations, discussed in previous chapters, seem now to indicate that the law of Melloni is *approximately* true with the following modification:

The cooling of a body, exposed to radiate to a clear night sky, is almost independent of the temperature of the surroundings, *provided that the relative humidity keeps a constant value.*

This conclusion, which can be drawn from the observations on the influence of humidity and temperature on the effective radiation, must be regarded as remarkable. It includes another consequence, namely, that a high incoming radiation (sky and sun) and a therefrom resulting tendency to an increase of the temperature, is generally *not* counterbalanced by a corresponding increase in the effective radiation from the surface of the earth to space. The variations of the incoming radiation are therefore, under constant temperature conditions, almost entirely counterbalanced by variations in convection, and evaporation (or other changes) of water.

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[1] Melloni, *loc. cit.* (chapter II).

CONCLUDING REMARKS

In this " Study of the Radiation of the Atmosphere," I have attempted an investigation of the influence of various factors—humidity, temperature, haze, clouds—upon the radiation of the atmosphere. The results of these investigations are briefly summarized at the beginning of the paper.

It may be of advantage here to state in a few words in what respects this study must be regarded as incomplete and in need of further extended investigations. In the first place, it will be noticed that my observations have been limited to a particular time of year; the observations in Algeria and in California have all been made during the periods July-August of the years 1912 and 1913.

Now the investigations, as yet unpublished, carried on at the Physical Institute of Upsala, indicate that the amount of ozone contained in the atmosphere is larger in winter time than in summer time. Further, it has been shown by K. Ångström[1] that the ozone has two strong absorption bands, the one at $\lambda=4.8\,\mu$, the other at $\lambda=9.1$ to $10\,\mu$, of which the latter especially is situated in a region of the spectrum where the radiation of a black body of the temperature of the atmosphere ought to have its maximum of radiation. Then it is obvious that the radiation of the atmosphere must be dependent also upon the quantity of ozone present. Spectroscopic investigations indicate that in the summer time the ozone present in the air is practically nil; it is therefore not liable to have introduced any complications into the results discussed in this paper. But in the winter the quantity of ozone is often considerable, and it is not impossible that the variations of the effective radiation in the winter may be partly due to variations in the quantity of ozone in the upper air layers. The consequence of the higher radiating power of the atmosphere, due to the presence of ozone, must be that the effective radiation ought to be found to be less in the winter than is to be expected from the observations discussed in this paper.

Another point where it is desirable that the observations of the " nocturnal radiation " should be extended, is in regard to conditions under which the quantity of water in the air is very small. Such

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[1] K. Ångström: Arkiv für Mat., Astr. och Fysik I, p. 347, 1904. *Ibidem,* I, p. 395, 1904.

observations will not only be more directly comparable with the observations on high mountains than those used here for such a comparison, but they will also furnish a basis for studying the variations in a dry atmosphere and the influences by which these variations are affected. Further, the study of the radiation of the upper air layers is as yet very incomplete and ought to be extended by means of continuous observations on high mountains or, perhaps better, from balloons. My observations indicate that the "perfectly dry atmosphere" has a radiating power as great as 50 per cent of the radiation of a black body at the temperature of the place of observation. The upper air layers—the stratosphere—must therefore have a considerable influence upon the heat economy of the earth as a whole. Observations at high altitudes of the absorption and radiation of the atmosphere are therefore very desirable.

Finally, means must be found to study the effective radiation during the daytime in a more systematic way than has been done in this paper. The effective temperature radiation—that is, the difference between the total effective radiation and the access of scattered skylight—can evidently be obtained by measuring these two last named quantities simultaneously; measurements that do not seem to involve insurmountable difficulties.

EXPLANATION OF FIGURES 17 TO 25

The figures give the effective radiation in $\frac{\text{cal.}}{\text{cm.}^2 \text{ min.}} \cdot 10^2$, plotted as ordinates against the time (in hours of the night) as abscissæ. The curves are governed by the observations given in several of the tables, XIV to XX. For the graphical interpretation I have chosen some of the observations that seem to me to bring forward, in a marked and evident way, the influence of humidity or temperature upon the radiation. They therefore represent cases where either the temperature has been almost constant (as on high mountains), and the humidity subjected to variations, or where the humidity has been constant and the temperature has varied.

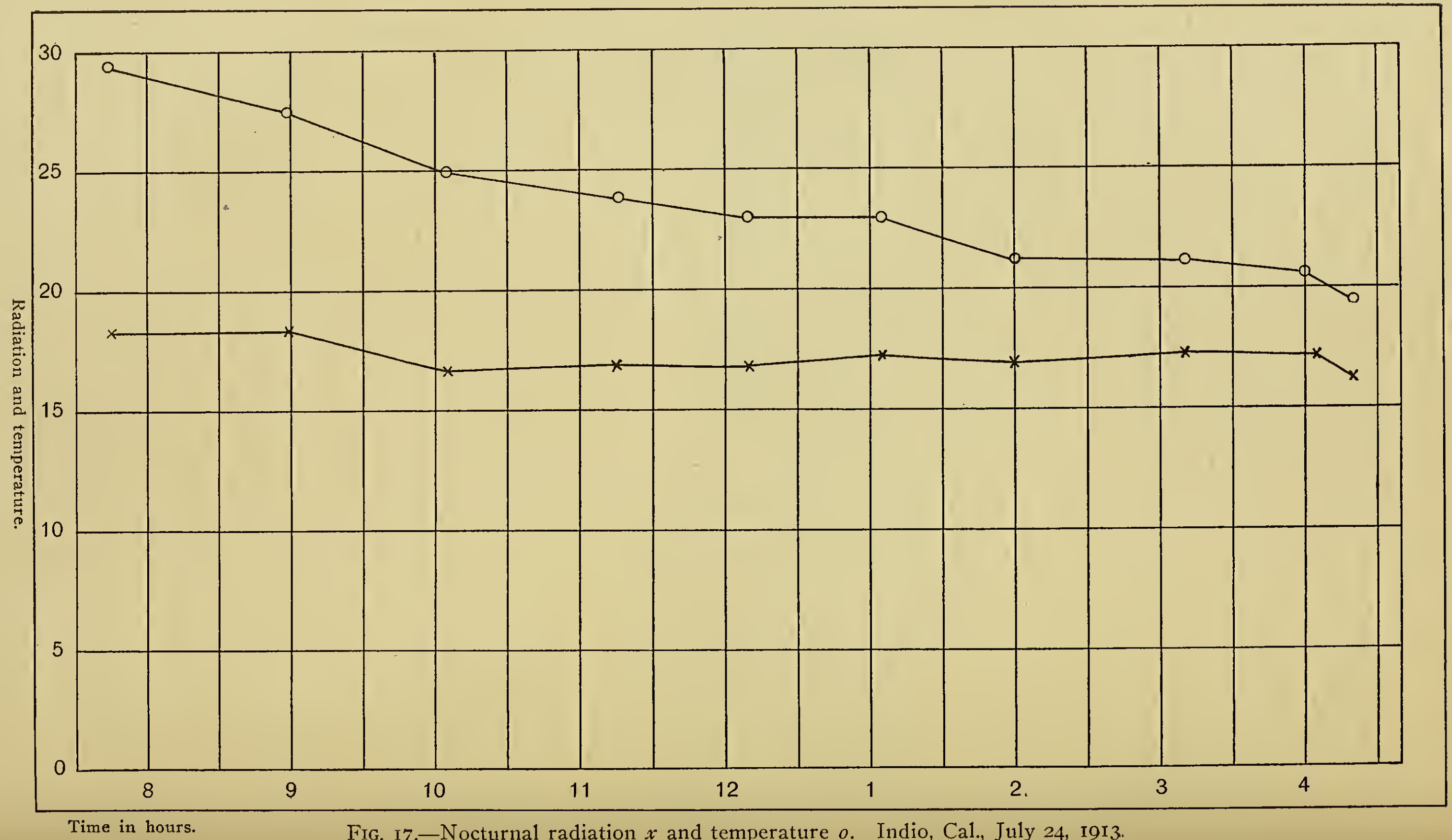

FIG. 17.—Nocturnal radiation *x* and temperature *o*. Indio, Cal., July 24, 1913.

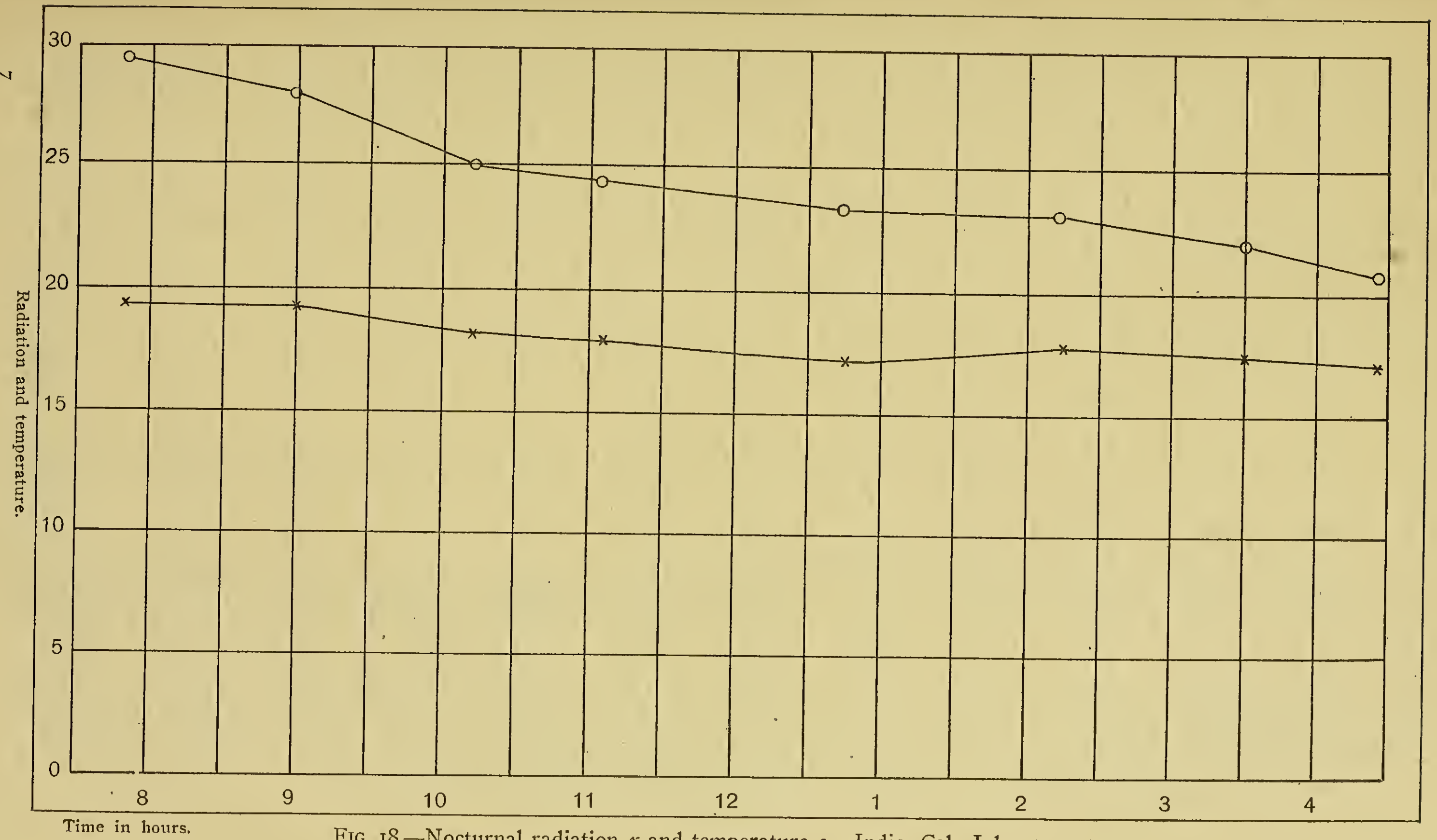

FIG. 18.—Nocturnal radiation *x* and temperature *o*. Indio, Cal., July 23, 1913

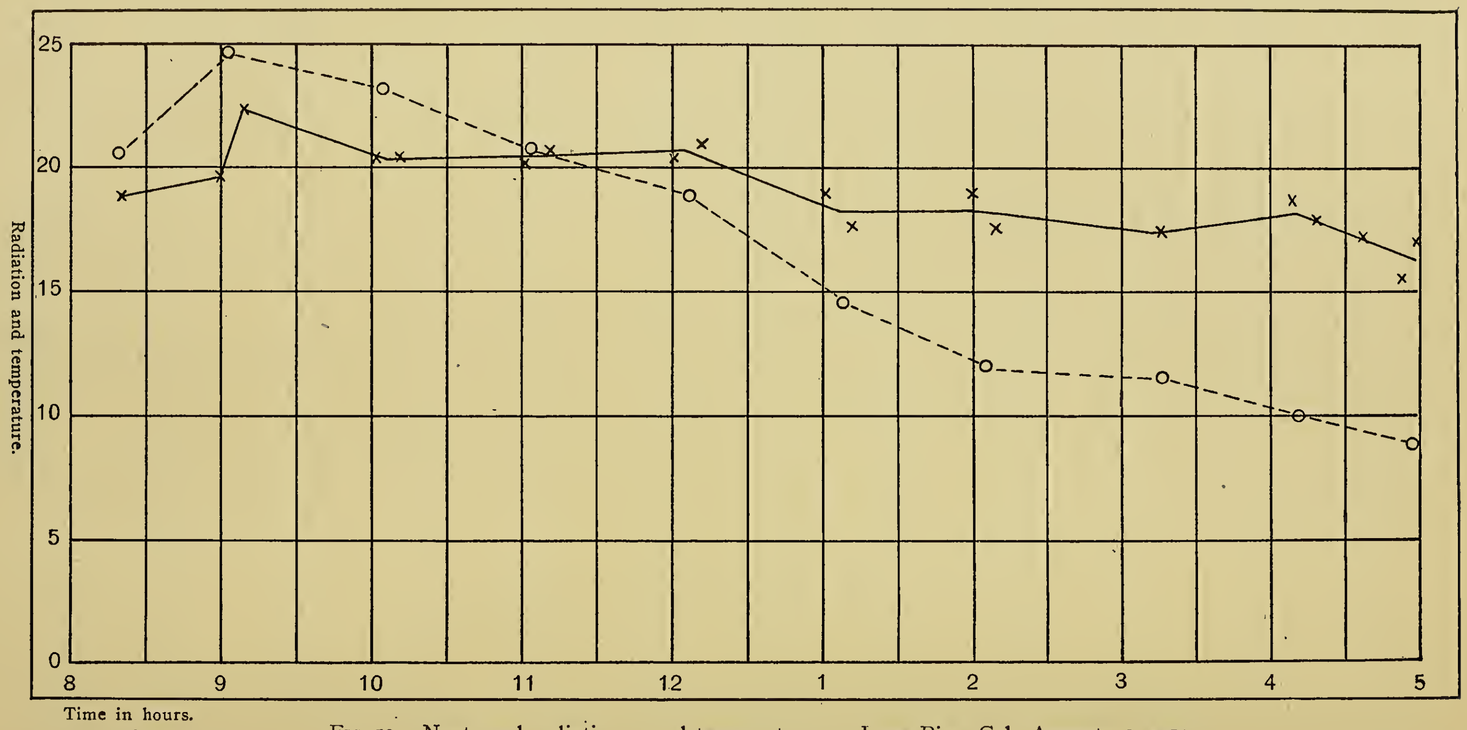

FIG. 19.—Nocturnal radiation *x* and temperature *o*. Lone Pine, Cal., August 11, 1913.

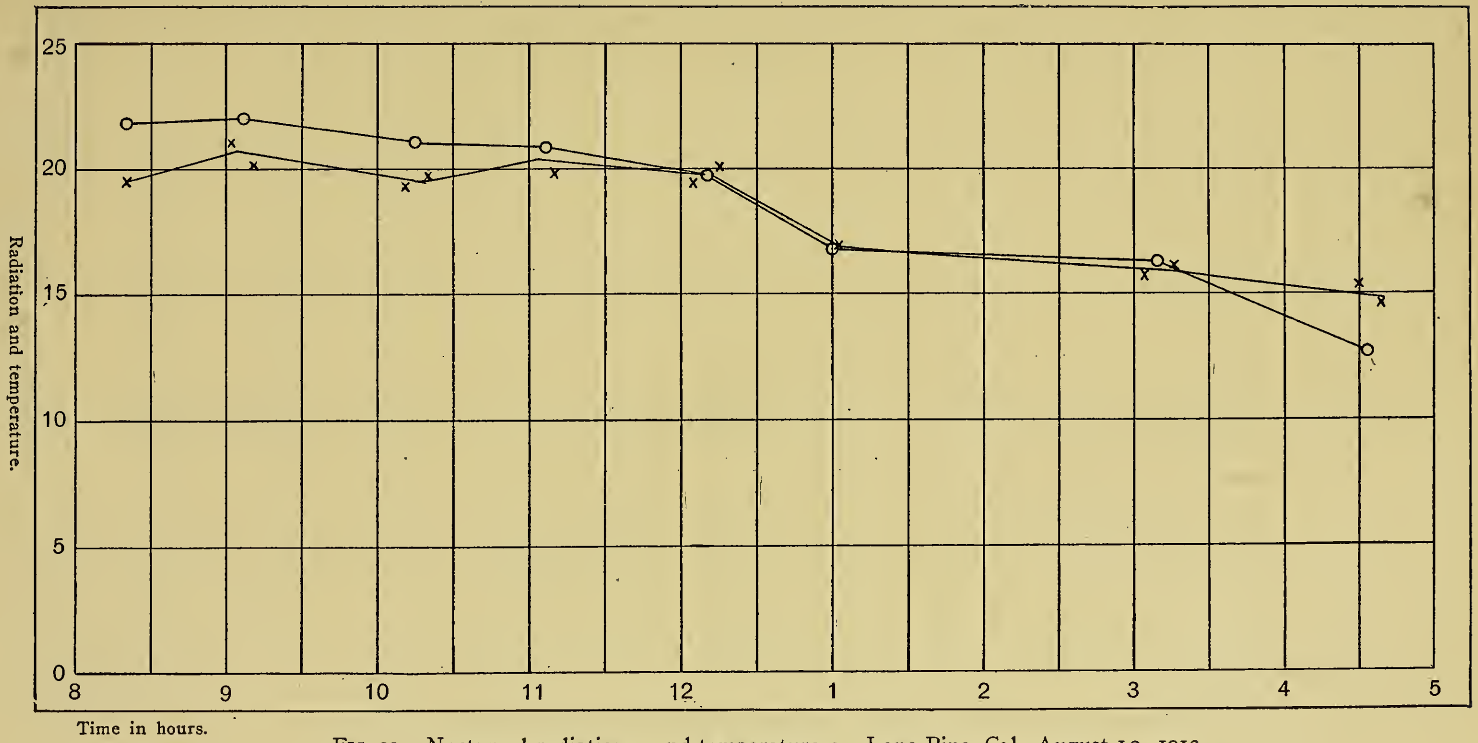

FIG. 20.—Nocturnal radiation *x* and temperature *o*. Lone Pine, Cal., August 10, 1913.

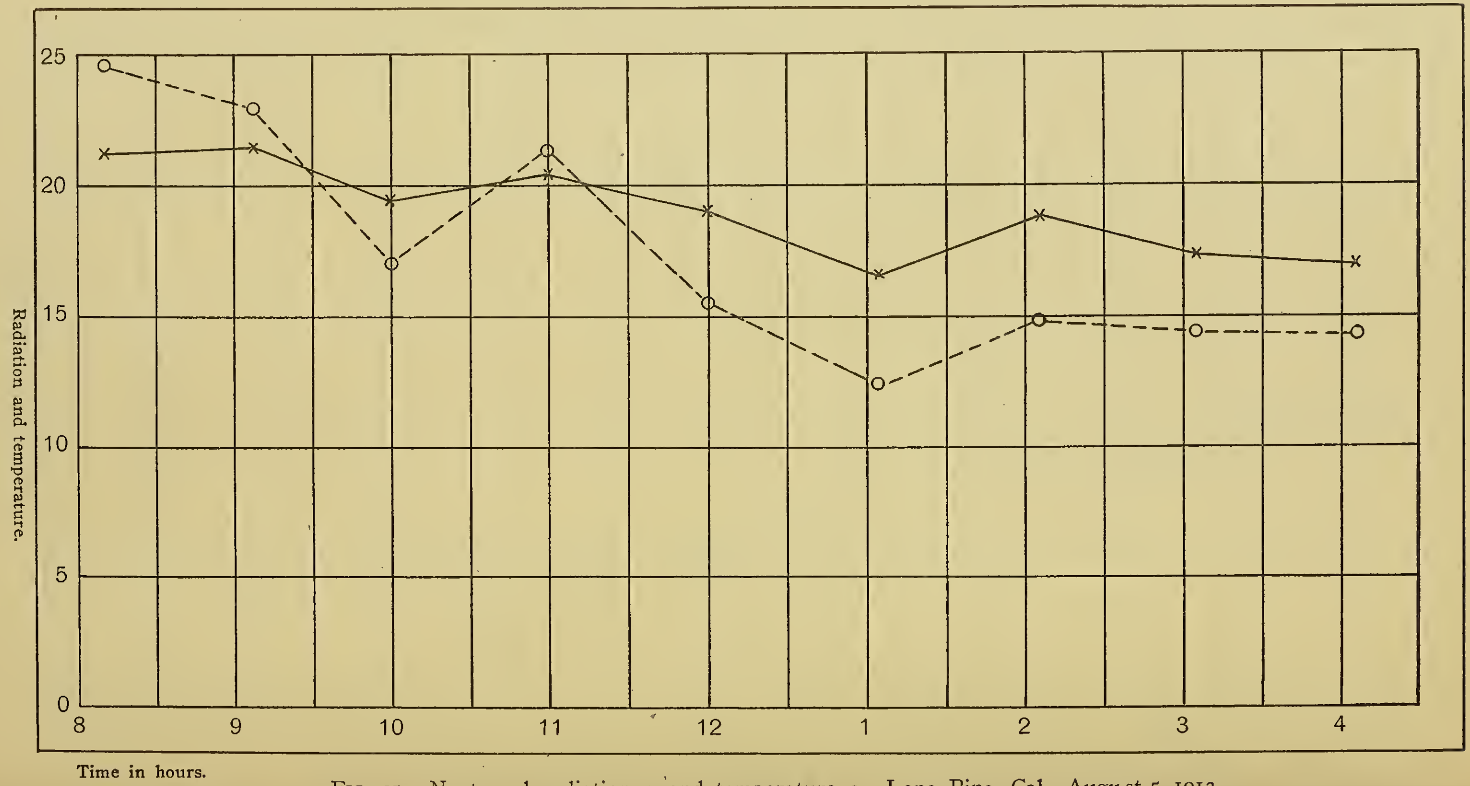

FIG. 21.—Nocturnal radiation *x* and temperature *o*. Lone Pine, Cal., August 5, 1913.

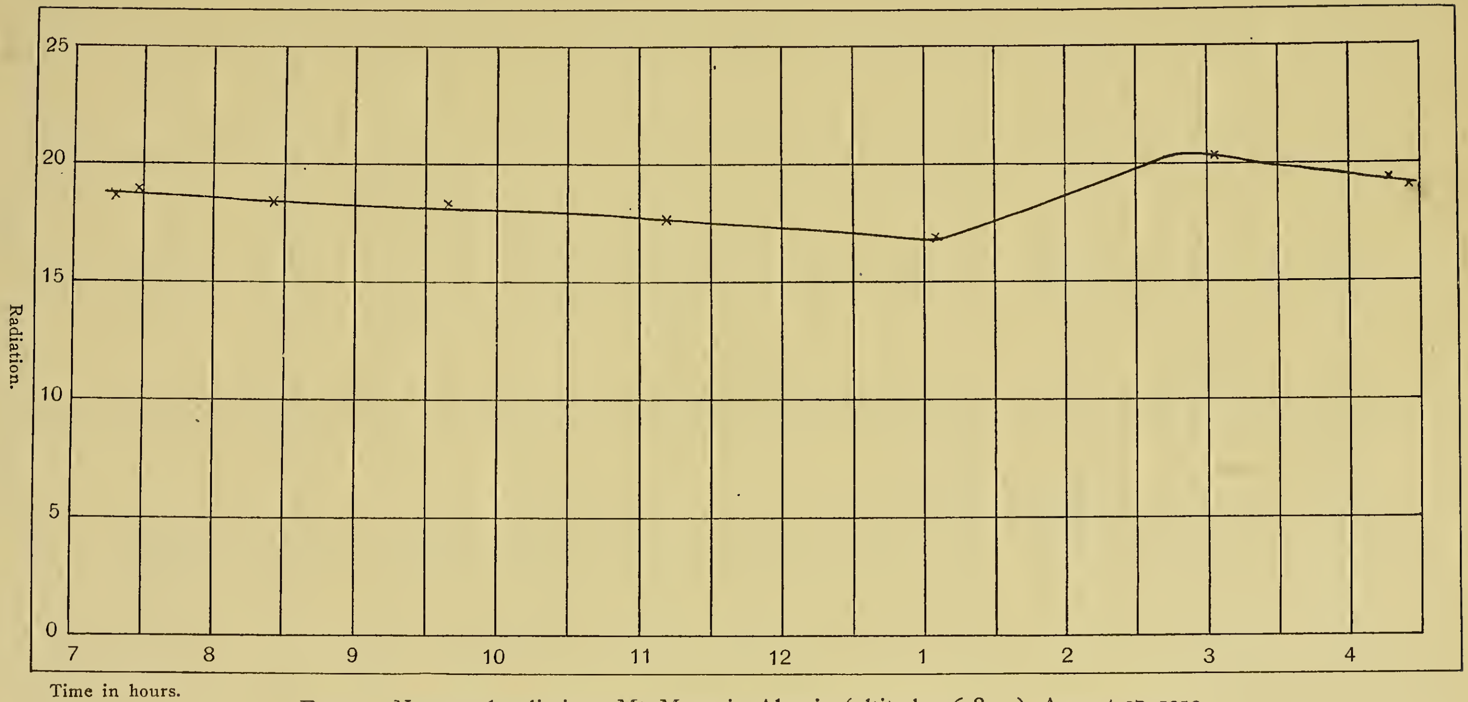

FIG. 22.—Nocturnal radiation. Mt. Mouzaia, Algeria (altitude 1,608 m.), August 27, 1912.

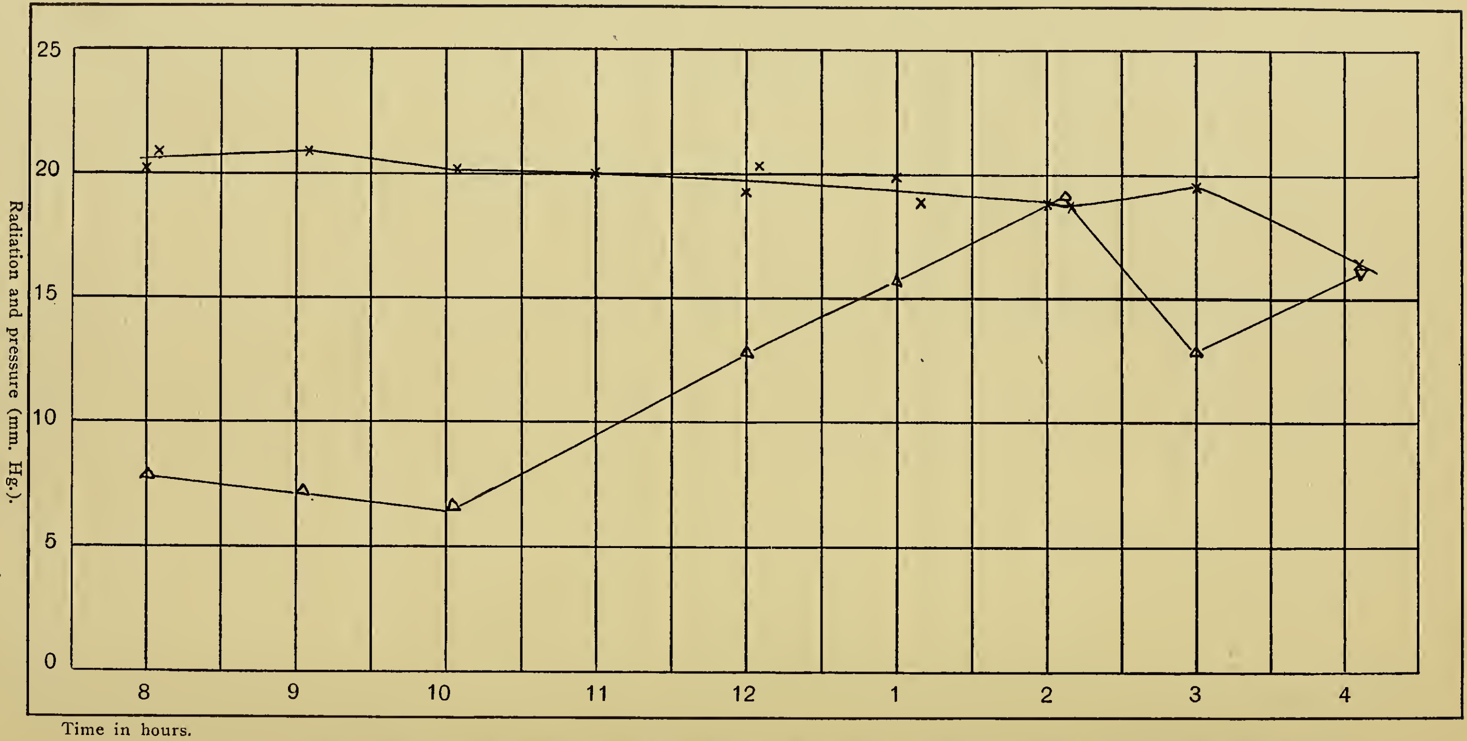

FIG. 23.—Nocturnal radiation x and water-vapor pressure Δ. Mt. San Antonio, Cal. (altitude 2,500 m.), July 12, 1913.

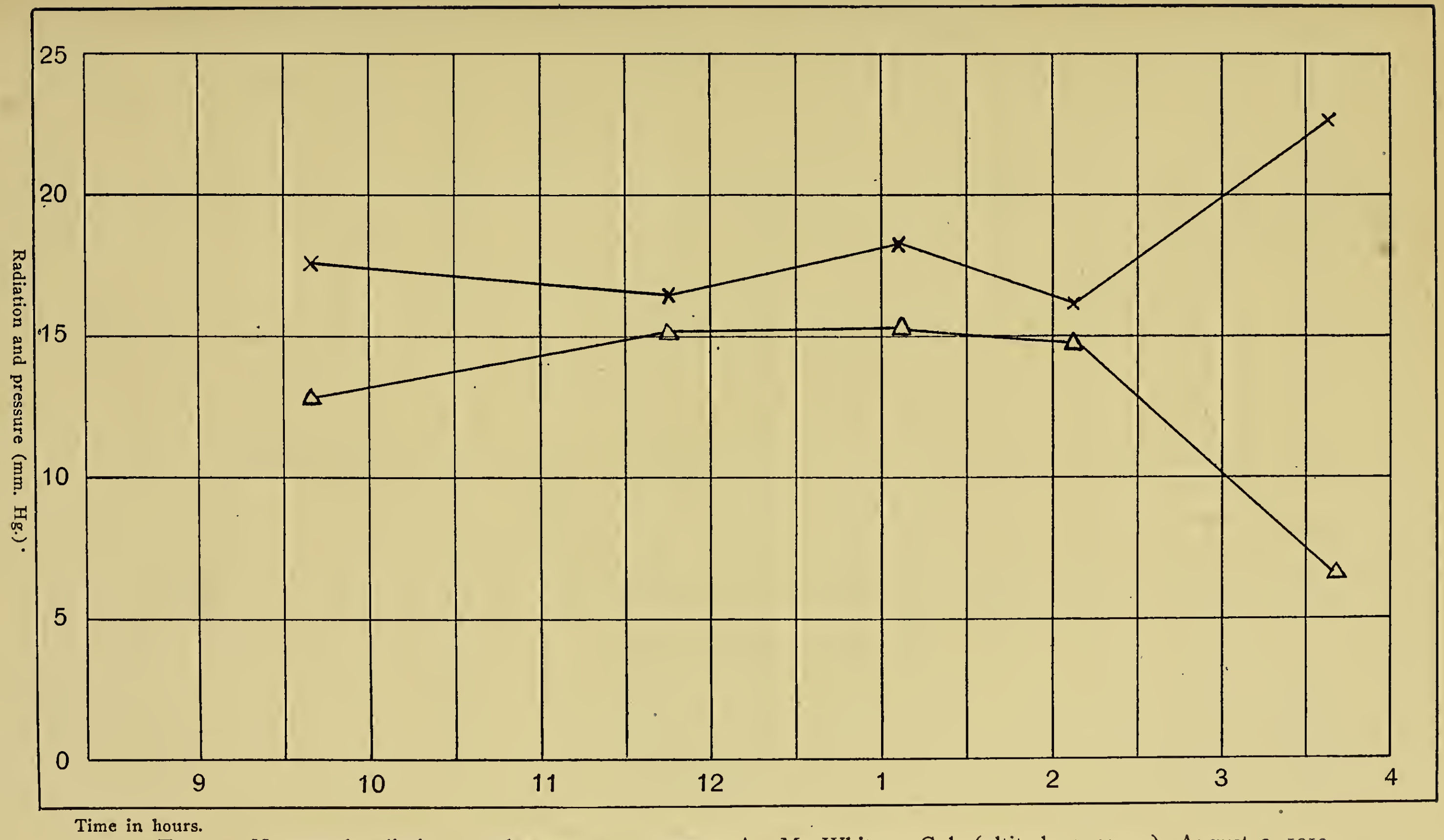

FIG. 24.—Nocturnal radiation *x* and water-vapor pressure Δ. Mt. Whitney, Cal. (altitude 4,420 m.), August 2, 1913.

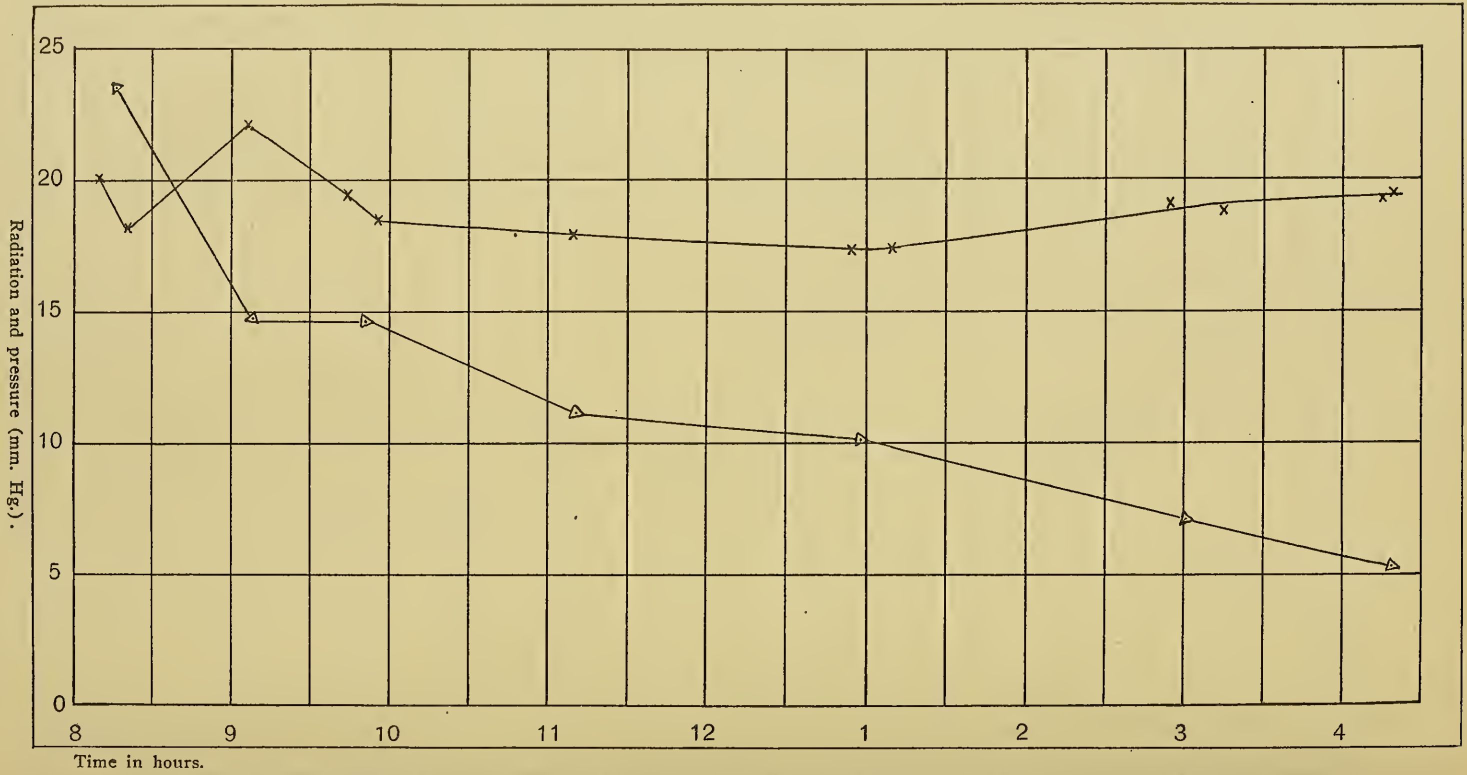

FIG. 25.—Nocturnal radiation x and water-vapor pressure Δ. Mt. Whitney, Cal. (altitude 4,420 m.), August 11, 1913.

EXPLANATION OF TABLES XIV TO XXI

In the following tables are included all the observations at Indio (Table XIV), at Lone Pine (Table XV), at Lone Pine Canyon (Table XVI), at Mount San Antonio (Table XVII), at Mount San Gorgonio (Table XVIII), at Mount Whitney (Table XIX), and at Mount Wilson (Table XX). Upon the values given in these tables, the studies of the total radiation are based. In the tables are given: (1) the date, (2) the time, (3) the temperature (t), (4) the pressure of aqueous vapor (H), (5) the radiation of a black body (St) at the temperature (t) (Kurlbaum's constant), (6) the observed effective radiation (Rt), (7) the difference between St and Rt, here defined as being the radiation of the atmosphere, (8) this radiation reduced to a temperature of 20° C., in accordance with the discussion presented in chapter V: B (E_{a20°), and finally *Remarks* in regard to the general meteorological conditions prevailing at the time of observation. With each night of observation is given the initials of the observers: A. K. Ångström, E. H. Kennard, F. P. Brackett, R. D. Williams, and W. Brewster.

Table XIV

Place: Indio. Altitude: 0 m. B = 760 mm. Instrument No. 17

Date	Time	t	H	S_t	R_t	$S_t - R_t$	E_{a20}	Remarks
July 22	7:50	26.6	13.59	0.618	0.123	0.495	0.453	A. K. Å. Cloudless sky, wind W., calm.
	8:40	24.9	13.67	0.604	0.118	0.486	0.455	
	10:00	28.3	12.24	0.632	0.129	0.503	0.451	
	10:15	27.5	11.86	0.625	0.143	0.482	0.436	
	11:00	27.8	11.43	0.628	0.147	0.481	0.433	
	12:10	26.1	10.87	......	......	......	......	
	1:00	26.4	11.13	0.616	0.140	0.476	0.438	
	2:15	25.8	10.64	0.611	0.140	0.471	0.436	
	3:45	23.6	10.77	0.593	0.133	0.460	0.440	
	4:30	22.8	10.67	0.587	0.136	0.451	0.435	
July 23	7:50	29.5	11.33	0.642	0.193	0.449	0.396	A. K. Å. Sky perfectly cloudless calm.
	9:00	28.1	11.30	0.630	0.193	0.437	0.391	
	10:15	25.2	11.56	0.606	0.182	0.424	0.394	
	11:05	24.7	11.41	0.602	0.181	0.421	0.396	
	12:45	23.6	10.47	0.593	0.172	0.421	0.402	
	2:15	23.3	10.52	0.591	0.178	0.413	0.397	
	3:30	22.2	10.52	0.582	0.175	0.407	0.395	
	4:25	21.0	10.82	0.572	0.171	0.401	0.396	
July 24	7:45	29.5	9.65	0.642	0.183	0.459	0.404	W B. Sky perfectly cloudless, calm.
	9:00	27.5	9.30	0.625	0.183	0.442	0.399	
	10:05	25.0	10.97	0.605	0.166	0.439	0.410	
	11:15	23.9	10.69	0.596	0.169	0.427	0.405	
	12:10	23.0	10.31	0.588	0.169	0.419	0.402	
	1:05	23.0	9.37	0.588	0.173	0.415	0.398	
	2:00	21.2	9.65	0.573	0.170	0.403	0.397	
	3:10	21.2	8.81	0.573	0.174	0.399	0.393	
	4:05	20.6	8.43	0.568	0.172	0.396	0.393	
	4:20	19.5	8.15	0.560	0.163	0.397	0.400	

Table XV

Place: Lone Pine. Altitude: 1,140 m. B = 650 mm. Instrument No. 18

Date	Time	t	H	S_t	R_t	$S_t - R_t$	E_{a20}	Remarks
Aug. 2	9:25	18.1	10.11	0.548	0.145	0.403	0.415	F. P. B., R. D. W. Cloudless, calm.
	10:00	19.4	8.99	0.559	0.144	0.415	0.419	
	11:05	17.4	9.71	0.543	0.127	0.416	0.433	
	12:10	21.3	10.20	0.575	0.149	0.426	0.420	
	1:05	18.2	10.58	0.548	0.134	0.414	0.426	
	2:00	18.1	10.50	0.547	0.136	0.411	0.423	
	3:30	17.5	10.24	0.544	0.141	0.403	0.419	
	4.00	16.7	10.01	0.538	0.151	0.387	0.407	
Aug. 3	8:00	20.0	8.44	0.564	0.175	0.389	0.389	R. D. W., F. P. B. Cloudless, calm.
	9:00	22.5	7.47	0.584	0.172	0.412	0.399	
	10:00	21.1	8.00	0.572	0.182	0.390	0.384	
	11:00	18.8	8.28	0.554	0.173	0.381	0.389	
	12:00	17.8	7.07	0.546	0.174	0.372	0.385	
	1:00	15.2	8.54	0.527	0.139	0.388	0.415	
	2:25	16.8	7.73	0.538	0.169	0.369	0.386	
	3:00	13:0	8.47	0.512	0.168	0.344	0.379	
	4:00	13.4	8.29	0.514	0.147	0.367	0.402	

TABLE XV—Continued

Place: Lone Pine. Altitude: 1,140 m. B = 650 mm. Instrument No. 18

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
Aug. 4	10:07	19.9	8.43	0.563	0.169	0.394	0.395	F. P. B. Cloudless, calm.
	11:00	19.0	7.08	0.556	0.167	0.389	0.395	
	12:00	17.3	9.01	0.542	0.183	0.359	0.374	R. D. W. Radiation variable.
	1:00	13.2	8.39	0.513	0.170	0.343	0.376	
	2:05	12.7	7.59	0.509	0.167	0.342	0.378	
	3:05	15.0	6.99	0.525	0.154	0.371	0.397	
	4:05	13.3	6.90	0.514	0.189	0.325	0.356	
Aug. 5	8:15	24.6	5.87	0.602	0.212	0.390	0.366	R. D. W., F. P. B. Radiation fluctuating.
	9:05	23.0	5.79	0.588	0.215	0.373	0.358	
	10:00	17.1	7.38	0.541	0.195	0.346	0.360	
	11:00	21.4	5.46	0.575	0.205	0.370	0.363	
	12:00	15.6	6.33	0.530	0.191	0.339	0.359	
	1:05	12.4	6.96	0.507	0.166	0.341	0.378	
	2:05	14.8	5.97	0.524	0.189	0.335	0.360	
	3:05	14.4	6.52	0.521	0.174	0.347	0.375	
	4:05	14.4	5.96	0.521	0.170	0.351	0.379	
Aug. 9	8:00	21.1	7.99	0.572	0.180	0.392	0.387	R. D. W., F. P. B. Hazy in the evening, perfectly cloudless.
	9:00	22.4	7.18	0.583	0.177	0.406	0.394	
	10:00	18.8	8.29	0.554	0.168	0.386	0.394	
	11:00	16.9	7.61	0.540	0.163	0.377	0.394	
	12:00	14.6	8.03	0.523	0.143	0.380	0.408	
	1:00	12.7	8.13	0.509	0.142	0.367	0.406	
	2:00	12.2	8.11	0.506	0.139	0.367	0.407	
	3:05	10.7	5.42	0.496	0.139	0.357	0.405	
	4:00	10.6	8.39	0.495	0.133	0.362	0.411	
Aug. 10	8:20	21.9	7.12	0.579	0.196	0.383	0.374	E. H. K. Few scattered clouds at N. horizon in the evening. Perfectly cloudless after 9:00.
	9:00	22.0	7.25	0.580	0.211	0.369	0.360	
	9:10	......	......	......	0.202	0.378	0.368	
	10:10	21.1	7.38	0.572	0.194	0.378	0.373	
	10:20	......	......	......	0.197	0.375	0.370	
	11:00	20.9	7.48	0.571	0.209	0.362	0.359	
	11:10	......	......	......	0.199	0.372	0.369	
	12:05	19.8	7.61	0.562	0.195	0.367	0.371	
	12:15	......	......	......	0.201	0.361	0.365	
	1:00	16.9	8.05	0.540	0.170	0.370	0.387	
	3:05	16.4	8.23	0.536	0.159	0.377	0.389	
	3:15	16.4	8.23	0.536	0.162	0.374	0.393	
	4:30	12.7	8.01	0.510	0.154	0.356	0.393	
	4:40	......	......	0.510	0.147	0.363	0.400	
Aug. 11	8:25	20.5	6.40	0.568	0.189	0.379	0.377	E. H. K. Perfectly cloudless. Breezy.
	9:00	24.6	6.12	0.602	0.197	0.405	0.381	
	9:10			0.602	0.223	0.379	0.356	
	10:00	23.2	5.78	0.590	0.204	0.386	0.371	
	10:10			0.590	0.204	0.386	0.371	
	11:00	20.7	5.78	0.569	0.202	0.367	0.363	
	11:10			0.569	0.207	0.362	0.358	
	12:00	18.9	6.59	0.555	0.204	0.351	0.358	
	12:10			0.555	0.210	0.345	0.352	
	1:00	14.3	6.18	0.521	0.189	0.332	0.359	
	1:10			0.521	0.176	0.345	0.372	
	2:00	12.0	5.78	0.505	0.190	0.315	0.351	
	2:10			0.505	0.176	0.329	0.365	

TABLE XV—Continued

Place: Lone Pine. Altitude: 1,140 m. B = 650 mm. Instrument No. 18

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
Aug. 11	3:00	11.6	6.27	0.502	0.196	0.306	0.343	E. H. K. Perfectly cloudless, fluctuations.
	3:25			0.502	0.155	0.347	0.384	
	4:10	9.8	5.36	0.490	0.187	0.303	0.349	
	4:20			0.490	0.180	0.310	0.356	
	4:40	10.0	5.16	0.491	0.173	0.318	0.364	
	4:50			0.491	0.156	0.335	0.385	
	5:00	8.9	5.37	0.484	0.171	0.313	0.365	
Aug. 12	7:00	25.6	7.31	0.610	0.208	0.402	0.372	E. H. K. Perfectly cloudless, windy.
	7:20	......	......	0.610	0.212	0.398	0.369	
	7:25	25.2	5.56	0.606	0.209	0.397	0.369	
	7:45	......	......	0.606	0.211	0.395	0.367	
	8:00	26.0	4.71	0.613	0.199	0.414	0.381	
	8:10			0.613	0.220	0.393	0.362	
	8:35	......	......	0.613	0.218	0.395	0.369	
	9:00	23.9	4.49	0.596	0.209	0.387	0.368	
	9:10			0.596	0.220	0.376	0.357	
	10:00	20.6	5.30	0.568	0.195	0.373	0.371	
	10:10			0.568	0.197	0.371	0.369	
	11:15	18.7	5.08	0.553	0.197	0.356	0.363	
	11:25			0.553	0.208	0.345	0.352	
	12:00	20.5	3.85	0.568	0.189	0.379	0.377	
	12:10			0.568	0.220	0.348	0.346	
	1:00	20.5	3.67	0.568	0.192	0.376	0.374	
	1:10			0.568	0.184	0.384	0.382	
	2:05	15.7	5.26	0.530	0.172	0.358	0.380	
	2:20			0.530	0.163	0.367	0.389	
	3:05	15.6	5.91	0.529	0.169	0.360	0.382	
	3:15			0.529	0.154	0.375	0.397	
Aug. 14	8:20	23.4	7.52	0.592	0.241	0.351	0.337	A. K. Å. Very clear
	8:25	......	......	0.592	0.231	0.361	0.347	
	8:50	21.3	4.69	0.574	0.231	0.343	0.338	

TABLE XVI

Place: Lone Pine Canyon. Altitude: 2,500 m. B = 498 mm. Instrument No. 22

Aug. 4	8:05	18.9	4.71	0.555	0.203	0.352	0.359	W. B. Cloudless.
	4:10	15.0	5.27	0.526	0.203	0.323	0.346	
Aug. 5	8:05	18.9	5.32	0.555	0.211	0.344	0.351	W. B. Cloudless.
	9:00	18.9	2.54	0.555	0.199	0.356	0.363	
	10:05	18.6	2.65	0.553	0.226	0.327	0.334	
	11:00	18.6	3.24	0.553	0.220	0.333	0.340	
	12:00	16.1	4.00	0.533	0.218	0.315	0.333	
	1:00	16.1	3.75	0.533	0.217	0.316	0.334	
	2:10	16.7	4.07	0.538	0.209	0.329	0.345	
	2:55	16.8	3.53	0.539	0.194	0.345	0.361	
	3:55	15.0	4.23	0.526	0.214	0.312	0.334	
Aug. 8	9:35	15.5	7.63	0.529	0.176	0.353	0.376	W. B. Cloudless.
	10:00	14.7	6.30	0.523	0.177	0.346	0.372	
Aug. 9	8:15	12.8	7.34	0.510	0.184	0.326	0.359	W. B. Cloudless.
	9:10	12.2	5.98	0.506	0.161	0.345	0.383	
	10:00	12.2	5.98	0.506	0.158	0.348	0.386	

TABLE XVI—Continued

Place: Lone Pine Canyon. Altitude: 2,500 m. B = 498 mm. Instrument No. 22

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
Aug. 9	10:55	12.5	6.09	0.508	0.154	0.354	0.391	W. B. Hazy but cloudless.
	12:00	12.8	5.52	0.510	0.169	0.341	0.375	
	1:00	11.9	5.88	0.504	0.169	0.335	0.374	
	2:00	12.8	5.18	0.508	0.161	0.347	0.382	
	3:00	12.0	5.04	0.505	0.169	0.336	0.375	
	3:55	12.0	5.04	0.505	0.147	0.358	0.397	
Aug. 10	9:15	12.2	5.93	0.506	0.166	0.340	0.378	W. B. Breezy, cloudless.
	3:10	10.6	6.53	0.495	0.172	0.323	0.367	
	4:00	10.6	6.06	0.495	0.168	0.327	0.371	

TABLE XVII

Place: Mt. San Antonio. Altitude: 3,000 m. B = 532 mm. Instrument No. 22

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
July 12	8:00	18.3	3.91	0.550	0.202	0.348	0.357	A. K. Å. Perfectly cloudless, windy.
	8:05	......	......	0.550	0.209	0.341	0.350	
	9:05	17.9	3.63	0.547	0.209	0.338	0.348	
	10:05	......	......	0.547	0.202	0.345	0.355	
	11:00	17.5	3.23	0.544	0.200	0.344	0.357	
	12:00	16.9	6.35	0.539	0.193	0.346	0.362	
	12:05	......	......	0.539	0.203	0.336	0.352	
	1:00	16.7	7.85	0.538	0.199	0.339	0.356	
	1:10	......	......	0.538	0.189	0.349	0.366	
	2:00	16.6	9.55	0.537	0.188	0.349	0.366	
	2:10	......	......	0.537	0.187	0.350	0.367	
	3:00	16.4	6.48	0.536	0.195	0.341	0.358	
	3:10	16.2	8.10	0.534	0.131	0.403	......	Clouds after 3:00.
	4:05	......	......	0.534	0.164	0.370	......	
July 13	7:10	11.8	2.46	0.503	0.203	0.300	0.335	A. K. Å. Hazy at N. horizon, cloudless.
	7:30	11.2	2.60	0.499	0.191	0.308	0.346	
	8:30	10.7	2.22	0.496	0.213	0.283	0.321	
	8:50	10.8	2.36	0.496	0.220	0.276	0.312	
	9:45	11.2	1.99	0.499	0.211	0.288	0.324	
	10:50	10.0	2.27	0.491	0.219	0.272	0.313	
	12:30	11.3	1.63	0.500	0.225	0.275	0.309	
	2:15	9.7	2.16	0.489	0.220	0.269	0.310	
	4:15	10.0	2.27	0.491	0.221	0.270	0.310	

TABLE XVIII

Place: Mt. San Gorgonio. Altitude: 3,500 m. B = 495 mm. Instrument No. 22

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
July 23	8:00	2.0	2.95	0.438	0.204	0.234	0.300	E. H. K. After stormy and rainy day perfectly cloudless night.
	9:00	1.1	2.66	0.432	0.215	0.217	0.282	
	10:20	1.3	......	0.433	0.215	0.218	0.283	
	11:00	0.9	......	0.431	0.205	0.226	0.294	
	12:05	0.9	......	0.431	0.207	0 224	0.292	
	1:20	0.4	......	0.428	0.208	0.220	0.290	
	2:00	0.2	2.61	0.426	0.208	0.218	0.288	
	3:00	0.0	1.80	0.425	0.208	0.217	0.288	
	4:00	—0.6	2.21	0.421	0.198	0.223	0.299	
July 24	8:20	2.8	1.91	0.443	0.211	0.232	0.295	F. P. B. Perfectly cloudless.
	9:00	2.3	1.54	0.440	0.215	0.225	0.289	
	10:00	2.2	......	0.439	0.215	0.224	0.287	
	11:00	1.6	1.88	0.435	0.223	0.212	0.274	
	12:00	1.8	1.14	0.436	0.221	0.215	0.276	

Table XIX

Place: Mt. Whitney. Altitude: 4,420 m. B = 446 mm. Instrument No. 17

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
Aug. 1	11:00	—2.9	3.70	0.407	0.189	0.218	0.302	E. H. K. Cloudless only about 11:00.
Aug. 2	9:40	—0.8	3.23	0.420	0.176	0.244	0.327	A. K. Å. Cloudless after cloudy and windy evening.
	11:45	—1.4	3.81	0.416	0.165	0.251	0.345	
	1:05	—1.4	3.79	0.416	0.183	0.233	0.320	
	2:05	—1.9	3.61	0.413	0.160	0.253	0.343	
	3:35	—1.1	1.68	0.418	0.226	0.192	0.260	
Aug. 3	7:30	0	3.75	0.425	0.194	0.231	0.306	E. H. K. Perfectly cloudless, balloon sent up, calm.
	8:05	0.3	3.30	0.413	0.207	0.206	0.271	
	9:05	—0.1	3.80	0.424	0.217	0.207	0.277	
	10:10	......	......	0.424	0.170	0.254	0.338	
	11:00	—0.1	3.18	0.424	0.177	0.247	0.329	
	12:05	—0.4	3.15	0.422	0.160	0.262	0.350	
	1:00	—0.6	2.97	0.421	0.171	0.250	0.335	
	2:10	—1.1	2.90	0.418	0.163	0.255	0.344	
	3:25	—1.1	1.70	0.418	0.167	0.251	0.339	
	4:10	—1.3	1.40	0.417	0.183	0.234	0.316	
	4:25	......	......	0.417	0.179	0.238	0.321	
	4:35	—1.6	1.76	0.415	0.182	0.233	0.317	
	4:45	......	......	0.415	0.190	0.225	0.306	
	5:00	—1.7	1.73	0.414	0.183	0.231	0.314	
Aug. 4	8:05	1.4	3.28	0.434	0.195	0.239	0.310	A. K. Å. Perfectly cloudless, balloon up, calm.
	8:25	......	......	0.434	0.199	0.235	0.304	
	9:00	1.3	2.59	0.433	0.193	0.240	0.311	
	9:10	......	......	0.433	0.195	0.238	0.308	
	10:00	1.1	2.39	0.432	0.190	0.242	0.315	
	10:10	......	......	0.432	0.194	0.238	0.309	
	11:00	0.6	2.46	0.429	0.194	0.235	0.308	
	11:10	......	......	0.429	0.189	0.240	0.314	
	12:00	0.6	2.42	0.429	0.188	0.241	0.315	
	12:10	......	......	0.429	0.188	0.241	0.315	
	1:00	0.6	2.44	0.429	0.180	0.249	0.327	
	1:10	......	......	0.429	0.182	0.247	0.324	
	2:15	0.0	2.32	0.425	0.179	0.246	0.326	
	2:30	......	......	0.425	0.184	0.241	0.319	
	3:00	0.2	2.00	0.426	0.213	0.213	0.281	
	3:10	......	......	0.426	0.228	0.198	0.262	
	3:20	0.0	1.93	0.425	0.200	0.225	0.298	
	3:30	......	......	0.425	0.210	0.215	0.285	
	4:00	0.0	2.21	0.425	0.202	0.223	0.295	
	4:10	......	......	0.425	0.223	0.202	0.267	
Aug. 5	7:10	1.9	2.67	0.437	0.179	0.258	0.332	E. H. K. Balloon up, breezy after 10:00.
	7:40	......	......	0.437	0.190	0.247	0.317	
	8:05	1.8	2.87	0.436	0.182	0.254	0.326	
	8:10	......	......	0.436	0.189	0.247	0.317	
	9:00	1.3	2.74	0.433	0.191	0.242	0.313	
	9:10	......	......	0.433	0.200	0.233	0.302	
	10:00	1.1	2.06	0.432	0.188	0.244	0.317	
	10:45	......	......	0.432	0.175	0.257	0.334	
	11:00	1.1	1.83	0.432	0.195	0.237	0.308	
	11:10	......	......	0.432	0.199	0.233	0.303	
	12:00	0.6	1.90	0.429	0.197	0.232	0.304	
	12:10	......	......	0.429	0.198	0.231	0.303	

TABLE XIX—Continued

Place: Mt. Whitney. Altitude: 4,420 m. B = 442 mm. Instrument No. 17

Date	Time	t	H	S_t	R_t	S_t-R_t	E_{a20}	Remarks
Aug. 5	1:10	0.3	1.86	0.427	0.185	0.242	0.318	E. H. K. Perfectly cloudless
	1:20	......	......	0.427	0.192	0.235	0.309	
	2:10	0.6	1.81	0.429	0.191	0.238	0.312	
	2:20	......	......	0.429	0.198	0.231	0.302	
	3:00	0.3	1.32	0.427	0.181	0.246	0.323	
	3:05	......	......	0.427	0.187	0.240	0.316	
	4:05	0.6	1.52	0.429	0.173	0.256	0.335	
	4:20	......	......	0.429	0.176	0.253	0.332	
Aug. 8	9:45	−1.3	3.59	0.417	0.173	0.244	0.330	A. K. Å. Cloudless after 9:30.
	10:00	......	......	0.417	0.162	0.255	0.344	
	10:35	−1.4	3.35	0.416	0.167	0.249	0.337	
	10.55	......	......	0.416	0.161	0.255	0.345	
Aug. 9	12:30	−3.0	3.51	0.407	0.150	0.257	0.356	A. K. Å. Cloudless after foggy afternoon.
	12:45	......	......	0.407	0.154	0.253	0.351	
	2:30	−3.6	3.07	0.403	0.152	0.251	0.351	
	4:35	−3.7	2.46	0.402	0.160	0.242	0.338	
	4:45	......	......	0.402	0.161	0.241	0.337	
Aug. 11	8:10	−2.2	2.37	0.412	0.201	0.211	0.289	A. K. Å. Cloudless after clear day. Radiation variable.
	8:20	......	......	0.412	0.181	0.231	0.316	
	9:05	−2.3	1.47	0.411	0.221	0.190	0.260	
	9:45	−2.4	1.47	0.410	0.196	0.214	0.293	
	9:55	......	......	0.410	0.183	0.227	0.311	
	11:10	−2.7	1.12	0.409	0.179	0.230	0.316	
	12:55	−3.0	1.02	0.407	0.172	0.235	0.325	
	1:10	......	......	0.407	0.174	0.233	0.322	
	2:55	−2.6	0.69	0.409	0.191	0.218	0.300	
	3:15	......	......	0.409	0.189	0.220	0.303	
	4:15	−2.5	0.54	0.410	0.193	0.217	0.298	
	4:20	......	......	0.410	0.194	0.216	0.297	
Aug. 12	8:00	−1.4	1.17	0.416	0.194	0.222	0.300	A. K. Å. Clouds after 8:30.
	8:10	......	......	0.416	0.192	0.224	0.303	

TABLE XX

Place: Mt. Wilson. Altitude: 1,730 m. B = 615 mm. Instrument No. 17

Aug. 27	9.10	18.9	12.37	0.555	0.143	0.412	0.420	A. K. Å. Calm and perfectly cloudless night.
	9:25	......	......	0.555	0.140	0.415	0.423	
	10:00	18.8	11.45	0.554	0.147	0.407	0.415	
	10:20	18.5	11.34	0.552	0.152	0.400	0.410	
	11:00	18.3	10.92	0.550	0.150	0.400	0.411	
	11:10	......	......	0.550	0.151	0.399	0.410	
	12:00	18.2	10.97	0.549	0.149	0.400	0.412	
	12:10	......	......	0.549	0.151	0.398	0.410	
	12:55	18.4	11.13	0.551	0.145	0.406	0.416	
	1:05	......	......	0.551	0.146	0.405	0.415	
	2:00	17.8	11.17	0.546	0.141	0.405	0.419	
	2:10	......	......	0.546	0.141	0.405	0.419	
	2:50	17.8	11.04	0.546	0.147	0.399	0.413	
	3:00	......	......	0.546	0.147	0.399	0.413	
	3:40	18.5	10.69	0.552	0.155	0.397	0.407	
	3:50	......	......	0.552	0.154	0.398	0.408	

TABLE XXI

Date	Time	Instr.	Place Observer	Altitude	Radiation	Humidity	Temp.	Remarks
Aug. 26	8:45	18	Bassour. C. G. A.	1160 m.	0.217	3.8	21.5°	Sky perfectly cloudless
26	9:00	17	Mousaïa Valley. A. K. Å.	540 m.	0.174	8.0	19.6°	Sky perfectly cloudless
27	9:05	18	Bassour. C. G. A.	1160 m.	0.188	8.5	21.5°	Sky perfectly cloudless
27	9:00	17	Peak of Mousaïa. A. K. Å.	1610 m.	0.183	8.6	18.2°	Sky perfectly cloudless
27	7 to 5	17	Peak of Mousaïa. A. K. Å.	1610 m.	0.186	7.7	16.8°	Sky perfectly cloudless

APPENDIX I

FREE-AIR DATA IN SOUTHERN CALIFORNIA, JULY AND AUGUST, 1913[1]

By the Aerial Section, U. S. Weather Bureau—Wm. R. Blair in Charge

[Dated, Mount Weather, Va., May 26, 1914]

The Astrophysical Observatory of the Smithsonian Institution, and the Mount Weather Observatory of the Weather Bureau co-operating during July and August, 1913, made observations in southern California: (*a*) Of solar radiation at high levels, by means of a photographically recording pyrheliometer, carried by free balloons; (*b*) of the total moisture content of the air above Mount Wilson, by means of the spectroscope; (*c*) of nocturnal radiation, by means of the K. Ångström compensation apparatus; (*d*) of the meteorological elements, air pressure, temperature, humidity, and movement, at different altitudes by means of meteorographs, carried by free balloons at Avalon, and by captive balloons at Lone Pine and at the summit of Mount Whitney. The pyrheliometric observations have already been discussed by C. G. Abbot in *Science,* March 6, 1914. It is the purpose of this present paper to communicate more particularly the meteorological observations.

A. The Free Balloon Observations

Morning and evening ascensions were made on July 23 and 24, 1913, and thereafter daily ascensions until August 12, 1913—23 ascensions in all. When a pyrheliometer was taken up, in addition to the meteorograph, the ascension for the day was so timed that the highest point would be reached about noon. On other days the ascensions were made shortly after sunrise or just before sunset. Table 1 shows the number of balloons recovered, their landing points, and other information of general interest.

Table 1.—*Statistics of sounding balloon flights from Avalon, Cal., during July and August, 1913*

Date	Hour	Balloons		Landing point	Horizontal distance traveled	Direction traveled	Highest altitude reached	Lowest temperature recorded
		Number	Ascensional force					
1913			*Kg.*		*Km.*		*M.*	*°C.*
July 23	6:06 a....	2	....	Huntington Beach, Cal....	42	NE.	25,160	—56.0
24	5:13 p....	2	0.8	Armada, Cal..............	122	ENE.	20,389	—55.8
26	5:11 p....	2	0.8	San Diego, Cal............	131	ESE.	....	....
27	4:57 p....	2	0.9	Oceanside, Cal............	91	E.	23,870	—64.7
28	5:05 p....	2	1.1	Chino, Cal.................	97	NE.	19,485	—62.6
29	11:10 a...	2	1.2	Los Angeles, Cal..........	80	N.	23,066	—60.4
30	10:54 a...	2	1.0	Atmore's Ranch, Cal.......	140	NNW.	32,643	—53.9
31	10:37 a...	2	1.6	Los Pasos Hills, Cal.......	122	NNW.	22,294	—58.9
Aug. 1	10:36 a...	2	1.4	New Hall, Cal.............	128	N.	23,466	—58.6
2	10:59 a...	2	1.3	Inglewood, Cal............	72	N.	21,302	—67.3
3	5:07 p....	2	0.9	Downey, Cal.	70	N.	17,428	—67.5
5	5:07 p....	2	0.8	Fullerton, Cal.............	75	NNE.	....	....
7	4:52 p....	2	0.8	Colton, Cal................	120	NE.	6,442	—25.2
8	5:23 p....	2	0.9	Baldwin Park, Cal.........	97	NNE.	14,100	—43.9
10	4:43 p....	2	0.9	Pacific Ocean.............	4	NW.	1,976	19.3

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[1] Reprinted by permission from the Monthly Weather Review, July, 1914, pp. 410-426.

All free balloons were started at Avalon, Santa Catalina Island, Cal. Because of the possibility of the instrument coming down in the ocean, balloons were sent up in pairs and with a float. This float weighed approximately 450 grams. Each balloon was filled until it would lift decidedly everything to be sent up except the float The balloons were then attached to the system in such a way that when either of them burst it would detach itself from the system, which then sank to the earth's surface with the remaining balloon. This device by which the balloons are connected with the system and which serves the purpose of releasing the burst balloon is shown in figure 1. It is made of spring brass wire of approximately 2.4 mm. diameter. The pressure of the springs *B* and *C* on the wire *A* at the points *D* and *E* is sufficient to prevent the rings from slipping off in case cord *F* or *G* becomes slack. The weight of the burst balloon or of what is left of it slips the ring off easily. Cords *F* and *G* must be so short that they will not twist above the device.

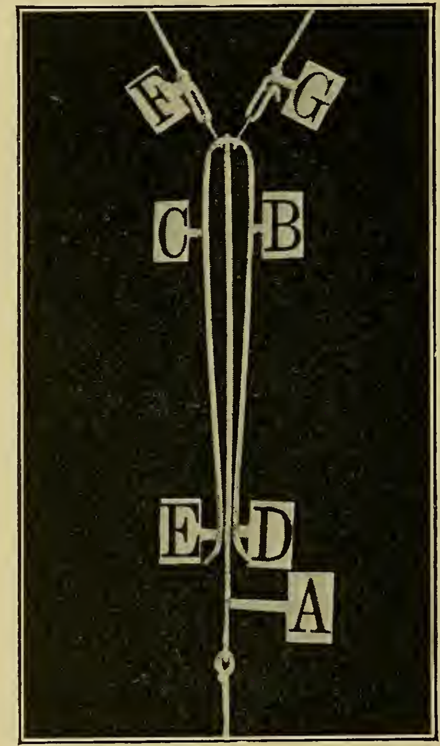

FIG. 1.—Device for releasing burst balloon.

The balloons used were of thick rubber, similar to those used at Huron in the early autumn of 1910 and at Fort Omaha in the late winter of 1911, but not so large. They were filled with electrolytic hydrogen which had been compressed in steel cylinders.

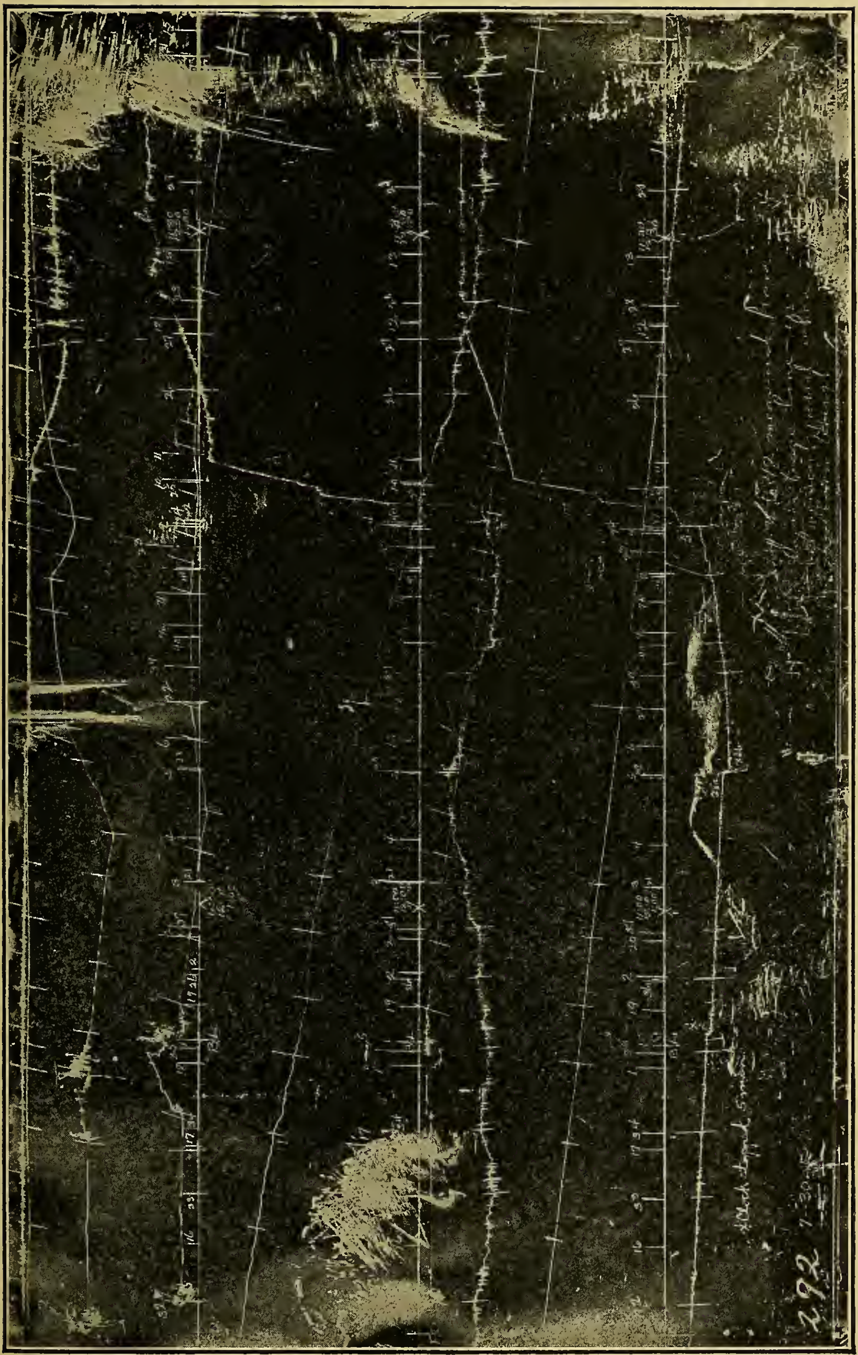

FIG. 2.—Record obtained in sounding balloon ascension of July 30, 1913.

TABLE 2.—*Temperatures recorded at different altitudes and ascensional rates of balloons for sounding balloon ascensions at Avalon, Cal., July and August, 1913.*

Altitude above surface	July 23		July 24		July 27		July 30		July 31		Aug. 1		Aug. 3		Means		Altitude above surface
	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	Rate of ascent	Tem-pera-ture	
Km.	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*M. p. s.*	°*C.*	*Km.*
1..............	4.02	18.5	3.14	14.6	3.33	13.3	1.58	18.2	3.97	21.6	2.78	24.2	2.90	30.0	3.10	20.1	1
2..............	4.17	12.6	3.33	14.7	3.27	9.6	1.55	20.3	4.17	18.7	2.90	18.3	3.03	21.8	3.20	16.6	2
3..............	4.44	5.5	3.51	8.1	3.27	2.5	1.63	18.5	4.27	12.8	3.03	10.9	3.06	14.6	3.32	10.4	3
4..............	4.63	− 1.0	3.58	2.4	3.27	− 4.7	1.81	11.0	4.33	5.8	3.17	3.6	3.09	7.3	3.41	3.5	4
5..............	4.76	− 7.9	3.51	− 2.8	3.33	−13.3	2.12	3.8	4.44	− 1.5	3.40	− 1.6	3.09	− 0.5	3.52	− 3.4	5
6..............	4.90	−14.7	3.51	− 9.3	3.44	−20.5	2.42	− 3.5	4.76	−11.3	3.51	− 9.5	3.21	− 8.2	3.68	−11.0	6
7..............	4.90	−21.6	3.51	−16.3	3.40	−29.0	2.67	− 9.8	5.21	−20.6	3.62	−17.5	3.27	−17.0	3.80	−18.8	7
8..............	4.90	−29.1	3.33	−20.8	3.40	−38.4	2.92	−15.9	5.46	−28.6	3.79	−23.5	3.27	−24.5	3.87	−25.8	8
9..............	4.83	−34.3	3.21	−26.3	3.40	−45.1	3.12	−22.8	5.65	−34.6	3.92	−30.0	3.12	−31.1	3.89	−32.0	9
10..............	4.90	−38.8	3.12	−31.7	3.33	−50.2	3.44	−30.2	5.95	−42.2	4.12	−36.6	3.14	−36.8	4.00	−38.1	10
11..............	5.56	−41.4	2.95	−38.2	3.30	−53.8	3.70	−37.3	6.41	−47.4	4.12	−43.2	3.33	−42.7	4.20	−43.4	11
12..............	5.13	−43.4	2.95	−42.4	3.37	−57.4	3.83	−44.2	6.41	−52.3	4.12	−49.4	3.33	−49.2	4.16	−48.3	12
13..............	5.56	−46.5	3.06	−45.5	3.37	−57.5	3.88	−49.1	6.54	−56.9	4.17	−52.3	3.37	−50.1	4.28	−51.1	13
14..............	4.07	−50.6	3.21	−46.6	3.44	−58.7	4.02	−51.3	6.67	−56.7	4.12	−49.8	3.37	−54.0	4.13	−52.5	14
15..............	4.17	−54.8	3.37	−49.6	3.88	−61.5	4.33	−49.2	6.67	−55.4	4.12	−50.5	3.37	−59.2	4.27	−54.3	15
16..............	4.63	−55.8	3.55	−52.2	4.57	−62.2	4.57	−50.3	6.80	−57.7	3.88	−54.0	3.33	−65.3	4.46	−56.8	16
17..............	5.38	−56.6	3.74	−55.4	3.70	−63.0	4.90	−49.8	6.94	−58.6	4.22	−56.0	3.51	−62.3	4.63	−57.4	17
18..............	6.29	−56.7	3.33	−55.6	3.47	−60.8	5.13	−53.0	7.58	−58.0	4.83	−58.0	3.51	−62.0	4.88	−57.7	18

The highest ascension of the series was made on July 30. This exceeds the previous highest ascension from this continent by more than two kilometers. The record obtained in this ascension is shown in figure 2.

In seven of the ascensions from which records were returned the instrument was carried to an altitude of 18 or more kilometers above sea level. The temperatures recorded and the ascensional rates of the balloons have been averaged and compared in table 2 and in figure 3. The mean of the observed temperatures in the seven ascensions does not show a minimum of temperature below the 18-kilometer level. The mean of the ascensional rates of the balloons shows, in general, an increase with altitude. Above the 18-kilometer level the individual ascensions show a decrease in the ascensional rates of the balloons soon after the minimum of temperature has been passed through. This relation between the air temperature and the ascensional rate of

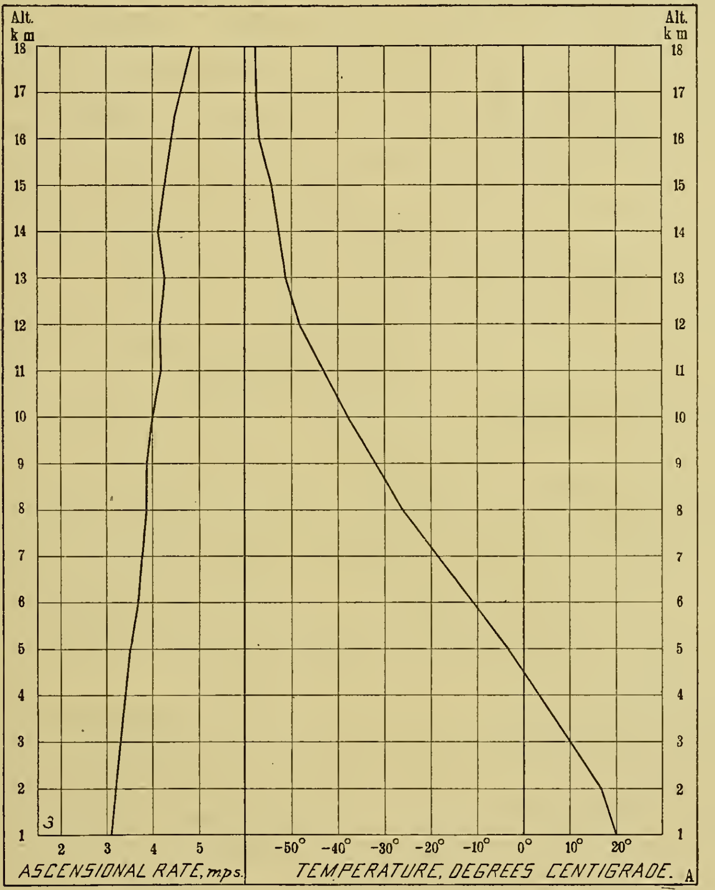

Fig. 3.—Relation between ascensional rates of balloons and air temperatures.

the balloons is similar to that already found. (See Bulletin Mount Weather Observatory, Washington, 1911, 4: 186.) It indicates that, in addition to the known factors entering into the ascensional rate of any balloon, there is the unknown factor of the difference in temperature between the gas in the balloon and the air through which the balloon is passing. While the temperature distribution in the free air is in general known, it would be impossible to predict, with sufficient accuracy for a particular ascension, the point of maximum ascensional rate or minor variations in the rate. On the other hand, careful observation of the ascensional rate of a free, sealed, rubber balloon might indicate fairly well the peculiarities of the temperature distribution at the time of the ascension. In this connection the author calls attention to an entirely erroneous statement in Bulletin of the Mount Weather Observatory, 4:186, regarding the adiabatic cooling of hydrogen gas. The approximate rate of cooling per kilometer came in some way to be considered the rate to the 15-kilometer level. The statement based on this error should not have appeared, nor is it needed to account for the observed peculiarities in the ascensional rate of free rubber balloons under consideration.

The instruments used were the same as those used in previous series of soundings. The calibration of the instruments was similar to that for previous series, except that the pressure and temperature elements were calibrated in a smaller chamber in which ventilation and temperature were under somewhat better control and in which temperatures down to —60° C. could easily be obtained. (See Bulletin Mount Weather Observatory, Washington, 1911, 4: 187.)

The data obtained in each ascension are presented in table 4 with interpolations at the 500-meter intervals up to 5 kilometers above sea level, and at 1-kilometer intervals above the 5-kilometer level. In figure 4 a diagram of the temperature-altitude relation is shown for each observation. Figure 5 shows the mean value of this relation for the period. The free air isotherms for the period are shown in figure 6. The horizontal projections of the balloon paths, as far as they could be observed, are shown in figure 7. Only one theodolite was used, the altitudes being computed from the observed air pressures.

An inversion of temperature, with the maximum temperature somewhere between the ½- and 2-kilometer levels, is shown in each curve of figure 4. This inversion of temperature is found, whether the observation be made in the morning, near noon, or in the late afternoon. It does not seem to accompany any particular wind direction. A similar inversion of temperature was observed in most of the ascensions made at Indianapolis, Fort Omaha, and Huron.

As shown in figure 5, the altitude at which the mean temperature for the period is a minimum is 17 kilometers. The minimum temperature observed in any ascension may be more than a kilometer above or below the height of this mean. In two ascensions, those of the 23d and 27th of July, the change of temperature with altitude begins to decrease at about the 8-kilometer level, while in the ascensions of August 2 and 3 this change does not take place until the 12-kilometer level. The temperature change from day to day is best shown in figure 6. The lowest temperature observed, —67.5° C., was at about the 16.5-kilometer level on August 3. About the same temperature had been observed at the 16-kilometer level on the day before.

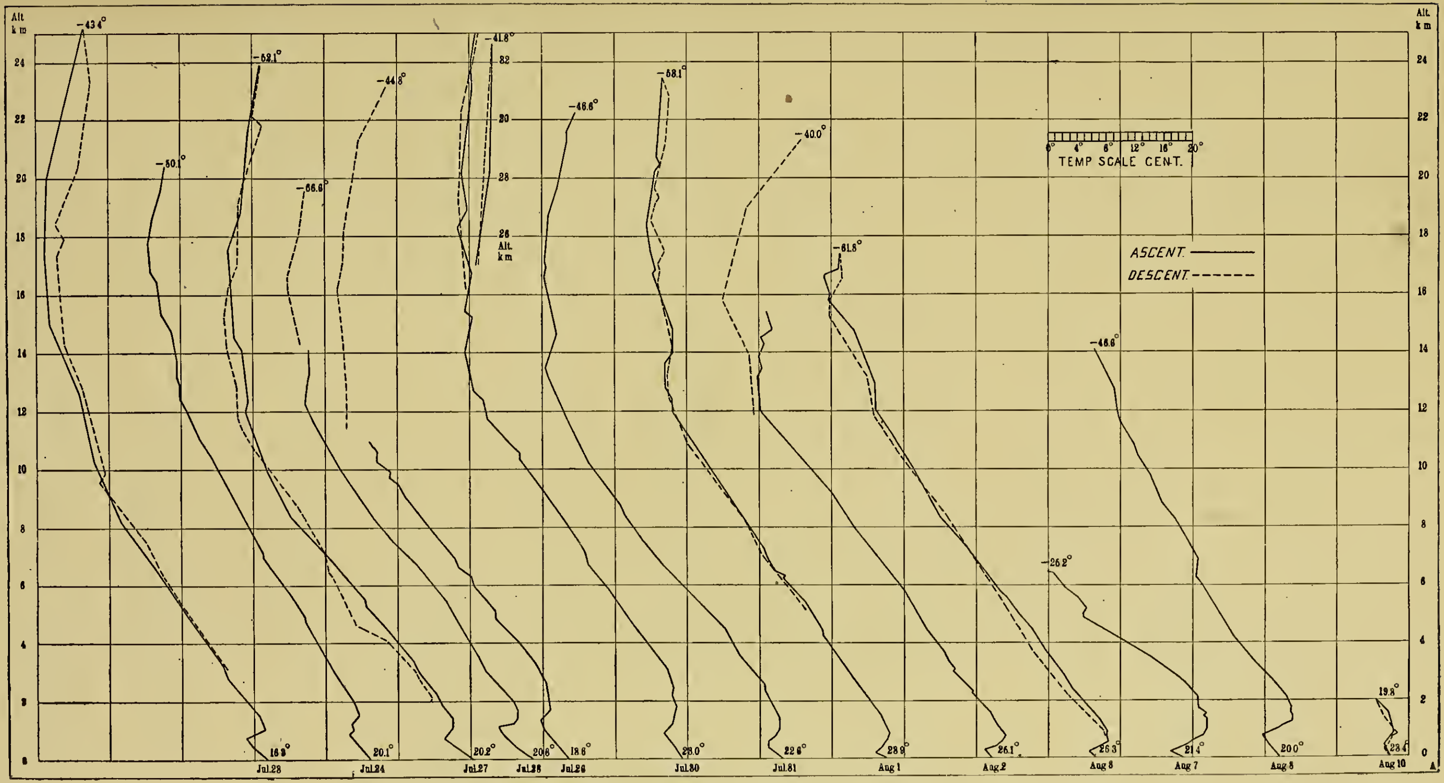

FIG. 4.—Vertical temperature gradients at Avalon, Cal., July 23-August 10, 1913.

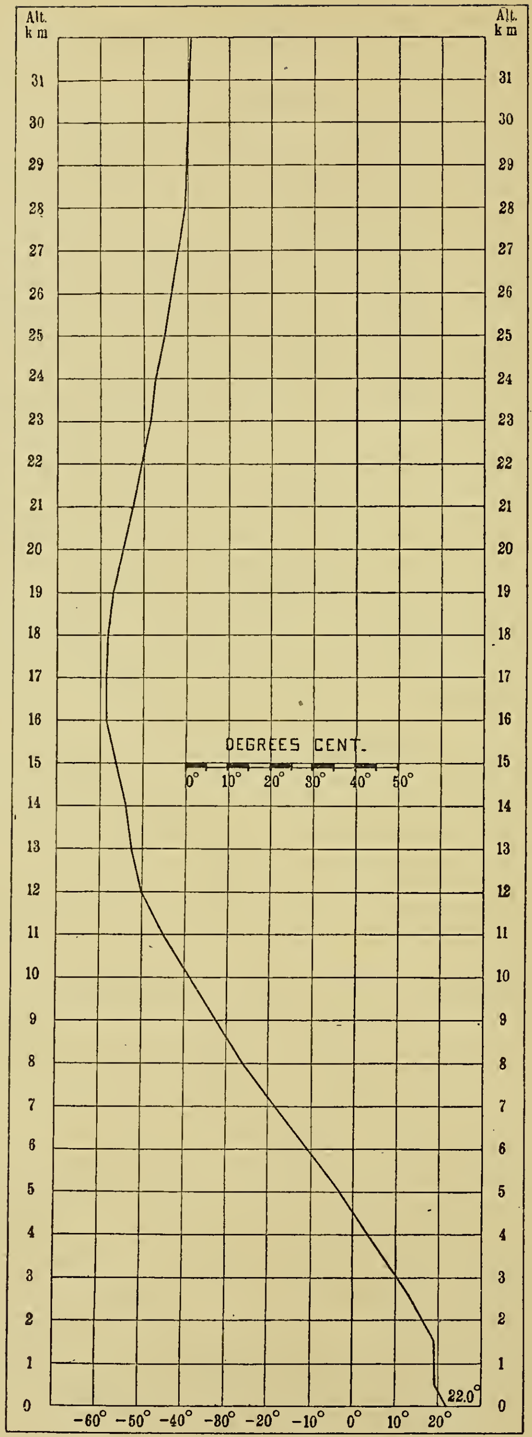

FIG. 5.—Curve showing mean temperature gradient at Avalon, Cal., July 23-August 3, 1913.

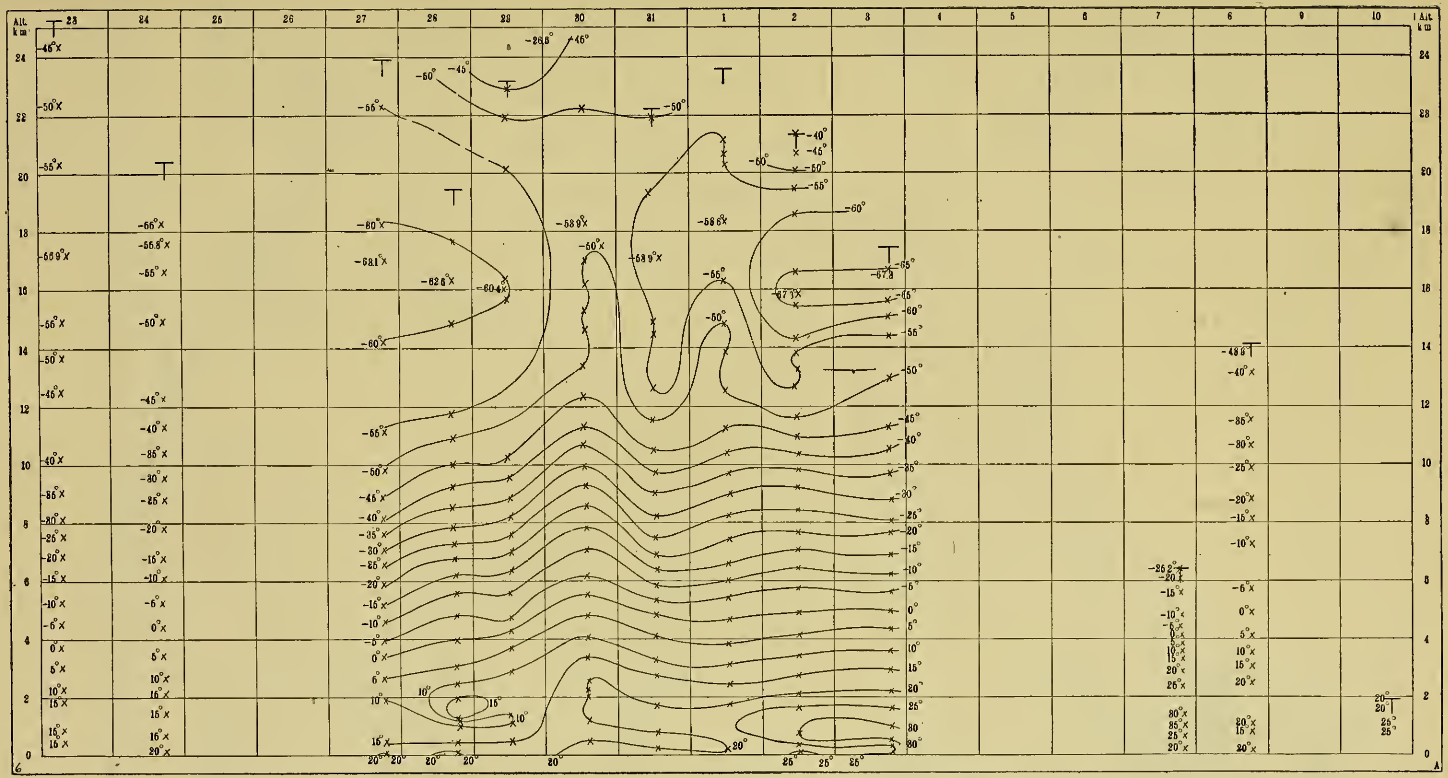

FIG. 6.—Free-air temperatures at Avalon, Cal., July 23-August 10, 1913.

FIG. 7.—Pressure distribution in the western United States, July 22-28, 1913.

Fig. 8.—Pressure distribution in the western United States, July 29-August 13, 1913.

A comparison of the curve shown in figure 5 with that shown in the Bulletin of the Mount Weather Observatory, 4 : 302, figure 31, shows the surface temperature indicated in figure 5 higher by 6.4° C., the minimum temperature lower by 3.5° C., the maximum next above this minimum less than 2° C. lower than the corresponding values shown in figure 31. The minimum temperature shown in figure 5 occurs at an altitude higher by 1.5 kilometers than that shown in figure 31. The maximum temperature next above the minimum temperature is shown at about the same altitude in both curves. The curves have the same general appearance. That shown in figure 5 represents summer conditions at latitude 33° N. That shown in figure 31 represents conditions in all seasons, to some extent, the late summer and early autumn being better represented than the other seasons, at about latitude 40° N.

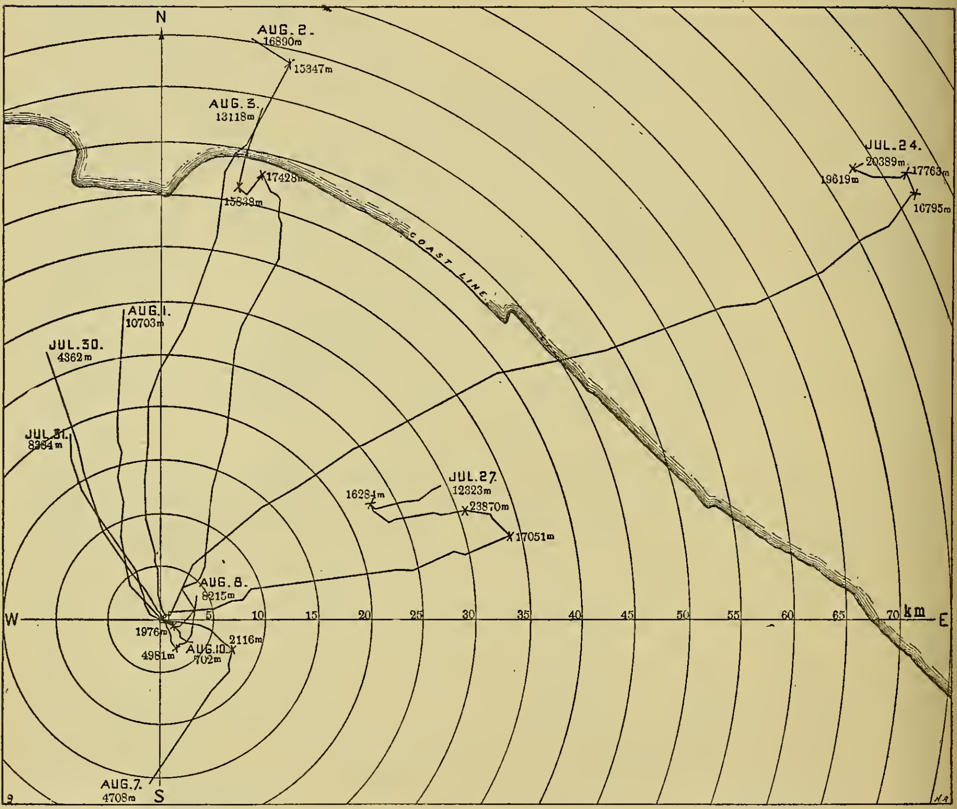

Fig. 9.—Horizontal projections of the paths of the sounding balloons liberated at Avalon, Cal., July 23-August 10, 1913.

The variations of humidity with altitude and from day to day are rather closely related to the variations of temperature. In table 3 the absolute humidities observed have been assembled and a mean shown.

TABLE 3.—*Absolute humidity (grams per cubic meter) at various levels on different dates, Avalon, Cal., 1913*

Date	Altitude (meters)																		
	34	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000
1913																			
July 23	12.651	10.109	9.248	6.942	5.597	4.495	3.354	2.291	1.608	1.106	0.793	0.415	0.207	0.095	0.055	0.034	0.024	0.019	0.013
24	11.363	9.740	8.808	7.562	4.993	3.871	2.976	2.329	1.820	1.441	1.162	....	....	....	....	....	0.035	0.023	0.016
27	11.949	9.687	8.708	7.288	5.003	2.852	1.661	1.301	1.064	0.839	0.581	0.289	0.118	0.040	0.017	0.009	0.006	0.003	0.003
28	10.813	8.755	7.980	5.330	3.642	2.985	2.429	1.480	1 015	0.698	0.516	0.272	0.125	0.051	0.023	0.010	0.005	0.003	0.003
29	9.933	9.372	8.913	7.645	4.711	3.056	1.964	1.163	0.674	0.384	0.265	0.112	0.060	0.019	0.011	0.006	0.002	....	....
30	12.415	11.913	10.625	6.418	5.922	4.108	2.351	1.381	0.993	0.780	0.687	0.330	0.219	0.103	0.048	0.020	0.010	0.004	0.003
31	12.952	11.261	8.640	4.717	2.379	1.434	1.444	1.210	0.855	0.580	0.344	0.193	0.118	0.062	0.034	0.014	0.007	0.004	0.002
Aug. 1	15.210	12.077	9.369	8.072	6.661	5.459	4.739	4.268	3.367	2.302	1.662	0.831	0.406	0.199	0.103	0.054	0.026	0 013	0.009
2	15.817	13.928	7.750	5.828	5.657	5.255	3.986	2.781	1.840	1.243	0.922	0.476	0.235	0.105	0.055	0.021	0.008	0.003	0.003
3	15.199	12.014	4.205	2.925	2.850	2.541	2.109	1.560	1.178	0.898	....	....	....	....	....	....	....	....	....
7	14.482	13.979	6.274	2.631	1.521	1.256	1.353	1.300	1.065	1.299	1.362	0.432	....	....	....	....	....	....	....
8	12.838	11.342	11.336	9.476	7.983	6.572	5.055	3.961	3.278	2.806	2.368	1.623	1.180	0.655	0.346	0.215	0.124	0.077	0.055
10	12.077	9.937	4.654	3.106	2.421	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Means.	12.900	11.086	8.193	5.995	4.565	3.657	2.785	2.085	1.563	1.198	0.969	0.497	0.296	0.148	0.077	0.043	0.025	0.017	0.012

Date.	Altitude (meters)																		
	14,000	15,000	16,000	17,000	18,000	19,000	20,000	21,000	22,000	23,000	24,000	25,000	26,000	27,000	28,000	29,000	30,000	31,000	32,000
1913																			
July 23	0.008	0.004	0.004	0.003	0.003	0.004	0.004	0.006	0.007	0.010	0.014	0.018	....	....	....	....	....	....	....
24	0.013	0.010	0.007	0.004	0.004	0.006	0.008	....	....	....	....	....	....	....	....	....	....	....	....
27	0.003	0.002	0.001	0.001	0.002	0.003	0.003	0.003	0.004	0.005	0.007	....	....	....	....	....	....	....	....
28	0.003	0.001	0.001	0.001	0.002	0.002	....	....	....	....	....	....	....	....	....	....	....	....	....
30	0.002	0.003	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.002	0.003	0.004	0.004	0.005	0.005	0.005	0.006	0.006
31	0.002	0.003	0.002	0.001	0.002	0.002	0.003	0.004	0.005	....	....	....	....	....	....	....	....	....	....
Aug. 1	0.012	0.011	0.007	0.005	0.004	0.004	0.006	0.006	0.007	0.008	....	....	....	....	....	....	....	....	....
2	0.003	0.004	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8	0.033	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Means.	0.009	0.005	0.003	0.002	0.003	0.003	0.004	0.004	0.005	0.006	0.008	0.010	0.004	0.004	0.005	0.005	0.005	0.006	0.006

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.* July 23, 1913.

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
A. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*^{3}		*M.p.s.*	
6 06.0	34	759.5	19.3	......	77	12.651	....	....	10/10 S. NNW.
6 08.0	489	719.8	14.3	1.1	83	10.111	N. 48° W.	1.1	
....	500	....	14.1	......	84	10.109	N. 47° W.	1.1	
6 09.1	737	699.0	12.4	0.8	92	9.972	N. 17° W.	1.0	In base of clouds. Inversion.
....	1,000	....	18.5	......	59	9.248	....	....	
6 10.2	1,032	675.0	18.9	−2.2	57	9.147	....	....	
6 12.2	1,454	642.3	17.1	0.4	49	7.068	....	....	
....	1,500	....	16.8	......	49	6.942	....	....	
....	2,000	....	12.6	......	51	5.597	....	....	
....	2,500	....	8.5	......	53	4.495	....	....	
6 17.4	2,784	547.5	6.3	0.8	54	3.975	....	....	
....	3,000	....	5.5	......	48	3.354	....	....	
6 18.9	3,194	520.8	4.9	0.3	43	2.888	....	....	
....	3,500	....	2.5	......	40	2.291	....	....	
....	4,000	....	− 1.0	......	36	1.608	....	....	
....	4,500	....	− 4.6	......	33	1.106	....	....	
6 24.5	4,719	430.1	− 6.1	0.7	31	0.919	....	....	
6 24.8	4,818	424.7	− 6.6	0.5	31	0.882	....	....	
....	5,000	....	− 7.9	......	31	0.793	....	....	
....	6,000	....	−14.7	......	29	0.415	....	....	
6 31.7	6,793	327.9	−20.0	0.7	27	0.241	....	....	
....	7,000	....	−21.6	......	27	0.207	....	....	
....	8,000	....	−29.1	......	25	0.095	....	....	
6 36.4	8,184	271.4	−30.5	0.8	25	0.082	....	....	
....	9,000	....	−34.3	......	25	0.055	....	....	
....	10,000	....	−38.8	......	25	0.034	....	....	
6 42.0	10,289	200.9	−39.9	0.4	25	0.030	....	....	
....	11,000	....	−41.4	......	24	0.024	....	....	
....	12,000	....	−43.4	......	23	0.019	....	....	
6 50.4	12,584	143.9	−44.6	0.2	22	0.016	....	....	
....	13,000	....	−46.5	......	22	0.013	....	....	
....	14,000	....	−50.6	......	21	0.008	....	....	
....	15,000	....	−54.8	......	20	0.004	....	....	
7 00.4	15,092	98.6	−55.2	0.2	20	0.004	....	....	
....	16,000	....	−55.8	......	20	0.004	....	....	
....	17,000	....	−56.6	......	20	0.003	....	....	
7 08.3	17,379	69.2	−56.9	0.1	20	0.003	....	....	Inversion.
....	18,000	....	−56.7	......	20	0.003	....	....	
....	19,000	....	−56.4	......	21	0.004	....	....	
7 15.1	19,983	46.1	−56.1	0.0	21	0.004	....	....	
....	20,000	....	−56.1	......	21	0.004	....	....	
....	21,000	....	−53.6	......	22	0.006	....	....	
....	22,000	....	−51.2	......	22	0.007	....	....	
....	23,000	....	−48.7	......	22	0.010	....	....	
....	24,000	....	−46.3	......	23	0.014	....	....	
....	25,000	....	−43.8	......	23	0.018	....	....	
7 26.8	25,160	21.5	−43.4	−0.1	23	0.019	....	....	
....	25,000	....	−43.0	......	23	0.020	....	....	
....	24,000	....	−42.1	......	21	0.020	....	....	
7 34.0	23,045	30.1	−41.1	−0.1	20	0.021	....	....	
....	23,000	....	−41.2	......	20	0.021	....	....	
....	22,000	....	−42.6	......	19	0.017	....	....	
....	21,000	....	−44.2	......	18	0.013	....	....	
7 43.9	20,314	45.0	−45.1	−0.4	17	0.011	....	....	
....	20,000	....	−46.4	......	17	0.010	....	....	
....	19,000	....	−50.5	......	17	0.006	....	....	
7 51.5	18,411	60.0	−52.8	0.5	17	0.005	....	....	Inversion.
....	18,000	....	−50.7	......	18	0.006	....	....	
7 54.2	17,857	65.3	−50.0	−0.3	18	0.007	....	....	
7 57.7	17,254	71.7	−52.1	0.1	18	0.005	....	....	Inversion.
....	17,000	....	−51.8	......	18	0.006	....	....	
....	16,000	....	−51.1	......	19	0.006	....	....	
....	15,000	....	−50.4	......	19	0.007	....	....	
8 10.9	14,285	112.3	−49.8	0.4	20	0.008	....	....	
....	14,000	....	−48.6	......	20	0.009	....	....	
....	13,000	....	−44.5	......	21	0.015	....	....	
8 18.3	12,603	144.3	−43.0	0.3	21	0.018	....	....	
....	12,000	....	−41.5	......	21	0.021	....	....	
....	11,000	....	−38.8	......	22	0.030	....	....	
....	10,000	....	−36.4	......	23	0.041	....	....	
8 31.8	9,855	214.8	−36.0	−0.5	23	0.042	....	....	
8 33.7	9,536	224.9	−37.7	0.8	23	0.035	....	....	Inversion.
....	9,000	....	−33.5	......	23	0.055	....	....	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued
July 23, 1913—Continued

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100 m.}$	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
A. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	$g./m.^3$		*M.p.s.*	
8 37.9	8,667	254.2	−31.0	0.8	23	0.071	....	....	
....	8,000	....	−25.8	.....	25	0.129	....	....	
8 44.3	7,456	300.3	−21.6	0.5	27	0.207	....	....	
....	7,000	....	−19.4	......	28	0.265	....	....	
8 50.0	6,384	346.9	−16.4	0.6	29	0.359	....	....	
....	6,000	....	−13.8	......	30	0.464	....	....	
8 56.9	5,038	413.0	− 7.7	0.7	32	0.832	....	....	
....	5,000	....	− 7.4	......	32	0.852	....	....	
....	4,500	....	− 4.0	......	32	1.126	....	....	
....	4,000	....	− 0.7	......	32	1.464	....	....	
9 02.3	3,794	483.6	0.6	......	32	1.612	....	....	

July 24, 1913

A. M.									
5 13.8	34	759.7	20.1	......	66	11.363	SW........	5.9	
5 15.0	290	737.3	17.7	0.9	69	10.315	S. 26° W..	5.9	Few S. Cu. SW.
....	500	....	15.8	......	73	9.740	S. 49° W..	4.8	
5 18.1	858	689.3	13.0	0.8	79	8.887	N. 83° W..	3.1	Inversion.
....	1,000	....	14.6	......	71	8.808	S. 68° W..	2.5	
5 18.8	1,005	677.4	14.6	−1.1	70	8.684	S. 67° W..	2.4	
5 20.1	1,220	660.3	13.7	0.4	63	7.398	S. 76° W..	1.3	Inversion.
....	1,500	....	16.3	......	55	7.562	S. 31° W..	6.2	
5 21.3	1,507	638.1	16.4	−0.9	55	7.608	S. 30° W..	6.4	
5 23.9	1,925	607.5	15.1	0.3	41	5.243	S. 29° W..	7.6	
....	2,000	....	14.7	......	40	4.993	S. 29° W..	8.0	
....	2,500	....	11.4	......	38	3.871	S. 25° W..	10.0	
5 29.0	2,984	534.9	8.3	0.6	36	3.015	S. 22° W..	11.9	
....	3,000	....	8.1	......	36	2.976	S. 22° W..	12.0	
....	3,500	....	5.2	......	34	2.329	S. 37° W..	12.8	
5 33.5	3,907	477.8	2.8	0.6	32	1.870	S. 49° W..	13.4	
....	4,000	....	2.4	......	32	1.820	S. 49° W..	13.6	
....	4,500	....	− 0.5	......	31	1.441	S. 48° W..	14.3	
5 37.8	4,759	429.8	− 1.9	0.6	30	1.249	S 48° W..	14.7	
5 38.3	4,853	424.7	− 1.9	0.0	30	1.249	S. 41° W..	21.7	
....	5,000	....	− 2.8	......	30	1.162	S. 44° W..	21.2	
5 42.1	5,588	386.9	− 6.2	0.6	29	0.852	S. 58° W..	18.9	
....	6,000	....	− 9.3	......	......	....	S. 58° W..	18.2	
5 48.2	6,968	323.4	−16.3	0.7	......	....	S. 58° W..	16.7	
....	7,000	....	−16.3	......	......	....	S. 60° W..	13.6	
5 48.8	7,114	317.0	−16.3	0.0	......	....	S. 66° W..	4.0	
5 53.1	7,999	281.8	−20.8	0.5	......	....	S. 62° W..	25.3	
....	8,000	....	−20.8	......	......	....	S. 62° W..	25.3	
....	9,000	....	−26.3	......	......	....	S. 63° W..	24.2	
5 58.5	9,171	240.2	−27.3	0.6	......	....	S. 63° W..	24.0	
....	10,000	....	−31.7	......	......	....	S. 72° W..	24.4	
6 05.2	10,423	201.6	−34.0	0.5	......	....	S. 77° W..	24.6	
....	11,000	....	−38.2	......	24	0.035	S. 72° W..	23.6	
6 08.9	11,016	185.3	−38.3	0.7	24	0.034	S. 72° W..	23.5	Few S. Cu. SW.
6 15.1	11,894	163.5	−41.8	0.4	25	0.024	S. 70° W..	19.2	
....	12,000	....	−42.4	......	25	0.023	S. 73° W..	18.7	
6 18.3	12,464	150.3	−45.1	0.6	24	0.016	S. 84° W..	16.4	
6 20.0	12,902	140.7	−45.1	0.0	24	0.016	S. 63° W..	22.2	
....	13,000	....	−45.5	......	24	0.016	S. 63° W..	20.4	
6 21.6	13,206	134.5	−46.1	0.3	24	0.014	S. 63° W..	16.1	
6 24.0	13,711	124.9	−46.0	0.0	23	0.014	S. 63° W..	18.2	
....	14,000	....	−46.6	......	23	0.013	S. 59° W..	18.4	
6 28.7	14,716	107.6	−47.9	0.2	23	0.012	S. 47° W..	18.8	
....	15,000	....	−49.6	.....	23	0.010	S. 54° W..	15.7	
6 32.8	15,297	98.5	−51.3	0.6	23	0.008	S. 61° W..	12.3	
....	16,000	....	−52.2	......	23	0.007	S. 48° W..	13.2	
6 36.6	16,453	82.3	−52.8	0.1	23	0.006	S. 39° W..	13.9	
6 38.7	16,795	78.3	−55.1	0.7	22	0.005	S. 57° W..	1.7	
....	17,000	....	−55.4	......	22	0.004	S. 40° W..	3.2	
6 42.4	17,763	67.6	−55.8	0.1	22	0.004	S. 22° E...	9.0	Inversion.
....	18,000	....	−55.6	......	22	0.004	S. 74° E...	6.3	
6 45.2	18,207	63.1	−55.1	−0.1	22	0.005	N. 60° E...	4.3	Few S. Cu. SW.
6 48.0	18,511	60.2	−54.8	−0.1	23	0.005	S. 85° E...	13.9	
....	19,000	....	−53.2	......	23	0.006	S. 75° E...	10.1	
6 53.3	19,619	50.8	−51.4	−0.3	24	0.009	S. 63° E...	5.3	
....	20,000	....	−50.8	......	24	0.008	S. 4° E...	4.4	
6 57.0	20,389	45.1	−50.1	−0.2	24	0.009	S. 57° W..	3.4	Balloons disappeared.

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

July 27, 1913

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	*°C.*		*P. ct.*	*g./m.*^{3}		*M.p.s.*	
4 57.5	34	759.2	20.2	......	69	11.949	S. 86° W..	3.9	2/10 S. Cu. WSW.
....	500	....	13.6	......	83	9.687	S. 80° W..	2.9	
5 00.3	704	701.3	10.9	1.4	89	8.786	S. 77° W..	2.5	Inversion.
....	1,000	....	13.3	......	76	8.708	S. 47° E...	1.0	
5 02.3	1,087	669.9	13.8	—0.8	72	8.507	S. 83° E...	0.6	
5 04.2	1,388	646.3	14.0	—0.1	65	7.775	N.41° W..	0.8	
....	1,500	....	13.2	......	64	7.288	N.44° W..	0.8	
5 07.0	1,912	607.0	10.0	0.8	59	5.504	N.56° W..	1.1	
....	2,000	....	9.6	......	55	5.003	N.87° W..	1.2	
5 09.0	2,263	581.8	8.2	0.5	44	3.661	S. 1° E...	1.6	
....	2,500	....	6.2	......	39	2.852	S..........	1.8	
5 13.0	2,980	532.8	2.5	0.8	29	1.661	S. 3° W..	2.3	
....	3,000	....	2.5	......	29	1.661	S. 7° W..	2.3	
5 15.0	3,395	505.9	0.5	0.5	27	1.351	N.85° W..	2.2	
....	3,500	....	— 0.5	......	28	1.301	N.86° W..	2.5	
....	4,000	....	— 4.7	......	32	1.064	S. 89° W..	3.8	
5 20.5	4,454	442.6	— 8.4	0.8	35	0.860	S. 85° W..	5.1	
....	4,500	....	— 8.7	......	35	0.839	S. 85° W..	5.2	
....	5,000	....	—13.3	......	36	0.581	S. 83° W..	6.2	
5 25.0	5,292	396.5	—15.9	0.9	37	0.478	S. 82° W..	6.7	
5 26.1	5,510	385.2	—16.3	0.2	34	0.425	S. 78° W..	8.2	
....	6,000	....	—20.5	......	34	0.289	S. 75° W..	8.3	
5 30.0	6,422	340.8	—24.1	0.9	34	0.206	S. 73° W..	8.4	
5 32.0	6,853	321.5	—27.6	0.8	31	0.133	S. 85° W..	8.7	
....	7,000	....	—29.0	......	31	0.118	S. 81° W..	8.2	
....	8,000	....	—38.4	......	28	0.040	S. 50° W..	4.6	
5 38.9	8,361	259.9	—41.7	0.9	27	0.027	S. 39° W..	3.3	
....	9,000	....	—45.1	......	26	0.017	S. 57° W..	5.2	
5 46.0	9,905	206.6	—49.9	0.5	25	0.010	S. 83° W..	8.0	
....	10,000	....	—50.2	......	25	0.009	S. 83° W..	8.3	
....	11,000	....	—53.8	......	24	0.006	S. 82° W..	12.3	
....	12,000	....	—57.4	......	23	0.003	S. 82° W..	16.3	
5 56.6	12,029	149.3	—57.5	0.4	23	0.003	S. 82° W..	16.4	Inversion.
5 59.5	12,369	141.8	—56.6	—0.3	23	0.004	N.87° W..	7.0	
....	13,000	....	—57.5	......	23	0.003	S. 83° W..	8.3	
....	14,000	....	—58.7	......	22	0.003	S. 67° W..	9.7	
6 07.3	14,080	108.4	—58.7	0.1	22	0.003	S. 66° W..	9.9	2/10 S. Cu. WSW.
6 09.7	14,541	101.0	—61.1	0.5	21	0.002	N.74° W..	7.4	
....	15,000	....	—61.5	......	21	0.002	N.81° W..	7.3	
....	16,000	....	—62.2	......	21	0.001	S. 83° W..	7.0	
....	17,000	....	—63.0	......	21	0.001	S. 68° W..	6.8	
6 20.6	17,051	67.7	—63.1	0.1	21	0.001	S. 67° W..	6.8	Inversion.
....	18,000	....	—60.8	......	21	0.002	S. 2° W..	6.2	
6 28.5	18,797	51.4	—58.7	—0.3	21	0.003	S. 53° E...	5.7	
....	19,000	....	—58.7	......	21	0.003	S. 51° E...	5.3	
....	20,000	....	—57.8	......	21	0.003	S 40° E...	3.6	
....	21,000	....	—57.0	......	21	0.003	S. 30° E...	1.9	
6 35.4	21,506	33.5	—56.5	—0.1	21	0.004	S. 25° E...	1.0	
....	22,000	....	—55.6	......	21	0.004	S. 36° E...	2.0	
....	23,000	....	—53.7	......	21	0.005	S. 59° E...	4.2	
6 41.5	23,870	23.0	—52.1	—0.1	21	0.006	S. 79° E...	6.1	Balloon burst.
....	23,000	....	—53.6	......	21	0.005	E..........	11.3	
6 44.3	22,179	29.7	—55.1	1.0	21	0.004	N.80° E...	16.2	Inversion.
....	22,000	....	—53.5	......	21	0.005	S. 88° E...	12.4	
6 45.4	21,821	31.3	—51.5	—0.4	21	0.007	S. 76° E...	8.2	
....	21,000	....	—54.3	......	21	0.005	S. 88° E...	10.9	
6 49.0	20,229	40.2	—57.2	—0.2	21	0.003	N.80° E...	13.6	
....	20,000	....	—57.5	......	21	0.003	N.77° E...	12.5	
6 51.1	19,098	48.0	—59.6	0.0	19	0.002	N.67° E...	7.8	
....	19,000	....	—59.6	......	19	0.002	N.70° E...	7.7	
....	18,000	....	—60.0	......	19	0.002	S. 84° E...	6.6	
....	17,000	....	—60.3	......	19	0.002	S. 57° E...	5.6	
6 57.9	16,916	67.9	—60.3	—0.4	19	0.002	S. 55° E...	5.5	
7 00.0	16,284	75.3	—63.1	—0.2	20	0.001	S. 34° E...	3.7	
....	16,000	....	—63.5	......	20	0.001	W	3.6	
7 03.1	15,228	89.0	—64.7	0.1	19	0.001	N.45° W..	3.4	Inversion.
....	15,000	....	—64.0	......	19	0.001	N.58° W..	4.5	
7 09.0	14,178	105.3	—63.7	0.2	20	0.001	S. 76° W..	8.6	
....	14,000	....	—63.3	......	20	0.001	S. 77° W..	8.6	
7 11.9	13,498	117.5	—62.0	0.2	21	0.001	S. 79° W..	8.6	
....	13,000	....	—61.0	......	21	0.002	S. 60° W..	8.3	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

July 27, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	*°C.*		*P. ct.*	*g./m*^{3}.		*M.p.s.*	
7 15.1	12,734	132.4	−60.4	0.0	21	0.002	S. 50° W..	8.2	
7 17.0	12,323	141.4	−60.4	0.0	21	0.002	S. 62° W..	10.0	Balloons disappeared.
....	12,000	....	−60.4	......	21	0.002	....	....	
7 18.9	11,801	153.2	−60.2	0.4	21	0.002	....	....	
7 21.2	11,355	164.7	−58.5	0.6	21	0.003	....	....	
....	11,000	....	−56.2	......	21	0.004	....	....	
7 24.8	10,587	184.9	−53.6	0.8	21	0.005	....	....	
....	10,000	....	−49.1	......	22	0.010	....	....	
....	9,000	....	−41.6	......	23	0.023	....	....	
7 35.0	8,602	248.5	−38.6	0.6	24	0.033	....	....	
....	8,000	....	−35.0	......	24	0.049	....	....	
7 42.5	7,034	310.3	−29.4	0.1	25	0.092	....	....	
....	7,000	....	−29.4	......	25	0.092	....	....	
7 45.3	6,443	336.6	−28.6	0.7	30	0.117	....	....	
7 46.8	6,184	348.7	−26.9	0.5	31	0.143	....	....	
....	6,000	....	−26.0	......	33	0.167	....	....	
....	5,000	....	−20.8	......	42	0.347	....	....	
7 54.7	4,615	431.6	−18.8	2.0	46	0.460	....	....	
....	4,500	....	−16.6	......	45	0.548	....	....	
7 57.1	4,094	461.8	− 8.6	0.9	41	0.991	....	....	
....	4,000	....	− 7.8	......	41	1.057	....	....	
7 58.7	3,733	484.0	− 5.4	0.9	39	1.224	....	....	
....	3,500	....	− 3.4	......	39	1.441	....	....	
....	3,000	....	1.1	......	38	1.981	....	....	
8 04.3	2,980	532.3	1.4	0.4	38	2.021	....	....	
8 06.0	2,733	548.5	2.5	0.7	39	2.234	....	....	
....	2,500	....	4.1	......	40	2.549	....	....	
8 10.3	2,132	590.7	6.8	0.4	41	3.118	....	....	
....	2,000	....	6.3	......	49	3.607	....	....	
8 11.5	1,977	602.2	6.2	......	50	3.656	....	....	

July 28, 1913

P. M.									
5 05.0	34	759.7	20.6	......	61	10.813	S........	....	9/10 S. Cu. WNW.
5 06.8	371	730.3	15.8	1.4	68	9.073	S. 16° W..	3.7	
....	500	....	14.5	......	71	8.755	S. 33° W..	3.0	
5 08.7	787	694.9	11.7	1.0	77	7.991	S. 68° W..	1.5	
5 10.0	962	680.5	10.4	0.7	84	8.036	N.67° W..	0.6	In base of S. Cu.
....	1,000	....	10.1	......	85	7.980	....	....	
5 10.9	1,117	667.8	9.7	0.5	86	7.872	....	....	Inversion.
5 11.4	1,218	659.9	15.0	−5.2	56	7.119	....	....	
5 12.3	1,377	647.4	16.2	−0.8	44	6.013	....	....	
....	1,500	....	16.2	......	39	5.330	....	....	
5 13.8	1,648	627.1	16.2	0.0	32	4.373	....	....	
5 15.2	1,923	607.1	15.4	0.3	29	3.777	....	....	
....	2,000	....	14.8	......	29	3.642	....	....	
....	2,500	....	10.0	......	32	2.985	....	....	
....	3,000	....	5.4	......	35	2.429	....	....	
5 20.3	3,048	530.1	5.0	0.9	35	2.366	....	....	
....	3,500	....	3.0	......	25	1.480	....	....	
5 22.9	3,535	499.1	3.0	0.4	24	1.421	....	....	
....	4,000	....	0.0	......	21	1.015	....	....	
5 27.4	4,498	442.6	− 2.8	0.6	18	0.698	....	....	
....	5,000	....	− 5.8	......	17	0.516	....	....	
5 31.6	5,406	394.3	− 8.1	0.6	16	0.403	....	....	
....	6,000	....	−12.7	......	16	0.272	....	....	
5 37.1	6,659	334.6	−18.1	0.8	16	0.171	....	....	
....	7,000	....	−21.4	......	16	0.125	....	....	
5 40.7	7,478	299.3	−26.3	1.0	16	0.078	....	....	
....	8,000	....	−30.7	......	16	0.051	....	....	
5 44.7	8,279	268.2	−33.0	0.8	16	0.040	....	....	
....	9,000	....	−37.8	......	15	0.023	....	....	
5 50.6	9,533	223.9	−41.5	0.7	14	0.014	....	....	
....	10,000	....	−44.7	......	14	0.010	....	....	
5 55.2	10,399	197.3	−47.2	0.7	14	0.008	....	....	
....	11,000	....	−50.6	......	14	0.005	....	....	
6 00.8	11,593	165.2	−53.6	0.5	13	0.003	....	....	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

July 28, 1913—Continued

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100\text{ m.}}$	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*^{3}		*M.p.s.*	
....	12,000	....	−55.7	......	14	0.003	....	....	
6 04.9	12,233	149.5	−56.8	0.5	14	0.002	....	....	Inversion.
....	13,000	....	−56.0	......	14	0.003	....	....	
6 09.3	13,096	131.0	−55.7	−0.1	14	0.003	....	....	Clock stopped at intervals. Time estimated.
6 11.3	13,293	127.1	−55.4	−0.2	13	0.003	....	....	
....	14,000	....	−55.7	......	13	0.003	....	....	
6 15.5	14,084	112.6	−55.7	0.0	13	0.003	....	....	Clock stopped, but started again at highest altitude.
....	19,485	48.1	−56.9	−0.1	13	0.002	....	....	
....	19,000	....	−57.5	......	13	0.002	....	....	
....	18,010	60.5	−58.8	−0.2	13	0.002	....	....	
....	18,000	....	−58.8	......	13	0.002	....	....	
....	17,000	....	−61.4	......	12	0.001	....	....	
....	16,489	77.1	−62.6	0.0	12	0.001	....	....	Inversion.
....	16,063	82.4	−62.4	0.2	12	0.001	....	....	
....	16,000	....	−62.2	......	12	0.001	....	....	
....	15,000	....	−60.1	......	13	0.001	....	....	
....	14,253	109.6	−58.5	......	13	0.002	....	....	

July 29, 1913

A. M.									
11 10.0	34	760.5	18.6	......	63	9.933	N.86° W..	2.5	9/10 S. Cu. NW.
11 11.3	418	726.8	15.2	0.9	73	9.393	N.85° W..	2.5	
....	500	....	14.5	......	76	9.372	N.80° W..	2.3	
....	1,000	....	10.6	......	92	8.913	N.48° W..	1.3	
11 13.3	1,012	677.0	10.4	0.8	92	8.802	N.47° W..	1.2	Balloon disappeared in S. Cu. Inversion.
11 14.8	1,330	651.6	9.4	0.3	97	8.713	....	....	
....	1,500	....	11.2	......	76	7.645	....	....	
11 16.5	1,684	624.4	12.7	−0.9	55	6.073	....	....	
....	2,000	....	12.2	......	44	4.711	....	....	
11 18.4	2,182	588.3	11.9	0.2	37	3.888	....	....	
....	2,500	....	11.4	......	30	3.056	....	....	
11 20.2	2,625	557.8	11.3	0.1	27	2.733	....	....	
....	3,000	....	9 3	......	22	1.964	....	....	
11 22.9	3,344	511.4	7.4	0.5	18	1.423	....	....	
....	3,500	....	6.1	......	16	1.163	....	....	
....	4,000	....	2.2	......	12	0.674	....	....	
11 25.7	4,041	469.4	1.8	0.8	11	0.601	....	....	
....	4,500	....	− 2.9	......	10	0.384	....	....	
11 28.6	4,832	424.8	− 6.2	1.0	9	0.265	....	....	Inversion.
....	5,000	....	− 6.2	......	9	0.265	....	....	
11 29.9	5,120	409.5	− 6.1	−0.3	9	0.267	....	....	
11 33.3	5,953	367.6	−13.4	0.9	7	0.112	....	....	
....	6,000	....	−13.4	......	7	0.112	....	....	
11 35.0	6,272	352.7	−14.2	0.3	8	0.119	....	....	
11 36.1	6.629	336.2	−18.9	1.3	7	0.069	....	....	
11 37.4	6,908	324.5	−19.7	0.3	7	0.064	....	....	
....	7,000	....	−20.4	......	7	0.060	....	....	
11 39.2	7,437	301.7	−23.7	0.8	5	0.032	....	....	
11 41.0	7,882	283.7	−27.8	0.9	5	0.021	....	....	
....	8,000	....	−28.6	......	5	0.019	....	....	
11 43.2	8,570	257.7	−33.2	0.8	6	0.015	....	....	
....	9,000	....	−36.4	......	6	0.011	....	....	
11 45.0	9,029	241.7	−36.7	0.8	6	0.010	....	....	
11 45.7	9,268	233.6	−38.2	0.6	7	0.010	....	....	
11 46.8	9,467	226.9	−39.1	0.5	7	0.009	....	....	
11 47.9	9,707	218.9	−42.5	1.4	7	0.006	....	....	Inversion.
11 48.1	9,928	212.2	−42.1	−0.2	7	0.007	....	....	
....	10,000	....	−43.4	......	7	0.006	....	....	
11 49.4	10,248	202.8	−47.2	1.6	6	0.003	....	....	Inversion. One balloon burst and was detached; remaining balloon had sufficient lifting force to continue ascent.
11 53.0	10,633	191.3	−46.9	−0.8	......	....	....	....	
11 53.8	10,747	188.2	−47.3	0.4	......	....	....	....	
11 53.9	10,794	186.5	−48.3	2.1	......	....	....	....	
11 55.0	10,915	183.3	−48.7	0.3	......	....	....	....	Clock stopped.
....	*11,000	....	*−49.3	......	*5	0.002	....	....	

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* Estimated by extrapolation from the ascent.

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

July 29, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity Rel.	Humidity Abs.	Wind Direction	Wind Vel.	Remarks
A. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.³*		*M.p.s.*	
....	*23,066	27.8	−44.3	−0.4	.....	....	....	....	Balloon burst.
....	23,000	....	−44.5	......	......	....	....	....	
....	22,000	....	−49.5	......	......	....	....	....	
....	21,305	36.3	−53.0	−0.2	......	....	....	....	
....	21,000	....	−53.5	......	......	....	....	....	
....	20,000	....	−55.2	......	......	....	....	....	
....	19,000	....	−56.7	......	......	....	....	....	
....	18,111	59.7	−58.4	0.0	......	....	....	....	
....	18,000	....	−58.3	......	......	....	....	....	
....	17,145	69.5	−58.5	−0.2	......	....	....	....	
....	17,000	....	−58.7	......	......	....	....	....	
....	16,141	81.4	−60.4	0.1	......	....	....	....	Inversion.
....	16,000	....	−60.2	......	......	....	....	....	
....	15,000	....	−59.2	......	......	....	....	....	
....	14,344	107.9	−58.3	0.1	3	0.001	....	....	
....	14,000	....	−58.3	......	3	0.001	....	....	
....	13,000	....	−57.6	......	3	0.001	....	....	
....	12,386	146.6	−57.3	0.0	3	0.001	....	....	
....	12,000	....	−57.3	......	3	0.001	....	....	
....	11,368	170.9	−57.3	......	4	0.001	....	....	
....	11,000	....	−50.4	......	5	0.002	....	....	

*Balloon burst; clock started running, but times of this and succeeding levels unknown.

July 30, 1913

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity Rel.	Humidity Abs.	Wind Direction	Wind Vel.	Remarks
A. M.									
10 54.0	34	760.0	23.0	......	61	12.415	NE........	....	Few Cu.
10 57.0	362	731.7	21.0	0.6	67	12.155	SE........	....	
....	500	....	19.9	......	70	11.913	S.	....	
11 01.0	695	703.8	18.3	0.8	74	11.463	S. 50° W..	0.6	
11 03.0	884	688.3	16.9	0.7	80	11.402	S. 56° W..	1.8	Inversion.
....	1,000	....	18.2	......	69	10.625	S. 1° W..	1.9	
11 06.0	1,184	664.5	19.9	−1.0	54	9.190	S. 86° W..	2.1	
11 07.3	1,338	652.7	20.4	−0.3	40	7.008	S. 42° E...	5.1	
....	1,500	....	20.7	......	36	6.418	S. 38° E...	6.4	
11 12.3	1,766	621.1	21.3	−0.2	29	5.353	S. 32° E...	8.7	
11 13.9	1,927	609.5	20.7	0.4	26	4.636	S. 42° E...	12.8	
....	2,000	....	20.3	......	34	5.922	S. 38° E...	12.4	
11 15.0	2,045	601.3	20.2	0.4	38	6.581	S. 35° E...	12.1	
11 16.9	2,185	591.5	19.6	0.4	45	7.525	S. 33° E...	15.8	Inversion.
11 18.9	2,413	576.7	20.4	−0.4	30	5.256	S. 32° E...	15.2	
11 20.0	2,499	570.3	20.1	0.3	24	4.132	S. 33° E...	14.8	
....	2,500	....	20.0	......	24	4.108	S. 33° E...	14.8	
....	3,000	....	18.5	......	15	2.351	S. 25° E...	16.0	
11 26.0	3,067	532.9	18.3	0.3	14	2.169	S. 24° E...	16.2	
11 29.0	3,339	516.7	16.1	0.8	11	1.494	S. 14° E...	17.8	
....	3,500	....	14.8	......	11	1.381	S. 14° E...	17.2	
....	4,000	....	11.0	......	10	0.993	S. 16° E...	15.4	
11 37.0	4,133	470.1	10.2	0.7	10	0.945	S. 16° E...	15.0	
11 39.0	4,362	457.3	8.2	0.9	10	0.832	S. 18° E...	17.1	Balloon disappeared.
....	4,500	....	7.2	......	10	0.780	....	....	Few Cu.
....	5,000	....	3.8	......	11	0.687	....	....	
11 45.0	5,157	414.9	2.7	0.7	12	0.697	....	....	
11 49.3	5,749	385.4	− 1.1	0.6	9	0.399	....	....	
....	6,000	....	− 3.5	......	9	0.330	....	....	
11 53.0	6,273	360.8	− 6.1	1.0	10	0.296	....	....	
11 55.5	6,672	342.7	− 9.2	0.8	10	0.230	....	....	
....	7,000	....	− 9.8	......	10	0.219	....	....	
11 58.5	7,093	324.5	− 9.9	0.2	10	0.217	....	....	
P. M.									
12 01.0	7,475	309.1	−12.2	0.6	8	0.142	....	....	
....	8,000	....	−15.9	......	8	0.103	....	....	
12 09.0	8,915	255.1	−22.1	0.7	7	0.051	....	....	
....	9,000	....	−22.8	......	7	0.048	....	....	
....	10,000	....	−30.2	......	6	0.020	....	....	
12 16.0	10,322	210.3	−32.6	0.7	6	0.016	....	....	Inversion.
12 17.0	10,521	204.6	−32.4	−0.1	6	0.016	....	....	
12 18.8	10,832	195.7	−35.6	1.0	6	0.012	....	....	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued.

July 30, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.³*		*M.p.s.*	
....	11,000	....	−37.3	......	6	0.010	....	....	
12 22.9	11,724	172.1	−43.6	0.9	6	0.005	....	....	
....	12,000	....	−44.2	......	6	0.004	....	....	
12 25.3	12,391	156.1	−44.9	0.2	6	0.004	....	....	
12 26.8	12,653	150.2	−48.4	1.3	6	0.003	....	....	
....	13,000	....	−49.1	......	6	0.003	....	....	
....	14,000	....	−51.3	......	6	0.002	....	....	
12 32.1	14,021	122.5	−51.3	0.2	6	0.002	....	....	Inversion.
....	15,000	....	−49.2	......	6	0.003	....	....	
12 37.0	15,241	102.1	−48.6	−0.2	6	0.003	....	....	
12 37.8	15,435	99.3	−51.4	1.4	6	0.002	....	....	
....	16,000	....	−50.3	......	6	0.002	....	....	
12 42.3	16,707	81.8	−49.0	0.2	6	0.003	....	....	
....	17,000	....	−49.8	......	6	0.002	....	....	
....	18,000	....	−53.0	......	6	0.002	....	....	
12 47.2	18,263	64.7	−53.9	0.3	6	0.001	....	....	Inversion.
12 50.1	18,877	58.9	−50.5	−0.6	5	0.002	....	....	
....	19,000	....	−50.7	......	5	0.002	....	....	
....	20,000	....	−52.3	......	5	0.001	....	....	
12 53.7	20,131	48.8	−52.5	0.2	5	0.001	....	....	Inversion.
....	21,000	....	−51.4	......	5	0.002	....	....	
....	22,000	....	−50.2	......	5	0.002	....	....	
....	23,000	....	−49.0	......	5	0.002	....	....	
1 01.8	23,005	31.5	−49.0	−0.1	5	0.002	....	....	
1 03.9	23,932	27.3	−49.5	0.1	5	0.002	....	....	Inversion.
....	24,000	....	−49.4	......	5	0.002	....	....	
....	25,000	....	−47.7	......	5	0.003	....	....	
....	26,000	....	−46.2	......	6	0.004	....	....	
....	27,000	....	−44.5	......	6	0.004	....	....	
....	28,000	....	−42.8	......	6	0.005	....	....	
1 11.0	28,062	14.7	−42.7	−0.2	6	0.005	....	....	
....	29,000	....	−42.5	......	6	0.005	....	....	
....	30,000	....	−42.4	......	6	0.005	....	....	
....	31,000	....	−42.1	......	6	0.006	....	....	
....	32,000	....	−41.9	......	6	0.006	....	....	
1 20.5	32,643	7.4	−41.8	0.0	6	0.006	....	....	
....	32,000	....	−42.1	......	6	0.006	....	....	
....	31,000	....	−42.9	......	6	0.005	....	....	
....	30,000	....	−43.4	......	5	0.004	....	....	
....	29,000	....	−44.0	......	5	0.004	....	....	
....	28,000	....	−44.7	......	5	0.003	....	....	
....	27,000	....	−45.4	......	5	0.003	....	....	
....	26,000	....	−46.0	......	5	0.003	....	....	
1 24.9	25,118	22.7	−46.6	−0.1	3	0.003	....	....	
....	25,000	....	−46.8	......	5	0.003	....	....	
....	24,000	....	−49.4	......	5	0.002	....	....	
....	23,000	....	−50.8	......	5	0.002	....	....	
(*)	22,249	35.1	−52.3	0.0	5	0.001	....	....	
....	22,000	....	−52.4	......	5	0.001	....	....	
....	21,000	....	−52.6	......	5	0.001	....	....	
....	20,000	....	−53.0	......	5	0.001	....	....	
....	19,051	57.2	−53.3	0.1	5	0.001	....	....	Inversion.
....	19,000	....	−53.2	......	5	0.001	....	....	
....	18,000	....	−52.4	......	5	0.001	....	....	
....	17,000	....	−51.5	......	6	0.002	....	....	
....	16,160	88.6	−50.8	......	6	0.002	....	....	
....	16,000	....	−50.6	......	6	0.002	....	....	

* Clock stopped at intervals; times of this and subsequent levels unknown.

July 31, 1913

A. M.									
10 37.5	34	762.0	22.9	......	64	12.952	....	....	5/10 Ci. S.
10 39.3	388	731.3	18.0	1.4	74	11.261	....	....	
....	500	....	18.0	......	74	11.261	....	....	
10 40.2	622	711.5	18.1	0.0	74	11.328	....	....	Inversion.
10 41.0	799	696.9	20.5	−1.4	63	11.102	S. 69° E...	1.5	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

July 31, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
A. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*^{3}		*M.p.s.*	
10 41.8	995	681.2	21.7	−0.6	46	8.690	S. 57° E...	5.6	
....	1,000	....	21.6	......	46	8.640	S. 57° E...	5.6	
10 43.2	1,403	649.7	21.7	0.0	28	5.289	S. 58° E...	6.5	
....	1,500	....	21.0	......	26	4.717	S. 52° E...	6.2	
10 45.6	1,898	613.4	19.2	0.5	16	2.613	S. 29° E...	5.1	
....	2,000	....	18.7	......	15	2.379	S. 24° E...	5.8	
10 47.3	2,354	581.4	17.0	0.5	10	1.434	S. 8° E...	8.5	
....	2,500	....	17.0	......	10	1.434	S. 20° E...	10.8	
10 48.3	2,542	568.6	17.0	0.0	10	1.434	S. 23° E...	11.5	
....	3,000	....	12.8	......	13	1.444	S. 25° E...	9.4	
10 50.2	3,109	531.7	12.0	0.9	13	1.375	S. 25° E...	8.9	
....	3,500	....	8.8	......	14	1.210	S. 22° E...	8.0	
10 52.0	3,588	501.7	8.1	0.8	14	1.158	S. 21° E...	7.7	
....	4,000	....	5.8	......	12	0.855	S. 27° E...	11.2	
10 54.5	4,418	456.2	3.7	0.5	10	0.620	S. 33° E...	15.0	
....	4,500	....	2.7	......	10	0.580	S. 33° E...	14.6	
....	5,000	....	− 1.5	......	8	0.344	S. 34° E...	12.8	
10 57.3	5,041	419.5	− 1.8	0.9	8	0.336	S. 34° E...	12.7	
11 00.2	5,795	381.0	− 9.3	1.0	9	0.205	S. 36° E...	13.7	
....	6,000	....	−11.3	......	10	0.193	S. 35° E...	14.6	
11 03.0	6,557	345.2	−16.7	1.0	12	0.145	S. 32° E...	16.9	
....	7,000	....	−20.6	......	14	0.118	S. 26° E...	16.2	
11 06.0	7,430	307.0	−24.4	0.9	16	0.094	S. 20° E...	15.7	
....	8,000	....	−28.6	......	16	0.062	S. 10° E...	14.4	
11 09.0	8,384	269.1	−31.3	0.7	16	0.048	S. 4° E...	13.6	Balloons disappeared in Cirrus clouds.
11 10.0	8,781	254.9	−32.8	0.4	16	0.041	....	....	
....	9,000	....	−34.6	......	16	0.034	....	....	
....	10,000	....	−42.2	......	15	0.014	....	....	
11 13.8	10,188	208.4	−43.6	0.8	15	0.012	....	....	5/10 Ci. S.
....	11,000	....	−47.4	......	14	0.007	....	....	
11 18.2	11,725	166.0	−51.1	0.5	14	0.005	....	....	
....	12,000	....	−52.3	......	14	0.004	....	....	
....	13,000	....	−56.9	......	13	0.002	....	....	
11 21.2	13,165	132.9	−57.6	0.5	13	0.002	....	....	
11 22.6	13,533	126.0	−58.5	0.2	13	0.002	....	....	Inversion.
....	14,000	....	−56.7	......	12	0.002	....	....	
11 23.9	14,154	114.2	−56.1	−0.4	12	0.002	....	....	
11 25.4	14,646	106.0	−54.5	−0.3	14	0.003	....	....	
....	15,000	....	−55.4	......	14	0.003	....	....	
....	16,000	....	−57.7	......	12	0.002	....	....	
11 29.6	16,166	83.7	−58.1	0.2	12	0.002	....	....	
11 30.1	16,600	78.1	−58.8	0.2	12	0.001	....	....	Inversion.
11 31.3	16,933	74.4	−58.4	−0.1	12	0.002	....	....	
....	17,000	....	−58.6	......	12	0.001	....	....	
11 31.8	17,134	72.0	−58.9	0.2	12	0.001	....	....	Inversion.
....	18,000	....	−58.0	......	12	0.002	....	....	
11 34.8	18,607	57.1	−57.6	−0.1	12	0.002	....	....	
....	19,000	....	−56.4	......	13	0.002	....	....	
11 36.4	19,580	49.1	−54.6	−0.3	13	0.003	....	....	
....	20,000	....	−53.7	......	13	0.003	....	....	
....	21,000	....	−51.9	......	13	0.004	....	....	
11 40.3	21,352	37.4	−51.2	−0.2	13	0.004	....	....	
11 41.5	21,557	36.2	−51.3	0.1	12	0.004	....	....	Inversion.
....	22,000	....	−49.8	......	13	0.005	....	....	
11 43.0	22,194	32.5	−48.6	−0.4	13	0.006	....	....	

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A. M.									
10 36.0	34	761.0	23.9	......	71	15.210	....	....	4/10 Ci. S.
10 36.8	179	748.4	20.0	2.7	74	12.667	....	....	Inversion.
10 38.0	365	732.4	22.4	−1.3	66	12.980	....	....	
....	500	....	23.1	......	59	12.077	....	....	
10 40.0	707	704.1	24.4	−0.6	46	10,137	S. 8° W..	0.5	
10 40.9	859	691.8	24.7	−0.2	44	9.862	S. 44° E...	2.6	
....	1,000	....	24.2	......	43	9.369	S. 39° E...	6.6	
10 41.9	1,015	679.6	24.2	0.3	42	9.151	S. 38° E...	7.3	
....	1,500	....	22.0	......	42	8.072	S. 42° E...	8.1	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

August 1, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt 100 m.	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
A. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*³		*M.p.s.*	
10 44.9	1,534	640.0	21.8	0.5	42	7.980	S. 42° E...	8.2	
....	2,000	....	18.3	......	43	6.661	S. 43° E...	7.0	
....	2,500	....	14.6	......	44	5.459	S. 44° E...	5.7	
10 51.1	2,555	567.8	14.0	0.8	44	5.263	S. 44° E...	5.5	
....	3,000	....	10.9	......	48	4,739	S. 36° E...	6.1	
....	3,500	....	7.4	......	54	4.268	S. 28° E...	6.7	
....	4,000	....	3.6	......	59	3.367	S. 19° E...	7.4	
10 58.8	4,238	468.7	2.2	0.7	61	3.424	S. 15° E...	7.7	
11 00.7	4,432	451.7	1.9	0.2	44	2.420	S. 4° E...	8.3	
....	4,500	....	1.5	......	43	2.302	S. 3° E...	8.5	
....	5,000	....	− 1.6	......	39	1.662	S..........	10.3	
11 05.5	5,381	400.9	− 4.0	0.6	36	1.266	S. 3° W..	11.6	
....	6,000	....	− 9.5	......	37	0.831	S. 7° E...	10.1	
11 09.8	6,233	359.7	−11.6	0.8	37	0.694	S. 12° E...	9.5	Inversion.
11 10.4	6,296	356.7	−10.8	−1.3	38	0.765	S. 8° W..	15.6	
11 11.2	6,426	350.6	−13.7	2.2	37	0.576	S. 12° W..	14.8	
11 12.8	6,880	330.7	−16.8	0.7	37	0.443	S. 6° W..	16.0	
....	7,000	....	−17.5	......	36	0.406	S. 1° E...	12.5	
11 14.9	7,218	315.8	−18.2	0.4	35	0.371	S. 13° E...	6.6	
....	8,000	....	−23.5	......	31	0.199	S. 6° E. .	8.3	
11 19.2	8,138	279.1	−24.3	0.7	30	0.178	S. 5° E...	8.6	
....	9,000	....	−30.0	......	30	0.103	S. 2° E...	11.3	
....	10,000	....	−36.6	......	31	0.054	S. 1° W..	14.3	
11 29.3	10,703	194.6	−41.4	0.7	31	0.031	S. 3° W..	16.5	Balloon disappeared in Ci.
....	11,000	....	−43.2	......	31	0.026	....	....	
11 34.5	11,966	161.7	−49.5	0.6	31	0.013	....	....	
....	12,000	....	−49.4	......	31	0.013	....	....	
11 36.0	12,366	152.5	−49.8	0.1	30	0.012	....	....	
11 37.2	12,827	142.1	−52.4	0.6	30	0.009	....	....	
....	13,000	....	−52.3	......	30	0.009	....	....	
11 40 8	13,650	125.4	−52.4	0.0	31	0.009	....	....	Inversion.
11 42.7	13,977	119.4	−49.8	−0.8	31	0.012	....	....	
....	14,000	....	−49.8	......	31	0.012	....	....	
11 45.2	14,778	106.0	−49.8	0.0	30	0.012	....	....	
....	15,000	....	−50.5	......	30	0.011	....	....	
....	16,000	....	−54.0	......	29	0.007	....	....	
11 53.9	16,717	78.7	−56.4	0.3	28	0.005	....	....	Inversion.
11 55.2	16,849	77.1	−55.5	−0.7	28	0.006	....	....	
....	17,000	....	−56.0	......	28	0.005	....	....	
11 57.0	17,493	69.7	−57.3	0.3	28	0.004	....	....	
....	18,000	....	−58.0	......	28	0.004	....	....	
12 00.0	18,395	60.6	−58.6	0.1	28	0.003	....	....	Inversion.
....	19,000	....	−57.6	......	29	0.004	....	....	
P. M.									
12 03.3	19,993	47.3	−56.2	−0.2	30	0.006	....	....	
....	20,000	....	−56.2	......	30	0.006	....	....	
12 06.0	20,195	45.7	−55.9	−0.1	30	0.006	....	....	
12 06.7	20,451	44.1	−54.2	−0.7	30	0.007	....	....	
12 07.2	20,675	42.6	−55.4	0.5	30	0.006	....	....	
....	21,000	....	−55.0	......	30	0.006	....	....	
....	22,000	....	−54.3	......	30	0.007	....	....	
....	23,000	....	−53.5	......	30	0.008	....	....	
12 11.3	23,466	27.7	−53.1	0.2	30	0.008	....	....	
....	23,000	....	−51.5	......	29	0.009	....	....	
12 12.6	22,792	30.8	−50.7	−0.1	28	0.010	....	....	
....	22,000	....	−51.4	......	28	0.009	....	....	
12 15.6	21,226	38.7	−52.0	−0.2	28	0.008	....	....	
....	21,000	....	−52.5	......	28	0.008	....	....	
....	20,000	....	−55.0	......	28	0.006	....	....	
12 17.7	19,666	49.8	−55.7	0.4	28	0.006	....	....	Inversion.
12 18.7	19,273	52.9	−54.0	−0.1	28	0.007	....	....	
12 19.3	19,133	54.1	−55.4	−0.4	28	0.006	....	....	
....	19,000	....	−55.7	......	28	0.006	....	....	
12 21.2	18,592	58.8	−57.3	0.4	28	0.004	....	....	Inversion.
....	18,000	....	−54.6	......	29	0.007	....	....	
12 23.0	17,483	69.8	−52.4	−0.5	29	0.008	....	....	
12 25.3	17,054	74.6	−54.8	0.3	28	0.006	....	....	Inversion.
....	17,000	....	−54.6	......	28	0.006	....	....	
12 25.7	16,773	77.7	−54.0	−0.2	28	0.007	....	....	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

August 1, 1913—Continued

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100\text{ m.}}$	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	g./*m.*^{3}		*M.p.s.*	
12 26.5	16,414	82.0	−54.8	0.2	29	0.006	....	....	Inversion.
....	16,000	....	−53.8	......	29	0.007	....	....	
....	15,000	....	−51.4	......	29	0.009	....	....	
12 32.4	14,227	114.8	−49.5	−0.2	29	0.012	....	....	
....	14,000	....	−50.0	......	29	0.011	....	....	
12 34.5	13,254	132.9	−51.5	0.1	28	0.009	....	....	Inversion.
....	13,000	....	−51.3	......	28	0.009	....	....	
12 37.6	12,441	150.0	−50.7	0.4	......	....	....	....	
....	12,000	....	−48.9	......	30	0.013	....	....	
....	11,000	....	−44.9	......	33	0.023	....	....	
12 42.0	10,857	190.0	−44.4	0.1	33	0.024	....	....	
....	10,000	....	−37.9	......	35	0.052	....	....	
12 47.5	9,303	237.2	−32.7	0.8	37	0.096	....	....	
....	9,000	....	−30.5	......	36	0.118	....	....	
12 51.7	8,188	276.8	−24.3	0.5	33	0.196	....	....	
....	8,000	....	−23.5	......	33	0.212	....	....	
12 55.9	7,058	322.6	−19.2	0.9	34	0.328	....	....	
....	7,000	....	−18.7	......	34	0.343	....	....	
....	6,000	....	−10.2	......	36	0.762	....	....	
1 00.4	5,719	384.0	− 7.7	0.7	36	0.936	....	....	
1 02.8	5,115	414.9	− 3.6	......	......	....	....	....	
....	5,000	....	− 3.0	......	37	1.411	....	....	

August 2, 1913

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100\text{ m.}}$	Rel.	Abs.	Direction	Vel.	Remarks
A. M.									
10 59.0	34	761.0	25.1	......	69	15.817	E..........	....	Inversion.
11 00.3	259	741.5	22.8	1.0	71	14.287	....	....	Cloudless.
11 01.5	437	726.5	26.7	−2.2	59	14.788	....	....	
....	500	....	27.9	......	52	13.928	....	....	
11 02.7	584	714.5	29.0	−1.6	45	12.801	....	....	
11 04.0	753	701.0	30.0	−0.6	34	10.212	S. 83° W..	1.1	
11 05.0	907	689.0	29.0	0.6	29	8.250	S. 64° W..	3.3	
....	1,000	....	28.5	......	28	7.750	S. 13° E...	2.3	
11 06.0	1,059	677.1	28.1	0.6	27	7.312	S. 62° E...	1.5	
11 07.0	1,197	666.6	27.4	0.5	24	6.253	S. 47° W..	3.7	
....	1,500	....	25.4	......	25	5.828	S. 21° E...	3.3	
11 10.0	1,618	635.3	24.7	0.6	25	5.603	S. 48° E...	3.1	
....	2,000	....	21.1	......	31	5.657	S. 33° E...	4.1	
11 14.5	2,289	587.7	18.4	0.9	35	5.454	S. 21° E...	4.9	Inversion.
11 14.9	2,328	584.7	19.1	−1.8	35	5.683	S. 12° E...	4.6	
....	2,500	....	17.3	......	36	5.255	S. 9° E...	5.2	
....	3,000	....	12.3	......	37	3.986	S. 1° E...	7.2	
11 19.6	3,015	539.0	12.2	1.0	37	3.961	S. 1° E...	7.3	Inversion.
11 20.0	3,053	536.2	12.6	−1.1	37	4.060	S. 7° E...	18.8	
11 22.0	3,307	520.1	10.6	0.8	33	3.197	S. 21° E...	7.2	
....	3,500	....	9.9	......	30	2.781	S. 10° E...	7.4	
11 24.0	3,661	498.3	9.2	0.4	28	2.483	S. 1° E...	7.5	
....	4,000	....	6.3	......	25	1.840	S. 6° E...	9.2	
11 29.0	4,437	453.2	2.9	0.8	22	1.294	S. 13° E...	11.4	
....	4,500	....	2.3	......	22	1.243	S. 12° E...	11.2	
....	5,000	....	− 0.6	......	20	0.922	S. 8° E...	10.4	
11 36.3	5,717	386.1	− 4.6	0.6	18	0.603	S. 2° E...	9.0	
....	6,000	....	− 6.8	......	17	0.476	S.........	9.0	
11 42.5	6,789	336.8	−12.7	0.8	16	0.272	S. 7° W..	9.2	
....	7,000	....	−14.4	......	16	0.235	S. 5° W..	9.6	
11 48.0	7,912	289.8	−21.7	0.8	15	0.114	S. 4° E...	11.6	
....	8,000	....	−22.5	......	15	0.105	S. 2° E...	11.5	
....	9,000	....	−28.5	......	14	0.055	S. 21° W..	11.0	
11 53.2	9,086	247.1	−29.0	0.6	14	0.053	S. 23° W..	10.9	
....	10,000	....	−37.1	......	13	0.021	S. 26° W..	10.8	
12 00.0	10,591	199.3	−42.2	0.9	13	0.012	S. 28° W..	10.7	
P. M.									
....	11,000	....	−45.6	......	13	0.008	S. 29° W..	11.0	
....	12,000	....	−54.0	......	12	0.003	S. 30° W..	11.8	
12 05.5	12,031	161.1	−54.4	0.8	12	0.003	S. 30° W..	11.8	
....	13,000	....	−55.2	......	13	0.003	S. 21° W..	21.7	
12 09.4	13,168	135.4	−55.3	0.8	13	0.003	S. 20° W..	23.3	Inversion.

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

August 2, 1913—Continued

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100\text{ m.}}$	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*³		*M.p.s.*	
12 11.0	13,449	130.0	−54.0	−0.5	13	0.003	S. 8° W..	19.3	
12 12.5	13,815	122.7	−55.0	0.3	13	0.003	S. 8° W..	24.3	Inversion.
....	14,000	....	−54.1	......	13	0.003	S. 8° W..	23.0	
12 14.1	14,284	114.4	−52.8	−0.5	13	0.004	S. 8° W..	20.8	
12 16.1	14,541	110.1	−54.1	0.5	12	0.003	S. 31° W..	18.3	Inversion. One balloon burst and became detached; the remaining balloon had sufficient lifting force to continue ascent.
12 17.3	14,799	105.7	−50.3	−1.5	12	0.005	S. 50° W..	14.7	
....	15,000	....	−50.9	......	12	0.004	S. 44° W..	18.4	
12 22.6	15,437	96.0	−52.1	0.3	12	0.004	S. 30° W..	27.2	
....	16,000	....	....	......	......	....	S. 4° E...	19.7	
12 32.0	*16,890	....	....	......	......	....	S. 59° E...	7.4	Balloon disappeared. Few Cu.
12 56.4	21,302	35.5	−40.0	−0.5	10	0.012	....	....	
....	21,000	....	−42.5	......	10	0.009	....	....	
....	20,000	....	−50.6	......	10	0.004	....	....	
....	19,000	....	−58.8	......	10	0.001	....	....	
12 57.9	18,990	53.9	−58.7	−0.3	10	0.001	....	....	
....	18,000	....	−61.8	......	10	0.001	....	....	
....	17,000	....	−63.9	......	10	0.001	....	....	
....	16,000	....	−66.6	......	10	0.001	....	....	
1 00.0	15,828	89.0	−67.3	0.5	10	0.001	....	....	Inversion.
....	15,000	....	−63.2	......	11	0.001	....	....	
....	14,000	....	−58.5	......	13	0.002	....	....	
1 01.8	13,908	120.5	−58.0	0.0	13	0.002	....	....	
....	13,000	....	−57.6	......	13	0.002	....	....	
....	12,000	....	−57.3	......	13	0.002	....	....	
1 03.3	11,896	164.5	−57.1	......	13	0.002	....	....	

*Clock stopped. Altitude computed from ascensional rate.

August 3, 1913

P. M. 5 07.0	34	756.9	26.3	......	62	15.199	....	....	Few Cu. over mountains on mainland. Inversion.
5 07.7	233	739.8	24.1	1.1	62	13.433	....	....	
....	500	....	30.0	......	40	12.014	....	....	
5 09.4	541	714.4	30.8	−2.2	37	11.604	....	....	
5 10.3	754	697.5	30.3	0.2	25	7.632	N.65° W..	2.7	
5 11.3	879	687.7	30.6	−0.2	18	5.585	N.65° W..	6.4	
....	1,000	....	30.0	......	14	4.205	N.62° W..	5.8	
5 13.0	1,079	672.3	29.5	0.5	11	3.216	N.60° W..	5.4	
5 14.0	1,284	656.9	28.1	0.7	11	2.979	S. 81° W..	5.3	
....	1,500	....	26.2	......	12	2.925	S. 75° W..	5.0	
....	2,000	....	21.8	......	15	2.850	S. 60° W..	4.5	
5 19.9	2,398	577.7	18.4	0.9	17	2.649	S. 49° W..	4.0	
....	2,500	....	17.7	......	17	2.541	S. 46° W..	4.2	
5 22.8	2,838	548.7	15.8	0.6	17	2.268	S. 36° W..	4.9	
....	3,000	....	14.6	......	17	2.109	S. 25° W..	5.2	
....	3,500	....	10.7	......	16	1.560	S. 9° E...	6.1	
5 28.0	3,804	488.8	8.4	0.8	15	1.264	S. 30° E...	6.6	
....	4,000	....	7.3	......	15	1.178	S. 9° E...	5.2	
5 31.0	4,459	451.3	4.5	0.6	14	0.916	S. 39° W..	1.8	
....	4,500	....	4.2	......	14	0.898	S. 42° W..	1.8	
5 34.0	4,996	422.0	− 0.2	0.9	......	....	S. 73° W..	2.2	
....	5,000	....	− 0.5	......	......	....	S. 73° W..	2.3	
5 37.0	5,533	394.7	− 3.8	0.7	......	....	S. 79° W..	4.8	
5 39.0	5,792	381.8	− 6.6	1.1	......	....	S. 48° W..	4.6	
....	6,000	....	− 8.2	......	......	....	S. 44° W..	4.2	
....	7,000	....	−17.0	......	......	....	S. 22° W..	2.5	
5 45.8	7,183	318.9	−17.4	0.8	......	....	S. 18° W..	2.2	
....	8,000	....	−24.5	......	......	....	S..........	3.5	
5 52.0	8,308	273.7	−27.2	0.9	......	....	S. 7° E...	4.0	
....	9,000	....	−31.1	......	......	....	S..........	5.9	
5 58.0	9,573	229.7	−34.4	0.6	......	....	S. 6° W..	7.6	
....	10,000	....	−36.8	......	......	....	S. 7° W..	7.7	
6 04.8	10,790	193.0	−41.5	0.6	......	....	S. 8° S...	7.9	
....	11,000	....	−42.7	......	......	....	S. 9° W..	9.4	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

August 3, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity Rel.	Humidity Abs.	Wind Direction	Wind Vel.	Remarks
P. M. *h. m.*	*M.*	*Mm.*	*°C.*		*P. ct.*	*g./m³.*		*M.p.s.*	
....	12,000	....	−49.2	......	......	....	S. 14° W.	16.4	
6 10.0	12,050	160.6	−49.7	0.7	......	....	S. 14° W.	16.8	
6 16.1	12,936	140.8	−49.9	0.0	......	....	S. 5° W.	22.3	
....	13,000	....	−50.1	......	......	....	S. 7° W.	21.3	
6 18.1	13,315	132.8	−51.3	0.4	......	....	S. 16° W.	16.7	
....	14,000	....	−54.0	......	......	....	S. 22° W.	18.4	
6 24.0	14,729	107.0	−56.8	0.4	......	....	S. 29° W.	20.3	
....	15,000	....	−59.2	......	......	....	S. 23° W.	18.2	
6 29.0	15,794	90.8	−65.7	0.8	......	....	S. 4° W.	12.2	Inversion.
6 30.1	15,975	88.2	−65.3	−0.2	......	....	S. 27° E.	9.4	
....	16,000	....	−65.3	......	......	....	S. 26° E.	9.4	
6 33.0	16,611	79.4	−67.5	0.3	......	....	S. 2° W.	9.2	Inversion.
6 34.0	16,714	78.1	−66.9	−0.6	......	....	S. 34° E.	5.3	
6 35.7	16,895	76.0	−62.4	−2.5	......	....	S. 48° E.	9.1	
....	17,000	....	−62.3	......	......	....	S. 45° E.	9.6	
6 38.4	17,428	69.4	−61.8	0.0	......	....	S. 31° E.	11.4	
....	17,000	....	−61.5	......	......	....	S. 84° E.	17.9	
6 40.0	16,492	79.9	−61.2	−0.6	......	....	N. 32° E.	25.8	
....	16,000	....	−64.3	......	......	....	S. 71° E.	12.5	
6 41.7	15,838	88.6	−65.4	0.0	......	....	S. 45° E.	7.8	
6 44.1	15,208	97.8	−65.4	0.6	......	....	S. 10° W.	20.3	Inversion.
....	15,000	....	−64.0	......	......	....	S. 11° W.	19.6	
....	14,000	....	−57.9	......	......	....	S. 15° W.	16.5	
6 50.0	13,118	135.3	−52.4	0.2	......	....	S. 18° W.	13.7	
....	13,000	....	−52.2	......	......	....	....	....	
....	12,000	....	−50.2	......	......	....	....	....	
6 54.3	11,782	166.0	−49.9	0.7	......	....	....	....	
....	11,000	....	−44.5	......	......	....	....	....	
7 00.3	10,052	213.6	−37 8	0.8	......	....	....	....	
....	10,000	....	−37.5	......	......	....	....	....	
....	9,000	....	−29.4	......	......	....	....	....	
7 04.2	8,539	263.6	−25.9	0.7	......	....	....	....	
....	8,000	....	−22.4	......	......	....	....	....	
7 10.0	7,080	321.0	−16.2	0.6	......	....	....	....	
....	7,000	....	−15.7	......	......	....	....	....	
....	6,000	....	− 9.4	......	......	....	....	....	
7 17.7	5,275	405.3	− 5.0	0.6	......	....	....	....	
....	5,000	....	− 3.2	......	......	....	....	....	
....	4,500	....	0.0	......	......	....	....	....	
....	4,000	....	3.1	......	......	....	....	....	
7 24.1	3,792	487.7	4.3	0.8	......	....	....	....	
....	3,500	....	6.6	......	......	....	....	....	
....	3,000	....	10.6	......	......	....	....	....	
....	2,500	....	14.5	......	......	....	....	....	
7 30.4	2,187	591.5	17.0	1.0	......	....	....	....	
....	2,000	....	18.9	......	......	....	....	....	
....	1,500	....	23.9	......	......	....	....	....	
7 34.1	1,208	662.5	26.7	0.9	......	....	....	....	
....	1,000	....	28.5	......	......	....	....	....	
7 35.9	849	690.0	29.8	0.4	......	....	....	....	
7 36.7	718	700.3	30.3	......	......	....	....	....	

August 7, 1913

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity Rel.	Humidity Abs.	Wind Direction	Wind Vel.	Remarks
P. M.									
4 52.0	34	756.4	21.4	......	78	14.482	E.	1.9	Few A. Cu., few S.
4 55.7	233	739.0	17.1	2.2	83	11.972	N. 51° W.	1.5	Inversion.
4 57.2	455	720.1	23.2	−2.7	70	14.411	S. 37° W.	2.0	
....	500	....	23.7	......	66	13.979	S. 53° W.	2.2	
4 58.9	665	703.0	26.0	−1.3	49	11.813	N. 69° W.	3.5	
5 00.7	772	694.5	28.8	−2.6	30	8.441	N. 80° W.	6.8	
....	1,000	....	29.9	......	21	6.274	N. 87° W.	7.1	
5 03.0	1,036	674.2	30.0	−0.5	20	6.007	N. 88° W.	7.2	
5 06.4	1,350	650.7	30.0	0.0	13	3.905	N. 82° W.	7.7	
5 07.8	1,440	644.1	28.8	1.3	10	2.814	N. 65° W.	4.5	
....	1,500	....	29.5	......	9	2.631	N. 69° W.	6.4	Inversion.
5 09.4	1,534	637.4	29.8	−1.1	9	2.674	N. 72° W.	7.3	
5 12.7	1,741	622.6	27.0	1.4	6	1.529	N. 43° W.	5.1	
....	2,000	....	26.9	......	6	1.521	N. 46° W.	6.5	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

August 7, 1913—Continued

Time	Altitude	Pressure	Temperature	Δt / 100 m.	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. h. m.	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*³		*M.p.s.*	
5 17.0	2,116	596.5	26.8	0.1	6	1.512	N.48° W..	7.1	
....	2,500	....	23.5	......	6	1.256	N. 7° E...	4.7	
5 23.0	2,551	567.5	22.8	0.9	6	1.207	N.14° E...	4.2	
5 26.0	2,796	551.5	20.5	0.9	7	1.234	N. 8° W..	3.1	
....	3,000	....	17.8	......	9	1.353	N. 7° E...	3.5	
5 35.6	3,459	510.1	11.8	1.3	12	1.253	N.40° E...	4.5	
....	3,500	....	11.1	......	13	1.300	N.40° E...	4.6	5/10 A. Cu.; S.
....	4,000	....	0.7	......	21	1.065	N.34° E...	6.4	
5 46.0	4,087	472.3	— 0.7	2.0	22	1.007	N.33° E...	6.7	At the base of A. Cu. 5:57 p. m. Balloons disappeared.
....	4,500	....	— 7.2	......	48	1.299	N.32° E...	7.8	
5 58.0	4,708	436.5	—10.2	1.6	61	1.292	N.32° E...	8.4	
6 02.0	4,851	428.8	—12.7	1.7	62	1.056	....	....	
6 04.3	4,987	421.0	—12.9	0.1	80	1.338	....	....	Inversion.
....	5,000	....	—12.7	......	80	1.362	....	....	
6 05.7	5,167	411.7	—11.7	—0.7	77	1.432	....	....	
6 14.0	5,575	390.3	—14.8	0.8	69	0.979	....	....	
6 20.0	5,881	374.8	—19.1	1.4	61	0.594	....	....	
6 24.0	5,967	370.4	—19.7	0.7	49	0.450	....	....	
....	6,000	....	—19.9	......	48	0.432	....	....	
6 36.1	6,405	349.1	—24.4	0.8	34	0.221	....	....	
6 41.0	6,442	347.5	—25.2	0.5	31	0.169	....	....	

August 8, 1913

P. M.									
5 23.5	34	755.6	20.0	......	75	12.838	S. 32° W..	4.3	4/10 S. Cu. SSE.
5 25.1	367	726.6	17.2	0.8	80	11.608	S. 32° W..	4.3	
....	500	....	16.4	......	82	11.342	S. 62° W..	3.3	
5 26.7	786	691.5	14.4	0.7	88	10.785	N.55° W..	0.9	Balloons in S. Cu. NW. Inversion.
....	1,000	....	19.8	......	67	11.336	N. 6° E...	1.9	
5 27.4	1,021	672.6	20.4	—2.6	64	11.213	N.12° E...	2.0	
5 28.4	1,122	664.7	21.8	—1.4	56	10.640	N.16° E...	0.4	
5 29.1	1,244	655.4	24.5	—2.2	49	10.859	S. 69° E...	0.2	
5 29.5	1,413	642.9	24.9	—0.2	45	10.200	S. 77° W..	1.0	
....	1,500	....	24.4	......	43	9.476	N.82° W..	1.5	
5 30.2	1,539	633.6	24.2	0.6	42	9.151	N.73° W..	1.8	Inversion.
5 30.7	1,711	621.3	24.3	—0.1	41	8.984	N.45° W..	5.2	
....	2,000	....	23.1	......	39	7.983	N.21° W..	6.0	
5 32.3	2,080	595.4	22.6	0.5	39	7.758	N.15° W..	6.2	
....	2,500	....	19.3	......	40	6.572	N.25° W..	3.6	
5 34.3	2,619	559.2	18.4	0.8	40	6.233	N.28° W..	2.8	
....	3,000	....	14.5	......	41	5.055	N.20° W..	4.1	
5 36.9	3,316	514.7	11.4	1.0	41	4.176	N.13° W..	5.2	
....	3,500	....	9.8	......	43	3.961	N.10° W..	4.6	
....	4,000	....	5.8	......	46	3.278	N. 2° W..	3.2	
5 40.5	4,198	462.6	4.2	0.8	48	3.079	N. 1° E...	2.7	
....	4,500	....	2.2	......	50	2.806	N.17° W..	3.0	
5 43.4	4,981	419.9	— 0.9	0.7	53	2.387	N.45° W..	3.4	
....	5,000	....	— 1.0	......	53	2.368	N.45° W..	3.4	
5 46.8	5,982	369.6	— 6.5	0.6	57	1.634	S. 50° W..	3.0	
5 47.1	5,997	368.4	— 6.9	2.7	59	1.637	S. 53° W..	5.8	
....	6,000	....	— 6.8	......	58	1.623	S. 53° W..	3.0	
5 48.0	6,299	354.5	— 8.7	0.6	58	1.390	S. 75° W..	5.5	Inversion.
5 49.2	6,615	....	— 8.4	—0.1	54	1.326	S. 45° W..	3.6	Pressure pen not recording. Altitude computed from ascensional rate.
5 50.0	6,840	....	— 8.1	—0.1	52	1.308	S. 22° W..	14.6	
....	7,000	....	— 8.9	......	50	1.180	S. 11° W..	12.0	
5 50.8	7,050	....	— 9.1	0.5	49	1.137	S. 7° W..	10.7	
5 53.2	7,750	....	—13.0	0.6	46	0.763	S. 14° W..	11.5	
....	8,000	....	—14.5	......	45	0.655	S. 16° W..	12.8	

TABLE 4.—*Results of sounding balloon ascensions, Avalon, Cal.*—Continued

August 8, 1913—Continued

Time	Altitude	Pressure	Temperature	$\frac{\Delta t}{100 \text{ m.}}$	Humidity		Wind		Remarks
					Rel.	Abs.	Direction	Vel.	
P. M. *h. m.*	*M.*	*Mm.*	°*C.*		*P. ct.*	*g./m.*^{3}		*M.p.s.*	
5 54.8	8,215	....	−15.9	0.6	45	0.582	S. 18° W..	14.0	6/10 S. Cu. SSE. Balloons disappeared in St. Cu. Observations of ascension were made through this film of St. Cu. which at times obscured balloons after 5:26.5 p. m.
5 56.2	8,650	....	−19.5	0.8	45	0.422	....	....	
5 56.8	8,850	....	−20.7	0.6	45	0.375	....	....	
....	9,000	....	−21.3	......	44	0.346	....	....	
5 57.7	9,080	....	−21.7	0.4	44	0.334	....	....	
5 59.8	9,700	....	−24.3	0.4	43	0.256	....	....	
....	10,000	....	−26.1	......	43	0.215	....	....	
6 02.2	10,415	....	−28.7	0.6	42	0.162	....	....	
6 03.1	10,730	....	−29.8	0.3	42	0.145	....	....	
....	11,000	....	−31.5	......	42	0.124	....	....	
6 05.8	11,575	....	−35.0	0.6	42	0.086	....	....	
....	12,000	....	−35.8	......	41	0.077	....	....	
6 07.5	12,080	....	−36.0	0.2	41	0.076	....	....	
6 09.4	12,700	....	−37.2	0.2	40	0.065	....	....	
....	13,000	....	−38.7	......	40	0.055	....	....	
6 11.2	13,250	....	−39.8	0.5	40	0.049	....	....	
....	14,000	....	−43.4	......	40	0.033	....	....	
6 13.8	14,100	....	−43.9	0.5	40	0.031	....	....	
August 10, 1913									
A. M.									
4 43.0	34	765.9	23.4	......	58	12.077	N.46° E...	2.8	Cloudless.
4 45.7	435	722.6	21.3	0.5	57	10.522	N.24° E...	1.1	Inversion.
....	500	....	21.9	......	52	9.937	N. 5° E...	1.7	
4 48.2	832	690.3	24.7	−0.9	27	6.052	N.89° W..	4.0	
....	1,000	....	24.5	......	21	4.654	S. 88° W..	3.5	
4 49.2	1,036	674.3	24.5	0.1	20	4.432	S. 87° W..	3.4	
....	1,500	....	23.3	......	15	3.106	N.47° W..	2.3	
4 52.4	1,549	635.7	23.2	0.3	14	2.882	N.42° W..	2.1	
4 54.9	1,976	604.8	19.3	0.6	15	2.464	N.47° W..	2.1	One balloon became detached; the other balloon with the meteorograph slowly descended.
....	2,000	....	19.0	......	15	2.421	N.47° W..	2.1	
....	1,500	....	21.0	......	13	2.358	N.43° W .	2.2	
5 00.9	1,385	647.8	21.5	0.7	13	2.428	N.42° W..	2.2	
5 03.0	1,253	657.7	22.4	0.8	9	1.770	N.23° W..	2.1	
....	1,000	....	24.5	......	8	1.773	N.44° W..	1.8	
5 09.0	785	694.2	26.2	−0.3	7	1,706	N.61° W..	1.5	
5 11.0	702	700.8	24.1	0.2	7	1.517	N.68° W.	3.9	Inversion. Balloon disappeared behind the mountains.
5 13.1	600	709.0	24.3	−0.5	7	1.534	....	....	
....	500	....	23.7	......	16	3.389	....	....	
5 16.6	360	728.9	23.0	−1.8	27	5.495	....	....	
5 18.3	263	737.1	21.3	......	44	8.122	....	....	Inversion.

The distribution of pressure at the earth's surface changes but little in type, and that never abruptly, during the period of observation, nor does the pressure itself vary much from day to day. Figures 7 and 8 show the pressure distribution in a general way for the whole period. The positions of the centers of high and low pressure at 8 a. m. or 8 p. m., seventy-fifth meridian time, are shown by the circles, in which dates are also indicated. In the case of high pressure, these circles are connected by solid lines; in the case of low pressure, by dashed lines.

In three of the ascensions, July 24 and 27 and August 3, the balloons were followed with the theodolite beyond the altitude at which the minimum temperature was recorded (see fig. 9). In another, August 2, the air movement could be observed up to 17 kilometers. On July 24 and 27 the winds were westerly, with a small south component up to the height at which the minimum temperature was found. Above this height the wind was easterly. On August 2 and 3 the winds were southerly, with a small west component up to the point of minimum temperature. Here again the winds became easterly. On July 24 the wind velocity increased as the easterly component made its appearance; on July 27 there was little change; on August 2 and 3 there was a decided decrease in velocity as the wind became easterly.

B. The Captive Balloon and Mountain Observations on and Near Mount Whitney

By W. R. Gregg

Meteorological observations, including some captive balloon ascensions, were made at Mount Whitney, Cal., from August 1 to 13, inclusive, and at Lone Pine, Cal., from August 1 to 4, inclusive. Mount Whitney is the highest peak of the Sierra Nevadas, its altitude being 4,420 meters. It lies in latitude 36° 35′ N. and longitude 118° 17′ W. On the north, south, and west it is surrounded by mountains, many of which are nearly as high as itself; its eastern slope is quite precipitous and at its foot lies Owens Valley, which is about 25 kilometers in width and extends in a north-northwest and south-southeast direction. East of this valley and running parallel to the Sierras is the Inyo Range, altitude about 3,000 meters. Lone Pine is situated about midway between these two ranges, near the northern end of Owens Lake. Its altitude is 1,137 meters and it lies in latitude 36° 35′ N. and longitude 118° 3′ W., about 25 kilometers due east from Mount Whitney. Topographically the location of Lone Pine is similar to that of Independence, Cal., which is about 25 kilometers north-northwest of it and therefore practically the same distance from Mount Whitney. Independence is in latitude 36° 48′ N., longitude 118° 12′ W., and has an altitude of 1,191 meters, or 54 meters higher than that of Lone Pine.

SURFACE OBSERVATIONS AT MOUNT WHITNEY

The instrumental equipment consisted of a Short and Mason aneroid barometer, sling psychrometer, small kite anemometer of the Robinson type, Marvin meteorograph, and Richard meteorograph. The Richard instrument recorded pressure and temperature only and the object in taking it was to obtain a surface record of these elements and also to provide a substitute in case the Marvin instrument were lost or injured. The latter recorded relative humidity in addition to pressure and temperature. In order to secure good ventilation during balloon ascensions a section of the horizontal screening tube containing the humidity and temperature elements had been cut out, thus exposing these elements directly to the air.

As soon as they were unpacked, both of these instruments were started recording and a continuous record of pressure, temperature, and relative humidity was obtained. The sheets were changed at 8 a. m. and 5 p. m., and eye readings of the aneroid barometer and psychrometer were taken at these times; also at 11 a. m. and 2 p. m., and during balloon ascensions. In addition, readings of the psychrometer were taken by Messrs. A. K. Ångström and E. H. Kennard, representing the Smithsonian Institution, during the nights when they were observing. These readings have also been used to check the meteorograph records.

The exposure of the instruments was fairly good. They were kept in an improvised shelter constructed from the boxes in which they were "packed" to the summit. The ventilation was good, but during those afternoons in which the sun shone, the air in the shelter was considerably heated. However, there were only four sunny afternoons, and furthermore, the eye readings at 2 p. m. and 5 p. m. leave but little interpolation necessary.

All of the instruments were calibrated before and after the expedition. Especial care was taken in the calibration of the aneroid barometer, tests being made to determine the correction for "lag" or "creeping" and for changes in temperature. The effect of the latter was found to be negligible.

Owing to the large scale value of the pressure elements in the meteorographs and to the effect of changes of temperature on those elements, it is impossible to obtain with much accuracy the hourly values. However, in table 5 are given the pressures observed at certain hours. The readings at 11 a. m. are uniformly higher than those at 8 a. m., 2 p. m., or 5 p. m. It is probable that the diurnal maximum occurs at about this time.

The range of pressure for the entire period is large, about 8 mm. The range for the same period at Independence is much less, about 5 mm. At both places the lowest readings were recorded on August 8 and 9, while a cyclonic disturbance was central over northern California. This low was attended by considerable cloudiness, with thunderstorms, and, at Mount Whitney, snowstorms. The greater pressure range at Mount Whitney than at Independence is accounted for by the cool weather during the passage of the low and the consequent crowding together of the isobars in the lower levels.

Tables 6, 7, and 8 contain the hourly values of temperature, relative humidity, and absolute humidity, respectively. Means have been computed for the 10 complete days, August 3 to 12, inclusive. Final conclusions may not be drawn from so short a record, but a few comparisons are of interest. The mean temperature was 0.7° C.; that in the free air at the same altitude and for the same time of year, as determined from five years' observations at Mount Weather, Va., is —2.0°. The mean temperature at Pikes Peak[1] for these 10 days in 1893 and 1894 was 2.8°. Pikes Peak has an altitude of 4,301 meters, or about 100 meters below that of Mount Whitney, and to correct for this difference in altitude about 0.6° should be subtracted from the value at Pikes Peak. The temperature at Mount Whitney was undoubtedly below normal, owing to the severe stormy weather which prevailed. However, the values at both places, compared with those at the same altitude above Mount Weather, indicate that in summer temperatures on mountains are higher than those in the free air, although difference in latitude, in this case about 2½°, should be considered. The times of maximum and minimum temperatures at Mount Whitney were 3 p. m. and 5 a. m., respectively; at Pikes Peak they were 1 p. m. and 5 a. m., respectively.

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[1] Annual Reports of Chief U. S. Weather Bureau, 1893, 1894, 1895-1896, Washington.

TABLE 5.—*Pressures at Mount Whitney, Cal., August 1-13, 1913*

Date	Hours																								Means
	A. M.												P. M.												
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
1913					*Mm.*			*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*		*Mm.*			*Mm.*	*Mm.*			*Mm.*	
Aug. 1	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
2	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	447.0	......	......	......	......	......	......	......	......
3	......	......	......	......	......	......	......	......	446.8	447.0	447.6	447.0	447.0	446.8	446.5	......	446.0	......	......	......	446.5	......	......	......	......
4	......	......	......	......	......	......	......	446.8	......	......	......	448.1	......	446.0	......	......	445.8	......	......	446.3	......	......	......	446.0	......
5	......	......	......	......	......	......	......	445.5	......	......	446.3	......	......	446.5	......	......	445.5	......	......	......	......	......	......	......	......
6	......	......	......	......	......	......	......	444.2	......	......	445.0	......	......	444.8	......	......	444.5	......	......	444.8	......	......	......	......	......
7	......	......	......	......	......	......	......	444.8	......	......	445.3	......	......	445.3	......	......	443.5	......	......	......	......	......	......	......	......
8	......	......	......	......	......	......	......	442.7	......	......	442.5	......	......	441.4	......	......	440.7	......	......	......	......	......	......	......	......
9	......	......	......	......	......	......	......	438.7	......	......	439.2	......	......	438.9	......	......	438.9	......	......	......	......	......	......	......	......
10	......	......	......	......	......	......	......	440.4	......	......	441.2	......	......	440.4	......	......	440.2	......	......	......	......	......	......	......	......
11	......	......	......	......	......	......	......	441.4	......	......	442.0	......	......	441.7	......	......	440.4	......	......	......	......	......	......	......	......
12	......	......	......	......	......	......	......	440.9	......	......	441.7	......	......	449.9	......	......	440.4	......	......	......	......	......	......	......	......
13	......	......	......	......	438.7	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......

TABLE 6.—*Hourly Temperatures at Mount Whitney, Cal., August 1-13, 1913*

Date	Hours																								Means
	A. M.												P. M.												
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
1913	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	
Aug. 1	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	—2.9*	......	......
2	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1.1	—0.1	—0.6	—1.1*	—1.2	—1.4*	......
3	—1.4*	—1.9*	—2.1	—2.8	—2.9	—2.5	—1.8	0.0*	1.0	2.2*	1.7*	3.9*	2.3*	3.1*	6.1*	5.6	4.8	3.2	1.4*	0.2*	—0.2*	0.0	—0.1*	—0.4*	0.8
4	—0.6*	—1.1*	—1.1	—1.3*	—1.7*	—1.8	—1.0	—0.7*	—0.7	0.7	2.1	3.9*	4.4	4.8*	4.9	5.0	4.7*	4.5	1.9*	1.4*	1.3*	1.1*	0.6*	0.6*	1.3
5	0.6*	0.2*	0.2*	—0.1*	—0.3	—0.1	0.9	1.8*	1.7	3.0	4.2*	5.0	5.8	6.6*	7.0	5.5	4.3*	4.0	1.9*	1.8*	1.2*	1.1*	1.1*	0.6*	2.4
6	0.3*	0.6*	0.3*	0.6*	(0.6)	(1.2)	(1.6)	2.0*	2.3	3.8	5.0*	5.6	6.2	6.2*	6.4	6.6	7.8*	7.5	4.5	2.5*	2.2	2.1	2.0	2.0	3.3
7	1.9	1.8	1.7	1.6	1.6	1.6	1.7	1.9*	3.0	3.3	4.4*	5.2	5.9	6.7*	7.0	6.8	3.9*	4.4	3.8	1.9	1.4	1.5	1.5	1.4	3.2
8	1.0	0.7	0.5	0.5	0.5	0.4	0.5	1.3*	1.3	—0.2	—0.7*	0.2	0.2	—0.8*	—0.3	0.3	1.0*	1.0	0.2	—0.6	—1.1	—1.3*	—1.4	—1.4	0.1
9	—1.5	—1.5*	—1.5	—1.5	—1.5	—1.7	—1.8	—2.0*	—2.4	—0.4	—1.3*	—1.0	—0.5	—0.2*	—2.0	—1.1	—1.1*	—1.3	—2.3	—2.2	—2.2	—2.4	—2.6	—2.7	—1.6
10	—3.1	—3.4	—3.6	—3.7	—3.7	—3.2	—1.9	—0.9*	—1.0	—0.8	—0.2*	0.0	—0.7	—0.5*	—0.5	—3.0	—0.7*	—0.9	—1.2	—1.7	—2.2	—2.3	—2.3	—2.4	—1.8
11	—2.4	—2.4	—2.5	—2.7	—2.8	—2.8	—2.8	—2.6*	—2.6	—1.0	—0.1*	0.3	1.4	2.2*	2.7	2.5	2.4*	2.0	—0.6	—2.2*	—2.3*	—2.4*	—2.7*	—2.8	—1.0
12	—3.0*	—2.8	—2.6*	—2.5*	—2.5	—2.5	—1.4	—0.2*	—0.2	1.3	2.8*	3.4	4.4	5.2*	5.6	4.0	4.0*	4.0	—0.3	—1.2	—1.4	—1.6	—1.3	—1.4	0.4
13	—2.0	—2.4	—2.5	—2.6	—3.3*	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Means	—0.8	—1.0	—1.1	—1.2	—1.3	—1.1	—0.6	0.1	0.2	1.2	1.8	2.6	2.9	3.3	3.7	3.2	3.1	2.8	0.9	0.0	—0.3	—0.4	—0.5	—0.6	0.7
Independence means	18.6	17.8	17.2	16.3	16.5	16.7	20.4	22.9	25.2	26.9	29.2	30.6	31.2	31.4	31.4	31.3	29.9	27.7	26.1	25.3	23.7	22.0	20.4	19.8	24.1
Δt per 100 m.	0.60	0.58	0.57	0.54	0.55	0.55	0.65	0.71	0.78	0.80	0.85	0.87	0.88	0.87	0.86	0.87	0.83	0.77	0.78	0.79	0.75	0.70	0.65	0.63	0.73

* Eye readings.

TABLE 7.—*Hourly relative humidities at Mount Whitney, Cal., August 1-13, 1913*

Date	Hours																								Means
	A. M.												P. M.												
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
1913 Aug. 1																							97*		
2																						75*		93*	
3	92*	92*	(80)	42	(50)	(60)	(70)	79*	(80)	80*	79*	74*	81*	76*	55*	60	68	71	80*	78*	85*	78	70*	72*	73
4	69*	71*	55	36*	45*	50	64	64*	68	(74)	77	77*	72	51*	60	62	62*	67	75*	66*	51*	45*	52*	51*	61
5	52*	52*	47*	50*	51	52	55	56*	48	40	32*	34	34	36*	40	45	49*	52	54*	51*	55*	43*	38*	42*	46
6	43*	40*	29*	34*	(42)	(50)	(58)	67*	64	50	57*	(58)	(59)	60*	58	57	57*	55	58	70	70	70	70	66	56
7	68	68	69	69	69	69	69	69*	68	65	63*	63	64	64*	66	68	70*	75	100	100	95	94	93	93	75
8	93	93	92	92	92	91	85	78*	80	92	93*	96	100	100*	100	100	82	82	84	85	86	86*	84	85	90
9	86	87*	87	87	88	90	94	95*	95	(92)	89*	85	90	100*	100	98	97*	99	100	100	100	99	99	98	94
10	96	93	90	85	80	85	87	86*	85	86	95*	93	92	91*	88	100	93*	94	100	100	94	99	100	100	92
11	100	100	100	96	94	94	63	50*	41	41	41*	41	41	41*	45	73	77*	72	67	63*	41*	40*	33*	31	62
12	31*	26	20*	18*	18	30	40	50*	48	46	43*	43	43	43*	47	56	62*	50	72	76	54	54	15	15	42
13	15	19	19	19	23*																				
Means	73	72	67	61	63	67	68	69	68	67	67	66	68	66	66	72	72	72	79	79	73	71	65	66	69

TABLE 8.—*Absolute humidities in grams per cubic meter at Mount Whitney, Cal., August 1-13, 1913*

Date.	Hours																								Means
	A. M.												P. M.												
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
1913 Aug. 1																							3.7*		
2																						3.3*		4.0*	
3	4.0*	3.8*	(3.3)	1.6	(1.9)	(2.4)	(2.9)	3.8*	(4.1)	4.5*	4.3*	4.7*	4.6*	4.5*	4.0*	4.2	4.5	4.3	4.3*	3.8*	4.0*	3.8	3.4*	3.4*	3.8
4	3.2*	3.1*	2.4	1.6*	1.9*	2.1	2.9	2.9*	3.1	(3.8)	4.3	4.8*	4.7	3.4*	4.0	4.2	4.1*	4.4	4.1*	3.5*	2.7*	2.3*	2.6*	2.6*	3.3
5	2.6*	2.5*	2.3*	2.4*	2.4	2.5	2.8	3.1*	2.6	2.4	2.1*	2.3	2.4	2.7*	3.1	3.1	3.2*	3.3	3.0*	2.8*	2.9*	2.2*	2.0*	2.1*	2.6
6	2.1*	2.0*	1.4*	1.7*	(2.1)	(2.6)	(3.1)	3.7*	3.6*	3.1	3.9*	(4.1)	(4.3)	4.4*	4.3	4.3	4.6*	4.4	3.8	4.0*	3.9	3.9	3.9	3.7	3.5
7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.8*	4.0	3.9	4.1*	4.3	4.6	4.8*	5.1	5.2	4.4*	4.9	6.2	5.5	5.1	5.0	5.0	4.9	4.4
8	4.8	4.7	4.6	4.6	4.6	4.5	4.3	4.1*	4.2	4.4	4.3*	4.7	4.9	4.5*	4.7	4.9	4.2*	4.2	4.1	3.9	3.8	3.8*	3.6	3.7	4.3
9	3.7	3.7	3.7	3.7	3.8	3.8	3.9	3.9*	3.8	(4.3)	3.9*	3.8	4.2	4.8*	4.1	4.3	4.3*	4.3	4.0	4.1	4.1	4.0	3.9	3.8	4.0
10	3.6	3.4	3.3	3.1	2.9	3.2	3.6	3.9*	3.8	3.9	4.5*	4.5	4.2	4.2*	4.1	3.8	4.3*	4.2	4.4	4.2	3.8	4.0	4.0	4.0	3.9
11	4.0	4.0	4.0	3.7	3.6	3.6	2.4	2.0*	1.6	1.9	2.0*	2.0	2.2	2.3*	2.6	4.2	4.4*	4.0	3.1	2.6*	1.7*	1.6*	1.3*	1.2	2.8
12	1.2*	1.0	0.8*	0.7*	0.7	1.2	1.7	2.4*	2.3	2.4	2.5*	2.6	2.8	2.9*	3.3	3.5	3.9*	3.2	3.4	3.3	2.3	2.3	0.7	0.6	2.2
13	0.6	0.8	0.8	0.7	0.9																				
Means	3.3	3.2	3.0	2.7	2.8	3.0	3.1	3.4	3.3	3.5	3.6	3.8	3.9	3.8	3.9	4.2	4.2	4.1	4.0	3.8	3.4	3.3	3.0	3.0	3.5

* Indicates eye readings. ( ) inclose estimated values. All others from meteorograph records.

Figure 10 shows mean hourly temperatures at Mount Whitney and Independence and for the same period during 1893 and 1894 at Pikes Peak. The range at the latter appears to be somewhat smaller than at Mount Whitney, and this may be due to the fact that conditions at Pikes Peak are more nearly like those of the free air, owing to its isolation and the consequent freer circulation. The curve for Independence shows the large diurnal range characteristic of valley stations. Beneath the mean temperatures for Mount Whitney in table 6 are given the means for the same period at Independence and the differences in temperature change per 100 meters altitude between the two places. The temperature change with altitude during the night hours is somewhat misleading, owing to a marked inversion of temperature between the surface of the valley and about 200 meters above it, as will be pointed out in discussing the Lone Pine observations. The hourly differences between Independence and Mount Whitney during the daytime are large, averaging about 0.85. The mean for the 24 hours is 0.73.

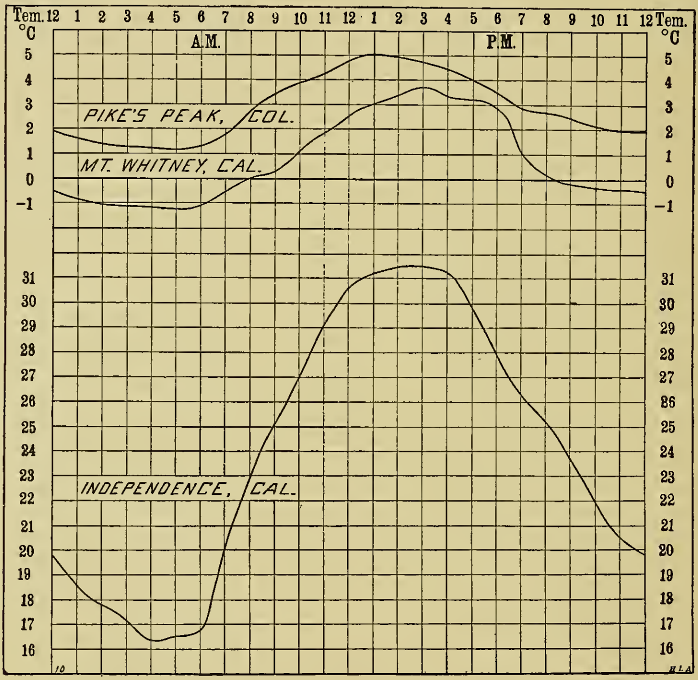

FIG. 10.—Mean hourly temperatures at Mount Whitney and Independence, Cal., August 3 to 12, incl., 1913, and at Pikes Peak, Col., August 3 to 12, incl., 1893 and 1894.

The relative humidity, table 7, was probably higher than normal for this season of the year, owing to the unusually stormy weather and the presence of snow on the ground. The mean was 69 per cent, the mean maximum 79 per cent at 7 to 8 p. m., and the mean minimum 61 per cent at 4 a. m. During the severe storm of August 8, 9, and 10, 100 per cent was frequently recorded. The absolute minimum was 15 per cent at midnight of the 12th.

TABLE 9.—*Wind velocities, in meters per second, at Mount Whitney, Cal., during August, 1913*

Date	Hours																							
	A. M.												P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1913 Aug. 1	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……
2	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	←	—	2.6	—	—	—
3	←	—	—	—	2.6	—	—	—	—	→	1.3	1.8	1.8	1.3	1.3	1.8	—*	—	2.1	→	3.6	←	3.8	—
4	←	—	—	—	3.8	—	—	—*	—	3.8	—	→	2.2	—*	—	1.5	—*	—	1.3	→	2.5	—	—	→
5	←	—	—	—	1.8	—	—	—*	—	1.5	—*	—	2.8	—*	—	2.1	—*	—	—	—	3.4	—	—	—
6	—	—	—	—	3.4	—	—	—*	—	0.9	—*	—	1.9	—*	—	1.2	—*	—	—	—	3.6	—	—	—
7	—	—	—	—	3.6	—	—	—*	—	3.7	—*	—	5.5	—*	—	3.6	—*	—	—	—	3.0	—	—	—
8	—	—	—	—	3.0	—	—	—*	—	2.4	—*	—	3.1	—*	—	1.5	—*	—	—	—	2.0	—	—	—
9	—	—	—	—	2.0	—	—	—*	—	2.8	—*	—	2.4	—*	—	3.7	—*	—	—	—	1.4	—	—	—
10	—	—	—	—	1.4	—	—	—*	—	1.4	—*	—	2.1	—*	—	2.8	—*	—	—	—	3.5	—	—	—
11	—	—	—	—	3.5	—	—	—*	—	4.1	—*	—	3.7	—*	—	3.7	—*	—	—	—	3.7	—	—	—
12	—	—	—	—	3.7	—	—	—*	—	4.9	—*	—	5.7	—*	—	4.6	—*	—	—	—	5.6	—	—	—
13	—	—	—	—	5.6	→	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……

Mean velocity for entire period, 3 m. p. s.
NOTE.—Anemometer read at the times indicated by *; figures are mean velocities between readings.

TABLE 10.—*State of weather at Mount Whitney, Cal., during August, 1913*

Date.	Hours																								Remarks
	A. M.												P. M.												
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
1913 Aug. 1.	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	←	—	—	Cloudy.		→	Clear	←	✱, ☈ until 10 p. m.
2.	—	—	—	—	—	—	—	—	—	—	—	Cloudy.		—	—	—	→	Pt. cldy.		Clear.		—	—	—	✱, ☈ in p. m.
3.	→	Pt. cldy.		Clear.		Pt. cldy.		←	—	—	—	Cloudy.		→	←	Pt. cldy.		→	←	Clear.		—	—	—	≡ 2a, Cu. from SE.
4.	—	—	—	—	—	—	—	—	—	—	—	Clear.		—	—	→	Pt. cldy.		←	Clear.		—	—	—	Cu. from S. ↯ in NE in evening.
5.	—	—	—	—	—	—	—	—	—	—	—	Clear.		—	—	—	—	—	—	—	—	—	—	—	Cu. & Cu. N. from S.; ↯ in NE. in evening.
6.	—	—	—	—	Clear.		—	—	—	—	—	→	←	—	—	Pt. cldy.		→	←	Clear.		—	—	—	Cu.&Cu. N. from S.; ☈ near by in p.m
7.	—	—	—	—	Clear.		—	—	→	←	—	Pt. cldy.		—	→	←	—	—	—	Cloudy.		—	—	—	☈ near by; ✱ 5:30 p.-12 p.
8.	—	—	—	—	—	—	—	—	—	—	—	Cloudy.		—	—	—	—	—	—	→	Pt. cldy.		Clear.		✱^{2}—4:30 p.
9.	Cl'r.	Pt. cldy.		←	—	—	—	—	—	—	—	Cloudy.		—	—	—	—	—	—	→	←	Pt. cldy.		—	Snow squalls. ✱^{2} 6 p.; ≡^{2}.
10.	Pt. cldy.		←	Clear.		→	←	Pt. cldy.		→	←	Cloudy.		—	—	—	—	—	—	—	—	—	—	→	✱^{2} 9:30 a.-9 p.
11.	←	Pt. cldy.		→	←	—	—	—	—	—	—	Clear.		—	—	—	—	—	—	—	—	—	—	—	Cu. from east and southeast.
12.	—	—	—	—	—	—	—	—	—	—	—	Clear.		—	—	—	—	—	—	—	—	—	—	→	Cu. from south.
13.	←	Pt. cldy.		—	—	→	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	……	Ci. and S. Cu. from south.

For the reasons given above, the absolute humidity, table 8, was also probably higher than normal. The mean was 3.5 grams per cubic meter, the mean maximum 4.2 at 4 to 5 p. m., and the mean minimum 2.7 at 4 a. m. The absolute maximum was 6.2 at 7 p. m. of the 7th and the absolute minimum 0.6 at midnight of the 12th.

Table 9 gives roughly the average wind velocities. Dial readings of the anemometer were made at the times indicated by stars. The figures between these stars represent average velocities for the intervals between readings. The mean for the entire period was 3.0 m. p. s. That at Pikes Peak for the same time of year was 6.0 m. p. s. This difference may be due partly to the fact that Pikes Peak stands out in the open, whereas Mount Whitney is surrounded by peaks nearly as high as itself, and also to the greater proximity of Pikes Peak to the cyclonic storm paths of the United States. The prevailing wind direction was southeast, but directions ranging between south and northeast were frequently observed, and a southwesterly wind prevailed during the blizzard of August 9.

In table 10 may be found the state of the weather for the period, together with notes on storms, kinds of clouds, and miscellaneous phenomena.

FREE-AIR OBSERVATIONS AT MOUNT WHITNEY, CAL.

The place from which balloon ascensions were made was about 60 meters to the northwest of the summit of Mount Whitney and about 10 meters below it. This was the only spot on the mountain that was fairly level and free from jagged surface rocks. While the balloon was being filled with gas it rested on a large piece of canvas to protect it from rocks and snow. The gas, compressed in steel cylinders, was furnished by the Signal Corps of the United States Army. A hand reel was used for reeling the wire in and out. Readings of the psychrometer, aneroid barometer, and anemometer were made with the aid of a pocket electric flash lamp.

Ascensions were made on only three nights, August 3, 4, and 5, and were begun immediately after sundown. On all other nights the weather was either too windy or too stormy. The balloon was allowed to take as great an altitude as possible and was then kept out until the wind aloft had increased to such an extent that it was necessary to reel in.

Table 11 contains the tabulated data for the three records obtained, and in figures 11 and 12 are plotted the temperature and absolute humidity gradients, respectively; the slight changes with time at the higher levels in each ascension are not plotted; only the ascent and descent proper. On August 3 and 4 these elements diminished with time by nearly the same amounts at all upper levels as at the surface. There was but little wind during these nights. On August 5, however, there was a fairly high northeast wind aloft and the temperature and humidity changed very little with time. The change with altitude in temperature was greater and in absolute humidity less than on the other nights.

TABLE II.—*Results of captive balloon ascensions at Mount Whitney, Cal., August 3-5, 1913*

Date and hour	Surface				At different heights above sea					
	Pressure	Temperature	Rel. hum.	Wind direction	Height	Pressure	Temperature	Humidity		Wind dir.
								Rel.	Abs.	
Aug. 3, 1913:	*Mm.*	°*C.*	*P. ct.*		*M.*	*Mm.*	°*C.*	*P. ct.*	*g./cu.m.*	
7:13 p. m.....	446.2	0.6	80	S.	4,410	446.2	0.6	80	4.0	S.
7:18 p. m.....	446.2	0.3	81	S.	4,533	439.3	−0.2	65	3.1	ESE.
7:25 p. m.....	446.2	0.1	80	S.	4,631	434.0	−0.9	65	2.9	ESE.
7:35 p. m.....	446.3	0.3	78	Calm.	4,689	430.9	−1.5	......	....	E.
7:45 p. m.....	446.3	0.2	78	Calm.	4,801	424.9	−2.3	......	....	E.
7:58 p. m.....	446.3	0.3	75	E.	4,683	431.2	−0.8	29	1.3	E.
8:06 p. m.....	446.3	0.3	73	E.	4,801	424.9	−1.5	18	0.8	E.
8:10 p. m.....	446.3	0.3	74	E.	4,744	427.9	−1.3	16	0.7	E.
8:15 p. m.....	446.4	0.2	75	E.	4,802	424.9	−2.3	13	0.5	E.
8:18 p. m.....	446.4	0.2	76	E.	4,664	432.4	−2.0	26	1.1	E.
8;31 p. m.....	446.4	0.1	78	ENE.	4,579	437.0	−1.5	67	2.9	ENE.
8:41 p. m.....	446.4	0.0	79	ENE.	4,509	440.9	−0.7	68	3.1	ENE.
8:51 p. m.....	446.5	−0.2	85	ENE.	4,410	446.5	−0.2	85	4.0	ENE.
Aug. 4, 1913;										
6:45 p. m.....	446.1	2.3	77	Calm.	4,410	446.1	2.3	77	4.4	Calm.
6:49 p. m.....	446.2	2.2	78	Calm.	4,627	434.3	1.4	......	....	Calm.
6:56 p. m.....	446.2	2.0	76	Calm.	4,852	422.3	−0.9	64	2.9	Calm.
7:04 p. m.....	446.2	1.8	74	Calm.	5,104	409.1	−2.2	37	1.5	Calm.
7:12 p. m.....	446.2	1.6	72	Calm.	5,359	396.1	−4.8	34	1.1	SSW.
7:22 p. m.....	446.2	1.6	71	Calm.	5,230	402.6	−4.4	33	1.1	S.
7:45 p. m....	446.3	1.5	70	Calm.	5,316	398.3	−5.6	24	0.7	WSW.
7:56 p. m.....	446.3	1.3	67	Calm.	5,216	403.3	−4.9	23	0.8	WSW.
8:25 p. m.....	446.3	1.1	60	E.	5,258	401.2	−4.4	19	0.6	SW.
8:55 p. m.....	446.2	1.1	55	Calm.	5,201	404.0	−3.6	12	0.4	SSW.
9:13 p. m.....	446.2	1.1	50	Calm.	5,229	402.6	−3.6	12	0.4	SSW.
9:39 p. m.....	446.2	0.9	46	Calm.	5,299	399.0	−5.6	12	0.4	S.
10:00 p. m....	446.2	0.8	45	Calm.	5,198	404.0	−4.3	12	0.4	S.
11:45 p. m....	446.0	0.6	51	E.	4,634	433.6	−1.9	10	0.4	E.
11:50 p. m....	446.0	0.6	51	E.	4,509	440.5	−0.7	23	1.1	E.
12:00 mdt....	446.0	0.6	51	E.	4,410	446.0	0.6	51	2.6	E.
Aug. 5, 1913:										
6:38 p. m.....	446.0	2.8	51	Calm.	4,410	446.0	2.8	51	3.0	Calm.
6:54 p. m.....	446.1	2.5	52	Calm.	4,625	434.3	0.8	54	2.8	SW.
7:30 p. m.....	446.2	1.8	50	Calm.	4,810	424.4	−1.4	54	2.3	NE.
7:37 p. m.....	446.3	1.8	45	Calm.	4,995	414.7	−2.8	54	2.1	NE.
7:52 p. m.....	446.4	1.9	47	Calm.	4,997	414.7	−3.5	54	2.0	NE.
8:05 p. m.....	446.4	1.8	53	Calm.	4,898	419.9	−2.7	54	2.1	NE.
8:17 p. m.....	446.5	1.7	57	Calm.	4,999	414.7	−3.4	54	2.0	NE.
8:42 p. m.....	446.6	1.3	55	Calm.	4,861	422.1	−1.8	54	2.3	NE.
8:56 p. m.....	446.7	1.2	55	Calm.	4,736	428.9	−0.3	53	2.5	NE.
9:05 p. m.....	446.7	1.3	55	NE.	4,820	424.4	−1.1	53	2.4	NE.
9:20 p. m.....	446.6	1.3	51	NE.	4,734	428.9	−0.3	51	2.4	NE.
9:44 p. m.....	446.5	1.2	46	NE.	4.604	435.8	1.0	48	2.5	NE.
11:00 p. m....	446.1	1.1	38	NE.	4,410	446.1	1.1	38	2.0	NE.

Aug. 3, 1913.—One captive balloon was used; capacity, 28.6 cu. m.
Few Cu., from the east, prevailed throughout the ascension.

Aug. 4, 1913.—One captive balloon was used; capacity, 28.6 cu. m.; lifting force at beginning of ascension, 5.4 kg.
Few Cu., from the south, at 7 p. m. Cloudless by 9 p. m. Lightning was seen over or near Death Valley. There was considerable electricity on the wire.

Aug. 5, 1913.—One captive balloon was used; capacity, 28.6 cu. m.
Few Cu., direction unknown, in early evening. Cloudless after 8.50 p. m. Lightning was seen on the eastern horizon, near Death Valley.

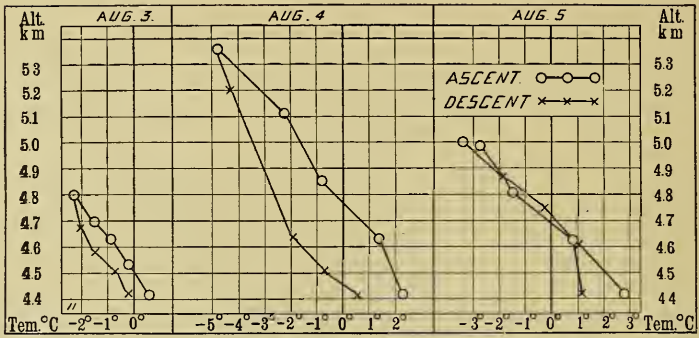

FIG. 11.—Temperature gradients (°C.), above Mount Whitney, Cal., August 3, 4, and 5, 1913.

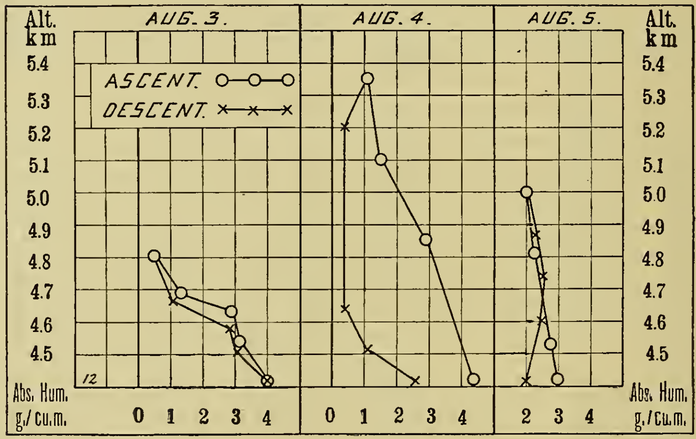

FIG. 12.—Absolute humidity gradients, grams per cubic meter, above Mount Whitney, Cal., August 3, 4, and 5, 1913.

TABLE 12.—*Temperature differences at 100-meter intervals above Mount Whitney, Cal., August 3, 4, 5, 1913*

Observations	Altitudes (meters)								
	100	200	300	400	500	600	700	800	900
Aug. 3, 1913:									
Ascent.........	0.6	0.8	0.9	0.6	....	....	....	....	....
Descent.......	0.5	1.0	0.4	0.2	....	....	....	....	....
Aug. 4, 1913:									
Ascent.........	0.4	0.4	0.9	1.0	0.7	0.5	0.6	1.0	1.0
Descent.......	1.3	1.0	0.5	0.4	0.5	0.4	0.4	0.4	0.4
Aug. 5, 1913:									
Ascent.........	0.9	1.0	1.1	1.2	0.8	0.8	....	....	....
Descent.......	0.1	0.1	0.9	1.2	1.1	1.2	....	....	....
Means.......	0.63	0.72	0.77	0.77	0.78	0.72	0.50	0.70	0.70

Table 12 contains the temperature differences at 100-meter intervals above the surface, as observed in all three ascensions. The mean gradient is 0.70 and is fairly constant at all altitudes up to 900 meters.

FREE-AIR OBSERVATIONS AT LONE PINE, CAL.

The balloon ascensions were carried out by Mr. P. R. Hathaway from a place about 1 kilometer north of Lone Pine. The instrumental and other equipment was similar to that used at Mount Whitney. Owing to leakage of a large number of gas tubes, only four ascensions were possible. These were made on August 1, 2, 3, and 4, and were begun shortly after sundown. Surface conditions for making ascensions at this time of day were usually excellent.

TABLE 13.—*Results of captive balloon observations at Lone Pine, Cal., August 1-4, 1913*

Date and hour	Surface				At different heights above sea					
	Pressure	Temperature	Rel. hum.	Wind direction	Height	Pressure	Temperature	Humidity		Wind dir.
								Rel.	Abs.	
Aug. 1. 1913:	*Mm.*	°*C.*	*P. ct.*		*M.*	*Mm.*	°*C.*	*P. ct.*	*g./cu.m.*	
9:18 p. m.....	660.3	16.7	79	Calm.	1,137	660.3	16.7	79	11.1	Calm.
9:30 p. m.....	660.4	16.7	79	Calm.	1,190	656.3	21.1	50	9.1	W.
9:37 p. m.....	660.5	16.8	78	Calm.	1,296	648.5	22.2	37	7.2	W.
9:44 p. m.....	660.6	17.2	77	Calm.	1,297	648.5	21.4	37	6.9	W.
10:10 p. m....	660.8	18.3	72	W.	1,311	647.7	23.0	28	5.7	W.
10:15 p. m...	660.8	16.7	80	Calm.	1,470	636.0	23.1	24	4.9	W.
10:43 p. m....	661.0	16.7	78	S.	1,204	655.8	22.3	46	9.0	S.
10:48 p. m....	661.1	16.7	78	S.	1,137	661.1	16.7	78	11.0	S.
Aug. 2, 1913:										
7:38 p. m.....	658.3	23.9	46	NNW.	1,137	658.3	23.9	46	9.9	NNW.
7:41 p. m.....	658.5	24.2	45	NNW.	1,253	649.9	27.2	30	7.7	N.
7:47 p. m.....	658.8	22.6	48	NNW.	1,355	642.8	27.1	17	4.4	N.
8:01 p. m.....	659.3	19.4	64	S.	1,958	600.4	23.0	17	3.5	Calm.
8:48 p. m.....	660.0	19.7	57	Calm.	2,273	579.8	19.2	23	3.8	SE.
9:30 p. m.....	660.9	18.6	66	Calm.	1,811	612.1	22.7	20	4.0	SE.
10:48 p. m....	662.6	17.5	69	S.	1,724	618.9	22.9	20	4.0	SW.
10:56 p. m....	662.8	18.0	64	S.	1,728	619.7	21.9	21	4.0	SW.
11:05 p. m....	662.9	16.4	77	S.	1,432	641.0	24.3	23	5.0	SE.
11:13 p. m....	662.9	16.7	75	S.	1,316	649.4	25.6	21	5.0	E.
11:19 p. m....	662.9	17.0	70	W.	1,234	655.5	25.5	21	4.9	E.
11:25 p. m....	662.9	17.2	70	W.	1,137	662.9	17.2	70	10.2	W.
Aug. 3, 1913:										
7:17 p. m.....	661.8	21.7	54	Calm.	1,137	661.8	21.7	54	10.2	Calm.
7:21 p. m.....	661.9	21.7	54	Calm.	1,296	650.0	28.4	26	7.2	SSE.
9:25 p. m.....	664.5	22.9	37	SSW.	1,137	664.5	22.9	37	7.5	SSW.
Aug. 4, 1913:										
7:19 p. m.....	656.9	19.9	58	Calm.	1,137	656.9	19.9	58	9.9	Calm.
7:22 p. m.....	657.0	19.8	57	Calm.	1,309	644.4	20.6	......	....	SE.
7:34 p. m.....	657.4	21.0	43	Calm.	2,367	572.2	23.2	......	....	SE.
7:56 p. m.....	658.2	22.2	39	S.	2,106	589.9	24.4	......	....	SSE.
8:02 p. m.....	658.3	22.7	38	S.	1,629	622.7	28.9	......	....	SSE.
8:05 p. m.....	658.3	23.0	38	S.	1,459	634.9	30.6	......	....	SSE.
8:55 p. m.....	658.2	26.4	27	S.	1,137	658.2	26.4	27	6.7	S.

Aug. 1, 1913.—One captive balloon was used; capacity, 28.6 cu. m. Cu. Nb., from the west, decreased from 5/10 to a few. Light rain fell for about two minutes at 9.35 p. m.

Aug. 2, 1913.—One captive balloon was used; capacity, 31.1 cu. m. St. Cu., from the south, decreased from 6/10 to a few.

Aug. 3, 1913.—One captive balloon was used; capacity, 31.1 cu. m. 1/10 Cu., direction unknown, disappeared before the end of the ascension.

Aug. 4, 1913.—One captive balloon was used; capacity, 31.1 cu. m. The sky was cloudless.

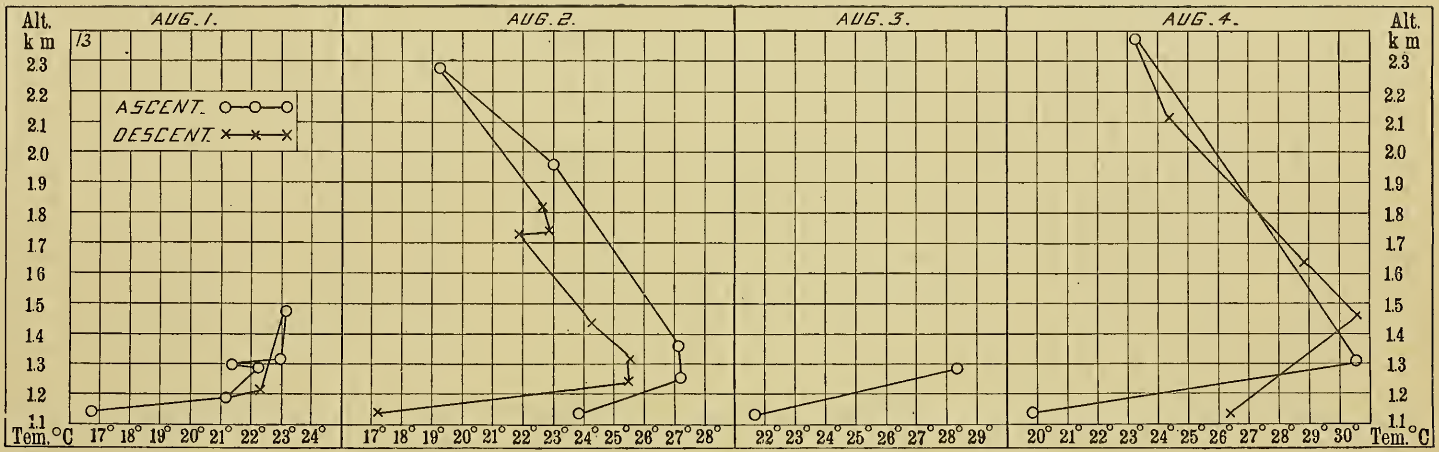

FIG. 13.—Temperature gradients (°C.), above Lone Pine, Cal., August 1, 2, 3, and 4, 1913.

The records obtained in the balloon ascensions are given in tabular form in table 13. Figures 13 and 14 show the temperature and absolute humidity gradients, respectively. There was always a marked inversion of temperature between the surface and 200 meters above it, amounting on the average to 6° C. (See table 14.) From 200 to 300 meters there was practically no change, but above 300 meters the temperature decreased with altitude at a fairly uniform rate, the mean difference per 100 meters being 0.73. On August 2 there was about equal cooling with time at all levels; on the 4th the temperature changed but little at upper levels and increased somewhat at the surface.

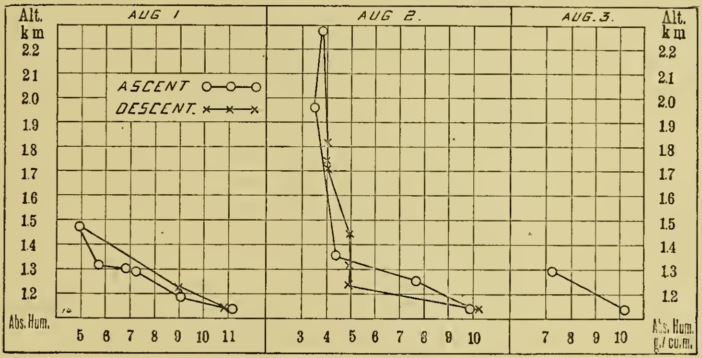

FIG. 14.—Absolute humidity gradients, grams per cubic meter, above Lone Pine, Cal., August 1, 2, and 3, 1914.

TABLE 14.—*Temperature differences at 100-meter intervals above Lone Pine, Cal., August 1-4, 1913*

Observations	Altitude (meters)											
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200
Aug. 1, 1913:												
Ascent	−4.8	−1.5	−0.1	......	......	......	......	......	......	......	......	......
Descent	−5.7	−0.3	−0.3	......	......	......	......	......	......	......	......	......
Aug. 2, 1913:												
Ascent	−2.7	−0.5	0.5	0.7	0.7	0.7	0.7	0.6	1.1	1.2	1.2	......
Descent	−8.3	0.1	1.1	0.8	0.8	−0.2	0.4	0.7	0.8	0.7	0.8	......
Aug. 3, 1913:												
Ascent	−4.2	......	......	......	......	......	......	......	......	......	......	......
Aug. 4, 1913:												
Ascent	−6.2	−4.3	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7
Descent	−1.3	−1.3	−1.3	0.5	1.0	0.9	1.0	0.9	0.9	0.8	0.5	0.5
Means	−4.74	−1.30	0.10	0.68	0.80	0.52	0.68	0.72	0.88	0.85	0.80	0.60

The absolute humidity (fig. 14) diminished rapidly from the surface to the altitude at which the highest temperature was recorded. Above this, on August 2, the only night in which a record of humidity at higher levels was obtained, it diminished slowly.

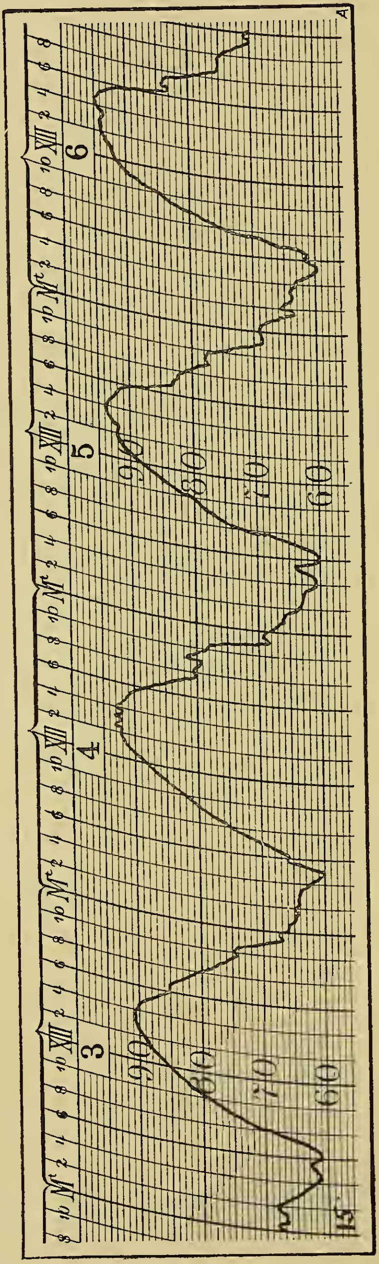

Fig. 15.—Thermograph record (°F.), at Independence, Cal., August 3-6, incl., 1914, showing fluctuations in temperature during night-time.

During the day there was a moderate breeze from the north blowing down the valley. This became very light toward evening, and at about the same time the temperature began to fluctuate, sudden changes of 2° to 5° C. occurring frequently between 6 p. m. and the time of minimum temperature. These fluctuations are well shown in the thermograph records at Independence, Cal. (fig. 15), and in table 15, which contains observed temperatures and humidities at Lone Pine, Cal. These observations have been referred to by Dr. Wm. R. Blair in his discussion of mountain and valley temperatures (Bulletin Mount Weather Observatory, Washington, 1914, **6**: 122) and are in accord with the conclusion there reached that "there is not a stream of cool air past the slope station, but a direct convective interchange between the cool air on the slope and the free air over the valley at the same or slightly lower levels." In general, as shown in table 15, the lower temperatures were accompanied by the higher absolute humidities.

Table 15.—*Fluctuations in surface temperature and humidity at Lone Pine, Cal., August 2 and 3, 1913*

Date	Time	Temperature	Relative humidity	Absolute humidity
1913	*P. m.*	*°C.*	*Per cent.*	*g./cu. m.*
Aug. 2	7:48	22.2	48	9.3
	7:51	20.6	56	9.9
	8:01	*19.4*	*64*	*10.6*
	8.45	20.0	56	9.6
	9:10	*16.7*	*75*	*10.6*
	9:21	18.7	64	10.2
	10:01	*16.7*	*75*	*10.6*
	11:00	18.3	62	9.6
	11:05	*16.4*	*77*	*10.7*
	11:48	18.9	60	9.6
Aug. 3	6:50	25.1	40	9.2
	7:40	*21.1*	*56*	*10.2*
	7:50	*19.4*	*56*	*9.3*
	8:05	20.8	45	8.1
	8:37	*19.4*	*52*	*8.6*
	9:09	21.1	42	7.7
	9:33	23.9	34	7.3
	9:43	*21.8*	*47*	*8.9*

Between 8 and 10.30 p. m. it was necessary to bring the balloon down because of southerly or southeasterly winds aloft. These winds gradually extended toward the surface and were warm and dry (table 13). The mixing of the upper southerly and the lower northerly currents seems to account for the variations in surface temperature and humidity already referred to.

The fact that the upper southerly wind is warm and dry suggests the probability that it originates over the Mohave Desert, which is about 150 kilometers south of Lone Pine. The heating and consequent rising of air over the desert in the daytime, which gives rise to the southerly current aloft, at the same time causes the surface northerly current down the valley.

APPENDIX II

SUMMARY OF SPECTROBOLOMETRIC WORK ON MOUNT WILSON DURING MR. ÅNGSTRÖM'S INVESTIGATIONS

By C. G. Abbot

Table 16, similar in form to tables 35 and 36 of Vol. III of the Annals of the Astrophysical Observatory of the Smithsonian Institution, contains a summary of all Mount Wilson spectrobolometric observations obtained by Mr. Aldrich, with accompanying measurements and reductions, for days in which Mr. Ångström obtained observations in California in 1913. The final column is of interest in connection with the pyrheliometric observations on Mount Whitney, given in Appendix III. The third column contains spectroscopic determinations by Mr. Fowle of the total depth of precipitable water existing as vapor above the observing station at Mount Wilson (latitude 34° 12′ 55″ N., longitude 118° 03′ 34″ W., elevation 1,727 meters or 5,665 feet). The letters given under "grade" have the following meanings: *vp*, very poor; *p*, poor; *g*, good; *vg*, very good; *e*, excellent. All observations were made between 6 and 10 o'clock in the morning except those of August 8, which were made between 2 and 6 o'clock in the afternoon. For a discussion of the methods and apparatus used the reader is referred to Vol. III of the Annals, cited above.

TABLE 16

Date	Pressure, water vapor	Precipitable water	Pyrheliometry			Bolometry Atmospheric transmission for different wave lengths											Solar constant (preliminary)	Ratio	True atmospheric transmission	True solar constant corrected for zero water vapor
			Grade	Apparent atmospheric transmission	Apparent solar constant	Grade	μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60				
1913	*cm.*	*cm.*		a	A_0												E_0	$\frac{E'_0}{A_0}$	$\frac{A_0 a}{E'_0}$	E'_0
July 23....	0.68	1.17	*g*	.865	1.711	*vg*—	.656	.730	.768	.786	.845	.917	.931	.956	.951	.973	1.914	1.131	.765	1.935
24....	0.73	1.15	*g*+	.869	1.685	*vg*+	.540	.692	.765	.814	.850	.930	.932	.956	.967	.989	1.890	1.135	.766	1.911
Aug. 3....	0.73	1.39	*vg*+	.861	1.716	*e*	.614	.712	.760	.808	.855	.908	.928	.948	.948	.977	1.903	1.124	.766	1.928
4....	0.55	1.19	*vg*	.867	1.646	*e*—	.621	.723	.783	.811	.853	.922	.951	.968	.969	.957	1.895	1.164	.745	1.916
5....	0.25	0.54	*g*+	.881	1.759	*e*	.621	.707	.766	.825	.843	.915	.936	.959	.964	.984	1.948	1.107	.796	1.958
P. M. 8....	1.04	2.06	*vp*	.762	1.769	*p*	.432	.541	.610	.676	.721	.816	.864	.916	.900	.916	2.016	1.162	.655	2.056
9....	0.69	1.34	*e*	.813	1.717	*e*—	.538	.608	.665	.728	.798	.854	.890	.921	.930	.968	1.932	1.140	.713	1.957
10....	0.68	1.30	*g*	.853	1.681	*vg*—	.552	.680	.737	.782	.824	.892	.919	.948	.947	.980	1.929	1.163	.734	1.954
11....	0.65	1.15	*vg*	.877	1.692	*vg*—	.562	.710	.774	.829	.863	.919	.931	.949	.965	.998	1.900	1.137	.772	1.921
12....	0.54	0.59	*e*—	.885	1.751	*vg*	.597	.750	.790	.816	.871	.930	.952	.974	.975	.966	1.928	1.108	.798	1.940
14....	0.32	0.65	*vg*	.883	1.757	*e*—	.670	.718	.781	.834	.861	.914	.942	.968	.946	.959	1.942	1.113	.793	1.955

APPENDIX III[1]

SOME PYRHELIOMETRIC OBSERVATIONS ON MOUNT WHITNEY

By A. K. Ångström and E. H. Kennard

In the summer of 1913 an expedition supported by a grant from the Smithsonian Institution proceeded to California in order to study the nocturnal radiation under different atmospheric conditions. In connection with these investigations we had an opportunity to measure the intensity of the solar radiation during seven clear days on the summit of Mount Whitney (4,420 m.). These measurements were made for different air masses and include observations of the total radiation and of the radiation in a special part of the spectrum, selected by means of an absorbing screen, as had been proposed by K. Ångström.[2] Our paper will present the results of the observations and a computation from them of the solar constant.

INSTRUMENTS

The observations were made with Ångström's pyrheliometer No. 158. With this instrument the energy of the radiation falling upon the exposed strip is given in calories per square centimeter per minute by the relation $I = kC^2$, where C is the compensating current sent through the shadowed strip, and k is a constant which was determined for this instrument at the solar observatory of the Physical Institute in Upsala and found to be 13.58.[3] The compensating current was furnished by four dry cells, which proved entirely suited to the purpose. It was measured by a Siemens and Halske milliammeter. For further details of the instrument and the method of using it, we refer to the original paper.[4]

The absorbing screen, used in order to study a limited part of the spectrum, was composed of a water cell, in which the water layer had a thickness of 1 cm., and a colored glass plate, Schott and Genossen, 436^{III}, the thickness of which was 2.53 mm. The transmission of the combination for different wave lengths as previously determined at Upsala by Mr. A. K. Ångström is given in figure 16. The maximum of transmission occurs at wave length 0.526 μ, and 85 per cent of the transmitted light is included between 0.484 μ and 0.570 μ.

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[1] Reprinted by permission from the Astrophysical Journal, Vol. 39, No. 4, pp. 350-360.

[2] Nova Acta Reg. Soc., Sc. Upsal., Ser. IV, **1**, No. 7.

[3] A comparison made at the Smithsonian Institution in Washington showed that the readings of this instrument are 4.57 per cent lower than the Smithsonian scale.

[4] Astrophysical Journal, **9**, 332, 1899.

The local time of each observation, from which the sun's zenith angle and finally the corresponding air mass was computed, was determined from the readings of three watches. Before and after the expedition to Mount Whitney, the watches were compared with the daily telegraphic time signal at Claremont, Cal. The time is probably accurate within half a minute.

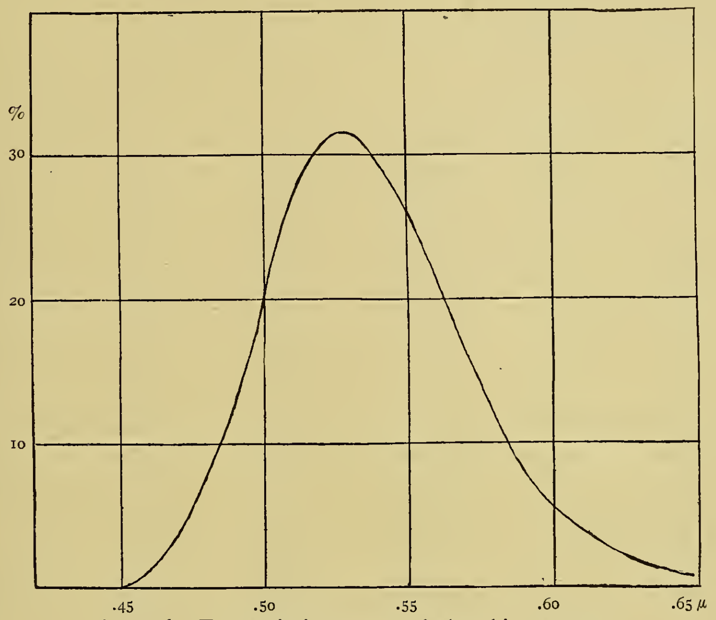

FIG. 16.—Transmission curve of absorbing screen.

RESULTS

The results are given in tables 17 and 18. Table 17 refers to the measurements of the total radiation and contains: (1) the date, (2) the local apparent time (t), (3) the computed air mass (m), (4) readings of the milliammeter (s), (5) the total radiation computed from the readings. Table 18 contains the same quantities relating to measurements taken with the absorbing screen.

Bemporad's[1] expression for the air mass in terms of the apparent zenith angle was employed. His values for 60°, 70°, 80°, and 85° were available in a short table given by F. Lindholm.[2] The differences between these values and the secant of the angle give the (negative) corrections to be applied to the secants of these angles. Through these values of the correction an algebraic curve of four terms was passed and the correction was then calculated for other angles. In obtaining the apparent zenith angle, allowance was made for refraction.

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[1] Mitteilungen der Grossherzoglichen Sternwarte zu Heidelberg, No. 4, 1904.

[2] Nova Acta Reg. Soc., Sc. Upsal., Ser. IV, **3**, No. 6.

Table 17.—*Measurements of total radiation*

	t		m	s Milliamp. $\times\frac{1}{3}$	Q_m $\frac{\text{cal.}}{\text{cm.}^2\text{min.}}$
	h.	m.			
August 2	6	34.2	3.337	100.1	1.224
	6	49.2	2.872	102.5	1.287
	7	30.7	2.088	106.3	1.381
	8	13.2	1.657	108.8	1.446
	9	20.7	1.299	111.3	1.514
August 4	6	28.3	3.630	99.4	1.202
	6	58.8	2.672	104.0	1.322
	7	6.8	2.501	104.1	1.325
	8	4.3	1.741	108.6	1.441
	9	6.8	1.359	110.5	1.493
	11	0.3	1.089	111.7	1.520
	11	8.8	1.081	112.0	1.533
August 5, A. M.	6	29.5	3.608	97.8	1.169
	7	2.0	2.616	103.0	1.296
	7	48.0	1.906	107.0	1.399
	8	59.0	1.397	110.6	1.495
	10	0.5	1.190	111.1	1.508
August 5, P. M.	2	0.3	1.193	111.2	1.511
	3	3.3	1.410	109.5	1.465
	4	4.3	1.830	106.3	1.381
	4	33.8	2.185	104.2	1.326
	5	4.8	2.783	100.1	1.224
	5	24.3	3.377	96.6	1.141
August 10	6	33.0	3.630	95.6	1.117
	7	3.0	2.681	100.5	1.235
	7	56.5	1.857	105.5	1.360
August 11	6	27.1	3.952	96.9	1.147
	6	54.6	2.914	101.9	1.269
	7	40.1	2.053	106.0	1.373
	8	41.6	1.514	109.3	1.460
	10	13.1	1.177	111.7	1.525
August 12	6	26.6	4.018	98.1	1.176
	6	59.1	2.817	103.6	1.312
	7	55.1	1.889	108.5	1.439
	8	57.1	1.435	111.1	1.509
	10	43.6	1.127	113.0	1.561

TABLE 18.—*Measurements with absorbing screen*

	t	m	s Milliamp. ×2	Q_m $\frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$
	h. m.			
August 2	6 18.2	4.044	104.5	0.0371
	6 54.7	2.733	114.1	0.0442
	7 25.7	2.158	122.0	0.0505
	8 22.7	1.589	125.4	0.0534
	8 31.7	1.530	126.8	0.0546
	9 15.2	1.319	128.8	0.0562
August 4	6 16.8	4.204	103.1	0.0361
	6 36.3	3.316	112.1	0.0426
	7 11.8	2.406	118.9	0.0480
	8 9.3	1.699	125.3	0.0533
	9 19.3	1.311	128.0	0.0556
	11 13.3	1.077	129.9	0.0573
August 5 A.M.	6 17.0	4.237	101.8	0.0352
	6 36 0	3.352	108.8	0.0402
	8 3.5	1.755	123.1	0.0515
	9 5.5	1.368	127.9	0.0554
	10 7.0	1.175	129.4	0.0568
August 5 P.M.	2 6.8	1.209	129.3	0.0567
	3 12.8	1.457	126.7	0.0545
	4 11.8	1.907	122.4	0.0509
	4 40.3	2.287	118.3	0.0475
	5 10.3	2.928	114.1	0.0441
	5 30.3	3.615	106.6	0.0386
August 9	6 14.4	4.607	96.0	0.0313
	6 33.9	3.559	103.4	0.0363
	11 38.9	1.126	128.8	0.0563
August 10	6 21.5	4.211	100.6	0.0344
	6 38.0	3.428	106.7	0.0387
	7 8.0	2.570	113.8	0.0439
	8 2.0	1.804	122.4	0.0508
	8 6.0	1.767	122.0	0.0505
August 11	6 14.6	4.716	102.5	0.0356
	6 33.6	3.641	107.9	0.0395
	7 0.1	2.770	114.6	0.0445
	7 45.1	1.992	122.1	0.0507
	8 51.1	1.462	127.1	0.0549
	10 18.6	1.166	129.9	0 0573
August 12	6 13.1	4.895	99.1	0.0333
	6 34.1	3.656	108.0	0.0397
	7 5.1	2.671	116.4	0.0459
	8 3.6	1.804	123.5	0.0517
	9 2.6	1.409	128.1	0.0557
	10 52.6	1.115	131.5	0.0587

GENERAL DISCUSSION OF THE EMPIRICAL METHODS FOR COMPUTING THE SOLAR CONSTANT

Empirical methods for determining the solar constant from pyrheliometric measurements alone have been proposed by K. Ångström[1] and by Fowle.[2] Both these methods are based upon results obtained from spectrobolometric observations. Ångström's method assumes that from Abbot and Fowle's observations we know both the distribution of energy in the sun's spectrum and the general transmission of the atmosphere for all wave lengths in terms of its value for any given wave length. It assumes further that the absorption caused by the water vapor is a known function of the water-vapor pressure at the earth's surface; for this, Ångström proposed an empirical formula based upon his spectrobolometric curves. The influence of diffusion and absorption can then be calculated if the transmission for some chosen wave length is known from pyrheliometric observations on a limited part of the spectrum.

Fowle's method is much briefer. He plots the logarithms of the observations against the air masses and extrapolates to air-mass zero by means of the straight line that best fits the points. To the "apparent solar constant" thus obtained he applies an empirical correction depending upon the locality, and derived from local spectrobolometric observations.

Since these methods are founded upon the spectrobolometric method, one may ask, what is the justification for using them instead of the latter? Can they be expected to give something more than the method upon which they are founded? To the first question one may reply that the justification lies in their simplicity, which makes it possible to apply them under a wide range of conditions where the more cumbersome bolometric method could never be used. A spectrobolometric investigation, like that of Abbot on Mount Whitney in 1910, will probably always be a rare event. But especially in regard to the question of solar variability it is desirable that the number of simultaneous observations be large and extended to as high altitudes as possible.

The second question, whether the abridged methods can ever deserve the same confidence, or even in rare cases give greater accuracy than the spectrobolometric observations, is one that must be answered rather through experimental results than through general considerations. Here, however, two points may be noted.

The first is, that the spectrobolometric method, which under ideal conditions is naturally superior to any abridged method, is in all practical cases a method involving a large number of precautions, some of which are very difficult to take. The abridged methods, founded as they are upon mean values, may possibly under special conditions avoid accidental errors to which single spectrobolometric series are subjected.

Secondly, it may be noted, that even in the analytical method of bolometry, there arises some uncertainty in regard to the ordinates of the bolometric curve, corrected for absorption, at the points where absorption bands are situated. This causes an uncertainty in the water-vapor correction in this method as well as in the abridged methods founded upon it.

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[1] Nova Acta Reg. Soc., Sc. Upsal., Ser. IV, **1**, No. 7.

[2] Annals of the Astrophysical Observatory, Smithsonian Inst., **2**, 114.

The methods just discussed lead to a numerical value for the solar constant. But the measurements in a selected part of the spectrum lead also to a direct test of solar variability, which seems likely to be especially valuable because these observations are not affected by aqueous absorption.

MEASUREMENTS WITH ABSORBING SCREEN

We may put:

$$I = I_0 e^{-\gamma m}$$

where I_0 is the energy transmitted through the absorbing screen at the limit of the atmosphere, I is its value after passing through the air mass m, and γ is a constant dependent upon the scattering power of the atmosphere. If now we plot log I against m, the points should lie on a straight line, whose ordinate for $m = 0$ is log I_0.

The values of I_0 thus obtained from our observations are given under the heading I_0 in table 19. The straight lines were run by the method of least squares, not so much because the presuppositions of this method seemed here to be satisfied, as because thereby all personal bias was eliminated. The "probable error" e of each value of I_0 is appended as a rough indication of its reliability, and the weighted mean I_0 is given at the bottom of the table. A comparison between the different values of I_0 shows that they all differ by less than 2 per cent; half of them by less than ½ per cent from the mean value. The deviation falls as a rule within the limits of the probable error.

This result thus fails to support the variability of the sun inferred by Abbot from simultaneous observations at Bassour and Mount Wilson. We cannot, however, with entire safety draw any conclusions about the total radiation from measurements in a limited part of the spectrum. All that can be said with certainty is that *a change of the energy in the green part of the solar spectrum exceeding 2 per cent during the period of our observations is improbable.*

If we, from this, are inclined to infer that the total solar radiation during the same period was constant, this inclination rests upon a statement by Abbot[1] himself to this effect: "So far as the observations[2] may be trusted, then, they show that a decrease of the sun's emission of radiation reduces the intensity of all wave lengths; but the fractional decrease is much more rapid for short wave lengths than for long."

Yet unpublished measurements by Mr. A. K. Ångström, in Algeria at 1,160 m. altitude, give a mean value for I_0 equal to 0.0708, which is in close agreement with the value 0.0702 given above. On the former occasion Mr. Abbot's spectrobolometric observations gave a mean value for the solar constant of 1.945. If we assume the energy transmitted by our green glass on Mount Whitney to bear the same ratio to the total energy, the Mount Whitney observations give a value for the solar constant reduced to mean solar distance equal to 1.929, which differs by less than 1 per cent from the former value.

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[1] Annals of the Astrophysical Observatory, Smithsonian Institution, **3**, 133. 1913.

[2] Observations of Bassour and Mount Wilson, 1911-1912.

MEASUREMENTS OF THE TOTAL RADIATION

The general basis of the Ångström-Kimball method of calculation has already been described. It is here convenient to make use of the spectrum of constant energy introduced by Langley, where the abscissa represents the energy included between an extreme (ultra-violet) wave length and the wave length corresponding to the abscissa ; the energy-density plotted as ordinate would then be constant. A table giving wave lengths and corresponding abscissæ is given by Kimball.[1]

Referred to such a spectrum, the atmospheric transmission y_x for any wave-length is well represented by the empirical formula

$$y_x = p^{m\delta} x^{nm\phi(\delta)} \qquad (1)$$

where x is the abscissa, m the air mass, and δ a quantity dependent upon the scattering power of the atmosphere. Ångström made the natural assumption $\phi(\delta) = \delta$. Kimball[2] finds that $\phi(\delta) = \sqrt{\delta}$ better fits the observations at Washington and Mount Wilson. In the latter case we have,

$$p = 0.93, \qquad n = 0.18$$

Making these substitutions in (1) and integrating,

$$Q_m = Q_0 \int_0^1 0.93^{m\delta} x^{0.18m\sqrt{\delta}} dx$$

or

$$Q_m = Q_0 \frac{0.93^{m\delta}}{1 + 0.18m\sqrt{\delta}}$$

Kimball then adds an empirical correction for the absorption due to water vapor, based upon bolometric measurements at Washington and at Mount Wilson, and finally obtains

$$Q_0 = \frac{Q_m}{\frac{0.93^{m\delta}}{1 + 0.18m\sqrt{\delta}} - [0.061 - 0.008\delta + 0.012E_0 m]} \qquad (2)$$

where E_0 represents the depth in millimeters to which the earth's surface would be covered by water if all the aqueous vapor were precipitated. We have adopted this expression, *but instead of attempting to determine E_0 from humidity measurements at the earth's surface we have eliminated it between two equations such as (2) involving different air masses.*

Kimball eliminates δ between two such equations. We have, however, followed the original method of K. Ångström and have determined δ for each day from our measurements with the green glass. The energy maximum of the light transmitted by it lies at 0.526 μ (see fig. 1), to which corresponds the abscissa 0.27 in the constant energy spectrum. Hence for the transmitted green light

$$I_m = I_0 0.93^{m\delta} 0.27^{0.18m\sqrt{\delta}}$$

from which δ can be computed. The values of δ thus obtained are given in table 19.

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[1] Bulletin of the Mount Weather Observatory, **1**, Parts 2 and 4.

[2] Ibid.

In order to compute Q_0, a smooth curve was drawn through the observations and values of Q_m for $m = 1$, 2, and 3 were read off from the curve. These values and the value of δ for the day were inserted in (2) and E_0 then eliminated between the first and second and the first and third of the equations thus obtained. The results are given in table 19 under the headings Q_{12}, Q_{13}; the mean of these for each day is given under $Q_{K\AA}$ and represents the solar constant as obtained for that day by the Ångström-Kimball method.

The mean value of all the measurements, reduced to mean solar distance, is 1.931 $\frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$ (Ångström scale) or 2.019 (Smithsonian scale). The maximum deviation from the mean is 3 per cent.

TABLE 19.—*Final results*

	p mm.	δ	I_0 $\frac{\text{cal.}}{\text{cm.}^2\text{min.}}$	e per cent	Q_{12} $\frac{\text{cal.}}{\text{cm.}^2\text{min.}}$	Q_{13} $\frac{\text{cal.}}{\text{cm.}^2\text{min.}}$	$Q_{K\AA}$ $\frac{\text{cal.}}{\text{cm.}^2\text{min.}}$	Q_F $\frac{\text{cal.}}{\text{cm.}^2\text{min.}}$
August 2.....	(3.0?)	0.30	0.0689	0.9	1.904	1.886	1.895	(1.820)
August 4.....	3.0	0.28	0.0678	0.9	1.847	1.829	1.838	1.793
August 5. A.M.	2.5	0.32	0.0683	0.3	1.871	1.874	1.873	1.832
August 5. P.M.	2.9	0.32	0.0684	0.8	1.887	1.900	1.894	1.878
August 9.....	......	(0.39)	(0 0688)	......	....	....	....	....
August 10.....	3.4	0.33	0.0670	0.7	....	1.826	(1.826)	(1.770)
August 11.....	2.2	0.30	0.0685	0.5	1.877	1.870	1.874	1.793
August 12.....	2.0	0.29	0.0685	0.5	1.896	1.888	1.892	1.802

Finally, Fowle's abridged method was applied to the same observations. Sufficient observations are not available for the elaboration of a special correction suited to Mount Whitney. But from the values of δ, it appears that the transmission over Mount Whitney was about the same as over Mount Wilson, where the average value of δ is 0.25; and the water-vapor pressure, the most uncertain factor, was low (2-4 mm.). Hence it may not be devoid of interest to apply here Fowle's rule as elaborated for Mount Wilson, which is: To the "apparent solar constant" obtained by straight-line extrapolation add 2.7 per cent and as many per cent as there are millimeters in the water-vapor pressure. The results thus obtained are given in table 19 under the heading Q_F; the mean water-vapor pressure is given under p.

$$\text{Weighted mean } I_0 = 0.0683 \frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$$

$$\text{reduced to mean solar distance } I_0 = 0\ 0702 \frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$$

(Ångström scale)

$$\text{Mean reduced to mean solar distance: } Q_{K\AA} = 1.931\ (\text{Å.}),$$

$$= 2.019\ (\text{Sm.}) \frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$$

$$Q_F = 1.872\ (\text{Å.}),$$

$$= 1.960\ (\text{Sm.}) \frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$$

SUMMARY

Our pyrheliometric observations on the top of Mount Whitney, extending from August 2 to August 12, 1913, have led to the following results:

1. A variation in the solar constant amounting to more than 2 per cent during this time is improbable.

2. The solar constant computed from the measurements in a selected part of the spectrum, reduced to mean solar distance, came out 1.929 $\frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$ (Smithsonian scale), with a possible error of 1.5 per cent. This value is obtained on the assumption that the energy included between 0.484μ and 0.576μ is a constant known fraction of the total energy in the solar spectrum.

3. The solar constant computed by the Ångström-Kimball method was found to be 2.019 $\frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$ (Smithsonian).

4. The solar constant computed according to Fowle's method comes out 1.960 $\frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$ (Smithsonian).

The value of the solar constant given in (2) is in close agreement with Abbot's mean value of 1.932 obtained from several series of observations made during the years 1902-1912 at much lower altitudes (*e. g.*, at 1160 m. in Algeria). The value given in (3) is also in close agreement with the solar constant computed by Kimball according to the same method from measurements at Washington. Consequently our observations give no support to a value of the solar constant greatly exceeding 2 $\frac{\text{cal.}}{\text{cm.}^2\text{ min.}}$.

Because of their bearing upon the question of solar variability, it seems desirable that the observations in selected parts of the spectrum by means of absorbing screens should be extended to different localities, and that if possible simultaneous measurements at elevated stations should be undertaken.

CORNELL UNIVERSITY,
December, 1913.

NOTE.—After the publication of the paper treating the pyrheliometric observations on Mt. Whitney by Dr. Kennard and myself, the spectrobolometric observations at Mt. Wilson have been published by Dr. Abbot. From both the simultaneous series, it is evident that our observations have been carried out during a period of relatively high constancy of the solar activity. No evidence in regard to the variability of the solar radiation can therefore with safety be drawn from these few observations alone. If the doubtful observations of August 8 and August 10 are excluded, the simultaneous observations at the two places seem, however, to confirm one another very well, as may be seen from figure 17. It seems, therefore, to be probable that the variations in the computed solar constant values are due to a real solar variability, the existence of which is very strongly indicated by the work of several expeditions of the Smithsonian Institution.[1]

ANDERS ÅNGSTRÖM.

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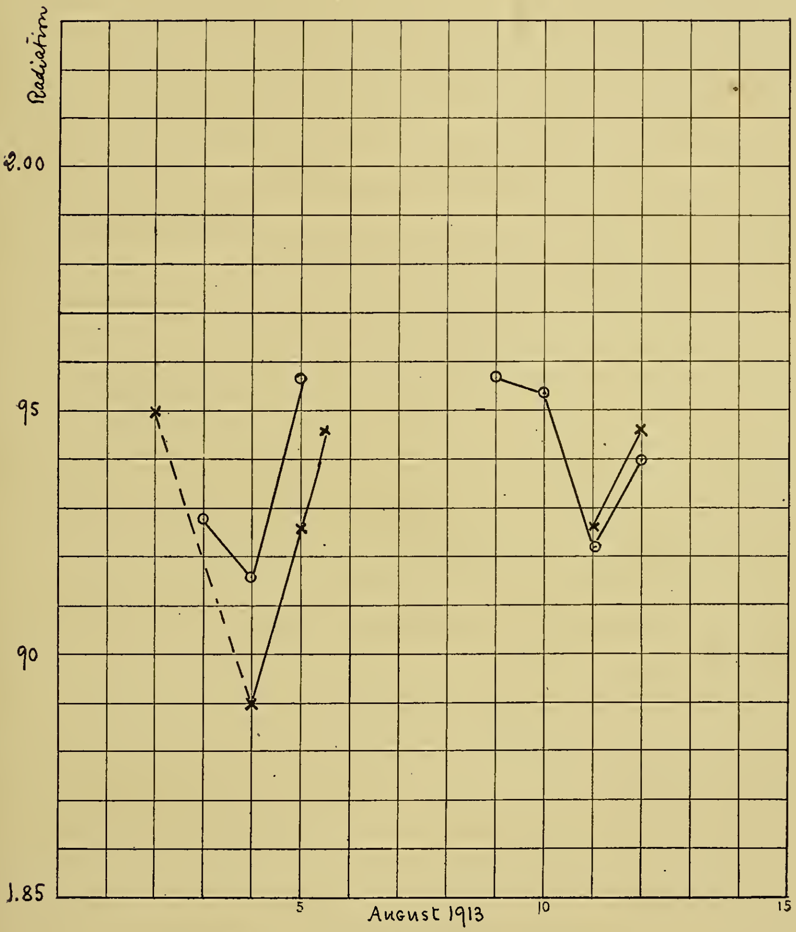
[1] Annals II and III of the Astrophysical Observatory of the Smithsonian Institution.



Circles: Mt. Wilson solar constant values.
Crosses: Mt. Whitney solar constant values.

FIG. 17.