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OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF MAY 29, 1919

(With One Plate)

BY
C. G ABBOT AND A. F. MOORE

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The station was located at El Alto, on the rim of the cañon in which La Paz, Bolivia, lies. The approximate location of El Alto is latitude, 16° 30′ S.; longitude, 4^h 33^m W.; altitude, 4,120 meters. Although at a high altitude the sky is rarely free from clouds, but very favorable conditions existed during the total and partial phases of the eclipse.

The Smithsonian Institution expedition to the eclipse consisted of Dr. C. G. Abbot and Mr. A. F. Moore. Dr. Abbot photographed the corona with two telescopes of eleven feet focus, and Mr. Moore carried on pyranometer observations during the eclipse, as well as at the same time on the day preceding, and at intervals during the night preceding. The telescopes were mounted in a vacant hotel building and the pyranometer was set up on top of a high stone fence, about one hundred feet back of the hotel building.

THE PHOTOGRAPHIC OBSERVATIONS

Owing to the shortness of the time available for preparation after the expected arrival of the party at La Paz every possible arrangement had been made in advance to set up the photographic apparatus quickly. For this purpose each of the three boxes which contained the apparatus was designed in form and construction so as to act as a support to some part of the photographic outfit when filled with stones and laid upon the floor of any room which might be found available for the observations. Also, every detail of the apparatus was carried without any dependence on such lumber or other material as might ordinarily be available. It was very fortunate that this was so, for the expedition was delayed so that the apparatus was set up only two days before the eclipse.

The briefness of the time available for preliminary tests was unfortunate in one respect. Owing to the very low altitude of the sun (only twenty minutes after sunrise) when the eclipse took place, the refraction of the terrestrial atmosphere was continually changing at the time, so that the apparent motion of the sun in the sky was at a variable rate not agreeing with that which prevailed later in the

day. A test of the clock was made on the day preceding the eclipse, but owing to the cloudiness it was not possible to follow quite up to the time of the eclipse. Such observations as were made on the preceding day, however, indicated that the clockwork moved a little too slowly and so the rate of the clock was increased about 3 per cent with the expectation of more exactly following the sun at the time of the eclipse. Unfortunately this proved to be too much of a correction, so that the clock moved a little too fast during the eclipse, and the images of the moon are not as truly round as they should be. Probably appreciable injury of definition has resulted from the slight drifting of the corona during the taking of the photograph. This might have been corrected, as the result proved, by mounting a following telescope in connection with the apparatus so that the observer might be in a position to guide the cameras during the eclipse. However, the moon's motion relative to the sun makes the moon unfit to follow upon, and it was supposed that the rays of the corona would be too indefinite so this was not thought worth while to arrange for. As it proved, there was a splendid prominence visible during the eclipse which would have been satisfactory to follow upon and it is perhaps to be regretted that some arrangement for following was not provided.

The two camera telescopes were rigidly fastened together. Exposures were made by the removal of two pasteboard boxes which covered the ends of the tubes but were separately mounted on hinged supports independent of the cameras. As the requisite time of exposure was not accurately known, it was arranged to expose one of the telescopes for 1 minute 30 seconds, the other for 2 minutes 45 seconds.

The program was carried through without any accident, and upon developing the two negatives both were found to be very good, but the exposure of 1 minute 30 seconds seemed to show quite as much extension of the corona as that of 2 minutes 45 seconds. As less drift of the clock occurred during the shorter interval than during the longer we give in the accompanying illustration only the result of the shorter exposure.

It is much to be regretted that the full excellence of the photograph cannot be produced in the illustration. There were a great number of sharp relatively narrow coronal streamers extending nearly two diameters in almost every direction from the sun. Decided evidences occur of coronal streamers at the north and south poles similar to those which are found at times of sun-spot minimum. The corona on this occasion was an intermediate type between a sun-spot maxi-

mum corona, equally extensive in all directions, and a sun-spot minimum corona, with relatively short polar streamers and long equatorial extensions. There was also a great sickle-shaped prominence which extended up from the sun to about one-quarter of a radius, then turned sharply round with a very long extension parallel to the sun's surface. Later in the day this prominence was repeatedly photographed with spectroheliographs in the United States, and then extended as a complete arch of very great height and span.

Taking into account the great length and beauty of the coronal streamers, the splendid crimson prominence throwing its glory over all, and the fact that the eclipse was observed so near sunrise from so great an elevation as 14,000 feet, with a snow-covered range of mountains upwards of 20,000 feet high as a background for the phenomenon, it seemed to the observers to be the grandest eclipse phenomenon which they had ever seen.

PYRANOMETRY

The object of the observations with the pyranometer was to obtain the intensity of the sky and solar radiation as the eclipse progressed, and at the time of totality to obtain the intensity of the radiation from the strips of the instrument to space, and compare the latter with similar radiation during the night preceding the eclipse. It was planned to take the night observations every two hours from nine o'clock until daylight, but unfortunately about eleven o'clock a heavy fog occurred which persisted until three o'clock and prevented the observations. Between three o'clock and daybreak there were intervals of cloudiness, but at sunrise the sky was perfectly clear, and remained so until nearly the end of the partial phase of the eclipse.

During the night and during the totality the observations were made with the hemispherical glass removed. At daybreak the glass was put on, and observations made on the scattered sky radiation until sunrise. As soon as the sun rose (about three-fourths eclipsed) the observations were alternated between sky plus the sun and sky alone, the latter condition being arranged by interposing a circular screen of metal to cut off the sun's rays. Both of these intensities were of course measured on a horizontal surface. The units are calories $\frac{cm^2}{min.}$.

In the reduction of the observations, curves are plotted with hour angles as abscissae, and the intensity of the sun plus sky, and of the sky alone as ordinates. These curves relate both to the day of the eclipse and to the day preceding. By subtracting the sky from the

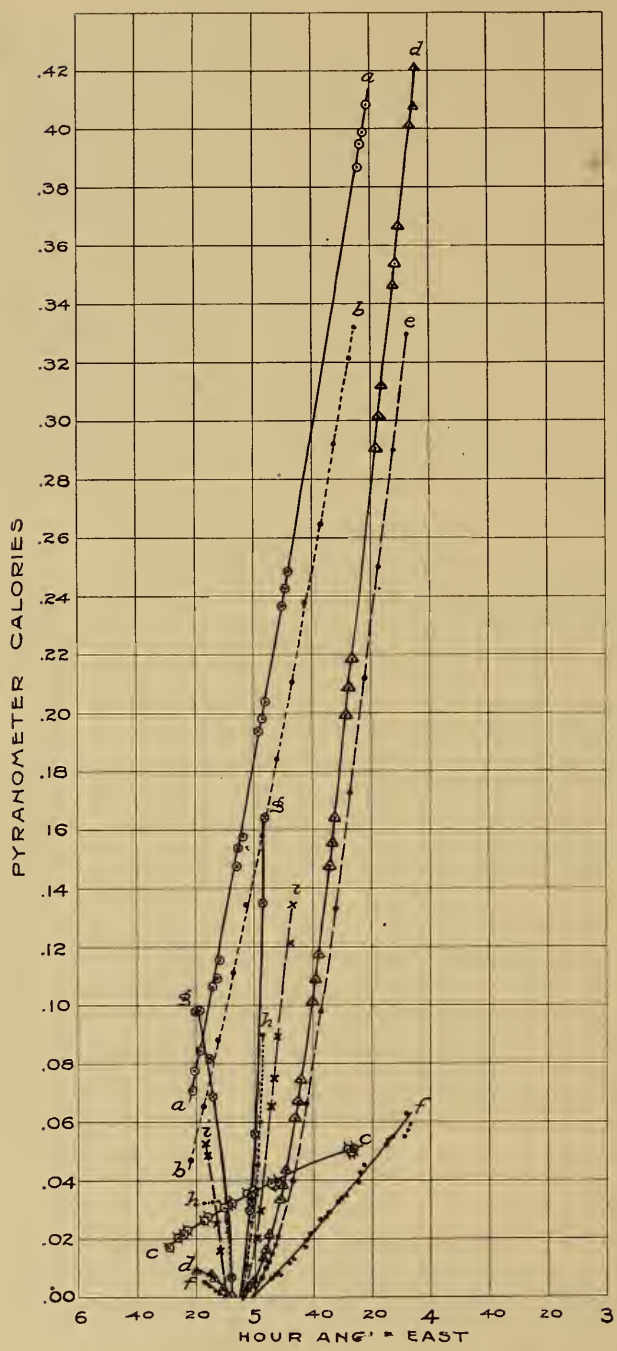

FIG. 1.—Measurements of solar and sky radiation.

aa, Sky + sun on horizontal surface, May 28, 1919; *dd*, ditto, ditto, May 29, 1919.
bb, Sun alone on horizontal surface, May 28, 1919; *ee*, ditto, ditto, May 29, 1919.
cc, Sky alone on horizontal surface, May 28, 1919; *ff*, ditto, ditto, May 29, 1919.
gg, *hh*, *ii*, same as *dd*, *ee*, *ff*, respectively, but ordinates 10-fold enlarged.

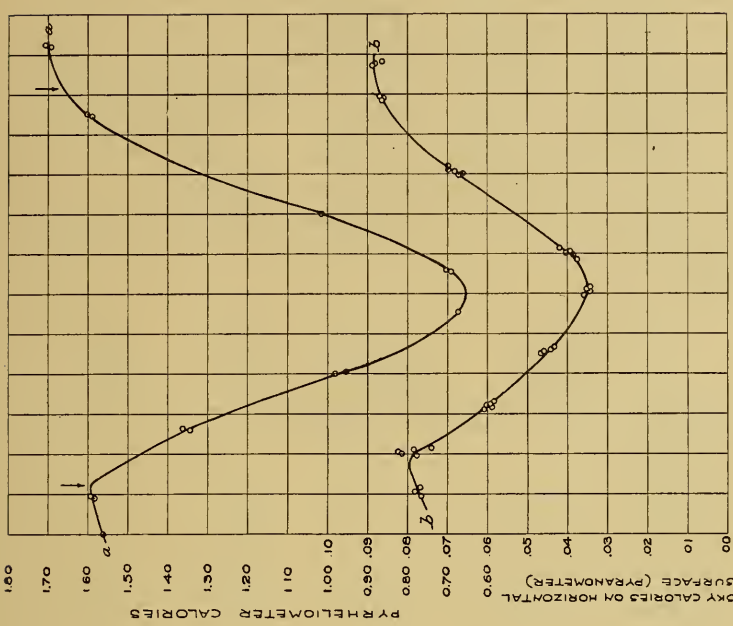

FIG. 3.—Measurements of solar and sky radiation.
aa, Sun alone on surface normal to the beam, Dec. 3, 1918.
bb, Sky alone on horizontal surface, Dec. 3, 1918.
Partial eclipse limits indicated by arrows.

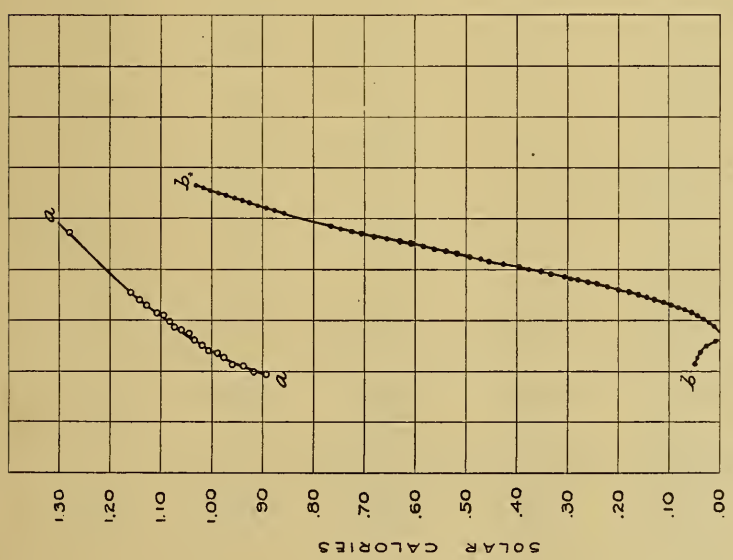

FIG. 2.—Measurements of solar radiation.
aa, Sun alone on surface normal to the beam, May 28, 1919.
bb, ditto, ditto, May 29, 1919.

sun plus sky, other curves are drawn showing the solar radiation as measured on a horizontal surface. Then a curve is drawn of the intensity of the solar radiation as measured on a surface at right angles to the direction of the solar beam. The points of this curve are obtained by dividing the solar intensity on a horizontal surface by the sine of the angle of altitude of the sun, computed from the hour angle, latitude, longitude and declination. (See figs. 1, 2.)

Following this are tables of the radiation measured during the night preceding the eclipse and during the totality and a comparison of these values.

Date	Hour Angle	1 2 Calories Measured on Horizontal Surface (observed)	3 Solar Calories on Horizontal Surface (from curves)	4 Sine of Apparent Altitude of Sun (Sin h′)	5 Solar Calories on Surface Normal to Beam
May 28 1919	Just before sunrise. Some cirri in northeast.				
	$-5^h\ 29^m$	.0171	.....	.0238	.....
	Sky only.				
	5 26	.0207	.....	.0348	.....
	5 24	.0217	.....	.0422	.....
	5 23	.0230	.....	.0460	.....
	Sky + Sun.				
	5 21	.0710	.0480	.0538	0.892
	5 20	.0775	.0522	.0570	0.916
	5 18	.0848	.0607	.0648	0.937
	Sky.				
	5 17	.0263	.0654	.0682	0.959
	5 16	.0273	.0700	.0722	0.969
	5 15	.0279	.0740	.0760	0.974
	Sky + Sun.				
	5 14	.1067	.0790	.0800	0.987
	5 13	.1094	.0828	.0838	0.989
	5 12	.1153	.0873	.0870	1.003
	Sky (clear overhead).				
	5 10	.0309	.0960	.0945	1.016
	5 09	.0312	.1004	.0982	1.033
	5 08	.0319	.1055	.1020	1.034
	Sky + Sun.				
	5 06	.1475	.1142	.1097	1.041
	5 05	.1538	.1184	.1135	1.043
	5 04	.1577	.1235	.1170	1.056
	Sky. Some cirri and streakiness overhead.				
	5 02	.0355	.1330	.1240	1.072
	5 01	.0355	.1376	.1282	1.074
	5.00	.0362	.1426	.1320	1.080
	Sky + Sun. Cirri overhead and in south.				
	4 58	.1936	.1530	.1400	1.093
	4 57	.1979	.1582	.1430	1.106
	4 56	.2038	.1630	.1470	1.109
	Sky. Cirri overhead.				
	4 54	.0391	.1738	.1542	1.127
	4 53	.0388	.1790	.1580	1.133
	4 52	.0394	.1841	.1615	1.140

Date	1 Hour Angle	2 Calories Measured on Horizontal Surface (observed)	3 Solar Calories on Horizontal Surface (from curves)	4 Sine of Apparent Altitude of Sun (Sin h′)	5 Solar Calories on Surface Normal to Beam
May 28 1919	Sky + Sun.				
	$-4^h\ 50^m$	.2367	.1945	.1690	1.151
	4 49	.2422	.1995	.1723	1.158
	4 48	.2481	.2043	.1762	1.162
	Sky. Considerable cirrus all over sky.				
	4 28	.0503	.3155	.2483	1.271
	4 27	.0500	.3212	.2519	1.275
	4 26	.0510	.3262	.2555	1.278
	Sky + Sun. Sky same as preceding.				
	4 24	.3869	.....	.2622	.....
	4 23	.3946	.....	.2660	.....
	4 22	.3988	.....	.2695	.....
	4 21	.4083	.....	.2720	.....
May 29 1919	Sky + Sun. Sky clear.				
	— 5 20	.0098	.....	.0570	.....
	5 19	.0098	.....	.0610	.....
	Sky.				
	5 17	.0053	.0032	.0682	.0469
	5 16	.0049	.0033	.0722	.0457
	Sky + Sun.				
	5 15	.0082	.0033	.0760	.0434
	5 14	.0069	.0033	.0800	.0412
	Sky.				
	5 13	.0026	.0033	.0838	.0394
	5 12	.0016	.0033	.0870	.0379
	Sky + Sun.				
	5 11	.0033	.0032	.0910	.0352
	5 10	.0030	.0027	.0945	.0286
	Sky.				
	5 09	No readable deflection.	.0021	.0982	.0214
	Sky + Sun.				
	5 08	.0007	.0007	.1020	.0069
	$5\ 07\ 30^s$	.0003	.0003	.1035	.0029
	AFTER TOTALITY				
	Sky + Sun.				
	5 02	.0030	.0018	.1240	.0145
	5 01	.0033	.0025	.1282	.0195
	5 00	.0056	.0035	.1320	.0265
	Sky.				
	4 59	.0020	.0046	.1360	.0338
	4 58	.0030	.0063	.1400	.0450
	Sky + Sun.				
	4 57	.0135	.0081	.1430	.0566
	4 56	.0164	.0102	.1470	.0694
	4 55	.0213	.0126	.1505	.0837
	Sky.				
	4 54	.0066	.0150	.1542	.0973
	4 53	.0075	.0180	.1580	.1139
	4 52	.0079	.0210	.1615	.1300

Date	1 Hour Angle	2 Calories Measured on Horizontal Surface (observed)	3 Solar Calories on Horizontal Surface (from curves)	4 Sine of Apparent Altitude of Sun (Sin h′)	5 Solar Calories on Surface Normal to Beam
May 29 1919	Sky + Sun.				
	$-4^h 51^m$	.0335	.0238	.1650	.1442
	4 50	.0381	.0273	.1690	.1615
	4 49	.0430	.0310	.1723	.1798
	Sky.				
	4 48	.0121	.0353	.1762	.2002
	4 47	.0135	.0400	.1800	.2222
	Sky + Sun.				
	4 46	.0617	.0441	.1838	.2398
	4 45	.0670	.0486	.1875	.2592
	4 44	.0745	.0538	.1910	.2815
	Sky.				
	4 43	.0174	.0592	.1948	.3038
	4 42	.0200	.0655	.1980	.3318
	4 41	.0213	.0710	.2018	.3520
	Sky + Sun.				
	4 40	.1014	.0772	.2055	.3757
	4 39	.1086	.0835	.2093	.3988
	4 38	.1175	.0905	.2125	.4258
	Sky.				
	4 37	.0263	.0980	.2160	.4537
	4 36	.0272	.1032	.2200	.4688
	4 35	.0289	.1100	.2237	.4920
	Sky + Sun.				
	4 34	.1477	.1175	.2270	.5175
	4 33	.1555	.1240	.2305	.5380
	4 32	.1640	.1315	.2340	.5620
	Sky.				
	4 31	.0328	.1390	.2380	.5840
	4 30	.0338	.1460	.2415	.6048
	4 29	.0348	.1543	.2450	.6300
	Sky + Sun.				
	4 28	.1996	.1630	.2485	.6560
	4 27	.2085	.1720	.2520	.6825
	4 26	.2182	.1800	.2555	.7048
	Sky.				
	4 25	.0394	.1870	.2590	.7220
	4 24	.0427	.1960	.2625	.7470
	4 23	.0460	.2035	.2660	.7650
	Sky + Sun.				
	4 18	.2904	.2425	.2830	.8570
	4 17	.3012	.2510	.2865	.8762
	4 16	.3118	.2590	.2900	.8930
	Sky.				
	4 15	.0525	.2670	.2935	.9100
	4 14	.0542	.2748	.2968	.9262
	4 13	.0552	.2828	.3000	.9422

Date	Hour Angle	1 2 Calories Measured on Horizontal Surface (observed)	3 Solar Calories on Horizontal Surface (from curves)	4 Sine of Apparent Altitude of Sun (Sin h′)	5 Solar Calories on Surface Normal to Beam
May 29 1919	Sky + Sun.				
	$-4^h\ 12^m$	.3463	.2900	.3035	.9555
	4 11	.3536	.2985	.3070	.9722
	4 10	.3662	.3065	.3103	.9880
	Sky.				
	4 09	.0558	.3145	.3138	1.0030
	4 08	.0578	.3222	.3170	1.0165
	4 07	.0594	.3300	.3200	1.0312
	Sky + Sun.				
	4 06	.4008	.....	.3238	.....
	4 05	.4078	.....	.3270	.....
	4 04	.4202	.....	.3302	.....
	Starting to cloud up overhead. End of eclipse.				

Following are the values obtained on the night preceding the eclipse. They were observed with the hemispherical glass removed and indicate the intensity of the long wave length radiation from the blackened strips of the pyranometer to space.

Date	Time—Local or Mean Solar—for La Paz p. m.	Current Squared (Ammeter Corrections Applied)	Calories from Horizontal Surface to Space	Time	Pressure Aqueous Vapor (m. m.)	
May 28 1919	9:04	.07215	.1417	9:08	4.57	Sky clear.
	9:07	.07162	.1408	....	....	....
	9:14	.07269	.1428	....	....	...
	At 11:00 p. m. and 1:00 a. m. (May 29) heavy fog.					
May 29	A. M. 3:21	.09571	.1881	3:31	4.32	Few floating clouds.
	3:24	.09326	.1834	....	....	....
	3:28	.07815	.1536	....	....	....
	3:36	.05784	.1130	....	....	....
	3:39	.04977	.0978	....	....	....
	At 4:00 a. m. nearly totally overcast with clouds.					
	5:36	.06489	.1275	5:44	4.04	Clouds in W. and N.
	5:49	.06389	.1255	....	....	Less clouds.
	5:54	.05851	.1150	....	....	Clearing overhead.
	Following clear overhead.					
	6:07	.06540	.1285	6:12	4.16	
	6:11	.05994	.1177	6:27	4.13	
	6:15	.05994	.1177	....	....	
	6:19	.05851	.1150	....	....	
	6:23	.05754	.1130	....	....	
	6:30	.05154	.1012	....	....	
	6:34	.05427	.1067	....	....	
	6:36:30	.05754	.1130	....	....	

The following were taken during totality. The agreement does not appear very good, but the observations taken with the glass removed are never as accurate and consistent as those taken with the

glass over the strips. This is due for the most part to wind blowing on the strips. However, it is entirely possible and in fact probable that during the totality there would be a change in the direction found, because the atmosphere undoubtedly cooled to an appreciable extent during totality.

The values obtained during totality are about the same as those obtained during the night preceding.

During Totality.

Date	Hour Angle	Current Squared	Calories from Horizontal Surface
May 29, 1919	$-5^h\ 05^m$	.05531	.1087
	$-5\ 03\ 30^s$	.06744	.1326
		Mean	.1206

The results of the preceding observations made with the pyranometer with the glass removed and purporting to give the outflow of radiation from a perfectly radiating horizontal surface in calories per sq. centimeter per minute must be regarded as provisional, as also all such values hitherto obtained with the pyranometer on the nocturnal radiation and on the outgoing radiation during the totality of the eclipse of June, 1918. The values are computed on the assumption that the blackened strips of the pyranometer radiated 95 per cent as much as a perfect radiator of the same dimensions would do. On account of the uncertainty existing as to the absorptive and radiative powers of lamp black for rays of very great wave length, the value 95 per cent must be regarded as a mere assumption. Comparisons have been made between the pyranometer and the Ångström pyrgeometer which has been much employed for measurements of nocturnal radiation. These comparisons indicate that either the pyrgeometer reads much too high or the pyranometer much too low, when the pyranometer observations are reduced as above explained.

Recently Mr. L. B. Aldrich has constructed and tried on Mt. Wilson a new instrument for measuring nocturnal radiation which is designed on the principle of the hollow chamber black body. Preliminary comparisons between this instrument and the pyranometer seem to show that we ought perhaps to use a coefficient of radiation for the latter under 95 per cent, or more nearly 80 per cent, so that perhaps the values here given should be increased by about 16 per cent, and also those published by Mr. Aldrich in his paper entitled "The Smithsonian Eclipse Expedition of June 8, 1918." However, the matter is not yet settled and requires further investigation.

PYRANOMETRIC OBSERVATIONS OF THE PARTIAL ECLIPSE OF THE SUN OF DECEMBER 3, 1918

Observations similar to those of May 29, 1919, were carried on by A. F. Moore and L. H. Abbot at the Smithsonian Observatory near Calama, Chile, during the partial solar eclipse of December 3, 1918. The sky radiation was measured on a horizontal surface by the pyranometer during the progress of the eclipse, and the intensity of the solar radiation on a surface normal to the beam was observed with a pair of pyrheliometers mounted equatorially.

In the accompanying curves the sky radiation is plotted to a scale ten times as large as that for the solar values. It will be seen that the curves are almost identical in shape, showing that throughout the eclipse the light from the sky falling on a horizontal surface was nearly directly proportional to the intensity of the solar radiation as measured on a surface normal to the beam. This proportionality would probably not hold under other circumstances when the change of solar intensity would be produced by atmospheric changes instead of by causes outside the atmosphere as during the eclipse. The departure from the means of the values before and after the eclipse, to the lowest point, is practically the same for both sun and sky. The drop in the solar radiation is 60 per cent and in the sky radiation 58 per cent. (See fig. 3.)

Following are the values obtained of the sky and solar radiation, at the hour angles and the apparent altitudes of the sun indicated.

PARTIAL ECLIPSE OF DECEMBER 3, 1918

1	2	3	4
Hour Angle	Pyranometer Calories Sky Radiation Horizontal Surface	Pyrheliometer Calories Solar Radiation Normal to Beam	Apparent Altitude of Sun
$-3^h\ 51^m$	.0767	.....	37° 0′
3 50	.0767	.....	37 12
3 49	.0781 (?)	.....	37 24
3 48	.0767	.....	37 37
3 47	.0767	.....	37 49
3 42	.....	1.584	39 01
3 41	.....	1.586	39 14
3 21	.0777	.....	43 46
3 20	.0814	.....	44 00
3 19	.0824	.....	44 13
3 18	.0784	.....	44 26
3 17	.0740	.....	44 38
3 08	.....	1.343	46 44
3 07	.....	1.363	46 58

1	2	3	4
Hour Angle	Pyranometer Calories Sky Radiation Horizontal Surface	Pyrheliometer Calories Solar Radiation Normal to Beam	Apparent Altitude of Sun
—2h 58m	.0609	.....	49° 02′
2 57	.0589	.....	49 15
2 56	.0602	.....	49 29
2 55	.0592	.....	49 42
2 54	.0583	.....	49 56
2 40	.....	0.980	53 10
2 39	.....	0.953	53 24
2 30	.0466	.....	55 29
2 29	.0459	.....	55 42
2 28	.0443	.....	55 56
2 27	.0433	.....	56 09
2 26	.0433	.....	56 23
2 09	.....	0.674	60 18
2 08	.....	0.669	60 31
2 01	.0359	.....	62 08
2 00	.0359	.....	62 21
1 59	.0343	.....	62 34
1 58	.0352	.....	62 47
1 57	.0343	.....	63 01
1 49	.....	0.690	64 51
1 48	.....	0.704	65 04
1 43	.0376	.....	66 13
1 42	.0385	.....	66 27
1 41	.0385	.....	66 41
1 40	.0402	.....	66 54
1 39	.0392	.....	67 08
1 38	.0415	.....	67 21
1 37	.0418	.....	67 35
1 20	.....	1.015	71 30
1 19	.....	1.011	71 44
1 01	.0670	.....	75 53
1 00	.0660	.....	76 07
0 59	.0680	.....	76 21
0 58	.0697	.....	76 35
0 57	.0693	.....	76 48
0 56	.0697	.....	77 02
0 31	.....	1.589	82 49
0 30	.....	1.602	83 03
0 23	.0863	.....	84 43
0 22	.0859	.....	84 56
0 21	.0869	.....	85 12
0 05 30s	.0887	.....	88 54
0 04 30	.0881	.....	89 06
0 03 30	.0861 (?)	.....	89 19
+0 04	.....	1.692	89 12
0 05	.....	1.706	89 00

TOTAL SOLAR ECLIPSE OF MAY 29, 1919.