TABLE 2.—*Vapor pressure at pyrheliometric stations on days when solar radiation intensities were measured.*

Washington, D. C.			Madison, Wis.			Lincoln, Nebr.			Santa Fe, N. Mex.		
Date.	8 a.m.	8 p.m.	Date.	8 a.m.	8 p.m.	Date.	8 a.m.	8 p.m.	Date.	8 a.m.	8 p.m.
1916.	*Mm.*	*Mm.*	1916.	*Mm.*	*Mm.*	1916.	*Mm.*	*Mm.*	1916.	*Mm.*	*Mm.*
Feb. 3	2.62	1.88	Feb. 1	0.66	0.74	Feb. 1	0.66	0.91	Feb. 1	0.86	1.02
7	3.81	1.12	2	0.53	0.71	2	0.71	1.37	3	1.52	2.62
14	0.91	1.12	7	0.36	0.51	8	1.96	3.81	8	3.30	2.62
15	0.96	2.49	13	0.86	1.07	13	0.66	1.37	10	2.49	3.15
16	2.16	2.87	27	1.12	1.32	14	1.52	3.45	11	3.00	4.17
19	1.24	1.68	29	1.32	1.32	15	2.16	4.37	14	3.30	1.88
21	2.16	1.45				16	4.37	6.76	16	2.26	2.62
26	3.30	2.49				17	4.75	5.16	18	3.15	3.45
28	1.32	1.45				18	3.45	4.95	19	2.49	2.87
						19	3.99	6.76	23	2.87	3.00
						20	4.37	6.02			
						21	4.17	7.04			
						23	3.15	4.57			
						24	3.99	3.63			
						29	1.68	3.45			

TABLE 3.—*Daily totals and departures of solar and sky radiation at Washington, D. C., during February, 1916.*

[Gram-calories per square centimeter of horizontal surface.]

Date.	Daily totals.	Departure from normal.	Excess or deficiency since first of month.
1916.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
Feb. 1	36	−167	−167
2	21	−185	−352
3	283	74	−278
4	313	100	−178
5	199	− 17	−195
6	233	13	−182
7	242	18	−164
8	231	3	−161
9	38	−194	−355
10	275	38	−317
Feb. 11	210	− 31	−348
12	58	−187	−535
13	34	−215	−750
14	405	152	−598
15	381	124	−474
16	308	48	−426
17	260	− 4	−430
18	210	− 57	−487
19	382	111	−376
20	331	57	−319
Decade departure			− 2
Feb. 21	434	156	−163
22	295	14	−149
23	199	− 86	−235
24	12	−276	−511
25	68	−223	−734
26	321	26	−708
27	273	− 25	−733
28	425	124	−609
29	205	− 99	−708
Decade departure			−389
Deficiency since first of year: Gram-calories			1,129
Deficiency since first of year: Per cent			8.8

Table 3 shows that at Washington the total solar and sky radiation was below the normal during the first and third decades of February. The deficiency for the month is 9.6 per cent of the average February total radiation, and the deficiency since the first of the year is 8.8 per cent of the average amount of radiation received in January and February.

At Washington, therefore, while there was more than the average amount of cloudiness during February, when the sky was clear the solar radiation was of average intensity. At Madison, Lincoln, and Santa Fe it was above its average intensity.

METEOR OBSERVATIONS.

The report of the committee on meteors of the American Astronomical Society, recently published with other reports by the society, points out the importance of the study of meteors and its profound relation to the earth's atmosphere, its gases, and the absorption phenomena that take place in its upper strata. Further great advantages must result from the application of more accurate methods of observation and photographic record. The chairman, Prof. Cleveland Abbe, states that suggestions for the construction of a photographic meteor-graph as devised by himself, have been submitted to the Research Laboratory of the Eastman Kodak Co., Rochester, N. Y.; as also suggestions for a less desirable but simpler form for the general use of those interested in the subject. Having no funds at his disposal, he has urged the Kodak Co. to construct a few copies and put them on the market, so that the world may realize the importance of the work. The report concludes as follows:

"It is not likely that I shall be able to contribute much more to this study, but I hope the Astronomical Society will stimulate some abler member to devote himself to this important branch of Astro-meteorological and physical study."

AREQUIPA PYRHELIOMETRY.[1]

(Summarized for the REVIEW.)

This paper is a summary of observations taken at the station of the Harvard College Observatory at Arequipa, Peru ($\phi = 16° 22' 28.0''$ S.; $\lambda = 4^h 46^m 11.73^s$ W.; alt. 2,451 m.) by its observers, with a Smithsonian silver-disk pyrheliometer lent for the purpose by the Smithsonian Institution. The observations have been reduced at the Astrophysical Observatory of the Smithsonian Institution under the direction of its director, C. G. Abbot. Humidity determinations were made sometimes by means of whirled wet- and dry-bulb thermometers, sometimes by the recording hair-hygrometer.

Monthly mean values are given in the author's Table 2, which is here reprinted, for the following elements:

$e_{1.2}$, intensity of solar radiation at air mass 1.2 (sun's zenith distance, z, 24°, sec. $z = 1.2$).

a_2, the transmission coefficient, computed from measurements of radiation intensity with sun at $z = 60°$ and $z = 0°$.

p, pressure of aqueous vapor.

e_0, empirical solar constant, computed by formulæ I and II given below.

n, number of days on which radiation was observed. The means inclosed by parentheses are based on very meager data.

[1] *Abbot, C. G.* Arequipa pyrheliometry. Washington, 1916. 23p. 2 figs. 8°. (Smithsonian misc. coll., v. 65, no. 9. Publ. 2367.)

TABLE 2.—*Monthly mean values for Arequipa, Peru.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1912.												
Radiation, $e_{1.2}$	......	......	......	......	......	......	......	1.487	1.487	1.558	1.547	1.520
Transmission, a_2	......	......	......	......	......	......	......	0.847	(0.821)	0.869	......	(0.848)
Vapor pressure, p	......	......	......	......	......	......	......	......	......	......	3.00	7.28
*Solar constant, e_0 I	......	......	......	......	......	......	......	(1.93)	(1.91)	(1.98)	(1.97)	1.94
*Solar constant, e_0 II	......	......	......	......	......	......	......	......	......	......	......	1.97
Number days, n	......	......	......	......	......	......	......	13	25	21	7	8
1913.												
Radiation, $e_{1.2}$	1.469	(1.464)	(1.321)	1.412	1.478	1.501	1.470	1.457	1.478	1.425	1.503	1.518
Transmission, a_2	(0.821)	......	(0.845)	0.851	0.878	0.879	0.875	0.856	0.848	0.826	(0.843)	0.831
Vapor pressure, p	8.95	(9.65)	(8.00)	6.89	4.29	3.71	3.07	4.56	4.87	6.00	6.70	7.24
*Solar constant, e_0 I	1.91	......	......	1.86	1.92	1.94	1.87	1.88	1.90	1.86	1.92	1.93
*Solar constant, e_0 II	1.91	......	......	1.89	1.92	1.93	1.89	1.89	1.92	1.89	1.95	1.95
Number days, n	5	1	1	6	12	15	17	19	18	13	12	15
1914.												
Radiation, $e_{1.2}$	1.495	1.463	1.470	1.485	1.451	1.496	1.514	1.516	1.521	1.542	1.529	1.544
Transmission, a_2	0.838	(0.861)	0.886	0.886	(0.882)	0.902	0.855	0.889	0.862	0.842	0.843	......
Vapor pressure, p	7.35	9.61	8.35	6.49	7.00	4.50	3.83	4.16	4.65	4.58	4.83	5.89
*Solar constant, e_0 I	1.91	1.91	1.93	1.95	1.94	1.96	1.95	1.96	1.94	1.95	1.92	1.94
*Solar constant, e_0 II	1.92	1.92	1.91	1.92	(1.90)	1.91	1.98	1.94	1.94	1.96	1.91	1.93
Number days, n	11	11	15	14	6	11	22	18	13	19	7	8
1915.												
Radiation, $e_{1.2}$	1.523	1.478	1.493	......	......	......	......	......	......	......	......	......
Transmission, a_2	......	(0.917)	0.881	......	......	......	......	......	......	......	......	......
Vapor pressure, p	5.19	8.50	7.93	......	......	......	......	......	......	......	......	......
*Solar constant, e_0 I	(1.90)	(1.92)	1.97	......	......	......	......	......	......	......	......	......
*Solar constant, e_0 II	......	(1.85)	1.96	......	......	......	......	......	......	......	......	......
Number days, n	3	4	7	......	......	......	......	......	......	......	......	......
Weighted mean, $e_{1.2}$	1.493	1.467	1.475	1.463	1.469	1.499	1.495	1.486	1.492	1.512	1.522	1.526
Values, a_2	0.832	(0.880)	0.878	0.870	0.880	0.885	0.865	0.865	0.850	0.845	0.843	0.835
All years, p	7.42	9.58	8.28	6.60	5.20	4.05	3.48	4.36	4.77	5.15	6.00	6.80
Total days, n	19	16	23	20	18	26	39	50	56	53	26	28
Weighted mean value for mean solar distance, $e_{1.2}$	1.448	1.434	1.462	1.474	1.502	1.547	1.543	1.521	1.511	1.500	1.488	1.480

* Computed by formulæ I and II as given below.

From the study of this table Mr. Abbot concludes that there is no indication that the years August, 1912, to March, 1915, inclusive, were other than normal years for Arequipa (unless as to the number of clear days, which is not discussed); a particularly interesting conclusion since the Mount Katmai eruption in June, 1912, inaugurated great decreases in direct solar radiation received at the earth's surface over the Northern Hemisphere, whose effects could still be there traced near the end of 1913. "The volcanic dust from Katmai, though general in the Northern Hemisphere, seems not to have crossed the equator."

The close connection at Arequipa between solar radiation at the earth's surface and atmospheric humidity, is brought out by a remarkably smooth curve defined by $e_{1.2}$ (reduced to mean solar distance) and p. Apparently the degree of atmospheric humidity at the earth's surface is a good index of the total quantity of humidity existing between this high-level station and the limit of the atmosphere. He says:

It is obvious, of course, that fluctuations of atmospheric transmission coefficients must also produce their effect on the observed intensity of observed solar radiation at the station. Such fluctuations are of two kinds: (1) Those associated with changes of water vapor; (2) those associated with changes of dustiness, such as those produced in the Northern Hemisphere by the Katmai eruption. The influence on the solar radiation of fluctuations of the first type, which are a function of the humidity, may be generally (for a high-level station like Arequipa) much greater than those associated with dust alone. But it might well be expected that for certain months of the year the dust fluctuations would be by no means negligible. However, restricting our thought to a high-level station like Arequipa, and remembering the powerful true absorption produced in the infra-red spectrum by water vapor and the large changes in this true absorption attending changes in humidity when the humidity and the air mass are both small, it is easy to see after all why the observed radiation at M=1.2 at Arequipa seems to be so well represented as a function of water vapor alone. For both the true absorption and a large proportion of the variable elements of the general scattering are functions of water vapor. Compared to these, the variable scattering produced by dry dust alone is generally small.

The relation between these factors at Arequipa are then brought out in two laws, one of which (I) expresses the radiation $e_{1.2}$ (reduced to mean solar distance) as a function of the vapor pressure, p, only, the other (II) as a function of vapor pressure, p, and the transmission a_2.

I. $e_{1.2}^{corr.}$ ($e_{1.2}$ reduced to mean solar distance)

$$=0.981+\frac{0.75}{p^{0.222}}, \qquad (1)$$

$$\text{II. } e_{1.2}^{corr.}=1.50+(5.25-p)0.19+(a_2-0.85)0.63. \qquad (2)$$

Dividing I and II by 1.93, the mean of his previous determinations for the solar constant, he derives two other laws for computing the solar constant e_0, as follows:

$$\text{I. } e_0=\frac{e_{1.2}^{corr.}}{0.508+\frac{0.389}{p^{0.222}}}, \qquad (3)$$

$$\text{II. } e_0=\frac{e_{1.2}^{corr.}}{0.777+(5.25-p)0.01+(a_2-0.85)0.33}. \qquad (4)$$

The monthly mean values of e_0 at Arequipa computed from formulæ I and II for e_0, together with the monthly means of spectrobolometric determinations made at Mount Wilson, Cal., for the years 1913 and 1914 are given below in the author's Table 3.

TABLE 3.—*Mean monthly solar constant values.*

Month.	1913					1914				
	July.	Aug.	Sept.	Oct.	Nov.	June.	July.	Aug.	Sept.	Oct.
	Gr.-cal.	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*	*Gr.-cal.*
Arequipa, I	1.87	1.89	1.90	1.86	1.92	1.96	1.95	1.96	1.94	......
Arequipa, II	1.89	1.89	1.92	1.89	......	1.91	1.98	1.94	1.94	......
Number of days	17	18	18	11	12	11	22	18	13	......
Mount Wilson	1.925	1.931	1.920	1.874	1.876	1.952	1.956	1.964	1.943	......
Number of days	3	18	25	24	5	14	14	22	18	......

Disregarding the months of lesser weight, indicated by the small number of days, it appears that these two widely separated stations agree in showing that the solar constant was decidedly higher in 1914 than in 1913.

Finally, the 29 days with solar-constant values available for favorable comparison between Arequipa and Mount Wilson have been grouped into high values and low values, as indicated by Mount Wilson work and the resulting mean solar constants (with their differences) are shown in Table 4.

TABLE 4.

Station.	Group A.	Number days.	Group B.	Number days.	A–B.
	Gr.-cal.		*Gr.-cal.*		*Gr.-cal.*
Mount Wilson	1.954	15	1.893	14	0.061
Arequipa, formula (3)	1.936	15	1.900	14	.036
Arequipa, formula (4)	1.943	13	1.907	14	.036

This tends to confirm the previously discovered short-period irregular solar variations.

The author sums up his results as follows:

Observations with the silver-disk pyrheliometer and nearly simultaneous measurements of atmospheric humidity have been made since August, 1912, at Arequipa, Peru, at the station of the Harvard College Observatory.

From these observations have been determined values of the solar radiation at Arequipa corresponding to sec. z=1.0, 1.2, and 2.0; values of pressure of aqueous vapor, and values of the diminution of radiation attending the passage of the sun from the zenith distance whose secant is 1.0 to that whose secant is 2.0.

Owing to other occupations the observers have generally made these observations when the sun was within 60° of the zenith. On this account determinations of atmospheric transparency are not always possible, and are of less weight than other data given.

The results are collected to give monthly mean values. These show a remarkably close connection between radiation and vapor pressure. Advantage is taken of this close correlation to determine by empirical formulæ values of the solar constant of radiation. These empirical values agree quite as well as could be expected with values obtained at Mount Wilson, Cal., by complete spectrobolometric and pyrheliometric measurements combined. The Arequipa results confirm the variability of the sun, both from year to year and from day to day, shown by investigations at Mount Wilson and elsewhere.

It seems probable that from observations similar to those at Arequipa, if conducted at 8 or 10 favorable stations of high level in various parts of the world, the variations of the sun could be determined almost or quite as certainly as from two stations equipped for complete spectrobolometric determinations of the solar constant.

The Arequipa results indicate that the volcanic dust which was general in the atmosphere in the Northern Hemisphere for more than a year after the volcanic eruption of Mount Katmai, Alaska, in June, 1912, did not influence the transparency of the atmosphere in Peru.

HORIZONTAL RAINBOWS ON LAKE MENDOTA.

By CHANCEY JUDAY.

[Laboratory of the Wisconsin Geological and Natural History Survey, Madison, Wis. Feb. 26, 1916.]

During the past decade horizontal rainbows or color spectra have been observed a number of times on the surface of Lake Mendota at Madison, Wis. These spectral phenomena have not appeared every year during this period of time, but they have been noted during at least 5 of the past 10 years and on more than one date in each of the 5 years. With one exception, namely, May 24, 1915, they have been confined to the autumn of the year. They have varied in extent from mere bright spots, in which the spectral colors were scarcely discernible, to brilliant bows which have attracted considerable attention.

Previous observations.

Such phenomena have been observed on various bodies of water in Europe, and the fact that they appear most frequently in autumn has led the Swiss and German writers to designate them as "Herbstiris." Apparently the first record of such a phenomenon is that cited by Forel,[1] who states that Wartmann observed two displays of iris on the surface of Lake Geneva, Switzerland. One was noted on November 2, 1868, and the other on February 11, 1872. Similar phenomena were noted on Lake Geneva by two other observers, one on July 5, 1871, and the other on December 28, 1876. Wartmann attributed the spectra which he saw to the existence at the surface of the water of a considerable quantity of powdery material. These small particles produced a series of depressions in the surface film which acted like a prism in dispersing the rays of light. Forel himself expresses the opinion that these spectra were produced by thin layers of oil on the surface of the water.

J. C. Maxwell[2] described a horizontal rainbow that was seen at about noon on January 26, 1870, on the frozen surface of the ditch surrounding St. John's College at Cambridge, England. He attributed the spectral display to drops of water on the surface of the ice. The angle between the bright red of the bow and the sun's ray was 41° 50′ while that of the blue was 40° 30′.

Hewitt[3] states that a horizontal rainbow was seen on Lake Windermere, England, by Kay in November, 1885. On November 6, 1903, Hewitt observed two spectra, one of which was fainter than the other, on one of the ponds in Vernon Park at Stockport, England. These rainbow colors were visible for more than four hours and were produced by droplets of water which a fog deposited upon a film of carbonaceous dust resting upon the surface of the pond.

Hann[4] observed a rainbow on Lake Constance on September 25, 1903, during a foggy morning. In describing the phenomenon he states that "es waren die Fusspunkte eines Regenbogens, der aber nur in dem Nebeldunste über dem See seinen Ursprung haben konnte."

On April 11, 1906, Church[5] saw a horizontal bow on Loch Lomond, Scotland. It was a perfectly still, cloudless day, and the phenomenon was attributed to a film of fog left undisturbed on the calm surface of the water.

Schaffers[6] has described a horizontal rainbow which he saw on a small pond in the vicinity of Louvain, Belgium. He attributed it to droplets of water about a tenth of a millimeter in diameter which rested upon a scum composed of minute animals and plants. This bow had the form of an arc of an ellipse. The angular distance of the primary bow was 40° to 42° and, rarely, a secondary bow appeared at an angle of 53°.

Schroeter[7] has described a rainbow which he saw on the surface of Lake Zurich. According to him it was produced by droplets of water deposited by mist or fog upon an oily scum that covered the surface of the lake. Wyss[8] has also observed this phenomenon on Lake Zurich a number of times, and he has attributed it to the presence at the surface of the lake of very large numbers of the small crustacean *Daphnia longispina*. These daphnids come to the surface in great numbers in the

[1] Le Léman. II, p. 505, 1895.
[2] Proc. Roy. Soc. Edinb., 1869–72, 7:69; Sci. papers, v. 2, p. 160.
[3] Nature (London), 1903, 69:57.
[4] Meteorolog. Ztschr., Wien, 1903, 20:520.
[5] Nature (London), 1906, 73:608.
[6] Nature (London), 1906, 74:125.
[7] Internat. Rev. d. ges. Hydrob. & Hydrog., 1908, 1:747.
[8] Revue Suisse de Zoöl., 1909, 17:441.