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SMITHSONIAN PYRHELIOMETRY AND THE STANDARD SCALE OF SOLAR RADIATION

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Since its beginning in 1890, the Astrophysical Observatory of the Smithsonian Institution has devoted much time to the development and improvement of pyrheliometers for the accurate measurement of total solar radiation. Numerous types have been investigated, and many thousands of individual measurements and intercomparisons of various pyrheliometers have been made. The two that have been most useful and satisfactory for our purposes are the water-flow pyrheliometer, a standard instrument, and the silver-disk pyrheliometer, a secondary instrument.

During the past 40 years, Andrew Kramer, veteran instrument maker of the Astrophysical Observatory, has constructed in our shop nearly 100 silver-disk pyrheliometers. Most of these instruments as completed have been sold or loaned to interested institutions and are now in use on every continent. The silver-disk instrument was devised and designed by Dr. Abbot. It is mechanically simple and rugged and with reasonable care it continues indefinitely to give reliable readings of solar radiation. Our faith in the permanence of the constant furnished with each instrument has been supported by many intercomparisons extending over long periods of time.[1] Since it is not practicable to use the silver-disk pyrheliometer as a standard instrument, the constant of each one is determined by careful comparisons against a standard pyrheliometer. One of our silver-disk instruments, A.P.O. No. 8_{bis} has been kept at the Observatory as a substandard since it was built 40 years ago, and a second one, S.I. No. 5_{bis} has been similarly used in recent years.

In the years 1910 to 1913, the Observatory conducted an intensive campaign to produce a standard pyrheliometer, and to establish the correct standard scale of solar radiation. The water-flow and water-stir standard pyrheliometers, both devised by Dr. Abbot, were selected

[1] See detailed tabulations of these comparisons in volumes 3 to 6 of the Annals of the Astrophysical Observatory.

for this work and many comparisons were made against various silver-disk instruments.[2] This campaign established a standard scale of radiation which we called the "Smithsonian revised pyrheliometry of 1913." The constants of all silver-disk pyrheliometers have been based on this scale. In the years 1915, 1916, and 1920 further comparisons were made against standard water-flow No. 3 on Mount Wilson, Calif., these results confirming the adopted scale of 1913.[3]

In 1932 a marked improvement was made in the standard water-flow pyrheliometer. This was suggested by V. M. Shulgin [4] and consisted in the substitution of two identical absorbing chambers instead of one. The advantages of this change and others of a minor nature are discussed in our paper "An Improved Water-flow Pyrheliometer and the Standard Scale of Solar Radiation" (Smithsonian Misc. Coll., vol. 87, No. 15, 1932). The new pyrheliometer proved free from the worst difficulty we had experienced with the earlier instrument, namely, irregular drift of the galvanometer zero. The results now obtained were more concordant and more satisfactory than ever before. Thirty-seven comparisons between the new water-flow No. 5 and our silver-disk pyrheliometer S.I. No. 5_{bis} showed the scale of our revised pyrheliometry of 1913 to be too high by 2.5 percent. In 1934 we repeated this work on Mount Wilson.[5] Forty-two comparisons showed the 1913 scale to be 2.3 percent too high.

Since 1934, 13 years have elapsed with no further comparisons against a water-flow standard. In August 1947 opportunity came to make further comparisons at Mount Wilson. In preparation for this, standard water-flow pyrheliometer No. 5 was altered as follows: New thermoelements of copper-constantan were substituted for the former nickel-platinum junctions. These and also the special glass housings for the thermoelements were made by L. B. Clark of this Institution in such form that the whole assembly could be waxed in place without the use of rubber tubing. On arrival at Mount Wilson, however, it was found that seams had opened up in the wax, owing probably to changes in temperature and jolting in transit from Washington. After considerable difficulty the wax was remelted and the whole made watertight.

All the precautions which we took in 1932 and 1934 to insure greater accuracy were again taken in the present comparisons. In addition, the following steps were taken:

[2] Ann. Astrophys. Obs., vol. 3, pp. 52-72, 1913.
[3] Ann. Astrophys. Obs., vol. 4, pp. 92-97, 1922.
[4] Monthly Weather Rev., August 1927, p. 361.
[5] Smithsonian Misc. Coll., vol. 92, No. 13, 1934.

1. An eyepiece of improved design was used to read the silver-disk pyrheliometer.

2. The rate of the seconds pendulum was carefully adjusted to indicate exact 1-second intervals.

3. A high-sensitivity D'Arsonval galvanometer was used. The total deflection for uncompensated solar heating was 44 cm. as compared with 10 cm. in the previous work.

4. All current measurements were made with a direct-reading potentiometer, using a 3-ohm standard resistance and a certified standard cell. Currents with this arrangement were read to 1 part in 5,000.

Comparisons were made on 2 days, August 26 and 27. Excellent skies prevailed on both days. In all the comparisons, C. G. Abbot read the silver-disk pyrheliometer and operated the shutter of the standard pyrheliometer. L. B. Aldrich made the galvanometer and current measurements.

Two silver-disk instruments, S.I. No. 5_{bis} and S.I. No. 79 were used. They had been carried by hand, one by each of the authors, from Washington, D. C., to Mount Wilson. The adopted constant of S.I. No. 5_{bis} (Smithsonian scale of 1913), as stated in our previous papers, is .3715. That of S.I. No. 79, as determined from 32 comparisons against substandard A.P.O. No. 8_{bis} in November and December, 1946, is .3736.

The results of our comparisons are summarized in table 1. With S.I. No. 5_{bis}, the mean of 18 comparisons against standard No. 5 gives .3626 as the constant of S.I. No. 5_{bis}. Thus the ratio of Smithsonian revised scale of 1913 to the scale of standard No. 5 is $\frac{.3715}{.3626}=1.0245$. The mean of 15 comparisons between S.I. No. 79 and Standard No. 5 gives .3650 as the constant of S.I. No. 79, and the ratio of the scale of 1913 to that of Standard No. 5 is $\frac{.3736}{.3650}=1.0235$. It is interesting to note that the average deviation of individual comparisons is only one-half of one percent, and the probable error of the means one-tenth of one percent.

The mean ratio for all 33 comparisons is 1.0240.

In 1932, 37 comparisons gave a mean ratio of 1.0248. In 1934, 42 values gave 1.0237. Thus the 1932, 1934, and 1947 means agree within 1 part in 1,000. We conclude that the scale of Smithsonian revised pyrheliometry of 1913 is very nearly 2.4 percent too high. Our silver-disk instruments have remained unchanged.

TABLE 1.—*Summary of 1947 comparisons*

Date 1947	Time		Calories by water-flow No. 5	Corrected reading of silver-disk S.I. No. 5b1s	Constant of silver-disk S.I. No. 5b1s	Deviation from mean
Aug. 26	10h	56m	1.510	4.154	.3635	+ 11
	11	03	1.502	4.158	.3612	− 14
		14	1.512	4.178	.3619	− 7
		22	1.509	4.170	.3619	− 7
		29	1.496	4.155	.3600	− 26
		36	1.497	4.149	.3608	− 18
Aug. 27	10	10	1.520	4.228	.3595	− 31
		17	1.519	4.135	.3674	+ 48
		24	1.531	4.249	.3603	− 23
		31	1.518	4.193	.3620	− 6
		42	1.528	4.204	.3635	+ 9
		49	1.525	4.193	.3637	+ 11
		56	1.523	4.186	.3638	+ 12
	11	04	1.527	4.212	.3625	− 1
		12	1.563	4.267	.3663	+ 37
		19	1.556	4.276	.3639	+ 13
		26	1.538	4.268	.3604	− 22
		33	1.538	4.217	.3647	+ 21

Mean, 18 values = .3626

Date 1947	Time		Calories by water-flow No. 5	Corrected reading of S.I. No. 79	Constant of S.I. No. 79	Deviation from mean
Aug. 26	7h	50m	1.373	3.730	.3681	+ 31
		57	1.379	3.754	.3673	+ 23
	8	04	1.393	3.794	.3672	+ 22
	9	37	1.472	4.051	.3634	− 16
		44	1.488	4.044	.3680	+ 30
Aug. 27	7	40	1.380	3.812	.3620	− 30
		47	1.394	3.867	.3605	− 45
		55	1.415	3.852	.3673	+ 23
	8	06	1.428	3.925	.3638	− 12
		13	1.441	3.898	.3697	+ 47
		58	1.470	4.004	.3671	+ 21
	9	05	1.438	3.992	.3602	− 48
		12	1.449	4.011	.3612	− 38
		25	1.451	3.998	.3629	− 21
		33	1.477	4.028	.3667	+ 17

Mean, 15 values = .3650

Average deviation, 33 values, .0022.

Probable error, .0003, or .08 percent.