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SILVER-DISK PYRHELIOMETRY

(With 1 Plate)

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In June and July 1932, Dr. C. G. Abbot and L. B. Aldrich compared silver-disk pyrheliometer S.I. 5_{bis} with an improved form of the water-flow pyrheliometer.[1]

The mean of 37 comparisons indicated the constant of S.I. 5_{bis} should be 0.3625. The original constant of S.I. 5_{bis} (0.3715) was determined by Dr. Abbot and W. H. Hoover in August 1931 by 24 comparisons with A.P.O. 8_{bis}. Eight more comparisons in September 1932 by Aldrich and Hoover indicated the constant of S.I. 5_{bis} should be 0.3718. Silver-disk pyrheliometer A.P.O. 8_{bis} has been used since 1912 solely for standardization at Washington. Thus the scale of the Smithsonian revised scale of 1913 is too high by the ratio 0.3718 to 0.3625, or 1.0256—about 2.5 percent.

The results of 42 more comparisons in July 1934 by the same observers were in close agreement with the results of 1932. The mean value of the constant of S.I. 5_{bis} in 1932 was 0.3625, and 0.3629 in 1934.[2]

No comparisons were made between 1934 and 1947. In August 1947, 18 comparisons gave 0.3626 as the constant of S.I. 5_{bis}.[3] The results of the comparisons between silver-disk pyrheliometer S.I. 5_{bis} and the standard water-flow pyrheliometer No. 5 in 1932, 1934, and 1947 are based on Dr. Abbot's habit of reading the silver-disk pyrheliometer. L. B. Aldrich made a few observations with S.I. 5_{bis} in 1932.

Since there is a small personal equation in reading the silver-disk pyrheliometer more comparisons were made in 1952 between S.I. 5_{bis} and the standard water-flow instrument No. 5. The results of

[1] Smithsonian Misc. Coll., vol. 87, No. 15, 1932.

[2] Smithsonian Misc. Coll., vol. 92, No. 13, 1934.

[3] Smithsonian Misc. Coll., vol. 110, No. 5, 1948.

1952 are based on A. G. Froiland's habit of reading the silver-disk pyrheliometer. In order to insure comparable results with the water-flow pyrheliometer no changes were made in the instrument.

Figure 1, A, B, and C, shows the instrument in some detail. The two chambers *a b c* and *a′ b′ c′* are almost exactly the same in all details. The distilled water enters at *d* and divides into two streams at

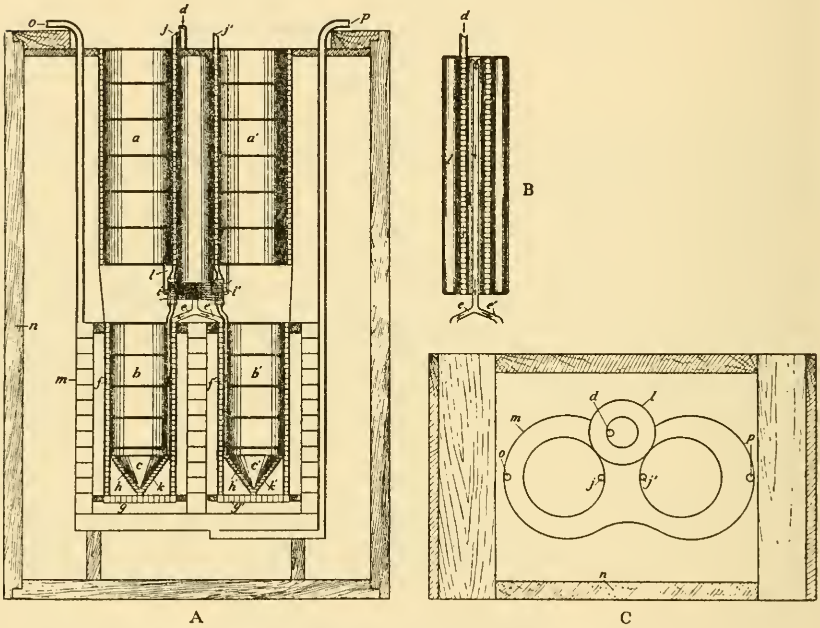

FIG. 1.—Standard water-flow pyrheliometer.

e and *e′*. The water flows around the receiver at *d* and *d′* and out of the instrument at *j* and *j′*. *i* and *i′* are the thermoelectric junctions used to determine the equality of temperature of the water streams outflowing from the two chambers. *m* is the water bath for the two receivers, water entering at *p* and being discharged at *o*. *n* is a wooden case surrounding the instrument. The heating coils are indicated by *k* and *k′*. Not shown is a shutter for alternating the chambers exposed to solar and electric heating. A detailed description of one of the receivers is given in volume 3 of the Annals of the Astrophysical Observatory.

In order to keep the water bath surrounding the two receivers and the distilled water entering the instrument at the same temperature, we used a 50-gallon drum of water as a source of water for the water bath. A circulating pump continually stirred the water in the drum and a bypass on the pump circulated some of the water through the water bath. The distilled water flowed through a coil in the drum before entering the instrument. Thus the bath water and the distilled water were always at the same temperature when leaving the drum.

All the precautions that were taken in 1932, 1934, and 1937 to insure greater accuracy were again taken in the present comparisons. In addition, we found it very important to have the rate of flow of water in the two receivers as near the same as possible. The water entering the receivers may not be at exactly the same temperature as the water bath around the receivers, thus any change in the temperature difference would produce a drift of the galvanometer.

In order to get the flow of water the same in the two circuits, we exposed both receivers to solar radiation and adjusted the flow of water until the galvanometer remained at the open circuit zero. Thus the two streams of water were at the same temperature and since they were both receiving the same amount of heat the rate of flow should be the same.

Water currents of approximately 50 cubic centimeters per minute in each branch of the pyrheliometer were found to give good results, but rates as low as 35 and as high as 65 cubic centimeters per minute were used without affecting the results. Temperature of the water bath varied from 23° to 28° C. on different days.

Table 1 gives the results of the comparisons. The mean of 100 observations gives 0.3622 as the constant of S.I. 5_{bis}. The average deviation from the mean is 0.27 percent and the maximum deviation from the mean about 0.9 percent. The above value is about .13 percent lower than the mean of the previous values.

Table 1.—*Summary of 1952 comparisons*

Date 1952	Time	Calories by water-flow No. 5	Corrected reading of silver-disk S.I. No. 5_{bis}	Constant of silver-disk S.I. No. 5_{bis}	Deviation from mean
Sept. 28	8:38	1.368	3.775	.3624	+ 2
	44	1.376	3.790	.3630	+ 8
	50	1.380	3.796	.3636	+ 14
	56	1.388	3.847	.3609	— 13
	9:05	1.400	3.877	.3611	— 11
	11	1.411	3.889	.3627	+ 5
	17	1.413	3.895	.3628	+ 6
	23	1.412	3.906	.3616	— 6
	29	1.418	3.931	.3608	— 14
	35	1.428	3.951	.3614	— 8

(*continued*)

TABLE 1.—*Summary of 1952 comparisons* (continued)

Date 1952	Time	Calories by water-flow No. 5	Corrected reading of silver-disk S.I. No. 5_{bis}	Constant of silver-disk S.I. No. 5_{bis}	Deviation from mean
Sept. 29	9:22	1.405	3.861	.3638	+16
	28	1.410	3.879	.3638	+16
	34	1.407	3.894	.3613	− 9
	40	1.408	3.899	.3612	−10
	46	1.415	3.918	.3611	−11
	52	1.419	3.937	.3604	−18
	58	1.425	3.947	.3609	−13
	10:04	1.434	3.944	.3635	+13
	10	1.445	3.975	.3635	+13
	11:14	1.447	3.986	.3630	+ 8
	20	1.454	4.018	.3620	− 2
	26	1.462	4.015	.3641	+19
	32	1.461	4.011	.3642	+20
	38	1.458	4.022	.3624	+ 2
	44	1.466	4.027	.3640	+18
	50	1.454	3.996	.3639	+17
	56	1.464	4.025	.3637	+15
	12:02	1.454	4.005	.3629	+ 7
	08	1.464	4.013	.3649	+27
	14	1.457	4.004	.3639	+17
Sept. 30	9:44	1.423	3.922	.3628	+ 6
	50	1.421	3.930	.3617	− 5
	56	1.430	3.961	.3610	−12
	10:02	1.431	3.949	.3624	+ 2
	08	1.426	3.945	.3613	− 9
	14	1.430	3.959	.3611	−11
	20	1.433	3.990	.3591	−31
	26	1.446	3.988	.3626	+ 4
	32	1.438	3.998	.3596	−28
	38	1.454	4.013	.3623	+ 1
Oct. 1	11:11	1.446	3.990	.3625	+ 3
	17	1.453	4.027	.3607	−15
	23	1.458	4.029	.3620	− 2
	29	1.458	4.020	.3628	+ 6
	35	1.458	4.029	.3619	− 3
	41	1.457	4.008	.3635	+13
	47	1.454	4.018	.3617	− 5
	53	1.469	4.058	.3621	− 1
	59	1.472	4.058	.3627	+ 5
	12:05	1.472	4.067	.3621	− 1
	13	1.463	4.054	.3610	−12
	19	1.458	4.023	.3623	+ 1
	25	1.461	4.048	.3609	−13
	31	1.465	4.037	.3628	+ 6
	37	1.447	3.994	.3623	+ 1
	43	1.451	4.007	.3621	− 1

(*continued*)

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TABLE I.—*Summary of 1952 comparisons* (concluded)

Date 1952	Time	Calories by water-flow No. 5	Corrected reading of silver-disk S.I. No. 5_{bis}	Constant of silver-disk S.I. No. 5_{bis}	Deviation from mean
	49	1.445	3.980	.3631	+ 9
	55	1.427	3.947	.3616	− 6
	1:01	1.418	3.878	.3657	+ 35
	07	1.427	3.918	.3642	+ 20
Oct. 9	8:17	1.447	3.971	.3644	+ 22
	23	1.450	3.995	.3630	+ 8
	29	1.463	4.050	.3613	− 9
	35	1.465	4.053	.3614	− 8
	41	1.478	4.065	.3635	+ 13
	47	1.479	4.087	.3619	− 3
	53	1.494	4.123	.3623	+ 1
	59	1.492	4.119	.3623	+ 1
	9:05	1.496	4.150	.3604	− 18
	11	1.506	4.166	.3616	− 6
	39	1.516	4.196	.3612	− 10
	45	1.526	4.235	.3604	− 18
	51	1.530	4.242	.3607	− 15
	57	1.534	4.245	.3615	− 7
	10:03	1.543	4.265	.3617	− 5
	09	1.550	4.276	.3625	+ 3
	15	1.548	4.276	.3620	− 2
	21	1.549	4.276	.3623	+ 1
	27	1.551	4.291	.3614	− 8
	33	1.548	4.291	.3607	− 15
	11:03	1.554	4.290	.3623	+ 1
	09	1.557	4.305	.3616	− 6
	15	1.558	4.311	.3613	− 9
	21	1.558	4.311	.3614	− 8
	27	1.558	4.311	.3613	− 9
	33	1.548	4.291	.3607	− 15
	39	1.553	4.297	.3614	− 8
	45	1.546	4.277	.3615	− 7
	51	1.546	4.296	.3599	− 23
	12:04	1.540	4.241	.3632	+ 10
Oct. 11	9:48	1.530	4.224	.3622	0
	54	1.535	4.226	.3632	+ 10
	10:00	1.537	4.218	.3645	+ 23
	06	1.541	4.240	.3635	+ 13
	12	1.545	4.250	.3636	+ 14
	18	1.549	4.276	.3623	+ 1
	24	1.548	4.276	.3619	− 3
	30	1.539	4.241	.3630	+ 8
	36	1.540	4.251	.3622	0
	42	1.543	4.261	.3621	− 1

Mean of 100 observations (6 days) 0.3622
Average deviation 0.00097

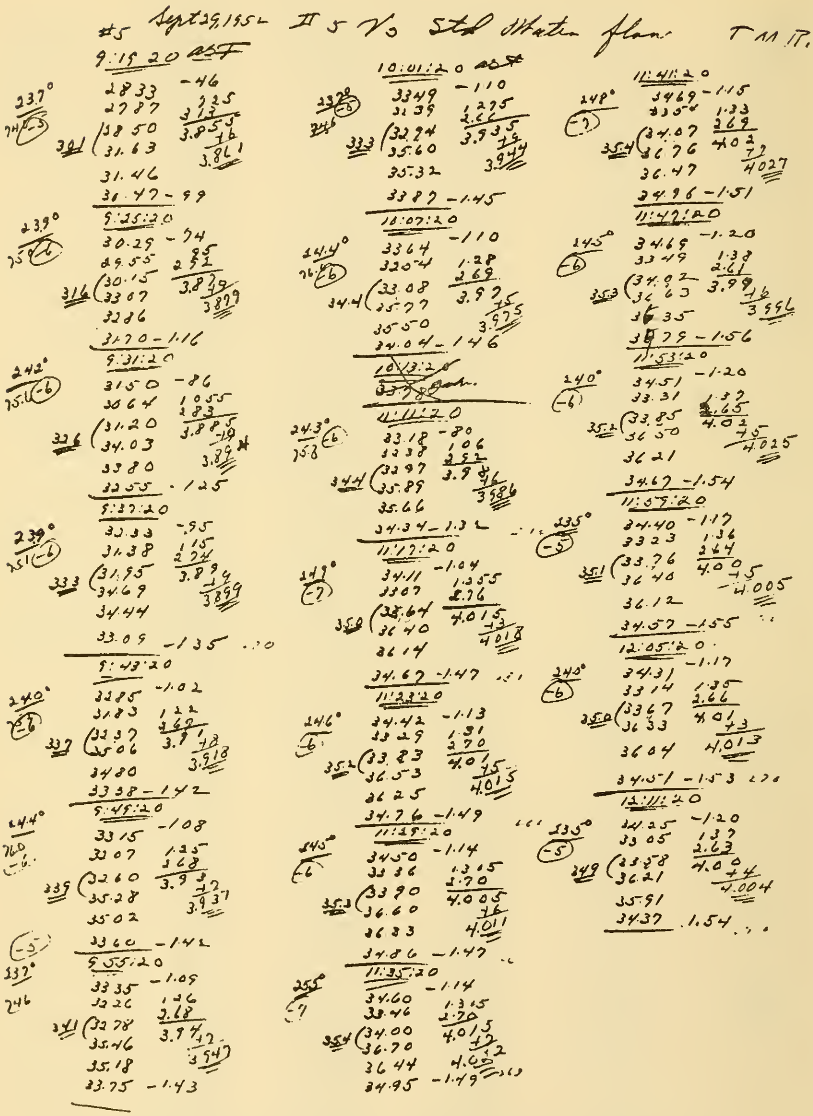

FIG. 2.—Photographic copy of Froiland's original reading of the silver-disk pyrheliometer.

STANDARD WATER-FLOW PYRHELIOMETER AS MOUNTED AT TABLE MOUNTAIN, CALIF.

Figure 2 is a photographic copy of A. G. Froiland's original readings of the silver-disk pyrheliometer S.I. 5_{bis} on September 29, 1952.

A summary of all the comparisons between S.I. 5_{bis} and standard water-flow No. 5 is given below:

No. of values	Date	Mean constant S.I. 5_{bis}
37	1932	.3625
42	1934	.3629
18	1947	.3626
100	1952	.3622

The variations in the above results are probably within the limit of error of the observations; thus we may assume the constant of S.I. 5_{bis} has remained constant since 1932.

The constant of S.I. 5_{bis}, as detemined by 32 comparisons with the standard silver-disk pyrheliometer A.P.O. 8_{bis} in 1931 and 1932, was 0.3718. The mean of 64 comparisons with A.P.O. 8_{bis} just before S.I. 5_{bis} was carried to Table Mountain, Calif., and 64 comparisons just after its return to Washington gave exactly the same constant. The mean of all good comparisons between S.I. 5_{bis} and A.P.O. 8_{bis} from 1931 to 1953 gives 0.3719 as the constant of S.I. 5_{bis}. This would indicate that A.P.O. 8_{bis} has remained unchanged since 1932.

The mean of all the above results would indicate that the scale of Smithsonian revised pyrheliometry of 1913 is very nearly 2.5 percent too high.

SOME EXPERIMENTS WITH THE SILVER-DISK PYRHELIOMETER

In the following series of experiments with the silver-disk pyrheliometer the source of radiation was a 100-watt microscope lamp. An enlarged image of the filament was focused on the silver disk by means of a lens and the voltage on the lamp maintained constant with a voltage regulator. Silver-disk pyrheliometer S.I. 5_{bis} was used in most of the tests.

A DETERMINATION OF THE CONSTANT K

A correction is added to the reading of the silver-disk pyrheliometer which depends upon the mean bulb temperature while exposed to radiation. The correction is $[K(T\text{-}30°)]\ R$ where T is the mean bulb temperature, R the rise in temperature in 100 seconds plus the cooling corrections, and K is a constant. The value of K in use is 0.0011. This value was determined experimentally, using two silver-disk pyrheliometers.[4] The present determination was made with one pyrheliometer.

In this experiment and all the following experiments the lamp was turned on about an hour before making a series of readings. The lamp was very constant during a day's observations and changed very little from day to day.

In one set of observations the following results were obtained: The mean of 18 observations at a mean bulb temperature of 34.°21 was 3.388, and a mean of 12 observations at a mean bulb temperature of 21.66 was 3.435. The above readings represent the rise in temperature of the silver disk with all corrections applied with the exception of the one depending on the mean bulb temperature. If this correction is applied, the two values should be the same. Thus $3.388 + [4.21\ K\ (3.388)] \equiv 3.435 + [-8.34\ K\ (3.435)]$, or K is equal to 0.001095. Other determinations of K with various temperature differences gave results of K between 0.00104 and 0.00118, with a mean value approximately 0.0011. One set of observations made with pyrheliometer S.I. 89 gave 0.00109. Some of the determinations of K were made with the pyrheliometer in a water-cooled chamber with a hole in one end to admit the radiation and a slot along one side to read the thermometer. Also an automatic shutter opening and closing device was used for some of the work. In any set of observations individual values were within ±0.3 percent of the mean.

SERIES OF OBSERVATIONS IN WHICH THE COOLING CORRECTION DURING THE FIRST 100 SECONDS IS ZERO OR NEAR ZERO

In making a series of readings it has been our practice to start readings 20 seconds after completing an observation. Thus a 4-minute shaded period occurs between each 2 minutes of exposure. Each value is independent and the total rise in temperature of the silver disk is much less than the rise in temperature of the silver disk with only a 2-minute shaded period between each 2-minute exposure.

In the following experiment sets of six readings each were taken and for each set the cooling correction for the first 100 seconds of the first reading was zero or near zero. Sets of readings were made at different temperatures and some were made with the automatic shutter opening and closing device. After the fifth reading the mean

[4] Smithsonian Misc. Coll., vol. 95, No. 23, 1937.

bulb temperature and the cooling correction remained about constant. The mean of 30 sets is given below:

No. of reading	1	2	3	4	5	6
Corrected reading	3.202	3.206	3.208	3.210	3.211	3.212

The above indicates some increase in the reading from 1 to 6. The change is small, however, after the second reading. This fact was noted about 20 years ago, when many comparisons were being made between the silver-disk and the Ångström pyrheliometers. Since that time, when using the silver-disk pyrheliometer, we have preheated the silver disk from one to three minutes before starting a series of readings. Series of readings taken after the silver disk was preheated gave very consistent readings. Some of the discrepancy in the readings shown above may be due to a delay in opening and closing the shutter or a time lag in reading the thermometer. The rate of movement of the mercury thread is different in the first two or three readings of a set from that in later readings of the set when the rate of heating and cooling remain about constant.

EFFECT OF DELAY IN OPENING AND CLOSING SHUTTER

A set of readings were made using the regular method of opening and closing the shutter and then a set in which there was a delay of 10 seconds in opening the shutter after the end of a shaded period and a delay of 10 seconds in closing the shutter after an exposure period. The results in the latter case were about 3 percent higher. Thus a delay in opening and closing the shutter of even one second may result in an error of 0.3 percent. Variation in the time of opening and closing the shutter may explain the variation of the results with the silver-disk pyrheliometer by different observers. The pyrheliometer readings in this series of tests were made by L. B. Aldrich and W. H. Hoover. With the regular method of reading the pyrheliometer and the shutter operated by hand there was a difference of about 0.2 percent between the readings of the two observers. When the automatic shutter-opening device was used this difference was reduced to 0.1 percent or less.

EFFECT ON THE PYRHELIOMETER READINGS WHEN READINGS ARE TAKEN BEFORE THE PYRHELIOMETER CHANGES TO AMBIENT TEMPERATURE

For this test the pyrheliometer was placed in the chamber of the water bath and the automatic shutter device was used when readings were made. With the water bath at 15° and the pyrheliometer at the same temperature, a few readings were made with the bath maintained at 15°. The temperature of the bath water was then changed to about 35° and readings made while the pyrheliometer was changing temperature. The first three readings were from 0.5 to 0.7 percent too high. When the pyrheliometer was about 5° below the temperature of the bath more readings were taken. These readings agreed with the original set of readings. These results indicate that the pyrheliometer should be near the ambient temperature before making an observation.

In a paper on the Abbot silver-disk pyrheliometer[5] L. B. Aldrich discussed in some detail the method of observing with the silver-disk pyrheliometer and listed some precautions to be taken to insure greater accuracy. One precaution should be added. The shutter should be opened immediately at the end of the first shaded period and closed immediately after the end of the exposed period. A delay of a few seconds may result in an error of 1 percent or more.

[5] Smithsonian Misc. Coll., vol. 111, No. 14, 1949.