SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 111, NUMBER 14

Hodgkins Fund

THE ABBOT SILVER-DISK PYRHELIOMETER

(With One Plate)

BY
L. B. ALDRICH
Director, Astrophysical Observatory

(Publication 3991)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
DECEMBER 8, 1949

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

Hodgkins Fund

THE ABBOT SILVER-DISK PYRHELIOMETER

By L. B. ALDRICH
Director, Astrophysical Observatory

(With One Plate)

DESCRIPTION OF INSTRUMENT

In 1922 Dr. C. G. Abbot published a paper (The Silver-Disk Pyrheliometer, Smithsonian Misc. Coll., vol. 56, No. 19) describing his pyrheliometer, the method of use and possible errors, and listing the constants of the various instruments. Since 1922 several modifications of the instrument and of its method of use have been adopted, and some 50 additional pyrheliometers have been prepared and sold to interested institutions throughout the world. It therefore seems advisable to bring Dr. Abbot's 1922 discussion up to date.

Volume 2 of the Annals of the Astrophysical Observatory of the Smithsonian Institution (p. 36) describes the original mercury pyrheliometer which Dr. Abbot built in 1902 and from which the silver-disk pyrheliometer developed. In 1909 the form of instrument shown in cross section in figure 1 was adopted. The following description of it is taken from Dr. Abbot's paper (Smithsonian Misc. Coll., vol. 56, No. 19):

> The silver disk, *a*, shown in cross-section [fig. 1], is bored radially with a hole to admit the cylindrical bulb of a thermometer, *b*. The hole in the disk has a thin lining of steel, so that a small quantity of mercury may be introduced without alloying the silver, in order to make a good heat conduction between the silver disk and the thermometer bulb. A soft cord soaked in shellac is forced down at the mouth of the hole to prevent escape of mercury, and a ring of Chatterton[1] wax is sealed over the outside of the cord to make the closure more perfect.
>
> The thermometer, *b*, is bent at a right angle, as shown, in order to make the instrument more compact and less fragile. A nickeled brass tube (shown partly cut away in the figure) supports and protects the thermometer. A slot is cut in the right-hand side of the support tube throughout almost its whole length to permit the reading of the thermometer. At the top of the support tube a short piece is removable, in order that heat may be applied to the overflow bulb of the thermometer, to dislodge mercury which sometimes collects there

[1] Picein wax has been used in recent years.

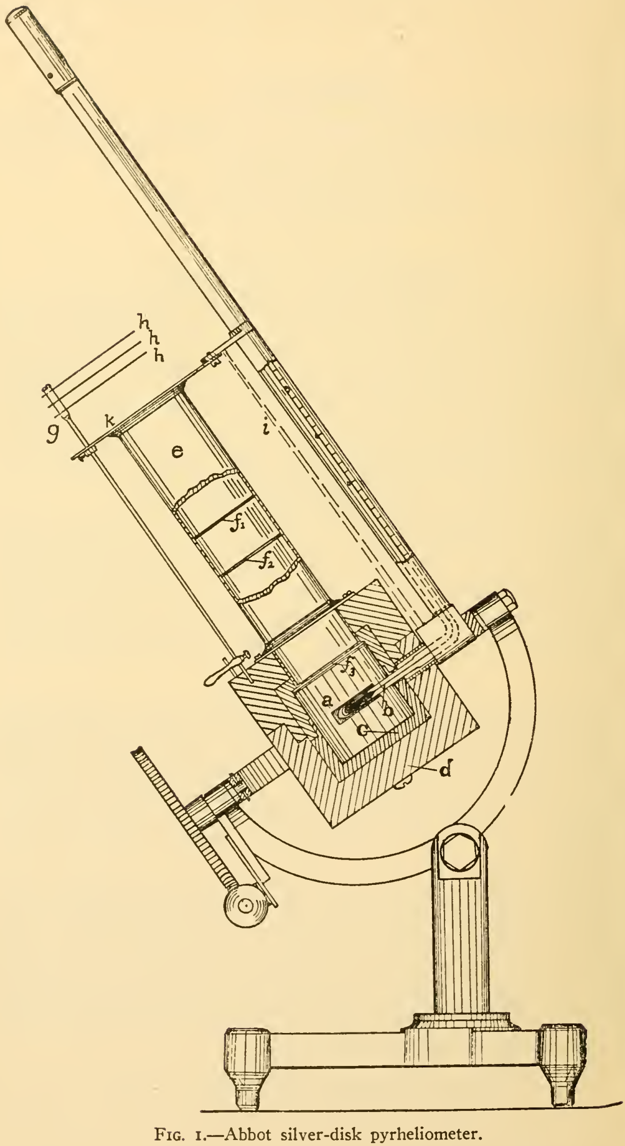

FIG. 1.—Abbot silver-disk pyrheliometer.

during transportation. The thermometer is graduated to tenths of degrees centigrade from −15° C. to +50° C. Two points, 0° and +50°, are first marked on the stem by the makers, and then the thermometer is graduated by equal linear intervals without regard to the variations of cross-section of bore of the stem. Before insertion in the instrument, a careful calibration of the thermometer stem is made.

The silver disk, *a*, is enclosed by a copper cylindrical box, *c*, halved together for convenience in construction. Three small steel wires, not shown in the figure, support the silver disk. These wires lie in the plane of the center of the disk at 120° intervals apart. Midway between them are three brass screws, not shown, which may be screwed through the walls of the box, *c*, up to their heads. These screws in that position clamp the silver disk tightly. Their purpose is to prevent the breakage of the thermometer if jarred during transportation. These screws must be loosened during observations.

The copper box, *c*, is enclosed by a wooden box, *d*, to protect the instrument from temperature changes. This box is also halved together and fastened by long wood-screws, one of which is seen near the letter, *d*, in the figure.

Sunlight may be admitted through the tube, *e*. This tube is provided with a number of diaphragms, f_1, f_2, f_3, having circular apertures. The aperture, f_3, nearest the silver disk is slightly smaller than the others, and slightly smaller than the disk itself. Thus it limits the cross-section of the sunbeam whose intensity is to be measured. The entire interior of the tube, *e*, the box, *c*, and the silver disk, *a*, are painted dead black with lamp-black mixed in alcohol, with a little shellac added to cause the lamp-black to stick. To secure a fine, even coat, the mixture is filtered through cheesecloth before applying, and on the disk it is warmed with an alcohol lamp until the brush marks disappear.

A rotatable shutter, *g*, with three nickeled parallel metal plates, *h h h*, is provided for cutting off the sunlight as desired. The top of the tube, *e*, carries a screen, *k*, large enough to shade the wooden box, *d*. This screen also supports the thermometer tube, and the axis of the exposing shutter just mentioned. A small hole in the part which supports the thermometer admits a little guiding beam of sunlight, *i*, whose use is to assure the observer that the instrument points toward the sun.

The pyrheliometer is carried upon an equatorial stand, as shown in the figure. A worm and wheel mechanism is provided for following the sun. No clockwork is needed, as it is sufficient for the observer to move the worm slightly two or three times a minute.

In 1927 two alterations were adopted: (1) the tube *e* was lengthened and (2) the base was enlarged to counteract top-heaviness due to the longer tube. These changes are shown in the photograph, plate 1. The short tube form of 1909 when the shutter was opened exposed each point on the silver disk to a cone of sky 10°38′ in diameter. Since the sun subtends a diameter less than 1/20th as great, the sky area exposed is at least 400 times that occupied by the sun. In very clear skies the radiation from this area of sky is negligible as compared to that from the sun. But measurement at Mount Harqua Hala in 1925 [2]

[2] Annals of the Astrophysical Observatory of the Smithsonian Institution, vol. 5, p. 83.

in a very hazy sky indicated that the readings were as much as $2\frac{1}{2}$ percent too high. To diminish the error from this source all silver-disk pyrheliometers made after 1926 carried tubes 32 cm. long in place of the original 15 cm. The exposed sky area was thus reduced from .0043 hemisphere to .0013. As opportunity has arisen the following older instruments have been similarly modernized by substituting the longer tube and enlarging the base: S.I. Nos. 1, 5, 16, 17, 26, 31, 41, 42, and 44. In hazy skies the error due to sky radiation now seldom exceeds $\frac{1}{2}$ percent.

While it is possible, from a study of the dimensions and physical properties of the instrument, to reduce its readings to heat units, there are uncertainties in thus using it as an absolute standard. We have preferred to consider it as a secondary instrument, the constant of each individual pyrheliometer being determined by careful comparisons with Smithsonian standard instruments.[3] Readings of the silver-disk instrument are proportional to the intensity of radiation of the sun, and are comparable one with another at all times and places. Multiplying the corrected readings by the constant of the instrument reduces them to true heat units.

DIRECTIONS FOR USE

These directions, with minor alterations to conform with our present practice, are taken from Dr. Abbot's paper, mentioned above.

SETTING UP

1. If the mercury column of the thermometer is broken, remove the little screw at the side near the upper end of the nickel-plated tube, and take off the upper portion of the tube. Then heat the exposed stem cavity of the thermometer gently in a smoky flame (a match flame is good) until the mercury is expelled from the cavity. Then, holding the thermometer vertical, shake the instrument repeatedly with a downward jerk until the mercury columns join.

2. Remove the two little ivory or fiber plugs (using pliers if necessary) and unscrew the two brass screws under them, and also unscrew the third similar screw seen through the trunnion on the other side of the case. About three complete turns of each screw is proper. Insert the two ivory plugs. *When packing the instrument again for*

[3] Descriptions of Smithsonian absolute standard pyrheliometers are given in Annals of the Astrophysical Observatory of the Smithsonian Institution, vol. 3, p. 52; vol. 6, p. 5; Smithsonian Misc. Coll., vol. 87, No. 15; vol. 92, No. 13; vol. 110, No. 5.

a journey, screw in the three screws as far as they will go. Their purpose is to clamp the silver disk to protect the thermometer during transportation.

3. Unscrew the two pivots from the sides of the ring of the mounting, insert the pyrheliometer so that the thermometer is *not* next to the worm wheel, and screw in the pivots.

4. Unclamp the half ring and set the polar axis approximately for the latitude of the place. The thermometer should be next to the *upper* end of the axis.

ADJUSTMENTS

5. For quick adjustment in right ascension guide the pyrheliometer with one hand and loosen the lower right-hand milled screw (as seen from the upper end of the polar axis). The worm may then be lowered out of engagement with the wheel and the change made.

6. To follow the sun, adjust in right ascension and declination until the sun shining through the little hole in the upper plate forms its image on the scratched spot on the nickeled piece below. When exposing to solar radiation rotate the worm screw a little (about once every half minute) to follow the sun.

7. When about to observe, push aside the cover, leaving only the shutter to shade the silver disk. When through with each series of readings, close the cover to keep out dust.

OBSERVATIONS

8. When reading the thermometer the observer should hold his head so that the reflection of each dark line of the scale near the degree to be observed, as seen in the mercury thread, is coincident with the corresponding dark line. This prevents parallactic errors of reading.

9. Having adjusted the instrument to point at the sun and opened the cover, read the thermometer exactly at 20 seconds after the beginning of the first minute. Read again after 100 seconds, or at the beginning of the third minute, and immediately after reading open the shutter to expose to the sun. Note that the instrument is then correctly pointed. After 20 seconds read again. After 100 seconds more (during which the pointing is corrected frequently), or at the beginning of the fifth minute read again, and immediately close the shutter. After 20 seconds read again. After 100 seconds read again, or at the beginning of the seventh minute. Continue the readings in the above order, as long as desired. Readings should be made within $\frac{1}{5}$ second of the prescribed time. Hold the watch directly opposite the degree to be observed, and close to the thermometer. Read the hundredths of degrees first, the degree itself afterward.

10. For results not requiring the highest accuracy the above described method of reading is satisfactory. As the result of long experience, we now use for greater accuracy several refinements of this method, as follows:

(a) A special reading glass is used. It consists of a small eyepiece of about 4 cm. focal length, mounted so that it can easily be held against and moved along the thermometer stem. In the focus exactly in the center of the field is a sharp needle point. By taking readings when the needle point is opposite the top of the mercury column, parallax errors are eliminated.

(b) Any simple device to beat regular intervals (such as 1, 5, or 10 seconds) permits the observer to concentrate on reading the thermometer instead of trying to read both watch and thermometer at the same time. Such a device also eliminates possible error due to eccentricity of the second hand of the watch.

(c) The instrument is set out in the sun at least 15 minutes before starting to read, and the shutter opened to the sun for about 1 minute during this period. In making a series of observations, the second set of readings is started 20 seconds after completing the first set of six readings. Thus a 4-minute shaded period occurs between each 2 minutes of exposure. Each set of six readings is quite independent.

11. For example:

Reading	1	2	3	4	5	6
Time	$11^h55^m20^s$	57^m00^s	57^m20^s	59^m00^s	59^m20^s	$0^h01^m00^s$
Reading	15°12	14°25	14°80	17°58	17°36	16°09
Condition ..	Shaded		Exposed		Shaded	

Air temperature 15°. Pyrheliometer "S.I.Q."

12. Subtract readings (2) from (1); (3) from (4); (6) from (5).

13. Take the algebraic means

$$\frac{(1)-(2)+(5)-(6)}{2}$$

and to them add $[(4)-(3)]$.

14. Call this result R_1. Find roughly the mean temperature T_1 during the interval of exposure (3) to (4).

15. Add to R_1 the percentage correction for graduation furnished with the instrument, then, after correcting, add to R_1, $K[(T_1-30°)R_1]$. K is a constant furnished with the instrument. If the prevailing temperature of the air differs much from 20°, add 0.0014 R for each 10° the air temperature falls below 20°. The result (which we will call $R^1{}_1$) is the final rate of rise per 100 seconds during the exposure (3) to (4) as reduced to the standard bulb temperature of 30°, and standard stem temperature of 20°.

16. (Note.) The approximate method of procedure stated in (13) and (15) is much easier than the exact method, and having been found by experiments to yield closely comparable results under all circumstances of use, within the error of measurement, it has been adopted, and the standardization of the instrument is made by this method.

17. To reduce the result R^1_1 to standard calories per square centimeter per minute, or to the Smithsonian scale of 1913, multiply by the factors furnished from the Smithsonian Institution with each instrument.

18. Example of reduction:

Number	1	2	3	4	5	6
Reading	15°12	14°25	14°80	17°58	17°36	16°09
Differences	0°87		2°780		1°27	
Cooling correction	....		1°070		....	
R_1	....		3°850		....	
T_1	....		16°2		....	
Scale correction	$-0.0020R_1=$		−0°008		....	
$KR(T-30°)$	$-(0.0011)(13.8)R_1=$		−0°058		....	
Air correction	$+0.0007R_1=$		+0°003		....	
R^1_1	....		3°787		....	

PRECAUTIONS

Constant watchfulness and care are needed to keep the instrument in best condition. For example, it should not be inverted or jarred, thus keeping the mercury column and the wax bond between thermometer and silver disk intact. The blackening of the silver disk should be examined periodically. If there is evidence of specks or spottedness, the surface should be carefully brushed with a soft camel's hair brush fastened to a long slender handle. The cover at the end of the tube should be kept closed when not in use. With care the blackness remains unchanged over many years. Our two substandard silver-disk instruments, A.P.O. No. 8_{bis} and S.I. No. 5 are evidence of this. Repeated comparisons against the absolute water-flow pyrheliometer over a period of 20 years have shown no evidence of change.

A silver-disk pyrheliometer ready for shipment, including standardization and boxing, costs the Smithsonian Institution about $200. While it is not desired to manufacture them extensively, it has been our practice to prepare and sell these pyrheliometers to individuals and institutions likely to use them for valuable and regular solar observations. The special reading glass above mentioned can be furnished for $10 additional.

Adopted constants of silver-disk pyrheliometers

Smithsonian pyrheliometry, scale of 1913

Instrument	Present constant	Location and remarks
S.I. 1	0.3733	U. S. Weather Bureau, 1910. Modernized, 1929.
S.I. 2	0.3743	Observatorie Physique Central Nicolas, St. Petersburg, Russia, 1910 (loan); National Observatory, Rio de Janeiro, Brazil, 1912.
S.I. 3	0.3625	Conservatoire des Arts et Métiers, Paris, France, 1911.
S.I. 4	0.3713	Royal University of Naples, Italy, 1911. Destroyed in World War II.
S.I. 5	0.3715	U. S. Department of Agriculture, Physical Laboratory, 1910. Modernized, 1931. On loan to Astrophysical Observatory since 1926.
S.I. 6	0.3666	Oficina Meteorológica, Buenos Aires, Argentina, 1911.
S.I. 7	0.3638	Do.
S.I. 8	0.3774	Central Observatory, Madrid, Spain, 1912.
S.I. 9	0.3738	Imperial College of Science and Technology, London, England, 1911.
S.I. 10	0.3762	Königlich Preussisches Meteorologisches Institut, Berlin, Germany, 1911.
S.I. 11	0.3769	Meteorological Observatory, Teneriffe, Canary Islands, 1911.
S.I. 12	0.3631	Königlich Preussisches Meteorologisches Institut, Berlin, Germany, 1912.
S.I. 13	0.3617	Schweizerische Meteorologische Centralanstalt, Zurich, Switzerland, 1912.
S.I. 14	0.3721	University of Toronto, Toronto, Canada, 1912. Modernized, 1937.
S.I. 15	0.3609	National Bureau of Standards, Washington, D. C., 1912.
S.I. 16	0.3634	University of Arizona, Tucson, Ariz., 1912. Modernized, 1929. Sent to Service Botanique, Tunis, 1932.
S.I. 17	0.3629	Harvard College Observatory Station, Arequipa, Peru, 1912. Sent to Smithsonian Observing Station, Calama, Chile, 1919. Modernized, 1929.
S.I. 18	0.3774	Observatorio Nacional, Rio de Janeiro, Brazil, 1913.
S.I. 19	0.3737	Aeronautisches Observatorium, Lindenberg, Germany, 1913.
S.I. 20	0.3657	Italian Indo-Asiatic Expedition, 1913. Returned to Washington, 1916. Repaired, 1919. Sent to Observtory, Helwan, Egypt, 1920.
S.I. 21	0.3711	Aeronautisches Observatorium, Lindenberg, Germany, 1913.
S.I. 22	0.3778	Observatorio Astronomico Nacional, Tacubaya, Mexico, 1913.
S.I. 23	0.3683	Landwirtschaftliches Institut, Moscow, Russia, 1914.
S.I. 24	0.3713	Meteorological Observatory, Teneriffe, Canary Islands, 1914.
S.I. 25	0.3717	Do.

Instrument	Present constant	Location and remarks
S.I. 26	0.3741	Meteorological and Geophysical Service, Batavia, Java, 1914. Modernized and returned, 1947.
S.I. 27	0.3679	Manila Observatory, Manila, P. I., 1915.
S.I. 28	0.3639	Meteorological Office, London, England, 1915.
S.I. 29	0.3674	Calama, Chile, Smithsonian South American Expedition, 1918.
S.I. 30	0.3622	Do.
S.I. 31	0.3748	Jewish Consumptives Relief Society, Edgewater, Colo., 1920. Repaired, modernized, and sent to Carnegie Institution, Colorado and California, 1931.
S.I. 32	0.3691	Mount Harqua Hala, Ariz., Smithsonian Solar Observing Station, 1920.
S.I. 33	0.3755	Reale Osservatorio Astronomico di Capodimonte, Naples, Italy, 1921.
S.I. 34	0.3730	Riverside College Observatory, Sydney, Australia, 1921. Turned over to Commonwealth Observatory, Mount Stromlo, 1946.
S.I. 35	0.3648	Do.
S.I. 36	0.3640	Institutul Meteorologic Central, Bucharest, Roumania, 1922.
S.I. 37	0.3648	University of Lemberg and Warsaw, Lemberg, Poland, 1922.
S.I. 38	0.3726	Argentine Meteorological Service, La Quiaca, Argentina, 1924.
S.I. 39	0.3764	Do.
S.I. 40	0.3553	Institut de Physique du Globe, Paris, France, 1924.
S.I. 41	0.3697	Observatory on Zugspitze, Germany, 1924 (loan). Modernized, 1927. Sent to Institute of Meteorology, Nanking, China, 1929.
S.I. 42	0.3679	Mount Harqua Hala, Ariz., 1923. Modernized, 1932, and sent to Carnegie Institution, Colorado and California, as substitute for S.I. 16.
S.I. 43	0.3735	Stellenbosch University, South Africa, 1924.
S.I. 44	0.3793	Meteorological Service, Rio de Janeiro, Brazil, 1925. Modernized and returned to Brazil, 1928.
S.I. 45	0.3658	University of Aberdeen, Scotland, 1925.
S.I. 46	0.3705	Meteorological Bureau, Riga, Latvia, 1925.
S.I. 47	0.3735	Smithsonian Solar Observing Station, Mount Brukkaros, Southwest Africa, 1926. Smithsonian Solar Observing Station, Calama, Chile, 1932. *Note.*—No. 47 and No. 48 have special 80-cm. tubes.
S.I. 48	0.3827	Do.
S.I. 49	0.3586	Battle Creek College, Mich., 1927.
S.I. 50	0.3800	Physikalisch-Meteorologisches Observatorium, Davos, Switzerland, 1927. Repaired and returned to Davos, 1934.
S.I. 51	0.3755	Meteorological Office, Simla, India, 1927.
S.I. 52	0.3787	University Observatory, Kiel, Germany, 1927.

Instrument	Present constant	Location and remarks
S.I. 53	0.3797	Commonwealth Solar Observatory, Canberra, Australia, 1928. Repaired and returned to Australia, 1937.
S.I. 54	0.3824	Commonwealth Solar Observatory, Canberra, Australia, 1928. Repaired and returned to Australia, 1939.
S.I. 55	0.3848	University of Illinois, Department of Botany, Urbana, 1928.
S.I. 56	0.3742	Universitäts-Sternwarte, Kiel, Germany, 1928.
S.I. 57	0.3818	Institut Scientifique Chérifien, Rabat, Morocco, 1929.
S.I. 58	0.3831	Oporto Observatory, Portugal, 1929.
S.I. 59	0.3851	University of Arizona, Tucson, 1930.
S.I. 60	0.3945	American Society of Heating & Ventilating Engineers, Pittsburgh, Pa., 1931. Repaired and returned to Pittsburgh, 1945.
S.I. 61	0.3867	Meteorological Service of Martinique, Fort de France, 1932.
S.I. 62	0.3960	Do.
S.I. 63	0.3821	Blue Hill Meteorological Observatory, Milton, Mass., 1932. Repaired and returned to Blue Hill, 1941.
S.I. 64	0.3870	Laboratoire Actinométrique de l'Observatorie de Trappes, France, 1933.
S.I. 65	0.3913	Institute of Meteorology, Nanking, China, 1933.
S.I. 66	0.3868	Institut de Physique du Globe, Paris, France, 1934.
S.I. 67	0.3877	Tananarive Observatory, Madagascar, 1935.
S.I. 68	0.3788	Institut de Physique du Globe, Paris, France, 1935.
S.I. 69	0.3849	Geophysical Observatory, Pilar, Argentina, 1936.
S.I. 70	0.3816	Do.
S.I. 71	0.3737	Commonwealth Solar Observatory, Canberra, Australia, 1936. Repaired and returned to Australia, 1937.
S.I. 72	0.3820	Commonwealth Solar Observatory, Canberra, Australia, 1936. Repaired and returned to Australia, 1939.
S.I. 73	0.3789	Eppley Laboratories, Newport, R. I., 1937. New thermometer inserted and returned, 1939.
S.I. 74	0.3962	University of Minnesota, Minneapolis, Minn., 1937.
S.I. 75	0.3847	R. Dvorak, Agent, Prague, Czechoslovakia, 1938.
S.I. 76	0.3876	Observatório Central Meteorológico, Lisbon, Portugal, 1940.
S.I. 77	0.3922	Geophysical Institute, University of Coimbra, Portugal, 1940.
S.I. 78	0.3926	U. S. Weather Bureau, Washington, D. C., 1944.
S.I. 79	0.3736	Physics Institute, Helsinki University, Finland, 1946.
S.I. 80	0.3776	Hebrew Technical College, Haifa, Palestine, 1947.
S.I. 81	0.3871	Institute for Advanced Learning, Dublin, Ireland, 1949.

Various A.P.O. instruments

Instrument	Constant	Location and remarks
A.P.O. IV	0.5118	Copper disk. 1906. Mount Wilson, Calif.
A.P.O. VII	0.5072	Copper disk. 1906. Mount Wilson, Calif.
A.P.O. VIII	0.5150	Copper disk. 1906. U. S. Weather Bureau and Mount Wilson.
A.P.O. 8	0.3760	First silver-disk instrument. 1909. Washington and Mount Wilson. Repaired 1910 and called A.P.O. 8_{bis}.
A.P.O. 8_{bis}	0.3786	Modernized 1927. Reserved at Washington for comparisons only.
A.P.O. 9	0.3631	Built 1910. Used at Washington, Mount Wilson, Mount Whitney, Algeria, Arizona. Modernized 1928 and called A.P.O. 9_{bis}.
A.P.O. 9_{bis}	0.3684	Zentralanstalt für Meteorologie und Geodynamik, Vienna, Austria, 1928.
A.P.O. 10	0.3720	Built 1923. Sent to Harqua Hala and Table Mountain.
A.P.O. 11	0.3675	Sent to Mount Brukkaros, Southwest Africa, 1925. Modernized and sent to Mount St. Katherine, Egypt, 1933. Repaired 1938 and sent to Tyrone, N. Mex., Miami, Fla., and Table Mountain, Calif.
A.P.O. 12	0.3618	Table Mountain, Calif., 1928.
A.P.O. 13	0.3893	Mount St. Katherine, Egypt, 1932. Rebuilt 1938 and sent to Tyrone, N. Mex., Miami, Fla., and Table Mountain, Calif.
A.P.O. 14	0.3854	Mount St. Katherine, 1932; Tyrone, N. Mex., Miami, Fla., Table Mountain, Calif.

Abbot Silver-disk Pyrheliometer, with Long Tube Adopted 1927