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Since 1910 nearly a hundred copies of the silver-disk pyrheliometer have been prepared at the Smithsonian Institution. They are in use in many countries. Observers, even those using other types of pyrheliometer, often express their results in terms of "the Smithsonian standard scale" which is carried to them by these silver-disk instruments, standardized against the water-flow pyrheliometer. Aldrich and Abbot, in 1947, made a painstaking comparison at Mount Wilson between two silver-disk instruments and the water-flow pyrheliometer. They obtained within one part in a thousand the same result as in 1934 and earlier.[1] Various observers have investigated old silver-disk instruments and find no evidence that there has been a change of their sensitiveness since 1910.

So the question of the standard scale depends on the adequacy of the water-flow pyrheliometer as a standard. Originally this instrument comprised a single deep test-tube-like blackened chamber of metal with hollow walls. In these walls, in the extreme rear wall, and in the walls of a hollow cone not quite at the rear, on which all the sun's rays fell directly, a current of water constantly flowed to carry off the solar heat as fast as absorbed. An electrical thermometer, meticulously calibrated by means of an extremely delicate standard mercury thermometer, registered the rise of temperature between the entrance and the exit of the stream of water. A carefully gaged diaphragm admitted the solar rays to the chamber. Other diaphragms of slightly larger diameter, along the vestibule and within the chamber, served the double purpose of opposing air currents, and of obstructing the entrance or the escape of stray light. The rate of flow of the water was determined by frequent weighings.

As all of the entering beam of sunlight fell upon the hollow blackened cone near the extreme rear of the chamber, over 95 percent of

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[1] Aldrich, L. B., and Abbot, C. G., Smithsonian pyrheliometry and the standard scale of solar radiation. Smithsonian Misc. Coll., vol. 110, No. 5, 1948.

the rays would be immediately absorbed on that cone and would give up their heat there into the flowing water. The remaining 5 percent or less would be scattered over an entire hemisphere, of which nearly the whole solid angle was included in the blackened walls of the chamber. Over 95 percent of the trifling amount of radiation scattered from the cone, impinging upon these walls, would be absorbed on them, and this heat also would be communicated to the flowing water. Only the measured aperture, through which solar rays entered, was open to free escape of the scattered rays. As this aperture subtended but 0.012 hemisphere as viewed from the hollow cone, less than 0.012 of 5 percent of the introduced solar radiation could freely escape. So, theoretically, the chamber was fully 99.94 percent "black."

Lest some unforeseen error should lurk in the device, two coils of insulated wire were wound upon the cone. One coil was wound in shellac directly upon the rear wall of the cone, being behind the water stream within the cone, but in front of the water stream in the extreme back wall of the chamber. This coil was more favorably situated than solar heating to convey electrically produced heat to the flowing water. The other insulated coil was of several millimeters thickness, was doughnut-shaped, and was stuck on with shellac to the front rim of the hollow cone, outside the area covered by the beam of sunlight. This coil was very unfavorably situated to give up electrically produced heat to the flowing water, since it must first give its heat to the air, and then to the walls of the chamber.

I have been describing Standard Pyrheliometer No. 3. On pages 61 and 63 of Annals of the Smithsonian Astrophysical Observatory, volume 3, 1913, there are given 24 tests, half with each of the two heating coils, where electrically introduced heat was measured by absorption in the flowing water. The results of 12 tests at Washington, April 18, 22, and 23, 1910, showed no certain difference as between the two coils, and gave a mean result of 99.85 percent heat found. The results of 12 tests at Mount Wilson, October 10 and 11, 1911, also equally divided between the two coils, gave 100.66 percent heat found. These results come to well within their probable error at exactly 100 percent heat found. They therefore indicate that heat introduced in the chamber, no matter whether more or less favorably for measurement than solar heat, is completely absorbed and accurately measured by the instrument. This, as we shall see later, is a critically important result.

Not content with this method of fixing the standard scale of pyrheliometry, we constructed another instrument of the hollow-chamber type. It was called the water-stir pyrheliometer, because, instead of carrying off absorbed heat in a flowing stream of water, the chamber was immersed in a water bath whose rate of rise of temperature, and cooling corrections, were observed after the methods of exact calorimetry. In this instrument only one insulated coil of wire was introduced, but it was wound in part within the wall of the sides of the chamber. Thus it had almost identically the same facility to give up its heat to the water as did the solar rays. Tests of electrical heating with this instrument were made on October 24 and 26, 1912, and recorded on page 67 of Annals, volume 3. Six tests gave 100.05 percent of heat found, and the results are even more consistent than the excellent ones with the water-flow pyrheliometer. Silver-disk pyrheliometer APO 8_{bis}, which we have ever since used as secondary standard, was compared on a number of occasions from 1910 to 1912, some at Washington, others at Mount Wilson, and with both the water-flow and the water-stir standards. The results are given at the bottom of page 70, Annals, volume 3. They give the following independent determinations of the constant for APO 8_{bis}: 0.3798, 0.3791, 0.3809, 0.3786, 0.3792, 0.3770, 0.3772.

Many years later the silver-disk pyrheliometers were altered to have longer vestibules so as to reduce the angular area of sky near the sun to which they were exposed. The water-flow standard pyrheliometer was also changed. A Russian, V. M. Shulgin, made the valuable suggestion that by using two chambers rather than one in the water-flow pyrheliometer, with the water stream divided just at the entrance of their walls, inequalities in rate of water flow would be the same in both. Hence if the solar heating in one chamber was continually being balanced by electrical heating in the other, the inequalities of flow of water would cease to produce fluctuations in the readings. In 1932 we introduced Shulgin's method, and, *depending on the results of 1910 to 1912, to the effect that solar heating and electrical heating are equally efficiently absorbed,* all subsequent standardizations of pyrheliometers by Smithsonian observers are based on the use of the standard water-flow pyrheliometer *as an electrical compensation instrument.* That is, we no longer measure the water-flow rate, or the rise of temperature of the water, but we balance solar heat in one chamber against electrical heat in the other, and reverse chambers as respects heating again and again. I repeat, *we now absolutely depend on the experiments I have quoted, of the years 1910 to 1912,* which prove that in our pyrheliometer electrical heat and solar heat are both fully absorbed in the water stream.

Prior to the adoption of V. M. Shulgin's suggestion of using two chambers in the water-flow pyrheliometer, we found great difficulty in producing a constant water stream. Air bubbles were carried along, and local fluctuations in temperature occurred owing to air currents affecting the short rubber tubes which had to be introduced to allow free movement. These irregularities, both of mechanical and heat natures, caused accidental differences of successive measurements so appreciable that great numbers of comparisons with silver-disk pyrheliometers had to be made to obtain accurate results. What with this source of error, and the effect of sky radiation from near the sun, which was minimized by using the longer vestibules of the silver-disk pyrheliometers after the year 1925, we found that the earlier determinations of the constants of silver-disk pyrheliometers were too high by 2.3 percent. This correction we published in the year 1934.[2] Nevertheless, so as not to upset the world's system of pyrheliometry, and the comparability over a long term of years of Smithsonian solar-constant results contained in volumes 2 to 6 of Annals of the Smithsonian Astrophysical Observatory, while we admit that the 1913 scale of pyrheliometry is 2.3 percent too high, we and those who follow us still use the Smithsonian scale of 1913.

The variability of the brightness of the sky may still slightly affect silver-disk pyrheliometry. However, as stated at pages 53 to 55, Annals, volume 6, we now eliminate variations of sky brightness as a source of error in solar-constant measurements.

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[2] Abbot, C. G., and Aldrich, L. B., The standard scale of solar radiation. Smithsonian Misc. Coll., vol. 92, No. 13, 1934.