An error in the Ångström pyrheliometric scale

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(Manuscript received May 25, 1966)

ABSTRACT

The poor thermal conductivity of the blackening applied to the receiving strips of the Ångström pyrheliometer has the consequence that equalizing the temperatures of the back surfaces does not strictly equalize the temperatures of the front surfaces. An examination of the resulting heat balances shows that an error of appreciable magnitude must exist.

Introduction

The events leading to the adoption of the International Pyrheliometric Scale 1956 have been discussed by several authors (Drummond, 1961), and these will not be repeated here. The primary problem was the disagreement of the Smithsonian scale, which was determined indirectly by the use of a calorimeter, and the Ångström scale, which is based upon the use of the Ångström compensation pyrheliometer as an absolute instrument with a calibration constant determined from basic principles.

The scale proposed by the International Radiation Conference, and adopted by the W. M. O., was essentially a compromise between the two scales, arrived at by considering the probable errors in each of the above-mentioned scales, and represented as the best approximation possible at that time. (See *IGY Instruction Manual*, Part VI.) It is therefore important to consider possible errors to either scale, or even new techniques, so that a more exact pyrheliometric scale may eventually be possible. The present paper concerns one possible error in the derivation of the calibration constant of the Ångström compensation pyrheliometer.

The temperature of the pyrheliometer elements

Figure 1 is a representation of the cross-section of the elements of an Ångström pyrheliometer. In operation the measurement sequence described below is applied several times with the role of the strips alternately interchanged. Radiation is allowed to reach strip *A*, and thus to raise its temperature. A current is introduced into strip *B*, and adjusted until the temperatures at the lower surfaces of the strips are equal as indicated by the null thermal current from the opposed thermojunctions in thermal contact with but electrically insulated from the lower part of the strips. The thermojunctions will affect the temperature of the strip near their location, but since they only serve to indicate the equality of temperature at some point below the manganin, this is unimportant so long as the symmetry between the strips is maintained. The basic assumption of the instrument is that after equilibrium is reached the energy loss from each of the elements will be the same. The product of the electrical resistance of strip *B* and the square of the current through it is the energy supplied to the strip, and thus equal to its energy loss. If the energy losses from the two strips are equal, then the energy supplied to strip B is equal to the energy absorbed by strip *A*, the energy absorbed being the product of the blackness of the strip and the radiation falling on it. If these parameters and the size of the strips are known the energy flux can thus be determined. Considerable work has been devoted to determination of the blackness of the strip, which is now accepted as 0.98. An end effect correction (Ångström, 1958) is necessitated by the dissimilar incomes at the ends of the two strips: the shielded ends of A receive no radiation whereas in the case of B

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Joule heating is distributed along its entire length.

The center portion of the strips, as shown in Fig. 1, is a 20-micron thick strip of manganin which is 2 cm long and 0.2 cm wide (Ångström, 1958; Lindholm, 1958). The strips are blackened by first platinizing by the method described by Kohlrausch and then blackening with soot by means of a candle. Values of the thickness of the blackening layers are not available (Wallen, 1966). The rate of heat loss from the heated strip can be taken to be proportional to the temperature difference between the strip and the air inside the instrument with the constant of proportionality approximately $k = 0.000287$ cal cm^{-2} sec^{-1}. The length of the strips, in relation to the width and thickness, is great enough to make it acceptable to treat the strips as infinitely long in the calculations that follow, and also to neglect any heat losses from the strips other than the losses at the upper and lower surfaces.

Let strip A receive a radiation flux R. After equilibrium is established the energy received is dissipated by two heat fluxes, L_1, upward, and L_2 downward through the strip to be lost at the lower surface. Strip B is supplied with a heating current which results in losses L_1' upward, and L_2' downward. The energy supplied per unit time to each unit area of the strip by the current is H, where $H = L_1' + L_2'$. The temperatures of the strips are as represented in Fig. 1, with T_a being the temperature of the air surrounding the strips. The energy loss from the strips will be assumed to be proportional to the difference in the temperature of the strip and the air, with the constant of proportionality being k for the upper surface of the strip and αk for the lower surface. H and R can be expressed in terms of these parameters as

$$H = k[(T_1' - T_a) + \alpha(T_4' - T_a)], \qquad (1a)$$

$$R = k[(T_1 - T_a) + \alpha(T_4 - T_a)]. \qquad (1b)$$

The thermal resistance, i.e. the ratio of thickness to thermal conductivity, of the upper and lower blackening layers of each of the strips is r_1 and r_2 respectively. The thermal resistance of the central region, the manganin portion, is negligible in comparison to r_1 and r_2, which means that one may take $T_2 = T_3$ and $T_2' = T_3'$. The temperature T_1 and T_1' can be expressed as

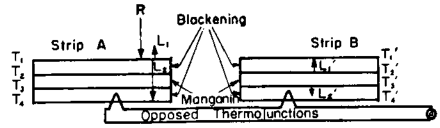

Fig. 1. Diagrammatic cross-section of the elements of an Ångström compensator pyrheliometer.

$$T_1 = T_4 + L_2(r_1 + r_2), \qquad (2a)$$

$$T_1' = T_4 + L_2' r_2 - L_1' r_1. \qquad (2b)$$

The matching of the temperatures on the lower side of the strips results in L_2 and L_2' as well as T_4 and T_4' being equal

$$R = k[(1+\alpha)(T_4 - T_a) + L_2' r_2 + L_2' r_1], \qquad (3a)$$

$$H = k[(1+\alpha)(T_4 - T_a) + L_2' r_2 - L_1' r_1] \qquad (3b)$$

or

$$R = H + k(L_2 + L_1) r_1 = H + k r_1 R. \qquad (4)$$

So R and H are not equal, but they are related by

$$H/R = 1 - k r_1. \qquad (5)$$

That is, H is less than R by a fractional amount $k r_1$.

Discussion

The thicknesses of the layers of blackening are not available, but the results of Blevin & Brown (1965) on camphor black indicate that the thickness of the soot must be at least 10^{-3}

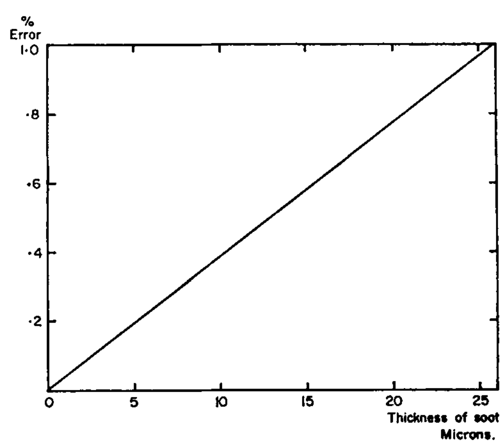

Fig. 2. Percentage error introduced by blackening.

cm to be effective throughout the required wavelength region. The thermal conductivity of the soot is quite low, being 0.000074 cal cm^{-1} sec^{-1} for Cabot number 5 lampblack (Smithsonian Physical Tables, 1934). This thickness and conductivity would certainly make the effect of the manganin strip negligible and probably also that of the platinum black for which, however, no values of the thermal conductivity have been found. The percentage error introduced by the soot, which is additive to the errors of the other two layers, is shown in Fig. 2.

The figure indicates that an error of 0.5 per cent could quite easily be due to the effect described above, but even an error of 1.0 per cent would not be unreasonable. This error is in the same direction as the error due to the end effect, and so it does nothing to bring the Smithsonian and the Ångström radiation scales into closer agreement, but increases the disagreement even further. The difference in aperture between the silver disk and Ångström instruments will always result in some error, but not large enough to explain the difference in the two scales. The lack of information on the thermal properties of the strips does not permit more definite conclusions concerning the actual error caused by the effect described above.

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ОДНА ОШИБКА В ПИРГЕЛИОМЕТРИЧЕСКОЙ ШКАЛЕ АНГСТРЕМА

Низкая теплопроводность зачернения, наложенного на приемные площадки пиргелиометра Ангстрема, приводит к тому, что выравнивание температуры обратных поверхностей площадок не может строго уравнять температуру экспозируемых поверхностей. Исследование результирующего баланса тепла показывает, что должна существовать ошибка заметной величины.