THE RADIANT LUMINOUS EFFICIENCY OF THE CARBON INCANDESCENT LAMP AND THE MECHANICAL EQUIVALENT OF LIGHT.

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IN several recent papers [1,2] we have described methods for obtaining the mechanical equivalent of light, and have arrived at an experimental value for that constant. According to our work, one lumen is .00159 watt of luminous flux.

Recently Pirani and Miething,[3] Meyer[4] and Langmuir,[5] using in part data of Lummer and Pringsheim[6] and Nernst[7] on black body brightness have arrived at figures 20 to 30 per cent. lower than ours. This discrepancy is far beyond any to be ascribed to known sources of error in our experimental work (we have estimated our figure to be right to within at least two per cent.), so that we have been interested in checking our work by independent experiments. We have already shown[8] that the method of obtaining this constant through black body brightness is not capable of fixing its value exactly in the present state of our knowledge of the black body constants. Our own experiments on the black body were not sufficiently consistent to warrant any definite conclusion as to the value of the mechanical equivalent thus derived. Our most reliable results—at the platinum melting point—appeared however to favor a figure of .00139, somewhat lower than our previous experimental value.

The present note describes a check on the order of magnitude of this constant by a method described before, which is excellent for this purpose

[1] Ives, Coblentz & Kingsbury, "The Mechanical Equivalent of Light," Phys. Rev., April, 1915, p. 269.

[2] Ives and Kingsbury, "Physical Photometry with a Thermopile Artificial Eye," Phys. Rev., Nov., 1915, p. 319.

[3] Pirani and Miething, "Strahlungsenergie, Temperatur und Helligkeit des Schwarzen Körpers," Ver. der Deutschen Physikalischen Ges., 13, 1915, p. 219.

[4] Meyer, "Der Schwarze Körper als Lichtquelle, etc.," Verh. d. D. Phys. Ges., 21, p. 384, 1915.

[5] Langmuir, "Radiation from Tungsten Filaments and the Mechanical Equivalent of Light," Abs. in Phys. Rev., Jan., 1916, p. 152.

[6] Lummer and Pringsheim, Physik. Zeitschrift, 3, 97, 1901–1902.

[7] Nernst, Physik. Zeitschrift, 7, p. 380, 1906.

[8] Ives and Kingsbury, "Mechanical Equivalent of Light as Obtained from the Brightness of the Black Body," Phys. Rev., 1916.

when the discrepancy in question is so large, although not suitable for exact determination of the value.

The method consists in brief in determining the radiant luminous efficiency of a chosen light source, and comparing this with the total luminous efficiency, thereby obtaining the efficiency losses due to conduction, convection, etc. These are then compared with the estimate of these losses as obtained by independent means.

Thus, as has been previously shown,[1] if F is the luminous flux, P the applied power, R the radiant power, L_T the total luminous efficiency, and L_R the radiant luminous efficiency,[9] then

$$\frac{R}{P} = \frac{\dfrac{F}{P}}{\dfrac{F}{R}} = \frac{L_T}{L_R}.$$

Now L_T is obtained by multiplying the efficiency as ordinarily expressed in lumens per watt, by the mechanical equivalent of light. It therefore involves directly the chosen value of the constant in question.

L_R is obtainable by measuring the radiation with and without the interposition of a "luminosity curve" template, it being understood of course that the luminosity curve employed is the one used to determine the mechanical equivalent.

The application of this process to the carbon incandescent lamp, whose efficiency losses are approximately known, will be recognized as one element in the published work on the determination of the mechanical equivalent,[1] and on the application of a small correction to the originally found value.[2] These determinations were made, however, as stated, on a high candle power concentrated filament lamp, matched in color with a standard, but which had not itself been measured for efficiency losses. Some question has been raised too in certain quarters as to the validity of part of the experimental work, so that a careful repetition seemed desirable. The work here described differs from the earlier study in the fact that a new regular "32 candle power" oval anchored filament lamp was used, that being the type for which Hyde [10] has given data on leading-in wire losses, this lamp being as well an original standard calibrated by the Electrical Testing Laboratories to be accurately 4.85 watts per mean spherical candle power or 2.59 lumens per watt. The use of this smaller lamp was made possible by the greater sensibility and completeness of the experimental means now at our disposal.

[9] For the symbols and relations here used see Ives "The Establishment of Photometry on a Physical Basis," Jnl. Franklin Institute, Oct., 1915, p. 409.

[10] Hyde, Cady and Worthing, "A Study of the Energy Losses in Electric Incandescent Lamps," Trans. Ill. Eng. Soc., April, 1911, p. 238.

In the experimental work particular attention was paid to the elimination of all possible errors. The "luminous efficiency meter" shown in Fig. 1 consists of a surface thermopile, before which are two tubes, one clear, the other containing the luminosity curve solution. Either of these can be turned into position at will, and they are of such lengths that when the thermopile mounting is pushed to place against either, the optical distance from light source to thermopile is the same. The luminosity curve solution is that described elsewhere,[2] with a protective water tank 2.5 cm. thick. These tanks are made of glass tubing with plane ends fastened on with paraffine, the whole cell being then embedded in plaster of Paris in a close fitting brass container.[11] (The maximum transmission of the two cells together is .57, by which figure the light deflections are divided.) Nickel plated front and cover (not shown in figure) give protection against air drafts and stray radiation.
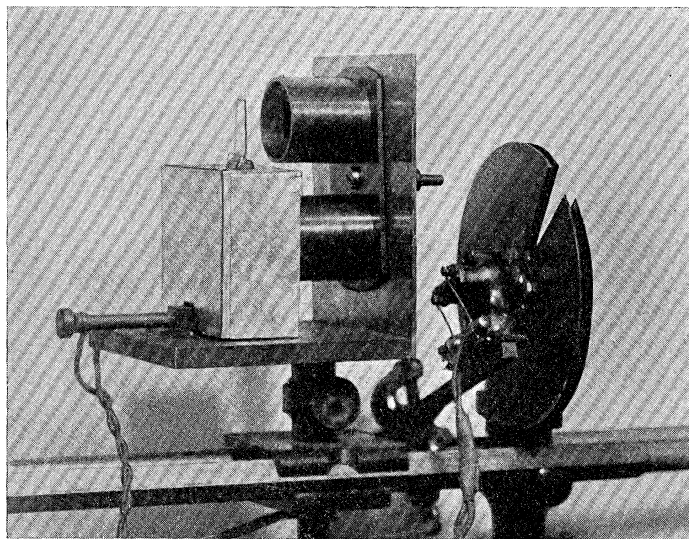

Fig. 1.

Radiant luminous efficiency meter, with cover and screening system removed.

In addition to a very complete screening system (not shown), two somewhat novel features deserve attention—the sector disc employed with the total radiation exposure to keep the total and luminous deflections approximately of the same magnitude, and the shutter. The disc (of

[11] For details of this construction see Ives and Kingsbury, "The Application of Crova's Method of Heterochromatic Photometry to Modern Incandescent Illuminants," Trans. Ill. Eng. Soc., X., No. 8, p. 716, 1915.

aluminum) had a one per cent. opening, and because of the small dimensions of the aperture its edges had to be very carefully bevelled and blackened. It was then calibrated photometrically. Its most important feature, however, was an additional protective disc of tin separated from the acting disc by about five millimeters' air space, and having an opening as small as possible without obscuring the calibrated opening. This cover disc was found necessary because when working with the rather long exposure required by this surface thermopile the disc would warm up enough to appreciably affect the result. The shutter, which was controlled from a distance, was made similarly double-walled.

Some question has been raised as to the thickness of water layer necessary to completely obstruct such infra-red radiation as the copper chloride element of the luminosity curve solution proper transmits. We have previously found two centimeters adequate, with varying thicknesses of water layer, so that the 2.5 cm. used in this arrangement of apparatus was thought ample. In order to test this again we have carried through with great care a number of critical measurements, of which one alone need be described. This was the measurement of the transmission of a 2.5 centimeter water layer, both visually and with the physical photometer comprised by the luminosity curve solution and water tank above described. If this measurement gave different results by the two methods it would indicate an outstanding error due to inadequate water protection. Identical values for this transmission were obtained by the visual method and the physical photometer, showing, as did our other tests, the protection against infra-red to be complete with the 2.5 cm. tank incorporated in the apparatus.

The experimental procedure was the same as that already described in the accounts of these researches,[1, 2] and need not be repeated here.

Our mean value from a long series of readings, for the luminous efficiency of the carbon lamp radiation is

$$L_R = .0045$$

in close agreement with previously obtained values by Karrer[12] and the writers,[1] with slightly different luminosity curve solutions.

Now the total luminous efficiency, L_T, if we use the authors' value for the mechanical equivalent of light, is, for 4.85 w.p.c. or 2.59 lumens per watt,—

$$2.59 \times .00159 = .00412$$

from which the radiation efficiency,

[12] Karrer, "A Method of Obtaining Radiant Luminous Efficiencies, etc.," PHYS. REV., March, 1915, p. 189.

$$\frac{R}{P} = \frac{L_T}{L_R} = \frac{.00412}{.0045} = .915$$

Now the leading-in wire losses as determined by Hyde [10] are from 4–5 per cent. To these must be added convection losses, roughly measured by Drysdale[13] as "noc more than 2 or 3 per cent.," and some additional loss (in the direction of measurement) due to the slightly different distribution of radiation by the heated glass bulb from that of the filament, which latter is all that we are concerned with in the "visible" measurement. This loss must be very small, probably not more than 2 per cent. Adding these together $5 + 2 + 2 = 9$, is a not improbable value for the losses, giving 91 per cent. as the radiation efficiency. (If these losses could be accurately determined by other than radiation measurements, a valuable independent method of obtaining the mechanical equivalent of light would be at hand.)

The experimental figure given above is therefore in excellent agreement with independent evidence on the radiation efficiency. If on the other hand we use the value of the mechanical equivalent arrived at by Pirani; .00123,—the radiation efficiency works out at 71 per cent., which is almost out of the question.

We conclude from this that the value .00159 is substantially correct for the mechanical equivalent of light, where light is defined by the luminosity curve, and measured by the photometric method (in agreement with that curve), used by us.

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[13] Drysdale, "Luminous Efficiency and the Mechanical Equivalent of Light," Illuminating Engeneer (London), Vol. I, p. 640, 1908.
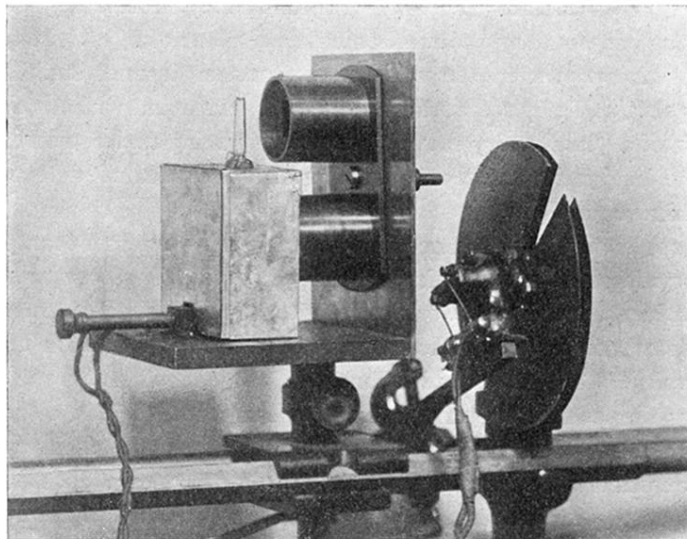
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