**Physics.** — *"The brightness of the black body and the mechanical equivalent of light."* By. Dr G. HOLST and J. SCHARP DE VISSER. (Communicated by Prof. H. KAMERLINGH ONNES.)

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*Introduction.* For various investigations it is of great importance to know the brightness of the black body at various temperatures. Direct measurements were made by LUMMER and PRINGSHEIM[1]) and by NERNST[2]). NERNST sums up his results in the formula $log\, H = 5{,}367 - \frac{11230}{T}$ ($H=$ intensity of 1 cm² in Hefner-candles, $T=$ absolute temperature). The curve corresponding to this formula passes closely through LUMMER and PRINGSHEIM's points. Recently, however, doubts have arisen as to these measurements. Various investigators starting from the spectral distribution of energy, the sensitiveness of the eye and the mechanical equivalent of light have calculated the brightness of the black body and all of them come to much higher values than were found experimentally. The following table shows the results:

| | formula $C_2=14600$ | $C_2=14600$ | $C_2=14392$ | $C_2=14400$ | $C_2=14370$ | $C_2=14450$ |
|---|---|---|---|---|---|---|
| $T$ | NERNST | LUMMER PRINGSHEIM | LANGMUIR 3) | PIRANI MIETHING 4) | IVES KINGSBURY 5) | FOOTE FAIRCHILD 6) |
| 1300 | 0.054 | 0.052 | 0.0784 | 0.095 | 0.0700 | 0.086 |
| 1400 | 0.222 | 0.219 | 0.300 | 0.340 | 0.262 | 0.333 |
| 1500 | 0.759 | 0.760 | 0.960 | 1.04 | 0.825 | 1.051 |

1) LUMMER and PRINGSHEIM. Phys. Zeitschr. (2) 97, 1901.
2) NERNST. Phys. Zeitschr. (7) 380, 1906.
3) LANGMUIR. Phys. Rev. (7) 302, 1916.
4) PIRANI and MIETHING. Verh. D. Phys. Ges. 219, 1915
5) IVES and KINGSBURY. Phys. Rev. (8) 323 1916 and mech. equiv. $M = 0.00159$ Phys. Rev. (8) 254, 1916.
6) FOOTE and FAIRCHILD. Scient. papers Bur. Stand. n° 270 and-$M = 0.00159$.

LANGMUIR has made a series of measurements on tungsten-lamps from which by means of the mean emissive power the brightness of the black body may be calculated. At the higher temperatures the results of these measurements are in good accordance with the calculated values. At the lower temperatures the measured values are considerably smaller. LANGMUIR ascribes this deviation to the influence of the Purkinje-effect in the photometric determinations. If the values found by NERNST and by LUMMER and PRINGSHEIM are reduced to the temperature-scale used by LANGMUIR, the results of their measurements are found to be very nearly in a constant ratio to those of LANGMUIR'S; LANGMUIR finds an intensity which is 1.15 times higher. It is, therefore, probable that in the measurement of the former investigators also the Purkinje-effect must have played a part. IVES and KINGSBURY [1]) have also pointed this out. It thus seemed to us worth while determining the intensity of the black body once more, arranging the method in such a manner that the Purkinje-effect cannot arise. We made our measurements in the neighbourhood of the melting-point of gold seeing that this temperature is sufficiently well ascertained to enable us from the intensity as measured, the known energy-distribution of the black body and the luminosity curve for the human eye to calculate the mechanical equivalent of light.

*Method and instruments.*

The arrangement of the method is rendered in fig. 1. Through the telescope $A$, the photometric prism $B$ and the two totally reflecting prisms $C$ and $D$, a small disc of alundum blackened with oxydes and placed in the furnace $E$ and a plate of ground glass $F$ are seen immediately beside each other. $F$ is provided with a diaphragm the opening of which is measured with great accuracy. $F$ is illuminated by a second plate of ground glass $G$ and a projection-lamp $H$, which is placed behind it. The three prisms $B$, and $C$ and $D$ are mounted on one plate $I$. They may be removed in a body and replaced in exactly the same position. When $I$ is removed the temperature of the furnace may be measured with the HOLBORN and KURLBAUM-pyrometer $J$ and the candle power of the ground-glass $F$ with the BRODHUN-sector photometer $K$.

In front of $F$ an additional rotating sector $L$ was placed. This sector rotated during the comparison between furnace and ground-glass but was stationary in the photometric measurement of $F$ in

[1]) IVES and KINGSBURY, Phys. Rev. (8) 177, 1916

order to obtain a greater intensity of light. Moreover a potassium bichromate filter $M$ was placed in front of $F$ by means of which

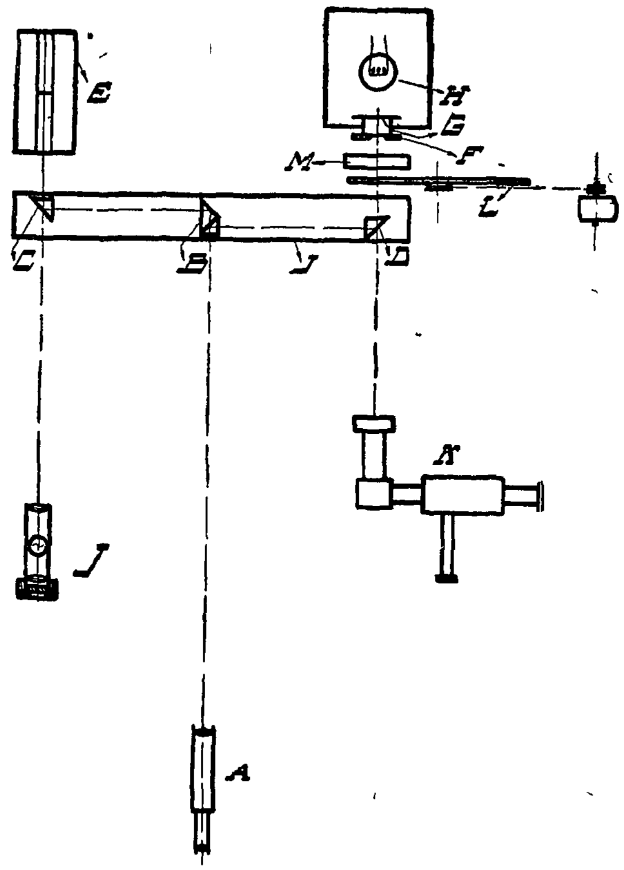


Fig. 1.

in the comparison of furnace and ground-glass the colour could be matched.

The measurement was made as follows. The plate $I$ with the prisms was removed and the temperature of the furnace was checked until it was properly constant. $I$ was then replaced and with the sector $L$ in motion the brightness of the ground-glass $F$ as seen through the telescope $A$ was made equal to that of the alundum disc in the furnace. This was attained by varying the current in the projection-lamp. As soon as equality was obtained the prisms $BCD$ were once more removed; the furnace-temperature was then again determined and the ground-glass $F$ was measured photometrically with the sector open. In this measurement the intensity was $\frac{200}{10}$ times greater than in the comparison furnace-ground glass. The photometric measurement of $F$ with the bichromate filter in front was difficult owing to the great difference in colour. For this reason $F$ was measured without the filter. From the brightness obtained in this way and the absorption of the filter the brightness of $F$ with the filter in front could be calculated. The absorption of the filter was determined separately with a flicker-photometer for the same spectral energy-distribution of the light-source. For this measurement the intensity of the ground glass was too small, however; according to IVES [1]) in order to obtain satisfactory results with a flicker-photometer the illumination of the photometer-fields must be about 25 metre-candles. This higher intensity was obtained by cementing together the two plates of ground glass with a drop of canada-balsam [2]). They became transparent thereby and the absorption in the bichromate filter could now be determined at a suitable brightness of the photometer-fields. Fig. 2 shows the ratio of the intensities with and without filter at various current-strengths through the projection-lamp. The measurements both with the flicker-photometer and the Brodhun-photometer are given in the figure. Although the determinations with the Brodhun-photometer will be seen to deviate mutually more than those with the flicker-photometer, the two series do not appear to give any systematic difference. This is not to be wondered at considering that all the measurements were made at such intensities of the photometer-fields that the Purkinje-effect could not have any influence.

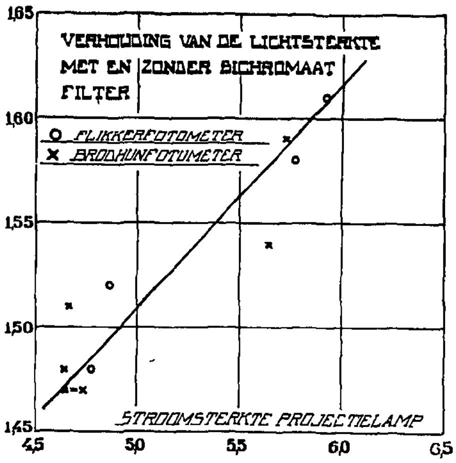


Fig. 2.

1) IVES. Phil. Mag. (24) 1912.

2) The glass-plates which we used were not completely free of colour. Otherwise they might have been simply removed.

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*The measurements.*

The pyrometer which was used for measuring the temperature had been very carefully standardized at the melting-point of gold. The greatest deviation in six measurements was 1° C. The active wave-length of the red glass filter (SCHOTT and GEN. N°. 2745) had been determined by the method of HYDE, CADY and FORSYTHE [1]) with a spectro-photometer. By means of photometric measurements the relation was established between the current in the pyrometer-lamp and the ratio of the intensity as measured at a definite temperature through the red filter to the intensity at the melting point of gold.

The constant of the BRODHUN-photometer was determined by means of a set of lamps which had been standardized in the Phys. Techn. Reichsanstalt.

The set of three prisms *B C D* was standardized separately. The determination of the absorption of the bichromate-filter was made by six observers. The results of four of these agreed to within about two percent. The other two obtained larger deviations. As with them similar irregularities had been noticed on a former occasion, their results were rejected.

The following results were thus arrived at:

| $T$ | $H$ candles/cm². | $T$ | $H$ candles/cm². |
|---|---|---|---|
| 1296 | 0.0743 | $1298^5$ | 0.0743 |
| $1301^5$ | 0.0716 | 1301 | 0.0682 |
| 1307 | 0.0784 | 1427 | 0.369 |
| 1307 | 0.0820 | $1415^5$ | 0.324 |

By means of a plot of the form $\log H = f\left(\frac{1}{T}\right)$ we found at the melting point of gold $T = 1336°$ $H = 0{,}119^{HK}/_{\mathrm{cm}^2}$.

The values found by us agree well with those calculated by others, but deviate very far from the numbers obtained by NERNST and by LUMMER and PRINGSHEIM. It is, therefore, very probable that in their measurements the Purkinje-effect must actually have played a part. NERNST used rods of an area of 10 mm². The intensity in his measurements was, therefore, very small indeed.

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[1]) HYDE, CADY and FORSYTHE Astrophys Journ. (42) 294, 1915.

*The mechanical equivalent of light.*

According to our results the brightness of the black body at 1336° $K$ would be 0,119 $^{Hk}/_{cm^2}$. The light-flux is therefore 0,119 $\pi$ $H^{lumen}/_{cm^2}$ But this flux is also equal to:

$$\frac{1}{M}\int_0^\infty E_\lambda V_\lambda d\lambda = \pi\, 0{,}119$$

where $M$ is the mechanical equivalent of light i. e. the number of watts required to obtain a light-flux of 1 $H$lumen of the wave-length for which the sensitiveness of the eye for light is a maximum; $E\lambda$ being the intensity of radiation of the black body in the wave-length $\lambda$ at 1336°, $V_\lambda$ the sensitiveness of the eye for light of wave-length $\lambda$.

Calculating $M$ for the determinations of the luminosity curve of a number of observers we found using the measurements of

| | |
|---|---|
| Coblentz and Emerson (125 persons)[1] | $M = 0{,}00154$ $^{Watts}/_{H\ Lumen}$ |
| Ives and Kingsbury (61 persons)[2] | 0,00151 |
| Nutting (21 persons)[3] | 0,00135. |

The constants in Planck's formula[4] were taken as follows:

$c_1 = 3{,}704\ 10^{-12}\ ^{Watts}/_{cm^2}$

$c_2 = 1{,}4300$ genomen.

With 1 watt a mean spherical intensity of 51.7 H-Candles may thus be obtained.

We add the results of a few more observers.

| | |
|---|---|
| Buisson and Fabry[5] | $M = 0{,}00130\ ^{W}/_{HL}$ |
| Nutting[6] (acetylene flame) | $M = 0{,}00108$ |
| Langmuir[7] (tungsten-lamp luminosity curve according to Nutting) | $M = 0{,}00109$ |
| Ives and Kingsbury[8] (various methods) | $M = 0{,}00143$ |
| Pirani and Miething[9] (measurement on lamps) | $M = 0{,}00123$ |

1) Coblentz and Emerson. Ref. El. World (69) 1117, 1917.

2) Ives and Kingsbury. Phys. Rev. (6) 319, 1915.

3) Nutting. Phil. Mag. (29) 301, 1915.

4) $c_2$ was taken in accordance with the new temperature scale of the Ph. T. R. This choice further involves $h = 6{,}55\ 10^{-27}$, $N = 6{,}05\ 10^{23}$, $\sigma = 5.75\ 10^{-12}$ $^{watts}/_{cm^2}$ in good agreement with the most recent measurements.

5) Buisson and Fabry. Compt. Rend. (153) 254, 1911. Comp. also Ives, Coblentz and Kingsbury. Phys Rev. (5) 269, 1915.

6) Nutting. Phil. Mag. (29) 301, 1915.

7) Langmuir. Phys. Rev. (7) 302 1916.

8) Ives and Kingsbury. Phys. Rev. 1915 and 1916, various articles. Final value in (8) 254, 1916.

9) Pirani and Miething. Verh. D. Phys. Ges. 219, 1915.

The agreement with IVES [1]) is thus pretty close. A large source of uncertainty is due to the sensitiveness of the eye. By selecting observers with normal eyes in the manner proposed by IVES and KINGSBURY [2]) it will undoubtedly be possible to obtain results which are in better mutual agreement.

*Eindhoven.* *Physical Lab. of Philips's Incandescent lamp-factory.*

1) With $c_2 = 14350$ we find $M = 0{,}00143$ W/HL (Note added in translation).

2) IVES and KINGSBURY. Trans. Ill. Eng. Soc. (X), 317, 1915.

Compare particularly RICHTMEYER and CRITTENDEN. Ill Eng. Soc. New-York. Febr. 10 and 11, 1916.