A NEW EXPERIMENTAL DETERMINATION OF THE BRIGHTNESS OF A BLACK BODY, AND OF THE MECHANICAL EQUIVALENT OF LIGHT.

By Edward P. Hyde, W. E. Forsythe and F. E. Cady.

Part I. Brightness of a Black Body as a Function of its Temperature.

THE brightness or candlepower per cm^2 of a black body at various temperatures has long been a matter of interest. Lummer and Kurlbaum,[1] in connection with their work on radiation, determined the relation between brightness and temperature for radiating platinum and expressed the opinion that the exponential relation found would hold at least approximately for a black body. Subsequently[2] Lummer and Pringsheim determined the brightness of a black body at three temperatures (1448° K., 1598° K. and 1708° K.) and extrapolated their observed curve to give the brightness up to 2073° K., at which temperature they ascribed the brightness of 100 Hefner candles per cm^2.

A couple of years later Nernst,[3] starting from one of the extrapolated points given by Lummer and Pringsheim, found a brightness of 91 Hefner candles per cm^2 at the temperature of melting platinum (taken by him as 2018° K.), and a brightness of 1210 Hefner candles per cm^2 at the temperature of melting iridium, which latter he calculated to be 2621° K. Subsequently[4] Nernst undertook a new set of measurements on the brightness of a black body, carrying his determinations over a range of temperature extending from about 1460° K. to about 2280° K. His temperature measurements of the black body were made with a Wanner pyrometer, and were based on a temperature of 1337° K. as the melting point of gold, and a value of 14600 μ deg. for the constant C_2 in the Planck equation.

From the observed data Nernst computed the values of the constants A and B in the equation

$$\log K = -\frac{A}{T} + B,$$

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[1] Verh. d. Deut. Phys. Gesel., 2, p. 90, 1900.

[2] Phys. Zeit., 3, p. 97, 1901.

[3] Ibid., 4, p. 733, 1903.

[4] Ibid., 7, p. 380, 1906.

which had first been given by Rasch[1] and subsequently deduced on what Nernst considers more justifiable theoretical grounds by Haber[2] and Lucas[3] as expressing the relation between brightness, K, and temperature, T. Nernst apparently relies on the values deduced from this equation as more accurate than the individual direct determinations. With the use of this equation he computes the brightness of the black body at the temperature of melting platinum, taken as 2018° K., to be 63.4 Hefner candles per cm^2, rather than 91 as given in his original paper. He offers an explanation of the cause of error in the earlier work.

It should be noted in passing that Rasch's equation is deducible from the Planck equation as the variation in brightness in some one wave-length, and so is the theoretical foundation for the method of heterochromatic photometry proposed some time earlier by Crova.[4] But it has been recognized for a long time that Crova's method is only approximate over more than a small temperature interval, since the effective wave-length varies with the temperature.[5]

Eisler[6] in 1904, assuming Planck's equation for the distribution of energy in the spectrum of a black body and using Langley's original data on visibility computed the relative brightnesses of a black body at different temperatures, obtaining a relation of brightness with temperature from which he computed the exponent x in the equation

$$\frac{H_1}{H_2} = \left(\frac{T_1}{T_2}\right)^x,$$

where H_1 and H_2 are the relative brightnesses at the two respective temperatures T_1 and T_2 taken close together. The curve of x as a function of temperature passes fairly closely through the points plotted from the observations of Lummer and Pringsheim.

Various computations[7] after the method of Eisler have been made in recent years, using visibility data obtained in more accurate ways and unquestionably much nearer the truth than the original data of Langley, but these computations are founded on the original experimental brightness values of Lummer and Pringsheim, and the subsequent values of Nernst, and there is reason to believe that these experimental values are subject to some error, and that, moreover, in each case there is some question about the relative computed brightnesses on account either of

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[1] Ann. d. Phys., 14, p. 193, 1904.

[2] Thermodynamik technisches Gasreactionen (Munich), 1905.

[3] Phys. Zeit., 6, p. 19, 1905.

[4] Comptes Rendus, 93, p. 512, 1881.

[5] PHYS. REV., 32, p. 320, 1911.

[6] Elek. Zeit., 25, p. 188, 1904.

[7] Elec. World, 57, p. 1565, 1911. Verh. d. Deut. Phys. Gessell., 17, p. 219, 1915.

the temperature scale or of the visibility data assumed. The only recent experimental data available are those of Langmuir,[1] and those of Ives and Kingsbury.[2] The former conducted his measurements on a tungsten filament, and his results are subject to some modification largely on account of the values assumed for the emissive power of tungsten which more precise determinations have shown to be in error. The experimental results of Ives and Kingsbury[3] determined both by the use of a black-body furnace and by the application of the wedge method in measuring black-body brightness at the melting points of platinum and gold respectively, are not very concordant, and are given but little weight by the authors themselves.

It therefore seemed opportune to the authors to undertake a new series of experimental determinations of black-body brightness as a function of temperature, and to compare these experimental results with the relative values computed on the assumption of the most probable visibility curve and of the Planck equation for spectral energy distribution after the manner of Eisler. Within the past few years much progress has been made in the establishment of the high temperature scale, and black-body furnaces may now be operated up to temperatures of at least 2600° K. under reasonably favorable conditions for brightness determinations, and with a considerable degree of confidence in the precision of the temperature measurements. Of course, the temperature scale assumed plays an important rôle. This question will be dealt with in some detail in a subsequent section.

In like manner much progress has recently been made in determining the visibility curve of the average eye, but, in the opinion of the authors, since all the recent determinations had been made by the flicker method, there seemed a necessity for a determination of visibility by the direct comparison method. The findings of the flicker method in the investigations of several observers were not very concordant, and the method itself was open to question. The present investigation was therefore interrupted to make a new determination of the visibility curve by the direct comparison method, as will be discussed in a separate section. Fortunately uncertainties in this function produce only second order errors in the relative brightness curve of a black body, and since the range of temperature that can be employed is not extremely large the errors in the relative computed brightnesses are quite small if the chosen visibility curve even roughly expresses the facts. To what extent these

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[1] Phys. Rev., (2), 7, p. 322, 1916.

[2] Phys. Rev., (2), 8, p. 177, 1916.

[3] Since this paper was written, Dr. Ives has published a note in the Journal of the Franklin Institute (186, p. 122, 1918), giving data which seem to verify this original value.

considerations are justified will become apparent in the presentation and discussion of the experimental data.

The second part of the paper deals with the evaluation of the mechanical equivalent of light based upon the observed values of black-body brightness and upon the assumption of the constant σ ($E = \sigma T^4$) in the Stefan-Boltzmann law, and of the visibility curve. In this case errors in the visibility curve enter as first order effects and so the precise knowledge of this function becomes of much greater importance.

Temperature Scale.—The relation between observed brightness and temperature of a black body obviously depends upon the chosen scale of temperature. It is customary, in establishing a temperature scale, to assume certain fixed points, such as the melting points of gold and palladium, and to determine other points of the scale on the assumption of some radiation law such as the Stefan-Boltzmann law or the Planck equation. The former of these is accepted without reservation, but there is some slight question regarding the latter, though it is generally believed to represent the facts and is assumed as the basis of optical pyrometry. The values of certain of the constants entering into these equations are still, however, the subject of much discussion and investigation. This is particularly true of the constant C_2 in the Planck equation

$$E_\lambda = C_1 \lambda^{-5} \frac{1}{\epsilon^{\frac{C_2}{\lambda T}} - 1}.$$

As already stated it is customary to assume certain fixed points, such as the melting-points of gold and palladium as measured with the gas thermometer. The best determinations of these values are those of Day and Sossman,[1] but recent investigations would seem to show that the two melting-point temperatures are not consistent with the most probable value of C_2 in the Planck equation.[2] In order to have a definite temperature scale on which to express measurements of temperature the laboratories of the General Electric Company agreed upon the adoption of the gold point as given by Day and Sossman (1336° K.), and of the value 14350 μ deg. for the constant C_2. On this scale the temperature of melting palladium must be changed from 1823° K., the value found by Day and Sossman, to 1828° K. if the earlier measurements of the present authors[3] are correct, since it was found that the value of Day and Sossman was confirmed only upon the assumption of the value of 14460 μ deg. for C_2, if the gold point was accepted as 1336° K.

[1] Am. Jour. of Sci., (4), 29, p. 93, 1910.

[2] Gen. Elec. Rev., 20, p. 819, 1917.

[3] Astrophys. Jour., 42, p. 300, 1915.

Visibility Data.—As stated in an earlier paragraph, there was much doubt in the minds of the authors regarding the acceptability of the various visibility data available when the present investigation was begun. This doubt arose partly from the inconsistency of the various published results but more largely from an inherent skepticism regarding the applicability of visibility data obtained with the flicker photometer to practical problems in heterochromatic photometry in which the method of direct comparison was employed, as in the present investigation.

It is true that only gross differences in the visibility curve can produce appreciable errors in the computed relative brightnesses of a black body at two temperatures differing by only a few hundred degrees, but uncertainties in the visibility curve produce first-order effects in the evaluation of the mechanical equivalent of light. And when the authors found that even the second-order errors in the computed relative brightnesses of a black body on the assumption of the most recently published visibility data[1] with the flicker photometer, as compared with the experimental values found using the direct-comparison method of photometry, were larger than might readily be justified on the ground of experimental error, it was decided to delay the publication of the present investigation until a new determination of the visibility of radiation, using the direct-comparison method, might be made. The results of this investigation, together with a more complete discussion of the question, have already been published.[2]

The visibility data obtained in that investigation will be used in computing the relative brightnesses of a black body at different temperatures, for comparison with the values experimentally observed, and in evaluating the mechanical equivalent of light. For the extreme red end of the spectrum not included in the investigation referred to, use will be made of the visibility data obtained by two of the present authors in an earlier study[3] of visibility in this region; and for the extreme blue end the data of Hartman[4] obtained also in this laboratory will be employed. The complete visibility curve used is that recommended in appendix II. of the recent paper to which reference has just been made.

Apparatus and Method.—The measurements of the brightness of a black body at various temperatures were carried out with two electrically heated black-body furnaces. Most of the measurements were made with a specially designed water-cooled carbon-tube furnace, the remaining ones being made with a platinum-wound porcelain furnace provided with

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[1] Bul. Bur. of Stds., 14, p. 167, 1917.

[2] Astrophys. Jour., 48, Sept., 1918.

[3] Ibid., 42, p. 285, 1915.

[4] Ibid., 47, p. 83, 1918.

a Lummer-Kurlbaum black-body tube. The set-up, with the carbon furnace,[1] is shown in Fig. 1, in which *F* is the carbon furnace supplied with a limiting diaphragm. Three different sizes were used with apertures varying from 4 to 5 mm. in diameter. For details of construction and operation of this furnace the reader is referred to a previous paper by the authors on "Color Temperature Scales for Tungsten and Carbon."[2] *P* is a Lummer-Brodhun contrast photometer of special design, in which the contrast is only about 3.5 per cent. on the average and is graduated in either direction from the center—the two features conducing to higher sensibility. *L* is the comparison lamp,—at low temperatures a carbon lamp and at the higher temperatures a vacuum tungsten lamp. A series of black velvet screens *D* with suitable openings shut off stray light from the photometer.

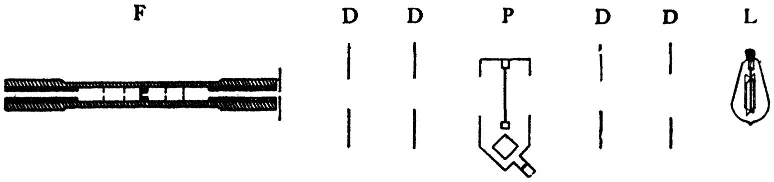

Fig. 1.
Diagrammatic Sketch of Apparatus.

The brightness measurements of the black body were always carried out with the comparison lamp at an approximate color match, except beyond 2400° above which temperature it was considered unsafe to operate the comparison lamp. The calibration of the comparison lamp at the various voltages, involving the difficulties of heterochromatic photometry, was made subsequently. In order to avoid the possible errors arising from individual idiosyncrasies of vision, the candlepower scale chosen was that given for a tungsten lamp by Middlekauff and Skogland.[3] The procedure of calibration consisted in transferring the photometer and comparison lamp to a standard photometer bench, and substituting a tungsten vacuum lamp for the black body. The comparison lamp was then brought successively to the various voltages used against the black body and readings were made against the tungsten lamp. In cases of large color difference blue screens calibrated at the Bureau of Standards were used. The relative candlepowers of the

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[1] Not as much weight is attached to the results obtained with the platinum-wound furnace because of the photometric difficulties at the low temperatures and with the necessarily small limiting diaphragm which the dimensions of the furnace demanded.

[2] PHYS. REV., (2), 10, p. 395, 1917.

[3] Bul. Bur. of Stds., 11, p. 483, 1915.

standard tungsten lamp were computed from the data of Middlekauff and Skogland, and hence the candlepowers of the comparison lamp, and so the brightnesses of the black body were obtained on this same scale.

The justification of the Middlekauff and Skogland candlepower scale as representative of the average eye may be arrived at through the intercomparison of the visibility curves of several members of this group with the average of the 125 observers employed in the investigation of Coblentz on the visibility of radiation. Such a comparison indicates that the mean of the eight observers employed by Middlekauff and Skogland is not markedly different from the mean of the 125 observers used by Coblentz. Other lines of reasoning would indicate that the scale of Middlekauff and Skogland is not far from correct, as representing an average eye, but that if any change were made it would be in the direction of raising the upper region of the candlepower curve slightly with respect to the curve for the lower temperatures. This change would be less than one per cent. and so, in the absence of more definite information, the Middlekauff-Skogland scale has been adopted in the present investigation.

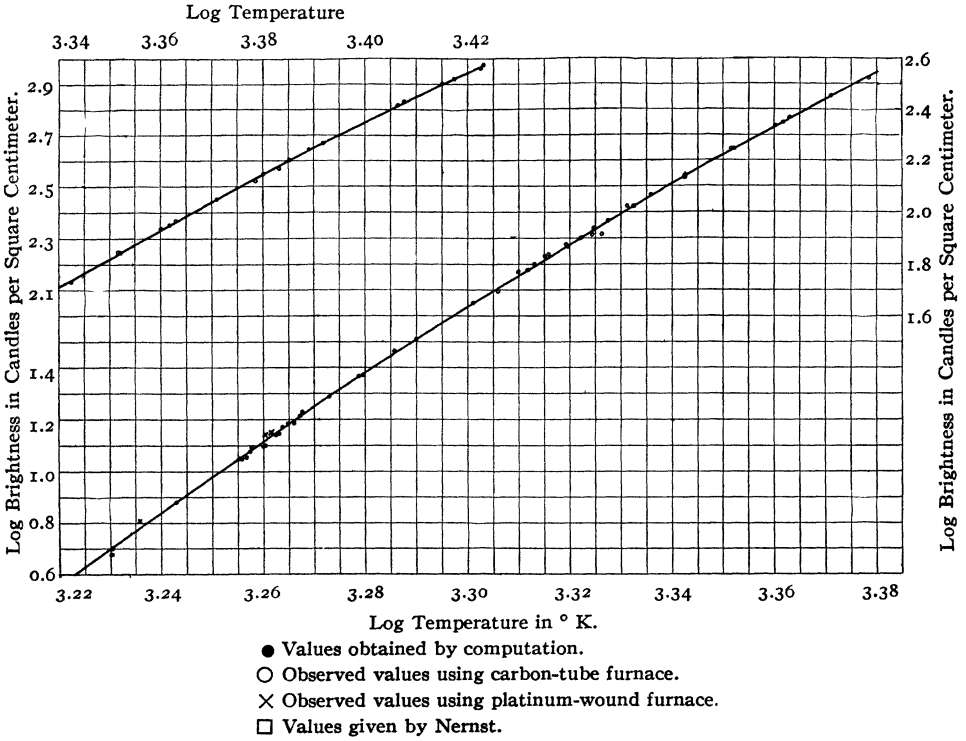

Fig. 2.

Brightness of a Black Body at Various Temperatures.

Experimental Results.—The results on black-body brightness expressed in candles per cm^2 as a function of the temperature in degrees K. are given in a logarithmic form in Fig. 2, and the corresponding numerical results, taken from the curve are given for every 50° in Table I. The circles on the plat are the observed points obtained with the carbon-tube furnace, and the x's are the observed points using the platinum-wound furnace. The curve is drawn according to a least-square solution applied to the 46 observed points and assuming the cubic equation,

TABLE I.

Brightness of a Black Body at Various Temperatures.

Temperature.	Brightness Candles per Square Centimeter.	Temperature.	Brightness Candles per Square Centimeter.
1700° K.	5.0_8	2200° K.	$137._6$
1750	7.6_4	2250	177.
1800	11.3	2300	226.
1850	16.3	2350	284.
1900	23.1	2400	354.
1950	32.2	2450	438.
2000	$44._3$	2500	537.
2050	$60._0$	2550	651.
2100	$80._1$	2600	785.
2150	$105._7$	2650	939.

$$u = a + bt + ct^2 + dt^3,$$

where u = log candles per cm^2,

$t = \log T - 3.2$,

T = temperature in degrees K.

The values of the constants were found to be as follows:

$$a = 0.2626, \qquad c = -12.38,$$

$$b = 14.959, \qquad d = -1.13.$$

The 46 points are so distributed with respect to the least square curve that 23 points lie on one side and 23 on the other, the maximum deviation of any point, as seen from the curve, being about 8 per cent. The two points furthest from the curve by Chauvenet's criterion could be discarded. Thirty points lie within 2.5 per cent. of the curve, the average deviation of all points being about 2.4 per cent. The upper one of the three points obtained by Lummer and Pringsheim is within about 3.5 per cent of the curve (the other two points are at lower temperatures than any included in our observations) and the later observations of Nernst, reduced to the present temperature scale, are indicated by □'s.

The dots are the points computed on the basis of the authors' recently published data on the visibility of radiation, as discussed above. These computed brightnesses are, of course, only relative, but the value at 2077° K., which is in the neighborhood of the color temperature of the 4-wpc carbon standard lamp, was taken from the least square solution, and the other points were plotted in terms of that. It is seen that the computed points lie on the observed curve within an error of less than 1 per cent. except at the extreme ends of the temperature range. This is better than might be expected owing to the inherent difficulties in the present experiment. Points computed from Coblentz's visibility data show a consistent difference from the observed curve, though the difference is nowhere large.

The accuracy indicated in the brightness measurements suggests the advisability of adopting tentatively the value 70.2 candles per cm^2 as the brightness of a black body at the temperature 2077° K. and as a value for a primary standard of light. The temperature chosen is approximately the color temperature of the standard 4-wpc carbon lamps.[1]

PART II. THE MECHANICAL EQUIVALENT OF LIGHT.

This term has come to be used to mean the watts per lumen of the monochromatic light of greatest visibility, corresponding, in the recent experiments of the authors, to a wave-length $\lambda = 0.556\ \mu$. It is a physical constant of theoretical interest, and also serves as a means of expressing the absolute efficiency of illuminants. It depends on the brightness of a black body, or other source with known emissive power, on the temperature scale chosen, also on the constant σ in the Stefan-Boltzmann law ($E = \sigma T^4$), and finally on the curve of relative visibility of radiation,—*i. e.*, provided it is evaluated in the way to be followed in this paper. It may be determined directly by measuring the radiant flux and the luminous flux from some monochromatic source in a wave-length at or near that of maximum visibility. Determinations have been carried out by this method,[2] but in the opinion of the authors the experimental difficulties are too great to justify much confidence in the results.

In the present investigation the mechanical equivalent M, following the usual procedure, has been evaluated in the following way. Let

$B_0 \equiv$ normal brightness of the black body at any temperature T expressed in candles per cm^2.

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[1] The data given above are somewhat different from those published in the advance note in the Journal of the Franklin Institute (Jour. of Franklin Inst., 181, p. 420, 1916.) These differences are due to the assumption of a different temperature scale and to the addition of several new observed points which produced a small change in the curve, particularly at the higher temperatures.

[2] Phys. Rev., (2), 5, p. 269, 1915.

$E_\lambda \equiv$ the radiant flux per cm² per unit wave-length at the wave-length λ.
$V_\lambda \equiv$ the relative visibility of radiation in any wave-length λ in terms of the maximum visibility taken equal to unity.

Then

$$B_0 = \frac{1}{\pi M}\int_0^\infty E_\lambda V_\lambda d\lambda \tag{1}$$

or

$$M = \frac{1}{\pi B_0}\int_0^\infty E_\lambda V_\lambda d\lambda. \tag{2}$$

In the present investigation the visibility function is assumed as extending from 0.40 μ in the blue to 0.76 μ in the red, the values assigned in the two extreme ends of the spectrum being taken from the previously published data of two of the present authors[1] in the red, and of Hartman[2] in the blue.[3] Beyond the chosen limits the added luminosity area would be entirely negligible.

The method employed in evaluating the integral in equation (1) was that of summating the product $E_\lambda V_\lambda \Delta\lambda$ for steps $\Delta\lambda = 0.01\ \mu$, and correcting for the errors of summation by the one third rule. The value of E_λ and therefore that of M depends upon the constant C_1 in Planck's equation, or its equivalent σ in the Stefan-Boltzmann equation, since these two constants are definitely related if C_2 is known. The latter is taken as 14350 μ deg., as discussed in the first part of the paper, and for σ the value $5.7 \times 10^{-12} \frac{\text{watts}}{\text{cm}^2\ \text{deg}^4}$, as found by Coblentz, has been assumed as the most probable value. On the basis of these values, C_1 comes out as 3.72×10^{-12} watts cm².

TABLE II.

Mechanical Equivalent M for Various Temperatures.

Temperature.	M in Watts per Lumen.	Temperature.	M in Watts per Lumen.
1700° K.	0.00147_8	2200° K.	$.00149_6$
1800	$.00149_1$	2300	$.00149_7$
1900	$.00149_8$	2400	$.00149_7$
2000	$.00149_8$	2500	$.00150_2$
2100	$.00149_7$	2600	$.00151_1$
Average.......	....	....	0.001496

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[1] *Loc. cit.*

[2] *Loc. cit.*

[3] The complete visibility curve used is given in Appendix II. of the paper by the present authors on "The Visibility of Radiation," Astrophys. Jour., Sept., 1918.

TABLE III.

Investigators.	**Recommended Values of the Mechanical Equivalent of Light in Watts per Lumen.**	**Visibility Data.**	**Constants** σ in $\frac{\text{Watts}}{\text{Cm.}^2}\text{Deg.}^4$ C_2 in μ Deg.	**Method.**
P. G. Nutting	0.00120±0.00005	Nutting	$\sigma=5.7\times10^{-12}$ (Presumably)	Measurements of total radiant flux and total luminous flux from acetylene. Coblentz' energy curve for acetylene used.
H. E. Ives	0.00160±0.00003	Ives & Kingsbury Curve from equation	$\sigma=5.7\times10^{-12}$	(1) Measurement of total radiant flux and total luminous flux from a monochromatic source. (2) Measurement of radiant flux through luminosity filter and integral luminous flux direct from the source.
	Secondary value 0.00154	Ives & Kingsbury	$\sigma=5.7\times10^{-12}$ $C_2=14350$	(3) Measurement of brightness of a platinum-wedge black body at the melting point of platinum taken as 2037° K.
W. W. Coblentz	0.00162±0.00005 Note: If in method (1) the final data of Hyde, Forsythe and Cady were used, the value derived by this method would be increased by approximately 1½ per cent.	Coblentz and Emerson	$C_2=14350$ Melting points as given by Day and Sossman	Several methods using observations by himself and others. (1) Computation using preliminary data on brightness of a black body by Hyde, Forsythe and Cady. (2) Direct measurement on monochromatic radiation, by Coblentz, Ives and Kingsbury. (3) Measurements on incandescent lamps by Coblentz and Emerson.
Hyde, Forsythe and Cady	0.00150±0.00005	Hyde, Forsythe and Cady	$\sigma=5.7\times10^{-12}$ $C_2=14350$ Melting point of gold 1336° K.	Direct measurement of brightness of carbon and platinum tube black bodies.

Substituting in equation (5) the brightness of the black body at any temperature, as given in the first part of this paper, a value of the mechanical equivalent M for any temperature is found. If the observed and computed curves of black-body brightness are the same throughout, then the value of M would be found to be the same for all temperatures, as might be expected. The differences between the two curves as presented in the first part of this paper are so small that the values for M computed for every 100°, as given in Table II., are sensibly constant, except at the extreme ends of the curve, the total range being only 2.2 per cent., and the range from 1800° to 2400° K. being only 0.5 per cent.

The average value from the present experiments is given in Table III., in comparison with the published values of other observers. In each case so far as is possible from the published reports, the method used, the visibility curve employed (if any) and the temperature scale involved are given.

SUMMARY.

1. A new set of experimentally determined values of the brightness of a black body from 1700° to 2600° K. are given on the assumption of a temperature scale based upon Planck's equation taking the gold point as 1336° K. and the constant C_2 as 14350 μ deg.

2. These values, as plotted in a curve obtained by a least-square solution, are compared with the relative computed values on the assumption of the visibility curve recently published by the authors.

3. A value of 70.2 candles per cm² as the brightness of a black body at a temperature of 2077° K. (color match with 4-wpc standard carbon lamps) is proposed tentatively as an absolute standard of light.

4. The mechanical equivalent of light for the wave-length of maximum visibility ($\lambda = 0.566\ \mu$) is computed to be 0.00150 ± 0.00005 watts per lumen.

APPENDIX I.

It is frequently desired to know the rate of change of candlepower or of brightness of a black body at any temperature with a change in temperature or a change in watts. Since the data presented in the body of this paper are somewhat different from other published data it seems advisable to compute these coefficients and at the same time to evaluate the Crova wave-length[1] at different points on the brightness-temperature scale.

Differentiating equation (1) for the brightness of a black body with reference to temperature, the following final equation is obtained:

$$\frac{dB_0}{dT}\frac{T}{B_0} = \frac{C_2}{T}\frac{\int_0^\infty \frac{1}{\lambda}E_\lambda V_\lambda d\lambda}{\int_0^\infty E_\lambda V_\lambda d\lambda}. \qquad (3)$$

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[1] *Loc. cit.*

If now the summation method employed in the body of the paper in computing the mechanical equivalent of light be used the integral in the denominator is at once obtained; and if the respective terms at any temperature are multiplied by the reciprocals of the wave-length and the summation made, the numerator is also obtained. The ratio of these two integrals at any temperature, multiplied by C_2/T gives the desired percentage change in brightness corresponding to a change of 1 per cent. in temperature. These results are shown in Fig. 3. Since $E = \sigma T^4$ expresses the relation between temperature and total watts radiated it follows that if the ordinates of the curve are divided by 4 the resultant curve will show the percentage change of brightness corresponding to a change of 1 per cent. in total watts radiated.

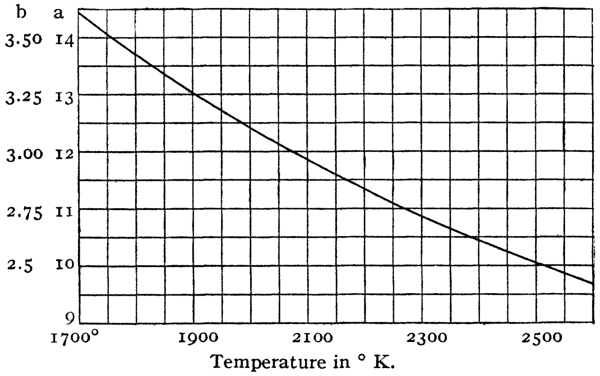

Fig. 3.

Percentage Changes in Brightness of a Black Body at Various Temperatures for (*a*) one per cent. change in temperature and for (*b*) one per cent. change in watts.

Moreover it follows from equation (3) that if λ_0 is the wave-length such that at some temperature the ratio of the two integrals in equation (3) is $1/\lambda_0$, then at that temperature

$$\frac{dB_0}{dT}\frac{T}{B_0} = \frac{C_2}{\lambda_0 T}, \tag{4}$$

or, the percentage change in brightness corresponding to a change of 1 per cent. in temperature is equal to $C_2/\lambda_0 T$.

But it follows immediately from Wien's equation that

$$\frac{dE_{\lambda T}}{dT} \cdot \frac{T}{E_{\lambda T}} = \frac{C_2}{\lambda T}, \tag{5}$$

or, the percentage change in watts radiated by a black body at any wave-length λ and at any temperature T, corresponding to a change of 1 per cent. in temperature is $C_2/\lambda T$. Hence if the particular value λ_0 be taken for λ, then from equations (4) and (5) it follows that the percentage change in brightness at any temperature, and the percentage change in watts emitted at that temperature in the wave-length λ_0, corresponding to a change of 1 per cent. in temperature, will be the same. By definition, therefore, λ_0 is the Crova wave-length for that temperature, and hence is readily evaluated since the two integrals in equation (3) are now known. The values of the Crova wave-length thus obtained are given in Fig. 4.

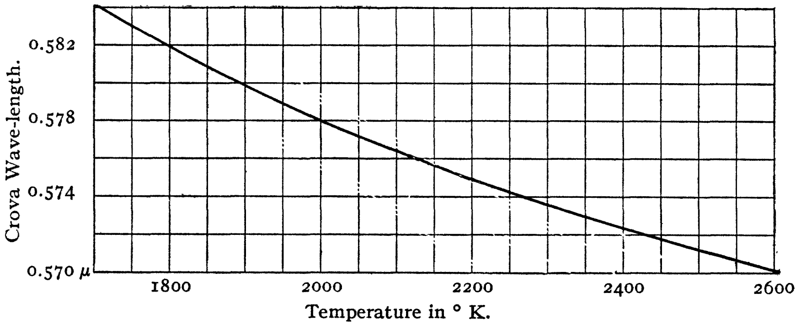

Fig. 4.

Crova Wave-length at Various Temperatures for Black Body Radiation.

It will be seen by comparison with the data published by Kingsbury[1] and by Coblentz[2] that the authors' values for the Crova wave-length are somewhat smaller. This difference is for the most part due to the difference in visibility curves since those obtained by the flicker method show larger values in the longer wave-lengths of the visible spectrum.

Nela Research Laboratory,
National Lamp Works of General Electric Co.,
Nela Park, Cleveland, Ohio,
September, 1918.

[1] Phys. Rev., (2), 7, p. 167, 1916.

[2] Bul. Bur. of Stds., 14, p. 255, 1918.