Div VII & IX

RADIATION FROM PLATINUM AT HIGH TEMPERATURES.

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The study of the emissive properties of substances which can be brought to high temperatures without undergoing chemical or physical changes of surface is important in optical pyrometry for the practical realization and measurement of high temperatures; for a knowledge of the emissive properties of platinum, for instance, at various temperatures, gives a ready means of obtaining true temperatures from observations of the "black-body temperatures" as measured by an optical pyrometer. A platinum strip may replace to advantage an experimental black body, especially at temperatures above 1,500° C., and may conveniently serve as a luminous source for the comparison or calibration of optical pyrometers.

It is the object of this paper to interpret the observations[a] of Dr. Waidner and the author on the departure of platinum from black-body radiation for red, green, and blue light, in terms of the now better known values of the higher temperatures involved, and as expressed by Wien's law as applied in a form first suggested by Lucas.[b]

For a black body, Wien's law for the distribution of energy in the spectrum may be written

$$\log E = \log C_1 - 5 \log \lambda - \frac{C_2 \log \varepsilon}{\lambda} \theta_1 \qquad (1)$$

where E is the energy radiated between wave lengths λ and $\lambda + d\lambda$, θ^1 the reciprocal of the absolute temperature, C_1 and C_2 constants, and ε, the logarithmic base.

For any other substance at the same photometric brightness we have

[a] C. W. Waidner and G. K. Burgess: Optical pyrometry; Bull. Bureau of Standards, **1**, p. 189; 1904.

[b] R. Lucas: Phys. ZS., **6**, pp. 19, 418; 1905.

$$\log E = \log C_1^1 - n \log \lambda - \frac{C_2^1 \log \varepsilon}{\lambda} \theta_2 \qquad (2)$$

in which $n>5$, $C_2^1>C_2$ and $\theta_2>\theta_1$. Thus, for platinum $n=6.42$ according to Paschen, and $n=6$ from Lummer and Pringsheim's work. The largest value of C_2 for the visible spectrum is that deduced from the measurements of Lummer[a] and Pringsheim: $C_2=5\lambda_m T=5\times 2940=14700$, and the smallest value of C_2^1 is $C_2^1=6\lambda^1{}_m T^1=6\cdot 2600=15600$.

That $\theta_2>\theta_1$, follows from the definition of a black body. C_1 and C_1^1 are both small and the difference of their logarithms is negligible in most of what follows.

We may shorten the expressions by grouping the various constants, as follows:

$$(A)\begin{cases}\log C_1 - 5 \log \lambda = K_1 \\ \log C_1^1 - n \log \lambda = K_1^1\end{cases} \qquad (B)\begin{cases}C_2 \dfrac{\log \varepsilon}{\lambda} = K_2 \\ C_2^1 \dfrac{\log \varepsilon}{\lambda} = K_2^1\end{cases}$$

Whence, by equating (1) and (2),

$$K_1 - K_2\theta_1 = K_1^1 - K_2^1\theta_2$$

Or, more simply,

$$\theta_1 = \alpha\theta_2 + \beta \qquad (3)$$

Where

$$\alpha = \frac{K_2^1}{K_2} = \frac{C_2^1}{C_2} \text{ by } (B) \qquad (4)$$

And

$$\beta = \frac{K_1 - K_1^1}{K_2} = \frac{\lambda\,(\log C_1 - \log C_1^1 + (n-5)\log \lambda)}{C_2 \log \varepsilon} \text{ by } (A) \text{ and } (B) \qquad (5)$$

or

$$\beta = K\lambda \log \lambda \qquad (5a)$$

where K is a constant, characteristic of the substance.

Furthermore, the constants α and β must lie within well-defined limits, as follows:

$$\alpha \gtrdot 1 \text{ since } C_2^1 > C_2 \qquad (6)$$

That is, α is always greater than unity, but approaches unity as the substance examined is more nearly a black body; $\alpha=1.06$ from

[a] A discussion of the values of these constants is given by Lummer in Reports to Congress of Physics, Paris, 1900, vol. 2, p. 41.

the data cited above. Again, α is independent of the wave length λ to a first approximation, by (4).

Since experiment shows $n > 5$, we have

$$\beta \geqslant 0 \tag{7}$$

or β approaches zero as the black body condition is approached, and equation (5a) shows the dependence of β upon the wave length, namely, that β increases as the product of the wave length into its logarithm. The constant n can evidently be computed by (5) if β and C_2 are known, or conversely, β may be calculated; but then, in these computations $\log C_1 - \log C_1^1$ is no longer negligible.

Equation (3) was deduced by Lucas,[a] although he does not show completely the interrelations of the constants involved nor the necessary limitations as to the numerical values of α and β.

Equation (3) with the above corollaries is fundamental and completely expresses the departure of any substance from a black body in terms of the temperature and two constants whose values are a measure of its emissive properties, and states that *the reciprocals of the temperatures of a black body and any substance having the same photometric brightness are directly proportional.*

As the equation is linear, a knowledge of the black body temperature and true temperature at two points only is sufficient to completely define the departure of the radiation of a given substance from that of a black body throughout the entire temperature scale, provided the substance undergoes no chemical change; and since α is a contant independent of λ, when equation (3) is determined for any single value of λ, that for any other value of λ in the visible spectrum is had by an observation of θ_2 at a single temperature. These facts are expressed by writing (3) in the form:

$$\theta_1 = \alpha\ \theta_2 + K \lambda \log \lambda \tag{8}$$

Experimetal verification of the above conclusions is had in the observations[b] of Dr. Waidner and the author on the relation between the black body temperature and the true temperature of platinum for wave lengths $\lambda = 0.651\mu$ (red), $\lambda = 0.550\mu$ (green), and $\lambda = 0.474\mu$ (blue). The observations were taken on a platinum strip mounted on a Joly meldometer, and the scale defined by melting points, that of platinum[c] being assumed as 1,715° C. and palladium (slightly impure) as 1,525° C.

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[a] Lucas, l. c.

[b] Waidner and Burgess, l. c.

[c] Holborn and Henning: Sitzungber., Berlin Akad., March 2, 1905, p. 311. Harker: Chem. News, **91**, pp. 262, 274; 1905.

The accompanying table gives S, the black body temperatures (absolute) of the platinum as measured by a Holborn-Kurlbaum optical pyrometer, corresponding to the true absolute temperatures T. θ_1 and θ_2 are the reciprocal temperatures, i e., $\theta_1=\frac{1}{S}$ and $\theta_2=\frac{1}{T}$, and the number of determinations of S is given in the column headed p.

Radiation from platinum.

T_{obs}	S_{obs}	θ_1	θ_2	T computed.	$T_{obs}-T_{calc}$	p
RED LIGHT: $\lambda=0.651\mu$. $\theta_1=1.0256\ \theta_2+0.0000357$.						
996	939	0.0010650	0.0010040	996.3	—0.3	6
1055	990	10101	9479	1052.5	+2.5	2
1223	1145	8734	8177	1224.3	—1.3	5
1337	1246	8026	7480	1337.9	—0.9	10
1500	1392	7184	6667	1502.2	—2.2	2
1606	1482	6748	6227	1604.7	+1.3	2
1798	1647	6072	5562	1794.5	+3.5	9
1988	1814	5513	5030	1989.1	—1.1	14
GREEN LIGHT: $\lambda=0.550\mu$. $\theta_1=1.0320\ \theta_2+0.0000218$.						
1337	1258	0.0007949	0.0007480	1334.9	+2.1	5
1500	1409	7097	6667	1500.3	—0.3	2
1606	1506	6640	6227	1607.0	—1.0	2
1798	1676	5967	5562	1795.2	+2.8	4
1988	1850	5405	5030	1989.6	—1.6	10
BLUE LIGHT: $\lambda=0.474\mu$. $\theta_1=1.034\ \theta_2+0.0000107$.						
1606	1529	0.0006540	0.0006227	1607.3	—1.3	2
1798	1699	5886	5562	1789.3	+8.7	2
1988	1885	5305	5030	1989.2	—1.2	8

The observations for the red ($\lambda=0.651\mu$) satisfy the equation, see (3),

$$\theta_1=1.0256\ \theta_2+0.0000357$$

the constants being determined by least squares.
Similarly, for the green ($\lambda=0.550$)

$$\theta_1=1.0320\ \theta_2+0.0000218$$

and for the blue ($\lambda=0.474$)

$$\theta_1=1.034\ \theta_2+0.0000107.$$

The values of T as computed from the formula $T=\frac{\alpha}{\theta_2-\beta}$ are given in the fifth column of the table and $\varDelta T$ in the sixth. The differences between the observed and computed values of T are well within the errors of observation.

It will be seen, moreover, that within the same limits the value of α (coefficient of θ_2) satisfies the necessary conditions of being slightly greater than unity (equation 6) and a constant nearly independent of the wave length (equation 4). The values of β also satisfy the condition expressed in equations (5a) and (8).

Lucas[a] discusses Holborn and Kurlbaum's[b] observations on platinum for red radiation ($\lambda=0.643$), and finds they satisfy the relation

$$\theta_1=0.9857\ \theta_2+0.0000598$$

with an average deviation of about 4° C. Holborn and Henning[c] find empirically for the same observations

$$\theta_1=\theta_2+0.000507.$$

The preceding deductions from Wien's law are general and apply to any substance conserving the optical properties of its surface with continued heating. The comparative ease with which α and β may be determined experimentally, and the simplicity of the linear relation connecting them, would seem to indicate the desirability of expressing mono-chromatic radiation properties in terms of these two constants α and β. To the same order of approximation, Planck's equation gives the same solution.

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[a] Lucas l. c.

[b] Holborn and Kurlbaum: Ann. d. Phys. **10**, p. 225; 1903.

[c] Holborn and Henning, l. c.