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ON THE EMISSIVE POWER OF WEDGE-SHAPED CAVITIES AND THEIR USE IN TEMPERATURE MEASUREMENTS

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In practically all investigations of the radiating properties of metallic and other surfaces, the least accurate and most difficult part has been the determination of the true temperature of the radiating surface. This is true even within the range of accurate thermo-electric measurements, but more especially above this range, say from 1700° C. up, where lie the working temperatures of the various incandescent lamps, carbon, tantalum, tungsten, and osmium. The only methods so far found available for use in this extreme range are the radiation methods, total or partial, based respectively upon the law of Stefan-Boltzman or the equation of Wien. As ordinarily applied to a radiating surface, however, these give not the *true* but the so-called black-body temperature, i.e., the temperature of the radiantly equivalent black body.

The device to be described promises to be of some value because it enables one with a calibrated optical pyrometer to determine the *true* temperature of a radiating surface. It is, of course, nothing but a special scheme for obtaining the Kirchhoff black-body conditions—a black body being defined, as usual, by the conditions, a = absorptive power = 1; it will have, of course, the maximum possible emissive power at any temperature. The special scheme referred to is shown in Fig. 1, where F is a flat conducting ribbon, heated by a longitudinal electric current as shown, and folded on a line parallel to the length so that the resulting cross-section perpendicular to the current-flow is a very narrow V—say with about 10° angular opening. If the ribbon is of uniform thickness and width it will be raised to a uniform temperature by a given current, except near the ends. The inside of the V might be then expected to be a close approximation to a black body, or total radiator, since it has but a small opening and uniformly heated walls, and if this were so, observations on it with an optical pyrometer would give the *true* and not the "black-body" temperature of its inside walls. The *outside* of the V will give radiation characteristic of the material of the ribbon, and could be used to study this radiation; but before we can draw conclusions as to the temperature of the *outside* surface we must evidently consider two questions:

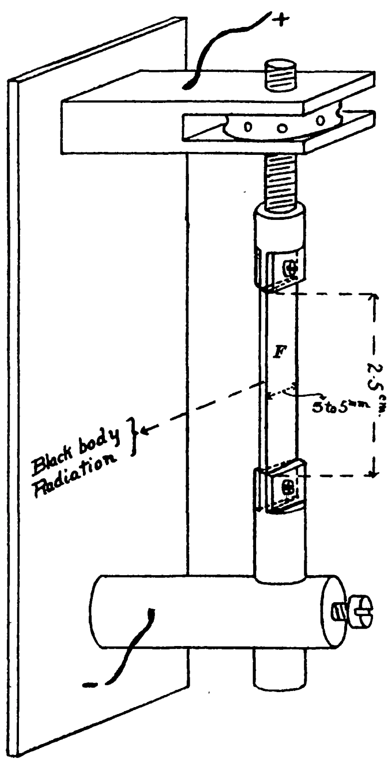

FIG. 1

1. How closely does the radiation from the inside of the V approximate that of a black body at the temperature of the *inside* walls?

2. How much real temperature difference is there between the inside and outside surface of the wall of the V?

The most convenient way of answering the first question follows the method used by Ch. Féry[1] in discussing the absorbing power of cones.

If AOB (Fig. 2) represents a section of the V perpendicular to its length, the walls being supposed plane and specularly reflecting,

[1] *Comptes Rendus*, **148**, 777, 1909.

then a ray entering in, or nearly in, the plane of the paper will be reversed in direction and emerge after $n=\frac{180}{\alpha}$ reflections. If the reflecting power of the surface is r, the effective reflecting power of the cavity will be r^n, and since there is no transmission the effective absorbing power will be $A=1-r^n$. Thus if $r=0.7$ (about that for a perfect surface of platinum) and $\alpha=10^\circ$, $r^n=0.0016$, and the emissive power $E=Ae=0.998e$, where e = emissive power of a total radiator. This departure from perfect emissivity ($E=e$) would correspond for $\lambda=0.658$ to a temperature difference of less than 0°5 at 1600° C. To this degree of accuracy, then,

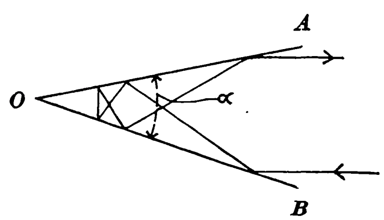

FIG. 2

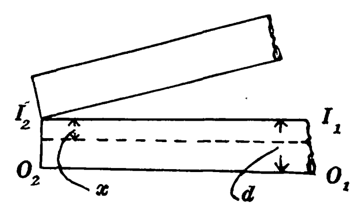

FIG. 3

optical pyrometer observations in the V aperture would give, under these conditions, the true temperature of the inside walls. If the inside surface of the wedge is matt instead of specularly reflecting, the previous conditions will not hold, but an estimate of the mean absorbing power may be obtained by considering the angle subtended by the opening at the middle point of the side, so that if the actual absorbing power of the surface is $A=0.8$ the average effective absorbing power is $A'=0.3+(0.9\times0.2\times0.8)+(0.9\times0.2)^2\times0.8+=0.97$. If $A=0.95$, $A'=0.995$. It is evident that, in order to obtain a given *effective* absorbing power with a matt surface, it must have a very much higher absorbing power (lower reflecting power) than is necessary with a specularly reflecting surface.[1]

The second question may be answered by the following consid-

[1] Féry (*op. cit.*), in computing the effective absorbing power of his cones, treats them as specularly reflecting though they are lamp-blacked. This assumption can hardly be correct, and must lead to too high a computed absorbing power.

erations. Let $I_1\ I_2\ O_1\ O_2$ (Fig. 3) represent a cross-section perpendicular to the edge of one wall of the wedge.

Assume that the heat energy is produced uniformly over the cross-section, and that none of it can escape from the inside $(I_1 I_2)$, but must pass by conduction to the outside $(O_1 O_2)$; these assumptions will at least give an upper limit to the temperature-difference between I and O. If t represents the temperature over any plane distant x from the inside, k the thermal conductivity at this temperature, w the calories converted into heat per unit length and unit cross-section of filament, then the following equation must hold for the heat passing across unit lateral area of the plane "x":

$$-k\frac{dt}{dx}=w\,x$$

Integrating from
$x=o$ to $x=d$

$$-k(t_o-t_d)=\tfrac{1}{2}\,w\,d^2$$

But $w\,d$ = energy dissipated per second per unit length and unit width of filament in calories—hence

$$-k(t_o-t_d)=\frac{1}{42}\;\frac{\text{total watts}}{\text{breadth}\times\text{length of filament}}$$

$$=\frac{W}{b\,l}$$

$$\text{so that: } t_o-t_d=\tfrac{1}{2}\frac{d}{k}\,\frac{W}{b\,l}\,.$$

In our case

$W=8.6$, $d=0.0035$ cm, $b=0.6$, $l=2.8$ cm;

data as to k for platinum near the melting point are not available, but using the value $\frac{.18 \text{ gr. cal}\times\text{cm}^2}{\text{cm}\times{}^\circ\text{ C.}}$ corresponding to 100° C. the computed value of t_o-t_d is 0°05 C. It is evident that even with a filament three times as thick, and supposing the conductivity at 1600° to be only $\frac{1}{5}$ as great as at 100°, the error due to this cause would be only 0°75, which for temperature measurements above 1000° C. is not a serious error. Moreover, if the conductivity is approximately known, this error can approximately be allowed for. For materials having very much poorer conductivity—for example, carbon—or which must be used of much greater thickness, the conductivity correction as above computed may amount to considerable and, in the absence of data on the value of k at these high temperatures, must be determined experimentally, preferably by observations on wedges with three different thicknesses of walls, graphically extrapolating to the case of zero thickness. Our observations indicate that this extrapolation can be quite accurately carried out, and it also seems probable that by comparison of the observed apparent temperature-differences between inside and outside, for various wall thicknesses with those computed as above, approximate values of the thermal conductivity k may be obtained at high temperatures beyond the range of the usual methods.

In order to test the degree to which the conditions assumed in this discussion could be easily realized in practice, I have carried out, with Mr. Forsythe's assistance, observations upon wedge filaments of pure platinum. We first determined the melting point of platinum by observing with an optical pyrometer on the inside of the wedge as the temperature was slowly raised to the melting point. The mean of several observations gave 1747° C., 8° below the correct value (1755°)—but quite a satisfactory agreement considering the impossibility of getting accurate pyrometer settings at the instant of melting. As a second test we determined the relation between the true and corresponding black-body temperature for platinum, by simultaneous observations on the inside and outside of the wedge. With very thin platinum foil (0.007 mm) it was difficult to get a properly formed wedge, but with a sheet 0.032 mm thick, burnished fairly flat and polished on the outside, the observations shown in Fig. 4 were obtained. They agree almost exactly with those of Waidner and Burgess[1] (shown by the line) which are the mean results of several methods. These results demonstrate, I think, that it is easy to realize the assumed conditions and thus to obtain accurate measurements of the true temperature of a radiating surface.

The device shown in Fig. 1 is a convenient one for use with filaments which can be heated in air, enabling them to be kept

[1] *Bulletin of the Bureau of Standards*, **3**, 202, 1907.

straight and taut when heated. Turned on its side it forms an optical meldometer for determining the melting points of substances placed upon the face. Wedges of thin platinum (0.01 mm) used in air showed some difference in temperature between the "open" and "closed" side of the outer surface, due to greater loss

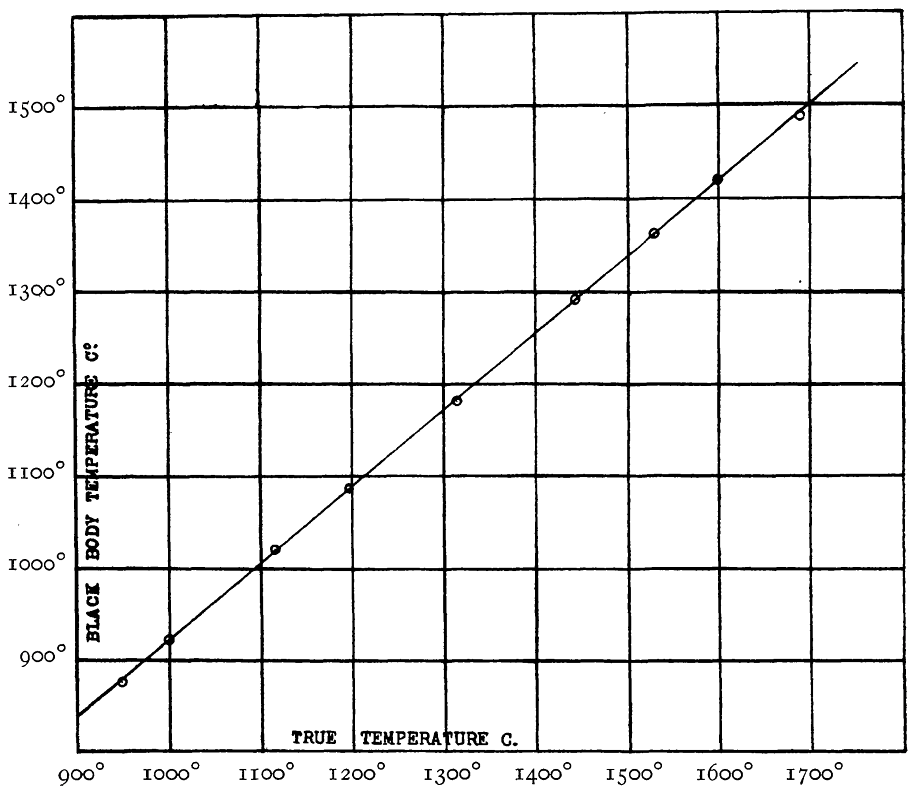

FIG. 4

of heat by convection currents at the opening. With the thicker walls (0.032 mm) this difference had almost disappeared, and was never noticeable in vacuum work. Moreover by sighting, inside and outside, at the middle of the face, this error can be minimized. If made with rounding apex these wedges often show a slight dark streak where the reflecting surface is normal to the opening, as would be expected.

SUMMARY

A discussion of the emissivity of a wedge-shaped aperture, particularly one with reflecting walls, and of the conduction of heat through the walls, leads to the conclusion that optical pyrometer observations on the inside of the wedge would give the true temperature of the outside surface. This is verified by experiment. The device is suggested as a simple means of accurately determining the true temperature of a radiating surface.

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