# THE EMISSIVITY OF OXIDIZED METALLIC SURFACES.[1]

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THE measurements here described were undertaken to secure data on the total radiation from oxidized metallic surfaces, at temperatures below 700° C. Total radiation includes all the energy dissipated from a surface by radiation, at wave-lengths from 0 to $\infty$. A large amount of accurate work on selective radiation is available, but comparatively little on total radiation. Data on the latter are necessary when dealing with heat losses from surfaces.

The emissivity of a body is here defined as the ratio of the energy radiated by a body of emissivity $e$, to the energy radiated by a black body, when both are at the same temperature. This is not the definition always used,[2] but it is the most convenient for comparing different surfaces when dealing with total radiation.[3] A "black body" is, of course, one that absorbs all the radiation incident upon it, no matter what the wave-length. From the Stefan-Boltzman law, for a black body

$$W = \sigma(T_1^4 - T_2^4),$$

where $W$ is the rate of heat loss, $\sigma$ is a constant experimentally determined, and $T_1$ and $T_2$ are the absolute temperatures respectively of the radiating surface and of the surroundings. Then for a body of emissivity $e$,

$$W = e\sigma(T_1^4 - T_2^4).$$

The construction of the apparatus used for comparing the radiation from various surfaces with that from a black body is shown in Figs. 1 and 2. It was our aim to construct a robust instrument that could be used in connection with a Leeds and Northrup potentiometer (read accurately to .001 millivolt), thus making it unnecessary to observe galvanometer deflections. Of course there are many radiometers far more delicate than this.

The absorbing disc $A$ (Fig. 1) is of platinum .25 mm. thick, coated with platinum-black on the side presented to the radiating surface. It is supported by three wires (one is shown at $K$), .25 mm. diameter, and

[1] From the heating device research laboratory, General Electric Company.

[2] Preston's Theory of Heat, 2d ed., 587.

[3] Poynting and Thompson's Heat, 233.

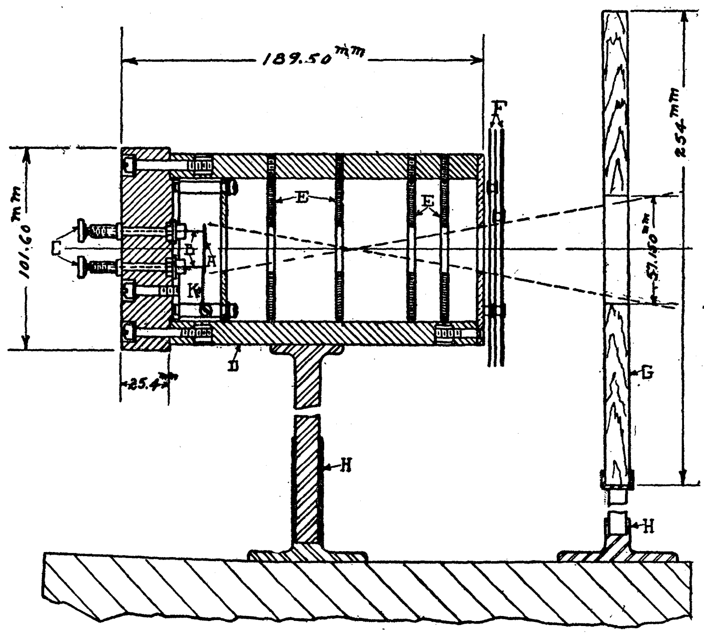


Fig. 1.

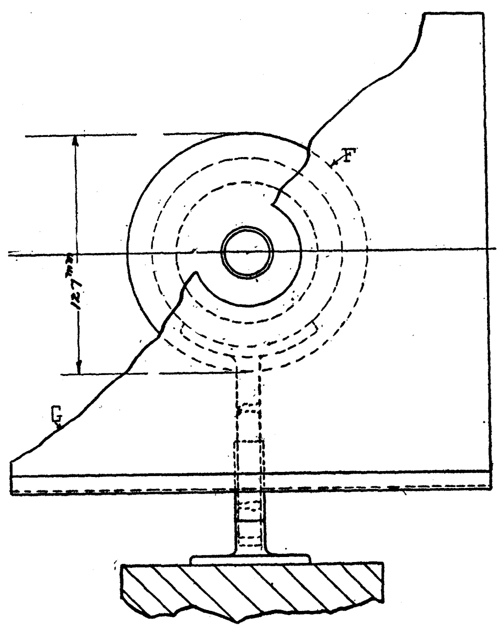


Fig. 2.

to the disc is soldered (on the polished side) a bismuth-iron thermo-couple *B*. The cold junctions of the thermo-couple are brought out to the binding posts *C*, which are always at room temperature. The walls *D* are of hard rubber, so thick that they can heat very slightly in the short time the instrument is exposed to a radiating surface for a measurement. Baffles *EE*, also of black hard rubber, prevent any heating of the absorber *A* by convection, and also prevent reflection of radiant heat from the walls *D* to the absorber. Three thin brass discs *F* protect the end wall *G* from being heated by the radiating surface. It was found necessary also to protect the side walls from radiation by placing a square wooden shield *G* between the radiometer and the radiating surface. This shield is somewhat larger than any of the radiating surfaces used in the measurements,

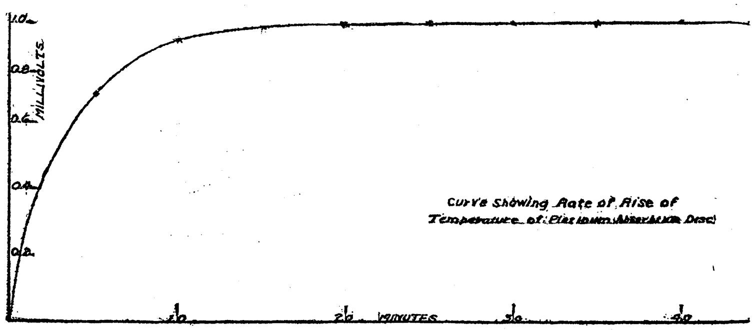


Fig. 3.

and is painted black on the side away from the radiometer to reduce reflection to a minimum. The cylinder *D* and the shield *G* are supported by brass rods fitting in tubes *HH* and can be adjusted at any height with thumb screws.

The curve in Fig. 3 for the rate of rise of temperature of the platinum absorber shows that it reaches a maximum temperature three minutes after exposure. All readings were taken after an exposure of four minutes, to make sure that the horizontal part of the curve had been reached. No lenses or reflectors are used in the design of the radiometer, and therefore the only chance of error from selective absorption is that the platinum absorber itself might possess this property. But platinum-black comes very close to being a black body, so that the possibility of error here is very slight.

The radiation through a relatively small opening in a closed uniform temperature surface has been shown to be black-body radiation, no matter what the material of the surface may be.[1] This fact was made use of in

[1] Balfour Stewart, Lessons in Elementary Physics.

calibrating the radiometer. Fig. 4 shows the "black body." $A$ is a large cast-iron pipe, closed at the rear with another heavy casting $B$. The pipe and the casting $B$ are heated by three "calorite" wire resistors $CC$ so connected that the energy dissipated by each heating unit can be adjusted independently. The temperature is thus kept very uniform. Five thermo-couples $DD$ were used for measuring the temperature, which could be kept uniform within 3° C. at 500° C. The iron castings were surrounded with insulation, as shown, which reduces the energy necessary for maintaining any temperature, and makes it easier to maintain a uniform temperature. A water jacket $E$ prevents the outher wall from heat-

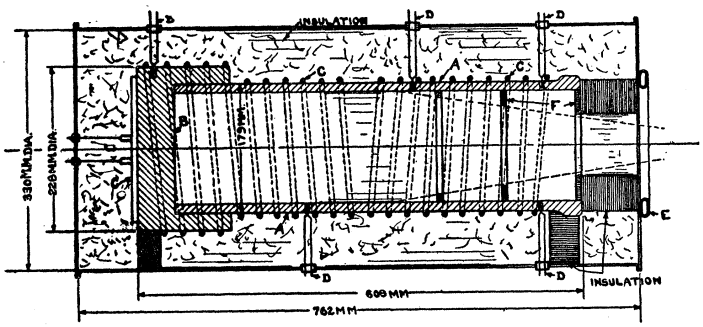


Fig. 4.

ing at the end. The baffles $FF$ make the inner surface approximate more closely to an entirely closed surface, thus reducing to a minimum the difference between the radiation from the casting and that from a perfectly black body.

The rate at which energy was radiated from the black body was calculated from its observed temperatures and the temperature of the surroundings, by substituting in the Stefan-Boltzman equation. A calibration curve was plotted for the radiometer showing the relation between millivolts and energy radiated. The temperature of the surroundings was taken as 25° C., in all measurements. Where the radiating surface is at a temperature above about 175° C., a change in the room temperature of a few degrees can easily be shown to introduce only a negligible error.

Since

$$e \equiv \frac{e\sigma(T_1^4 - T_2^4)}{\sigma(T_1^4 - T_2^4)}$$

the value of $\sigma$ does not affect the results and temperature errors also correct themselves to a certain extent. The platinum-platinum-iridium thermo-couples used for measuring the temperatures of the black body and of the oxidized surfaces were calibrated under exactly the same conditions.

A metal disc 19.1 cm. diameter and 6 mm. to 13 mm. thick, mounted vertically, with its exposed surface flush with the end of a horizontal iron cylinder (the axis of the disc and the cylinder coinciding) formed the radiating surface of which the emissivities were measured.[1] The heating unit was made of a calorite resistance ribbon between two mica discs. This unit was clamped between the radiating disc and a thin disc of sheet steel. The cylinder back of the 19 cm. disc was filled with good heat insulating material, thus decreasing the energy necessary to maintain the radiating disc at any temperature. The thermo-couple was held firmly against the back of the disc under the head of a screw, the two leads being brought out to the cold junction (kept in oil) through the heat insulation. There was a space of about 19 mm. between the edges of the disc and the inside of the cylinder walls which was also filled with insulation, held in place with a mica ring. The surface of each disc was cleaned and polished before it was mounted.

The thermo-couple measures the temperature of the back of the metal disc and not that of the radiating surface itself. In some cases—as with copper and other good heat conductors—this drop in temperature between the two surfaces of the disc is negligible. With poor heat conductors—as certain alloys—it is very important to make a correction at higher temperatures. We had previously accurately measured the thermal conductivity at various temperatures of nearly all the metals or alloys used in these experiments, and for those which we had not measured ourselves the values were obtained from the literature.[2] The wattmeter readings gave the total energy required to maintain a surface at any temperature. The watts per square centimeter lost from the surfaces by radiation and convection was calculated by subtracting the heat conducted through the insulation, from the wattmeter reading. Then the actual temperature of the radiating surface is

$$T_1 = t - WRL,$$

where $t$ is the temperature as measured with the thermo-couple, $W$ is the heat flux through the metal disc, $R$ is the thermal resistivity of the metal and $L$ is the thickness of the plate. As this correction is in all cases rela-

[1] The method of mounting the metal plate is fully described with drawings by I. Langmuir in J. Am. Elec. Soc., XXIII., 14 (1913).

[2] Jaeger and Disselhorst, Wiss. Abh. d. Phys. Techn. Reichanst., 3, 269 (1900); Angell, PHYS. REV., XXXIII., 421 (1911).

tively small, any possible error in it becomes negligible in the final results. With the type of heating unit used, the thickness of the plate was always made great enough to insure a very uniform temperature over its surface.

We found on beginning the measurements given below that the emis-

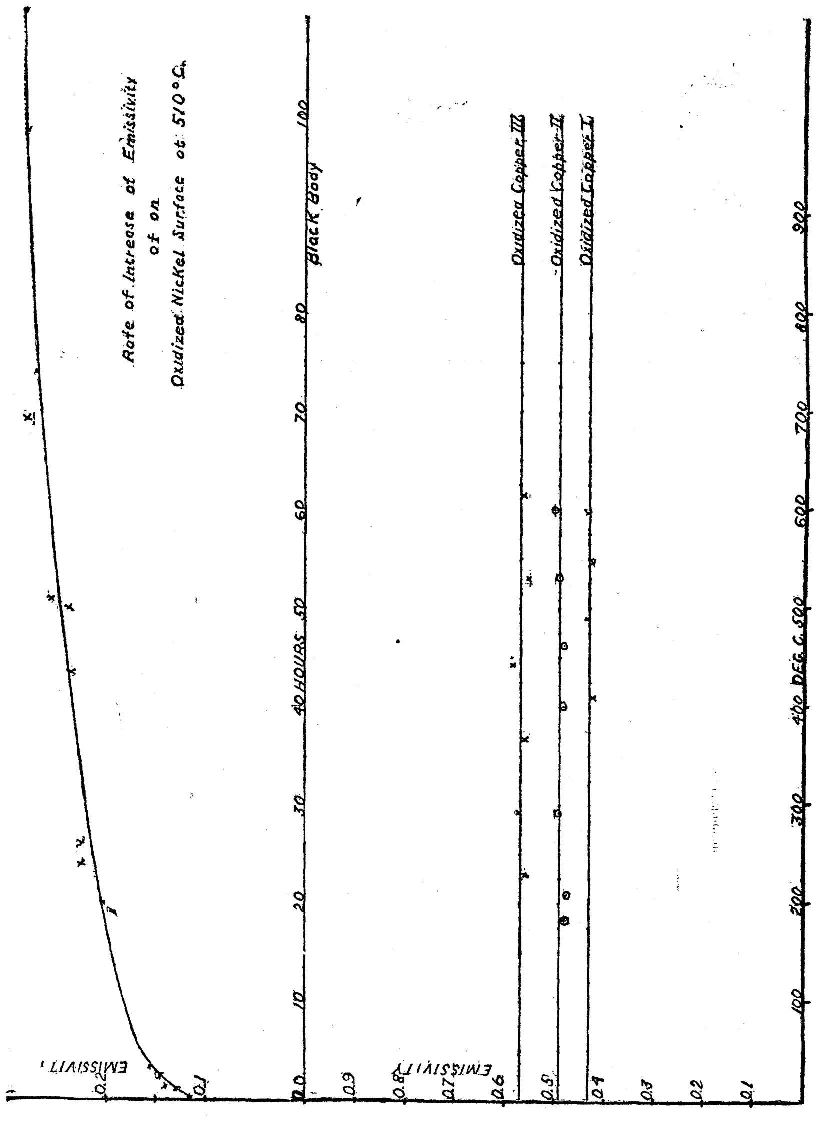


Fig. 5.

sivity increases (1) with the temperature to which the surface has pre-
sivity of a surface depends on the depth of oxidation; that is, the emis-

viously been heated and (2) with the time the surface is kept at any temperature. In Fig. 5 is shown the rate of increase of the emissivity of an oxidized nickel surface at 510° C. Zero time is here taken as the time when we could get the first measurement after the surface had been quickly heated to 510° C., starting with a polished surface. The constant value is seen to be .283. The temperature was then increased to 583°, where the constant value of the emissivity was .410. In Fig. 6 it is seen that the maximum emissivity is .49, when the surface is heated to 640° C. With the exception of the oxidized copper surface, in all the measurements made, the method was to start with a polished surface which was kept at the maximum temperature for which a point is given on the curves, until the emissivity had become constant. Measurements were then taken at various lower temperatures.

Fig. 5 shows a series of measurements at different temperatures for oxidized copper. Curves I. and II. were determined by measuring the

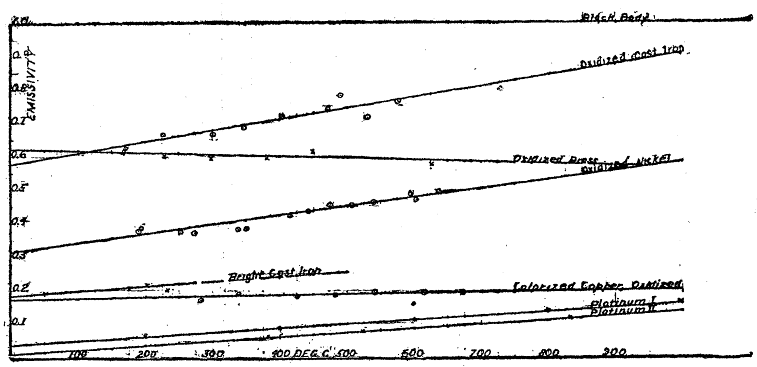


Fig. 6.

emissivity before it had become constant at the maximum temperatures for which results are given. Then observations were taken at various lower temperatures as explained above. Curve III. was obtained in the usual way, by heating the surface at the maximum temperature until the radiation was constant. It is seen that if a copper surface is heated for even a *very short time* at a temperature $A$ about 50° higher than temperature $B$, the emissivity has reached or passed the maximum value it would attain if the surface had been kept at $B$ indefinitely.

The curves for calorized copper and calorized steel (Figs. 6 and 7) refer to plates of the above metals which have been impregnated with aluminum in their surfaces. This process requires that they be heated to a temperature above that at which measurements were made, so that we would expect no variation of emissivity with time of heating. This agrees with the experimental results.

The emissivities of platinum and silver (Figs. 6 and 7) are taken from the literature, and are given here for comparison. The values for silver and platinum I. are calculated from Hagen and Ruben's formula[1] for long wave-length radiation:

$$e = .365 \frac{r}{\lambda},$$

where $e$ = emissivity,

$r$ = electrical resistivity in ohms per $cm^3$,

$\lambda$ = wave-length of radiant energy in cm.

$\lambda$ is determined by Wien's law, which gives the relation between the

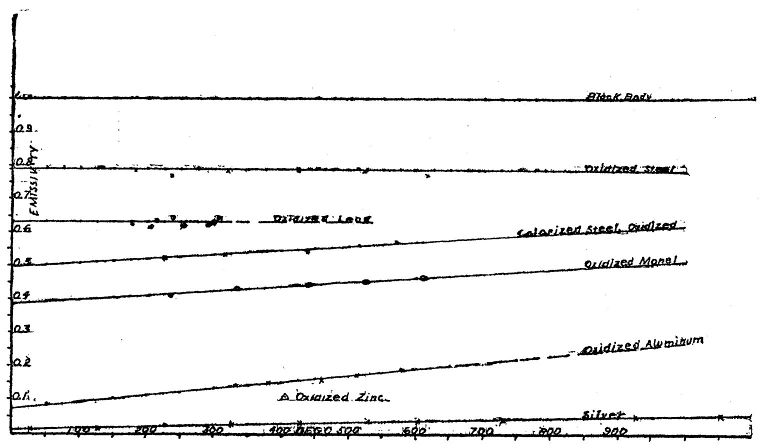


Fig. 7.

absolute temperature $T$ and the wave-length of maximum intensity, viz.,

$$\lambda_m = \frac{.290}{T} \text{ cm.}$$

For the sample of silver for which the emissivity is here calculated, $r = 1.76 \times 10^{-6}$ at 0° C. Jaeger and Disselhorst[2] found the temperature coefficient of the electrical resistivity of silver to be .0040. Therefore

$$e = .61 \times 10^{-3} \sqrt{T(1 + .0040T)}.$$

Platinum I. is a sample used by I. Langmuir in measuring convection losses.[3] He measured the electrical resistivity at various temperatures, and the emissivity is calculated from these results as for silver. The

[1] Hagen and Ruben's Ann. Phys., 8, 1 (1902).

[2] Jaeger and Disselhorst, Phys. Tech. Reich., 3, 269 (1900).

[3] I. Langmuir, Phys. Rev., XXXIV., 401 (1912).

curve platinum II. is taken from actual measurements of emissivity by Lummer and Kurlbaum.[1]

The values of emissivities in the following table are taken from the curves and are given here for convenience.

| | Temperature, Deg. C. | | |
|---|---|---|---|
| | 200 | 400 | 600 |
| Silver | .020 | .030 | .038 |
| Platinum (1) | .060 | .086 | .110 |
| Oxidized zinc | —— | .110 | —— |
| Oxidized aluminum | .113 | .153 | .192 |
| Calorized copper, oxidized | .180 | .185 | .190 |
| Cast iron | .210 | —— | —— |
| Oxidized nickel | .369 | .424 | .478 |
| Oxidized monel | .411 | .439 | .463 |
| Calorized steel, oxidized | .521 | .547 | .570 |
| Oxidized copper | .568 | .568 | .568 |
| Oxidized brass | .610 | .600 | .589 |
| Oxidized lead | .631 | —— | —— |
| Oxidized cast iron | .643 | .710 | .777 |
| Oxidized steel | .790 | .788 | .787 |
| Black body | 1.00 | 1.00 | 1.00 |

## CONCLUSIONS.

1. The emissivity of an oxidized metallic surface depends on the depth of the surface oxidation. Therefore it is a function (*a*) of the temperature to which the surface has previously been heated and (*b*) of the time the surface has been maintained at the temperature.

2. The emissivities of certain surfaces have been measured at various temperatures and the results are given here. The surfaces were oxidized at about 600° (the temperature of oxidation is always the highest shown on the temperature-emissivity curves) until the emissivity had become constant.

3. It is possible that the variations so often found in scientific literature in measurements of heat losses from surfaces are due to changes in the radiation and not to unsteady convection losses.

[1] Lummer and Kurlbaum, Verh. Phys., Ges., Berlin, 17, 106 (1898).