NORMAL SPECTRAL EMISSIVITY OF GOLD, PLATINUM, AND TUNGSTEN

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Experimental findings are given for the normal spectral emissivity of gold, platinum, and tungsten within the spectral range 1-10 μm at temperatures of 100-400°C. The experimental results were compared with reported data and used to verify the validity of the Hagen—Rubens formula.

The optical properties of metals and their dependence on temperature has been the subject of intensive investigation [1, 2] and are of great practical and scientific interest. The normal spectral emissivity and absorbance of metals were principally investigated at high and low temperatures situated at both ends of the temperature range 50-800°C. However, it is precisely the temperature range itself that is interesting from the engineering point of view, for it is there that one encounters the working temperatures for various devices and designs.

Measurements of the normal spectral emissivity were made in air at temperatures of 100, 200, 300, and 400°C by the method of comparing the metal surface emission with the black-body radiation of a ring-shaped model at the same temperature. Interference filters were used for monochromatization of the emissions within the range 2-10 μm; the filters had a transmission of 40-60%, and the spectral transmission half-width $\Delta\lambda$ at the 0.5 level of maximum transmission wave length λ_{max} was equal to $\Delta\lambda/\lambda_{max} = 0.05 \pm 0.01$. A cooled Ge—Hg photoresistor was used as the radiation receiver in the 5-10 μm spectral range, and a cooled In—Sb photoresistor in the 3-5 μm range. The method used for measurement is described in detail in [3]. Within the 1-3 μm spectral range a DMR-4 double monochromator and a PbS radiation receiver were used for measuring. The monochromator was calibrated with VSB-2 type lamps (containing Cd, Bi, and Zn vapors); the lamps were supplied with power from 2 PPBL-3 type generator. The spectral lines of the radiating lamps were identified with the help of data from [4 and 5].

The purity of the metals measured was: Au was 99.99%, Pt was 99.9%, and W was 99.8% pure. The tungsten test sample was cut off from a 0.04 mm thick polished strip, while the gold and platinum samples were 0.1 and 1.0 mm respectively. The surface of the platinum sample was ground with No. 0 emery paper and then polished with No. 20 diamond paste. The samples were not given any heat treatment. Before measuring, the samples were washed in a trisodium phosphate + OP 7 solution at a temperature of 70-90°C, and then in ethyl alcohol.

Figure 1 shows the results of measurements of the gold, platinum, and tungsten test samples. The vertical lines on the diagram indicate the scattering limits of the experimental data obtained in six series of measurements at each temperature. To avoid having an oxide film affect the experimental results when measuring the tungsten, a new sample was used for each measurement series. Curve 5 in Fig. 1b) shows the spectral characteristics of the radiated surface of the platinum test sample in delivery condition. Obviously, such a spectral dependence of emissivity is characteristic of the surface layer, the properties of which differ from those of platinum, and which were then removed by mechanical surface treatment. The microroughness of the surface was not determined. However, the measurements of the gold test sample with shining and dull surfaces (after treatment with No. 20 diamond paste) did not reveal any affect of the surface condition on the value of the emissivity. Figure 1a and b give the experimental results obtained by other authors, although such a comparison is less graphic than the same results presented in the form

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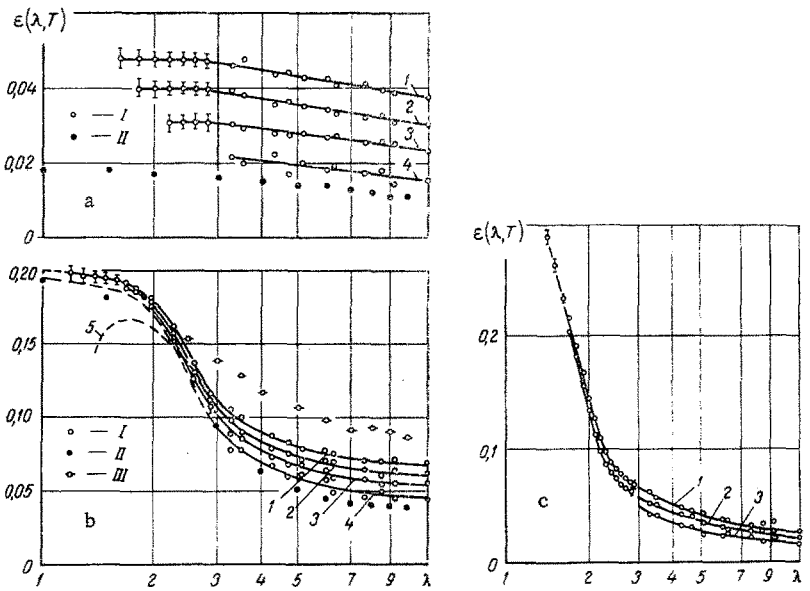

Fig. 1. Normal spectral emissivity. Measurement results: a) gold; I) our data; II) measurements of reflectivity of dusted layers, T ≈ 20°C [6]; 1) 400°C; 2) 300°C; 3) 200°C; 4) 100°C; b) Platinum, 99.9% pure; I) our data; II) measurements of reflectivity of dusted layers, T ≈ 20°C [6]; III) measurement of emissivity, T = 1400° K [9]; 1) 400°C; 2) 300°C; 3) 200°C; 4) 100°C; c) Tungsten, 99.8% pure; I) our data; 1) 300°C; 2) 200°C; 3) 100°C, λ, μm.

of emissivities as a function of temperature, drawn for each wave length. These dependences are shown in Fig. 2 in the form of curves that approximate the experimental results for the metals in question. Several values of emissivity shown in Fig. 2 were obtained in conformity with Kirchhoff's law for the measurement of reflectivity in thick metal films [6] and massive metals [8, 10, and 11], and were also calculated with respect to the optical constants [18, and 19] for the corresponding temperatures. The remaining values are the result of indirect measurements of normal spectral emissivity [7, 9, and 12-16].

As follows from Fig. 2a, the data for gold from [6] and [8] coincide well with the long-wave spectral region up to $\lambda = 0.5$ μm. For $\lambda = 10$ μm the data from [7] show the values understated by over 100% compared with data extrapolations of our experiment. The experimental data for platinum at $\lambda < 0.6$ μm are taken from [6] and [10]. Nevertheless, as a comparison of the data from [10] and [8] for gold has shown, the reflectivity values from [10] obtained at a temperature of 50°C were 17% understated on the average for all wave lengths. Apparently the same error will hold also for the reflectivity of platinum from [10]. It should be noted that as a result of the errors inherent in the measurement method used (a black-body recess-type reflectometer), the measurement errors can grow with an increase in the wave length and the temperature of the test sample. Thus, the data in Fig. 2c for wave lengths 0.4 and 0.5 μm at temperatures of 1000, 1200, and 1400°C were obtained by our having introduced the reflectivity values for platinum at 50°C from [10] into platinum reflectivity values taken from [6] for the same temperature and the corresponding variations in reflectivity at the other temperatures. The solid curves in Fig. 2c were drawn under the assumption that the temperature dependence of reflectivity of platinum at wave lengths within the 0.4-10 μm range was analogous to the temperature dependence at a wave length of 10 μm. Probably, the emissivity values that correspond to these curves can differ from the actual values at short wave lengths, although this difference will be small, as may be seen by comparing them with the emissivity values for platinum obtained at a wave length of 0.66 μm by the tube method described in [12]. Fig. 2c shows analogous data for tungsten. It is clear from the figure that our experimental findings coincide well with the data in [14]. The data of De Vos [13] have turned out to be too high, whereupon the divergence from the data in [14] becomes greater with an increase in wave length. This fact was discovered experimentally within the visible region of the spectrum by Larrabee [16], and the reliability of the conclusions was doubted in [17]. The values for normal emissivity calculated according to the formula:

$$\varepsilon_n(\lambda) = \frac{4n}{(n+1)^2 + k^2} \qquad (1)$$

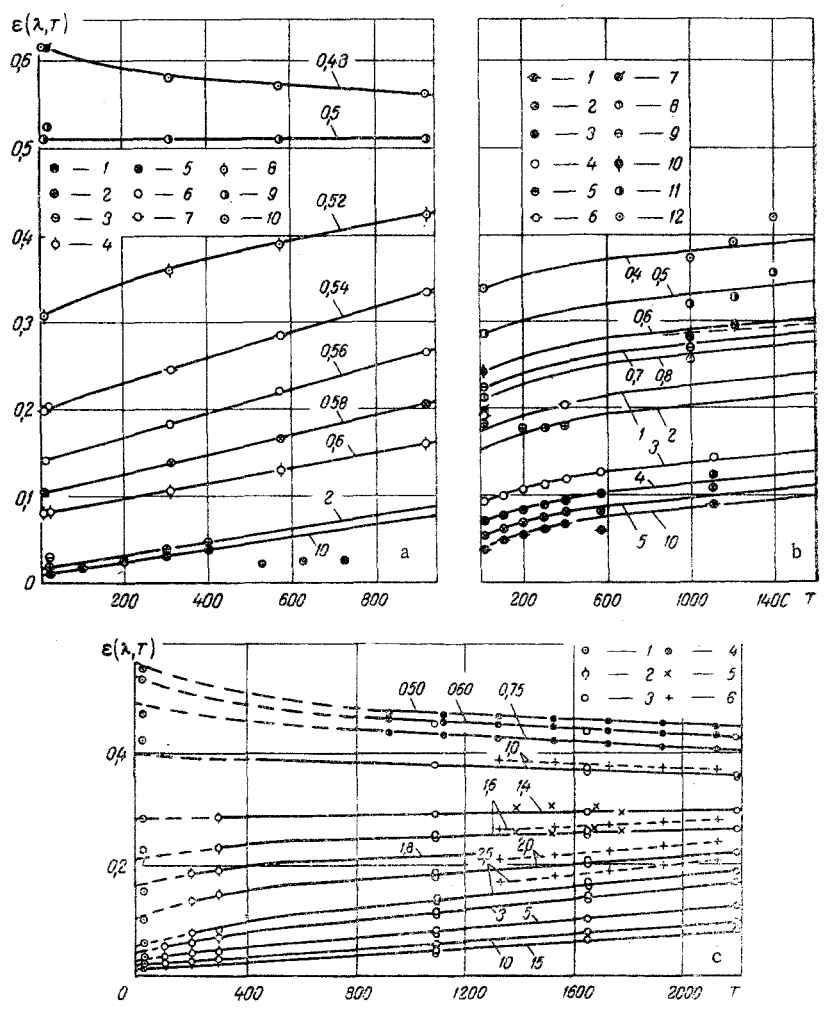

Fig. 2. Temperature dependence of spectral emissivity according to the data of various investigators; a) Gold; 1) λ = 10 μm; 2) 2; 3) 0.7; 4) 0.6; 5) 0.58; 6) 0.56; 7) 0.54) 8) 0.52; 9) 0.50); 10) 0.48 μm; T = 10; 310; 570; 920°C [8]; T $\approx$ 20°C [6]; T = 800°K (527°C); 900°K (627°C); 1000°K (727°C) [7]; T = 100-400°C according to our data; b) Platinum; 1) λ = 10 μm; 2) 5; 3) 4; 4) 3; 5) 2; 6) 2; 6) 1; 7) 0.9; 8) 0.8; 9) 0.7; 10) 0.6; 11) 0.5; 12) 0.4 μm; T $\approx$ 20°C [6]; T = 1500°R (560°C) [11]; T = 1000, 1200, 1400°C [10]; T = 1400°K (1127°C) [9]; dash-line curve represents the findings of [12] for λ = 0.66 μm; T = 100-400° according to our data; c) tungsten; 1) [19]; 2) our data; 3) [14]; 4) [15]; 5) [18]; 6) [13]. Numbers at the curves give the wave length in μm.

with respect to the optical constants n and k taken from [18] also tallied well with the results of [14].

The values of normal emissivity that correspond to the curves in Fig. 2 were compared with the values obtained from the calculation according to the Hagen–Rubens formula:

$$\varepsilon_n(\lambda) = 0{,}365\left(\frac{\rho}{\lambda}\right)^{1/2} - 0{,}0464\frac{\rho}{\lambda}. \qquad (2)$$

Values of specific electrical resistance ρ for gold and platinum for the selected temperatures were taken from [20]. For the temperature range 100-900°C, values of the specific resistance of platinum were obtained by using the Wiedemann–Franz relation for heat conductivity taken from [21]. For tungsten the

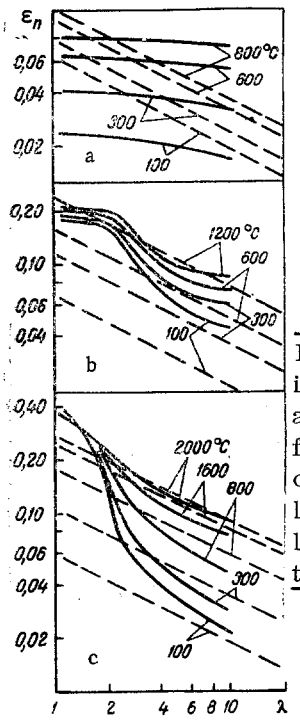

Fig. 3. Comparison of experimental data with calculation according to the Hagen—Rubens formula: solid curves represent our experimental results; dash-line curves represent the calculation; a) gold; b) platinum; c) tungsten.

electrical resistivity values were taken from [22]. The results of the comparison are shown in Fig. 3. It may be inferred from the figure that within the one to ten micron spectral range the Hagen—Rubens formula is not generally speaking valid for the metals under study within the temperature range 100-800°C. However, at temperatures greater than 1000°C the values of normal emissivity obtained by using this formula correspond satisfactorily with the experimental results for platinum and tungsten.

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