TOTAL RADIATIVE PROPERTIES OF GOLD, PLATINUM, AND TUNGSTEN

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The total radiative properties of gold, platinum, and tungsten are calculated from data on their spectral radiative and reflecting properties.

At the present time experiment offers the only way of obtaining data on the radiative properties of metals. The spectral and total normal and hemispherical emittances are measured independently of one another by various methods [1]. It is, therefore, of interest to consider the possibility of obtaining all data characterizing the radiative properties of metals from an experimental determination of the spectral dependences of their normal emittances and reflectances.

We examine this possibility in the present paper for the three metals gold, platinum, and tungsten which differ in their physical properties.

The total normal emittance is determined by integrating the spectral normal emittance over the spectrum, using the expression

$$\varepsilon_{tn}(T) = \frac{C_1}{\sigma T^4} \int\limits_0^\infty \varepsilon_n(\lambda,\ T)\, \lambda^{-5} \left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]^{-1} d\lambda. \quad (1)$$

In practice, one can without loss of accuracy integrate over a finite spectral range whose limits are determined by the given temperature.

The total hemispherical emittance can be determined by integrating the angular emittance over the spectrum and over the angles describing radiation into a hemisphere outside the radiating surface,

$$\varepsilon_{th}(T) = \frac{C_1}{\sigma T^4} \int\limits_0^\infty \int\limits_0^{2\pi} \int\limits_0^{\pi/2} \varepsilon(\theta,\ \varphi,\ \lambda,\ T)\, \lambda^{-5} \left[\exp\left(\frac{C_2}{\lambda T}\right) - 1\right]^{-1} \sin\theta \cos\theta\, d\theta\, d\varphi\, d\lambda. \quad (2)$$

However, obtaining the necessary values of $\varepsilon(\theta,\ \varphi,\ \lambda,\ T)$ experimentally involves practically insurmountable difficulties. For example, it is shown theoretically in [2] that ε_{tn} and ε_{th} for metals are connected by a definite relation, but the available experimental data [1, 3] are inadequate to permit a test of this relation for actual metals.

It is known [4] that complete information on the optical properties of metals contains the spectral dependence of the normal reflectance over a wide region of the spectrum. This is true also for the spectral normal emittance which, according to Kirchhoff's law, is related to the reflectance by the simple expression

$$\varepsilon_n(\lambda,\ T) = 1 - \rho_n(\lambda,\ T). \quad (3)$$

Using the Kramers–Kronig relation and the available data on the spectral normal emittances of gold, platinum, and tungsten [5], we calculated their optical constants, which enabled us to compute the corresponding values of the spectral hemispherical emittance at any given temperature by using the equations [6]

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TABLE 1. Total Radiative Properties of Gold, Platinum, and Tungsten

T, °C	Tungsten			Gold			Platinum		
	ε_{tn}	ε_{th}	ε_{th}^*	ε_{tn}	ε_{th}	ε_{th}^*	ε_{tn}	ε_{th}	ε_{th}^*
0	0,0152	0,0196	0,0195	0,0085	0,0110	0,0110	0,0276	0,0352	0,0351
100	0,0239	0,0305	0,0305	0,0159	0,0204	0,0204	0,0437	0,0550	0,0549
200	0,0329	0,0416	0,0417	0,0241	0,0307	0,0308	0,0579	0,0714	0,0716
300	0,0415	0,0515	0,0522	0,0336	0,0424	0,0425	0,0698	0,0860	0,0860
400	0,0500	0,0620	0,0625	0,0419	0,0525	0,0527	0,0820	0,0992	0,0999
500	—	—	—	0,0493	0,0612	0,0615	—	—	—
600	0,0725	0,0872	0,0890	0,0584	0,0719	0,0725	0,1028	0,1225	0,123
700	—	—	—	0,0674	0,0825	0,0831	—	—	—
800	0,0984	0,117	0,118	0,0769	0,0933	0,0941	0,121	0,143	0,143
900	—	—	—	0,0843	0,1017	0,1025	—	—	—
1000	0,126	0,146	0,148	—	—	—	0,139	0,162	0,162
1200	0,154	0,177	0,178	—	—	—	0,154	0,177	0,178
1400	—	—	—	—	—	—	0,167	0,191	0,191
1500	0,193	0,216	0,216	—	—	—	—	—	—
1800	0,228	0,251	0,248	—	—	—	—	—	—
2000	0,249	0,266	0,267	—	—	—	—	—	—
2500	0,291	0,317	0,302	—	—	—	—	—	—

Note. ε_{th}^* is the total hemispherical emittance obtained from Eq. (5).

$$\varepsilon_{h,s}(\lambda) = 8n - 8n^2 \ln\left(\frac{1+2n+n^2+k^2}{n^2+k^2}\right) + \frac{8n(n^2-k^2)}{k}\,\mathrm{arctg}\left(\frac{k}{n+n^2+k^2}\right),$$

$$\varepsilon_{h,p}(\lambda) = \frac{8n}{n^2+k^2} - \frac{8n^2}{(n^2+k^2)^2}\ln(1+2n+n^2+k^2) + \frac{8n(n^2-k^2)}{k^2(n^2+k^2)^2}\,\mathrm{arctg}\left(\frac{k}{1+n}\right), \qquad (4)$$

$$\varepsilon_h(\lambda) = [\varepsilon_{h,s}(\lambda) + \varepsilon_{h,p}(\lambda)]/2.$$

The total normal and hemispherical emittances were found as functions of the temperature by integrating $\varepsilon_n(\lambda, T)$ and $\varepsilon_h(\lambda, T)$, respectively, according to Eq. (1). The limits of integration were determined by the spectral region in which more than 99% of black-body energy is radiated at the given temperature. The short-wavelength limit of this region corresponds to $\lambda T = 1200\ \mu K$, and the long-wavelength limit, to $\lambda T = 2700\ \mu K$ [7].

It was found that independently of the physical properties of the metal and its temperature, the total normal and total hemispherical emittances are connected by the relation

$$\varepsilon_{th} = 1.3\varepsilon_{tn}\exp(-0.78\varepsilon_{tn}). \qquad (5)$$

Table 1 lists the values of ε_{tn} and ε_{th} calculated by using our values of the optical constants, and the values of ε_{th} from Eq. (5).

A comparison of the entries in Table 1 with the handbook values [1] shows that our method of determining the radiative properties of metals gives good results. In the future this approach will enable us to decrease the number of measurements and to concentrate most of our attention on refining the existing data and obtaining missing data on the spectral radiative and reflecting properties of metals and alloys.

NOTATION

$\hat{n}$, complex index of refraction; $\hat{n} = n - ik$, $i = \sqrt{-1}$; n, index of refraction; k, extinction coefficient; $\varepsilon_n(\lambda, T)$, spectral normal emittance; $\rho_n(\lambda, T)$, spectral normal reflectance; $\varepsilon(\theta, \varphi, \lambda, T)$, spectral angular emittance; θ, φ, angles determining the direction of the radiation; ε_{tn}, total normal emittance; ε_{th}, total hemispherical emittance; C_1, first Planck radiation constant; C_2, second Planck radiation constant; σ, Stefan–Boltzmann constant; λ, wavelength; T, absolute temperature.

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