High-temperature emissivities of copper, aluminum, and silver

K. G. Ramanathan and S. H. Yen

Physics Department, University of New Orleans, New Orleans, Louisiana 70122

Using a transient calorimetric technique, the total hemispherical emissivities ϵ_h of very pure copper, aluminum, and silver have been measured at various temperatures in the range 335–1100°K. By carrying out measurements on a sphere, a thin circular disk, and a thin square plate all made of the same copper sample, it is shown that the measured ϵ_h is practically independent of the shape of the specimen. Measured ϵ_h values of Cu, Al, and Ag show considerable departure from the theoretical predictions of Davisson and Weeks and the data of previous investigators. ϵ_h data are presented in tabular form at 20°K intervals for all three materials in the range 400–1000°K.

I. INTRODUCTION

Past investigations of the propagation of an electromagnetic wave inside a pure metal may be broadly subdivided into two categories depending upon whether the mean free path l of the conduction electrons is long or short compared with the penetration depth δ of the wave into the medium. Thus at low temperatures at which l is very long, we observe such phenomena as anomalous skin effect and superconductivity with which we are not concerned in this paper. The former has been extensively studied by London,[1] Pippard,[2] Reuter and Sondheimer,[3] and Chambers.[4] At high temperatures l is short in comparison with δ, even for such short waves as in the near-infrared region of spectrum. Consequently, the classical wave propagation equations combined with Ohm's law should lead to a correct prediction of the behavior of the optical properties of the conductor when its absolute temperature T is well above its Debye characteristic temperature.

Accordingly, by taking into account the angular dependence of emission of monochromatic radiation predicted by Fresnel's law, Davisson and Weeks[5] derived for the total hemispherical emissivity of a metal the expression

$$\epsilon_h = 0.751(T\rho)^{1/2} - 0.632(T\rho) + 0.670(T\rho)^{3/2} - 0.607(T\rho)^2, \tag{1}$$

where the electrical resistivity ρ is in Ω cm. Thus, the thermal radiation emitted by the polished surface of the metal at classical temperatures depends primarily on its ρ and T. The spectral emissivity $\epsilon_{\lambda n}$, in a direction perpendicular to the surface of a conductor for wavelength λ, has been expressed in terms of ρ by Foote[6] in the relation

$$\epsilon_{\lambda n} = 0.365(\rho/\lambda)^{1/2} - 0.067(\rho/\lambda), \tag{2}$$

where λ is in cm.

Because the resistivity of a good conductor is of the order of 10^{-6} Ω cm above 300 K,[7,8] the first terms on the right of Eqs. (1) and (2) are the major contributors to ϵ_h and $\epsilon_{\lambda n}$. At these temperatures, the existing experimental data of ρ vs T for pure metals are very nearly proportional to T in accordance with the prediction of Bloch.[9] Therefore, to a first order of approximation, we may expect $\epsilon_{\lambda n}$ and ϵ_h to be proportional to $T^{1/2}$ and T, respectively, under the specfiied conditions.

The temperature variations of $\epsilon_{\lambda n}$ of polished surfaces of Cu, Ag, Al, Au, and Pt have been studied by several investigators[10-12] at different wavelengths in the spectral range of 0.55–14 μm. Most of these investigators reported that $\epsilon_{\lambda n}$ varied strongly with surface roughness, extent of oxidation, and also slightly with temperature. Because the total emission from a solid is made up of a continuous spectrum of wavelengths, mostly in the infrared, the work of these investigators suggests that ϵ_h of pure metals may also be well described by the dominant term of Eq. (1), which is proportional to T.

Early investigation of the temperature dependence of ϵ_h of copper and aluminum by Best[13] were carried out on hollow, spherical shells fabricated from thin sheets of metals, by a steady-state technique in which the power lost by radiation from the surface is determined by the electrical power required to maintain the surface at a constant temperature. Large conduction losses through power leads and thermocouple leads, the liberal use of a silver cement in the specimen assembly, and nonuniformity of the temperature inside the sphere are three of the many sources of error in this technique. Therefore, it is not surprising that the results obtained for copper by Best, in the range 373–673 K, showed hardly any temperature dependence. His results for aluminum were very much higher than the theoretically predicted values. The measurements on copper by Butler and Inn,[14] Gaumer et al.,[15] and Thaler et al.,[16] and those on silver by Zimmermann,[17] Butler et al.,[18] and Thaler et al. were also unsatisfactory for one or more of several reasons. Some of these are (a) use of low-purity commercial grade materials with high intrinsic ρ values, (b) use of a coating of an absorbing material like Parson's black on the inner wall of the vacuum chamber, which results in a considerable increase in outgassing and in a higher ultimate pressure, (c) formation of a high-resistivity surface layer on the metal due to prolonged annealing at T > 1000 K in an inadequate vacuum, and (d) use of large hollow specimens with seams, enclosing electrical heating assemblies which could produce a nonuniform specimen temperature, a large correction term on account of the power leads, and a large systematic error. Therefore, the present work was undertaken with a view to (i) obtain accurate measurements of ϵ_h on polished surfaces of very pure Cu, Al, and Ag at small intervals of temperature in the range 335–1000 K, (ii) compare

our results with Eq. (1), and (iii) investigate whether a change in the polishing technique produces any significant change in the measured values of ϵ_h.

II. EXPERIMENTAL TECHNIQUE

The transient calorimetric technique used in this research is shown schematically in Fig. 1. In this technique, a vacuum-enclosed, thermally isolated specimen of mass M and surface area A is preheated to a temperature T, which is well above that of the surrounding walls. It is then allowed to cool by radiating to the walls maintained at T_0. Under these conditions the total power lost by the specimen may be considered as the sum of the powers lost by radiation $\dot{Q}_r$, by thermocouple conduction $\dot{Q}_c$, and by conduction $\dot{Q}_g$, through the residual gas surrounding the specimen. Hence we have

$$-M C_p (dT/dt) = \epsilon_h \sigma A \ (T^4 - T) + \dot{Q}_c + \dot{Q}_g, \qquad (3)$$

where C_p is the specific heat at constant pressure, dT/dt is the time rate of change of temperature, and σ is the Stefan-Boltzmann constant. The mass and the area of the specimen are measured accurately at room temperature. The areas at higher temperatures are calculated by applying a correction for thermal expansion of the metal. ϵ_h is then calculated using values of C_p for the pure materials, obtained from published literature,[19-23] and using values of T and dT/dt measured with the thermocouple. The method by which dT/dt was obtained is described later.

The high-purity copper, aluminum, and silver specimens used in this investigation were made from polycrystalline samples with percentage purities of 99.999. The copper and aluminum samples were purchased from the Materials Research Corp. and the silver from the Ventron Corp.

Because results of previous investigators,[13-18] obtained by using specimens of different shapes, showed
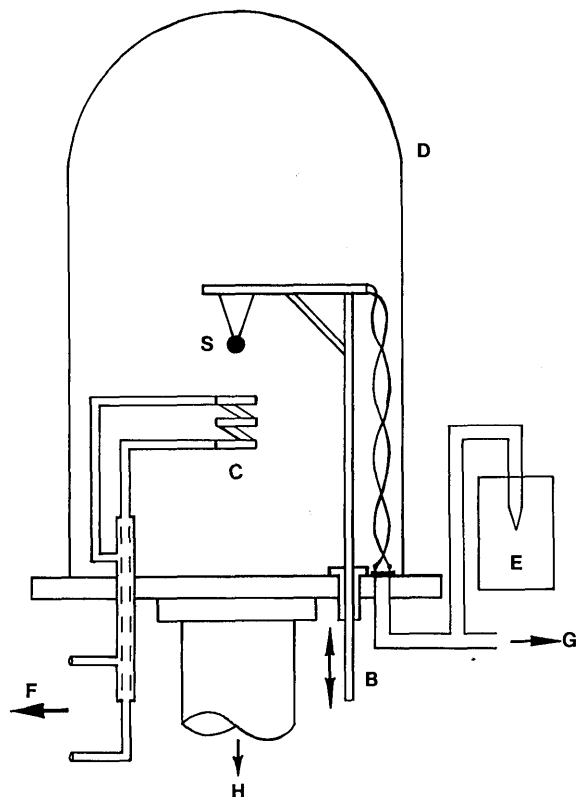

FIG. 1. Schematic drawing of experimental arrangement: S, specimen; B, Plexiglas support; C, rf coil; D, Pyrex glass bell jar; E, reference junction in ice bath; F, water-cooled power leads to rf generator; G, electrical leads to recorder; H, connection to cold trap and diffusion pump.

some disagreement, it was felt necessary to investigate first the effect, if any, of the shapes of the specimens on the measured emissivities. Accordingly, measurements were made on three different copper specimens with the shapes described in Table I. The

TABLE I. Description of the specimens of 99.999% pure metals used in this research.

Specimens	Shape	Mass, g[b]	Diameter[c] or side, cm	Thickness[c] or alt, cm	Surface[c] area, cm^2	Surface[d] preparation
Cu I	Circular disk	3.4180	1.9024	0.1385	6.5210	M
Cu II	Square plate	2.7673	1.4350	0.1526	4.9940	M
Cu III[a]	Sphere	9.0180	1.2450		4.8908	M
Cu IV[a]	Sphere	8.9772	1.2430		4.8719	E
Al I	Circular plate	0.5806	0.9630	0.2960	2.3526	E
Ag I	One-base spherical segment	4.8835	0.9755	0.8225	2.9139	M

[a]Cu III and Cu IV refer to the same sphere but differ in polishing technique.
[b]Masses include those of pins used for fixing thermocouples.
[c]All dimensions were measured at room temperature.
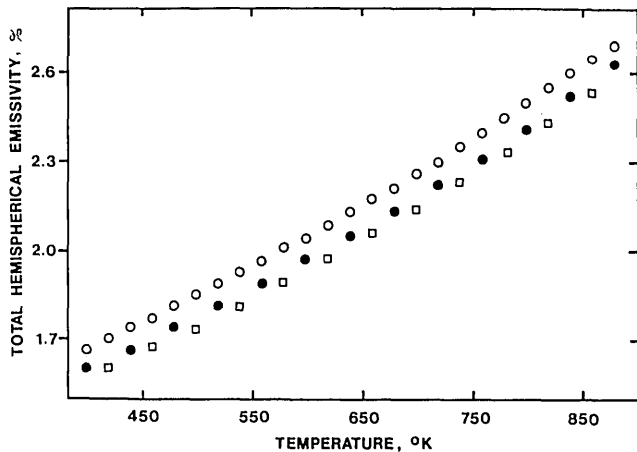[d]M, mechanical polishing. E, electropolishing.

FIG. 2. Comparison of temperature variations of measured E_h of three mechanically polished copper specimens of different shapes: o, circular disk Cu I; □, square plate Cu II; ●, sphere Cu III.

ϵ_h vs T curves of these three specimens are reproduced in Fig. 2 from which it is seen that the shape effect, if it exists, is only of the order of the accuracy of the present measurements. It is reasonable to assume that this conclusion holds good for aluminum as well as for silver. Therefore, only one specimen of each of these two materials was studied. Descriptions of the aluminum and silver specimens are also given in Table I.

Mechanical polishing was performed only on the copper and silver surfaces. This was done first on a 600-grade silicon carbide paper and then on a clean, soft cloth lap saturated with Brasso or Silvo. The technique of mechanical polishing was not used for aluminum because of the very soft nature of this material. Electropolishing of aluminum and copper was accomplished by using the techniques suggested by Tegart.[24] Electropolishing of silver was not attempted because of the highly poisonous nature of the chemicals recommended for this metal.

After polishing a specimen, the surface was first washed thoroughly with acetone and then with distilled water to ensure removal of the polishing agent. A spot-welded chromel-alumel thermocouple junction, used for measuring the temperature, was carefully press-fitted into a small hole that had been drilled into the specimen, with the aid of a short pin made out of the same material. The bare thermocouple wires were 5 mils (0.0127 cm) in diameter for the heavy spherical specimens, and were only 2 mils (0.0051 cm) for the plates which were relatively lighter. The wire sizes were chosen so that they were strong enough to support the weight of the specimen and at the same time contributed only a minimum to the correction term $\dot{Q}_c$. The specimen was then supported by its thermocouple wires from the Plexiglas support B, inside the 75 cm high, 45 cm diameter Pyrex bell jar D, shown in Fig. 1.

The procedure used in each experimental run was first to evacuate the bell jar and to locate the specimen S, inside the water-cooled rf coil C, by moving the Plexiglas support without disturbing the vacuum. The power for the coil was supplied by a 1 kW rf generator. After the specimen had been heated to a predetermined temperature, the generator was turned off. The specimen was then moved away from the coil and set approximately in the center of the bell jar allowing it to cool by radiating to the surroundings maintained at a constant room temperature. The output of the thermocouple, compensated by a reference junction E, at 0 °C, was continuously recorded by a Leeds and Northrup Speedomax-W recorder. Temperature versus time curves were then obtained from the emf versus time curves.

The slopes of the temperature-time curve in a particular portion of any cooling curve was determined by using a least-squares method to fit a parabola to a set of seven adjacent experimental points in that interval. The calculated derivative at the midpoint was assumed to be the slope of the curve at that point. The parabola was then shifted along the experimental points to obtain slopes at the other points.

III. ERRORS AND ACCURACIES

In calculating ϵ_h from Eq. (3), we assumed that at any instant, the cooling specimen was at a uniform temperature. This assumption is true, within a very small fraction of a degree, for such small specimens with very high thermal conductivities as were used in this investigation. A thermal analysis using the Fourier heat-conduction equation was made to determine the limit of validity of this assumption. Assuming the cooling rate to be the same at all points inside a sphere and the temperature distribution to be spherically symmetric, the temperature difference between the center and the surface was found to be given by

$$\Delta T = (MC_p/4\pi k r)(\partial T/\partial t), \tag{4}$$

where k is the heat conductivity and r the radius of the sphere. Using the known values of C_p and k (Ref. 25) in Eq. (4), ΔT was found to be about 0.005 K for both the copper and silver spheres for a specimen temperature of 700 K. ΔT was even smaller for $T < 700$ K. Similar calculations were made for the plate specimens of copper and aluminum, for which the ΔT's were estimated to be smaller than the corresponding values for the spheres.

As mentioned previously, in some of the earlier investigations,[14-16,26] in which the transient calorimetric technique was used, the walls of the evacuated enclosure were coated with some highly absorbing material to ensure that the energy radiated from the specimen was absorbed completely by the walls. Very simple considerations will show that the cooling rate of the specimen and the measured ϵ_h are affected only to an insignificant extent by the absence of this coating if the ratio A/A_w, of the surface areas of the specimen and the walls, is a very small fraction. If R_w is the nonzero reflectivity of the walls, the power that is first emitted by the specimen and reintercepted by it after a single diffuse reflection from the walls is approximately given by $\dot{Q}_r(A/A_w)R_w$. The fractional power reabsorbed by
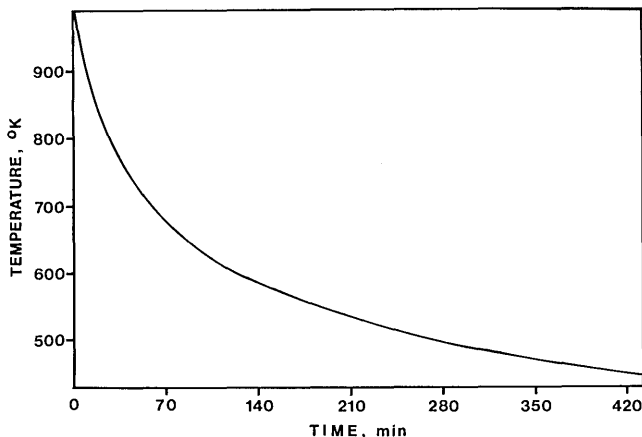
FIG. 3. Temperature vs time curve for the electropolished copper sphere Cu IV. The zero of the time scale has been fixed arbitrarily.

the specimen is thus given by $(A/A_w)R_w\epsilon_h$. Under present experimental conditions, A/A_w is of the order of 10^{-4}, which results in an insignificantly small value of 10^{-6} for $(A/A_w)R_w\epsilon_h$. The power reabsorbed after two or more reflections from the walls of the enclosure can be shown to be even less significant. The correction term $\dot{Q}_g$ was than less 0.5% of $\dot{Q}_c$ in a vacuum of 1×10^{-6} torr, maintained during all experiments. For a specimen temperature of 400 K, $\dot{Q}_c/\dot{Q}_r$ was estimated to be only 0.6% and 3.5%, respectively, for the two sizes, 2 mils (0.0051 cm) and 5 mils (0.0127 cm), of thermocouple wires used. At higher specimen temperatures $\dot{Q}_c/\dot{Q}_r$ was even smaller.

The usual formulation of Kirchhoff's law assumes thermodynamic equilibrium between a radiating object and its surrounding walls. Therefore the validity of the law is restricted to the special case when $T = T_0$. Under present experimental conditions in which $T > T_0$, Eq. (3) should be written

$$-MC_p\left(\frac{dT}{dt}\right) = A\sigma\epsilon_h T^4 - \alpha_h(T, T_0)A\sigma T_0^4 + \dot{Q}_c + \dot{Q}_g, \quad (5)$$

where $\alpha_h(T, T_0)$ is the total hemispherical absorptivity of the specimen at temperature T when the walls are at T_0. However, it has been pointed out by Eckert[27] that, for metals, the relation

$$\alpha_h(T, T_0) = \epsilon_h(T, T_0) \quad (6)$$

holds good in the infrared region. Therefore, when $T/T_0 > 2$, the error involved in replacing $\alpha_h(T, T_0)$ by ϵ_h at T in Eq. (5) is negligible. When $1 < T/T_0 < 2$, this substitution is a fairly good approximation because in this classical region, ϵ_h of a pure normal metal is continuous and varies only slightly with temperature.

The thermocouple wires were obtained from the Omega Engineering Co. The emf vs T table for chromel-alumel supplied by the company was used in determining specimen temperatures. The recorder has been calibrated with a precision microvolt potentiometer. Though the precision with which any particular temperature could be determined from a cooling curve

was 0.05 K, the actual temperature of the specimen could have been in error by several degrees due to possible systematic errors. However, the cooling rates $(-dT/dt)$, calculated from the cooling curve, were certainly accurate to better than 5×10^{-5} K/s, which causes a fractional error of less than 1%. The overall accuracy in the measurement of ϵ_h is estimated to be better than 3% and the maximum absolute error is 6%.

IV. RESULTS AND DISCUSSION

Typical T vs t and $(-dT/dt)$ vs T curves obtained for Cu IV are shown in Figs. 3 and 4, respectively. The specific-heat values of copper, required for calculating ϵ_h, were those of Pawel[19] and of Lyusternik.[20] The data of these authors were chosen because each of them had obtained results for the entire range of 400–1000 K from measurements on single specimens with purities of 99.99% and 99.9%, respectively. In spite of the difference in purities of the two specimens used by these two authors, their data show good agreement indicating that specific heat is a property which is not very sensitive to traces of impurities in this temperature range. The data obtained for the copper sphere, Cu III and Cu IV, are compared in Fig. 5 with the results of previous investigators and with the theoretical predictions of Eq. (1) evaluated by using resistivity data for this metal from the AIP Handbook.[7] It is seen that the ϵ_h vs T curves of previous researchers are considerably higher than ours. However, the two curves obtained by us show remarkable agreement even though the surfaces were prepared by different techniques. Another noteworthy feature in Fig. 5 is that our results are only about 50% of the theoretically predicted values at $T > 600$ K. A large difference is also observed between the slopes of the experimental and theoretical curves. As a consequence, the difference between the theoretical and experimental values of ϵ_h decreases steadily as T is decreased.

In Fig. 6 our ϵ_h vs T curve for aluminum is compared with the data of Best[13] and with Eq. (1) evaluated by using the published resistivity data of Simmons

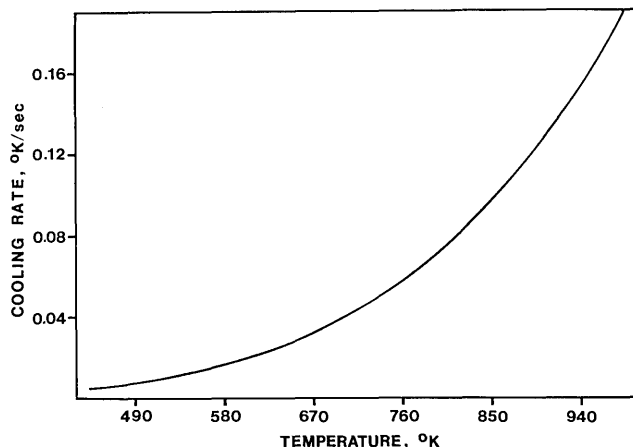FIG. 4. The cooling rate $(-dT/dt)$ vs temperature curve for the electropolished copper sphere Cu IV.
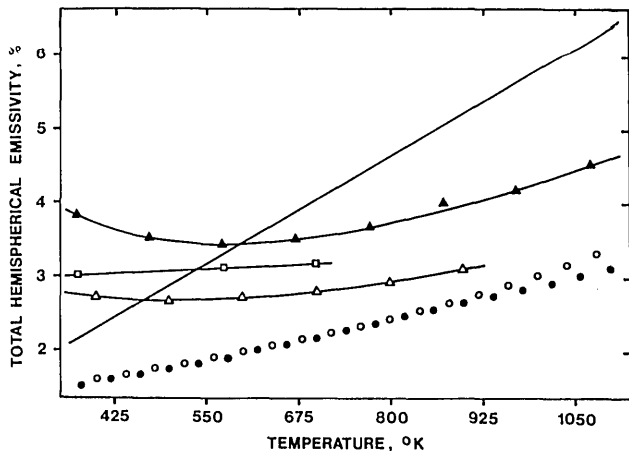
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FIG. 5. Comparison of results of present research on copper with those of previous workers and with theory: ●, present work, electropolished sphere Cu IV; ○, present work, mechanically polished sphere Cu III; -▲-, Butler and Inn[16]; -□-, Best[15]; -△-, Gaumer et al.[17]; ——, theory of Davisson and Weeks.[5]

and Balluffi.[8] The specific-heat data used in obtaining our results for the entire range were taken from the work of Pochapsky[21] who used a specimen of 99.9% purity. It is clear that the results of Best are almost 100% higher than ours. The theoretical curve is also considerably above our experimental curve which is seen to show linearity with T. The discrepancy between the theoretical and experimental slopes is also obvious.

The C_p values of silver used in calculating ϵ_h from Eq. (3) are those of Eastman et al.[22] and Bronson et al.[23] Our measured ϵ_h values are compared in Fig. 7 with those of Butler et al.[18] and with the predictions of Eq. (1) evaluated by using the resistivity values obtained from the AIP Handbook.[7] Again, the theoretical curve given by Eq. (1) is far above our curve in the entire temperature range. For ready reference, ϵ_h

FIG. 6. Comparison of results of present research on aluminum with those of Best and with theory: ●, present work, electropolished plate Al I; -○-, Best[15]; ——, theory of Davisson and Weeks.[5]
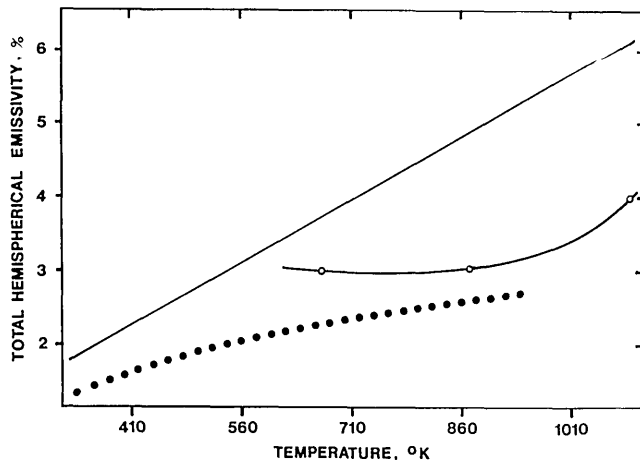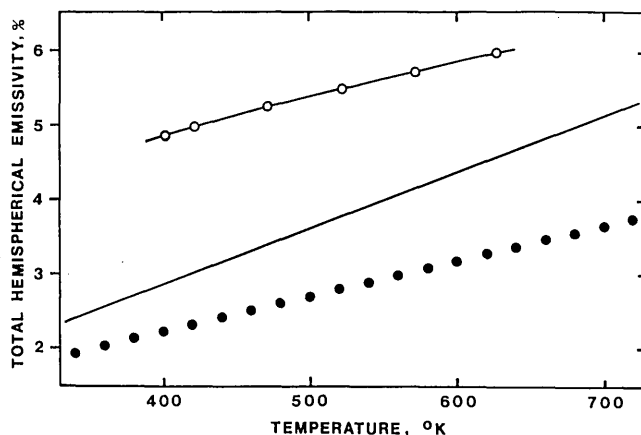

FIG. 7. Comparison of results of present research on silver with those of Butler et al. and with theory: ●, present work, mechanically polished spherical segment of one base Ag I; -○-, Butler et al.[19]; ——, theory of Davisson and Weeks.[5]

vs T data obtained by curve fitting all experimental points are presented in Table II for the three metals Cu, Al, and Ag at 20 K intervals.

The optical properties of a metal are known to be

TABLE II. Comparison of averaged ϵ_h values of present research on Cu, Al, and Ag with the theoretical predictions of Eq. (1) in the range 400–1000 K.

Temperature K	ϵ_h in percent								
	Copper					Aluminum		Silver	
	Cu I	Cu II	Cu III	Cu IV	Eq. (1)	Al I	Eq. (1)	Ag I	Eq. (1)
400	1.67	1.56	1.60	1.55	2.28	2.23	2.85	1.58	2.22
420	1.71	1.60	1.62	1.60	2.40	2.33	3.00	1.66	2.33
440	1.74	1.63	1.66	1.62	2.53	2.42	3.16	1.72	2.45
460	1.77	1.67	1.70	1.65	2.64	2.52	3.31	1.80	2.56
480	1.81	1.70	1.74	1.69	2.76	2.62	3.46	1.85	2.67
500	1.85	1.73	1.77	1.73	2.88	2.70	3.61	1.90	2.78
520	1.89	1.77	1.81	1.77	3.00	2.80	3.76	1.95	2.89
540	1.93	1.81	1.85	1.81	3.11	2.89	3.81	2.00	3.00
560	1.96	1.85	1.89	1.85	3.22	2.99	4.07	2.05	3.12
580	2.01	1.89	1.93	1.89	3.35	3.08	4.22	2.10	3.23
600	2.04	1.93	1.97	1.94	3.46	3.18	4.37	2.15	3.35
620	2.08	1.97	2.02	1.99	3.58	3.27	4.51	2.19	3.46
640	2.13	2.02	2.05	2.04	3.70	3.37	4.66	2.23	3.57
660	2.17	2.06	2.10	2.07	3.80	3.46	4.81	2.27	3.68
680	2.21	2.10	2.13	2.10	3.91	3.56	4.97	2.30	3.80
700	2.26	2.14	2.17	2.15	4.05	3.65	5.13	2.33	3.92
720	2.30	2.18	2.22	2.22	4.14	3.75	5.28	2.37	4.03
740	2.35	2.23	2.27	2.27	4.26	3.84	5.43	2.40	4.14
760	2.40	2.28	2.31	2.30	4.37	3.93	5.58	2.43	4.25
780	2.45	2.33	2.36	2.35	4.50			2.47	4.36
800	2.50	2.38	2.41	2.40	4.62			2.50	4.47
820	2.55	2.43	2.46	2.45	4.73			2.52	4.59
840	2.60	2.48	2.52	2.50	4.85			2.55	4.71
860	2.65	2.53	2.57	2.54	4.97			2.58	4.82
880	2.70	2.58	2.63	2.58	5.10			2.61	4.94
900	2.76	2.63	2.68	2.63	5.21			2.63	5.05
920			2.75	2.67	5.34				
940			2.81	2.72	5.45				
960			2.87	2.76	5.57				
980			2.94	2.81	5.70				
1000			3.00	2.85	5.82				

[a]Column Cu IV gives our best values for copper.

affected significantly by the physical condition of its surface. Therefore the resistivity which must be used to evaluate ϵ_h in Eq. (1) should be the resistivity ρ of the metal at the surface layer. This can be expressed by the equation

$$\rho = \rho_L + \rho_i + \rho_c, \tag{7}$$

where ρ_L is the resistivity caused by thermal vibrations of the lattice, ρ_i is the resistivity caused by scattering of the electron waves by impurity atoms, and ρ_c is the resistivity arising from cold working and the introduction of foreign atoms in the surface layer during its preparation. As has been shown by Pawlek and Rogalla,[28] ρ_L is the dominant contributor to ρ for a specimen at temperatures around room and above. This conclusion is strongly supported by the results of high-frequency surface resistivity measurements of Chambers[4] at room and at very low temperatures.

The thickness of surface layer removed from the copper sphere by electropolishing was estimated to be about 10 μm. By removal of such a thick layer, it is believed that much of the strains and impurity atoms introduced in the surface layer during any mechanical polishing process should have been removed. If the high-temperature values of ρ_L had been comparable to $\rho_i + \rho_c$ in the mechanically polished sphere, a significant lowering of ϵ_h vs T curve could have been expected after electrolytic polishing. The fact that very little difference has been observed is, therefore, a verification of Pawlek and Rogalla's view that at high temperatures $\rho_L \gg \rho_i + \rho_c$. This also enables us to conclude that any further improvement in the technique of surface preparation will perhaps produce only an insignificant change in the ϵ_h vs T curve in this temperature range.

An examination of all the results obtained in this research, therefore, leads us to the inescapable conclusion that Eq. (1) is not adequate to represent the true behavior of the emissive properties of copper, aluminum, and silver at high temperatures. In order to
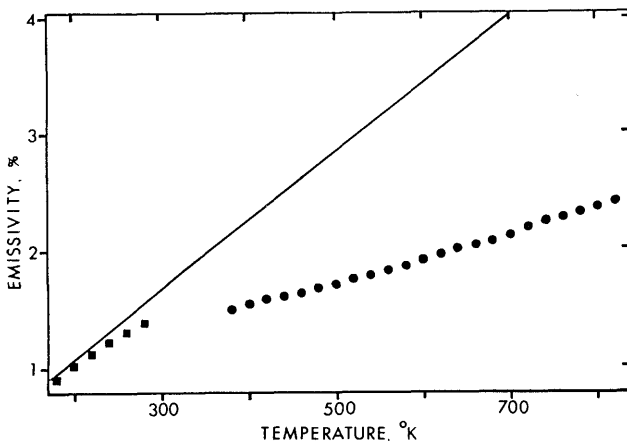
FIG. 9. Continuous plot of high- and low-temperature ϵ_h vs T data for electrolytically polished aluminum: •, present research; o, Estalote and Ramanathan[29]; —, Davisson and Weeks.[5]

further substantiate this conclusion the best ϵ_h vs T data for the range of 150–300 K for electrolytically polished Cu and Al, published by Estalote and Ramanathan,[29] elsewhere in this number of the journal, are plotted continuously along with our best high-temperature data for these metals in Figs. 8 and 9, respectively. It is seen that the low- and high-temperature data fit together as well as may be expected, without any significant discontinuity. It is also seen that in both these figures the unbroken lines representing Eq. (1) are higher than the experimental curves in the entire range of 150–1100 K. Further, at any one temperature, the slopes of the theoretical curves are larger than the corresponding experimental slopes. Consequently, the largest disparity between theory and experiment observed at the highest temperature decreases steadily as T decreases and nearly vanishes around 150 K.

The results of a recent investigation[26] of the temperature variation of ϵ_h of Ni and Fe seem to indicate that ferromagnetic metals might perhaps have a different emissive behavior. Before any attempt to modify theory[30] is made, it is necessary to carry out measurements on other metals. A careful investigation of the temperature dependence of the spectral emissivities of pure metals may also be expected to elucidate theory.

ACKNOWLEDGMENTS

FIG. 8. Continuous plot of high- and low-temperature ϵ_h vs T data for electrolytically polished copper: •, best data, Cu IV, obtained in this research; ■, best data obtained by Estalote and Ramanathan[29] for the range of 150–300 K; —, Davisson and Weeks.[5]
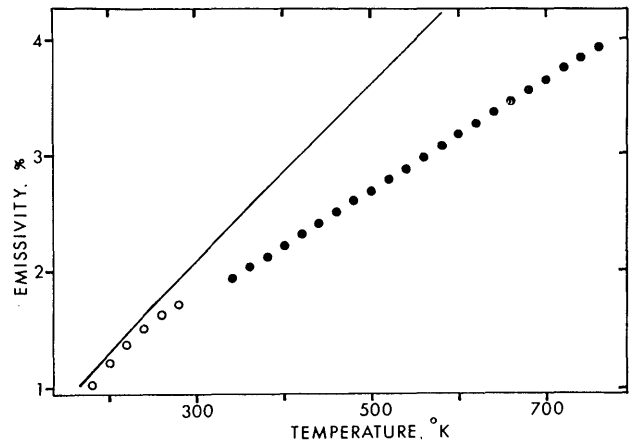
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[30]After submitting this paper for publication the present authors came across an article entitle "Theoretical and experimental studies of the total emittance of metals," by W. J. Parker and G. L. Abbott, published in *Symposium on Thermal Radiation of Solids* edited by S. Katzoff (U. S. GPO, Washington D. C., NASA SP-55, 1965), pp. 11–28. In this article the authors have modified the theory of Davisson and Weeks[5] by taking into account the finite, nonzero, relaxation times of the conduction electrons in metals. For the particular case of a zero relaxation time the numerical result of Parker and Abbott is practically the same as Eq. (1) for good conductors for which $\rho T < 0.1$. The effect of a nonzero relaxation time is to bring down the ϵ_h values at all temperatures. However, Parker and Abbott concluded that their experimental data for the metals Ta, Nb, W, and Mo qualitatively agreed with Eq. (1) and with their theoretical result for a zero relaxation time. On the other hand the results reported in this paper for Cu, Al, and Ag appear to lend support to the relaxation theory of Parker and Abbott. It is hoped that a detailed analysis of the effect of finite relaxation times of conduction electrons on the emissive behavior of metals will form the subject matter of a future communication.