SOME THERMAL PROPERTIES OF TANTALUM

By C. L. Utterback and L. A. Sanderman
University of Washington, Seattle

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Abstract

Measurements have been made on the total radiation from very pure, well seasoned tantalum from 1000°K to 2220°K. A spectral temperature scale, $\lambda = 0.667\mu$, is given up to 2100°K. The variation of the resistance of tantalum has been measured up to 2600°K and the thermoelectric power of tantalum with pure platinum has been measured up to 692°K.

Total Radiation

THE total radiation from tantalum was measured by using, as a radiator, a wedge shaped piece of the metal as described by Mendenhall.[1] The V-shaped wedge was formed from a tantalum ribbon which was 0.035 cm thick. It was 3.5 cm long, 1 cm wide, and had an opening of 6 degrees. The arrangement of the apparatus used and the method of making observations on radiation have been sufficiently described by one of us[2] that further description is unnecessary. The tantalum used in the experiments here described contained less than 0.2 percent carbon.

Measurements of total radiation were made on five samples of the metal. The results are shown in Fig. 1.

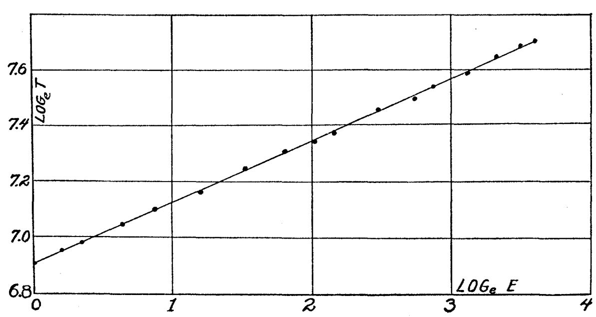

Fig. 1. Logarithmic plot of energy against temperature.

From 1000°K to 2200°K the curve is a straight line. The total emission of energy may be represented by an equation of the form

$$E = cT^n \tag{1}$$

in which the value of n is constant and equal to 4.72 over the range studied. This is not in agreement with the results of Worthing,[3] who finds the value of n to be a constant and equal to 4.80 from 1600°K to 2800°K.

[1] C. E. Mendenhall, Astrophys. J. **33**, 91 (1911).
[2] C. L. Utterback, Phys. Rev. **34**, 785 (1929).
[3] A. G. Worthing, Phys. Rev. **28**, 190 (1926).

Worthing's value of 4.80, for n, however, did not result from a direct observation of the rate of emission of energy and of the temperature. His value of n is dependent upon his value of the spectral emissivity of tantalum and that in turn is determined by the manner in which the spectral emissivity curve is located.[4] In discussing his value of $(T/E)(dE/dT)$, Worthing suggests, since it does not tend toward the theoretical value of 4, with increasing T, that some error might exist in the location of his curve. If such error exists, it will, of course, affect the value of $(T/E)(dE/dT)$, as well as the dependence of $(T/E)(dE/dT)$ on T. In our measurements of total radiation the true temperature of the radiator was directly observed by means of an optical pyrometer, calibrated against a black body held at the palladium point, sighted in the opening of the V-shaped wedge. A decrease of $(T/E)(dE/dT)$ with increasing T has not been found to exist with other metals,[2] except at transformation points where $(T/E)(dE/dT)$ changes abruptly, nor do the present authors find any change in this quantity for tantalum up to 2200°K.

Temperature Scale, $\lambda = 0.667\mu$

Wedge shaped filaments of the same dimensions as described above were used for determining the temperature scale. The apparatus for the total radiation experiments had been provided with two windows at right angles to each

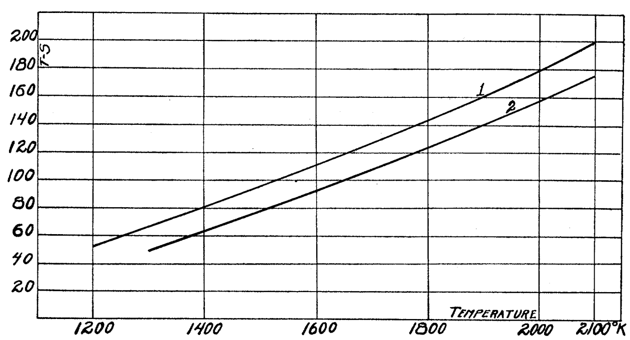

Fig. 2. Tantalum temperature scale, $\lambda = .667\mu$. Curve 1 is drawn from the results given by Worthing. Curve 2 is from those of the present authors.

other so that it could also be used for these measurements. Temperature readings were taken, simultaneously, on the outside face of the V, through one of the windows and in the opening of the wedge through the other. The surface of the metal filament was carefully polished before placing it in the vacuum chamber. It was heated very gradually to incandescence by means of storage batteries. A two stage diffusion pump backed by an oil pump was kept running during the preliminary heating and while making observations. During the observations the filaments showed no pitting. They maintained a good polish during the measurements.

In Fig. 2 the true temperature T is plotted against T-S, where S is the black body temperature of the tantalum. A comparison of curves 1 and 2

[4] A. G. Worthing, Phys. Rev. **28**, 174 (1926).

shows a small difference between our values of *T-S* and those obtained by Worthing.[4] This difference is slightly greater around 1300°K and 2100°K than at intermediate temperatures. The scale shown by curve 2 is in better agreement with Worthing's scale for tantalum than it is with Mendenhall and Forsythe's[5] scale or with McCauley's[6] scale. In an excellent comparison of tantalum temperature scales, determined before 1926, Worthing suggests that the scale of Mendenhall and Forsythe and the scale of McCauley might be questioned on the ground of lack of "blackness" of the V-shaped wedges used by these experimenters. However, in the present work wedges, with a slightly smaller opening than the ones used by Mendenhall and Forsythe, were used with very consistent results which are not greatly different from those of Worthing. It is our experience that open wedge shaped radiators of sufficiently small openings give considerably more consistent and reproducible results than the methods used by Worthing in the determination of the spectral emissivity.

Temperature Coefficient of Resistance

A filament in the form of a No. 24 tantalum wire, of the same purity as the metal used in the wedges, was used for the resistance measurements. The wire, 10 cm long, was mounted in a lamp by means of tungsten seals. Two

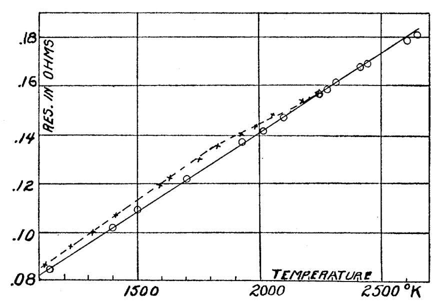

Fig. 3. Variation of the resistance of tantalum with temperature.

potential leads, of No. 36 tantalum wire, of the same purity as the filament, were welded to the filament 3 cm apart. These were connected, through tungsten seals, to a Leeds and Northrup type K potentiometer. The wire was heated by means of storage batteries. The resistance between the potential leads was computed from the current and potential readings. The lamp was evacuated by means of a two stage diffusion pump backed by an oil pump. The pressure in the lamp was maintained at a low value, never exceeding 10^{-6} mm of mercury. The filament was very free from pits and maintained an exceedingly good polish throughout the observation. The black body temperature of the wire was measured, at several points along the wire, with the optical pyrometers and the true temperature computed by means of the tantalum temperature scale previously determined. The results are given in Fig. 3.

[5] C. E. Mendenhall and W. E. Forsythe, Astrophys. J. **37**, 380 (1913).
[6] C. B. McCauley, Astrophys J. **37**, 164 (1913).

The variation in temperature with resistance is fairly well represented by the equation

$$R_T = R_{1000}[1 + \alpha(T - 1000)] \qquad (2)$$

for values of T from 1000°K to 2600°K, where α has the value $81.5 \cdot 10^{-5}$. Worthing's[3] data are not sufficient to compare his result with this as his measurements do not extend to temperatures lower than 1600°K. However, if his values of resistivity be extrapolated to 1000°K, and α calculated from his data its value is about $79 \cdot 10^{-5}$. Worthing's measurements on resistivity were made up to 2800°K. He used the same type of lamp, with potential leads from the filament, as was used by the present writers. It was our experience that the lamps begin to blacken a noticeable amount at 2600°K, due to the evaporation of the tantalum and for that reason temperatures higher than this were measured with considerable uncertainty.

In Fig. 3 the dotted line shows the behavior of the resistance before the filament was well seasoned. Each sample of tantalum used in the experiments was heated to 2200°K before measurements were made. All of the filaments mounted in lamps showed an irregular change in resistance between the temperatures of 1700°K and 2200°K before heating to 2200°K. This irregular change in resistance was accompanied by mechanical changes in the wire. An irregular twisting and bending of the wire between supports occurred if the filament was mounted, as it was in some lamps, in the form of a loop or a double loop.

Thermoelectric Power

A piece of seasoned No. 30 tantalum wire was welded to a piece of No. 32 platinum wire and the thermal e.m.f.'s measured at the following temperatures: 19.2°C, 165.2°C, 232°C, 269°C and 419.4°C. The e.m.f.'s at these temperatures were 80, 230, 570, 700 and 1710 microvolts respectively. These values when plotted gave a curve which is represented well by the equation

$$\log_{10} E = A \log_{10} t + B \qquad (3)$$

in which the value of A is 2.06 and that of B is -2.16 when E was expressed in microvolts and t in degrees centigrade. This gives a value for dE/dT which varies almost linearly with the temperature.

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