The Rate of Evaporation of Tantalum

D. B. LANGMUIR AND L. MALTER
Research and Engineering Department, RCA Manufacturing Company, Harrison, New Jersey
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The rate of evaporation of tantalum was determined by measuring the change of resistance and the change of weight of uniform filaments. Temperatures were held constant throughout each run by adjustments of voltage V and current A so that $VA^{\frac{1}{3}}$ remained approximately unchanged. The rate of evaporation can be expressed by $\log_{10}M=7.86-39{,}310/T$, where M is the rate of evaporation in grams per cm^2 per sec. and T is the temperature on the Kelvin scale.

THE rate of evaporation of tantalum as a function of temperature, which appears not to have been reported previously in the literature,[1] was measured in the experiments described below. The amount of evaporation was measured by observing both the loss of weight and the increase of resistance of wires heated electrically in vacuum. The temperature scale published in an accompanying paper by the authors was used.[2]

EXPERIMENTAL METHOD

Tantalum filaments (manufactured by the Fansteel Company) having a diameter of 0.030 cm and a length of 15 cm were mounted in the shape of hairpin loops in evacuated bulbs and heated with a regulated power supply for varying lengths of time depending upon the temperature. All the wire used was aged in vacuum for times varying from 4 to 100 hours at about 2200°K before being placed in the final experimental bulbs. Tungsten wires 0.005 cm in diameter welded to the tantalum 2.5 cm from each end served as potential leads, so that measurements of voltage drop were not affected by cooling at the ends.

When temperatures were so high that the complete evaporation run lasted only a few hours or less, direct current was used for power, and values of voltage and current were followed with potentiometer measurements. For longer runs the use of direct current was impracticable because of the difficulty of obtaining a constant source of sufficient power, and so regulated alternating current was employed. With direct current, measurements of voltage V and current A were made at several stages of each evaporation. The temperature of the tube while heated by alternating current was determined by observing the current flowing in a photoelectric cell placed near the tube, and measuring the direct heating current which gave the same light output. As the ripple in light output caused by the alternating-current heating was of the order of one percent, the error due to temperature fluctuations caused by a.c. is negligible.

The mean temperature which prevailed during an evaporation was determined from the value of $VA^{\frac{1}{3}}$ which most nearly corresponded to conditions during operation. All measured values of V and A which corresponded to a.c. operating temperatures were plotted and successive points joined by a line. A straight line with slope such that $VA^{\frac{1}{3}}=$constant (i.e., an isothermal) was then drawn so that the area between it and the operating line was the same on one side as on the other. The maximum variation in temperature from the mean during any run lay between 5 and 10 degrees. This corresponds to a change in evaporation rate sufficiently small that averaging can introduce no serious error.

After about ten percent of the mass of a filament had evaporated, the tube was opened and the mass per unit length of the center portion of the wire compared with that of a sample of the batch of aged wire from which the tube was made. The change in mass was also computed from the change in resistance. This was observed from the $V-A$ plot for the operating tempera-

[1] The vapor pressures of about 30 elements are discussed in a review by C. Zwikker, Physica 8, 241 (1928). Dr. Zwikker has informed us that one of the curves there marked "Ta" actually refers to thallium.
[2] L. Malter and D. B. Langmuir, Phys. Rev. 55, 743 (1939).

ture. The criterion for constant temperature at beginning and end of run was that $VA^{\frac{1}{3}}$ be the same.

Results

The change in diameter of a filament as determined by weight was on the average 2.5 percent greater than the value obtained by purely electrical measurements. Differences as large as 7 percent were observed in individual cases. As these discrepancies are definitely larger than the experimental error for either type of measurement, some change of the tantalum during the evaporation runs seems to be indicated. This change amounts to about 0.2 percent of the value of the resistivity. The variation of resistivity among supposedly identical samples of tantalum was found during work on the tantalum temperature scale[1] to be of this same order of magnitude.

The rate of evaporation as a function of temperature as determined from weight measurements is plotted in Fig. 1. The curve can be represented by the equation:

$$\log_{10} M = 7.86 - 39{,}310/T,$$

in which M is the rate of evaporation in grams/cm^2 sec. and T is the temperature on the Kelvin scale. Values of evaporation rate and vapor pressure for 200-degree temperature intervals are given in Table I. The vapor pressure was calculated from the evaporation rate using the equation:[3]

$$P = 1700 M T^{\frac{1}{2}},$$

in which it is assumed that there is no lessening of the evaporation rate caused by reflection of atoms at the surface.

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TABLE I. *Values of the evaporation rate and vapor pressure of tantalum at various temperatures.*

T °K	M g/cm^2 sec.	P dynes/cm^2
2000	1.63×10^{-12}	1.27×10^{-7}
2200	9.78×10^{-11}	8.01×10^{-6}
2400	3.04×10^{-9}	2.58×10^{-4}
2600	5.54×10^{-8}	4.90×10^{-3}
2800	6.61×10^{-7}	6.07×10^{-2}
3000	5.79×10^{-6}	5.40×10^{-1}
3200	3.82×10^{-5}	3.77
3269 (M.P.)	6.80×10^{-5}	6.75

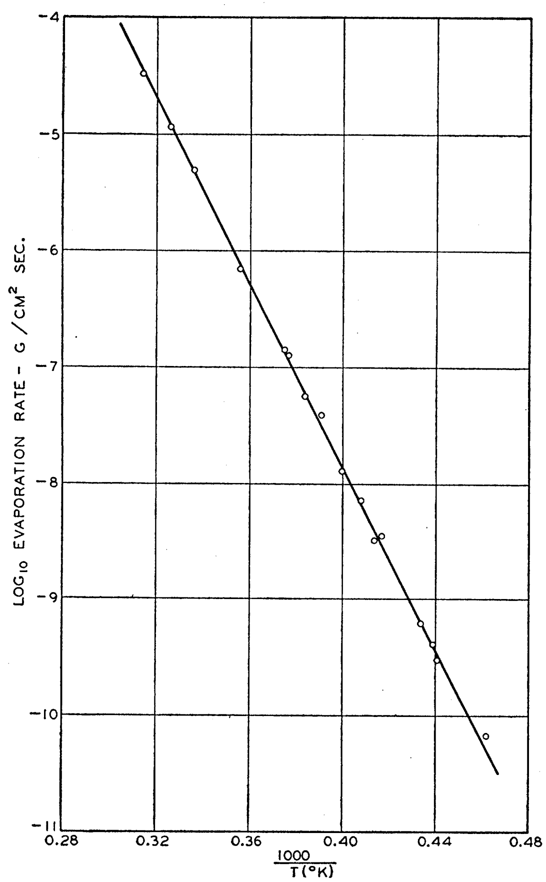

FIG. 1. Rate of evaporation of tantalum as a function of temperature.

[3] H. S. Taylor, *Treatise on Physical Chemistry* (D. Van Nostrand Company, second edition, 1931), Vol. I, p. 245.