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Thermal Conductivity of Nickel and Uranium[1]

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Introduction

The thermal conductivity of a metal can be measured at any temperature by a method in which the conductivity of the metal under investigation is compared with the known conductivity of some metal chosen as a standard (1). The rate of heat flow, Q, in a cylindrical specimen of unknown conductivity, is given by the equation $Q = -K_1AG_1$, where K_1 is the unknown thermal conductivity, A is the cross-sectional area, and $G_1 = (\Delta T/\Delta x)_1$ is the temperature gradient. If a cylindrical bar of equal cross-sectional area and known thermal conductivity, K_2, is placed in series with the specimen so that the rate of heat flow is the same in both bars, we have $Q = -K_2AG_2$, where $G_2 = (\Delta T/\Delta X)_2$ is the temperature gradient in the standard sample. From these two expressions for Q, the unknown thermal conductivity, $K_1 = (G_2/G_1)K_2$, can be found if the temperature gradients in the two rods are measured.

In principle, the comparison method is simple but, in practice, complications may arise at high temperatures in providing good thermal contacts, in preventing radial heat losses, and in making reliable temperature measurements. The method has not, therefore, been characterized by high precision at elevated temperatures. The purpose of this investigation was (a) to develop improvements in the apparatus for measuring thermal conductivities of metals at high temperatures by the comparison method, and (b) to determine the thermal conductivities of nickel and uranium in the temperature range 100° C. to 650° C. by the comparison method.

Apparatus

In the vacuum furnace shown in Fig. 1, pressures as low as 2 x 10^{-6} mm of Hg were attained at 700° C. The specimen was placed between two Armco iron standards and, in order to achieve good thermal contact, the ends of the rods were grounded flat and jointed together with stainless steel studs. The temperature gradients in the three sections of the compound bar were measured by the twelve chromel-alumel thermocouples TC1 to TC12 (Fig. 1). Since the success of the method depends upon the elimination of radial heat losses, the sample was surrounded by a guard tube (B in Fig. 1)

[1]The work was performed in the Ames Laboratory of the Atomic Energy Commission.

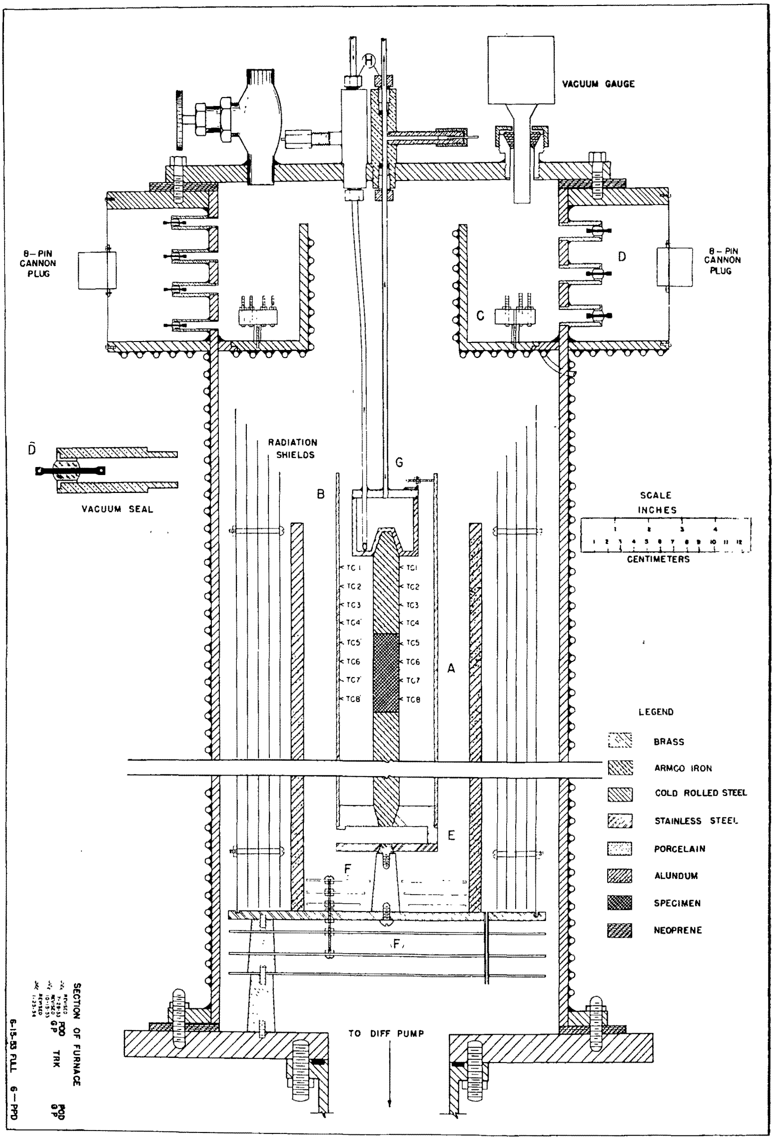

Figure 1. Vacuum Furnace for Thermal Conductivity Measurements.

capable of closely duplicating the temperature gradient in the sample. The guard tube had twelve separate resistance windings, which were distributed evenly along its length, and the power to each winding could be controlled individually. The twelve guard thermocouples TC1′ to TC12′ (Fig. 1) were in the same horizontal planes as the corresponding thermocouples on the sample; and the temperatures at TC1 and TC1′, at TC2 and TC2′, etc., could be matched either manually or automatically to better than 1° C.

The source block (E in Fig. 1) was made of stainless steel and the heater element consisted of molybdenum wire wound on an alundum tube. The sink (G in Fig. 1.) was also made of stainless steel and tap water was used as a coolant. The main source of power for the furnace was provided by 90 to 300 volts d.c. applied to four molybdenum windings wrapped on an alundum cylinder. The power to these four windings was controlled by Flexopulse repeat cycle timers which determined the fraction of time the windings were receiving power.

Results

After the furnace had been evacuated and heated, a gradient was established in the sample and a corresponding gradient established in the guard tube. When steady state conditions had been obtained, the sample thermocouples were read and recorded. The thermal conductivity of the Armco iron standards has been determined by Powell (2), Van Dusen and Shelton (3), and by Armstrong and Dauphinee (4). The results of Armstrong and Dauphinee were used in this investigation.

The thermal conductivities of commercial A nickel and pure uranium are shown in Figs. 2 and 3. The results are in approximate agreement with measurements by other investigators using other methods. The nickel data show a Curie temperature slightly below the temperature 360° C. characteristic of pure nickel. It is known that non-ferromagnetic impurities decrease the Curie temperature of nickel. The analysis of our nickel specimen gave the following percentages: 99.54 nickel, 0.25 manganese, 0.07 iron, 0.03 each of cobalt, magnesium, and silicon, and smaller amounts of several other metals. When the nickel data are compared with the data of Van Dusen and Shelton (3), Hugon and Jaffray (5), and Hogan and Sawyer (6), the slope of our curve below the Curie temperature appears too steep and suggests that our low temperature data may be too high.

The data for uranium were fitted to the curve: $K = 0.255 + 0.299(10^{-3})\ T - 0.801\ (10^{-6})\ T^2 + 0.716\ (10^{-9})\ T^3$, where $373 < T < 933$ and T is in degrees Kelvin. The root-mean-square deviation was 0.011. When the uranium data are compared with the data of other investigators (7, 8, 9), the agreement is good in magnitude but our data indicate greater deviation from a linear temperature dependence. The estimated total error in our uranium data was seven per cent. The greatest source of error was inaccuracy in the measurement of small temperature intervals by thermocouples.

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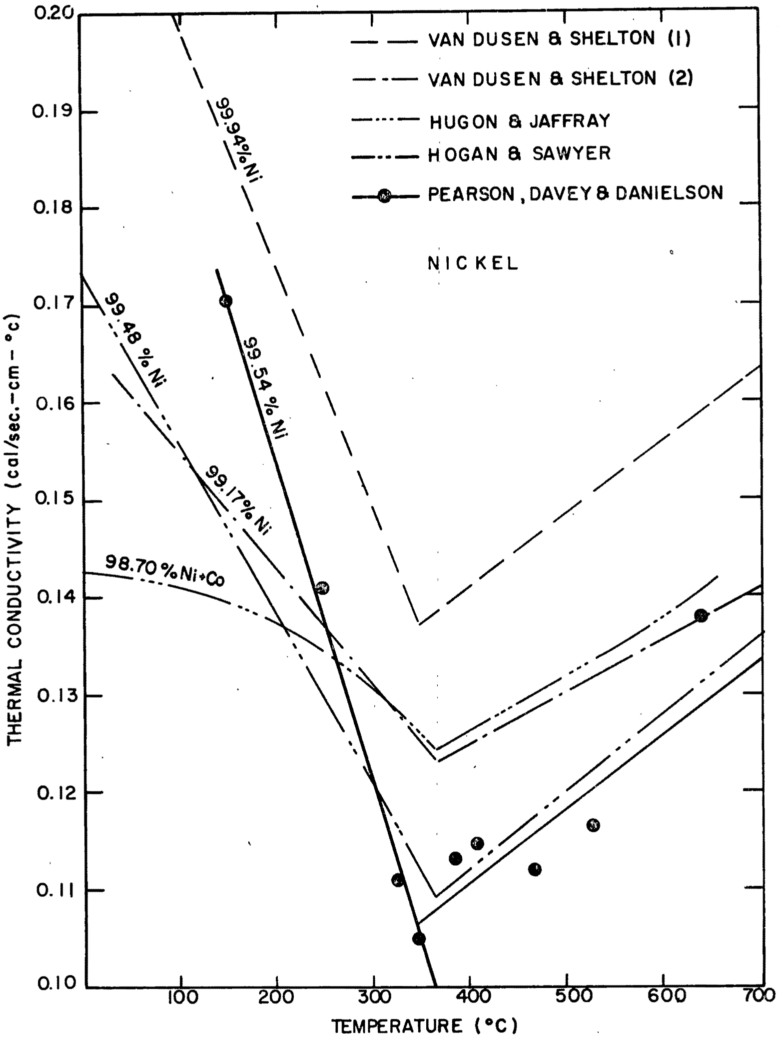

Figure 2. Thermal Conductivity of Commercial A Nickel.

Conclusion

An improved apparatus for measuring the thermal conductivity of metals at high temperatures by the gradient comparison method has been constructed. Our data for commercial A nickel and for pure uranium from 150° C. to 650° C. indicate that the comparison method is comparable (but not superior) to other methods of measuring thermal conductivity at high temperatures.

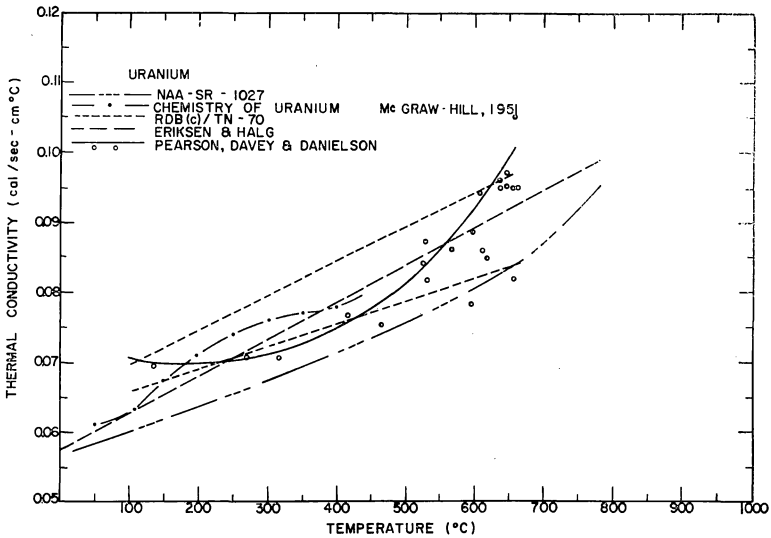

Figure 3. Thermal Conductivity of Pure Uranium.

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