Melting and High-Temperature Electrical Resistance of Gold under Pressure*

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The electrical resistance of gold was measured over the temperature range 30°C to the melting point and over a pressure range 0–70 kbar. At constant pressure, a sudden twofold increase in resistance sharply indicated the melting point and was used to determine the solid-liquid phase line to 70 kbar. The experimental melting curve has an initial slope, 5.91°C/kbar, in very good agreement with Clapeyron's equation, and has a form satisfying a Simon's equation with a coefficient $c=2.2\pm0.1$. The electrical resistance data show a decrease in the temperature coefficient of resistivity at higher pressures, while the resistance at the melting point appears to be a constant independent of pressure.

I. INTRODUCTION

In many high-pressure high-temperature experiments it would be convenient to use the electrical resistance of a material as an indication of its temperature. There have been occasions where the resistance of noble metals has been used for this purpose.[1,2] In these cases it was assumed that the increase of resistance with temperature is independent of pressure; thus measurements at atmospheric pressure were used as the temperature calibration. One object of this experiment is to determine the temperature dependence of the electrical resistance of gold as a function of pressure. Resistance measurements were made from room temperature to the melting point for the pressure range 0–70 kbar. At the melting point there is an abrupt resistance increase; thus the melting temperature was also determined as a function of pressure.

Gold is ideal for this type of study. First it is chemically inert which is of prime importance to the experimentalist, for in high-pressure studies the materials are in intimate contact with their surroundings. The electronic and thermodynamic properties of gold however give rise to more fundamental reasons for studying this material. The conduction electrons in gold behave as nearly free electrons with an isotropic effective mass and there are no isomorphic phase transitions to pressures as high as 100 kbar.[3] Thus one might expect the resistance and melting curves to be accurately represented by a simple semiclassical model of an ideal metal.

1. Electrical Resistance

The theory of the electrical resistance of metals at atmospheric pressure has met with considerable success,[4] especially for metals in which the Fermi surface is nearly spherical and lies entirely within one Brillouin zone. The extension of this theory to the range of high pressures is discussed by Lawson.[5] In the region where the temperature is greater than approximately twice the Debye temperature θ, one can write a simple expression for resistance as a function of pressure P and temperature T. Starting from a formula for the pressure coefficient of resistance, derived by Lennsen and Michels[6] for nearly free electrons, we arrive at the equation

$$R(P,T)=CT[V(P,T)]^{2\gamma-4/3}, \qquad (1)$$

where C is a constant, $V(P,T)$ is the volume and γ is the Grüneisen constant. We now define the ratio

$$r_p(T,T_0)\equiv R(P,T)/R(P,T_0) = T/T_0[V(P,T)/V(P,T_0)]^{2\gamma-4/3}. \qquad (2)$$

The accuracy of this equation at atmospheric pressure was determined by comparing the measured resistance ratio[7] with that calculated from Eq. (2) using experimental thermal-expansion data[8,9] and $\gamma=3.00$.[10] Calculated and measured values agree to better than 0.5% from room temperature to the melting point. Another check on Eq. (1) is possible using compressibility measurements at room temperature[11,12] and calculating $R(P,T_0)/R(0,T_0)$. These values agree with Bridgman's high-pressure resistance measurements[3] to better than 1.5% up to 50 kbar. For high pressure and temperature effects it is convenient to write

$$r_p(T,T_0)/r_0(T,T_0) = [V(P,T)V(0,T_0)/V(0,T)V(P,T_0)]^{2\gamma-4/3}. \qquad (3)$$

All quantities on the right-hand side are known except $V(P,T)$. Even without an exact knowledge of the equation of state, it is obvious that (3) predicts a very small negative effect of pressure on $r_p(T,T_0)$. This is

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