Experimental Determination of the
Temperature Dependence of Metallic
Work Functions at Low Temperatures

Progress Report

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Abstract

The progress made under ERDA Contract No. E(11-1)-2314 (Mod 2) is described. This progress includes measurements of the temperature dependence of the work functions for niobium and aluminum between 2 K and 20 K and the development of a simple theoretical model to explain the effects of adsorbed ⁴He gas on the temperature dependence of the work function in niobium.

The progress made under ERDA Contract No. E(11-1)-2314 (Mod 2) has been primarily in two areas: 1) the temperature derivative of the electronic work function, dW/dT , has been measured in niobium between 2.7 K and 19 K and in aluminum between 5 K and 13 K, and 2) a model has been developed to explain the effects of an adsorbed helium gas layer on the dW/dT measurements in niobium. The details of this progress is as follows:

1) Preliminary reports on the dW/dT measurements on niobium were given at the Washington meeting of the American Physical Society in April (C00-2314-5) and at the 14th International Conference on Low Temperature Physics in August (C00-2314-7). These early measurements did not show any signs of the superconducting transition. This was a matter of some concern so considerable effort was put into increasing the signal to noise ratio as well as improving the thermometry. In addition the data analysis has been computerized so that statistical errors can be handled in a more satisfactory way. Since data can be analyzed on the computer as it is taken, decisions about data taking can now be made during an experimental run.

The effects of the efforts described above can be seen for the case of niobium in figure 1. Above about 6 K the scatter in the data is considerably lower than in previous presentations, the typical error being about $1 \mu V/K$. The data below 6 K shows a bit more scatter because it is all taken at very low heater powers so that the raw signals are quite small. It should be noted that the data extend to about 2.5 K now.

The most interesting feature of the data shown in figure 1 is the rather sharp drop in dW/dT at the superconducting transition temperature, T_c . The temperature dependence of dW/dT seems to be linear above T_c and, within experi-

mental precision, constant below T_c . Thus above T_c the temperature dependence (but not the magnitude) of dW/dT agrees with simple theories which predict that the temperature dependence should be dominated by the effects of thermal expansion on the electron density. However, below T_c these theories predict a T^3 dependence for dW/dT which does not appear to agree with the experiments. Another puzzling feature of the data is that the magnitude of dW/dT seems to be 50 to 100 times greater than these theories predict.

The other metal for which data on the temperature dependence of dW/dT has been obtained is aluminum. This data is shown in figure 2. Aluminum is a much simpler metal than niobium and the hope was that it would conform the simple theories much better. It can be seen in figure 2 that the magnitude of dW/dT in aluminum is similar to that in niobium but that the sign is different. It also appears that there may be some structure in the temperature dependence of dW/dT . This data has only been obtained in the last month so we are not yet prepared to speculate on it.

2) It was noted in early experiments at Leiden that an adsorbed layer of helium gas has an enormous effect on the temperature dependence of the work function of a metal. This has been confirmed in our experiments and we have developed a simple theoretical model to explain it.

The model is based upon the assumptions (1) that at low pressures less than a monolayer of ^4He gas is physically adsorbed onto the surface of the sample, (2) that the change in the work function is proportional to the percentage coverage of the sample surface by the ^4He and (3) that the percentage coverage at any temperature can be calculated using the Langmuir adsorption isotherm.

Under these assumptions we find that the work function $W(T)$ is given by

$$W(T) = \frac{kDn_0 e^{E_0/kT}}{T^{3/2} + Dn_0 e^{E_0/kT}}$$

where

k = proportionality constant between W and percentage covered

n_0 = total moles of ^4He

E_0 = binding energy of adsorbed ^4He atom

D = geometrical constant

A fit of this relation to the data taken for ^4He gas adsorbed on niobium is shown in figure 3. Since we can only estimate the constants k , n_0 and D , we have performed a large number of fits with different values for them. The best fits are always obtained for $E_0/k = 16$ K. Thus it seems that the binding energy of a ^4He atom to a niobium surface is about 16 K, a very reasonable number.

We are presently considering methods for establishing the values of the parameters k , n_0 and D experimentally so that we can be sure of measuring a unique value for E_0 .

The principal investigator devoted about 25% of his time to this project during the months of March-May, 1975 and September-November, 1975. During the months of June, July and August, 1975, the principal investigator worked on this project essentially full time. It is anticipated that he will devote about 25% of his time to the project between now and the end of the contract year.

Articles Published:

1. U.J. Gibson and P.B. Pipes, Phys. Rev. B 11, 4219 (1975) C00-2314-3.
2. P.B. Pipes and D.H. Darling, Proc. of 14th Int. Conf. on Low Temp. Physics 4, 521 (1975) C00-2314-7.

Papers Presented:

1. U.J. Gibson and P.B. Pipes, Bull. Am. Phys. Soc. 20, 616 (1975) C00-2314-6.
2. D.H. Darling and P.B. Pipes, Bull. Am. Phys. Soc. 20, 616 (1975) C00-2314-5.

FIGURE CAPTIONS

Figure 1. Experimental Results for Temperature Derivative of Work Function in Niobium

Figure 2. Experimental Results for Temperature Derivative of Work Function in Aluminum

Figure 3. Comparison of Experimental and Theoretical Results for ^4He Adsorbed on Niobium

FIGURE 1

FIGURE 2

$W(4.2) - W(T)$ (ARBITRARY UNITS)

FIGURE 3