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Effect of Pressure on the Superconducting Transition Temperature of Lanthanum*

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The variation of the superconducting transition temperature of hcp lanthanum has been measured as a function of pressure up to 10 kbar. An approximately linear increase of T_c with applied pressure was observed ($\partial T_c/\partial P \sim 14\times10^{-5}$ °K bar^{-1}). The relation of this behavior to two recently proposed theories for the superconductivity of lanthanum is discussed.

I. INTRODUCTION

In view of the recent suggestions by Kondo[1] and Kuper, Jensen, and Hamilton[2] for the mechanism responsible for the occurrence of superconductivity in lanthanum it was decided to study the effect of pressure upon the superconducting transition temperature. Both mechanisms evoke either a narrow band or a sharp $4f$ level lying just above the Fermi surface. Kondo proposed that there is an interaction between this narrow band, irrespective of whether it is empty or partially occupied, and the conduction band.[3] He then showed, using the BCS formalism for the electrons in the conduction band, that the presence of this narrow band increased the superconducting transition temperature. Kuper *et al.*, on the other hand, suggested that it is a magnetic interaction, arising from the partial occupation of the nearby $4f$ level, which gives rise to the necessary electron-electron interaction for superconductivity in lanthanum. In both theories the value of the superconducting transition temperature T_c is dependent on the magnitude of the energy gap between the $4f$ band and the Fermi surface, and both theories predict that as the energy gap increases T_c will decrease.

It is known that the application of a sufficiently high pressure ($\sim$8 kbar) at room temperature to the normal face-centered cubic (γ) phase of cerium results in a collapse to a denser (α) phase,[4] but without a change of structure.[5] It has been suggested[6,7] that this transition is associated with the transfer of the single localized $4f$ electron in γ cerium into the conduction band of α cerium. Evidence in agreement with this suggestion has been obtained from low-temperature paramagnetic scattering of neutrons from cerium by Wilkinson, Child, McHargue, Koehler, and Wollan[8] who were able to interpret their data assuming zero localized moment in α cerium. It may be argued, therefore, that the application of pressure to cerium results in a displacement of the $4f$ level to a higher energy relative to the Fermi surface. Allowing that the application of pressure tends to raise the $4f$ level in cerium, it may also be argued that this will be true for the unoccupied $4f$ level in lanthanum. As a consequence of such a movement of the $4f$ level on the application of pressure and on the basis of the above theories, one would expect a dramatic decrease in the superconducting transition temperature of lanthanum.

It has been observed that the majority of superconductors show an increase in volume below the superconducting transition temperature. A simple thermodynamic argument leads one to expect that T_c will decrease upon the application of pressure which is in agreement with observation. Lanthanum, however, is anomalous and shows a *decrease* in volume[9] below the superconducting transition temperature. Therefore one would expect T_c to increase with pressure, in contradiction to the prediction of the above theories.

The purpose of the following is to attempt to clarify the position by a report of some preliminary measurements of the variation of the superconducting transition temperature of lanthanum under pressure.

II. MEASUREMENTS

Measurements were made on samples of lanthanum obtained from two separate sources. One sample was kindly supplied by the U. S. Bureau of Mines, denoted as U.S.B.M., and the other was obtained from the Lunex Company. The analyses in wt%, as supplied with the samples, gave the following impurities: U.S.B.M. O 0.016, C 0.047, Al 0.01, Fe 0.006, Mo 0.014, Si 0.012, Ce 0.07; Lunex O 0.08, Fe 0.01, Mg 0.01, Nb 0.015, Nd 0.01, Er 0.01, all other impurities were less than 0.01 wt% in both cases.

Pressure applied to the sample, in a pressure capsule, at room temperature was retained by a clamp technique (Bowen and Jones[10]). The sample was cooled to its superconducting transition temperature by suspension over a bath of liquid helium. Temperatures were measured with a calibrated carbon resistor mounted

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