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Pressure Effect on Superconducting Lead*

M. Garfinkel† and D. E. Mapother
Department of Physics, University of Illinois, Urbana, Illinois

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Techniques are described for measuring the effect of hydrostatic pressure on the critical field, H_c, of superconducting Pb. Pressures up to 650 atm were applied using solid helium as the pressure fluid. Observations were made from about 7 to 1°K, and values of dH_0/dP, dT_c/dP, and the temperature variation of $(\partial H_c/dP)_T$ are reported. From these data the value of $(1/\gamma^*)(d\gamma^*/dP)$ is deduced, where γ^* is the temperature coefficient per unit volume of the normal electronic specific heat. The observed data are accurately represented over the full range of measurement by the equation $H_c(P,T)=H_0(P)f(t)$ where $t=T/T_c$ and $f(t)$ is independent of pressure. The "similarity principle" requirement, $H_0(P)/T_c(P)=\text{const}$, is shown to be invalid for Pb. The results provide the basis for a discussion of the pressure effects on the net interaction potential, V, of the Bardeen, Cooper, Schrieffer theory and the density of electronic states near the Fermi surface.

I. INTRODUCTION

It has long been recognized that the superconducting transition may be displaced by the application of hydrostatic pressure.[1] However, the effect is very small and, until recently, experimental work has been largely confined to the changes in critical field, H_c, near the critical temperature, T_c, or the displacement of T_c itself. The present work describes the results of measurements of the pressure variation of H_c for lead over the temperature range from T_c (7.175°K) to about 1°K.

In fundamental physical terms the analysis of the observed effect is complicated by several concurrent effects which result from the application of pressure. A theoretical approach to the situation is provided by the expression

$$kT_c=1.14\hbar\omega\exp[-1/N(0)V], \tag{1}$$

from the theory of Bardeen, Cooper, and Schrieffer (hereafter BCS).[2] In Eq. (1), ω is a characteristic phonon frequency (proportional to the Debye θ), $N(0)$ is the density of states at the Fermi level, and V characterizes the net electron-electron interaction. Each of these parameters is sensitive to pressure.

Reduction of the specific volume under pressure changes the lattice vibrational frequency, ω, leading to a displacement in T_c as seen in the simpler isotope effect.[3] The change in phonon spectrum may also affect V since that term contains the electron-phonon interaction responsible for superconductivity. Finally, the reduction in specific volume affects $N(0)$ in a manner which may be separated (at least formally) as follows: (a) an increase in the spatial density of electrons, and (b) a modification of the electronic band structure due to the reduced interatomic spacing.

In the present case, the total change in $N(0)$ with pressure can be obtained from γ, the temperature coefficient of the normal electronic specific heat. The value of γ can be deduced thermodynamically from the temperature dependence of the critical field as $T\to 0$°K. A somewhat analogous measurement (but presumably without the complication of changes in the phonon spectrum) has recently been described where the changes in $N(0)V$ were due to dilute impurity additions (which have the effect of depressing T_c of the impure superconductor).[4,5]

From an experimental standpoint, Pb should be a favorable element on which to study the effect of pressure upon γ. Because of its high critical temperature, a reduced temperature $t=T/T_c=0.14$ is readily achieved with Pb without recourse to the special techniques necessary to make measurements below 1°K. It is thus convenient to obtain a relatively close approximation to the limiting low-temperature behavior of H_c from which γ must be derived.

II. EXPERIMENTAL

A. Apparatus and Procedure for Work Near T_c

The experimental procedure followed in this work was different above 4.2°K from what it was in the liquid helium range. For the work above 4.2°K the apparatus and general procedure were similar to that described by Hake and Mapother.[6] We will therefore give only a brief outline.

Two identical samples were placed in an isothermal container whose temperature was regulated electronically to about 10^{-4}°K. One of the samples had pressure applied to it while the other served as a comparison sample. The critical field values of the two samples were alternately measured and the results plotted with time. In this way temperature drifts were readily apparent

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† Present address: General Electric Research Laboratory, Schenectady, New York.

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