resistivity in this case is again roughly proportional to T^{-3}, with a somewhat larger phonon mean free path (or filamental diameter), 1.1×10^{-3} cm, for diffuse scattering.

It should be mentioned that although thermal resistivity maxima have been reported previously for cylindrical specimens in *transverse* magnetic fields, both for pure metals[7-10] and for dilute alloys,[11-13] no longitudinal field maxima were reported for any of these specimens. In the pure metals these transverse field maxima occur in the intermediate state range $0.5<H/H_c<1.0$ and are probably due to scattering of electrons[7] at the boundaries between superconducting and normal laminas perpendicular to the axis of the cylinder.

I wish to thank Professor John K. Hulm for suggesting this research and for his constant advice, aid, and encouragement.

[1] J. W. Stout and L. Guttman, Phys. Rev. **88**, 703 (1952).
[2] D. Shoenberg, *Superconductivity* (Cambridge University Press, London, 1952), second edition, p. 117.
[3] J. K. Hulm, Proc. Roy. Soc. (London) **A204**, 98 (1950).
[4] J. K. Hulm, National Bureau of Standards Circular **519**, 37 (1952).
[5] H. B. G. Casimir, Physica **5**, 495 (1938).
[6] R. E. B. Makinson, Proc. Cambridge Phil. Soc. **34**, 474 (1938).
[7] R. T. Webber and D. A. Spohr, Phys. Rev. **84**, 384 (1951).
[8] D. P. Detwiler and H. A. Fairbank, Phys. Rev. **88**, 1049 (1952).
[9] J. L. Olsen and C. A. Renton, Phil. Mag. **43**, 946 (1952).
[10] J. K. Hulm, Phys. Rev. **90**, 1116 (1953).
[11] K. Mendelssohn and J. L. Olsen, Proc. Phys. Soc. (London) **A63**, 2 (1950).
[12] K. Mendelssohn and J. L. Olsen, Phys. Rev. **80**, 859 (1950).
[13] J. L. Olsen, Proc. Phys. Soc. (London) **A65**, 518 (1952).

Penetration Depth of Superconductors

M. C. STEELE AN M. F. M. OSBORNE
Naval Research Laboratory, Washington, D. C.
(Received July 13, 1953)

WE have been considering a model for superconductivity in which the electrons move in parabolic potential wells. This model is quite analogous to Einstein's model in which he put the ions into parabolic wells and obtained the specific heat of the lattice. The parameters of the present model are the number of electrons per well, the number of wells per cc, and the fundamental frequency associated with the well. By choosing parabolic wells we are able to solve for the electronic energy eigenvalues in the presence of a magnetic field without having to use perturbation theory.[1] When appropriate values are assigned to the parameters of the model, it is found to represent the thermodynamic (specific heat and magnetic moment) properties of a superconductor quite nicely.

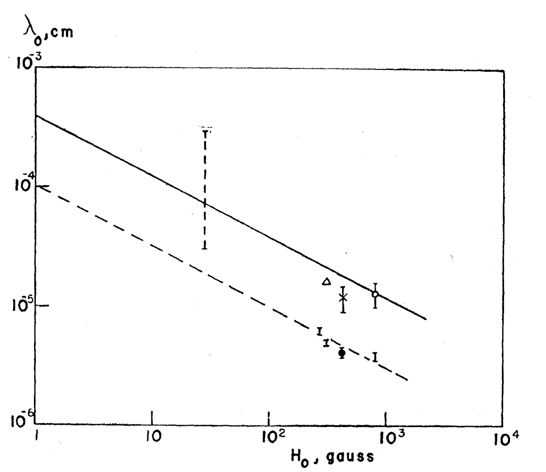

FIG. 1. Logλ_0 *vs* logH_0. The experimental points are taken from the following sources:
I, (Pb, Sn, In) J. M. Lock, Proc. Roy. Soc. (London) **A208**, 391 (1951).
●, (Hg) E. Laurmann and D. Shoenberg, Proc. Roy. Soc. (London) **A198**, 560 (1949).
○, (Pb) M. C. Steele, Phys. Rev. **78**, 791 (1950).
×, (Hg) Appleyard, Bristow, London, and Misener, Proc. Roy. Soc. (London) **A172**, 540 (1939).
△, (Sn) N. E. Alekseevsky, J. Phys. (U.S.S.R.) **4**, 401 (1941).
⁞, (Cd) M. C. Steele and R. A. Hein, Phys. Rev. **87**, 908 (1952).

If we identify the size of the well (at an energy equal to the Fermi energy) with the penetration depth, we obtain the following relation between λ_0, the penetration depth at $T=0$°K, and H_0, the critical magnetic field at $T=0$°K:

$$\lambda_0=1.6(\hbar c/eH_0)^{\frac{1}{2}}. \tag{1}$$

Here $\hbar$, c, and e have their usual values. Equation (1) is plotted in Fig. 1 as the solid curve, with experimental points from the sources indicated. The dashed curve is drawn parallel to the theoretical curve to fit the data of the Cambridge workers, since their results fall in a separate group. The numerical factor of Eq. (1) has to be 0.41 in order to get the dashed curve. The trend of λ_0 with H_0, as well as the absolute values, are quite well represented.

A relation equivalent to Eq. (1) can also be obtained from a totally different development; namely London's[2] concept of superficial currents whose elemental charges each carry an angular momentum of $\hbar$. Starting from London's[2] equation (4) for the critical surface mass transfer R_c,

$$R_c=(mc/4\pi e)H_0,$$

and, assuming that at $T=0$°K

$$R_c\simeq n\hbar,$$

where n is the number of superconducting electrons per cc, we obtain

$$H_0=4\pi ne\hbar/mc.$$

Combining this with London's[2] equation (6),

$$\lambda_0^2=mc^2/4\pi ne^2,$$

yields

$$\lambda_0=(\hbar c/eH_0)^{\frac{1}{2}},$$

which is just our Eq. (1) with a slightly different numerical factor.

Details of the present model will be given in a subsequent paper.

[1] C. G. Darwin, Proc. Cambridge Phil. Soc. **27**, 86 (1931).
[2] F. London, Revs. Modern Phys. **17**, 310 (1945).

Paramagnetic Resonance in *N*- and *P*-Type Silicon*

F. K. WILLENBROCK AND N. BLOEMBERGEN
Division of Applied Science, Harvard University, Cambridge, Massachusetts
(Received July 13, 1953)

WE have independently observed the paramagnetic resonance recently reported for *N*-type silicon by Portis, Kip, Kittel, and Brattain[1] and have also observed the resonance for *P* type. Our measurements were made on two samples of *N* type and three samples of *P*-type silicon[2] with impurity concentrations ranging from 5×10^{17} to 5×10^{18} cm^{-3}. The experiment was performed at 9000 Mc/sec at 78°K.

By comparison with the free radical α,α-diphenyl β-picryl hydrazyl,[3] it was established that the g factor for both holes and electrons is 2.00. The line widths at half-maximum absorption are 4 to 5 gauss for both *N* and *P* type. The intensity of the absorption signal is found to be roughly proportional to the impurity concentration. As it has been shown[1] that the resonance is the result of the spin of the free carriers, this implies that the impurities are nearly completely ionized in our samples. Experiments at liquid helium temperatures may give information about the effective mass of the holes.

* This research was assisted in part by the U. S. Office of Naval Research.
[1] Portis, Kip, Kittel, and Brattain, Phys. Rev. **90**, 5, 988 (1953).
[2] Supplied through the courtesy of W. H. Brattain, Bell Telephone Laboratories, Murray Hill, New Jersey.
[3] C. H. Townes and J. Turkevich, Phys. Rev. **77**, 1, 148 (1950).