proposed originally by Pippard[2] in analogy with the anomalous skin effect theory. The consequences of such a relation are quite different from that of the London theory when the magnetic field varies rapidly with distance, and can be tested experimentally.

Several years ago, experiments were conducted on penetration of magnetic fields through thin cylindrical films, in an attempt to measure the penetration depth parameter (λ) and to determine the law of penetration. The films, of tin or lead, were deposited on tubes of glass, brass, or plastic, and were ordinarily about 6 cm long and 4 mm in diameter. The tubes were rotated about their axes by a motor during deposition, and film thicknesses were measured by multiple beam interferometry. In the experiment, an alternating field ($\sim$500 cps) was provided by a solenoid outside and coaxial with the film, and field penetration was detected by a small pickup coil inside the tube. With the aid of careful shielding (which is made possible by the favorable geometry) and good amplification, alternating fields of the order of 10^{-5} oersted were detectable. The experiment was complicated by sudden breakthroughs and nonlinear penetration which could be localized to particular spots on the films. To ensure linearity it was, therefore, necessary to work with external ac fields of not more than 1% of the critical field, although superimposed dc fields had very little effect.

Even with small applied ac fields, the observed penetrations were too large for the London theory with any reasonable value of λ. Therefore measurements were suspended before much quantitative data had been accumulated. However, this is a situation in which the magnetic field varies by a factor of the order of 10^4 in a distance of a few hundred angstroms. Thus a nonlocal theory should give considerably different results, and the experiments might give a critical test of this theory.

According to the London theory,

$$H_0/H_i=(r/2\lambda)\sinh(d/\lambda), \qquad (1)$$

where r is the cylinder radius, H_i is the magnetic field inside the cylinder, H_0 is the field outside, and d is the film thickness.

On the basis of the nonlocal theory, using the solution obtained by Peter,[3] one finds

$$\frac{H_0}{H_i}=\frac{3rd^2}{8\lambda^2\xi_0}\left\{\ln\left(\frac{\xi}{d}\right)+0.423+\frac{2d}{3\xi}-\frac{d^2}{12\xi^2}\left[\ln\left(\frac{\xi}{d}\right)+2.006\right]\right\},$$

where ξ is the range of coherence, and ξ_0 is the range in a large, unstrained sample.

Experimentally, we have data on two films. (1) Tin film on brass, $r=2.77$ mm, $d=935$ A, (a) at $T=3.23$°K, $H_0/H_i=5.9\times10^3$; (b) at 2.40°K, $H_0/H_i=1.41\times10^4$. (2) Tin film on glass, $r=2.00$ mm, $d=660$ A; at 2.25°K, $H_0/H_i=6.7\times10^3$. To fit these values with the London equation we would need the following values of λ_0: (1a), $\lambda_0=1010$ A; (1b), $\lambda_0=955$ A; (2), $\lambda_0=980$ A, where $\lambda_0=\lambda[1-(T/T_c)^4]^{\frac{1}{2}}$ is the penetration depth at absolute zero. These values are impossibly large, and do not agree with any of the experimental measurements.

On the other hand, if we use the nonlocal theory with the experimental value of $\lambda_0=5.1\times10^{-6}$ cm, and the theoretical[1] $\xi_0=2500$ A, and solve for ξ, we obtain: (1a), $\xi=1000$ A; (1b), $\xi=1260$ A; (2), $\xi=1450$ A. These values of ξ are quite reasonable, and are comparable with the normal electron free path in similar films.

These measurements of field penetration through thin films give strong support to the nonlocal theory, but are not yet complete enough to investigate the details of the relation between current and field.

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[1] Bardeen, Cooper, and Schrieffer, Phys. Rev. **108**, 1175 (1957).
[2] A. B. Pippard, Proc. Roy. Soc. (London) **A216**, 547 (1953).
[3] M. Peter, Phys. Rev. **109**, 1857 (1958), following Letter.

Penetration of Electromagnetic Fields through Superconducting Films

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IN their new theory, Bardeen *et al.*[1] arrive at a nonlocal expression for the connection between fields and currents in superconductors which has the form of a system of integro-differential equations. The equation proposed by Pippard[2] is of this type and has been shown to be in fair agreement with the theory of Bardeen *et al.*:

$$-\mathbf{j}(\mathbf{r})=\frac{3c}{\xi_0(4\pi)^2\lambda_L{}^2}\int\frac{\mathbf{r}'(\mathbf{r}'\cdot\mathbf{A})e^{-r'/\xi}}{r'^4}dr', \qquad (1)$$

where $\mathbf{A}\equiv\mathbf{A}(\mathbf{r}+\mathbf{r}')$. An approximate solution is given below for the case of superconducting films, assuming that the electromagnetic field is known on one side of the film, and that the integral is to be taken over the film only. The calculations apply to the experiments of Schawlow[3] and also to experiments on transmission of plane waves through plane films,[4] if x_1 is replaced by $L/2\pi$.[5] (We set $x_1=$ inner radius of cylindrical shield, $L=$ vacuum wavelength, $d=$ film thickness, $\lambda_L=$ London penetration depth.) Terms of the order d/x_1 have been neglected in the calculations. Thus we obtain Eq. (9) of Pippard's paper,[2] but with finite limits of integration:

$$\frac{d^2A(x)}{dx^2}=\frac{2\beta}{x_1}\int_0^d k\left(\frac{x-y}{\xi}\right)A(y)dy,$$
$$\beta=\frac{3\sqrt{3}x_1}{16\pi\lambda_\infty^3}=\frac{3x_1}{8\xi_0\lambda_L^2}. \qquad (2)$$

λ_∞ has been introduced because, according to Pippard, it has closer correlation with the measured penetration depth than λ_L. A solution of this equation is obtained through an iterative method. The function $k((x-y)/\xi)$ is developed in terms of increasing order in x/ξ, d/ξ. By inserting $A^{(1)}=H_1(\frac{1}{2}x_1+x)$ into (2), we obtain $d^2A^{(4)}/dx^2$, and so forth. We obtain:

$$\frac{H^{(5)}}{H_1}=1+\beta d^2\left\{\frac{x}{d}\left(0.423+\frac{d}{\xi}-0.335\frac{d^2}{\xi^2}\right)+\frac{x^2}{d\xi}\left(-1+0.502\frac{d}{\xi}\right)+\frac{x^3}{d^2\xi}\left(\frac{2}{3}-0.335\frac{d}{\xi}\right)+\left(\frac{1}{2}-\frac{x^2}{24\xi^2}\right)\frac{x^2}{d^2}\ln\left(\frac{\xi}{x}\right)+\left(\frac{1}{2}-\frac{(d-x)^2}{24\xi^2}\right)\frac{(d-x)^2}{d^2}\ln\left(\frac{d-x}{\xi}\right)+\left(\frac{1}{2}-\frac{d^2}{24\xi^2}\right)\ln\left(\frac{\xi}{d}\right)\right\}.$$

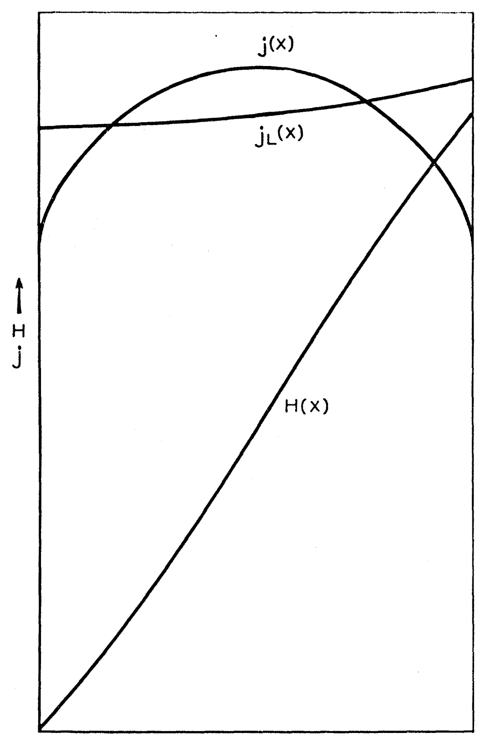

FIG. 1. Penetration of magnetic field difference $H(x)$ and current $j(x)$ through superconducting film according to Pippard's equation. $H(x)=[H^{(5)}(x)-H_1]/\beta d^2$ and $j(x)=j^{(5)}(x)/\beta d$ are plotted in arbitrary units; $j_L(x)$ is the current according to the London theory, given in the same units as $j(x)$.

The fields and currents are finite everywhere. The iterative procedure is found to improve the expression for the field penetration by three orders of magnitude in d/λ_∞ in each step. If d/λ_∞ becomes too large, a solution can be obtained by approximating (2) by a system of linear equations.

Figure 1 shows $[H^{(5)}(x)-H_1]/\beta d^2$ and $j^{(5)}(x)/\beta d$ for $d/\xi=0.2$. For comparison, the current which would result from the London theory, $j_L(x)$, has also been plotted. For larger values of d/ξ, $j(x)$ is of course no longer symmetrical about the film center.

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[1] Bardeen, Cooper, and Schrieffer, Phys. Rev. **108**, 1175 (1957).
[2] A. B. Pippard, Proc. Roy. Soc. (London) **A216**, 547 (1953).
[3] A. L. Schawlow, Phys. Rev. **109**, 1856 (1958), preceding Letter.
[4] R. E. Glover, III, and M. Tinkham [Phys. Rev. **108**, 243 (1957)] have used this geometry. In our case, the substratum is very thin compared with L; however, our film is not very thin compared with λ.
[5] Because of the formal analogy of Pippard's and Sondheimer's equations, the calculations also apply to the anomalous skin effect in normal conducting films.

Lack of Metallic Transition in LiH and $LiAlH_4$ under Static Pressure*†

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ALDER and Christian[1,2] have reported that the resistivities of $LiAlH_4$, I_2, and several alkali halides of large atomic number decrease by factors of about 10^6 under shock pressures ranging from 50 to 280 kilobars. Of the ionic substances, $LiAlH_4$ exhibited the effect at the lowest pressure (50 kilobars).

Somewhat earlier we had examined the pressure dependence of the conductivity of LiH in a primitive apparatus patterned after that of Bridgman.[3] The sample in powder form was compressed between two Carboloy pistons in the form of truncated cones between which the resistance was measured. The resistivity of LiH was sensibly unchanged to 80 kilobars. At higher pressures a drop in resistance by 10^9 was observed. Subsequent experiments showed that the pistons had shorted, so the observed drop in resistance was spurious. These early experiments thus provided only a negative result to 80 kilobars for LiH.

After Alder and Christian's work, it seemed most desirable to do static experiments on $LiAlH_4$ and to extend the range of pressure for LiH. New apparatus[4] of the same general type was employed in this second series of experiments. This incorporated provision for raising the temperature while at high pressure. The samples were prepared in a nitrogen atmosphere in a dry box by weighing an appropriate amount of material