Temperature Dependence of Penetration Depth of a Magnetic Field in Superconductors

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August 9, 1948

IN view of conflicting statements in recent discussions[1,2] of the temperature variation of λ (penetration depth of a magnetic field into a superconductor), it is worth reviewing the available experimental data. The only evidence providing a sensitive test of any proposed law is that from the magnetic properties of the small particles in colloids,[3] which gives essentially $\lambda(T)/\lambda(0)$ (the absolute value of $\lambda(0)$ could not be deduced since the particle size was not accurately known). So far results have been obtained only for mercury and these show (Fig. 1) that

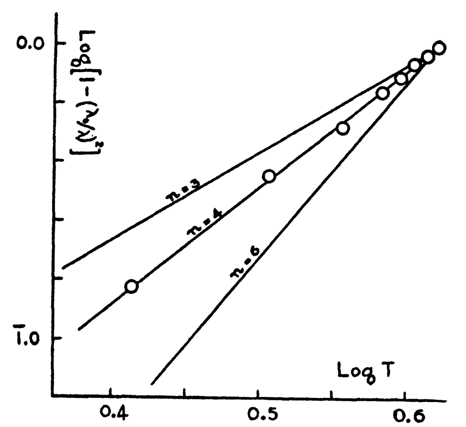

FIG. 1. Log $[1-(\lambda_0/\lambda)^2]$ *vs.* $\log T$ for Hg.

the law

$$[\lambda(0)/\lambda(T)]^2 = 1-(T/T_c)^n \tag{1}$$

with $n=4$ is very well obeyed, provided it is assumed (as is probably justified) that the spread in particle size in the colloid used was not sufficient to affect the results. This law is consistent with the Gorter-Casimir theory[4] if it is combined with the London theory[5] and the superconductor is assumed to have a parabolic H_c-T relation or a specific heat proportional to T^3. The relation (1) and this theoretical interpretation were first pointed out by Daunt[1] but owing to a misprint, only recently noticed, the n in (1) appeared as 3 instead of 4; a discussion has also been given by Miller.[6]

Other experiments have been of three kinds, (a) various measurements of $\Delta\lambda = (\lambda(T)-\lambda(T_0))$, with T_0 usually about 2.1°K,[7–10] (b) measurements of r-f resistance[11–13] from which λ can be deduced, but only indirectly and on the basis of an assumed model of the resistive process, and (c) measurements of the critical fields of thin wires[14] and thin films.[15] The measurements of $\Delta\lambda$ are all consistent within experimental error with (1), but they are not sufficiently accurate to prove the truth of (1) or to indicate more than a rough value of n, unless $\lambda(0)$ is already known. It should be noted that the full curves of $\Delta\lambda$ against T for mercury published by Désirant and Shoenberg and by Laurmann and Shoenberg in preliminary notes[8,9] are curves *calculated* from the colloid data (using a value of $\lambda(0)$ deduced by combining the colloid data with the $\Delta\lambda$ data from thin wires[8]); it is therefore impossible to deduce from these curves anything regarding n that is not already contained in the original colloid data. A detailed discussion of experiments on $\Delta\lambda$ was given at the recent conference on metals in Amsterdam.[16] As regards the r-f resistance measurements, it should be emphasized that any derivation of λ from them is only as reliable as the theoretical model of the resistive mechanism assumed; recent measurements at a higher frequency[17] suggest that the frequency dependence is not in accord with the theoretical model used by Pippard to derive values of λ. Thus it is unsafe as yet to use r-f resistance measurements as evidence for any particular law of temperature variation of λ. It may be noticed that the same theoretical model is partially involved also in Pippard's method[7] for $\Delta\lambda$, but since the specific theoretical assumptions enter only in a correction term, the results of this method should be reliable except very close to T_c. The critical field measurements again lead only indirectly to information about λ and, as has been discussed elsewhere,[8] their interpretation must await the development of a detailed theory.

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Frictional Electricity

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August 14, 1948

IN Phys. Rev. **66**, 9–16 (1944) you published a paper by Mr. D. E. Debeau on frictional electricity. He got the remarkable result that the charge produced on small insulating particles sliding down a metal depended very much on the pressure of the air. At very low pressures of the order of 10^{-4} mm of mercury the charge is large; as the pressure is increased up to about 1 mm it gets less and less and thereafter increases again with further pressure increase. The charge at 1 mm was only about 1/7 of that at 10^{-4}. He explains this result as being due to adsorbed layers of gas but to explain the minimum he is driven to the conclusion there must be two adsorbed layers.