detailed calculations show that they lead to correct results as far as functional dependence is concerned.

[13]C. Herring, Phys. Rev. 96, 1163 (1956).

[14]For ∇T along [010] and any $\perp H$, $Q_p = 0.06\,Q_{p\parallel} + 0.94\,Q_{p\perp}$. The relative contributions should be combined with relative magnitude to get the average exponents for Q_p. The relative magnitudes of $Q_{p\parallel}$ and $Q_{p\perp}$ have not been calculated, but for a rough estimate we can use the limiting classical values from reference 5, $Q_{p\parallel} \simeq 10\,Q_{p\perp}$, and obtain the weighted average used above.

TEMPERATURE DEPENDENCE OF CRITICAL CURRENT DENSITY IN SUPERCONDUCTING TIN THIN FILMS

J. E. Mercereau and L. T. Crane
Scientific Laboratory, Ford Motor Company, Dearborn, Michigan
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Measurements of critical current density in thin tin films have been made utilizing an induction method. The results of this technique confirm previous critical current measurements[1,2] near T_c but further reveal a peak in the critical current density near a reduced temperature (T/T_c) of 0.65. Such peaks would not have been resolved by the previous technique[2] which relied on the expected[3] monotonic decrease of critical current with increasing temperature. This unusual behavior deviates markedly from theoretical predictions except near T_c. At the lowest temperatures the magnitude of the critical current is considerably lower than the asymptotic value ($j_c = n_s e\Delta/p_f \sim 10^8$ A cm^{-2}) expected at $T=0$.

The present measurements use an alternating current technique that reveals more detail of the critical current temperature dependence than is easily obtained from magnetic moment measurements[2] of superconducting rings. The configuration of the apparatus is shown in Fig. 1. The field coil, F, 10 cm in diameter and 3 cm long, is wrapped on the outside of a glass Dewar containing the helium bath. The superconducting ring, R, is a 1770Å tin film, 1 mm long, evaporated on a glass tube having 10 mm o.d. and 7 mm i.d. This ring is supported in the helium bath coaxially at the center of the field coil. A 2500-turn sensing coil, S, is placed inside of the glass tube so as to monitor changes in flux through the superconducting ring. Since this coil extends $\frac{1}{2}$ mm beyond the ends of the tin ring, and since its effective diameter is about half that of the ring, it actually monitors both flux changes applied to the ring by an external field and flux changes due to currents in the ring. The field coil is sinusoidally driven by an audio-frequency generator and power amplifier, producing a field varying as shown in Fig. 2, (A). The sensing coil is connected directly to an oscilloscope. As the field amplitude is increased from zero, a correspondingly increasing sinusoidal wave form is observed from the sensing coil. Then, when the field amplitude is just sufficient to induce a critical current in the ring, a single peak appears at the nodes of the sensing-coil voltage wave form. With further advances in field amplitude, the peak grows in amplitude and moves to increasingly early time positions relative to its original position. At very large field amplitudes the peak occurs at the maxima of the sensing-coil wave, and no further peaks are produced.

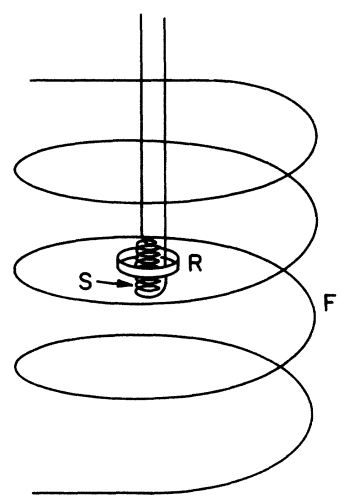

FIG. 1. Field coil (F), superconducting ring (R), and sensing coil (S).

There is also a noticeable break in slope at the nodes of the sensing-coil wave form when the peak is well developed. Figure 2, (D) shows the shape of the sensing-coil wave form, with the peaks at time α and the break in slope at time β. The shape of this wave form can only mean that when the current reaches its critical value, it remains fixed in value even though the applied field continues to rise and the excess flux leaks into the ring. When the applied field begins to decrease at time

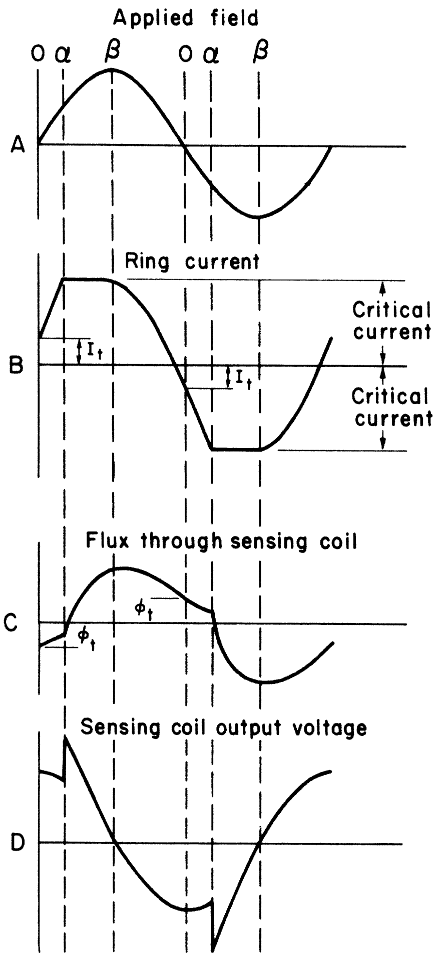

FIG. 2. Wave forms of the applied field (A), ring current (B), flux through sensing coil (C), and sensing coil output voltage (D).

β, the ring current then begins to decrease as well. This is illustrated in Fig. 2, (B), in which I_t is the current corresponding to the flux trapped in the ring during the previous half cycle. The critical current is reached at time α, and this point will move to the left when applied field is increased. Thus the ring current can be shifted in phase by nearly 45° if sufficiently large fields are applied. The flux linking the sensing coil thus has the form shown in Fig. 2, (C), where φ_t is the trapped flux from the previous cycle. Because this flux contains components from both the applied field and the current in the ring, its phase is not shifted as far as the phase of the ring current. The sudden discontinuance of shielding by the ring at time α produces a break in slope in the sensing-coil flux, but the onset of shielding again at time β will only produce a second-order change in sensing-coil flux. The output voltage is the time derivative of this flux, and has a peak at time α, but only a change in slope at time β, as shown in Fig. 2, (D).

These measurements were made by finding the threshold at which the peak began to be produced in the sensing-coil voltage. The applied field amplitude was calculated from a measurement of the voltage applied to the field coil, and the maximum current amplitude in the ring was calculated using the inductance of the ring measured in the superconducting state. The maximum field amplitude used for these measurements was 2.5 gauss. Very consistent measurements were obtained at all applied field frequencies from 50 cps to 2 kc/sec, but most measurements were taken at 1 kc/sec. Maximum random error was $\pm 0.025 \times 10^6$ A/cm^2.

Figure 3 shows the measured critical current density in the tin ring as a function of reduced temperature $t = T/T_c$. In the initial measurements, the presence of the voltage peak produced a ringing in the sensing coil below $t = 0.75$. This ringing was

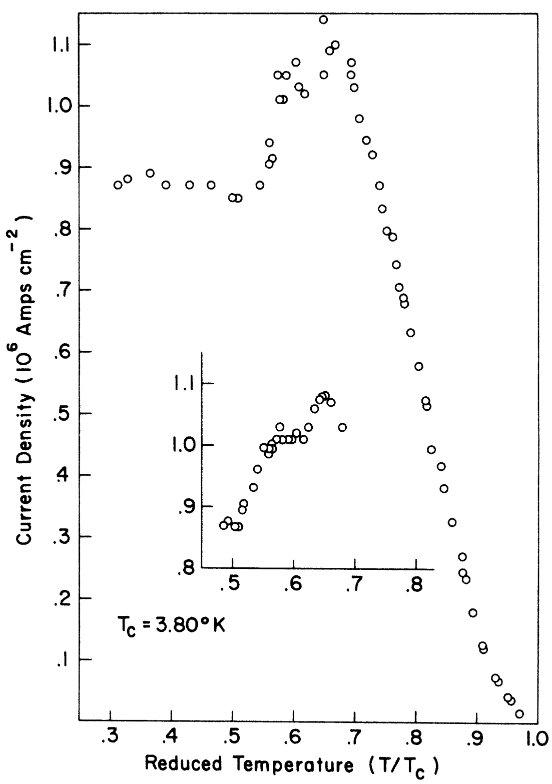

FIG. 3. Critical current density as a function of reduced temperature (T/T_c) measured in a thin film ring of length 1 mm, diameter 1 cm, thickness 1770 Å.

later damped out by shunting the sensing coil with a resistor and capacitor in series, and much more accurate data were obtained in the low-temperature region. The inset in Fig. 3 shows some of these later data separately. The position and shape of the large peak in critical current density were entirely reproducible in all measurements. Data were taken going from higher to lower temperatures, and from lower to higher temperatures, and no measurable effects of any kind were found. The region of the helium λ transition ($t = 0.57$) was studied very carefully since it lay in the region of the current density peak, but no effects were found which seemed attributable to that transition. These measurements are in very close agreement with the data of Mercereau and Hunt, except that their data were obtained in a manner such that the peak in critical current density was never detected.

Because of the earlier measurements,[1,2] as well as the predictions of all theories of superconductivity, the critical current density was expected to decrease monotonically with increasing temperature. The fact that the critical current density is considerably smaller near 0°K than theory predicts, and the presence of the large structured peak in critical current density centered at $t = 0.65$, indicates that some process not presently accounted for in any theory is the limiting factor in the critical current density in soft superconducting films.

The authors are pleased to acknowledge helpful discussions with A. W. Overhauser.

[1]J. E. Mercereau and T. K. Hunt, Phys. Rev. Letters 8, 243 (1962).

[2]J. E. Mercereau and T. K. Hunt, in Proceedings of the Eighth International Conference on Low Temperature Physics (to be published).

[3]K. T. Rogers, thesis, University of Illinois, 1960 (unpublished).

COMMENTS ON CORRELATION CALCULATIONS IN ANISOTROPIC DIFFUSION*

James G. Mullen
Argonne National Laboratory, Argonne, Illinois
(Received July 25, 1962)

In a recent paper the author[1] has treated the problem of correlation in anisotropic diffusion, specifically evaluating the correlations for vacancy self-diffusion for a number of cases. The approach used involves calculating the net "back jump probability" ξ_1 by a Bardeen-Herring calculation, and then expressing ξ_j as a function of ξ_1, which completely specifies the correlations. This procedure is also applicable to impurity anisotropic diffusion, and it is possible to analytically express the correlations to any accuracy that one is willing to solve simultaneous linear accelerations. Huntington and Ghate[2] have extended these considerations to the case of impurity anisotropic diffusion by a somewhat different approach than is outlined above. They demonstrate the value of this alternative approach by evaluating correlations for impurity diffusion in the hcp lattice. Unfortunately, their procedure, like the one outlined above, requires the solution of many simultaneous linear equations, with the complexity of equations increasing as the number of uniquely specified frequencies is increased. Even though Huntington and Ghate chose many (eight) frequency factors as a model for impurity diffusion in the hcp lattice, their calculation included only two dissociative jump frequencies and neglected returning vacancies which leave the first coordination shell. This greatly oversimplified calculation has two difficulties: (1) For any given example it requires a great deal of algebraic gymnastics to solve for the correlations, despite the simplifying assumptions, and (2) it is not accurate because of the simplifying assumptions. To improve on this calculation by either of the above mentioned approaches is in principle possible, although it hardly appears reasonable considering the algebraic difficulties, and the present state of experiment in this field would hardly warrant such tedious calculations. Thus, it is the purpose of the present Letter to propose a new method of calculating correlations for impurity diffusion, which can be applied to any lattice, isotropic or anisotropic, and which permits all symmetrically inequivalent dissociative jump frequencies to be uniquely specified without adding to the complexity of the calculation. The method is compared with other methods for the fcc, bct, and hcp lattices. To aid in this comparison an accurate empirical representation of previously calculated[1] self-diffusion correlations is