Larmor frequency, and the liquid line is broader than the solid line at all the attempted frequencies. It is presumed that most of the observed temperature dependence in the solid is due to spin-lattice relaxation processes since $\omega_0\tau_c \approx 1$ in this region (ω_0 is the Larmor frequency and τ_c the correlation time). In the vicinity of the melting point both the solid and liquid absorption lines were observed simultaneously. The absorption line of the liquid was noticeably broader than the solid line and shifted towards a lower field by 250 milligauss in a field of 7975 gauss. The difference in Knight-shift values in a field of 2925 gauss was 83 milligauss.

Measurements of T_1 and T_2 at 11.0 Mc/sec and 3.3 Mc/sec are plotted as a function of the temperature in Fig. 2. These results agree qualitatively with those reported by Holcomb and Norberg but fall systematically lower at each temperature point. The precision and scatter of the pulsed data is such that the true behavior of the relaxation times may well be masked by the inaccuracy in the data. It should be noted, however, that the field dependence of the resonance linewidth observed in the solid by cw techniques is not evident in the results of Fig. 2. No dependence upon Larmor frequency was observed by Holcomb and Norberg.

It would be of some interest to extend these measurements to higher frequencies to see whether the solid line becomes broader than the liquid line at some point. The dependence of the solid linewidth (and hence the observed broadening upon melting) on the applied field may provide the key to the explanation of this anomalous transition in alkali metals. To explain the observed

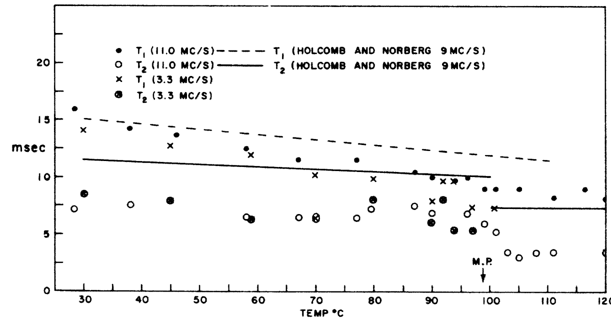

FIG. 2. Relaxation times of Na^{23} versus temperature.

experimental results, one may have to appeal to at least two distinct interactions: one field-independent interaction responsible for the broad liquid line but quenched in the solid by the cubic symmetry of the lattice, and a second field-dependent interaction responsible for the solid linewidth that can be averaged nearly to zero due to increased diffusion in the liquid.

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SUPERCURRENT DISSIPATION*

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The stability of dc supercurrents over periods of 10^5 years has been established.[1] Explanations of this persistence utilizing zero-temperature Bose gas models have been advanced by several authors[2]; however, these models are simplified in that a spectrum of excitations is known to exist at finite temperatures.[3] The role of these excitations in electrical conduction is not well understood. In this experiment ac magnetic fields were applied along the axis of hollow superconducting cylinders. The attenuation, that is ratio of the applied ac field to the field at the center of the cylinder, was measured at different temperatures. The results indicate that the cylinder did not exhibit persistent current behavior but rather a dissipative behavior similar to that of the normal state. Below the transition temperatures, this dissipation fell off from that of the normal

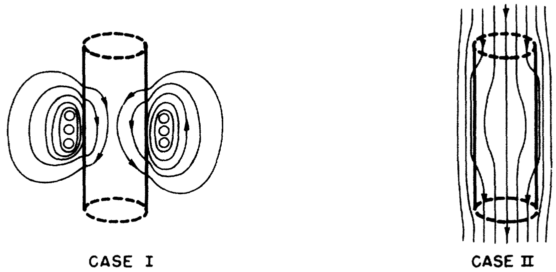

FIG. 1. Flux lines are shown entering the cylinder in two different field geometries. In case I the field is applied only along the middle of the cylinder; in case II, along the entire length. The field coils are shown for case I.

state in a manner which suggested a relation to the energy gap.

The ac magnetic field was homogeneous over the length of the cylinder. This is fundamentally different from the configuration in which the field is applied only along the middle. The two configurations are illustrated in Fig. 1. In case I, if the flux lines are to enter more than permitted by the penetration depth, the section of the wall through which they pass must be maintained in the normal state. These normal regions will make this type of penetration energetically impossible for small fields. This does not hold for case II, as the flux lines, once having passed through the wall, may enter through the end holes. Thus, if any dissipative mechanisms (which must always cause flux lines to enter) exist, they would be suppressed in case I but observable in case II. Penetration depth effects contribute in both cases but are unimportant in this experiment due to the large wall thickness. The case I configuration has often been used to measure penetration depth; the reported experiments on field penetration into long superconductive cylinders have all been of this type.[4]

The cylinders were formed by pressure welding two edges of a freshly etched, 99.999% pure, polycrystalline indium foil. The results given here are for a radius of 0.75 cm, a wall thickness of 50 μ, a length of 9.0 cm, and residual resistivity ratio $\rho_{300}/\rho_{3.5}=1.5\times10^3$. Results for a 500-$\mu$ wall thickness with $\rho_{300}/\rho_{3.5}=7\times10^3$ were essentially the same. The applied ac magnetic field was of sinusoidal waveform. The frequency was varied from 23 cps to 25 kc/sec and the amplitude from 1 to 250 milligauss. The attenuated field was measured at the center of the cylinder with a short, untuned, copper coil.

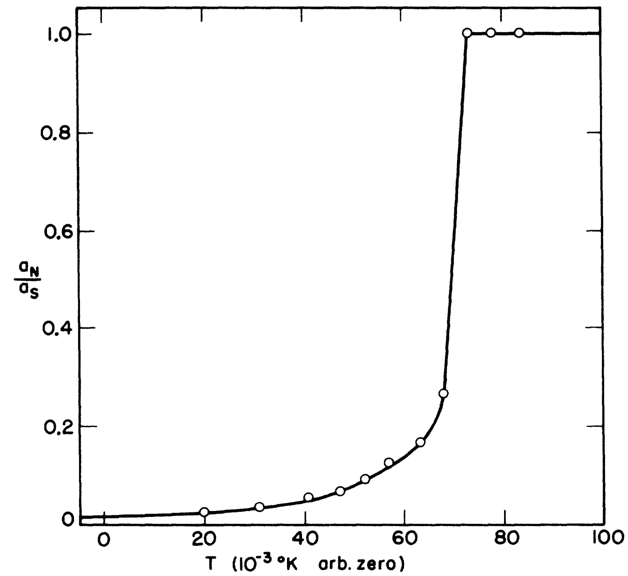

FIG. 2. Normalized attenuation versus temperature for an In cylinder of 50-μ wall thickness at 2 kc/sec with an applied field of 0.25 gauss.

The results showed that, if the applied ac field amplitude was less than a certain temperature-dependent critical field (usually a few percent of the bulk critical field), the attenuated sine wave was undistorted and the attenuation nearly independent of the applied field amplitude. Higher fields resulted in nonlinear switching effects. In both superconductive and normal states, the attenuation was proportional to the applied field frequency over most of the frequency range. Only data taken in this range and for which the waveform was undistorted are reported here. Figure 2 shows a plot of the attenuation for a typical transition. The sharp approach to the normal state is indicative of high sample homogeneity.

It is of interest to plot the logarithm of the attenuation against Δ/kT, where Δ is the BCS energy gap normalized to unity. Such a plot is shown in Fig. 3. The slope of the best fit line is 18. Points having abscissas less than 0.1 could not be obtained due to the great slope of $\Delta(T)$ near $T=T_c$. The extrapolation through this region to the normal-state attenuation (at $\Delta=0$) is off by 30%; this error vanished if the Fermi-Dirac, rather than the Maxwell-Boltzman, distribution function was used. The temperature range used was not great enough to positively verify the $1/T$ dependence; however, the form shown seems to result in the best fit.

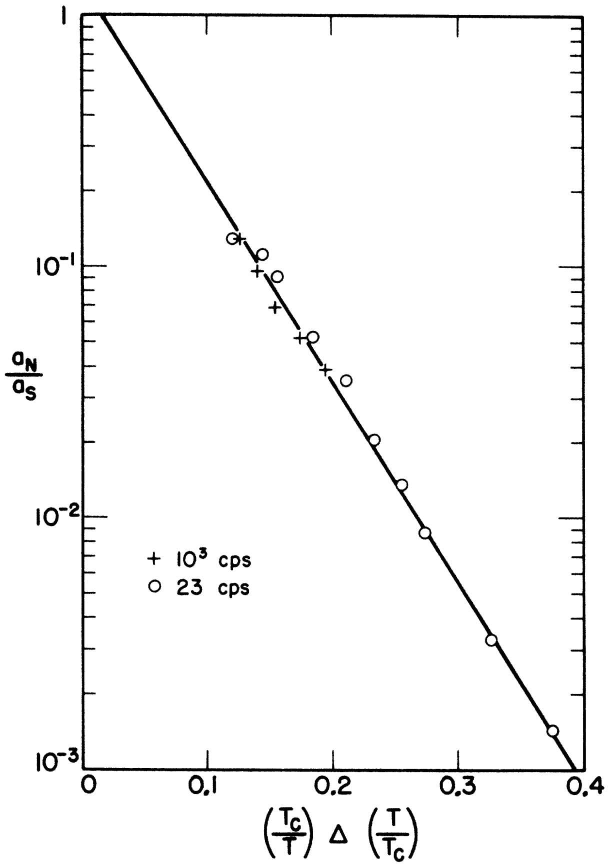

FIG. 3. The same transition as shown in Fig. 2 plotted logarithmically. Δ is the BCS energy-gap parameter normalized to unity at zero temperature. The observed normal-state attenuation of unity for $\Delta = 0$ is not marked. The lower points were taken at 23 cps to suppress skin effect.

The linear, frequency-proportional attenuation of the superconducting state suggests strongly an Ohmic dissipation; penetration depth effects should be frequency independent. The Ohmic interpretation, however, fits the data less well in the region where the classical skin effect should become important. At 23 cps a small nonlinearity was observed which did not vanish as the field was reduced. This caused a slight waveform distortion and, although the attenuation still followed the same exponential dependence, the slope went to infinity as the field went to zero. This nonlinearity vanished at higher frequencies. At 25 kc/sec, where the sensitivity was greatest, no unusual effects were observed when the flux within the cylinder was reduced to the order of one quantum unit.[5]

These results seem to have little in common with existing theories, none of which predict behavior relating to the normal state. It would be very difficult to account for the linear attenuation with a domain model which must involve nonlinear effects when the ac field locally exceeds H_c. Such domains are probably the cause of the switching effects observed at high fields. The field more likely enters the metal in a very fine structure, possibly turbulent vortices of the Abrikosov type. Tinkham[6] has pointed out that such vortices should exist in long, thin sheets such as this cylinder wall. From a more macroscopic point of view, the currents seem to follow Ohm's law. The particular conditions which cause the behavior reported in this experiment, rather than the more usual persistent current behavior, are not yet known.

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