APPARENT STRUCTURE ON THE FAR INFRARED ENERGY GAP IN SUPERCONDUCTING LEAD AND MERCURY[*]

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We have performed two different experiments which provide evidence for apparent structure on the edge of the energy gap in superconducting lead and mercury at low temperatures (~1.5°K). In one experiment, described in a previous Letter by two of us,[1] we measure the far infrared power reaching a bolometer after many reflections from the walls of a nonresonant cavity. The power is called P_S and P_N for the superconducting and normal states, respectively. Figure 1 shows the data for a lead and a mercury cavity. The sudden decrease in $(P_S-P_N)/P_N$ with increasing photon energy signifies the onset of absorption in the superconducting state due to the excitation of electrons across the energy gap. We believe that the dip in the curve at photon energies just below the main absorption edge represents a precursor absorption in the superconducting state, since the absorption in the normal state is expected to rise smoothly and monotonically with increasing frequency. This dip is evident in our previously published data[1] on lead. Repetition of the experiment has confirmed this feature in lead, and has shown an even more pronounced dip for mercury.

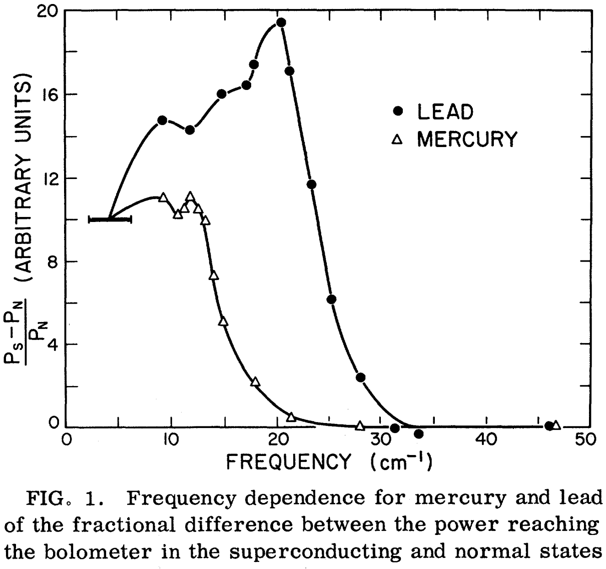

FIG. 1. Frequency dependence for mercury and lead of the fractional difference between the power reaching the bolometer in the superconducting and normal states. These curves have been normalized for display purposes so that the ordinate of the lowest frequency point is the same for each of them. The horizontal bar indicates the approximate bandwidth of the lowest frequency point. The bandwidth for the other points was ~10%.

The structure was actually first noticed in measurements by two of us (D.M.G. and M.T.) of far infrared transmission through films about 10 A thick. These experiments are similar to those performed on lead and tin by Glover and Tinkham,[2] but with accuracy improved by changes in optics and radiation detection. The magnitude of the ratio T_S/T_N of the transmission through the superconducting film to that through the normal film is measured as a function of photon energy. The data are analyzed, using the Kramers-Kronig relations and a conductivity sum rule,[3] to obtain the frequency dependence of $\sigma_1(\omega)/\sigma_N$ and $\sigma_2(\omega)/\sigma_N$, where σ_1 and σ_2 are the real and imaginary parts of the superconducting conductivity, and σ_N is the normal conductivity. The simplest models for an energy gap, of width $\hbar\omega_g$, predict that $\sigma_1(\omega)$ is zero for $\omega<\omega_g$, and that $\sigma_1(\omega)$ rises monotonically towards σ_N for $\omega>\omega_g$. Actually, there appears to be a preliminary hump in $\sigma_1(\omega)/\sigma_N$ for lead before the main absorption sets in, as shown in Fig. 2. The curve for a second lead film has a qualitatively similar frequency dependence. Unfortunately, the mercury films have not been reproducible enough to permit a meaningful calculation of the conductivity ratio. However, a dip in the transmission ratio, corresponding to a hump in $\sigma_1(\omega)/\sigma_N$, is clearly evident in the transmission curves of two different

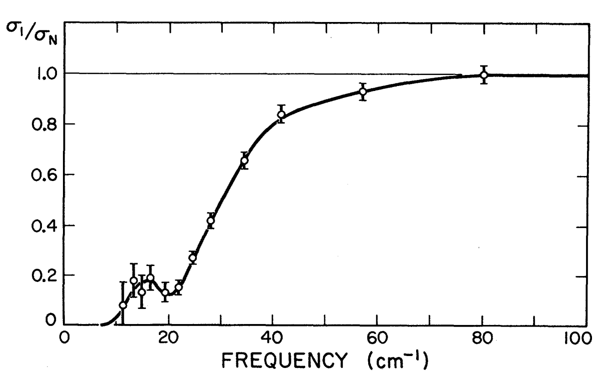

FIG. 2. Frequency dependence of σ_1/σ_N for a lead film with a resistance 197 ohms per square. The bandwidth of each point is ~10%.

mercury films which we have examined. (The transmission through the lead films in the normal state disagreed slightly with the value calculated from the dc resistance. The small ambiguity in the interpretation of the data which this introduces does not affect the qualitative features of the conductivity curve.)

It seems likely that the precursor hump in the conductivity curves for the films is due to the same cause as the dip in the power ratio curve for the bulk samples. For both of the metals under discussion, the structure in the film data and that in the bulk data occur at approximately the same frequency, relative to the frequency at which the main onset of absorption sets in. This structure may be associated with anisotropy of the energy gap. Such anisotropy has been observed in ultrasonic attenuation measurements[4] on tin, and could also account for the observed nonexponential electronic specific heat, as has been pointed out, for instance, by Cooper.[5] The electronic specific heat which is inferred for lead and mercury from critical field data shows a deviation from the exponential which is an order of magnitude greater than that for any of the other superconductors measured.[6,7] This large deviation may well be associated with the marked structure that we observe for these two metals. On the other hand, the structure may be due to the production of collective excitations by the absorption of photons. Anderson has pointed out,[8] on the basis of microscopic considerations, that collective excited states might have energies which lie below the top of the gap predicted by the theory of Bardeen, Cooper, and Schrieffer.[9] The collective excitations may perhaps also be described macroscopically in terms of longitudinal oscillations in the metal. In the case of bulk samples, transverse oscillations may also play a role in explaining the observed effects. Both of these possibilities have been proposed tentatively by Ferrell.[10]

The far-infrared experiments on these and other metals will be reported more fully in forthcoming publications.

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OVERHAUSER EFFECT IN METALLIC LITHIUM

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The enhanced nuclear polarization produced by the saturation of electron spin resonance in metals can be detected in two ways: (a) by observing the enhancement of the nuclear signal, a method widely used since the pioneer work of Carver and Slichter[1]; (b) by observing the shift of the electron spin resonance brought about by the polarization of the nuclei, a method proposed by Overhauser[2] and analyzed by Kaplan[3] but never carried out experimentally so far.

We present a preliminary report of a detection of Overhauser nuclear polarization in lithium metal using both methods. The sample was lithium hydride heavily irradiated by pile neutrons. A sharp (0.3 gauss) electron spin resonance line, observed by Doyle *et al.*[4] in LiH irradiated with ultraviolet radiation, was attributed by them to conduction electrons in colloidal particles of lithium metal. In our sample, with negligible inhomogeneous broadening, the electron spin resonance line had at room temperature and 10 000 Mc/sec a width of 0.125 gauss (peak to peak of