the lower branch the absorption should equal a constant term, plus a term varying as the sine squared of the angle between 110 and the rf field; thus as the disk is rotated in its own plane, there should be two absorption maxima 180° apart. The conclusions were well substantiated by experiment, except at the low-frequency end, where the upper branch also showed some sensitivity. The agreement indicates one, or at most two domains (in directions of equal latitude, with longitudes 180° apart), on the low field-branch. Four domains 90° apart in longitude would have given four absorption maxima.

The formula for linewidth (between points of $\frac{1}{2}$ maximum absorption on either side of resonance) is given by

$$\Delta H=\frac{\alpha}{|d\omega_{\rm res}/dH|}\frac{\gamma}{M}\left(E_{\theta\theta}+\frac{1}{\sin^2\theta}E_{\varphi\varphi}\right),$$

in terms of the Landau-Lifschitz loss parameter α. The α measured at 1920 Mc/sec on the upper branch of the curve was about twice that found in similar material at 24 kMc/sec.[3] This increase is yet unaccounted for.

The author is indebted to Dr. A. M. Clogston for suggesting the experiment, to Dr. L. R. Walker for his continued interest in the theory, to Dr. J. F. Dillon, Jr. for supervising the sample preparation, to Mr. J. H. Rowen for valuable advice on instrumentation, to Mrs. A. Rebarber for the computations, and to Mr. J. Davis for assistance in the experiment. The single crystal was supplied by Dr. W. Clarke of Linde Air Products.

[1] Composition approximate.
[2] This formula was also derived, independently, by J. Smit, (Talk at Conference on Ferrimagnetism at the Naval Ordnance Laboratory, 11–12 Oct., 1954), and by P. Tannenwald and B. Lax (private communication). The latter have done theoretical work of the kind reported here.
[3] Galt, Yager, and Merritt, Phys. Rev. **93**, 1119 (1954).

Ultrasonic Attenuation Due to Lattice-Electron Interaction in Normal Conducting Metals

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In a recent letter to the editor,[1] Bömmel published some experimental results on the attenuation of sound waves at ultrasonic frequencies for single lead crystals, which showed that there was an increase in attenuation at very low temperatures for the normal conducting state which disappeared in the superconducting state. This attenuation difference occurred for both shear and longitudinal waves and increased in proportion to the square of the frequency. From 1.6°K to 4°K the difference was independent of the temperature and was 0.106 neper per cm for longitudinal waves of 26.65 Mc/sec and 0.061 neper per cm for shear waves of 9.5 Mc/sec. Figure 1 shows complete measurements

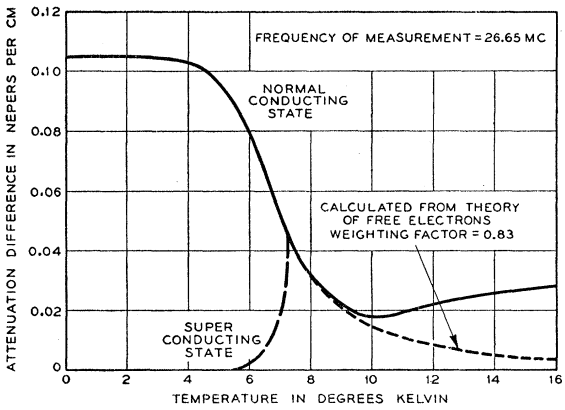

FIG. 1. Comparison of measured attenuation of a lead single crystal with that calculated from free electron theory.

for longitudinal waves. Bömmel has recently measured the same effect for a single tin crystal with the results shown by Fig. 2 for a longitudinal wave of 28.5 Mc/sec.

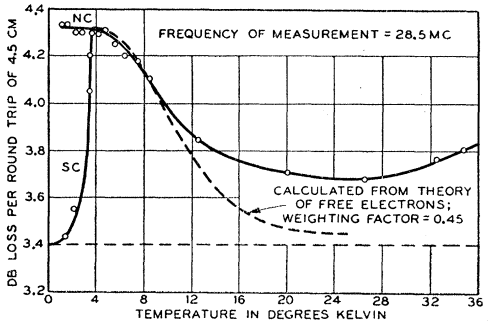

FIG. 2. Comparison of measured attenuation in tin with that calculated from free electron theory.

A curve of similar shape is obtained for shear waves with a value of 0.036 neper per cm at 17 Mc/sec and 1.5°K for the difference between normal and superconducting states.

It is the purpose of this note to point out that a simple phenomenological concept of the interaction between the lattice vibrations and the electron gas gives values of attenuations which agree well with the measured results. The concept considered is that in the normal state a lattice vibration can communicate energy to the electron gas by a viscous reaction, i.e., transfer of momentum, and is damped by the viscosity of the gas, while in the superconducting state the lattice is not able to transfer momentum to the electron gas and the damping disappears.

For the most general case the attenuations[2] caused by the energy loss due to the shear and compressional viscosities of the electron gas are for longitudinal and

shear waves in the lattice

$$A_l(\text{nepers/cm})=\frac{2\pi^2f^2}{\rho v_l^3}\left(\frac{4}{3}\eta+\chi\right);\quad A_s=\frac{2\pi^2f^2}{\rho v_s^3}\eta, \tag{1}$$

where ρ is the density of the crystal, f is the frequency, η the shear viscosity, χ the compressional viscosity, v_l and v_s the velocities of longitudinal and shear waves respectively. This concept accounts directly for the increase in attenuation with the square of the frequency. The velocities of the waves were measured by Bömmel and were respectively $v_l=2.35\times10^5$ cm/sec, $v_s=1.266\times10^5$ cm^2/sec for lead and $v_l=3.48\times10^5$ cm/sec, $v_s=1.9\times10^5$ cm/sec for tin at 1.5°K. With these values the viscosities calculated are

$$\begin{aligned}\text{Lead: } &\eta=0.787 \text{ poise}; \quad \chi=0.05 \text{ poise};\\ \text{Tin: } &\eta=0.314 \text{ poise}; \quad \chi=0.03 \text{ poise}.\end{aligned} \tag{2}$$

The values of compressional viscosity are small and are probably within the experimental error, nearly zero.

To see if these values are reasonable for the viscosity of an electron gas, we make use of the formula for viscosity[3]:

$$\eta=Nm\bar{l}\bar{v}/3, \tag{3}$$

where N is the number of electrons per cc, m their mass, $\bar{l}$ the mean free path (in this case between electrons and lattice atoms) and $\bar{v}$ the mean velocity. These last two quantities can be evaluated from the theory of the free electron gas[4] and are

$$\bar{v}^2=\frac{3}{5}\frac{\hbar^2}{m^2}(3\pi^2N)^{\frac{2}{3}};\quad \bar{l}=\frac{\sigma m\bar{v}}{Ne^2}, \tag{4}$$

where e is the charge on the electron, $\hbar$ is Planck's constant divided by 2π, and σ is the electrical conductivity in cgs units. Introducing (4) in (3) and substituting $\sigma=9\times10^{11}/R$, where R is the resistivity in ohm cm, the value of η becomes

$$\eta=9\times10^{11}\hbar^2(3\pi^2N)^{\frac{2}{3}}/(5e^2R). \tag{5}$$

The value of N for monovalent metals is equal to the number of atoms, which for lead and tin are respectively 3.33×10^{22} and 3.72×10^{22} per cc. For quadrivalent metals no adequate theory exists for correlating the number of electrons with the number of atoms, but experiments[5] on tin indicate that the ratio is between 0.43 and 1.1. All the other values are known and the viscosity is determined in terms of the measured resistivity by the equations

$$\begin{aligned}\eta_l&=(N_e/N_a)^{\frac{2}{3}}\times8.6\times10^{-9}/R;\\ \eta_t&=(N_e/N_a)^{\frac{2}{3}}\times9.2\times10^{-9}/R.\end{aligned} \tag{6}$$

The measured resistivities[6] for lead and tin are shown in Fig. 3. Using the values of Fig. 3 and Eq. (6) to determine the viscosity, and substituting in Eq. (1) for a longitudinal wave, the calculated attenuations are shown by the dashed lines. Best agreements are obtained if the factors N_e/N_a are

$$N_e/N_a=0.75, \text{ lead}; \quad N_e/N_a=0.3, \text{ tin}.$$

These values account well for the shapes of the measured curves. Above 10°K additional loss occurs due to dislocation motions.

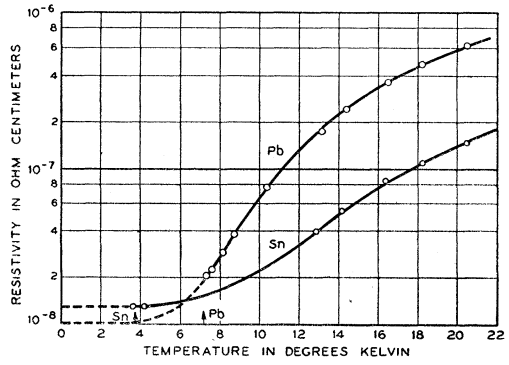

FIG. 3. Resistivity of lead and tin (along tetragonal axis) at low temperatures.

[1] H. E. Bömmel, Phys. Rev. **96**, 220 (1954).
[2] See W. P. Mason's *Piezoelectric Crystals and Their Application to Ultrasonics* (D. Van Nostrand and Company, New York, 1950), p. 478.
[3] See G. Joos, *Theoretical Physics* (Hafner Publishing Company, New York, 1950), p. 562.
[4] See C. Kittel, *Introduction to Solid State Physics* (John Wiley and Company, New York, 1953), Chap. 12.
[5] See E. H. Sondheimer, Advances in Physics **1**, No. 1, 1–43 (1952).
[6] *International Critical Tables*. The value for tin is the value at room temperature for the tetragonal axis reduced by the factors found for polycrystal tin.

Can Helium-3 Be Expected to Exhibit Superfluidity at Sufficiently Low Temperatures?*

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LIQUID helium of atomic mass 4, below its λ point, is the only liquid which has so far been found to show superfluidity. According to the two-fluid hypothesis, it is actually only a certain part of the liquid helium, the superfluid, which has this property. The superfluid is a low-energy form of helium, there being a considerable energy gap between the level of an atom of superfluid and the lowest possible energy of an atom of normal fluid. Under these circumstances it is understandable that a force exerted at one point of a body of superfluid would be felt all through the superfluid, and that it would be set in motion almost immediately. For any force which tends to compress the superfluid, tends to raise the energy level of the entire mass. To avoid this,