Ultrasonic Attenuation in Superconducting and Normal-Conducting Tin at Low Temperatures

H. E. BÖMMEL

Bell Telephone Laboratories, Murray Hill, New Jersey

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MEASUREMENTS on ultrasonic absorption in single crystals of lead at low temperatures have been previously reported.[1] They showed a strong increase in the temperature range from about 10°K −1.5°K if the sample was kept normal-conducting, and a sudden decrease at the superconducting transition temperature when it was cooled without a magnetic field. Similar results have been reported by Mackinnon[2] in polycrystalline tin.

Theoretical considerations by Kittel,[3] Mason,[4] and Morse[5] suggest that, at sufficiently high frequencies and low temperatures, the main ultrasonic attenuation is due to the interactions of the lattice vibrations with the free electron gas and is proportional to the electrical conductivity.

New measurements were carried out in single crystals of tin of two different purities: 99.98% and 99.998%. The results in the less pure tin were similar to those in lead and have already been reported.[4]

For the measurements in the purer tin, two cylindrical samples 21 mm in diameter, 16.5 mm and 9 mm long, respectively, were used. Special care was taken not to disturb the crystalline structure while preparing the specimens. They were cut with an acid-string saw and ground in liquid nitrogen.

Figure 1 shows the resulting attenuation *versus* temperature curve, the maximum attenuation being about 100 times larger than in the less pure tin at the same frequency. From this, the electrical conductivity can be estimated to be of the order of 10^{10} ohms^{-1} cm^{-1}.

While in lead and in the less pure tin the attenuation in the normal-conducting state was independent of a magnetic field, the attenuation in the pure tin showed a very pronounced magnetic field dependence. It seems likely that this is due to the magnetoresistive effect. One can estimate that at a conductivity of 10^{10} ohms^{-1} cm^{-1} this effect should appear at fields of the order of several hundred gauss. Figure 2 shows the field dependence for the 16.5-mm specimen.

The transverse field curve of Fig. 2 shows a dip at about 200 gauss. In order to study this further, the shorter sample was used since, because of its lower loss, it permitted measurements up to higher frequencies. In this sample the effect was more pronounced and appeared in the longitudinal as well as in the transverse field. Measurements were made at 10.3, 20, and 28 Mc/sec. Within the accuracy of the experiments the position of the dip shifted to higher fields proportional to the frequency.

No definite explanation can yet be given for the above-mentioned phenomenon. The electrical conductivity and therefore the mean free path of the electrons are so high that one may have to take into account size effects as they occur when the mean free path becomes comparable to the dimensions of the specimen. In this case special magnetoresistive effects
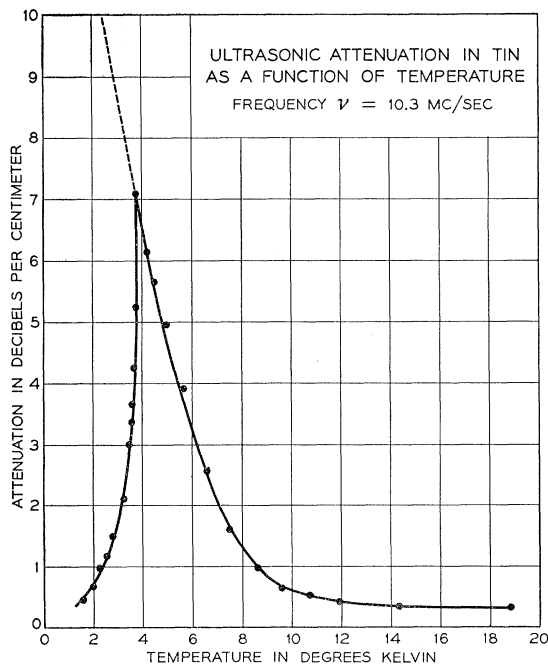

FIG. 1. Ultrasonic attenuation in a single crystal of tin as a function of temperature. Frequency $\nu = 10.3$ Mc/sec. The dotted line indicates the attenuation in the normal conducting state. Its value at 1.6°K is about 12 db/cm.
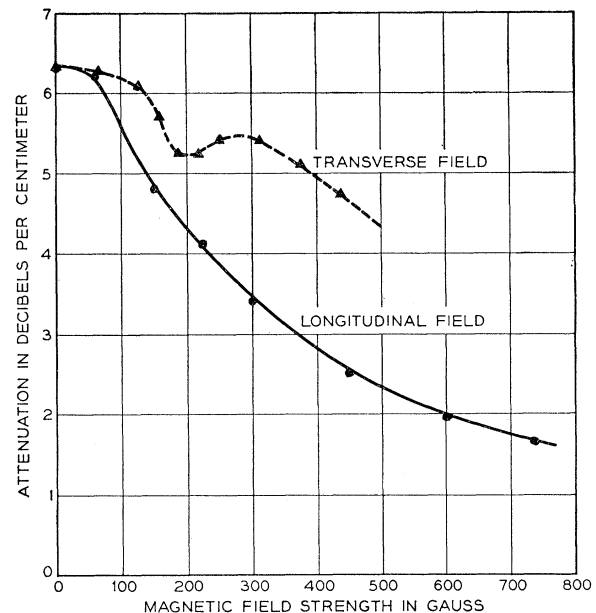

FIG. 2. Ultrasonic attenuation in a single crystal of tin as a function of magnetic field strength. Frequency $\nu = 10.3$ Mc/sec. Temperature $T = 4.2$°K.

due to boundary scattering[6] should occur, and one might suggest that the observed phenomenon is due to a superposition of the ordinary magnetoresistive effect with those mentioned above. A more systematic investigation, especially the dependence on size, frequency, and crystal orientation, is in progress.

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Nuclear Spin-Lattice Relaxation in Solid Hydrogen

TADASHI SUGAWARA

The Research Institute for Iron, Steel, and Other Metals, Tôhoku University, Sendai, Japan

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IN solid hydrogen, the crystalline potential is not the same for different *ortho*-molecules and in general has no particular symmetry, as the solid consists of a random mixture of *ortho*- and *para*-molecules. Accordingly, the lowest rotational state ($J=1$) of the *ortho*-molecule splits into three sublevels, whose separations are expressed in terms of the potential. Most of the line-width data of the nuclear resonance absorption[1,2] were well accounted for by the above supposition originally made by Reif and Purcell. At temperatures not too low, the transition among the rotational sublevels can take place with large probability and this will give the dominant mechanism for the nuclear spin-lattice relaxation. The spin-lattice relaxation time is expected to be distributed over a wide range, as the transition probability can be related to the crystalline potential. The main purpose of this note is to get information on the distribution of the relaxation time from the saturation experiments.

All the measurements were carried out at 8.2 Mc/sec by using an rf spectrometer of the Pound-Watkins type.
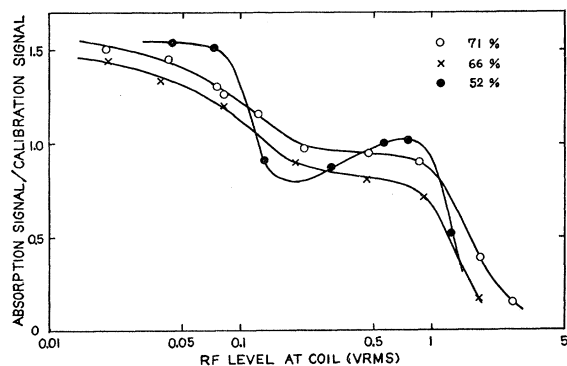

FIG. 1. The saturation curve of the central peak at 4.2°K in solid hydrogen containing 71, 66, and 52% *ortho*-hydrogen.
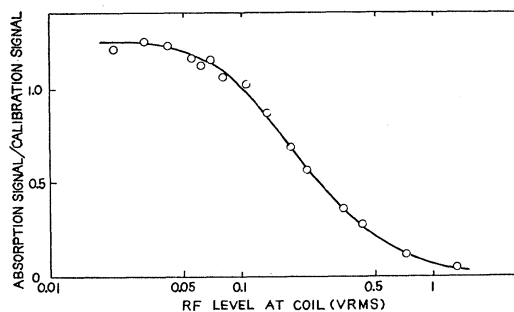

FIG. 2. The saturation curve of the side peaks at 1.2°K in solid hydrogen containing 69% *ortho*-hydrogen.

Derivatives of absorption lines at different oscillation levels were obtained in samples containing various concentrations of *ortho*-hydrogen at temperatures below 4.2°K. As was reported previously,[2] the spectrum in high-concentration hydrogen was a single peak with a width of several gauss at high temperatures; as the temperature is reduced, this peak became flanked by two side peaks of about 40-gauss separation. The line width of the central peak decreased with increasing rf level, while the separation of the side peaks remained constant. Some of the saturation curves are shown in Fig. 1 and Fig. 2 by plotting the ratio of the maximum deflection of the recording meter to the calibration signal as a function of the rf voltage at the sample coil. The curve for the central peak, which does not follow the form usually observed in systems having a single relaxation time,[3] shows that the relaxation time is not unique as had been expected. A theoretical treatment of the saturation phenomena in solid hydrogen would be necessary in order to obtain the distribution function of the relaxation time. However, we may be certain that the distribution has a nearly flat maximum in high-concentration hydrogen and two peaks in low-concentration hydrogen. A single relaxation time is expected from the form of the saturation curve of the side peaks. A preliminary value of about 0.5 second has been obtained from this curve, and this value is in disagreement with the result of Hatton and Rollin.[4]

The effect of paramagnetic oxygen upon the relaxation was also studied in connection with its remarkable effect on the *ortho-para* conversion rate in solid hydrogen.[5] Oxygen up to about 0.05% did not show any observable effect on the saturation curve. An order-of-magnitude estimation of the relaxation time due to the magnetic interaction between proton and oxygen (0.05%) gives a fairly large value, which seems to give no measurable effect on the saturation curve under the experimental conditions of this research.

A full account of this work will be published elsewhere.

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