Letters to the Editor

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Ultrasonic Attenuation in Superconducting Lead

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IN a previous paper Bömmel and Olsen[1] described an attempt to find an influence of superconductivity on ultrasonic velocity and attenuation. Using a frequency of 1 Mc/sec, the authors could find only a not very reproducible increase of the sound attenuation during the penetration or ejection of the magnetic flux used to destroy superconductivity. Experiments are now being carried out in the frequency range from 9–27 Mc/sec and the preliminary results show marked effects.

The superconductive specimens used were two cylindrical single crystals of lead, about 1.25 cm in diameter, 2.2 cm and 0.63 cm long. The first one was used for measurements with longitudinal waves and the second for shear waves. Unfortunately, some recrystallization could not be avoided during cutting and surfacing of the originally perfect crystal specimens. The absolute values of the measured attenuations must, therefore, be too high, due to losses at grain boundaries, etc. In further experiments, the technique of preparing the specimens will be improved.

The measurements were made by an ultrasonic pulse technique with apparatus similar to one described by McSkimin.[2] With the samples used, the apparatus was sensitive enough to detect changes in attenuation in the order of 10^{-3} neper cm and changes in velocity in the order of 1 part in 10^5. A variable longitudinal magnetic field could be applied in order to keep the specimens normal-conducting below the transition temperature, T_c.

The results obtained with longitudinal and shear waves were very similar.

No change could be observed in sound velocity within the whole frequency range. This means that any change due to the superconducting transition must be of the order of 1 part in 10^5 or less. This is in agreement with what one would expect from thermodynamical reasons.[3]

The sound attenuation showed a very pronounced decrease in the superconducting state, the amount of which increased with increasing frequency. Figure 1

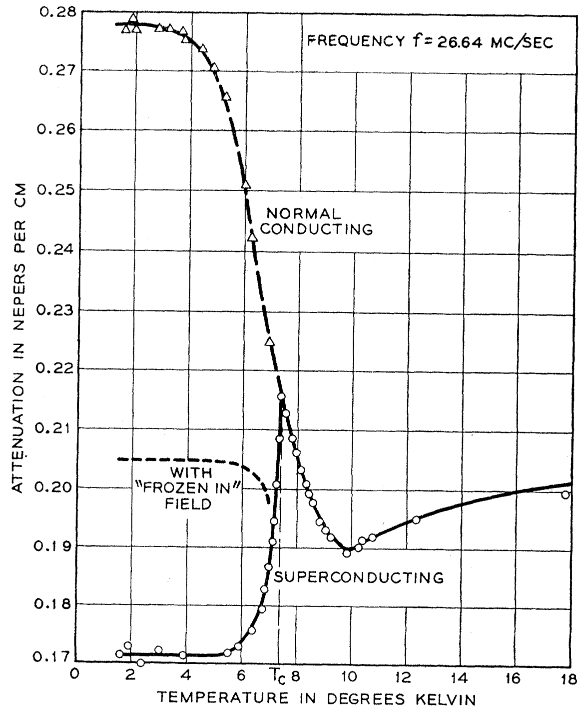

FIG. 1. Attenuation of longitudinal waves in superconducting lead as function of temperature.

gives a typical result obtained with longitudinal waves at a frequency of 26.64 Mc/sec. When the specimen was cooled and kept normal conducting by a magnetic field, the attenuation curve, after passing through a flat minimum at about 9.8°K increased continuously, with no discontinuity at T_c, till about 4°K and then flattened out between 4°K and 1.5°K. When the specimen was cooled without application of a magnetic field, the attenuation dropped down very sharply at the transition temperature and seemed to remain constant between about 5°K and 1.5°K.

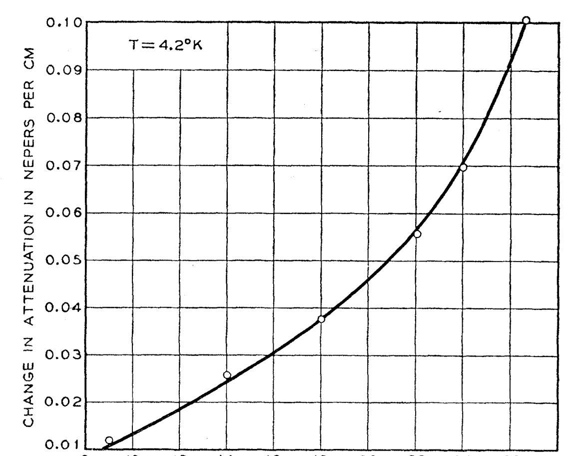

FIG. 2. Change in attenuation between normal and superconducting state for longitudinal waves as function of frequency.

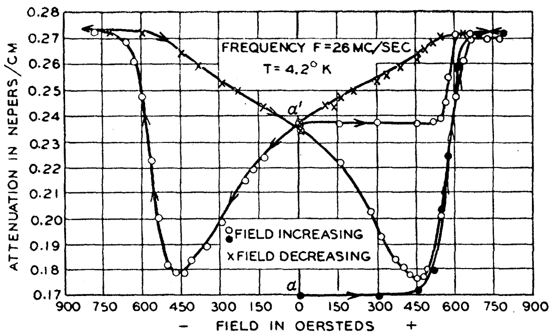

FIG. 3. Effect of "frozen in" field on attenuation in superconducting lead.

Figure 2 shows how the difference $\Delta\alpha$ in attenuation between the normal and superconducting states at 4.2°K changes with frequency, approximately a square law curve within the used frequency range. The ratio $\Delta\alpha/\alpha_n$ (α_n= total loss in normal conducting state at 4.2°K) changed from about 0.15 at 9 Mc/sec to 0.38 at 26.64 Mc/sec. These latter values must be regarded as minimum values since, for the reasons mentioned above, the actual values of α_n are probably smaller. For the same reason it has not yet been possible to make a statement about the actual value of the residual attenuation in the superconducting state which might be of great interest.

When superconducivity was destroyed by the magnetic field H and then re-established by turning off the field, the attenuation did not drop down to the original α, but (depending on the shape of the specimen and the speed of the field change) only to a 30–60 percent higher value α' (marked in Fig. 1 by the dotted line), indicating that a great part of the magnetic flux remained "frozen in." The attenuation as a function of H followed the curve given in Fig. 3. The form of this "magnetization curve" and the large hysteresis have not yet been fully explained and will be the subject of special investigation.

The curves in Fig. 1 look somewhat similar to the well known curves of thermal conduction as a function of temperature. This could suggest that a great part of the acoustic loss at low temperature might be due to loss from heat conduction, but since one gets the same effect with shear waves, this possibility seems to be ruled out.

Further experiments with better crystal samples, other elements, compounds, normal conducting materials, and a greater frequency range are in progress. The reported results might be a further support for the conception that superconductivity is mainly due to interactions between electrons and lattice vibrations, but it seems reasonable not to begin theoretical speculations about the observed effect before further experiments are carried out. Besides its theoretical interest, the effect might provide a very useful means for the study of superconducting properties, as, for example, observations in the intermediate state, etc.

The author wishes to express his gratitude to Mr. H. J. McSkimin for lending him his ultrasonic equipment and to Mr. T. B. Bateman for valuable help with the experiments.

[1] H. E. Bömmel and J. L. Olsen, Phys. Rev. **91**, 1017 (1953).
[2] H. J. McSkimin, J. Appl. Phys. **24**, 988 (1953).
[3] D. Schoenberg, *Superconductivity* (Cambridge University Press, Cambridge, 1952), p. 74.

New Minority Carrier Phenomenon in Germanium

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It is now well known that minority carriers can be injected into germanium by means of a point contact or P-N junction biased in the direction of easy flow of current carriers. An experiment reported by Haynes and Shockley[1] is considered a classical illustration of this phenomenon.

We have discovered that a P-N junction of indium alloyed to germanium and biased in the high-resistance direction can withdraw minority carriers from a bar of N-type germanium, and that the deficit can be propagated down the bar by means of an electrical field. The phenomenon is the exact inverse of the Haynes-Shockley effect and consequently we have named the withdrawal of minority carriers "minority carrier egression."

In Fig. 1, a bar of N-type germanium is provided with two indium alloyed P-N junctions labeled emitter and collector. In the Haynes-Shockley experiment, the emitter is biased positively by the proper position of switch S_2. The synchroverter switch S_1 opens and closes the emitter circuit with a repetition rate of 1000 cps and

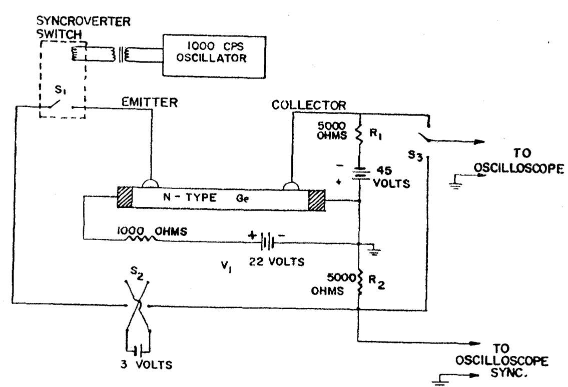

FIG. 1. Circuit used to compare minority carrier injection and egression.