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A NEW EFFECT IN THE LOW MAGNETIC FIELD ULTRASONIC ATTENUATION OF IMPURE SUPERCONDUCTING NIOBIUM

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A NEW EFFECT IN THE LOW MAGNETIC FIELD ULTRASONIC ATTENUATION OF IMPURE SUPERCONDUCTING NIOBIUM*

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ABSTRACT

Changes have been found in the ultrasonic attenuation of superconducting niobium at magnetic fields less than 20% of H_{c1}. An interpretation is made based upon the effects of low critical field impurity phases.

The general form of the magnetic field dependence of the attenuation of ultrasonic waves in type II superconductors is well known; the attenuation is constant until the magnetic field penetrates the material near H_{c1}, then increases monotonically in the mixed state, and levels off at H_{c2}. Some departures from this idealized behavior have recently been reported[1, 2], but such departures have been at magnetic fields larger than H_{c1} where the material was known to be in the mixed state.

We have observed some new phenomena in the ultrasonic attenuation of niobium which occur at magnetic fields well below the lower critical field. Measurements were done on a rod of niobium, one inch long by one

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quarter inch in diameter, whose resistivity ratio, $\frac{\rho(300)}{\rho(4.2)}$, was 70. The usual pulse-echo techniques with a gated integrator were employed, and the frequency was 940 MHz, unless otherwise specified. Examples of the observations are in the curves in Figure 1, for which the temperature ranged from $2.2^{\circ}K$ to $3.2^{\circ}K$, and the sample was oriented with its axis perpendicular to the magnetic field. There is a sharply defined double step increase in attenuation of about 0.2 db while the total superconducting to normal change in attenuation is about 30 db, these measurements being for the first sound pulse. The low field attenuation change depends strongly upon temperature; the threshold field for change increases with decreasing temperature. In the temperature region of $3^{\circ}K$ the steps move rapidly to lower fields, and near $3.2^{\circ}K$ they disappear entirely. Above this temperature no change was observed in the attenuation with field until the lower critical field of niobium is reached.

The position of the low field threshold depends markedly on the magnetic history of the specimen. As long as the lower critical field is not exceeded, the position of the steps in increasing field remains the same as for the virgin sample when it is cycled. If H_{c1} is exceeded during the cycling, the steps appear at higher fields than for the virgin run; the maximum increase appears when the upper critical field, H_{c2}, is exceeded. For example, at $2.05^{\circ}K$ the threshold field for the virgin run is about 140 gauss, while the threshold field for the next run, after H_{c2} has been exceeded, is about 230 gauss.

A similar set of measurements was done on another niobium crystal, one half inch long by one quarter inch in diameter, which was taken from the same zone refined crystal as the previous sample. These measurements were done at a frequency of 270 MHz, where it was possible to achieve a better system signal to noise ratio than at 940 MHz. It was found in this sample that at 1.5°K the total superconducting to normal attenuation change was 18 db for the sixth echo while the low field attenuation change was 1.8 db. A set of measurements was done in which the low field attenuation change was determined as a function of sample orientation in the magnetic field. At a temperature of 1.5°K the set of curves shown in Figure 2 was produced. These curves show that the field dependence of the two steps with orientation is different. The first step moves to lower fields as the sample is rotated from the perpendicular to the parallel orientation, while the second step moves to higher fields. For angles smaller than about 20° the second step runs into the attenuation increase at H_{c1}. For angles near perpendicular there is evident an initial decrease in the attenuation as the magnetic field is increased; for angles smaller than about 60° this initial decrease disappears.

Low magnetic field-attenuation measurements were done under the same conditions as above on a niobium sample of resistivity ratio 700. No trace of the effects seen in the previous two samples were encountered, so that it seems likely that these phenomena depend upon the presence of impurities in the niobium. A mechanism has been suggested[3] in which the impurities agglomerate, possibly about dislocations and that these form a separate phase or phases. The low magnetic field steps then might represent the superconducting to normal transitions of these phases. The orientation data suggests how the impurity phases might be disposed within the niobium crystal. For example, it can be seen from Figure 2 that the field for the onset of the second attenuation step increases approximately as $1/\sin\theta$, where θ is the angle between the field and the sample axis, and that no distinct step is observed for angles smaller than 20°. It is possible to explain this dependence by assuming an anisotropic segregation of the impurity phase having the characteristics of lamellae perpendicular to the sample axis. The effective magnetic field that would penetrate through such normal regions is $H_{applied}\sin\theta$. If H_c is the critical field of the impurity phase then the external field necessary to produce H_c in the lamellae is $H_c/\sin\theta$. When θ becomes very small, $H_c/\sin\theta$ becomes very large, but the lower critical field of the niobium is reached at one kilogauss, so that at $\theta = 15^{\circ}$ the second low field attenuation step would merge with the flux penetration into the niobium. These observations are consistent with the above hypothesis. The fact that the first step moves to lower fields while the second step moves to higher fields with sample rotation suggests either that the two phases to which they correspond have grown in widely different directions within the crystal but are chemically and structurally the same, or simply that they are chemically and/or structurally different.

The hysteretic behavior indicates that the impurity phase transition, as measured ultrasonically, is not reversible as the attenuation step always appears at lower fields in decreasing field. This is typically observed in the ultrasonic attenuation of all but the most perfect superconducting specimens. The hysteresis further suggests that when the niobium has been brought to fields large enough for it to trap magnetic flux, this trapped flux greatly increases the critical field of the impurity phases.

If the phenomena described above are common to type II superconducting materials, a result of some practical importance concerns the effect that they might have upon the generation of losses in the presence of alternating fields or currents. Since relatively low fields are required to make the impurity phases normal, and since their critical temperature is quite low, such normal phases might be present under a wide variety of conditions of interest. Induced joule losses in only a small fraction of the superconducting medium represents a serious limitation for many applications of superconductive devices.

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1. E. M. Forgan and C. E. Gough, Physics Letters 21, 133 (May, 1966).

2. Tsuda et al., Physics Letters 22, 412 (September, 1966).

3. M. Garbuny, private communication.

FIGURE CAPTIONS

1. Ultrasonic Attenuation at Low Fields for Several Temperatures.

2. Orientation Dependence of Low Field Ultrasonic Attenuation.

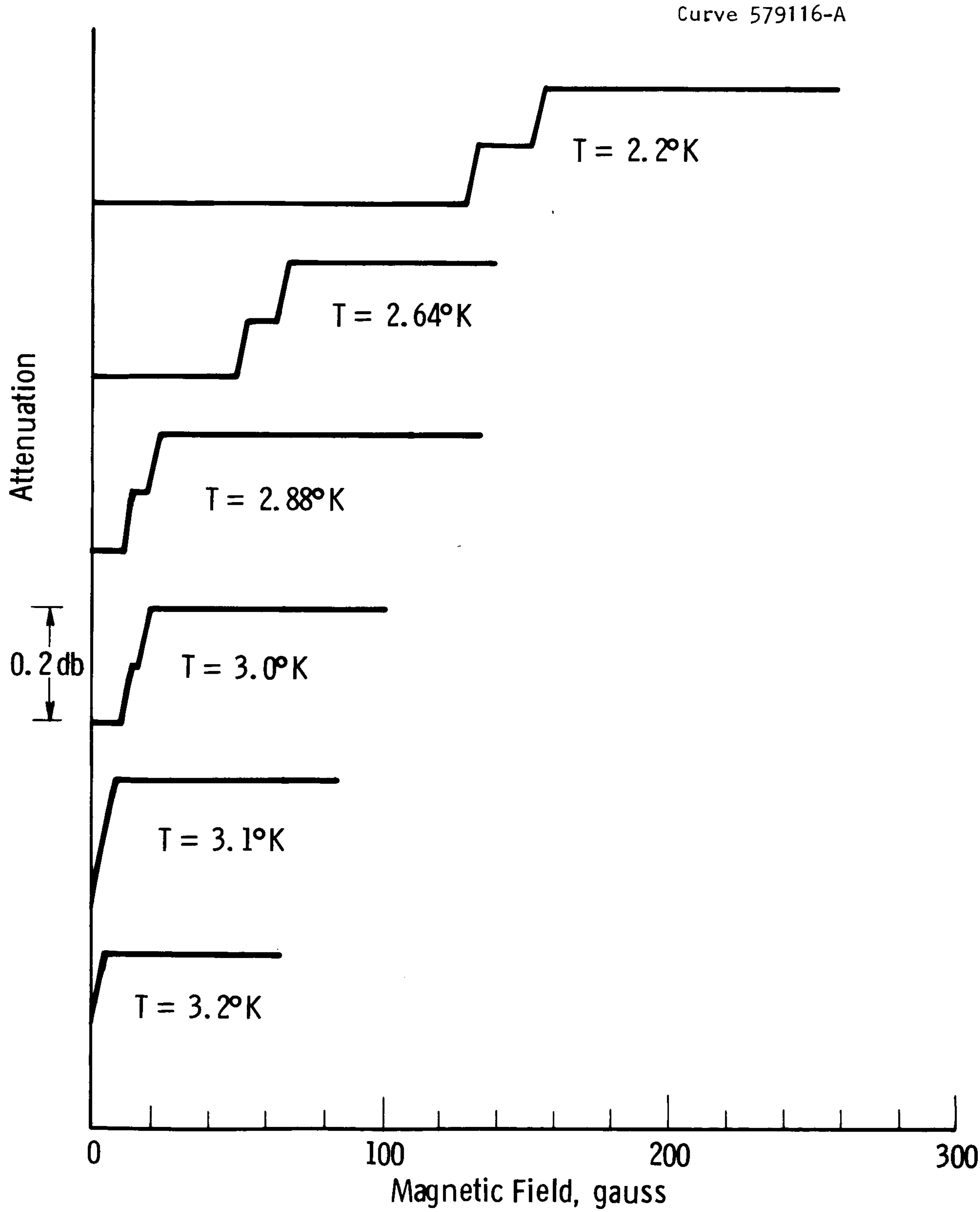
Curve 579116-A
T = 2.2°K
T = 2.64°K
T = 2.88°K
T = 3.0°K
T = 3.1°K
T = 3.2°K
Attenuation
0.2 db
0
100
200
300
Magnetic Field, gauss

Fig. 1

Curve 579178-A

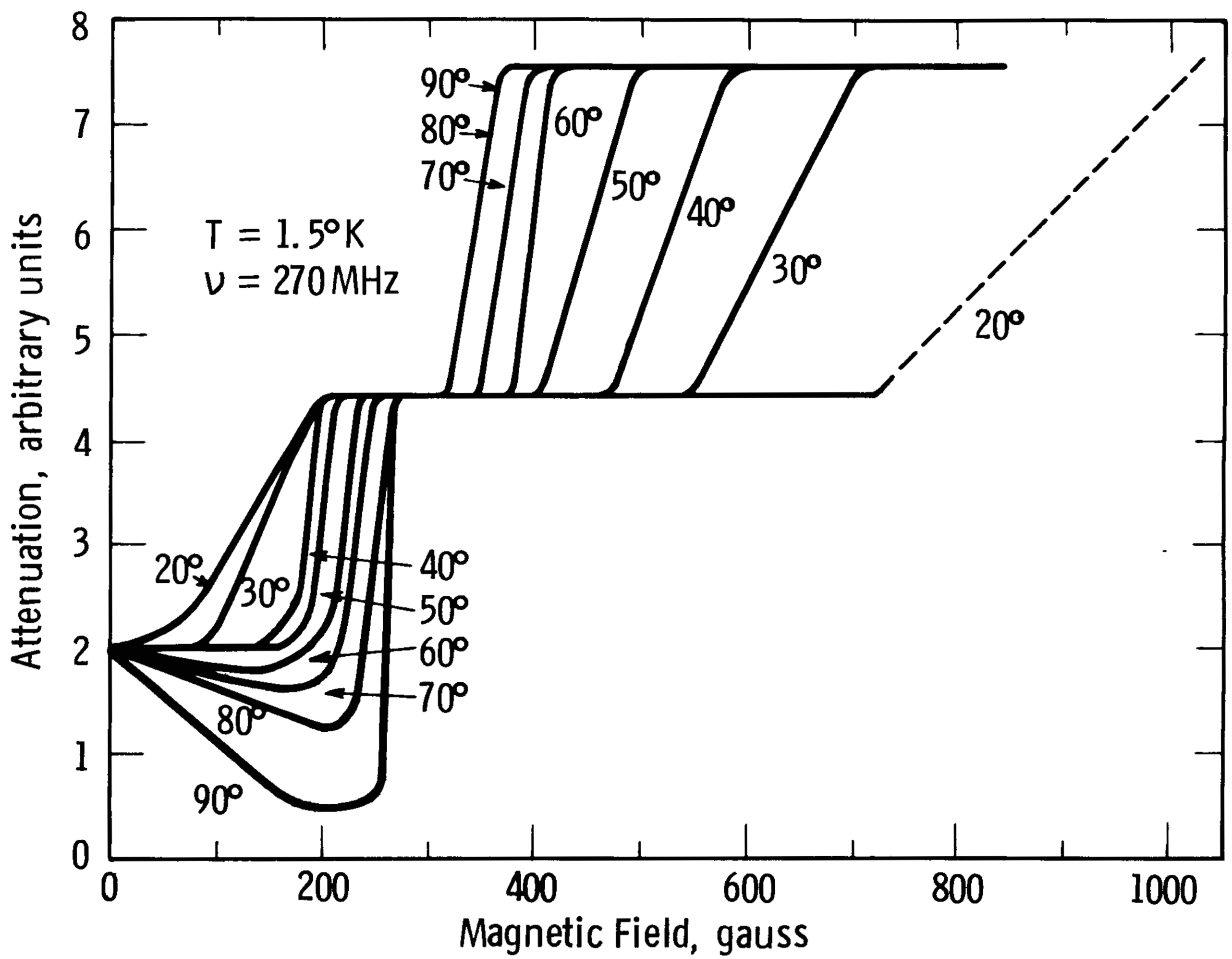

Fig. 2