Acoustomagnetic effect in aluminum and in tin

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An acoustomagnetic effect is observed, wherein a metal becomes magnetized in an inhomogeneous acoustic field. The distribution of the magnetization over the sample and the temperature dependence of the effect are investigated.

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An acoustic wave propagating through a metal drags the conduction electrons. In a homogeneous sound field this leads to the appearance of an electric voltage V_{ph} along the sample. Under the simplest assumption that the entire energy W of the sound wave is transferred to the conduction electrons, with a simple Fermi surface, we obtain

$$V_{ph} = W \frac{1}{enu}, \tag{1}$$

where n is the density of the conduction electrons and u is the speed of sound. This corresponds to a value $v_{ph} = V_{ph}/W \sim 10^{-10}$ V W^{-1} cm^2 for metals such as lead and aluminum. The appearance of the electric voltage V_{ph} was experimentally observed in tin,[1] although the experimentally observed v_{ph} turned out to be much less than given by (1), and was quite anisotropic. It is obvious that v_{ph} is the acoustoelectric effect usually observed in semiconductors.

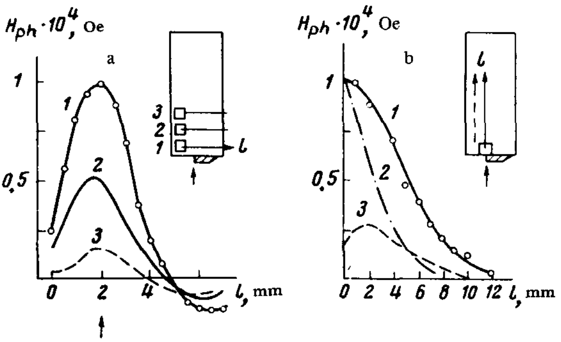

FIG. 1. Distribution of the acoustomagnetic field H_{ph} over the cross section of an aluminum sample. The coil motion is shown on the inserts. a) Distribution of H_{ph} perpendicular to the sound propagation, at distances 1.5 mm (1), 4.5 mm (2), and 7.5 mm (3) from the radiator. b) Propagation of H_{ph} along the sound; curves 1 and 3 correspond to $\omega \approx 15$ MHz (3—meaning coil moves at a distance ~1.5 mm from the abrupt boundary of the sound field, marked by an arrow). Curve 2—$\omega = 44$ MHz (the scale is arbitrary).

In the case of an inhomogeneous sound field in a plane perpendicular to the sound propagation, circular currents are produced in the sample, which is magnetized as a result. In metals with a conductivity $\sigma \sim 10^{10}\ \Omega^{-1}\,\mathrm{cm}^{-1}$ we can expect that owing to v_{ph} a sound flux of density $W \sim 10^{-3}$ W/cm^2 will result in an acoustomagnetic field of the order of 10^{-3}—10^{-4} Oe. Such fields can be measured by modern methods.

The acoustomagnetic field H_{ph} will obviously be inhomogeneous over the sample cross section. The largest values of H_{ph} should be observed at the boundary of the sound flux, where the inhomogeneity of W is maximal. Along the sound flux one should expect a decrease of H_{ph}, similar to the decrease of W. All these regularities are observed in direct measurements of the acoustomagnetic field.

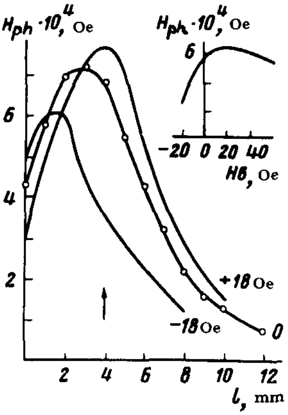

FIG. 2. Variation of the distribution of H_{ph} along the sound propagation in an external field (tin). The inserts shows a plot of H_{ph} at a distance 4 mm from the radiator.

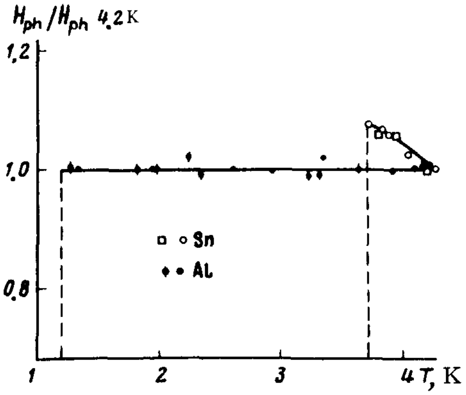

FIG. 3. Relative change of H_{ph} with temperature for several tin and aluminum samples. The dashed lines show the vanishing of H_{ph} at T_c. The directions of H_{ph} are different for tin and aluminum.

To measure the acoustomagnetic effect we used single-crystal samples of tin and aluminum measuring (8—10) × 20 × (1—2) mm. The axis of highest symmetry of the crystal was perpendicular to the (8—10) × 20 face. The residual resistivity of the samples was $\sim 10^{-10}$ Ωcm. The sample was clamped with its narrow face to an ultrasonic converter in such a way that the sound field occupied only part of the sample cross section (see Fig. 1). The magnetic field in the direction perpendicular to the (8—10) × 20 plane was measured with the aid of the SKIMP installation[2] receiving coil, which was placed on the surface of the sample. In the experiment we determined the current produced in the coil when the ultrasound was turned on. The main experiments were performed with perpendicular-mode oscillations of frequency 14.3 and 44 MHz.

Figure 1 shows sections through the acoustomagnetic field, determined in this case with the aid of moving coils. It is clearly seen (Fig. 1a) that the maximum of H_{ph} indeed coincide with the sharp boundary of the sound field. No substantial spreading of the acoustomagnetic field into the interior of the sample is noted. The acoustomagnetic field attenuates along the propagation direction of the ultrasound faster the stronger the attenuation of the ultrasound (Fig. 1c).

The detailed distribution of the sample magnetization is determined by the distribution of the currents over the sample. In particular, an important role in the character of the variation of H_{ph} near the radiator is played by the sample boundary.

The distribution of the currents over the sample, and by the same token the magnetization, can be varied with an external magnetic field (Fig. 2).

The acoustomagnetic field, just as the acoustoelectric one, is a reflection in fact of a single physical phenomenon, namely the dragging of the conduction electrons by the sound. In the case of the acoustomagnetic effect the role of the accompanying phenomena due to the thermal heating of the sample is not so large since heating the sample can give rise to circular current only under special conditions.[3] In our experiments circular currents of thermal origin were observed only in the case of bismuth.

Figure 3 shows the temperature dependence of the acoustomagnetic effect in aluminum and tin. These results indicate that the dragging of the conduction electrons by sound does not depend on the temperature. Some increase (5—10%) of the acoustomagnetic effect in tin is obviously connected with the temperature dependence of the conductivity. In some of these experiments we used a single crystal with a 2×4 mm opening inside of which the acoustomagnetic field was measured.

Experiments with such samples have shown that in the superconducting state, at $W \sim 10^{-2}$ W/cm^2, the acoustomagnetic field is less than 10^{-7} Oe. In the normal state the field was -4×10^{-4} and 10^{-4} Oe, respectively for Al and Sn. Additional experiments have shown that for aluminum $v_{ph} \sim 2\times10^{-10}$ V W^{-1} cm^2, which is close to the calculated value.

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