Acoustoelectric effect in silver

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A method has been developed for measuring the acoustoelectric field E^A : the field which results from the entrainment of electrons by a sound wave. This method can be used for any sufficiently pure metal. The acoustoelectric field has been measured for silver single crystals over the temperature interval 1.3–7 K. A pronounced anisotropy of E^A has been found. It is linked with particular features of the Fermi surface and with a theory derived previously by Suslov.

A sound wave propagating through a conductor induces an "acoustic voltage" V^A. The effect as first seen in metals in Ref. 1, but the experimental procedure used there could provide reliable measurements only at temperatures at which the thermal emf of the metal was zero. Furthermore, the complexity of the Fermi surface of tin—the metal which has been studied in most detail—has made it difficult to compare the experimental results with the theory.[2] In the present letter we describe a new procedure which makes it possible to measure the acoustic voltage of essentially any sufficiently pure metal at liquid-helium temperatures. We report measurements of the acoustic voltage of silver, which is a metal with a comparatively simple Fermi surface.

The apparatus used in the present experiments is shown in Fig. 1. The test sample (3), of highly pure silver, with $R_{300}/R_{4.2} \sim 6500$, with a length ~ 5 cm and a cross section of 3×3 mm^2, of known orientation, is held in a vacuum chamber (2) with a germanium-wafer window (6) 0.2 mm thick (single crystal; the sound propagates along the [111] axis). An ultrasonic wave (L mode, $f = 26$ MHz) with a power W_0 ($\sim 4\times 10^{-4}$ W) enters the silver through this window. The sample is centered in the column (7) in the chamber by washers (5) with paper spacers. The sample is pressed against the germanium window by a weight (4) with a needle. The sample, the window, and the ultrasonic transducer (1, lithium niobate) are held in acoustic contact by a layer of GKZh oil. The temperature of the sample is measured by a carbon thermometer (9).

To determine the acoustoelectric field E^A we measured the voltage (V^A) along the sample between the point at which an acoustic power W passes through the cross section of the sample and the upper end of the sample, where the sound is completely damped. The acoustic power at the lower end of the sample, W_0, is determined from the heating of the sample. The potential difference is measured by a bridge arrangement with a SKIMP device[3] used as null detector. The superconducting leads of the measurement system are soldered to thin projections from the surface of the sample formed by electric-erosion cutting. The leads leave the chamber through insulating beads (8) with soldered platinum capillaries. The contacts with the sample are at various distances from its end, so that the changes in W along the length of the sample can be measured, and the sound damping Γ can be determined. This method elimi-

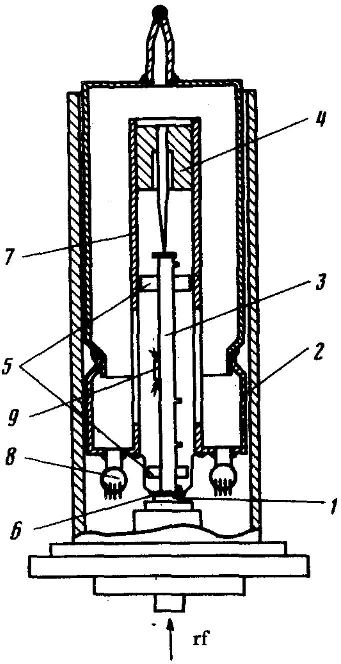

FIG. 1. The experimental apparatus (explained in the text proper).

nates the loss of acoustic power and heat through the side walls and upper end of the sample and makes it a simple matter to calculate the voltage due to the heating of the sample by the sound wave. In our case, this correction did not exceed 10% of V^A.

The sound damping Γ in silver is significantly anisotropic (Fig. 2). The damping values which we found are consistent with previous measurements[4,5] and with theoretical predictions[2] (dashed curves in Fig. 2).

The acoustoelectric field,

$$E^A = \frac{SV_0^A}{W_0}\Gamma, \tag{1}$$

where S is the cross-sectional area of the sample, is independent of the temperature over the interval 1.3–7 K. Figure 2 shows how the orientation of the sample affects E^A; the dashed line here is the calculated value of E^A from Ref. 2. We see that there is a qualitative difference between the theoretical and experimental results.

The Fermi surface of silver is known to be a sphere with necks along the principal diagonals of the reciprocal-lattice cube. In the τ approximation, the acoustoelectric field can be written an the sum of contributions from the spherical part or "belly," $E^A_{\rm sph}$, and from the neck, $f(\beta)$:

$$E^A = E^A_{\rm sph} + \sum_{k=1}^{4} f(\beta_k), \tag{2}$$

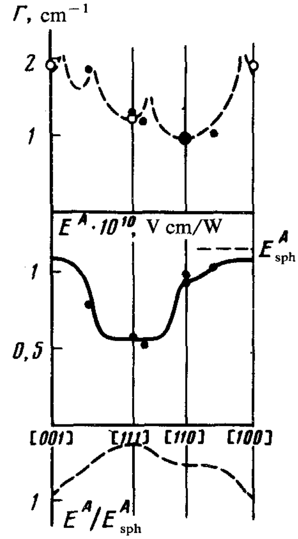

FIG. 2. Damping of sound and the acoustoelectric field in silver. The results of Refs. 2 and 4 are set equal to the results of the present study at the [110] point (the open circles are data from Ref. 4). For a sample with $\phi = 24°$ and $\theta = 37.5°$, we have $\Gamma = 1.27\ \mathrm{cm}^{-1}$ and $E^A = 0.71 \times 10^{-10}$ V cm/W.

where β_k is the angle between the sound propagation direction and the neck. The field E^A_{sph} can be calculated from[1,6]

$$\Gamma_{sph} = \frac{\pi^2 N m V_F}{3\rho_0 V_l^2} f; \quad E^A_{sph} = \frac{\Gamma_{sph}}{e V_l N};$$

with $f = 26$ MHz we find $E^A_{sph} = 1.16 \times 10^{-10}$ V cm/W.

The calculations of the acoustoelectric field in Ref. 2 used the function $f(\beta)$ shown by the dashed curve in Fig. 3. We can use the experimental data to reconstruct this function by solving the inverse problem. It is simple to show that the unknown function can be written in the form

$$f(\beta) = C(1 + 3\cos 2\beta) + \tilde{f}(\beta), \tag{3}$$

where C is an arbitrary constant, since the expression $\Sigma C(1 + 3\cos 2\beta_k)$ vanishes in the summation over all the necks by virtue of the cubic symmetry of the lattice, and $\tilde{f}(\beta)$ is a particular solution which does not contain $\cos 2\beta$.

The solid curve in Fig. 3a shows the function $\tilde{f}(\beta)$ constructed from the experimental data. Shown by the dashed curve here is the function $\tilde{f}(\beta)$ which describes the angular dependence of E^A in Ref. 2. The dashed curve in Fig. 3b shows the function $f(\beta)$ according to Ref. 2, while the solid curve here shows $f(\beta)$ as determined from the experimental data and set equal to the theoretical value at the point $\beta = 0$ by choosing an appropriate value for the coefficient C in expression (3).

It can be seen from Fig. 3 that the function $f(\beta)$ predicted by the theory of Ref. 2

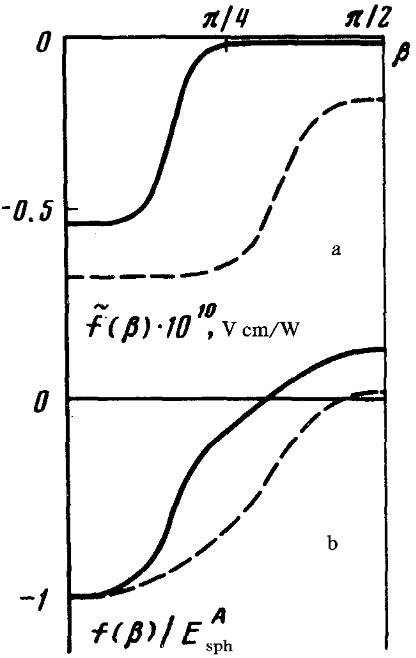

FIG. 3. Angular dependence of the contribution of the neck to the acoustoelectric field.

is similar to that reconstructed from the experimental data, but since the contributions of the "belly" and the neck are opposite in sign even a very slight change in $f(\beta)$ leads to a substantial change in E^A in the given direction [see (2)]. The solid curve in Fig. 2 shows a calculation of E^A from (2) and from the function $f(\beta)$.

There is some discrepancy between the theoretical function $f(\beta)$ and the corresponding function determined from the experimental data, and this discrepancy indicates that the theory should be refined.

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