Transport of acoustic field by conduction electrons in gallium

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(Submitted February 24, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 8, 428–432 (20 April 1976)

We report experimental observation of a new effect wherein the strain field of a sound wave in pure gallium is transported by conduction electrons moving on an orbit in a magnetic field perpendicular to the sound.

PACS numbers: 72.55.+s

In the study of sound absorption in high-purity gallium (electron impurity mean free path $l \sim 1$ cm) in weak magnetic fields at $\mathbf{q} \perp \mathbf{H}$ ($\mathbf{q}$ is the wave vector of the sound), it was observed that the receiving system registers ultrasonic signals whose time of passage t_H through the sample is much shorter than the rresponding time t_s for the longitudinal ultrasonic wave and depends strongly . the magnetic field. The amplitudes of these signals are linear in the magnide of the exciting sound.

We propose that we have observed a new phenomenon wherein the sound field ; transported through the metal by the conduction electrons. The theory of this fect has been developed in[1], and we confine ourselves here to a qualitative nalysis. On entering the sample, the sound field generates a spatially-ordered istribution of the electron density, which follows the potential relief of the ave. In a field **H** perpendicular to **q**, this distribution is transported over a epth $2cp/eH$ (p is the Fermi momentum), and generates there a sound field at propagates further with the velocity of sound. The sound field is thus transorted on part of the sample with Fermi velocity. This phenomenon is the acustic analog of the anomalous penetration of the electric field in the sense that ı both cases the external perturbations are transported by electrons moving on e orbit over a distance equal to double the Larmor radius.

The foregoing allows us to draw a number of conclusions: 1) the main contriution to the effect is made by electrons with $p=p_{\text{ext}}$; 2) just as in the case of he anomalous penetration of the electric field, the sound field can be transportd over a chain of orbits with $n=1,2,3,\ldots$; 3) the conditions for the existence f the effect are determined by the inequality $l \geq 2cp_{\text{ext}}/eH \leq D$, where D is the ninimum dimension of the sample in a plane passing through its central section erpendicular to H; 4) $t_H = t_S - ncp_{\text{ext}}/veH$ (v is the speed of sound), i.e., it is inear in the reciprocal field; 5) the phase of the high-frequency oscillations in he signal transported in this manner is equal to $q(L-2ncp_{\text{ext}}/eH)$ (L is the ength of the sample), i.e., it is also linear in the reciprocal field.

The measurements were performed with an installation[2] that produced coerent high-frequency signals with quartz-stabilized frequency. This made it ossible to measure t_H of sufficiently weak signals with acceptable accuracy by letermining the interference of the investigated signal with a comparison signal stretched over time from zero to t_s. The variation of the phase of the reistered signals in the chosen time interval, given by the position of the strobng pulse and its width, was also determined from the results of the interference. We investigated samples of different orientations and different dimensions with conservation of the orientation. The working frequencies were 50, 100, and 200 MHz. The longitudinal sound was generated by lithium-niobate lates with fundamental frequency 66 MHz.

The described phenomenon is observed in all samples practically for all wave directions, but is most clearly pronounced at **q**‖**b** and at an angle 40—50° between **H** and **a** (apparently because of the concrete peculiarities of the strain potential).

The points in Fig. 1 mark the results of direct measurements of t_H on a sample with $L=12.44$ mm, $t_S=3.05$ μsec. In accordance with conclusion (2), two pulses are clearly observed, corresponding to $n=1$ and 2. Further, in accordance with conclusion (4), t_H is linear in the reciprocal field. The extremal momentum of the electrons, obtained from the slope of the $t_H=f(1/H)$ straight line and equal to $k_{\text{ext}}=7.5\times10^7$ cm^{-1}, is in full agreement with the investigations of the geometric resonance.[3]

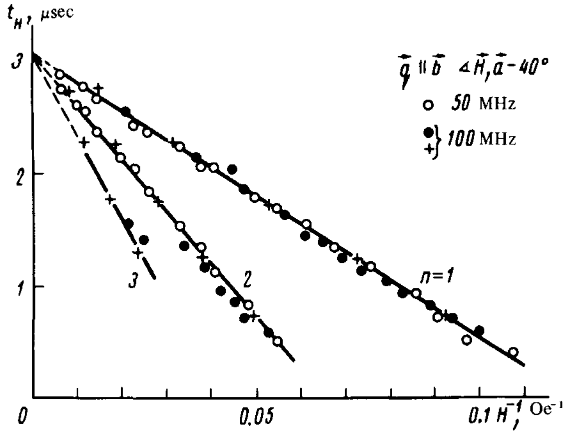


FIG. 1. Dependence of t_H on $1/H$; $T=1.7$°K.

Much more accurate data can be obtained by plotting with an x–y recorder the results of the interference of the investigated signal and the comparison signal at a definite position of the strobing pulse. An example of such a plot is shown in Fig. 2. Here one oscillation of the plot corresponds to a 2π change in the phase of the investigated signal.

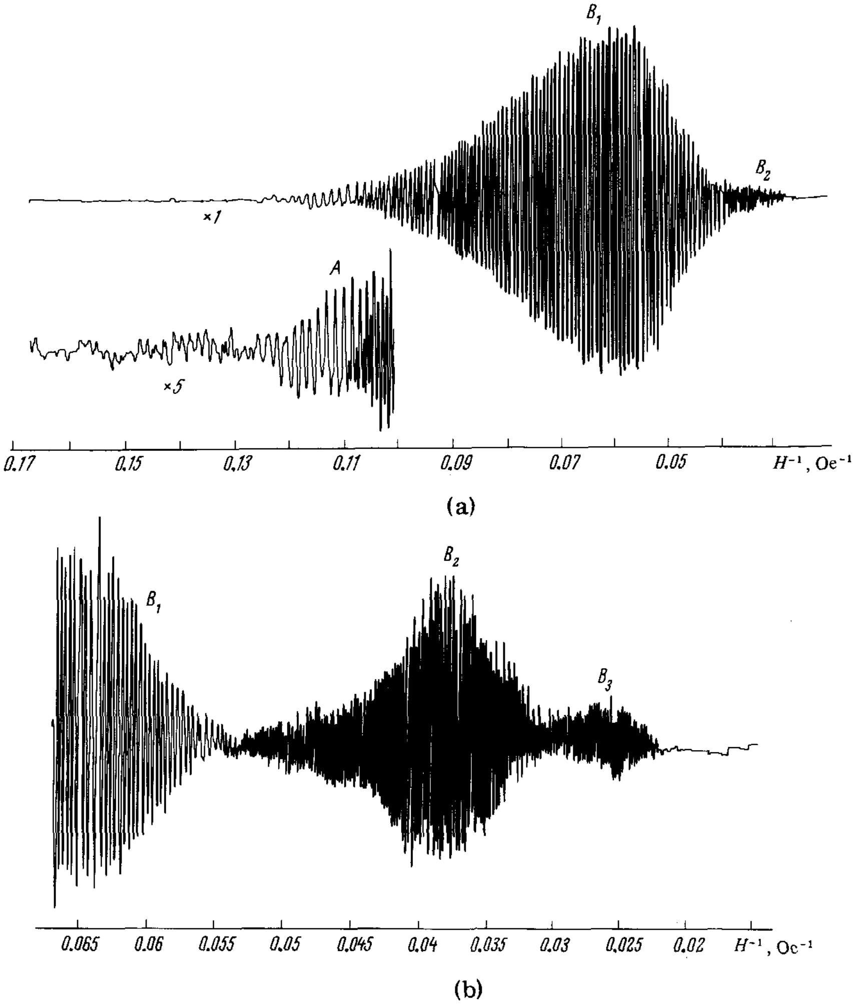
In weak fields, a period is observed with $K_{ext}=4.1\times10^7$ cm^{-1}, which agrees with conclusion (3), followed by oscillations with $K_{ext}=7.5\times10^7$ cm^{-1} and with $n=1, 2$, and 3. The periods with $n=2$, and 3 actually correspond to transport of the sound field over a chain of orbits, since the determination of K_{ext} withou allowance for the multiplicity n leads to values that approach ($n=2$) and exceed ($n=3$) the reciprocal-lattice period, something which either disagrees with the model of the Fermi surface of gallium ($n=2$), or contradicts entirely the translational-symmetry considerations ($n=3$).

The period of the discussed oscillations does not depend on L, in agreement with conclusion (5). This, in our opinion, indicates that it is impossible to interpret the described phenomenon as a manifestation of some other type of excitations.

The termination of the oscillations with this period on Fig. 2 corresponds to the instant when the leading front of the pulse passes through the trailing edge of the strobing signal. The values of t_H determined in this manner are marked by crosses in Fig. 1.

The amplitude of the resultant signals depends on t_H and on the frequency of the sound. In the most intense case, at t_H= close to t_s, when l already exceeds greatly the extremal diameter of the orbit, the ratio of the transmitted sound pulse and the discussed signal amounts to 24, 12, and 9 dB for 50, 100, and 20 MHz, respectively.

The conclusion drawn in[4] that there exist "anomalously large oscillations of the speed of sound" in gallium at **q**∥**b** and at an angle ≈ 40–50 ° between **H** and **a** is, in our opinion in error. The displacements of the sound-pulse front



IG. 2. Plot of the interference pattern as a function of $1/H$ at $q \parallel b$ and an an-
le 40° between H and a; $T = 1.7$°K, a) $f = 50$MHz; b) $f = 100$ MHz; A—oscillations
$_{ext} = 4.1 \times 10^7$; B_1, B_2, and B_3—oscillations with $K_{ext} = 7.5 \times 10^7$ cm^{-1} at values
$= 1, 2, 3$. Strobe position 1.5—1.9 μsec.

bserved in[4] can be fully explained as being due to interference between the
ignals discussed in the present paper and the sound pulse. According to our
ata, the change of either the phase or the group velocity of the sound under
onditions analogous to those in[4] does not exceed 10^{-3}.

We are grateful to É. N. Bogachek, A. S. Rozhavskiĭ, and R. I. Shekhter for
seful discussions.

E. N. Bogachek, A. S. Rozhavskiĭ, and R. I. Shekhter, this issue, p. 391.

[2] P. A. Bezuglyĭ and N. G. Burma, Fizika kondensirovannogo sostoyaniya (Physics of the Condensed State), Tr. FTINT Akad. Nauk Ukr. SSR, No. XV, 125, 1971.

[3] C. Alguié and J. Lewiner, Phys. Rev. **B6**, 4490 (1972).

[4] A. G. Shepelev, O. P. Ledenev, and G. D. Filimonov, Pis'ma Zh. Eksp. Teor Fiz. **22**, 148 (1975) [JETP Lett. **22**, 67 (1975)].