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# GEOMETRIC RESONANCE IN ELECTROMAGNETIC EXCITATION OF SOUND IN METALS

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The amplitude of excited sound in a strong magnetic field parallel to the surface experiences oscillations corresponding to geometric resonance. The oscillation amplitude is proportional to the deformation-potential tensor at a definite point of the Fermi surface.

The interaction of electrons with sound is usually described with the aid of the deformation tensor $\lambda_{ik}(\vec{p}) = \lambda_{ik}(-\vec{p})$, which characterizes the change of the dispersion law $\varepsilon(\vec{p})$ upon deformation. The corresponding volume force in the equation of motion of the elastic medium is

$$F_i = \frac{\partial}{\partial x_k} < \lambda_{ik} f > \qquad (1)$$

($f\delta(\varepsilon - \mu)$ is the non-equilibrium part of the distribution function, and the angle brackets denote integration over the Fermi surface). When the electron system is perturbed by an external electromagnetic wave, the force (1) is responsible for the deformation mechanism of sound excitation.

It is of interest to look into the singularities of sound excitation under anomalous skin effect conditions. It is known that under such conditions the contribution of different electron groups to the penetration of the electromagnetic field into the interior of the sample is quite different, so that the form of $\varepsilon(\vec{p})$ can be reconstructed from the experimental data. We show below that when sound is excited in the presence of a strong magnetic field $H_0$ under conditions when the radius R of the Larmor orbit exceeds the length of the sound wave, there should be observed sound-amplitude oscillations of appreciable magnitude, due to the electrons from the extremal Fermi-surface section perpendicular to $H_0$, which glide parallel to the sample surface. This makes it possible to determine the value of $\hat{\lambda}(\vec{p})$ on the Fermi surface directly from experimental data on sound generation.

We consider the excitation of sound in a half-space $z > 0$ in the presence of a strong magnetic field $H_0$ parallel to the surface ($\gamma = (\Omega\tau)^{-1} << 1$, $\Omega$ is the cyclotron frequency, and $\tau$ is the relaxation time). Let us find the amplitude of the transverse sound wave excited by the force (1). As usual in the anomalous skin effect, we use in (1) the distribution function f without allowance for the boundary conditions, we neglect the field $E_z$, and continue the field $E_{x,y}$ in even fashion to the region $z < 0$. It is easy to show that far from the surface

$$u_i = \frac{\pi e}{i\rho s^2} < \frac{\lambda_{iz}}{\Omega} \int_{-\infty}^{\phi} d\phi' \, \mathrm{v}\, \mathrm{E}(k) \exp \int_{\phi}^{\phi'} \gamma \, d\phi'' \sin \frac{k}{\Omega} \int_{\phi}^{\phi'} v_z d\phi'' > ,$$

$$E(k) = \frac{2i\omega c^{-1}H(0)}{k^2 - 4\pi i\omega c^{-2}\sigma(k)}, \quad k = \omega/s.$$

Here ρ is the density, s the speed of sound, ω the wave frequency, H(0) the magnetic field of the wave near the surface, and σ(k) the Fourier component of the conductivity (cf., e.g., [1]). We note that (2) contains that part of the function f, which is even with respect to the substitution $\vec{v} \to -\vec{v}$, whereas the current j = e<vf>, the distribution of which is responsible for the penetration of the field into the sample, is determined by the part odd in v. We confine ourselves henceforth to the case of a convex Fermi surface and short sound waves: kR >> 1. We present first the results pertaining to the case when $\lambda_{1z} \neq 0$ at $v_z = 0$. Using the stationary-phase method, we obtain for $H_0 \perp E \parallel x$:

$$u_x = -\frac{ieE(k)}{\rho s\omega h^3}\left\{\int \frac{dS}{v}\frac{v_x\lambda_{xz}}{v_z} + \frac{2\lambda^0_{xz}}{v_0\bar{\gamma}_0}\left(\frac{2\pi}{|kD''_0|}\right)^{1/2}\cos\left(kD_0 - \frac{\pi}{4}\right)\right\}. \tag{3}$$

At $H_0 \parallel E$ there remains only the first term in (3). This term describes the contribution of all the electrons on the Fermi surface to the generation effect: the dependence on the magnetic field is contained only via E(k). At $H_0 = 0$ it coincides with the result [2] for the case kℓ >> 1 and does not depend on the temperature.

The notation in the second term is as follows: D is the extremal diameter of the electron orbit, corresponding to the Fermi-surface section normal to $H_0$ and lying in the plane $v_z = 0$, $D'' = d^2D/dp_z^2$, the subscript 0 denotes the point $v_z = 0$ on the extremal orbit, and $\bar{\gamma}$ is the value of $(\Omega\tau)^{-1}$ averaged over the orbit. The second term describes the oscillations periodic in $H_0^{-1}$ that correspond to establishment of an integer number of acoustic half-waves on the orbit diameter, i.e., to the known geometric resonance. We note that the σ(k) oscillations causing the anomalous penetration of the field into the sample, as well as the oscillations of the sound damping factor Γ, have under the conditions of geometric resonance the same period in $H_0$ as (3), but are shifted in phase by π/2 relative to (3) [1, 3]. For σ and Γ, the relative value of the amplitude of the oscillations is $\sim(kD_0)^{-1/2} << 1$, whereas in (3) it is of the order of $(kD_0)^{-1/2}\gamma^{-1}$, i.e., it can be appreciable. The oscillations in (3) are proportional to the value of the tensor $\lambda_{xz}$ at the Fermi-surface point corresponding to the intersection of the plane $v_z = 0$ with the extremal orbit. By varying the direction of $H_0$ and using samples with different crystallographic orientations relative to the sample surface, it is possible to obtain the value of $\hat{\lambda}(p)$ at different points of the Fermi surface from measurements of the oscillation amplitude. It is necessary for this purpose to determine the monotonic part of $\underline{u}$, and this can be done with measurements at $H_0 = 0$. The parameters $v_0$ and $D''_0$ which enter in the amplitude of the oscillations are obtained from data on the Fermi surfaces. In the easily realized case $k^2 << 4\pi\omega c^{-2}\sigma(k)$, the quantity $\bar{\gamma}$ actually drops out from the absolute value of $u_{osc}$, and in this case $u_{osc} \sim H^{1/2}\omega^{-1/2}$.

In the case when $\lambda_{xz} = 0$, the results at $v_z = 0$ are qualitatively altered. We present the data obtained for a spherical Fermi surface, when we can put $\lambda_{xz} = (\lambda/v^2)v_xv_z$. The first term in (3) remains unchanged, while the relative value of the second term decreases to $(3/2)\pi^{-1/2}(kR)^{-3/2}\sin(2kR - \pi/4)$, so that now the principal role in the oscillations are assumed by the corresponding parts of σ(k) and E(k), the relative magnitude of which is $2(\pi kR)^{-1/2}\sin(2kR - \pi/4)$.

The results of experimental observation of sound excitation in Ag single crystals under the conditions described above were published recently [4]. Oscillations periodic in $H_0^{-1}$ were observed, but vanished at $H_0 \parallel E$ and with increasing temperature, and there was no temperature dependence of u in weak fields. All this agrees qualitatively with our results. It is noted in [4] that the oscillations are not due to geometric resonance for Γ, and in particular u and Γ differ slightly in phase. In our opinion, it is desirable to perform experiments with an essentially nonspherical Fermi surface, where considerable differences between $u_{osc}$ and $\Gamma_{osc}$ can be expected both in magnitude and in phase.

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## ANOMALOUS DISSIPATION AND PENETRATION OF STRONG ELECTROMAGNETIC RADIATION INTO A BOUNDED PLASMA

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We consider the stationary picture of penetration of a transverse wave with frequency close to the plasma frequency into a bounded plasma. The parametric growth of the longitudinal noise leads to a considerable increase of the effective collision frequency and to a decrease of the wave penetration in comparison with the usual "collision" values.

Anomalous absorption of an electromagnetic field in a plasma was experimentally observed relatively recently [1 - 3]. Theoretically, such a phenomenon can be produced by the parametric excitation predicted by Silin [4], of longitudinal oscillations in a plasma placed in a high-frequency electric field. Unlike [5 - 8], which dealt with the stationary turbulent state resulting from the development of a parametric instability in a homogeneous plasma under the influence of a homogeneous electric field, we consider here the stationary picture of the penetration of a transverse wave into a semi-bounded plasma (z > 0) with allowance for emergence of the excited longitudinal oscillations in the inhomogeneous field of the pump wave. We investigate the normal incidence of a transverse wave of frequency $\omega_0$ close to the plasma frequency $\omega_p$. The parametric interaction of the plasma with ion-acoustic oscillations, which arises under the influence of a strong electromagnetic field of an incident wave, occurs only in the region near the boundary, where the amplitude of the penetrating field is large enough (the interaction region). On emerging from the interaction region, the parametrically growing plasma noise and ion-acoustic noise carries the energy of the external field out of the region of its localization. The external-field energy then goes over into longitudinal-noise energy and the amplitude $E_0(z)$ of the transverse wave decreases with increasing distance from the boundary. Such a decrease is irreversible, since the number of excited waves in the considered case of strong excess above threshold turns out to be quite large.