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POSSIBLITY OF EXPERIMENTALLY MEASURING THE ELECTROMAGNETIC FIELDS PRODUCED IN A METAL IN WHICH TRANSVERSE ULTRASONIC WAVES PROPAGATE

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We describe briefly the idea of an experiment in which it is possible to obtain quantities characterizing the change of the Fermi energy due to shifts in the lattice.

If a solid contains inhomogeneous elastic deformations produced by external forces or an acoustic wave, then this leads to the occurrence in the solid of extraneous electromotive forces analogous to those produced by the temperature gradient. The presence of a density gradient leads to the occurrence of potential extraneous emfs in the static state. In the absence of equilibrium, for example, when a transverse acoustic wave propagates, there can occur also non-potential emfs, leading to the appearance of current.

The microscopic theory of such phenomena is contained in a number of papers [1]. These lead to more definite expressions for these emfs.

In the presence of transverse acoustic oscillations (displacement along the z axis, wave vector along the x axis, frequency ω), which can be in the form of either a traveling wave or a standing wave, the emf K_z which enters in Ohm's law $j_z = \sigma(E_z + K_z)$ turns out to be

$$K_z = -\frac{m\omega^2 u_z}{e}\left[1 - i\omega\tau\left(\frac{v_F}{s_t}\right)^2\alpha\right],$$

where m and e are the mass and charge of the electron, τ is the collision time, v_F the Fermi velocity, s_t the velocity of the transverse sound. In this formula we assume the absence of temporal and spatial dispersion, i.e., $\omega\tau(v_F/s_t)^2 \ll 1$. The dimensionless coefficient α is of the order of λ/ε_F, where ε_F is the Fermi energy and λ is of the order of the "deformation potential" λ_{ij}, which determines the dependence of the electron energy in the metal on its deformation

$$\epsilon(\mathbf{p}) = \epsilon_0(\mathbf{p}) + \lambda_{ij}(\mathbf{p})u_{ij}.$$

If we neglect anisotropy, then the coefficient α is given by

$$\alpha = \frac{1}{\epsilon_F v_F^2} \overline{v_x v_z \lambda_{xz}} \,.$$

The superior bar denotes here averaging over the Fermi surface. We note that the Fermi velocity v_F has been introduced into the formula for convenience, and actually does not enter the expression for K_z.

The first term in the expression for K_z is obviously the Stewart-Tolman emf; interest attaches to the second term, which appears at sufficiently large ω.

From Maxwell's equations we obtain the value of the electric and magnetic fields excited by the transverse oscillations. For a traveling wave we have

$$E_z = \frac{m\omega^2 u_z}{e} \; \frac{1 - i\omega\tau (v_F/s_t)^2 \alpha}{1 + ik^2\delta^2}, \qquad B_y = -\frac{c}{s_t} E_z \,,$$

where

$$k = \frac{\omega}{s_t} \,, \quad \delta^2 = \frac{c^2}{4\pi\sigma\omega},$$

δ is the thickness of the skin layer for the frequency ω. For the standing wave, the expression for the amplitude of the electric field remains unchanged, but the phase of the magnetic field is shifted by $\pi/2$ in time and by a quarter-wavelength in space.

Since $(v_F/s_t)^2 \sim m_i/m$ (where m_i is the mass of the lattice ion), the second term in the brackets $\alpha\omega\tau(m_i/m)$ in the expression for the electric field (and accordingly for the magnetic field), under attainable conditions ($\omega \sim 10^6$ sec^{-1} and $u_z \sim 10^{-5}$ cm), for a metal with good conductivity at low temperatures ($\sigma \sim 10^{21}$ sec^{-1}), $\tau \sim 10^{-10}$ sec) will be of the order of unity. We then obtain $E \sim 10^7$ V/cm, $B \sim 10^5$ G, i.e., quantities perfectly accessible to measurement.

The experiment can be performed either with a vibrating plate or with torsional oscillations of a rod, and the fields can be measured at the surface of the sample. Of course, the measurements should be carried out with the generator turned off, for "after-sound." It is necessary to carry out simultaneously measurements of the displacement u_z. In particular, one can use for this the fact that even a small external magnetic field B^0 parallel to the direction of propagation of the wave (our x axis) will produce, by induction, a magnetic field B_z directed along the z axis (parallel to the displacement u_z), in phase with the velocity $\dot{u}_z$ (at $k\delta \ll 1$), and equal in magnitude to $(\Omega_e/\omega)B_y^{ST}$, where $B_y^{ST} = (m\omega^2 u_z/e)(c/s_t)$ - is the Stewart-Tolman field and $\Omega_e = eB^0/mc$ is the electron cyclotron frequency of the external field. It is easy to verify that the y and z components of the external field produce neither a current nor its magnetic field. This induction field B_z could be measured (using a vibrating sample in the form of a parallelepiped, with sides along the axes x, y, and z) in its central face parallel to the xz plane. If we measure the phase difference between this field and the field B_y, then we can obtain immediately the quantity $\omega\tau(v_F/s_t)^2\alpha$ of interest to us.

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The term $m_2\xi\beta^{-1}[1 + m_2\xi)^2]^{-1}$ should be subtracted from expression (9) on p. 224; where reference is made in the article to Eqs. (9) and (11), read (7) and (9), respectively. These errors were made by the authors.