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Abstract

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On Oscillations of the Tunnel Current in a Magnetic Field

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1. As is known, one of the fundamental problems of the physics of metals is the determination of the energy spectrum of conduction electrons. Numerous theoretical and experimental works have been devoted to this question (see, for example, the review ([1]), where a detailed bibliography is given). At present, in order to reconstruct the Fermi surface of electrons in a metal, experimental data are used that relate to the de Haas–van Alphen effect, cyclotron resonance, the anomalous skin effect, ultrasound absorption in metals, and galvanomagnetic phenomena. In this connection, reliable data on the extremal cross sections of the Fermi surface can be obtained from the de Haas–van Alphen effect; extremal values of effective masses, from cyclotron resonance; values of momentum on the Fermi surface, from ultrasound absorption at low temperatures in a magnetic field; and the general topological properties of the Fermi surface, from galvanomagnetic phenomena.

However, as far as we know, there is no such experiment in which it would be possible simultaneously to obtain reliable data on the extremal cross sections and the effective masses corresponding to these same sections. In this connection, difficulties usually arise in reconciling experimental data obtained in studies of cyclotron resonance and of the de Haas–van Alphen effect.

The study of oscillations of the tunnel current in a magnetic field can apparently make it possible to determine simultaneously the values of the extremal cross sections, as well as the values of the effective masses corresponding to these extremal sections.

2. Let us consider the passage of an electric current in a magnetic field through two identical single crystals separated by a sufficiently thin dielectric layer, whose crystallographic axes are oriented in the same way, in the case when a constant potential difference φ is maintained between them. The external magnetic field $\mathbf{H}$ is applied perpendicular to the interface.

The magnitude of the current is then determined by the formula

$$j_z = \frac{e^2 H}{(2\pi\hbar)^2 c} \sum_{n,\sigma} \int dp_z v_z D(p_z)[f_1 - f_2], \tag{1}$$

where $D(p_z)$ is the transmission coefficient of a conduction electron through the potential barrier; n and p_z are the quantum numbers characterizing the state of the electron in the magnetic field; σ is the spin (the z-axis is directed along $\mathbf{H}$); v is the electron velocity;

$$f = \left[e^{\frac{\varepsilon-\zeta}{T}} + 1\right]^{-1}; \qquad \zeta_1 - \zeta_2 = e\varphi.$$

Passing in the usual way ([2]) from summation over n to integration, one can calculate the principal and oscillatory parts of the electric

of the current $j = j_0 + \sum_k j_{\mathrm{os}}(k)$, where

$$j_0 = -\frac{e^2\varphi}{2(2\pi\hbar)^3} \overline{D_\zeta} \int v_z \frac{\partial p_\perp^2}{\partial \varepsilon} dp_z; \tag{2}$$

$$j_{\mathrm{os}}(k) = \sum_j A_j(\zeta) \sin\left[\left(\frac{cS_j(\zeta)}{e\hbar H} - \pi\frac{e\varphi}{\hbar\omega_{Hj}}\right)k + \beta_j\right] \sin\left(\pi\frac{e\varphi}{\hbar\omega_{Hj}}k\right). \tag{2'}$$

The summation in formula (2′) is carried out over all extremal sections of the Fermi surface $S_j(\zeta)$, and

$$A_j(\zeta) = -\frac{e}{2\pi^2\hbar}\left(\frac{eH}{ck}\right)^2 \frac{m_j(\partial v_{zj}/\partial p_z) D_\zeta \Psi(k\lambda_j)}{(dS_j/dE)_\zeta \, |\partial^2 S_j/\partial p_z^2|_\zeta}, \tag{3}$$

$$\beta_j = -\frac{\pi}{2} \pm \frac{\pi}{2} - \pi\gamma k\sigma_{zj} = 0. \tag{3'}$$

The plus sign in formula (3′) corresponds to the case $\partial^2 S_j/\partial p_z^2 < 0$, and the minus sign to $\partial^2 S_j/\partial p_z^2 > 0$; $2\pi m_j = (\partial S/\partial E)_\zeta$ is the effective mass of the electron corresponding to the j-th extremal section; $\Psi(x) = x/\operatorname{sh} x$; $\lambda_j = 2\pi^2 \left(T/\hbar\omega_{Hj}\right)_\zeta$.

As is evident from formula (2), the electric current j oscillates not only when the magnetic field is varied, but also when the potential difference φ between the crystals is varied. The oscillations with respect to H are determined, just as in the de Haas–van Alphen effect, by the extremal sections, while the oscillations with respect to φ are determined by the effective masses of the conduction electrons.

Let us also note that, owing to the factor $\psi(k\lambda_j)$, in magnetic fields of the order of 10^3-10^4 oersted the current oscillations, like the oscillations of the magnetic moment in the de Haas–van Alphen effect, will be observed mainly only for small groups of electrons, to which small effective masses correspond.

Using formulas (2) and (2′), one can estimate the ratio (j_{os}/j_0). If $m_j = 10^{-28}$ g, $H = 10^4$ oersted, $T = 4°$K, $e\varphi = \frac{1}{2}\hbar\omega_{Hj}$, then $(j_{\text{os}}/j_0) = 10^{-6}$.

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CITED LITERATURE

1. A. B. Pippard, *Rep. on Progress in Phys.*, **23**, 176 (1960).
2. I. M. Lifshits, A. M. Kosevich, ZhETF, **29**, 730 (1955).

Note: Figure translations are in progress. See original paper for figures.