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ROLE OF MAGNETIC BREAKDOWN IN GALVANOMAGNETIC PHENOMENA

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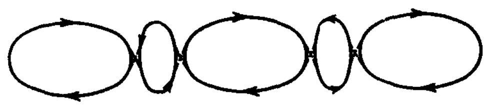
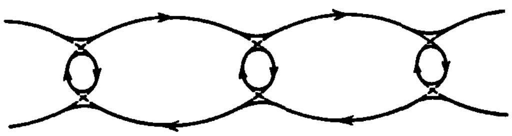
Submitted 17 January 1967
ZhETF Pis'ma 5, No. 8, 269-271 (15 April 1967)

As is well known, magnetic breakdown, occurring in relatively weak fields [1,2], changes the character of electron trajectories in a magnetic field. This circumstance can exert an appreciable influence on the dependence of the components of the electric conductivity tensor on the magnetic field [3,4]. Naturally, the role of magnetic breakdown is most important in those cases when a closed trajectory turns into an open one or vice-versa (see the figure).


a


b

We shall henceforth assume that breakdown results in open trajectories (Fig. a). In the opposite case (Fig. b) it is simply necessary to move from stronger to weaker fields.

In constructing a theory for galvanomagnetic phenomena with allowance for breakdown, Falicov and Sievert [5] started from the following assumptions: 1) The system of electron trajectories is strictly periodic; 2) the breakdown between classical trajectories is described by a probability p - the relation between the phases of the quasiclassical wave functions on neighboring trajectories was not taken into account.

We note that the first assumption is satisfied only for strictly fixed directions of the magnetic field. A slight tilt of the latter changes greatly the character of the trajectories. As to the second assumption, it has applicability limits which were not stipulated by the authors of [5]. Indeed, a connection between the quasiclassical sections of the trajectories denotes that breakdown can result in a certain quantum nonlocalized state, similar to the band state in a crystal lattice [6,7]. In this case, in calculating the galvanomagnetic characteristics it is necessary to start from a new band structure, the parameters of which depend essentially on the breakdown probability and on the relation between the phases of the wave functions on the quasiclassical sections of the trajectories. Estimates show [7] that the conductivity-tensor component perpendicular to the direction of the open section is of the order of $p^2\sigma_0$ (σ_0 - electric conductivity at H = 0), and the corresponding resistance-tensor component increases quadratically with the magnetic field.

The occurrence of a band state is possible if the path traversed by the "new" particle between the collisions is large compared with the dimensions of the individual classical orbit. In our case it means that it is necessary to satisfy the condition

$$v_{gr}\tau \gg r_H, \tag{1}$$

where v_{gr} is the group velocity of the "new" quasiparticle, r_H is the classical orbit radius in a magnetic field, and τ is the free-path time. If $v_{gr} = pv_F$ (v_F is the Fermi velocity), then condition (1) is equivalent to

$$p \gg \gamma = r_H/l \quad (l = v_F\tau). \tag{2}$$

In the opposite limiting case ($p \ll \gamma$), the diffusion approximation is valid: the particle revolves many times on a classical orbit, and rarely jumps over to the neighboring orbit forgetting its prior history (phase averaging takes place). The jump can occur either as a result of breakdown (the probability per unit time is $p\omega_H$, where ω_H is the cyclotron frequency), or the result of an ordinary collision (probability $1/\tau$). Consequently, the effective diffusion coefficient D is $(1/\tau + p\omega_H)r_H^2$. The Einstein relation modified for the case of a degenerate gas yields a mobility $u = D/\epsilon_F$. Consequently the diffusion conductivity is of the order of

$$\sigma_{dif} = ne^2u \approx (p\gamma + \gamma^2)\,\sigma_0. \tag{3}$$

From the derivation of (3) we see that it depends on whether the breakdown results in one or two directions of open sections. In order of magnitude, formula (3) coincides, naturally, with the corresponding formula obtained by Falicov and Sievert [5].

Strictly speaking, the formula obtained is valid only when the ordinary term in the electric conductivity ($\sim\gamma^2\sigma_0$) is the principal one. One can assume, however, that for an arbitrary magnetic-field direction the conditions for the occurrence of a bound quantum state become more stringent, and the diffusion approximation "works" in a wider range (at a larger value of the breakdown probability p than required by inequality (2)). This would signify that: 1) a situation is possible at which the second term in formula (2) would determine the dependence of the electric conductivity on the magnetic field; 2) an additional sharp anisotropy of resistance, due to breakdown, should be observed.

The asymptotic dependence of the resistance on the magnetic field greatly depends, as always, on the magnitude of the off-diagonal element of the tensor σ_{ik}, and is not the same in metals with unequal number of electrons and holes ($n_1 \neq n_2$) as for metals with $n_1 = n_2$ (see [8]).

It should be noted that formula (3) is certainly not applicable to an ideal crystal at zero temperature ($l = \infty$). If there are no real dissipative processes, a stationary state cannot be established in a metal in an external electric field. The asymptotic value of the electric conductivity is determined by the structure of the produced quantum states and by the mean free path. This question calls for further research. It can only be stated that if a current state is produced, then the electric conductivity will increase with increasing mean free path. On the other hand, if the state is currentless, then an increase in the mean free path leads to a decrease in the corresponding component of the electric conductivity (a diffusion situation is realized on the basis of new states, see the derivation of formula (3)).

The authors are grateful to V. G. Peschanskii for acquainting them with his results prior to publication.

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THERMAL PROPERTIES OF ANOMALOUS SUPERCONDUCTORS

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Submitted 20 January 1967
ZhETF Pis'ma 5, No. 8, 271-274 (15 April 1967)

It is well known that the experimental data for different properties of the so-called anomalous superconductors (which include primarily Pb, Hg, Nb, and NbN) are in poor agreement with the theoretical formulas obtained in ordinary superconductivity theory (see [1]). In these superconductors, the electron-phonon interaction is not weak and consequently the ratio $\pi T_k/\theta$ (θ - Debye temperature) is not negligibly small (for example, $\pi T_k/\theta \simeq 0.25$ for Pb).

The ratio $\Delta(o)/T_k$ and other characteristics of anomalous superconductors were calculated in [2] numerically and in [3] analytically on the basis of the Froehlich model, which takes direct account of the interaction of the electrons with the lattice.

We consider here the jump of the specific heat on going from the superconducting to the normal state, and the behavior of the thermal conductivity near T_k for superconductors with strong coupling.

We write the equation for the self-energy part $\Sigma(\omega_n, T)$, describing the pairing of the electrons [4]:

$$\Sigma(\omega_n, T) = \frac{T}{(2\pi)^3} g^2 \sum_{\omega_{n'}} \int d\mathbf{k} \frac{\omega^2}{\omega^2 + (\omega_n - \omega_{n'})^2} \cdot \frac{\Sigma(\omega_{n'}, T)}{\omega_{n'}^2(1+\gamma\Sigma^2/\omega^2)+\xi^2+\Sigma^2(\omega_{n'},T)}, \tag{1}$$

$\omega_n = (2n + 1)\pi T$, ω - phonon energy. The term $\sim\omega_{n'}^2\Sigma^2/\omega^2$ in the denominator of the intergrand (1) is the result of the Σ-dependence of the function $\Sigma_1(\omega_n, T)$ which describes the scattering (we shall not write out the corresponding expression in detail). By regarding the addi-