Galvanomagnetic properties of $Hg_{3-\delta}AsF_6$

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(Submitted 23 June 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **36**, No. 3, 69–72 (5 August 1982)

The dependence of the magnetoresistance as a function of temperature and constant external magnetic field in the entire range of fields up to magnetic breakdown is obtained for $Hg_{3-\delta}AsF_6$ in the electron–phonon interaction model. The results of the theory qualitatively agree with experiment.[1,2] The dependences found for the Hall components of the resistance need to be checked experimentally.

PACS numbers: 72.20.My, 72.80.Jc

The compound $Hg_{3-\delta}AsF_6$ is of great interest because of the uniform nature of its structure and the unusual electric properties associated with it.[1,2] The $Hg_{3-\delta}AsF_6$ crystal consists of AsF_6^-, complexes, which form the basic tetragonal body-centered lattice. Within this lattice there are two families of parallel chains of mercury atoms running (without intersecting) in two mutually perpendicular directions.

The compound $Hg_{3-\delta}AsF_6$ exhibits metallic conductivity. It has been established experimentally[1,2] that the specific resistance ρ in the plane of the chains as a function of temperature T and constant external magnetic field H normal to this plane has the form:

$$\rho(H, T) = \rho_0(H) + \rho_1(T). \qquad (1)$$

The measurements were performed in the temperature range $2\ \text{K} < T < 20\ \text{K}$ and range of fields $0 < H < 180$ kG. It has been established that $\rho_1(T) \sim T^3$, while $\rho_0(H) \to 0$ as $H \to 0$, increases monotonically with increasing H, entering a narrow plateau, beyond which it increases linearly $\rho_0(H) \sim H$ up to the upper boundary of the interval of the measurements.[2]

In this paper, the dependence $\rho(H, T)$ is obtained from a theoretical analysis of a model with electron–phonon interaction and a Fermi surface (see Fig. 1), which qualitatively corresponds to the real crystal $Hg_{3-\delta}AsF_6$.[3–5]

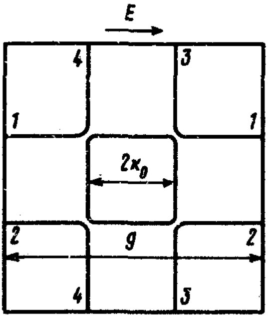

FIG. 1. Cross section of the Fermi surface with the surface parallel to the chains. The cylinder with the smaller base is filled with electrons, while the cylinder with the larger base is filled with "holes."[3]

According to Refs. 2 and 3, the Ψ functions of an electron in mutually perpendicular chains overlap weakly. For this reason,[5] an electron can reach one flat section of the Fermi surface from another, (by being scattered by a phonon) perpendicular to it, only from the region of the "corner" (Fig. 1). It is assumed that a "corner" δ in momentum space is much smaller than the other characteristic dimensions of the Fermi surface, as well as the thermal momentum of the phonon q_T. Thus, ignoring[5] electron diffusion along the Fermi surface in the direction of the field **H** (normal to the plane in Fig. 1), we can write the kinetic equation for an electron in the repeating-band scheme in the form (we shall present it only for the 3-3 plane in Fig. 1):

$$-V\frac{d\phi_3}{dk}+\sum_{n=-\infty}^{+\infty}\Big[\delta(k-k_0-ng)X_3^{+}+a\Lambda(k-k_0-ng)\Big(A_1^{+}-A_3^{+}+\frac{eEv_F}{a}\Big)$$
$$+\delta(k+k_0-ng)X_3^{-}+a\Lambda(k+k_0-ng)\Big(A_2^{+}-A_3^{-}+\frac{eEv_F}{a}\Big)\Big]$$
$$+a\int_{-\infty}^{+\infty}e^{-\lambda|k-k'|}(\phi_3(k')-\phi_3(k))dk=eEv_F\,, \tag{2}$$

where

$$A_i^{\pm}=\int_{-\infty}^{+\infty}e^{-\lambda|\pm k_0-k'|}\phi_i(k')dk'\,;\quad i=1,2,3,4 \tag{3}$$

$$\Lambda(k)=\frac{\delta^2}{2(k^2+\delta^2)}\,. \tag{4}$$

Further,

$$-\phi_i(k)\frac{dn(k)}{d\epsilon}$$

is the nonequilibrium correction to the electron distribution function $n(k)$ on the ith plane of the Fermi surface, $\lambda\sim(q_T)^{-1}$,

$$\frac{a}{\lambda} \sim \frac{1}{\tau_{11}} \sim \frac{T^3}{\Theta_D^2} \tag{5}$$

is the electron–phonon collision frequency at temperatures much lower than the Debye temperature Θ_D, v_F is the Fermi velocity for the electron along the chain, $-e$ is the electron charge,

$$V = \frac{eH}{c} v_F , \tag{6}$$

and c is the speed of light.

The δ functions in (2) take into account the jumps in the function $\phi_i(k)$ as a result of a transition between sections of the Fermi surface which belong to different energy bands.

The terms with $A(k)$ in (2) (missing in Ref. 6) are responsible for electron "hops" beyond the "corner" of the Fermi surface as a result of scattering by a phonon, which is important in weak fields H when $\rho_0(H) < \rho_1(T)$.

Solving the system of equations (2) and (3), we find the components of the conductivity tensor $(4k_0 < g)$:

$$\sigma_{xx} = \frac{2e^2 g_z g v_F}{h^3\left(1 + \frac{V^2\lambda^4}{a^2}\right)^{1/2}} \frac{1}{V}\left[\frac{2}{\theta} + \frac{2g}{1-\exp(g\Theta)} + \frac{\pi\delta a\nu g}{1-\pi\delta a\nu}\right] \tag{7}$$

$$\sigma_{yx} = \frac{2e^2 g_z g v_F}{h^3} \frac{1}{V}\left[(4k_0 - g) - \frac{g}{\left(1 + \frac{V^2\lambda^4}{a^2}\right)^{1/2}} \frac{\operatorname{sh}\left(\frac{4k_0 - g}{2}\theta\right)}{\operatorname{sh}\left(g\frac{\theta}{2}\right)}\right], \tag{8}$$

where

$$\nu = -\frac{1}{V\lambda}; \quad \theta = \left[1 - \left(1 + \frac{V^2\lambda^4}{a^2}\right)^{1/2}\right]\frac{a}{V\lambda},$$

g is the size of the Brillouin band in the plane of Fig. 1, and g_z is its size in a perpendicular direction.

The behavior of the components of the resistance tensor ρ_{xx} and ρ_{xy}, determined from (7) and (8), as functions of H and T, differs qualitatively in the two regions of values of the parameter $\delta g/q_T^2$:

$$\delta g/q_T^2 \ll 1 \tag{9}$$

and

$$\delta g/q_T^2 \gg 1 . \tag{10}$$

In large and intermediate fields, the regions (9) and (10) do not differ

$$\rho_{xx} = \frac{h^3}{2e^2 g_z g v_F} \frac{V}{2g\left(1+\frac{V^2\lambda^4}{a^2}\right)^{1/2}} \frac{1}{\left[\left(1+\frac{V^2\lambda^4}{a^2}\right)^{-1} + \left(\frac{4k_0 - g}{2g}\right)^2\right]}, \quad (11)$$

$$\rho_{xy} = -\frac{h^3}{2e^2 g_z g v_F} \frac{V}{(g-4k_0)} \frac{1}{1+[2g/(4k_0-g)]^2\left(1+\frac{V^2\lambda^4}{a^2}\right)^{-1}} \quad (12)$$

(compare Ref. 6) and the electron wanders along the electron and "hole" orbits, crossing from one to another in q_T neighborhoods of the "corners." It is evident that ρ_{xx} does not depend on T for $V \ll a/\lambda^2$, reaches a plateau[1)] at $V \gtrsim V_0 = a/\lambda^2 \sim T^4$, whose position along the H axis depends on T in accordance with Ref. 1.

In the case (9), in fields

$$V \ll \frac{a}{g\lambda^3}, \quad (13)$$

when the relatively frequently electron–phonon collisions inhibit the twisting of the electron trajectory, instead of (11), we obtain

$$\rho_{xx} = \frac{h^3}{2e^2 g_z g^2 v_F}\left(V + \frac{\pi\delta a}{\lambda}\right), \quad (14)$$

in qualitative agreement with (1).[2)] In the limit $V \to 0$, we find from (7)

$$\text{a) } \rho_{xx} \sim \delta a/\lambda \sim T^3, \qquad \text{b) } \rho_{xx} \sim a/g\lambda^3 \sim T^5 \quad (15)$$

for regions (9) and (10), respectively, (in agreement with Refs. 2 and 5).

For ρ_{xy}, we find

$$\rho_{xy} = -\frac{h^3}{2e^2 g_z g v_F} \frac{V^3\lambda^6(g-4k_0)(g-2k_0)k_0}{12a^2g^2} \sim H^3T^{-10} \quad (16)$$

in the range of fields

$$\frac{\delta a}{\lambda} < V \ll \frac{a}{g\lambda^3}; \quad (17)$$

and

$$\rho_{xy} = -\frac{h^3}{2e^2 g_z g v_F} \frac{V\pi^2\delta^2\lambda^4 k_0(g-2k_0)(g-4k_0)}{12g^2} \sim HT^{-4} \quad (18)$$

for

$$V \ll \frac{\delta a}{\lambda}. \quad (19)$$

The predictions (12), (16), and (18) obtained for the Hall component of the resistance ρ_{xy} must be checked experimentally.

I thank A. A. Abrikosov for formulating the problem and for useful discussions.

[1)]The linear growth $\rho_{xx} \sim H$ in the region beyond the plateau could be related to magnetic breakdown in the vicinity of the "corners" of the Fermi surface[2] and must be examined separately.

[2)]The applicability of (14) and (18) is bounded below by fields $V \sim \delta^2 a$, which is related to the replacement of k by $\pm k_0$ in the exponent in (3). However, it can be shown that the limiting values $\rho_{xx}(V \to 0, T)$ are valid with a relative error $\sim(\delta/q_T) \ll 1$. Experimentally,[2] $\rho_{xx} \sim H^2$ only at $H < 1$ G.

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Translated by M. E. Alferieff
Edited by S. J. Amoretty