Nature of the intensification of a cyclotron resonance in potassium in a normal magnetic field

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The cyclotron-resonance peak which has been observed [G. A. Baraff et al., Phys. Rev. Lett. 22, 590 (1969)] in potassium in a magnetic field directed perpendicular to the surface may be due to an effect of zero-curvature points of the Fermi surface on the cyclotron orbit of effective electrons.

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Recent experimental data [2, 3] have altered the picture of the Fermi surface of potassium as a closed, nearly spherical surface. That picture had been drawn on the basis of an analysis of de Haas-van Alphen oscillations [4]. Coulter and Datars [2] have observed open orbits for several directions of the magnetic field. Jensen and Plummer [8] have discussed photoemission data which imply the existence of small energy gaps in potassium, as in sodium. According to the explanation offered for these results [2, 3, 6], there are charge density waves in the ground state of the conduction electrons in potassium. These waves lead to discontinuities of spherical Fermi surface at several planes.

The observed distortions of the Fermi sphere should be accompanied by the occurrence of transitions from a positive curvature to a negative curvature, i.e., by the presence of points or lines of zero curvature. Such points or lines will lead to characteristic effects in the dispersion and absorption of short-wave sound [7, 8]. They will now be suggested that an intensification of the resonance occurs because zero-curvature points fall on the cyclotron orbit of effective electrons, as predicted in Ref. [9].

In calculating the conductivity $\sigma$ for a resonant circular polarization of an alternating field of frequency $\omega$ under conditions corresponding to the anomalous skin effect, the deviations of the Fermi surface from a spherical shape are important only for the component of the electron velocity which runs normal to the boundary, $v_\psi$. We can accordingly write the conductivity in a normal field as follows [3]:

$$\sigma = \frac{ie^2}{2\pi^3h^2} \int dp_x \int dp_y \int dp_z \frac{mv_\psi^2(p_z)}{w - v_\psi(p_z, \psi)} \approx \frac{e^2}{4\pi^2h^2} q^2 F(1+s),$$

(1)

where $m$ and $v_\psi(p_z)$ are the cyclotron mass and transverse velocity component on a spherical Fermi surface; $w = (\omega - \Omega + i\nu)/q$; $\Omega$ is the cyclotron frequency; $\nu$ is the collision frequency; and $q$ is a wave vector. The integration in (1) is carried out over the momentum projection $p_z$ and over the angle $\psi = \Omega t$ ($t$ is the time of motion along the orbit). The asymptotic behavior of the integral is calculated in the limit $w \to 0$. For a spherical Fermi surface, $v_\psi$ is independent of $\psi$, and we have $s = 0$. The quantity $s$ describes the contribution of a point of zero curvature if it corresponds to effective electrons with $v_\psi(p_z, \psi) = 0$. The minimum of the function $v_\psi(p_z, \psi)$ under the conditions $p_z = p_{z0}$ and $\psi = \psi_0$ would be one possibility for a point of this type. Near it, for small values of $p_z - p_{z0}$, $\psi - \psi_0$, we can write

$$v_\psi(p_z, \psi) = a(p_z - p_{z0})^2 + 2b(p_z - p_{z0})(\psi - \psi_0) + c(\psi - \psi_0)^2; \quad a > 0;$$

$$ac - b^2 > 0.$$

(2)
The corresponding value of \( s \) is
\[
s = \eta (\pi - i \ln w_0/w),
\]
where the parameters \( \eta \) and \( w_0 \) characterize the properties of the Fermi surface near the point of zero curvature. In particular, \( \eta \) is, in order of magnitude, the relative size of the region in which dependence (2) holds. Since the distortions of the Fermi sphere are small, we have \( \eta \ll 1 \); in calculating the surface impedance from (1)–(3) we can therefore expand it in powers of \( \eta \). The resonant increment in which we are interested turns out to be small, in accordance with the experimental results of Ref. [1]. We write, in the linear approximation in \( \eta \), the result calculated for the ratio of the real part of the impedance in a magnetic field, \( R(H) \) to that without the field, \( R(0) \) (this ratio was measured in Ref. [1]):
\[
\frac{R(H)}{R(0)} = 1 - \frac{\eta}{3} \left[ \sqrt{3} \ln \sqrt{\Delta^2 + \gamma^2} + \text{sign} \Delta \arctan \frac{\gamma}{\sqrt{\Delta^2 + \gamma^2}} \right],
\]
where \( \Delta = 1 - H/H_r \), \( H_r \) is the resonant value of the field, and \( \gamma = \nu/\omega \ll 1 \). Expression (4) describes a positive, asymmetric, resonance peak with an abrupt low-field cutoff and a slow decay with distance from the point of the resonance. The peak observed in Ref. [1] has specifically this qualitative shape. A particularly important point is that the height of the peak, which is not explained in the model of a spherical Fermi surface, can be reconciled with (4) at a plausible value of \( \eta \). The scale of the variations and the height of the peak near the resonance (\( |\Delta| \lesssim 0.1 \)) are close to those observed at values of \( \eta \) and \( \gamma \) on the order of \( 10^{-1} \div 10^{-2} \) (Fig. 1).

A resonance may also be caused by the appearance of zero-curvature points of other types. For example, a narrower peak arises in the case in which we have \( ac - b^2 \to 0 \) in Eq. (2). Simulating the function \( v_s(p_z, \psi) \) by the functional dependence \( v_s(p_z, \psi) = a[p_z - p_0(\psi)]^2 \) over a small but nonzero interval of \( \psi \) for this case, we find \( s = \eta \sqrt{w_0/w} \). The \( \Delta \)-dependence factor in the term proportional to \( -\eta \) in Eq. (4) takes the form \( \text{Re} \{1/\sqrt{\Delta + i\gamma}\} + (2 + \sqrt{3}) \ln \{1/\sqrt{\Delta + i\gamma}\} \).

Expression (4) was derived without allowance for the Fermi-liquid interaction or the surface scattering of electrons. These factors may influence the position and intensity of the resonance peak, so this peak may shift slightly and change in shape when these factors are taken into consideration. However, the basic result will remain in force. A cyclotron resonance is amplified in a normal field because of the existence of zero-curvature points.

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