Cyclotron resonance in organic layered conductors

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Abstract

The propagation of electromagnetic and acoustic waves in organic layered conductors with Q2D electron energy spectrum of an arbitrary form in a strong quantizing magnetic field **H** have been considered taking into account the Fermi-liquid correlation of charge carriers.

Key words: layered conductors; electromagnetic and acoustic waves; magnetic field

In a strong magnetic field **H**, when the spacing $\hbar\Omega$ between quantizied energy levels ε_N of charge carriers is much greater than the width $\hbar/\tau$ of the levels, damping of electromagnetic and acoustic waves in conductors is of the resonant character, the resonant values of the magnetic field H_{res} containing the information on the energy spectrum for charge carriers ($\hbar$ is the Planck constant, τ is the free path time of electrons, Ω is the frequency of their rotation in a magnetic field).

In low-dimensional conductors attenuation of the waves is sensitive to the direction of the wave vector **k** as well as to the wave polarization. We consider the resonant absorption of electromagnetic and acoustic waves propagating along the normal to the layers **n** in organic layered conductors having Q2D electron energy spectrum of an arbitrary form. In Q2D conductors charge carriers energy

$$\varepsilon(\mathbf{p}) = \sum_{\infty}^{n=0} \varepsilon_n(p_x, p_y) \cos(\frac{anp_z}{\hbar} + \alpha_n(p_x, p_y)), \qquad (1)$$

$$\alpha_n(-p_x, -p_y)) = -\alpha_n(p_x, p_y))$$

is weakly dependent on the momentum projection $p_z = \mathbf{pn}$, i.e. the maximum value at the Fermi surface $\varepsilon(\mathbf{p}) = \varepsilon_F$ of the function $\varepsilon(\mathbf{p}) - \varepsilon_0 = \eta\varepsilon_F$ is much less than the Fermi energy ε_F (η is the quasi-two-dimensionality parameter). Since the spacing between the layers a is much greater than the distance between atoms within a layer, there are grounds to suppose that the tight bundle approximation is valid for electrons belonging to different layers, and coefficients $\varepsilon_n(p_x, p_y)$ decrease rapidly with increasing n. However, the analysis of galvanomagnetic phenomena in charge transfer complexes on the basis of tetrathiafulvalene salts (in particular, the dependence of the resistance across the layers on the angle θ between the vectors **H** and **n** [**?**,**?**]), proves that in stationary fields agreement of the theory with experiment is possible only when all terms, or at least more than two of them, are taken into account in the expression (1) for the Q2D spectrum.

In the millimeter and submillimeter ranges for the electromagnetic wave frequency ω and in a strong magnetic field a quantum $\hbar\omega$ of electromagnetic field energy is comparable to the spacing between quantized electron energy levels. The resonance correspond to those values of the magnetic fields H_{res} at which the following condition is satisfied

$$\frac{\omega - \Omega_{res}}{\omega} = k^2 l r_H \cos 2\theta. \qquad (2)$$

Here $l = v_F\tau$, $r_H = cp_F/eH$, v_F and p_F are the characteristic Fermi velocity and momentum of charge carriers, $\Omega_{res} = eH_{res}/mc$, e, m are the charge and the

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effective mass of conduction electrons, c is the velocity of light.

For θ different from $\pi/2$, the drift of charge carriers along the wave vector $\mathbf{k}$ leads not only to the shift of resonant frequency due to the Doppler effect, but also to extra broadening of the resonant lines.

$$\frac{H - H_{res}}{H_{res}} = [(kr_H \eta \cos\theta)^2 + (r_H/l)^2]^{1/2} \tag{3}$$

Joint solution of the set of Maxwell equations and quantum kinetic equation for the density matrix makes it possible to obtain the dispersion equation for the wave. In the case of isotropic in the layers-plane dependence of the energy of charge carriers on their momentum, the dispersion equation takes the simple enough form

$$k_{\pm}^2 c^2 g_{\pm}(k) = \omega\omega_p^2 (i + \omega L g_{\pm}(k)) \tag{4}$$

where ω_p is the plasma frequency for electron system, L is the constant of the Fermi-liquid interaction and

$$g_{\pm}(k) = [(k_{\pm} v\eta)^2 + (\frac{1}{\tau} - i\omega \pm \Omega)^2]^{1/2}. \tag{5}$$

Account of the anisotropy in the layers-plane of the charge carriers energy spectrum results in appearance of several resonant lines. This is connected with the presence of multiple harmonics in the time-dependence of the projection of the charge carriers velocity $\mathbf{v}$ on the layers-plane. Because of the dependence of the solution for the dispersion equation upon the Fermi-liquid interaction constant, measurements of the resonant line width and of the shift of the resonant frequency at $kr_H\eta << 1$, enable the intensity of the Fermi-liquid correlation of conduction electrons to be determined.

Of interest is the case when $\theta = \pi/2$ and a considerable part of charge carriers move along open orbits, their velocity in the layers-plane being almost constant. The time-dependence of electron velocity along the normal to the layers has the form

$$v_z(t) = \sum_{n=1}^{\infty} v_z^n \sin(n\Omega_0 t + \alpha_n), \tag{6}$$

where $\Omega_0 = eHav_x/c\hbar$ in the main approximation in the small quasi-two-dimensionality parameter η.

The cyclotron resonance occurs when

$$\omega = n\Omega_0^{extr} \tag{7}$$

and the resonant line width is determined by the charge carriers free path time only.

By studying cyclotron resonance for various orientations of the strong magnetic field we can determine the distribution of charge carriers velocity over the entire Fermi surface.

If the temperature smearing T of the Fermi distribution function is less than the spacing between the energy levels, the cyclotron resonance may also take place in the range of low frequencies. It is possible even at $\omega << \Omega$ when electron transitions with absorption of the quantum $\hbar\omega$ of the wave energy, occur between the states with the same quantum number N. The resonance is most pronounced when an acoustic wave propagates through a Q2D conductor placed in a magnetic field, oriented along the normal to the layers ($\theta = 0$). This is the case when damping of the longitudinally polarized acoustic wave is related only to the renormalization of the electron spectrum in deformed crystal and Joule losses are absent. In a wide range for the sound wave frequency ω the H-dependence of the rate of sound attenuation Γ has the form of giant resonant oscillations. Between the resonant peaks there are regions of high acoustic transparency.

We calculate the rate of sound attenuation Γ of the electron system in the quasiclassical approximation , assuming that η is not very small quantity, i.e $\hbar\Omega/\varepsilon_F << \eta << 1$. In this case electrons with large quantum numbers N make the main contribution to Γ, and one can consider that their energy spectrum is equidistant.

At $kl << \varepsilon_F/\hbar\Omega$ a peak of absorption is connected with a singularity of the electron density of states at the section of the Fermi surface cut by the plane $p_z = const$, whose area has an extremum as a function of p_z. Thus, the extremal area determines the period of resonant oscillations of Γ. The height of the resonant peaks has the form

$$\Gamma^{max} \simeq \Gamma_0 \frac{\hbar\Omega}{(T\varepsilon_F)^{1/2}} \eta^{3/2} kl, \tag{8}$$

and outside the peak the background part of $\Gamma(H)$ is $(\eta\mu/T)^{1/2}$ times smaller than Γ^{max}. Compared to an isotropic metal, attenuation of sound wave in a Q2D conductor is very weak, and a plot of the H-dependence of $\Gamma(H)$ lies much below the analogous curve $\Gamma_M(H)$ for an isotropic metal. For $kl < (\varepsilon_F/T)^{1/2}$ the ratio of the maximum values of sound attenuation rate is

$$\frac{\Gamma^{max}}{\Gamma_M^{max}} \simeq \eta^{3/2}. \tag{9}$$

If the magnetic field is deviated from the normal to the layers, Joule losses are essential, and the rate of sound absorption becomes equal in order of magnitude to the absorption rate of a normal metal with the same density of charge carriers.

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