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Oscillations of the Relaxation Time in Strong Magnetic Fields

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Résumé.— Les oscillations quantiques de la magnetoconductivité et de la force magnetoélectrique sont calculées d'un modèle de bande de conduction parabolique. L'on montre que la contribution principale à ces effets est due aux oscillations du temps de relaxation.

Abstract.— Quantum oscillations of the longitudinal magnetoconductivity and magnetothermopower were calculated for a simple model of solid with parabolic electron band. It is shown that the main contribution originates in oscillations of the relaxation time.

Introduction.— A strong magnetic field applied to the system of electrons causes the quantization of the electron energy spectrum. The quantum effects become particularly important at low temperatures and manifest themselves e.g. in the oscillatory behavior of the magnetic susceptibility and transport coefficients as functions of the magnetic field. The theory predicts that both the density of electron states \( \rho(E_F) \) and the electron mean lifetime \( \tau(E_F) \) at the Fermi energy \( E_F \) will oscillate while changing magnetic field \( /1,2/. \) The density of states give the main contribution to the oscillations of susceptibility. In this communication we shall demonstrate that, at least for a simple model, the oscillations of the longitudinal magnetoconductivity are mainly due to the oscillations in the relaxation time. This effect will even be more pronounced in the longitudinal magnetothermopower \( S \) which is related to the longitudinal conductivity \( \sigma_\parallel \) by the Mott formula

\[
S = eLT \sigma_\parallel \frac{d \sigma_\parallel}{dE_F}, \tag{1}
\]

If the scattering of electrons is elastic, and \( \omega \) \( \gg kT \) holds \( /3/ \) (\( L \) is the Lorenz number, \( \omega = eH/mc \) is the cyclotron frequency).

The Model and Basic Formulae.— Let the electron structure is given by a parabolic dispersion law, and the randomly distributed impurities are described by \( \delta \)-function-like potentials. The scattering of electrons calculated self-consistently leads to the damping of singularities in the density of states and yields the oscillatory self-energy of electrons \( \Sigma \), which is related to the mean lifetime \( \tau \) by expression \( \tau = \Sigma/2\Gamma, \Gamma = -\text{Im} \Sigma \). The longitudinal conductivity was calculated via the Kubo formula and can be written in the well known form

\[
\sigma_\parallel = \frac{e^2}{m} \tau N_{||}, \tag{2}
\]

where the effective number of carriers \( N_{||} \) is given \( /2,4/ \) by relation

\[
N_{||} = -\frac{1}{\pi} \Im \sum \frac{\hbar^2k^2}{m} (1 - \frac{\hbar^2}{2m}) G_\alpha. \tag{3}
\]

Here \( G_\alpha \) denotes the resolvent

\[
G_\alpha = \left( E_F - E_\alpha - \Sigma(E_F) \right)^{-1}; \quad E_\alpha = \omega(\alpha + 1/2) + \frac{\hbar^2k^2}{2m}. \tag{4}
\]

where \( E_\alpha \) is the eigenenergy of electron state \( \alpha \), a substitutes for \( (n,k_x,k_z) \). The effective number \( N_{||} \) becomes close to the number of electrons only in the low field limit \( \omega t << 1 \) and if the Landau-Peierls criterion \( E_F >> \Gamma \) is well satisfied \( /4/ \). Let us also note that for the short-range scattering potential of impurities the relaxation time appearing in \( (2) \) is just equal to the mean lifetime.

Results and Discussion.— In order to analyse semi-quantitatively the behaviour of conductivity, it is useful to separate all quantities of interest into the smooth and oscillatory parts using the Poisson summation formula

\[
\sum_{n=0}^{\infty} f(n) \sim \int f(x) + 2 \sum_{n=1}^{\infty} \left( \int f(x) \cos(2\pi nx) dx \right). \tag{5}
\]

Then we can write \( N_{||} = N_\parallel + N_{osc}, \tau = \tau_\parallel + \tau_{osc} \) and the longitudinal conductivity reads

\[
\sigma_\parallel = \tau_\parallel \left( 1 - \frac{N_{osc}}{N_\parallel} \right) \left( 1 + \frac{\tau_{osc}}{\tau_\parallel} \right), \tag{6}
\]

where smooth \( \tau_\parallel \omega \epsilon^2 \tau_\parallel N_\parallel /m \) is multiplied by two oscillating factors proportional to the relative magnitudes of oscillations in \( N_{||} \) and \( \text{Im} \tau \).

Since \( \tau_{osc}/\tau_\parallel \) is approximately equal to the
The relative oscillation amplitudes of \( \tau_{osc}/\tau_0 \) (full line) and \( N_{osc}/N_0 \) (broken line) as functions of inverse magnetic field.

Though the quantity \( E_F/\hbar \) ranges only from 2 to 7 and the condition \( E_F >> \hbar \) is only approximately valid, the relative changes of \( N_{osc}/N_0 \) do not exceed 10\% those of \( \tau_{osc}/\tau_0 \).

The relative magnitude of oscillations of the longitudinal magnetoconductivity itself is shown on figure 2, together with the derivative with respect to the \( E_F \), which forms the main contribution to the thermopower (1). The very large oscillations, which even change the sign of \( \sigma_{||}' \), can be understood on the basis of intimate relation between the derivatives of \( \sigma_{||} \) with respect to \( E_F \) and with respect to \( 1/B \).

References