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Hydrodynamic effects in electric conductivity of two dimensional metals

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Abstract. The qualitatively new mechanisms of electric conductivity of a hydrodynamic type having no anologs in a three-dimensional case and connected with the specificity of electron-phonon relaxation in two-dimensional systems have been predicted.

Introduction

Recent experimental discovery of a temperature minimum of electric resistivity of a potassium thin samples and anomalies in the temperature behaviour of resistivity in a number of other metals once again drew attention to the role of normal collisions between quasiparticles in electric conductivity [1, 2], and, in particular, to the hydrodynamic relaxation mechanism. In a hydrodynamic situation, frequent normal collisions and scattering on the boundary form the Poiseuille flow of electron gas [3], with the sample resistivity being decreased with increasing temperature. However, in ordinary metals it is extremely difficult to observe this effect alone.

New effects

We have shown that in two-dimensional (layered) metallic systems, qualitatively new mechanisms of the influence of normal collisions on momentum relaxation processes having no anologs in a three-dimensional case can manifest themselves. The region in which the effect of the N-process on electric conductivity can appear is rather broader for two-dimensional systems than for three-dimensional metals. A characteristic property of these mechanisms is close interrelation of specific processes of electron-phonon relaxation in 2D-systems [4] with quasiparticle motion in coordinate space. Below we shall explain the physical nature of the effects proposed (more detailed explanation may be found in [5]).

At the most natural configuration, when conducting layers are parallel to the sample surface, the formation of the electron-phonon mechanism of a hydrodynamic type is connected with taking into account the quasi-two-dimensionality of an electron spectrum leading to electron scattering on the sample surface. Here, as it is in 2D-case, the phonon exchange is possible between electron states with opposite momenta which, however, turn out to be nonequivalent owing to spatial inhomogeneity of the problem. As a result, diffusion of a nonequilibrium momentum appears in the coordinate space with the step time $\sim l_{ep}/v$ and step length $\sim \gamma l_{ep}$ ($l_{ep} \propto T^{-5}$ is the ordinary mean free path with respect to normal electron-phonon collisions, v is the Fermi velocity, $\gamma \ll 1$ is the characteristic angle of the Fermi surface deviation from a cylindrical form). The temperature dependence of resistivity is of anomalous character: $d\rho/dT < 0$.

On the other hand, if an electron spectrum is sufficiently close to a two-dimensional one, a mechanism connected with spatial phonon diffusion is to be taken into consideration. Phonons can provide transfer of a momentum between layers and its escape to the boundary. A phonon reaches the boundary as a result of random roaming caused by collisions with electrons. The total path to approach the surface is $\sim d^2/l_{pe}$ ($l_{pe} \propto T^{-1}$ is the phonon-electron m.f.p.). Correspondingly, for the electron system this mechanism leads to the effective relaxation time $\sim d^2 l_{ep}/l_{pe}^2 v$. It is interesting that in the present case $d\rho/dT > 0$, though with increasing temperature the phonon path to the boundary is elongated, but this hydrodynamic effect is suppressed by more rapid growth of phonons number.

The estimations show that the conditions of the experimental realization of the effects predicted are considerably easier than both the Poiseuille flow of electrons in the three-dimensional case and volume two-dimensional effects.

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