ON THERMOMAGNETIC EFFECTS IN SUPERCONDUCTORS

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It is shown that the Righi-Leduc coefficient does not change when a metal changes from the normal to the superconducting state.

WE shall write down a transport equation for the distribution function for the electronic excitations to study thermomagnetic effects in superconductors.

Changing in the Hamiltonian for a system of electrons in a magnetic field from the second-quantization amplitudes to the amplitudes of the electronic excitations, following Bogolyubov,[1] we find an expression for the Lorentz force acting upon an excitation

$$F = \frac{e}{c}\,[\mathbf{v}\times\mathbf{H}]\,\frac{\xi}{|\xi|},$$

where

$$\mathbf{v} = \partial\varepsilon/\partial\mathbf{p}, \qquad \varepsilon = \sqrt{\xi^2+\Delta^2}, \qquad \xi = (p^2 - p_0^2)/2m$$

(ξ is the energy of an electron in the normal metal calculated from the Fermi surface, and Δ is the gap in the energy spectrum). The transport equation for electronic excitations, when there is a temperature gradient along the x axis and a magnetic field perpendicular to the thermal current, is then of the form

$$-\frac{\partial f}{\partial\varepsilon}\frac{\varepsilon}{T}v_x\frac{\partial T}{\partial x} + \frac{eH}{c}\left(v_y\frac{\partial f}{\partial p_x} - v_x\frac{\partial f}{\partial p_y}\right)\frac{\xi}{|\xi|} = -\frac{f-f_0}{\tau}. \qquad (1)$$

It was shown in reference 2 that the relaxation time τ is equal to $\tau = \tau_0\epsilon/|\xi|$, where τ_0 is the relaxation time for the normal electrons. We assume that either the dimensions of the solid are less than the penetration depth, or that $\partial H/\partial z = 0$ [in the latter case one must average Eq. (3) given in the following over z].

Solving Eq. (1) by the method of successive approximations ($f = f_0 + f^{(1)} + f^{(2)}$ we find the additional terms in the distribution function which are caused by the presence of the temperature gradient and the magnetic field:

$$f^{(1)} = \frac{p_x}{m}\tau_0\frac{\partial f_0}{\partial\varepsilon}\frac{\varepsilon}{T}\frac{\partial T}{\partial x}\frac{\xi}{|\xi|}, \qquad f^{(2)} = \tau_0^2\frac{1}{T}\frac{eH}{cm}\frac{\partial T}{\partial x}\frac{\varepsilon^2}{|\xi|}\frac{\partial f_0}{\partial\varepsilon}v_y,$$

$$f_0 = (e^{\varepsilon/kT}+1)^{-1}. \qquad (2)$$

The magnitude of the Righi-Leduc effect, which is well known to be the appearance of a temperature gradient perpendicular to the direction of the resulting heat current, is determined by the coefficient

$$L = \frac{\partial T}{\partial y'}\Big/\frac{\partial T}{\partial x'}H$$

(the x′ axis coincides with the direction of the resulting heat current). One can show easily that $L = Q_y/Q_x H$, where

$$Q_x = 2h^{-3}\int\varepsilon v_x f^{(1)}\,d\mathbf{p}; \quad Q_y = 2h^{-3}\int\varepsilon v_y f^{(2)}\,d\mathbf{p}.$$

From (2) we find

$$Q_y = 2h^{-3}\tau_0^2\frac{1}{T}\frac{eH}{mc}\frac{\partial T}{\partial x}\int\frac{\varepsilon^3}{|\xi|}\frac{\partial f_0}{\partial\varepsilon}v_y^2\,d\mathbf{p},$$

$$Q_x = 2h^{-3}\tau_0\frac{1}{T}\frac{\partial T}{\partial x}\int\frac{\varepsilon^3}{|\xi|}\frac{\partial f_0}{\partial\varepsilon}v_x^2\,d\mathbf{p}.$$

We have thus

$$Q_y/Q_x = \tau_0 eH/mc. \qquad (3)$$

This relation is independent of the magnitude Δ of the gap. The magnitude of the Righi-Leduc coefficient is thus not changed when the metal changes from the normal to the superconducting state and is equal to $L = \tau_0 e/mc$.

The Nernst-Ettingshausen effect which is the occurrence of an electric field perpendicular to the direction of the resulting heat current is clearly absent in the case of superconductors.

[1] N. N. Bogolyubov, JETP **34**, 58 (1958), Soviet Phys. JETP **7**, 41 (1958).

[2] B. T. Geĭlikman, JETP **34**, 1042 (1958), Soviet Phys. JETP **7**, 721 (1958).

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