Effect of magnetic field on the paraconductivity of superconductors

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It is shown that the magnetic field decreases the paraconductivity in the Gaussian region of fluctuations of the order parameter and intensifies the paraconductivity in the critical region near the transition temperature $T_c(H)$.

Aslamazov and Larkin[1] calculated the dissipative contribution of the order-parameter fluctuations to the conductivity of a superconductor near the transition temperature $t = (T - T_c/T_c) > 0$. They showed that the fluctuation correction to the conductivity—the paraconductivity—increases in proportion to $t^{d/2-2}$ as T_c is approached (d is the dimensionality of the transition). Since the superconducting Fermi liquid is charged, it should have a strong effect on the fluctuations of the magnetic-field parameters which are being measured.[2]

We will generalize the result obtained by Aslamazov and Larkin,[1] taking into account the external magnetic field $\mathbf{H}$ and the anisotropy $m_{\alpha\beta}$. We will make use of the method of calculating the paraconductivity proposed by Abrikosov[3] in his book.

In high-T_c superconductors the temperature interval in which the fluctuations are felt is much broader than that in low-temperature superconductors, and it is useful to identify the critical region and the regions in which the Gaussian approximation can be used.[4]

In the first case the functional $\Gamma\Lambda$ in the approximation quadratic in the order parameter ψ, in a coordinate system associated with the major axes of the tensor m, is given by

$$\Omega = \int dV \psi^* [\alpha t + \frac{1}{4m_i}(p_i - \frac{2e}{c}A_i)^2]\psi, \tag{1}$$

where $\mathbf{H} = \text{curl } \mathbf{A} = (00H)$.

Transforming to a representation of the order parameter in terms of the eigenfunctions of the operator in (1), $|q\rangle = |np_2p_3\rangle$, we write the following expression for the fluctuating probability:

$$w \sim \exp\{-T^{-1}\sum_q [\alpha t_H + \epsilon_q]|\psi_q|^2\}. \tag{2}$$

Here

$$\epsilon_q = \frac{p_3^2}{4m_3} + \frac{eH}{m_\perp c} n, \quad m_\perp = (m_1 m_2)^{1/2},$$

$$t_H = \frac{T - T_c(H)}{T_c} = t + \frac{eH}{2m_\perp c\alpha}. \qquad (3)$$

The mean-square fluctuation of the order parameter, calculated with allowance for distribution (2), is

$$\langle |\psi_q|^2 \rangle = T(\alpha t_H + \epsilon_q)^{-1}. \qquad (4)$$

A dissipative current appears in an electric field $(00E)$. The generalized equation for ΓΛ [Eq. (19.49) in Ref. 3] in external uniform fields E and H is

$$2\gamma eE \frac{\partial}{\partial p_3} \psi_q + (\alpha t_H + \epsilon_q)\psi_q = 0. \qquad (5)$$

Solving Eq. (5) in an approximation linear in E and calculating the average current j_3, we find the following expression for the longitudinal conductivity:

$$\sigma_{33} = \frac{\gamma e^2 T}{m_3} \sum_q (\alpha t_H + \epsilon_q)^{-2} = \frac{\gamma T e^3 H}{2\pi m_3^{1/2} c} \sum_{n=0} (\alpha t_H + \frac{eH}{m_\perp c} n)^{-3/2}. \qquad (6)$$

In the fields (at temperatures) $eH/m_\perp c < \alpha t_H$ the sum can be estimated from Poisson's formula

$$\sigma_{33} \approx \frac{\gamma T m_\perp e^2}{\pi m_3^{1/2} c(\alpha t)^{1/2}} - \frac{T\gamma e^4 H^2}{32\pi(m_1 m_2 m_3)^{1/2} c^2 (\alpha t)^{5/2}}. \qquad (7)$$

If the inverse inequality holds, $eH/m_\perp c > \alpha t_H$, the sum can be estimated by using only the term $n = 0$.

$$\sigma_{33} \approx \frac{\gamma T e^3 H}{2\pi m_3^{1/2} c(\alpha t_H)^{3/2}}; \qquad (8)$$

i.e., the magnetic field suppresses the paraconductivity in the Gaussian region.

In the immediate vicinity of the transition temperature $T_c(H)$ (see below) the Gaussian approximation, which assumes $t_H > t_{Gi}$, is inapplicable. In the critical region one should use the generalized functional ΓΛ with parameters which depend on t in a power-law manner.[4] In the approximation quadratic in ψ the coefficient α in (1) should be replaced with $\alpha t^{1/3}$ (Ref. 4). As a result, the transition temperture in a magnetic field [which is the second critical field $H_{c2}(T)$] is redefined

$$t_H^{4/3} = t^{4/3} + \frac{eH}{2m_\perp c\alpha}, \qquad (9)$$

and αt_H in Eq. (6) is replaced with $\alpha t_H^{4/3}$, resulting in an obvious change in expression

(7) and (8) in the critical region $t_H < t_{Gi}$. In the latter case the paraconductivity intensifies near the transition: $\sigma_{33} \sim t_H^{-2}$.

We have assumed above that the transverse dimensions of the conductor exceed its magnetic length, $(c/eH)^{1/3}$.

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[3]A. A. Abrikosov, *Foundations of the Theory of Metals*, Nauka, Moscow, 1987, p. 520.

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