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ON NON LINEAR EXTERNAL FIELD EFFECTS IN QUASI-SUPERCONDUCTING FILMS

G. PARISI[☆]*Laboratori Nazionali del C.N.E.N., Frascati, Italy*

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Using an improved Hartree-Fock approximation on the Landau Ginzburg equation we compute the extra conductivity for quasi-superconducting thin films near the phase transition in the non linear region.

A large part of our theoretical understanding of superconductivity is due to the fact that the linearized Landau Ginzburg theory holds also very near to the phase transition [1]. However the situation in thin superconducting films is dramatically different: because of the onset of very important fluctuations, heavy deviations from this simple minded theory are already seen at $T - T_c \sim 10^{-2} \text{K}$ [2].

Marcelia [3] has shown that the insertion of the fluctuation term in the Hartree-Fock approximation is sufficient to explain the measurement of the zero current extra conductivity within the Landau Ginzburg theory. A critical test of the validity of this approximation may be done in the high current region where non linear effects show up [4, 5]. Deviations from linearity in the $I-V$ plot at fixed temperature may be computed by use of Marcelia's approximation on the time dependent Landau Ginzburg equation, treating it then exactly, without resorting to external field perturbation expansion.

The final formulae do not show a very simple analytic form, but some qualitative properties are easily detected: at low electric fields the extra conductivity $\sigma_0(T)$ is independent from the field and proportional to $\exp\{(T_c^* - T)/T\}$. If the current exceeds some critical value $I_c(T) \propto [\sigma_0(T)]^{1/2}$ the extraconductivity decreases by increasing field. The range of the linear approximation may be very small.

We start from a generalized Langevin equation for the order parameter [5]

$$\left\{ \tau \frac{\partial}{\partial \tau} - \frac{\hbar^2 (\nabla - 2ieA)^2}{2m} + a(T - T_c^*) + b \langle |\psi|^2 \rangle \right\} \psi(x, t) = f(x, t) \quad (1)$$

where $f(x, t)$ is a random force with stochastic autocorrelation.

We introduce an electric field using a time dependent vector potential. Looking for quasi stationary solutions, one finds that the order parameter correlation function $G(X, M, E) \equiv \langle \psi^+(x) \psi(0) \rangle$ satisfies asymptotically a simple differential equation [5], whose solutions depend on the electric field E and on the parameter $M = a(T - T_c^*) + b \langle |\psi|^2 \rangle$. The self consistency condition $M = a(T - T_c^*) + bG(0, M, E)$, which M must satisfy, allows us to compute it as function of the electric field and of the temperature. One thus obtains the following explicit results:

$$M = a(T - T_c^*) + \frac{bkTm}{2\pi d \hbar^2} \int_{Q^2 2m/\hbar^2}^{\infty} \frac{d\lambda}{\lambda} \exp[-\lambda M - \lambda^3 A E^2] \quad (2)$$

$$J = \frac{ae^2 TE}{16hd} \int_{Q^2 2m/\hbar^2}^{\infty} d\lambda \exp[-\lambda M - \lambda^3 A E^2]; \quad A = \frac{7\pi^2 e^2 \hbar^2}{6.144 m K^2}$$

where d is the film thickness and Q is a small parameter of the dimension of length, which forbids an unphysical increasing of the correlation function at very small distances and avoids the appearance of spurious ultraviolet

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divergences.

Letting the solution of the first equation into the second we find the current as function of the temperature and of the external electric field. The old results by Marcelia are recovered by taking only the first term in E . For sufficient high $T - T_c^*$ the $b\langle|\psi|^2\rangle$ term is negligible in the self consistency condition and the expression for the current becomes the one previously found by Schmid. [5].

These formulae do not predict the appearance of persistent currents [6]: therefore they cannot be valid below the transition. One expects different mechanisms to operate in this region. However their validity, at least in the region where the zero current resistivity theory by Marcelia works, is sound.

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