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G. Parisi: ON THE MEAN LIFE ON PERSISTENT CURRENT
IN TWO DIMENSIONAL SUPERCONDUCTOR.

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ABSTRACT. -

Using an approximated form of the time dependent Landau Ginsburg equation we find that in a two dimensional system quasi persistent current are present, their mean life being exponentially large.

It is well known that rigorous theorems⁽¹⁾ state that in a two dimensional system the onset of very large fluctuations prevents the appearance of a second order phase transition characterized by long range order. These theorems imply that really persistent currents cannot be present in a two dimensional superconductor; however persistent currents have been observed in a two dimensional clean Al films: their mean life was greater than ten hours and compatible with infinity⁽²⁾.

In order to understand how no contradictions arise among the experimental and the theoretical results, we study the approach to equilibrium using a time dependent Landau Ginsburg equation⁽³⁾, where we take care of the effect of fluctuation in some approximated way^(4, 5). In this model we found as expected that in the infinite time limit the mean value of the order parameter $\langle \psi \rangle$ is zero; however, if at some time long range order is present, $\langle \psi \rangle$ decays with a mean life which is exponentially increasing with decreasing the temperature.

For typical films used in (3) the theoretical mean life increases of a factor ~ 10 each milliKelvin.

We start from the following form of the time dependent Landau Ginsburg for the order parameter:

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

2.

The function $f(x,t)$ is a random force with stochastic autocorrelation, eq.(1) has the form of a Langevin equation.

The quantity $\langle |\psi(t)|^2 \rangle$ can be written as

$$(2) \quad \langle |\psi|^2 \rangle = \frac{1}{2\pi} \int_{p^2 < \frac{1}{Q^2}} d^2 p G(p, t)$$

where $G(p, t)$ is the Fourier transform of the order parameter correlation function $G(x, t) = \langle \psi(x, t), \psi(0, t) \rangle$ and Q is an ultraviolet cutoff, having the dimension of a length.

Using standard methods⁽³⁾ one finds that, if the mean value of the order parameter is different from zero in the infinite time limit, in the same limit a $1/p^2$ singularity must be present in the propagator; the integral in (2) is not convergent: an asymptotically different from zero mean value of the order parameter is thus not consistent.

If we suppose that at the initial time the mean value of the order parameter is different from zero and we study the time evolution of the system, we find that at very large time the correlation function has the form:

$$\frac{1}{p^2} \left\{ 1 - \exp \left[- \frac{\hbar^2 p^2}{2m\tau} t \right] \right\}$$

Substituting in (2) one obtains:

$$(3) \quad \langle |\psi|^2 \rangle = \frac{bKTm}{2\pi d\hbar^2} \lg \frac{t\hbar^2}{2m\tau Q^2}$$

This quantity is really divergent for $t = \infty$ but may be relatively small also after times that are very large on the human scale. The time evolution of the order parameter turns out to be approximately

$$\langle \psi \rangle = \left[\frac{a}{b} (T_c - T^x) - \frac{KTm}{2\pi d} \lg \left(\frac{t\hbar^2}{2m\tau Q^2} \right) \right]$$

the mean life being equal to

$$\frac{2m\tau Q^2}{2} \exp \left\{ \frac{2\pi a\hbar^2}{bKTm} d (T_c - T^x) \right\} .$$

The conclusions are that the system has a simple Landau Ginsburg behaviour for finite time; the only effect of the fluctuations being a shift in the transition temperature⁽⁶⁾.

Although more theoretical and experimental work should be done to understand in all the details the behaviour of a system whose relaxation time may go to infinity, we believe that we have identified a possible mechanism which account for persistent currents in superconducting thin films: all "no-go" theorems are based on a mild logarithmical divergence of an integral and this is a mathematical and not a physical infinity. Rigorous theorems can be applied only in exact equilibrium situations and they are of no practical interest if the relaxation time may go to infinity.

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