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ON FLUCTUATION-INDUCED DIAMAGNETISM OF A SUPERCONDUCTIVE GLASS

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1. Introduction

Recent data for high-T_c (HTS) oxides indicate that superconducting fluctuations are strong at temperatures in the vicinity of T_c and above (see,e.g.,[1] and references therein). Moreover, these fluctuations were also observable as a diamagnetic (DM) contribution to the magnetic susceptibility above T_c [2,3]. Usually, in order to compare the experimental data with theory, the Lawrence-Doniach model [4] for a layered superconductor is elaborated. Gerhardts [5] was the first who proposed an advanced theory concerning the behaviour of the DM fluctuations in a system of Josephson-coupled layers. On the other hand, one observes constant growth of evidences in favour of a superconductive glass (SG) behaviour in HTS. In the frame of the SG model (see, e.g.,[6-10]), rather a successful description of both equilibrium (magnetic phase boundary $T_c(H)$ [6,7,9]) and nonequilibrium (long-time relaxation of remanent magnetization [6,8,9], critical neutron scattering by diamagnetic correlations [10]) properties of HTS has been achieved.

In this Letter we consider, via the SG model, fluctuation-induced diamagnetism of weak-links-containing systems.

2. Model of the Superconductive Glass

As is well known [7] the Hamiltonian of the SG model in the pseudospin representation has a form

$$\hat{H} = -\mathrm{Re} \sum_{ij} J_{ij} S_i^* S_j , \tag{1}$$

where

$$J_{ij} = J(T)\exp(iA_{ij}), \; S_i = \exp(if_i),$$

$$A_{ij} = \pi H(x_i+x_j)(y_i-y_j)/\phi_o, \quad \phi_o = hc/2e. \tag{2}$$

The model (1) describes the interaction between superconductive clusters (with phases f_i) via Josephson junctions (with an energy $J(T)$) on a 2-D disordered lattice (with cluster coordinates $r_i = (x_i, y_i, 0)$) in a frustrated external magnetic field $H = (0,0,H)$.So,as usual, we have neglected the shielding current effects. The field is normal to the ab-plane where a glass-like picture of HTS is established.

According to the fluctuation-dissipation theorem (see, e.g.,[12]), we calculate the enhancement of FID parallel to the c-axis (on a square lattice with side d) within the SG model by the Kubo formula :

$$\chi_{\parallel}(\omega) = \int_0^{\infty} dt \cos(\omega t) \sum_q \overline{<\mu_q(t)\mu_{-q}(0)>}/k_B T \tag{3}$$

Here, μ_q is the Fourier transform of the Josephson current density j_{ij} induced DM moment [10]:

$$\mu_q = N^{-1} \sum_{ik} e^{iq(r_i - r_k)} \mu_{ik} \quad , \mu_{ik} = j_{ik}(x_i y_k - x_k y_i)/2c \ , \tag{4}$$

$$j_{ij} = j_c \sin(f_i - f_j - A_{ij}) \ , \ j_c = 2eJ(T)/\hbar d \ . \tag{5}$$

The bar denotes the configurational averaging with a Gauss-like distribution function over cluster coordinates (x_i, y_j) [7]. Since it is the long-time behaviour of the correlator (3), which completely define glassy properties of the SG model and observable experimental peculiarities, in what follows we restrict ourselves to a low-frequency ($\omega \to 0$) behaviour of FID.

By using the mode-coupling approximation scheme (see e.g.[12]) in the critical region near the transition to the SG phase (when $\varepsilon \ll 1$, $\varepsilon = (T-T_C)/T_C$) we have [8,10] :

$$\chi_{\parallel}(p,H) = -\chi(H)g(p) \ , \tag{6}$$

where

$$\chi(H) = \chi(0)/(1+H^2/H_0^2)^3, \quad \chi(0) = \pi s p_0^4 J^2(T)/2k_B T\phi_0^2 d \ ,$$

$$g(p) = [2p-2p^2+3p^3+p^4+4p^4e^p Ei(-p)+p^5e^p Ei(-p)]/6p^4 \ . \qquad (7)$$

Here $p = p_0\varepsilon$, $p_0 = s/\xi_0^2$, $H_0 = \phi_0/2s$, s is the projected area of superconductive loops with a uniform phase, ξ_0 is the coherence length perpendicular to the c-axis, $Ei(-p)$ is an integral exponential function.

3. Discussion

Let us consider two limiting cases of eq.(6). When $p \gg 1$ ($s \gg \xi^2$), i.e. well above T_c, eq.(6) reduces to the two-dimensional Aslamazov-Larkin-like law [1] :

$$\chi_\parallel/\chi(0) \sim -(1/3)s^4/p_0\varepsilon \ . \qquad (8)$$

In the opposite case, when $p \ll 1$ ($s \ll \xi^2$), i.e. in the region near T_c, $\chi_\parallel$ approaches the three-dimensional form of the XY-like model (cf.[13], where a similar law for an excess conductivity $\sigma_\perp \sim \varepsilon^{-2.8}$ for HTS ceramics was registered) :

$$\chi_\parallel/\chi(0) \sim -(1/6)s^4/p_0^3\varepsilon^3 - (1/3)s^4\ln(p_0\varepsilon) \ . \qquad (9)$$

Thus, we have the following picture. The closer the temperature to T_c, the more important become effects due to the granularity of the system. It seems to us that an experimental observation of such a crossover between two- and three-dimensional laws of FID would be oné more evidence in favour of glassy behaviour of the HTS.

To compare the model predictions with the experimental data for HTS, it is interesting to consider a magnetic field dependence of FID (6). Figure 1 shows the behaviour of reduced FID $-\chi_\parallel(H)/\chi(0)$ versus reduced magnetic field $h = H/H_0$ for various temperatures above T_c (in reduced units $t = T/T_c(0)$). It is seen that susceptibility decreases with increasing temperature t in qualitative agreement with the experimental data (see e.g.[2-4]).

In conclusion, fluctuation-induced diamagnetism (FID) of a superconductive glass (SG) was considered. It was found that samples with weak links should show a crossover between two- and three-dimensional behaviours of FID, similar to that

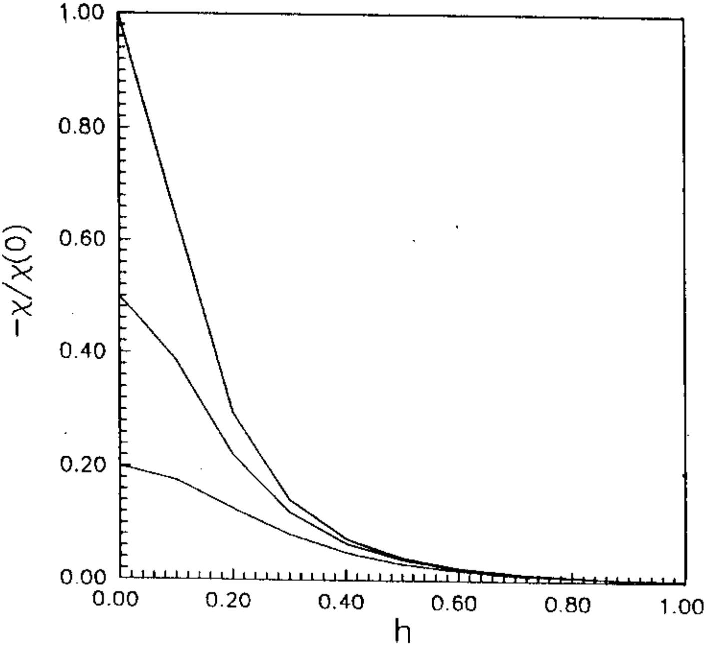

Fig.1: The behaviour of reduced susceptibility $-\chi_{\parallel}/\chi(0)$ versus reduced magnetic field $h=H/H_0$ at reduced temperature $t=T/T_c(0)$ (up to down: $t=1.01;1.02;1.05$).

(but not the same) discussed for layered superconductors [4,5].

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