PSEUDOGAP REGIME IN HIGH $T_c$-CUPRATES AS A MANIFESTATION OF A DYNAMICAL PHASE SEPARATION

L.P. Gor'kov (NHMFL); G.B. Teitel’baum (Zavoiskii Inst., Kazan, Russia)

Introduction

The popular view is that the pseudogap state in cuprates arises as a crossover in the density of states. We investigated an alternative view taking into account an inherent tendency of high-$T_c$ materials to the phase separation [1] now confirmed by numerous experimental data. Analyzing existing NMR data we have shown[2] that the pseudogap behavior of the nuclear spin relaxation for cuprates may be considered as a manifestation of the frustrated phase separation to the “metallic” (holes enriched) and “AF” (holes depleted) regions. The temperature variation of the relative volumes of the coexisting phases having different fluctuation rates would result in the transfer of the fluctuation spectral weight away from the NMR resonance frequency to be seen as a pseudogap suppression of the relaxation rate.

While at high enough temperatures itinerant holes and Cu $d^9$ spins form a homogeneous phase, at a certain temperature $T^*(x)$ the first order transition takes place and the frustrated phase separation to the $x=0$ and to the finite $x$ phases starts. (For interacting holes rigidly localized on Cu’s in the CuO$_2$ plane the lattice “liquid-gas” transition at some $T^*$ is known from the exact solution of the 2D Ising-problem). Taking hole-doped La$_{1-x}$Sr$_x$CuO$_4$, for the sake of argument, missing (with respect to the Sr ionicity) holes’ density in the AF area must be recompensed by local metallic inclusions or droplets with higher hole’s content. Tiny structure of sub-phases caused by charge neutrality condition leads to strong fluctuations in islands’ sizes and positions [1]. Phase boundaries move rapidly, inducing the strong hyperfine field fluctuations (note that a Cu-site merely looses spin when a “metallic” regions crosses over the position of that $^{63}$Cu nuclear spin).

Experimentally one sees only one nuclear resonance frequency, this provides an evidence in favor of the dynamical picture. We discuss only $1/\tau_1$ behavior because for cuprates spin fluctuations on Cu-site prevail over the Korringa mechanisms.

Results and discussion

After the careful analysis of the existing experimental data for the nuclear spin relaxation in different materials we have found that after an appropriate vertical offset all $1/\tau_1$ curves collapse onto the same $T$ dependence above their $T_c$ and below 300K[2,3]. In this temperature region the nuclear spin relaxation is a sum from two parallel processes:

$$ 1/\tau_1 = 1/\tau_{11}(x) + 1/\tau_1(T). $$

Here $1/\tau_{11}(x) > 0$ depends only on temperature and degree of disorder, while $1/\tau_1(T)$ depends only on temperature and is very near to the $1/\tau_1$ dependence for the two chains’ material YBCO 124 above its $T_c=62K$. Since for all materials with non-zero $1/\tau_1(x)$ incommensurate (IC) magnetic peaks at $x=\pm \delta$, and $x=\pm \delta$ were observed at neutron scattering, we conjectured $1/\tau_1(x)$ be related with these IC peaks ($\delta$ is the IC splitting parameter). For La$_{1.86}$Sr$_{0.14}$CuO$_4$ the detailed experimental data available [4] that provide the correct estimate for the offset $1/\tau_1(x)$.

As for $1/\tau_1(T)$, we ascribe its temperature dependence to the crossover from the local regime to the dynamical one, when the hyperfine field fluctuates due to the fast variations in the configuration of the $d^9$ holes surrounding the copper nuclei. In the first case the relaxation is determined by the spin susceptibility, and in the second one by the probability to have the AF hyperfine field at the given nuclei.

To summarize, the nuclear spin relaxation for a broad class of cuprates is due to two independent mechanisms: relaxation on the "stripe"-like excitations and an "universal" temperature dependent term. IC "stripes" always come about with external doping and may be pinned by structural defects. The whole pattern fits well the notion of the dynamical phase separation into coexisting metallic and IC magnetic phases. Among the most recent our results is the reconstruction of the 1$^{st}$ order phase transition line, $T^*(x)$, that agrees well with the phase diagram for LSCO in the $(x,T)$-plane measured by other means.

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References