Disorder-Induced Static Antiferromagnetism in Cuprate Superconductors

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Introduction
There is much evidence to suggest that the cuprate high temperature superconductors are unusual because of their proximity to a magnetic state. In the past several years, several kinds of experimental probes have reported seeing long-range antiferromagnetic order in the superconducting state at low temperatures in the material La\(_{1-x}\)Sr\(_x\)CuO\(_4\). One well-known neutron study [1] which observed field observed order also noted a residual staggered magnetic signal in an underdoped sample in zero field. This effect does not occur in the cleaner cuprate materials like YBa\(_2\)Cu\(_3\)O\(_7\). We proposed that each impurity induces a small magnetic droplet around itself, and that quasi-long range magnetic order occurs when these bubbles overlap. To test this hypothesis, we performed simulations of a d-wave superconductor in the presence of local Coulomb interactions and nonmagnetic disorder.

Results and Discussion
This problem was studied by solving the Bogoliubov-de Gennes equations for a d-wave superconductor including a Hartree treatment of the Hubbard interaction, known to produce a good description of impurity-induced magnetism in NMR experiments in Zn-substituted YBCO[2]. We modeled dopant Sr impurities in LSCO with weak potentials. A schematic of results is shown in Fig. 1a. Magnetic droplets created around individual nonmagnetic impurities in the correlated system interact via an effective collective exchange, which may be understood by the need to maintain Neel coherence among the different droplets. In 1b, a typical magnetization map of the disordered superconductor is shown for \(U=3.2t\), and in 1c) the Fourier transform of \(m(r)\) yields the structure factor \(S(q)\), compared to the same quantity measured in the Lake et al. experiment (1d).

![Figure 1](image)

The effect of such static magnetism on scattering by quasiparticles was also studied[3], where it was found that universal transport coefficients such as that predicted for thermal conductivity are strongly suppressed by magnetic scattering of this type. This explains several recent experiments on underdoped cuprates where strong deviations from the expected universal value were seen, and suggests that the conclusion of large gap slopes near the d-wave node deduced from these results is incorrect.

Conclusions
This work strongly suggests that the physics of underdoped, intrinsically doped cuprates is dominated by magnetic fluctuations pinned by dopant disorder. Such tendencies are strongly enhanced in both the superconducting and pseudogap states due to incipient bound state formation around nonmagnetic impurities.

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References