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SUPERCONDUCTIVITY OF THE MIXED s and d-TYPE SYMMETRY IN THE t-J MODEL

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Abstract. Mean-field studies of the t-J model show that doping of holes suppresses an antiferromagnetic ordering and simultaneously stabilizes superconductivity with the mixed s- and d-type symmetry. The flux state and the charge density wave are not stable in the model.

Introduction

In a vast literature of on the t-J model doped by holes one can meet a group of works, in which the ground state is superconducting with the s+id-type symmetry [1-3]. There are also papers indicating on the flux state and the charge density wave (CDW) as the most stable [4-6]. Here, we want to re-investigate the problem focusing our attention on mixing of different phases.

Mean-field formalism for the ground state

The t-J Hamiltonian can be express by means of the spin fermion field $f^+_{i\sigma}$ and the charged bose field b^+_i as

$$H = -t \sum_{i,j,\sigma}{}' b_i f^+_{i\sigma} f_{j\sigma} b^+_j - J/2 \sum_{i,j,\sigma}{}' \left(f^+_{i\sigma} f_{i\sigma} f^+_{j-\sigma} f_{j-\sigma} + f^+_{i\sigma} f_{j\sigma} f^+_{j-\sigma} f_{i-\sigma} \right)$$
$$\mu \sum_{i,\sigma} f^+_{i\sigma} f_{i\sigma} - \lambda \sum_i \left(b^+_i b_i + \sum_\sigma f^+_{i\sigma} f_{i\sigma} - 1 \right) . \quad (1)$$

The superconducting order parameter is defined by [7]

$$\Delta\, e^{i\pi\alpha/2} = \langle f_{i+} f_{i+x-} \rangle + \langle f_{i+} f_{i-x-} \rangle , \quad \Delta\, e^{-i\pi\alpha/2} = \langle f_{i+} f_{i+y-} \rangle + \langle f_{i+} f_{i-y-} \rangle . \quad (2)$$

The phase α says about symmetry of a wave function of the Cooper pair. We also consider the antiferromagnetic (AF) ordering, the CDW and the flux phase (with an arbitrary value of the flux Φ through the plaquette [7]).

In the mean-field formalism the Hamiltonian (1) is decomposed into a bosonic and a fermionic part. We proved that for any type of the fermionic modulations bosons condense at the wave vector $q = 0$ (in contrast to an assumption in [5]; see also [6]). Therefore, all bosonic bond variables are spatially uniform. The fermionic part of the Hamiltonian one can easily diagonlize and find self-consistent equations for the order parameters. First the stability conditions in the space of the interaction parameter J/t and the hole concentration δ are studied separately for each type of the ordering. The analyze shows that the CDW could exist inside the AF region and the flux phase - inside the superconducting region. Next, the stability conditions for a mixture of the CDW with the AF ordering and the flux phase with the superconductivity are studied. The CDW and the flux phase are unstable. A similar procedure is applied for an analyze of a composition of the other phases. The final result, the phase diagram for the t-J model is presented in Fig. 1.

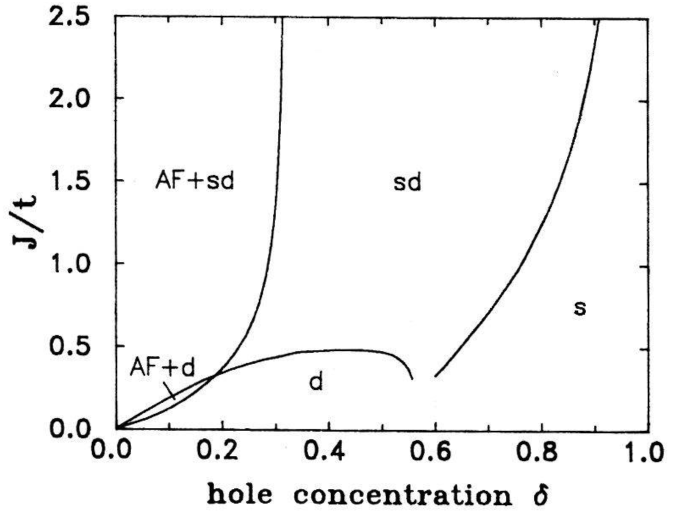

Fig. 1 Stability diagram of the t-J model. AF, s and d denote the regions where the antiferromagnetic ordering, the superconductivity with the s-type and the d-type symmetry exist, respectively.

Conclusions

The most stable solutions in the t-J model are the AF state and the superconductivity, which may be the s-type, the d-type symmetry, or their coherent composition. At $\delta = 0$ there is only the AF ordering ($\Delta = 0$) [8]. The superconductivity is stabilized by doping and Δ increases with δ.

It is worth to mention that Affleck et al. [9] claimed that the superconducting state of the s+id-type symmetry [1] and the flux state with $\Phi = hc/2e$ [4] are equivalent. It is true only at $\delta = 0$, where the kinetic part of the t-J Hamiltonian may be neglected. In this case, however, the both orderings are suppressed by the AF state.

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