COMPETING SPIN WAVES AND SUPERCONDUCTING FLUCTUATIONS IN STRONGLY CORRELATED ELECTRON SYSTEMS

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Abstract

A special diagram technique recently proposed for strongly correlated electron systems is used to study the pecularities of a spin-density-wave (SDW) in competition with superconductivity. This method allows to formulate the Dyson equations for the renormalized electron propagators of the coexisting phases of SDW antiferromagnetism and superconductivity. We find the surprising result that triplet supercondctivity appears provided that we have coexistence of singlet superconductivity and SDW antiferromagnetism. A special ansatz, which takes into account the full Green's functions as well as the dynamical structure of the correlations, is used to establish the equations determining the gap functions and order parameters.

Keywords: Strongly correlated electron systems, Spin-density-wave, Singlet and triplet superconductivity

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1. INTRODUCTION

The spin-density-wave (SDW) state, firstly introduced by Overhauser (Overhauser, 1960, 1962) for the electron gas in crystals, has the wave length $\lambda = 2\pi/|\mathbf{Q}|$ in direction of the vector $\mathbf{Q}$ in the Brillouin zone. These oscillations are commensurate with the crystal structure if the vector $2\mathbf{Q}$ is equal to a vector of the reciprocical lattice. In this paper we discuss strongly correlated elcetron sytems on the basis of the Hubbard model and assume that the strong intra-atomic Coulomb correlations lead to the spontaneous formation of a permanent static SDW existing under certain conditions. The SDW is a special case of collective motions of electron–hole pairs. The broken symmetry is manifested by the transition from the paramagnetic state to the itinerant antiferromagnetic phase. In the case of helicoidal (spiral) polarisation of the SDW, as discussed here, the new phase is characterized by the simultaneous presence of propagators with diagonal spin indices and (anomalous) propagators having off-diagonal spin indices. The transition to the SDW state with broken translational symmetry usually is of second order. This transition is similar to the superconducting transition, which is also discussed in this paper. In the latter case the phase transition is accompanied by a spontanously broken gauge symmetry of the ground state, leading to the appearance of anomalous pairing propagators which do not conserve the number of particles.

The SDW and superconductivity result from the Coulomb interactions of the electrons in the system. In the case of strongly correlated electrons considered here, the strong on-site electron repulsion is (together with the number of electrons per site) is the dominant parameter of the theory. As an elemental model which takes this into account, we use the Hubbard Hamiltonian and the method of broken symmetry in order to discuss the coexistence of a SDW with spiral polarization and superconductivity.

The Hubbard Hamiltonian has the form:

$$H^0 = -\mu \sum_{i\sigma} c^\dagger_{i\sigma} c_{i\sigma} + U \sum_i n_{i\uparrow} n_{i\downarrow}, \tag{1}$$

$$H^1 = \sum_{ij\sigma} t(j-i) c^\dagger_{j\sigma} c_{i\sigma}. \tag{2}$$

Here c_i and $c^\dagger_i$ are the destruction and creation operators of the electrons at site i, respectively; μ is the chemical potential of the system, $t(j-i)$ is the transfer matrix element and U is the on–site Coulomb repulsion, which is kept in the zero order Hamiltonian.

In order to take into account from the beginning the static SDW, we use the following unitary transformation,

$$\widetilde{H} = \Omega H \Omega^{-1} \tag{3}$$