Electron Dynamics and High-Temperature Superconductivity in Cuprates

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During the last decades the electron dynamics in cuprates has been an object of the numerous investigations. Apparently, from a knowledge of the ground state structure and contribution of the electron-electron correlations in the thermodynamic potential we can understand the mechanism of high-temperature superconductivity. It is necessary to point out that the available experimental and theoretical data reflect an extremely complicated character of the interplay between charge, spin and lattice degrees of freedom. Unfortunately, the series of observed phenomena in cuprates is not reproduced by existing theories.

In this work, in the framework of doped Hubbard model the conception of effective field with parameters of order is proposed. It is considered the most general case of relation between Coulomb repulsion U and hopping integral t, when $U \sim t$. By diagrammatic method based on the scattering matrix formalism the effective field with self-consistent parameters of order is extracted from the Hubbard Hamiltonian. This is a zeroth approximation which coincides with a known approximation Hubbard I. For a half filled band the parameters of order determine both the site electron-hole occupancy and a metal or insulator state. This approximation does not describe a phase transition metal-insulator. That's why in work one-loop diagrams were accounted for Green's functions. It allowed to calculate the spectral density and chemical potential of electron subsystem with correlations in paramagnetic state. For a half filled band the metal state is found to be stable at temperature $T=0$ and $U/W<2.1$, where W is bandwidth. Also, a step-like character of the resistivity as a function of the electron doping is observed that is in correspondence with experiment.

The next part of this work is devoted to problem of high-temperature superconductivity. The presented theory is developed as applied to BCS Hamiltonian with exchange binding J. The transformation of the Hamiltonian to real site representation from the wave subspace was made. The perturbation theory of superconductivity with account for smallness of band gap relatively Fermi energy E_F has been presented. In this case the effective self-consistent field is formed by BCS-type bond of the exchange origin and we have ordinary approximation Hubbard I. In the limit of the strongly correlated electrons there is a fundamental difference between metal and doped Mott insulator because of existence a pure hole state and different parameters of order. For the pure t-J model it has been proved that the singlet electron pairs are destroyed by a strong effective kinematic field. Indeed, in the superconductive state the chemical potential μ renormalized by electron correlations was obtained to be in a very narrow energy area, i.e. $J/4 \le \mu \le J/3$. This condition forbids the realization of the superconductivity by spin-fluctuation mechanisms.

It has been considered the t-J model with Holstein polaron excitations and one Einstein phonon mode. The electron-phonon interaction with binding constant g plays an important role in the correlation narrowing of the band. In this case the chemical potential is decreased. It was obtained that at $g/W=0.07$ the necessary condition on μ may be realized. For optimally doped cuprate with phonon frequency75 mV, $J/W=0.058$ and $W=4$ eV we obtained the value of the critical temperature equal to 100K. The calculated critical temperature of the superconductivity and the gap function are in a good agreement with experimental data for cuprates. Near the Fermi level along the nodal direction a strong electron-phonon binding enforces the degree of coherency of the electron-polaron excitations that is supported by ARPES data.

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