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The role of anomalous strength operator in the high-T_c superconductivity theory

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Abstract

The diagram series structure for Matsubara Green's functions in the Hubbard operators representation have been analyzed for the superconducting (SC) phase in the *t–J*-model. It has been found that the Hubbard operator diagram technique besides anomalous self-energy operator includes also anomalous strength operator (ASO). With account for ASO Gor'kov equations have been written. ASO are shown to be very essential when anomalous averages are calculated. The anomalous self-energy operator and ASO were derived in one-loop approximation. It has turned out that strength operator components depend on Matsubara frequency. As a result the SC phase is described by infinite set of integral equations. When deriving the equation for transition temperature in SC phase with s- and d-order parameter symmetry this system has been solved exactly. On the basis of numerical calculations it has been found that the account for strength operator components has fully suppressed SC phase with s-order parameter symmetry in the *t–J*-model.

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Most of the theoretical researches of the high-temperature superconductivity (HTSC) has been carried out on the basis of effective Hamiltonians [1] derived from Hubbard model [2] or its generalization [3]. The present paper aims at HTSC properties of *t–J*-model with taking into account strength operator components. The Hamiltonian of the model is given by

$$H = \sum_{f\sigma}(\varepsilon-\mu)X_f^{\sigma\sigma} + \sum_{fm\sigma} t_{fm} X_f^{\sigma 0} X_m^{0\sigma} + \sum_{fm} J_{fm}(X_f^{+-}X_m^{-+} - X_f^{++}X_m^{--}). \quad (1)$$

SC-phase description is carried out using graphical form of perturbation theory for Matsubara Green's functions in atomic representation

$$D_{\alpha\beta}(f\tau; g\tau') = -\langle T_\tau \tilde{X}_f^{\alpha}(\tau)\tilde{X}_g^{-\beta}(\tau')\rangle, \quad (2)$$

where α and β stand for two indices of the one-ionic states, e.g. (0σ), $(\bar{\sigma}0)$, $(+-)$. T_τ is time-ordering operator over Matsubara time τ. In the right side of Eq. (2) Hubbard operators are taken in Heisenberg representation:

$$\tilde{X}_f^{\alpha}(\tau) = \exp(\tau H) X_f^{\alpha} \exp(-\tau H), \quad 0<\tau<1/T. \quad (3)$$

It is repeatedly noted in literature that the one of Hubbard operators diagram technique (HODT) peculiarities is related to the presence in graphical series for Matsubara Green's functions, so called ending diagrams. Ending diagrams define analytical contribution in the strength operator. It is known that for *t–J*-model in one-loop approximation there are four diagrams for anomalous component of mass operator $\Sigma_{0\uparrow,\downarrow 0}(k, i\omega_m)$ (Fig. 1).

In graphical series of perturbation theory, anomalous components of strength operator in one-loop approximation $P_{0\sigma,\bar{\sigma}0}$ are determined by four diagrams (Fig. 2).

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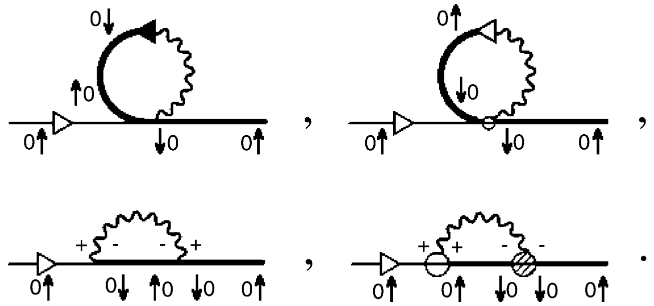

Fig. 1. Diagrams for anomalous component of mass operator $\Sigma_{0\uparrow,\downarrow 0}(k,\mathrm{i}\omega_m)$.

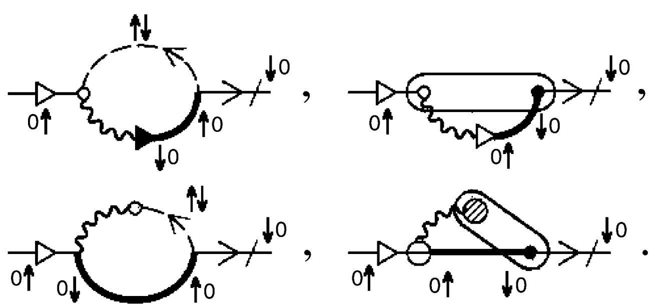

Fig. 2. Diagrams for anomalous component of strength operator.

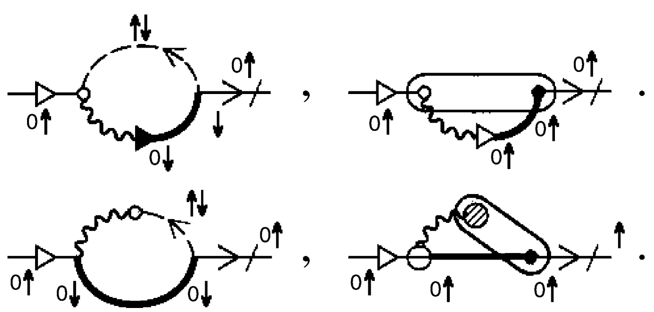

Fig. 3. Diagrams for normal component of the strength operator $P_{0\uparrow,\downarrow 0}$.

Essentially that in analytical form $P_{0\sigma,\bar{\sigma}0}$ depend on Matsubara frequencies. Thus SC phase is described by infinite system of self-consistent integral equations.

Besides anomalous components of strength operator in one-loop approximation also exist normal components. There are four one-loop diagrams for normal component of the strength operator $P_{0\uparrow,0\uparrow}$ (Fig. 3) and two diagrams for normal component of the mass operator $\Sigma_{0\uparrow,0\uparrow}$ (Fig. 4).

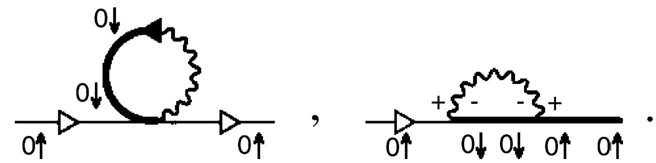

Fig. 4. Diagram for normal component of the mass operator $\Sigma_{0\uparrow,0\uparrow}$.

To obtain the analytical expressions for mass and strength operators these graphs have been used. As a result the infinite set of equations which described the superconducting phase have been derived. When the equation on T_c was obtained this infinite system of equations have been solved explicitly. The result can be produced in the form of equation on T_c which was solved numerically. For s-order parameter symmetry equation on T_c becomes

$$1 + 2T\sum_{\omega_m} \frac{(1/N)\sum_q t_q A(q,\mathrm{i}\omega)}{1 - n/2(1+n/2)(1/N)\sum_k t_k^2 A(k,\mathrm{i}\omega)} = 0,$$

$$A(q,\mathrm{i}\omega_m) = \frac{1}{(\mathrm{i}\omega_m)^2 - \xi_q(\mathrm{i}\omega)^2},$$

$$\xi_q(\mathrm{i}\omega) = \varepsilon - \mu + P_{0\uparrow,0\uparrow}(\mathrm{i}\omega_m)t_q + \Sigma_{0\uparrow,0\uparrow}. \quad (4)$$

It has been found that solutions of this equation do not exist. Thus taking into account components of strength operator has put down SC-phase.

Present results show that in the general case it is necessary to take into account contributions of normal and anomalous components of mass and strength operators. In the research it has been shown that in case of s-order parameter symmetry the contribution completely suppressed the solution which was found earlier.

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