Spin-triplet superconductivity in two-dimensional Hubbard model on triangular lattice

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Abstract

We discuss the possibility of spin-triplet superconductivity in two-dimensional Hubbard model on triangular lattice within the third order perturbation theory. We obtain spin-triplet superconducting state. It is found that the vertex terms which are not included in the interaction mediated by the spin fluctuation is essential for realizing the spin-triplet pairing for our searched values of parameters. We argue that the present mechanism of spin-triplet superconductivity can be applied to heavy-fermion superconductors UNi_2Al_3, UPt_3.

Key words: spin-triplet superconductivity; vertex correction; UNi_2Al_3; UPt_3

1. Introduction

Spin-triplet(ST) superconductors(SC) have attracted much interest since the mechanism of these superconductivity has not been well known. In STSC Sr_2RuO_4, Nomura and Yamada have recognized that the momentum and frequency dependence of the effective interaction between electrons which is not included in the interaction mediated by the spin fluctuation is essential for realizing the ST pairing and have explained the superconducting mechanism within the third order perturbation theory(TOPT) [1]. The perturbation approach is sensitive to the dispersion of the bare energy band by its nature. Therefore it is important to evaluate superconducting transition temperature T_c on the basis of the detailed electronic structure in each system. Stimulated by the desire to explain the superconducting mechanism of UNi_2Al_3(STSC indicated recently [2]),UPt_3(STSC), we calculate here T_c of ST superconductivity in two-dimensional Hubbard model on triangular lattice within TOPT.

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2. Formulation

We adopt the following Hubbard Hamiltonian, $H = \sum_{\mathbf{k},\sigma} (\epsilon(\mathbf{k}) - \mu)\, a^\dagger_{\mathbf{k}\sigma} a_{\mathbf{k}\sigma} + \frac{U}{2N} \sum_{\sigma \neq \sigma'} \sum_{\mathbf{k}_1\mathbf{k}_2\mathbf{k}_3\mathbf{k}_4} \delta_{\mathbf{k}_1+\mathbf{k}_2,\mathbf{k}_3+\mathbf{k}_4} a^\dagger_{\mathbf{k}_1\sigma} a^\dagger_{\mathbf{k}_2\sigma'} a_{\mathbf{k}_3\sigma'} a_{\mathbf{k}_4\sigma}$, where μ, U, and $\epsilon(\mathbf{k})$ are the chemical potential, the Coulomb repulsion, and the dispersion of the bare energy band on two-dimensional triangular lattice, respectively. We obtain T_c by solving the Éliashberg's equation(Fig. 1). We expand normal self-energy, effective interaction

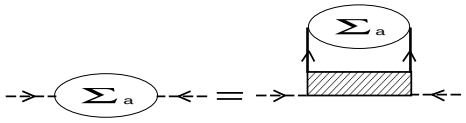

Fig. 1. The Éliashberg's equation. The thick line represents Green's function with self-energy correction. The shaded rectangular represents the effective interaction.

with respect to U up to third order, respectively(Fig. 2(a),(b)). The diagrams enclosed by the dashed line in Fig. 2(b) are the vertex correction terms which are not direct contribution from spin fluctuations.The other diagrams are included in RPA.

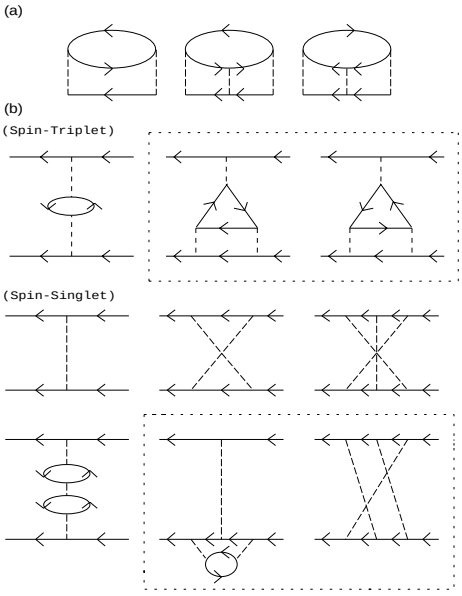

Fig. 2. (a) The Feynman diagrams of the normal self-energy up to third order. (b) The Feynman diagrams of the effective interaction up to third order. The solid and dashed lines correspond to the bare Green's function and the interaction, respectively.

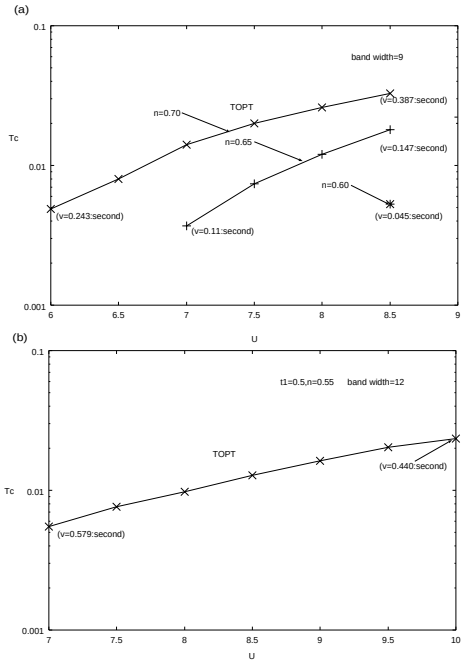

Fig. 3. (a)The calculated T_c as U is varied for various values the electron number n per one spin site.(b) The calculated T_c as U is varied at $n = 0.55, t_1 = 0.5$ "(v=***:second)"in these figures means that eigen value v calculated by second order perturbation theory is v=*** at T_c calculated by TOPT.

3. Calculated Results

We calculate here T_c of two models. At first, we consider a possible model of UNi_2Al_3. In the case of spin-singlet(SS) SC UPd_2Al_3, we have adopted following dispersion of the bare energy band in the previous work [3], $\epsilon(\mathbf{k}) = -4\cos(\frac{\sqrt{3}}{2}k_x)\cos(\frac{1}{2}k_y) - 2t_m\cos(k_y)$ where $t_m \neq 1$ reflecting the effect of AF order with a large magnetic moment of $0.8\mu_B$. In the case of UNi_2Al_3, we assume here that $t_m \simeq 1$ reflecting SDW order with a tiny moment of $0.2\mu_B$, although the detailed electronic structure of UNi_2Al_3 has not been investigated. So we try to investigate the possibility of ST superconductivity near the previous model of UPd_2Al_3. In the case of $t_m = 1$, we obtain the highest T_c of ST superconducting state(Fig. 3(a)). In the next, we adopt following dispersion of the bare energy band, $\epsilon(\mathbf{k}) = -4\cos(\frac{\sqrt{3}}{2}k_x)\cos(\frac{1}{2}k_y) - 2\cos(k_y) - t_1\left(4\cos(\frac{\sqrt{3}}{2}k_x)\cos(\frac{3}{2}k_y) + 2\cos(\sqrt{3}k_y)\right)$ which reproduce quasi two-dimensional Fermi surface of UPt_3. In this case, we obtain the highest T_c of ST superconducting state(Fig. 3(b)). In all results mentioned above , the vertex terms is essential for realizing the ST pairing state, although only the second order term (which is only term included in RPA within TOPT) does not give rise to the ST pairing state within the precision of our numerical calculations.

4. Discussion and Conclusion

From our calculation, it has been found that the vertex terms gives rise to the ST pairing state, while, in the case of SSSC [3–5], it has been found that the vertex correction terms reduce T_c within TOPT. We consider that the obtained ST superconducting state reflects frustrate geometry of triangular lattice because of high electron density. In conclusion, we have discussed the possibility of ST superconductivity of two-dimensional Hubbard model on triangular lattice within TOPT and have obtained ST superconducting state. We have tried to apply the presented mechanism to heavy-fermion SC UNi_2Al_3, UPt_3.

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