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Theory of Superconductivity in Heavy Fermion Systems

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In this presentation, we show the results obtained within the third-order perturbation theory for superconductivity in some typical heavy fermion compounds. This approach has been useful in discussing the pairing symmetry and mechanism of superconductivity in high-T_c cuprates and Sr_2RuO_4. Although the perturbation thoery with respect to the on-site repulsion U is the approach from a weak correlation limit, we indicate here that it is valuable also for heavy fermion superconductors. It is important that the normal state above T_c is the Fermi liquid state with heavy electron mass, and the large mass enhancement factor does not have remarkable wave vector dependence as implied by the Kadowaki-Woods relation. In this case, we discuss superconductivity by starting with the renormalized quasi-particle picture. The obtained results are illustrated below.

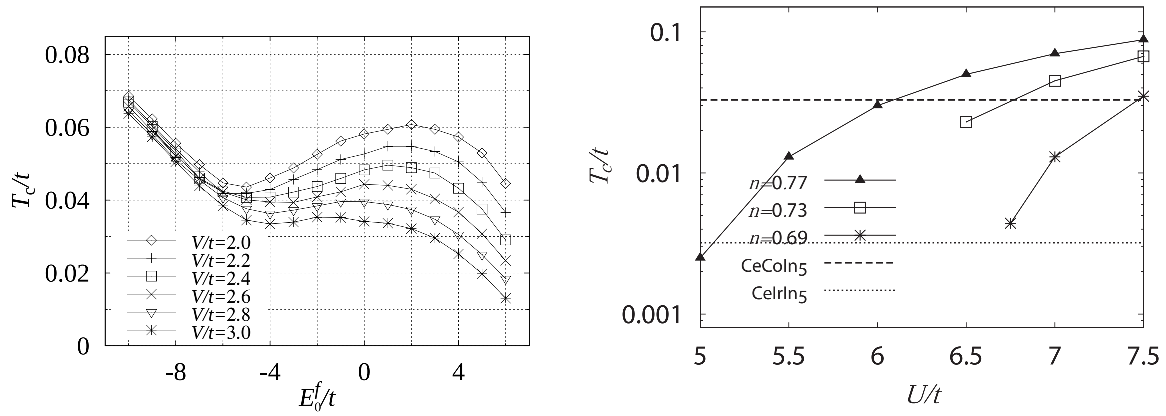

Figure 1: Left: f-level E_0^f dependence of T_c within the third-order perturbation theory in the periodic Anderson model for $CeCu_2(Si,Ge)_2$. Right: U dependence of T_c for some electron density n in the Hubbard model on the 2D square lattice. The tendency that T_c increases with increasing n is consistent with its x-dependence in $CeIr_xCo_{1-x}In_5$.

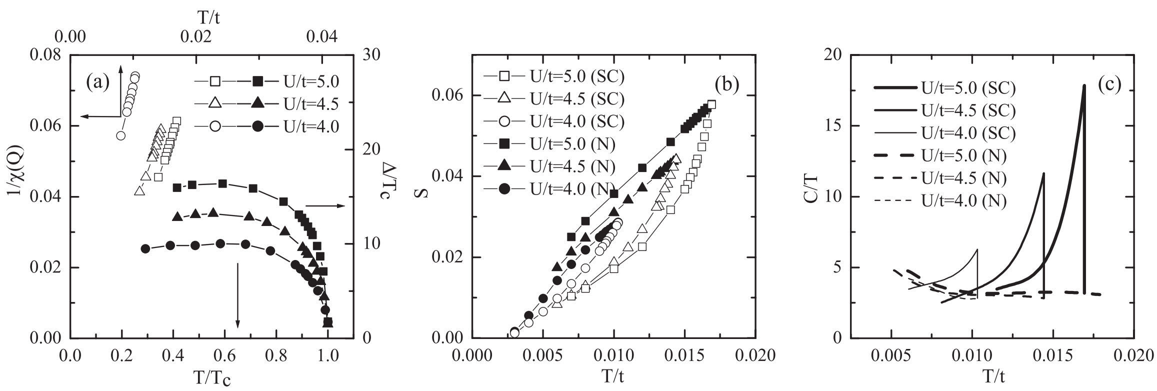

Figure 2: (a) Temperature dependence of $1/\chi(Q)$ and the magnitude of the gap function Δ/T_c. They are obtained within the fluctuation-exchange approximation. (b) The entropy S and (c) the specific heat C in the normal and the superconducting states. As U/t is larger, the superconductivity becomes the strong coupling, and the jump of C/T at T_c is enhanced. This is consistent with the large specific heat jump in $CeCoIn_5$.

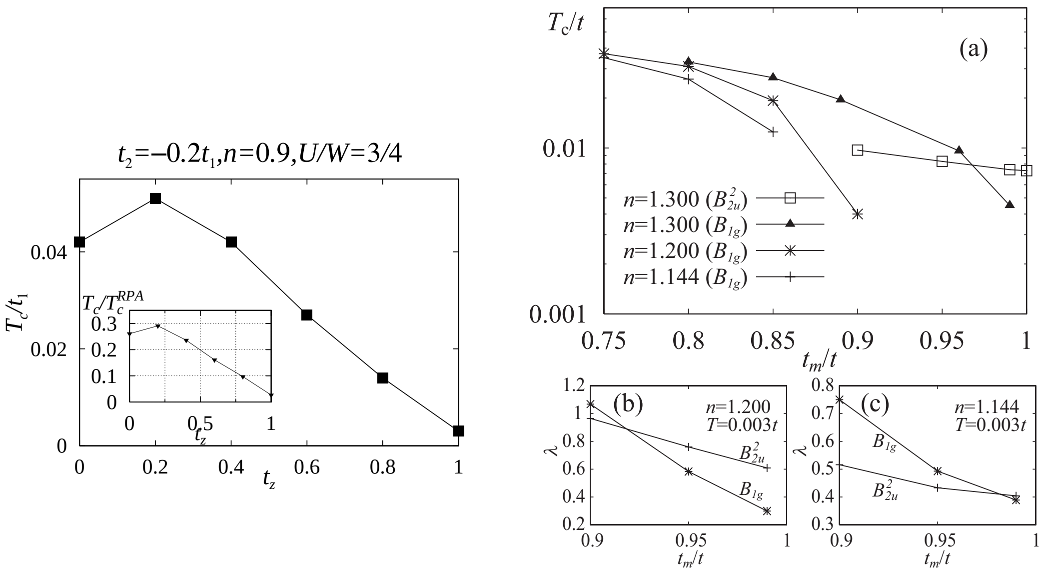

Figure 3: Left: t_z dependence of T_c/t_1 in the 3D cubic Hubbard model. In the inset, $T_c/T_c^{\rm RPA-like}$ as a function of the anisotropy t_z. $t_z = 0$ and 1 correspond to 2D and 3D systems, respectively. T_c in 3D systems becomes one-order smaller than that in 2D systems. This tendency corresponds to difference of T_c between $CeCoIn_5$ and $CeIn_3$. Right: (a) T_c as a function of the distortion ratio t_m/t in the Hubbard model on a distorted triangular lattice. (b) and (c) illustrate, respectively, the eigen values λ of the Éliashberg equation for $n = 1.200$ and $n = 1.144$ at $T = 0.003t$. $\Delta_{B_{1g}}$ (d_{xy}-wave singlet) is stable in a wide range of t_m/t, while $\Delta^2_{B_{2u}}$ (p-wave triplet) only in the vicinity of $t_m/t = 1$. Although the region of $\Delta^2_{B_{2u}}$ becomes wider as n decreases, the transition temperature is suppressed abruptly. This can correspond to the fact that singlet pairing with line nodes in UPd_2Al_3 and triplet pairing in UNi_2Al_3 are realized.

[1] Y. Yanase, T. Jujo, T. Nomura, H. Ikeda, T. Hotta and K. Yamada, Phys. Rep. **387** (2003) 1