Theory of Superconductivity in Strongly Correlated Electron Systems

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S.Sasaki, H.Ikeda and K.Yamada, J.Phys.Soc.Jpn.74,1397(05)

1S.Shinkai, H.Ikeda and K.Yamada, J.Phys. Soc. Jpn.74,in press.

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- YBaCu3O7 nd small, γsmall,

Tc is high(90K)

- La2-xSr x CuO4   nd large,γlarge,

Tc is low(40K)

What is the origin of the difference of Tc ?

Tc is determined by two parameters.
One is the renormalization factor z .
The other is the anisotropic interaction.

Electronic Structure of Cuprates

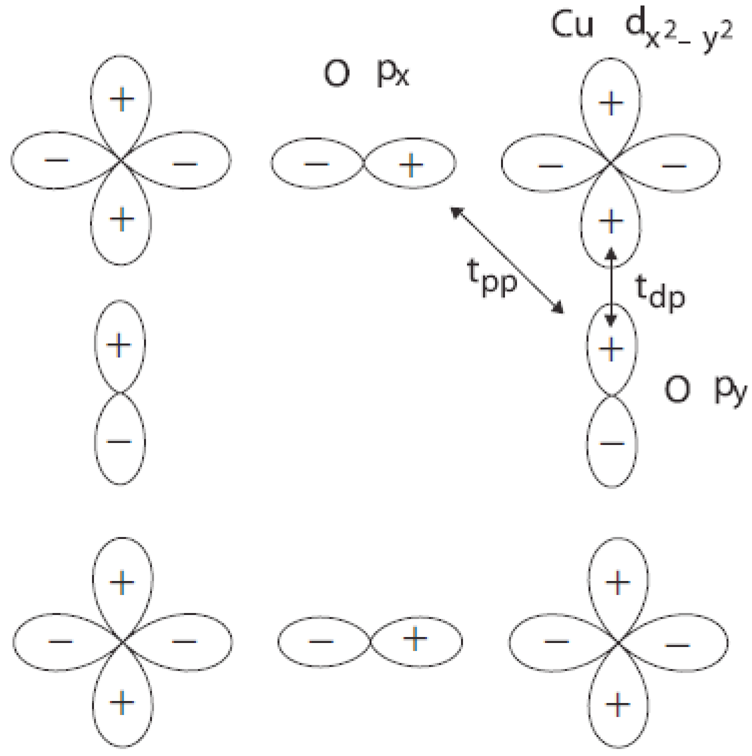


Fig. 1. Lattice structure of d–p model. t_{dp} and t_{pp} are the hopping integrals.

Fermi Surface

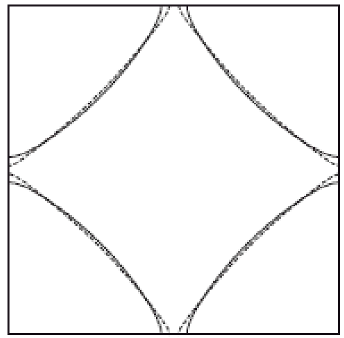


Fig. 2. The unbroken and broken lines are the Fermi surfaces in the case of $T = 0.01$, $t_{pp} = 0.30$ and $n = 4.90$ for $\varepsilon_d - \varepsilon_p = 1.0$ and $\varepsilon_d - \varepsilon_p = 3.0$, respectively.

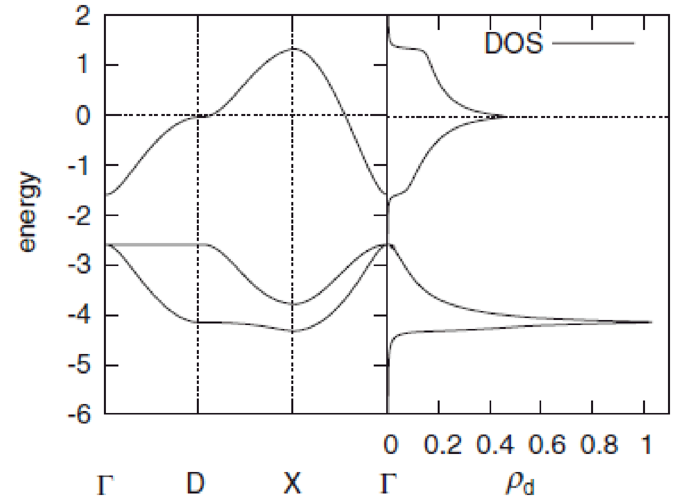


Fig. 3. Band structure and density of states for d-electron $\rho_d(\varepsilon)$ in case of $\varepsilon_d - \varepsilon_p = 1.0$.

Band Structure

nd/$2n_p$

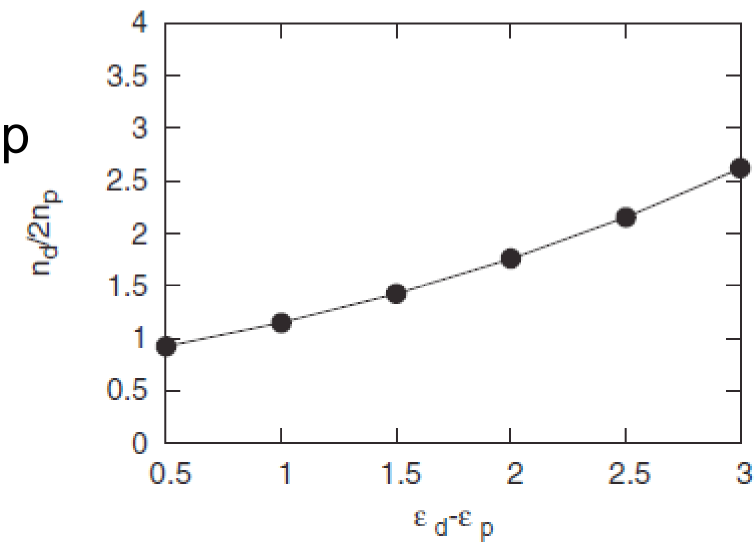


Fig. 5. $\varepsilon_d - \varepsilon_p$ dependence of $n_d/2n_p$.

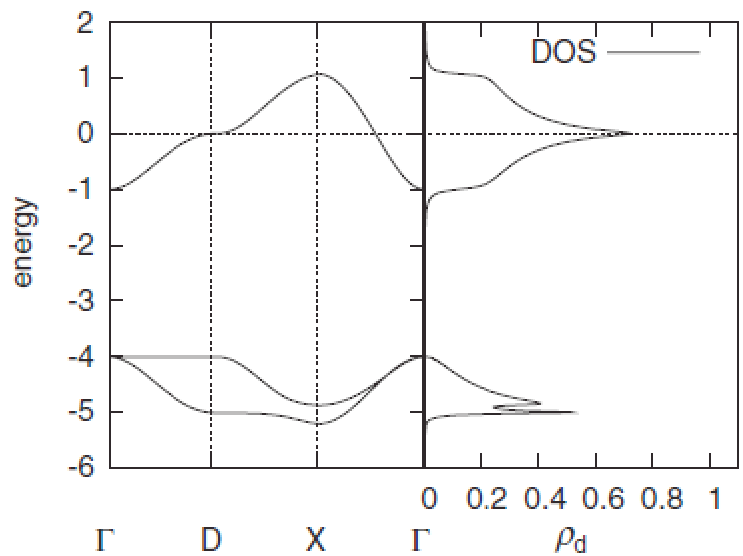


Fig. 4. Band structure and density of states for d-electron $\rho_d(\varepsilon)$ in case of $\varepsilon_d - \varepsilon_p = 3.0$.

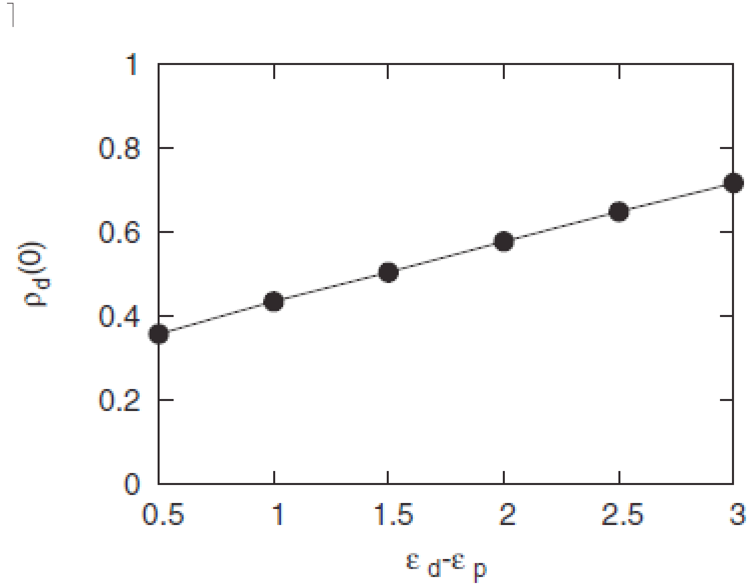


Fig. 6. $\varepsilon_d - \varepsilon_p$ dependence of $\rho_d(0)$.

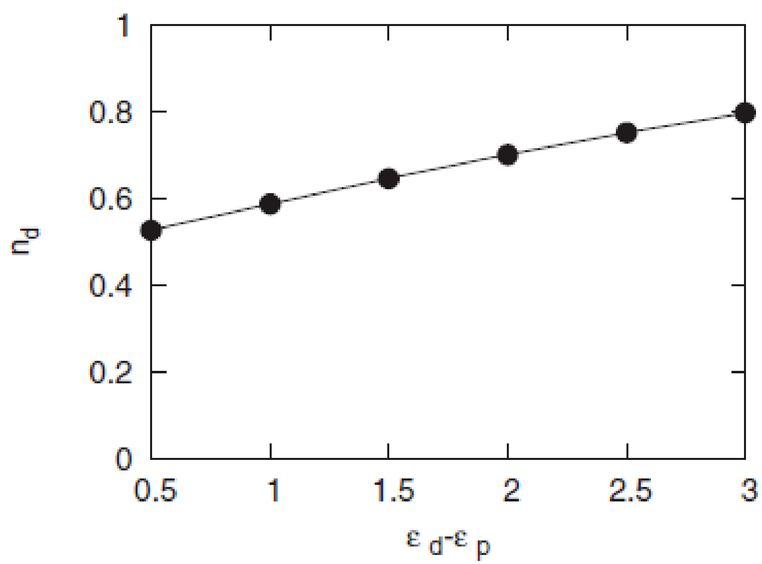


Fig. 7. $\varepsilon_d - \varepsilon_p$ dependence of n_d.

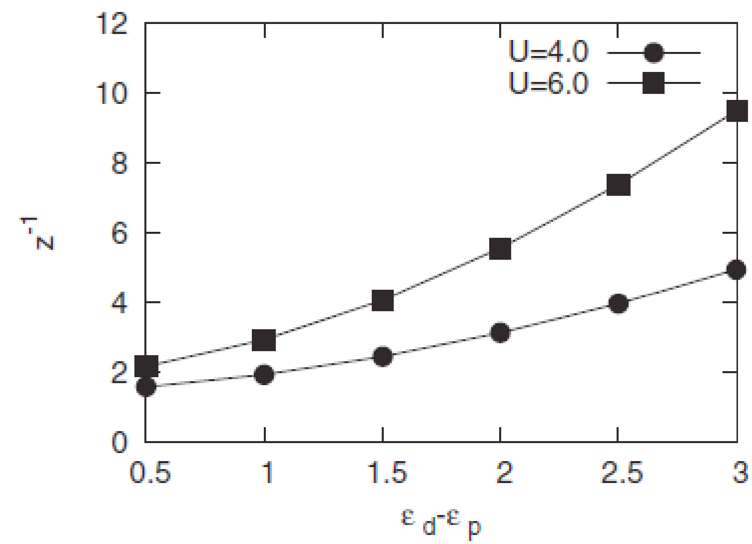
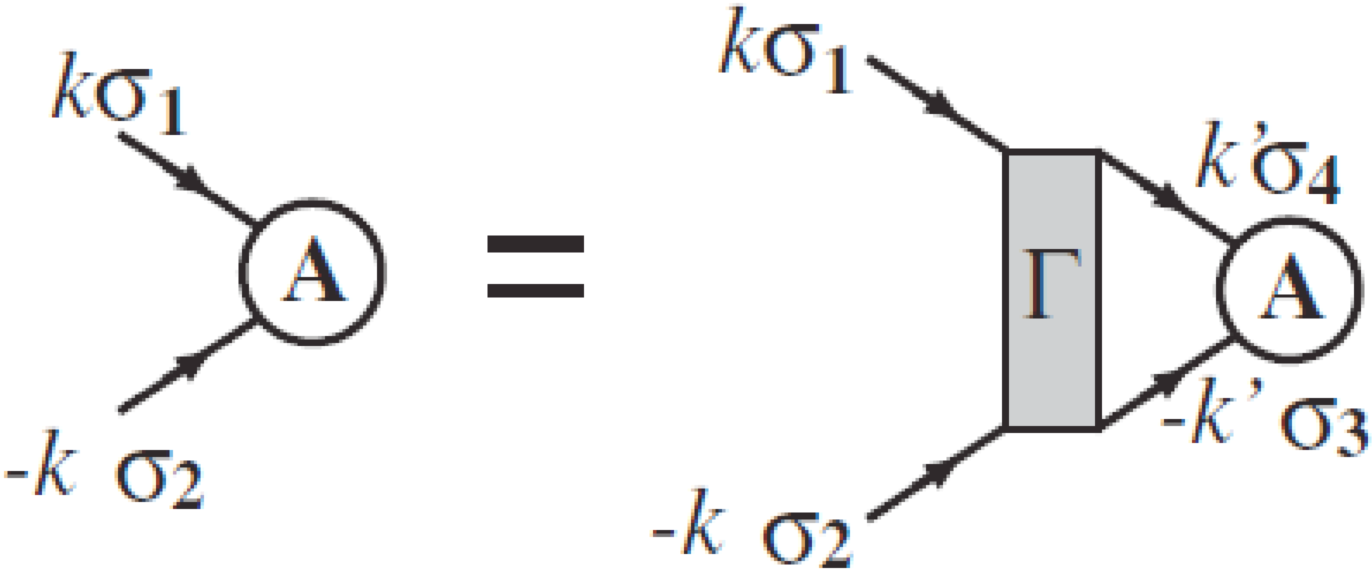
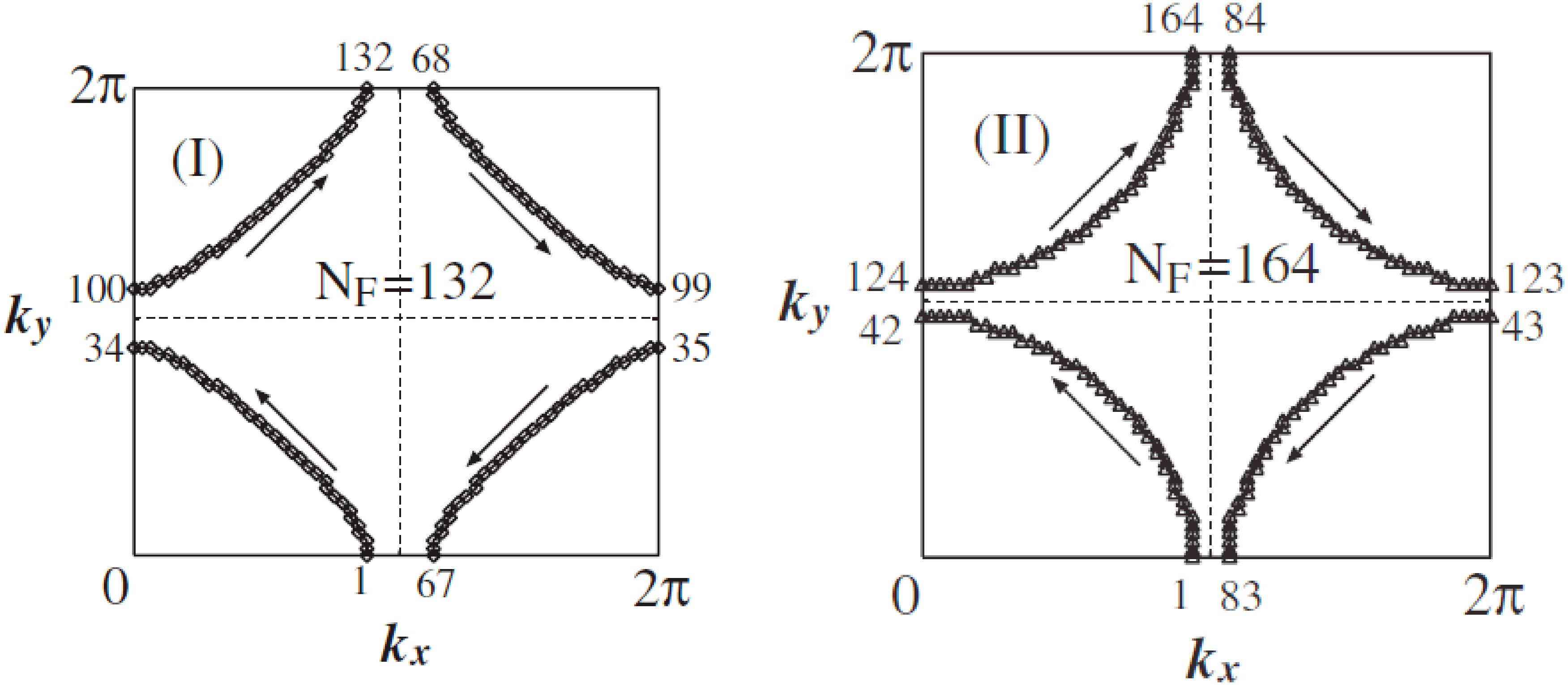


Fig. 8. $\varepsilon_d - \varepsilon_p$ dependence of $z^{-1} = \langle z^{-1}(\boldsymbol{k})\rangle$.

$$\Sigma^{\mathrm{A}}_{\sigma_1\sigma_2}(k) = -\frac{T}{N}\sum_{k'\sigma_3\sigma_4} \Sigma^{\mathrm{A}}_{\sigma_4\sigma_3}(k')|G_0(k')|^2\Gamma_{\sigma_1\sigma_2,\sigma_3\sigma_4}(k,k'),$$



Fermi surface (I) n=0.980 (II) n=1.334



Critical Temperature Tc with and without Selfenergy Correction

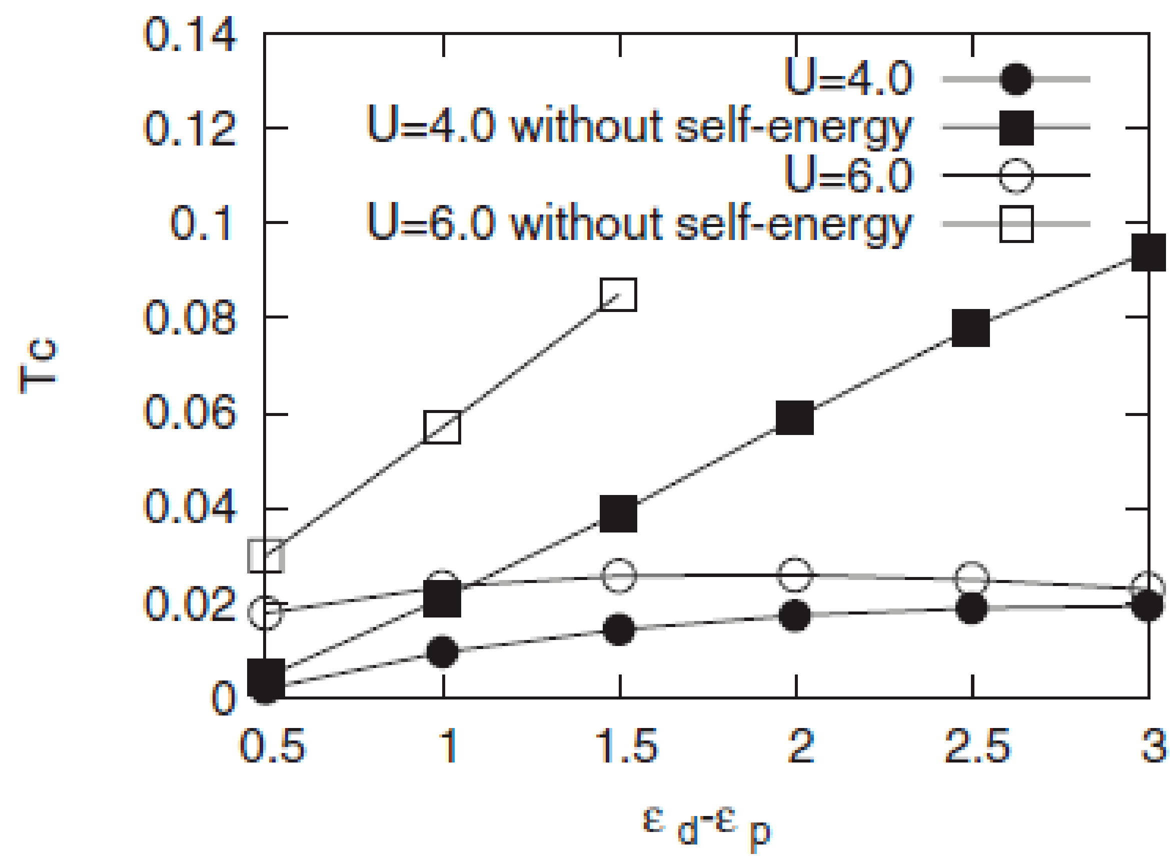


Fig. 9. $\varepsilon_d - \varepsilon_p$ dependence of T_c.

Forth Order Perturbation Theory for Selfenergy in Two dimensional Hu b bard Model

- S.Shinkai, H.Ikeda and K.Yamada J.Phys.Soc.Jpn.74,No.9

$$H = H_0 + H_{\mathrm{int}},$$

$$H_0 = \sum_{\boldsymbol{k}\sigma} \xi(\boldsymbol{k}) c^{\dagger}_{\boldsymbol{k}\sigma} c_{\boldsymbol{k}\sigma},$$

$$\xi(\boldsymbol{k}) = -2t\Big(\cos k_x + \cos k_y\Big) - 4t' \cos k_x \cos k_y - \mu.$$

$$H_{\mathrm{int}} = \frac{U}{2N} \sum_{\boldsymbol{k}_i} \sum_{\sigma \neq \sigma'} \delta_{\boldsymbol{k}_1+\boldsymbol{k}_2,\boldsymbol{k}_3+\boldsymbol{k}_4} c^{\dagger}_{\boldsymbol{k}_1\sigma} c^{\dagger}_{\boldsymbol{k}_2\sigma'} c_{\boldsymbol{k}_3\sigma'} c_{\boldsymbol{k}_4\sigma}.$$

Fermi Surface and Diagrams

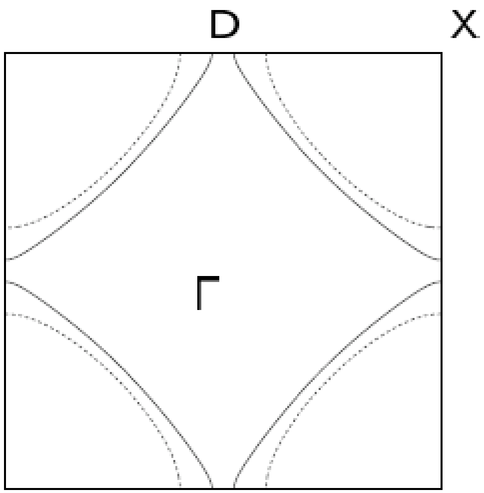
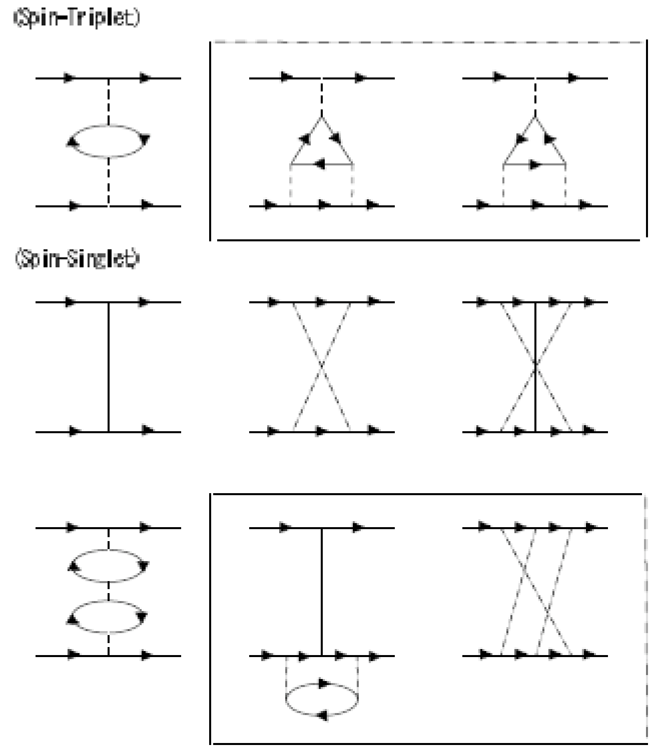


Fig. 1. The Fermi surfaces in the case of $t = 1$, $t' = -0.15$ and $T = 0.01$. The solid (dashed) line is the result for $n = 0.9$ ($n = 1.1$). The symbols Γ, D and X represent the symmetry points (0,0), (0,π) and (π, π) respectively.



Density of States and Mass Enhancement Factor

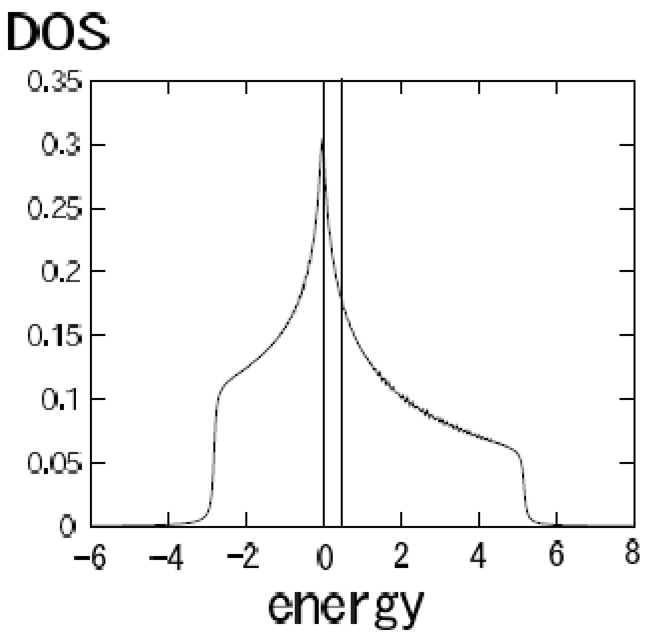


Fig. 2. The density of state in the case of $t = 1$, $t' = -0.15$ and $T = 0.01$. The dotted line and the zero energy represent the Fermi level for $n = 0.9$. And the dashed line represents the Fermi level for $n = 1.1$.

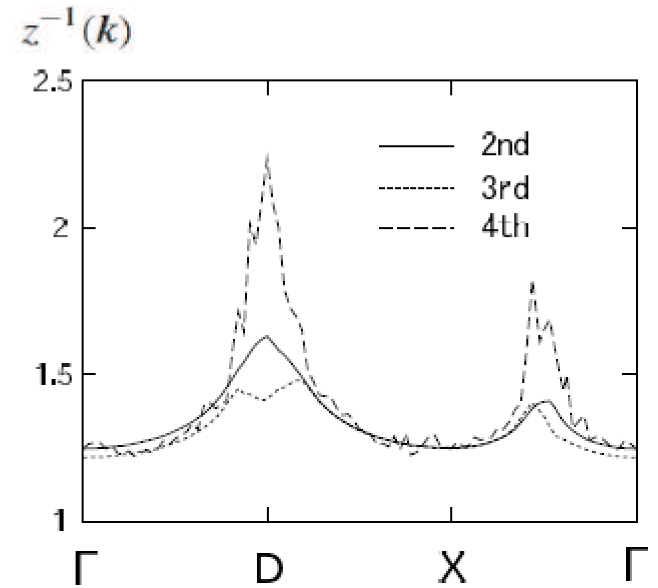


Fig. 4. The mass enhancement factor $z^{-1}(\boldsymbol{k})$ in the case of $n = 0.9$ and $U = 3$. The solid, dotted and dashed lines are the results in the calculations up to the second, third and fourth order, respectively. $z^{-1}(\boldsymbol{k}) = 1$ means the mass of the free electrons.

Momentum Dependence of Mass Enhancement Factor

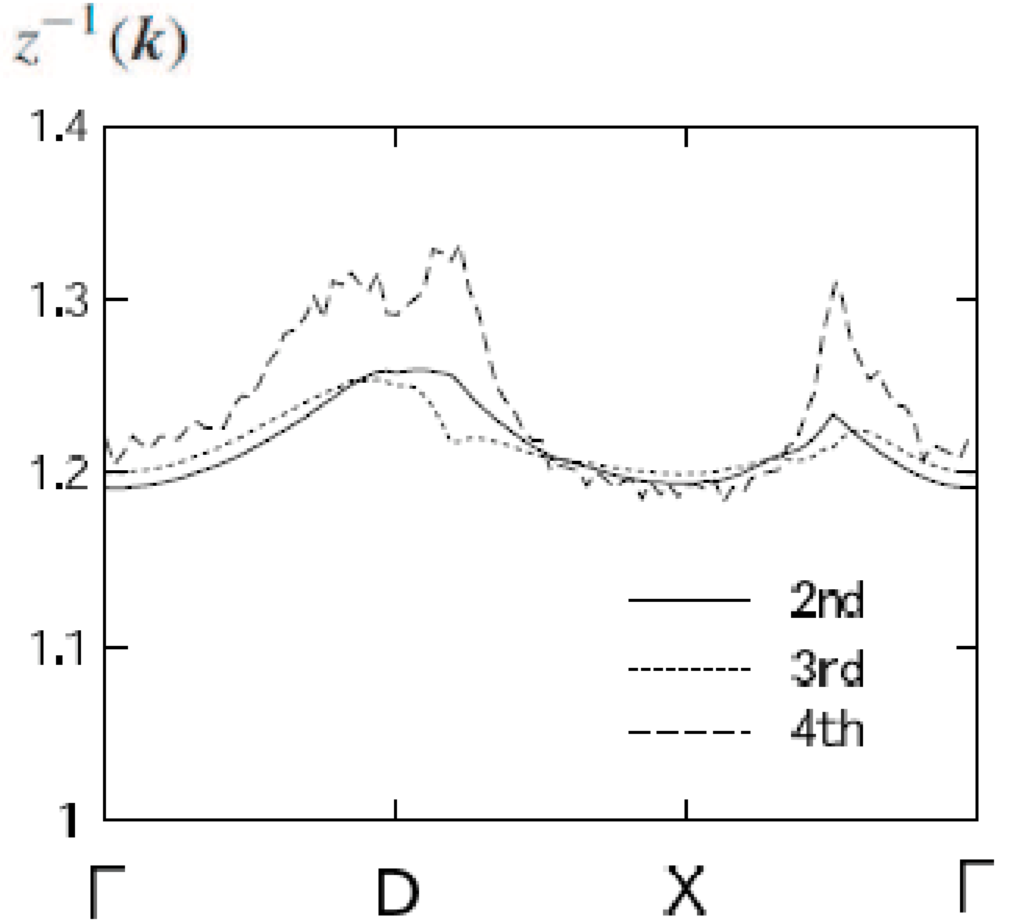


Fig. 6. The mass enhancement factor $z^{-1}(\boldsymbol{k})$ in the case of $n = 1.1$ and $U = 3$. The solid, dotted and dashed lines are the results in the calculations up to the second, third and fourth order, respectively. $z^{-1}(\boldsymbol{k}) = 1$ means the mass of the free electrons.

Susceptibility and Mass Enhancement Factor

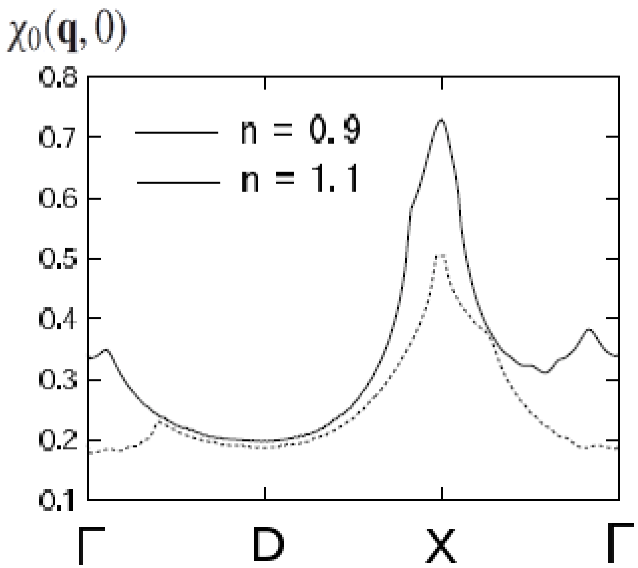


Fig. 3. The bare spin susceptibilities $\chi_0(\boldsymbol{q}, 0)$ in the case of $t = 1$, $t' = -0.15$ and $T = 0.01$. The solid (dashed) line is the result for $n = 0.9$ ($n = 1.1$).

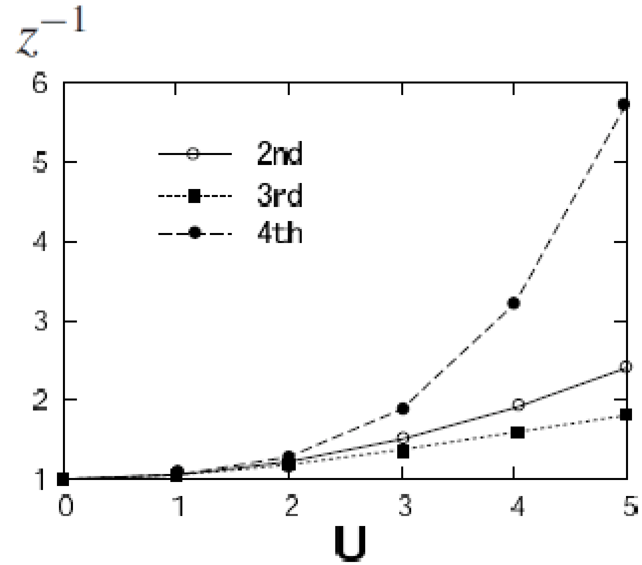


Fig. 5. The U-dependence of the mass enhancement factor z^{-1} in the case of $n = 0.9$. The solid, dotted and dashed lines are the results in the calculations up to the second, third and fourth order, respectively. z^{-1} is the average of $z^{-1}(\boldsymbol{k})$ at the Fermi point near $(0, \pi)$ and that near $(\pi/2, \pi/2)$.

Mass Enhancement Factor

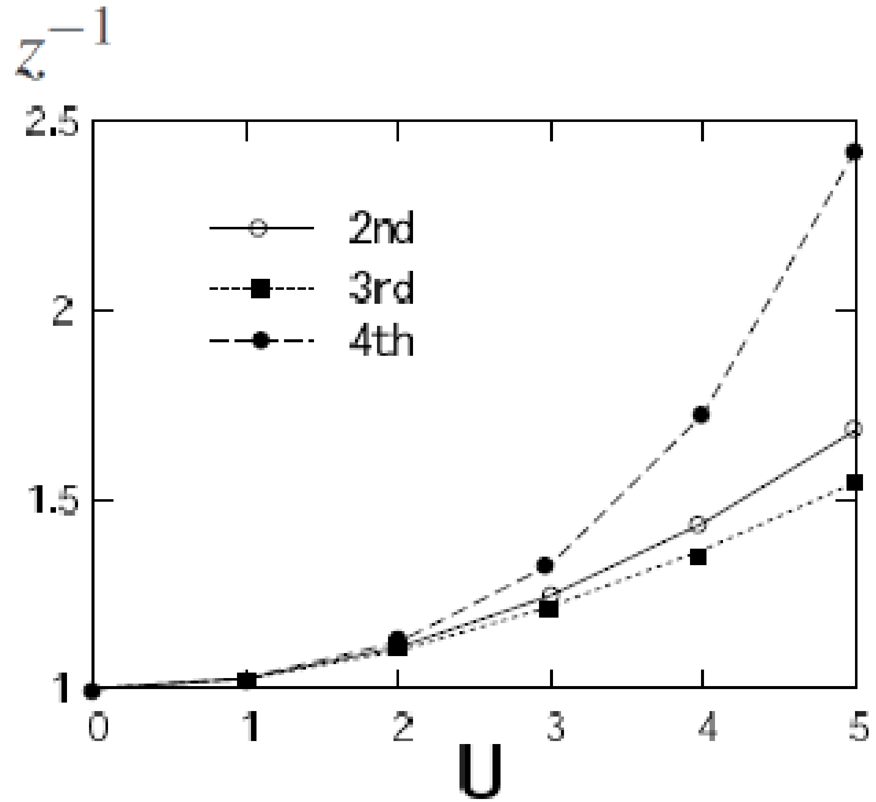
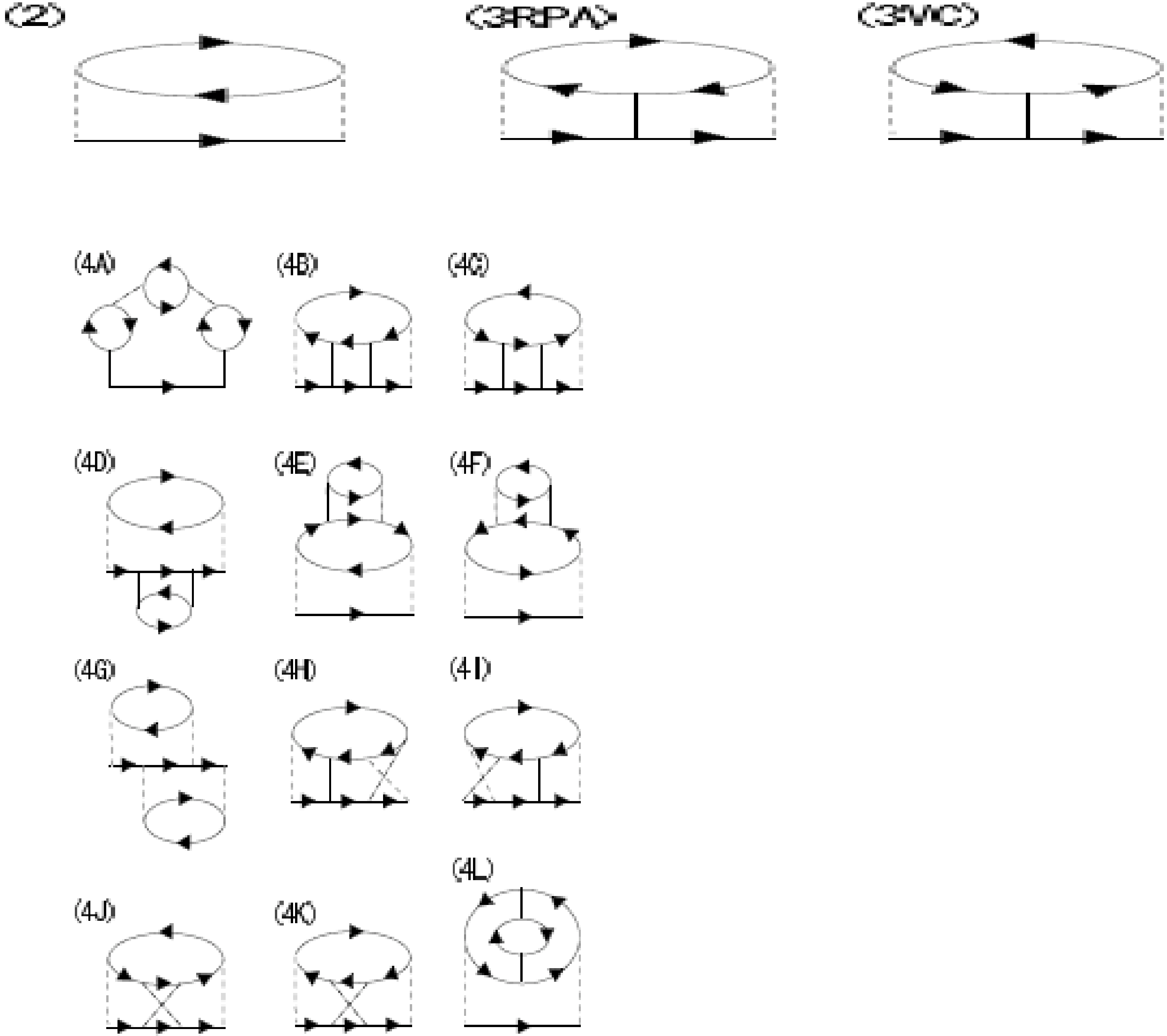


Fig. 7. The U-dependence of the mass enhancement factor z^{-1} in the case of $n = 1.1$. The solid, dotted and dashed lines are the results in the calculations up to the second, third and fourth order, respectively.


(2)
(3RPA)
(3VC)
(4A)
(4B)
(4C)
(4D)
(4E)
(4F)
(4G)
(4H)
(4I)
(4J)
(4K)
(4L)

Conclusion

- Tc is determined by two factors.
2. One is the renormalization factor z, which determines the band width of quasi-particles.
3. The other is momentum dependence of interaction between quasi-particles, which determines the attractive force.

We have calculated the Tc by using perturbation theory up to the fourth order terms for the vertex and selfenergy.

Tc in the Strongly Correlated Electron Systems

	Band Width of QP;W*	Tc
• Cuprates	1000 (1/z=10)	100
Organic	100	10
Heavy Fermion	10 (1/z=1000)	1
$PuCoGa_5$	100	10

Energy Scale is determined by W*