Theory of Nernst Coefficient and Magnetoresistance in High-T_c Cuprates: the Role of Superconducting Fluctuations

Hiroshi Kontani [a,1],

[a] *Department of Physics, Faculty of Science, Saitama University, 255 Shimo-Okubo, Saitama 338-8570, Japan*

Abstract

We study the the Nernst coefficient (ν) and the magnetoresistance ($\Delta\rho/\rho$) in hole-doped high-T_c cuprates, which increase drastically below the pseudo-gap temperature, T^*. This unexpected result attracts great attention in that it reflects the fundamental feature of the electronic state in the pseudo-gap region, which has been a central issue on high-T_c cuprates. In this article, we study these transport phenomena in terms of the fluctuation-exchange (FLEX)+T-matrix approximation. We focus on the role of the vertex corrections (VC's) which are necessary to keep the conservation laws, and find that both nu and $\Delta\rho/\rho$ are strongly enhanced by the VC's due to the antiferromagnetic (AC) and the superconducting (SC) fluctuations. In conclusion, the pseudo-gap region in high-T_c cuprates is well described by the AF and SC fluctuation scenario based on the Fermi liquid theory.

Key words: Nernst coefficient; vertex correction ; FLEX+T-matrix approximation; Fermi liquid theory

1. FLEX+T-matrix Approximation

It is well-known that various striking anomalous transport phenomena are observed in high-T_c cuprates. Recently, it is found that the Nernst coefficient (ν) in hole-doped compounds increases drastically below the pseudo-gap temperature, T^* [1]. Here, we study this mysterious behavior of ν in terms of the FLEX+T-matrix approximation. In this theory, the d-wave SC fluctuations, which are mediated by the antiferromagnetic (AF) fluctuations, become dominant below T^*. In the present article, we analyze the role of the VC's for currents in the framework of the conserving approximation, and calculate various transport coefficients for high-T_c cuprates.

In the self-consistent FLEX+T-matrix approximation, the full Green function and the self-energy are given by

$$G_{\mathbf{k}}(\epsilon_n) = (i\epsilon_n + \mu - \epsilon^0_{\mathbf{k}} - \Sigma_{\mathbf{k}}(\epsilon_n))^{-1}, \quad (1)$$

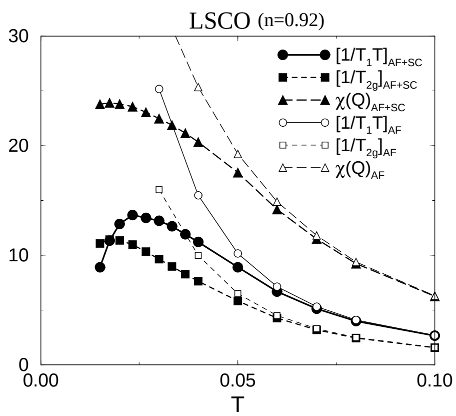

Fig. 1. χ_Q, $1/T_1T$ and $1/T_{2g}$ studied by the FLEX+T-matrix approximation (AF+SC). Results by the FLEX approximation (AF) is also shown. $T = 0.1$ corresponds to $300 \sim 400$K.

$$\Sigma_{\mathbf{k}}(\epsilon_n) = \Sigma^{\rm FLEX}_{\mathbf{k}}(\epsilon_n) + \Sigma^{\rm SCF}_{\mathbf{k}}(\epsilon_n), \quad (2)$$

where $\Sigma^{\rm FLEX}$ is given by the diagrams for the FLEX approximation, and $\Sigma^{\rm SCF}$ is given by the T-matrix ap-

[1] E-mail: kon@phy.saitama-u.ac.jp

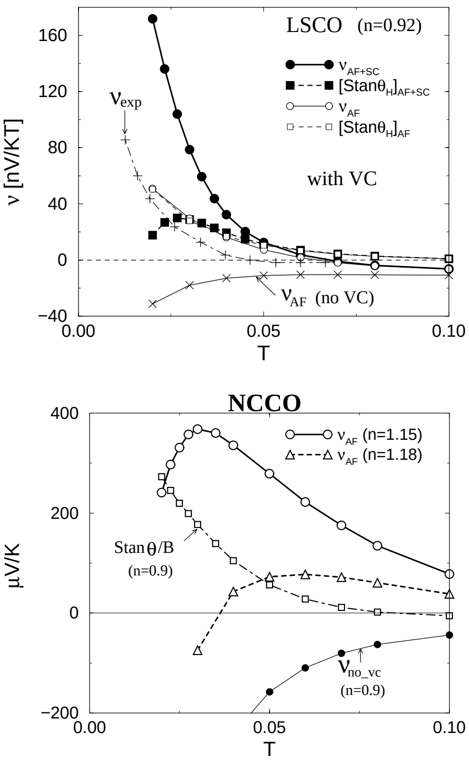

Fig. 2. ν and $S\tan\theta_{\rm H}$ given by the FLEX+T-matrix approximation (AF+SC) for LSCO and NCCO. $\nu_{\rm exp}$ is the experimental data for LSCO ($x = 0.07$) reported in ref.[1].

proximation. Namely, the former and the latter are given by the one-loop approximation in terms of the AF and d-SC fluctuations, respectively. $\epsilon^0_{\mathbf{k}}$ is the tight binding dispersion of a non-interacting electron, and ϵ_n is a Matsubara frequency for fermion. $\Sigma^{\rm FLEX}_{\mathbf{k}}(\epsilon_n)$ and $\Sigma_{\mathbf{k}}(\epsilon_n)$ are caused by the AF and SC fluctuations, respectively. The formalism for the FLEX+T-matrix approximation is explained in ref.[2] in detail.

In the present numerical study for the Hubbard model, we put $U = 4.5$ and $(t, t', t'') = (-1, 0.15, -0.05)$ for $La_{2-x}Sr_xCuO_4$ (LSCO). where t, t', t'' are the nearest, the next-nearest and the third-nearest neighbor hoppings, respectively. Figure 1 shows the staggered susceptibility (χ_Q) and the nuclear relaxation rates ($1/T_1T$, $1/T_{2g}$). As for $1/T_1T$, the pseudo-gap behavior is recognized below $T^* \approx 0.03$, which cannot be reproduced by the FLEX approximation.

2. Theory of Transport Phenomena

Next, we calculate various transport coefficients by using the FLEX+T-matrix approximation, in the framework of the conserving approximation. We calculate the VC's for electron current and the heat one self-consistently. by including all the Maki-Thompson-type diagrams given by both AF and SC fluctuations. The method of calculating the VC's is explained in ref.[2] and ref.[3] in detail.

Figure 2 shows the obtained Nernst coefficient (ν) and $S\tan\theta_{\rm H} \equiv S\sigma_{xy}/\sigma$ (S being the thermoelectric power) for LSCO and NCCO. First, we discuss the drastic enhancement of the Nernst coefficient below T^*, which is very mysterious and intriguing phenomenon in the pseudo-gap region. In fig. 2, $\nu_{\rm AF+SC}$ starts to increase drastically below T^*, and its magnitude is consistent with experimental values [1]. In contrast, $S\tan\theta_{\rm H}$ decreases at lower temperatures, reflecting the suppression of the AF fluctuations below T^*.

On the other hand, ν in the electron-doped compound (NCCO) is positive and very large below the room temperatures. As shown in fig. 2, the present study is also able to reproduce this behavior successfully.

We note that other transport quantities like the Hall coefficient, the magnetoresistance, and the thermoelectric power show anomalous temperature and doping dependences in high-$T_{\rm c}$ cuprates. They are well reproduced by the present study based on the FLEX+T-matrix approximation [2–5].

3. Conclusion

In conclusion, we studied the electronic properties and the transport phenomena in the pseudo-gap region using the FLEX+T-matrix approximation. Below T^* in hole-doped compounds, the Nernst coefficient increase drastically. In the present study, we could reproduce the characteristic behaviors of all the coefficients satisfactorily. Especially, the drastic increases of ν and $\Delta\rho/\rho$ are naturally explained as the quasiparticle origin, by taking the VC's due to the AF and SC fluctuations correctly. As a result, the present study gives the concrete evidence that the pseudo-gap region in high-T_c cuprates is well described as the Fermi liquid with strong AF and SC fluctuations.

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