Magnon scattering processes and low temperature resistivity in CMR manganites

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Low temperature resistivity of CMR manganites is investigated. At the ground state, conduction electrons are perfectly spin polarized, which is called half-metallic. From one-magnon scattering processes, it is discussed that the resistivity of a half metal as a function of temperature scales as \( \rho(T) - \rho(0) \propto T^3 \). We take \((\text{Nd}_{0.8}\text{Tb}_{0.2})_{0.6}\text{Sr}_{0.4}\text{MnO}_3\) as an example to compare theory and experiments. The result is in a good agreement.

1 Introduction.

One of the novel characters of colossal magnetoresistance (CMR) manganites is its half-metallic ground state \( [1] \). Due to the strong Hund’s coupling between localized \( t_{2g} \) spins and itinerant \( e_g \) electrons, conduction electrons are perfectly spin polarized at the ferromagnetic ground state \( [2] \). Half metallic natures of manganites are important to understand various properties of CMR manganites at low temperatures. Especially, spin valve mechanism of the inter-domain tunneling currents is considered to be the origin of the low field magnetoresistance phenomena in polycrystals \( [3] \) as well as heterojunctions \( [4] \).

Low temperature resistivity behavior is another feature of half metals. It has been first pointed out by Kubo and Ohata \( [5] \) that the perfect spin polarization of conduction electrons make a qualitative change in the scattering processes of charge carriers by magnon-electron interactions. Half metals
belong to a different universality class from conventional itinerant weak ferromagnets.

Let us discuss the detail of the magnon-electron scattering process through the temperature dependence of the resistivity in half metals. In conventional itinerant weak ferromagnets, one magnon scattering is the dominant process at low temperatures to give $T^2$ resistivity. However, for half metals, such a scattering process is prohibited at the ground state since the process involves low energy propagators of spin-flipped quasi-particles for the intermediate states. Based on a rigid band electronic structures of half metals, Kubo and Ohata discussed that the most dominant scattering process is the two-magnon scattering, which gives $T^{4.5}$.

At finite temperatures, however, it is necessary to take into account the effect of spin fluctuations which breaks down the perfect spin polarization. In the absence of spin gaps, magnetization deviates from its saturation values as $\delta M \propto T^{3/2}$ in three dimensions. In the strong Hund’s coupling limit, spin polarization of the conduction electrons are proportional to the total spin polarization. Namely, at finite temperatures, half-metallic structure of conduction electrons breaks down. As a consequence, the rigid band approaches should not be justified. Taking into account the non rigid band behavior due to spin fluctuations, one of the author (N.F.) derived that the most dominant contribution for the low temperature resistivity is from an unconventional one-magnon scattering processes. In this case, the resistivity is proportional to the product of following two quantities; (a) magnon population $\delta M$, and (b) density of states of the minority spin quasiparticles which should also scale as $\delta M$. As a consequence, we obtain

$$\rho(T) - \rho(0) \propto (\delta M)^2 \propto T^3.$$  \hspace{1cm} (1)

Experimentally, it has been reported that the low temperature resistivity for La$_{1-x}$Sr$_x$MnO$_3$ as well as Sm$_{0.6}$Sr$_{0.4}$MnO$_3$ scales as $T^3$, which is another evidence for the half-metallic behaviors of CMR manganites. In this paper, we investigate the temperature dependence of the resistivity in CMR manganite (Nd,Tb)$_{0.6}$Sr$_{0.4}$MnO$_3$ in detail as another candidate to investigate the half-metallic nature at low temperatures. From its resistivity as a function of temperature, we discuss the electronic structures as well as scattering processes in the low temperature region.
2 Low temperature resistivity in manganites.

Here we show the low temperature resistivity of a CMR manganite in the ferromagnetic metal region. Single crystal samples of $(Nd_{0.8}Tb_{0.2})_{0.6}Sr_{0.4}MnO_3$ are used for the resistivity measurement. Details of the sample preparation have been reported in ref. [8]. Curie temperature is estimated as $T_c \approx 200\text{K}$, which is substantially decreased from the value for $La_{0.6}Sr_{0.4}MnO_3$, $T_c \approx 400\text{K}$. This means that this compound is in the narrow bandwidth region.

In Fig. 1 we show the resistivity as a function of temperature. The data can be fitted in the form $\rho(T) - \text{const.} \propto T^3$ at the low temperature region. A crossover in temperature dependence is observed at $T^* \approx 50\text{K}$, above which the resistivity scales as $\rho(T) - \text{const.} \propto T^2$ at $T > T^*$. At the lowest temperature limit we see an upturn of the resistivity which presumably indicates the localization of carriers, as also seen in $La_{1-x}Sr_xMnO_3$ near the metal-
insulator transition \[\text{[1]}\]. Together with the fact that the value of the residual resistivity is large, the system seems to be substantially influenced by the randomness due to ternary mixture of A-site ions. Nevertheless, we see $T^3$ dependence of resistivity which indicates the robustness of the one-magnon scattering processes in half metals.

3 Discussion

Thus (Nd$_{0.8}$Tb$_{0.2}$)$_{0.6}$Sr$_{0.4}$MnO$_3$ show a common feature in low temperature resistivity as La$_{1-x}$Sr$_x$MnO$_3$ and Sm$_{0.6}$Sr$_{0.4}$MnO$_3$. In CMR manganites, phase controls have been performed through the chemical pressure effects in A-site substitutions. For the above example, $T_c$ varies from $T_c \sim 350\text{K}$ ((La,Sr)MnO$_3$) to $T_c \sim 120\text{K}$ ((Sm,Sr)MnO$_3$). This indicates that, once the ferromagnetic metal phases are stabilized, they share a common feature based on the half-metallic structure of conduction electrons. We also note that similar $T^3$ behavior in resistivity is reported for CrO$_2$ films \[\text{[10]}\], which is another candidate for a half metal. This work was supported by the Grant-In-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture.

References

[1] N. Furukawa: in Physics of Manganites, edited by T. Kaplan and S. Mahanti (Plenum Publishing, New York, 1999).

[2] C. Zener: Phys. Rev. 82 (1951) 403.

[3] H. Hwang, S.-W. Cheong, N. Ong and B. Batlogg: Phys. Rev. Lett. 77 (1996) 2041.

[4] J. Sun, W. Gallgher, P. Duncombe, L. Krushin-Elbaum, R. Altman, A. Gupta, Y. Lu, G. Gong and G. Xiao: Appl. Phys. Lett. 69 (1996) 3266.

[5] K. Kubo and N. Ohata: J. Phys. Soc. Jpn. 33 (1972) 21.

[6] I. Mannari: Prog. Theor. Phys. 22 (1959) 325.

[7] N. Furukawa: J. Phys. Soc. Jpn. 69 (2000) 1954.
[8] T. Akimoto, Y. Moritomo, A. Nakamura and N. Furukawa: Phys. Rev. Lett. in print, cond-mat/0009035.

[9] T. Okuda, A. Asamitsu, Y. Tomioka, T. Kimura, Y. Taguchi and Y. Tokura: Phys. Rev. Lett. 81 (1998) 3203.

[10] X. W. Li, A. Gupta, T. McGuire, P. Duncombe and G. Xiao: J. Appl. Phys. 85 (1999) 5585.