論文内容の要旨

論文題目

Anomalous transport properties in quasi-two dimensional heavy fermion systems near a quantum critical point
準２次元重い電子化合物の

量子臨界点近傍における異常輸送現象

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One of the most interesting and puzzling issues in the research of strongly correlated electron systems is anomalous transport phenomena. In conventional metals, the fundamental transport coefficients, such as the dc-resistivity, Hall coefficient, and magnetoresistance, are well-described by Landau Fermi liquid theory. The dc-resistivity ρ_{xx} which stems from electron-electron scattering varies as $\rho_{xx} \propto T^2$. The Hall coefficient R_H signifies the topology of Fermi surface and carrier density. It is given as $R_H = 1/ne$, where n is a carrier density, and is independent of temperature. The magnetoresistance due to an orbital motion of carriers obeys a simple scaling law, so-called "Kohler's rule", $\Delta\rho_{xx}/\rho_{xx}(0) = F(\mu_0 H/\rho_{xx}(0))$, where $\Delta\rho_{xx} \equiv \rho_{xx}(H) - \rho_{xx}(0)$ and $F(x)$ is a function depending on the details of the electronic structure.

Within the last decade, however, it has been found that in strongly correlated electron systems, including heavy fermion compounds, organics, and high-T_c cuprates, these transport coefficients show a striking deviation from Fermi liquid behavior. Such a non-Fermi liquid is remarkably observed when the system approaches in the vicinity of a quantum critical point (QCP). Among these materials, the electron transport properties in high-T_c cuprates have been studied most extensively. In the optimally doped region, the resistivity exhibits a T-linear dependence $\rho_{xx} \propto T$ in a wide temperature range. The Hall coefficient displays peculiar temperature and doping dependence and its value becomes much larger than $1/ne$ at low temperatures. It

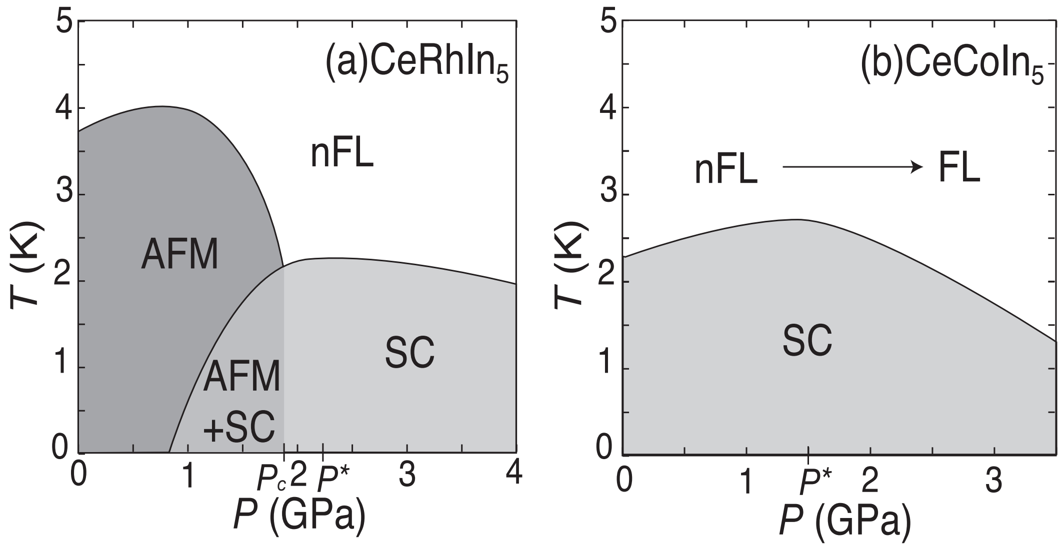

Figure 1: Schematic $P-T$ phase diagrams for (a) $CeRhIn_5$ and (b) $CeCoIn_5$. At $P \sim P^*$, a non-Fermi liquid liquid (nFL) to Fermi liquid (FL) crossover occurs and T_c reaches a broad maximum. In $CeRhIn_5$, P_c is a critical pressure which separates the AF metallic and superconducting state, indicating that the AF QCP is located at P_c. In $CeCoIn_5$, the AF QCP appears to be at a slightly negative inaccessible pressure.

has been pointed out that the Hall problem can be simplified when analyzed in terms of $\cot\Theta_H$, where $\Theta_H \equiv \tan^{-1}(\rho_{xy}/\rho_{xy})$ is the Hall angle and ρ_{xy} is the Hall resistivity. In high-T_c cuprates, the cotangent of Hall angle approximately varies as $\cot\Theta_H \equiv \rho_{xx}/\rho_{xy} \propto T^2$. The magnetoresistance violates Kohler's rule and a new scaling relation, $\Delta\rho_{xx}/\rho_{xx}(0) \propto \tan^2\Theta_H$, has been proposed to explain the temperature and field dependence of the magnetoresistance. Moreover, a giant enhancement of the Nernst coefficient ν_H, which is three orders of magnitude larger than that expected for conventional metals, is observed. Despite of many experimental and theoretical studies, a common agreement on the origin of the observed unusual transport properties is still lacking. A most important question is whether these anomalous transport properties are specific to high-T_c cuprates or represent universal features in the strongly correlated electron systems.

The resent discovery of heavy fermion compound $CeMIn_5$ (M = Co, Rh, and Ir) has attracted great interest in the strongly correlated systems. $CeMIn_5$ crystalizes in a quasi two-dimensional structure which can be viewed as alternating layers of $CeIn_3$ and MIn_2 stacked sequentially along c-axis. Figures 1 (a) and (b) show the schematic pressure-temperature phase diagram for $CeRhIn_5$ and $CeCoIn_5$, respectively. $CeRhIn_5$ is an antiferromagnetic (AF) metal with T_N = 3.8 K at ambient pressure. Above $P_c \simeq 2$ GPa, $CeRhIn_5$ shows superconductivity without long-range magnetic order, indicating an AF QCP. $CeCoIn_5$ and $CeIrIn_5$ are superconductors with $T_c = 2.3$ K and 0.4 K, respectively, at ambient pressure. It is speculated that $CeCoIn_5$ is located in the vicinity of the AF QCP, which is in a slightly negative pressure region. Below P^*, at which T_c shows a broad maximum, non-Fermi liquid behavior observed in transport or thermodynamic properties. On the other hand, at $P > P^*$ the non-Fermi liquid behavior is strongly suppressed and recovery of the Fermi liquid behavior is observed. $CeMIn_5$ bears some resemblance to high-T_c cuprates. The main Fermi surface is cylindrical and it is widely believed that the superconducting gap of $CeMIn_5$ has d-wave symmetry with line nodes perpendicular to the plane. The superconductivity occurs in the neighborhood of AF ordered state.

$CeMIn_5$ is very suitable for the detailed study of the tranpsport phenomena in strongly correlated systems. This is because the ground state can be tuned, ranging from the AF ordered state metal to the Fermi liquid state through the non-Fermi liquid state, by applying pressure without introducing additional scattering centers and with keeping the carrier number unchanged (Fig. 1 (a) and (b)). In addition, $CeMIn_5$ is in a very clean regime. In fact, the quasi particle mean free path in the superconducting state of $CeCoIn_5$ is as long as a few μm. This is important because the intrinsic transport properties relevant to the electron-electron correlation are often masked by the impurity scattering. Moreover, while anomalous Hall term due to skew scattering masks ordinary Hall effect in most heavy fermion systems, the skew scattering term in $CeMIn_5$ is absent or very small. This enable us to make a detailed study of normal Hall effect and magnetoresistance.

In order to clarify the anomalous transport properties observed in strongly correlated systems, we have performed the systematic studies of the dc-resistivity, Hall effect, and magnetoresistance for $CeMIn_5$ as a function of temperature, magnetic field, and pressure. We have revealed several unusual features in transport properties near the AF QCP in the present work. The amplitude of the Hall coefficient is dramatically enhanced with decreasing temperature and attains a value much larger than $1/|ne|$ at low temperatures. Furthermore, the magnetoresistance strongly violates the Kohler's rule. The resistivity shows T-linear dependence, the cotangent of Hall angle $\cot\Theta_H$ varies as $\cot\Theta_H \propto T^2$, and the magnetoresistance is well-scaled by the $\tan^2\Theta_H$. These anomalous transport properties are pronounced when the AF spin fluctuations are enhanced in the vicinity of the AF QCP, indicating that AF spin fluctuations strongly affect the transport phenomena. We have shown that the anomalous transport properties can be accounted for in terms of a resent spin fluctuation theory. All of the anomalous behavior of dc-resistivity, Hall effect, and magnetoresistance are well scaled by a single parameter, the AF correlation length ξ_{AF}, for a wide range of the parameters, temperature, magnetic field, and pressure. These anomalous behavior observed in the transport phenomena of $CeMIn_5$ bear a striking resemblance to the normal-state properties of high-T_c cuprates, indicating universal transport properties of strongly correlated quasi two-dimensional electron systems in the presence of strong AF fluctuations.