(29c3)

Extended Kadowaki-Woods relation in orbitally degenerate systems

Hiroshi Kontani

Department of Physics, Saitama University,
255 Shimo-Okubo, Sakura-ku, Saitama 338-8570, Japan

The Kadowaki-Woods (K-W) relation $A\gamma^{-2} \approx 10^{-5}$ [$\mu\Omega$cm(mol·K/mJ)^2], where A is the coefficient of the T^2 term in the resistivity and γ is the T-linear specific heat coefficient, is satisfied in many Ce- and U-based heavy Fermion (HF) systems as well as in d-electron heavy electron systems like LiV_2O_4 and A-15 compounds. Thus, the K-W relation has been considered as one of the remarkably robust signature of Fermi liquids, irrespective of the value of the effective mass m^*. Recently, however, various Fermi liquid systems which do not follow the K-W relation have been found experimentally. Especially, Tsujii et al. revealed that $A\gamma^{-2} \approx 0.4 \times 10^{-6}$ [$\mu\Omega$cm(mol·K/mJ)^2] in many Yb-based HF systems, which is about 20∼30 times smaller than the conventional K-W ratio. The origin of the violation of the K-W relation should be a very important and fundamental subject on the FL theory.

Here, we focus attention on the fact that materials with smaller $A\gamma^{-2}$ have *almost fully degenerate ground states*[1]. We present a theoretical study on the K-W relation in orbitally degenerate periodic Anderson model, within the dynamical-mean-field-approximation (DMFA). Based on the Fermi liquid theory, we derive *the generalized K-W relation in the strong coupling limit* ($m^*/m_{\rm band} \gg 1$) as follows [2]:

$$\begin{aligned} A\gamma^{-2} &= \frac{h}{e^2 k_{\rm B}^2} \cdot \frac{9(3\pi^2)^{-1/3}}{n^{4/3} a^3 N_{\rm A}^2} \frac{1}{\frac{1}{2}N(N-1)} \\ &\approx \frac{1 \times 10^{-5}}{\frac{1}{2}N(N-1)} \quad \mu\Omega{\rm cm}[{\rm mol} \cdot {\rm K/mJ}]^2, \end{aligned} \tag{1}$$

where N is the f-orbital degeneracy. Here, we put $h/e^2 = 2.6 \times 10^4\ \Omega$, $k_{\rm B} = 1.38 \times 10^{-23}$ JK^{-1}, and assumed that $n^{-1/3} \approx a \approx 1 \times 10^{-8}$cm ($a$ being the lattice spacing). According to eq. (1), $A\gamma^{-2} \approx 1 \times 10^{-5}\mu\Omega{\rm cm}[{\rm mol} \cdot {\rm K/mJ}]^2$ for $N = 2$ ($J = 1/2$), which corresponds to the Kramers doublet ground state case due to strong CEF. On the other hand, $A\gamma^{-2} \approx 0.36 \times 10^{-6}\mu\Omega{\rm cm}[{\rm mol} \cdot {\rm K/mJ}]^2$ for $N = 8$ ($J = 7/2$), which corresponds to Yb-based HF systems with weak CEF. This result is consistent with the experiment reported in ref.[1]. The *generalized K-W relation* proposed in the present work is confirmed in various HF compounds with $N = 2 \sim 8$ [3]. Its importance will increase further as various new compounds with orbital degeneracy are discovered in future.

In $PrOs_2Sb_{12}$, $A\gamma^{-2} \approx 0.0075 \times 10^{-5}\mu\Omega{\rm cm}[{\rm mol} \cdot {\rm K/mJ}]^2$ is observed in the absence of the magnetic field B, which is more than 100 times smaller than the conventional K-W ratio. Interestingly, in the field-induced ordered state under B ∼5T, $A\gamma^{-2} \approx 1 \times 10^{-5}\mu\Omega{\rm cm}[{\rm mol} \cdot {\rm K/mJ}]^2$ is observed. We will discuss this mysterious phenomena from the viewpoint of the orbital degeneracy.

[1] N. Tsujii, K. Yoshimura and K. Kosuge: J. Phys. Condens. Matter **15** (2003) 1993.
[2] H. Kontani: cond-mat/0308484.
[3] N. Tsujii, H. kontani and K. Yoshimura: in preparation.