

Preface

We present a recent advancement in the theory of transport phenomena based on the Fermi liquid theory. In conventional metals, various transport coefficients are scaled by the quasiparticles relaxation time, τ , which implies that the relaxation time approximation (RTA) holds well. However, such a simple scaling does not hold in many strongly correlated electron systems, reflecting their unique electronic states. The most famous example would be cuprate high- T_c superconductors (HTSCs), where almost all the transport coefficients exhibit a significant deviation from the RTA results. Similar anomalous transport phenomena have been observed in metals near their antiferromagnetic (AF) quantum critical points (QCPs). Now, we have to demonstrate whether the anomalous transport phenomena in HTSC is the evidence of non-Fermi liquid ground state, or it is just the violation of the RTA in strongly correlated Fermi liquids. For these purpose, we develop a method for calculating various transport coefficients beyond the RTA by employing field theoretical techniques.

In a Fermi liquid, collisions between excited quasiparticles induce a finite current in the Fermi sea, which is called current vertex correction (CVC). The existence of CVC was first noticed by Landau. On the basis of the Fermi liquid theory, we develop a transport theory involving resistivity and Hall coefficient by including the CVC to satisfy the conservation laws. We find that the CVC exhibits singular momentum dependence in a nearly AF Fermi liquid, which is induced by the strong backward scattering due to AF fluctuations. Evidently, this fact explains the significant enhancement in the Hall coefficient, magnetoresistance, thermoelectric power, and Nernst coefficient in nearly AF metals. This fact strongly suggests the validity of the Fermi liquid description of HTSCs for a wide range of doping; from over-doped to slightly under-doped regime. Further, the present theory can explain very similar anomalous transport phenomena occurring in CeMIn_5 ($M = \text{Co}$ or Rh), which is a heavy-fermion system near the AF QCP, and in the organic superconductor κ -(BEDT-TTF).

In this text, we also discuss the interesting spin-related transport phenomena that are widely observed in various d - and f -electron systems. In multiband systems with spin-orbital interaction, the Bloch electron acquires the trajectory- and

spin-dependent Berry phase, which works as the spin-dependent outer magnetic field. This mechanism presents the anomalous Hall effect (AHE) in ferromagnetic metals and spin Hall effect (SHE) in paramagnetic metals. The Hall conductivity due to this mechanism is independent of τ , in highly contrast to the ordinary Hall conductivity $\sigma_{xy}^{\text{ord}} \propto \tau^2$. Due to this fact, the SHC and AHE are called the quantum transport phenomena. In Part I, we explain how to calculate these quantum transport phenomena based on the Nakano-Kubo formula. In Part II, we study the “giant SHE” that are recently observed in various transition metals, which attracts great attention for the application of the spintronics. We also study the “spin-structure-driven AHE” realized in several pyrochlore compounds.

Recently, various new strongly correlated compounds with spin and orbital degrees of freedoms had been synthesized intensively, by which the condensed matter physics acquires rich variety. One of the example is the Fe-based HTSC discovered by Kamihara and Hosono in 2008. We hope that the present text would be helpful in developing the modern transport theory for these new materials.

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