ELECTRON CORRELATION IN METALS

Since the discovery of high T_c superconductivity, the role of electron correlation in superconductivity has been an important new issue in condensed matter physics. Here the role of electron correlation in metals is explained in detail on the basis of the Fermi liquid theory. The book discusses the following issues: enhancements of electronic specific heat and magnetic susceptibility; effects of electron correlation on transport phenomena such as electric resistivity and Hall coefficient; magnetism; Mott transition and unconventional superconductivity. These originate commonly from the coulomb repulsion between electrons. In particular, superconductivity in strongly correlated electron systems is discussed with a unified point of view. This book is written to explain interesting physics in metals for undergraduate and graduate students and researchers in condensed matter physics.

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Preface

P. W. Anderson has achieved many brilliant theories in the wide field of condensed matter physics. His book titled *Basic Notions of the Condensed Matter Physics* was published in 1984. In this book Anderson stresses two basic principles of condensed matter physics. One of the principles is ‘broken symmetry’. This means that condensed matter systems undergo phase transition to take a state possessing lower symmetry than that of the Hamiltonian. This statement corresponds to the appearance of a ferromagnetic state and a superconducting state, etc. at low temperatures. This principle manifests discontinuous change.

Another basic principle is the principle of ‘adiabatic continuity’. This principle tells us that when we study a generally complicated physical system we can refer to a simple system that contains the essential nature of the real system and understand the complicated system on the basis of knowledge of the simple system. Anderson stresses that the most beautiful and appropriate example showing the importance of the continuity principle is Landau’s Fermi liquid theory. Following the continuity principle, we start from a non-interacting Fermi gas and introduce interactions among particles gradually. There exists a one-to-one correspondence between the free particle system before the introduction of the interactions and the Fermi liquid after the introduction. It is the basic character of the Fermi liquid at low temperatures that we can introduce interactions as slowly as possible owing to the long lifetime of quasi-particles. Even though many-body interactions exist among particles, by considering quasi-particles renormalized by the interactions we can treat them as if they are free particles. By this procedure strongly interacting Fermi systems are much simplified. Strictly speaking, however, the systems cannot be completely free particle systems even after renormalization; there remain damping effects giving a finite lifetime and weak renormalized interactions among quasi-particles. In particular, since attractive forces make the Fermi surface unstable, it is only the repulsive force that can be continuously renormalized on the basis of the Fermi liquid theory. This fact plays an important role in many-body problems.

After reducing systems to weakly interacting quasi-particle systems following the Fermi liquid theory, we can then discuss phase transitions such as superconductivity, induced by the renormalized interactions among quasi-particles.

Fermi liquid theory, which was introduced by Landau for liquid ^{3}He, has been applied to electrons in metals and developed. Along with progress in the electron theory of solids, strongly interacting electron systems have been studied actively for various metals. By this development, the Fermi liquid theory has been made profound and based on microscopic foundations. After completion of the many-body theory of electron gas and the BCS theory of superconductivity, in the 1960s magnetism of transition metals and Mott transitions of their oxides were studied as main issues of electron correlation. Then, the discovery of the Kondo effect and the study of the Anderson Hamiltonian relating to the appearance and disappearance of localized moments in metals followed. Recently, we have studied heavy electrons whose masses are thousands of times as large as the free electron mass. These electrons are nothing but the quasi-particles in the Fermi liquid theory. Our present subject in electron correlation is the study of copper-oxide superconductors as metallic systems near the Mott insulator. These are called strongly correlated electron systems. The normal state of strongly correlated electron systems can be described as the Fermi liquid. In recent years it has been made clear that the Fermi liquid theory contains various fruitful physical properties. At present the Fermi liquid theory is in the course of development.

The Hubbard Hamiltonian contains a wealth of physics, such as metal–insulator transitions and magnetic transitions. Although the theory of the Hubbard Hamiltonian has been greatly developed, as seen in the study of the Mott transition using an infinite-dimensional model, we are still far from a complete understanding. Recently, the new problem of whether the Hubbard system can exhibit superconductivity has been added, as an important problem to be solved. In this book we show that superconductivity is actually realized owing to electron correlation in the Hubbard Hamiltonian.

The purpose of this book is to introduce the Fermi liquid theory and to describe the physics of strongly correlated electron systems. I intend to introduce unique and rich physical phenomena in each system mentioned above; I would like to describe the universality of the Fermi liquid and the basic principles common to various systems. At this point, I believe there exists a powerful theory that is not changed by details of experimental data. Nature is much more complicated than we can imagine, but it is not capricious.

To accomplish the purpose of this book, I intend to introduce the microscopic Fermi liquid theory developed by Luttinger *et al.* and describe the concepts confirmed through its development, although I am not sure whether I have succeeded in this task or not.

I am grateful to Professor Kei Yosida for valuable discussions over the course of 30 years. I should like to thank Drs Hiroshi Kontani and Hiroaki Ikeda for valuable discussions and comments during the preparation of this book. Professor Veljko Zlatić also gave me valuable advice.

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