Preface

The measurements of the Hall coefficient R_H and the Seebeck coefficient (thermopower) S are known to give the sign of the carrier charge q. Sodium (Na) forms a body-centered cubic (BCC) lattice, where both R_H and S are negative, indicating that the carrier is the "electron." Silver (Ag) forms a face-centered cubic (FCC) lattice, where the Hall coefficient R_H is negative but the Seebeck coefficient S is positive. This complication arises from the Fermi surface of the metal. The "electrons" and the "holes" play important roles in conducting matter physics. The "electron" ("hole"), which by definition circulates counterclockwise (clockwise) around the magnetic field (flux) vector $\mathbf{B}$ cannot be discussed based on the prevailing equation of motion in the electron dynamics: $\hbar\, d\mathbf{k}/dt = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$, where $\mathbf{k} = k$-vector, $\mathbf{E} =$ electric field, and $\mathbf{v} =$ velocity. The energy-momentum relation is not incorporated in this equation.

In this book we shall derive Newtonian equations of motion with a symmetric mass tensor. We diagonalize this tensor by introducing the principal masses and the principal axes of the inverse-mass tensor associated with the Fermi surface. Using these equations, we demonstrate that the "electrons" ("holes") are generated, depending on the curvature sign of the Fermi surface. The complicated Fermi surface of Ag can generate "electrons" and "holes," and it is responsible for the observed negative Hall coefficient R_H and positive Seebeck coefficient S. When the Fermi surface is nonspherical, the conduction electron moves anisotropically with different effective masses (m_1, m_2, m_3). The magnetic oscillations in the susceptibility χ and the magnetoresistance arise from the oscillatory density of states assocated with the Landau states upon the application of a magnetic field. The most direct probe of the Fermi surface can be made by observing the cyclotron resonance. A magnetic field is applied to a pure sample at liquid helium temperatures. The sign of the charge carrier can be determined by using the circularly polarized lasers. The data are analyzed in terms of Shockley's formula or its simplified version. Most often, the intrinsic effective masses for a semiconductor or metal can be determined directly after simple analyses.

In the present volume, we mainly deal with the behaviors of the fermionic conduction electrons. In the companion volume, called book2 in the text, superconductivity and quantum Hall effect are treated. The charge carriers in the supercurrent are the Cooper pairs, each composed of a pair of electrons bound by the phonon exchange attraction. The statistics of a composite particle with respect to the center-of-mass motion follows Ehrenfest–Oppenheimer–Bethe's rule: a composite moves as a fermion (boson) if it contains an odd (even) number of elementary fermions. Accordingly the Cooper pair moves as a boson since the pair contains two electrons. The different statistics generate very different behavior. The quantum Hall effect arises from the supercurrent generated in a two-dimensional system subject to a magnetic field.

The text is composed of three parts: preliminaries, Bloch electron dynamics, and applications (fermionic systems). Part I, Chapters 1 through 6, starts with an introduction and then deals with the phonons (quanta of lattice vibrations), the free-electron model, the kinetic theory of electron transport, the magnetic susceptibility, and the Boltzmann equation method. These materials are normally covered in introductory solid-state physics courses; however, they are prerequisite to the theoretical developments in Part II, Chapters 7 through 10. The Bloch theorem, the self-consistent mean field theory, the Fermi surface, the Bloch electron (wave packet) dynamics with Newtonian equations of motion are discussed in Part II. In Part III, Chapters 11 through 15, a selection of applications for fermionic systems (mostly electrons) are discussed: the de Haas–van Alphen oscillations in susceptibility, the Shubnikov–de Haas oscillations in magnetoresistance, the angle-dependent cyclotron resonance, the Seebeck coefficient arising from the thermal diffusion, and the infrared-laser Faraday rotation.

The present book is written for first-year graduate students in physics, chemistry, electrical engineering, and material sciences. Dynamics, quantum mechanics, thermodynamics, statistical mechanics, electromagnetism, and solid-state physics at the undergraduate level are prerequisite. The authors believe that the students should learn physics, starting from the bottom up and following all theoretical developments with step-by-step calculations. We have included many problems, most of them elementary excercises in the text. The students learn key concepts more firmly by working out these problems.

The prevalent equations of motion for the electron in a crystal is challenged in this book, but all arguments leading to the new equations of motion are based on the principles of quantum statistical mechanics (Heisenberg uncertainty and Pauli exclusion principles). Condensed matter physicists, chemists, and material scientists, theoretical and experimental, are invited to examine this text.

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Shigeji Fujita, Buffalo, New York, USA
and
Kei Ito, Tokyo, Japan
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