Fundamentals of Condensed Matter Physics

Based on an established course and covering the fundamentals, central areas, and contemporary topics of this diverse field, *Fundamentals of Condensed Matter Physics* is a much-needed textbook for graduate students.

The book begins with an introduction to the modern conceptual models of a solid from the points of view of interacting atoms and elementary excitations. It then provides students with a thorough grounding in electronic structure and many-body interactions as a starting point to understanding many properties of condensed matter systems – electronic, structural, vibrational, thermal, optical, transport, magnetic, and superconducting – and the methods used to calculate them.

Taking readers through the concepts and techniques, the text gives both theoretically and experimentally inclined students the knowledge needed for research and teaching careers in this field. It features over 246 illustrations, 9 tables and 100 homework problems, as well as numerous worked examples, for students to test their understanding.

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To Suzy and Jane

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Preface

The field of condensed matter physics is the largest branch of physics worldwide and probably the most diverse. Undergraduate courses in this area are ubiquitous and most research universities offer graduate courses. Over the past 50 years, the undergraduate course has been open to physicists, chemists, materials scientists, engineers, and, to a smaller extent, biologists. The graduate course slowly evolved in many institutions from a course for theorists to one that welcomed students interested in a career in experimental condensed matter physics and materials research. In recent years, the proportion of chemists, materials scientists, engineers, and researchers in nanoscience has increase significantly in graduate courses in condensed matter physics.

There are numerous undergraduate texts. The prime example is *Introduction to Solid State Physics (ISSP)* authored by C. Kittel. At the graduate level, no single text has emerged as the canonical choice. N. Ashcroft and N. D. Mermin's book *Solid State Physics* is sometimes chosen since it contains advanced topics going beyond Kittel's *ISSP*, although Ashcroft & Mermin is often used as an undergraduate text. J. Ziman's *Principles of the Theory of Solids* is at roughly the same level as Ashcroft & Mermin, with excellent physical examples and discussions of concepts. C. Kittel's *Quantum Theory of Solids,* which was written for the graduate course at the University of California, Berkeley, at a time when students taking the course were predominantly theorists, is somewhat limited in scope and generally considered difficult by graduate students not intent on a career in theoretical condensed matter physics. Other texts, such as those by J. Callaway, O. Madelung, M. Marder, and J. Patterson and B. Bailey, are considered to be at the right level and suitable. Many others are in the recommended, but not required, category and are useful when specific subjects are considered. Examples include those authored by E. Kaxiras, R. Martin, M. Balkanski and R. Wallis, P. Yu and M. Cardona, and M. Cohen and J. Chelikowsky for electronic and optical properties of solids; M. Tinkham, P. de Gennes, and R. Schrieffer for superconductivity; G. Mahan for many-particle physics; and P. Chailken and T. Lubensky for phase transitions and soft matter systems. There are also many other excellent texts on specific subjects in this field.

The present text, *Fundamentals of Condensed Matter Physics*, is intended to cover the "mainstream" subjects in this field at the graduate level. It is probably impossible to produce a book that fills the complete bill for a course, as J. D. Jackson's E&M text has done for electricity and magnetism, because the range of topics is so broad. To cover the whole field would require many volumes. Hence the intent here is to write a text that covers the central topics on a level that will prepare a student to enter research, and that can serve as a higher-level source to sit alongside undergraduate texts for researchers in this field.

This text is based on lectures given as part of the condensed matter physics graduate course at Berkeley since 1965. The course, called Physics 240A and B, is a two-semester (or three-quarter) course covering 90 hours of lectures. In addition, there is a weekly discussion section for going over problem sets. Over the decades, this course was taught by one of the authors, either Marvin L. Cohen or Steven G. Louie, with guest lecturers from time to time. Student evaluations of the course have been high. The class size has typically been 20–30 students plus auditors. Of the more than one thousand students who took this course, a fair number have taken academic positions and have reported back that they have used their course notes successfully to teach similar courses in various departments including physics, chemistry, materials science, and engineering.

The book is divided into four main parts. Part I is devoted to the development of basic concepts. It begins with an introduction to the modern conceptual models of a solid from the points of view of (i) interacting atoms and (ii) elementary excitations, and then develops a thorough grounding on the basic elements needed to understand many of the properties of solids and the methods used to calculate them. Part II concerns the fundamentals of electron interactions, electron dynamics, and response functions, that control and exhibit the properties of and phenomena in condensed matter. Parts III and IV focus on the different properties and phenomena that are central to modern condensed matter and materials research. These include vibrational, thermal, optical, and transport properties, superconductivity, magnetism, and lower-dimensional systems, with emphasis on developing a physical understanding of real material systems. A range of theoretical techniques is developed as needed. The mathematical level varies, as does the degree of detail, in a manner similar to what one would experience in the world of research. Topics and techniques, such as band structure methods, pseudopotentials, density functional theory, effective Hamiltonians, electron dynamics, dielectric functions, electron–electron and electron–hole interactions, Berry's phase, Boltzmann transport theory, optical response, cooperative phenomena, many-body Green's functions, and diagrammatic and quasiparticle approaches, are explored and motivated by "real problems" associated with understanding and calculating material properties. Experimental techniques are described but not in detail.

Because of the breadth of the field and the limitation to one volume, some subjects are not treated in depth and others are left out completely. However, the success of the course at Berkeley, and hopefully this text, is that it takes a student through the concepts and techniques for many central areas of condensed matter physics, and establishes the level needed to start current research. Hence, the intent is to take students with a good knowledge of graduate quantum mechanics and undergraduate condensed matter physics to a level where they can do cutting-edge research. The book is suitable for a one-semester course (covering most of Parts I and II and some selected topics in Parts III and IV) or a two-semester course (covering essentially all of Parts I–IV with the option of omitting some topics as desired by the instructor).

This book would not have been possible without help from many people. We would especially like to thank Ms. Katherine de Raadt for her help with editorial matters and for producing the manuscript. We would like to acknowledge Cheol-Hwan Park for some of his class notes from the Berkeley course, David Penn for suggestions and critical readings of part of the text, Felipe Jornada and Sangkook Choi for producing most of the figures and for useful suggestions, and Meng Wu for his contributions in producing the problem sections. We profited from helpful corrections of the various chapters of the text by Gabriel Antonius, Brad Barker, Ting Cao, Sinisa Coh, Zhenglu Li, Jamal Mustafa, Chin-Shen Ong, Diana Qiu, Liang Tan, and Derek Vigil-Fowler. Finally, we thank Simon Capelin of Cambridge University Press for his guidance and patience.

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