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凝聚态物理

（影印版）

〔美〕米斯拉（P. K. Misra）著

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序　言

物理学是研究物质、能量以及它们之间相互作用的科学。她不仅是化学、生命、材料、信息、能源和环境等相关学科的基础，同时还是许多新兴学科和交叉学科的前沿。在科技发展日新月异和国际竞争日趋激烈的今天，物理学不仅囿于基础科学和技术应用研究的范畴，而且在社会发展与人类进步的历史进程中发挥着越来越关键的作用。

我们欣喜地看到，改革开放三十多年来，随着中国政治、经济、教育、文化等领域各项事业的持续稳定发展，我国物理学取得了跨越式的进步，做出了很多为世界瞩目的研究成果。今日的中国物理正在经历一个历史上少有的黄金时代。

在我国物理学科快速发展的背景下，近年来物理学相关书籍也呈现百花齐放的良好态势，在知识传承、学术交流、人才培养等方面发挥着无可替代的作用。从另一方面看，尽管国内各出版社相继推出了一些质量很高的物理教材和图书，但系统总结物理学各门类知识和发展，深入浅出地介绍其与现代科学技术之间的渊源，并针对不同层次的读者提供有价值的教材和研究参考，仍是我国科学传播与出版界面临的一个极富挑战性的课题。

为有力推动我国物理学研究、加快相关学科的建设与发展，特别是展现近年来中国物理学者的研究水平和成果，北京大学出版社在国家出版基金的支持下推出了“中外物理学精品书系”，试图对以上难题进行大胆的尝试和探索。该书系编委会集结了数十位来自内地和香港顶尖高校及科研院所的知名专家学者。他们都是目前该领域十分活跃的专家，确保了整套丛书的权威性和前瞻性。

这套书系内容丰富，涵盖面广，可读性强，其中既有对我国传统物理学发展的梳理和总结，也有对正在蓬勃发展的物理学前沿的全面展示；既引进和介绍了世界物理学研究的发展动态，也面向国际主流领域传播中国物理的优秀专著。可以说，“中外物理学精品书系”力图完整呈现近现代世界和中国物理

科学发展的全貌，是一部目前国内为数不多的兼具学术价值和阅读乐趣的经典物理丛书。

“中外物理学精品书系”另一个突出特点是，在把西方物理的精华要义“请进来”的同时，也将我国近现代物理的优秀成果“送出去”。物理学科在世界范围内的重要性不言而喻，引进和翻译世界物理的经典著作和前沿动态，可以满足当前国内物理教学和科研工作的迫切需求。另一方面，改革开放几十年来，我国的物理学研究取得了长足发展，一大批具有较高学术价值的著作相继问世。这套丛书首次将一些中国物理学者的优秀论著以英文版的形式直接推向国际相关研究的主流领域，使世界对中国物理学的过去和现状有更多的深入了解，不仅充分展示出中国物理学研究和积累的“硬实力”，也向世界主动传播我国科技文化领域不断创新的“软实力”，对全面提升中国科学、教育和文化领域的国际形象起到重要的促进作用。

值得一提的是，“中外物理学精品书系”还对中国近现代物理学科的经典著作进行了全面收录。20 世纪以来，中国物理界诞生了很多经典作品，但当时大都分散出版，如今很多代表性的作品已经淹没在浩瀚的图书海洋中，读者们对这些论著也都是“只闻其声，未见其真”。该书系的编者们在这方面下了很大工夫，对中国物理学科不同时期、不同分支的经典著作进行了系统的整理和收录。这项工作具有非常重要的学术意义和社会价值，不仅可以很好地保护和传承我国物理学的经典文献，充分发挥其应有的传世育人的作用，更能使广大物理学人和青年学子切身体会我国物理学研究的发展脉络和优良传统，真正领悟到老一辈科学家严谨求实、追求卓越、博大精深的治学之美。

温家宝总理在 2006 年中国科学技术大会上指出，“加强基础研究是提升国家创新能力、积累智力资本的重要途径，是我国跻身世界科技强国的必要条件”。中国的发展在于创新，而基础研究正是一切创新的根本和源泉。我相信，这套“中外物理学精品书系”的出版，不仅可以使所有热爱和研究物理学的人们从中获取思维的启迪、智力的挑战和阅读的乐趣，也将进一步推动其他相关基础科学更好更快地发展，为我国今后的科技创新和社会进步做出应有的贡献。

“中外物理学精品书系”编委会　主任
中国科学院院士，北京大学教授
王恩哥
2010 年 5 月于燕园

Physics of Condensed Matter

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For Swayamprava, Debasis, Moushumi, Sandeep,
and Annika, Millan, Kishen, Nirvaan

Preface

This textbook is designed for a one-year (two semesters) graduate course on condensed matter physics for students in physics, materials science, solid state chemistry, and electrical engineering. It can also be used as a one-semester course for advanced undergraduate majors in physics, materials science, chemistry, and electrical engineering, and another one-semester course for graduate students in these areas. The book assumes a working knowledge of quantum mechanics, statistical mechanics, electricity and magnetism, and Green's function formalism (for the second-semester curriculum). The book is written as a two-semester graduate-level textbook, but it can also be used as a reference book by faculty and other researchers actively engaged in research in condensed matter physics. With judicious choice of topics, the book can be divided into two parts: "Fundamental Concepts" designed to be taught in the first semester, and "Research Applications" to be taught in the second semester. Obviously, the first part can be taught to advanced undergraduate majors as an introductory course.

The later chapters are self-contained. Each research topic has a brief introduction, a review, and a summary of basic foundations for advanced research. This is done with the belief that the students will develop the skills and will be sufficiently prepared to develop an interest in one of the vast areas of the topics covered under the umbrella of "condensed matter physics." In fact, this wide diversity of topics, the research on which has been increasing exponentially during the past decade, makes it nearly impossible to write a two-semester textbook for graduate students. Probably that is the reason for a dearth of graduate-level textbooks in condensed matter physics. This has led to an increasingly difficult task for the instructor because he or she has to prepare notes from a variety of textbooks, reference books, and review articles, especially to teach in the second-semester graduate level.

There has been slow but steady growth in the area of solid state physics after it was recognized as a separate branch of physics around 1940, probably after the publication of the book *The Modern Theory of Solids* by Seitz. The main reason for this growth is solid state physics is essentially the applied branch of physics with a variety of technological applications and has attracted students from other disciplines. The slow but steady growth accelerated in the 1960s because of extensive research funding due to the space program, and eventually solid state physics became the major branch of physics attracting the maximum number of faculty and students. The American Physical Society officially changed the name of its largest group from "Solid State Physics" to "Condensed Matter Physics," thereby including liquids and other soft materials. This change in 1978 has led to explosive growth in condensed matter physics during the past 30 years, and the material for supplementing the available textbooks has risen exponentially. In addition, research in various areas has accelerated rapidly, fueled by grants and a need for fast development in computer memory and storage as well as other applications of nanoscience and nanotechnology. The subject, which has now become multidisciplinary, includes materials science, solid state chemistry, and electrical engineering.

Recently, I wrote a book called *Heavy-Fermion Systems*, which is a part of the book series "Handbook of Metal Physics," of which I am the series editor. A large number of distinguished physicists and chemists contributed to the book series and I have learned much while editing their work. These are advanced research–level books, but it became obvious that there is a need for a one-year (two-semester) graduate-level textbook in condensed matter physics that includes material on some of the new topics covered in this book series as well as in many other advanced research–level books and research reviews in prestigious journals. A graduate student should have the choice to select a topic for research after being taught in the classroom in order to acquire enough background on the topic. I have endeavored to do just that in this textbook, which has been limited to 18 chapters and 3 appendices. The project has taken several years, much longer than I had originally planned. I have learned a lot during this period, including the fact that the boundaries between the various disciplines in physics, chemistry, electrical engineering, and materials science are getting blurred.

The book has three objectives:

1. To present a coherent, clear, and intelligible picture of simple models of crystalline solids in the first few chapters. The properties of real solids, which are more complicated, are dealt with in later chapters. The more advanced topics are dealt with in the later part of each chapter (after the first few introductory chapters). Each chapter includes a collection of problems in order to enable students to have a grasp of the topics taught in the chapter. The problems at the end of each chapter are designed to make the students derive some of the formulas of analytical development with no intrinsic interest. The objective is to keep the book within a reasonable length, but more importantly, with the belief that the mathematical steps are better understood if they are derived by the students with the aid of hints and suggestions. In the second part of the book (Research Applications), some of the problems at the end of the chapter are extensions of the advanced topics covered in the chapter. In this part, some other problems are designed to make the applications of the topics more clear. It is up to the instructor to choose and assign the problems, and some instructors have their own list of problems. However, students should at least read all the problems even if they do not have any motivation or intention to solve them.
2. To present a comprehensive account of the modern topics in condensed matter physics by including introductory accounts of the areas where intense research is going on at present. To be able to do so, I have included chapters on Spintronics (Chapter 11), Heavy Fermions (Chapter 15), Metallic Nanoclusters (Chapter 16), and Novel Materials (Chapter 18). In addition, I have included sections on ZnO (Section 9.9), graphene (Section 10.7), graphene-based electronics (Section 10.8), quantum hall effect (Section 12.5), fractional quantum hall effect (Section 12.6), high-temperature superconductivity (Section 14.9), liquid ^{3}He (Section 17.3), and quasicrystals (Section 17.5). Most of these topics are normally not included in standard textbooks in condensed matter physics. In fact, condensed matter physics is rapidly growing as an interdisciplinary subject because of its application in nanoscience and other areas of fast-growing science and technology. The objective of this book is to present the fundamental concepts as well as the methods for advanced research in this area.
3. To keep the size of the book within a reasonable length so that it can be taught as a two-semester course, I have avoided too many diagrams as well as excluded material not usually taught but included in most standard textbooks. I have also avoided including too many tables that list the properties of solids because these can be easily found in books specifically designed to provide such information. In addition, I have made a comprehensive review of many important topics such as band-structure calculations (Chapter 5), but left the details for students to learn if they are interested in doing research involving such topics.

I have consulted a large number of research papers and books while writing this textbook. It is not possible to acknowledge all these books and research papers at the appropriate places as is usually done in advanced research–level books. I have acknowledged whenever I have reprinted a figure with the permission of the author/publisher from a research paper published in a research journal or a book. I have also acknowledged at appropriate places whenever I have used any material published in research journals. There is a list of references at the end of each chapter where I have acknowledged the books and research papers I have used as primary sources of reference while writing this textbook.

ACKNOWLEDGMENTS

I learned the skills to do research in theoretical solid state physics from Professor Laura M. Roth who was my Ph.D. advisor at Tufts University. I have improved those skills by working as a postdoctoral research associate with Professor Leonard Kleinman of the University of Texas at Austin. I learned a lot of basic techniques as well as gained physical insight to solve a variety of research problems during my 10 years of collaboration with late Professor Joseph Callaway of Louisiana State University. I am also thankful to Professor S. D. Mahanti of Michigan State University with whom I have collaborated and published several important research papers on applications of many-body theory. I am thankful to the distinguished physicists and chemists who have contributed to the book series "Hand Book of Metal Physics," of which I had the privilege to be the Series Editor. I am thankful to the large number of colleagues and friends with whom I have consulted while writing this book, especially on their opinion as to what subjects should be included in a two-semester graduate-level textbook. I am also thankful to the graduate students who have worked on their Ph.D. theses under my supervision, for their patience as well as confidence in my ability to simultaneously work on a variety of research topics in condensed matter physics.

I am grateful to Ms. Patricia Osborn, Acquisitions Editor for Mathematics and Physics at Elsevier, who has made many helpful suggestions as well as helped me whenever I have requested her. She has been very gracious and prompt in her replies to my numerous questions. This book could not have been published without her help and support. I am grateful to Mr. Gavin Becker, Assistant Editor of Mathematics and Physics at Elsevier, for his help. I am also grateful to Ms. Sarah Binns, Associate Project Manager at Elsevier, for helping me at every step in successfully completing this book.

I am particularly grateful to Professor Larry Pinsky (Chair) and Professor Gemunu Gunaratne (Associate Chair) of the Department of Physics of the University of Houston for their hospitality, encouragement, and continuing help. I am also grateful to Professor C. S. Ting of the Centre of High T_c at the University of Houston for his friendship and generosity.

Finally, I express my gratitude to my wife and children who have loved me all these years even though I have spent most of my time in the physics department(s) learning physics, doing research, supervising graduate students and post-docs, publishing research papers, writing grant proposals and books, as well as editing a book series on Metal Physics. There is no way I can compensate for the lost time except to dedicate this textbook to them. I am thankful to my daughter-in-law Roopa, who has helped me significantly in my present endeavor. My fondest hope is that when my grandchildren Annika and Millan attend college in 2021 and Kishen and Nirvaan in 2024, at least one of them would be attracted to study condensed matter physics when they see this book in their college library.

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