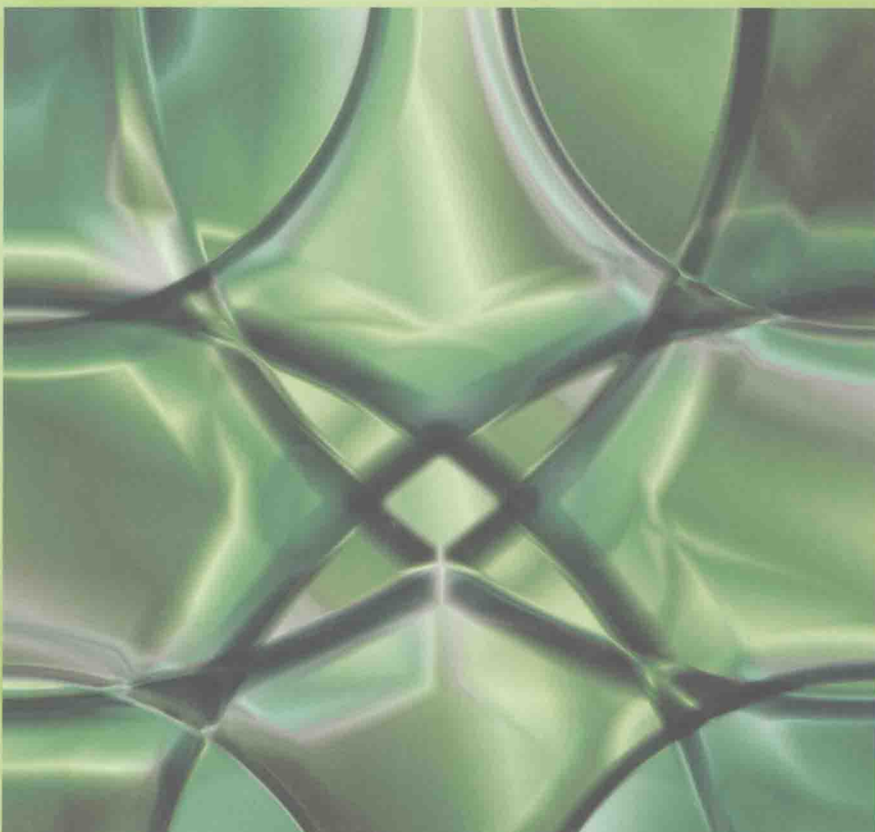
Fundamentals of

CONDENSED MATTER AND CRYSTALLINE PHYSICS



David L. Sidebottom

Fundamentals of Condensed Matter and Crystalline Physics

An Introduction for Students of Physics and Materials Science

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Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9781107017108

First published 2012

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication Data

Sidebottom, David L., 1961–
Fundamentals of condensed matter and crystalline physics: An Introduction for Students of
Physics and Materials Science / David L. Sidebottom, Creighton University, Omaha.
pages cm
Includes bibliographical references and index.
ISBN 978-1-107-01710-8
1. Condensed matter–Textbooks. 2. Crystals–Textbooks. I. Title.
QC173.454.S53 2012
530.4′1–dc23
2011046218

ISBN 978-1-107-01710-8 Hardback

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Fundamentals of Condensed Matter and Crystalline Physics

This undergraduate textbook merges traditional solid state physics with contemporary condensed matter physics, providing an up-to-date introduction to the major concepts that form the foundations of condensed materials. The main foundational principles are emphasized, providing students with the knowledge beginners in the field should understand. The book is structured in four parts, and allows students to appreciate how the concepts in this broad area build upon each other to produce a cohesive whole as they work through the chapters. Illustrations work closely with the text to convey concepts and ideas visually, enhancing student understanding of difficult material, and end-of-chapter exercises, varying in difficulty, allow students to put into practice the theory they have covered in each chapter, and reinforce new concepts. Additional resources including solutions to exercises, lesson plans and pre-lecture reading quiz questions are available online at www.cambridge.org/sidebottom.

David L. Sidebottom is Associate Professor in the Physics Department at Creighton University. He is an experienced teacher and has taught a wide variety of courses at both undergraduate and graduate level in subject areas including introductory physics, thermodynamics, electrodynamics, laser physics and solid state physics. He has taught a course on solid state physics since 2003, adapting and revising its content to reflect the broader themes of condensed matter physics beyond those of the conventional solid state. This textbook stems from that course.

Preface

Purpose and motivation

This textbook was designed to accompany a one-semester, undergraduate course that itself is a hybridization of conventional solid state physics and "softer" condensed matter physics.

Why the hybridization? Conventional (crystalline) solid state physics has been pretty much understood since the 1960s at a time when non-crystalline physics was still a fledgling endeavour. Some 50 years later, many of the foundational themes in condensed matter (scaling, random walks, percolation) have now matured and I believe the time is ripe for both subjects to be taught as one. Moreover, for those of us teaching at smaller liberal arts institutions like my own, the merging of these two subjects into one, better accommodates a tight curriculum that is already heavily laden with required coursework outside the physics discipline.

Why the textbook? For some years now I have taught a one-semester course, originally listed as "solid state physics", which evolved through each biannual reincarnation into a course that now incorporates many significant condensed matter themes, as well as the conventional solid state content. In past offerings of the course, a conventional solid state textbook was adopted (Kittel's *Introduction to Solid State Physics*) and students were provided with handouts for the remaining material. This worked poorly. Invariably, the notation and style of the handouts clashed with that of the textbook and the disjointed presentation of the subject matter was not only annoying to students, but a source of unnecessary confusion. Students were left with the impression that solid state and condensed matter were two largely unrelated topics being crammed into a single course. Frustrated, I opted to spend a portion of a recent sabbatical assembling all of the material into a single document that would better convey the continuity of these two fields by threading both together into a seamless narrative.

So if you are looking for a reference-style textbook that provides a comprehensive coverage of the entire field of condensed matter, read no further because this is not it. This textbook was not written for practitioners, but rather for novices. It was designed to help students comprehend, not so much the details, but the major concepts that form the foundations of condensed matter and crystalline physics. At the very least I want students to leave the course able to comprehend the meaning behind terminology used by solid state physicists (e.g., "symmetry operations", "Brillouin zones", "Fermi sufaces") and condensed matter physicists (e.g, "mean field theory", "percolation", "scaling laws", "structure factors") so that they might rapidly acclimate to current research in either field.

Layout and use

I confess that my inspiration for the textbook style was Kittel's *Introduction to Solid State Physics*, which has been a valuable guide for maintaining the development at a level appropriate for an undergraduate audience. Although criticized by some, his text is now in its eighth edition and has remained a popular choice for many undergraduate courses on solid state physics (including my own). Those familiar with Kittel, will find that this hybrid textbook incorporates most of the same subject matter (albeit abbreviated in places and arranged in a different order due to the way it is now interwoven with other non-crystalline topics) as is found in the first twelve chapters of Kittel.

Students will need a limited exposure to both quantum mechanics and statistical mechanics. The level of quantum mechanics that is provided in an introductory sophomore-level course on modern physics (1D wave mechanics, particle in a box, harmonic oscillators) should be sufficient. Beyond that, statistical mechanics and thermodynamics (specifically, Boltzmann statistics and free energies) are introduced periodically throughout the text and this is more likely to be the deficiency for some students. In an effort to help alleviate this and other potential deficiencies, an appendix is included which provides an introduction to such things as statistical mechanics, Fourier transforms and the use of Dirac delta functions.

The text is divided into four major parts: Structure, Scattering, Dynamics, and Transitions. Within each part are anywhere from four to six chapters designed more to delineate topics than to represent equal amounts of material. Although a common rule of thumb would be to allot three, 50-minute lecture periods per chapter, several chapters (e.g., 2, 3, 7, 10, 14, 15) could be adequately discussed in just two periods and Chapter 5 could likely be addressed in a single period. The lesson plan that I have adopted looks something like this:

	Lecture #1 (50 min)	Lecture #2 (50 min)	Lecture #3 (50 min)
Week	Chapter	Chapter	Chapter
1	1	1	1
2	2	2,3	3
3	4	4	5
4	6	6	6,7
5	7	7,8	8
6	8	9	9
7	10	10	11

	Lecture #1 (50 min)	Lecture #2 (50 min)	Lecture #3 (50 min)
Week	Chapter	Chapter	Chapter
8	11	11	12
9	12	12,13	13
10	13	13	13
11	14	14	15
12	15	16	16
13	16,17	17	17
14	18	18	18

Can all these topics be covered in a semester? Maybe. In my experience, I have so far only managed to cover about 85%. Topics to skip are really a matter of preference. I had no reservations about skipping the subject of bonds and cohesion (Chapter 3) and only modest discomfort at skipping the subject of bulk dynamics (Chapter 14). Others that are less interested in amorphous solids could skip glass structure (Chapter 2), but I would advise not to skip the material on scattering from self-similar objects (Chapter 8), as this contributes an important conceptual foundation for much of the materials in the last four chapters (Chapters 15–18) of the text.

Some might be tempted to skip the development of scattering theory presented in Chapter 5, so let me petition against this. In my experience, students struggle with the concept of reciprocal space primarily because of how most conventional solid state textbooks mysteriously introduce it directly after discussing Bragg's law. Students rarely grasp the significance of this abstract space and probably question why it is introduced at all, given how Bragg's law seems sufficient. By first introducing the fundamentals of scattering in Chapter 5, the reciprocal space appears more naturally as the discrete set of scattering wave vectors for which non-zero scattering occurs. Bragg's law is only presented as a consequence.

Anywhere from five to ten exercises can be found at the end of each chapter. These come in a variety of difficulty levels and are designed mostly to help students digest the material and develop skills. Many of the easier problems are derived from the text itself and ask students to complete the missing steps in a derivation. Although some may see this as aimless "busy work", for many undergraduate students (in my experience) these exercises represent a challenging skill yet to be mastered.

For students

Good luck and I hope this textbook helps you. Please let me know what you do and don't like about the textbook so that I can improve it in the future.

Acknowledgements

Let me start by thanking the many students that have taken my course in the past several years, and in particular the 2011 class (David, Jamison, Clifford, Nathan, Stan, Tri and Yuli), who braved an early prototype of the textbook and provided many valuable suggestions for revision and improvement. I thank also several close colleagues, Chris Sorensen, Jeppe Dyre and Per Jacobsson whose positive feedback on an early draft inspired me considerably and eventually prompted me to seriously consider publication. I am especially indebted to Chris who has been a mentor to me throughout the years and who helped immensely by giving an early draft of the textbook a thorough read.

Naturally, the support of Creighton University in the form of employment and a sabbatical leave is gratefully acknowledged. Grateful too am I for support from the faculty and staff in my department who have tolerated my erratic behavior during the past two years. I am especially grateful for advice given to me by Robert Kennedy about the publishing process.

And last, but certainly not least, I want to acknowledge the support and encouragement from my best friend and wife, Lane. Thank you, my love.

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