Preface

This book is written and organized around three topics: electron diffraction, electron optics, and electron crystallography. It is intended as an advanced undergraduate- or graduate-level text in support of course materials in materials science, physics, or chemistry departments. High-resolution transmission electron microscope imaging and scanning transmission electron microscopy are treated as major applications of electron optics, as well as powerful electron crystallographic techniques for structure determination. The emphasis here is on the fundamentals and applications of electron diffraction and imaging in materials research, especially in the study of nanoscience. For this purpose, we have included theory for electron wave propagation, electron diffraction and imaging, and a detailed treatment of electron optics, aberration correction, and instrument techniques, on a level that can be followed by a materials science or physics graduate student. For crystallography, we have emphasized the fundamentals of symmetry, structure and bonding, diffuse scattering, imaging of defects, strain measurement, and determination of nanostructures. Structure determination of large crystals, including polymeric and biological samples, is not discussed specifically in this book, although the electron diffraction and imaging theories presented here and instrumental techniques apply equally to these topics.

Transmission electron microscopy (TEM) traditionally refers to electron diffraction and imaging techniques that are enabled by a transmission electron microscope (with the same TEM acronym). Scanning transmission electron microscopy (STEM) embodies a separate set of techniques. The development of modern TEMs that function as both TEM and STEM has brought them together, as complementary techniques, often abbreviated as S/TEM. For this reason, we have simply used TEM in the book's title. STEM, more than TEM, is associated with powerful analytical techniques, such as electron energy loss spectroscopy and energy-dispersive X-ray spectroscopy. This aspect of TEM is not covered here, and readers are referred to the excellent books on these subjects by Egerton (2011), Hawkes and Spence (2007), and Pennycook and Nellist (2011).

The materials included here come from multiple sources. Firstly, we have updated our previous book on “Electron Microdiffraction” (Plenum, New York, 1992, by J.C.H. Spence and J.M. Zuo). The previous Chaps. 2–4, 7, and 9 are now parts of Chaps. 3, 5, 12, 13, and 10, respectively. The new Chap. 10 on instrumental techniques also incorporates the previous Chap. 6. The previous Chap. 8 is now separated into Chap. 14, which discusses atomic-resolution imaging and Chap. 15 on the characterization of defects. Secondly, we have incorporated much new teaching material throughout the book, such as waves and wave properties (Chap. 2), kinematical theory of electron diffraction (Chap. 4), electron optics (Chaps. 6 and 7), diffuse scattering (Chap. 13), and electron imaging (Chaps. 14 and 15). This material is based on the lectures given to graduate students at University of Illinois, Urbana-Champaign in two courses: diffraction physics and advanced electron microscopy. The writing of Chaps. 6 and 7 has benefitted from the special invited lectures given by Prof. Harald Rose in 2011 to the advanced electron microscopy class.

In writing this book, we have also relied on the original research work by many graduate students, post-docs, and our collaborators. To them, we owe special thanks, especially to Profs. Michael O’Keeffe, Ragnvald Hoier (1938–2009), Miyoung Kim, Randi Holmestad, Jerome Pacuad, Jean-Paul Morniroli, Syo Matsumura, Yoshitsugu Tomokiyo and Drs. Bin Jiang, Weijie Huang, Jing Tao, Jiong Zhang, Min Gao, Celik Ayten, Shankar Sivaramakrishnan, Amish Shah, Ke Ran, Wenpei Gao, and Honggyu Kim. The work at University of Illinois was funded by the Department of Energy, Basics Science and Division of Materials Research, National Science Foundation. Especially, JMZ wishes to thank Dr. Jane Zhu at the Department of Energy for the support of the electron nanocrystallography project.

On reading the literature, one is struck by the enormous variety of applications of TEM/STEM. These include studies of various defects, grain boundaries and interfaces in a broad range of materials, analyses of the symmetry changes which accompany phase transitions, polarization and charge ordering including charge-density waves in layered structures, accurate mapping of the distribution of valence electrons in crystals, phase identification and strain measurement around defects, precipitates and interfaces in alloys or semiconductors, in addition to the characterization of all sorts of nanostructures. To review all this work, published in a vast number of papers, and draw out its implications for materials physics would be a Herculean task. Our aim has been a limited one, to explain the principles of TEM, to provide the theory in a consistent format and to convey enough understanding to students and researchers to let them get started with modern TEM for materials characterization. Thus, to experts in the field, some examples in this book may seem somewhat oversimplified. Also, we have cited references that are directly related to our discussions. We offer our apologies to many of our colleagues whose works were not covered or cited here. With regret, for reasons of space, we have not been able to include the topics of structure determination (see Zou et al. 2011), electron tomography, or coherent diffractive imaging.

Several chapters were written during the sabbatical stay of JMZ at CEA, Grenoble, France, in the fall of 2014. He is therefore grateful to Drs. Jean-Luc Rouviere and Alain Fontaine for their hospitality and also to the Nanoscience Foundation, Grenoble, for the Chair of Excellence position which made his visit possible.

The study of electron diffraction and imaging can be significantly helped by computer simulations. For this purpose, we have made available of computer programs listed in the "Electron Microdiffraction" book on the website http://cbed.matse.illinois.edu/, as well as links to other online resources.

Urbana, USA — Jian Min Zuo
Tempe, USA — John C.H. Spence
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Much of this book was written during a sabbatical visit by J.C.H.S. to the Max Planck Institute in Stuttgart during 1991. We are therefore grateful to Profs. M. Ruhle and A. Seeger for acting as hosts during this time and to the Alexander von Humboldt Foundation for the Senior Scientist Award which made this visit possible. The Ph.D. work of one of us (J.M.Z.) has also provided much of the background to the book, together with our recent papers with various collaborators. Of these, perhaps the most important stimulus to our work on convergent beam electron diffraction resulted from a visit to the National Science Foundation's Electron Microscopy Facility at Arizona State University by Prof. R. Hoier in 1988 and from a return visit to Trondheim by J.C.H.S. in 1990. We are therefore particularly grateful to Prof. R. Hoier and his students and coworkers for their encouragement and collaboration. At ASU, we owe a particular debt of gratitude to Prof. M. O'Keeffe for his encouragement. The depth of his understanding of crystal structures and his role as passionate skeptic have frequently been invaluable. Professor John Cowley has also been an invaluable sounding board for ideas and was responsible for much of the experimental and theoretical work on coherent nanodiffraction. The sections on this topic derive mainly from collaborations by J.C.H.S. with him in the seventies. Apart from that, we have tried to review the literature as impartially as possibly and at the same time bring out the underlying concepts in a clear and unified manner, so that the book will be useful for graduate students. We are particularly grateful to Dr. J.A. Eades for his critical review of Chap. 7. We apologize to those authors whose work may have been overlooked among the many hundreds of papers. In order to make the book more practically useful, we have included some FORTRAN source listings, together with POSTSCRIPT code which allows the direct printing of Kikuchi and HOLZ line

patterns on modern laser printers from the programs. Support from NSF award DMR-9015867 (“Electron Crystallography”) and the facilities of the NSF-ASU National Center for High Resolution Electron Microscopy is gratefully acknowledged.

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http://www.springer.com/978-1-4939-6605-9

Advanced Transmission Electron Microscopy
Imaging and Diffraction in Nanoscience
Zuo, J.M.; Spence, J.C.H.
2017, XXVI, 729 p. 310 illus., 218 illus. in color.,
Hardcover
ISBN: 978-1-4939-6605-9