Nanostructures and Nanotechnology

Focusing on the fundamental principles of nanoscience and nanotechnology, this carefully developed textbook will equip students with a deep understanding of the nanoscale.

- Each new topic is introduced with a concise summary of the relevant physical principles, emphasising universal commonalities between seemingly disparate areas, and encouraging students to develop an intuitive understanding of this diverse area of study.
- Accessible introductions to condensed matter physics and materials systems provide students from a broad range of scientific disciplines with all the necessary background.
- Theoretical concepts are linked to real-world applications, allowing students to connect theory and practice.
- Chapters are packed with engaging color illustrations and problems to help students develop and retain their understanding, and are accompanied by suggestions for additional reading.

Containing enough material for a one- or two-semester course, this is an excellent resource for senior undergraduate and graduate students with backgrounds in physics, chemistry, materials science, and electrical engineering.

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Preface

This book is intended to provide a physical foundation for students interested in nanoscale science and technology. Developed while teaching a two-course graduate sequence on the topic, this book is my attempt to lay out the physical underpinnings of this incredibly broad topic while striking a balance between depth and approachability.

When I set out to develop and teach these courses, I found that most books on this subject were very specialized (for example, dealing only with nanoscale electronics), more focused on research rather then pedagogy (collections of review articles rather than an actual textbook), or not sufficiently technical (more like a series of *Scientific American* articles rather than a quantitative approach). I have tried to get to the physical basis of nanoscale science, the origins of the fascinating properties of materials at previously inaccessible size scales. A common thread through much of the material is the breakdown of the simplifying approximations that we have made in developing our physical models of macroscopic systems. I've also tried to indicate the underlying connections between some superficially disparate topics (e.g., band theory, coupled mechanical oscillators, and plasmons). Hopefully this approach allows students to develop an intuition for, and the ability to reason critically about, the nanoscale world. By focusing on the fundamentals rather than the latest research results (though those are mentioned when appropriate), I also hope that this text will stand the test of time, rather than appearing dated as soon as it is published. Of course, during the writing of this book, a number of other texts more or less in a similar or complementary spirit have appeared. These include *Introduction to Nanoscale Science and Technology*, edited by M. Di Ventra, S. Evoy, and J. R. Heflin, Jr. (Springer, 2004); and *Introduction to Nanoscience* by S. Lindsay (Oxford, 2009).

When teaching this material as a course or course sequence, I recommend supplementing the exercises with short-answer questions based on readings from the current literature. I had reasonable success assigning midterm and final papers. Whether they want careers in academia or industry, students need to become facile at writing, both short (one paragraph) responses to conceptual questions or questions about readings, and longer (5–10 page) essays that demonstrate analysis and critical thinking.

Many of the topics in this book deserve much more extensive treatment than what I have been able to provide. To compensate for the limitations necessitated by finite space, I have tried to give ample suggestions for further reading, including book-length treatments and review articles. Some areas, while extremely interesting, I decided were "too physicsy" for the intended broader audience. This is the reason for my extremely limited mention of both nanoscale superconductivity and the integer and fractional quantum Hall effects. I have similarly steered clear of quantum computing, a discipline certainly connected to

nanoscale science and nanoelectronics, but just as certainly a distinct field. Likewise, some topics (e.g., the physical chemistry of catalysis at nanoparticle surfaces; the molecular biology of many biological motors) are far enough removed from my own expertise that I could not possibly treat them adequately. If you feel that your favorite nano topic gets short shrift, *mea culpa*. I have also done my best to cite explicitly in the text and in the "Suggested Reading" the many books and reference works that I consulted during the writing of this book. Truly, I would never have been able to put this together without the hard work of many authors before me. Any omissions or mistakes are my responsibility.

This book would never have been possible without the support and encouragement of many people and groups over the last several years. I would particularly like to acknowledge the Alfred P. Sloan Foundation, for their original sponsorship of a professional masters program that spurred the development of this course material. I also owe a debt to the National Science Foundation (specifically awards DMR-0347253, DMR-0855607, and DMR-1305879), whose educational mandate dovetailed perfectly with the opportunity to create these courses and this book. I hope this work has the educational broader impact that NSF is meant to encourage.

My colleagues within Rice University have been nothing but supportive, especially my former department chairman Professor Barry Dunning, my former dean Professor Kathy Matthews, my current chairman Professor Tom Killian, and my faculty colleagues within the Physics and Astronomy Department. I thank all the students, both in my research group and in the courses, that have helped me formulate my thinking about these subjects through their rigorous questions and insightful conversations. They are too numerous to mention, but I'm very appreciative of their insights. My father, Michael Natelson, and my faculty colleague Professor Rui-Rui Du deserve special gratitude for their time spent reading the manuscript. Finally, special thanks to my wife and sons, whose love and support have helped keep me sane during this whole process.