Nanotechnology

Understanding Small Systems

THIRD EDITION

Ben Rogers
Jesse Adams
Sumita Pennathur

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Preface

THIS IS THE THIRD EDITION of this book. But from the first edition, we knew we did not want this to be a book that glosses over the nitty-gritty stuff, assuming you already know everything, nor a book that uses "hand-waving" to magically skirt around real explanations of the complex stuff. The tone of the book is intended to make it more readable—which is to say that it is not too "textbook-y." Having used hundreds of textbooks ourselves, we knew how we did not want this one to be, and that was stodgy.

This book is about nanotechnology, a gigantic topic about small things. It is a book that is intended to excite, inspire, and challenge you. We want to uncover the most important things about nanotechnology and give you the tools you need to dig deeper on your own. We want you to enjoy learning (maybe even laugh) and for you to find out a lot in a short time. There will be plenty of rigorous scientific support, but concepts will be conveyed in clear, simple language that you can digest and apply immediately. We do "back-of-the-envelope" calculations together throughout the process so that you get a good feeling for the numbers of nanotechnology. Creative problem sets (Homework Exercises) follow each chapter to test your understanding of new concepts.

Nanotechnology represents a convergence of many sciences and technologies at the nanometer scale. In fact, it is becoming its own discipline altogether. It requires the ability to apply various scientific principles to system-level design and analysis. The multidisciplinary nature of nanotechnology—which draws from physics, chemistry, biology, medicine, and engineering—has the inherent challenge of teaching students with backgrounds in different knowledge domains.

And because the synthesis of disciplines is at the core of nanotechnology, we focus on *systems* in this book. A system is a set of interacting, interrelated, or interdependent elements that are put together to form a complex whole. We discuss nanotechnology on a system-by-system basis to foster both an appreciation and an understanding of this multifaceted topic.

We start with an overview treatment of nanotechnology, with special emphasis on the history, key personalities, and early milestones. Then onto the issues, promises, and fundamentals of nanotechnology. In fact, Chapter 1, "Big Picture and Principles of the Small World," stands alone as a comprehensive introduction, intended to answer your first questions as to what nanotechnology really is and could be. This chapter is self-contained and comprehensive; there is enough information for a freshman or general public course. It includes a discussion of the effects this new industry could have on human life, careers, education, and the environment.

Chapter 2 discusses scaling laws, giving us intuition about the physical ramifications of miniaturization. (While we think this is a useful chapter, be warned: it could bore you. If so, feel free to skip or skim it and use it as a reference.)

Then we dive headlong into nanotechnology. We begin with an "Introduction to Nanoscale Physics" (Chapter 3). Then we tackle the eight main disciplines: nanomaterials (Chapter 4), nanomechanics (Chapter 5), nanoelectronics (Chapter 6), nanoscale heat transfer (Chapter 7), nanophotonics (Chapter 8), nanoscale fluid mechanics (Chapter 9), nanobiotechnology (Chapter 10), and nanomedicine (Chapter 11). In these "nano" chapters, we provide the specific, fundamental differences between macroscale and nanoscale phenomena and devices, using applications to teach key concepts.

Welcome!

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Ben Rogers

Thanks to all my family, friends, and mentors. You are all the best and this is dedicated to your hard work.

Jesse Adams

I thank Anthony T. Chobot III, Anthony T. Chobot IV, and Zofia Lakshmi Chobot for their undying love and support, and for allowing me the opportunity to be a part of this work. Additionally, I thank all my educators throughout the years for giving me the guidance and motivation to contribute to such a textbook.

Sumita Pennathur

AN INVITATION

One more thing. We put a lot of work into making this book useful for you. So, we invite every reader to comment on this book and tell us how we can make it even better. We want your suggestions for future editions and corrections to any errors you may discover. Please e-mail suggestions, questions, comments, and corrections to michael.slaughter@taylorandfrancis.com. We list the names of helpful readers here, in this section.

Here are those who have already contributed to this ever-improving book: Ongi Englander, Ed Hodkin, Morteza Mahmoudi, Aaron S. Belsh, Eva Wu, Brett Pearson, John C. Bean, Darryl Wu, Lia Hankla, and Alec Hendricks.

That said, let us get started!

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Ben Rogers is a writer and an engineer (BS 2001; MS 2002, University of Nevada, Reno). He has done research at Nanogen, the Oak Ridge National Laboratory, and NASA's Jet Propulsion Laboratory, and published many technical papers, as well as fictional works and essays (which can be found at http://readrogers.com/). He is currently the principal engineer at NevadaNano and lives in Reno with his wife and two daughters.

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Also by these authors: *Nanotechnology: The Whole Story* (CRC Press, 2013), a general audience take on the best-selling, award-winning book, *Nanotechnology: Understanding Small Systems* (CRC Press, 2014).

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