

INTRODUCTION TO NANOSCIENCE

Introduction to Nanoscience

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Preface

Nanoscience is not physics, chemistry, engineering, or biology. It is all of them, and the first motivation for this text is to present an integrated description. A second motivation for this book lies with the *complexity* of nanostructures, an issue that is not widely addressed. Richard Feynman described the remarkable consequences of scale and quantum effects in his visionary essay “There’s Plenty of Room at the Bottom” and I think enough of it to have purchased the rights to reproduce it here (as Appendix B). But nanoscale objects, where hundreds, thousands, or hundreds of thousands of atoms make up systems, are complex enough to show what is called “emergent behavior”: Quite new phenomena arise from rare configurations of the system. We will encounter this in the Kramers theory of reactions in Chapter 3, the Marcus theory of electron transfer in Chapter 8, and several times again in the final chapter on Nanobiology.

I teach the class on which this book is based to upper division undergraduates and beginning graduate students, and do not impose prerequisites for enrollment. I do this precisely because of the integrative nature of the material. I would like biologists to be able to get the gist of quantum mechanics and statistical mechanics. To this end, much of the material is conceptual, and conceptual questions have been included at the end of Chapter 2 (quantum mechanics) and Chapter 3 (statistical mechanics). It is possible to teach to a broad audience: a social sciences undergraduate (from the Center for Nanotechnology in Society at Arizona State University) has scored better on the conceptual quantum test than some physics graduate students!

The class does not have to be taught this way and much of the introductory material may be skipped in the appropriate settings. But physics majors will want to review the material on reaction kinetics and chemical equilibria. Some of the material on Brownian motion may not have been covered in the undergraduate curriculum. The chemical aspects of molecular electronics (Chapter 8) will probably be completely new too. Chemistry majors may want to review aspects of quantum mechanics, and the basics of statistical mechanics and fluctuations. The use of a partition function to justify what is normally done on the basis of mass action will be new to most chemistry students. The properties of electrons in periodic solids (Chapter 7) are not part of the regular chemistry curriculum either.

The mathematics has been kept to a minimum. Introductory calculus and some knowledge of linear algebra is a sufficient background for the student who wants to follow all of the mathematical detail presented in the text and its appendices. Bibliographies and references to the primary research literature at the end of every chapter also make this a suitable starting point for research in nanoscience. One last goal was to make this the “handbook” containing the stuff that I want the students in my lab to know, and I hope I have succeeded.

Solutions to most of the problems are given in Appendix M. They include detailed derivations where needed for support of the main text. A CD contains Powerpoint presentations for the lectures, as well as color figures and movies.

A book produced to a deadline, its production taking second place to all the other demands of an academic job, is bound to contain mistakes. They are far fewer in number because of the critical input of many of my colleagues and students. Mark Ratner read most of the first draft, providing valuable comments. I received valuable feedback from Nongjian Tao, Timothy Newman, Otto Sankey, John Spence, Larry Nagahara, Peiming Zhang, and Ralph Chamberlin. Students in my class helped me refine the problems at the end of each chapter and caught many errors in this version. They include Ashley Kibel, Eric Alonas, Shreya Bhattacharya, Kevin Brown, Jared Burdick, Di Cao, Shuai Chang, Eric Dailey, Shaoyin Guo, Kaushik Gurunathan, Billie Harvey, Shuao Huang, Deepthi Jampala, Parminder Kaur, Steven Klein, Lisha Lin, Hao Liu, Dan and Alise Martin, Chelsea Mcintosh, Douglas Moorhead, Jeff Moran, Pei Pang, Peter Pelletier, Suman Ranjit, Kamil Salloum, Dan Shea, Nathaniel Sylvain, Matthijs Smith, Jill Stock, Tim Lomb and Nick Teodori. Hao Liu also created the cover art. Hosam Yousif checked the problems and produced clean solutions for Chapters 1 through 5. I am grateful to Maggie Black for tracking down permissions and taking care of copyright issues. Health issues did not get in the way of this project thanks to the diligent care of Dr. Alan Wachter M.D. Finally, the debt I owe to my remarkable wife, Christine, is enormous. She is constantly supportive, loving, and kind.

Tempe, AZ, 2008

Contents

1 What is Nanoscience?	1
1.1 About size scales	1
1.2 History	2
1.3 Feynman scorecard	3
1.4 Schrödinger’s cat—quantum mechanics in small systems	8
1.5 Fluctuations and “Darwinian Nanoscience”	9
1.6 Overview of quantum effects and fluctuations in nanostructures	11
1.7 What to expect in the rest of this book	12
1.8 Bibliography	13
1.9 Exercises	13
References	14

Part I: The Basics

2 Quantum mechanics	19
2.1 Why physics is different for small systems—the story of the Hitachi experiment	20
2.2 The uncertainty principle	25
2.3 The Hitachi microscope as a quantum system	26
2.4 Probability amplitudes and the rules of quantum mechanics	27
2.5 A word about “composite” particles	30
2.6 Wavefunctions	31
2.7 Dirac notation	32
2.8 Many particle wavefunctions and identical particles	33
2.9 The Pauli exclusion principle	35
2.10 The Schrödinger equation: a tool for calculating probability amplitudes	36
2.11 Problems involving more than one electron	38
2.12 Solution of the one-electron time-independent Schrödinger equation for a constant potential	40
2.13 Electron tunneling through a potential barrier	41
2.14 The Hitachi experiment with wavefunctions	42
2.15 Some important results obtained with simple 1-D models	43
2.16 The hydrogen atom	51
2.17 Multielectron atoms	57
2.18 The periodic table of the elements	59

2.19	Approximate methods for solving the Schrödinger equation	61
2.20	Chemical bonds	64
2.21	Eigenstates for interacting systems and quasiparticles	68
2.22	Getting away from wavefunctions: density functional theory	69
2.23	Bibliography	72
2.24	Exercises	72
	References	74
3	Statistical mechanics and chemical kinetics	76
3.1	Macroscopic description of systems of many particles	77
3.2	How systems get from here to there: entropy and kinetics	79
3.3	The classical probability distribution for noninteracting particles	82
3.4	Entropy and the Boltzmann distribution	84
3.5	An example of the Boltzmann distribution: ions in a solution near an electrode	86
3.6	The equipartition theorem	88
3.7	The partition function	89
3.8	The partition function for an ideal gas	91
3.9	Free energy, pressure, and entropy of an ideal gas from the partition function	93
3.10	Quantum gasses	96
3.11	Fluctuations	100
3.12	Brownian motion	102
3.13	Diffusion	105
3.14	Einstein–Smoluchowski relation	107
3.15	Fluctuations, chemical reactions, and the transition state	108
3.16	The Kramers theory of reaction rates	109
3.17	Chemical kinetics	111
3.18	Acid–base reactions as an example of chemical equilibrium	114
3.19	The Michaelis–Menten relation and on-off rates in nano–bio interactions	117
3.20	Rate equations in small systems	120
3.21	Nanothermodynamics	120
3.22	Modeling nanosystems explicitly: molecular dynamics	121
3.23	Systems far from equilibrium: Jarzynski’s equality	124
3.24	Fluctuations and quantum mechanics	125
3.25	Bibliography	128
3.26	Exercises	128
	References	131

Part II: Tools

4 Microscopy and manipulation tools	135
4.1 The scanning tunneling microscope	135
4.2 The atomic force microscope	144
4.3 Electron microscopy	158
4.4 Nano-measurement techniques based on fluorescence	163
4.5 Tweezers for grabbing molecules	168
4.6 Chemical kinetics and single molecule experiments	172
4.7 Bibliography	173
4.8 Exercises	173
References	175
5 Making nanostructures: top down	178
5.1 Overview of nanofabrication: top down	178
5.2 Photolithography	179
5.3 Electron beam lithography	183
5.4 Micromechanical structures	185
5.5 Thin film technologies	187
5.6 Molecular beam epitaxy	190
5.7 Self-assembled masks	191
5.8 Focused ion beam milling	193
5.9 Stamp technology	195
5.10 Nanoscale junctions	197
5.11 Bibliography	197
5.12 Exercises	198
References	199
6 Making nanostructures: bottom up	201
6.1 Common aspects of all bottom-up assembly methods	201
6.2 Organic synthesis	202
6.3 Weak interactions between molecules	210
6.4 Vesicles and micelles	214
6.5 Thermodynamic aspects of self-assembling nanostructures	216
6.6 A self-assembled nanochemistry machine—the mitochondrion	219
6.7 Self-assembled molecular monolayers	220
6.8 Kinetic control of growth: nanowires and quantum dots	222
6.9 DNA nanotechnology	223
6.10 Bibliography	229
6.11 Exercises	229
References	230

Part III: Applications

7	Electrons in nanostructures	235
7.1	The vast variation in the electronic properties of materials	235
7.2	Electrons in nanostructures and quantum effects	236
7.3	Fermi liquids and the free electron model	237
7.4	Transport in free electron metals	240
7.5	Electrons in crystalline solids: Bloch's theorem	240
7.6	Electrons in crystalline solids: band structure	242
7.7	Electrons in 3D—why copper conducts; Fermi surfaces and Brillouin zones	245
7.8	Electrons passing through tiny structures: the Landauer resistance	246
7.9	Charging nanostructures: the Coulomb blockade	250
7.10	The single electron transistor	252
7.11	Resonant tunneling	254
7.12	Coulomb blockade or resonant tunneling?	256
7.13	Electron localization and system size	257
7.14	Bibliography	259
7.15	Exercises	259
	References	260
8	Molecular electronics	262
8.1	Why molecular electronics?	263
8.2	Lewis structures as a simple guide to chemical bonding	264
8.3	The variational approach to calculating molecular orbitals	268
8.4	The hydrogen molecular ion revisited	270
8.5	Hybridization of atomic orbitals	275
8.6	Making diatomic molecules from atoms with both s- and p-states	276
8.7	Molecular levels in organic compounds: the Hückel model	279
8.8	Delocalization energy	280
8.9	Quantifying donor and acceptor properties with electrochemistry	284
8.10	Electron transfer between molecules—the Marcus theory	292
8.11	Charge transport in weakly interacting molecular solids—hopping conductance	298
8.12	Concentration gradients drive current in molecular solids	299
8.13	Dimensionality, 1-D conductors, and conducting polymers	300
8.14	Single molecule electronics	302
8.15	Wiring a molecule: single molecule measurements	303

8.16	The transition from tunneling to hopping conductance in single molecules	307
8.17	Gating molecular conductance	309
8.18	Where is molecular electronics going?	312
8.19	Bibliography	313
8.20	Exercises	313
	References	315
9	Nanostructured materials	318
9.1	What is gained by nanostructuring materials?	318
9.2	Nanostructures for electronics	319
9.3	Zero-dimensional electronic structures:	
	quantum dots	322
9.4	Nanowires	323
9.5	2-D nanoelectronics: superlattices and heterostructures	326
9.6	Photonic applications of nanoparticles	329
9.7	2-D photonics for lasers	331
9.8	3-D photonic bandgap materials	333
9.9	Physics of magnetic materials	335
9.10	Superparamagnetic nanoparticles	337
9.11	A 2-D nanomagnetic device: giant magnetoresistance	338
9.12	Nanostructured thermal devices	340
9.13	Nanofluidic devices	341
9.14	Nanofluidic channels and pores for molecular separations	342
9.15	Enhanced fluid transport in nanotubes	343
9.16	Superhydrophobic nanostructured surfaces	345
9.17	Biomimetic materials	346
9.18	Bibliography	348
9.19	Exercises	348
	References	350
10	Nanobiology	353
10.1	Natural selection as the driving force for biology	353
10.2	Introduction to molecular biology	354
10.3	Some mechanical properties of proteins	360
10.4	What enzymes do	361
10.5	Gatekeepers—voltage-gated channels	363
10.6	Powering bio-nanomachines: where biological energy comes from	364
10.7	Adenosine triphosphate—the gasoline of biology	365
10.8	The thermal ratchet mechanism	366
10.9	Types of molecular motor	367
10.10	The central role of fluctuations in biology	372
10.11	Do nanoscale fluctuations play a role in the evolution of the mind?	377

10.12 Bibliography	378
10.13 Exercises	378
References	379
A Units, conversion factors, physical quantities, and useful math	381
A.1 Length	381
A.2 Mass and force	381
A.3 Time	381
A.4 Pressure	381
A.5 Energy and temperature	381
A.6 Electromagnetism	382
A.7 Constants	382
A.8 Some useful material properties	382
A.9 Some useful math	382
B There's plenty of room at the bottom	384
C Schrödinger equation for the hydrogen atom	396
C.1 Angular momentum operators	396
C.2 Angular momentum eigenfunctions	397
C.3 Solution of the Schrödinger equation in a central potential	398
D The damped harmonic oscillator	400
E Free energies and choice of ensemble	405
E.1 Different free energies for different problems	405
E.2 Different statistical ensembles for different problems	407
F Probabilities and the definition of entropy	408
G The Gibbs distribution	409
H Quantum partition function for a single particle	411
I Partition function for N particles in an ideal gas	413
J Atomic units	414
K Hückel theory for benzene	415
L A glossary for nanobiology	417
M Solutions and hints for the problems	424
Index	447