



CHEMICAL PRINCIPLES

THE QUEST FOR INSIGHT

Fifth Edition

PETER ATKINS / LORETTA JONES

This page intentionally left blank



CHEMICAL PRINCIPLES

The Quest for Insight

FIFTH EDITION

PETER ATKINS

Oxford University

LORETTA JONES

University of Northern Colorado



W. H. Freeman and Company
New York

PUBLISHER: Clancy Marshall
SENIOR ACQUISITIONS EDITOR: Jessica Fiorillo
SENIOR DEVELOPMENTAL EDITOR: Randi Rossignol
MARKETING MANAGER: John Britch
MEDIA AND SUPPLEMENTS EDITOR: Dave Quinn
ASSISTANT EDITOR: Tony Petrites
PHOTO EDITOR: Bianca Moscatelli
COVER/TEXT DESIGNER: Blake Logan
SENIOR PROJECT EDITOR: Georgia Lee Hadler
COPY EDITOR: Margaret Comaskey
ILLUSTRATION COORDINATOR: Bill Page
ILLUSTRATIONS: Peter Atkins with Network Graphics
PRODUCTION COORDINATOR: Paul Rohloff
COMPOSITION: MPS Limited, A Macmillan Company
PRINTING AND BINDING: Quebecor

Library of Congress Control Number:
2009936820

ISBN-13: 978-1-4292-1955-6

ISBN-10: 1-4292-1955-6

©2010, 2008, 2005, 2002 by P. W. Atkins and L. L. Jones

All rights reserved

Printed in the United States of America

First printing



W. H. Freeman and Company
41 Madison Avenue
New York, NY 10010
Houndmills, Basingstoke RG21 6XS, England
www.whfreeman.com

CONTENTS IN BRIEF

FUNDAMENTALS

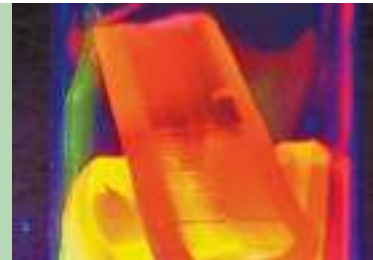
F1

Introduction and Orientation, Matter and Energy, Elements and Atoms, Compounds, The Nomenclature of Compounds, Moles and Molar Masses, Determination of Chemical Formulas, Mixtures and Solutions, Chemical Equations, Aqueous Solutions and Precipitation, Acids and Bases, Redox Reactions, Reaction Stoichiometry, Limiting Reactants

1	ATOMS: THE QUANTUM WORLD	1
2	CHEMICAL BONDS	55
	MAJOR TECHNIQUE 1: INFRARED SPECTROSCOPY	90
3	MOLECULAR SHAPE AND STRUCTURE	93
	MAJOR TECHNIQUE 2: ULTRAVIOLET AND VISIBLE SPECTROSCOPY	130
4	THE PROPERTIES OF GASES	133
5	LIQUIDS AND SOLIDS	171
	MAJOR TECHNIQUE 3: X-RAY DIFFRACTION	203
6	INORGANIC MATERIALS	205
7	THERMODYNAMICS: THE FIRST LAW	235
8	THERMODYNAMICS: THE SECOND AND THIRD LAWS	287
9	PHYSICAL EQUILIBRIA	333
	MAJOR TECHNIQUE 4: CHROMATOGRAPHY	381
10	CHEMICAL EQUILIBRIA	383
11	ACIDS AND BASES	423
12	AQUEOUS EQUILIBRIA	475
13	ELECTROCHEMISTRY	515
14	CHEMICAL KINETICS	561
	MAJOR TECHNIQUE 5: COMPUTATION	610
15	THE ELEMENTS: THE MAIN GROUP ELEMENTS	611
16	THE ELEMENTS: THE d-BLOCK	667
17	NUCLEAR CHEMISTRY	705
18	ORGANIC CHEMISTRY I: THE HYDROCARBONS	735
	MAJOR TECHNIQUE 6: MASS SPECTROMETRY	758
19	ORGANIC CHEMISTRY II: POLYMERS AND BIOLOGICAL COMPOUNDS	761
	MAJOR TECHNIQUE 7: NUCLEAR MAGNETIC RESONANCE	791

This page intentionally left blank

CONTENTS



Preface	xv	F DETERMINATION OF CHEMICAL FORMULAS	F45
FUNDAMENTALS	F1	F.1 Mass Percentage Composition	F46
INTRODUCTION AND ORIENTATION	F1	F.2 Determining Empirical Formulas	F47
Chemistry and Society	F1	F.3 Determining Molecular Formulas	F49
Chemistry: A Science at Three Levels	F2	Exercises	F50
How Science Is Done	F2	G MIXTURES AND SOLUTIONS	F51
The Branches of Chemistry	F4	G.1 Classifying Mixtures	F51
Mastering Chemistry	F4	G.2 Separation Techniques	F53
A MATTER AND ENERGY	F5	G.3 Concentration	F54
A.1 Physical Properties	F5	G.4 Dilution	F57
A.2 Force	F9	TOOLBOX G.1 HOW TO CALCULATE THE VOLUME OF STOCK SOLUTION REQUIRED FOR A GIVEN DILUTION	F57
A.3 Energy	F10	Exercises	F58
Exercises	F13	H CHEMICAL EQUATIONS	F60
B ELEMENTS AND ATOMS	F15	H.1 Symbolizing Chemical Reactions	F60
B.1 Atoms	F15	H.2 Balancing Chemical Equations	F62
B.2 The Nuclear Model	F16	Exercises	F64
B.3 Isotopes	F17	I AQUEOUS SOLUTIONS AND PRECIPITATION	F65
B.4 The Organization of the Elements	F18	I.1 Electrolytes	F65
Exercises	F21	I.2 Precipitation Reactions	F67
C COMPOUNDS	F22	I.3 Ionic and Net Ionic Equations	F67
C.1 What Are Compounds?	F22	I.4 Putting Precipitation to Work	F69
C.2 Molecules and Molecular Compounds	F23	Exercises	F70
C.3 Ions and Ionic Compounds	F24	J ACIDS AND BASES	F72
Exercises	F28	J.1 Acids and Bases in Aqueous Solution	F72
D THE NOMENCLATURE OF COMPOUNDS	F29	J.2 Strong and Weak Acids and Bases	F74
D.1 Names of Cations	F29	J.3 Neutralization	F75
D.2 Names of Anions	F29	Exercises	F76
D.3 Names of Ionic Compounds	F31	K REDOX REACTIONS	F77
TOOLBOX D.1 HOW TO NAME IONIC COMPOUNDS	F31	K.1 Oxidation and Reduction	F78
D.4 Names of Inorganic Molecular Compounds	F32	K.2 Oxidation Numbers: Keeping Track of Electrons	F79
TOOLBOX D.2 HOW TO NAME SIMPLE INORGANIC MOLECULAR COMPOUNDS	F33	TOOLBOX K.1 HOW TO ASSIGN OXIDATION NUMBERS	F80
D.5 Names of Some Common Organic Compounds	F35	K.3 Oxidizing and Reducing Agents	F81
Exercises	F36	K.4 Balancing Simple Redox Equations	F83
E MOLES AND MOLAR MASSES	F37	Exercises	F84
E.1 The Mole	F37		
E.2 Molar Mass	F39		
Exercises	F44		

L REACTION STOICHIOMETRY	F85
L.1 Mole-to-Mole Predictions	F86
L.2 Mass-to-Mass Predictions	F86
TOOLBOX L.1 HOW TO CARRY OUT MASS-TO-MASS CALCULATIONS	F87
L.3 Volumetric Analysis	F89
TOOLBOX L.2 HOW TO INTERPRET A TITRATION	F90
Exercises	F93
M LIMITING REACTANTS	F95
M.1 Reaction Yield	F95
M.2 The Limits of Reaction	F96
TOOLBOX M.1 HOW TO IDENTIFY THE LIMITING REACTANT	F97
M.3 Combustion Analysis	F100
Exercises	F103

Chapter 1

ATOMS: THE QUANTUM WORLD

INVESTIGATING ATOMS	1
1.1 The Nuclear Model of the Atom	2
1.2 The Characteristics of Electromagnetic Radiation	3
1.3 Atomic Spectra	6
QUANTUM THEORY	8
1.4 Radiation, Quanta, and Photons	8
1.5 The Wave-Particle Duality of Matter	13
1.6 The Uncertainty Principle	15
1.7 Wavefunctions and Energy Levels	17
THE HYDROGEN ATOM	22
1.8 The Principal Quantum Number	22
1.9 Atomic Orbitals	23
1.10 Electron Spin	30
1.11 The Electronic Structure of Hydrogen	30
<i>Box 1.1 How Do We Know . . . That an Electron Has Spin?</i>	31
MANY-ELECTRON ATOMS	32
1.12 Orbital Energies	32
1.13 The Building-Up Principle	33
TOOLBOX 1.1 HOW TO PREDICT THE GROUND-STATE ELECTRON CONFIGURATION OF AN ATOM	36
1.14 Electronic Structure and the Periodic Table	37
<i>Box 1.2 The Development of the Periodic Table</i>	38
THE PERIODICITY OF ATOMIC PROPERTIES	39
1.15 Atomic Radius	39

1.16 Ionic Radius	40
1.17 Ionization Energy	42
1.18 Electron Affinity	44
1.19 The Inert-Pair Effect	46
1.20 Diagonal Relationships	46
1.21 The General Properties of the Elements	46
Exercises	49

Chapter 2 CHEMICAL BONDS

IONIC BONDS	55
2.1 The Ions That Elements Form	56
2.2 Lewis Symbols	58
2.3 The Energetics of Ionic Bond Formation	58
2.4 Interactions Between Ions	59
COVALENT BONDS	63
2.5 Lewis Structures	63
2.6 Lewis Structures of Polyatomic Species	64
TOOLBOX 2.1 HOW TO WRITE THE LEWIS STRUCTURE OF A POLYATOMIC SPECIES	65
2.7 Resonance	67
2.8 Formal Charge	69
TOOLBOX 2.2 HOW TO USE FORMAL CHARGE TO DETERMINE THE MOST LIKELY LEWIS STRUCTURE	70
EXCEPTIONS TO THE OCTET RULE	71
2.9 Radicals and Biradicals	72
2.10 Expanded Valence Shells	72
<i>Box 2.1 What Has This to Do with . . . Staying Alive?</i>	73
2.11 The Unusual Structures of Some Group 13/III Compounds	75
IONIC VERSUS COVALENT BONDS	76
2.12 Correcting the Covalent Model: Electronegativity	76
2.13 Correcting the Ionic Model: Polarizability	78
THE STRENGTHS AND LENGTHS OF COVALENT BONDS	79
2.14 Bond Strengths	79
2.15 Variation in Bond Strength	80
2.16 Bond Lengths	81

<i>Box 2.2 How Do We Know . . . the Length of a Chemical Bond?</i>	83
Exercises	84

MAJOR TECHNIQUE 1: INFRARED SPECTROSCOPY	90
--	----

Chapter 3 MOLECULAR SHAPE AND STRUCTURE

THE VSEPR MODEL	93
-----------------	----

<i>Box 3.1 Frontiers of Chemistry: Drugs by Design and Discovery</i>	94
--	----

3.1 The Basic VSEPR Model	94
---------------------------	----

3.2 Molecules with Lone Pairs on the Central Atom	98
---	----

TOOLBOX 3.1 HOW TO USE THE VSEPR MODEL	100
--	-----

3.3 Polar Molecules	101
---------------------	-----

VALENCE-BOND THEORY	104
---------------------	-----

3.4 Sigma and Pi Bonds	105
------------------------	-----

3.5 Electron Promotion and the Hybridization of Orbitals	107
--	-----

3.6 Other Common Types of Hybridization	108
---	-----

3.7 Characteristics of Multiple Bonds	111
---------------------------------------	-----

MOLECULAR ORBITAL THEORY	113
--------------------------	-----

3.8 The Limitations of Lewis's Theory	113
---------------------------------------	-----

<i>Box 3.2 How Do We Know . . . That Electrons Are Not Paired?</i>	114
--	-----

3.9 Molecular Orbitals	115
------------------------	-----

3.10 Electron Configurations of Diatomic Molecules	116
--	-----

<i>Box 3.3 How Do We Know . . . the Energies of Molecular Orbitals?</i>	117
---	-----

TOOLBOX 3.2 HOW TO DETERMINE THE ELECTRON CONFIGURATION AND BOND ORDER OF A HOMONUCLEAR DIATOMIC SPECIES	118
--	-----

3.11 Bonding in Heteronuclear Diatomic Molecules	120
--	-----

3.12 Orbitals in Polyatomic Molecules	121
---------------------------------------	-----

Exercises	124
-----------	-----

MAJOR TECHNIQUE 2: ULTRAVIOLET AND VISIBLE SPECTROSCOPY	130
---	-----

Chapter 4 THE PROPERTIES OF GASES

THE NATURE OF GASES	134
---------------------	-----

4.1 Observing Gases	134
---------------------	-----

4.2 Pressure	134
--------------	-----

4.3 Alternative Units of Pressure	136
-----------------------------------	-----

THE GAS LAWS	138
--------------	-----

4.4 The Experimental Observations	138
-----------------------------------	-----

4.5 Applications of the Ideal Gas Law	141
---------------------------------------	-----

TOOLBOX 4.1 HOW TO USE THE IDEAL GAS LAW	142
--	-----

4.6 Gas Density	145
-----------------	-----

4.7 The Stoichiometry of Reacting Gases	147
---	-----

4.8 Mixtures of Gases	148
-----------------------	-----

MOLECULAR MOTION	152
------------------	-----

4.9 Diffusion and Effusion	152
----------------------------	-----

4.10 The Kinetic Model of Gases	153
---------------------------------	-----

4.11 The Maxwell Distribution of Speeds	157
---	-----

<i>Box 4.1 How Do We Know . . . the Distribution of Molecular Speeds?</i>	158
---	-----

REAL GASES	159
------------	-----

4.12 Deviations from Ideality	159
-------------------------------	-----

4.13 The Liquefaction of Gases	160
--------------------------------	-----

4.14 Equations of State of Real Gases	161
---------------------------------------	-----

Exercises	163
-----------	-----

Chapter 5 LIQUIDS AND SOLIDS

INTERMOLECULAR FORCES	171
-----------------------	-----

5.1 The Origin of Intermolecular Forces	172
---	-----

5.2 Ion–Dipole Forces	172
-----------------------	-----

5.3 Dipole–Dipole Forces	174
--------------------------	-----

5.4 London Forces	175
-------------------	-----

5.5 Hydrogen Bonding	178
----------------------	-----

5.6 Repulsions	179
----------------	-----

LIQUID STRUCTURE	179
------------------	-----

5.7 Order in Liquids	180
----------------------	-----

5.8 Viscosity and Surface Tension	180
-----------------------------------	-----

SOLID STRUCTURES	182
------------------	-----

5.9 Classification of Solids	182
------------------------------	-----

<i>Box 5.1 How Do We Know . . . What a Surface Looks Like?</i>	183
--	-----

5.10 Molecular Solids	184
-----------------------	-----

5.11 Network Solids	185	7.4 Heat	243
5.12 Metallic Solids	186	7.5 The Measurement of Heat	243
5.13 Unit Cells	188	7.6 The First Law	247
5.14 Ionic Structures	191	7.7 A Molecular Interlude: The Origin of Internal Energy	251
THE IMPACT ON MATERIALS	194	ENTHALPY	252
5.15 Liquid Crystals	194	7.8 Heat Transfers at Constant Pressure	252
5.16 Ionic Liquids	195	7.9 Heat Capacities at Constant Volume and Constant Pressure	254
Exercises	196	7.10 A Molecular Interlude: The Origin of the Heat Capacities of Gases	255
MAJOR TECHNIQUE 3: X-RAY DIFFRACTION	203	7.11 The Enthalpy of Physical Change	257

Chapter 6 INORGANIC MATERIALS

METALLIC MATERIALS	205	7.12 Heating Curves	259
6.1 The Properties of Metals	205	<i>Box 7.1 How Do We Know . . . the Shape of a Heating Curve?</i>	260
6.2 Alloys	207	THE ENTHALPY OF CHEMICAL CHANGE	261
6.3 Steel	208	7.13 Reaction Enthalpies	261
6.4 Nonferrous Alloys	209	7.14 The Relation Between ΔH and ΔU	263
HARD MATERIALS	210	7.15 Standard Reaction Enthalpies	264
6.5 Diamond and Graphite	210	7.16 Combining Reaction Enthalpies: Hess's Law	265
6.6 Calcium Carbonate	211	TOOLBOX 7.1 HOW TO USE HESS'S LAW	266
6.7 Silicates	212	7.17 The Heat Output of Reactions	267
6.8 Cement and Concrete	214	<i>Box 7.2 What Has This to Do with . . . the Environment?</i>	268
6.9 Borides, Carbides, and Nitrides	215	7.18 Standard Enthalpies of Formation	271
6.10 Glasses	216	7.19 The Born–Haber Cycle	274
6.11 Ceramics	217	7.20 Bond Enthalpies	276
MATERIALS FOR NEW TECHNOLOGIES	218	7.21 The Variation of Reaction Enthalpy with Temperature	278
6.12 Bonding in the Solid State	218	Exercises	280
6.13 Semiconductors	220		
6.14 Superconductors	221		
6.15 Luminescent Materials	223		
6.16 Magnetic Materials	224		
6.17 Composite Materials	225		
NANOMATERIALS	226		
6.18 The Nature and Uses of Nanomaterials	226		
6.19 Nanotubes	227		
6.20 Preparation of Nanomaterials	228		
Exercises	231		

Chapter 7 THERMODYNAMICS: THE FIRST LAW

SYSTEMS, STATES, AND ENERGY	235
7.1 Systems	236
7.2 Work and Energy	236
7.3 Expansion Work	237

Chapter 8 THERMODYNAMICS: THE SECOND AND THIRD LAWS

ENTROPY	287
8.1 Spontaneous Change	287
8.2 Entropy and Disorder	288
8.3 Changes in Entropy	290

8.4 Entropy Changes Accompanying Changes in Physical State	295	COLLIGATIVE PROPERTIES	352
8.5 A Molecular Interpretation of Entropy	298	9.14 Molality	352
8.6 The Equivalence of Statistical and Thermodynamic Entropies	301	TOOLBOX 9.1 HOW TO USE THE MOLALITY	353
8.7 Standard Molar Entropies	303	9.15 Vapor-Pressure Lowering	356
<i>Box 8.1 Frontiers of Chemistry: The Quest for Absolute Zero</i>	304	9.16 Boiling-Point Elevation and Freezing-Point Depression	358
8.8 Standard Reaction Entropies	307	9.17 Osmosis	360
GLOBAL CHANGES IN ENTROPY	308	TOOLBOX 9.2 HOW TO USE COLLIGATIVE PROPERTIES TO DETERMINE MOLAR MASS	362
8.9 The Surroundings	308	BINARY LIQUID MIXTURES	365
8.10 The Overall Change in Entropy	310	9.18 The Vapor Pressure of a Binary Liquid Mixture	365
8.11 Equilibrium	314	9.19 Distillation	367
GIBBS FREE ENERGY	315	9.20 Azeotropes	368
8.12 Focusing on the System	315	THE IMPACT ON BIOLOGY AND MATERIALS	369
8.13 Gibbs Free Energy of Reaction	318	9.21 Colloids	370
8.14 The Gibbs Free Energy and Nonexpansion Work	321	9.22 Bio-based and Biomimetic Materials	371
8.15 The Effect of Temperature	323	<i>Box 9.1 Frontiers of Chemistry: Drug Delivery Exercises</i>	372 373
8.16 Impact on Biology: Gibbs Free Energy Changes in Biological Systems	325	MAJOR TECHNIQUE 4: CHROMATOGRAPHY	381
Exercises	326		
Chapter 9 PHYSICAL EQUILIBRIA		Chapter 10 CHEMICAL EQUILIBRIA	
PHASES AND PHASE TRANSITIONS	333	REACTIONS AT EQUILIBRIUM	384
9.1 Vapor Pressure	334	10.1 The Reversibility of Reactions	384
9.2 Volatility and Intermolecular Forces	335	10.2 Equilibrium and the Law of Mass Action	385
9.3 The Variation of Vapor Pressure with Temperature	335	10.3 The Thermodynamic Origin of Equilibrium Constants	390
9.4 Boiling	338	10.4 The Extent of Reaction	395
9.5 Freezing and Melting	339	10.5 The Direction of Reaction	396
9.6 Phase Diagrams	340	EQUILIBRIUM CALCULATIONS	397
9.7 Critical Properties	342	10.6 The Equilibrium Constant in Terms of Molar Concentrations of Gases	398
SOLUBILITY	344	10.7 Alternative Forms of the Equilibrium Constant	400
9.8 The Limits of Solubility	344	10.8 Using Equilibrium Constants	401
9.9 The Like-Dissolves-Like Rule	345	TOOLBOX 10.1 HOW TO SET UP AND USE AN EQUILIBRIUM TABLE	401
9.10 Pressure and Gas Solubility: Henry's Law	347	THE RESPONSE OF EQUILIBRIA TO CHANGES IN CONDITIONS	405
9.11 Temperature and Solubility	348	10.9 Adding and Removing Reagents	405
9.12 The Enthalpy of Solution	349	10.10 Compressing a Reaction Mixture	408
9.13 The Gibbs Free Energy of Solution	351		

10.11 Temperature and Equilibrium	410
10.12 Catalysts and Haber's Achievement	413
10.13 The Impact on Biology: Homeostasis	413
Exercises	414

AUTOPROTOLYSIS AND pH	464
11.18 Very Dilute Solutions of Strong Acids and Bases	464
11.19 Very Dilute Solutions of Weak Acids	466
Exercises	468

Chapter 11 ACIDS AND BASES

THE NATURE OF ACIDS AND BASES	423
11.1 Brønsted–Lowry Acids and Bases	423
11.2 Lewis Acids and Bases	426
11.3 Acidic, Basic, and Amphoteric Oxides	428
11.4 Proton Exchange Between Water Molecules	429
11.5 The pH Scale	431
11.6 The pOH of Solutions	434
WEAK ACIDS AND BASES	435
11.7 Acidity and Basicity Constants	435
11.8 The Conjugate Seesaw	438
11.9 Molecular Structure and Acid Strength	440
11.10 The Strengths of Oxoacids and Carboxylic Acids	442
THE pH OF SOLUTIONS OF WEAK ACIDS AND BASES	445
11.11 Solutions of Weak Acids	445
TOOLBOX 11.1 HOW TO CALCULATE THE pH OF A SOLUTION OF A WEAK ACID	445
11.12 Solutions of Weak Bases	448
TOOLBOX 11.2 HOW TO CALCULATE THE pH OF A SOLUTION OF A WEAK BASE	448
11.13 The pH of Salt Solutions	450
POLYPROTIC ACIDS AND BASES	454
11.14 The pH of a Polyprotic Acid Solution	455
11.15 Solutions of Salts of Polyprotic Acids	456
11.16 The Concentrations of Solute Species	457
TOOLBOX 11.3 HOW TO CALCULATE THE CONCENTRATIONS OF ALL SPECIES IN A POLYPROTIC ACID SOLUTION	458
11.17 Composition and pH	461
<i>Box 11.1 What Has This to Do with . . . the Environment?</i>	462

Chapter 12 AQUEOUS EQUILIBRIA

MIXED SOLUTIONS AND BUFFERS	475
12.1 Buffer Action	476
12.2 Designing a Buffer	477
12.3 Buffer Capacity	482
TITRATIONS	483
12.4 Strong Acid–Strong Base Titrations	483
<i>Box 12.1 What Has This to Do with . . . Staying Alive?</i>	484
TOOLBOX 12.1 HOW TO CALCULATE THE pH DURING A STRONG ACID–STRONG BASE TITRATION	485
12.5 Strong Acid–Weak Base and Weak Acid–Strong Base Titrations	486
TOOLBOX 12.2 HOW TO CALCULATE THE pH DURING A TITRATION OF A WEAK ACID OR A WEAK BASE	490
12.6 Acid–Base Indicators	492
12.7 Stoichiometry of Polyprotic Acid Titrations	494
SOLUBILITY EQUILIBRIA	496
12.8 The Solubility Product	497
12.9 The Common-Ion Effect	499
12.10 Predicting Precipitation	501
12.11 Selective Precipitation	502
12.12 Dissolving Precipitates	504
12.13 Complex Ion Formation	505
12.14 Qualitative Analysis	507
Exercises	509

Chapter 13 ELECTROCHEMISTRY

REPRESENTING REDOX REACTIONS	515
13.1 Half-Reactions	516
13.2 Balancing Redox Equations	516
TOOLBOX 13.1 HOW TO BALANCE COMPLICATED REDOX EQUATIONS	517

GALVANIC CELLS	522	REACTION MECHANISMS	580
13.3 The Structure of Galvanic Cells	522	14.7 Elementary Reactions	580
13.4 Cell Potential and Reaction Gibbs Free Energy	524	14.8 The Rate Laws of Elementary Reactions	581
13.5 The Notation for Cells	526	14.9 Chain Reactions	585
TOOLBOX 13.2 HOW TO WRITE A CELL REACTION CORRESPONDING TO A CELL DIAGRAM	528	14.10 Rates and Equilibrium	586
13.6 Standard Potentials	529	MODELS OF REACTIONS	587
13.7 The Electrochemical Series	534	14.11 The Effect of Temperature	587
13.8 Standard Potentials and Equilibrium Constants	536	14.12 Collision Theory	591
TOOLBOX 13.3 HOW TO CALCULATE EQUILIBRIUM CONSTANTS FROM ELECTROCHEMICAL DATA	537	<i>Box 14.2 How Do We Know . . . What Happens During a Molecular Collision?</i>	593
13.9 The Nernst Equation	538	14.13 Transition State Theory	594
13.10 Ion-Selective Electrodes	541	ACCELERATING REACTIONS	595
ELECTROLYTIC CELLS	542	14.14 Catalysis	595
13.11 Electrolysis	542	14.15 Industrial Catalysts	597
13.12 The Products of Electrolysis	544	<i>Box 14.3 What Has This to Do with . . . the Environment?</i>	598
TOOLBOX 13.4 HOW TO PREDICT THE RESULT OF ELECTROLYSIS	545	14.16 Living Catalysts: Enzymes	600
THE IMPACT ON MATERIALS	547	Exercises	602
13.13 Applications of Electrolysis	547	MAJOR TECHNIQUE 5: COMPUTATION	610
13.14 Corrosion	548		
13.15 Practical Cells	550		
<i>Box 13.1 Frontiers of Chemistry: Fuel Cells</i>	552		
Exercises	553		
Chapter 14 CHEMICAL KINETICS		Chapter 15 THE ELEMENTS: THE MAIN GROUP ELEMENTS	
REACTION RATES	561	PERIODIC TRENDS	611
14.1 Concentration and Reaction Rate	561	15.1 Atomic Properties	611
<i>Box 14.1 How Do We Know . . . What Happens to Atoms During a Reaction?</i>	564	15.2 Bonding Trends	613
14.2 The Instantaneous Rate of Reaction	565	HYDROGEN	615
14.3 Rate Laws and Reaction Order	566	15.3 The Element	615
CONCENTRATION AND TIME	572	<i>Box 15.1 What Has This to Do with . . . the Environment?</i>	616
14.4 First-Order Integrated Rate Laws	572	15.4 Compounds of Hydrogen	618
14.5 Half-Lives for First-Order Reactions	576	GROUP 1: THE ALKALI METALS	619
14.6 Second-Order Integrated Rate Laws	578	15.5 The Group 1 Elements	620
		15.6 Compounds of Lithium, Sodium, and Potassium	622
		GROUP 2: THE ALKALINE EARTH METALS	623
		15.7 The Group 2 Elements	624
		15.8 Compounds of Beryllium, Magnesium, and Calcium	625
		GROUP 13/III: THE BORON FAMILY	628
		15.9 The Group 13/III Elements	628
		15.10 Group 13/III Oxides and Halides	630
		15.11 Boranes and Borohydrides	632
		GROUP 14/IV: THE CARBON FAMILY	633
		15.12 The Group 14/IV Elements	633

<i>Box 15.2 Frontiers of Chemistry:</i>	
<i>Self-Assembling Materials</i>	636
15.13 Oxides of Carbon and Silicon	637
15.14 Other Important Group 14/IV Compounds	639
GROUP 15/V: THE NITROGEN FAMILY	640
15.15 The Group 15/V Elements	641
15.16 Compounds with Hydrogen and the Halogens	642
15.17 Nitrogen Oxides and Oxoacids	644
15.18 Phosphorus Oxides and Oxoacids	646
GROUP 16/VI: THE OXYGEN FAMILY	647
15.19 The Group 16/VI Elements	648
15.20 Compounds with Hydrogen	650
15.21 Sulfur Oxides and Oxoacids	652
GROUP 17/VII: THE HALOGENS	654
15.22 The Group 17/VII Elements	654
15.23 Compounds of the Halogens	656
GROUP 18/VIII: THE NOBLE GASES	659
15.24 The Group 18/VIII Elements	659
15.25 Compounds of the Noble Gases	660
Exercises	661

Chapter 16

THE ELEMENTS: THE d-BLOCK

THE d-BLOCK ELEMENTS AND THEIR COMPOUNDS	667
16.1 Trends in Physical Properties	668
16.2 Trends in Chemical Properties	669
SELECTED ELEMENTS: A SURVEY	671
16.3 Scandium Through Nickel	671
16.4 Groups 11 and 12	676
COORDINATION COMPOUNDS	680
16.5 Coordination Complexes	680
<i>Box 16.1 What Has This to Do with . . . Staying Alive?</i>	681
TOOLBOX 16.1 HOW TO NAME d-METAL COMPLEXES AND COORDINATION COMPOUNDS	683
16.6 The Shapes of Complexes	685
16.7 Isomers	686
<i>Box 16.2 How Do We Know . . . That a Complex Is Optically Active?</i>	689

THE ELECTRONIC STRUCTURES OF COMPLEXES	691
16.8 Crystal Field Theory	691
16.9 The Spectrochemical Series	693
16.10 The Colors of Complexes	696
16.11 Magnetic Properties of Complexes	697
16.12 Ligand Field Theory	698
Exercises	700

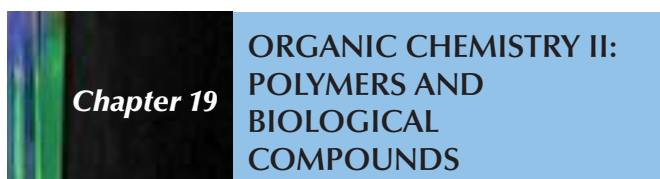
Chapter 17 NUCLEAR CHEMISTRY

NUCLEAR DECAY	705
17.1 The Evidence for Spontaneous Nuclear Decay	706
17.2 Nuclear Reactions	707
17.3 The Pattern of Nuclear Stability	710
17.4 Predicting the Type of Nuclear Decay	712
17.5 Nucleosynthesis	712
<i>Box 17.1 What Has This to Do with . . . Staying Alive?</i>	714
NUCLEAR RADIATION	715
17.6 The Biological Effects of Radiation	715
<i>Box 17.2 How Do We Know . . . How Radioactive a Material Is?</i>	717
17.7 Measuring the Rate of Nuclear Decay	717
17.8 Uses of Radioisotopes	721
NUCLEAR ENERGY	721
17.9 Mass–Energy Conversion	722
17.10 Nuclear Fission	724
17.11 Nuclear Fusion	726
17.12 The Chemistry of Nuclear Power	728
Exercises	730

Chapter 18 ORGANIC CHEMISTRY I: THE HYDROCARBONS

ALIPHATIC HYDROCARBONS	735
18.1 Types of Aliphatic Hydrocarbons	736
TOOLBOX 18.1 HOW TO NAME ALIPHATIC HYDROCARBONS	738
18.2 Isomers	740
18.3 Properties of Alkanes	743

18.4 Alkane Substitution Reactions	744	<i>Box 19.1 Frontiers of Chemistry: Conducting</i>	
18.5 Properties of Alkenes	745	<i>Polymers</i>	778
18.6 Electrophilic Addition	746	19.14 Carbohydrates	781
AROMATIC COMPOUNDS	748	19.15 Nucleic Acids	782
18.7 Nomenclature of Arenes	748	Exercises	785
18.8 Electrophilic Substitution	749	MAJOR TECHNIQUE 7: NUCLEAR MAGNETIC	
IMPACT ON TECHNOLOGY: FUELS	751	RESONANCE	791
18.9 Gasoline	751	Appendix 1 Symbols, Units, and Mathematical	
18.10 Coal	752	Techniques	A1
Exercises	753	1A Symbols	A1
MAJOR TECHNIQUE 6: MASS SPECTROMETRY	758	1B Units and Unit Conversions	A3
		1C Scientific Notation	A5
		1D Exponents and Logarithms	A6
		1E Equations and Graphs	A7
		1F Calculus	A7
		Appendix 2 Experimental Data	A11
		2A Thermodynamic Data at 25°C	A11
		2B Standard Potentials at 12°C	A18
		2C Ground-State Electron	
		Configurations	A20
		2D The Elements	A22
		2E The Top 23 Chemicals by	
		Industrial Production in	
		the United States in 2008	A32
		Appendix 3 Nomenclature	A33
		3A The Nomenclature of Polyatomic	
		Ions	A33
		3B Common Names of Chemicals	A34
		3C Names of Some Common	
		Cations with Variable Charge	
		Numbers	A34
		Glossary	B1
		Answers	C1
		Self-Tests B	C1
		Odd-Numbered Exercises	C10
		Illustration Credits	D1
		Index	E1



COMMON FUNCTIONAL GROUPS	761
19.1 Haloalkanes	762
19.2 Alcohols	762
19.3 Ethers	763
19.4 Phenols	764
19.5 Aldehydes and Ketones	764
19.6 Carboxylic Acids	765
19.7 Esters	766
19.8 Amines, Amino Acids, and	
Amides	767
TOOLBOX 19.1 HOW TO NAME SIMPLE COMPOUNDS	
WITH FUNCTIONAL GROUPS	769
THE IMPACT ON TECHNOLOGY	770
19.9 Addition Polymerization	770
19.10 Condensation Polymerization	772
19.11 Copolymers	775
19.12 Physical Properties of Polymers	775
THE IMPACT ON BIOLOGY	777
19.13 Proteins	777

LETTER FROM THE AUTHORS

Dear Colleagues,

It is with great pleasure that we offer the fifth edition of *Chemical Principles: The Quest for Insight*. The new edition is designed, like its predecessors, to encourage students to think and to develop a solid understanding of chemistry by first building a qualitative understanding and then showing how to express those qualitative concepts quantitatively.

Because college students often have forgotten much of their high school chemistry, the book begins with a *Fundamentals* section that reviews the basic ideas of chemistry such as nomenclature, concentration, and stoichiometry. The main part of the book starts with an investigation of the structure of the atom, goes on to show how atomic properties determine the types of bonds that atoms form, and then investigates how the properties of molecules and ions contribute to the structure, reactions, and properties of bulk matter.

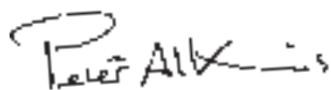
We have updated much of the content and the format of the periodic table. We have also introduced a new materials chapter following the solid state chapter. This chapter serves as a review of the first five chapters and introduces students to the chemistry that is the basis of the exciting field of nanotechnology. In this chapter students also see how the chemical principles they are learning, even at an early stage in their course, apply to modern research and applications such as ceramic and magnetic materials and electronic components. In later chapters we investigate further properties of materials as new concepts are introduced.

We have enhanced our approach to problem solving to help students develop the kinds of problem-solving skills that experts use. That is, we want students to learn to solve problems as chemists do. Consequently, in the worked examples we begin, where appropriate, with an *Anticipate* section that encourages students to estimate the answer and develop their powers of insight and judgment. Then we present a general *Plan* that encourages readers to collect their thoughts and establish an approach to the problem. After the fully worked out *Solve* section, we encourage students to reflect on their original anticipation in a brief *Evaluate* section. In addition, for a number of calculations we encourage students to organize their thinking by asking *What should we assume?* before proceeding. Almost all the worked examples are accompanied by graphic thumbnail interpretations of each step, which were introduced in the fourth edition as an entirely new way to help students make connections among the different levels of chemical description. The thumbnails have been developed further for this edition.

We hope you will like the scattering of *Thinking points* throughout the text, which are intended to encourage and emphasize our underlying strategy: to get students to think as well as to learn. We have also generated a new art program for a great deal of the book, which we hope will enhance the learning experience by conveying insight into the molecular world.

We are grateful for the feedback and support we have received from those who have used the previous four editions. The suggestions readers have given us have helped us to refine the book and make it more interesting and useful for students. We hope that you and your students find the book to be a refreshing and intriguing introduction to chemistry.

Yours sincerely,



Peter Atkins



Loretta Jones

PREFACE

CHEMICAL PRINCIPLES

This text is designed for a rigorous course in introductory chemistry. Its central theme is to challenge students to think and question while providing a sound foundation in the principles of chemistry.

At the same time, students of all levels benefit from assistance in learning how to think, pose questions, and approach problems. To that end, *Chemical Principles* is organized in a logical way that builds understanding and offers students a wide array of pedagogical support.

ATOMS-FIRST ORGANIZATION

Chemical Principles presents the concepts of chemistry in a logical sequence that enhances student understanding. The **atoms-first sequence** starts with the behavior of atoms and molecules and builds to more complex properties and interactions.

- **Atoms and molecules** come first (including discussions of quantum mechanics and molecular orbitals), providing the foundation for understanding bulk properties and models of gases, liquids, and solids. Chapter 1 has been reorganized in this edition to give readers a gentler introduction to atoms and their structure.
- Next comes an exploration of **thermodynamics and equilibrium**, which builds on a conceptual understanding of entropy and free energy. This integrated presentation lays a common foundation for related concepts and provides a basis for the form of the equilibrium constant.
- **Kinetics** then shows the dynamic nature of chemistry and the crucial role of insight and model building in identifying reaction mechanisms.


COVERING THE BASICS

The **Fundamentals** sections, which precede Chapter 1, are identified by green-edged pages. These 13 minichapters provide a streamlined overview of the basics of chemistry. They can be used either to provide a useful, succinct review of basic material to which students can refer for extra help as they progress through the course, or as a concise, quick survey of material before starting on the main text.

Diagnostic Test for the Fundamentals Sections. This test allows instructors to determine what their students understand and where they need additional support. Instructors can then make appropriate assignments from the Fundamentals sections. The test includes 5 to 10 problems for each Fundamentals section. The diagnostic test was created by Cynthia LaBrake at the University of Texas, Austin and can be found on the Instructor's Resource CD ROM and on the Instructor pages of the Web site.

FLEXIBLE MATH COVERAGE

Optional Use of Calculus. The *How do we do that?* feature sets off derivations of key equations and encourages students to appreciate the power of mathematics. Almost all the calculus in the text is confined to this feature, so it can easily be avoided or emphasized as the instructor chooses.

A selection of end-of-chapter exercises that make use of calculus are provided and marked with a .

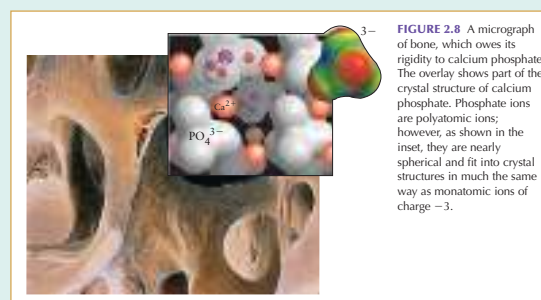


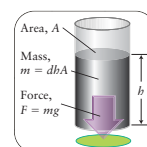
FIGURE 2.8 A micrograph of bone, which owes its rigidity to calcium phosphate. The overlay shows part of the crystal structure of calcium phosphate. Phosphate ions are polyatomic ions; however, as shown in the inset, they are nearly spherical and fit into crystal structures in much the same way as monatomic ions of charge -3 .

HOW DO WE DO THAT?

We want to find the relation between the height, b , of the column of mercury in a barometer and the atmospheric pressure, P . Suppose the cross-sectional area of the cylindrical column is A . The volume of mercury in the column is the height of the cylinder times its area, $V = bA$. The mass, m , of this volume of mercury is the product of mercury's density, d , and the volume; so $m = dV = dbA$. The mercury is pulled down by the force of gravity; and the total force that its mass exerts at its base is the product of the mass and the acceleration of free fall (the acceleration due to gravity), g : $F = mg$. Therefore, the pressure at the base of the column, the force divided by the area, is

From $P = F/A$ and $F = mg$:

$$P = \frac{mg}{A} = \frac{mg}{A} = \frac{dbA}{A}g = dbg$$



This equation shows that the pressure, P , exerted by a column of mercury is proportional to the height of the column. Mercury inside a tube sealed at one end and inverted in a pool of mercury will fall until the pressure exerted by the mercury balances the atmospheric pressure. Therefore, the height of the column can be used as a measure of atmospheric pressure.

EXAMPLE 4.3 Using the combined gas law when one variable is changed

Assume that, when you press in the piston of a bicycle pump, the volume inside the pump is decreased from about 100. cm³ to 20. cm³ before the air flows into the tire. Suppose that the compression is isothermal; estimate the final pressure of the compressed air in the pump, given an initial pressure of 1.00 atm.

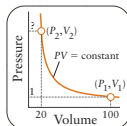
Anticipate The volume is reduced by a factor of 5, so we should expect a fivefold increase in pressure.

PLAN Follow the second procedure in Toolbox 4.1. Only the pressure and volume change, so all other variables cancel, resulting in Boyle's law.

SOLVE

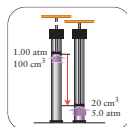
Step 1 Rearrange $P_1V_1/n_1T_1 = P_2V_2/n_2T_2$ to find P_2 by multiplying both sides by n_2T_2/V_2 , and set $n_2 = n_1$ (no change in the amount) and $T_2 = T_1$ (no change in temperature):

$$P_2 = \frac{P_1V_1}{n_1T_1} \times \frac{n_2T_2}{V_2} \stackrel{n_2=n_1}{=} \frac{P_1V_1}{n_1T_1} \times \frac{n_1T_1}{V_2} = P_1 \times \frac{V_1}{V_2}$$



Step 2 Substitute the data:

$$P_2 = (1.00 \text{ atm}) \times \frac{100 \text{ cm}^3}{20 \text{ cm}^3} = 5.0 \text{ atm}$$



Evaluate The final pressure is higher by a factor of 5 (more precisely, 5.0), as expected.

Self-Test 4.8A A sample of argon gas of volume 10.0 mL at 200. Torr is allowed to expand isothermally into an evacuated tube with a volume of 0.200 L. What is the final pressure of the argon in the tube?

[Answer: 10.0 Torr]

- **Toolboxes** show students how to tackle *major types* of calculations, demonstrating how to connect concepts to problem solving. They are designed as learning aids and handy summaries of key material. Each Toolbox is immediately followed by a related example.

EMPHASIS ON PROBLEM SOLVING

- **NEW! Anticipate/Plan/Solve/Evaluate Strategy.** This problem-solving approach encourages students to anticipate or predict what a problem's answer should be and to map out the solution before trying to solve the problem. Following the solution, the original anticipation is evaluated. The accompanying graphics provide the opportunity for visualizing and interpreting each step of the solution and the final result.

- **Self-Tests** occur as pairs throughout the book. They enable students to test their understanding of the material covered in the preceding section or Worked Example. The answer to the first self-test is provided immediately and the answer to the second can be found at the back of the book.

- **NEW! Thinking Points** encourage students to speculate about the implications of what they are learning and to transfer their knowledge to new situations.

The relative energies of the d-orbitals are different in complexes with different shapes. For example, in a tetrahedral complex, the three t_2 -orbitals point more directly at the ligands than the two e-orbitals do. As a result, in a tetrahedral complex, the t_2 -orbitals have a higher energy than the e-orbitals (Fig. 16.29). The ligand field splitting, Δ_T (where the T denotes tetrahedral), is generally smaller than in octahedral complexes, in part because there are fewer repelling ligands.

Thinking point: Into what groups do you think the d-orbitals are split in a square-planar complex?

TOOLBOX 7.1**HOW TO USE HESS'S LAW****CONCEPTUAL BASIS**

Because enthalpy is a state function, the enthalpy change of a system depends only on its initial and final states. Therefore, we can carry out a reaction in one step or, if that is not convenient, visualize it as the sum of several steps; the reaction enthalpy is the same in each case.

PROCEDURE

To use Hess's law to find the enthalpy of a given reaction, we find a sequence of reactions with known reaction enthalpies that adds up to the reaction of interest.

Step 1 Select one of the reactants in the overall reaction and write down a chemical equation in which it also appears as a reactant.

Step 2 Select one of the products in the overall reaction and write down a chemical equation in which it also appears as

a product. Add this equation to the equation written in step 1 and cancel species that appear on both sides of the equation.

Step 3 Cancel unwanted species in the sum obtained in step 2 by adding an equation that has the same substance or substances on the opposite side of the arrow.

Step 4 Once the sequence is complete, combine the standard reaction enthalpies.

In each step, we may need to reverse the equation or multiply it by a factor. Recall from Eq. 16 that, if we want to reverse a chemical equation, we have to change the sign of the reaction enthalpy. If we multiply the stoichiometric coefficients by a factor, we must multiply the reaction enthalpy by the same factor.

This procedure is illustrated in Example 7.9.

CUTTING EDGE CHEMISTRY FOR ALL STUDENTS

Of special interest to **Engineering students:**

- Liquid Crystals (Section 5.15)
- Colloids (Section 9.21)
- Applications of Electrolysis (Section 13.13)
- Fuels (Section 18.9 and Box 7.2)
- Polymerization and Polymers (Sections 19.9–19.12)
- Corrosion (Section 13.14)
- Fuel Cells (Box 13.1 Frontiers of Chemistry)
- Industrial Catalysts (Section 14.15)
- Self Assembling Materials (Box 15.2 Frontiers of Chemistry)
- The whole of Chapter 6, Inorganic Materials

Of special interest to **Biology students:**

- Drugs by Design and Discovery (Box 3.1 Frontiers of Chemistry)
- Gibbs Free Energy Changes in Biological Systems (Section 8.16)
- Colloids (Section 9.21)
- Bio-based and Biomimetic Materials (Section 9.22)
- Homeostasis (Section 10.13)
- Physiological Buffers (Box 12.1 What Has This to Do with . . . Staying Alive?)
- Living Catalysts: Enzymes (Section 14.16)
- Why We Need to Eat d-Metals (Box 16.1 What Has This to Do with . . . Staying Alive?)
- Nuclear Medicine (Box 17.1 What Has This to Do with . . . Staying Alive?)
- The Biological Effects of Radiation (Section 17.6)
- Proteins (Section 19.13)
- Carbohydrates (Section 19.14)
- Nucleic Acids (Section 19.15)

Of special interest to **Environmental Science** students:

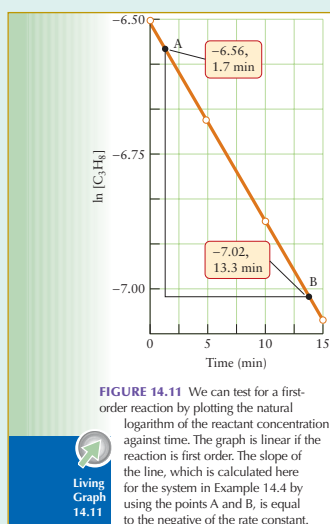
- Green Chemistry promotes environmentally sound chemistry. Green chemistry passages in the text and green chemistry end-of-chapter exercises are accompanied by an icon.
- Alternative Fuels (Box 7.2 What Has This to Do with . . . the Environment?)
- Acid Rain and the Gene Pool (Box 11.1 What Has This to Do with . . . the Environment?)
- Protecting the Ozone Layer (Box 14.3 What Has This to Do with . . . the Environment?)
- The Greenhouse Effect (Box 15.1. What Has This to Do with . . . the Environment?)
- Coal (Section 18.10)

• **NEW!** Chapter 6, **Inorganic Materials**. This new chapter reviews the first five chapters and introduces students to the chemistry that is the basis of the exciting new field of nanotechnology. In this chapter students also see how the chemical principles they are learning apply to cutting edge research and applications such as ceramic and magnetic materials and electronic components.

MEDIA INTEGRATION

Selected figures and exercises throughout the book are accompanied by **media link icons** that direct students to Web-based resources. These integrated links to the companion Web site are designed to make the text more dynamic and interactive. *Chemical Principles* contains media links to:

- **Living Graphs.** Selected graphs in the text are available in interactive form on the Web site. Students can manipulate parameters and see cause and effect relationships.
- **Animations.** Selected art in the text is supported by media. Students can view motion, three dimensions, and atomic and molecular interactions and learn to visualize like chemists—at a molecular level. To focus their attention, questions on each animation have been added in this edition.
- **Lab Videos.** Video clips of many of the reactions described in the book are provided on the book's Web site.



dense materials. Branched polymer chains cannot fit together as closely and form weaker, less dense materials (Fig. 19.15). A soft, lightweight body armor has been developed by creating arrays of long polyethylene chains that are closely aligned in the same direction, giving rise to very strong intermolecular forces. This body armor is reported to be 15 times stronger than steel, yet has such a low density that it floats on water. It is also soft and flexible, so it is comfortable to wear (Fig. 19.16).



FIGURE 19.16 Recruits at the New York Police Academy are issued bullet-proof vests. The high-density polyethylene body armor protects law enforcement personnel without restricting movement because it is soft and flexible.

6.11 Ceramics

Many of the materials used in the most advanced technologies are based on a material characteristic of one of the oldest technologies: common clay. Most clays used commercially are oxides of silicon, aluminum, and magnesium. *China clay* contains primarily kaolinite, a form of aluminum aluminosilicate that can be obtained reasonably free of the iron impurities that make many clays look reddish brown, and so it is white. However, other clays contain the iron oxides that cause the orange color of terra cotta tiles and flower pots.

The appearance of a flake of clay reflects its internal structure, which is something like an untidy stack of papers (Fig. 6.23). Sheets of tetrahedral silicate units or octahedral units of aluminum or magnesium oxides are separated by layers of water molecules that serve to bind the layers of the flake together. Each flake of clay is surrounded by a double layer of ions that separates the flakes by repelling the like charges on the other flakes. This repulsion allows the flakes to slide past one another and gives the clay the ability to flow in response to stress. As a result, clays can be easily molded.

When clay is baked in a kiln, it forms the hard, tough *ceramic* materials used in firebricks, tiles, and pots as the water is driven out and strong chemical bonds form between the flakes. Large amounts of china clay, which is used to make ceramics such as porcelain and china, are applied in the coating of paper (such as this page) to give a smooth, non-absorbent surface. Clay was the first substance to be made into a ceramic, an inorganic material that has been hardened by heating to a high temperature. Today a wide variety of compounds, often oxides, are used to create ceramics with specific properties.



FIGURE 6.23 The layers of clay particles can be seen in this micrograph. Because the surfaces of these layers have like charges, they repel one another and easily slide past one another, making clay soft and malleable.

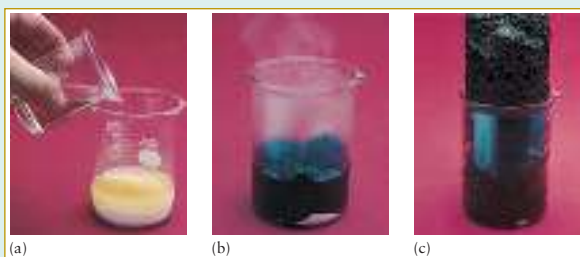
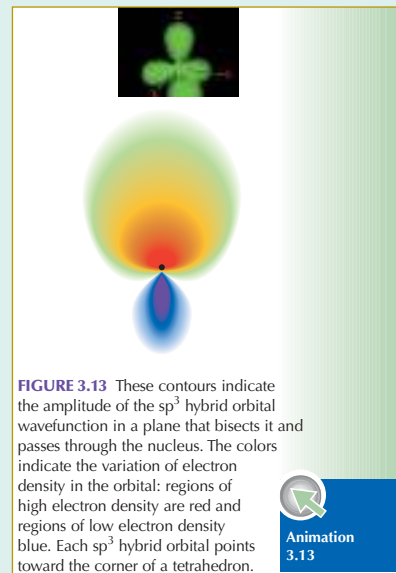


FIGURE 15.48 Sulfuric acid is a dehydrating agent. When concentrated sulfuric acid is poured on to sucrose (a), the sucrose, a carbohydrate, is dehydrated (b), leaving a frothy black mass of carbon (c).

Lab Video 15.48

- **Tools.** Tools on the book's Web site allow the study of chemical calculations, graphing, and exploration of periodic properties from different points of view.
- **End-of-Chapter Exercises.** Selected exercises direct students to use media to solve problems.



16.98 *cis*-Platin is an anticancer drug with a structure that can be viewed on the Web site. (a) What is the formula and systematic name for the compound *cis*-Platin? (b) Draw any isomers that are possible for this compound. Label any isomers that are optically active. (c) What is the coordination geometry of the platinum atom?

INSTRUCTOR AND STUDENT SUPPORT

We believe a student needs to interact with a concept several times in a variety of scenarios in order to obtain a thorough understanding. With that in mind, W. H. Freeman and Company has developed the most comprehensive student learning package available.

FOR THE INSTRUCTOR

Instructor's Solutions Manual by Carl Hoeger, University of California, San Diego, Laurence Lavelle, University of California, Los Angeles, and Yinfa Ma, University of Missouri-Rolla ISBN: 1-4292-3892-5

The *Instructor's Solutions Manual* contains full, worked-out solutions to all even-numbered exercises. Worked-out solutions for odd-numbered exercises can be found in the *Student Study Guide and Solutions Manual*.

Test Bank by Robert Balahura, University of Guelph, and Mark Benvenuto, University of Detroit Mercy

The *Test Bank* offers over 1400 multiple-choice, fill-in-the-blank, and essay questions, and is available exclusively on the *Instructor's Resource CD*.

Instructor's Resource CD ISBN: 1-4292-5808-X

To help instructors create their own Web sites and prepare dynamic lectures, the CD contains:

- All the illustrations from the text in .jpg files and preformatted PowerPoint slides
- All animations, lab videos, and living graphs from the Book Companion Site
- All solutions to the end-of-chapter exercises, in editable Microsoft Word files
- Diagnostic Test for the Fundamentals sections
- The electronic *Test Bank*, which includes over 1400 multiple-choice, fill-in-the-blank, and essay questions

Electronic Instructor Resources

Instructors can access valuable teaching tools through www.whfreeman.com/chemicalprinciples5e. These password-protected resources are designed to enhance lecture presentations, and include all the illustrations from the text-book (in .jpg and PowerPoint format), Lecture PowerPoint slides, Clicker Questions, and more. There's also a Diagnostic Test for the Fundamentals sections, which allows instructors to determine what their students understand and where they need additional support. Instructors can then make appropriate assignments from the Fundamentals sections. This test includes 5 to 10 problems for each Fundamentals section.

WebAssign Premium

For instructors interested in online homework management, W. H. Freeman and WebAssign have partnered to deliver WebAssign Premium—a comprehensive and flexible suite of resources. Combining the most widely used online homework platform with a wealth of visualization and tutorial resources, WebAssign Premium extends and enhances the classroom experience for instructors and students by combining algorithmically generated versions of selected end-of-chapter questions with a fully interactive eBook at an affordable price. See below for more details, or visit www.webassign.net to sign up for a faculty demo account.

LabPartner Chemistry

W. H. Freeman's latest offering in custom lab manuals provides instructors with a diverse and extensive database of experiments published by W. H. Freeman and Hayden-McNeil Publishing—all in an easy-to-use, searchable online system. With the click of a button, instructors can choose from a variety of traditional and inquiry-based labs. LabPartner Chemistry sorts labs in a number of ways, from topic, title, and author, to page count, estimated completion time, and prerequisite knowledge level. Add content on lab techniques and safety, reorder the labs to fit your syllabus, and include your original experiments with ease. Wrap it all up in an array of bindings, formats, and designs. It's the next step in custom lab publishing—the perfect partner for your course.

FOR THE STUDENT

***Student Study Guide and Solutions Manual* by John Krenos and Joseph Potenza, Rutgers University, Laurence Lavelle, University of California, Los Angeles, Yinfa Ma, University of Missouri Rolla, and Carl Hoeger, University of California, San Diego ISBN: 1-4292-3135-1**

The Student Study Guide and Solutions Manual provides students with a combined manual designed to help them to improve their problem-solving skills, avoid common mistakes, and understand key concepts. After a brief review of each section's critical ideas, students are taken through worked-out examples, try-it-yourself examples, and chapter quizzes, all structured to reinforce chapter objectives and build problem-solving techniques. The solutions manual includes detailed solutions to all odd-numbered exercises in the text.

***ACS Molecular Structure Model Set* by Maruzen Company, Ltd.
ISBN: 0-7167-4822-3**

Molecular modeling helps students understand physical and chemical properties by providing a way to visualize the three-dimensional arrangement of atoms. This model set uses polyhedra to represent atoms, and plastic connectors to represent bonds (scaled to correct bond length). Plastic plates representing orbital lobes are included for indicating lone pairs of electrons, radicals, and multiple bonds—a feature unique to this set.

***Bridging to the Lab* by Loretta Jones, University of Northern Colorado, and Roy Tasker, University of Western Sydney ISBN: 0-7167-4746-4**

The *Bridging to the Lab* modules are computer-based laboratory simulations with engaging activities that emphasize experimental design and visualization of structures and processes at the molecular level. The modules are designed to help students connect chemical principles from lecture with their practical applications in the lab. Every module has a built-in accountability feature that

records section completion for use in setting grades and a workbook for recording student work.

Used either as pre-laboratory preparation for related laboratory activities or to expose students to additional laboratory activities not available in their program, these modules motivate students to learn by proposing real-life problems in a virtual environment. Students make decisions on experimental design, observe reactions, record data, interpret these data, perform calculations, and draw conclusions from their results. Following a summary of the module, students test their understanding by applying what they have learned to new situations or by analyzing the effect of experimental errors.

For more information, visit www.whfreeman.com/bridgingtothelab

Chemistry Laboratory Student Notebook, Second Edition ISBN: 0-7167-3900-3

A convenient $8\frac{1}{2} \times 11$, 3-hole-punched format contains 114 pages of graph paper, carbon included. The new edition adds tables and graphs that make the *Notebook* a handy reference as well.

PREMIUM MULTIMEDIA RESOURCES

The *Chemical Principles* Book Companion Site, which can be accessed at www.whfreeman.com/chemicalprinciples5e, also contains a plethora of Premium Student Resources. Students can unlock these resources with the click of a button, putting extensive concept and problem-solving support at their fingertips. Some of the resources available are:

Toolbox Tutorials present major types of calculations, in an interactive format. They demonstrate the connections between concepts and problem solving and are designed as hands-on learning aids and handy summaries of key materials:

ChemCasts replicate the face-to-face experience of watching an instructor work a problem. Using a virtual whiteboard, these video tutors show students the steps involved in solving key worked examples, while explaining the concepts along the way. They are easy to view on a computer screen or download to an iPod.

ChemNews from *Scientific American* provides a streaming newsfeed of the latest articles from *Scientific American*.

The multimedia-enhanced eBook contains the complete text with a wealth of helpful functions. All student multimedia, including the Toolbox Tutorials, ChemCasts, and ChemNews, are linked directly from the eBook pages. Students are thus able to access supporting resources when they need them—taking advantage of the “teachable moment” as they read. Customization functions include instructor and student notes, document linking, and editing capabilities.

Online Learning Environments

The above resources are available in two platforms. WebAssign Premium offers the most effective and widely used online homework system in the sciences, and is designed specifically for those instructors seeking graded homework management. The Student Companion Web site provides student-oriented support materials independent of any homework system.

WEBASSIGN PREMIUM  WebAssign Premium

For instructors interested in online homework management, WebAssign Premium features a time-tested, secure online environment already used by millions of students worldwide. Featuring algorithmic problem generation and supported by a

wealth of chemistry-specific learning tools, WebAssign Premium for *Chemical Principles, Fifth Edition* presents instructors with a powerful assignment manager and study environment. WebAssign Premium provides the following resources:

- Algorithmically generated problems: Students receive homework problems containing unique values for computation, encouraging them to work out the problems on their own.
- Complete access to the interactive eBook, from a live table of contents, as well as from relevant problem statements.
- Links to Toolbox Tutorials, ChemCasts, and other interactive tools are provided as hints and feedback to ensure a clearer understanding of the problems and the concepts they reinforce.

STUDENT COMPANION WEB SITE

The *Chemical Principles* Book Companion Site, www.whfreeman.com/chemicalprinciples5e, provides a range of tools for problem solving and chemical explorations. They include:

- An interactive Periodic Table of the Elements
- A calculator adapted for solving equilibrium calculations
- Two- and three-dimensional curve plotters
- “Living Graphs,” which allow the user to control the parameters
- Animations that allow students to visualize chemical events on a molecular level
- Diagnostic Test for the Fundamentals sections
- Web-based Assessment. An excellent online quizzing bank of multiple-choice questions for each text chapter (not from the test bank). Students receive instant feedback and can take the quizzes multiple times. Instructors can go into a protected Web site to view results by quiz, student, or question, or can get weekly results via e-mail. Excellent for practice testing and/or homework.

ACKNOWLEDGMENTS

We are grateful to the many instructors, colleagues, and students who have contributed their expertise to this edition. We would like above all to thank those who carefully evaluated the fourth edition and commented on drafts of the fifth edition:

- | | |
|--|---|
| Yiyang Bai, <i>Houston Community College System Central Campus</i> | Gert Latzel, <i>Riemerling, Germany</i> |
| Maria Ballester, <i>Nova Southeastern University</i> | Nancy E. Lowmaster, <i>Allegheny College</i> |
| Patricia D. Christie, <i>Massachusetts Institute of Technology</i> | Matthew L. Miller, <i>South Dakota State University</i> |
| Henderson J. Cleaves, II, <i>University of California, San Diego</i> | Clifford B. Murphy, <i>Boston University</i> |
| Ivan J. Dmochowski, <i>University of Pennsylvania</i> | Maureen Murphy, <i>Huntingdon College</i> |
| Ronald Drucker, <i>City College of San Francisco</i> | Enrique Peacock-Lopez, <i>Williams College</i> |
| Christian Ekberg, <i>Chalmers University of Technology, Sweden</i> | LeRoy Peterson, Jr., <i>Francis Marion University</i> |
| Bryan Enderle, <i>University of California, Davis</i> | Tyler Rencher, <i>Brigham Young University</i> |
| David Erwin, <i>Rose-Hulman Institute of Technology</i> | Michael Samide, <i>Butler University</i> |
| Justin Fermann, <i>University of Massachusetts</i> | Gordy Savelle, <i>Itasca Community College</i> |
| Regina F. Frey, <i>Washington University</i> | Lori Slavin, <i>College of Saint Catherine</i> |
| P. Shiv Halasyamani, <i>University of Houston</i> | Mike Solow, <i>City College of San Francisco</i> |
| Jameica Hill, <i>Wofford College</i> | John E. Straub, <i>Boston University</i> |
| Alan Jircitano, <i>Penn State, Erie</i> | Laura Stultz, <i>Birmingham-Southern College</i> |
| | Peter Summer, <i>Lake Sumter Community College</i> |
| | David W. Wright, <i>Vanderbilt University</i> |
| | Mamudu Yakubu, <i>Elizabeth City State University</i> |
| | Meishan Zhao, <i>University of Chicago</i> |

The contributions of the reviewers of the first, second, and third editions remain embedded in the text, so we also wish to renew our thanks to:

Thomas Albrecht-Schmidt, <i>Auburn University</i>	Julie Ellefson Kuehn, <i>William Rainey Harper College</i>
Matthew Asplund, <i>Brigham Young University</i>	Cynthia LaBrake, <i>University of Texas, Austin</i>
Matthew P. Augustine, <i>University of California, Davis</i>	Brian B. Laird, <i>University of Kansas</i>
David Baker, <i>Delta College</i>	Yinfa Ma, <i>University of Missouri-Rolla</i>
Alan L. Balch, <i>University of California, Davis</i>	Paul McCord, <i>University of Texas, Austin</i>
Mario Baur, <i>University of California, Los Angeles</i>	Alison McCurdy, <i>Harvey Mudd College</i>
Robert K. Bohn, <i>University of Connecticut</i>	Charles W. McLaughlin, <i>University of Nebraska</i>
Paul Braterman, <i>University of North Texas</i>	Patricia O'Hara, <i>Amherst College</i>
William R. Brennan, <i>University of Pennsylvania</i>	Noel Owen, <i>Brigham Young University</i>
Ken Brooks, <i>New Mexico State University</i>	Donald Parkhurst, <i>The Walker School</i>
Julia R. Burdge, <i>University of Akron</i>	Montgomery Pettitt, <i>University of Houston</i>
Paul Charlesworth, <i>Michigan Technological University</i>	Joseph Potenza, <i>Rutgers University</i>
Patricia D. Christie, <i>Massachusetts Institute of Technology</i>	Wallace Pringle, <i>Wesleyan University</i>
William Cleaver, <i>University of Vermont</i>	Philip J. Reid, <i>University of Washington</i>
David Dalton, <i>Temple University</i>	Barbara Sawrey, <i>University of California, San Diego</i>
J. M. D'Auria, <i>Simon Fraser University</i>	George Schatz, <i>Northwestern University</i>
James E. Davis, <i>Harvard University</i>	Paula Jean Schlax, <i>Bates College</i>
Walter K. Dean, <i>Lawrence Technological University</i>	Carl Seliskar, <i>University of Cincinnati</i>
Jimmie Doll, <i>Brown University</i>	Robert Sharp, <i>University of Michigan, Ann Arbor</i>
Ronald Drucker, <i>City College of San Francisco</i>	Peter Sheridan, <i>Colgate University</i>
Jetty Duffy-Matzner, <i>State University of New York, Cortland</i>	Jay Shore, <i>South Dakota State University</i>
Robert Eierman, <i>University of Wisconsin</i>	Herb Silber, <i>San Jose State University</i>
Kevin L. Evans, <i>Glenville State College</i>	Lee G. Sobotka, <i>Washington University</i>
Donald D. Fitts, <i>University of Pennsylvania</i>	Michael Sommer, <i>Harvard University</i>
Lawrence Fong, <i>City College of San Francisco</i>	Nanette A. Stevens, <i>Wake Forest University</i>
Regina F. Frey, <i>Washington University</i>	Tim Su, <i>City College of San Francisco</i>
Dennis Gallo, <i>Augustana College</i>	Sara Sutcliffe, <i>University of Texas, Austin</i>
David Harris, <i>University of California, Santa Barbara</i>	Larry Thompson, <i>University of Minnesota, Duluth</i>
Sheryl Hemkin, <i>Kenyon College</i>	Dino Tinti, <i>University of California, Davis</i>
Michael Henschman, <i>Brandeis University</i>	Sidney Toby, <i>Rutgers University</i>
Geoffrey Herring, <i>University of British Columbia</i>	David Vandebout, <i>University of Texas, Austin</i>
Timothy Hughbanks, <i>Texas A&M University</i>	Deborah Walker, <i>University of Texas, Austin</i>
Paul Hunter, <i>Michigan State University</i>	Lindell Ward, <i>Franklin College</i>
Keiko Jacobsen, <i>Tulane University</i>	Thomas R. Webb, <i>Auburn University</i>
Robert C. Kerber, <i>State University of New York, Stony Brook</i>	Peter M. Weber, <i>Brown University</i>
Robert Kolodny, <i>Armstrong Atlantic State University</i>	David D. Weis, <i>Skidmore College</i>
Lynn Vogel Koplitz, <i>Loyola University</i>	Ken Whitmire, <i>Rice University</i>
Petra van Koppen, <i>University of California, Santa Barbara</i>	James Whitten, <i>University of Massachusetts, Lowell</i>
Mariusz Kozik, <i>Canisius College</i>	Gang Wu, <i>Queen's University</i>
	Zhiping Zheng, <i>University of Arizona</i>
	Marc Zimmer, <i>Connecticut College</i>
	Martin Zysmilich, <i>Massachusetts Institute of Technology</i>

Some contributed in substantial ways. Leroy Laverman, University of California at Santa Barbara, carefully reviewed the entire text and all the art, leading to considerable improvements. Roy Tasker, University of Western Sydney, contributed to the Web site for this book, designed related animations, and selected the icons for the animation media links. Michael Cann, University of Scranton, opened our eyes to the world of green chemistry in a way that has greatly enriched this book. We would also like to thank Nathan Barrows, Arizona State University, for contributing to the Self-Test answers. The supplements authors, especially John Krenos, Joseph Potenza, Laurence Lavelle, Yinfa Ma, and Carl Hoeger, have offered us

- [**click Sailing Bright Eternity \(Galactic Center, Book 6\)**](#)
- [Care of Wooden Floors here](#)
- [click Slavoj Žižek \(Routledge Critical Thinkers\)](#)
- [click The Rough Guide to Norway \(6th Edition\) here](#)
- [read online Improving Reading Comprehension of Middle and High School Students \(Literacy Studies: Perspectives from Cognitive Neurosciences, Linguistics, Psychology and Education, Volume 10\) pdf, azw \(kindle\)](#)
- [Sky Strike \(The Zone, Book 4\) pdf](#)

- <http://crackingscience.org/?library/Holy-Spy--A-John-Shakespeare-Mystery--John-Shakespeare-Mystery--Book-7-.pdf>
- <http://yachtwebsitedemo.com/books/Fueled-By-Failure--Using-Detours-and-Defeats-to-Power-Progress.pdf>
- <http://www.gateaerospaceforum.com/?library/Lights-On---The-Science-of-Power-Generation.pdf>
- <http://tuscalaural.com/library/The-Rough-Guide-to-Norway--6th-Edition-.pdf>
- <http://www.mmastyles.com/books/Improving-Reading-Comprehension-of-Middle-and-High-School-Students--Literacy-Studies--Perspectives-from-Cognitive->
- <http://kamallubana.com/?library/Sky-Strike--The-Zone--Book-4-.pdf>