

INTRODUCTION TO **General**
Organic and
Biochemistry 10e

BETTELHEIM BROWN CAMPBELL FARRELL TORRES



Period number → 1
 Group number, U.S. system → 1A 2A
 Group number, IUPAC system → (1) (2)

METALS
METALLOIDS
NONMETALS

	8A (18)																		
	Helium 2 He 4.0026																		
														3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	
														Boron 5 B 10.811	Carbon 6 C 12.011	Nitrogen 7 N 14.0067	Oxygen 8 O 15.9994	Fluorine 9 F 18.9984	Neon 10 Ne 20.1797
2	Lithium 3 Li 6.941	Beryllium 4 Be 9.0122											Aluminum 13 Al 26.9815	Silicon 14 Si 28.0855	Phosphorus 15 P 30.9738	Sulfur 16 S 32.066	Chlorine 17 Cl 35.4527	Argon 18 Ar 39.948	
3	Sodium 11 Na 22.9898	Magnesium 12 Mg 24.3050	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8) (9) (10)			1B (11)	2B (12)							
4	Potassium 19 K 39.0983	Calcium 20 Ca 40.078	Scandium 21 Sc 44.9559	Titanium 22 Ti 47.867	Vanadium 23 V 50.9415	Chromium 24 Cr 51.9961	Manganese 25 Mn 54.9380	Iron 26 Fe 55.845	Cobalt 27 Co 58.9332	Nickel 28 Ni 58.6934	Copper 29 Cu 63.546	Zinc 30 Zn 65.38	Gallium 31 Ga 69.723	Germanium 32 Ge 72.61	Arsenic 33 As 74.9216	Selenium 34 Se 78.96	Bromine 35 Br 79.904	Krypton 36 Kr 83.80	
5	Rubidium 37 Rb 85.4678	Strontium 38 Sr 87.62	Yttrium 39 Y 88.9059	Zirconium 40 Zr 91.224	Niobium 41 Nb 92.9064	Molybdenum 42 Mo 95.96	Technetium 43 Tc (97.907)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.9055	Palladium 46 Pd 106.42	Silver 47 Ag 107.8682	Cadmium 48 Cd 112.411	Indium 49 In 114.818	Tin 50 Sn 118.710	Antimony 51 Sb 121.760	Tellurium 52 Te 127.60	Iodine 53 I 126.9045	Xenon 54 Xe 131.29	
6	Cesium 55 Cs 132.9054	Barium 56 Ba 137.327	Lanthanum 57 La 138.9055	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.9488	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.2	Iridium 77 Ir 192.22	Platinum 78 Pt 195.084	Gold 79 Au 196.9666	Mercury 80 Hg 200.59	Thallium 81 Tl 204.3833	Lead 82 Pb 207.2	Bismuth 83 Bi 208.9804	Polonium 84 Po (208.98)	Astatine 85 At (209.99)	Radon 86 Rn (222.02)	
7	Francium 87 Fr (223.02)	Radium 88 Ra (226.0254)	Actinium 89 Ac (227.0278)	Rutherfordium 104 Rf (261.11)	Dubnium 105 Db (262.11)	Seaborgium 106 Sg (263.12)	Bohrium 107 Bh (262.12)	Hassium 108 Hs (265)	Meitnerium 109 Mt (266)	Darmstadtium 110 Ds (271)	Roentgenium 111 Rg (272)	Copernicium 112 Cn (285)	— 113 Discovered 2004	— 114 Discovered 1999	— 115 Discovered 2004	— 116 Discovered 1999	— 117 — (292)	— 118 Discovered 2006	

Uranium
92 ← Atomic number
U ← Symbol
238.0289 ← Atomic weight

Note: Atomic masses are 2007 IUPAC values (up to four decimal places). Numbers in parentheses are atomic masses or mass numbers of the most stable isotope of an element.

Lanthanides
Actinides

Cerium 58 Ce 140.115	Praseodymium 59 Pr 140.9076	Neodymium 60 Nd 144.24	Promethium 61 Pm (144.91)	Samarium 62 Sm 150.36	Europium 63 Eu 151.965	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.9253	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.9303	Erbium 68 Er 167.26	Thulium 69 Tm 168.9342	Ytterbium 70 Yb 173.54	Lutetium 71 Lu 174.9668
Thorium 90 Th 232.0381	Protactinium 91 Pa 231.0388	Uranium 92 U 238.0289	Neptunium 93 Np (237.0482)	Plutonium 94 Pu (244.664)	Americium 95 Am (243.061)	Curium 96 Cm (247.07)	Berkelium 97 Bk (247.07)	Californium 98 Cf (251.08)	Einsteinium 99 Es (252.08)	Fermium 100 Fm (257.10)	Mendelevium 101 Md (258.10)	Nobelium 102 No (259.10)	Lawrencium 103 Lr (262.11)

STANDARD ATOMIC WEIGHTS OF THE ELEMENTS 2010 Based on relative atomic mass of $^{12}\text{C} = 12$, where ^{12}C is a neutral atom in its nuclear and electronic ground state.[†]

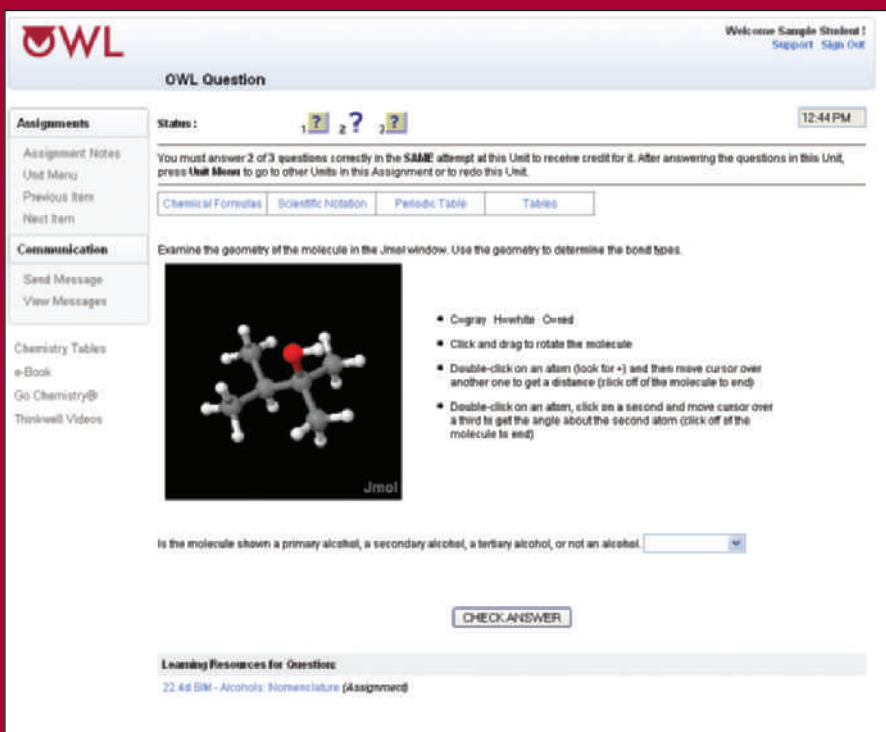
Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium*	Ac	89	(227)	Molybdenum	Mo	42	95.96(2)
Aluminum	Al	13	26.9815386(8)	Neodymium	Nd	60	144.22(3)
Americium*	Am	95	(243)	Neon	Ne	10	20.1797(6)
Antimony	Sb	51	121.760(1)	Neptunium*	Np	93	(237)
Argon	Ar	18	39.948(1)	Nickel	Ni	28	58.6934(4)
Arsenic	As	33	74.92160(2)	Niobium	Nb	41	92.90638(2)
Astatine*	At	85	(210)	Nitrogen	N	7	14.0067(2)
Barium	Ba	56	137.327(7)	Nobelium*	No	102	(259)
Berkelium*	Bk	97	(247)	Osmium	Os	76	190.23(3)
Beryllium	Be	4	9.012182(3)	Oxygen	O	8	15.9994(3)
Bismuth	Bi	83	208.98040(1)	Palladium	Pd	46	106.42(1)
Bohrium	Bh	107	(264)	Phosphorus	P	15	30.973762(2)
Boron	B	5	10.811(7)	Platinum	Pt	78	195.084(9)
Bromine	Br	35	79.904(1)	Plutonium*	Pu	94	(244)
Cadmium	Cd	48	112.411(8)	Polonium*	Po	84	(209)
Cesium	Cs	55	132.9054519(2)	Potassium	K	19	39.0983(1)
Calcium	Ca	20	40.078(4)	Praseodymium	Pr	59	140.90765(2)
Californium*	Cf	98	(251)	Promethium*	Pm	61	(145)
Carbon	C	6	12.0107(8)	Protactinium*	Pa	91	231.03588(2)
Cerium	Ce	58	140.116(1)	Radium*	Ra	88	(226)
Chlorine	Cl	17	35.453(2)	Radon*	Rn	86	(222)
Chromium	Cr	24	51.9961(6)	Rhenium	Re	75	186.207(1)
Cobalt	Co	27	58.933195(5)	Rhodium	Rh	45	102.90550(2)
Copernicium*	Cn	112	(285)	Roentgenium	Rg	111	(272)
Copper	Cu	29	63.546(3)	Rubidium	Rb	37	85.4678(3)
Curium*	Cm	96	(247)	Ruthenium	Ru	44	101.07(2)
Darmstadtium	Ds	110	(271)	Rutherfordium	Rf	104	(261)
Dubnium	Db	105	(262)	Samarium	Sm	62	150.36(2)
Dysprosium	Dy	66	162.500(1)	Scandium	Sc	21	44.955912(6)
Einsteinium*	Es	99	(252)	Seaborgium	Sg	106	(266)
Erbium	Er	68	167.259(3)	Selenium	Se	34	78.96(3)
Europium	Eu	63	151.964(1)	Silicon	Si	14	28.0855(3)
Fermium*	Fm	100	(257)	Silver	Ag	47	107.8682(2)
Fluorine	F	9	18.9984032(5)	Sodium	Na	11	22.9896928(2)
Francium*	Fr	87	(223)	Strontium	Sr	38	87.62(1)
Gadolinium	Gd	64	157.25(3)	Sulfur	S	16	32.065(5)
Gallium	Ga	31	69.723(1)	Tantalum	Ta	73	180.9488(2)
Germanium	Ge	32	72.64(1)	Technetium*	Tc	43	(98)
Gold	Au	79	196.966569(4)	Tellurium	Te	52	127.60(3)
Hafnium	Hf	72	178.49(2)	Terbium	Tb	65	158.92535(2)
Hassium	Hs	108	(277)	Thallium	Tl	81	204.3833(2)
Helium	He	2	4.002602(2)	Thorium*	Th	90	232.03806(2)
Holmium	Ho	67	164.93032(2)	Thulium	Tm	69	168.93421(2)
Hydrogen	H	1	1.00794(7)	Tin	Sn	50	118.710(7)
Indium	In	49	114.818(3)	Titanium	Ti	22	47.867(1)
Iodine	I	53	126.90447(3)	Tungsten	W	74	183.84(1)
Iridium	Ir	77	192.217(3)	Ununhexium	Uuh	116	(292)
Iron	Fe	26	55.845(2)	Ununoctium	Uuo	118	(294)
Krypton	Kr	36	83.798(2)	Ununpentium	Uup	115	(228)
Lanthanum	La	57	138.90547(7)	Ununquadium	Uuq	114	(289)
Lawrencium*	Lr	103	(262)	Ununseptium	Uus	117	(292)
Lead	Pb	82	207.2(1)	Ununtrium	Uut	113	(284)
Lithium	Li	3	6.941(2)	Uranium*	U	92	238.02891(3)
Lutetium	Lu	71	174.9668(1)	Vanadium	V	23	50.9415(1)
Magnesium	Mg	12	24.3050(6)	Xenon	Xe	54	131.293(6)
Manganese	Mn	25	54.938045(5)	Ytterbium	Yb	70	173.54(5)
Meitnerium	Mt	109	(268)	Yttrium	Y	39	88.90585(2)
Mendelevium*	Md	101	(258)	Zinc	Zn	30	65.38(2)
Mercury	Hg	80	200.59(2)	Zirconium	Zr	40	91.224(2)

[†]The atomic weights of many elements can vary depending on the origin and treatment of the sample. This is particularly true for Li; commercially available lithium-containing materials have Li atomic weights in the range of 6.939 and 6.996. The uncertainties in atomic weight values are given in parentheses following the last significant figure to which they are attributed.

*Elements with no stable nuclide; the value given in parentheses is the atomic mass number of the isotope of longest known half-life. However, three such elements (Th, Pa, and U) have a characteristic terrestrial isotopic composition, and the atomic weight is tabulated for these. <http://www.chem.qmw.ac.uk/iupac/AtWt/>

Get a Better Grade in Chemistry!

Log in now to the leading online learning system for chemistry. Score better on exams, access step-by-step solutions, and more!



The screenshot shows the OWL Question interface. At the top, it says "OWL Question" and "Welcome Sample Student!". Below that, there are navigation tabs for "Chemical Formulas", "Scientific Notation", "Periodic Table", and "Tables". The main content area displays a question: "Examine the geometry of the molecule in the Jmol window. Use the geometry to determine the bond types." Below the text is a 3D ball-and-stick model of a molecule in a Jmol window. To the right of the model are instructions: "Click and drag to rotate the molecule", "Double-click on an atom (look for +) and then move cursor over another one to get a distance (click off of the molecule to end)", and "Double-click on an atom, click on a second and move cursor over a third to get the angle about the second atom (click off of the molecule to end)". Below the model is a dropdown menu with the text "Is the molecule shown a primary alcohol, a secondary alcohol, a tertiary alcohol, or not an alcohol." and a "CHECK ANSWER" button. At the bottom, there are "Learning Resources for Questions" including "22.46 ILM - Alcohols: Nomenclature (Assignment)".

- **Master chemistry and improve your grade** using OWL's step-by-step tutorials, interactive simulations, and homework questions that provide instant answer-specific feedback. Available 24/7.
- **Learn at your own pace with OWL**, a study smart system that ensures you've mastered each concept before you move on.
- **Access the Cengage YouBook**, a media-rich, interactive e-version of your textbook.

"OWL saved my grade in Chemistry."

– Daniel D'Costa, Student, *Hofstra University*

To get started, use the access code that may have been packaged with your text or purchase access online. Check with your instructor to verify that OWL is required for your course before purchasing.

www.cengage.com/OWL

This page intentionally left blank

INTRODUCTION TO

General, Organic, and Biochemistry

TENTH EDITION

Frederick A. Bettelheim

William H. Brown

Beloit College

Mary K. Campbell

Mount Holyoke College

Shawn O. Farrell

Olympic Training Center

Omar J. Torres

College of the Canyons



This is an electronic version of the print textbook. Due to electronic rights restrictions, some third party content may be suppressed. Editorial review has deemed that any suppressed content does not materially affect the overall learning experience. The publisher reserves the right to remove content from this title at any time if subsequent rights restrictions require it. For valuable information on pricing, previous editions, changes to current editions, and alternate formats, please visit www.cengage.com/highered to search by ISBN#, author, title, or keyword for materials in your areas of interest.

**Introduction to General, Organic,
and Biochemistry, Tenth Edition**
**Frederick A. Bettelheim, William H.
Brown, Mary K. Campbell, Shawn O. Farrell,
Omar J. Torres**

Publisher: Mary Finch

Developmental Editor: Sandra Kiselica

Assistant Editor: Elizabeth Woods

Editorial Assistant: Krista Mastroianni

Senior Media Editor: Lisa Weber

Media Editor: Stephanie VanCamp

Marketing Manager: Nicole Hamm

Marketing Assistant: Julie Stefani

Marketing Communications Manager: Linda Yip

Content Project Manager: Teresa L. Trego

Design Director: Rob Hugel

Art Director: Maria Epes

Manufacturing Planner: Karen Hunt

Rights Acquisitions Specialist: Dean Dauphinais

Production Service: PreMediaGlobal

Text Designer: Bill Reuter Design

Photo Researcher: Chris Altof/Bill Smith Group

Text Researcher: Sue C. Howard

Copy Editor: PreMediaGlobal

Illustrator: PreMediaGlobal, 2064 Design

OWL Producers: Stephen Battisti, Cindy Stein,
David Hart (Center for Educational Software
Development, University of Massachusetts,
Amherst)

Cover Designer: Bill Reuter Design

Cover Images: Main image ©Dave Reede/Getty
Images, from left to right ©Ottmar Diez/Getty
Images, ©Chris Hill/Getty Images,
©David Norton Photography/Alamy,
© PhotoResearchers, Inc.

Compositor: PreMediaGlobal

© 2013, 2010 Brooks/Cole, Cengage Learning

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced, transmitted, stored or used in any form or by any means graphic, electronic, or mechanical, including but not limited to photocopying, recording, scanning, digitizing, taping, Web distribution, information networks, or information storage and retrieval systems, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the publisher.

For product information and technology assistance, contact us at
Cengage Learning Customer & Sales Support, 1-800-354-9706

For permission to use material from this text or product,
submit all requests online at **cengage.com/permissions**

Further permissions questions can be emailed to
permissionrequest@cengage.com

Library of Congress Control Number: 2011934948

ISBN-13: 978-1-133-10508-4

ISBN-10: 1-133-10508-4

Brooks/Cole

20 Davis Drive
Belmont, CA 94002-3098
USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil, and Japan. Locate your local office at:

www.cengage.com/global

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

For your course and learning solutions, visit **academic.cengage.com**

Purchase any of our products at your local college store or at our preferred online store **www.cengagebrain.com**

Unless otherwise noted, all art appearing in this book is © Cengage Learning 2013.

To Carolyn, with whom life is a joy. —WB

To my family and friends – thank you for all your support.

I couldn't have done it without you. — MC

To my lovely wife, Courtney — Between textbook revisions,

a full-time job, and school, I have been little more than

a ghost around the house, hiding in my study writing.

Courtney held the family together, taking care of our children

and our home while maintaining her own writing schedule.

None of this would have been possible without her love,

support, and tireless effort. —SF

To my loving family and friends who have supported me through

this journey: Mom, Dad, Lisa, Abuela, René, Ryan, Deanna,

and Dianne. I could not have made it without your urging

and support. I am truly blessed to have each of

you in my life. — OT

Contents in Brief

General Chemistry

- Chapter 1** Matter, Energy, and Measurement 1
- Chapter 2** Atoms 31
- Chapter 3** Chemical Bonds 68
- Chapter 4** Chemical Reactions 108
- Chapter 5** Gases, Liquids, and Solids 140
- Chapter 6** Solutions and Colloids 177
- Chapter 7** Reaction Rates and Chemical Equilibrium 210
- Chapter 8** Acids and Bases 239
- Chapter 9** Nuclear Chemistry 275

Organic Chemistry

- Chapter 10** Organic Chemistry 305
- Chapter 11** Alkanes 322
- Chapter 12** Alkenes and Alkynes 353
- Chapter 13** Benzene and Its Derivatives 383
- Chapter 14** Alcohols, Ethers, and Thiols 399
- Chapter 15** Chirality: The Handedness of Molecules 423
- Chapter 16** Amines 446
- Chapter 17** Aldehydes and Ketones 464
- Chapter 18** Carboxylic Acids 483
- Chapter 19** Carboxylic Anhydrides, Esters, and Amides 508

Biochemistry

- Chapter 20** Carbohydrates 529
- Chapter 21** Lipids 559
- Chapter 22** Proteins 592
- Chapter 23** Enzymes 633
- Chapter 24** Chemical Communications: Neurotransmitters and Hormones 658
- Chapter 25** Nucleotides, Nucleic Acids, and Heredity 687
- Chapter 26** Gene Expression and Protein Synthesis 721
- Chapter 27** Bioenergetics: How the Body Converts Food to Energy 753
- Chapter 28** Specific Catabolic Pathways: Carbohydrate, Lipid, and Protein Metabolism 774
- Chapter 29** Biosynthetic Pathways 799
- Chapter 30** Nutrition 814
- Chapter 31** Immunochemistry 835
- Chapter 32** Body Fluids

(Find this chapter on this book's companion web site. To access, enter ISBN 1-133-10508-4 at www.cengagebrain.com)

Contents

Chapter 1 Matter, Energy, and Measurement 1

- 1.1 Why Do We Call Chemistry the Study of Matter? 1
- 1.2 What Is the Scientific Method? 3
- 1.3 How Do Scientists Report Numbers? 5
 - How To... Determine the Number of Significant Figures in a Number 6**
- 1.4 How Do We Make Measurements? 7
- 1.5 What Is a Handy Way to Convert from One Unit to Another? 12
 - How To... Do Unit Conversions by the Factor-Label Method 13**
- 1.6 What Are the States of Matter? 17
- 1.7 What Are Density and Specific Gravity? 18
- 1.8 How Do We Describe the Various Forms of Energy? 20
- 1.9 How Do We Describe Heat and the Ways in Which It Is Transferred? 21
 - Summary 26
 - Problems 26
 - Chemical Connections**
 - 1A Drug Dosage and Body Mass 11
 - 1B Hypothermia and Hyperthermia 22
 - 1C Cold Compresses, Waterbeds, and Lakes 23

Chapter 2 Atoms 31

- 2.1 What Is Matter Made Of? 31
- 2.2 How Do We Classify Matter? 32
- 2.3 What Are the Postulates of Dalton's Atomic Theory? 35
- 2.4 What Are Atoms Made Of? 38
- 2.5 What Is the Periodic Table? 43
- 2.6 How Are the Electrons in an Atom Arranged? 49
- 2.7 How Are Electron Configuration and Position in the Periodic Table Related? 56
- 2.8 What Is a Periodic Property? 57
 - Summary 60
 - Problems 61
 - Chemical Connections**
 - 2A Elements Necessary for Human Life 33

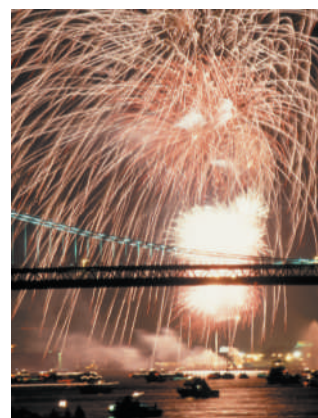
- 2B Abundance of Elements Present in the Human Body and in the Earth's Crust 37
- 2C Strontium-90 45
- 2D The Use of Metals as Historical Landmarks 47

Chapter 3 Chemical Bonds 68

- 3.1 What Do We Need to Know Before We Begin? 68
- 3.2 What Is the Octet Rule? 68
- 3.3 How Do We Name Anions and Cations? 71
- 3.4 What Are the Two Major Types of Chemical Bonds? 73
- 3.5 What Is an Ionic Bond? 75
- 3.6 How Do We Name Ionic Compounds? 77
- 3.7 What Is a Covalent Bond? 79
 - How To... Draw Lewis Structures 82**
- 3.8 How Do We Name Binary Covalent Compounds? 87
- 3.9 What Is Resonance? 89
 - How To... Draw Curved Arrows and Push Electrons 90**
- 3.10 How Do We Predict Bond Angles in Covalent Molecules? 92
- 3.11 How Do We Determine If a Molecule Is Polar? 96
 - Summary 98
 - Problems 100
 - Chemical Connections**
 - 3A Coral Chemistry and Broken Bones 73
 - 3B Ionic Compounds in Medicine 80
 - 3C Nitric Oxide: Air Pollutant and Biological Messenger 88

Chapter 4 Chemical Reactions 108

- 4.1 What Is a Chemical Reaction? 108
- 4.2 How Do We Balance Chemical Equations? 109
 - How To... Balance a Chemical Equation 109**
- 4.3 How Can We Predict If Ions in Aqueous Solution Will React with Each Other? 113



- 4.4 What Are Oxidation and Reduction? 116
 - 4.5 What Are Formula Weights and Molecular Weights? 121
 - 4.6 What Is a Mole and How Do We Use It to Calculate Mass Relationships? 122
 - 4.7 How Do We Calculate Mass Relationships in Chemical Reactions? 126
 - 4.8 What Is Heat of Reaction? 132
 - Summary 133
 - Problems 133
- Chemical Connections**
- 4A Solubility and Tooth Decay 116
 - 4B Voltaic Cells 119
 - 4C Artificial Pacemakers and Redox 120

Chapter 5 Gases, Liquids, and Solids 140

- 5.1 What Are the Three States of Matter? 140
 - 5.2 What Is Gas Pressure and How Do We Measure It? 141
 - 5.3 What Are the Laws That Govern the Behavior of Gases? 142
 - 5.4 What Are Avogadro's Law and the Ideal Gas Law? 146
 - 5.5 What Is Dalton's Law of Partial Pressures? 148
 - 5.6 What Is the Kinetic Molecular Theory? 150
 - 5.7 What Types of Attractive Forces Exist Between Molecules? 151
 - 5.8 How Do We Describe the Behavior of Liquids at the Molecular Level? 155
 - 5.9 What Are the Characteristics of the Various Types of Solids? 162
 - 5.10 What Is a Phase Change and What Energies Are Involved? 164
 - Summary 169
 - Problems 170
- Chemical Connections**
- 5A Breathing and Boyle's Law 143
 - 5B Hyperbaric Medicine 149
 - 5C Blood Pressure Measurement 157
 - 5D The Densities of Ice and Water 160
 - 5E Supercritical Carbon Dioxide 167

Chapter 6 Solutions and Colloids 177

- 6.1 What Do We Need to Know as We Begin? 177
- 6.2 What Are the Most Common Types of Solutions? 178
- 6.3 What Are the Distinguishing Characteristics of Solutions? 178
- 6.4 What Factors Affect Solubility? 180
- 6.5 What Are the Most Common Units for Concentration? 183
- 6.6 Why Is Water Such a Good Solvent? 189
- 6.7 What Are Colloids? 194
- 6.8 What Is a Colligative Property? 196

- Summary 203
 - Problems 204
- Chemical Connections**
- 6A Acid Rain 179
 - 6B The Bends 182
 - 6C Electrolyte Solutions in Body and Intravenous Fluids 190
 - 6D Hydrates and Air Pollution: The Decay of Buildings and Monuments 193
 - 6E Emulsions and Emulsifying Agents 196
 - 6F Reverse Osmosis and Desalinization 201
 - 6G Hemodialysis 203

Chapter 7 Reaction Rates and Chemical Equilibrium 210

- 7.1 How Do We Measure Reaction Rates? 210
 - 7.2 Why Do Some Molecular Collisions Result in Reaction Whereas Others Do Not? 212
 - 7.3 What Is the Relationship Between Activation Energy and Reaction Rate? 214
 - 7.4 How Can We Change the Rate of a Chemical Reaction? 216
 - 7.5 What Does It Mean to Say That a Reaction Has Reached Equilibrium? 220
 - 7.6 What Is an Equilibrium Constant and How Do We Use It? 223
 - How To... Interpret the Value of the Equilibrium Constant, K** 226
 - 7.7 What Is Le Chatelier's Principle? 228
 - Summary 234
 - Problems 234
- Chemical Connections**
- 7A Why High Fever Is Dangerous 219
 - 7B The Effects of Lowering Body Temperature 221
 - 7C Timed-Release Medication 222
 - 7D Sunglasses and Le Chatelier's Principle 231
 - 7E The Haber Process 233



Chapter 8 Acids and Bases 239

- 8.1 What Are Acids and Bases? 239
- 8.2 How Do We Define the Strength of Acids and Bases? 241
- 8.3 What Are Conjugate Acid–Base Pairs? 243
 - How To... Name Common Acids** 245
- 8.4 How Can We Tell the Position of Equilibrium in an Acid–Base Reaction? 246
- 8.5 How Do We Use Acid Ionization Constants? 248
- 8.6 What Are the Properties of Acids and Bases? 249

- 8.7 What Are the Acidic and Basic Properties of Pure Water? 252
How To... Use Logs and Antilogs 254
- 8.8 What Are pH and pOH? 255
- 8.9 How Do We Use Titrations to Calculate Concentration? 258
- 8.10 What Are Buffers? 261
- 8.11 How Do We Calculate the pH of a Buffer? 265
- 8.12 What Are TRIS, HEPES, and These Buffers with the Strange Names? 266
- Summary 269
 Problems 270

Chemical Connections

- 8A Some Important Acids and Bases 242
- 8B Drugstore Antacids 253
- 8C Respiratory and Metabolic Acidosis 267
- 8D Alkalosis and the Sprinter's Trick 269

Chapter 9 Nuclear Chemistry 275

- 9.1 How Was Radioactivity Discovered? 275
- 9.2 What Is Radioactivity? 276
- 9.3 What Happens When a Nucleus Emits Radioactivity? 278
How To... Balance a Nuclear Equation 279
- 9.4 What Is Nuclear Half-Life? 282
- 9.5 How Do We Detect and Measure Nuclear Radiation? 285
- 9.6 How Is Radiation Dosimetry Related to Human Health? 288
- 9.7 What Is Nuclear Medicine? 291
- 9.8 What Is Nuclear Fusion? 295
- 9.9 What Is Nuclear Fission and How Is It Related to Atomic Energy? 297
- Summary of Key Questions 299
 Summary of Key Reactions 300
 Problems 300

Chemical Connections

- 9A Radioactive Dating 284
- 9B The Indoor Radon Problem 291
- 9C How Radiation Damages Tissues: Free Radicals 292
- 9D Radioactive Fallout from Nuclear Accidents 299

Chapter 10 Organic Chemistry 305

- 10.1 What Is Organic Chemistry? 305
- 10.2 Where Do We Obtain Organic Compounds? 307
- 10.3 How Do We Write Structural Formulas of Organic Compounds? 309
- 10.4 What Is a Functional Group? 311
- Summary 316
 Problems 317

Chemical Connections

- 10A Taxol: A Story of Search and Discovery 308

Chapter 11 Alkanes 322

- 11.1 What Are Alkanes? 322
- 11.2 How Do We Write Structural Formulas of Alkanes? 323
- 11.3 What Are Constitutional Isomers? 324
- 11.4 How Do We Name Alkanes? 327
- 11.5 Where Do We Obtain Alkanes? 331
- 11.6 What Are Cycloalkanes? 331
- 11.7 What Are the Shapes of Alkanes and Cycloalkanes? 333
How To... Draw Alternative Chair Conformations of Cyclohexane 335
- 11.8 What Is *Cis-Trans* Isomerism in Cycloalkanes? 337
- 11.9 What Are the Physical Properties of Alkanes and Cycloalkanes? 340
- 11.10 What Are the Characteristic Reactions of Alkanes? 342
- 11.11 What Are Some Important Haloalkanes? 344

- Summary of Key Questions 345
 Summary of Key Reactions 346
 Problems 347

Chemical Connections

- 11A The Poisonous Puffer Fish 337
- 11B Octane Rating: What Those Numbers at the Pump Mean 343
- 11C The Environmental Impact of Freons 345



Chapter 12 Alkenes and Alkynes 353

- 12.1 What Are Alkenes and Alkynes? 353
- 12.2 What Are the Structures of Alkenes and Alkynes? 354
- 12.3 How Do We Name Alkenes and Alkynes? 356
- 12.4 What Are the Physical Properties of Alkenes and Alkynes? 363
- 12.5 What Are the Characteristic Reactions of Alkenes? 363
- 12.6 What Are the Important Polymerization Reactions of Ethylene and Substituted Ethylenes? 372
- Summary of Key Questions 375
 Summary of Key Reactions 376
 Problems 376

Chemical Connections

- 12A Ethylene: A Plant Growth Regulator 354
- 12B *Cis* Double Bonds in Fatty Acids 355
- 12C The Case of the Iowa and New York Strains of the European Corn Borer 360
- 12D *Cis-Trans* Isomerism in Vision 362
- 12E Recycling Plastics 373

Chapter 13 Benzene and Its Derivatives 383

- 13.1 What Is the Structure of Benzene? 383
- 13.2 How Do We Name Aromatic Compounds? 385
- 13.3 What Are the Characteristic Reactions of Benzene and Its Derivatives? 388
- 13.4 What Are Phenols? 391
- Summary of Key Questions 395
- Summary of Key Reactions 395
- Problems 395

Chemical Connections

- 13A DDT: A Boon and a Curse 387
- 13B Carcinogenic Polynuclear Aromatics and Smoking 388
- 13C Iodide Ion and Goiter 389
- 13D The Nitro Group in Explosives 390
- 13E FD & C No. 6 (a.k.a. Sunset Yellow) 392
- 13F Capsaicin, for Those Who Like It Hot 393

Chapter 14 Alcohols, Ethers, and Thiols 399

- 14.1 What Are the Structures, Names, and Physical Properties of Alcohols? 400
- 14.2 What Are the Characteristic Reactions of Alcohols? 403
- 14.3 What Are the Structures, Names, and Properties of Ethers? 410
- 14.4 What Are the Structures, Names, and Properties of Thiols? 413
- 14.5 What Are the Most Commercially Important Alcohols? 415
- Summary of Key Questions 416
- Summary of Key Reactions 417
- Problems 417

Chemical Connections

- 14A Nitroglycerin: An Explosive and a Drug 404
- 14B Breath-Alcohol Screening 409
- 14C Ethylene Oxide: A Chemical Sterilant 411
- 14D Ethers and Anesthesia 412

Chapter 15 Chirality: The Handedness of Molecules 423

- 15.1 What Is Enantiomerism? 423
- How To...* Draw Enantiomers 427
- 15.2 How Do We Specify the Configuration of a Stereocenter? 430
- 15.3 How Many Stereoisomers Are Possible for Molecules with Two or More Stereocenters? 433
- 15.4 What Is Optical Activity, and How Is Chirality Detected in the Laboratory? 437
- 15.5 What Is the Significance of Chirality in the Biological World? 439

- Summary 440
- Problems 440

Chemical Connections

- 15A Chiral Drugs 437

Chapter 16 Amines 446

- 16.1 What Are Amines? 446
- 16.2 How Do We Name Amines? 449
- 16.3 What Are the Physical Properties of Amines? 451
- 16.4 How Do We Describe the Basicity of Amines? 452
- 16.5 What Are the Characteristic Reactions of Amines? 454
- Summary of Key Questions 458
- Summary of Key Reactions 458
- Problems 458

Chemical Connections

- 16A Amphetamines (Pep Pills) 447
- 16B Alkaloids 448
- 16C Tranquilizers 452
- 16D The Solubility of Drugs in Body Fluids 455
- 16E Epinephrine: A Prototype for the Development of New Bronchodilators 457



Chapter 17 Aldehydes and Ketones 464

- 17.1 What Are Aldehydes and Ketones? 464
- 17.2 How Do We Name Aldehydes and Ketones? 465
- 17.3 What Are the Physical Properties of Aldehydes and Ketones? 468
- 17.4 What Are the Characteristic Reactions of Aldehydes and Ketones? 469
- 17.5 What Is Keto-Enol Tautomerism? 475
- Summary of Key Questions 476
- Summary of Key Reactions 476
- Problems 477

Chemical Connections

- 17A From Moldy Clover to a Blood Thinner 468

Chapter 18 Carboxylic Acids 483

- 18.1 What Are Carboxylic Acids? 483
- 18.2 How Do We Name Carboxylic Acids? 483
- 18.3 What Are the Physical Properties of Carboxylic Acids? 486
- 18.4 What Are Soaps and Detergents? 487
- 18.5 What Are the Characteristic Reactions of Carboxylic Acids? 493
- Summary of Key Questions 500
- Summary of Key Reactions 500
- Problems 501

Chemical Connections

- 18A *Trans* Fatty Acids: What Are They and How Do You Avoid Them? 489
- 18B Esters as Flavoring Agents 497
- 18C Ketone Bodies and Diabetes 500

Chapter 19 Carboxylic Anhydrides, Esters, and Amides 508

- 19.1 What Are Carboxylic Anhydrides, Esters, and Amides? 508
- 19.2 How Do We Prepare Esters? 511
- 19.3 How Do We Prepare Amides? 512
- 19.4 What Are the Characteristic Reactions of Anhydrides, Esters, and Amides? 513
- 19.5 What Are Phosphoric Anhydrides and Phosphoric Esters? 520
- 19.6 What Is Step-Growth Polymerization? 521
- Summary of Key Questions 523
- Summary of Key Reactions 524
- Problems 525

Chemical Connections

- 19A The Pyrethrins—Natural Insecticides of Plant Origin 510
- 19B The Penicillins and Cephalosporins: β -Lactam Antibiotics 511
- 19C From Willow Bark to Aspirin and Beyond 512
- 19D Ultraviolet Sunscreens and Sunblocks 516
- 19E Barbiturates 519
- 19F Stitches That Dissolve 523

Chapter 20 Carbohydrates 529

- 20.1 Carbohydrates: What Are Monosaccharides? 529
- 20.2 What Are the Cyclic Structures of Monosaccharides? 534
- 20.3 What Are the Characteristic Reactions of Monosaccharides? 539
- 20.4 What Are Disaccharides and Oligosaccharides? 544
- 20.5 What Are Polysaccharides? 548
- 20.6 What Are Acidic Polysaccharides? 551
- Summary of Key Questions 552
- Summary of Key Reactions 553
- Problems 554

Chemical Connections

- 20A Galactosemia 534
- 20B L-Ascorbic Acid (Vitamin C) 538
- 20C Testing for Glucose 542
- 20D A, B, AB, and O Blood Types 545
- 20E Is There a Connection Between Carbohydrates and Obesity? 550

Chapter 21 Lipids 559

- 21.1 What Are Lipids? 559
- 21.2 What Are the Structures of Triglycerides? 560
- 21.3 What Are Some Properties of Triglycerides? 561

- 21.4 What Are the Structures of Complex Lipids? 563
- 21.5 What Role Do Lipids Play in the Structure of Membranes? 564
- 21.6 What Are Glycerophospholipids? 565
- 21.7 What Are Sphingolipids? 568
- 21.8 What Are Glycolipids? 568
- 21.9 What Are Steroids? 570
- 21.10 What Are Some of the Physiological Roles of Steroid Hormones? 577
- 21.11 What Are Bile Salts? 582
- 21.12 What Are Prostaglandins, Thromboxanes, and Leukotrienes? 583
- Summary 587
- Problems 588

Chemical Connections

- 21A Waxes 563
- 21B Transport Across Cell Membranes 566
- 21C Ceramides, Oxygen, Cancer, and Strokes 570
- 21D Lipid Storage Diseases 571
- 21E Anabolic Steroids 579
- 21F Oral Contraception 582
- 21G Action of Anti-inflammatory Drugs 585
- 21H Why Should We Eat More Salmon? 586

Chapter 22 Proteins 592

- 22.1 What Are the Many Functions of Proteins? 592
- 22.2 What Are Amino Acids? 593
- 22.3 What Are Zwitterions? 594
- 22.4 What Determines the Characteristics of Amino Acids? 598
- 22.5 What Are Uncommon Amino Acids? 600
- 22.6 How Do Amino Acids Combine to Form Proteins? 601
- 22.7 What Are the Properties of Proteins? 604
- 22.8 What Is the Primary Structure of a Protein? 607
- 22.9 What Is the Secondary Structure of a Protein? 610
- 22.10 Interlude: How Does the Presence of Transition Metals Affect the Structure of Proteins? 612
- 22.11 What Is the Tertiary Structure of a Protein? 616
- 22.12 What Is the Quaternary Structure of a Protein? 620
- 22.13 How Are Proteins Denatured? 624
- Summary 627
- Problems 628

Chemical Connections

- 22A Aspartame, the Sweet Peptide 603
- 22B AGE and Aging 605
- 22C The Use of Human Insulin 609



- 22D Sickle Cell Anemia 610
- 22E Protein/Peptide Conformation-Dependent Diseases 619
- 22F Proteomics, Ahoy! 623
- 22G Quaternary Structure and Allosteric Proteins 624
- 22H Laser Surgery and Protein Denaturation 626

Chapter 23 Enzymes 633

- 23.1 What Are Enzymes? 633
- 23.2 How Are Enzymes Named and Classified? 635
- 23.3 What Is the Terminology Used with Enzymes? 637
- 23.4 What Factors Influence Enzyme Activity? 637
- 23.5 What Are the Mechanisms of Enzyme Action? 638
- 23.6 How Are Enzymes Regulated? 644
- 23.7 How Are Enzymes Used in Medicine? 647
- 23.8 What Are Transition-State Analogs and Designer Enzymes? 649

Summary 653

Problems 653

Chemical Connections

- 23A Muscle Relaxants and Enzyme Specificity 635
- 23B Enzymes and Memory 640
- 23C Active Sites 641
- 23D Medical Uses of Inhibitors 643
- 23E Glycogen Phosphorylase: A Model of Enzyme Regulation 649
- 23F Enzymes Are First-Rate Organic Chemists 651
- 23G Catalytic Antibodies Against Cocaine 652

Chapter 24 Chemical Communications: Neurotransmitters and Hormones 658

- 24.1 What Molecules Are Involved in Chemical Communications? 658
- 24.2 How Are Chemical Messengers Classified as Neurotransmitters and Hormones? 660
- 24.3 How Does Acetylcholine Act as a Messenger? 663
- 24.4 What Amino Acids Act as Neurotransmitters? 669
- 24.5 What Are Adrenergic Messengers? 670
- 24.6 What Is the Role of Peptides in Chemical Communication? 676
- 24.7 How Do Steroid Hormones Act as Messengers? 678

Summary 682

Problems 683

Chemical Connections

- 24A Zebrafish, Synapses, and Sleep 664
- 24B Botulism and Acetylcholine Release 665
- 24C Alzheimer's Disease and Chemical Communication 666
- 24D Parkinson's Disease: Depletion of Dopamine 674
- 24E Nitric Oxide as a Secondary Messenger 675

- 24F Diabetes 680
- 24G Hormones and Biological Pollutants 682

Chapter 25 Nucleotides, Nucleic Acids, and Heredity 687

- 25.1 What Are the Molecules of Heredity? 687
- 25.2 What Are Nucleic Acids Made Of? 688
- 25.3 What Is the Structure of DNA and RNA? 693
- 25.4 What Are the Different Classes of RNA? 699
- 25.5 What Are Genes? 702
- 25.6 How Is DNA Replicated? 702
- 25.7 How Is DNA Repaired? 710
- 25.8 How Do We Amplify DNA? 710

Summary 717

Problems 717

Chemical Connections

- 25A Who Owns Your Genes 692
- 25B Telomeres, Telomerase, and Immortality 704
- 25C DNA Fingerprinting 706
- 25D The Human Genome Project: Treasure or Pandora's Box? 708
- 25E Synthetic Genome Created 712
- 25F Did the Neandertals Go Extinct? 714



Chapter 26 Gene Expression and Protein Synthesis 721

- 26.1 How Does DNA Lead to RNA and Protein? 721
- 26.2 How Is DNA Transcribed into RNA? 723
- 26.3 What Is the Role of RNA in Translation? 725
- 26.4 What Is the Genetic Code? 726
- 26.5 How Is Protein Synthesized? 728
- 26.6 How Are Genes Regulated? 734
- 26.7 What Are Mutations? 741
- 26.8 How and Why Do We Manipulate DNA? 744
- 26.9 What Is Gene Therapy? 746

Summary 749

Problems 750

Chemical Connections

- 26A Breaking the Dogma: The Twenty-First Amino Acid 734
- 26B Viruses 735
- 26C Mutations and Biochemical Evolution 741
- 26D Silent Mutations 742
- 26E p53: A Central Tumor Suppressor Protein 743
- 26F Human Diversity and Transcription Factors 744
- 26G Twenty Years of Cystic Fibrosis Trials and Tribulations 748

Chapter 27 Bioenergetics: How the Body Converts Food to Energy 753

- 27.1 What Is Metabolism? 753
- 27.2 What Are Mitochondria and What Role Do They Play in Metabolism? 754
- 27.3 What Are the Principal Compounds of the Common Metabolic Pathway? 757
- 27.4 What Role Does the Citric Acid Cycle Play in Metabolism? 760
- 27.5 How Do Electron and H⁺ Transport Take Place? 764
- 27.6 What Is the Role of the Chemiosmotic Pump in ATP Production? 766
- 27.7 What Is the Energy Yield Resulting from Electron and H⁺ Transport? 768
- 27.8 How Is Chemical Energy Converted to Other Forms of Energy? 768

Summary 770
Problems 771

Chemical Connections

27A Uncoupling and Obesity 765

Chapter 28 Specific Catabolic Pathways: Carbohydrate, Lipid, and Protein Metabolism 774

- 28.1 What Is the General Outline of Catabolic Pathways? 774
- 28.2 What Are the Reactions of Glycolysis? 775
- 28.3 What Is the Energy Yield from Glucose Catabolism? 780
- 28.4 How Does Glycerol Catabolism Take Place? 782
- 28.5 What Are the Reactions of β -Oxidation of Fatty Acids? 782
- 28.6 What Is the Energy Yield from Stearic Acid Catabolism? 784
- 28.7 What Are Ketone Bodies? 785
- 28.8 How Is the Nitrogen of Amino Acids Processed in Catabolism? 787
- 28.9 How Are the Carbon Skeletons of Amino Acids Processed in Catabolism? 791
- 28.10 What Are the Reactions of Catabolism of Heme? 793

Summary 795
Problems 795

Chemical Connections

- 28A Lactate Accumulation 779
- 28B Ketoacidosis in Diabetes 786
- 28C How Does the Body Select Proteins for Degradation? Why Is It Important? 791
- 28D Hereditary Defects in Amino Acid Catabolism: PKU 793

Chapter 29 Biosynthetic Pathways 799

- 29.1 What Is the General Outline of Biosynthetic Pathways? 799
- 29.2 How Does the Biosynthesis of Carbohydrates Take Place? 800
- 29.3 How Does the Biosynthesis of Fatty Acids Take Place? 804
- 29.4 How Does the Biosynthesis of Membrane Lipids Take Place? 807
- 29.5 How Does the Biosynthesis of Amino Acids Take Place? 809

Summary 811
Problems 811

Chemical Connections

- 29A Photosynthesis 802
- 29B The Biological Basis of Obesity 806
- 29C Essential Amino Acids 809

Chapter 30 Nutrition 814

- 30.1 How Do We Measure Nutrition? 814
- 30.2 Why Do We Count Calories? 818
- 30.3 How Does the Body Process Dietary Carbohydrates? 820
- 30.4 How Does the Body Process Dietary Fats? 821
- 30.5 How Does the Body Process Dietary Protein? 821
- 30.6 What Is the Importance of Vitamins, Minerals, and Water? 823

Summary 832
Problems 833

Chemical Connections

- 30A The New Food Guide 817
- 30B Why Is It So Hard to Lose Weight? 819
- 30C Iron: An Example of a Mineral Requirement 828
- 30D Food for Performance Enhancement 829
- 30E Organic Food—Hope or Hype? 830
- 30F Depression in America—Don't Worry; Be Happy 831



Chapter 31 Immunochemistry 835

- 31.1 How Does the Body Defend Itself from Invasion? 835
- 31.2 What Organs and Cells Make Up the Immune System? 837
- 31.3 How Do Antigens Stimulate the Immune System? 840
- 31.4 What Are Immunoglobulins? 841

- 31.5 What Are T Cells and T-Cell Receptors? 846
 - 31.6 How Is the Immune Response Controlled? 848
 - 31.7 Immunization 849
 - 31.8 How Does the Body Distinguish “Self” from “Nonself”? 853
 - 31.9 How Does the Human Immunodeficiency Virus Cause AIDS? 857
 - Summary 866
 - Problems 867
- Chemical Connections**
- 31A Monoclonal Antibodies Wage War on Breast Cancer 845
 - 31B Antibiotics: A Double-Edged Sword 855
 - 31C Why Are Stem Cells Special? 861
 - 31D A Little Swine Goes a Long Way 864
 - 31E Immunologists Take on the Flu Virus 865

Chapter 32 Body Fluids

(Find this chapter on this book’s companion web site. To access, enter ISBN 1-133-10508-4 at www.cengagebrain.com)

Appendix I Exponential Notation A1

Appendix II Significant Figures A5

Answers to In-Text and Odd-Numbered End-of-Chapter Problems A8

Glossary G1

Index I1

Preface

The cure for boredom is curiosity
There is no cure for curiosity.

—DOROTHY PARKER

Perceiving order in nature is a deep-seated human need. It is our primary aim to convey the relationship among facts and thereby present a totality of the scientific edifice built over the centuries. In this process, we marvel at the unity of laws that govern everything in the ever-exploding dimensions: from photons to protons, from hydrogen to water, from carbon to DNA, from genome to intelligence, from our planet to the galaxy and to the known Universe. Unity in all diversity.

As we prepare the tenth edition of our textbook, we cannot help but be struck by the changes that have taken place in the last 40 years. From the slogan of the '70s, "Better living through chemistry" to today's saying "Life by chemistry," one is able to sample the change in the focus. Chemistry helps to provide not just the amenities of a good life, but it is at the core of our concept and pre-occupation with life itself. This shift in emphasis demands that our textbook designed primarily for the education of future practitioners of Health Sciences should attempt to provide both the basics as well as the scope of the horizon within which chemistry touches our life.

The increasing use of our textbook made this new edition possible and we wish to thank our colleagues who adopted the previous editions for their courses. Testimony from colleagues and students indicates that we managed to convey our enthusiasm for the subject to students, who find this book to be a great help in studying difficult concepts.

Therefore, in the new edition we strive further to present an easily readable and understandable text along with more application problems related to the Health Sciences. At the same time, we emphasize the inclusion of new relevant concepts and examples in this fast growing discipline especially in the biochemistry chapters. We maintain an integrated view of chemistry. From the very beginning of the book, we include organic compounds and biochemical substances to illustrate the principles. The progress is ascension from the simple to the complex. We urge our colleagues to advance to the chapters of biochemistry as fast as possible, because there lies most of the material that is relevant to the future professions of our students.

Dealing with such a giant field in one course, and possibly the only course in which our students get an exposure to chemistry, makes the selection of the material an overarching enterprise. We are aware that even though we tried to keep the book to a manageable size and proportion, we included more topics than could be covered in the course. Our aim was to give enough material from which the instructor can select the topics he or she deems important. The wealth of problems, both drill and challenging, provides students with numerous ways to test their knowledge from a variety of angles.

Audience and Unified Approach

This book is intended for non-chemistry majors, mainly those entering health sciences and related fields, such as nursing, medical technology, physical therapy, and nutrition. In its entirety, it can be used for a one-year (two-semester or three-quarter) course in chemistry, or parts of the book can be used in a one-term chemistry course.

We assume that the students using this book have little or no background in chemistry. Therefore, we introduce the basic concepts slowly at the beginning and increase the tempo and the level of sophistication as we go on. We progress from the basic tenets of general chemistry to organic and then to biochemistry. Throughout we integrate the parts by keeping a unified view of chemistry. For example, we frequently use organic and biological substances to illustrate general principles.

While teaching the chemistry of the human body is our ultimate goal, we try to show that each subsection of chemistry is important in its own right, besides being required for future understanding.

Chemical Connections (Medical and Other Applications of Chemical Principles)

The Chemical Connections boxes contain applications of the principles discussed in the text. Comments from users of the earlier editions indicate that these boxes have been especially well received, and provide a much-requested relevance to the text. For example, in Chapter 1, students can see how cold compresses relate to waterbeds and to lake temperatures (Chemical Connections 1C). New up-to-date topics include coverage of omega-3 fatty acids and heart disease (Chemical Connections 21H), and the search for treatments for cystic fibrosis (Chemical Connections 26G).

The presence of Chemical Connections allows a considerably degree of flexibility. If an instructor wants to assign only the main text, the Chemical Connections do not interrupt continuity, and the essential material will be covered. However, because they enhance core material, most instructors will probably wish to assign at least some of the Chemical Connections. In our experience, students are eager to read the relevant Chemical Connections, without assignments and they do with discrimination. From such a large number of boxes, an instructor can select those that best fit the particular needs of the course. So that students can test their knowledge, we provide problems at the end of each chapter for all of the Chemical Connections; these problems are now identified within the boxes.






Metabolism: Color Code

The biological functions of chemical compounds are explained in each of the biochemistry chapters and in many of the organic chapters. Emphasis is placed on chemistry rather than physiology. Positive feedback about the organization the metabolism chapters has encouraged us to maintain the order (Chapters 26-28).

First, we introduce the common metabolic pathway through which all food will be utilized (the citric acid cycle, and oxidative phosphorylation), and only after that do we discuss the specific pathways leading to the common pathway. We find this a useful pedagogic device, and it enables us to sum the caloric values of each type of food because its utilization through the

common pathway has already been learned. Finally, we separate the catabolic pathways from the anabolic pathways by treating them in different chapters, emphasizing the different ways the body breaks down and builds up different molecules.

The topic of metabolism is a difficult one for most students, and we have tried to explain it as clearly as possible. We enhance the clarity of presentation by the use of a color code for the most important biological compounds. Each type of compound is screened in a specific color, which remains the same throughout the three chapters. These colors are as follows:

	ATP and other nucleoside triphosphates
	ADP and other nucleoside diphosphates
	The oxidized coenzymes NAD^+ and FAD
	The reduced coenzymes NADH and FADH_2
	Acetyl coenzyme A

In figures showing metabolic pathways, we display the numbers of the various steps in yellow. In addition to this main use of a color code, other figures in various parts of the book are color coded so that the same color is used for the same entity throughout. For example, in all figures that show enzyme-substrate interactions, enzymes are always shown in blue and substrates in orange.

Features

- **Problem-Solving Strategies** The in-text examples include a description of the strategy used to arrive at a solution. This will help students organize the information in order to solve the problem.
- **[New] Interactive Examples in OWL** allow students to work some of in-text examples multiple times in slightly different versions to encourage thinking their way through the example instead of passively reading through to the solution.
- **[UPDATED] Visual Impact** We have introduced illustrations with heightened pedagogical impact. These include ones that show the microscopic and macroscopic aspects of a topic under discussion, such as Figures 6.4 (Henry's Law) and 6.11 (electrolytic conductance). The Chemical Connections essays have been enhanced further with more photos that illustrate each topic.
- **Key Questions** We use a Key Questions framework to emphasize key chemical concepts. This focused approach guides students through each chapter by using section head questions.
- **[UPDATED] Chemical Connections** Over 150 essays describe applications of chemical concepts presented in the text, linking the chemistry to their real uses. Many new application boxes on diverse topics were added such as, Electrolyte Solutions in Body and Intravenous Fluids (Chapter 6), DDT, A Boon and a Curse (Chapter 13), Carbohydrates and Obesity (Chapter 20), and Depression and Nutrient Deficiency (Chapter 30).
- **Summary of Key Reactions** In each organic chemistry chapter (10–19) there is an annotated summary of all the new reactions introduced. Keyed to sections in which they are introduced, there is also an example of each reaction.
- **[UPDATED] Chapter Summaries** Summaries reflect the Key Questions framework. At the end of each chapter, the Key Questions are restated

and the summary paragraphs that follow are designed to highlight the concepts associated with the questions.

- **[NEW] GOB OWL Problems** The number of end-of-chapter problems assignable in GOB OWL, the web-based homework system that accompanies this book, has doubled in this edition.
- **[UPDATED] Looking Ahead Problems** At the end of most chapters, the challenge problems are designed to show the application of principles in the chapter to material in the following chapters.
- **[UPDATED] Tying-It-Together and Challenge Problems** At the end of most chapters, these problems build on past material to test students' knowledge of the concepts. In the Challenge Problems, associated chapter references are given.
- **[UPDATED] How To Boxes** These boxes emphasize the skills students need to master the material. They include topics such as, "How to Determine the Number of Significant Figures in a Number" (Chapter 1) and "How to Draw Enantiomers" (Chapter 15).
- **Molecular Models** Ball-and-stick models, space-filling models, and electron-density maps are used throughout the text as appropriate aids to visualizing molecular properties and interactions.
- **Margin Definitions** Many terms are also defined in the margin to help students learn terminology. By skimming the chapter for these definitions students will have a quick summary of its contents.
- **Margin Notes** Additional bits of information, such as historical notes and reminders, complement nearby text.
- **Answers to all in-text and odd-numbered end-of-chapter problems** Answers to selected problems are provided at the end of the book. Detailed worked-out solutions to these same problems are provided in the Student Solutions Manual.
- **Glossary** The glossary at the back of the book gives a definition of each new term along with the number of the section in which the term is introduced.

Organization and Updates

General Chemistry (Chapters 1–9)

- **Chapter 1, Matter, Energy, and Measurement**, serves as a general introduction to the text and introduces the pedagogical elements that are new to this edition. A new example on unit conversions was added, as well as various application problems related to a clinical setting. Thirteen new problems were added.
- In **Chapter 2, Atoms**, we introduce four of the five ways we use to represent molecules throughout the text: we show water as a molecular formula, a structural formula, a ball-and-stick model, and a space-filling model. Nine new problems were added.
- **Chapter 3, Chemical Bonds**, begins with a discussion of ionic compounds, followed by a discussion of molecular compounds. New problems dealing with biomolecules were added.
- **Chapter 4, Chemical Reactions**, was reorganized in order for students to better understand the various intricacies in writing and balancing chemical reactions before stoichiometry is introduced. This chapter includes the How To box, *How to Balance a Chemical Equation*, which illustrates a step-by-step method for balancing an equation. Several challenge problems were added.

- In **Chapter 5, Gases, Liquids, and Solids**, we present intermolecular forces of attraction in order of increasing energy, namely London dispersion forces, dipole-dipole interactions, and hydrogen bonding. Section 5.9 was updated to include a more descriptive overview of the various types of crystalline solids, and increased coverage of allotropes of carbon. Nine new problems were added.
- **Chapter 6, Solutions and Colloids**, opens with a listing of the most common types of solutions, followed by a discussion of the factors that affect solubility, the most common units for concentration, and closes with an enhanced discussion of colligative properties. A new Chemical Connections box on electrolytes and eight new problems were added.
- **Chapter 7, Reaction Rates and Chemical Equilibrium**, shows how these two important topics are related to one another. A How To box shows how to *Interpret the Value of the Equilibrium Constant, K*. In addition, nine new problems were added.
- **Chapter 8, Acids and Bases**, introduces the use of curved arrows to show the flow of electrons in organic reactions. Specifically, we use them here to show the flow of electrons in proton-transfer reactions. The major theme in this chapter is the discussion of acid-base buffers and the Henderson-Hasselbalch equation. Information on the activity series and seven new problems were added.
- **Chapter 9, Nuclear Chemistry**, highlights nuclear applications to medicine.

Organic Chemistry (Chapters 10–19)

- **Chapter 10, Organic Chemistry**, is an introduction to the characteristics of organic compounds and to the most important organic functional groups. Seven new problems were added.
- In **Chapter 11, Alkanes and Cycloalkanes**, we introduce the concept of a line-angle formula and continue using them throughout the organic chapters. They are easier to draw than the usual condensed structural formulas and are easier to visualize. A new box on *How To... Draw Alternative Chair Conformations of Cyclohexane* was added, along with nine new problems.
- In **Chapter 12, Alkenes and Alkynes**, we introduce a new, simple way of looking at reaction mechanisms: add a proton, take a proton away, break a bond and make a bond. The purpose of this introduction to reaction mechanisms is to demonstrate to students that chemists are interested not only in what happens in a chemical reaction, but also in how it happens. Eight new problems were added to this chapter.
- **Chapter 13, Benzene and Its Derivatives**, includes a discussion of phenols and antioxidants. A new Chemical Connections box on *DDT* and 15 new problems were added.
- **Chapter 14, Alcohols, Ethers, and Thiols**, discusses the structures, names, and properties of alcohols first, and then gives a similar treatment to ethers, and finally thiols. Twelve new problems were added.
- In **Chapter 15, Chirality: The Handedness of Molecules**, the concept of a stereocenter and enantiomerism is slowly introduced, using 2-butanol as a prototype. We then treat molecules with two or more stereocenters and show how to predict the number of stereoisomers possible for a particular molecule. We also explain *R,S* convention for assigning absolute configuration to a tetrahedral stereocenter. Many new problems deal with drug development.

- In **Chapter 16, Amines**, we trace the development of new asthma medications from epinephrine, which can be viewed as a lead drug to albuterol (Proventil).
- **Chapter 17, Aldehydes and Ketones**, has a discussion of NaBH_4 as a carbonyl-reducing agent with emphasis on it as a hydride transfer reagent. We then make the parallel to NADH as a carbonyl reducing agent and hydride transfer agent. A new Chemical Connections box on *Warfarin* and eight new problems round out this chapter.
- **Chapter 18, Carboxylic Acids**, focuses on the chemistry and physical properties of carboxylic acids. There is a brief discussion of *trans* fatty acids, omega-3 fatty acids, and the significance of their presence in our diets. Ten new problems, many on pharmacology, complete this chapter.
- **Chapter 19, Anhydrides, Esters, and Amides**, describes the chemistry of these three important functional groups with emphasis on their acid-catalyzed and base-promoted hydrolysis, and reactions with amines and alcohols. New summary tables for reactions and ten new problems were added to this chapter.

Biochemistry (Chapters 20–31)

- **Chapter 20, Carbohydrates**, begins with the structure and nomenclature of monosaccharides, their oxidation, reduction, and formation of glycosides and concludes with a discussion of the structure of disaccharides, polysaccharides, and acidic polysaccharides. A new Chemical Connections box on *Carbohydrates and Obesity* and six new problems were added.
- **Chapter 21, Lipids**, covers the most important features of lipid biochemistry, including membrane structure, and the structures and functions of steroids. New Chemical Connections boxes on *Ceramides and Oxygen Deprivation* and on *Omega-3 Fatty Acids and Heart Disease* were included.
- **Chapter 22, Proteins**, covers the many facets of protein structure and function. It gives an overview of how proteins are organized, beginning with the nature of individual amino acids and how this organization leads to their many functions. This supplies the student with the basics needed to lead into the sections on enzymes and metabolism. A new section on *Transition Metals and their Effect on the Structure of Proteins* was added.
- **Chapter 23, Enzymes**, covers the important topic of enzyme catalysis and regulation. The focus is on how the structure of an enzyme leads to the vast increases in reaction rates with enzyme-catalyzed reactions. Specific medical applications of enzyme inhibition are included, as well as an introduction to the fascinating topic of transition state analogs and their use as potent inhibitors. A new Chemical Connections on *The Role of Enzymes* was added.
- In **Chapter 24, Chemical Communications**, we see the biochemistry of hormones and neurotransmitters. The health-related implications of how these substances act in the body is the main focus of this chapter. New information on the possible causes of Alzheimer's disease is explored. A new Chemical Connections on *Zebrafish, Nerve Synapses, and Sleep* was added.
- In **Chapter 25, Nucleic Acids, Nucleotides and Heredity**, introduces DNA and the processes surrounding its replication and repair. How nucleotides are linked together and the flow of genetic information that occurs due

to the unique properties of these molecules is emphasized. The sections on the types of RNA have been greatly expanded as our knowledge increases daily about these important nucleic acids. The uniqueness of an individual's DNA is described with a chemical connections box that introduces DNA fingerprinting and how forensic science relies on DNA for positive identification. Three new Chemical Connections boxes were added: *Who Owns Your Genes*, *Synthetic Genome Created*, and *Did the Neandertals Go Extinct?*

- **Chapter 26, Gene Expression and Protein Synthesis**, shows how the information contained in the DNA blueprint of the cell is used to produce RNA and eventually protein. The focus is on how organisms control the expression of genes through transcription and translation. The chapter ends with the timely and important topic of gene therapy, which is the attempt to cure genetic diseases by giving an individual a gene he or she was missing. A new Chemical Connections on *Cystic Fibrosis* research was added.
- **Chapter 27, Bioenergetics**, is an introduction to metabolism that focuses strongly on the central pathways, namely the citric acid cycle, electron transport, and oxidative phosphorylation.
- In **Chapter 28, Specific Catabolic Pathways**, we address the details of carbohydrate, lipid, and protein breakdown, concentrating on the energy yield. A new Chemical Connections box on *How the Body Selects Proteins for Degradation* was included.
- **Chapter 29, Biosynthetic Pathways**, starts with a general consideration of anabolism and proceeds to carbohydrate biosynthesis in both plants and animals. Lipid biosynthesis is linked to the production of membranes, and the chapter concludes with an account of amino acid biosynthesis. New information on glucose consumption and metabolism was added.
- In **Chapter 30, Nutrition**, we take a biochemical approach to understanding nutrition concepts. Along the way, we look at a revised version of the Food Guide Pyramid, and debunk some of the myths about carbohydrates and fats. A new Chemical Connections box on *Depression and Nutrition* was added.
- **Chapter 31, Immunochemistry**, covers the basics of our immune system and how we protect ourselves from foreign invading organisms. Considerable time is spent on the acquired immunity system. No chapter on immunology would be complete without a description of the Human Immunodeficiency Virus. The chapter includes a new section on Immunization, new Chemical Connections boxes on *Influenza* and the *Flu Vaccine*, and eight new problems.
- **Chapter 32, Body Fluids**, can be found on the companion web site, which is accessible from www.cengagebrain.com. Search for this textbook's ISBN: 1-133-10508-4 to find this resource.

Alternate Version

General, Organic and Biochemistry, 10e, Hybrid Version with OWL
ISBN-10: 1-133-10982-9; ISBN-13: 978-1-133-10982-2

This briefer paperback version of General, Organic and Biochemistry does not contain the end-of-chapter problems, which can be assigned in OWL. Access to OWL and the Cengage YouBook is packaged with the hybrid version. The Cengage YouBook is the full version of the text, with all end-of-chapter questions and problem sets.

Supporting Materials

OWL for General, Organic and Biochemistry/Allied Health

Instant Access OWL with Cengage YouBook (6 months)

ISBN: 978-1-133-22999-5

Instant Access OWL with Cengage YouBook (24 months)

ISBN: 978-1-133-35129-1

By Roberta Day, Beatrice Botch and David Gross of the University of Massachusetts, Amherst, William Vining of the State University of New York at Oneonta, and Susan Young of Hartwick College. **OWL** Online Web Learning offers more assignable, gradable content (including end-of chapter questions specific to this textbook), and more reliability and flexibility than any other system. OWL's powerful course management tools allow instructors to control due dates, number of attempts, and whether students see answers or receive feedback on how to solve problems. OWL includes the **Cengage YouBook**, an interactive and customizable Flash-based eBook. Instructors can publish web links, modify the textbook narrative as needed with the text edit tool, quickly re-order entire sections and chapters, and hide any content they don't teach to create an eBook that perfectly matches their syllabus. The Cengage YouBook includes animated figures, video clips, highlighting, notes, and more.

Developed by chemistry instructors for teaching chemistry, OWL is the only system specifically designed to support **mastery learning**, where students work as long as they need to master each chemical concept and skill. OWL has already helped hundreds of thousands of students master chemistry through a wide range of assignment types, including tutorials, interactive simulations, and algorithmically generated homework questions that provide instant, answer-specific feedback.

OWL is continually enhanced with online learning tools to address the various learning styles of today's students such as:

- **Quick Prep** review courses that help students learn essential skills to succeed in General and Organic Chemistry.
- **Jmol** molecular visualization program for rotating molecules and measuring bond distances and angles.
- **Go Chemistry®** mini video lectures on key concepts that students can play on their computers or download to their video iPods, smart phones, or personal video players.

In addition, when you become an OWL user, you can expect service that goes far beyond the ordinary. To learn more or to see a demo, please contact your Cengage Learning representative or visit us at www.cengage.com/owl.

For Instructors

Power Lecture Instructor's CD/DVD Package with JoinIn® and ExamView®

ISBN: 978-1-133-10540-4

This digital library and presentation tool includes:

- **PowerPoint® lecture slides** written for this text by William H. Brown that instructors can customize by importing their own lecture slides or other materials.
- **Image libraries** that contain digital files for figures, photographs, and numbered tables from the text, as well as multimedia animations in a variety of digital formats. Use these files to print transparencies, create your own PowerPoint slides, and supplement your lectures.



Online Web
Learning

PowerLecture™



- Digital files of the complete **Instructor's Manual** by Mark Erickson and Andrew Piefer (Hartwick College) and **ExamView Test Bank** by Bette Kruez (University of Michigan, Dearborn).
- Sample chapters from the **Student Solutions Manual and Study Guide**.
- **ExamView testing software** that enables you to create, deliver, and customize tests using the more than 1,500 test bank questions written specifically for this text.
- **JoinIn student response (clicker) questions** written for this book for use with the classroom response system of the instructor's choice.

Chemistry CourseMate

Instant Access (two semesters) ISBN: 978-1-4282-7175-3

Chemistry CourseMate is available to complement this text. Chemistry CourseMate includes an interactive eBook, interactive teaching and learning tools such as quizzes, flashcards, videos, and more. Chemistry CourseMate also includes the Engagement Tracker, a first-of-its-kind tool that monitors student engagement in the course. Go to login.cengage.com to access these resources. Look for the CourseMate icon, which denotes a resource available within CourseMate.

Instructor Companion Site Supporting materials are available to qualified adopters. Please consult your local Cengage Learning sales representative for details. Go to login.cengage.com, find this textbook, and choose Instructor Companion Site to see samples of these materials, request a desk copy, locate your sales representative, and download the WebCT or Blackboard versions of the Test Bank.

Instructor's Manual for *Laboratory Experiments for General, Organic & Biochemistry, Eighth Edition*, by Frederick A. Bettelheim and Joseph M. Landesberg. This manual will help instructors in grading the answers to questions and in assessing the range of experimental results obtained by students. The Instructor's Manual also contains important notes for students and details on how to handle the disposal of waste chemicals. Available on the Instructor Companion Site.

For Students



Visit cengagebrain.com

To access these and additional course materials, please visit www.cengagebrain.com. At the cengagebrain.com home page, search for this textbook's ISBN (from the back cover of your book). This will take you to the product page where these resources can be found. (Instructors can log in at login.cengage.com.)



Instant Access Go Chemistry® for General Chemistry

Pressed for time? Miss a lecture? Need more review? Go Chemistry® for General Chemistry is a set of 27 downloadable mini video lectures. Developed by award-winning chemists, Go Chemistry helps you quickly review essential topics—whenever and wherever you want! Each video contains animations and problems and can be downloaded to your computer desktop or portable video player (like iPod or iPhone) for convenient self-study and exam review. Selected Go Chemistry videos have e-flashcards to briefly introduce a key concept and then test student understanding of the basics with a series of questions. OWL includes five Go Chemistry videos. Students can enter ISBN: 978-0-495-38228-7 at www.cengagebrain.com to download two free videos or to purchase instant access to the 27-video set or to individual videos.



Chemistry CourseMate

Instant Access (two semesters) ISBN: 978-1-4282-7175-3

Chemistry CourseMate is available with this book to help you make the grade. Chemistry CourseMate includes an interactive eBook with highlighting, note taking and search capabilities, as well as interactive learning tools such as quizzes, flashcards, videos, and more. Go to login.cengage.com to access these resources, and look for the CourseMate icon to find resources related to your text in Chemistry CourseMate.

Student Study Guide by William Scovell of Bowling Green State University includes reviews of chapter objectives, important terms and comparisons, focused reviews of concepts, and self-tests. ISBN: 978-1-133-10541-1.

Student Solutions Manual by Mark Erickson and Andrew Piefer (Hartwick College). This ancillary manual contains complete worked-out solutions to all in-text and odd-numbered end-of-chapter problems. ISBN: 978-1-133-10910-5.

Laboratory Experiments for General, Organic & Biochemistry, Eighth Edition, by Frederick A. Bettelheim and Joseph M. Landesberg (Adelphi University). Forty-eight experiments illustrate important concepts and principles in general, organic and biochemistry. Includes eleven organic chemistry experiments, seventeen biochemistry experiments, and twenty general chemistry experiments. Many experiments have been revised, and a new addition is an experiment on the properties of enzymes. All experiments have new Pre- and Post-lab Questions. The large number of experiments allows sufficient flexibility for the instructor. ISBN: 978-1-133-10602-9.

Survival Guide for General, Organic, and Biochemistry by Richard Morrison, Charles H. Atwood, and Joel Caughran (University of Georgia). Available free in a package with any Cengage Chemistry text or available for separate purchase at www.cengagebrain.com. Modeled after Atwood's widely popular *General Chemistry Survival Guide*, this straightforward, thorough guide helps students make the most of their study time for optimal exam results. The *Survival Guide* is packed with examples and exercises to help students master concepts and improve essential problem-solving skills through detailed step-by-step problem-solving sequences. This reader-friendly guide gives students the competency—and confidence—they need to survive and thrive in the GOB course. ISBN: 978-0-495-55469-1.

Acknowledgments

The publication of a book such as this requires the efforts of many more people than merely the authors. We would like to thank the following professors who offered many valuable suggestions for this new edition:

We are especially grateful to Bette Kruez, University of Michigan, Dearborn and Robert Keil, Moorpark College, who read page proofs with eyes for accuracy.

We give special thanks to Sandi Kiselica, our Senior Development Editor, who has been a rock of support through the entire revision process. We appreciate her constant encouragement as we worked to meet deadlines; she has also been a valuable resource person. We appreciate the help of our other colleagues at Brooks/Cole: executive editor Mary Finch, production manager Teresa Trego, assistant editor Krista Mastroianni, media editors Lisa Weber and Stephanie vanCamp, and senior project manager Patrick Franzen of PreMediaGlobal.

We so appreciate the time and expertise of our reviewers who have read our manuscript and given us helpful comments. They include:

Reviewers of the 10th Edition:

Julian Davis, *University of the Incarnate Word*

Robert Keil, *Moorpark College*

Margaret Kimble, *Indiana University, Purdue University, Fort Wayne*

Bette Kruez, *University of Michigan, Dearborn*

Timothy Marshall, *Pima Community College*

Donald Mitchell, *Delaware Technical and Community College*

Paul Root, *Henry Ford Community College*

Ahmed Sheikh, *West Virginia University*

Steven Socol, *McHenry County College*

Susan Thomas, *University of Texas, San Antonio*

Holly Thompson, *University of Montana*

Janice Webster, *Ivy Tech Community College*

Reviewers of the 9th Edition:

Allison J. Dobson, *Georgia Southern University*

Sara M. Hein, *Winona State University*

Peter Jurs, *The Pennsylvania State University*

Delores B. Lamb, *Greenville Technical College*

James W. Long, *University of Oregon*

Richard L. Nafshun, *Oregon State University*

David Reinhold, *Western Michigan University*

Paul Sampson, *Kent State University*

Garon C. Smith, *University of Montana*

Steven M. Socol, *McHenry County College*

Health-Related Topics

Key

ChemConn = Chemical Connections Box number

Sect. = Section number

Prob. = Problem number

A, B, AB and O Blood Types	ChemConn 20D	Autooxidation	Sect. 13.5C
Abundance of Elements in the Human Body and in the Earth's Crust	ChemConn 2B	Azithromycin	Prob. 18.54
Acid Rain	ChemConn 6A	B Cells	Sect. 31.2C
Acid and Base Burns of the Cornea	ChemConn 9B	Barbiturates	ChemConn 19E
Acidic Polysaccharides	Sect. 20.6	Basal Caloric Requirement	Sect. 30.2
Acidosis	ChemConn 8C	Base Excision Repair (BER) of DNA	Sect. 25.7
Acquired Immunity	Sect. 31.1	Bends	ChemConn 6B
Adjuvants	Sect. 31.7D	BHT as an Antioxidant in Foods	Sect. 13.4C
Advanced Glycation End Products	ChemConn 22B	Bile Salts	Sect. 21.11
AGE and Aging	ChemConn 22B	Biological Pollutants	ChemConn 24G
AIDS	Sect. 31.9	Blood Alcohol Screening	ChemConn 14B
Alkaloids	ChemConn 16B	Blood Buffers	Sect. 8.10D
Alkalosis and the Sprinter's Trick	ChemConn 8D	Blood pH	Sect. 8.10
Alzheimer's Disease	ChemConn 24C	Blood Pressure Measurement	ChemConn 5C
Amoxicillin	Prob. 15.32	Bone, Artificial	ChemConn 3A
Amphetamines	ChemConn 16A	Bone Density and Solubility Equilibrium	Sect. 7.6
Anabolic Steroids	ChemConn 21E	Botox	ChemConn 24C
Antacids	ChemConn 98B	Botulism	ChemConn 24B
Antibiotics	ChemConn 31B	Breath Alcohol Screening	ChemConn 14B
Antibodies and Cancer Therapy	ChemConn 31B	Breathing and Boyle's Law	ChemConn 5A
Antidepressants	Sect. 24.5F	Bronchodilators and Asthma	ChemConn 16E
Antigens	Sect. 31.1	Brown Fat and Hibernation	ChemConn 27A
Antihistamines	Sect. 24.5E	Buffers	Sect. 8.10
Anti-inflammatory Drugs	ChemConn 21G	Calcium as a Signaling Agent	Sect. 24.3C
Anticoagulants	ChemConn 17A	Calorie Counting	Sect. 30.2
Antioxidants	Sect. 13.5C	Cancer Cell Growth and Metabolic State	Sect. 27.1
Artificial Pacemakers and Redox	ChemConn 4C	Cancer Therapy Antibodies	ChemConn 31A
Ascorbic Acid (Vitamin C)	ChemConn 20B	Cannabinoid Receptors	ChemConn 30F
Aspartame	Prob. 19.13, ChemConn 22A	Captopril and ACE Inhibitors	Prob. 15.31
Aspirin and Other NSAIDs	ChemConn 19C	Capsaicin, for Those Who Like It Hot	ChemConn 13F
Asthma	Sect. 21.12	Carcinogenic Polynuclear Aromatics and Smoking	ChemConn 13B
Atherosclerosis: Levels of LDL and HDL	Sect. 21.9E	Carcinogens	Sect. 26.7
Atomic Energy	Sect. 9.8	β -Carotene	Prob. 12.58
Atropine	Prob. 16.54	Cataracts	ChemConn 22B
Attention Deficit Disorder (ADD)	ChemConn 24D	Cephalosporins	ChemConn 19B
Autoimmune Diseases	Sect. 31.7	Ceramides and Oxygen Deprivation	ChemConn 21C
Automobile Air Bags	Prob. 5.54	Cetylpyridinium Chloride	Prob. 18.25
		Chiral Drugs	ChemConn 15A
		Chirality in the Biological World	Sect. 15.5
		Chlorine Dioxide	Probs. 3.102, 4.59
		Cholera	Sect. 24.5E
		Cholesterol	Sect. 21.9F

<i>Cis-Trans</i> Isomerism in Vision	ChemConn 12.C	Gene Therapy	Sect. 26.9
Cocaine	ChemConn 16B	Genetic Code	Sect. 26.4
Cocaine Addiction	ChemConn 23G	Genetic Fingerprinting	Sect. 26.8
Cold Compresses	ChemConn 1C	Gout	Sect. 6.6B
Chondroitin Sulfate	Prob. 20.79	G-protein/cAMP Cascade	Sect. 24.5C
Coniine	ChemConn 16B	Haber Process	ChemConn 8E
Connection between		Heart Enzymes	Sect. 23.7
Carbohydrates and Obesity	ChemConn 20E	Heavy Metal Poisoning	Sect. 22.13
Coral Chemistry and Broken Bones	ChemConn 3A	Heme Products in Bruises	Sect. 28.10
Cornea Burns	ChemConn 9B	Hemodialysis	ChemConn 6G
COX-2 Inhibitor Drugs	ChemConn 21G	Hemoglobin	ChemConn 22G
Creatine: Performance Enhancement	ChemConn 30D	Hemolysis	Sect. 6.8C
Crenation	Sect. 6.8C	Heparin	Sect. 20.6B, Prob. 20.68
Cystic Fibrosis	ChemConn 26G	High Fever	ChemConn 8A
Cytokines	Sect. 13A	HIV Protease Inhibitors	ChemConn 23D
DDT	ChemConn 13A	Hormones	Sect. 24.2
DEET	Prob. 19.43	How Soap Cleans	Sect. 18.4C
Depression	ChemConn 30F	Human Insulin	ChemConn 22C
Diabetes	ChemConn 24F	Hyaluronic Acid	Sect. 20.6
Dialysis	Sect. 6.8C	Hyperbaric Medicine	ChemConn 5B
Dietary Reference Intake	Sect. 30.1	Hypoglycemic Awareness	ChemConn 22C
Dieting and Weight Loss	Sect. 30.2	Hypothermia and Hyperthermia	ChemConn 1B
2,4-Dinitrophenol as an Uncoupling		Immune System	Sect. 31.1
Agent	ChemConn 27A	Immunization	Sect. 31.7
DNA Fingerprinting	ChemConn 25C	Immunoglobulin	Sect. 31.4
Drug Dosage and Body Mass	Prob. 1.100, ChemConn 1A	Immunosuppressant FK-506	Probs. 15.44, 17.54
Eicosapentenoic Acid	ChemConn 21H	Indoor Radon Problem	ChemConn 9B
Emulsions and Emulsifying Agents	ChemConn 6E	Influenza Vaccine	ChemConn 31E
Enantiomers of Ibuprofen	Sect. 15.2	Innate Immunity	Sect. 31.1
Environmental Impact of Freons	ChemConn 11C	Insulin	Sect. 2.8
Enzymes in Medical Diagnosis	Sect. 23.7	Insulin, Structure	Sect. 22.8
Enzymes in Therapy	Sect. 23.7	Insulin, Use	ChemConn 22C
Ephedrine	Probs. 3.107, 15.24	Iodide Ion and Goiter	ChemConn 13C
Erythromycin A	Prob. 14.64	Ionic Compounds in Medicine	ChemConn 3B
Epinephrine	ChemConn 16E	Ionizing Radiation	Sect. 9.5
Essential Amino Acids	Sect. 30.5, ChemConn 29C	Iron and Mineral Requirements	ChemConn 30C
Esters, as Flavoring Agents	ChemConn 18B	Ketoacidosis in Diabetes	ChemConn 28B
Ethers and Anesthesia	ChemConn 14D	Ketone Bodies	ChemConn 18C, Sect. 28.7
Ethylene Oxide, as a Chemical Sterilant	ChemConn 14C	Lactate Accumulation	ChemConn 28A
Ethylene, a Plant Growth Regulator	ChemConn 12A	Laetrile	Prob. 20.71
Fatty Acids	ChemConn 12B, Sect. 18.4A	Laser In Situ Keratomileusis (LASIK)	ChemConn 22H
Fever, as a Protective Mechanism	ChemConn 8A	Laser Surgery and Protein Denaturation	ChemConn 22H
Fever, Dangers of	ChemConn 8A	Librium	ChemConn 16C
Fluid Mosaic, Model of Membranes	Sect. 21.5	Lipid Storage Diseases	ChemConn 21D
Fluoride Ion in Dental Decay	ChemConn 4A	Local Anesthetics for Dentistry	Prob. 19.44
Fluoxetine (Prozac)	Prob. 13.51	Lowering Body Temperature	ChemConn 7B
Fish in Diet – Health Benefits	ChemConn 21H	Lunesta	Prob. 15.46
Food for Performance	ChemConn 30D	Lycopene	Prob. 12.57
Food Guide Pyramid	ChemConn 30A	Mad Cow Disease	ChemConn 22E
Free Radicals	ChemConn 9C, Sect. 13.4C	Medical Uses of Inhibitors	ChemConn 23D
Galactosemia	ChemConn 20A	Menstrual Cycle	Sect. 21.10B
Gallstones	Sect. 21.9A	Metformin (Glucophage)	Prob. 16.28
Gene Patents	ChemConn 25A	Methodone	ChemConn 16D

Methamphetamine	ChemConn 16A	Radiation Sickness	Sect. 9.6
Methylparaben	Prob. 18.47	Radioactive Dating	ChemConn 9A
Milk of Magnesia	ChemConn 8A	Radioactive Fallout from Nuclear Accidents	ChemConn 9D
Monoclonal Antibodies	ChemConn 31A	Radioactive Isotopes, in Nuclear Imaging	Sect. 9.7A
Morphine and Enkephalins	Sect. 24.6	Radioactive Isotopes, in Medical Therapy	Sect. 9.7B
Morphine and Morphine Analogs	Prob. 16.59	Recommended Daily Allowances (RDA)	Sect. 30.1
MSG and Headaches	ChemConn 24F	Relative Sweetness	Sect. 20.4D
Muscle Relaxants	ChemConn 23A	Reverse Osmosis and Desalinization	ChemConn 6F
Mutagens	Sect. 26.7	Roentgens, Rads, and Rems	Sect. 9.6
Mutations and Biochemical Evolution	ChemConn 26E	SCID	Sect. 26.9
Naproxen	Sects. 15.2, 15.5	SCUBA Diving	Prob. 5.111
Neurotransmitters	Sect. 22.4	Sickle Cell Anemia	ChemConn 22D
Neurotransmitters and Disease	Sect. 24.1	Significance of Chirality in the Biological World	Sect. 15.5
Nicotine	ChemConn 16B	Side Effects of COX Inhibitors	Sect. 21.12
Nitric Oxide	ChemConn 3C, 24E	Solubility of Drugs in Body Fluids	ChemConn 16D
Nitrous Oxide (“Laughing Gas”)	Prob. 3.78	Solubility and Tooth Decay	ChemConn 5A
Nitroglycerin, an Explosive and a Drug	ChemConn 14A	Sports Drinks	Sect. 21.11, ChemConn 30D
NMDA Receptors	Sect. 24.4	Statins	Sect. 29.4
NO Release and Impotence	ChemConn 24E	Stem Cells	ChemConn 31C
Nuclear Medicine	Sect. 9.7	Stitches That Dissolve	ChemConn 19F
Nutritional Causes of Depression	ChemConn 30F	Strontium-90	ChemConn 2C
Nutritional Daily Values	Sect. 30.1	Sunglasses and Le Chatelier’s Principle	ChemConn 7D
Obesity	Sect. 30.2	Sunscreens and Sunblocks	ChemConn 19D
Omega-3 Fatty Acids	ChemConn 21H	Swine Flu	ChemConn 31D
Oncogenes and Cancer	ChemConn 26F	Synapses and Sleep	ChemConn 24A
Oral Contraception	ChemConn 21F	Synthetic Food Dyes	ChemConn 13E
Organic Food and Health	ChemConn 30E	Synthetic Genome	ChemConn 25E
Oseltamivir (Tamiflu)	Prob. 15.45	T Cells	Sect. 31.2C
Osmotic Pressure	Sect. 6.8C	Tamoxifen and Breast Cancer	Prob. 16.32
Parkinson’s Disease	ChemConn 24E, Sect. 22.4	Taxol	ChemConn 10A
Paroxetine	Prob. 15.31	Telomeres and Immortality	ChemConn 25B
Paternity Testing	ChemConn 25C	Terpin Hydrate	Prob. 12.52
Penicillins	ChemConn 19B	Testing for Glucose	ChemConn 20C
Peramivir for Influenza A (H1N1) and Swine Flu	Prob. 19.46	Tetrodotoxin	ChemConn 11A
Phenols as Antioxidants	Sect. 13.4C	Timed-Released Medication	ChemConn 7C
Phencyclidine (PCP)	Sect. 24.4B	Tranquilizers	ChemConn 16C
Phenylketonuria	ChemConn 28E	<i>Trans</i> Fatty Acids	ChemConn 18A
Photorefractive Keratectomy (PRK)	ChemConn 22H	Transport Across Cell Membranes	ChemConn 21B
Photosynthesis	ChemConn 29A	Tumor Suppressors	ChemConn 26E
Poison Ivy	Sect. 13.4A	Urinometer	Sect. 1.7
Poisonous Puffer Fish	ChemConn 11A	Vaccines	Sect. 31.7
Polynuclear Aromatic Hydrocarbons (PAHs)	Sect. 13.2D, ChemConn 13B	Valium	ChemConn 16C
Positron Emission Tomography (PET)	Sect. 9.7A	Viagra	ChemConn 23D, 24E
Prion Disease	ChemConn 22E	Viagra and Blood Vessel Dilation	ChemConn 24E
Propofol	Sect. 20.3	Viruses	ChemConn 26B
Protein Degradation Diseases	ChemConn 28C	Vitamin A and Vision	ChemConn 12C
Proteomics	ChemConn 22F	Vitamin Excess	Sect. 30.6
Pyrethrins	ChemConn 19A	Vitamins and Depression	ChemConn 30F
Quaternary Structure and Allosteric Proteins	ChemConn 22G	Vitamins and Minerals	Sect. 30.6
Radiation	Sect. 9.2	Vitamins, in Diet	Sect. 30.6
Radiation Dosimetry	Sect. 9.6	Xeroderma Pigmentosum	Sect 25.7
		Zebrafish Synapses	ChemConn 24A

This page intentionally left blank

Matter, Energy, and Measurement

1



James Balog/Getty Images

A woman climbing a frozen waterfall in British Columbia.

1.1 Why Do We Call Chemistry the Study of Matter?

The world around us is made of chemicals. Our food, our clothing, the buildings in which we live are all made of chemicals. Our bodies are made of chemicals, too. To understand the human body, its diseases, and its cures, we must know all we can about those chemicals. There was a time—only a few hundred years ago—when physicians were powerless to treat many diseases. Cancer, tuberculosis, smallpox, typhus, plague, and many other sicknesses struck people seemingly at random. Doctors, who had no idea what caused any of these diseases, could do little or nothing about them. Doctors treated them with magic as well as by such measures as bleeding, laxatives, hot plasters, and pills made from powdered stag-horn, saffron, or gold. None of these treatments was effective, and the doctors, because they came into direct contact with highly contagious diseases, died at a much higher rate than the general public.

Key Questions

- 1.1 Why Do We Call Chemistry the Study of Matter?
- 1.2 What Is the Scientific Method?
- 1.3 How Do Scientists Report Numbers?

How To . . . Determine the Number of Significant Figures in a Number

- 1.4 How Do We Make Measurements?
- 1.5 What Is a Handy Way to Convert from One Unit to Another?

How To . . . Do Unit Conversions by the Factor-Label Method

- 1.6 What Are the States of Matter?
- 1.7 What Are Density and Specific Gravity?
- 1.8 How Do We Describe the Various Forms of Energy?
- 1.9 How Do We Describe Heat and the Ways in Which It Is Transferred?



Sign in to OWL at www.cengage.com/owl to view tutorials and simulations, develop problem-solving skills, and complete online homework assigned by your professor.

Medical practice over time.

- (a) A woman being bled by a leech on her left forearm; a bottle of leeches is on the table. From a 1639 woodcut.
 (b) Modern surgery in a well-equipped operating room.



(a)



(b)

Courtesy of the National Library of Medicine

Photo by Bob Riha, Jr. Used courtesy of Childrens Hospital Los Angeles.

Medicine has made great strides since those times. We live much longer, and many once-feared diseases have been essentially eliminated or are curable. Smallpox has been eradicated, and polio, typhus, bubonic plague, diphtheria, and other diseases that once killed millions no longer pose a serious problem, at least not in the developed countries.

How has this medical progress come about? The answer is that diseases could not be cured until they were understood, and this understanding has emerged through greater knowledge of how the body functions. It is progress in our understanding of the principles of biology, chemistry, and physics that has led to these advances in medicine. Because so much of modern medicine depends on chemistry, it is essential that students who intend to enter the health professions have some understanding of basic chemistry. This book was written to help you achieve that goal. Even if you choose a different profession, you will find that the chemistry you learn in this course will greatly enrich your life.

The universe consists of matter, energy, and empty space. **Matter** is anything that has mass and takes up space. **Chemistry** is the science that deals with matter: the structure and properties of matter and the transformations from one form of matter to another. We will discuss energy in Section 1.8.

It has long been known that matter can change, or be made to change, from one form to another. In a **chemical change**, more commonly called a **chemical reaction**, substances are used up (disappear) and others are formed to take their places. An example is the burning of the mixture of hydrocarbons usually called “bottled gas.” In this mixture of hydrocarbons, the main component is propane. When this chemical change takes place, propane and oxygen from the air are converted to carbon dioxide and water. [Figure 1.1](#) shows another chemical change.

Matter also undergoes other kinds of changes, called **physical changes**. These changes differ from chemical reactions in that the identities of the substances do not change. Most physical changes involve changes of state—for example, the melting of solids and the boiling of liquids. Water remains water whether it is in the liquid state or in the form of ice or steam. The conversion from one state to another is a physical—not a chemical—change. Another important type of physical change involves making or separating mixtures. Dissolving sugar in water is a physical change.

When we talk about the **chemical properties** of a substance, we mean the chemical reactions that it undergoes. **Physical properties** are all properties that do not involve chemical reactions. For example, density, color, melting point, and physical state (liquid, solid, gas) are all physical properties.

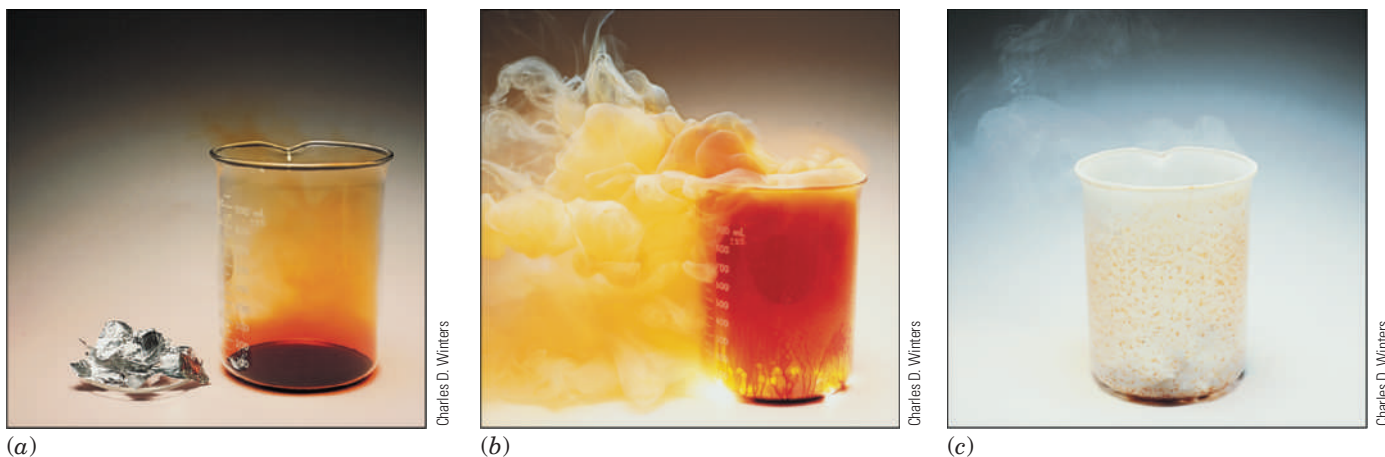


FIGURE 1.1 A chemical reaction. (a) Bromine, an orange-brown liquid, and aluminum metal. (b) These two substances react so vigorously that the aluminum becomes molten and glows white hot at the bottom of the beaker. The yellow vapor consists of vaporized bromine and some of the product of the reaction, white aluminum bromide. (c) Once the reaction is complete, the beaker is coated with aluminum bromide and the products of its reaction with atmospheric moisture. (Note: This reaction is dangerous! Under no circumstances should it be done except under properly supervised conditions.)

1.2 What Is the Scientific Method?

Scientists learn by using a tool called the **scientific method**. The heart of the scientific method is the testing of theories. It was not always so, however. Before about 1600, philosophers often believed statements just because they sounded right. For example, the great philosopher Aristotle (384–322 BCE) believed that if you took the gold out of a mine it would grow back. He believed this idea because it fitted in with a more general picture that he had about the workings of nature. In ancient times, most thinkers behaved in this way. If a statement sounded right, they believed it without testing it.

About 1600 CE, the scientific method came into use. Let us look at an example to see how the scientific method operates. The Greek physician Galen (200–130 BCE) recognized that the blood on the left side of the heart somehow gets to the right side. This is a fact. A **fact** is a statement based on direct experience. It is a consistent and reproducible observation. Having observed this fact, Galen then proposed a hypothesis to explain it. A **hypothesis** is a statement that is proposed, without actual proof, to explain the facts and their relationship. Because Galen could not actually see how the blood got from the left side to the right side of the heart, he came up with the hypothesis that tiny holes must be present in the muscular wall that separates the two halves.

Up to this point, a modern scientist and an ancient philosopher would behave the same way. Each would offer a hypothesis to explain the facts. From this point on, however, their methods would differ. To Galen, his explanation sounded right and that was enough to make him believe it, even though he couldn't see any holes. His hypothesis was, in fact, believed by virtually all physicians for more than 1000 years. When we use the scientific method, however, we do not believe a hypothesis just because it sounds right. We test it, using the most rigorous testing we can imagine.

William Harvey (1578–1657) tested Galen's hypothesis by dissecting human and animal hearts and blood vessels. He discovered that one-way



Galen did not do experiments to test his hypothesis.



A PET scanner is an example of how modern scientists do experiments to test a hypothesis.

Hypothesis A statement that is proposed, without actual proof, to explain a set of facts and their relationship

valves separate the upper chambers of the heart from the lower chambers. He also discovered that the heart is a pump that, by contracting and expanding, pushes the blood out. Harvey's teacher, Fabricius (1537–1619), had previously observed that one-way valves exist in the veins, so that blood in the veins can travel only toward the heart and not the other way.

Harvey put these facts together to come up with a new hypothesis: Blood is pumped by the heart and circulates throughout the body. This was a better hypothesis than Galen's because it fitted the facts more closely. Even so, it was still a hypothesis and, according to the scientific method, had to be tested further. One important test took place in 1661, four years after Harvey died. Harvey had predicted that because there had to be a way for the blood to get from the arteries to the veins, tiny blood vessels must connect them. In 1661, the Italian anatomist Malpighi (1628–1694), using the newly invented microscope, found these tiny vessels, which are now called capillaries.

Malpighi's discovery supported the blood circulation hypothesis by fulfilling Harvey's prediction. When a hypothesis passes the tests, we have more confidence in it and call it a theory. A **theory** is the formulation of an apparent relationship among certain observed phenomena, which has been verified to some extent. In this sense, a theory is the same as a hypothesis except that we have a stronger belief in it because more evidence supports it. No matter how much confidence we have in a theory, however, if we discover new facts that conflict with it or if it does not pass newly devised tests, the theory must be altered or rejected. In the history of science, many firmly established theories have eventually been thrown out because they could not pass new tests.

One of the most important ways to test a hypothesis is by a controlled experiment. It is not enough to say that making a change causes an effect, we must also see that the lack of that change does not produce the observed effect. If, for example, a researcher proposes that adding a vitamin mixture to the diet of children improves growth, the first question is whether children in a control group who do not receive the vitamin mixture do not grow as quickly. Comparison of an experiment with a control is essential to the scientific method.

The scientific method is thus very simple. We don't accept a hypothesis or a theory just because it sounds right. We devise tests, and only if the hypothesis or theory passes the tests do we accept it. The enormous progress made since 1600 in chemistry, biology, and the other sciences is a testimony to the value of the scientific method.

You may get the impression from the preceding discussion that science progresses in one direction: facts first, hypothesis second, theory last. Real life is not so simple, however. Hypotheses and theories call the attention of scientists to discover new facts. An example of this scenario is the discovery of the element germanium. In 1871, Mendeleev's Periodic Table—a graphic description of elements organized by properties—predicted the existence of a new element whose properties would be similar to those of silicon. Mendeleev called this element eka-silicon. In 1886, it was discovered in Germany (hence the name), and its properties were truly similar to those predicted by theory.

On the other hand, many scientific discoveries result from **serendipity**, or chance observation. An example of serendipity occurred in 1926, when James Sumner of Cornell University left an enzyme preparation of jack bean urease in a refrigerator over the weekend. Upon his return, he found that his solution contained crystals that turned out to be a protein. This chance discovery led to the hypothesis that all enzymes are proteins. Of course, serendipity is not enough to move science forward. Scientists must have the creativity and insight to recognize the significance of their observations. Sumner fought for more than 15 years for his hypothesis to gain

Theory The formulation of an apparent relationship among certain observed phenomena, which has been verified. A theory explains many interrelated facts and can be used to make predictions about natural phenomena. Examples are Newton's theory of gravitation and the kinetic molecular theory of gases, which we will encounter in Section 6.6. This type of theory is also subject to testing and will be discarded or modified if it is contradicted by new facts.

acceptance because people believed that only small molecules can form crystals. Eventually his view won out, and he was awarded a Nobel Prize in chemistry in 1946.

1.3 How Do Scientists Report Numbers?

Scientists often have to deal with numbers that are very large or very small. For example, an ordinary copper penny (dating from before 1982, when pennies in the United States were still made of copper) contains approximately

29,500,000,000,000,000,000 atoms of copper

and a single copper atom weighs

0.0000000000000000000000023 pound

which is equal to

0.0000000000000000000000104 gram

Many years ago, an easy way to handle such large and small numbers was devised. This method, which is called **exponential notation**, is based on powers of 10. In exponential notation, the number of copper atoms in a penny is written

$$2.95 \times 10^{22}$$

and the weight of a single copper atom is written

$$2.3 \times 10^{-25} \text{ pound}$$

which is equal to

$$1.04 \times 10^{-22} \text{ gram}$$

The origin of this shorthand form can be seen in the following examples:

$$100 = 1 \times 10 \times 10 = 1 \times 10^2$$

$$1000 = 1 \times 10 \times 10 \times 10 = 1 \times 10^3$$

What we have just said in the form of an equation is “100 is a one with two zeros after the one, and 1000 is a one with three zeros after the one.” We can also write

$$1/100 = 1/10 \times 1/10 = 1 \times 10^{-2}$$

$$1/1000 = 1/10 \times 1/10 \times 1/10 = 1 \times 10^{-3}$$

where negative exponents denote numbers less than 1. The exponent in a very large or very small number lets us keep track of the number of zeros. That number can become unwieldy with very large or very small quantities, and it is easy to lose track of a zero. Exponential notation helps us deal with this possible source of determinant error.

When it comes to measurements, not all the numbers you can generate in your calculator or computer are of equal importance. Only the number of digits that are known with certainty are significant. Suppose that you measured the weight of an object as 3.4 g on a balance that you can read to the nearest 0.1 g. You can report the weight as 3.4 g but not as 3.40 or 3.400 g because you do not know the added zeros with certainty. This becomes even more important when you do calculations using a calculator. For example, you might measure a cube with a ruler and find that each side is 2.9 cm. If you are asked to calculate the volume, you multiply $2.9 \text{ cm} \times 2.9 \text{ cm} \times 2.9 \text{ cm}$. The calculator will then give you an answer that is 24.389 cm^3 . However, your initial measurements were good to only one decimal place, so your final



Corbis/SuperStock



© Skip O'Donnell/iStockphoto.com



Dean Fox / SuperStock

Photos showing different orders of magnitude.

1. Group picnic in stadium parking lot (~10 meters)
2. Football field (~100 meters)
3. Vicinity of stadium (~1000 meters).

answer cannot be good to three decimal places. As a scientist, it is important to report data that have the correct number of **significant figures**. A detailed account of using significant figures is presented in Appendix II. The following How To box describes the way to determine the number of significant figures in a number. You will find boxes like this at places in the text where detailed explanations of concepts are useful.

How To . . .

Determine the Number of Significant Figures in a Number

1. Nonzero digits are always significant.

For example, 233.1 m has four significant figures; 2.3 g has two significant figures.

2. Zeros at the beginning of a number are never significant.

For example, 0.0055 L has two significant figures; 0.3456 g has four significant figures.

3. Zeros between nonzero digits are always significant.

For example, 2.045 kcal has four significant figures; 8.0506 g has five significant figures.

4. Zeros at the end of a number that contains a decimal point are always significant.

For example, 3.00 L has three significant figures; 0.0450 mm has three significant figures.

5. Zeros at the end of a number that contains no decimal point may or may not be significant.

We cannot tell whether they are significant without knowing something about the number. This is the ambiguous case. If you know that a certain small business made a profit of \$36,000 last year, you can be sure that the 3 and 6 are significant, but what about the rest? The profit might have been \$36,126 or \$35,786.53, or maybe even exactly \$36,000. We just don't know because it is customary to round off such numbers. On the other hand, if the profit were reported as \$36,000.00, then all seven digits would be significant.

In science, to get around the ambiguous case, we use exponential notation. Suppose a measurement comes out to be 2500 g. If we made the measurement, then we know whether the two zeros are significant, but we need to tell others. If these digits are *not* significant, we write our number as 2.5×10^3 . If one zero is significant, we write 2.50×10^3 . If both zeros are significant, we write 2.500×10^3 . Because we now have a decimal point, all the digits shown are significant. We are going to use decimal points throughout this text to indicate the number of significant figures.

Example 1.1 Exponential Notation and Significant Figures

Multiply:

(a) $(4.73 \times 10^5)(1.37 \times 10^2)$

(b) $(2.7 \times 10^{-4})(5.9 \times 10^8)$

Divide:

(c) $\frac{7.08 \times 10^{-8}}{300.}$

(d) $\frac{5.8 \times 10^{-6}}{6.6 \times 10^{-8}}$

(e) $\frac{7.05 \times 10^{-3}}{4.51 \times 10^5}$

Use your calculator for this example.

Strategy and Solution

The way to do calculations of this sort is to use a button on scientific calculators that automatically uses exponential notation. The button is usually labeled “E.” (On some calculators, it is labeled “EE.” In some cases, it is accessed by using the second function key.)

- (a) Enter 4.73E5, press the multiplication key, enter 1.37E2, and press the “=” key. The answer is 6.48×10^7 . The calculator will display this number as 6.48E7. This answer makes sense. We add exponents when we multiply, and the sum of these two exponents is correct ($5 + 2 = 7$). We also multiply the numbers, 4.73×1.37 . This is approximately $4 \times 1.5 = 6$, so 6.48 is also reasonable.
- (b) Here we have to deal with a negative exponent, so we use the “+/-” key. Enter 2.7E+/-4, press the multiplication key, enter 5.9E8, and press the “=” key. The calculator will display the answer as 1.593E5. To have the correct number of significant figures, we should report our answer as 1.6E5. This answer makes sense because 2.7 is a little less than 3 and 5.9 is a little less than 6, so we predict a number slightly less than 18; also, the algebraic sum of the exponents ($-4 + 8$) is equal to 4. This gives 16×10^4 . In exponential notation, we normally prefer to report numbers between 1 and 10, so we rewrite our answer as 1.6×10^5 . We made the first number 10 times smaller, so we increased the exponent by 1 to reflect that change.
- (c) Enter 7.08E+/-8, press the division key, enter 300., and press the “=” key. The answer is 2.36×10^{-10} . The calculator will display this number as 2.36E - 10. We subtract exponents when we divide, and we can also write 300. as 3.00×10^2 .
- (d) Enter 5.8E+/-6, press the division key, enter 6.6E+/-8, and press the “=” key. The calculator will display the answer as 87.878787878788. We report this answer as 88 to get the right number of significant figures. This answer makes sense. When we divide 5.8 by 6.6, we get a number slightly less than 1. When we subtract the exponents algebraically ($-6 - [-8]$), we get 2. This means that the answer is slightly less than 1×10^2 , or slightly less than 100.
- (e) Enter 7.05E+/-3, press the division key, enter 4.51E5, and press the “=” key. The calculator displays the answer as 1.5632E-8, which, to the correct number of significant figures, is 1.56×10^{-8} . The algebraic subtraction of exponents is $-3 - 5 = -8$.

Problem 1.1

Multiply:

(a) $(6.49 \times 10^7)(7.22 \times 10^{-3})$ (b) $(3.4 \times 10^{-5})(8.2 \times 10^{-11})$

Divide:

(a) $\frac{6.02 \times 10^{23}}{3.10 \times 10^5}$ (b) $\frac{3.14}{2.30 \times 10^{-5}}$

1.4 How Do We Make Measurements?

In our daily lives, we are constantly making measurements. We measure ingredients for recipes, driving distances, gallons of gasoline, weights of fruits and vegetables, and the timing of TV programs. Doctors and nurses measure pulse rates, blood pressures, temperatures, and drug dosages. Chemistry, like other sciences, is based on measurements.



© 2003 Richard Megnief/Fundamental Photographs, NYC

The label on this bottle of water shows the metric size (one liter) and the equivalent in quarts.

Metric system A system of units of measurement in which the divisions to subunits are made by a power of 10

Table 1.1 Base Units in the Metric System

Length	meter (m)
Volume	liter (L)
Mass	gram (g)
Time	second (s)
Temperature	Kelvin (K)
Energy	joule (J)
Amount of substance	mole (mol)

A measurement consists of two parts: a number and a unit. A number without a unit is usually meaningless. If you were told that a person's weight is 57, the information would be of very little use. Is it 57 pounds, which would indicate that the person is very likely a child or a midget, or 57 kilograms, which is the weight of an average woman or a small man? Or is it perhaps some other unit? Because so many units exist, a number by itself is not enough; the unit must also be stated.

In the United States, most measurements are made with the English system of units: pounds, miles, gallons, and so on. In most other parts of the world, however, few people could tell you what a pound or an inch is. Most countries use the **metric system**, a system that originated in France about 1800 and that has since spread throughout the world. Even in the United States, metric measurements are slowly being introduced (Figure 1.2). For example, many soft drinks and most alcoholic beverages now come in metric sizes. Scientists in the United States have been using metric units all along.

Around 1960, international scientific organizations adopted another system, called the **International System of Units** (abbreviated **SI**). The SI is based on the metric system and uses some of the metric units. The main difference is that the SI is more restrictive: It discourages the use of certain metric units and favors others. Although the SI has advantages over the older metric system, it also has significant disadvantages. For this reason, U.S. chemists have been very slow to adopt it. At this time, approximately 40 years after its introduction, not many U.S. chemists use the entire SI, although some of its preferred units are gaining ground.

In this book, we will use the metric system (Table 1.1). Occasionally we will mention the preferred SI unit.

A. Length

The key to the metric system (and the SI) is that there is one base unit for each kind of measurement and that other units are related to the base unit only by powers of 10. As an example, let us look at measurements of length. In the English system, we have the inch, the foot, the yard, and the mile (not to mention such older units as the league, furlong, ell, and rod). If you want to convert one unit to another unit, you must memorize or look up these conversion factors:

$$5280 \text{ feet} = 1 \text{ mile}$$

$$1760 \text{ yards} = 1 \text{ mile}$$

$$3 \text{ feet} = 1 \text{ yard}$$

$$12 \text{ inches} = 1 \text{ foot}$$

FIGURE 1.2 Road sign in Massachusetts showing metric equivalents of mileage.



© 1992 Kip Petricolas/Fundamental Photographs, NYC

Table 1.2 The Most Common Metric Prefixes

Prefix	Symbol	Value
giga	G	$10^9 = 1,000,000,000$ (one billion)
mega	M	$10^6 = 1,000,000$ (one million)
kilo	k	$10^3 = 1000$ (one thousand)
deci	d	$10^{-1} = 0.1$ (one-tenth)
centi	c	$10^{-2} = 0.01$ (one-hundredth)
milli	m	$10^{-3} = 0.001$ (one-thousandth)
micro	μ	$10^{-6} = 0.000001$ (one-millionth)
nano	n	$10^{-9} = 0.000000001$ (one-billionth)
pico	p	$10^{-12} = 0.000000000001$ (one-trillionth)

Exponential notation for quantities with multiple zeros is shown in parentheses.

All this is unnecessary in the metric system (and the SI). In both systems the base unit of length is the **meter (m)**. To convert to larger or smaller units, we do not use arbitrary numbers like 12, 3, and 1760, but only 10, 100, 1/100, 1/10, or other powers of 10. This means that *to convert from one metric or SI unit to another, we only have to move the decimal point*. Furthermore, the other units are named by putting prefixes in front of “meter,” and *these prefixes are the same throughout the metric system and the SI*. Table 1.2 lists the most important of these prefixes. If we put some of these prefixes in front of “meter,” we have

$$1 \text{ kilometer (km)} = 1000 \text{ meters (m)}$$

$$1 \text{ centimeter (cm)} = 0.01 \text{ meter}$$

$$1 \text{ nanometer (nm)} = 10^{-9} \text{ meter}$$

For people who have grown up using English units, it is helpful to have some idea of the size of metric units. Table 1.3 shows some conversion factors.

Table 1.3 Some Conversion Factors Between the English and Metric Systems

Length	Mass	Volume
1 in. = 2.54 cm	1 oz = 28.35 g	1 qt = 0.946 L
1 m = 39.37 in.	1 lb = 453.6 g	1 gal = 3.785 L
1 mile = 1.609 km	1 kg = 2.205 lb	1 L = 33.81 fl oz
	1 g = 15.43 grains	1 fl oz = 29.57 mL
		1 L = 1.057 qt

Some of these conversions are difficult enough that you will probably not remember them and must, therefore, look them up when you need them. Some are easier. For example, a meter is about the same as a yard. A kilogram is a little over two pounds. There are almost four liters in a gallon. These conversions may be important to you someday. For example, if you rent a car in Europe, the price of gas listed on the sign at the gas station will be in Euros per liter. When you realize that you are spending two dollars per liter and you know that there are almost four liters to a gallon, you will realize why so many people take the bus or a train instead.

B. Volume

Volume is space. The volume of a liquid, solid, or gas is the space occupied by that substance. The base unit of volume in the metric system is the **liter (L)**.

Conversion factors are defined. We can use them to have as many significant figures as needed without limit. This point will not be the case with measured numbers.