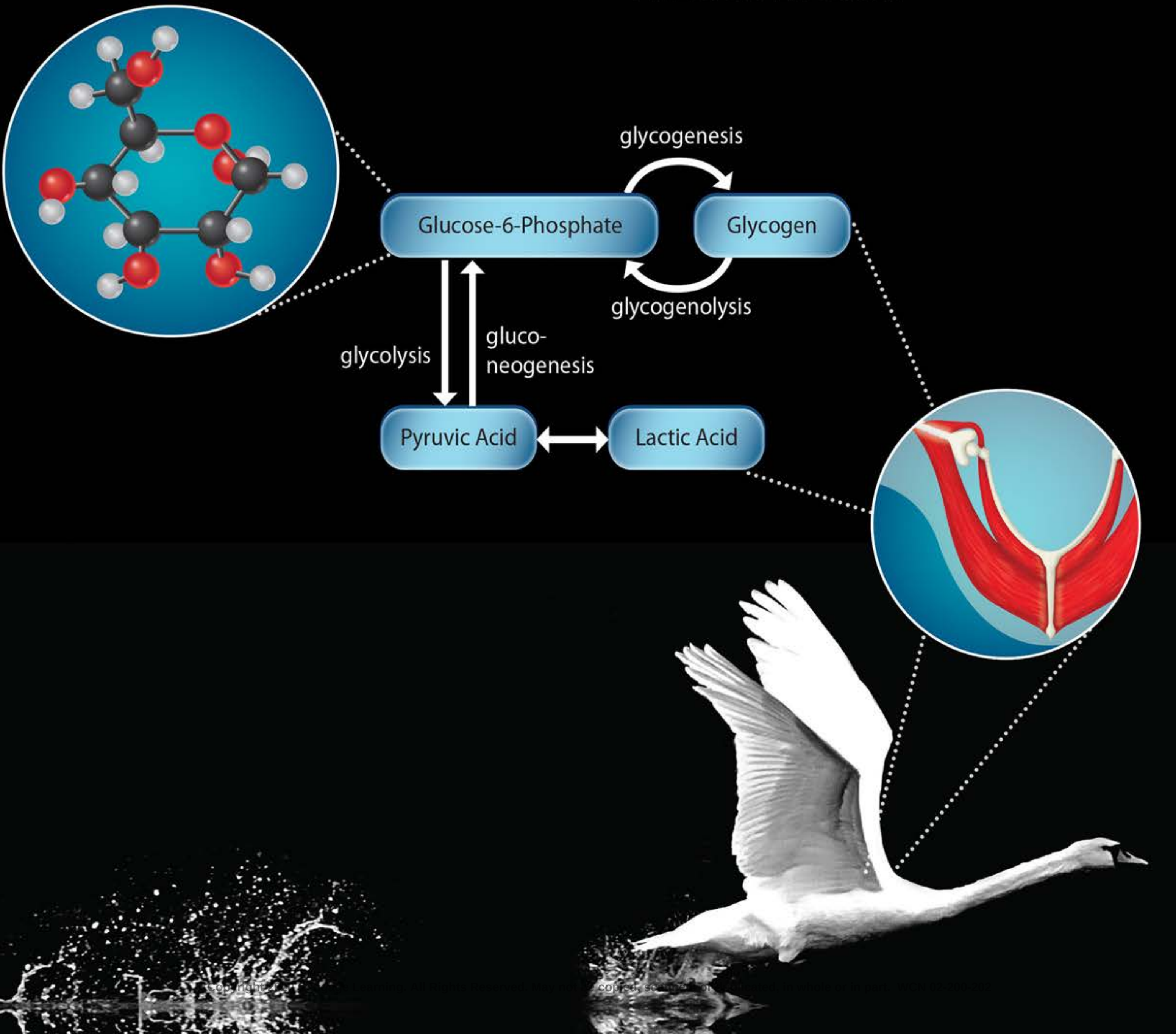
Bettelheim | Brown | Campbell | Farrell | Torres

Introduction to General, Organic, and Biochemistry

TWELFTH EDITION



Periodic Table of Elements

- MAIN GROUP METALS
- TRANSITION METALS
- METALLOIDS
- NONMETALS

Uranium	
92	Atomic number
U	Symbol
238.0289	Atomic weight

	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1	Hydrogen 1 H 1.008																	Helium 2 He 4.0026
2	Lithium 3 Li 6.94	Beryllium 4 Be 9.0122											Boron 5 B 10.81	Carbon 6 C 12.011	Nitrogen 7 N 14.007	Oxygen 8 O 15.999	Fluorine 9 F 18.9984	Neon 10 Ne 20.1797
3	Sodium 11 Na 22.9898	Magnesium 12 Mg 24.3050											Aluminum 13 Al 26.9815	Silicon 14 Si 28.085	Phosphorus 15 P 30.9738	Sulfur 16 S 32.06	Chlorine 17 Cl 35.45	Argon 18 Ar 39.948
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 72.64	Arsenic 33 As 74.9216	Selenium 34 Se 78.96	Bromine 35 Br 79.904	Krypton 36 Kr 83.798
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 (97.9072)	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 131.293
6	Cesium 55 Cs 132.9055	Barium 56 Ba 137.327	Lanthanum 57 La 138.9055	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.9479	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.23	Iridium 77 Ir 192.217	Platinum 78 Pt 195.084	Gold 79 Au 196.9666	Mercury 80 Hg 200.59	Thallium 81 Tl 204.38	Lead 82 Pb 207.2	Bismuth 83 Bi 208.9804	Polonium 84 Po (208.9824)	Astatine 85 At (209.9871)	Radon 86 Rn (222.0176)
7	Francium 87 Fr (223.0197)	Radium 88 Ra (226.0254)	Actinium 89 Ac (227.0278)	Rutherfordium 104 Rf (265.1167)	Dubnium 105 Db (268.125)	Seaborgium 106 Sg (271.133)	Bohrium 107 Bh (272)	Hassium 108 Hs (277.150)	Meitnerium 109 Mt (276.151)	Darmstadtium 110 Ds (281.162)	Roentgenium 111 Rg (280.164)	Copernicium 112 Cn (285.174)	Nihonium 113 Nh (284.178)	Flerovium 114 Fl (289.189)	Moscovium 115 Mc (288.192)	Livermorium 116 Lv (293)	Tennessine 117 Ts (294)	Oganesson 118 Og (294)

Lanthanides	Cerium 58 Ce 140.116	Praseodymium 59 Pr 140.9077	Neodymium 60 Nd 144.242	Promethium 61 Pm (144.9127)	Samarium 62 Sm 150.36	Europium 63 Eu 151.964	Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.9254	Dysprosium 66 Dy 162.500	Holmium 67 Ho 164.9303	Erbium 68 Er 167.259	Thulium 69 Tm 168.9342	Ytterbium 70 Yb 173.054	Lutetium 71 Lu 174.9668
Actinides	Thorium 90 Th 232.0381	Protactinium 91 Pa 231.0359	Uranium 92 U 238.0289	Neptunium 93 Np (237.0482)	Plutonium 94 Pu (244.0642)	Americium 95 Am (243.0614)	Curium 96 Cm (247.0704)	Berkelium 97 Bk (247.0703)	Californium 98 Cf (251.0796)	Einsteinium 99 Es (252.0830)	Fermium 100 Fm (257.0951)	Mendelevium 101 Md (258.0984)	Nobelium 102 No (259.1010)	Lawrencium 103 Lr (262.1096)

Note: Atomic masses are 2009 IUPAC values (up to four decimal places). Numbers in parentheses are atomic masses or mass numbers of the most stable isotope of an element.

STANDARD ATOMIC WEIGHTS OF THE ELEMENTS 2010 Based on relative atomic mass of $^{12}C = 12$, 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)	Mendelevium*	Md	101	(258)
Aluminum	Al	13	26.9815386(8)	Mercury	Hg	80	200.59(2)
Americium*	Am	95	(243)	Molybdenum	Mo	42	95.96(2)
Antimony	Sb	51	121.760(1)	Moscovium	MC	115	(289)
Argon	Ar	18	39.948(1)	Neodymium	Nd	60	144.22(3)
Arsenic	As	33	74.92160(2)	Neon	Ne	10	20.1797(6)
Astatine*	At	85	(210)	Neptunium*	Np	93	(237)
Barium	Ba	56	137.327(7)	Nickel	Ni	28	58.6934(4)
Berkelium*	Bk	97	(247)	Niobium	Nb	41	92.90638(2)
Beryllium	Be	4	9.012182(3)	Nitrogen	N	7	14.0067(2)
Bismuth	Bi	83	208.98040(1)	Nihonium	Nh	113	(286)
Bohrium	Bh	107	(264)	Nobelium*	No	102	(259)
Boron	B	5	10.811(7)	Oganesson	Og	118	(294)
Bromine	Br	35	79.904(1)	Osmium	Os	76	190.23(3)
Cadmium	Cd	48	112.411(8)	Oxygen	O	8	15.9994(3)
Cesium	Cs	55	132.9054519(2)	Palladium	Pd	46	106.42(1)
Calcium	Ca	20	40.078(4)	Phosphorus	P	15	30.973762(2)
Californium*	Cf	98	(251)	Platinum	Pt	78	195.084(9)
Carbon	C	6	12.0107(8)	Plutonium*	Pu	94	(244)
Cerium	Ce	58	140.116(1)	Polonium*	Po	84	(209)
Chlorine	Cl	17	35.453(2)	Potassium	K	19	39.0983(1)
Chromium	Cr	24	51.9961(6)	Praseodymium	Pr	59	140.90765(2)
Cobalt	Co	27	58.933195(5)	Promethium*	Pm	61	(145)
Copernicium*	Cn	112	(285)	Protactinium*	Pa	91	231.03588(2)
Copper	Cu	29	63.546(3)	Radium*	Ra	88	(226)
Curium*	Cm	96	(247)	Radon*	Rn	86	(222)
Darmstadtium	Ds	110	(271)	Rhenium	Re	75	186.207(1)
Dubnium	Db	105	(262)	Rhodium	Rh	45	102.90550(2)
Dysprosium	Dy	66	162.500(1)	Roentgenium	Rg	111	(272)
Einsteinium*	Es	99	(252)	Rubidium	Rb	37	85.4678(3)
Erbium	Er	68	167.259(3)	Ruthenium	Ru	44	101.07(2)
Europium	Eu	63	151.964(1)	Rutherfordium	Rf	104	(261)
Fermium*	Fm	100	(257)	Samarium	Sm	62	150.36(2)
Flerovium	Fl	114	(289)	Scandium	Sc	21	44.955912(6)
Fluorine	F	9	18.9984032(5)	Seaborgium	Sg	106	(266)
Francium*	Fr	87	(223)	Selenium	Se	34	78.96(3)
Gadolinium	Gd	64	157.25(3)	Silicon	Si	14	28.0855(3)
Gallium	Ga	31	69.723(1)	Silver	Ag	47	107.8682(2)
Germanium	Ge	32	72.64(1)	Sodium	Na	11	22.9896928(2)
Gold	Au	79	196.966569(4)	Strontium	Sr	38	87.62(1)
Hafnium	Hf	72	178.49(2)	Sulfur	S	16	32.065(5)
Hassium	Hs	108	(277)	Tantalum	Ta	73	180.9488(2)
Helium	He	2	4.002602(2)	Technetium*	Tc	43	(98)
Holmium	Ho	67	164.93032(2)	Tellurium	Te	52	127.60(3)
Hydrogen	H	1	1.00794(7)	Tennessine	Ts	117	(293)
Indium	In	49	114.818(3)	Terbium	Tb	65	158.92535(2)
Iodine	I	53	126.90447(3)	Thallium	Tl	81	204.3833(2)
Iridium	Ir	77	192.217(3)	Thorium*	Th	90	232.03806(2)
Iron	Fe	26	55.845(2)	Thulium	Tm	69	168.93421(2)
Krypton	Kr	36	83.798(2)	Tin	Sn	50	118.710(7)
Lanthanum	La	57	138.90547(7)	Titanium	Ti	22	47.867(1)
Lawrencium*	Lr	103	(262)	Tungsten	W	74	183.84(1)
Lead	Pb	82	207.2(1)	Uranium*	U	92	238.02891(3)
Lithium	Li	3	6.941(2)	Vanadium	V	23	50.9415(1)
Livermorium	Lv	116	(292)	Xenon	Xe	54	131.293(6)
Lutetium	Lu	71	174.9668(1)	Ytterbium	Yb	70	173.54(5)
Magnesium	Mg	12	24.3050(6)	Yttrium	Y	39	88.90585(2)
Manganese	Mn	25	54.938045(5)	Zinc	Zn	30	65.38(2)
Meitnerium	Mt	109	(268)	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 terrestial isotopic composition, and the atomic weight is tabulated for these. **http://www.chem.qmw.ac.uk/iupac/AtWt/**

INTRODUCTION TO

General, Organic, and Biochemistry

TWELFTH EDITION

INTRODUCTION TO

General, Organic, and Biochemistry

TWELFTH EDITION

FREDERICK A. BETTELHEIM

WILLIAM H. BROWN
Beloit College

MARY K. CAMPBELL

SHAWN O. FARRELL

OMAR J. TORRES
College of the Canyons

SARA MADSEN
South Dakota State University

CENGAGE

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

Introduction to General, Organic, and Biochemistry, Twelfth Edition

Frederick A. Bettelheim, William H. Brown, Mary K. Campbell, Shawn O. Farrell, Omar J. Torres, Sara K. Madsen

Product Director: Thais Alencar

Product Manager: Helene Alfaro

Learning Designer: Peter McGahey

Subject Matter Expert: Dakin Sharum

Product Assistant: Nellie Mitchell

Marketing Manager: Janet del Mundo

Content Manager: Teresa L. Trego

Digital Delivery Lead: Beth McCracken

Production Service: MPS Limited

Photo Researcher: Lumina Datamatics

Text Researcher: Lumina Datamatics

Art Director: Marissa Falco

Text Designer: Shawn Girsberger

Cover Designer: Marissa Falco

Cover Image: J. Parsons/Getty Images

Compositor: MPS Limited

For product information and technology assistance, contact us at **Cengage Customer & Sales Support, 1-800-354-9706** or **support.cengage.com.**

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

Library of Congress Control Number: 2019930131

Student Edition:
ISBN: 978-1-337-57135-7
Loose-leaf Edition:
ISBN: 978-1-337-57145-6

Cengage
20 Channel Center Street
Boston, MA 02210
USA

Cengage is a leading provider of customized learning solutions with employees residing in nearly 40 different countries and sales in more than 125 countries around the world. Find your local representative at **www.cengage.com.**

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

To learn more about Cengage platforms and services, register or access your online learning solution, or purchase materials for your course, visit **www.cengage.com.**

Printed in the United States of America
Print Number: 01 Print Year: 2019

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

To my family and friends, without whose support this would not have been possible, and to all of my students, past and future, especially the non-traditional ones, who have inspired me to try to be the best teacher I can be —SF

To my loving family and friends who have supported me through this journey: Mom, Dad, Lisa, Abuela, René, Ryan, 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

To my family who have supported me from the beginning: Theo, Mom, Dad, Koeen, and Mark. All of you have helped me find everlasting creativity and confidence. I love you very much. —SKM

Contents in Brief

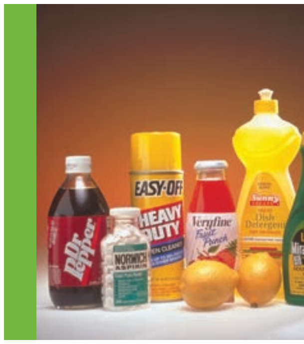
General Chemistry

Organic Chemistry

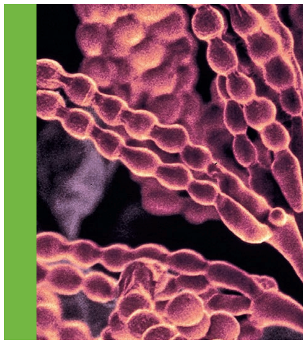
Biochemistry

To access this online-only chapter, search for ISBN 978-1-337-57135-7 at www.cengage.com and visit this book's companion website.

Contents



EASY-OFF



CHAPTER 25 Gene Expression and Protein Synthesis 731

CHAPTER 26 Bioenergetics: How the Body Converts Food to Energy 766

CHAPTER 27 Specific Catabolic Pathways: Carbohydrate, Lipid, and Protein Metabolism 790

CHAPTER 28 Biosynthetic Pathways 820

CHAPTER 29 Nutrition 838

To access this online-only chapter, search for ISBN 978-1-337-57135-7 at www.cengage.com and visit this book's companion website.

Preface

Welcome to the 12th edition of *Introduction to General, Organic, and Biochemistry*. We wish to sincerely thank our colleagues who not only adopted the previous editions for their courses but also offered sage advice on suggested changes and updates to this edition.

With all the continuous advances in the field, this edition emphasizes the inclusion of new relevant concepts and examples in this fast-growing discipline, especially in the biochemistry chapters. Based on valuable feedback from reviewers, we also strive to consolidate content in a more meaningful and manageable manner while preserving an integrated view of chemistry. This new edition continues with the tradition of providing a solid foundation on which instructors can build upon, and chapter resources are conceived and written with flexibility in mind, affording instructors the opportunity to seamlessly select applicable topics for discussion with their students. The wealth of problems, both practical and challenging, provide students with numerous ways to test their knowledge from a variety of viewpoints.

From the very beginning of the book, we include organic compounds and biochemical substances to illustrate relevant and overlapping principles. This progression ascends from the simple to the complex. We encourage our colleagues to advance to the chapters of biochemistry as quickly as possible, because there lies most of the material that is relevant to the future professions of our students.

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 necessary for understanding future topics.

© michaeljung/ShutterStock.com

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 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 21F), and the search for treatments for cystic fibrosis (Chemical Connections 26F).

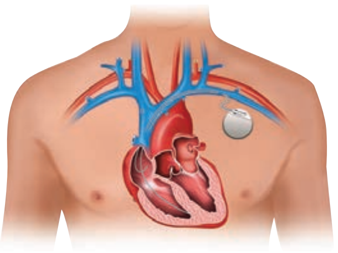
The inclusion of Chemical Connections allows for a considerable degree of flexibility. If an instructor wants to assign only the main text, the Chemical Connections do not interrupt continuity, and the essential material will be covered. However, because they enhance the core material, most instructors 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.

CHEMICAL CONNECTIONS 4C **Artificial Pacemakers and Redox**

An artificial pacemaker is a small electrical device that uses electrical impulses, delivered by electrodes contacting the heart muscles, to regulate the beating of the heart. The primary purpose of a pacemaker is to maintain an adequate heart rate, either because the heart's native pacemaker does not beat fast enough, or perhaps there is a blockage in the heart's electrical conduction system. When a pacemaker detects that the heart is beating too slowly, it sends an electrical signal to the heart, generated via a redox reaction, so that the heart muscle beats faster. Modern pacemakers are externally programmable and allow a cardiologist to select the optimum pacing modes for individual patients.

Early pacemakers generated an electrical impulse via the following redox reaction:

$$Zn + Hg^{2+} \longrightarrow Zn^{2+} + Hg$$



A pacemaker is a medical device that uses electrical impulses, delivered by electrodes contacting the heart muscles, to regulate the beating of the heart.

The zinc atom is oxidized to Zn^{2+}, and Hg^{2+} is reduced to Hg. Many contemporary artificial pacemakers contain a lithium-iodine battery, which has a longer battery life (10 years or more). Consider the unbalanced redox reaction for the lithium-iodine battery:

$$Li + I_2 \longrightarrow LiI$$

The lithium atom is oxidized to Li^+, and the I_2 molecule is reduced to I^-. When the pacemaker fails to sense a heartbeat within a normal beat-to-beat time period, an electrical signal produced from these reactions is initiated, stimulating the ventricle of the heart. This sensing and stimulating activity continues on a beat-by-beat basis. More complex systems include the ability to stimulate both the atrial and ventricular chambers. ■

Test your knowledge with Problem 69.

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 of the metabolism chapters has encouraged us to maintain the order (Chapters 26–27).

First, we introduce the common metabolic pathway through which all food is 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.
- **Visual Impact** We have introduced illustrations with heightened pedagogical impact. Some of these show the microscopic and macroscopic aspects of a topic under discussion, such as Figures 6-3 (Henry's Law) and 6-10 (electrolytic conductance). The Chemical Connections essays have been enhanced further with more photos to illustrate each topic.
- **[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.
- **Summary of Key Reactions** In each organic chemistry chapter (10–18) 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.
- **Chapter Summaries** Summaries reflect the Chapter contents. At the end of each chapter, summary paragraphs highlight the concepts.
- **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.
- **Tying-It-Together and Challenge Problems** At the end of most chapters, these problems build on past material to test students' knowledge of these concepts. In the Challenge Problems, associated chapter references are given.
- **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 14).
- **Molecular Models** Ball-and-stick models, space-filling models, and electron-density maps are used throughout the text as appropriate aids for 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.
- **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, with an emphasis on solving conversion problems related to a clinical setting. Concepts of heat from prior editions were moved to a later chapter. New problems were added.
- In **Chapter 2, Atoms,** we introduce four of the five ways used 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. Seventeen new problems were added.
- **Chapter 3, Chemical Bonds,** begins with a discussion of ionic compounds, followed by a discussion of molecular compounds. Fourteen new problems were added.
- **Chapter 4, Chemical Reactions, and Energy Calculations** introduces 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. This chapter also incorporates and expands the discussion on heat of reaction with sample problems.
- 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. Ten 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 and the most common units for concentration, and closes with an enhanced discussion of colligative properties. Seven 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, eight 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 was added on solving problems using the activity series, along with eleven new problems.
- **Chapter 9, Nuclear Chemistry,** highlights nuclear applications in medicine. Four new problems were added.

Organic Chemistry (Chapters 10–18)

- **Chapter 10, Organic Chemistry,** is an introduction to the characteristics of organic compounds and to the most important organic functional groups. Eight new problems were added.
- In **Chapter 11, Alkanes,** we introduce the concept of a line-angle formula, which we will continue to use throughout the organic chapters. These are easier to draw than the usual condensed structural formulas and are easier to visualize. The discussion on the conformation of alkanes

has been reduced and instead concentrates on the conformations of cycloalkanes. Fifteen new problems were added, including concepts from prior chapters.

- In **Chapter 12, Alkenes, Alkynes, and Aromatic Compounds** 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. Content on aromatic compounds was also added to this chapter and condensed from previous editions. We refined the discussion of these reaction mechanisms in this edition and added a new problem to the end-of-chapter exercise about a compound once used as a flame retardant in polystyrene-foam building insulation and why its use is now prohibited.

  While aromatic compounds are seemingly similar to alkenes via the presence of the carbon-carbon double bond, they do have different reactions. For instance, aromatic compounds can undergo substitution. In contrast to alkenes that can do addition reactions. The 11th edition Chapter 13 was consolidated into the 12th edition Chapter 12. The close proximity of the content in one chapter will better contrast similarities and differences between alkenes/alkynes and aromatic compounds.
- **Chapter 13, Alcohols, Ethers, and Thiols,** discusses the structures, names, and properties of alcohols first, and then gives a similar treatment to ethers, and finally thiols. The chapter opener was changed to contrast the chemical and physical differences between the alcohol, ether, and thiol functional groups. Each functional group's reactions were compared in a real-world application. In addtion, through out the chapter figures and examples, more colors were implemented to better reference and contrast with the text. In a simple example of this, using red for oxygen, blue/green for partial positive charges and red for partial negative charges was implemented in to various figures. Also, all hydrogen bonding interactions are now shown consistently in each figure with blue dots.
- In **Chapter 14, 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. Twenty new problems were added to reinforce new content and address concepts from previous chapters.
- In **Chapter 15, Amines,** the initial introductory example problem opens using the central nervous stimulant nicotine. This molecule is used to assist students in the stepwise classification of amines. In addtion to this chapter, the tranquilizer Chemical Connection was expanded to include a small data portion on opioid use.
- **Chapter 16, Aldehydes and Ketones,** has a discussion of $NaBH_4$ as a carbonyl-reducing agent with emphasis on its use as a hydride-transfer reagent. We then make the parallel to NADH as a carbonyl-reducing agent and hydride-transfer agent. Nine new problems were added.
- **Chapter 17, Carboxylic Acids,** focuses on the chemistry and physical properties of carboxylic acids. To continue the discussion on trans fatty acids from the previous edition, the chapter opener shows products that have that might have low levels of trans fatty acids. In addition, this

leads into the trans fatty acid Chemical Connection. Then, this chapter implements more acid base terminology.

- **Chapter 18, Carboxylic 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. A short presentation about Green Chemistry is presented in this chapter. In the section about characteristic reactions of esters, the 12 Principles of Green Chemistry are introduced.

Biochemistry (Chapters 19–30)

- **Chapter 19, Carbohydrates,** begins with the structure and nomenclature of monosaccharides, including their oxidation, reduction, and the formation of glycosides, then concludes with a discussion of the structure of disaccharides, polysaccharides, and acidic polysaccharides. The descriptions of these structures, especially glucose stereochemistry, have been clarified in this edition. Three new example problems are offered in the chapter, as well as 5 new end of chapter problems. A new section was added to help students learn how to convert Fisher projections to Haworth projections
- **Chapter 20, Lipids,** covers the most important features of lipid biochemistry, including membrane structure and the structures and functions of steroids. In this edition, we have stressed the need for students to recall material from earlier chapters, especially structure and reactions of carboxylic acids. The chapter also has an increased emphasis on membrane transport and an update on possible classification of *trans* fatty acids as food additives. A new section on fatty acid basics was added using some material from previous chapters so that this chapter can be read more easily on its own. A new Chemical Connections box on Butter and Margarine was added, along with 7 new example problems and 10 end of chapter problems
- **Chapter 21, 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. Points causing difficulty for students in the last edition, mostly pertaining to the roles of amino acids in proteins and bonding in transition-metal complexes, have been clarified. This chapter also has 7 new example problems, including sections on how to remember amino acid abbreviations. There is a new section on myoglobin and hemoglobin structure, and a new Chemical Connections box about peptide hormones
- **Chapter 22, Enzymes,** covers the important topic of enzyme catalysis and regulation. This discussion has been modified for a stronger correlation with pathways to be discussed in Chapter 28. Specific medical applications of enzyme inhibition are included, A new Chemical Connections box describes how enzymes are involved with our perception of taste. A new section on enzyme inhibition was added. Five new example problems were added along with 3 end of chapter problems.
- In **Chapter 23, Chemical Communications,** we see the biochemistry of hormones and neurotransmitters. This chapter has been reorganized for better flow in introducing the different ways of classifying neurotransmitters. The health-related implications of how these substances act in the body is the main focus of this chapter. Along with a new Chemical

Connections box focusing on Alzheimer's disease and diabetes, the section on depression was expanded to include new information on deep brain stimulation. Seven new example problems were added.

- **Chapter 24, Nucleotides, Nucleic Acids, and Heredity,** introduces DNA and the processes encompassing its replication and repair. How nucleotides are linked together and the flow of genetic information due to the unique properties of these molecules is emphasized. An exciting new section on the medical application of RNA has been added, including a focus on the hottest topic today - CRISPR technology. Eight example problems and 8 end of chapter problems have also been added.
- **Chapter 25, Gene Expression and Protein Synthesis,** shows how the information contained in the DNA blueprint of a cell is used to produce RNA and, eventually, protein. The focus is on how organisms control the expression of genes through transcription and translation. Five new example problems were added, along with 10 new end of chapter problems
- **Chapter 26, Bioenergetics,** is an introduction to metabolism that focuses strongly on the central pathways, namely the citric acid cycle, electron transport, and oxidative phosphorylation. Eight example problems and 8 end of chapter problems were added.
- In **Chapter 27, Specific Catabolic Pathways,** we address the details of carbohydrate, lipid, and protein breakdown, concentrating on energy yield. A new section was added to better explain the shuttle mechanisms and how carnitine is used to carry fatty acids across the mitochondrial membrane. Nine new example problems were included.
- **Chapter 28, 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 material has been added to aid the student with the big picture concepts of tying metabolism together. A new Chemical Connections box about the enzyme Acetyl-CoA Carboxylase and its relationship to obesity was added, along with 5 new example problems and 4 end of chapter problems
- In **Chapter 29, 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 Connection was added about one of the hottest topics in nutrition—gluten sensitivity. Six new example problems and 4 end of chapter problems were added.
- **Chapter 30, 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. New sections were written to cover some hot topics, such as miniature antibodies, regulatory T cells, and new material on the search for an antibody against HIV. A new Chemical Connection was written about one of the biggest topics in medicine—inflammation. Eight new example problems were added, along with 24 new end of chapter problems.
- **Chapter 31, Body Fluids**
  To access this online-only chapter, search for ISBN 978-1-337-57135-7 at www.cengagebrain.com and visit this book's companion website.

Supporting Materials

Please visit **http://www.cengage.com/chemistry/bettelheim/gob12e** for information about the student and instructor resources for this text.

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 for Jordan Fantini, Denison University, who read page proofs with eyes for accuracy.

Thank you to everyone at Cengage for their support through this revision process: Learning Designer Peter McGahey, Content Manager Teresa L. Trego, and Subject Matter Expert Dakin Sharum. Thank you to MPS Limited for their work on this project.

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 12th Edition:

Stephen Z. Goldberg, *Professor of Chemistry, Adelphi University*

David E. Binkley, Jr., *MS/MA Ed, Adjunct Professor, Departments of Chemistry and Education, Baldwin Wallace University*

Billy Samulak, *PhD, Fitchburg State University*

Dr. Amanda R. Knapp, *Mars Hill University*

Dr. Radhika Venkatraman Kumar, *Adelphi University*

Thomas Ott, *PhD, Oakland University*

Dr. Pradyumna Kumar Pradhan, *UNC Greensboro*

Dr. Michael Staude, *Trine University*

Dick Trent, *Elgin Community College*

Steven M. Socol

Matthew Marmorino, *Indiana University South Bend*

Deborah Heyl-Clegg, *Eastern Michigan University*

Regan Silvestri, *Lorain County Community College, Elyria, Ohio*

Daniel A. Barr, *PhD, University of Mary*

Dr. David Baker, *Delta College*

Betty Owen, *Northeast Mississippi Community College*

Ashley N. Lamm, *Assistant Professor, Eastern Washington University*

Corey P. Causey

Kristi Mock, *University of Toledo*

Kateri Ahrendt

Nathan S. Werner, *Southern Utah University*

D. David Nowack

Luna Zhang, *Immaculata University*

Riham Mahfouz, *Associate Professor of Chemistry, Thomas Nelson Community College*

Polina Pine, *PhD, Loyola University Chicago*

Reviewers of the 11th Edition:

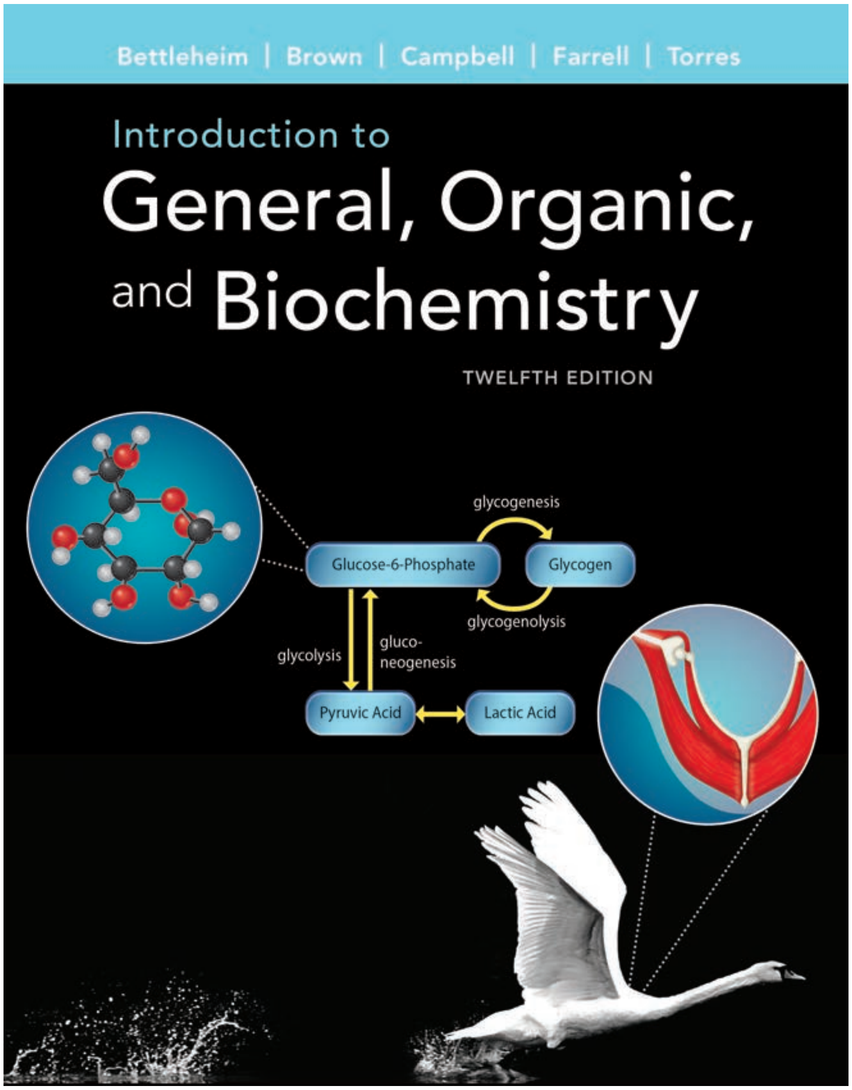
Jennifer Barber, *Atlanta Metropolitan State College*
Ling Chen, *Borough of Manhattan Community College*
Kyle Craig, *Walla Walla University*
Sidnee-Marie Dunn, *South Puget Sound Community College*
Timothy Marshall, *Pima Community College*
Lynda Peebles, *Texas Woman's University*
Rill Reuter, *Winona State University*
Susan Sawyer, *Kellogg Community College*
Theresa Thewes, *Edinboro University of Pennsylvania*

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*

About the Cover

From the "nanoworld" to the macroworld, chemistry and biochemistry allow us to understand how living things work. The initial chapters of this book help us learn about atoms, what they are, what they do, and how they form molecules like the glucose-6-phosphate shown in the upper left of the figure. Molecules then undergo thousands of reactions in the body, forming new molecules and using or releasing energy. Some of these reactions can be organized into pathways, like glycogenesis shown by the glucose-6-phosphate forming glycogen, or like glycolysis shown by the glucose-6-phosphate forming pyruvic acid or lactic acid. These pathways work to allow tissues to function correctly. As a goose takes off from the lake, it will need energy produced from some of these pathways to fuel its flight muscles.



Health-Related Topics

Key

ChemConn = Chemical Connections Box number
Sect. = Section number
Prob. = Problem number

Matter, Energy, and Measurement

1

CONTENTS

© Gorodenkoff/Shutterstock.com

Scientists in action in the laboratory, investigating the phenomena of chemistry.

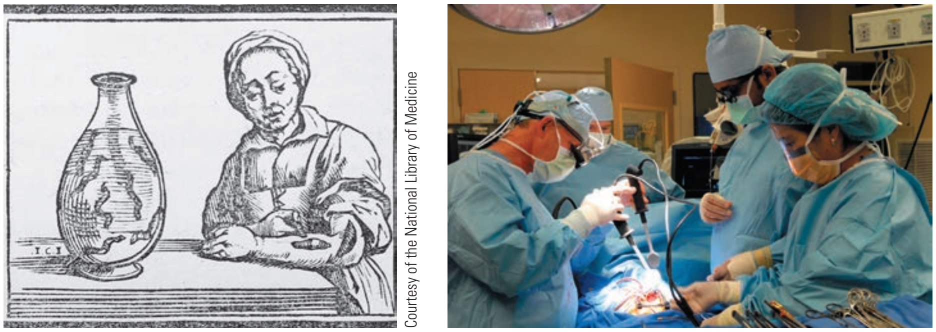
1.1 Chemistry and the Study of Matter

The world around us is made of chemicals. Our food, our clothing, the buildings in which we live are all made of chemicals. While it is easy to believe that chemistry occurs in the laboratory, it also occurs in our daily lives. Think about why the sky is blue, why washing with soap cleans our hands, why we may cry while cutting onions, why meals are cooked faster in a pressure cooker, and why ice floats in a glass of water. These phenomena all occur because of chemistry that we witness every day.

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 or by such measures as bleeding, laxatives, hot plasters, and pills made from powdered staghorn, saffron, or gold. None of these treatments were effective, and the doctors, because they came into direct contact with highly contagious diseases, died at a much higher rate than the general public.

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 developed countries.

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.



Courtesy of the National Library of Medicine

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

(a) (b)

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 has been 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 introduce energy in Section 1.8 and discuss further in Section 4.8.

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,** some substances are used up (disappear) and others are formed to take their place. An example is the burning of a 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.

Charles D. Winters

Charles D. Winters

Charles D. Winters

(a) (b) (c)

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.)

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.

1.2 The Scientific Method

Scientists learn by using a tool called the **scientific method.** The heart of the scientific method is the testing of theories. Prior to1600, philosophers often believed scientific 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 fit 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. ▶

Courtesy of the National Library of Medicine

Galen did not do experiments to test his hypothesis.

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. ▶

Lawrence Berkeley Nat'l Lab – Roy Kaltschmidt, photographer

Using a PET scanner is an example of how modern scientists collect information to confirm a diagnosis and test a hypothesis.

William Harvey (1578–1657) tested Galen's hypothesis by dissecting human and animal hearts and blood vessels. He discovered that one-way 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 fit the facts more closely. Even so, it was still a hypothesis and, according to the scientific method, had to

Hypothesis A statement that is proposed, without actual proof, to explain a set of facts and their relationship 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 enough 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. For example, during the late twentieth century, two scientists claimed to have discovered that nuclear fusion, which you will read about in Section 9.8, could be accomplished at room temperature, a theory known as cold fusion. However, after scientists were subsequently unable to replicate the expected results associated with the nuclear experiment, the theory of cold fusion was rejected.

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.

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 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 Reporting Numbers in Science

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 completely of copper) contains approximately

$$29{,}500{,}000{,}000{,}000{,}000{,}000{,}000 \text{ atoms of copper}$$

and a single copper atom weighs

$$0.00000000000000000000000023 \text{ pound}$$

which is equal to

$$0.000000000000000000000104 \text{ gram}$$

One can easily see how cumbersome it would be to report numbers in this way. A method, called **exponential notation,** was devised many years ago to handle large and small numbers, 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 systematic 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 you measured the weight of an object as 3.4 g on a balance that reads 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 use 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 cm × 2.9 cm × 2.9 cm. The calculator will then give you an answer that is 24.389 cm^3. 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.

Photos showing different orders of magnitude.

SuperStock/iskodonnell

1. Football field ~10 meters

Tom Martin

2. Football field (~100 meters)

Dean Fox / SuperStock

3. Vicinity of stadium (~1000 meters).

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) $\dfrac{7.08 \times 10^{-8}}{300.}$ (d) $\dfrac{5.8 \times 10^{-6}}{6.6 \times 10^{-8}}$ (e) $\dfrac{7.05 \times 10^{-3}}{4.51 \times 10^5}$

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 $-3 - 5 = -8$.

QUICK CHECK 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) $\dfrac{6.02 \times 10^{23}}{3.10 \times 10^5}$ (b) $\dfrac{3.14}{2.30 \times 10^{-5}}$

1.4 Making 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.

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 57 kilograms, which is the weight of an average person? 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,

Alyssa White/Cengage Learning

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)
Amount of substance	mole (mol)

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 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:

$$5280 \text{ feet} = 1 \text{ mile}$$
$$1760 \text{ yards} = 1 \text{ mile}$$
$$3 \text{ feet} = 1 \text{ yard}$$
$$12 \text{ inches} = 1 \text{ foot}$$

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*.

GIPhotoStock Z/Alamy

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

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)

Conversion factors are defined numbers. We use them as though they have an infinite number of significant figures.

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).** This unit is a little larger than a quart (Table 1.3). The only other common metric unit for volume is the milliliter (mL), which is equal to 10^{-3} L. ▶

$$1 \text{ mL} = 0.001 \text{ L (or } 1 \times 10^{-3} \text{ L)}$$
$$1000 \text{ mL (or } 1 \times 10^{3} \text{ mL)} = 1 \text{ L}$$


Jonnie Miles/Getty Images

Hypodermic syringe. Note that the volumes are indicated in milliliters.