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

BETTELHEIM BROWN CAMPBELL FARRELL TORRES

METALS	METALLOIDS	NONMETALS

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

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

Period	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** 1.0079																	Helium 2 He 4.0026
2	Lithium 3 Li 6.941	Beryllium 4 Be 9.0122											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
3	Sodium 11 Na 22.9898	Magnesium 12 Mg 24.3050											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
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

Lanthanides	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
Actinides	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)

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.

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
Actinium*	Ac	89	(227)
Aluminum	Al	13	26.9815386(8)
Americium*	Am	95	(243)
Antimony	Sb	51	121.760(1)
Argon	Ar	18	39.948(1)
Arsenic	As	33	74.92160(2)
Astatine*	At	85	(210)
Barium	Ba	56	137.327(7)
Berkelium*	Bk	97	(247)
Beryllium	Be	4	9.012182(3)
Bismuth	Bi	83	208.98040(1)
Bohrium	Bh	107	(264)
Boron	B	5	10.811(7)
Bromine	Br	35	79.904(1)
Cadmium	Cd	48	112.411(8)
Cesium	Cs	55	132.9054519(2)
Calcium	Ca	20	40.078(4)
Californium*	Cf	98	(251)
Carbon	C	6	12.0107(8)
Cerium	Ce	58	140.116(1)
Chlorine	Cl	17	35.453(2)
Chromium	Cr	24	51.9961(6)
Cobalt	Co	27	58.933195(5)
Copernicium*	Cn	112	(285)
Copper	Cu	29	63.546(3)
Curium*	Cm	96	(247)
Darmstadtium	Ds	110	(271)
Dubnium	Db	105	(262)
Dysprosium	Dy	66	162.500(1)
Einsteinium*	Es	99	(252)
Erbium	Er	68	167.259(3)
Europium	Eu	63	151.964(1)
Fermium*	Fm	100	(257)
Fluorine	F	9	18.9984032(5)
Francium*	Fr	87	(223)
Gadolinium	Gd	64	157.25(3)
Gallium	Ga	31	69.723(1)
Germanium	Ge	32	72.64(1)
Gold	Au	79	196.966569(4)
Hafnium	Hf	72	178.49(2)
Hassium	Hs	108	(277)
Helium	He	2	4.002602(2)
Holmium	Ho	67	164.93032(2)
Hydrogen	H	1	1.00794(7)
Indium	In	49	114.818(3)
Iodine	I	53	126.90447(3)
Iridium	Ir	77	192.217(3)
Iron	Fe	26	55.845(2)
Krypton	Kr	36	83.798(2)
Lanthanum	La	57	138.90547(7)
Lawrencium*	Lr	103	(262)
Lead	Pb	82	207.2(1)
Lithium	Li	3	6.941(2)
Lutetium	Lu	71	174.9668(1)
Magnesium	Mg	12	24.3050(6)
Manganese	Mn	25	54.938045(5)
Meitnerium	Mt	109	(268)
Mendelevium*	Md	101	(258)
Mercury	Hg	80	200.59(2)

Name	Symbol	Atomic Number	Atomic Weight
Molybdenum	Mo	42	95.96(2)
Neodymium	Nd	60	144.22(3)
Neon	Ne	10	20.1797(6)
Neptunium*	Np	93	(237)
Nickel	Ni	28	58.6934(4)
Niobium	Nb	41	92.90638(2)
Nitrogen	N	7	14.0067(2)
Nobelium*	No	102	(259)
Osmium	Os	76	190.23(3)
Oxygen	O	8	15.9994(3)
Palladium	Pd	46	106.42(1)
Phosphorus	P	15	30.973762(2)
Platinum	Pt	78	195.084(9)
Plutonium*	Pu	94	(244)
Polonium*	Po	84	(209)
Potassium	K	19	39.0983(1)
Praseodymium	Pr	59	140.90765(2)
Promethium*	Pm	61	(145)
Protactinium*	Pa	91	231.03588(2)
Radium*	Ra	88	(226)
Radon*	Rn	86	(222)
Rhenium	Re	75	186.207(1)
Rhodium	Rh	45	102.90550(2)
Roentgenium	Rg	111	(272)
Rubidium	Rb	37	85.4678(3)
Ruthenium	Ru	44	101.07(2)
Rutherfordium	Rf	104	(261)
Samarium	Sm	62	150.36(2)
Scandium	Sc	21	44.955912(6)
Seaborgium	Sg	106	(266)
Selenium	Se	34	78.96(3)
Silicon	Si	14	28.0855(3)
Silver	Ag	47	107.8682(2)
Sodium	Na	11	22.9896928(2)
Strontium	Sr	38	87.62(1)
Sulfur	S	16	32.065(5)
Tantalum	Ta	73	180.9488(2)
Technetium*	Tc	43	(98)
Tellurium	Te	52	127.60(3)
Terbium	Tb	65	158.92535(2)
Thallium	Tl	81	204.3833(2)
Thorium*	Th	90	232.03806(2)
Thulium	Tm	69	168.93421(2)
Tin	Sn	50	118.710(7)
Titanium	Ti	22	47.867(1)
Tungsten	W	74	183.84(1)
Ununhexium	Uuh	116	(292)
Ununoctium	Uuo	118	(294)
Ununpentium	Uup	115	(228)
Ununquadium	Uuq	114	(289)
Ununseptium	Uus	117	(292)
Ununtrium	Uut	113	(284)
Uranium*	U	92	238.02891(3)
Vanadium	V	23	50.9415(1)
Xenon	Xe	54	131.293(6)
Ytterbium	Yb	70	173.54(5)
Yttrium	Y	39	88.90585(2)
Zinc	Zn	30	65.38(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 terrestial isotopic composition, and the atomic weight is tabulated for these. **http://www.chem.qmw.ac.uk/iupac/AtWt/**

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General, Organic, and Biochemistry

TENTH EDITION

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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

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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

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

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Printed in the United States of America
1 2 3 4 5 6 7 15 14 13 12 11

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

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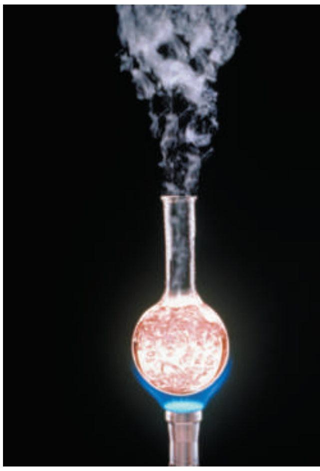

Preface

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.

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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*
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Health-Related Topics

Key

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

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Matter, Energy, and Measurement

1

James Balog/Getty Images

A woman climbing a frozen waterfall in British Columbia.

Key Questions

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.

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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

(*a*)

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

(*b*)

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.

Charles D. Winters

(*a*) Charles D. Winters (*b*) Charles D. Winters (*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.)

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.

Courtesy of the National Library of Medicine

Galen did not do experiments to test his hypothesis.

Lawrence Berkeley Nat'l Lab – Roy Kaltschmidt, photographer

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

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 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.

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 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

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

and a single copper atom weighs

$$0.00000000000000000000000023 \text{ pound}$$

which is equal to

$$0.0000000000000000000000104 \text{ gram}$$

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:

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

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

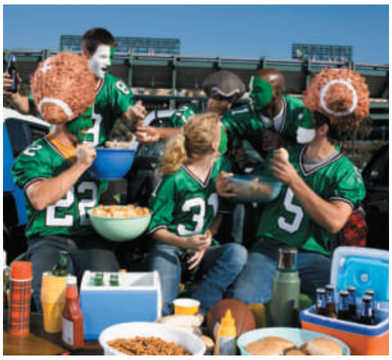
What we have just said in the form of an equation is "100 is a one with two zeros after the one, and 1000 is a one with three zeros after the one." We can also write

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

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

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 cm × 2.9 cm × 2.9 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



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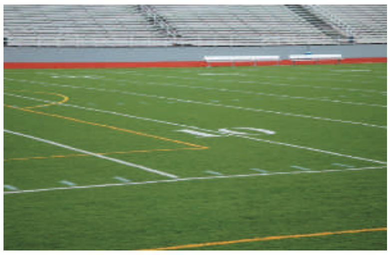

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Photos showing different orders of magnitude.
1. Group picnic in stadium parking lot (~10 meters)
2. Football field (~100 meters)
3. Vicinity of stadium (~1000 meters).

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

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:

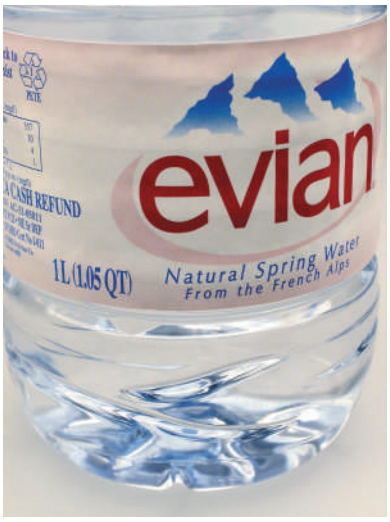
(a) $(6.49 \times 10^7)(7.22 \times 10^{-3})$ (b) $(3.4 \times 10^{-5})(8.2 \times 10^{-11})$

Divide:

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

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.



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

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.

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

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.

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. 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.

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

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.

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

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

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

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).**