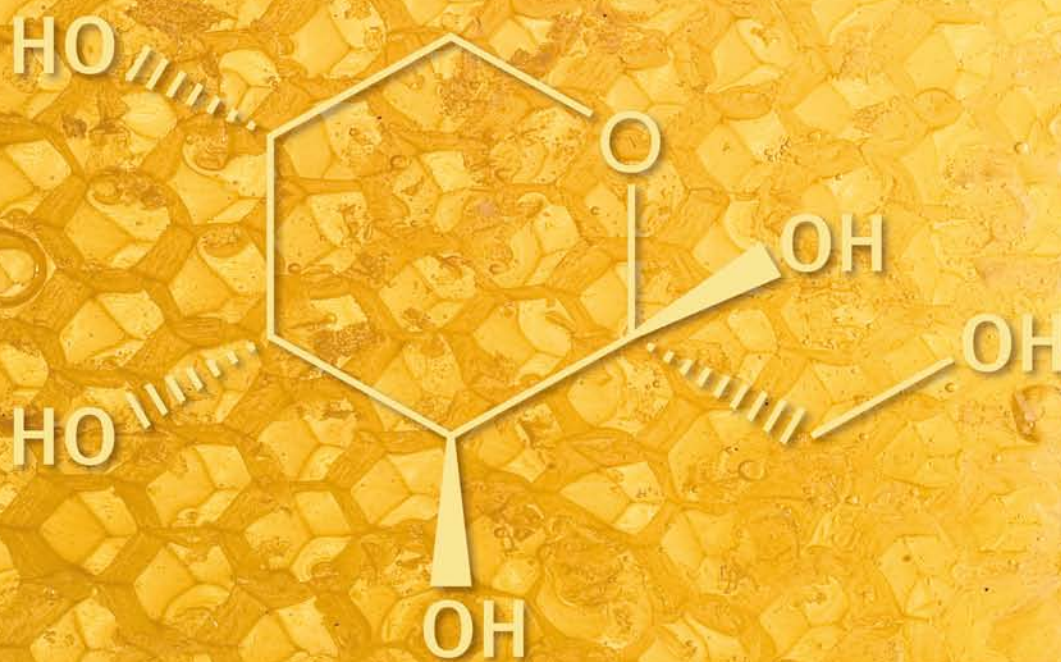


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INTRODUCTION TO
**General,
Organic, and
Biochemistry**



11TH EDITION

Period	1		2		3-10										11		12		13-18					
	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol	Number	Symbol				
1	1	H 1.0079																			2	He 4.0026		
2	3	Li 6.941	4	Be 9.0122	5	B 10.81	6	C 12.011	7	N 14.0067	8	O 15.9994	9	F 18.9984	10	Ne 20.1797								
3	11	Na 22.9898	12	Mg 24.3050	13	Al 26.9815	14	Si 28.0855	15	P 30.9738	16	S 32.066	17	Cl 35.4527	18	Ar 39.948								
4	19	K 39.0983	20	Ca 40.078	21	Sc 44.9559	22	Ti 47.867	23	V 50.9415	24	Cr 51.9961	25	Mn 54.9380	26	Fe 55.845	27	Co 58.9332	28	Ni 58.6934	29	Cu 63.546	30	Zn 65.38
5	37	Rb 85.4678	38	Sr 87.62	39	Y 88.9059	40	Zr 91.224	41	Nb 92.9064	42	Mo 95.96	43	Tc (97.907)	44	Ru 101.07	45	Rh 102.9055	46	Pd 106.42	47	Ag 107.8682	48	Cd 112.411
6	55	Cs 132.9054	56	Ba 137.327	57	Lanthanum 138.9055	58	Ce 138.9055	59	Pr 140.9076	60	Nd 144.24	61	Pm (144.91)	62	Sm 150.36	63	Eu 151.965	64	Gd 157.25	65	Tb 158.9253	66	Dy 162.50
7	87	Fr (223.02)	88	Ra (226.0254)	89	Ac (227.0278)	90	Th (232.0381)	91	Pa (231.0388)	92	U 238.0289	93	Np (237.0482)	94	Pu (244.664)	95	Am (243.061)	96	Cm (247.07)	97	Bk (247.07)	98	Cf (251.08)

Uranium

92

← Atomic number

U

← Symbol

238.0289

← Atomic weight

- METALS
- METALLOIDS
- NONMETALS

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

Lanthanides

Actinides

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

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium*	Ac	89	(227)	Molybdenum	Mo	42	95.96(2)
Aluminum	Al	13	26.9815386(8)	Neodymium	Nd	60	144.22(3)
Americium*	Am	95	(243)	Neon	Ne	10	20.1797(6)
Antimony	Sb	51	121.760(1)	Neptunium*	Np	93	(237)
Argon	Ar	18	39.948(1)	Nickel	Ni	28	58.6934(4)
Arsenic	As	33	74.92160(2)	Niobium	Nb	41	92.90638(2)
Astatine*	At	85	(210)	Nitrogen	N	7	14.0067(2)
Barium	Ba	56	137.327(7)	Nobelium*	No	102	(259)
Berkelium*	Bk	97	(247)	Osmium	Os	76	190.23(3)
Beryllium	Be	4	9.012182(3)	Oxygen	O	8	15.9994(3)
Bismuth	Bi	83	208.98040(1)	Palladium	Pd	46	106.42(1)
Bohrium	Bh	107	(264)	Phosphorus	P	15	30.973762(2)
Boron	B	5	10.811(7)	Platinum	Pt	78	195.084(9)
Bromine	Br	35	79.904(1)	Plutonium*	Pu	94	(244)
Cadmium	Cd	48	112.411(8)	Polonium*	Po	84	(209)
Cesium	Cs	55	132.9054519(2)	Potassium	K	19	39.0983(1)
Calcium	Ca	20	40.078(4)	Praseodymium	Pr	59	140.90765(2)
Californium*	Cf	98	(251)	Promethium*	Pm	61	(145)
Carbon	C	6	12.0107(8)	Protactinium*	Pa	91	231.03588(2)
Cerium	Ce	58	140.116(1)	Radium*	Ra	88	(226)
Chlorine	Cl	17	35.453(2)	Radon*	Rn	86	(222)
Chromium	Cr	24	51.9961(6)	Rhenium	Re	75	186.207(1)
Cobalt	Co	27	58.933195(5)	Rhodium	Rh	45	102.90550(2)
Copernicium*	Cn	112	(285)	Roentgenium	Rg	111	(272)
Copper	Cu	29	63.546(3)	Rubidium	Rb	37	85.4678(3)
Curium*	Cm	96	(247)	Ruthenium	Ru	44	101.07(2)
Darmstadtium	Ds	110	(271)	Rutherfordium	Rf	104	(261)
Dubnium	Db	105	(262)	Samarium	Sm	62	150.36(2)
Dysprosium	Dy	66	162.500(1)	Scandium	Sc	21	44.955912(6)
Einsteinium*	Es	99	(252)	Seaborgium	Sg	106	(266)
Erbium	Er	68	167.259(3)	Selenium	Se	34	78.96(3)
Europium	Eu	63	151.964(1)	Silicon	Si	14	28.0855(3)
Fermium*	Fm	100	(257)	Silver	Ag	47	107.8682(2)
Fluorine	F	9	18.9984032(5)	Sodium	Na	11	22.98976928(2)
Francium*	Fr	87	(223)	Strontium	Sr	38	87.62(1)
Gadolinium	Gd	64	157.25(3)	Sulfur	S	16	32.065(5)
Gallium	Ga	31	69.723(1)	Tantalum	Ta	73	180.9488(2)
Germanium	Ge	32	72.64(1)	Technetium*	Tc	43	(98)
Gold	Au	79	196.966569(4)	Tellurium	Te	52	127.60(3)
Hafnium	Hf	72	178.49(2)	Terbium	Tb	65	158.92535(2)
Hassium	Hs	108	(277)	Thallium	Tl	81	204.3833(2)
Helium	He	2	4.002602(2)	Thorium*	Th	90	232.03806(2)
Holmium	Ho	67	164.93032(2)	Thulium	Tm	69	168.93421(2)
Hydrogen	H	1	1.00794(7)	Tin	Sn	50	118.710(7)
Indium	In	49	114.818(3)	Titanium	Ti	22	47.867(1)
Iodine	I	53	126.90447(3)	Tungsten	W	74	183.84(1)
Iridium	Ir	77	192.217(3)	Ununhexium	Uuh	116	(292)
Iron	Fe	26	55.845(2)	Ununoctium	Uuo	118	(294)
Krypton	Kr	36	83.798(2)	Ununpentium	Uup	115	(228)
Lanthanum	La	57	138.90547(7)	Ununquadium	Uuq	114	(289)
Lawrencium*	Lr	103	(262)	Ununseptium	Uus	117	(292)
Lead	Pb	82	207.2(1)	Ununtrium	Uut	113	(284)
Lithium	Li	3	6.941(2)	Uranium*	U	92	238.02891(3)
Lutetium	Lu	71	174.9668(1)	Vanadium	V	23	50.9415(1)
Magnesium	Mg	12	24.3050(6)	Xenon	Xe	54	131.293(6)
Manganese	Mn	25	54.938045(5)	Ytterbium	Yb	70	173.54(5)
Meitnerium	Mt	109	(268)	Yttrium	Y	39	88.90585(2)
Mendelevium*	Md	101	(258)	Zinc	Zn	30	65.38(2)
Mercury	Hg	80	200.59(2)	Zirconium	Zr	40	91.224(2)

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

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

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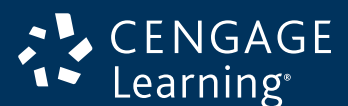
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INTRODUCTION TO

General, Organic, and Biochemistry

ELEVENTH EDITION

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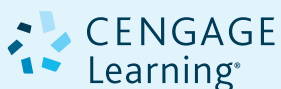
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To Carolyn, with whom life is a joy. —WB

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,
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To my loving family and friends who have supported me through
this journey: Mom, Dad, Lisa, Abuela, René, Ryan,
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and support. I am truly blessed to have each of
you in my life. — OT

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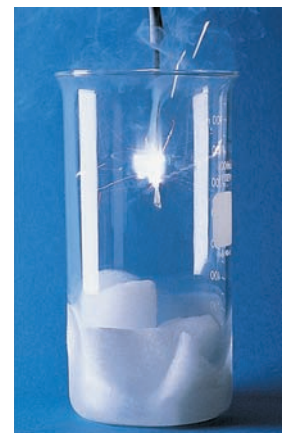
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To access this online-only chapter, search for ISBN 978-1-285-86975-9 at www.cengagebrain.com and visit this book's companion website.

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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 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 eleventh 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 can sense 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 conception of and preoccupation 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 a scope of the horizon within which chemistry touches our lives.

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 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 basic principles. This progression ascends 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 one course. Our aim was to provide enough material from which the instructor can select the topics he or she deems important. The wealth of problems, both drill and challenging, provide 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 necessary for understanding future topics.

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.

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 26–28).

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 6-4 (Henry's Law) and 6-11 (electrolytic conductance). The Chemical Connections essays have been enhanced further with more photos to 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.
- **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.
- **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.
- **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 15).
- **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. Six 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. Twelve new problems were added.
- **Chapter 3, Chemical Bonds**, begins with a discussion of ionic compounds, followed by a discussion of molecular compounds. Twenty-one new problems were added.
- **Chapter 4, Chemical Reactions**, 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. Twenty-three new 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. Fifteen new challenge 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 challenge 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, six 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 six new problems.

- **Chapter 9, Nuclear Chemistry**, highlights nuclear applications in medicine. A new Chemical Connections box on magnetic resonance imaging (MRI) was added, along with two new problems.

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. The list of common organic functional groups has been expanded in this edition to include amides, and a schematic of a tripeptide is presented to illustrate the importance of amide bonds in the structure of polypeptides and proteins.
- 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. Chemical Connections Box 11C, “The Environmental Impact of Freons,” has been extended to include some possible replacements for refrigerant gases and their ozone-depleting potential.
- 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. 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.
- **Chapter 13, Benzene and Its Derivatives**, includes a discussion of phenols and antioxidants. A short history of chemistry was added for this edition that discusses structures proposed in the 19th century as alternatives to those proposed by Kekulé. We lengthened the discussion on the reactions of phenols to include the oxidation of phenols to quinones, the use of the hydroquinone-to-quinone interconversion in black-and-white photography, the role of Coenzyme Q (ubiquinone) in the respiratory chain as a carrier of electrons, and the structure of vitamin K and its role in blood clotting. A new problem at the end of the chapter challenges students to propose additional alternative structures for C_6H_6 consistent with the tetravalence of carbon.
- **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. A new Chemical Connections box, “The Importance of Hydrogen Bonding in Drug-Receptor Interactions,” was added, and several new puzzle problems dealing with the interconversion of alcohol and alkenes were added to the end-of-chapter exercises.
- 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. The discussion on the structure and stereochemistry of Tamiflu has been expanded, and a problem showing the different odors of the enantiomers of carvone was added.

- In **Chapter 16, Amines**, we trace the development of new asthma medications from epinephrine, which can be viewed as a historical precursor to albuterol (Proventil).
- **Chapter 17, 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. In this edition, the discussion on the mechanism of the acid-catalyzed formation of acetals has been broadened.
- **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. The discussion on carboxylic acids has been expanded to include molecules that contain an aldehyde or ketone group in addition to a carboxyl group.
- **Chapter 19, 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 was inserted on the structure and nomenclature of lactones and how to recognize them when they are embedded in macromolecules, and two new end-of-chapter problems have been added: Problem 19-48, which illustrates how an insect utilizes a plant-derived chemical as a raw material from which to synthesize a compound that impacts its species survival, and Problem 19-49, which describes polyester polymers that are biodegradable by microbial enzymes by composting.

Biochemistry (Chapters 20–31)

- **Chapter 20, 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. Eight new end-of-chapter problems were added.
- **Chapter 21, 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. The Chemical Connections “Anabolic Steroids” has been updated to reflect new and continuing incidents in professional sports. One new end-of-chapter exercise has been added.
- **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. 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. Eight new end-of-chapter problems were added.

- **Chapter 23, 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, as well as an introduction to the fascinating topic of transition-state analogs and their use as potent inhibitors. One of these medical applications is enhanced in an updated section on the use of abzymes in treatment of AIDS. A new Chemical Connections box discussing enzyme mechanisms using chymotrypsin was included as an example, and a new figure was added to illustrate the binding of effectors to allosteric enzymes. Nine new end-of-chapter problems were added.
- In **Chapter 24, 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, a new section on the fight against depression was added.
- **Chapter 25, 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. The sections on the types of RNA have been expanded again as our knowledge increases daily about these important nucleic acids. This edition introduces three of the newest RNA types to be discovered: long non-Coding RNA, Piwi-associated RNA, and circular RNA. 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.
- **Chapter 26, 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. A new section was added on epigenetics, one of the hottest topics in the field. Two new Chemical Connections boxes were added. The first explores how protein synthesis is related to creating memories. The second expands on the importance of epigenetics by looking at how it affects disease states.
- **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. A new Chemical Connections box on role of ATP in cell signaling was added, along with four new end-of-chapter problems.
- In **Chapter 28, Specific Catabolic Pathways**, we address the details of carbohydrate, lipid, and protein breakdown, concentrating on energy yield. A new Chemical Connections box on manipulating carbohydrate metabolism to treat obesity was added, and four new end-of-chapter exercises were also 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. A new Chemical Connections box on statin drugs as inhibitors of cholesterol biosynthesis was inserted, and two new end-of-chapter exercises were also included.

- 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 the causes of obesity 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 and a new Chemical Connections box, “Immunology and Oncology.” The chapter has also been shortened and streamlined to make some of the very technical material simpler to digest.
- **Chapter 32, Body Fluids**
To access this online-only chapter, search for ISBN 978-1-285-86975-9 at www.cengagebrain.com and visit this book's companion website.

Supporting Materials

Please visit <http://www.cengage.com/chemistry/bettelheim/gob11E> for information about the student and instructor resources for this text.

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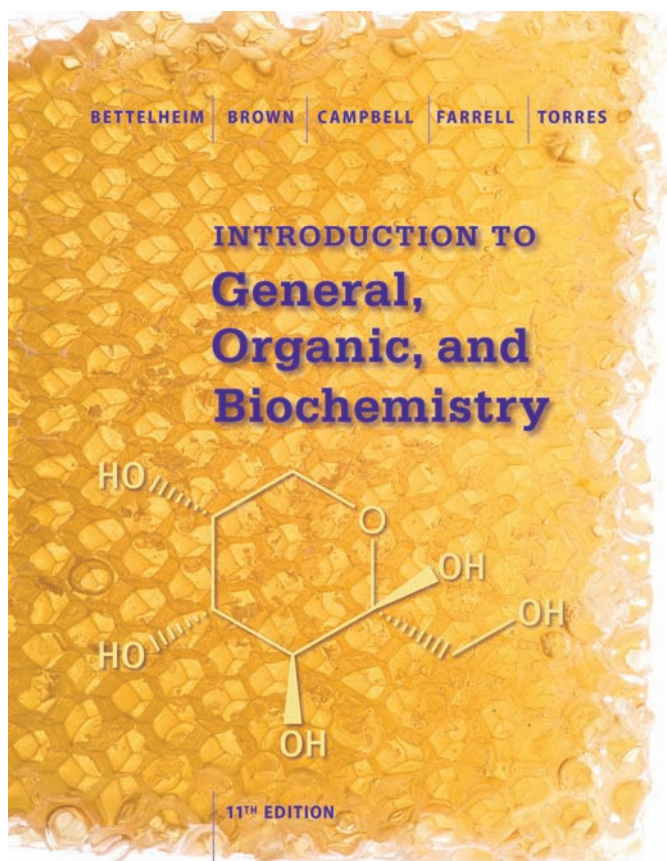
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About the Cover

Honeycomb consists of a repeating structural pattern of hexagons, and just as hexagons are the repeating structural unit of honeycomb, the hexagonal-six-membered rings of cyclohexane and benzene are repeating structural units of the organic and bioorganic molecules that make up the molecules of the natural world around us. Honey, which fills each hexagonal unit of honeycomb, derives its sweetness from the carbohydrates glucose and fructose ($C_6H_{12}O_6$). Glucose and fructose have the same molecular formula and both can exist in nature in the form of six-membered-rings as seen on the cover, which shows a six-membered ring form of fructose. Chemically, honey is not only a nutritional powerhouse, but it also has medicinal uses due to its antibacterial and healing properties. Another major component of honeycomb is beeswax, or triacontyl palmitate, $CH_3(CH_2)_{14}COO(CH_2)_{29}CH_3$, an ester of palmitic acid. Beeswax is also an important chemical substance because it is used in the production of foods, cosmetics, and pharmaceuticals.



Health-Related Topics

Key

ChemConn = Chemical Connections Box number

Sect. = Section number

Prob. = Problem number

A, B, AB, and O Blood Types	ChemConn 20D	Automobile Air Bags	Prob. 5-54
Abundance of Elements in the Human Body and in the Earth's Crust	ChemConn 2B	Autoxidation	Sect. 13-4D
Acetaminophen (Tylenol)	Probs. 1-45, 1-112	Azithromycin	Prob. 18-54
Acid Rain	ChemConn 6A	B Cells	Sect. 31-2C
Acidic Polysaccharides	Sect. 20-6	Barbiturates	ChemConn 19E
Acidosis	ChemConn 8C	Basal Caloric Requirement	Sect. 30-2
Acquired Immunity	Sect. 31-1	Base Excision Repair (BER) of DNA	Sect. 25-7
Adjuvants	Sect. 31-6D	Bends, the	ChemConn 6B
Advanced Glycation End Products	ChemConn 22B	BHT as an Antioxidant in Foods	Sect. 13-4D
AGE and Aging	ChemConn 22B	Bile Salts	Sect. 21-11
AIDS	Sect. 31-8	Blood Alcohol Screening	ChemConn 14C
Alkaloids	ChemConn 16B	Blood Buffers	Sect. 8-10D
Alkalosis and the Sprinter's Trick	ChemConn 8D	Blood pH	ChemConn 8C
Alzheimer's Disease	ChemConn 24C	Blood Pressure Measurement	Sect. 32-8, Probs. 32-36–32-38
Amoxicillin	Prob. 15-32	Bone, Artificial	ChemConn 5C
Amphetamines	ChemConn 16A, Prob. 24-50	Bone Density and Solubility Equilibrium	ChemConn 3A
Anabolic Steroids	ChemConn 21C	Botox	Sect. 7-6
Androstenedione	Prob. 3-126	Botulism	ChemConn 24B
Antacids	ChemConn 8B	Breath Alcohol Screening	ChemConn 24B
Antibiotics	ChemConn 31B	Breathing and Boyle's Law	ChemConn 14C
Antibodies and Cancer Therapy	ChemConn 31A	Bronchodilators and Asthma	ChemConn 5A
Antidepressants	Probs. 24-79, 24-80, Sect. 24-5F	Brown Fat and Hibernation	ChemConn 16E
Antigens	Sect. 31-1C	Buffers	ChemConn 27A
Antihistamines	Sect. 24-5G	Caffeine	Sect. 8-10
Anti-inflammatory Drugs	ChemConn 21E	Calcium as a Signaling Agent	Prob. 4-103
Anticoagulants	ChemConn 17A	Calorie Counting	Sect. 24-3C
Antioxidants	Sect. 13-4D	Cancer Cell Growth and Metabolic State	Sect. 30-2
Artificial Pacemakers and Redox	ChemConn 4C	Cancer Therapy Antibodies	Sect. 27-1
Ascorbic Acid (Vitamin C)	ChemConn 20B	Cannabinoid Receptors	ChemConn 31A
Aspartame	Prob. 19-13, ChemConn 22A	Captopril and ACE Inhibitors	ChemConn 30F
Aspirin and Other NSAIDs	ChemConn 19C	Capsaicin, for Those Who Like It Hot	Prob. 15-31
Asthma	Sect. 21-12	Carcinogenic Polynuclear Aromatics and Smoking	ChemConn 13F
Atherosclerosis: Levels of LDL and HDL	Sect. 21-9E	Carcinogens	ChemConn 13B
Atomic Energy	Sect. 9-9	β -Carotene	Sect. 26-7
Atropine	Prob. 16-54	Cataracts	Prob. 12-72
Attention Deficit Disorder (ADD)	ChemConn 24D	Cephalosporins	ChemConn 22B
Autoimmune Diseases	Sect. 31-7C	Cetylpyridinium Chloride	ChemConn 19B
		Chiral Drugs	Prob. 18-25
		Chirality in the Biological World	ChemConn 15A
		Chlorine Dioxide	Sect. 15-5
		Cholera	Probs. 3-102, 4-59
			Sect. 24-5E

Cholesterol	Sect. 21-9F	Food for Performance	ChemConn 30E
<i>Cis-Trans</i> Isomerism in European Corn Borer	ChemConn 12C	Food Guide Pyramid	ChemConn 30A
Cocaine	ChemConn 16B	Free Radicals	ChemConn 9C, Sect. 13-4D
Cocaine Addiction	ChemConn 23G	Galactosemia	ChemConn 20A
Cold Compresses	ChemConn 1C	Gallstones	Sect. 21-9A
Chondroitin Sulfate	Prob. 20-79	Gene Patents	ChemConn 25A
Coniine	ChemConn 16B	Gene Therapy	Sect. 26-9
Connection between Carbohydrates and Obesity	ChemConn 20E	Genetic Code	Sect. 26-4
Coral Chemistry and Broken Bones	ChemConn 3A	Gout	Sect. 6-6B
COX-2 Inhibitor Drugs	ChemConn 21G	G-protein/cAMP Cascade	Sect. 24-5C
Creatine: Performance Enhancement	ChemConn 30D	Haber Process	ChemConn 7E
Crenation	Sect. 6-8C	Heart Enzymes	Sect. 23-7
Cystic Fibrosis	ChemConn 26F	Heavy Metal Poisoning	Sect. 22-13
Cytokines	Sect. 31-2A	Heme Products in Bruises	Sect. 28-10
DDT	ChemConn 13A	Hemodialysis	ChemConn 6G
DEET	Prob. 19-43	Hemoglobin	ChemConn 22G
Depression	ChemConn 24G, 30G	Hemolysis	Sect. 6-8C
Diabetes	ChemConn 24F	Heparin	Sect. 20-6B, Prob. 20-68
Dialysis	Sect. 6-8D	High Fever	ChemConn 7A
Dietary Protein	Prob. 22-96	HIV Protease Inhibitors	ChemConn 23D
Dietary Reference Intake	Sect. 30-1	Hormones	Sect. 24-2
Dieting and Weight Loss	Prob. 20-77, Sect. 30-2	How Soap Cleans	Sect. 18-4C
2,4-Dinitrophenol as an Uncoupling Agent	ChemConn 27A	Human Insulin	ChemConn 22C
DNA Fingerprinting	ChemConn 25C	Hyaluronic Acid	Sect. 20-6A
Drug Dosage and Body Mass	Prob. 1-100, ChemConn 1A	Hyperbaric Medicine	ChemConn 5B
Eicosapentenoic Acid	ChemConn 21F	Hypoglycemic Awareness	ChemConn 22C
Emulsions and Emulsifying Agents	ChemConn 6E	Hypothermia and Hyperthermia	ChemConn 1B
Enantiomers of Ibuprofen	Sect. 15-2	Immune System	Sect. 31-1
Environmental Impact of Freons	ChemConn 11C	Immunization	Sect. 31-6
Enzyme Regulation	ChemConn 23E, Sect. 23-6A	Immunoglobulin	Sect. 31-4
Enzymes in Medical Diagnosis	Sect. 23-7	Immunology and Oncology	ChemConn 31C
Enzymes in Therapy	Sect. 23-7	Immunosuppressant FK-506	Probs. 15-44, 17-55
Ephedrine	Probs. 3-107, 15-24	Indoor Radon Problem	ChemConn 9B
Epigenetics and DNA	Sect. 26-10	Influenza Vaccine	ChemConn 31E
Epigenetics, Cancer, and Aging	ChemConn 26G	Innate Immunity	Sect. 31-1A
Epinephrine	ChemConn 16E	Insulin	Sect. 22-8
Erythromycin A	Prob. 14-65	Insulin, Structure	Sect. 22-8
Essential Amino Acids	Sect. 30-5, ChemConn 29D	Insulin, Use	ChemConn 22C
Esters, as Flavoring Agents	ChemConn 18B	Iodide Ion and Goiter	ChemConn 13C
Ethers and Anesthesia	ChemConn 14E	Ionic Compounds in Medicine	ChemConn 3B
Ethylene Oxide, as a Chemical Sterilant	ChemConn 14D	Ionizing Radiation	Sect. 9-5
Ethylene, a Plant Growth Regulator	ChemConn 12A	Iron and Mineral Requirements	ChemConn 30C
Fatty Acids	ChemConn 12B, Sect. 18-4A	Ketoacidosis in Diabetes	ChemConn 28C
Fever, as a Protective Mechanism	ChemConn 7A	Ketone Bodies	ChemConn 18C, Sect. 28-7
Fever, Dangers of	ChemConn 7A	Lactate Accumulation	ChemConn 28A
Fluid Mosaic, Model of Membranes	Sect. 21-5	Laetrite	Prob. 20-71
Fluoride Ion in Dental Decay	ChemConn 4A	Laser In Situ Keratomileusis (LASIK)	ChemConn 22H
Fluoxetine (Prozac)	Probs. 24-49, 24-81	Laser Surgery and Protein Denaturation	ChemConn 22H
Fish in Diet – Health Benefits	ChemConn 21F	Librium	ChemConn 16C
		Lipid Storage Diseases	ChemConn 21B
		Local Anesthetics for Dentistry	Prob. 19-44
		Lowering Body Temperature	ChemConn 7B

Lunesta	Prob. 15-46	Polynuclear Aromatic	
Lycopene	Prob. 12-71	Hydrocarbons (PAHs)	Sect. 13-2D, ChemConn 13B
Mad Cow Disease	ChemConn 22E	Positron Emission Tomography (PET)	Sect. 9-7A
Magnetic Resonance Imaging	ChemConn 9D	Prion Disease	ChemConn 22E
Medical Uses of Inhibitors	ChemConn 23D	Propofol	Sect. 20-3D
Memory and Protein Synthesis	ChemConn 26B	Proteomics	ChemConn 22F
Menstrual Cycle	Sect. 21-10B	Pyrethrins	ChemConn 19A
Metformin (Glucophage)	Prob. 16-28	Quaternary Structure and	
Methadone	ChemConn 16D	Allosteric Proteins	ChemConn 22G
Methamphetamine	ChemConn 16A	Radiation	Sect. 9-2
Methylparaben	Prob. 18-47	Radiation Dosimetry	Sect. 9-6
Milk of Magnesia	ChemConn 8A	Radiation Sickness	Sect. 9-6
Monoclonal Antibodies	ChemConn 31A	Radioactive Dating	ChemConn 9A
Morphine and Enkephalins	Sect. 24-6	Radioactive Fallout from Nuclear	
Morphine and Morphine Analogs	Prob. 16-59	Accidents	ChemConn 9E
MSG and Headaches	ChemConn 24E	Radioactive Isotopes, in Nuclear Imaging	Sect. 9-7A
Muscle Relaxants	ChemConn 23A	Radioactive Isotopes, in Medical Therapy	Sect. 9-7B
Mutagens	Sect. 26-7	Recommended Daily Allowances (RDA)	Sect. 30-1
Mutations and Biochemical Evolution	ChemConn 26C	Relative Sweetness	Sect. 20-4D
Naproxen	Sects. 15-2, 15-5B	Reverse Osmosis and Desalinization	ChemConn 6F
Neurotransmitters	Sect. 22-5, Sect. 24-1	Roentgens, Rads, and Rems	Sect. 9-6
Nicotine	ChemConn 16B	SCID	Sect. 26-9
Nitric Oxide	ChemConn 3C, 24E	SCUBA Diving	Prob. 5-111
Nitrous Oxide ("Laughing Gas")	Prob. 3-78	Sickle Cell Anemia	ChemConn 22D
Nitroglycerin, an Explosive and a Drug	ChemConn 14B	Significance of Chirality in the	
NMDA Receptors	Sect. 24-4B	Biological World	Sect. 15-5
NO Release and Impotence	ChemConn 24E	Side Effects of COX Inhibitors	Sect. 21-12
Nuclear Medicine	Sect. 9-7	Solubility of Drugs in Body Fluids	ChemConn 16D
Nutritional Causes of Depression	ChemConn 30G	Solubility and Tooth Decay	ChemConn 4A
Nutritional Daily Values	Sect. 30-1	Sports Drinks	Sect. 21-11, ChemConn 30D
Obesity	ChemConn 28B, 30C, Sect. 30-2	Statins	ChemConn 29C
Omega-3 Fatty Acids	ChemConn 21F	Stem Cells	Sect. 31-2C
Oncogenes and Cancer	ChemConn 26E	Stitches That Dissolve	ChemConn 19F
Oral Contraception	ChemConn 21D	Strontium-90	ChemConn 2C
Organic Food and Health	ChemConn 30F	Sunglasses and Le Chatelier's Principle	ChemConn 7D
Oseltamivir (Tamiflu)	Prob. 15-45	Sunscreens and Sunblocks	ChemConn 19D
Osmotic Pressure	Sect. 6-8C	Swine Flu	ChemConn 31D
Parkinson's Disease	ChemConn 24D, Sect. 22-5	Synapses and Sleep	ChemConn 24A
Paroxetine	Prob. 15-35	Synthetic Food Dyes	ChemConn 13E
Paternity Testing	ChemConn 25C	Synthetic Genome	ChemConn 25E
Penicillins	ChemConn 19B	T Cells	Sect. 31-2C
Peramivir for Influenza A (H1N1) and		Tamoxifen and Breast Cancer	Prob. 16-32
Swine Flu	Prob. 19-46	Taxol	ChemConn 10A
Phenols as Antioxidants	Sect. 13-4D	Tears	ChemConn 32E, Probs. 32-47–32-50
Phencyclidine (PCP)	Sect. 24-4B	Telomeres and Immortality	ChemConn 25B
Phenylketonuria (PKU)	ChemConn 28D	Terpin Hydrate	Prob. 12-52
Photorefractive Keratectomy (PRK)	ChemConn 22H	Testing for Glucose	ChemConn 20C
Photosynthesis	ChemConn 29A	Tetrodotoxin	ChemConn 11A
Poison Ivy	Sect. 13-4A	Timed-Released Medication	ChemConn 7C
Poisonous Puffer Fish	ChemConn 11A	Tranquilizers	ChemConn 16C

<i>Trans</i> Fatty Acids	Sect. 21-3B, ChemConn 18A	Viruses	Sect. 26-1
Transport Across Cell Membranes	Sect. 21-5B	Vitamin A and Vision	ChemConn 12D
Tumor Suppressors	ChemConn 26E	Vitamin Excess	Sect. 30-6
Urinometer	Sect. 1-7B	Vitamins and Depression	ChemConn 30G
Vaccines	Sect. 31-6	Vitamins and Minerals	Sect. 30-6
Valium	ChemConn 16C	Vitamins, in Diet	Sect. 30-6
Viagra	ChemConn 23D, 24E	Xeroderma Pigmentosum	Sect 25-7
Viagra and Blood Vessel Dilation	ChemConn 24E	Zebrafish Synapses	ChemConn 24A

Matter, Energy, and Measurement

1



A woman climbing a frozen waterfall.

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 or by such measures as bleeding, laxatives, hot plasters, and pills made from powdered stag-horn, 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.

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

KEY QUESTIONS

- 1-1 Why Do We Call Chemistry the Study of Matter?
- 1-2 What Is the Scientific Method?
- 1-3 How Do Scientists Report Numbers?
How To . . . Determine the Number of Significant Figures in a Number
- 1-4 How Do We Make Measurements?
- 1-5 What Is a Handy Way to Convert from One Unit to Another?
How To . . . Do Unit Conversions by the Factor-Label Method
- 1-6 What Are the States of Matter?
- 1-7 What Are Density and Specific Gravity?
- 1-8 How Do We Describe the Various Forms of Energy?
- 1-9 How Do We Describe Heat and the Ways in Which It Is Transferred?

► Medical practice over time.

(a) A woman being bled by a leech on her left forearm; a bottle of leeches is on the table. From a 1639 woodcut.

(b) Modern surgery in a well-equipped operating room.



(a)

Courtesy of the National Library of Medicine



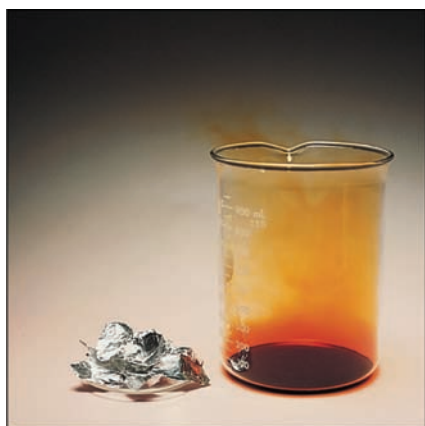
(b)

Photo by Bobi Rihna, Jr. Used courtesy of Childrens Hospital Los Angeles.

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 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**, 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.



(a)

Charles D. Winters



(b)

Charles D. Winters



(c)

Charles D. Winters

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 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 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. ◀

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.



Courtesy of the National Library of Medicine

▶ Galen did not do experiments to test his hypothesis.



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.

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

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 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.

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 atoms of copper

and a single copper atom weighs

0.0000000000000000000000023 pound

which is equal to

0.00000000000000000000000104 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 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 $2.9 \text{ cm} \times 2.9 \text{ cm} \times 2.9 \text{ cm}$. The calculator will then give you an answer that is 24.389 cm^3 . However, your initial measurements were good to only one decimal place, so your final 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.

► Photos showing different orders of magnitude.



SuperStock/iskodanell

1. Group picnic in stadium parking lot (~10 meters)



© iStockphoto.com/iskodanell

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:

$$(a) (4.73 \times 10^5)(1.37 \times 10^2) \qquad (b) (2.7 \times 10^{-4})(5.9 \times 10^8)$$

Divide:

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

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 $-3 - 5 = -8$.

Problem 1-1

Multiply:

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

Divide:

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

1-4 How Do We Make Measurements?

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

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,



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)
Energy	joule (J)
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*.

FIGURE 1-2 Road sign in California showing metric equivalents of mileage.



GIPhotoStock Z/Alamy

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 can use them to have as many significant figures as needed without limit.

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. ◀

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

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



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