General, Organic & Biological Chemistry 7TH EDITION

H. Stephen Stoker

Key: 24 **Cr** 52.00 — Atomic number / Symbol / Atomic mass

Nonmetals → (right of the stepped line) ; Metals ← (left of the stepped line)

Period	1 Group IA	2 Group IIA	3 Group IIIB	4 Group IVB	5 Group VB	6 Group VIB	7 Group VIIB	8 Group ←	9 Group VIIIB	10 Group →	11 Group IB	12 Group IIB	13 Group IIIA	14 Group IVA	15 Group VA	16 Group VIA	17 Group VIIA	18 Group VIIIA
1	1 **H** 1.01																	2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.41	31 **Ga** 69.72	32 **Ge** 72.64	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (263)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (267)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 **—** (284)	114 **—** (289)	115 **—** (288)	116 **—** (292)	117 **—** (293)	118 **—** (294)

58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
90 **Th** (232)	91 **Pa** (231)	92 **U** (238)	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Atomic Numbers and Atomic Masses of the Elements

Based on ${}^{12}_{6}C$. Numbers in parentheses are the mass numbers of the most stable isotopes of radioactive elements.

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	(227)	Meitnerium	Mt	109	(276)
Aluminum	Al	13	26.98	Mendelevium	Md	101	(258)
Americium	Am	95	(243)	Mercury	Hg	80	200.59
Antimony	Sb	51	121.76	Molybdenum	Mo	42	95.94
Argon	Ar	18	39.95	Neodymium	Nd	60	144.24
Arsenic	As	33	74.92	Neon	Ne	10	20.18
Astatine	At	85	(210)	Neptunium	Np	93	(237)
Barium	Ba	56	137.33	Nickel	Ni	28	58.69
Berkelium	Bk	97	(247)	Niobium	Nb	41	92.91
Beryllium	Be	4	9.01	Nitrogen	N	7	14.01
Bismuth	Bi	83	208.98	Nobelium	No	102	(259)
Bohrium	Bh	107	(264)	Osmium	Os	76	190.23
Boron	B	5	10.81	Oxygen	O	8	16.00
Bromine	Br	35	79.90	Palladium	Pd	46	106.42
Cadmium	Cd	48	112.41	Phosphorus	P	15	30.97
Calcium	Ca	20	40.08	Platinum	Pt	78	195.08
Californium	Cf	98	(251)	Plutonium	Pu	94	(244)
Carbon	C	6	12.01	Polonium	Po	84	(209)
Cerium	Ce	58	140.12	Potassium	K	19	39.10
Cesium	Cs	55	132.91	Praseodymium	Pr	59	140.91
Chlorine	Cl	17	35.45	Promethium	Pm	61	(145)
Chromium	Cr	24	52.00	Protactinium	Pa	91	(231)
Cobalt	Co	27	58.93	Radium	Ra	88	(226)
Copernicium	Cn	112	(285)	Radon	Rn	86	(222)
Copper	Cu	29	63.55	Rhenium	Re	75	186.21
Curium	Cm	96	(247)	Rhodium	Rh	45	102.91
Darmstadtium	Ds	110	(271)	Roentgenium	Rg	111	(280)
Dubnium	Db	105	(262)	Rubidium	Rb	37	85.47
Dysprosium	Dy	66	162.50	Ruthenium	Ru	44	101.07
Einsteinium	Es	99	(252)	Rutherfordium	Rf	104	(263)
Erbium	Er	68	167.26	Samarium	Sm	62	150.36
Europium	Eu	63	151.96	Scandium	Sc	21	44.96
Fermium	Fm	100	(257)	Seaborgium	Sg	106	(266)
Fluorine	F	9	19.00	Selenium	Se	34	78.96
Francium	Fr	87	(223)	Silicon	Si	14	28.09
Gadolinium	Gd	64	157.25	Silver	Ag	47	107.87
Gallium	Ga	31	69.72	Sodium	Na	11	22.99
Germanium	Ge	32	72.64	Strontium	Sr	38	87.62
Gold	Au	79	196.97	Sulfur	S	16	32.07
Hafnium	Hf	72	178.49	Tantalum	Ta	73	180.95
Hassium	Hs	108	(277)	Technetium	Tc	43	(98)
Helium	He	2	4.00	Tellurium	Te	52	127.60
Holmium	Ho	67	164.93	Terbium	Tb	65	158.93
Hydrogen	H	1	1.01	Thallium	Tl	81	204.38
Indium	In	49	114.82	Thorium	Th	90	(232)
Iodine	I	53	126.90	Thulium	Tm	69	168.93
Iridium	Ir	77	192.22	Tin	Sn	50	118.71
Iron	Fe	26	55.85	Titanium	Ti	22	47.87
Krypton	Kr	36	83.80	Tungsten	W	74	183.84
Lanthanum	La	57	138.91	Uranium	U	92	(238)
Lawrencium	Lr	103	(262)	Vanadium	V	23	50.94
Lead	Pb	82	207.19	Xenon	Xe	54	131.29
Lithium	Li	3	6.94	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.91
Magnesium	Mg	12	24.31	Zinc	Zn	30	65.41
Manganese	Mn	25	54.94	Zirconium	Zr	40	91.22

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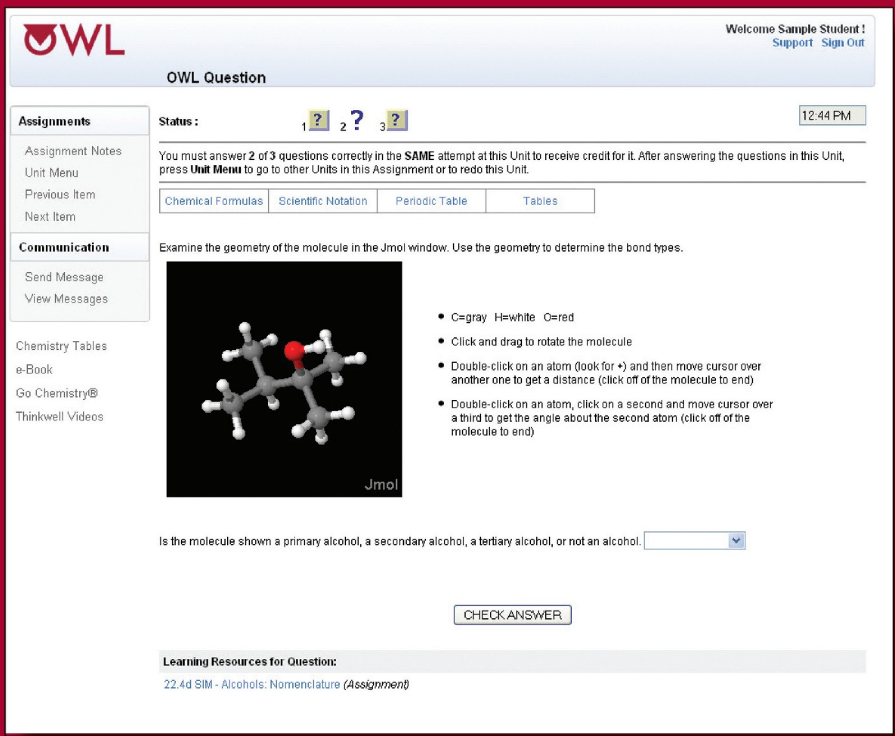

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General, Organic, and Biological
CHEMISTRY

SEVENTH EDITION

H. Stephen Stoker
Weber State University

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Brief Contents

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PART III BIOLOGICAL CHEMISTRY

Preface

The positive responses of instructors and students who used the previous six editions of this text have been gratifying—and have led to the new seventh edition that you hold in your hands. This new edition represents a renewed commitment to the goals I initially set when writing the first edition. These goals have not changed with the passage of time. My initial and still ongoing goals are to write a text in which:

- The needs are simultaneously met for the many students in the fields of nursing, allied health, biological sciences, agricultural sciences, food sciences, and public health who are required to take such a course.
- The development of chemical topics always starts out at ground level. The students who will use this text often have little or no background in chemistry and hence approach the course with a good deal of trepidation. This "ground level" approach addresses this situation.
- The amount and level of mathematics is purposefully restricted. Clearly, some chemical principles cannot be divorced entirely from mathematics and, when this is the case, appropriate mathematical coverage is included.
- The early chapters focus on fundamental chemical principles, and the later chapters—built on these principles—develop the concepts and applications central to the fields of organic chemistry and biochemistry.

New Features Added to the Seventh Edition

Two new features are present in this seventh edition of the text. They are: (1) Section Quick Quizzes, and (2) Section Learning Focus Statements.

Section Quick Quizzes: Each section in each chapter of the text now ends with a "Section Quick Quiz." Depending on the section length and the number of concepts covered, the quick quiz consists of two to six multiple choice questions which highlight the key terms and concepts covered in the section that a student should be aware of after the initial reading of the text section. Answers to the quick quiz questions are given immediately following the set of questions. The word "quick" in the phrase "quick quiz" is significant. The questions are designed to generate immediate answers. In most cases a time of no more than a minute is sufficient to complete the quiz.

Two important purposes for this new quick quiz feature are: (1) to serve as a guide to the most important terms and concepts found in the section under study, and (2) to serve as an important review system for a student when he or she is studying for an upcoming class exam on the subject matter under study.

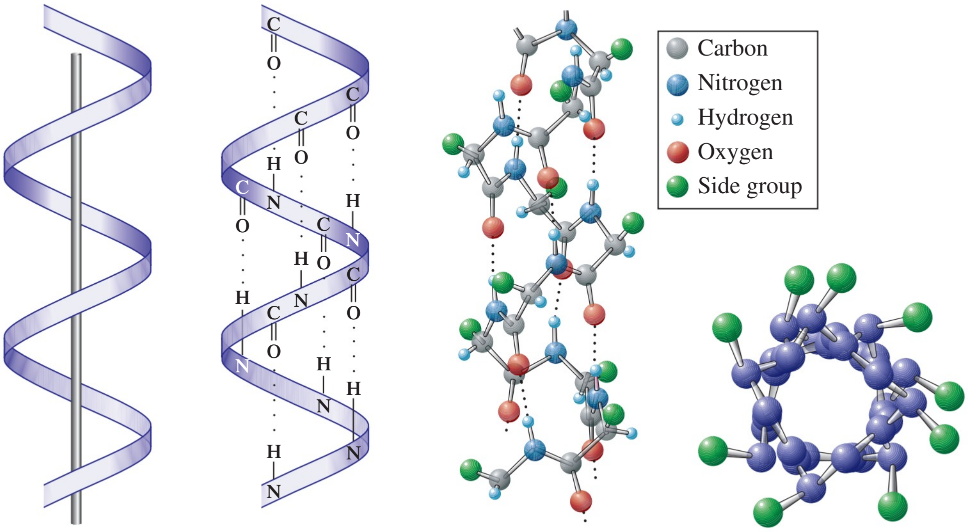
Learning Focus Statements: Learning focus statements are now found at the beginning of each section in each chapter of the text. These statements provide the student with insights into the focus of the section in terms of topics covered and the needed learning outcomes associated with these topics.

Important Continuing Features in the Seventh Edition

Focus on Biochemistry Most students taking this course have a greater interest in the biochemistry portion of the course than the preceding two parts. But biochemistry, of course, cannot be understood without a knowledge of the fundamentals of organic chemistry, and understanding organic chemistry in turn depends on knowing the key concepts of general chemistry. Thus, in writing this text, I essentially started from the back and worked forward. I began by determining what topics would be considered in the biochemistry chapters and then tailored the organic and then general sections to support that presentation. Users of the previous editions confirm that this approach ensures an efficient but thorough coverage of the principles needed to understand biochemistry.

Art Program See the story of general, organic, and biological chemistry come alive on each page! In addition to the narrative, the art and photography program helps tell a very important story—the story of ourselves and the world around us. Chemistry is everywhere! An integrated talking label system in the art and photography program gives key figures a "voice" and helps students learn more effectively.

Emphasis on Visual Support I believe strongly in visual reinforcement of key concepts in a textbook; thus this book uses art and photos wherever possible to teach key concepts. Artwork is used to make connections and highlight what is important for the student to know. Reaction equations use color to emphasize the portions of a molecule that undergo change. Colors are likewise assigned to things like valence shells and classes of compounds to help students follow trends. Computer-generated, three-dimensional molecular models accompany many discussions in the organic and biochemistry sections of the text. Color photographs show applications of chemistry to help make concepts real and more readily remembered. The following example is representative of the art program.



a Arrangement of protein backbone with no detail shown.

b Backbone arrangement with hydrogen-bonding interactions shown.

c Backbone atomic detail shown, as well as hydrogen-bonding interactions.

d Top view of an α helix showing that amino acid side chains (R groups) point away from the long axis of the helix.

Chemistry at a Glance Visual summaries called *Chemistry at a Glance* pull together material from several sections of a chapter to help students see the larger picture. Representative of such features are those entitled

- Relationships involving the Mole Concept (Section 6-7)
- Factors that increase Chemical Reaction Rates (Section 9-6)
- Properties of Alkanes and Cycloalkanes (Section 12-17)

- Types of Glycosidic Linkages for Disaccharides and Polysaccharides (Section 18-17)
- Types of Lipids in Terms of How They Function (Section 19-14)
- Summary of the Reactions of the Citric Acid Cycle (Section 23-7)

Given the popularity of the *Chemistry at a Glance* summaries in the previous editions, several new ones have been added and several existing ones have been revised. New and revised *Chemistry at a Glance* topics include:

- Types of Unsaturated Hydrocarbon (Section 13-16)
- Summary of Chemical Reactions Involving Alcohols (Section 14-9)
- Summary of Chemical Reactions Involving Carboxylic Acids (Section 16-7)
- Constitution Isomers and Stereoisomers (Section 18-6)
- Interrelationships Among Carbohydrate, Lipid, and Protein Metabolism (Section 26-8)

Chemical Connections In every chapter *Chemical Connection* boxes emphasize the relevancy of chemical topics under consideration. They focus on issues relevant to a student's own life in terms of health issues, societal issues, and environmental issues. Representative of issues selected for *Chemical Connection* coverage are the following:

- Fresh Water, Seawater, Hard Water, and Soft Water (Section 4-8)
- The Chemical Sense of Smell (Section 5-8)
- Stratospheric Ozone: An Equilibrium Situation (Section 9-8)
- Red Wine and Resveratrol (Section 14-14)
- The Fatty Content of Tree Nuts and Peanuts (Section 19-4)

New topics selected for *Chemical Connection* emphasis in this edition are:

- Electrons in Excited States (Section 3-7)
- Edible Fiber and Health (Section 18-17)
- The Circadian Clock: Clock Genes (Section 22-9)
- EPO: Red Blood Cells, Mutations, and Athletic Performance (Section 22-13)
- Adenosine Phosphates and Muscle Relaxation/Contraction (Section 23-3)
- Phytochemicals: Compounds with Color and Antioxidant Properties (Section 23-11)

Updated *Chemical Connection* boxes include

- Elemental Composition of the Human Body (Section 1-7)
- Combustion Reactions: Carbon Dioxide and Global Warming (Section 9-1)
- Human Body Temperature and Chemical Reaction Rates (Section 9-6)
- Electrolytes and Body Fluids (Section 10-15)
- Caffeine: A Widely Used Central Nervous System Stimulant (Section 17-9)
- Lactose Intolerance or Lactase Persistence (Section 18-13)
- Trans Fatty Acid Content of Foods (Section 19-6)
- Enzymes, Prescription Medications and the "Grapefruit Effect" (Section 21-11)

Commitment to Student Learning In addition to the study help *Chemistry at a Glance* offers, the text is built on a strong foundation of learning aids designed to help students master the course material.

- **Problem-solving pedagogy.** Because problem solving is often difficult for students in this course to master, I have taken special care to provide support to help students build their skills. Within the chapters, worked-out *Examples* follow the explanation of many concepts. These examples walk students through the thought processes involved in problem solving, carefully outlining all of the steps involved.

Diversity of Worked-out Examples *Worked-out examples* are a standard feature in the general chemistry portion of all textbooks for this market. This relates primarily to the mathematical nature of many general chemistry topics. In most texts, fewer worked-out examples appear in the organic chemistry chapters, and still fewer (almost none) are found in the biochemistry portion due to decreased dependence of the topical matter on mathematical concepts. Such is not the case in this textbook. All chapters in the latter portions of the text contain numerous worked-out examples. Several additional worked-out examples have been added to this new edition. Newly added worked-out examples include the following topics:

- Classifying Matter as a Pure Substance or a Mixture (Section 1-3)
- Classifying Substances as Elements or Compounds (Section 1-7)
- Distinguishing Between Chemical Symbols and Chemical Formulas (Section 1-8)
- Diagramming Coordinate Covalent Bond Formation Using Lewis Structures (Section 5-2)
- Using Delta Notation to Specify the Direction of Bond Polarity (Section 5-6)
- Using Electronegativity Difference to Predict Chemical Bond Type (Section 5-7)
- Using Clinical Laboratory Concentration Units (Section 8-7)
- Converting an Ion Concentration from moles/L to mEq/L (Section 10-13)
- Identifying Components of a Nucleotide (Section 22-1)
- **Margin notes.** Liberally distributed throughout the text, *margin notes* provide tips for remembering and distinguishing between concepts, highlight links across chapters, and describe interesting historical background information.
- **Defined terms.** All definitions are highlighted in the text when they are first presented, using boldface and italic type. Each defined term appears as a complete sentence; students are never forced to deduce a definition from context. In addition, the definitions of all terms appear in the combined *Index/Glossary* found at the end of the text. A major emphasis in this new edition has been "refinements" of the defined terms. All defined terms were reexamined to see if they could be stated with greater clarity. The result was a "rewording" of many defined terms.
- **Concepts to Remember review.** A concise review of key concepts presented in each chapter appears at the end of the chapter, placed just before the end-of-chapter problems. This is a helpful aid for students as they prepare for exams.
- **End-of-chapter problems.** An extensive set of end-of-chapter problems complements the worked-out examples within the chapters. These end-of-chapter problems are organized by topic and paired, with each pair testing similar material. The answer to the odd-numbered member of the pair is given at the back of the book are two problem-set features:

    Problems denoted with a ▲ involve concepts found not only in the section under consideration but also concepts found in one or more earlier sections of the chapter.

Over 1000 of the 3284 total end-of-chapter problems are new to this edition of the text. This total number of end-of-chapter problems significantly exceeds that of most other texts.

Content Changes Coverage of a number of topics has been expanded in this edition. The two driving forces in expanded coverage considerations were (1) the requests of users and reviewers of the previous editions and (2) my desire to incorporate new research findings, particularly in the area of biochemistry, into the text. Topics with expanded coverage include:

- Clinical Laboratory Concentration Units (Section 8-5)
- Concentration Units for Isotopic Solutions (Section 8-10)
- Equivalents and Milliequivalents of Electrolytes (Section 10-15)
- Charge Balance in Electrolytic Solutions (Section 10-15)

- Preparation of Alkenes (Section 13-9)
- Functional Group Isomerism (Section 14-7)
- Alcohol Condensation Reactions (Section 14-9)
- Carboxylic Acid Decarboxylation Reactions (Section 16-9)
- OxyContin Formulations (Section 17-12)
- Medical Uses of Enzymes (Section 21-11)
- Fat-Soluble Vitamins (Section 21-15)
- The Human Transcriptome (Section 22-9)
- Mutations (Section 22-13)
- Transamination Reactions (Section 26-3)
- Proteins and the Element Sulfur (Section 26-8)

Supporting Materials

Please visit **http://www.cengage.com/chemistry/stoker/gob7E** for information about the student and instructor resources for this text.

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Basic Concepts About Matter

1

Chapter Outline

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Numerous physical and chemical changes in matter occur during a volcanic eruption.

In this chapter, the question "What exactly is chemistry about?" is addressed. In addition, common terminology associated with the field of chemistry is considered. Much of this terminology is introduced in the context of the ways in which matter is classified. Like all other sciences, chemistry has its own specific language. It is necessary to restrict the meanings of some words so that all chemists (and those who study chemistry) can understand a given description of a chemical phenomenon in the same way.

1-1 Chemistry: The Study of Matter

LEARNING FOCUS

Define the term *matter*; indicate whether or not various entities are considered to be matter.

Chemistry *is the field of study concerned with the characteristics, composition, and transformations of matter.* What is matter? **Matter** *is anything that has mass and occupies space.* The term *mass* refers to the amount of matter present in a sample. ◀

▶ *The mass of a sample of matter is a measure of the amount of matter present in the sample.*

Matter includes all naturally occurring things—both living and nonliving—that can be seen (such as plants, soil, and rocks), as well as things that cannot be seen (such as air and bacteria). Matter also includes materials that do not occur naturally, that is, synthetic materials that are produced in a laboratory or industrial setting using, directly or indirectly, naturally occurring starting materials. Various forms of energy such as heat, light, and electricity are not considered to be matter. However, chemists must be concerned with energy as well as with matter because nearly all changes that matter undergoes involve the release or absorption of energy. ◀

▶ *The universe is composed entirely of matter and energy.*

The scope of chemistry is extremely broad, and it touches every aspect of our lives. An iron gate rusting, a chocolate cake baking, the production in a laboratory of an antibiotic or a plastic composite, the diagnosis and treatment of a heart attack, the propulsion of a jet airliner, and the digesting of food all fall within the realm of chemistry. The key to understanding such diverse processes is understanding the fundamental nature of matter, which is what is now considered.

Section 1-1 Quick Quiz

1. Which of the following is a characteristic of all types of matter?
   - **a.** naturally occurring
   - **b.** visible to the naked eye
   - **c.** has mass
   - **d.** no correct response
2. Which of the following is classified as matter?
   - **a.** heat energy
   - **b.** a scientific theory
   - **c.** chocolate milk
   - **d.** no correct response
3. Which of the following processes does not fall within the realm of chemistry?
   - **a.** detonation of an explosive
   - **b.** cooking of a hamburger patty
   - **c.** production of a blood pressure medication
   - **d.** no correct response

Answers: 1. c; 2. c; 3. d

1-2 Physical States of Matter

LEARNING FOCUS

Characterize each of the three states of matter in terms of the definiteness or indefiniteness of its shape and volume.

Three physical states exist for matter: solid, liquid, and gas. The classification of a given matter sample in terms of physical state is based on whether its shape and volume are definite or indefinite. ◀

▶ *The* volume *of a sample of matter is a measure of the amount of space occupied by the sample.*

Solid *is the physical state characterized by a definite shape and a definite volume.* A dollar coin has the same shape and volume whether it is placed in a large container or on a table top (Figure 1-1a). For solids in powdered or granulated forms, such as sugar or salt, a quantity of the solid takes the shape of the portion of the container it occupies, but each individual particle has a definite shape and definite volume. **Liquid** *is the physical state characterized by an indefinite shape and a definite volume.* A liquid always takes the shape of its container to the extent that it fills the container (Figure 1-1b). **Gas** *is the physical state characterized by an indefinite shape and an indefinite volume.* A gas always completely fills its container, adopting both the container's volume and its shape (Figure 1-1c).

The state of matter observed for a particular substance depends on its temperature, the surrounding pressure, and the strength of the forces holding its structural particles together. At the temperatures and pressures normally encountered on Earth, water is one of the few substances found in all three physical states: solid ice, liquid

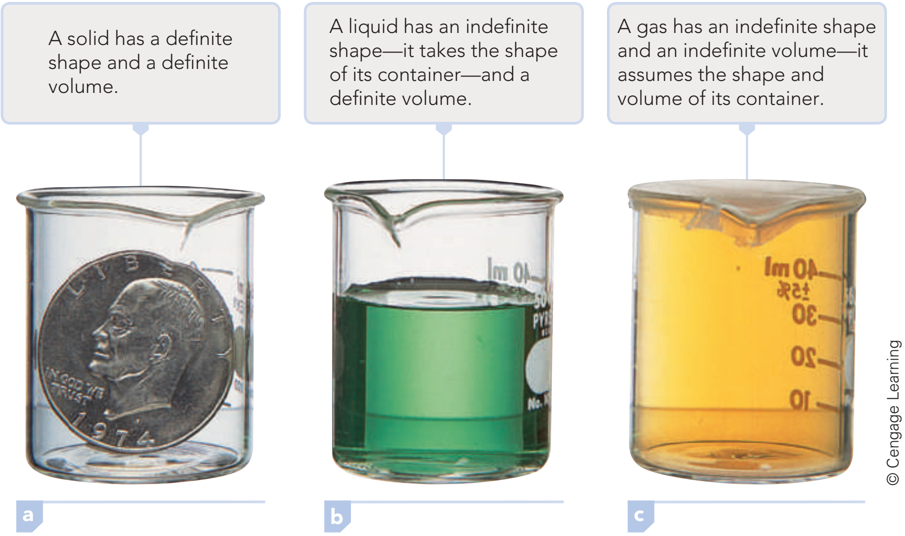

Figure 1-1 A comparison of the volume and shape characteristics of solids, liquids, and gases.

water, and gaseous steam (Figure 1-2). Under laboratory conditions, states other than those commonly observed can be attained for almost all substances. Oxygen, which is nearly always thought of as a gas, becomes a liquid at −183°C and a solid at −218°C. The metal iron is a gas at extremely high temperatures (above 3000°C).

Section 1-2 Quick Quiz

1. Which of the following is a characteristic of both liquids and gases?
a. definite shape
b. definite volume
c. indefinite shape
d. no correct response

2. The characterization "completely fills its container" describes the
a. solid state
b. liquid state
c. gaseous state
d. no correct response

3. The characterization "indefinite shape, definite volume" applies to
a. a solid
b. a liquid
c. both a solid and a liquid
d. no correct response

Answers: 1. c; 2. c; 3. b

1-3 Properties of Matter

LEARNING FOCUS

Classify a given property of a substance as a *physical property* or a *chemical property*.

Various kinds of matter are distinguished from each other by their properties. A **property** *is a distinguishing characteristic of a substance that is used in its identification and description.* Each substance has a unique set of properties that distinguishes it from all other substances. Properties of matter are of two general types: physical and chemical.

A **physical property** *is a characteristic of a substance that can be observed without changing the basic identity of the substance.* Common physical properties include color, physical state (solid, liquid, or gas), melting point, boiling point, and hardness. ◀

▶ *Physical properties are properties associated with a substance's physical existence. They can be determined without reference to any other substance, and determining them causes no change in the identity of the substance.*

Figure 1-2 Water can be found in the solid, liquid, and vapor (gaseous) forms simultaneously, as shown here at Yellowstone National Park.

FRILET Patrick / Hemis / Alamy

Andy Levin/Science Source

Figure 1-3 The green color of the Statue of Liberty results from the reaction of the copper skin of the statue with the components of air. That copper will react with the components of air is a chemical property of copper.

▶ *Chemical properties describe the ability of a substance to form new substances, either by reaction with other substances or by decomposition.*

During the process of determining a physical property, the physical appearance of a substance may change, but the substance's identity does not. For example, it is impossible to measure the melting point of a solid without changing the solid into a liquid. Although the liquid's appearance is much different from that of the solid, the substance is still the same; its chemical identity has not changed. Hence, melting point is a physical property.

A **chemical property** *is a characteristic of a substance that describes the way the substance undergoes or resists change to form a new substance.* For example, copper objects turn green when exposed to moist air for long periods of time (Figure 1-3); this is a chemical property of copper. The green coating formed on the copper is a new substance that results from the copper's reaction with oxygen, carbon dioxide, and water present in air. The properties of this new substance (the green coating) are very different from those of metallic copper. On the other hand, gold objects resist change when exposed to air for long periods of time. The lack of reactivity of gold with air is a chemical property of gold.

Most often, the changes associated with chemical properties result from the interaction (reaction) of a substance with one or more other substances. However, the presence of a second substance is not an absolute requirement. Sometimes the presence of energy (usually heat or light) can trigger the change known as *decomposition.* That hydrogen peroxide, in the presence of either heat or light, decomposes into the substances water and oxygen is a chemical property of hydrogen peroxide. ◀

When chemical properties are specified, conditions such as temperature and pressure are usually given because they influence the interactions between substances. For example, the gases oxygen and hydrogen do not react with each other at room temperature, but they react explosively at a temperature of several hundred degrees.

EXAMPLE 1-1

Classifying Properties as Physical or Chemical

Classify each of the following properties of selected metals as a *physical* property or a *chemical* property.

a. Iron metal rusts in an atmosphere of moist air.
b. Mercury metal is a liquid at room temperature.
c. Nickel metal dissolves in acid to produce a light green solution.
d. Potassium metal has a melting point of 63°C.

Solution

a. *Chemical property*. The interaction of iron metal with moist air produces a new substance (rust).
b. *Physical property*. Visually determining the physical state of a substance does not produce a new substance.
c. *Chemical property*. A change in color indicates the formation of a new substance.
d. *Physical property*. Measuring the melting point of a substance does not change the substance's composition.

The focus on relevancy feature Chemical Connections 1-A—Carbon Monoxide: A Substance with Both "Good" and "Bad" Properties—discusses the important concept that a decision about the significance or usefulness of a substance should not be made solely on the basis of just one or two of its many chemical or physical properties. The discussion there focuses on both the "bad" and "good" properties possessed by the gas carbon monoxide.

CHEMICAL CONNECTIONS 1-A

Carbon Monoxide: A Substance with Both "Good" and "Bad" Properties

Possession of a "bad" property, such as toxicity or a strong noxious odor, does not mean that a chemical substance has nothing to contribute to the betterment of human society. The gas carbon monoxide is an important example of this concept.

It is common knowledge that carbon monoxide is toxic to humans and at higher concentrations can cause death. This gas, which can be present in significant concentrations in both automobile exhaust and cigarette smoke, impairs human health by reducing the oxygen-carrying capacity of the blood. It does this by interacting with the hemoglobin in red blood cells in a way that prevents the hemoglobin from distributing oxygen throughout the body. Someone who dies from carbon monoxide poisoning actually dies from lack of oxygen. (Additional information about the human health effects of the air pollutant carbon monoxide is found in Chemical Connections 6-A) Because of its toxicity, many people automatically label carbon monoxide a "bad substance," a substance that is not wanted and not needed.

The fact that carbon monoxide is colorless, odorless, and tasteless is very significant. Because of these properties, carbon monoxide gives no warning of its initial presence. Several other common air pollutants are more toxic than carbon monoxide. However, they have properties that warn of their presence and hence are not considered as "dangerous" as carbon monoxide.

Despite its toxicity, carbon monoxide plays an important role in the maintenance of the high standard of living we now enjoy. Its contribution lies in the field of iron metallurgy and the production of steel. The isolation of iron from iron ores, necessary for the production of steel, involves a series of high-temperature reactions, carried out in a blast furnace, in which the iron content of molten iron ores reacts with carbon monoxide. These reactions release the iron from its ores. The carbon monoxide needed in steel-making is obtained by reacting coke (a product derived by heating coal to a high temperature without air being present) with oxygen.

The industrial consumption of the metal iron, both in the United States and worldwide, is approximately 10 times greater than that of all other metals combined. Steel production accounts for nearly all of this demand for iron. Without steel, our standard of living would drop dramatically, and carbon monoxide is necessary for the production of steel.

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Carbon monoxide is needed to produce molten iron from iron ore in a blast furnace.

Is carbon monoxide a "good" or a "bad" chemical substance? The answer to this question depends on the context in which the carbon monoxide is encountered. In terms of air pollution, it is a "bad" substance. In terms of steel-making, it is a "good" substance. A similar "good–bad" dichotomy exists for almost every chemical substance.

Section 1-3 Quick Quiz

1. Which of the following statements about various substances describes a *physical* property of the substance?
   a. Copper metal can be drawn into thin wires.
   b. Gold metal does not tarnish in air.
   c. Hydrogen peroxide decomposes in the presence of light.
   d. no correct response
2. Which of the following statement about various substances describes a *chemical* property of the substance?
   a. Silver metal will not dissolve in hydrochloric acid.
   b. Beryllium metal has a silvery-gray color.
   c. Water (ice) melts at 32°F.
   d. no correct response
3. In which of the following pairs of properties are both *physical* properties?
   a. low density, flammable
   b. reacts with oxygen, does not react with iodine
   c. very brittle, very toxic
   d. no correct response

Answers: 1. a; 2. a; 3. d

1-4 Changes in Matter

LEARNING FOCUS

Classify a given change that occurs in matter as a *physical change* or a *chemical change*.

Changes in matter are common and familiar occurrences. Changes take place when food is digested, paper is burned, and a pencil is sharpened. Like properties of matter, changes in matter are classified into two categories: physical and chemical.

A **physical change** *is a process in which a substance changes its physical appearance but not its chemical composition.* A new substance is never formed as a result of a physical change. ◀

▶ *Physical changes need not involve a change of state. Pulverizing an aspirin tablet into a powder and cutting a piece of adhesive tape into small pieces are physical changes that involve only the solid state.*

A change in physical state is the most common type of physical change. Melting, freezing, evaporation, and condensation are all changes of state. In any of these processes, the composition of the substance undergoing change remains the same even though its physical state and appearance change. The melting of ice does not produce a new substance; the substance is water both before and after the change. Similarly, the steam produced from boiling water is still water.

A **chemical change** *is a process in which a substance undergoes a change in chemical composition.* Chemical changes always involve conversion of the material or materials under consideration into one or more new substances, each of which has properties and a composition distinctly different from those of the original materials. Consider, for example, the rusting of iron objects left exposed to moist air (Figure 1-4). The reddish-brown substance (the rust) that forms is a new substance with chemical properties that are obviously different from those of the original iron.

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Figure 1-4 As a result of chemical change, bright steel girders become rusty when exposed to moist air.

EXAMPLE 1-2

Correct Use of the Terms *Physical* and *Chemical* in Describing Changes

Complete each of the following statements about changes in matter by placing the word *physical* or *chemical* in the blank.

a. The fashioning of a piece of wood into a round table leg involves a __________ change.
b. The vigorous reaction of potassium metal with water to produce hydrogen gas is a __________ change.
c. Straightening a bent piece of iron with a hammer is an example of a __________ change.
d. The ignition and burning of a match involve a __________ change.

Solution

a. *Physical.* The table leg is still wood. No new substances have been formed.
b. *Chemical.* A new substance, hydrogen, is produced.
c. *Physical.* The piece of iron is still a piece of iron.
d. *Chemical.* New gaseous substances, as well as heat and light, are produced as the match burns.

Chemists study the nature of changes in matter to learn how to bring about favorable changes and prevent undesirable ones. The control of chemical change has been a major factor in attaining the modern standard of living now enjoyed by most people in the developed world. The many plastics, synthetic fibers, and prescription drugs now in common use are produced using controlled chemical change.

Chemistry at a Glance—Use of the Terms *Physical* and *Chemical*—reviews the ways in which the terms *physical* and *chemical* are used to describe the properties of substances and the changes that substances undergo. Note that the term *physical*, used as a modifier, always conveys the idea that the composition (chemical identity) of a substance did not change, and that the term *chemical*, used as a modifier, always conveys the idea that the composition of a substance did change.

Section 1-4 Quick Quiz

1. Which of the following processes is not a *physical* change?
   a. crushing ice cubes to make ice chips
   b. melting ice cubes to produce liquid water
   c. freezing liquid water to produce ice cubes
   d. no correct response
2. Which of the following processes is an example of *chemical* change?
   a. grating a piece of cheese
   b. burning a piece of wood
   c. pulverizing a hard sugar cube
   d. no correct response
3. Which of the following is always a characteristic of *chemical* change?
   a. heat is produced
   b. light is emitted
   c. one or more new substances are produced
   d. no correct answer

Answers: 1. d; 2. b; 3. c

1-5 Pure Substances and Mixtures

LEARNING FOCUS

Know the major differences among the matter classifications *pure substance, heterogeneous mixture,* and *homogeneous mixture.*

In addition to its classification by physical state (Section 1-2), matter can also be classified in terms of its chemical composition as a pure substance or as a mixture. A **pure substance** *is a single kind of matter that cannot be separated into other kinds of matter by any physical means.* All samples of a pure substance contain only that substance and nothing else. Pure water is water and nothing else. Pure sucrose (table sugar) contains only that substance and nothing else. ◀

▶ Substance *is a general term used to denote any variety of matter.* Pure substance *is a specific term that is applied to matter that contains only a single substance. All samples of a pure substance, no matter what their source, have the same properties under the same conditions.*

A pure substance always has a definite and constant composition. This invariant composition dictates that the properties of a pure substance are always the same under a given set of conditions. Collectively, these definite and constant physical and chemical properties constitute the means by which we identify the pure substance.

A **mixture** *is a physical combination of two or more pure substances in which each substance retains its own chemical identity.* Components of a mixture retain their

CHEMISTRY AT A GLANCE Use of the Terms *Physical* and *Chemical*

PHYSICAL

This term conveys the idea that the composition (chemical identity) of a substance DOES NOT CHANGE.

Physical Properties

Properties observable without changing composition

- Color and shape
- Solid, liquid, or gas
- Boiling point, melting point

Physical Changes

Changes observable without changing composition

- Change in physical state (melting, boiling, freezing, etc.)
- Change in state of subdivision with no change in physical state (pulverizing a solid)

CHEMICAL

This term conveys the idea that the composition (chemical identity) of a substance DOES CHANGE.

Chemical Properties

Properties that describe how a substance changes (or resists change) to form a new substance

- Flammability (or non-flammability)
- Decomposition at a high temperature (or lack of decomposition)
- Reaction with chlorine (or lack of reaction with chlorine)

Chemical Changes

Changes in which one or more new substances are formed

- Decomposition
- Reaction with another substance

identity because they are physically mixed rather than chemically combined. Consider a mixture of small rock salt crystals and ordinary sand. Mixing these two substances changes neither the salt nor the sand in any way. The larger, colorless salt particles are easily distinguished from the smaller, light-gray sand granules.

One characteristic of any mixture is that its components can be separated by using physical means. In our salt–sand mixture, the larger salt crystals could be—though very tediously—"picked out" from the sand. A somewhat easier separation method would be to dissolve the salt in water, which would leave the undissolved sand behind. The salt could then be recovered by evaporation of the water. Figure 1-5a shows a mixture of potassium dichromate (orange crystals) and iron filings. A magnet can be used to separate the components of this mixture (Figure 1-5b).

Another characteristic of a mixture is variable composition. Numerous different salt–sand mixtures, with compositions ranging from a slightly salty sand mixture to a slightly sandy salt mixture, could be made by varying the amounts of the two components. ◀

▶ *Most naturally occurring samples of matter are mixtures. Gold and diamond are two of the few naturally occurring pure substances. Despite their scarcity in nature, numerous pure substances exist. They are obtained from natural mixtures by using various types of separation techniques or are synthesized in the laboratory from naturally occurring materials.*

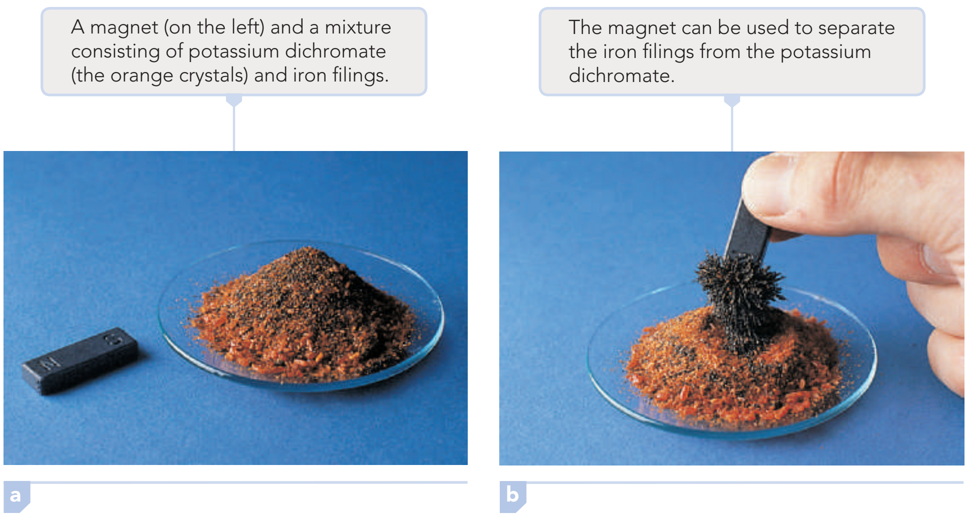

Figure 1-5 Physical separation of the two components of a mixture using the magnetic properties of one of the mixture components.

(a) James Scherer © Cengage Learning; (b) © Cengage Learning

Mixtures are subclassified as heterogeneous or homogeneous. This subclassification is based on visual recognition of the mixture's components. A **heterogeneous mixture** *is a mixture that contains visibly different phases (parts), each of which has different properties.* A nonuniform appearance is a characteristic of all heterogeneous mixtures. Examples include chocolate chip cookies and blueberry muffins. Naturally occurring heterogeneous mixtures include rocks, soils, and wood.

A **homogeneous mixture** *is a mixture that contains only one visibly distinct phase (part), which has uniform properties throughout.* The components present in a homogeneous mixture cannot be visually distinguished. A sugar–water mixture in which all of the sugar has dissolved has an appearance similar to that of pure water. Air is a homogeneous mixture of gases; motor oil and gasoline are multicomponent homogeneous mixtures of liquids; and metal alloys such as 14-karat gold (a mixture of copper and gold) are examples of homogeneous mixtures of solids. The homogeneity present in solid-state metallic alloys is achieved by mixing the metals while they are in the molten state. ◀

▶ *All human body fluids, such as urine, blood, or sweat are mixtures of many substances. Since their components cannot be visually distinguished from each other, they are* homogeneous *mixtures.*

Figure 1-6 summarizes key concepts presented in this section about various classifications of matter.

EXAMPLE 1-3

Classifying Matter as a Pure Substance or a Mixture

Classify each of the following as a *heterogeneous mixture*, a *homogeneous mixture*, or a *pure substance*. Assume that each sample has been well stirred.

a. a "pinch" of table salt, one quart of water
b. a "pinch" of ground black pepper, one quart of water
c. one substance present, one phase present
d. two substances present, same properties throughout

Solution

a. Two substances present means *mixture*; since table salt is soluble in water only one phase is present, a characteristic of a *homogeneous mixture*.
b. Two substances present means *mixture*; since black pepper is insoluble in water two phases are present (solid and liquid), a characteristic of a *heterogeneous mixture*.
c. One substance present means *pure substance* rather than mixture; a mixture requires the presence of two substances. The presence of two phases does not cause the classification to change from pure substance to mixture. An example of a "one substance, two phase" situation is ice cubes in water. Water (a pure substance) is present in two states (solid and liquid).
d. This *mixture* (two substances present) is a *homogeneous mixture* as the same properties throughout denotes homogeneity.

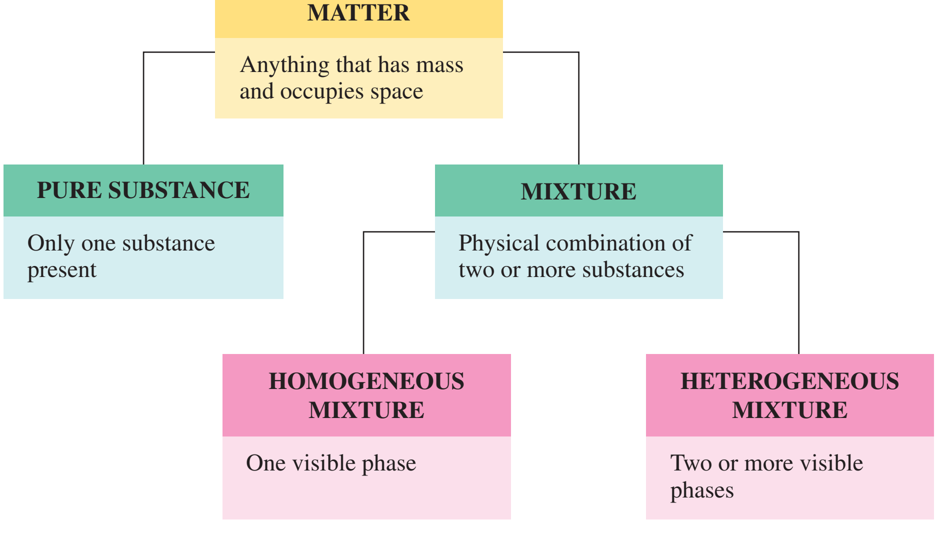

Figure 1-6 Matter falls into two basic classes: pure substances and mixtures. Mixtures, in turn, may be homogeneous or heterogeneous.