Cengage

TENTH EDITION

CHEMISTRY FOR TODAY

GENERAL, ORGANIC, AND BIOCHEMISTRY

SEAGER | SLABAUGH | HANSEN

PERIODIC TABLE OF THE ELEMENTS

KEY

- 79 — Atomic number
- Au — Symbol
- Gold — Name
- 197.0 — Atomic weight (rounded to four significant figures)

Metals · Metalloids · Nonmetals, noble gases

Group number, IUPAC system — (1)
Group number, U.S. system — IA
Group designation — (2) IIA
Period number

Period	(1) IA	(2) IIA	(3) IIIB	(4) IVB	(5) VB	(6) VIB	(7) VIIB	(8) VIIIB	(9) VIIIB	(10) VIIIB	(11) IB	(12) IIB	(13) IIIA	(14) IVA	(15) VA	(16) VIA	(17) VIIA	Noble Gases (18) VIIIA	Period
1	1 **H** Hydrogen 1.008																	2 **He** Helium 4.003	1
2	3 **Li** Lithium 6.94	4 **Be** Beryllium 9.012											5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18	2
3	11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.31											13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.06	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95	3
4	19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.87	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.63	33 **As** Arsenic 74.92	34 **Se** Selenium 78.96	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80	4
5	37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.96	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.1	45 **Rh** Rhodium 102.9	46 **Pd** Palladium 106.4	47 **Ag** Silver 107.9	48 **Cd** Cadmium 112.4	49 **In** Indium 114.8	50 **Sn** Tin 118.7	51 **Sb** Antimony 121.8	52 **Te** Tellurium 127.6	53 **I** Iodine 126.9	54 **Xe** Xenon 131.3	5
6	55 **Cs** Cesium 132.9	56 **Ba** Barium 137.3	57 **La** Lanthanum 138.9	72 **Hf** Hafnium 178.5	73 **Ta** Tantalum 180.9	74 **W** Tungsten 183.8	75 **Re** Rhenium 186.2	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.2	78 **Pt** Platinum 195.1	79 **Au** Gold 197.0	80 **Hg** Mercury 200.6	81 **Tl** Thallium 204.4	82 **Pb** Lead 207.2	83 **Bi** Bismuth 209.0	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)	6
7	87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (265)	105 **Db** Dubnium (268)	106 **Sg** Seaborgium (271)	107 **Bh** Bohrium (270)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (276)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (280)	112 **Cn** Copernicium (285)	113 **Nh** Nihonium (284)	114 **Fl** Flerovium (289)	115 **Mc** Moscovium (288)	116 **Lv** Livermorium (293)	117 **Ts** Tennessine (294)	118 **Og** Oganesson (294)	7

Mass numbers in parentheses are the most stable radioactive isotope.

Period															Period
6	58 **Ce** Cerium 140.1	59 **Pr** Praseodymium 140.9	60 **Nd** Neodymium 144.2	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.4	63 **Eu** Europium 152.0	64 **Gd** Gadolium 157.3	65 **Tb** Terbium 158.9	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 164.9	68 **Er** Erbium 167.3	69 **Tm** Thulium 168.9	70 **Yb** Ytterbium 173.0	71 **Lu** Lutetium 175.0	6
7	90 **Th** Thorium 232.0	91 **Pa** Protactinium 231.0	92 **U** Uranium 238.0	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)	7

TENTH EDITION

Chemistry for Today

General, Organic, and Biochemistry

Spencer L. Seager
Weber State University

Michael R. Slabaugh
University of South Dakota
Weber State University

Maren S. Hansen
University of South Dakota

Cengage

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This 10th edition is dedicated to the memory of Wayne Aprill, a high school science teacher who touched the lives of everyone around him; students, family and many good friends.

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Maren S. Hansen has been a science teacher at West High School, where she taught honors biology. She has also taught AP biology and biology in the International Baccalaureate Program. She received her B.A. and master of education degrees from Weber State University. Her professional interests have focused upon helping students participate in Science Olympiad and Science Fair. Other interests include adventure travel, mountain hiking, gardening, and the company of friends and family. She hopes to share her love of science with her two children. She currently serves as an adjunct professor at the University of South Dakota, where she teaches online courses in general chemistry, elementary organic chemistry, and elementary biochemistry.

Brief Contents

Contents

Chapter 8

Reaction Rates and Equilibrium 236

Chapter 9

Acids, Bases, and Salts 260

Chapter 10

Radioactivity and Nuclear Processes 304

Chapter 22

Nutrition and Energy for Life 706

Chapter 23

Carbohydrate Metabolism 736

Chapter 24

Lipid and Amino Acid Metabolism 762

Preface

The Image of Chemistry

We, as authors, are pleased that the acceptance of the previous nine editions of this textbook by students and their teachers has made it possible to publish this tenth edition. In the earlier editions, we expressed our concern about the negative image of chemistry held by many of our students, and their genuine fear of working with chemicals in the laboratory. Unfortunately, this negative image not only persists, but seems to be intensifying. Reports in the media related to chemicals or to chemistry continue to be primarily negative, and in many cases seem to be designed to increase the fear and concern of the general public. With this edition, we continue to hope that those who use this book will gain a more positive understanding and appreciation of the important contributions that chemistry makes in their lives.

Theme and Organization

This edition continues the theme of the positive and useful contributions made by chemistry in our world.

This text is designed to be used in either a two-semester or three-quarter course of study that provides an introduction to general chemistry, organic chemistry, and biochemistry. Most students who take such courses are majoring in nursing, other health professions, or the life sciences, and consider biochemistry to be the most relevant part of the course of study. However, an understanding of biochemistry depends upon a sound background in organic chemistry, which in turn depends upon a good foundation in general chemistry. We have attempted to present the general and organic chemistry in sufficient depth and breadth to make the biochemistry understandable.

The decisions about what to include and what to omit from the text were based on our combined 75-plus years of teaching, input from numerous reviewers and adopters, and our philosophy that a textbook functions as a personal tutor to each student. In the role of a personal tutor, a text must be more than just a collection of facts, data, and exercises. It should also help students relate to the material they are studying, carefully guide them through more difficult material, provide them with interesting and relevant examples of chemistry in their lives, and become a reference and a resource that they can use in other courses or their professions.

New to This Edition

In this tenth edition of the text, we have some exciting new features, including Career Focus boxes written by Monica Linford and Health Connections. We have also retained features that received a positive reception from our own students, the students of other adopters, other teachers, and reviewers. Over 133 figures and 170 examples have been added to the chapters. Many of these new figures and examples are health-related. Moreover, 559 end-of-chapter exercises have been added.

Also new to this edition are many new photographs and updated art to further enhance student comprehension of key concepts, processes, and test preparation.

Revision Summary of Tenth Edition

Chapter 1

- New Career Focus
- New Career Description
- 8 new or revised figures
- 11 new or revised Examples
- New photography
- 22 new Exercises

Chapter 2

- New Career Focus
- New Career Description
- 5 new or revised Examples
- 7 new or revised figures
- New photography
- 10 new Exercises

Chapter 3

- New Career Focus
- New Career Description
- 4 new or revised Examples
- 4 new or revised figures
- New photography
- 10 revised Exercises

Chapter 4

- New Career Focus
- New Career Description
- 10 new or revised Examples
- 6 new or revised figures
- New photography
- 12 new or revised Exercises

Chapter 5

- New Career Focus
- New Career Description
- 4 new or revised figures
- 6 new or revised Examples
- New photography
- 11 new or revised Exercises

Chapter 6

- New Career Focus
- New Career Description
- 8 new or revised Examples
- 8 new or revised figures
- New photography
- 22 new Exercises

Chapter 7

- New Career Focus
- New Career Description
- 8 new or revised figures
- New photography
- 7 new or revised Examples
- 9 new Exercises

Chapter 8

- New Career Focus
- New Career Description
- 3 new or revised Examples
- Several revised figures
- New photography

Chapter 9

- New Career Focus
- New Career Description
- 7 new or revised Examples
- 12 new or revised figures
- New photography
- 19 new Exercises

Chapter 10

- New Career Focus
- New Career Description
- 3 new or revised Examples
- 7 new or revised figures
- New photography
- 5 new Exercises

Chapter 11

- New Career Focus
- New Career Description
- 9 new or revised Examples
- 9 new or revised figures
- New photography
- 30 new Exercises

Chapter 12

- New Career Focus
- New Career Description
- 7 new or revised Examples
- 7 new or revised figures
- New photography
- 29 new Exercises

Chapter 13

- New Career Focus
- New Career Description
- 12 new or revised Examples
- 6 new or revised figures
- New photography
- 33 new Exercises

Chapter 14

- New Career Focus
- New Career Description
- 6 new or revised Examples
- New photography
- 36 new Exercises

Chapter 15

- New Career Focus
- New Career Description
- 4 new or revised Examples
- 5 new or revised figures
- New photography
- 31 new Exercises

Chapter 16

- New Career Focus
- New Career Description
- 11 new or revised Examples
- 5 new or revised figures
- New photography
- 31 new Exercises

Chapter 17

- New Career Focus
- New Career Description
- 7 new or revised Examples
- 4 new or revised figures
- New photography
- 30 new Exercises

Chapter 18

- New Career Focus
- New Career Description
- 10 new or revised Examples
- 7 new or revised figures
- New photography
- 30 new Exercises

Chapter 19

- New Career Focus
- New Career Description
- 7 new or revised Examples
- 5 new or revised figures
- New photography
- 30 new Exercises

Chapter 20

- New Career Focus
- New Career Description
- 5 new or revised Examples
- 6 new or revised figures
- New photography
- 30 new Exercises

Chapter 21

- New Career Focus
- New Career Description
- 5 new or revised Examples
- New photography
- 30 new Exercises

Chapter 22

- New Career Focus
- New Career Description
- 6 new or revised Examples
- Figure revised to show a current food label
- New photography
- 30 new Exercises

Chapter 23

- New Career Focus
- New Career Description
- 5 new or revised Examples
- New photography
- 30 new Exercises

Chapter 24

- New Career Focus
- New Career Description
- 8 new or revised Examples
- New photography
- 30 new Exercises

Chapter 25

- New Career Focus
- New Career Description
- 4 new or revised Examples
- New photography
- 30 new Exercises

Features

Each chapter has features especially designed to help students study effectively, as well as organize, understand, and enjoy the material in the course.

Career Focus. These features introduce the diverse fields of health care. The purpose of the career focus features is to stimulate inquiry; for that reason, we've placed them at the beginning of each chapter of the book. Vocabulary and scenarios may be unfamiliar to you who are studying these course materials, but our intent is to raise interest and pique your curiosity. A career description can be found at the end of each chapter before the Concept Summary.

Health Career Focus

STERILE PROCESSING TECHNICIAN

"Without us, nothing happens in this hospital. We're essential to every treatment, procedure, and surgery that occurs in this facility."

"Here's my locker where I change into my PPE, or personal protective equipment—just as if I were dressing for surgery—including foot coverings and a face shield."

"There, behind that window, we receive trays of used surgical equipment. We meticulously wash the blood, bone, and tissue off and get them ready for steam-pressure sterilization. This job isn't for the squeamish."

"One of the most important parts of my job is actually counting the instruments, making sure each item returns from surgery and is recorded carefully in the database. I also monitor equipment for

Chapter Outlines and Learning Objectives. At the beginning of each chapter, a list of learning objectives provides students with a convenient overview of what they should gain by studying the chapter. In order to help students navigate through each chapter and focus on key concepts, these objectives are repeated at the beginning of the section in which the applicable information is discussed. The objectives are referred to again in question format the concept summary at the end of each chapter. Thus, students begin each chapter with a set of objectives and end with an indication of how well they satisfied the objectives.

Key Terms. Identified within the text by the use of bold type, key terms are defined in the margin near the place where they are introduced. Students reviewing a chapter can quickly identify the important concepts on each page with this marginal glossary. A full glossary of key terms and concepts appears at the end of the text.

Environmental Connections. These boxed features contain current chemistry-related environmental issues such as "Ozone: Good Up High, Bad Nearby" and "CO_2 Emissions: A Blanket around the Earth."

Health Connections. These boxed features contain current chemistry-related health issues such as "Add Color to Your Diet," and suggestions for maintaining good health such as "Consider the Mediterranean Diet," "Cut Back on Processed Meat," and "Try a Little Chocolate."

HEALTH CONNECTIONS 14.1

Faking a Tan

Many people believe that a suntan makes one look healthy and attractive. Studies, however, indicate that this perception is far from the truth. According to these studies, sunbathing, especially when sunburn results, ages the skin prematurely and increases the risk of skin cancer. Cosmetic companies have developed a tanning alternative for those not willing to risk using the sun but who want to be "fashionably" tan.

Tanning lotions and creams that chemically darken the skin are now available. The active ingredient in these "bronzers" is dihydroxyacetone (DHA), a colorless compound classified by the Food and Drug Administration as a safe skin dye.

$$HO-CH_2-\overset{\overset{\large O}{\|}}{C}-CH_2-OH$$

dihydroxyacetone (DHA)

Within several hours after application, DHA produces a brown skin color by reacting with the outer layer of the skin, which consists of dead cells. Only the dead cells react with DHA, so the color gradually fades as the dead cells slough off and are replaced. This process generally leads to the fading of chemical tans within a few weeks. Another problem with chemical tans is uneven skin color. Areas of skin such as elbows and knees, which contain a thicker layer of dead cells, may absorb and react with more tanning lotion and become darker than other areas.

Perhaps the greatest problem with chemical tans is the false sense of security they might give. Some people with chemical tans think it is safe to go into the sun and get a deeper tan. This isn't true. Sunlight presents the same hazards to chemically tanned skin that it does to untanned skin.

Some DHA-containing products.

Examples. To reinforce students in their problem-solving skill development, complete step-by-step solutions for numerous examples are included.

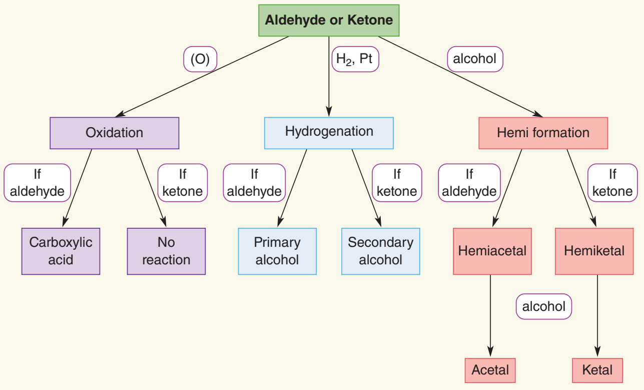
Learning Checks. Short self-check exercises follow examples and discussions of key or difficult concepts. A complete set of solutions is included in Appendix C. These allow students to measure immediately their understanding and progress.

Study Tools. Most chapters contain a *Study Tools* feature in which a challenging topic, skill, or concept of the chapter is addressed. Study suggestions, analogies, and approaches are provided to help students master these ideas.

STUDY TOOLS 14.1

A Reaction Map for Aldehydes and Ketones

This reaction map is designed to help you master organic reactions. Whenever you are trying to complete an organic reaction, use these two basic steps: (1) Identify the functional group that is to react, and (2) Identify the reagent that is to react with the functional group. If the reacting functional group is an aldehyde or a ketone, find the reagent in the summary diagram, and use the diagram to predict the correct products.



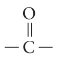
Concept Summary. Located at the end of each chapter, this feature provides a concise review of the concepts and challenges students to check their achievement of the learning objectives related to the concepts.

Concept Summary

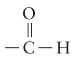
14.1 The Nomenclature of Aldehydes and Ketones

Learning Objective: Can you recognize the carbonyl group in compounds and classify the compounds as aldehydes or ketones? Can you assign IUPAC name to aldehydes and ketones?

- The functional groups characteristic of aldehydes and ketones are very similar.



- They both contain a carbonyl group.
- Aldehydes have a hydrogen attached to the carbonyl carbon.



- The polarity of the carbonyl group and the fact that aldehydes and ketones can form hydrogen bonds with water explain why the low-molecular-weight compounds of these organic classes are water-soluble.

14.3 Chemical Properties

Learning Objective: Can you write key reactions for aldehydes and ketones?

- Aldehydes are prepared by the oxidation of primary alcohols.
- Ketones are prepared by the oxidation of secondary alcohols.
- Aldehydes can be further oxidized to carboxylic acids, but ketones resist oxidation.
- Thus, aldehydes are oxidized by Tollens' reagent (Ag^+) and Benedict's solution (Cu^{2+}), whereas ketones are not.
- A characteristic reaction of both aldehydes and ketones is the addition of hydrogen to the carbonyl double bond to form alcohols.

Key Terms and Concepts. These are listed at the end of each chapter for easy review, with a reference to the chapter section in which they are presented.

Key Equations. This feature provides a useful summary of general equations and reactions from the chapter. This feature is particularly helpful to students in the organic chemistry chapters.

Exercises. Nearly 2200 end-of-chapter exercises are arranged by section. Approximately half of the exercises are answered in the back of the text. Solutions and answers to all exercises are provided in the Instructor's Manual. We have included a significant number of clinical and other familiar applications of chemistry in the exercises.

Chemistry for Thought. Included at the end of each chapter are special questions designed to encourage students to expand their reasoning skills. Some of these exercises are based on photographs found in the chapter, while others emphasize clinical or other useful applications of chemistry.

Possible Course Outlines

This text may be used effectively in either a two-semester or three-quarter course of study:

First semester: Chapters 1–13 (general chemistry and three chapters of organic chemistry)

Second semester: Chapters 14–25 (organic chemistry and biochemistry)

First semester: Chapters 1–10 (general chemistry)

Second semester: Chapters 11–21 (organic chemistry and some biochemistry)

First quarter: Chapters 1–10 (general chemistry)

Second quarter: Chapters 11–18 (organic chemistry)

Third quarter: Chapters 19–25 (biochemistry)

Supporting Materials

Additional instructor resources for this product are available online. Instructor assets include an Instructor's Manual including solutions to exercises, an Educator's Guide describing digital homework assets, a Transition Guide (9th to 10th edition), PowerPoint® slides, and a Test Bank powered by Cognero®. Sign up or sign in at **www.cengage.com** to search for and access this product and its online resources.

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Michael R. Slabaugh
Maren S. Hansen

1 Matter, Measurements, and Calculations

VanoVasaio/Shutterstock.com

Health Career Focus

STERILE PROCESSING TECHNICIAN

"Without us, nothing happens in this hospital. We're essential to every treatment, procedure, and surgery that occurs in this facility."

"Here's my locker where I change into my PPE, or personal protective equipment—just as if I were dressing for surgery—including foot coverings and a face shield."

"There, behind that window, we receive trays of used surgical equipment. We meticulously wash the blood, bone, and tissue off and get them ready for steam-pressure sterilization. This job isn't for the squeamish."

"One of the most important parts of my job is actually counting the instruments, making sure each item returns from surgery and is recorded carefully in the database. I also monitor equipment for proper temperatures and settings to ensure we meet protocols."

"This job requires extreme attention to detail. I initial everything I sterilize. My work is traceable to me. Precision is important."

Follow-up to this Career Focus appears at the end of the chapter before the *Concept Summary*.

Learning Objectives

When you complete the study of this chapter, you should be able to:

1. Explain what matter is. **(Section 1.1)**
2. Explain the difference between the terms *physical* and *chemical* as applied to the properties of matter and changes in matter. **(Section 1.2)**
3. Describe matter in terms of the accepted scientific model. **(Section 1.3)**
4. On the basis of observation or information given to you, classify matter into the correct category of each of the following pairs: heterogeneous or homogeneous, solution or pure substance, and element or compound. **(Section 1.4)**
5. Recognize the use of measurement units in everyday activities. **(Section 1.5)**

6 Recognize units of the metric system, and convert measurements done using the metric system into related units. **(Section 1.6)**

7 Express numbers using scientific notation and do calculations with numbers expressed in scientific notation. **(Section 1.7)**

8 Express the results of measurements and calculations using the correct number of significant figures. **(Section 1.8)**

9 Use the factor-unit method to solve numerical problems. **(Section 1.9)**

10 Do calculations involving percentages. **(Section 1.10)**

11 Do calculations involving densities. **(Section 1.11)**

CHEMISTRY is often described as the scientific study of matter. In a way, almost every study is a study of matter, because matter is the substance of everything. However, chemists are especially interested in matter; they study it and attempt to understand it from nearly every possible point of view.

The chemical nature of all matter makes an understanding of chemistry useful and necessary for individuals who are studying in a wide variety of areas, including the health sciences, natural sciences, home economics, education, environmental science, and law enforcement.

Matter comes in many shapes, sizes, and colors that are interesting to look at and describe. Early chemists did little more than describe what they observed, and their chemistry was a descriptive science that was severely limited in scope. It became a much more useful science when chemists began to make quantitative measurements, do calculations, and incorporate the results into their descriptions. Some fundamental ideas about matter are presented in this chapter, along with some ideas about quantitative measurement, the scientific measurement system, and calculations.

1.1 What Is Matter?

Learning Objective 1 Explain what matter is.

Definitions are useful in all areas of knowledge. They provide a common vocabulary for both presentations to students and discussions between professionals. You will be expected to learn a number of definitions as you study chemistry, and the first one is a definition of *matter*. Earlier, we said that matter is the substance of everything. That isn't very scientific, even though we think we know what it means. If you stop reading for a moment and look around, you will see a number of objects that might include people, potted plants, walls, furniture, books, windows, and a TV set or radio. The objects you see have at least two things in common: Each one has mass, and each one occupies space. These two common characteristics provide the basis for the scientific definition of matter. **Matter** is anything that has mass and occupies space. You probably understand what is meant by an object occupying space, especially if you have tried to occupy

matter Anything that has mass and occupies space.

the same space as some other object. The resulting physical bruises leave a lasting mental impression.

You might not understand the meaning of the term *mass* quite as well, but it can also be illustrated "painfully." Imagine walking into a very dimly lit room and being able to just barely see two large objects of equal size on the floor. You know that one is a bowling ball and the other is an inflated plastic ball, but you can't visually identify which is which. However, a hard kick delivered to either object easily allows you to identify each one. The bowling ball resists being moved much more strongly than does the inflated ball. Resistance to movement depends on the amount of matter in an object, and **mass** is an actual measurement of the amount of matter present.

mass A measurement of the amount of matter in an object.

The term *weight* is probably more familiar to you than *mass*, but the two are related. All objects are attracted to each other by gravity, and the greater their mass, the stronger the attraction between them. The **weight** of an object on Earth is a measurement of the gravitational force pulling the object toward Earth. An object with twice the mass of a second object is attracted with twice the force, and therefore has a weight twice the weight of the second object. The mass of an object is constant, no matter where it is located (even if it is in a weightless condition in outer space). However, the weight of an object depends on the strength of the gravitational attraction to which it is subjected. For example, a rock that weighs 16 pounds on Earth would weigh about 2.7 pounds on the moon (see **Figure 1.1**) because the gravitational attraction on the moon is only about one-sixth that of Earth. However, the rock contains the same amount of matter and thus has the same mass whether it is located on Earth or on the moon.

weight A measurement of the gravitational force acting on an object.

alsen/431 images/Pixabay

FIGURE 1.1 Objects on the moon would weigh about one-sixth of their weight on Earth.

Despite the difference in meaning between mass and weight, the determination of mass is commonly called "weighing." We will follow that practice in this book, but we will use the correct term *mass* when referring to an amount of matter.

1.2 Properties and Changes

Learning Objective 2 Explain the difference between the terms *physical* and *chemical* as applied to the properties of matter and changes in matter.

When you looked at your surroundings earlier, you didn't have much trouble identifying the various things you saw. For example, unless the decorator of your room had unusual tastes, you could easily tell the difference between a TV set and a potted plant by observing characteristics such as shape, color, and size. Our ability to identify objects or materials and discriminate between them depends on such characteristics. Scientists prefer to use the term *property* instead of *characteristic*, and they classify properties into two categories, physical and chemical.

Physical properties are those that can be observed or measured without changing or trying to change the composition of the matter i.e.—no original substances are destroyed, and no new substances appear. For example, you can observe the color or measure the size of a sheet of paper without attempting to change the paper into anything else. Color and size are physical properties (see **Figure 1.2**) of the paper. **Chemical properties** are the properties that matter demonstrates when attempts are made to change it into other kinds of matter. For example, a sheet of paper can be burned; in this process, the paper is changed into a new substance. On the other hand, attempts to burn a piece of glass under similar conditions fail. The ability of paper to burn is a chemical property, as is the inability of glass to burn.

physical properties Properties of matter that can be observed or measured without trying to change the composition of the matter being studied.

chemical properties Properties that matter demonstrates when attempts are made to change it into new substances.

You can easily change the size of a sheet of paper by cutting off a piece. The paper sheet is not converted into any new substance by this change, but it is simply made smaller. **Physical changes** can be carried out without changing the composition of a substance. However, there is no way you can burn a sheet of paper without changing it into new substances. Thus, the change that occurs when paper burns is called a **chemical change. Figure 1.3** shows an example of a chemical change, the burning of magnesium metal. The bright light produced

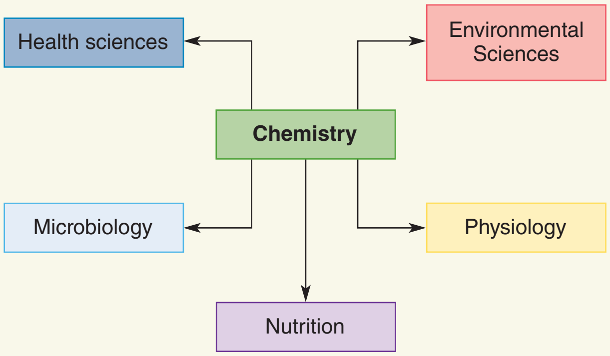
physical changes Changes matter undergoes without changing composition.

chemical changes Changes matter undergoes that involve changes in composition.

ENVIRONMENTAL CONNECTIONS 1.1

A Central Science

Chemistry is often referred to as the "central science" because it serves as a necessary foundation for many other scientific disciplines. Regardless of which scientific field you are interested in, every single substance you will discuss or work with is made up of chemicals. Also, many processes important to those fields will be based on an understanding of chemistry.



Chemistry is the foundation for many other scientific disciplines.

We also consider chemistry a central science because of its crucial role in responding to the needs of society. We use chemistry to discover new processes, develop new sources of energy, produce new products and materials, provide more food, and ensure better health.

As you read this text, you will encounter chapter-opening applications of chemistry in the health-care professions. Within the chapters, Environmental Connections and Health Connections boxes focus on specific topics that play essential roles in meeting the needs of society.

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Chemicals are present in everything we can touch, smell, or see. Chemistry is all around us.

FIGURE 1.2 Some physical properties of matter.

by this chemical change led to the use of magnesium in the flash powder used in early photography. Magnesium is still used in fireworks to produce a brilliant white light.

Example 1.1 Classifying Changes as Physical or Chemical

Classify each of the following changes as physical or chemical: (a) a match is burned; (b) iron is melted; (c) limestone is crushed; (d) limestone is heated, producing lime and carbon dioxide; (e) an antacid seltzer tablet is dissolved in water; and (f) a rubber band is stretched.

Solution

Changes b, c, and f are physical changes because no composition changes occurred and no new substances were formed.

The others are chemical changes because new substances were formed as illustrated. A match is burned—combustion gases are given off, and matchstick wood is converted to ashes. Limestone is heated—lime and carbon dioxide are the new substances. A seltzer tablet is dissolved in water—the fizzing that results is evidence that at least one new material (a gas) is produced.

✔ **LEARNING CHECK 1.1** Classify each of the following changes as physical or chemical, and, in the cases of chemical change, describe one observation or test that indicates new substances have been formed: (a) milk sours, (b) a wet handkerchief dries, (c) fruit ripens, (d) a stick of dynamite explodes, (e) air is compressed into a steel container, and (f) water boils.

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1. A strip of magnesium metal.

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2. After being ignited with a flame, the magnesium burns with a blinding white light.

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3. The white ash of magnesium oxide from the burning of several magnesium strips.

FIGURE 1.3 A chemical change occurs when magnesium metal burns.

Among the most common physical changes are changes in state, such as the melting of solids to form liquids, the sublimation of solids to form gases, or the evaporation of liquids to form gases. These changes take place when heat is added to or removed from matter, as represented in **Figure 1.4**. We will discuss changes in state in more detail in Chapter 6.

FIGURE 1.4 Examples of physical change.

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a Solid iodine becomes gaseous iodine when heated.

b Liquid benzene becomes solid benzene when cooled.

1.3 A Model of Matter

Learning Objective 3 Describe matter in terms of the accepted scientific model.

Model building is a common activity of scientists, but the results in many cases would not look appropriate on a fireplace mantle. **Scientific models** are explanations for observed behavior. Some, such as the well-known representation of the solar system, can easily be depicted in a physical way. Others are so abstract that they can be represented only by mathematical equations.

scientific models Explanations for observed behavior in nature.

Our present understanding of the nature of matter is a model that has been developed and refined over many years. Based on careful observations and measurements of the properties of matter, the model is still being modified as more is learned. In this book, we will concern ourselves with only some very basic concepts of this model, but even then these basic ideas will provide a powerful tool for understanding the behavior of matter.

The study of the behavior of gases—such as air, oxygen, and carbon dioxide—by some of the earliest scientists led to a number of important ideas about matter. The volume of a gas kept at a constant temperature was found to change with pressure. An increase in pressure caused the gas volume to decrease, whereas a decrease in pressure permitted the gas volume to increase. It was also discovered that the volume of a gas maintained at constant pressure increased as the gas temperature was increased. Gases were also found to have mass and ability to mix rapidly with one another when brought together.

FIGURE 1.5 A hang glider soars far above the ground. How does this feat confirm that air is matter?

A simple model for matter was developed that explained these gaseous properties, as well as many properties of solids and liquids. Some details of the model are discussed in Chapter 6, but one conclusion is important to us now I.e., all matter is made up of particles that are too small to see (see **Figure 1.5**). The early framers of this model called the small particles *molecules.* It is now known that molecules are the constituent particles of many, but not in all substances. In this chapter, we will limit our discussion to substances made up of molecules. Substances that are not made of molecules will be discussed in **Sections 4.3** and **4.11**.

The results of some simple experiments will help us formally define the term *molecule.* Suppose you have a container filled with oxygen gas and you perform a number of experiments with it. You find that a glowing splinter of wood bursts into flames when placed in the gas. A piece of moist iron rusts much faster in the oxygen than it does in air. A mouse or other animal can safely breathe the gas.

Now suppose you divide another sample of oxygen, the same size as the first into two smaller samples. The results of similar experiments done with these samples would be the same as before. Continued subdivision of an oxygen sample into smaller and smaller samples does not change the ability of the oxygen in the samples to behave just like the oxygen in the original sample. We conclude that the physical division of a sample of oxygen gas into smaller and smaller samples does not change the oxygen into anything else—it is still oxygen. Is there a limit to such divisions? What is the smallest sample of oxygen that will behave like the larger sample? We hope you have concluded that the smallest sample must be a single molecule. Although its very small size would make a one-molecule sample difficult to handle, it would nevertheless behave just as a larger sample would—it could be stored in a container, it would make wood burn rapidly, it would rust iron, and it could be breathed safely by a mouse.

We are now ready to formally define the term *molecule.* A **molecule** is the smallest particle of a pure substance that has the properties of that substance and is capable of a stable independent existence. Alternatively, a molecule is defined as the limit of physical subdivision for a pure substance.

molecule The smallest particle of a pure substance that has the properties of that substance and is capable of a stable independent existence. Alternatively, a molecule is the limit of physical subdivision for a pure substance.

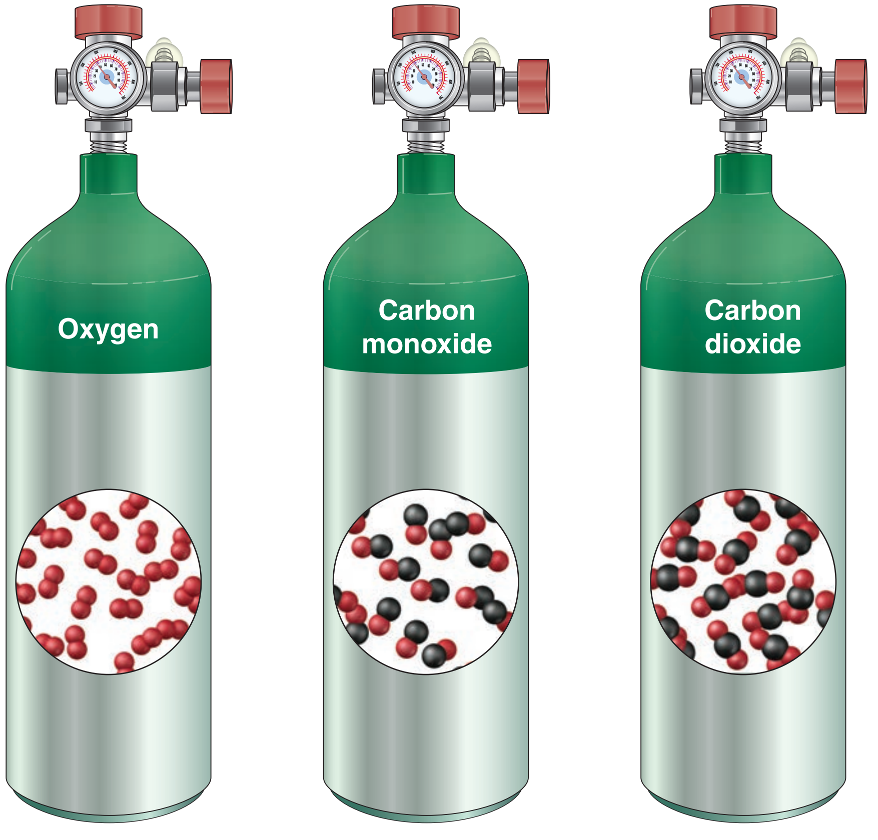
In less formal terms, these definitions indicate that a sample of pure substance—such as oxygen, carbon monoxide, or carbon dioxide—can be physically separated into smaller and smaller samples only until there is a single molecule. Any further separation cannot be done physically, but if it were done (chemically), the resulting sample would no longer have the same properties as the larger sample.

The idea that it might be possible to chemically separate a molecule into smaller particles grew out of continued study and experimentation by early scientists. In modern terminology, the smaller particles that make up molecules are called atoms. John Dalton (1766–1844) is generally credited with developing the first atomic theory containing ideas that are still used today. The main points of his theory, which he proposed in 1808, can be summarized in the following five statements:

1. All matter is made up of tiny particles called atoms.
2. Substances called elements are made up of atoms that are all identical.
3. Substances called compounds are combinations of atoms of two or more elements.
4. Every molecule of a specific compound always contains the same number of atoms of each kind of element found in the compound.
5. In chemical reactions, atoms are rearranged, separated, or combined, but are never created nor destroyed.

Early scientists used graphic symbols such as circles and squares to represent the few different atoms that were known at the time. Instead of different shapes, we will use representations such as those in **Figure 1.6** for oxygen, carbon monoxide, and carbon dioxide molecules.

FIGURE 1.6 Symbolic representations of molecules.



diatomic molecules Molecules that contain two atoms.

homoatomic molecules Molecules that contain only one kind of atom.

heteroatomic molecules Molecules that contain two or more kinds of atoms.

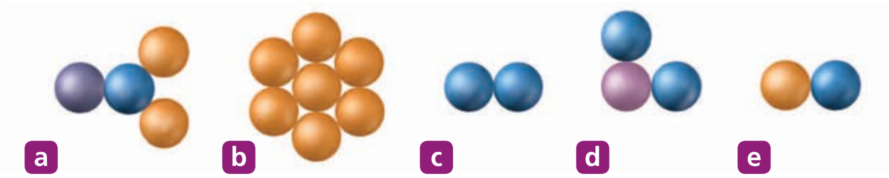
triatomic molecules Molecules that contain three atoms.

polyatomic molecules Molecules that contain three or more atoms.

The three pure substances just mentioned illustrate three different types of molecules found in matter. Oxygen molecules consist of two oxygen atoms, and are called **diatomic molecules** to indicate that fact. Molecules, such as oxygen, that contain only one kind of atom are also called **homoatomic molecules** to indicate that the atoms are all of the same kind. Carbon monoxide molecules also contain two atoms and therefore are diatomic molecules. However, in this case the atoms are not identical, a fact indicated by the term **heteroatomic molecule**. Carbon dioxide molecules consist of three atoms that are not all identical, so carbon dioxide molecules are described by the terms **triatomic** and heteroatomic. The words *diatomic* and *triatomic* are commonly used to indicate two and three atom molecules respectively, but the word **polyatomic** is usually used to describe molecules that contain more than three atoms.

Example 1.2 Classifying Molecules

Use the terms *diatomic, triatomic, polyatomic, homoatomic,* or *heteroatomic* to classify the following molecules correctly:



Solution

a. Polyatomic and heteroatomic (contains more than three atoms, and the atoms are not all identical)
b. Polyatomic and homoatomic (more than three atoms, and the atoms are all identical)
c. Diatomic and homoatomic (two atoms, and the atoms are identical)
d. Triatomic and heteroatomic (three atoms, and the atoms are not identical)
e. Diatomic and heteroatomic (two atoms, and the atoms are not identical)

✔ LEARNING CHECK 1.2 Use the terms *diatomic, triatomic, polyatomic, homoatomic,* or *heteroatomic* to classify the following molecules correctly:

a. Water molecules have been found to contain two hydrogen atoms and one oxygen atom.
b. Molecules of ozone contain three oxygen atoms.
c. Natural gas is made up primarily of methane molecules, which contain one atom of carbon and four atoms of hydrogen.

The subdivision of molecules into smaller particles is a chemical change. How far can such subdivisions of molecules go? You are probably a step ahead of us and have guessed that the answer is atoms. In fact, this provides us with a definition of atoms. An **atom** is the limit of chemical subdivision. In less formal terms, atoms are the smallest particles of matter that can be produced as a result of chemical changes. However, all chemical changes do not necessarily break molecules into atoms. In some cases, chemical changes might just divide a large molecule into two or more smaller molecules. Also, as we will see later, some chemical changes form larger molecules from smaller ones. The important point is that only chemical changes will produce a division of molecules, and the smallest particles of matter that can possibly be produced by such a division are called atoms.

atom The limit of chemical subdivision for matter.

FIGURE 1.7 A pure substance such as salt has a constant composition, 100%.

1.4 Classifying Matter

Learning Objective 4 On the basis of observation or information given to you, classify matter into the correct category of each of the following pairs: heterogeneous or homogeneous, solution or pure substance, and element or compound.

Unknown substances are often analyzed to determine their compositions. An analyst, upon receiving a sample to analyze, will always ask an important question: Is the sample a pure substance or a mixture? Any sample of matter must be one or the other. Pure water and sugar are both pure substances, but you can create a mixture by stirring together some sugar and pure water.

What is the difference between a pure substance and a mixture? Two differences are that a **pure substance** has a constant composition (see **Figure 1.7**) and a fixed set of physical and chemical properties. Pure water, for example, always contains the same proportions of hydrogen and oxygen and freezes at a specific temperature. A **mixture** of sugar and water, however, can vary in composition, and the properties will be different for

pure substance Matter that has a constant composition and fixed properties.

mixture A physical blend of matter that can theoretically be physically separated into two or more components.