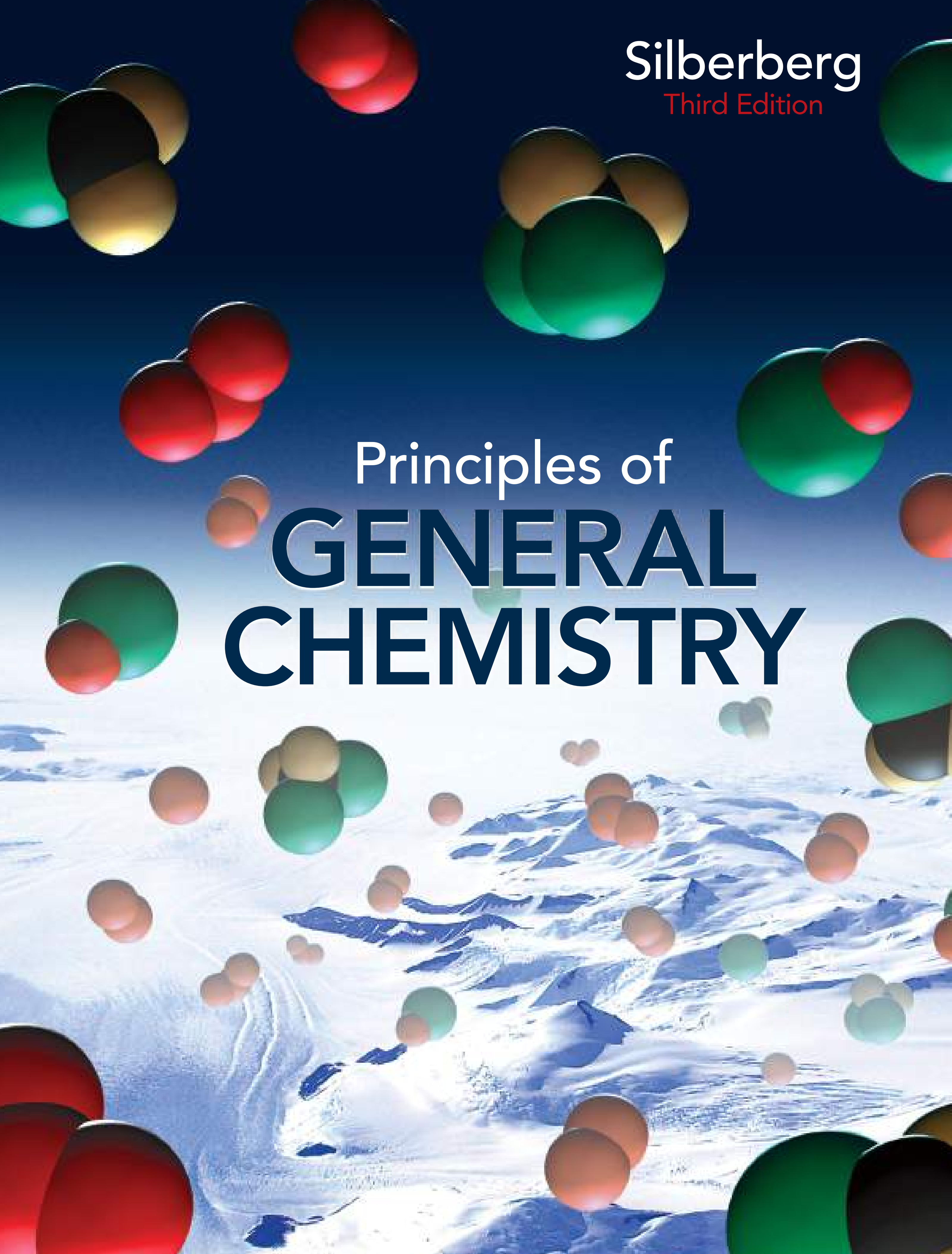
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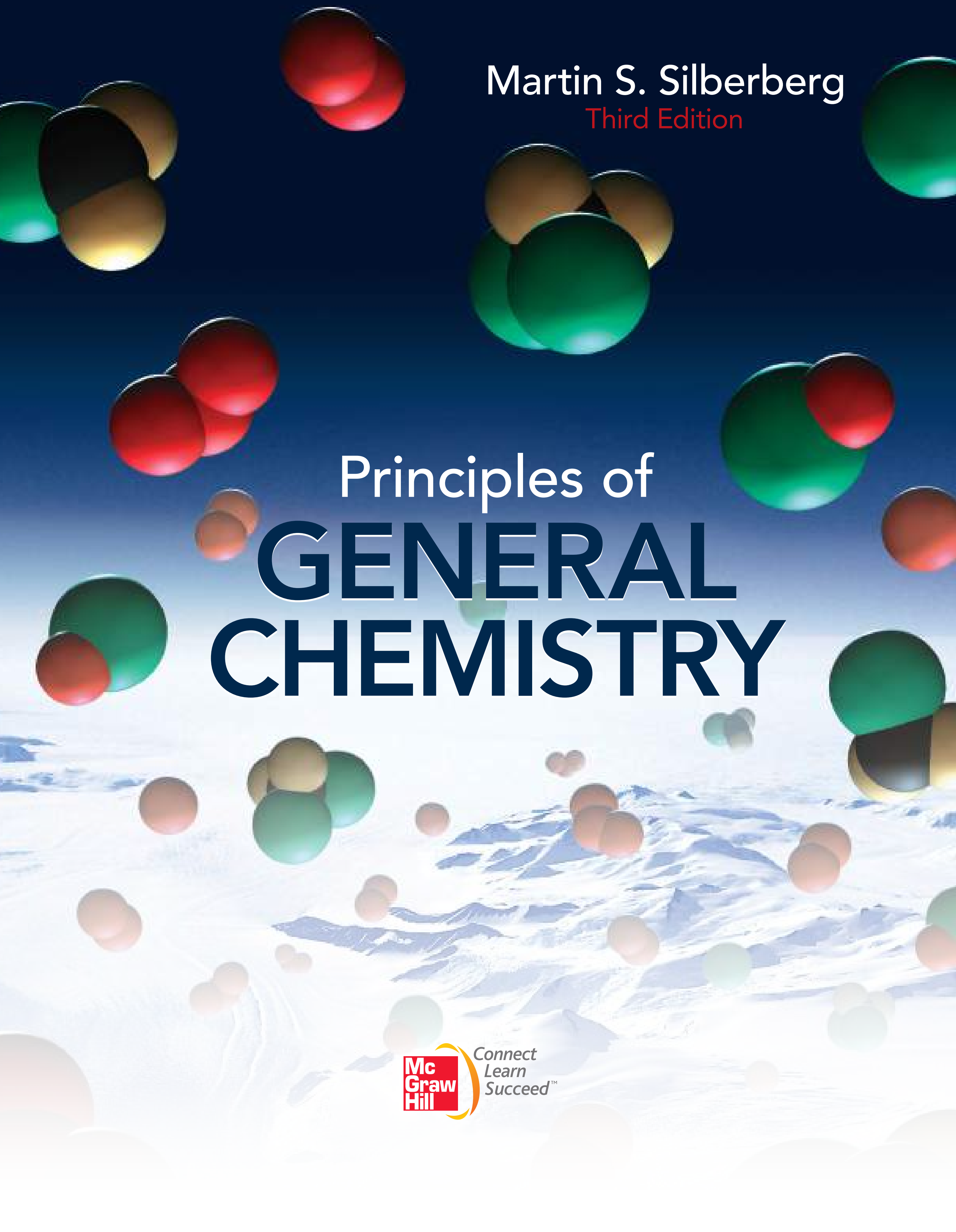

Martin S. Silberberg

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To Ruth and Daniel, with all my love
and
To the memory of my brother Bruce,
whose love, humor, and encouragement was
invaluable and will be profoundly missed.

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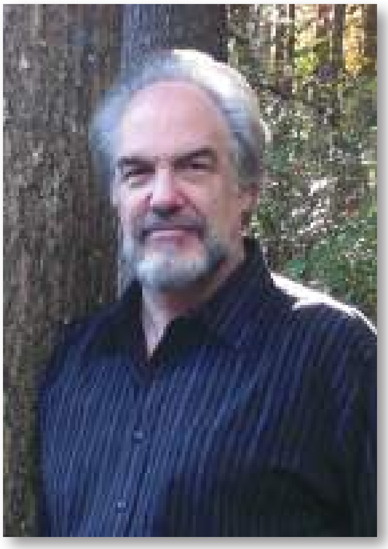
About the Author



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Preface

As the new century unfolds, chemistry will play its usual, crucial role in dealing with complex environmental, medical, and industrial issues. And, as the complexities increase and more information is needed to understand them, many chemistry instructors want a more focused text to serve as the core of a powerful electronic teaching and learning package. This new, Third Edition of *Principles of General Chemistry* is the ideal choice, designed to cover key principles and skills with great readability, the most accurate molecular art available, a problem-solving approach that is universally praised, and a supporting suite of electronic products that sets a new standard in academic science.

HOW *PRINCIPLES* AND *CHEMISTRY* ARE THE SAME

Principles of General Chemistry was created from its parent text, *Chemistry: The Molecular Nature of Matter and Change,* when four expert chemistry teachers—three consulting professors and the author—joined to distill the concepts and skills at the heart of general chemistry. *Principles* covers all the material a science major needs to continue in premedical studies, engineering, or related fields. It maintains the same high standards of accuracy, clarity, and rigor as its parent and adopts the same three distinguishing hallmarks:

1. *Visualizing chemical models.* In many places in the text, concepts are explained first at the macroscopic level and then from a molecular point of view. Placed near many of these discussions, the text's celebrated graphics depict the phenomenon or change at the observable level in the lab, at the atomic level with superbly accurate molecular art, and at the symbolic level with the balanced equation.
2. *Thinking logically to solve problems.* The problem-solving approach, based on a four-step method widely approved by chemical educators, is introduced in Chapter 1 and employed *consistently* throughout the text. It encourages students to first plan a logical approach, and only then proceed to the arithmetic solution. A check step, universally recommended by instructors, fosters the habit of considering the reasonableness and magnitude of the answer. For practice and reinforcement, each worked problem has a matched follow-up problem, for which an abbreviated, multistep solution—not merely a numerical answer—appears at the end of the chapter.
3. *Applying ideas to the real world.* For today's students, who may enter one of numerous chemistry-related fields, especially important applications—such as climate change, enzyme catalysis, materials science, and others—are woven into the text discussion, and real-world scenarios are used in many worked in-chapter sample problems as well as end-of-chapter problems.

Principles and *Chemistry* also share a common topic sequence, which provides a thorough introduction to chemistry for science majors:

- Chapters 1 through 6 cover unit conversions and uncertainty, introduce atomic structure and bonding, discuss stoichiometry and reaction classes, show how gas behavior is modeled, and highlight the relation between heat and chemical change.
- Chapters 7 through 15 take an "atoms-first" approach, as they move from atomic structure and electron configuration to how atoms bond and what the resulting molecules look like and why. Intermolecular forces are covered by discussing the behavior of liquids and solids as compared with that of gases, and then leads the different behavior of solutions. These principles are then applied to the chemistry of the elements and to the compounds of carbon.
- Chapters 16 through 21 cover dynamic aspects of reaction chemistry, including kinetics, equilibrium, entropy and free energy, and electrochemistry.
- Chapters 22 and 23 cover transition elements and nuclear reactions.

HOW *PRINCIPLES* AND *CHEMISTRY* ARE DIFFERENT

Principles presents the same authoritative coverage as *Chemistry* but in 240 fewer pages. It does so by removing most of the boxed application material, thus letting instructors choose applications tailored for *their* course. Moreover, several topics that are important areas of research but not central to general chemistry were left out, including colloids, polymers, liquid crystals, and so forth. And mainstream material from the chapter on isolating the elements was blended into the chapter on electrochemistry.

Despite its much shorter length, *Principles of General Chemistry* includes *all* the pedagogy so admired in *Chemistry.* It has all the worked sample problems and about two-thirds as many end-of-chapter problems, still more than enough problems for every topic, with a high level of relevance and many real-world applications. The learning aids that students find so useful have also been retained—Concepts and Skills to Review, Section Summaries, Key Terms, Key Equations, and Brief Solutions to Follow-up Problems.

In addition, three aids not found in the parent *Chemistry* help students focus their efforts:

- *Key Principles.* At the beginning of each chapter, short bulleted paragraphs state the main concepts concisely, using many of the same phrases and terms (in *italics*) that appear in the pages to follow. A student can preview these principles before reading the chapter and then review them afterward.
- *"Think of It This Way . . ." with Analogies, Mnemonics, and Insights.* This recurring feature provides analogies for difficult concepts (e.g., the "radial probability distribution" of apples around a tree) and amazing quantities (e.g., a stadium and a marble for the relative sizes of atom and nucleus), memory shortcuts (e.g., which reaction occurs at which electrode), and useful insights (e.g., similarities between a saturated solution and a liquid-vapor system).
- *Problem-Based Learning Objectives.* The list of learning objectives at the end of each chapter includes the end-of-chapter problems that relate to each objective. Thus, a student, or instructor, can select problems that review a given topic.

WHAT'S NEW IN THE *THIRD EDITION*

To address dynamic changes in how courses are structured and how students learn—variable math and reading preparation, less time for traditional studying, electronic media as part of lectures and homework, new challenges and options in career choices—the author and publisher consulted extensively with students and faculty. Based on their input, we developed the following ways to improve the text as a whole as well as the content of individual chapters.

Global Changes to the Entire Text

Writing style and content presentation. Every line of every discussion has been revised to optimize clarity, readability, and a more direct presentation. The use of additional subheads, numbered (and titled) paragraphs, and bulleted (and titled) lists has eliminated long unbroken paragraphs. Main ideas are delineated and highlighted, making for more efficient study and lectures. As a result, the text is over 20 pages shorter than the *Second Edition.*

More worked problems. The much admired—and imitated—four-part (plan, solution, check, practice) *Sample Problems* occur in both data-based and molecular-scene format. To deepen understanding, *Follow-up Problems* have worked-out solutions at the back of each chapter, with a road map when appropriate, effectively doubling the number of worked problems. This edition has 15 more sample problems, many in the earlier chapters, where students need the most practice in order to develop confidence.

Art and figure legends. Figures have been made more realistic and modern. Figure legends have been greatly shortened, and the explanations from them have either been added to the text or included within the figures.

Page design and layout. A more open look invites the reader while maintaining the same attention to keeping text and related figures and tables near each other for easier studying.

Section summaries. This universally approved feature is even easier to use in a new bulleted format.

Chapter review. The unique *Chapter Review Guide* aids study with problem-based learning objectives, key terms, key equations, and the multistep Brief Solutions to Follow-up Problems (rather than just numerical answers).

End-of-chapter problem sets. With an enhanced design to improve readability and traditional and molecular-scene problems updated and revised, these problem sets are far more extensive than in other brief texts.

Content Changes to Individual Chapters

- Chapter 2 presents a new figure and table on molecular modeling, and it addresses the new IUPAC recommendations for atomic masses.
- Discussion of empirical formulas has been moved from Chapter 2 to Chapter 3 so that it appears just before molecular formulas.
- Chapter 3 has some sample problems from the *Second Edition* that have been divided to focus on distinct concepts, and it contains seven new sample problems.
- Chapters 3 and 4 include more extensive and consistent use of stoichiometry reaction tables in limiting-reactant problems.
- Chapter 4 presents a new molecular-scene sample problem on depicting an ionic compound in aqueous solution.
- Chapter 5 includes a new discussion on how gas laws apply to breathing.
- Chapter 5 groups stoichiometry of gaseous reactions with other rearrangements of the ideal gas law.
- Chapter 17 makes consistent use of quantitative benchmarks for determining when it is valid to assume that the amount reacting can be neglected.

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A Guide to Student Success: How to Get the Most Out of Your Textbook

ORGANIZING AND FOCUSING

Chapter Outline

The chapter begins with an outline that shows the sequence of topics and subtopics.

Key Principles

The main principles from the chapter are given in concise, separate paragraphs so you can keep them in mind as you study. You may also want to review them when you are finished.

Why do substances behave as they do? That is, why is table salt (or any other ionic substance) a hard, brittle, high-melting solid that conducts a current only when molten or dissolved in water? Why is candle wax (along with most covalent substances) low melting, soft, and nonconducting, even though diamond (as well as a few other exceptions) is high melting and extremely hard? And why is copper (and most other metals) shiny, malleable, and able to conduct a current whether molten or solid? The answers lie in the *type of bonding within the substance*. In Chapter 8, we examined the properties of individual atoms and ions. But the behavior of matter really depends on how those atoms and ions bond.

9.1 • ATOMIC PROPERTIES AND CHEMICAL BONDS

Before we examine the types of chemical bonding, we should start with the most fundamental question: why do atoms bond at all? In general, *bonding lowers the*

CONCEPTS & SKILLS TO REVIEW before studying this chapter

- characteristics of ionic and covalent compounds; Coulomb's law (Section 2.7)
- polar covalent bonds and the polarity of water (Section 4.1)
- Hess's law, ΔH°_{rxn}, and ΔH°_f (Sections 6.5 and 6.6)
- atomic and ionic electron configurations (Sections 8.2 and 8.4)
- trends in atomic properties and metallic behavior (Sections 8.3 and 8.4)

Section Summaries

A bulleted list of statements conclude each section, immediately reiterating the major ideas just covered.

STEP-BY-STEP PROBLEM SOLVING

Using this clear and thorough problem-solving approach, you'll learn to think through chemistry problems logically and systematically.

Sample Problems

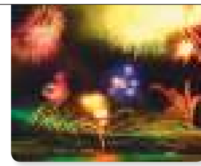
A worked-out problem appears whenever an important new concept or skill is introduced. The step-by-step approach is shown consistently for every sample problem in the text.

- **Plan** analyzes the problem so that you can use what is known to find what is unknown. This approach develops the habit of thinking through the solution *before* performing calculations.
- In many cases, a **Road Map** specific to the problem is shown alongside the plan to lead you visually through the needed calculation steps.
- **Solution** shows the calculation steps *in the same order* as they are discussed in the plan and shown in the road map.
- **Check** fosters the habit of going over your work quickly to make sure that the answer is reasonable, chemically and mathematically—a great way to avoid careless errors.
- **Comment,** shown in many problems, provides an additional insight, and alternative approach, or a common mistake to avoid.
- **Follow-up Problem** gives you immediate practice by presenting a similar problem that requires the same approach.

7 Quantum Theory and Atomic Structure

Key Principles to focus on while studying this chapter

- In a vacuum, *electromagnetic radiation* travels at the *speed of light* (*c*) in waves. The properties of a wave are its *wavelength* (λ, distance between corresponding points on adjacent waves), *frequency* (ν, number of cycles the wave undergoes per second), and *amplitude* (the height of the wave), which is related to the *intensity* (brightness) of the radiation. Any region of the *electromagnetic spectrum* includes a range of wavelengths. ***(Section 7.1)***
- In everyday experience, energy is diffuse and matter is chunky, but certain phenomena—*blackbody radiation* (the light emitted by hot objects), the *photoelectric effect* (the flow of current when light strikes a metal), and *atomic spectra* (the specific colors emitted from a substance that is excited)—can only be explained if energy consists of "packets" *(quanta)* that occur in, and thus change by, *fixed amounts*. The energy of a quantum is related to its frequency. ***(Section 7.1)***
- According to the *Bohr model,* an atomic spectrum consists of separate lines because an atom has certain energy levels *(states)* that correspond to electrons in *orbits* around the nucleus. The energy of the atom changes when the electron moves from one orbit to another as the atom absorbs (or emits) light of a specific frequency. ***(Section 7.2)***
- *Wave-particle duality* means that matter has wavelike properties (as shown by the *de Broglie wavelength* and *electron diffraction*) and energy has particle-like properties (as shown by *photons* of light having *momentum*). These properties are observable only on the atomic scale, and because of them, we can never simultaneously know the position and speed of an electron in an atom *(uncertainty principle)*. ***(Section 7.3)***
- According to the *quantum-mechanical model* of the H atom, each energy level of the atom is associated with an *atomic orbital (wave function),* a mathematical description of the electron's position in three dimensions. We can know the *probability* that the electron is within a particular tiny volume of space, but *not* its exact location. The probability is highest for the electron being near the nucleus, and it decreases with distance. ***(Section 7.4)***



Light from Excited Atoms In a fireworks display and many other everyday phenomena, we see the result of atoms absorbing energy and then emitting it as light. In this chapter, we explore the basis of these phenomena and learn some surprising things about the makeup of the universe.

Outline

7.1 **The Nature of Light**
Wave Nature of Light
Particle Nature of Light
7.2 **Atomic Spectra**
Line Spectra and the Rydberg Equation
Bohr Model of the Hydrogen Atom
Energy Levels of the Hydrogen Atom
Spectral Analysis
7.3 **The Wave-Particle Duality of Matter and Energy**
Wave Nature of Electrons and Particle Nature of Photons
Heisenberg's Uncertainty Principle

Concepts and Skills to Review

This unique feature helps you prepare for the upcoming chapter by referring to key material from earlier chapters that you should understand *before* you start reading the current one.

Summary of Section 13.3

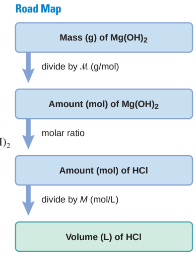
- A solution that contains the maximum amount of dissolved solute in the presence of excess undissolved solute is saturated. A saturated solution is in equilibrium with excess solute, because solute particles are entering and leaving the solution at the same rate.
- Most solids are more soluble at higher temperatures.
- All gases have a negative ΔH_{soln} in water, so heating lowers gas solubility in water.
- Henry's law says that the solubility of a gas is directly proportional to its partial pressure above the solution.

Sample Problem 3.25 Calculating Quantities of Reactants and Products for a Reaction in Solution

Problem Specialized cells in the stomach release HCl to aid digestion. If they release too much, the excess can be neutralized with an antacid. A common antacid contains magnesium hydroxide, which reacts with the acid to form water and magnesium chloride solution. As a government chemist testing commercial antacids, you use 0.10 *M* HCl to simulate the acid concentration in the stomach. How many liters of "stomach acid" react with a tablet containing 0.10 g of magnesium hydroxide?

Plan We are given the mass (0.10 g) of magnesium hydroxide, $Mg(OH)_2$, that reacts with the acid. We also know the acid concentration (0.10 *M*) and must find the acid volume. After writing the balanced equation, we convert the mass (g) of $Mg(OH)_2$ to amount (mol) and use the molar ratio to find the amount (mol) of HCl that reacts with it. Then, we use the molarity of HCl to find the volume (L) that contains this amount (see the road map).

Road Map



Solution Writing the balanced equation:

$$Mg(OH)_2(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + 2H_2O(l)$$

Converting from mass (g) of $Mg(OH)_2$ to amount (mol):

$$\text{Amount (mol) of } Mg(OH)_2 = 0.10\ \cancel{g\ Mg(OH)_2} \times \frac{1\ mol\ Mg(OH)_2}{58.33\ \cancel{g\ Mg(OH)_2}} = 1.7\times10^{-3}\ mol\ Mg(OH)_2$$

Converting from amount (mol) of $Mg(OH)_2$ to amount (mol) of HCl:

$$\text{Amount (mol) of HCl} = 1.7\times10^{-3}\ \cancel{mol\ Mg(OH)_2} \times \frac{2\ mol\ HCl}{1\ \cancel{mol\ Mg(OH)_2}} = 3.4\times10^{-3}\ mol\ HCl$$

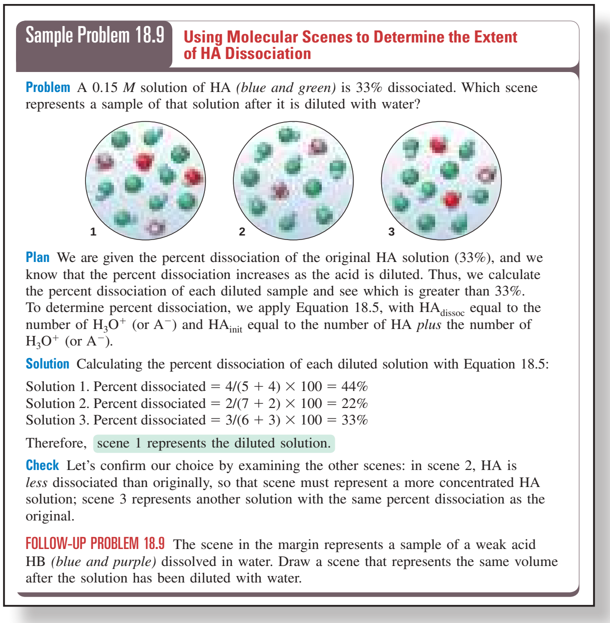
Converting from amount (mol) of HCl to volume (L):

$$\text{Volume (L) of HCl} = 3.4\times10^{-3}\ \cancel{mol\ HCl} \times \frac{1\ L}{0.10\ \cancel{mol\ HCl}} = 3.4\times10^{-2}\ L$$

Check The size of the answer seems reasonable: a small volume of dilute acid (0.034 L of 0.10 *M*) reacts with a small amount of antacid (0.0017 mol).

Comment In Chapter 4, you'll see that this equation is an oversimplification, because HCl and $MgCl_2$ exist in solution as separated ions.

FOLLOW-UP PROBLEM 3.25 Another active ingredient in some antacids is aluminum hydroxide. Which is more effective at neutralizing stomach acid, magnesium hydroxide or aluminum hydroxide? [*Hint:* "Effectiveness" refers to the amount of acid that reacts with a given mass of antacid. You already know the effectiveness of 0.10 g of $Mg(OH)_2$.]



Sample Problem 18.9 **Using Molecular Scenes to Determine the Extent of HA Dissociation**

Problem A 0.15 *M* solution of HA *(blue and green)* is 33% dissociated. Which scene represents a sample of that solution after it is diluted with water?

Plan We are given the percent dissociation of the original HA solution (33%), and we know that the percent dissociation increases as the acid is diluted. Thus, we calculate the percent dissociation of each diluted sample and see which is greater than 33%. To determine percent dissociation, we apply Equation 18.5, with HA_{dissoc} equal to the number of H_3O^+ (or A^-) and HA_{init} equal to the number of HA *plus* the number of H_3O^+ (or A^-).

Solution Calculating the percent dissociation of each diluted solution with Equation 18.5:

Solution 1. Percent dissociated = $4/(5 + 4) \times 100 = 44\%$
Solution 2. Percent dissociated = $2/(7 + 2) \times 100 = 22\%$
Solution 3. Percent dissociated = $3/(6 + 3) \times 100 = 33\%$

Therefore, scene 1 represents the diluted solution.

Check Let's confirm our choice by examining the other scenes: in scene 2, HA is *less* dissociated than originally, so that scene must represent a more concentrated HA solution; scene 3 represents another solution with the same percent dissociation as the original.

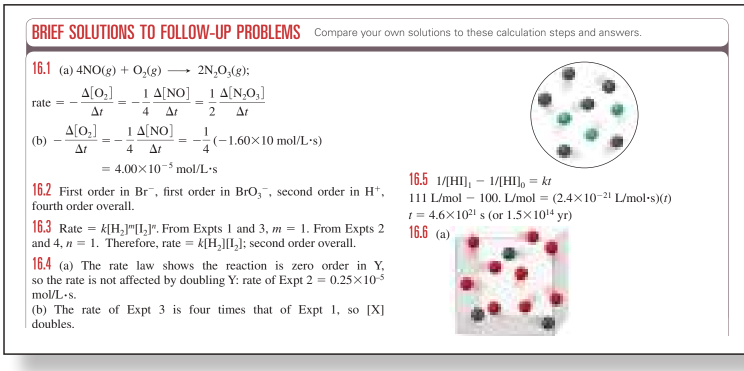
FOLLOW-UP PROBLEM 18.9 The scene in the margin represents a sample of a weak acid HB *(blue and purple)* dissolved in water. Draw a scene that represents the same volume after the solution has been diluted with water.

Unique to *Principles of General Chemistry:* Molecular-Scene Sample Problems

These problems apply the same stepwise strategy to help you interpret molecular scenes and solve problems based on them.

Brief Solutions to Follow-up Problems

These provide multistep solutions at the end of the chapter, not just a one-number answer at the back of the book. This fuller treatment provides an excellent way for you to reinforce problem-solving skills.



BRIEF SOLUTIONS TO FOLLOW-UP PROBLEMS Compare your own solutions to these calculation steps and answers.

16.1 (a) $4NO(g) + O_2(g) \longrightarrow 2N_2O_3(g)$;

$$\text{rate} = -\frac{\Delta[O_2]}{\Delta t} = -\frac{1}{4}\frac{\Delta[NO]}{\Delta t} = \frac{1}{2}\frac{\Delta[N_2O_3]}{\Delta t}$$

(b) $$-\frac{\Delta[O_2]}{\Delta t} = -\frac{1}{4}\frac{\Delta[NO]}{\Delta t} = -\frac{1}{4}(-1.60\times10 \text{ mol/L·s}) = 4.00\times10^{-5} \text{ mol/L·s}$$

16.2 First order in Br^-, first order in BrO_3^-, second order in H^+, fourth order overall.

16.3 Rate = $k[H_2]^m[I_2]^n$. From Expts 1 and 3, $m = 1$. From Expts 2 and 4, $n = 1$. Therefore, rate = $k[H_2][I_2]$; second order overall.

16.4 (a) The rate law shows the reaction is zero order in Y, so the rate is not affected by doubling Y: rate of Expt 2 = 0.25×10^{-5} mol/L·s.
(b) The rate of Expt 3 is four times that of Expt 1, so [X] doubles.

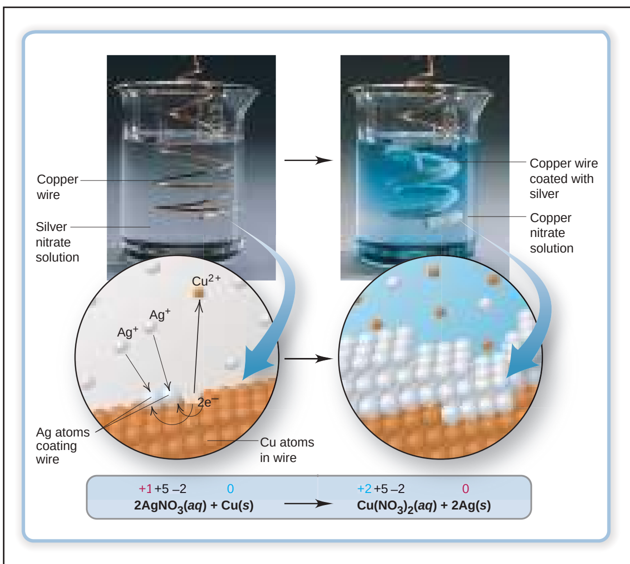
16.5 $1/[HI]_1 - 1/[HI]_0 = kt$
111 L/mol − 100. L/mol = $(2.4\times10^{-21}$ L/mol·s$)(t)$
$t = 4.6\times10^{21}$ s (or 1.5×10^{14} yr)

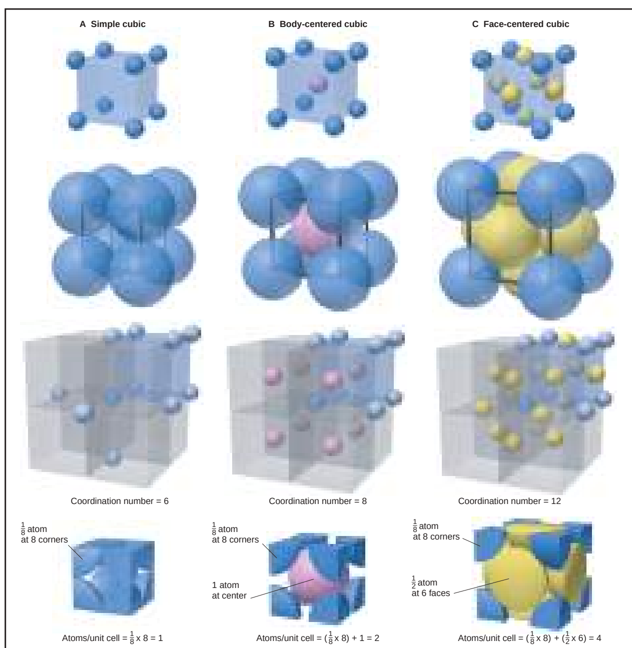
16.6 (a)

VISUALIZING CHEMISTRY

Three-Level Illustrations

A Silberberg hallmark, these illustrations provide macroscopic and molecular views of a process to help you connect these two levels of reality with each other and with the chemical equation that describes the process in symbols.





Cutting-Edge Molecular Models

Author and artist worked side by side and employed the most advanced computer-graphic software to provide accurate molecular-scale models and vivid scenes.

REINFORCING THE LEARNING PROCESS

Chapter Review Guide

A rich catalog of study aids ends each chapter to help you review its content:

- **Learning Objectives** are listed, with section, sample problem, and end-of-chapter problem numbers, to help you focus on key concepts and skills.
- **Key Terms** are boldfaced within the chapter and listed here by section (with page numbers); they are defined again in the Glossary.
- **Key Equations and Relationships** are highlighted and numbered within the chapter and listed here with page numbers.

CHAPTER REVIEW GUIDE

The following sections provide many aids to help you study this chapter. (Numbers in parentheses refer to pages, unless noted otherwise.)

Learning Objectives These are concepts and skills to review after studying this chapter.

Related section (§), sample problem (SP), and upcoming end-of-chapter problem (EP) numbers are listed in parentheses.

1. Explain how solubility depends on the types of intermolecular forces (like-dissolves-like rule) and understand the characteristics of solutions consisting of gases, liquids, or solids (§13.1) (SP 13.1) (EPs 13.1–13.12)
2. Understand the enthalpy components of ΔH_{soln}, the dependence of ΔH_{hydr} on charge density, and why a solution process is exothermic or endothermic (§13.2) (EPs 13.13–13.15, 13.18–13.25, 13.28)
3. Comprehend the meaning of entropy and how the balance between ΔH and ΔS governs the solution process (§13.2) (EPs 13.16, 13.17, 13.26, 13.27)
4. Distinguish among saturated, unsaturated, and supersaturated solutions and explain the equilibrium nature of a saturated solution (§13.3) (EPs 13.29, 13.35)
5. Describe the effect of temperature on the solubility of solids and gases in water and the effect of pressure on the solubility of gases (Henry's law) (§13.3) (SP 13.2) (EPs 13.30–13.34, 13.36)
6. Express concentration in terms of molarity, molality, mole fraction, and parts by mass or by volume and be able to interconvert these terms (§13.4) (SPs 13.3–13.5) (EPs 13.37–13.58)
7. Describe electrolyte behavior and the four colligative properties, explain the difference between phase diagrams for a solution and a pure solvent, explain vapor-pressure lowering for non-volatile and volatile nonelectrolytes, and discuss the van't Hoff factor for colligative properties of electrolyte solutions (§13.5) (SPs 13.6–13.9) (EPs 13.59–13.83)

Key Terms These important terms appear in boldface in the chapter and are defined again in the Glossary.

Section 13.1
solute (392)
solvent (392)
miscible (392)
solubility (*S*) (392)
like-dissolves-like rule (393)
hydration shell (393)
ion–induced dipole force (393)
dipole–induced dipole force (393)
alloy (396)

Section 13.2
heat of solution (ΔH_{soln}) (397)
solvation (397)
hydration (398)
heat of hydration (ΔH_{hydr}) (398)
charge density (398)
entropy (*S*) (399)

Section 13.3
saturated solution (401)
unsaturated solution (401)
supersaturated solution (401)
Henry's law (403)

Section 13.4
molality (*m*) (404)
mass percent [% (w/w)] (405)
volume percent [% (v/v)] (405)
mole fraction (*X*) (405)

Section 13.5
colligative property (408)
electrolyte (408)
nonelectrolyte (408)
vapor pressure lowering (ΔP) (408)
Raoult's law (409)
ideal solution (409)
boiling point elevation (ΔT_b) (410)
freezing point depression (ΔT_f) (411)
semipermeable membrane (412)
osmosis (412)
osmotic pressure (Π) (413)
ionic atmosphere (415)

Key Equations and Relationships Numbered and screened concepts are listed for you to refer to or memorize.

13.1 Dividing the general heat of solution into component enthalpies (397):

$$\Delta H_{soln} = \Delta H_{solute} + \Delta H_{solvent} + \Delta H_{mix}$$

13.2 Dividing the heat of solution of an ionic compound in water into component enthalpies (398):

$$\Delta H_{soln} = \Delta H_{lattice} + \Delta H_{hydr\ of\ the\ ions}$$

13.3 Relating gas solubility to its partial pressure (Henry's law) (403):

$$S_{gas} = k_H \times P_{gas}$$

13.4 Defining concentration in terms of molarity (404):

$$\text{Molarity } (M) = \frac{\text{amount (mol) of solute}}{\text{volume (L) of solution}}$$

13.5 Defining concentration in terms of molality (404):

$$\text{Molality } (m) = \frac{\text{amount (mol) of solute}}{\text{mass (kg) of solvent}}$$

13.6 Defining concentration in terms of mass percent (405):

$$\text{Mass percent } [\% \text{ (w/w)}] = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100$$

13.7 Defining concentration in terms of volume percent (405):

$$\text{Volume percent } [\% \text{ (v/v)}] = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100$$

13.79 What is the minimum mass of glycerol ($C_3H_8O_3$) that must be dissolved in 11.0 mg of water to prevent the solution from freezing at −15°C? (Assume ideal behavior.)

180 Calculate the molality and van't Hoff factor (*i*) for the following aqueous solutions:
(a) 1.00 mass % NaCl, freezing point = −0.593°C
(b) 0.500 mass % CH_3COOH, freezing point = −0.159°C

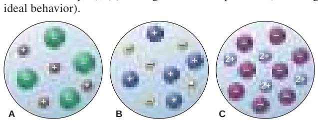
13.81 Calculate the molality and van't Hoff factor (*i*) for the following aqueous solutions:
(a) 0.500 mass % KCl, freezing point = −0.234°C
(b) 1.00 mass % H_2SO_4, freezing point = −0.423°C

13.82 In a study designed to prepare new gasoline-resistant coatings, a polymer chemist dissolves 6.053 g of poly(vinyl alcohol) in enough water to make 100.0 mL of solution. At 25°C, the osmotic pressure of this solution is 0.272 atm. What is the molar mass of the polymer sample?

13.83 The U.S. Food and Drug Administration lists dichloromethane (CH_2Cl_2) and carbon tetrachloride (CCl_4) among the many cancer-causing chlorinated organic compounds. What are the partial pressures of these substances in the vapor above a solution of 1.60 mol of CH_2Cl_2 and 1.10 mol of CCl_4 at 23.5°C? The vapor pressures of pure CH_2Cl_2 and CCl_4 at 23.5°C are 352 torr and 118 torr, respectively. (Assume ideal behavior.)

Comprehensive Problems

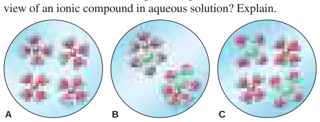
13.84 The three aqueous ionic solutions represented below have total volumes of 25. mL for A, 50. mL for B, and 100. mL for C. If each sphere represents 0.010 mol of ions, calculate: (a) the total molarity of ions for each solution; (b) the highest molarity of solute; (c) the lowest molality of solute (assuming the solution densities are equal); (d) the highest osmotic pressure (assuming ideal behavior).



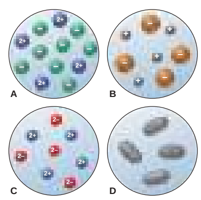
13.85 Gold occurs in seawater at an average concentration of 1.1×10^{-2} ppb. How many liters of seawater must be processed to recover 1 troy ounce of gold, assuming 81.5% efficiency (*d* of seawater = 1.025 g/mL; 1 troy ounce = 31.1 g)?

13.86 Use atomic properties to explain why xenon is 11 times as soluble as helium in water at 0°C on a mole basis.

13.87 Which of the following best represents a molecular-scale view of an ionic compound in aqueous solution? Explain.



13.88 Four 0.50 *m* aqueous solutions are depicted. Assume the solutions behave ideally: (a) Which has the highest boiling point? (b) Which has the lowest freezing point? (c) Can you deter[…] which one has the highest osmotic pressure? Explain.



13.89 "De-icing salt" is used to melt snow and ice on streets. [The] highway department of a small town is deciding whether to [use] NaCl or $CaCl_2$, which are equally effective, to use for this purp[ose]. The town can obtain NaCl for \$0.22/kg. What is the maximum [the] town should pay for $CaCl_2$ to be cost effective?

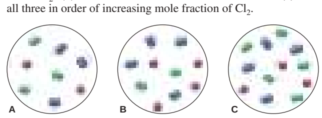
13.90 Thermal pollution from industrial wastewater causes the t[em]perature of river or lake water to increase, which can affect [fish] survival as the concentration of dissolved O_2 decreases. Use the [fol]lowing data to find the molarity of O_2 at each temperature (ass[ume] the solution density is the same as water):

Temperature (°C)	Solubility of O_2 (mg/kg H_2O)	Density of H_2O (g/mL)
0.0	14.5	0.99987
20.0	9.07	0.99823
40.0	6.44	0.99224

13.91 A chemist is studying small organic compounds for [their] potential use as an antifreeze. When 0.243 g of a compoun[d is] dissolved in 25.0 mL of water, the freezing point of the solution is −0.201°C. (a) Calculate the molar mass of the compound (*d* of water = 1.00 g/mL). (b) Analysis shows that the compound is 53.31 mass % C and 11.18 mass % H, the remainder being O. Calculate the empirical and molecular formulas of the compound. (c) Draw a Lewis structure for a compound with this formula that forms H bonds and another for one that does not.

13.92 Is 50% by mass of methanol dissolved in ethanol different from 50% by mass of ethanol dissolved in methanol? Explain.

13.93 Three gaseous mixtures of N_2 *(blue)*, Cl_2 *(green)*, and Ne *(purple)* are depicted below. (a) Which has the smallest mole fraction of N_2? (b) Which have the same mole fraction of Ne? (c) Rank all three in order of increasing mole fraction of Cl_2.



13.94 Four U tubes each have distilled water in the right arm, a solution in the left arm, and a semipermeable membrane between arms. (a) If the solute is KCl, which solution is most concentrated?

End-of-Chapter Problems

An exceptionally large number of problems ends each chapter. These are sorted by section, and many are grouped in similar pairs, with one of each pair answered in Appendix E (along with other problems having a colored number). Following these section-based problems is a large group of Comprehensive Problems, which are based on concepts and skills from any section and/or earlier chapter and are filled with applications from related sciences.

Think of It This Way

Analogies, memory shortcuts, and new insights into key ideas are provided in "Think of It This Way" features.

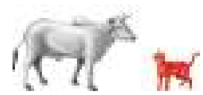
Here are some memory aids to help you connect the half-reaction with its electrode:

1. The words *anode* and *oxidation* start with vowels; the words *cathode* and *reduction* start with consonants.
2. Alphabetically, the *A* in anode comes before the *C* in cathode, and the *O* in oxidation comes before the *R* in reduction.
3. Look at the first syllables and use your imagination:

ANode, OXidation; REDuction, CAThode ⟹ AN OX and a RED CAT

THINK OF IT THIS WAY

Which Half-Reaction Occurs at Which Electrode?



Summary of Section 21.1

- An oxidation-reduction (redox) reaction involves the transfer of electrons from a reducing agent to an oxidizing agent.
- The half-reaction method of balancing divides the overall reaction into half-reactions that are balanced separately and then recombined.
- There are two types of electrochemical cells. In a voltaic cell, a spontaneous reaction generates electricity and does work on the surroundings. In an electrolytic cell, the

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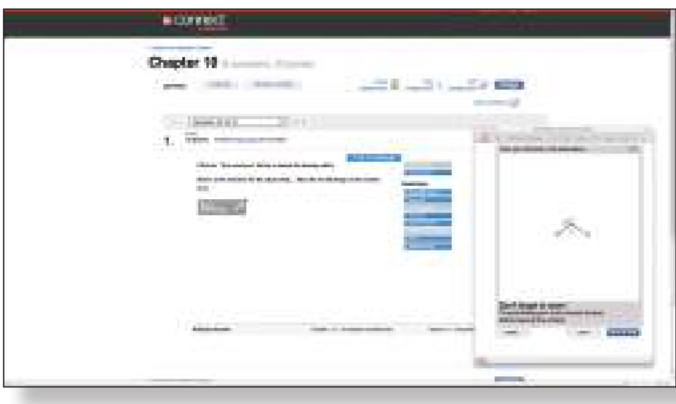

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Computerized Test Bank Prepared by Walter Orchard, Professor Emeritus of Tacoma Community College, over 2300 test questions to accompany *Principles of General Chemistry* are available utilizing Brownstone's Diploma testing software. *Diploma's* software allows you to quickly create a customized test using McGraw-Hill's supplied questions or by authoring your own. *Diploma* allows you to create your tests without an Internet connection—just download the software and question files directly to your computer.

Instructors' Solutions Manual This supplement, prepared by Patricia Amateis of Virginia Tech, contains complete, worked-out solutions for *all* the end-of-chapter problems in the text. It can be found within the Instructors Resources, on the Connect: Chemistry site.

Content Delivery Flexibility *Principles of General Chemistry,* by Martin Silberberg, is available in other formats in addition to the traditional textbook, giving instructors and students more choices for the format of their chemistry text.

Cooperative Chemistry Laboratory Manual Prepared by Melanie Cooper of Clemson University, this innovative manual features open-ended problems designed to simulate experience in a research lab. Working in groups, students investigate one problem over a period of several weeks, so they might complete three or four projects during the semester, rather than one preprogrammed experiment per class. The emphasis is on experimental design, analytic problem solving, and communication.

LEARNING SYSTEM RESOURCES FOR STUDENTS

Student Study Guide This valuable study guide, prepared by Libby Bent Weberg, is designed to help you recognize your learning style; understand how to read, classify, and create a plan for solving a problem; and practice your problem-solving skills. For each section of each chapter, the guide provides study objectives and a summary of the corresponding text. Following the summary are sample problems with detailed solutions. Each chapter has true-false questions and a self-test, with all answers provided at the end of the chapter.

Student Solutions Manual This supplement, prepared by Patricia Amateis of Virginia Tech, contains detailed solutions and explanations for all problems in the main text that have colored numbers.

Connect Chemistry With Connect Chemistry, you can practice solving assigned homework problems using the Silberberg problem-solving methodology applied in the textbook. Algorithmic problems serve up multiple versions of similar problems for mastery of content, with hints and feedback for common incorrect answers to help you stay on track. Where appropriate, you engage in accurate, professional-grade chemical drawing through the use of CambridgeSoft's ChemDraw tool, which is implemented directly into homework problems. Check it out at www.mcgrawhillconnect.com/chemistry.

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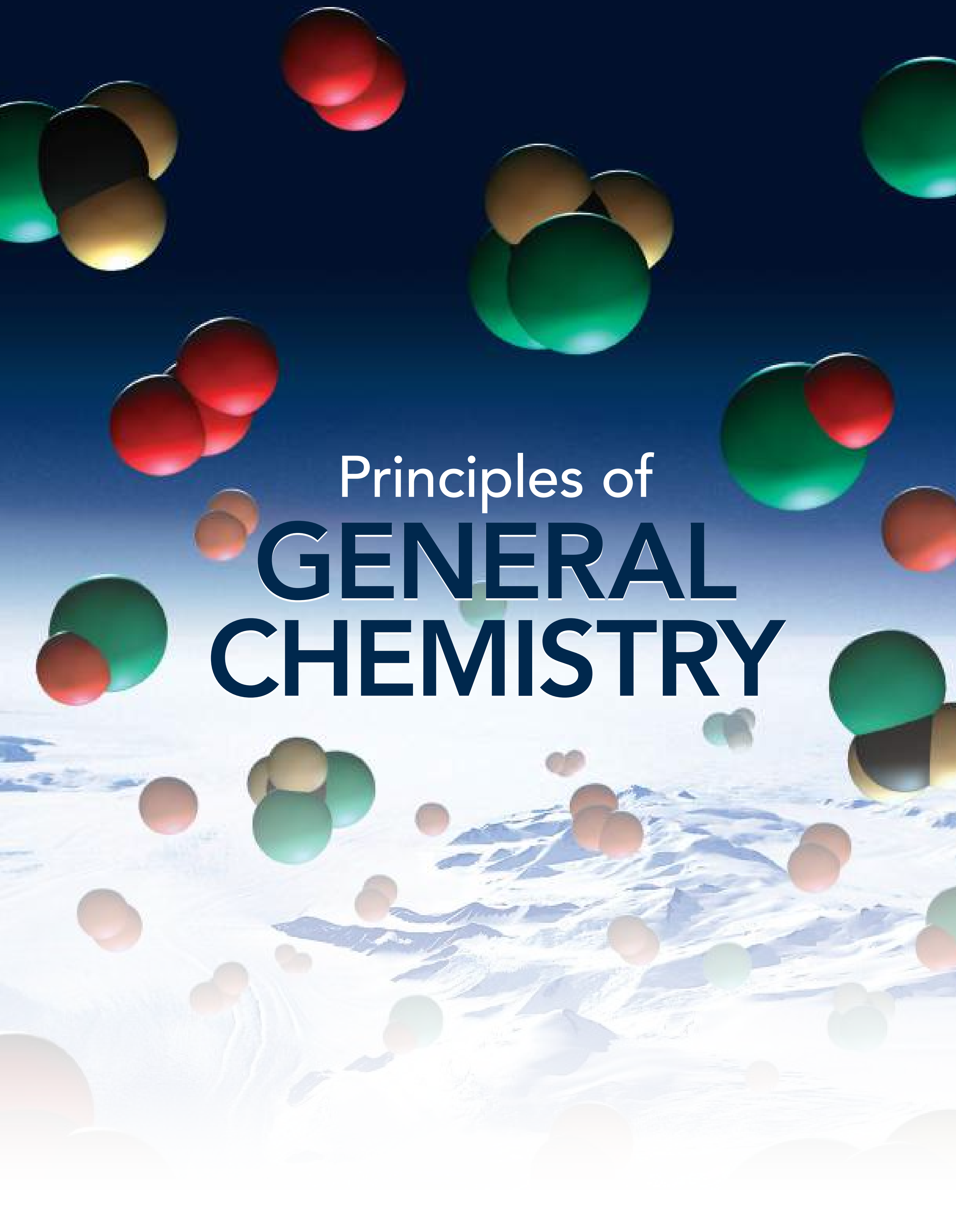
Animations for MP3/iPod A number of animations are available for download to your MP3/iPod through the textbook's Connect website.

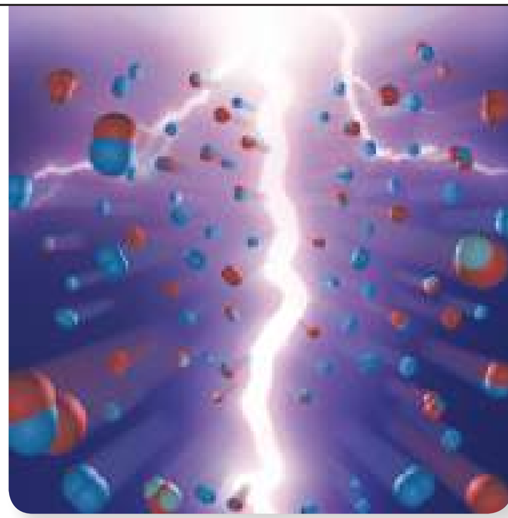
Principles of GENERAL CHEMISTRY



1 Keys to the Study of Chemistry

Key Principles
to focus on while studying this chapter

- *Matter* can undergo two kinds of change: *physical change* involves a change in *state*—gas, liquid, or solid—but not in ultimate makeup *(composition)*; *chemical change (reaction)* is more fundamental because it does involve a change in composition. The changes we observe result ultimately from changes too small to observe. ***(Section 1.1)***
- *Energy* occurs in different forms that are interconvertible, even as the total quantity of energy is conserved. When opposite charges are pulled apart, their *potential energy* increases; when they are released, potential energy is converted to the *kinetic energy* of the charges moving together. Matter consists of charged particles, so changes in energy accompany changes in matter. ***(Section 1.1)***
- The *scientific method* is a way of thinking that involves making *observations* and gathering *data* to develop *hypotheses* that are tested by *controlled experiments* until enough results are obtained to create a *model (theory)* that explains an aspect of nature. A sound theory can predict events but must be changed if new results conflict with it. ***(Section 1.2)***
- Any *measured quantity* is expressed by a number together with a *unit*. *Conversion factors* are ratios of equivalent quantities having different units; they are used in calculations to change the units of quantities. *Decimal prefixes* and *exponential notation* are used to express very large or very small quantities. ***(Section 1.3)***
- *The SI system* consists of seven *fundamental units*, each identifying a physical quantity such as length (meter), mass (kilogram), or temperature (kelvin). These are combined into many *derived units* used to identify quantities such as volume, density, and energy. *Extensive properties*, such as mass, depend on sample size; *intensive properties*, such as temperature, do not. ***(Section 1.4)***
- *Uncertainty* characterizes every measurement and is indicated by the number of *significant figures*. We *round* the final answer of a calculation to the same number of digits as in the least certain measurement. *Accuracy* refers to how close a measurement is to the true value; *precision* refers to how close measurements are to one another. ***(Section 1.5)***



A Molecular View Within a Storm Lightning supplies the energy for many atmospheric chemical changes to occur. In fact, all the events within and around you have causes and effects at the atomic level of reality.

Outline

1.1 Some Fundamental Definitions
Properties of Matter
States of Matter
Central Theme in Chemistry
Importance of Energy

1.2 The Scientific Approach: Developing a Model

1.3 Chemical Problem Solving
Units and Conversion Factors
A Systematic Approach

1.4 Measurement in Scientific Study
Features of SI Units
SI Units in Chemistry
Extensive and Intensive Properties

1.5 Uncertainty in Measurement: Significant Figures
Determining Significant Digits
Calculations and Rounding Off
Precision, Accuracy, and Instrument Calibration

CONCEPTS & SKILLS TO REVIEW
before studying this chapter

- exponential (scientific) notation (Appendix A)

Maybe you're taking this course because chemistry is fundamental to understanding other natural sciences. Maybe it's required for your major. Or maybe you just want to learn more about the impact of chemistry on society or even on your everyday life. For example, did you have cereal, fruit, and coffee for breakfast today? In chemical terms, you enjoyed nutrient-enriched, spoilage-retarded carbohydrate flakes mixed in a white emulsion of fats, proteins, and monosaccharides, with a piece of fertilizer-grown, pesticide-treated fruit, and a cup of hot aqueous extract of stimulating alkaloid. Earlier, you may have been awakened by the sound created as molecules aligned in the liquid-crystal display of your clock and electrons flowed to create a noise. You might have thrown off a thermal insulator of manufactured polymer and jumped in the shower to emulsify fatty substances on your skin and hair with purified water and formulated detergents. Perhaps you next adorned yourself in an array of pleasant-smelling pigmented gels, dyed polymeric fibers, synthetic footwear, and metal-alloy jewelry. After breakfast, you probably abraded your teeth with a colloidal dispersion of artificially flavored, dental-hardening agents, grabbed your laptop (an electronic device containing ultrathin, microetched semiconductor layers powered by a series of voltaic cells), collected some books (processed cellulose and plastic, electronically printed with light- and oxygen-resistant inks), hopped in your hydrocarbon-fueled, metal-vinyl-ceramic vehicle, electrically ignited a synchronized series of controlled gaseous explosions, and took off for class!

But the true impact of chemistry extends much farther than the products we use in daily life. The most profound questions about health, climate change, even the origin of life, ultimately have chemical answers.

No matter what your reason for studying chemistry, this course will help you develop two mental skills. The first, common to all science courses, is the ability to solve problems systematically. The second is specific to chemistry, for as you comprehend its ideas, you begin to view a hidden reality filled with incredibly minute particles moving at fantastic speeds, colliding billions of times a second, and interacting in ways that determine how all the matter inside and outside of you behaves. This chapter holds the keys to enter this world.

1.1 • SOME FUNDAMENTAL DEFINITIONS

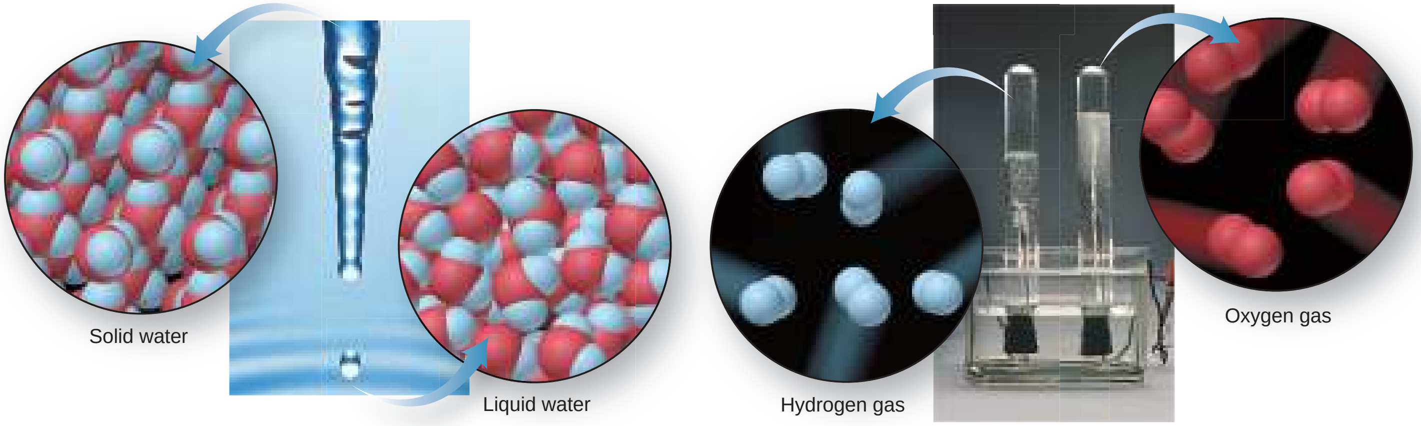
A good place to begin our exploration of chemistry is to define it and a few central concepts. **Chemistry** is *the study of matter and its properties, the changes that matter undergoes, and the energy associated with those changes.*

The Properties of Matter

Matter is the "stuff" of the universe: air, glass, planets, students—*anything that has mass and volume.* (In Section 1.4, we discuss the meanings of mass and volume in terms of how they are measured.) Chemists want to know the **composition** of matter, *the types and amounts of simpler substances that make it up.* A *substance* is a type of matter that has a defined, fixed composition.

We learn about matter by observing its **properties,** *the characteristics that give each substance its unique identity.* To identify a person, we might observe height, weight, hair and eye color, fingerprints, and even DNA pattern, until we arrive at a unique conclusion. To identify a substance, we observe two types of properties, *physical* and *chemical,* which are closely related to two types of change that matter undergoes:

- **Physical properties** are characteristics a substance shows *by itself, without changing into or interacting with another substance*. These properties include melting point, electrical conductivity, and density. A **physical change** occurs when a substance *alters its physical properties, **not** its composition.* For example, when ice melts,



A Physical change:
Solid form of water becomes liquid form. Particles before and after remain the same, which means composition did ***not*** *change.*

B Chemical change:
Electric current decomposes water into different substances (hydrogen and oxygen). Particles before and after are different, which means composition ***did*** *change.*

Figure 1.1 The distinction between physical and chemical change.

several physical properties change, such as hardness, density, and ability to flow. But the composition of the sample does *not* change: it is still water. The photograph in Figure 1.1A shows what this change looks like in everyday life. The "blow-up" circles depict a magnified view of the particles making up the sample. In the icicle, the particles lie in a repeating pattern, whereas they are jumbled in the droplet, but *the particles are the same* in both forms of water.

Physical change (same substance before and after):

$$\text{Water (solid form)} \longrightarrow \text{water (liquid form)}$$

- **Chemical properties** are characteristics a substance shows *as it changes into or interacts with another substance (or substances)*. Chemical properties include flammability, corrosiveness, and reactivity with acids. A **chemical change,** also called a **chemical reaction,** occurs when *a substance (or substances) is converted into a different substance (or substances).* Figure 1.1B shows the chemical change (reaction) that occurs when you pass an electric current through water: the water decomposes (breaks down) into two other substances, hydrogen and oxygen, that bubble into the tubes. The composition *has* changed: the final sample is no longer water.

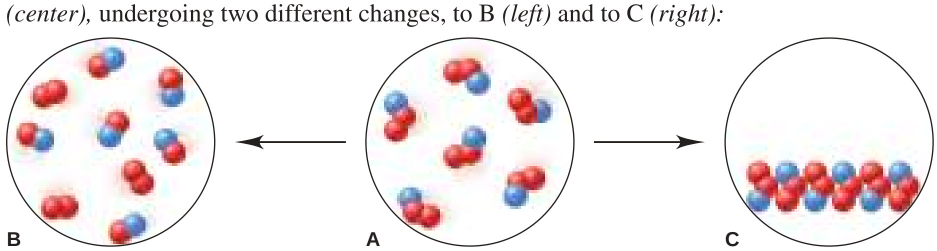
  Chemical change (different substances before and after):

$$\text{Water} \xrightarrow{\text{electric current}} \text{hydrogen} + \text{oxygen}$$

Let's work through a sample problem that uses atomic-scale scenes to distinguish between physical and chemical change.

Sample Problem 1.1 Visualizing Change on the Atomic Scale

Problem The scenes below represent an atomic-scale view of a sample of matter, A *(center),* undergoing two different changes, to B *(left)* and to C *(right):*

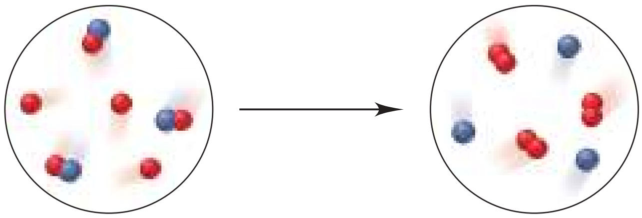


Decide whether each depiction shows a physical or a chemical change.

Plan Given depictions of two changes, we have to determine whether each represents a physical or a chemical change. The number and colors of the little spheres that make up each particle tell its "composition." Samples with particles of the *same* composition but in a different arrangement depict a *physical* change, whereas samples with particles of a *different* composition depict a *chemical* change.

Solution In A, each particle consists of one blue and two red spheres. The particles in A change into two types in B, one made of red and blue spheres and the other made of two red spheres; therefore, they have undergone a chemical change to form different particles. The particles in C are the same as those in A, but they are closer together and arranged differently; therefore, they have undergone a physical change.

FOLLOW-UP PROBLEM 1.1 Is the following change chemical or physical? (Compare your answer with the one in Brief Solutions to Follow-up Problems at the end of the chapter.)



The States of Matter

Matter occurs commonly in *three physical forms* called **states:** solid, liquid, and gas. We'll define the states and see how temperature can change them.

Defining the States On the macroscopic scale, each state of matter is defined by the way the sample fills a container (Figure 1.2, *flasks at top*):

- A **solid** has a fixed shape that does not conform to the container shape. Solids are *not* defined by rigidity or hardness: solid iron is rigid and hard, but solid lead is flexible, and solid wax is soft.
- A **liquid** has a varying shape that conforms to the container shape, but only to the extent of the liquid's volume; that is, a liquid has *an upper surface.*
- A **gas** also has a varying shape that conforms to the container shape, but it fills the entire container and, thus, does *not* have a surface.

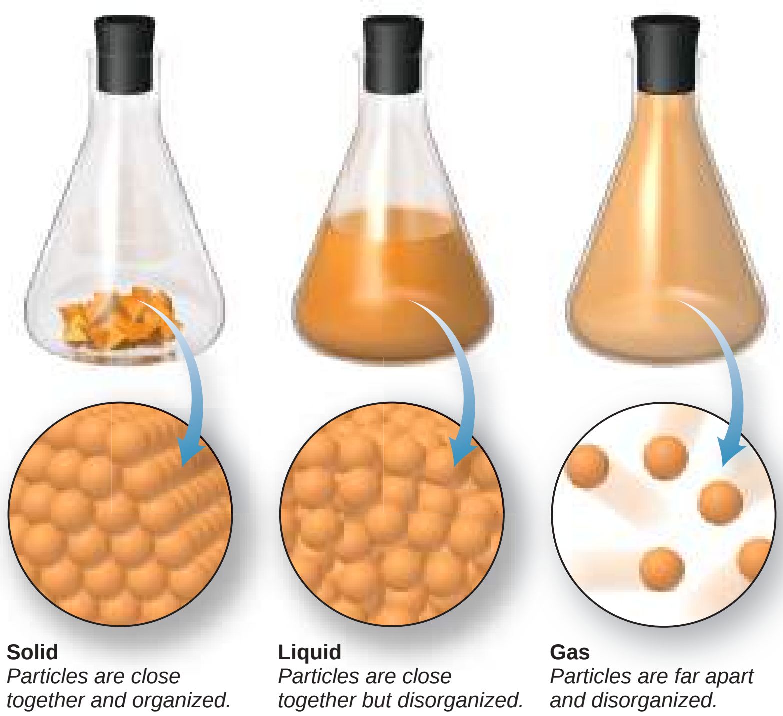


Figure 1.2 The physical states of matter.