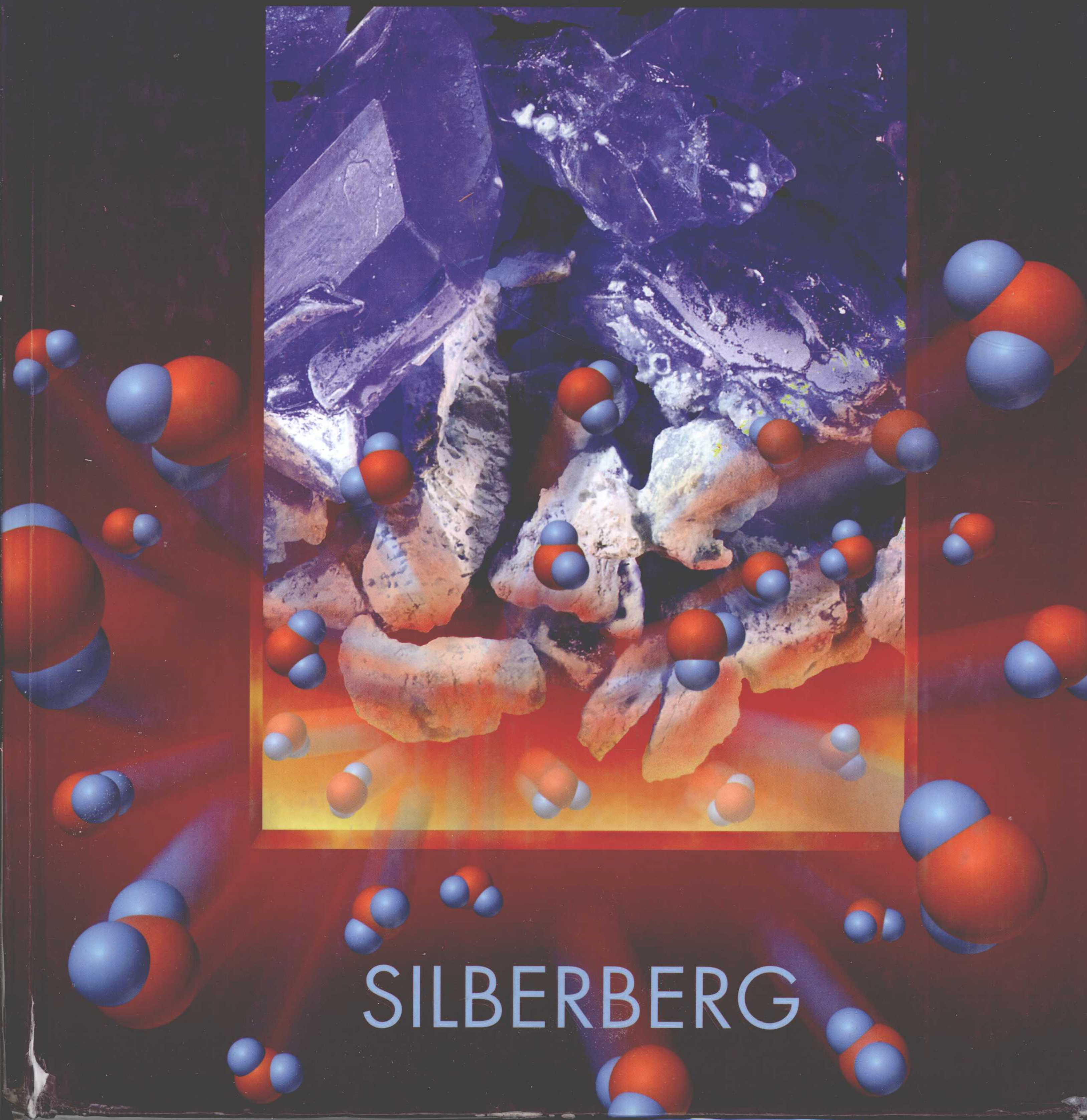
PRINCIPLES OF

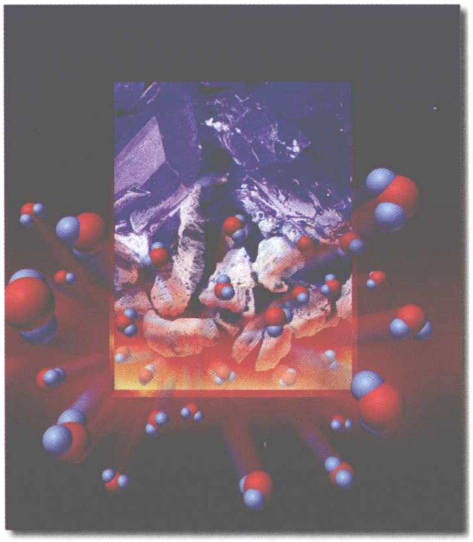
GENERAL CHEMISTRY



SILBERBERG

Martin S. Silberberg

Principles of GENERAL CHEMISTRY



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PRINCIPLES OF GENERAL CHEMISTRY

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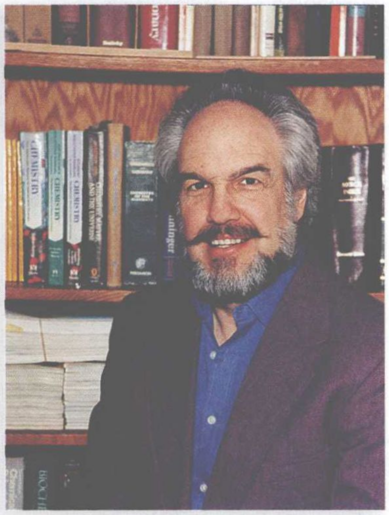

Martin S. Silberberg received a B.S. in Chemistry from the City University of New York and a Ph.D. in Chemistry from the University of Oklahoma. He then accepted a research position in analytical biochemistry at the Albert Einstein College of Medicine in New York City, where he developed advanced methods to study fundamental brain mechanisms as well as neurotransmitter metabolism in Parkinson's disease. Following his years in research, Dr. Silberberg joined the faculty of Simon's Rock College of Bard, a liberal arts college known for excellence in teaching small classes of highly motivated students. As Head of the Natural Sciences Major and Director of Premedical Studies, he has taught courses in general chemistry, organic chemistry, biochemistry, and liberal arts chemistry. The close student contact has afforded him insights into how students learn chemistry, where they have difficulties, and what strategies can help them succeed. Dr. Silberberg has applied these insights in a broader context by establishing a text writing, editing, and consulting company. Before writing his own text, he worked as a consulting and developmental editor on chemistry, biochemistry, and physics texts for several major college publishers. He resides with his wife and son in the Pioneer Valley near Amherst, Massachusetts, where he enjoys the rich cultural and academic life of the area and relaxes by cooking, gardening, and hiking.

Preface

CREATING A NEW TEXT

Like the science of chemistry itself, the teaching of chemistry is evolving, and the course texts that professors and students rely on must do so as well. The large, thousand-page or more books that most courses use provide a complete survey of the field, with a richness of relevance and content. *Chemistry: The Molecular Nature of Matter and Change,* the parent of this new text, stands at the forefront of dynamic, modern texts. Yet, extensive market research demonstrates that some professors prefer a less expansive treatment, with coverage confined to the core principles and skills. Such a text would allow professors to enrich their course with topics relevant to their own students. And, most importantly, it would allow the entire book to be more easily covered in one year—all the essential material a science major needs to go on to other courses in chemistry and related disciplines.

Sensing the need for a more succinct text, we created *Principles of General Chemistry*. This new text retains the molecular artwork, problem-solving approach, and student-friendly pedagogy so admired in its parent, *Chemistry: The Molecular Nature of Matter and Change.* This new text is leaner and more concise, targeting only the topics that a general chemistry course at this level should include and that instructors expect to see.

Crafting the content of the new text involved assessing which topics constituted the core of a general chemistry course and distilling them from the parent text. To confirm my assessment, we invited three professors to serve as content editors and review my suggested changes. Using their experience and my detailed outline, the content editors pruned the parent text to generate a rough draft, which I then reworked into the final manuscript. It was very gratifying, even remarkable, to find that the four of us defined the essential content of the modern general chemistry course in virtually identical terms.

HOW *CHEMISTRY* AND THE NEW *PRINCIPLES OF GENERAL CHEMISTRY* ARE ALIKE

Both *Chemistry: The Molecular Nature of Matter and Change* and *Principles of General Chemistry* maintain the same high standards of accuracy, depth, clarity, and rigor and have the same three distinguishing hallmarks:

1. *Visualizing chemical models.* In many discussions, concepts are explained first at the macroscopic level and then from a molecular point of view. Placed near the related discussion, the text's celebrated graphics bring the point home for today's visually oriented students—depicting the change at the observable level in the lab, at the molecular level, and, when appropriate, 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 *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 just a brief 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, real-world applications are woven into the worked in-text sample problems and the chapter problem sets.

HOW *CHEMISTRY* AND *PRINCIPLES OF GENERAL CHEMISTRY* ARE DIFFERENT

Principles of General Chemistry achieves authoritative topic coverage in 300 fewer pages than its parent text, thereby appealing to today's efficiency-minded instructors and value-conscious students. To accomplish this shortening, most of the material in the boxed applications essays and margin notes was removed, thereby allowing instructors to include their own favorite examples.

The content editors and I also felt that several other topics, while constituting important fields of modern research, were not central to the core subject matter of general chemistry; these include colloids, green chemistry, and much of advanced materials. The chapters on descriptive chemistry, organic chemistry, and transition elements were tightened extensively, and the chapter on the industrial isolation of the elements was removed (except for a few topics that were blended into the chapter on electrochemistry).

The new text includes all the worked sample problems of the parent text but has about one-third fewer end-of-chapter problems. Nevertheless, there are more than enough representative problems for every topic, and they are packed with relevance and real-world applications.

Principles of General Chemistry is a powerhouse of pedagogy. All the learning aids that students find so useful in the parent text have been retained—Concepts and Skills to Review, Section Summaries, Key Terms, Key Equations, and Brief Solutions to Follow-up Problems. In addition, two new aids help students further focus their efforts:

1. *Key Principles.* At the beginning of each chapter, short paragraphs state the main concepts concisely, using many of the same phrases and terms that will appear in the pages that follow. A student can preview these principles before reading the chapter and then review them afterward.
2. *Problem-Based Learning Objectives.* At the end of each chapter, the list of learning objectives now includes the numbers of homework problems that relate to each objective. Thus, a student, or an instructor, can select problems that apply specifically to a given topic.

The new text is a lean and direct introduction to chemistry for science majors. Unlike its parent, which offers almost any topic that *any* instructor could want, *Principles of General Chemistry* offers every topic that *every* instructor would need.

Acknowledgments

Principles of General Chemistry and its author are fortunate to have supplement authors so committed to accuracy and clarity for student and instructor. Patricia Amateis of Virginia Tech diligently prepared the *Instructors' Solutions Manual* and *Student Solutions Manual.* Libby Weberg has prepared the *Student Study Guide.* S. Walter Orchard of Tacoma Community College updated the *Test Bank.* Christina Bailey of California Polytechnic University provided the excellent *PowerPoint Lecture Outlines* that appear on the Digital Content Manager CD.

It was a great pleasure to work closely with the three content editors, Patricia Amateis of Virginia Tech, Ramesh Arasasingham of the University of California–Irvine, and Steven Keller of the University of Missouri–Columbia. All three are superb professors dedicated to making general chemistry an enriching experience for their students. Their help and insight has ensured that this first edition contains all the essential principles necessary for the science major, two-semester, general chemistry course.

Special thanks go to Professor Dorothy B. Kurland for her exceptionally thorough accuracy check of the entire text. And I extend my gratitude to all the other professors who reviewed portions of this first edition or participated in our developmental survey process to assess the content needs for the text:

Edwin H. Abbott, *Montana State University*
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The superb publishing team at McGraw-Hill Higher Education has done a terrific job once again in the development and production of this new text, and they have my deepest appreciation. Heading the team with guidance, friendship, and support were Michael Lange, Vice President—New Product Launches, Director of Marketing Kent Peterson, and Publisher Thomas Timp. Senior Developmental Editor Donna Nemmers was in charge throughout the project overseeing innumerable text and supplement details; Lead Project Manager Peggy Selle handled the complex production expertly; Senior Designer David Hash supervised the modern interior design by freelancer Jamie O'Neal; and Marketing Manager Tami Hodge applied her enthusiasm and skill to presenting this new book and its supplements to the academic community.

A wonderful group of expert freelancers made indispensable contributions as well. I never could have finished this project on time without the hard work and remarkable organizational and personal skills of Freelance Developmental Editor Karen Pluemer. Jane Hoover performed a masterful copyediting job once again, and Katie Aiken and Janelle Pregler followed with superb proofreading. Chris Hammond of Photofind found some striking new photos. And my friend Michael Goodman created the exciting new cover.

As always, my wife Ruth was there every step of the way, from helping to set up the project to checking and correcting manuscript and proofs. I rely daily on her devoted support. And my son Daniel not only contributed his artistic skill in helping to design artwork, but, as a recent chemistry student, he also provided valuable input on the clarity of explanations.

A Guide to Student Success

This guided tour of ***Principles of General Chemistry*** will show you how the special features of this text can help you be successful in this course.

Chapter Opener

The opener provides a thought-provoking figure and legend that relate to a main topic of the chapter.

Key Principles

The main principles from the chapter are presented in a few sentences so that you can keep them in mind as you study. You can also use this list for review when you finish the chapter.

Measuring the Burn When a forest burns or a lake melts, indeed in any chemical or physical change, the reactants contain different quantities of energy than the products. In this chapter, you'll apply natural law to measure these changes.

CHAPTER SIX

Thermochemistry: Energy Flow and Chemical Change

Key Principles

- Chemical or physical change is *always* accompanied by a change in the energy that the matter contains.
- To study a *change in energy* (ΔE), scientists conceptually divide the universe into *system* (the part being studied) and *surroundings* (everything else). All energy changes occur as *heat* (q) and/or *work* (w) transferred either from the surroundings to the system or from the system to the surroundings ($\Delta E = q + w$). Thus, the total energy of the universe is constant (*law of energy conservation, or first law of thermodynamics*).
- No matter how a particular change in energy occurs, the magnitude of ΔE is the same. The internal energy of a system (E) is a *state function,* a thermodynamic variable whose change depends *only* on its initial and final values.
- *Enthalpy* (H) is related to E. The *change in enthalpy* (ΔH) equals the heat transferred at constant pressure, q_P. Most laboratory, environmental, and biological changes occur at constant P, so ΔH is more relevant than ΔE and easier to measure.
- The enthalpy change of a reaction, called the *heat of reaction* (ΔH_{rxn}), is negative (< 0) if the reaction releases heat (*exothermic*) and positive (> 0) if it absorbs heat (*endothermic*); for example, the combustion of methane is exothermic ($\Delta H_{rxn} < 0$), and the melting of ice is endothermic ($\Delta H_{rxn} > 0$).
- The more heat a substance absorbs, the higher its temperature becomes, but each substance has its own *heat capacity,* the heat required for a given temperature rise. Knowing this capacity and measuring ΔT in a *calorimeter,* we can find ΔH_{rxn}.
- The quantity of heat lost or gained in a reaction is related *stoichiometrically* to the amounts of reactants and products.
- Because H is a state function, we can find ΔH of any reaction by imagining that it occurs as the sum of other reactions whose ΔH values we know or can measure (*Hess's law of heat summation*).
- Chemists define a set of conditions, called *standard states,* in order to compare heats of different reactions. Each substance has a *standard heat of formation* (ΔH_f°), the heat of reaction when the substance is formed from its elements under these conditions. ΔH_f° values are used to calculate the *standard heat of reaction* (ΔH_{rxn}°).

Outline

Chapter Outline

The outline shows the sequence of topics and subtopics.

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 this one.

Concepts & Skills to Review Before You Study This Chapter

- classification of mixtures (Section 2.9)
- calculations involving mass percent (Section 3.1) and molarity (Section 3.5)
- electrolytes; water as a solvent (Sections 4.1 and 12.5)
- mole fraction and Dalton's law of partial pressures (Section 5.4)
- types of intermolecular forces and the concept of polarizability (Section 12.3)
- vapor pressure of liquids (Section 12.2)

Nearly all the gases, liquids, and solids that make up our world are *mixtures*—two or more substances physically mixed together but not chemically combined. Synthetic mixtures, such as glass and soap, usually contain relatively few components, whereas natural mixtures, such as seawater and soil, are more complex, often containing more than 50 different substances. Living mixtures, such as trees and students, are the most complex—even a simple bacterial cell contains well over 5000 different compounds (Table 13.1).

Table 13.1 Approximate Composition of a Bacterium

Substance	Mass % of Cell	Number of Types	Number of Molecules

SOLVING PROBLEMS STEP-BY-STEP

Sample Problems

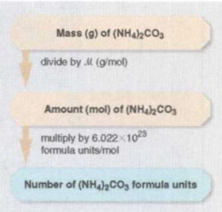
A worked-out problem appears whenever an important new concept or skill is introduced. The step-by-step approach is shown consistently for every sample problem in the text.

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

SAMPLE PROBLEM 3.2 Calculating the Moles and Number of Formula Units in a Given Mass of a Compound

Problem Ammonium carbonate is a white solid that decomposes with warming. Among its many uses, it is a component of baking powder, fire extinguishers, and smelling salts. How many formula units are in 41.6 g of ammonium carbonate?

Plan We know the mass of compound (41.6 g) and need to find the number of formula units. As we saw in Sample Problem 3.1(b), to convert grams to number of entities, we have to find number of moles first, so we must divide the grams by the molar mass ($\mathcal{M}$). For this, we need $\mathcal{M}$, so we determine the formula (see Table 2.5) and take the sum of the elements' molar masses. Once we have the number of moles, we multiply by Avogadro's number to find the number of formula units.



Solution The formula is $(NH_4)_2CO_3$. Calculating molar mass:

$$\begin{aligned}\mathcal{M} &= (2 \times \mathcal{M} \text{ of N}) + (8 \times \mathcal{M} \text{ of H}) + (1 \times \mathcal{M} \text{ of C}) + (3 \times \mathcal{M} \text{ of O})\\ &= (2 \times 14.01 \text{ g/mol}) + (8 \times 1.008 \text{ g/mol}) + 12.01 \text{ g/mol} + (3 \times 16.00 \text{ g/mol})\\ &= 96.09 \text{ g/mol}\end{aligned}$$

Converting from grams to moles:

$$\text{Moles of } (NH_4)_2CO_3 = 41.6 \cancel{\text{g } (NH_4)_2CO_3} \times \frac{1 \text{ mol } (NH_4)_2CO_3}{96.09 \cancel{\text{g } (NH_4)_2CO_3}} = 0.433 \text{ mol } (NH_4)_2CO_3$$

Converting from moles to formula units:

$$\begin{aligned}\text{Formula units of } (NH_4)_2CO_3 &= 0.433 \cancel{\text{mol } (NH_4)_2CO_3} \times \frac{6.022\times10^{23} \text{ formula units } (NH_4)_2CO_3}{1 \cancel{\text{mol } (NH_4)_2CO_3}}\\ &= 2.61\times10^{23} \text{ formula units } (NH_4)_2CO_3\end{aligned}$$

Check The units are correct. The mass is less than half the molar mass ($\sim 42/96 < 0.5$), so the number of formula units should be less than half Avogadro's number ($\sim 2.6\times10^{23}/6.0\times10^{23} < 0.5$).

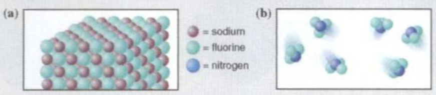
Comment A *common mistake* is to forget the subscript 2 outside the parentheses in $(NH_4)_2CO_3$, which would give a much lower molar mass.

FOLLOW-UP PROBLEM 3.2 Tetraphosphorus decaoxide reacts with water to form phosphoric acid, a major industrial acid. In the laboratory, the oxide is used as a drying agent.
(a) What is the mass (in g) of 4.65×10^{22} molecules of tetraphosphorus decaoxide?
(b) How many P atoms are present in this sample?

Molecular-view Sample Problems unique to Silberberg texts, conceptual (picture) problems apply this stepwise strategy to help you interpret molecular scenes and solve problems based on them.

SAMPLE PROBLEM 2.14 Determining Formulas and Names from Molecular Depictions

Problem Each box contains a representation of a binary compound. Determine its formula, name, and molecular (formula) mass.



Plan Each of the compounds contains only two elements, so to find the formula, we find the simplest whole-number ratio of one atom to the other. Then we determine the name (see Sample Problems 2.5, 2.6, and 2.11) and the mass (see Sample Problem 2.13).

Solution **(a)** There is one brown (sodium) for each green (fluorine), so the formula is NaF. A metal and nonmetal form an ionic compound, in which the metal is named first: sodium fluoride.

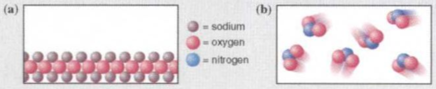
$$\begin{aligned}\text{Formula mass} &= (1 \times \text{atomic mass of Na}) + (1 \times \text{atomic mass of F})\\ &= 22.99 \text{ amu} + 19.00 \text{ amu} = 41.99 \text{ amu}\end{aligned}$$

(b) There are three green (fluorine) for each blue (nitrogen), so the formula is NF_3. Two nonmetals form a covalent compound. Nitrogen has a lower group number, so it is named first: nitrogen trifluoride.

$$\begin{aligned}\text{Molecular mass} &= (1 \times \text{atomic mass of N}) + (3 \times \text{atomic mass of F})\\ &= 14.01 \text{ amu} + (3 \times 19.00 \text{ amu}) = 71.01 \text{ amu}\end{aligned}$$

Check **(a)** For binary ionic compounds, we predict ionic charges from the periodic table (see Figure 2.10). Na forms a 1+ ion, and F forms a 1− ion, so the charges balance with one Na^+ per F^-. Also, ionic compounds are solids, consistent with the picture. **(b)** Covalent compounds often occur as individual molecules, as in the picture. Rounding in (a) gives 25 + 20 = 45; in (b), we get 15 + (3 × 20) = 75, so there are no large errors.

FOLLOW-UP PROBLEM 2.14 Each box contains a representation of a binary compound. Determine its name, formula, and molecular (formula) mass.



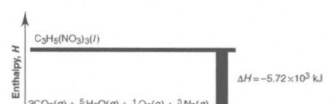
Brief Solutions to Follow-up Problems

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

Brief Solutions to Follow-up Problems

6.1 $$\begin{aligned}\Delta E &= q + w\\ &= \left(-26.0 \text{ kcal} \times \frac{4.184 \text{ kJ}}{1 \text{ kcal}}\right) + \left(+15.0 \text{ Btu} \times \frac{1.055 \text{ kJ}}{1 \text{ Btu}}\right)\\ &= -93 \text{ kJ}\end{aligned}$$

6.2 The reaction is exothermic.



6.3 $\Delta T = 25.0°C - 37.0°C = -12.0°C = -12.0 \text{ K}$

$$\text{Mass (g)} = 1.11 \text{ g/mL} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times 5.50 \text{ L} = 6.10\times10^3 \text{ g}$$

$$\begin{aligned}q &= c \times \text{mass} \times \Delta T\\ &= (2.42 \text{ J/g·K})\left(\frac{1 \text{ kJ}}{1000 \text{ J}}\right)(6.10\times10^3 \text{ g})(-12.0 \text{ K})\\ &= -177 \text{ kJ}\end{aligned}$$

6.4 $$\begin{aligned}-q_{\text{solid}} &= q_{\text{water}}\\ -[(0.519 \text{ J/g·K})(2.050 \text{ g})(x - 74.21)] &= [(4.184 \text{ J/g·K})(26.05 \text{ g})(x - 27.20)]\\ x &= 27.65 \text{ K}\end{aligned}$$

$\Delta T_{\text{diamond}} = -46.56 \text{ K}$ and $\Delta T_{\text{water}} = 0.45 \text{ K}$

6.5 $$\begin{aligned}-q_{\text{sample}} &= q_{\text{calorimeter}}\\ -(0.8650 \text{ g C})\left(\frac{1 \text{ mol C}}{12.01 \text{ g C}}\right)(-393.5 \text{ kJ/mol C}) &= (2.613 \text{ K})x\\ x &= 10.85 \text{ kJ/K}\end{aligned}$$

6.6 $C_2H_4(g) + H_2(g) \longrightarrow C_2H_6(g) + 137 \text{ kJ}$

$$\begin{aligned}\text{Heat (kJ)} &= 15.0 \text{ kg} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol } C_2H_6}{30.07 \text{ g } C_2H_6} \times \frac{137 \text{ kJ}}{1 \text{ mol}}\\ &= 6.83\times10^4 \text{ kJ}\end{aligned}$$

6.7

$$\begin{aligned}&2NO(g) + \tfrac{3}{2}O_2(g) \longrightarrow N_2O_5(s) && \Delta H = -223.7 \text{ kJ}\\ &2NO_2(g) \longrightarrow 2NO(g) + O_2(g) && \Delta H = 114.2 \text{ kJ}\end{aligned}$$

$$\cancel{2NO(g)} + \tfrac{1}{2}\cancel{\tfrac{3}{2}}O_2(g) + 2NO_2(g) \longrightarrow N_2O_5(s) + \cancel{2NO(g)} + \cancel{O_2(g)}$$

$$2NO_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow N_2O_5(s) \qquad \Delta H = -109.5 \text{ kJ}$$

6.8 (a) $C(\text{graphite}) + 2H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow CH_3OH(l) \qquad \Delta H_f^\circ = -238.6 \text{ kJ}$

(b) $Ca(s) + \tfrac{1}{2}O_2(g) \longrightarrow CaO(s) \qquad \Delta H_f^\circ = -635.1 \text{ kJ}$

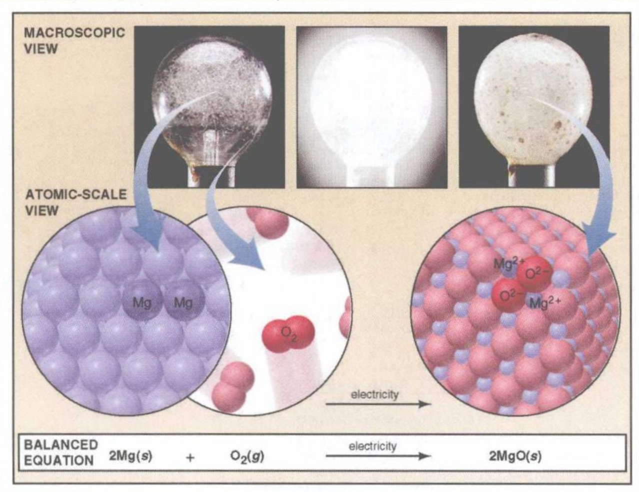
(c) $C(\text{graphite}) + \tfrac{1}{4}S_8(\text{rhombic}) \longrightarrow CS_2(l) \qquad \Delta H_f^\circ = 87.9 \text{ kJ}$

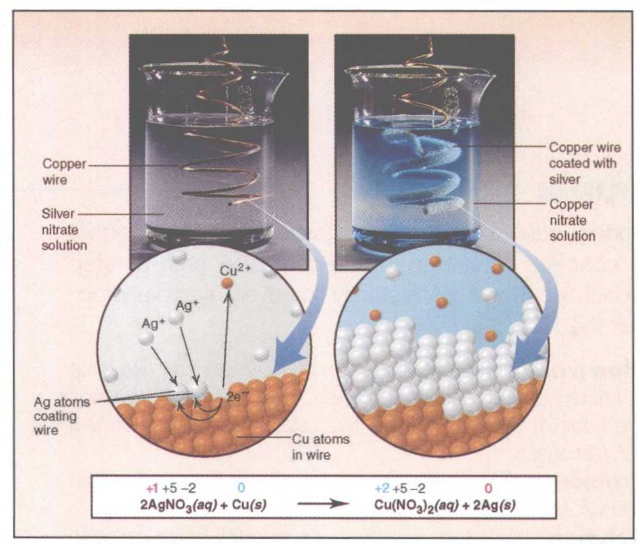
6.9 ΔH_f° of $CH_3OH(l)$

$$\begin{aligned}&= -\Delta H^\circ_{\text{rxn}} + 2\Delta H_f^\circ[H_2O(g)] + \Delta H_f^\circ[CO_2(g)]\\ &= 638.5 \text{ kJ} + (2 \text{ mol})(-241.8 \text{ kJ/mol}) + (1 \text{ mol})(-393.5 \text{ kJ/mol})\\ &= -238.6 \text{ kJ}\end{aligned}$$

Three-Level Illustrations

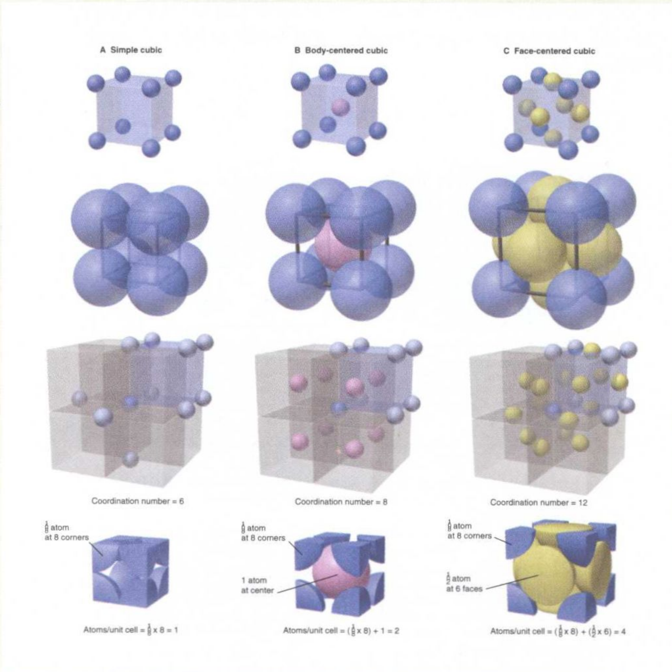
A Silberberg hallmark, these illustrations provide macroscopic and molecular views of a process that help you connect these two levels of reality with each other and with the chemical equation that describes the process in symbols.





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.

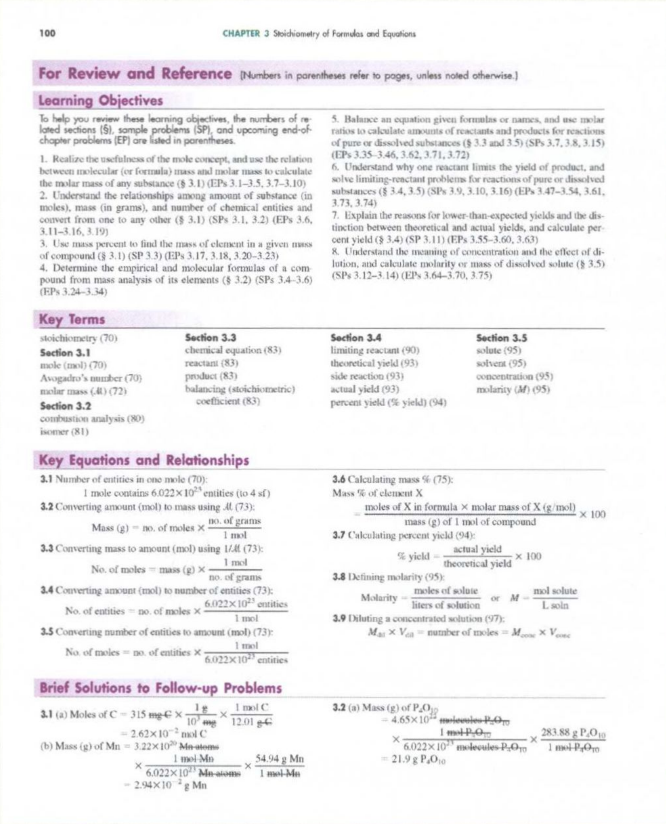


REINFORCING THE LEARNING PROCESS

For Review and Reference

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 focus you 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 screened and numbered within the chapter and listed here with page numbers.



100 CHAPTER 3 Stoichiometry of Formulas and Equations

For Review and Reference (Numbers in parentheses refer to pages, unless noted otherwise.)

Learning Objectives

To help you review these learning objectives, the numbers of related sections (§), sample problems (SP), and upcoming end-of-chapter problems (EP) are listed in parentheses.

1. Realize the usefulness of the mole concept, and use the relation between molecular (or formula) mass and molar mass to calculate the molar mass of any substance (§ 3.1) (EPs 3.1–3.5, 3.7–3.10)
2. Understand the relationships among amount of substance (in moles), mass (in grams), and number of chemical entities and convert from one to any other (§ 3.1) (SPs 3.1, 3.2) (EPs 3.6, 3.11–3.16, 3.19)
3. Use mass percent to find the mass of element in a given mass of compound (§ 3.1) (SP 3.3) (EPs 3.17, 3.18, 3.20–3.23)
4. Determine the empirical and molecular formulas of a compound from mass analysis of its elements (§ 3.2) (SPs 3.4–3.6) (EPs 3.24–3.34)
5. Balance an equation given formulas or names, and use molar ratios to calculate amounts of reactants and products for reactions of pure or dissolved substances (§ 3.3 and 3.5) (SPs 3.7, 3.8, 3.15) (EPs 3.35–3.46, 3.62, 3.71, 3.72)
6. Understand why one reactant limits the yield of product, and solve limiting-reactant problems for reactions of pure or dissolved substances (§ 3.4, 3.5) (SPs 3.9, 3.10, 3.16) (EPs 3.47–3.54, 3.61, 3.73, 3.74)
7. Explain the reasons for lower-than-expected yields and the distinction between theoretical and actual yields, and calculate percent yield (§ 3.4) (SP 3.11) (EPs 3.55–3.60, 3.63)
8. Understand the meaning of concentration and the effect of dilution, and calculate molarity or mass of dissolved solute (§ 3.5) (SPs 3.12–3.14) (EPs 3.64–3.70, 3.75)

Key Terms

stoichiometry (70)

Section 3.1
mole (mol) (70)
Avogadro's number (70)
molar mass ($\mathcal{M}$) (72)

Section 3.2
combustion analysis (80)
isomer (81)

Section 3.3
chemical equation (83)
reactant (83)
product (83)
balancing (stoichiometric) coefficient (83)

Section 3.4
limiting reactant (90)
theoretical yield (93)
side reaction (93)
actual yield (93)
percent yield (% yield) (94)

Section 3.5
solute (95)
solvent (95)
concentration (95)
molarity (M) (95)

Key Equations and Relationships

3.1 Number of entities in one mole (70):
1 mole contains 6.022×10^{23} entities (to 4 sf)

3.2 Converting amount (mol) to mass using $\mathcal{M}$ (73):
$$\text{Mass (g)} = \text{no. of moles} \times \frac{\text{no. of grams}}{1 \text{ mol}}$$

3.3 Converting mass to amount (mol) using $1/\mathcal{M}$ (73):
$$\text{No. of moles} = \text{mass (g)} \times \frac{1 \text{ mol}}{\text{no. of grams}}$$

3.4 Converting amount (mol) to number of entities (73):
$$\text{No. of entities} = \text{no. of moles} \times \frac{6.022\times10^{23} \text{ entities}}{1 \text{ mol}}$$

3.5 Converting number of entities to amount (mol) (73):
$$\text{No. of moles} = \text{no. of entities} \times \frac{1 \text{ mol}}{6.022\times10^{23} \text{ entities}}$$

3.6 Calculating mass % (75):
Mass % of element X
$$= \frac{\text{moles of X in formula} \times \text{molar mass of X (g/mol)}}{\text{mass (g) of 1 mol of compound}} \times 100$$

3.7 Calculating percent yield (94):
$$\%\text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

3.8 Defining molarity (95):
$$\text{Molarity} = \frac{\text{moles of solute}}{\text{liters of solution}} \quad \text{or} \quad M = \frac{\text{mol solute}}{\text{L soln}}$$

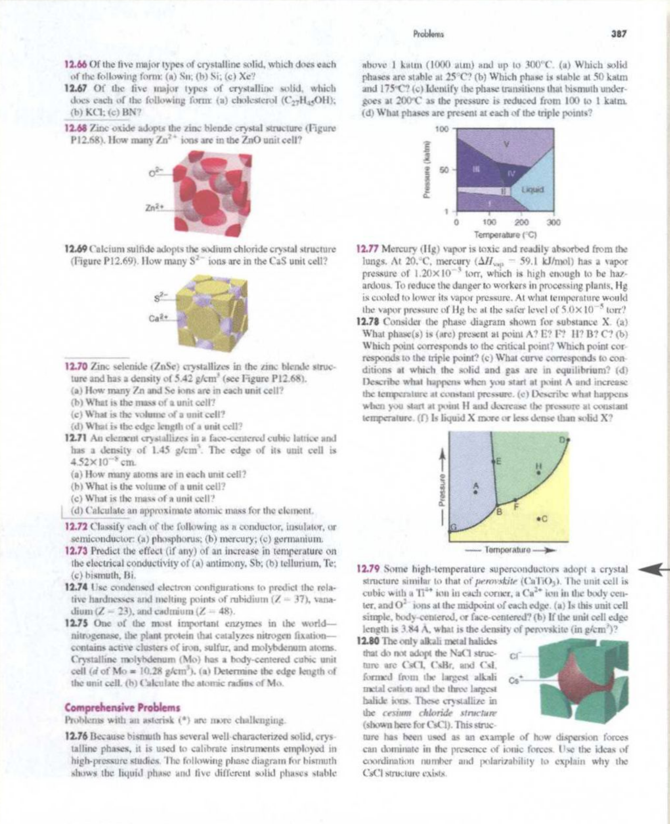
3.9 Diluting a concentrated solution (97):
$$M_{dil} \times V_{dil} = \text{number of moles} = M_{conc} \times V_{conc}$$

Brief Solutions to Follow-up Problems

3.1 (a) Moles of C $= 315 \text{ mg C} \times \frac{1 \text{ g}}{10^3 \text{ mg}} \times \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 2.62\times10^{-2} \text{ mol C}$

(b) Mass (g) of Mn $= 3.22\times10^{20} \text{ Mn atoms} \times \frac{1 \text{ mol Mn}}{6.022\times10^{23} \text{ Mn atoms}} \times \frac{54.94 \text{ g Mn}}{1 \text{ mol Mn}} = 2.94\times10^{-2} \text{ g Mn}$

3.2 (a) Mass (g) of P_4O_{10} $= 4.65\times10^{22} \text{ molecules } P_4O_{10} \times \frac{1 \text{ mol } P_4O_{10}}{6.022\times10^{23} \text{ molecules } P_4O_{10}} \times \frac{283.88 \text{ g } P_4O_{10}}{1 \text{ mol } P_4O_{10}} = 21.9 \text{ g } P_4O_{10}$



Problems 387

12.66 Of the five major types of crystalline solid, which does each of the following form: (a) Sn; (b) Si; (c) Xe?
12.67 Of the five major types of crystalline solid, which does each of the following form: (a) cholesterol ($C_{27}H_{45}OH$); (b) KCl; (c) BN?
12.68 Zinc oxide adopts the zinc blende crystal structure (Figure P12.68). How many Zn^{2+} ions are in the ZnO unit cell?

12.69 Calcium sulfide adopts the sodium chloride crystal structure (Figure P12.69). How many S^{2-} ions are in the CaS unit cell?

12.70 Zinc selenide (ZnSe) crystallizes in the zinc blende structure and has a density of 5.42 g/cm³ (see Figure P12.68).
(a) How many Zn and Se ions are in each unit cell?
(b) What is the mass of a unit cell?
(c) What is the volume of a unit cell?
(d) What is the edge length of a unit cell?
12.71 An element crystallizes in a face-centered cubic lattice and has a density of 1.45 g/cm³. The edge of its unit cell is 4.52×10^{-8} cm.
(a) How many atoms are in each unit cell?
(b) What is the volume of a unit cell?
(c) What is the mass of a unit cell?
(d) Calculate an approximate atomic mass for the element.
12.72 Classify each of the following as a conductor, insulator, or semiconductor: (a) phosphorus; (b) mercury; (c) germanium.
12.73 Predict the effect (if any) of an increase in temperature on the electrical conductivity of (a) antimony, Sb; (b) tellurium, Te; (c) bismuth, Bi.
12.74 Use condensed electron configurations to predict the relative hardnesses and melting points of rubidium ($Z = 37$), vanadium ($Z = 23$), and cadmium ($Z = 48$).
12.75 One of the most important enzymes in the world—nitrogenase, the plant protein that catalyzes nitrogen fixation—contains active clusters of iron, sulfur, and molybdenum atoms. Crystalline molybdenum (Mo) has a body-centered cubic unit cell (d of Mo = 10.28 g/cm³). (a) Determine the edge length of the unit cell. (b) Calculate the atomic radius of Mo.

Comprehensive Problems

Problems with an asterisk (*) are more challenging.

12.76 Because bismuth has several well-characterized solid, crystalline phases, it is used to calibrate instruments employed in high-pressure studies. The following phase diagram for bismuth shows the liquid phase and five different solid phases stable above 1 katm (1000 atm) and up to 300°C. (a) Which solid phases are stable at 25°C? (b) Which phase is stable at 50 katm and 175°C? (c) Identify the phase transitions that bismuth undergoes at 200°C as the pressure is reduced from 100 to 1 katm. (d) What phases are present at each of the triple points?

12.77 Mercury (Hg) vapor is toxic and readily absorbed from the lungs. At 20.°C, mercury ($\Delta H_{vap} = 59.1$ kJ/mol) has a vapor pressure of 1.20×10^{-3} torr, which is high enough to be hazardous. To reduce the danger to workers in processing plants, Hg is cooled to lower its vapor pressure. At what temperature would the vapor pressure of Hg be at the safer level of 5.0×10^{-5} torr?
12.78 Consider the phase diagram shown for substance X. (a) What phase(s) is (are) present at point A? E? F? H? B? C? (b) Which point corresponds to the critical point? Which point corresponds to the triple point? (c) What curve corresponds to conditions at which the solid and gas are in equilibrium? (d) Describe what happens when you start at point A and increase the temperature at constant pressure. (e) Describe what happens when you start at point H and decrease the pressure at constant temperature. (f) Is liquid X more or less dense than solid X?

12.79 Some high-temperature superconductors adopt a crystal structure similar to that of *perovskite* ($CaTiO_3$). The unit cell is cubic with a Ti^{4+} ion in each corner, a Ca^{2+} ion in the body center, and O^{2-} ions at the midpoint of each edge. (a) Is this unit cell simple, body-centered, or face-centered? (b) If the unit cell edge length is 3.84 Å, what is the density of perovskite (in g/cm³)?
12.80 The only alkali metal halides that do not adopt the NaCl structure are CsCl, CsBr, and CsI, formed from the largest alkali metal cation and the three largest halide ions. These crystallize in the *cesium chloride structure* (shown here for CsCl). This structure has been used as an example of how dispersion forces can dominate in the presence of ionic forces. Use the ideas of coordination number and polarizability to explain why the CsCl structure exists.

End-of-Chapter Problems

The numerous problems that end each chapter are sorted by section. Many are grouped in similar pairs, and the answer to one of each pair appears in Appendix E. 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. Especially challenging problems are indicated with an asterisk.

Section Summaries

Concise summary paragraphs conclude each section, immediately restating the major ideas just covered.

SECTION SUMMARY

Surface tension is a measure of the energy required to increase a liquid's surface area. Greater intermolecular forces within a liquid create higher surface tension. Capillary action, the rising of a liquid through a narrow space, occurs when the forces between a liquid and a solid surface (adhesive) are greater than those within the liquid itself (cohesive). Viscosity, the resistance to flow, depends on molecular shape and decreases with temperature. Stronger intermolecular forces create higher viscosity.

Supplements for the Instructor

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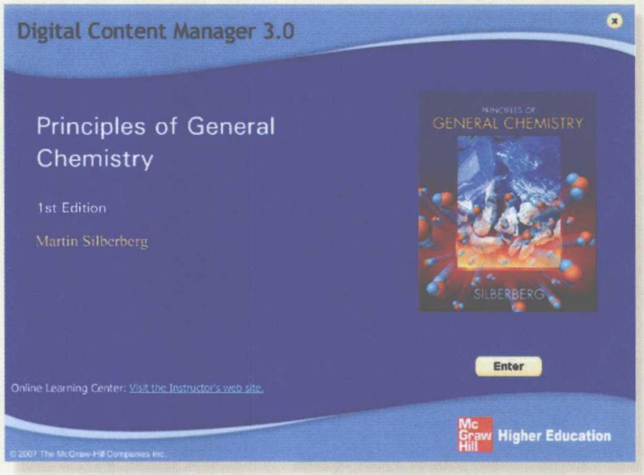

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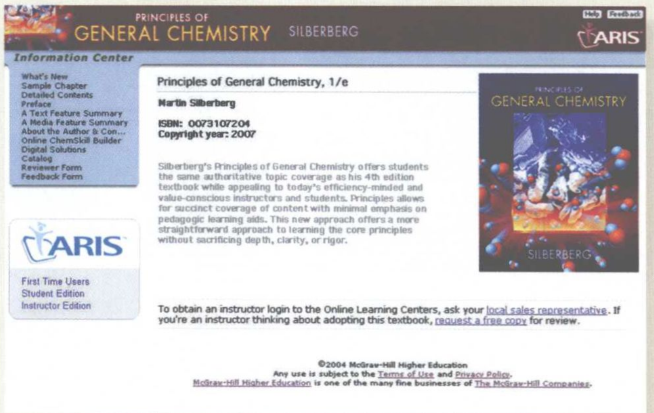
- **Art and Photo Library** Full-color digital files of all of the illustrations and many of the photos in the text can be readily incorporated into lecture presentations, exams, or custom-made classroom materials.
- **Worked Example Library** and **Table Library** Access the worked examples and visual tables from the text in electronic format for inclusion in your classroom presentations or materials.

Chemistry Animations DVD

This DVD contains more than 300 animations, several authored by Martin Silberberg. This easy-to-use DVD allows you to view the animations quickly and import them into PowerPoint to create multimedia presentations.

ARIS



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Instructor's Testing and Resource CD-ROM

This cross-platform CD-ROM includes the *Instructor's Solutions Manual,* which provides all answers for the textbook's end-of-chapter problems, and the Test Bank, which offers additional questions that can be used for homework assignments and/or exams; both are available in Word and PDF formats. The computerized Test Bank utilizes testing software to allow you to quickly create customized exams by sorting questions by format, editing existing questions, adding new ones, and scrambling questions for multiple versions of the same test.

Instructor's Solutions Manual

By Patricia Amateis of Virginia Tech

This supplement contains complete, worked-out solutions for all the end-of-chapter problems in the text. It can be found within the secure Instructor's Center, within the Online Learning Center.

PRINTED SUPPLEMENTS

Transparencies

This boxed set of 300 full-color transparency acetates features images from the text that are modified to ensure maximum readability in both small and large classroom settings.

Primis LabBase

By Joseph Lagowski of University of Texas at Austin

More than 40 general chemistry lab experiments are available in this database collection, some from the *Journal of Chemical Education* and others provided by Professor Lagowski, enabling you to create your own custom laboratory manual.

General Chemistry Laboratory Manual

By Petra A. M. van Koppen of University of California, Santa Barbara

This definitive lab manual for the two-semester general chemistry course contains 21 experiments that cover the most commonly assigned experiments for the introductory level.

Cooperative Chemistry Laboratory Manual

By Melanie Cooper of Clemson University

This innovative guide 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, thus completing three or four projects during the semester, rather than one preprogrammed experiment per class. The emphasis here is on experimental design, analysis, problem solving, and communication.

Learning Aids for Students

MULTIMEDIA SUPPLEMENTS

ARIS for *Principles of General Chemistry* is your online source page for help. Text-specific features to complement and solidify lecture concepts include:

- Online homework and quizzes (which are automatically graded and recorded for your instructor)
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PRINTED SUPPLEMENTS

Student Solutions Manual

By Patricia Amateis of Virginia Tech
This supplement contains detailed solutions and explanations for all even-numbered problems in the main text.

Chemistry Resource Card

The resource card is a quick and easy source of information on general chemistry. Without having to consult the text, you have right at hand the periodic table and list of elements, tables for conversion factors, equilibrium and thermodynamic data, nomenclature, and key equations.

Brief Contents

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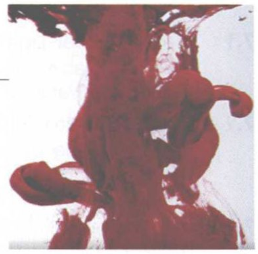

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