The background of the cover is a complex, three-dimensional illustration. It features a dense, repeating pattern of small, light-gray spheres that create a sense of depth and texture, resembling a molecular lattice or a crystalline structure. Scattered throughout this pattern are numerous larger, multi-colored spheres. These spheres are primarily red, blue, and white, with some appearing as single colors and others as combinations (e.g., red and blue, red and white, blue and white). They are arranged in a way that suggests molecular models or atoms interacting within a field. The overall color palette is dominated by the light gray of the spheres, with vibrant accents of red, blue, and white.

# Silberberg CHEMISTRY

The Molecular Nature of Matter and Change

3rd Edition

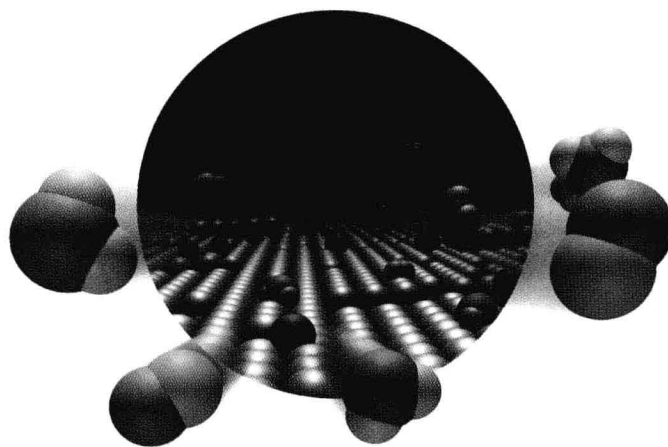


Martin S. Silberberg

Third Edition

# CHEMISTRY

The Molecular Nature of Matter and Change



## Consultants

Randy Duran

*University of Florida—Gainesville*

L. Peter Gold (emeritus)

*Pennsylvania State University*

Charles G. Haas (emeritus)

*Pennsylvania State University*

Arlan D. Norman

*University of Colorado—Boulder*



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CHEMISTRY: THE MOLECULAR NATURE OF MATTER AND CHANGE  
THIRD EDITION

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COVER IMAGE: A molecular view at the beginning of the first step in the synthesis of nitric acid shows ammonia and oxygen landing on the surface of a platinum catalyst and forming water and nitric oxide, which then leave the surface. In a few moments, the platinum will become covered with reacting molecules. Catalysts speed up reactions and are essential parts of many industrial and virtually all biological processes.

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With all my love,

For Ruth,  
who lives it with me every day,

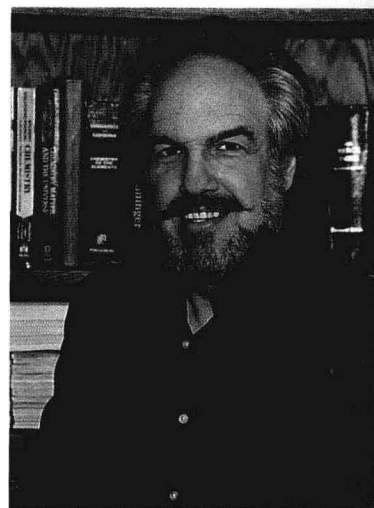
and

For Daniel,  
who makes it all worthwhile



# ABOUT THE AUTHOR AND CONSULTANTS

**Martin S. Silberberg** received his B.S. in chemistry from the City University of New York in 1966 and his Ph.D. in chemistry from the University of Oklahoma in 1971. He then accepted a research position at the Albert Einstein College of Medicine, where he studied the chemical nature of neurotransmission and Parkinson's disease. In 1977, Dr. Silberberg joined the faculty of Simon's Rock College of Bard (Massachusetts), a liberal arts college known for its excellence in teaching small classes of highly motivated students. As Head of the Natural Sciences Major and Director of Premedical Studies, he taught courses in general chemistry, organic chemistry, biochemistry, and nonmajors chemistry. The close student contact afforded him insights into how students learn chemistry, where they have difficulties, and what strategies can help them succeed. In 1983, Dr. Silberberg decided to apply these insights in a broader context and established a text writing and editing company. Before writing his own text, he worked on chemistry, biochemistry, and physics texts for several major college publishers. He resides with his wife and child in Massachusetts. For relaxation, he cooks, sings, and walks in the woods.



**Randy Duran** is a Professor in Chemistry within the Butler Polymer Laboratory and Adjunct Professor in Materials Science at the University of Florida. He obtained a B.S. degree in polymer engineering from Case Western Reserve University and a Ph.D. in polymer physical chemistry from the University Louis Pasteur, Strasbourg, France. In addition to teaching general chemistry and advanced courses in physical and polymer chemistry, Dr. Duran maintains an active research program in the area of polymer surfaces and interfaces. Dr. Duran is Florida's Executive Committee Member, coordinating activities at the Material Research Collaborative Access Team Beamline at the Advanced Photon Source Synchrotron at Argonne National Laboratories. He also directs the National Science Foundation Research Experiences for Undergraduates site in chemistry at the University of Florida. His hobbies include travel, snow skiing, and gardening.

**L. Peter Gold**, emeritus Professor of Chemistry at The Pennsylvania State University, grew up in Massachusetts and obtained his undergraduate and graduate education at Harvard University. He taught general chemistry to over 10,000 students, as well as physical chemistry and physical chemistry lab. His hobbies included music, both as a performer and a listener, computers, and omnivorous reading.

**Editor's Note:** Known as a fine teacher and mentor, Peter was actively involved as a consultant since the first edition. He passed away near the completion of the third edition.

**Charles G. Haas**, emeritus Professor of Chemistry at The Pennsylvania State University, earned his Ph.D. at the University of Chicago under the supervision of Norman Nachtrieb. During his 38-year career at Penn State, he taught general chemistry, undergraduate and graduate inorganic chemistry, and courses in chemical education for public school teachers at all levels. He was honored with both the College of Science Noll Award and the University Amoco Award for teaching. His research focus is on transition metals chemistry and coordination compounds. Since his retirement, he has spent much of his time reading, traveling worldwide, and enjoying collegiate athletics.



**Arlan D. Norman** conducted undergraduate studies at the University of North Dakota, graduate work at Indiana University, and postdoctoral research at the University of California—Berkeley; he is a Distinguished Alumnus of the University of North Dakota. Dr. Norman is Professor of Chemistry and Biochemistry at the University of Colorado—Boulder, where he has taught general and inorganic chemistry for the past 33 years, concentrating on the teaching of molecular graphics, modeling, and visualization techniques. He is currently the Associate Dean for Natural Sciences at the University of Colorado—Boulder. He is a main-group element synthetic chemist, with research interests in new materials applications of phosphorus compounds, for which he has been awarded Alfred P. Sloan and University of Colorado Council of Research and Creative Work fellowships. Dr. Norman is a Nordic skier and an avid cyclist: he has cycled extensively in Italy, New Zealand, and Ireland.

*For the First and Second Editions*

**Robert L. Loeschen** earned a B.S. in Chemistry from the University of Illinois and a Ph.D. from the University of Chicago. He joined the faculty at California State University—Long Beach in 1969. Trained as an organic chemist, he teaches a wide variety of courses, including general chemistry for science majors, chemistry for nursing majors (he coauthored a text for this subject), organic chemistry for nonmajors, organic chemistry for majors, and occasionally a graduate course in his research specialty, organic photochemistry. At present, he spends half his time in the chemistry department and half his time as Associate Dean for the College of Natural Sciences and Mathematics. When he is not teaching or deaning, he plays golf or putters in his woodworking shop.



# PREFACE

Sometimes, when a new edition is in the works, a friend will ask, with a disbelieving tone, “Is there really anything new in chemistry?” What a question! As in any dynamic, modern science, theories in chemistry are refined to reflect new data, established ideas are applied to new systems, and connections are forged with other sciences to uncover new information. But chemistry, as the science of matter and its changes, is central to so many sciences—physical, biological, environmental, medical, and engineering—that it must evolve continuously to allow their progress. Designing safer, “greener” ways to make medicines, fuels, and other commodities; modeling our atmosphere and oceans to predict changes and their effects; and synthesizing new materials with revolutionary properties are among the countless areas in which chemistry is evolving.

In fact, just since the *Second Edition* of this text, hybrid gasoline-electric cars are already on the roads, and cars powered by hydrogen-based fuel cells are being developed by every automobile company. Numerous university and industrial web sites detail research efforts in the amazing field of nanotechnology, exploring the development of molecular-scale computers and biosensors. And, behold, our genes have now been mapped, and the clues they hold to disease, aging, and the miracle of our biology are there to be uncovered.

On the other hand, the basic concepts of chemistry still form the essence of the course. The mass laws and the mole concept still inform the amounts of substances in a chemical reaction; atomic properties, and the periodic trends and types of bonding emerging from them, still determine molecular structure, which in turn still governs the forces between molecules and the resulting physical behavior of substances; and the central concepts of kinetics, equilibrium, and thermodynamics still account for the dynamic aspects of chemical change.

The challenge for a modern chemistry text, then, is to do two jobs at once: to present the fundamental principles clearly and to apply them to the emerging areas of chemistry today. Like chemistry itself, the *Third Edition of Chemistry: The Molecular Nature of Matter and Change* has evolved in important ways to meet this challenge. This Preface explains these changes, and the Guided Tour that follows shows actual pages from the book that demonstrate its features.

## OVERALL APPROACH TO TEACHING CHEMISTRY

As a species evolves, most of the structures that work well and keep it thriving and successful stay the same. And so it is with an evolving textbook. The three essential themes developed in the first two editions—visualizing chemical models, thinking through a quantitative problem, and demonstrating the amazing relevance of chemistry to society—continue to help students learn chemistry.

### Visualizing Chemical Models

Because chemistry deals with observable changes in the world around us that are caused by unobservable atomic-scale events, a size gap of mind-boggling proportions must be spanned. Throughout the text, concepts are explained at the macroscopic level and then from a molecular point of view, with the text’s well-known, ground-breaking illustrations placed next to the discussion to bring the point home to today’s visually oriented students.



## Thinking Logically to Solve Problems

The problem-solving approach, based on a widely accepted, four-step method, is introduced in Chapter 1 and employed consistently throughout the text. It encourages students to first plan a logical approach to a problem, and only then proceed to solve it quantitatively. The Check, a step unique to this text and universally recommended by instructors, fosters the habit of assessing the reasonableness and magnitude of the answer. For practice and reinforcement, each worked problem is followed immediately by a similar one, for which an abbreviated solution is given at the end of the chapter.

## Applying Ideas and Skills to the Real World

An understanding of modern chemistry influences a person's attitudes about public policy issues, such as the environment, health care, and energy use, while at the same time explains everyday phenomena, such as the spring in a running shoe, the workings of a ballpoint pen, and the fragrance of a rose. Today's students may enter one of the emerging chemically related, hybrid fields—biomaterials science, nanotechnology, or planetary geochemistry, for example—and their text should keep them abreast of such career directions. But this content is only useful if it advances understanding of a principle being discussed. In addition to countless passages in the main text, four key displayed features seen in the previous two editions—Chemical Connections, Tools of the Laboratory, Galleries, and Margin Notes—provide relevant handles for what may seem abstract ideas.

## INNOVATIVE TOPIC TREATMENT

A look at the Detailed Contents shows another aspect of this evolving text that has helped it thrive and, thus, has not changed: a topic order common to most general chemistry courses that incorporates flexibility for instructors to customize their approach. Innovative topic treatments appear in each chapter, but the presentation of the chemistry of the elements, organic chemistry, and biochemistry are especially novel. Rather than leaving these important topics for the end of the course, they are optimally placed for relating principles just learned.

The Interchapter and Chapter 14 apply principles from Chapters 7–13 (atomic structure, periodicity, bonding, molecular shape and polarity, and physical states) to all the main-group elements, thus emphasizing the gradation in element properties, rather than fostering misleading divisions between metals and nonmetals. Chapter 15 is a natural extension of descriptive chemistry, showing how the chemistry of organic and biological compounds arises from the atomic properties of carbon and its few bonding partners. Chapter 22 follows the example of Chapter 14 by applying the principles of kinetics, equilibrium, thermodynamics, and electrochemistry from Chapters 16–21 to the geochemistry, environmental chemistry, and industrial chemistry of the elements. The extensive coverage of biochemistry, more than in any other mainstream text, forms a major portion of Chapter 15 and is integrated into many other chapters in the text, margin notes, and boxed essays. Topics explore molecular shape in physiology, solubility factors in the structures of cell membranes and the action of antibiotics, principles of catalysis that apply to enzymes, principles of equilibrium that relate to metabolic control, electrochemical processes that produce and utilize ATP, and many more.

## WHAT'S NEW IN THE *THIRD EDITION*?

This edition evolved from extensive and very positive reviewer feedback, which indicated no need for major structural change. Nevertheless, to improve the overall usability for both student and instructor, several changes were made to improve the pedagogy and enhance the content.



## Improving the Pedagogy

My guiding principle throughout the conception, writing, and illustrating of all three editions has been to create a “teaching” text, one with thorough explanations that foresee student confusion before it arises. In addition, the text is replete with learning aids, which are highlighted in the Guided Tour and in the comments to the student that follow this Preface. This edition has these improvements:

- Every paragraph was examined for clarity and directness.
- A cleaner, more open page layout improves readability. Many figures now appear in the text column to help clear the margins.
- The Plan sections of the sample problems are designed to simulate an interchange between student and instructor as they think through the solution. To clarify the process, every Plan now begins explicitly with the known, incorporating data from the problem statement, and points toward the unknown.
- More challenging problems have been added to each end-of-chapter problem set.
- Every figure or table is placed as close to the related text as possible; in only one or two instances must a student turn a page to see a figure being discussed.
- Many new figures that depict the observable and molecular levels simultaneously have been added, and many more molecular models have been included.
- All chapter end matter is now keyed to the text pages on which the items appear.
- Unit canceling is now color-coded for clarity.
- The worked sample problems are now attractively set off to delineate them clearly.
- Nearly every chapter now includes multimedia features—animation, demonstration, or movie—indicated by a margin icon.

## Enhancing the Content

Many detailed changes have been made to achieve the highest standards of accuracy and pedagogy, ranging from clarifying a definition to simplifying a calculation step to correcting a mineral source. But several significant changes were made in order to emphasize a concept, include a topic that was lacking, or make coverage more consistent and up-to-date. Here are the most extensive changes:

- Chapter 4 has been redesigned. Following a presentation of the polar nature of water, the chapter covers ionic equations and then devotes a section to each of the three reaction types—precipitation, acid-base, and redox. Focusing on elements as reactants or products allows a discussion of types of redox reactions and greater emphasis on activity series. The brief introduction to equilibrium now includes the idea of a constant ratio of products to reactants.
- Chapter 12 includes two topics in advanced materials. The first is the physical behavior of polymers, and the discussion highlights their mass, shape, crystallinity, and viscosity—quantitative concepts that allow meaningful homework problems. The second is an overhaul of the earlier coverage of nanotechnology, this time based on the latest material from government, industrial, and academic research labs.
- Chapter 16 now includes a more complete treatment of reaction order. Because of their importance in catalyzed processes, zero-order reactions are now covered alongside first- and second-order reactions.
- Chapter 20 now includes an exceptionally consistent treatment of entropy, and the concept of reversibility is used to clarify the relationship between free energy and work.
- Chapter 21 now employs the most widely approved method for calculating cell potential, based consistently on the half-cell potentials of the cathode and anode compartments.
- Discussions of ozone depletion (Chapter 16), acid rain (Chapter 19), batteries (Chapter 21), and radioactive tracers (Chapter 24) have been thoroughly updated using input from experts.



### Multimedia Icon

An icon indicates a multimedia feature is available. Click on [www.mhhe.com/silberberg3](http://www.mhhe.com/silberberg3).

Multimedia features are available for instructors on the Chemistry Animations Library 2003 CD-ROM.



# GUIDED TOUR

This *Guided Tour to Chemistry: The Molecular Nature of Matter and Change*, Third Edition, has been designed to walk you through the features of a chapter. As you examine them, note the following:

- Each chapter begins by orienting you to the topic flow.
- The multipart sample problems help you plan, execute, and check the solution.
- Illustrations are placed very close to the related text.
- The art depicts a chemical reaction on several levels of reality simultaneously.
- The relevance of chemistry is clearly demonstrated.
- The end-of-chapter material provides many ways to review and practice the concepts and skills covered.

## Chapter Outline

The outline details the topic flow of the chapter by listing the major topics and the subtopics within them.

## Concepts and Skills to Review

This unique feature helps you prepare for the current chapter by listing important material from previous chapters that you should understand *before* you start reading.

### CHAPTER 6

#### THERMOCHEMISTRY: ENERGY FLOW AND CHEMICAL CHANGE

##### CHAPTER OUTLINE

- 6.1 Forms of Energy and Their Interconversion
  - System and Surroundings
  - Energy: Flow to and from a System
  - Heat and Work
  - Energy Conservation
  - Units of Energy
  - State Functions
- 6.2 Enthalpy: Heats of Reaction and Chemical Change
  - The Meaning of Enthalpy
  - Comparing  $\Delta E$  and  $\Delta H$
  - Exothermic and Endothermic Processes
  - Types of Enthalpy Change
  - Bond Strength and Heat of Reaction
- 6.3 Calorimetry: Laboratory Measurement of Heats of Reaction
  - Specific Heat Capacity
  - The Practice of Calorimetry
- 6.4 Stoichiometry of Thermochemical Equations
- 6.5 Hess's Law of Heat Summation
- 6.6 Standard Heats of Reaction ( $\Delta H^\circ_{\text{rxn}}$ )
  - Formation Equations
  - Determining  $\Delta H^\circ_{\text{rxn}}$  from  $\Delta H^\circ_f$



Figure: The wonder of a burning match. When a match burns, the chemical reaction that occurs releases energy, as do many other processes. Still others absorb energy. Our ability to understand and measure changes in matter and energy is crucial to the ultimate fate of modern society, and in this chapter, we begin an exploration of the factors that govern these changes.

### 6.1 Forms of Energy and Their Interconversion

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#### CONCEPTS & SKILLS

- to review before you study this chapter
  - energy and its interconversion (Section 1.1)
  - distinction between heat and temperature (Section 1.5)
  - nature of chemical bonding (Section 2.7)
  - calculations of reaction stoichiometry (Section 3.4)
  - properties of the gaseous state (Section 5.1)
  - relation between kinetic energy and temperature (Section 5.6)

All changes in matter, whether chemical or physical, are accompanied by changes in the energy content of the matter. In the inferno of a forest fire, as wood is converted to ash and gases, its energy content changes, and that difference in energy before and after the change is *released* as heat and light. In contrast, some of the energy in a flash of lightning is *absorbed* when atmospheric  $\text{N}_2$  and  $\text{O}_2$  react to form  $\text{NO}$ . Energy is *absorbed* when snow melts and is *released* when water vapor condenses to rain.

The production and usage of energy in its many forms have an enormous impact on society. Some of the largest industries manufacture products that release, absorb, or limit the flow of energy. Common fuels—oil, wood, coal, and natural gas—release chemical energy for heating and to power combustion engines and steam turbines. Fertilizers help crops absorb solar energy and convert it to the chemical energy of food, which our bodies convert into other forms. Many plastic, fiberglass, and ceramic materials serve as insulators that limit energy flow.

In this chapter, we investigate the heat, or *thermal energy*, associated with changes in matter. We first examine some basic ideas of **thermodynamics**, the study of heat and its transformations. Then, we discuss **thermochemistry**, the branch of thermodynamics that deals with the heat involved in chemical reactions. We explore changes at the molecular level to find out where the heat change of a reaction comes from. Then we learn how heat is measured in order to focus on the key value: the quantity of heat released or absorbed in a reaction. The chapter ends with an overview of current and future energy sources and the conflicts between energy demand and environmental quality.

Thermodynamics is a fascinating field, a rigorously logical, highly mathematical branch of science that is as relevant in everyday life as it is in the laboratory or the environment. Our discussion of thermodynamics here, and later in Chapter 20, is confined mostly to chemical applications, but also tries to show how widely these ideas can be applied.

### 6.1 FORMS OF ENERGY AND THEIR INTERCONVERSION

As we discussed in Chapter 1, all energy is either potential or kinetic, and these forms are convertible from one to the other. An object has potential energy by virtue of its position and kinetic energy by virtue of its motion. The potential energy of a weight raised above the ground is converted to kinetic energy as it falls (see Figure 1.3). When the weight hits the ground, it transfers some kinetic energy to the soil and pebbles, causing them to move, thereby doing *work*. In addition, some of the transferred kinetic energy appears as *heat*, as it slightly warms the soil and pebbles. Thus, the potential energy of the weight is converted to kinetic energy, which is transferred to the ground as work and as heat.

Modern atomic theory allows us to consider other forms of energy—solar, electrical, nuclear, and chemical—as examples of potential and kinetic energy on the atomic and molecular scales. No matter what the details of the situation, *when energy is transferred from one object to another, it appears as work and/or as heat*. In this section, we examine this idea in terms of the loss or gain of energy that takes place during a chemical or physical change.

#### The System and Its Surroundings

To make a meaningful observation and measurement of a change in energy, we must first define the **system**, that part of the universe whose change we are going to observe. The moment we define the system, everything else relevant to the change is defined as the **surroundings**.



Wherever You Look, There Is a System In the example of the weight hitting the ground, if we define the falling weight as the system, the soil and pebbles that are moved and warmed are the surroundings. An astronomer may define a galaxy as the system and nearby galaxies as the surroundings. An ecologist studying African wildlife can define a zebra herd as the system and other animals, plants, and water supplies as the surroundings. A microbiologist may define a certain cell as the system and the extracellular solution as the surroundings. Thus, in general, it is the experiment and the experimenter that define the system and the surroundings.

## Chapter Opener

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



# CONSISTENT PROBLEM-SOLVING APPROACH

## Sample Problem

A multipart worked-out problem appears when an important new concept or skill is introduced. A step-by-step approach is used for every sample problem presented in the text.

## Steps

### Plan

analyzes steps needed to take what is known and find what is unknown. This approach helps you think through the solution *before* performing calculations.

### Solution

shows the calculation steps in the same order as detailed in the Plan and Roadmap.

### Check

fosters the habit of quickly going over your work to make sure the answer is chemically and mathematically reasonable—a great way to avoid careless errors on exams.

### Comment

provides an additional insight, alternative approach, or common mistake to avoid.

### Follow-up Problem

gives you immediate practice with the new skill by presenting a similar problem.

## SAMPLE PROBLEM 13.7 Determining the Boiling Point Elevation and Freezing Point Depression of a Solution

**Problem** You add 1.00 kg of ethylene glycol antifreeze ( $\text{C}_2\text{H}_6\text{O}_2$ ) to your car radiator, which contains 4450 g of water. What are the boiling and freezing points of the solution?  
**Plan** To find the boiling and freezing points of the solution, we first find the molality by converting the given mass of solute (1.00 kg) to amount (mol) and dividing by mass of solvent (4450 g). Then we calculate  $\Delta T_b$  and  $\Delta T_f$  from Equations 13.11 and 13.12 (using constants from Table 13.6). We add  $\Delta T_b$  to the solvent boiling point and subtract  $\Delta T_f$  from the solvent freezing point. The roadmap shows the steps.

**Solution** Calculating the molality:

$$\text{Moles of } \text{C}_2\text{H}_6\text{O}_2 = 1.00 \text{ kg } \text{C}_2\text{H}_6\text{O}_2 \times \frac{10^3 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol } \text{C}_2\text{H}_6\text{O}_2}{62.07 \text{ g } \text{C}_2\text{H}_6\text{O}_2} = 16.1 \text{ mol } \text{C}_2\text{H}_6\text{O}_2$$

$$\text{Molality} = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{16.1 \text{ mol } \text{C}_2\text{H}_6\text{O}_2}{4450 \text{ g } \text{H}_2\text{O} \times \frac{1 \text{ kg}}{10^3 \text{ g}}} = 3.62 \text{ m } \text{C}_2\text{H}_6\text{O}_2$$

Finding the boiling point elevation and  $T_{b(\text{solution})}$ , with  $K_b = 0.512^\circ\text{C}/m$ :

$$\Delta T_b = \frac{0.512^\circ\text{C}}{m} \times 3.62 \text{ m} = 1.85^\circ\text{C}$$

$$T_{b(\text{solution})} = T_{b(\text{solvent})} + \Delta T_b = 100.00^\circ\text{C} + 1.85^\circ\text{C} = 101.85^\circ\text{C}$$

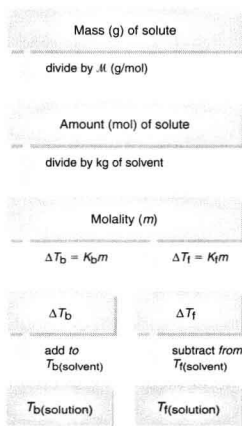
Finding the freezing point depression and  $T_{f(\text{solution})}$ , with  $K_f = 1.86^\circ\text{C}/m$ :

$$\Delta T_f = \frac{1.86^\circ\text{C}}{m} \times 3.62 \text{ m} = 6.73^\circ\text{C}$$

$$T_{f(\text{solution})} = T_{f(\text{solvent})} - \Delta T_f = 0.00^\circ\text{C} - 6.73^\circ\text{C} = -6.73^\circ\text{C}$$

**Check** The changes in boiling and freezing points should be in the same proportion as the constants used. That is,  $\Delta T_b/\Delta T_f$  should equal  $K_b/K_f$ ;  $1.85/6.73 = 0.275 = 0.512/1.86$ .  
**Comment** These answers are only approximate because the concentration far exceeds that of a *dilute* solution, for which Raoult's law is most useful.

**FOLLOW-UP PROBLEM 13.7** What is the minimum concentration (molality) of ethylene glycol solution that will protect the car's cooling system from freezing at  $0.00^\circ\text{F}$ ? (Assume the solution is ideal.)



## Problem-Solving Roadmaps

are included in many worked exercises. They are block diagrams, *specific* to the problem, that visually lead you through the steps.

## Brief Solutions to Follow-up Problems (continued)

$$\begin{aligned} 13.5 \text{ Mass } \% \text{ HCl} &= \frac{\text{mass of HCl}}{\text{mass of soln}} \times 100 \\ &= \frac{11.8 \text{ mol HCl}}{1 \text{ L soln}} \times \frac{36.46 \text{ g HCl}}{1 \text{ mol HCl}} \times \frac{1 \text{ mL}}{10^3 \text{ mL}} \times 100 \\ &= \frac{1.190 \text{ g}}{1 \text{ mL soln}} \times \frac{10^3 \text{ mL}}{1 \text{ L}} \\ &= 36.2 \text{ mass } \% \text{ HCl} \end{aligned}$$

$$\begin{aligned} \text{Mass (kg) of soln} &= 1 \text{ L soln} \times \frac{1.190 \times 10^{-3} \text{ kg soln}}{1 \times 10^{-3} \text{ L soln}} \\ &= 1.190 \text{ kg soln} \end{aligned}$$

$$\begin{aligned} \text{Mass (kg) of HCl} &= 11.8 \text{ mol HCl} \times \frac{36.46 \text{ g HCl}}{1 \text{ mol HCl}} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \\ &= 0.430 \text{ kg HCl} \end{aligned}$$

$$\begin{aligned} \text{Molality of HCl} &= \frac{\text{mol HCl}}{\text{kg water}} = \frac{\text{mol HCl}}{\text{kg soln} - \text{kg HCl}} \\ &= \frac{11.8 \text{ mol HCl}}{0.760 \text{ kg } \text{H}_2\text{O}} = 15.5 \text{ m HCl} \end{aligned}$$

$$\begin{aligned} X_{\text{HCl}} &= \frac{\text{mol HCl}}{\text{mol HCl} + \text{mol } \text{H}_2\text{O}} \\ &= \frac{11.8 \text{ mol}}{11.8 \text{ mol} + \left(760 \text{ g } \text{H}_2\text{O} \times \frac{1 \text{ mol}}{18.02 \text{ g } \text{H}_2\text{O}}\right)} = 0.219 \end{aligned}$$

$$\begin{aligned} 13.6 \Delta P &= X_{\text{aspirin}} \times P_{\text{methanol}}^0 \\ &= \frac{2.00 \text{ g}}{180.15 \text{ g/mol}} \times \frac{101 \text{ torr}}{32.04 \text{ g/mol}} \\ &= 0.713 \text{ torr} \end{aligned}$$

$$\begin{aligned} 13.7 m &= \frac{(0.00^\circ\text{F} - 32^\circ\text{F}) \left(\frac{5^\circ\text{C}}{9^\circ\text{F}}\right)}{1.86^\circ\text{C}/m} = 9.56 \text{ m} \end{aligned}$$

$$\begin{aligned} 13.8 \Pi &= MRT \\ &= (0.30 \text{ mol/L}) \left(0.0821 \frac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}}\right) (37^\circ\text{C} + 273.15) \\ &= 7.6 \text{ atm} \end{aligned}$$

## Brief Solutions to Follow-up Problems

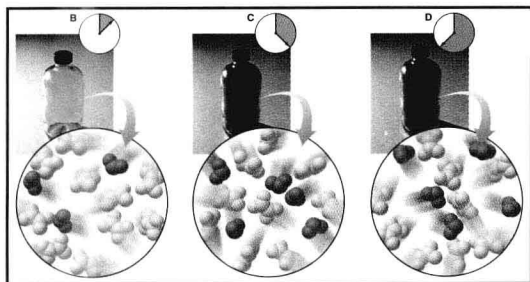
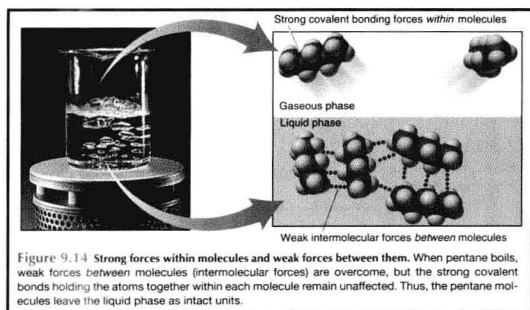
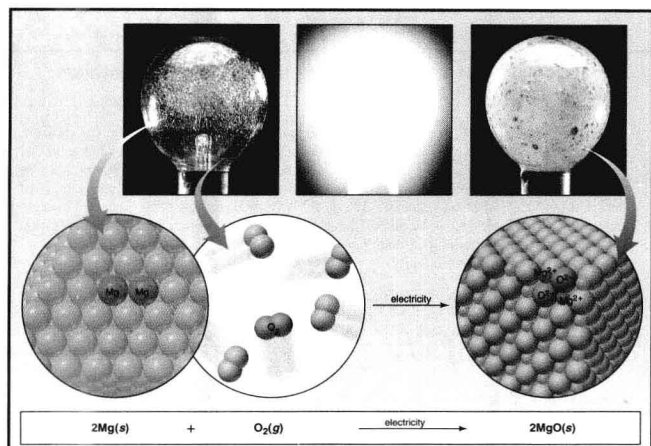
These provide brief solutions at the end of the chapter, not just a numerical answer at the back of the book. This fuller treatment effectively **doubles** the number of worked-out problems and is an excellent way for you to reinforce skills.



# ILLUSTRATIONS AND PAGE LAYOUT DESIGNED TO MAXIMIZE UNDERSTANDING

## Three-Level Illustrations

A Silberberg trademark, these illustrations provide macroscopic and molecular views of a process, so you learn to 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 models and vivid molecular-level scenes. Included in the third edition are over 50 new pieces of art.

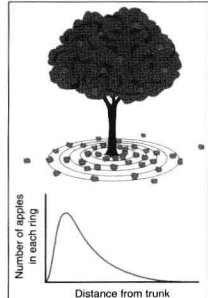
## Page Layout

Author and pager worked side by side to create a book of two-page spreads that place figures as close as possible to their related text. In some cases, art is even wrapped by text, so you can read concepts and see them depicted simultaneously.

Figure 2.13 The formation of an ionic compound. A, The two elements as seen in the laboratory. B, The elements as they might appear on the atomic scale. C, The neutral sodium atom loses one electron to become a sodium cation ( $\text{Na}^+$ ), and the chlorine atom gains one electron to become a chloride anion ( $\text{Cl}^-$ ). Note that when atoms lose electrons, they become ions that are smaller, and when they gain electrons, they become ions that are larger. D,  $\text{Na}^+$  and  $\text{Cl}^-$  ions attract each other and lie in a three-dimensional crystalline array. E, This cubic array is reflected in the structure of crystalline  $\text{NaCl}$ , which occurs naturally as the mineral halite, hence the name halogen for the Group 7A(17) elements.

## Margin Notes

Over 135 short, lively explanations apply ideas in the related text. You'll explore how your body and the Earth control their temperatures, how crime labs track illegal drugs, how your lungs work, how fat-free chips and decaf coffee are made, the principle of a winning poker hand, the risks of nuclear radiation, handy tips for memorizing relationships, and much more.









# TOOLS THAT REINFORCE THE CONCEPTS

## SECTION SUMMARY

Ions are precipitated selectively by adding a precipitating ion until the  $K_{sp}$  of one compound is exceeded as much as possible without exceeding the  $K_{sp}$  of the other. An extension of this approach is to control the equilibrium of the slightly soluble compound by simultaneously controlling an equilibrium system that contains the precipitating ion, separate the two through pre-

## Chapter Perspective

This chapter is the last of three that explore the nature and variety of equilibrium systems. In Chapter 17, we discussed the central ideas of equilibrium in the context of gaseous systems. In Chapter 18, we extended our understanding to acid-base equilibria. In this chapter, we highlighted three types of aqueous ionic systems and examined their role in the laboratory and the environment. The equilibrium constant, in all its forms, is a number that provides a limit to changes in a system, whether a chemical reaction, a physical change, or the dissolution of a substance. You now have the skills to predict whether a change will take place and to calculate its result, but you still do not know why the change occurs in the first place, or why it stops when it does. In Chapter 20, you'll find out.

## Section Summaries and Chapter Perspective

Concise paragraphs conclude each section, immediately restating the major ideas just covered. Each chapter ends with a brief overview that places it in the context of previous and upcoming topics.

## For Review and Reference

(Numbers in parentheses refer to pages, unless noted otherwise.)

### Learning Objectives

Relevant section and/or sample problem (SP) numbers appear in parentheses.

Understand These Concepts

Master These Skills

1. The distinction between the rate and the extent of a reaction

1. Writing the reaction quotient ( $Q$ ) from a balanced equation

2. Calculating  $K$  for a reaction consisting of several steps

2. Calculating  $K$  for a reaction multiplied by a coefficient (SP 17.3)

3. Calculating  $K$  for a reaction involving heterogeneous systems (Section 17.2)

3. Using  $K$  and  $Q$  to determine reaction direction (SP 17.5)

4. Finding quantities (concentrations or pressures) into  $Q$  to find  $K$

4. Using  $K$  to determine quantities and find  $K$  for a reaction table to determine quantities and find  $K$  for a reaction table (SP 17.7)

5. Using  $K$  to determine quantities and find  $K$  for a reaction table to determine quantities and find  $K$  for a reaction table (SP 17.7)

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## For Review and Reference

### Learning Objectives

are listed, with section and/or sample problem numbers, to help you focus on key concepts and skills.

### Key Terms

are boldfaced within the chapter. They are arranged here by section (with page number) and defined again in the Glossary.

### Key Equations and Relationships

are screened and numbered within the chapter and listed here with page number.

### Highlighted Figures and Tables

are listed by page number, so you can find them easily and review their essential content.

### Key Terms

Section 17.1

Section 17.2

Section 17.3

Section 17.4

Section 17.5

Section 17.6

Section 17.7

Section 17.8

Section 17.9

Section 17.10

Section 17.11

Section 17.12

Section 17.13

Section 17.14

Section 17.15

Section 17.16

Section 17.17

Section 17.18

Section 17.19

Section 17.20

Section 17.21

Section 17.22

Section 17.23

Section 17.24

Section 17.25

Section 17.26

Section 17.27

Section 17.28

Section 17.29

Section 17.30

Section 17.31

Section 17.32

Section 17.33

Section 17.34

Section 17.35

Section 17.36

Section 17.37

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Section 17.44

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Section 17.48

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Section 17.51

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Section 17.53

Section 17.54

Section 17.55

Section 17.56

Section 17.57

Section 17.58

Section 17.59

Section 17.60

Section 17.61

Section 17.62

Section 17.63

Section 17.64

Section 17.65

Section 17.66

Section 17.67

Section 17.68

Section 17.69

Section 17.70

Section 17.71

Section 17.72

reaction quotient ( $Q$ ) (max-

imum reaction quotient) (717)

Le Chatelier's principle (736)

Huber process (744)

metabolic pathway (745)

Key Equations and Relationships

17.1 Defining equilibrium in terms of reaction rates (715):

At equilibrium:  $\text{rate}_{\text{fwd}} = \text{rate}_{\text{rev}}$

17.2 Defining the equilibrium constant for the reaction:

$A \rightleftharpoons B$  (716)

$K = \frac{[B]}{[A]}$

17.3 Defining the equilibrium constant in terms of the reaction quotient ( $Q$ ):

At equilibrium:  $Q = K$

17.4 Expressing  $Q$  for the reaction  $aA + bB \rightleftharpoons cC + dD$  (718):

$Q_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}$

17.5 Finding the overall  $K$  for a reaction sequence (719):

$K_{\text{overall}} = K_1 \times K_2 \times \dots$

Highlighted Figures and Tables

These figures (F) and tables (T) provide a quick review of key ideas.

17.2 The range of equilibrium constants (716)

17.3 The change in  $Q$  during a reaction (717)

17.4 Ways of expressing  $Q$  (723)

17.5 Reaction direction and the relative values of  $Q$  and  $K$  (726)

17.6 Steps in solving equilibrium problems (736)

17.7 Effect of added  $\text{Cl}_2$  on the  $\text{PCl}_5$ - $\text{Cl}_2$ - $\text{PCl}_3$  system (738)

17.8 Effect of pressure (volume) on an equilibrium system (740)

17.9 Effect of disturbances on an equilibrium system (745)

Brief Solutions to Follow-up Problems

17.1 (a)  $Q_c = \frac{[\text{NO}]^2 [\text{H}_2\text{O}]^2}{[\text{N}_2] [\text{H}_2] [\text{O}_2]}$

(b)  $Q_c = \frac{[\text{NO}]^2}{[\text{N}_2] [\text{O}_2]}$

17.2  $\text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{HBr}(\text{g})$

$Q_{\text{c,initial}} = \frac{[\text{HBr}]^2}{[\text{H}_2] [\text{Br}_2]}$

$Q_{\text{c,initial}} = \frac{[\text{HBr}]^2}{[\text{H}_2] [\text{Br}_2]} \times \frac{[\text{H}_2] [\text{Br}_2]}{[\text{HBr}]^2} = 1$

17.3 (a)  $K_c = \frac{[\text{H}_2] [\text{I}_2]}{[\text{HI}]^2} = 2.8 \times 10^{-2}$

(b)  $K_c = \frac{[\text{H}_2] [\text{I}_2]}{[\text{HI}]^2} = 2.8 \times 10^{-2}$

17.4  $K_c = \frac{[\text{H}_2] [\text{I}_2]}{[\text{HI}]^2} = 2.8 \times 10^{-2}$

$= 4.07 \times 10^{-2}$

17.5  $Q_c = \frac{[\text{PCl}_5] [\text{Cl}_2]}{[\text{PCl}_3]^2} = 0.24 (0.47) = 0.113 (0.035)$

$Q_c < K_c$ , so  $\text{PCl}_5$  is forming.

17.6 From the reaction table for  $2\text{NO} + \text{O}_2 \rightleftharpoons 2\text{NO}_2$

$P_{\text{NO}} = 1.000 \text{ atm}$ ,  $x = 0.500 \text{ atm}$ ,  $x = 0.404 \text{ atm}$

Also,  $P_{\text{NO}_2} = 1.012 \text{ atm}$  and  $P_{\text{O}_2} = 0.988 \text{ atm}$ , so

$K_p = \frac{(P_{\text{NO}_2})^2}{(P_{\text{NO}})^2 (P_{\text{O}_2})} = 1.3 \times 10^2$

17.7 Since  $\Delta H_{\text{rxn}} = 0$ ,  $K_p = K_c = 2.3 \times 10^4$  (0.781 (0.209))

Thus,  $P_{\text{NO}_2} = 2.7 \times 10^{-16} \text{ atm}$

17.8 From the reaction table:

$[\text{H}_2] = [\text{I}_2] = x$

$[\text{HI}] = 0.242 - 2x$

Thus,  $K_c = \frac{[\text{H}_2] [\text{I}_2]}{[\text{HI}]^2} = \frac{x^2}{(0.242 - 2x)^2} = 2.1 \times 10^{-2}$

Taking the square root of both sides, neglecting the negative root, and solving gives  $x = [\text{H}_2] = [\text{I}_2] = 8.02 \times 1$



# SUPPLEMENTS FOR THE INSTRUCTOR

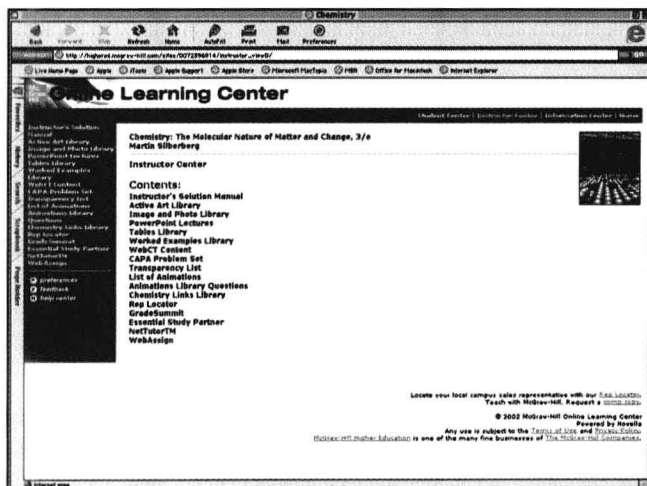
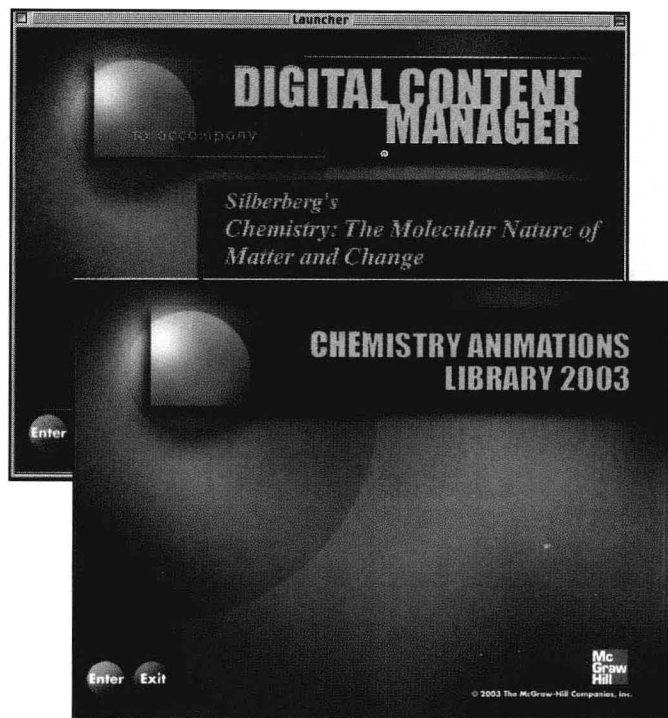
## Multimedia Supplements

### Digital Content Manager

This multimedia collection of visual resources allows instructors to utilize artwork from the text in multiple formats to create customized classroom presentations, visually based tests and quizzes, dynamic course website content, or attractive printed support materials. The digital assets on this cross-platform CD-ROM are grouped by chapter within easy-to-use folders.

### Chemistry Animations Library 2003 CD-ROM

This CD-ROM contains over 300 animations, several authored by Martin Silberberg. With an easy-to-use application, the CD enables users to quickly view the animations and import them into PowerPoint to create multimedia presentations.



### Online Learning Center (Instructor Center)

The Instructor Center is an online repository for teaching aids. It houses downloadable and printable versions of traditional ancillaries plus a wealth of online content.

All Online Learning Center material is available at WebCT and Blackboard. All end-of-chapter problems from the text are included within these course delivery systems.



### Brownstone's DIPLOMA®

With its Test Generator, On-Line Testing Program, Internet Testing, and Grade Management Systems, Brownstone's Diploma is an invaluable instructor resource. This user-friendly software's testing capability is consistently ranked number one over other products.

## Printed Supplements

### Instructor's Solutions Manual

This printed supplement contains complete, worked-out solutions for all the end-of-chapter problems in the text.

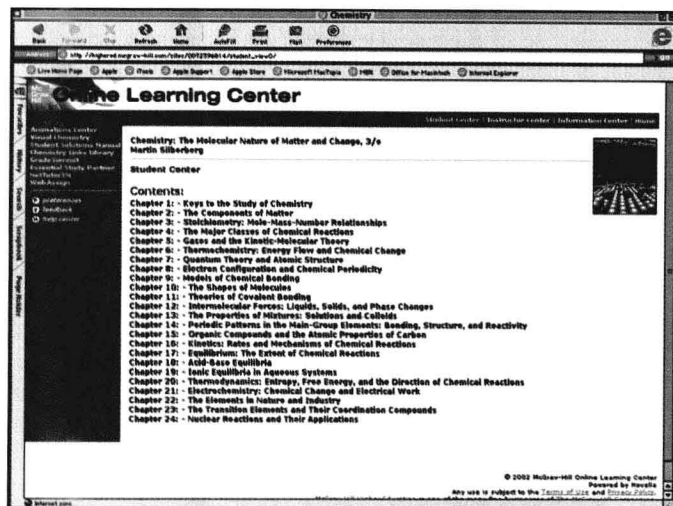
### Transparencies

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.



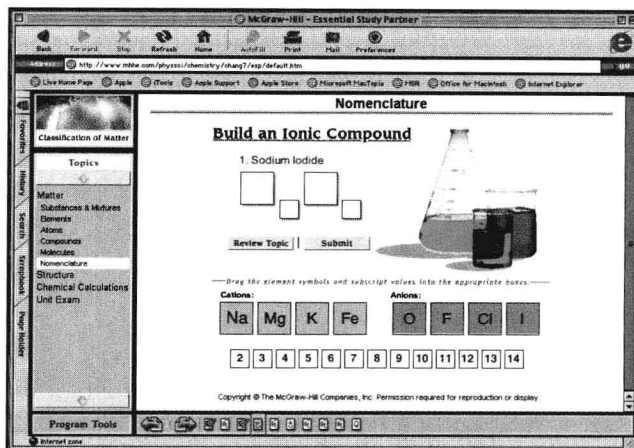
# SUPPLEMENTS FOR THE STUDENTS

## Multimedia Supplements



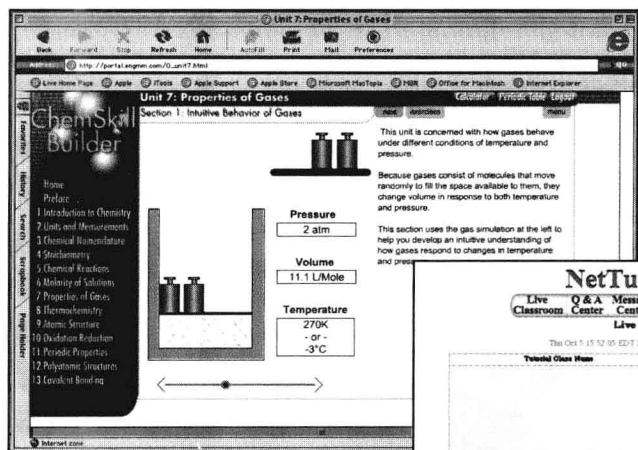
## Online Learning Center (Student Center)

The Student Center of the OLC features quizzes, interactive learning games, and study tools tailored to coincide with each chapter of the text.



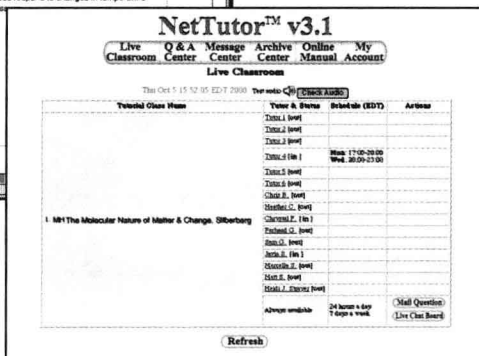
## Essential Study Partner

Located within the OLC, this online resource consists of a collection of interactive study modules containing hundreds of animations, learning activities, and quizzes designed to help students grasp complex concepts.



## ChemSkill Builder

This incredible online tool contains more than 1500 algorithmically generated questions, each with tutorial feedback. There is a direct correlation between student time investment in this program and increased problem-solving ability. A record of student work is maintained in an online gradebook so that homework can be done at home, in a dorm room, or in a university lab.



## NetTutor™

Located within the OLC, NetTutor is a revolutionary online environment that allows users to participate in real-life group learning sessions. Students can communicate with live tutors, submit specific questions, or browse archives of previously asked questions and their answers.

## Printed Supplements

### Student Study Guide

This excellent resource reinforces the most important points in every chapter of the book.

### Student Solutions Manual

This manual contains complete worked-out solutions to all follow-up problems and nearly half the end-of-chapter problems in the text.



# ACKNOWLEDGMENTS

A small army of exceptional people from publishing, Academia, and industry helped give life to the *Third Edition*. Deepest thanks go, as always, to my team of consultants—Randy Duran, Peter Gold, Chuck Haas, and Arlan Norman—for their continued support and expert advice on countless points of content. I am extremely grateful to Bob Loesch of California State University—Long Beach for his superb consulting on past editions.

In the final days of this revision, I was deeply saddened to learn that Peter Gold had passed away. From the beginning, Peter was a guiding force in shaping the content and pedagogy of the text; his insight, wit, and friendship will be sorely missed.

Many other professors played essential roles in creating this edition. Most fortunately, I again had the exceptional talents of Dorothy B. Kurland for the project, this time as in-depth reviewer of the entire manuscript. And I was privileged to have Jim Horvath of the University of Florida supply excellent advice and comments for three-quarters of the chapters. Expert contributors helped me keep key topics as up-to-date as possible: Randy Duran for the discussion of polymers (Ch. 12), Robert M. Metzger of the University of Alabama for the nanotechnology discussion (Ch. 12), Jonathan Kurland of Dow Chemical Company for the boxed essays on ozone depletion (Ch. 16) and acid rain (Ch. 19), Perla B. Balbuena of the University of South Carolina and John S. Newman of the University of California—Berkeley for

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