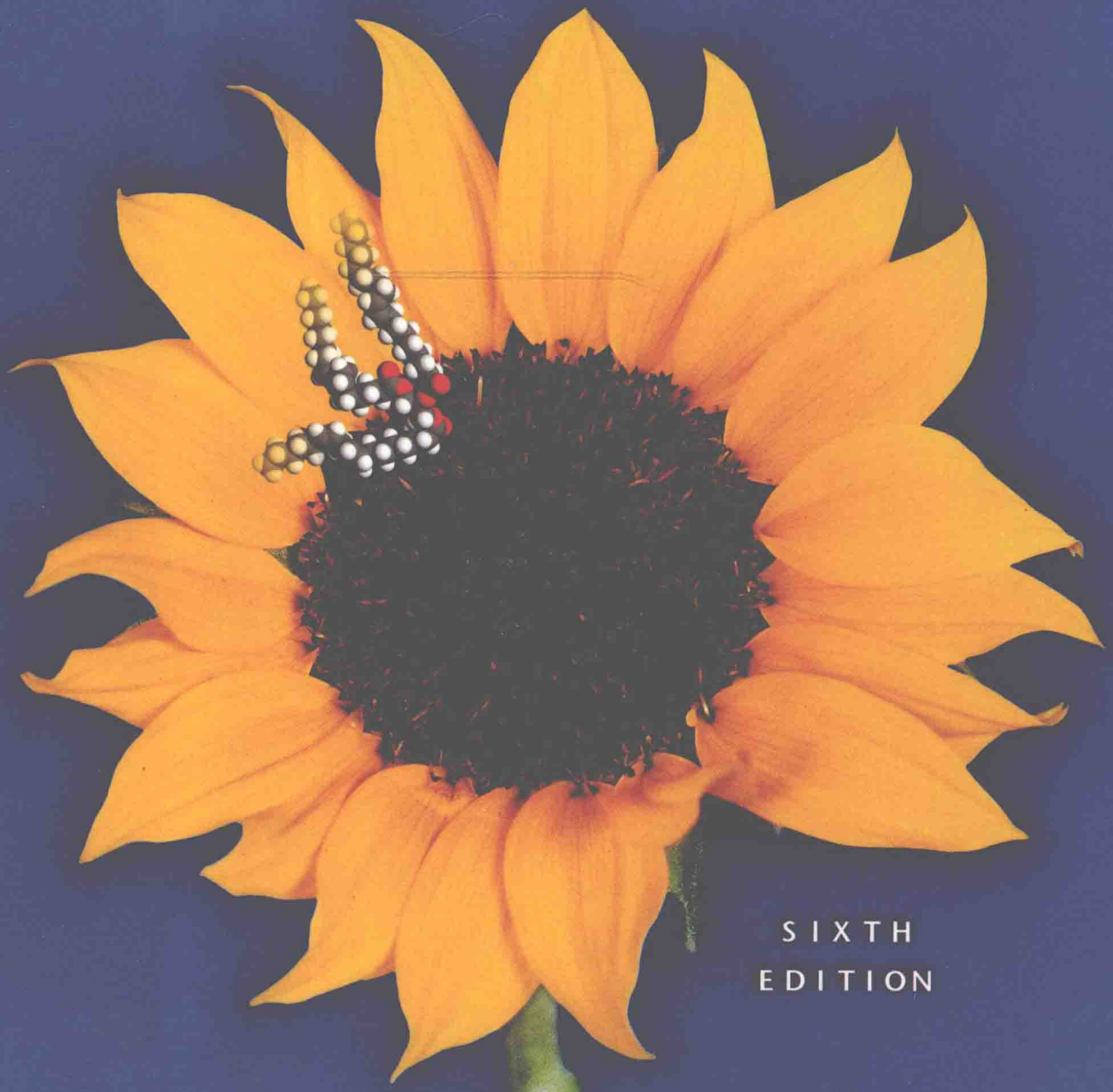
GENERAL CHEMISTRY

with Qualitative Analysis



SIXTH EDITION

Whitten • Davis • Peck

GENERAL CHEMISTRY

with Qualitative Analysis

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(Photo © Masao Ota/Photonica, molecular structure by Jim Birk and Kara Birk.)

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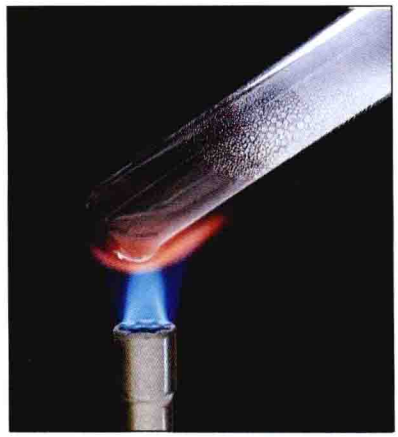
TO THE INSTRUCTOR

General Chemistry and General Chemistry with Qualitative Analysis, *sixth edition, are intended for use in the introductory chemistry course taken by students of chemistry, biology, geology, physics, engineering, and related subjects. Although some background in high school science is assumed, no specific knowledge of topics in chemistry is presupposed. These books are self-contained presentations of the fundamentals of chemistry. The aim is to convey to students the dynamic and changing aspects of chemistry in the modern world.*



Mercury(II) oxide, a red compound, decomposes when heated into the two elements: mercury (a metal) and oxygen (a nonmetal).

CHANGES TO THE SIXTH EDITION

In revising *General Chemistry* and *General Chemistry with Qualitative Analysis*, we have incorporated many helpful suggestions that we received from professors who used earlier editions.

This text provides students with an understanding of fundamental concepts of chemistry; their ability to solve problems is based on this understanding. Our goal in this revision is to provide students with the best possible tool for learning chemistry by incorporating and amplifying features that enhance their understanding of concepts and guide them through the more challenging aspects of learning chemistry. Here are some of the new features:

CD-ROM References: Margin callouts direct students to specific topic screens on the *Saunders Interactive General Chemistry CD-ROM* by John Kotz and Bill Vining.

Conceptual Exercises: This new type of end-of-chapter question emphasizes conceptual understanding rather than computation.

Macro-Micro Art has been utilized wherever appropriate to improve student visualization of molecular-level aspects of chemical properties and concepts.

Molecular Art: Computer-generated molecular art has been specially prepared for this text by Professor James P. Birk and Kara Birk (Arizona State University).

Stereoviews: A collection of stereoviews has been prepared for this text by Professor James P. Birk and Kara Birk. These are chosen to emphasize the three-dimensional aspects of molecular structure. Each copy of the text is equipped with a pair of stereoglasses for easy viewing. Stereoart is indicated by the icon shown in the margin.

World Wide Web Site: This extensive Web site at http://www.harcourtcollege.com/ provides a wide variety of material to enhance student learning, including many aspects specific to this text. Pointers to this and other Web sites are provided in this text and in appropriate ancillaries.

We have also made the following changes in the order, depth of coverage, and presentation based on detailed comments by reviewers:

- The discussion of chemical reactions (Chapter 4) has been extensively revised to include oxidation-reduction reactions, combination reactions, displacement reactions, and three kinds of metathesis reactions. An introduction to the formalism of oxidation numbers early in this chapter allows the correlation of oxidation-reduction reactions with other reaction types. A summary table helps students to recognize and utilize the important aspects of each reaction type.
- The presentation of solubility guidelines (Chapter 4) has been reorganized and clarified.
- We have reorganized the coverage of acid–base equilibria to discuss hydrolysis of ions before presenting buffers. Additional emphasis is put on recognizing buffer solu-

tions produced by various approaches and then on facilitating their treatment using the Henderson-Hasselbalch equation.

- Molecular visualization has been improved by introducing new computer-generated ball-and-stick and space-filling models, macro-micro art, and stereoviews.
- The discussion of titrations has been consolidated into Chapter 11 (overall stoichiometry of titrations) and Chapter 19 (titration curves and indicators).
- Spontaneity (forward and reverse) is discussed in terms of product-favored and reactant-favored processes, terminology that we find is more meaningful to students. This consistent presentation helps to consolidate the concepts of thermodynamics (Chapter 15), kinetics (Chapter 16), and equilibrium (Chapters 17 through 20).
- The presentation of organic chemistry has been reorganized. Chapter 27 now presents classes of compounds and their structures, nomenclature with major emphasis on the principal functional groups, three fundamental classes of organic reactions (substitution, addition, and elimination), and an introduction to polymers. This chapter should be suitable for programs in which only one chapter of organic chemistry is to be covered in a general chemistry course. Chapter 28 then presents a more structured discussion of the geometries of organic molecules, isomerism, selected specific reaction types (Brønsted-Lowry acid–base, redox, carboxylic acid derivative formation, and ester hydrolysis), and finally an introduction to some important classes of biopolymers (carbohydrates, polypeptides, and nucleic acids).
- We have updated many numerical data, including values of ionization energies, electron affinities, atomic and ionic radii, and bond energies.

PROVEN FEATURES

We have also continued to employ and amplify features that were well received in earlier editions of the text:

- A chapter **Outline** and a list of **Objectives** are provided at the beginning of each chapter. These allow students to preview the chapter prior to reading it.
- **Margin notes** are used to point out historical facts, provide additional information, emphasize further some important points, relate information to ideas developed earlier, and note the relevance of discussions.
- **Key Terms** are boldfaced in the text and are defined at the end of each chapter, immediately reinforcing terminology and concepts.
- **Figures** have been redrawn as necessary to improve appearance and clarity, and many new **photographs** have been added to illustrate important points and provide visual interest.

- **Problem-Solving Tips:** Found in almost every chapter, these highlighted helpful hints show students how to avoid common mistakes and pitfalls, and guide them through more complex subject areas. These tips are based on the authors' experiences and sensitivity to difficulties that the students face. Many new tips, based on suggestions by reviewers and students, appear in this edition.

- **"Chemistry in Use" boxes:** This successful feature from previous editions has been retained, with the introduction of several interesting new topics; many popular essays from previous editions are still available on the textbook Web site. These are identified in several categories to show why topics are important: The Environment, The Development of Science, Research & Technology, and Our Daily Lives. "Chemistry in Use" boxes are identified by the special icon shown in the margin.

- **Enrichment** sections provide more insight into selected topics for better-prepared students, but can be easily omitted without any loss of continuity. Enrichment sections are marked with a special icon (see margin).
- **Titles appear on each Example** so students can see more clearly what the Example is explaining. This is also useful for review purposes before exams. A note at the end of most Examples, "You should now work Exercise X," encourages students to practice the appropriate end-of-chapter Exercise and more closely ties illustrative Examples to related Exercises, thereby reinforcing concepts. Each Example also contains a **Plan** that explains the logic used to solve the problem.
- The end-of-chapter **Exercises** have been carefully examined and revised: more than one half of the problems are new or modified. All Exercises have been carefully reviewed for accuracy. The **"Building Your Knowledge"** category of end-of-chapter questions that ask students to apply knowledge they learned in previous chapters to the current chapter. These questions help students retain previously learned information and show them that chemistry is an integrated science.
- **A Glossary** is included in the index, so students can look up a term at the back of the book as well as in the Key Terms at the end of the chapter.

We have also continued to use many ideas and teaching philosophies developed over the six editions of this text:

We have kept in mind that chemistry is an experimental science and have emphasized the important role of theory in science. We have presented many of the classic experiments followed by interpretations and explanations of these milestones in the development of scientific thought.

We have defined each new term as accurately as possible and illustrated its meaning as early as was practical. We begin each chapter at a very fundamental level and then progress through carefully graded steps to a reasonable level of sophistication. *Numerous* illustrative Examples are provided throughout the text and keyed to end-of-chapter Exercises. The first Examples in each section are quite simple, the last considerably more complex. The unit-factor method has been emphasized where appropriate.

We believe that the central concepts of chemical change are best understood in the sequence of chemical thermodynamics *(Is the forward or the reverse reaction favored?)*, followed by chemical kinetics *(How fast does the reaction go?)* and then by chemical equilibrium *(How far does the reaction go?)*. Our presentation in Chapters 15 through 17 reflects this belief.

We have used color extensively to make it easier to read the text and comprehend its organization. A detailed description of our pedagogical use of color is given on page xxx in the "To the Student" section. Pedagogical use of color makes the text more clear, more accurate, and easier to understand.

We have used a blend of SI and more traditional metric units, because many students plan careers in areas in which SI units are not yet widely used. The health-care fields, the biological sciences, textiles, and agriculture are typical examples. We have used the joule rather than the calorie in nearly all energy calculations. We have emphasized the use of natural logarithms in mathematical relationships and problems, except where common practice retains the use of base-10 logarithms, such as in pH and related calculations and in the Nernst equation.

ORGANIZATION

There are 28 chapters in *General Chemistry*, and eight additional chapters in *General Chemistry with Qualitative Analysis.*

We present stoichiometry **(Chapters 2 and 3)** before atomic structure and bonding **(Chapters 5–9)** to establish a sound foundation for a laboratory program as early as possible. These chapters are virtually self-contained to provide flexibility to those who wish to cover structure and bonding before stoichiometry.

Because much of chemistry involves chemical reactions, we have introduced chemical reactions in a simplified, systematic way early in the text **(Chapter 4).** A logical, orderly introduction to formula unit, total ionic, and net ionic equations is included so that this information can be used throughout the remainder of the text. Solubility guidelines are clarified in this chapter, so that students can use them in writing chemical equations in their laboratory work. Finally, naming inorganic compounds gives students early exposure to systematic nomenclature.

Many students have difficulty systematizing and using information, so we have done our utmost to assist them. At many points throughout the text we summarize the results of recent discussions or illustrative examples in tabular form to help students see the "big picture." The basic ideas of chemical periodicity are introduced early **(Chapters 4 and 6)** and are used throughout the text. The simplified classification of acids and bases introduced in Chapter 4 is expanded in **Chapter 10:** Acids, Bases, and Salts, after the appropriate background on structure and bonding. References are made to the classification of acids and bases and to the solubility guidelines throughout the text to emphasize the importance of systematizing and using previously covered information. **Chapter 11** covers solution stoichiometry for both acid–base and redox reactions, emphasizing the mole method.

After our excursion through Gases and the Kinetic–Molecular Theory **(Chapter 12),** Liquids and Solids **(Chapter 13),** and Solutions **(Chapter 14),** students have the appropriate background for a wide variety of laboratory experiments.

Comprehensive chapters are presented on Chemical Thermodynamics **(Chapter 15)** and Chemical Kinetics **(Chapter 16).** The distinction between the roles of standard and nonstandard Gibbs free energy change in predicting reaction spontaneity is clearly discussed. Chapter 16, Chemical Kinetics, provides early and consistent emphasis on the experimental basis of kinetics.

These chapters provide the necessary background for a strong introduction to Chemical Equilibrium in **Chapter 17.** This is followed by three chapters on Equilibria in Aqueous Solutions. A chapter on Electrochemistry **(Chapter 21)** completes the common core of the text except for Nuclear Chemistry **(Chapter 26),** which is self-contained and may be studied at any point in the course.

A group of basically descriptive chapters follow. For the sixth edition, we have condensed this section of the book. **Chapter 22,** Metals I: Metallurgy and **Chapter 23,** Metals II: Properties and Reactions, give broad coverage to the chemistry of metals. **Chapter 24** covers Some Nonmetals and Metalloids, and **Chapter 25,** Coordination Compounds, is a sound introduction to that field. Throughout these chapters, we have been careful to include appropriate applications of the principles that have been developed in the first part of the text to explain descriptive chemistry.

Organic chemistry is discussed in Chapters 27 and 28. **Chapter 27** (Organic Chemistry I: Formulas, Names, and Properties) presents the classes of organic compounds, their structures and nomenclature (with major emphasis on the principal functional groups), and some fundamental classes of organic reactions. **Chapter 28** (Organic Chemistry II: Shapes, Selected Reactions, and Biopolymers) presents isomerism and geometries of organic molecules, selected specific types, and an introduction to biopolymers.

Eight additional chapters are included in *General Chemistry with Qualitative Analysis.* In **Chapter 29,** important properties of the metals of the cation groups are tabulated, their properties are discussed, the sources of the elements are listed, their metallurgies are described, and a few uses of each metal are given.

Chapter 30 is a detailed introduction to the laboratory procedures used in semimicro qualitative analysis.

Chapters 31–35 cover the analysis of the groups of cations. (Cations that create serious disposal problems are no longer used in the qualitative analysis chapters. Mercury, silver, lead, and most chromium have been removed.) Each chapter includes a discussion of the important oxidation states of the metals, an introduction to the analytical procedures, and comprehensive discussions of the chemistry of each cation group. Detailed laboratory instructions, set off in color, follow. Students are alerted to pitfalls in advance, and alternate confirmatory tests and "clean-up" procedures are described for troublesome cations. A set of Exercises accompanies each chapter.

In **Chapter 31,** the traditional Group I has been replaced by the traditional Group IIA (minus lead). Traditional Group IIB (minus mercury) constitutes the first part of **Chapter 32;** then Groups I and II (traditional IIA + IIB minus lead and mercury) make up the last part of Chapter 32. **Chapter 33** includes all of the usual Group III elements. **Chapter 34** covers Group IV and **Chapter 35** discusses Group V.

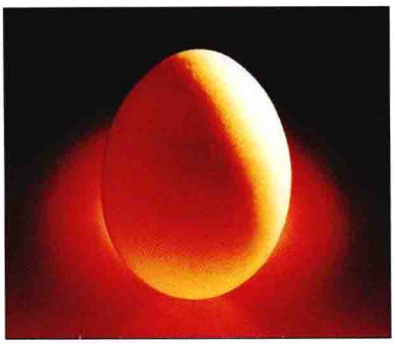
Chapter 36 contains a discussion of some of the more sophisticated ionic equilibria of qualitative analysis. The material is presented in a single chapter for the convenience of the instructor.

A FLEXIBLE PRESENTATION

We have exerted great effort to make the presentation as flexible as possible to give instructors the freedom to choose the order in which they teach topics. Some examples follow:

1. We have clearly delineated the parts of Chapter 15, Chemical Thermodynamics, that can be moved forward for those who wish to cover thermochemistry (Sections 15-1 through 15-8) after stoichiometry (Chapters 2 and 3).
2. Chapter 4, Some Types of Chemical Reactions, is based on the periodic table and introduces chemical reactions just after stoichiometry. Reactions are classified as (a) oxidation-reduction reactions, (b) combination reactions, (c) displacement reactions, and (d) metathesis reactions (three types).
3. Some instructors prefer to discuss gases (Chapter 12) after stoichiometry (Chapters 2 and 3). Chapter 12 can be moved to that position.
4. Chapter 5 (The Structure of Atoms), Chapter 6 (Chemical Periodicity), and Chapter 7 (Chemical Bonding) provide comprehensive coverage of these key topics.
5. As in earlier editions, Molecular Structure and Covalent Bonding Theories (Chapter 8) includes parallel comprehensive VSEPR and VB descriptions of simple molecules. This approach has been widely accepted. However, some instructors prefer separate presentations of these theories of covalent bonding. The chapter has been carefully organized into numbered subdivisions to accommodate these professors; detailed suggestions are included at the beginning of the chapter.
6. Chapter 9 (Molecular Orbitals in Chemical Bonding) is a "stand-alone chapter" that may be omitted or moved with no loss in continuity.
7. Chapter 10 (Reactions in Aqueous Solutions I: Acids, Bases, and Salts) and Chapter 11 (Reactions in Aqueous Solution II: Calculations) include comprehensive discussions of acid–base and redox reactions in aqueous solutions, and solution stoichiometry calculations for acid–base and redox reactions.

SUPPLEMENTS



The calcium carbonate, $CaCO_3$, in an eggshell has the same crystal structure as in the mineral calcite.

INSTRUCTOR ANCILLARIES

Instructor Solutions Manual by M. Larry Peck, Raymond E. Davis, and Kenneth W. Whitten. Contains answers and solutions to all odd-numbered end-of-chapter Exercises.

Test Bank by Frank L. Kolar, Texas A&M University.

ExaMaster+™ Computerized Test Bank is a software version of the printed Test Bank, which enables instructors to add or edit problems and to create their own texts. Available in all major platforms.

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Instructor CD-ROM. This valuable resource contains hundreds of text illustrations, PowerPoint™ files, and selected movie clips and animations. Can be used in conjunction with various types of presentation software.

WebCT Course developed by Charles Atwood and Joel Caughran at the University of Georgia. Contact Saunders College Publishing for more information on this online course management system.

STUDENT ANCILLARIES

Student Solutions Manual by Wendy Keeney-Kennicutt and Yi-Noo Tang of Texas A&M University. Contains answers and solutions to all even-numbered end-of-chapter Exercises. Solutions are divided by section for easy reference by students.

Student Study Guide by Raymond E. Davis. Includes Chapter Summaries that highlight the main themes, study goals with section references, lists of important terms, a preliminary test for each chapter that provides an average of 80 drill and concept questions, and answers to the preliminary tests.

Problem Solving in General Chemistry by Leslie N. Kinsland, University of Southwestern Louisiana. This valuable study tool sharpens students' problem-solving skills. Contains a brief discussion of topics, a variety of examples and exercises, and answers to all the exercises.

Student Lecture Outline by Charles Atwood, Kenneth W. Whitten, and Richard Hedges of Texas A&M University. The outline helps students organize the material, prepare for class, and reduce the burden of note-taking in class. It provides great flexibility for the professor and makes more time available for other activities. Also comes with a special **PowerPoint™ CD-ROM** developed by Charles Atwood and Joel Caughran of the University of Georgia.

Saunders Interactive General Chemistry CD-ROM by John Kotz, State University of New York at Oneonta, and Bill Vining, University of Massachusetts. Considered the best general chemistry CD-ROM available by allowing the student to interact with

the information. Integrated video, animation, and audio enhance the traditional chemistry presentation. Students can also perform simulations of laboratory experiments. Available for both Macintosh and Windows.

World Wide Web Site at http://www.harcourtcollege.com. Contains real-world applications, self-quizzing and testing, chapter summaries, and a host of other features.

Stereoscopic Glasses are packaged free with every new purchase of this text in order to see many of the molecules in 3-D.

LABORATORY MANUAL and WEBCT COURSE

Standard and Microscale Experiments in General Chemistry, 4/e by Carl Bishop and Muriel Bishop, Clemson University, and Kenneth W. Whitten. Many new microscale experiments have been added to this comprehensive manual containing almost 50 experiments. All new pre- and post-laboratory worksheets will familiarize students with the basics of the experiment and to help them draw conclusions. An **Instructor's Manual** accompanies this title.

WebCT Course based on the Bishop Laboratory Manual was developed by Charles Atwood and Joel Caughran of the University of Georgia. This online course includes pre-lab quizzes, emphasizes safety procedures, and much more.

OTHER SUPPORTING MATERIALS

Chemistry Demonstration Videotapes feature Bassam Shakhashiri of the University of Wisconsin-Madison performing 50 three- to five-minute demonstrations. An accompanying manual describes each presentation and includes discussion questions.

Periodic Table Videodisc: Reactions of the Elements by Alton Banks, North Carolina State University, features still and live footage of the elements, their uses, and their reactions with air, water, acids, and bases. Available to qualified adopters, and available in CD-ROM format through JCE:Software, Chemistry Department, University of Wisconsin, Madison, WI 53706, 1-800-991-5534.

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The red anthocyanin pigment in the common geranium is a naturally occurring acid–base indicator.

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REVIEWERS OF THE SIXTH EDITION

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TO THE STUDENT

We have written this text to assist you as you study chemistry. Chemistry is a fundamental science—some call it the central science. As you and your classmates pursue diverse career goals you will find that the vocabulary and ideas presented in this text will be useful in more places and in more ways than you may imagine now.

We begin with the most basic vocabulary and ideas. We then carefully evolve increasingly sophisticated ideas that are necessary and useful in all the other physical sciences, the biological sciences, and the applied sciences such as medicine, dentistry, engineering, agriculture, and home economics.

We have made the early chapters as nearly self-contained as possible. The material can be presented in the order considered most appropriate by your professor. Some professors will cover chapters in different orders or will omit some chapters completely—the text was designed to accommodate this.

Early in each section we have attempted to provide the experimental basis for the ideas we evolve. By *experimental basis* we mean the observations and experiments on the phenomena that have been most important in developing concepts. We then present an explanation of the experimental observations.

Chemistry is an experimental science. We know what we know because we (literally thousands of scientists) have observed it to be true. Theories have been evolved to explain experimental observations (facts). Successful theories explain observations fully and accurately. More importantly, they enable us to predict the results of experiments that have not yet been performed. Thus, we should always keep in mind the fact that experiment and theory go hand-in-hand. They are intimately related parts of our attempt to understand and explain natural phenomena.

"*What is the best way to study chemistry?*" is a question we are asked often by our students. While there is no single answer to this question, the following suggestions may be helpful. Your professor may provide additional suggestions. A number of supplementary materials accompany this text. All are designed to assist you as you study chemistry. Your professor may suggest that you use some of them.

Students often underestimate the importance of the act of *writing* as a tool for learning. Whenever you read, do not just highlight passages in the text, but also *take notes.* Whenever you work problems or answer questions *write yourself explanations* of why each step was done or how you reasoned out the answer. Keep a special section of your notebook for working out problems or answering questions. The very act of writing forces you to concentrate more on what you are doing, and you learn more. This is true even if you never go back to review what you wrote earlier. Of course, these notes will also help you to review for an examination.

You should always read over the assigned material before it is covered in class. This helps you to recognize the ideas as your professor discusses them. Take careful class notes. *At the first opportunity*, and certainly the same day, you should recopy your class notes. As you do this, fill in more detail where you can. Try to work the illustrative examples that your professor solved in class, without looking at the solution in your notes. If you must look at the solution, look at only one line (step), and then try to figure out the next step. Read the assigned material again and take notes, integrating these with your class notes. Reading should be much more informative the second time.

Review the "key terms" at the end of the chapter to be sure that you know the exact meaning of each. Work the illustrative examples in the text while covering the solutions

Ice is slightly less dense than liquid water, so ice floats in water.

with a sheet of paper. If you find it necessary to look at the solutions, look at only one line at a time and try to figure out the next step. Answers to illustrative examples are displayed on blue backgrounds. At the end of most examples, we suggest related questions from the end-of-chapter exercises. You should work these suggested exercises as you come to them. Make sure you read the Problem-Solving Tips; these will help you avoid common mistakes and understand more complex ideas.

This is a good time to work through the appropriate chapter in the STUDY GUIDE TO GENERAL CHEMISTRY. This will help you to see an overview of the chapter, to set specific study goals, and then to check and improve your grasp of basic vocabulary, concepts, and skills. Next, work the assigned exercises at the end of the chapter.

The Appendices contain much useful information. You should become familiar with them and their contents so that you may use them whenever necessary. Answers to selected even-numbered numerical exercises are given at the end of the text so that you may check your work.

The World Wide Web (Internet) is an increasingly important source of many kinds of information. The extensive Web site at http://www.harcourtcollege.com provides a wide variety of material to enhance your learning, including many features specific to this text. Pointers to this and other Web sites are provided in this text and in appropriate ancillaries. We would appreciate hearing about other chemistry-related Web sites that you have found interesting or useful. You will also find many references throughout this text to the *Saunders Interactive General Chemistry CD-ROM* by John Kotz and Bill Vining. This multimedia presentation contains more than 600 screens including full-motion videos showing chemical reactions in progress, animations and other presentations of key concepts and experiments, an interactive periodic table of the elements, and narrated problem-solving hints and suggestions.

We heartily recommend the STUDY GUIDE TO GENERAL CHEMISTRY by Raymond E. Davis, the SOLUTIONS MANUAL by Wendy Keeney-Kennicutt and Yi-Noo Tang, PROBLEM SOLVING FOR GENERAL CHEMISTRY by Leslie Kinsland, and the STUDENT LECTURE OUTLINE by Charles Atwood, Kenneth W. Whitten, and Richard Hedges, all of which were written to accompany this text. The STUDY GUIDE provides an overview of each chapter and emphasizes the threads of continuity that run through chemistry. It lists study goals, tells you which ideas are most important and why they are important, and provides many forward and backward references. Additionally, the STUDY GUIDE contains many easy to moderately difficult questions that enable you to gauge your progress. These short questions provide excellent practice in preparing for examinations. Answers are provided for all questions, and many have explanations or references to appropriate sections in the text.

The SOLUTIONS MANUAL contains detailed solutions and answers to all even-numbered end-of-chapter exercises. It also has many helpful references to appropriate sections and illustrative examples in the text.

PROBLEM SOLVING FOR GENERAL CHEMISTRY provides a valuable study tool if you want more practice with problem solving. It contains a brief discussion of appropriate topics, a variety of examples to illustrate the topics, a set of exercises coded by topic, miscellaneous exercises, and answers to all exercises.

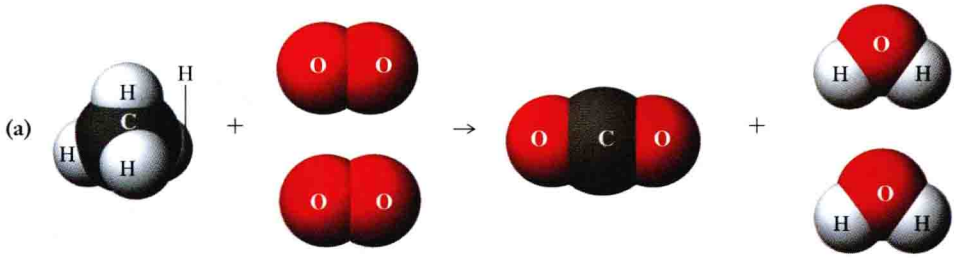
The STUDENT LECTURE OUTLINE helps you organize material in the text and serves as a helpful classroom note-taking supplement, so you can pay more attention to the lecture. It is packaged with a PowerPoint™ CD-ROM.

If you have suggestions for improving this text, please write to us and tell us about them. You can contact us by email via http://www.harcourtcollege.com (the Saunders College Web site).

MOLECULAR ART

This edition contains extensive new molecular art, most of it computer generated. Some examples of the ways in which molecular art is used in this edition are:

1. **Structures or reactions.** Molecular art is used to give a molecular-level view of a concept being discussed, as in the following interpretation of a balanced chemical equation.



(b) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Table 2-6 on page 53 uses this art to illustrate two common representations of molecules—ball-and-stick and space-filling models.

2. **Macro-micro art.** Molecular art presented together with a photograph of a sample or an experiment clarifies the molecular behavior.