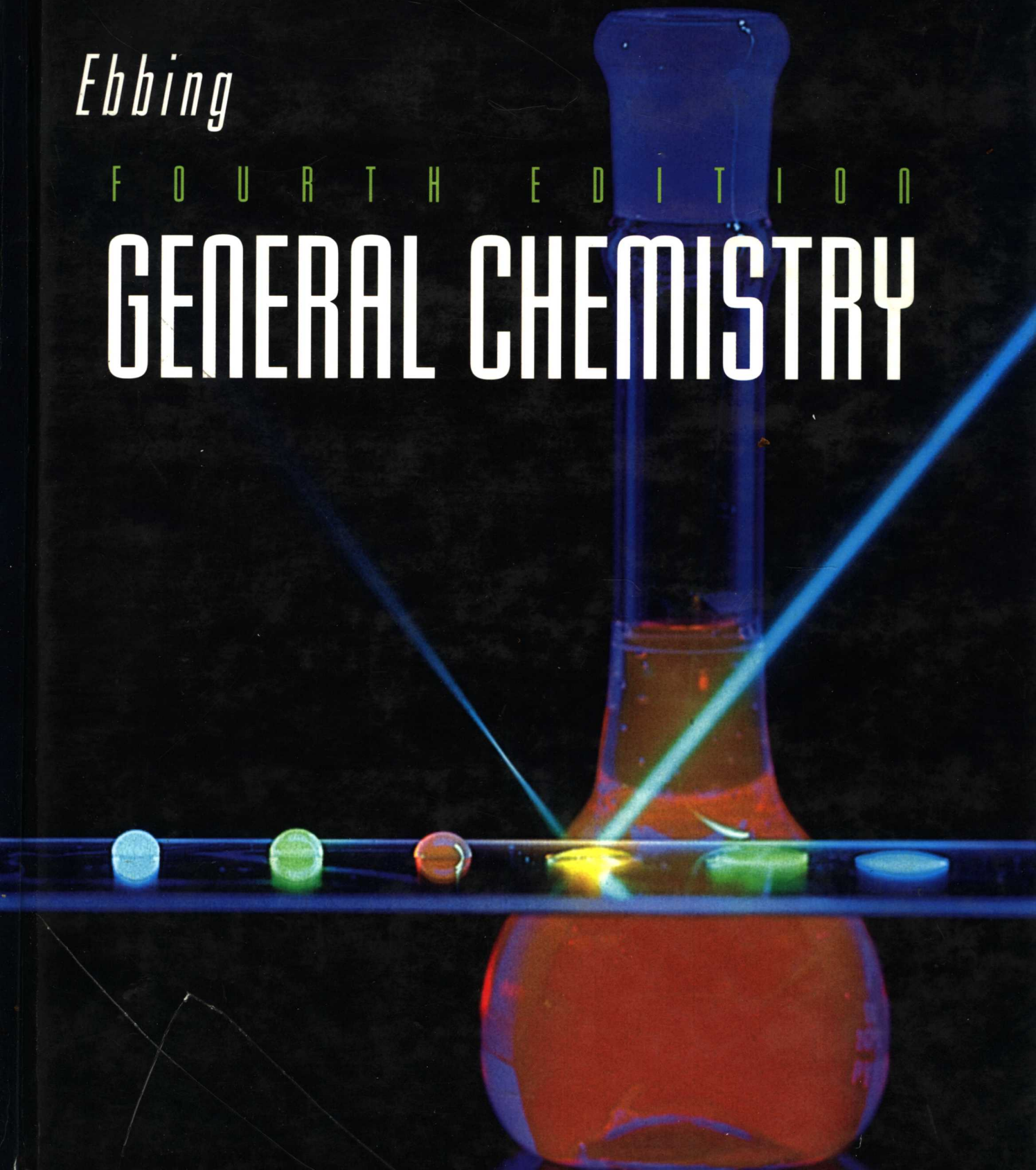
Ebbing

FOURTH EDITION

GENERAL CHEMISTRY



General Chemistry

FOURTH EDITION

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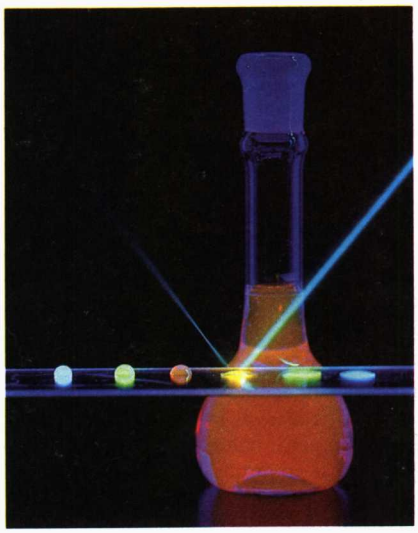

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Credits: Figure 4.11 is from *Principles of Instrumental Analysis,* Third Edition by Douglas A. Skoog, copyright © 1985 by Saunders College Publishing, reproduced by permission of the publisher.

A list of credits follows the index.

Cover Photograph: The characteristics of molecular substances depend on the structure of the molecules that make up that substance. By altering the structure of molecules in precise ways, chemists have found that they can tailor the characteristics of substances. The experiment shown here demonstrates the differences in "wettabilities" of the left and right sides of a glass plate that has been coated with two different substances (octadecyl trichlorosilane on the left and 3-aminopropyl trimethoxysilane on the right); each coating is a single molecule thick. On the right side, droplets of water flatten out because molecules of water in the droplet are attracted to the molecules in the coating on that side of the glass. On the left side, the droplets bead up, because the molecules of water in the drop are not attracted to the molecules in the coating on that side of the glass. Each droplet of water contains a different dye that fluoresces a particular color as a result of the ultraviolet light that shines on the droplets. A blue argon-ion laser light shines on one of the droplets.

Cover photograph by James Scherer.
Cover design by Judy Arisman.

Values for atomic weights listed in the periodic table on the inside front cover of this book are from the IUPAC report "Atomic Weights of the Elements 1989," *Pure and Applied Chemistry,* Vol. 63, No. 7 (1991), pp. 975–1002 (© 1991 IUPAC).

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Foreword

The world of chemistry is indeed a world of change. Since the appearance of the third edition of this book only three years ago, some very significant advances have occurred. One aim of this new edition is to give the reader a sense of the change and excitement in chemistry today while also conveying in the most effective manner the essential principles governing the science. The fourth edition of *General Chemistry* includes examples of recent developments in the field, and through expansion of the color photography program more chemistry is vividly illustrated. Marginal notes, figures, supplementary essays, and examples highlight current areas of research, focusing on aspects of chemistry relevant to modern science and technology.

One of the most exciting aspects of chemistry is that it is still quite realistic to expect that individual scientists working in their laboratories can discover and characterize new substances having novel properties leading to practical applications. Consider, for example, the discovery of new forms of the element carbon as well-defined clusters of carbon atoms, including the 60-atom cluster called buckminsterfullerene or "buckyballs." Chemists, physicists, and materials scientists working in academic, government, and industrial labs are researching these carbon materials to determine whether they have unique chemical and physical properties that might make them useful in catalysis or as superconductors. The fact that an individual scientist can "make a difference" remains one of the most compelling reasons to choose chemistry as a career.

Stimulating the users of *General Chemistry* to pursue careers in chemistry is one goal of the text. A core science that has associated with it a major worldwide industry, chemistry offers many rewards as a vocation. The U.S. chemical industry is very strong, employing around one million people and contributing positively to trade balance. We realize that the majority of users of this book will not become chemists; however, learning chemistry is important to beginning a career in any one of many other disciplines. Chemistry plays a vital role in such areas as electronic and optical devices for advanced computers and communications systems; biotechnology; and high-performance materials. Chemistry will also be a central scientific discipline in the efforts to understand global climate change, develop affordable energy resources, and combat AIDS and other epidemic diseases. Indeed, scientists with a strong background in chemistry have become leaders in molecular biology, advanced materials, medicine, and environmental science. Thus, preparing people broadly for careers in scientific and technical fields is a second aim of this text.

A third aim of *General Chemistry* is to help its users become more scientifically and technically literate so that they may function as responsible members of society. Many of the problems facing the world concern scientific and technological issues such as the state of the global environment, human health, energy at affordable costs, and international security. Since the last edition of this text was published, a war took place in the Middle East and the Soviet Union has collapsed.

The outcomes of these events have placed more emphasis on international cooperation in areas that involve understanding of scientific issues, such as environmental clean-up and development of new industries. Knowedge of chemistry is essential to understanding many of these areas.

As consulting editor for *General Chemistry,* I have worked closely with the author, Darrell Ebbing, and members of the Houghton Mifflin editorial, production, and art team. Some of my specific activities have included reading and criticizing new text, contributing ideas for the cover photo and other illustrations, and writing or rewriting certain pieces. In addition, as we worked on this revision Darrell Ebbing and I have been sensitive to input from the user community and from a distinguished reviewer panel. We are grateful to all those individuals whose constructive criticisms and suggestions have helped us make changes in the text that reflect recent advances in the field as well as new information regarding how best to present the principles of chemistry.

General Chemistry will help prepare its readers for tomorrow's technological world. Through extensive problems and examples, this text introduces many aspects of chemistry in a problem-solving setting. Although solving problems builds confidence in the ability to apply principles of chemistry and is an important component of chemistry, such application of knowledge cannot replace the excitement of actually contributing to the expansion of knowledge. As students address problems in this text, they will be able to envision problems that can be answered only with new experiments and theory. Even a short exposure to chemistry by using *General Chemistry* will prepare users to pose such questions and pursue their answers in a research laboratory. If career paths lead students elsewhere, their grasp of the issues and the procedures used to resolve scientific and technological problems facing our world will still be enhanced by an engagement with *General Chemistry*.

Mark S. Wrighton

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Preface

TO THE STUDENT

The purpose of this textbook is to introduce you to the basic facts and principles of chemistry. Chemistry is a vital and dynamic science. It is of fundamental importance not only to all the other sciences and modern technology but also to any explanation of the material things around us. Consider these diverse questions. What is the environmental role of ozone in the earth's atmosphere? What is responsible for the red color of Io, one of Jupiter's moons? And finally, how can we see inside the brain of a patient without doing harm? All of these questions involve chemistry, and they are just some of the questions you will explore in your reading of this text. I hope I have piqued your curiosity. In your study of general chemistry, you will discover many things, but ultimately you will find that there is so much more to learn and that it is exciting to discover and to question.

The challenge to any author of a general chemistry text is to present a solid understanding of the basic facts and principles of chemistry while retaining the excitement of the subject. Mark Wrighton, the consulting editor for this text, and I feel strongly that the way to do this is by constantly relating the subject matter to real substances and problems in the real world. We begin the study of chemistry with the discovery of the anticancer activity of a bright yellow substance called cisplatin. We use this discovery to illustrate the introductory ideas presented. In Chapter 2, we start by looking at sodium (a soft, reactive metal) and chlorine (a pale green gas) and the reaction between them to produce sodium chloride (ordinary table salt). Each of these substances is quite different, and the reaction, which is shown in an accompanying photograph, is a dramatic example of the transformation that occurs when substances react. With this vivid picture in mind, we go on to explain substances and chemical reactions in terms of atomic theory. In each chapter, wherever we introduce basic principles of chemistry, we keep close contact with the world of real chemical substances and their everyday applications.

Features of the Text

Each individual learns in a different way. For that reason, we have incorporated a number of different features into the text to help you master the subject. We hope that by becoming familiar with these features, which are listed below, you will be able to tailor a study program that meets your particular needs.

CHAPTER OUTLINE Each chapter is preceded by an outline. A chapter is broken into parts, and these are divided into sections and possibly subsections. A glance at the outline will give you an overview of what you are going to encounter in a particular chapter. Your instructor may refer to this outline in describing any changes in order or any omissions of material he or she plans to make. You may find this outline of value in reviewing. For example, when you finish studying a

chapter go over the outline and try to fill in the main details of the discussion under each heading.

CHAPTER THEME We begin each chapter with a theme, something specific that reveals the real-world relevance of the chapter topic. As mentioned earlier, we open Chapter 2 ("Atoms, Molecules, and Ions") with a discussion of sodium, chlorine, and sodium chloride. This chapter theme then leads naturally into a series of questions (for example, How do we explain the differences in properties of different forms of matter?), which we answer later in the chapter.

COLOR ILLUSTRATIONS Most people are strongly visual in their learning. Fortunately, chemistry presents many opportunities for beautiful photography and colorful graphics. When you see something, you tend to remember it. With this in mind, we have chosen color illustrations that both clarify the discussion and help you visualize it. Also, for the first time in this text, computer-generated color images have been used for all molecular models. These images convey the three-dimensionality of molecules more effectively than conventionally drawn figures.

PROBLEM-SOLVING PROGRAM You learn only to the extent that you are involved with a subject, and you learn by doing. It often looks deceptively easy when your instructor explains how to solve a problem. But problem solving is like learning to swim or to play a musical instrument. It becomes easy only with practice. To learn to solve chemistry problems, you must work through the solutions on your own, building your skills by practicing with many different problems. Chemistry builds one principle on another, and fact on fact. The secret of problem solving in chemistry (if secret is the right word) is to know what you learned earlier so well that when you approach a new problem, you know how to put the pieces together.

Recognizing the importance of problem solving in chemistry, we felt the burden could be much reduced if we followed a consistent problem-solving program. We introduce each problem-solving skill by an *Example,* in which you are led through the reasoning that is involved in working out a particular type of problem. The skill has been selected to represent a specific category of problems encountered frequently in general chemistry. Each Example is accompanied by an *Exercise,* which is a similar problem that you can try; the answers are at the end of the book. (Some Exercises are unaccompanied by an Example because the problem solving is not sufficiently complex to justify a formal Example; you will be able to work the Exercise by following the preceding text discussion.) At the end of the Exercise is a list of corresponding end-of-chapter *Practice Problems*. Try some of these to gain mastery of that problem-solving skill.

VOCABULARY Chemistry uses words in a precise way, and it is important that you develop a vocabulary of terms in order to read and communicate effectively. When a new important word is introduced in the text, we have flagged it by putting it in boldface type. The definition of that word will generally follow in the same sentence in italic type. (In any case, the definition will appear in italic type close to the boldface word.) All of these words are collected at the end of the chapter in the list of *Important Terms*. They also appear, along with a few other words, in the *Glossary* at the end of the book. Whenever you are reading along and you encounter a word whose definition you do not recall, look in the Glossary.

CHECKLIST FOR REVIEW When it comes to reviewing, students generally develop their own techniques. What we have tried to do is accommodate these differences by presenting various review possibilities. For example, you may find that the list of *Important Terms* is useful, not only because it is a list of new words, but

also because as you look over the words you see the structure of the chapter. As you mentally note this structure, try to recall the ideas associated with the words. Many chapters also introduce one or more mathematical equations to be used in problem solving. In the chapter, these are noted in blue type; then, in the Checklist for Review, they are listed as *Key Equations*. The *Summary of Facts and Concepts* presents a verbal summary of the chapter. Study this, and as you go over each statement, try to flesh out points. (Imagine you are the instructor, and try to explain the ideas and relate the facts to another student.) Finally, we present a list of *Operational Skills*. This is a summary of the chapter's problem-solving skills. Each operational skill tells you what information is needed and what is to be solved for in a given type of problem. Each operational skill also refers back to the Examples that discuss that problem-solving skill.

END-OF-CHAPTER QUESTIONS AND PROBLEMS The end-of-chapter questions and problems begin with *Review Questions*. These have been designed to test your understanding of the chapter concepts and theory. Generally, they can be answered by straightforward recall or by simple extension of the chapter material. After these questions, we have listed several sections of problems to help you gain mastery of problem-solving skills. The problems are in matched pairs, with the odd-numbered ones (numbers given in blue type) having answers at the end of the book. The problems are divided into three groups: Practice Problems, Unclassified Problems, and Cumulative-Skills Problems. The *Practice Problems* are keyed to a particular topic or skill by heading; the *Unclassified Problems* are not. The *Cumulative-Skills Problems* require you to combine several skills, often from previous chapters. By their nature, these are often challenging problems, but by working some of these, you will be building your skills.

On the inside back cover of this book is a list of *Locations of Important Information*. This lists the pages of the text or the appendix where you will find data for problem solving.

TO THE INSTRUCTOR

The objectives for this revision are essentially those that we set for the earlier editions. They are (1) to explain chemical principles as clearly as possible by relating abstract concepts to specific real-world events; (2) to offer an abundance of meaningful instructional aids, particularly with respect to problem solving; (3) to present topics in a logical, yet flexible, order; and (4) to introduce descriptive chemistry early on and throughout the text, both to enliven the discussion of principles and to introduce the chemical facts students should know in order to be chemically literate. The enthusiastic response of instructors and students to the previous editions of this book has been most gratifying, and I am encouraged that we have succeeded in some measure in fulfilling the objectives we set for the book. Our plan for the fourth edition was to strengthen the implementation of these objectives without tampering with the main organization and study aids of the previous edition. The organization and key revisions of the text are described below.

Organization of the Text

Instructors appear to be in considerable agreement on the order of chapters in a general chemistry text (with a few variations). A glance at the *Contents in Brief* will show you that the chapter organization in this text is a typical one. The

chapters fall into five groups. The first group, Chapters 1 through 6, introduces the basics of chemistry; Chapters 7 through 10 treat atomic and molecular structure; and Chapters 11 and 12 discuss the states of matter and solutions. Chapters 13 through 19 describe chemical reactions and equilibria. The final block of material, Chapters 20 through 25, describes nuclear chemistry and the chemistry of the elements.

Flexible Chapter Order

Although the order of chapters in the text is a typical one, individual chapters are written in such a way to give you flexibility in designing a syllabus. For example, the presentation of gases in Chapter 5 allows you to cover problems on gas volumes immediately after the general discussion of stoichiometry in Chapter 4. But if you prefer, you can cover the chapter on gases just before Chapter 11 on liquids and solids. Chapter 6 introduces the concepts of energy and heat of reaction; it also extends the application of stoichiometry to include heat. However, if you would rather cover this chapter just before Chapter 18 on thermodynamics, you can do that without difficulty.

Chapter 14 on chemical kinetics immediately precedes the chapter on chemical equilibrium, in order to give some depth to the discussion of how a reaction attains equilibrium. But the discussion of chemical equilibrium (Chapter 15) stands on its own, so you can cover the kinetics chapter later, say just before Chapter 20 on nuclear chemistry. Chapter 18 on thermodynamics follows the group of chapters on equilibrium. If you wish to treat thermodynamics first, you can cover all but the last part of Chapter 18 (on free energy and equilibrium constants) just before Chapter 15. Then you can cover the last part of Chapter 18 once you have defined the equilibrium constant.

Chapter Revisions

The principal revisions in this edition are as follows. The first part of Chapter 1 was rewritten to provide a smoother introduction, and the introductory section on matter that was in Chapter 2 was moved here to provide more chemistry before launching into a discussion of measurement. The discussion of the atom in Chapter 2 was strengthened by adding material on the experimental basis of atomic structure, which had previously been presented later in the book. Chapter 3 now includes a brief discussion of oxidation–reduction reactions, although the discussion on balancing equations for these reactions is still in Chapter 13. Gravimetric analysis was added to Chapter 4 to round out the treatment of quantitative analysis. In Chapter 6, the section on Hess's law was rewritten to clarify the discussion. Chapter 7 is now titled "Quantum Theory of the Atom," since the material on the basic structure of the atom now appears in Chapter 2. The discussion of formal charge in Chapter 9 was amplified and given a separate section. The section on molecular orbital theory of metals has been moved from Chapter 10 to Chapter 21. An optional box on liquid crystal displays was added to Chapter 11, and a Special Topic section on entropy and disorder was added to Chapter 18. Chapters 21 and 22 on the main-group elements were completely rewritten and are now titled "Metallurgy and Chemistry of the Main-Group Metals" and "Chemistry of the Nonmetals," respectively. The section on the chemistry of two transition elements in Chapter 23 was rewritten, and a subsection on natural and synthetic rubber was added to Chapter 24.

Illustration Program

Enhancement of the illustration program was a high priority for this revision. Each figure in the previous edition was scrutinized both for accuracy and for clarity. New color photographs were added to further enhance the coverage of descriptive chemistry throughout the text. Some of these are set-up photographs of chemical experiments; others are photographs of applications of chemistry. New to this edition is a series of photographs of computer-generated molecular models. Chemists are increasingly using such models to improve their understanding of the three-dimensional character of molecules, and these photos should aid students' understanding as well.

Flexible Treatment of Descriptive Chemistry

In each succeeding revision of this book, we have increased the emphasis on descriptive chemistry, primarily because of the vividness that descriptive chemistry adds to the subject. Descriptive chemistry is incorporated into this text in several ways. First, it occurs throughout the main text to illustrate concepts, and it is used in examples, problems, and margin notes. However, because a consistent, carefully planned program of descriptive chemistry also seems desirable, we developed the *Profile of a Chemical* series of boxed essays. These 25 essays appear at the ends of Chapters 2 through 19. Each of these essays is short and focuses on a single substance, so that the essay can be easily assimilated by the student without requiring lecture time (although demonstrations or videos can help the student visualize the subject of the essay). The Profile series begins with two reactive elements and progresses to acids and bases, nonmetals, metals, and oxidizing and reducing agents. By the end of the series, the student will have covered a substantial amount of descriptive chemistry, including such environmental issues as stratospheric ozone depletion and the greenhouse effect.

Descriptive chemistry is still treated in separate chapters in the book. Chapter 3 provides an introduction to chemical reactions and facilitates the early treatment of descriptive chemistry. Chapter 13 further explains acid–base and oxidation–reduction concepts, which were introduced briefly in Chapter 3. The text ends with a block of descriptive chemistry chapters. Chapter 21 deals with metallurgy and the main-group metals, and Chapter 22 discusses the nonmetals. The last three chapters cover the transition elements (Chapter 23), organic chemistry (Chapter 24), and biochemistry (Chapter 25).

Chapter Essays and Special Topics

In addition to the Profile of a Chemical series, the text includes two other series of essays. One is the new series *A Chemist Looks At*. These essays explore topics of general interest, such as human vision and acid rain, explaining them in terms of the chemistry the student has just learned. Another is the *Instrumental Methods* series. When students realize that modern chemistry is very much dependent on sophisticated instruments, they often become quite excited by the subject. Each of the essays in this series focuses on an instrumental method used by research chemists, such as mass spectrometry or infrared spectroscopy. The essays are short and provide only enough detail to whet the student's appetite. In addition to these boxed essays, the text includes a number of optional *Special Topic* sections. These are extensions of the material discussed just prior to the Special Topic. You can

assign these optional essays and special topics depending on the time available and the course you want to design.

COMPLETE INSTRUCTIONAL PACKAGE

This text is complemented by a complete package of instructional materials:

For the Student

Study Guide for General Chemistry, Larry K. Krannich, University of Alabama at Birmingham, and Joan I. Senyk. This student study guide reinforces principles and extends problem-solving presentation by offering diagnostic tests, additional worked-out examples and problems, and solutions to all in-chapter exercises.

Student's Solutions Manual, George H. Schenk, Wayne State University. This manual provides complete worked-out solutions to all odd-numbered problems, solutions to in-chapter exercises, and answers to review questions.

Experiments in General Chemistry, R.A.D. Wentworth, Indiana University. This laboratory manual includes 41 experiments, with pre-lab assignments. An instructor's resource manual is also available.

Qualitative Analysis and Ionic Equilibrium, George H. Schenk, Wayne State University. This manual covers chemical principles and laboratory procedures needed for the qualitative-analysis portion of the general chemistry laboratory.

For the Instructor

Instructor's Annotated Edition, Darrell D. Ebbing, Wayne State University. The IAE comprises the student text and a program of annotations to assist the instructor in syllabus and lecture preparation. Many of the annotations refer to such material as transparencies, software, and videos available with this text. Others suggest ways to integrate other instructional media with your use of this text.

Instructor's Resource Manual, Darrell D. Ebbing, Wayne State University. This manual contains additional examples, lecture demonstrations, suggestions for alternate sequencing, and transparency masters.

Test Bank, Ron Ragsdale, University of Utah. The printed test bank contains more than 2000 multiple-choice questions organized by chapter. These test items are also available on disk for the IBM® PC and the Macintosh.® A call-in test service is also available, allowing you to order printed tests by calling Houghton Mifflin's toll-free number.

Electronic Problem Sets, Walter S. Hamilton, Texas Woman's University. This algorithm-based problem generator provides students with extra practice problems coordinated with 240 end-of-chapter problems.

Solutions Manual, George H. Schenk, Wayne State University. This manual contains answers to all review questions and worked-out solutions to all problems and in-chapter exercises.

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Transparencies. 252 full-color transparencies of figures, tables, and photographs selected from the text are provided.

Video Lecture Demonstrations, John Luoma, Cleveland State University; John J. Fortman and Rubin Battino, Wright State University; and Patricia L. Samuel, Boston University. More than 80 demonstrations are provided to supplement your lectures.

Videodisc. The videodisc provides more than 30 new lecture demonstrations and photographs from the text. For more information, contact Houghton Mifflin Company.

ACKNOWLEDGMENTS

The preparation of an introductory textbook, even a revision, is a complex project involving many people. The plan for the fourth edition began with a meeting where we brainstormed ideas with a number of professors. Then, Houghton Mifflin commissioned a series of reviews of the third edition. Unsolicited letters from users also provided input for this revision. The first draft was read in whole or in part by a number of reviewers whose comments were used in preparing the final manuscript. Finally, at the galley-proof and page-proof stages, accuracy reviewers provided the final checks needed to produce a technically accurate book. I owe each of these people a debt of gratitude beyond measure. The following is a list of the contributors in alphabetical order:

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Mark Wrighton was again consulting editor for this edition. As always, he was a source of new ideas, and once again he came up with a dramatic photograph for the cover. Mark assembled a team to help with the laboratory and computer work needed for the new photographs. As I wrote, I generated ideas for the set-up photographs, but it was Eric Wollman, Helen Tatistcheff, and Jie Yu who took my terse descriptions and did the experiments necessary for the photographic setups. Eric and Helen also did the work necessary to obtain the computer-generated molecular models, which add so much to the present edition. My profuse thanks to Mark and to Eric, Helen, and Jie for making it all come together.

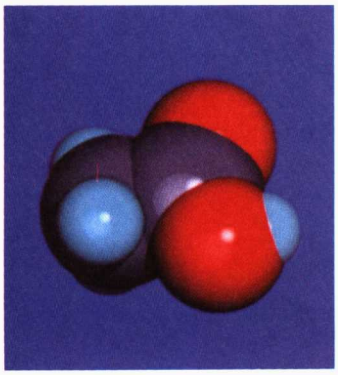
George Schenk again took on the enormous task of preparing the Solutions Manual to the text. John Goodenow of Lawrence Technological University reworked the problems to check their accuracy and then assembled the answer section. I want to thank both George and John for their prodigious efforts on these important tasks. I also want to thank Steven Gammon of the University of Idaho for his software annotations in the Instructor's Annotated Edition.

Larry Krannich prepared the revision of the Study Guide, and Rupert Wentworth prepared the laboratory manual. Both Larry and Rupert contributed to the text through the suggestions they developed while at work on their respective instructional materials. I want to thank each of them for everything they have done.

Finally, I again must thank my family for providing the support I needed to finish this task. To my wife Jean, to my son Russell, to my daughters Julie and Linda and their husbands Tony and Brad, and to my grandchildren Trevor, Geneva, Warren, Caroline, and Darrell, I dedicate this book.

Darrell D. Ebbing

Contents in Brief



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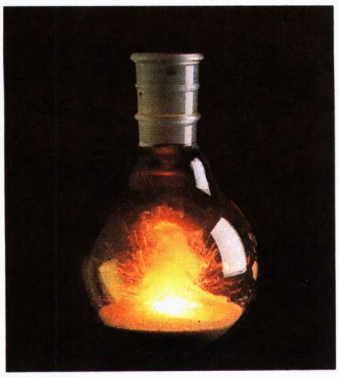

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