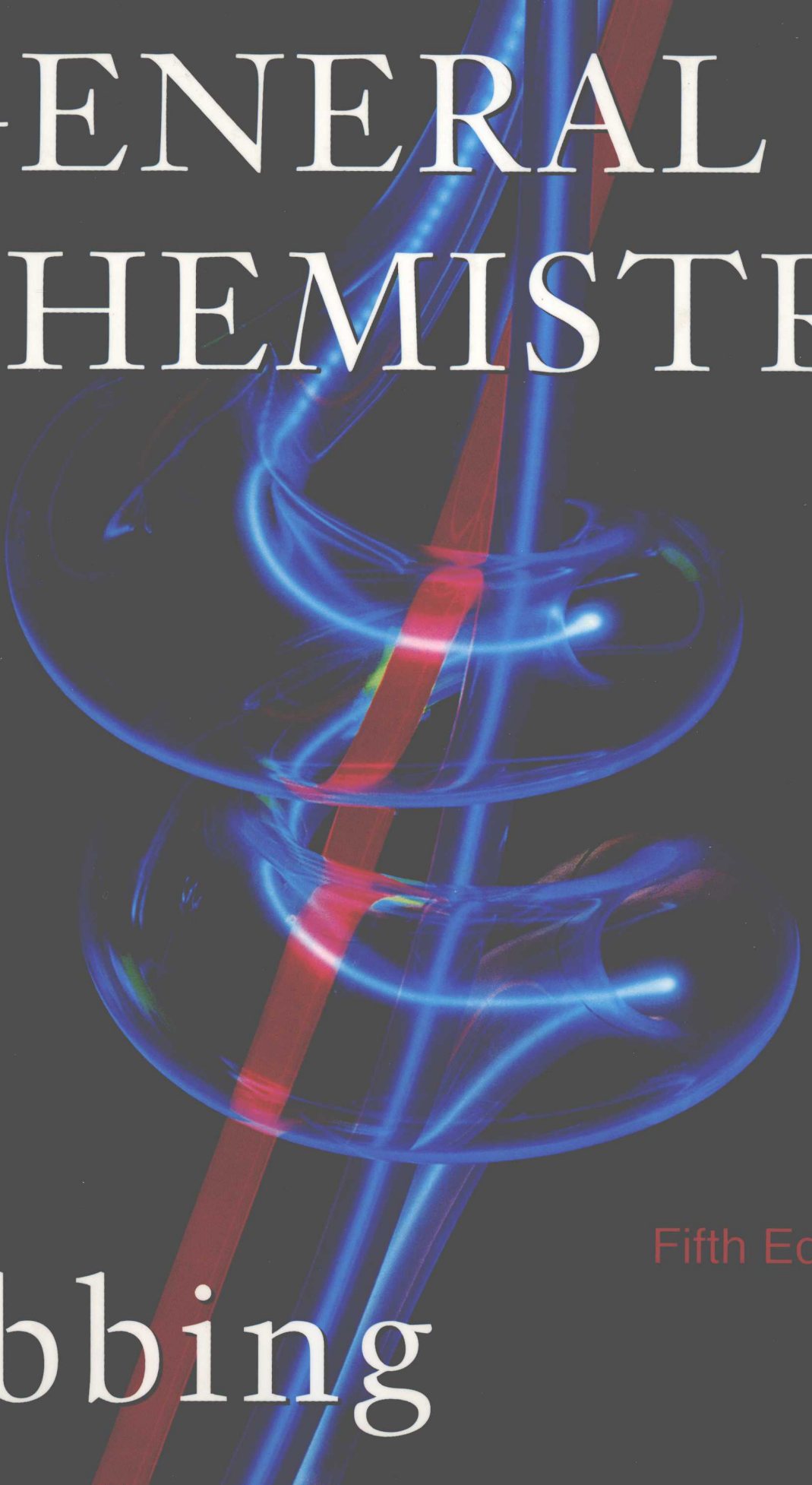
GENERAL CHEMISTRY



Fifth Edition

Ebbing

GENERAL CHEMISTRY

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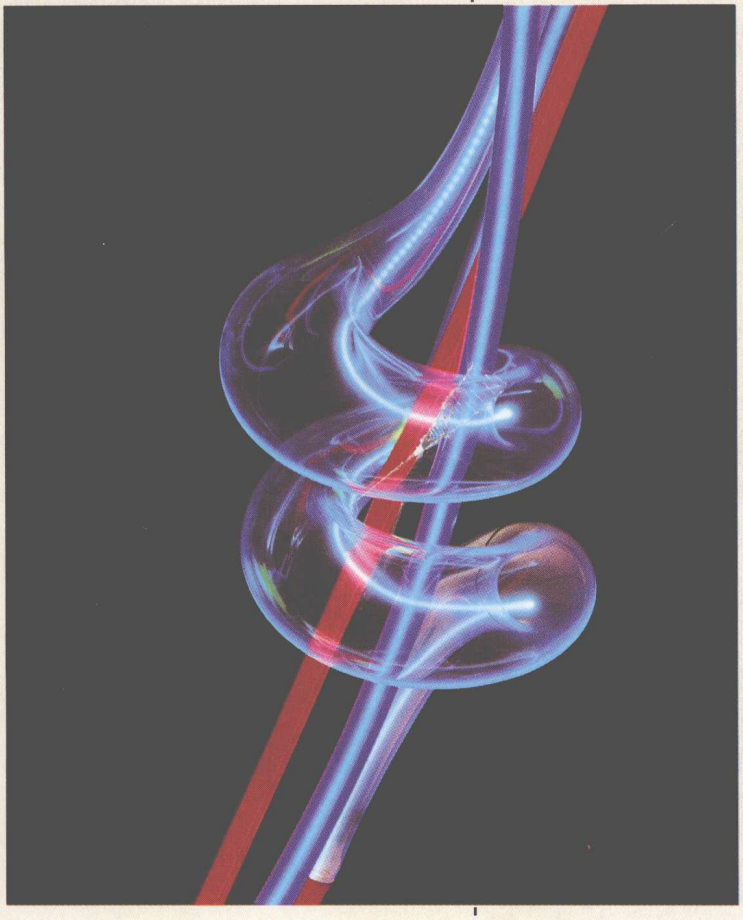

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Warning: This book contains text descriptions of chemical reactions and photographs of experiments that are potentially dangerous and harmful if undertaken without proper supervision, equipment, and safety precautions. DO NOT attempt to perform these experiments relying solely on the information presented in this text.

Credits: A list of credits precedes the index.

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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. 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. The artwork in this edition has been completely rerendered using the latest technology. During the review process, we closely examined each piece of art to make sure it conveyed its meaning effectively and accurately. In addition to rendered art, we have incorporated a large number of photographs depicting chemical reactions and showing computer-generated models of molecules. I believe you will find that the new art and photography makes your study of chemistry easier and more pleasant.

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. Most of these examples include a *Problem Strategy* that underscores the thinking process involved in beginning a problem. 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 shaded in color; 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 having answers at the end of the book. The problems are divided into four groups: Practice Problems, Unclassified Problems, Cumulative-Skills Problems, and Conceptual 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. Many chapters have one or two *Conceptual Problems.* Each of these is open-ended and may require some library work. Each requires you to draw upon what you know to conceptualize the problem and formulate a possible solution. Like real-life problems, sometimes there is no "right" answer.

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 fifth 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, Chapter 3 on chemical reactions discusses oxidation–reduction reactions in the last two sections. You can easily defer coverage of these sections until later in the course, if you prefer. Chapter 5 on gases 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 13 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 14) 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 14. Then you can cover the last part of Chapter 18 once you have defined the equilibrium constant.

Text Revisions

The major text changes in this edition were in the area of chemical reactions. First, Chapter 3 on chemical reactions was entirely rewritten. The emphasis is now on the classification of chemical reactions into precipitation reactions, acid–base reactions, and oxidation–reduction reactions. Because this is such an important topic and because of its early position, we also felt that some of the concepts deserved to be fleshed out a bit more. Another major change was to rearrange the advanced material on acids and bases so that it now appears in two contiguous chapters, Chapter 15 (Acids and Bases) and Chapter 16 (Acid–Base Equilibria)

Numerous small revisions were made to improve the exposition in certain areas. The most important of these revisions were in Chapter 2 on naming compounds, Chapter 5 on real gases, Chapter 6 on the distinction between heat and

temperature, Chapter 7 on light frequency and on the uncertainty principle, Chapter 12 on fractional distillation, Chapter 13 on the rate-determining step, and Chapter 18 on entropy and disorder. A section that reviews oxidation–reduction reactions was added at the beginning of Chapter 19 on electrochemistry. Some additions were also made to Chapter 22 (nonmetal chemistry).

Addition to the Problem-Solving Program

The problem-solving program in this book has received high praise; each in-text example highlights a broad class of problem and includes a detailed solution. We have always tried to show the student the thinking process in problem-solving. In this edition, we have added *Problem Strategies* to the worked-out examples to strengthen this aspect of problem solving. Our purpose here is to emphasize that there are strategies to solving problems. We hope that those students who tend to use rote methods will eventually learn the value of problem-solving strategies.

We have added more difficult problems to the *Unclassified Problems* and *Cumulative-Skills Problems* sections, and we have added a new class of problem: *Conceptual Problems.* These are meant to be open-ended and more "true-to-life." They will challenge the student to think deeply and to forage broadly for a solution.

New Illustration Program

The enhancement of the illustration program was a high priority in the previous edition. Now, with this edition, all of the art was re-rendered electronically, and this gave us the opportunity again to review each piece of art and ask ourselves whether it was as clear and as accurate as can be. The drawings for this edition are more life-like and less schematic. For instance, orbitals have been given a more three-dimensional rendering, and their accuracy checked against computational software. Also, we have added line art where we thought that it aided the text discussion. Similarly, we looked at each photograph. Any that were unclear or otherwise did not meet our high standards were replaced. The result is an illustration program that reinforces the text discussion with a strong visual component.

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, early program of descriptive chemistry also seems desirable, we developed the *Chemical That Matters* series of boxed essays. These 22 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). 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. The text ends with a block of descriptive chemistry chap-

ters. 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

In addition to the *Chemical That Matters* series, the text includes two other series of essays. One is the 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. You can assign these optional essays depending on the time available and the course you want to design.

COMPLETE INSTRUCTIONAL PACKAGE

This text is complemented by a complete package of print and electronic ancillaries.

PRINT ANCILLARIES

For the Student

Study Guide for General Chemistry, Larry K. Krannich, University of Alabama at Birmingham, and Joan I. Senyk. Each chapter is constructed to reinforce the students' understanding of concepts and operational skills presented in the text. For each chapter there is a list of key terms and their definitions, a diagnostic test with answers, a summary of major concepts and operational skills, additional practice problems and their solutions, and a chapter post-test with answers available.

Student's Solutions Manual, David Bookin, Mount San Jacinto College, and George H. Schenk, Wayne State University. This manual contains the solutions to all in-chapter exercises, answers to review questions, and complete worked-out solutions to all odd-numbered end-of-chapter problems.

Experiments in General Chemistry, R. A. D. Wentworth, Indiana University. Forty experiments parallel the material found in the textbook. Each lab exercise has a pre-lab assignment, background information, clear instructions for performing the experiment, and a convenient section for reporting results and observations. An instructor's resource manual is also available.

Qualitative Analysis and Ionic Equilibrium, George H. Schenk, Wayne State University. This laboratory manual presents a traditional qualitative analysis scheme that can be used with the text or can stand alone. It stresses the chemistry of metal ions and anions. Each exercise has a preliminary report and a final report for pre-lab and post-lab activities.

Guide to the Internet, James Dix, SUNY–Binghamton. This booklet describes how to access the latest chemistry news and information using the Internet. It is a

step-by-step guide designed to make this option available to everyone, regardless of prior experience with the Internet.

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, videos, and electronic ancillaries 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 offers information about chapter essays, suggestions for alternate sequencing of topics, short chapter descriptions, a master list of operational skills, correlation of cumulative-skills problems with text topics, alternate examples for lectures, suggested lecture demonstrations, information on software, a list of overhead transparencies, and transparency masters.

Test Bank, Ron Ragsdale, University of Utah. The printed test bank contains more than 2000 multiple-choice questions organized by chapter. Over one-third of the questions in this edition are new. These test items are available on disk for the IBM (Windows) 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.

Solutions Manual, David Bookin, Mount San Jacinto College. This complete Solutions Manual provides step-by-step solutions to all problems and in-chapter exercises as well as answers to all review questions.

Transparencies. Over 250 full-color transparencies of figures, tables, and photographs selected from the text are provided.

ELECTRONIC ANCILLARIES

For the Student

Interactive Chemistry CD. This CD, available for the IBM-PC and Macintosh, will include animations of difficult concepts in chemistry, more than 100 interactive molecular models, video clips demonstrating key concepts in chemistry, and a problems tutorial. The problems tutorial will also be available on floppy disk for those students who do not have a CD player.

For the Instructor

Instructor's Lecture Resources CD. This rich resource of teaching aids includes: lecture manager software that allows you to customize the materials on the CD to fit your lecture, line art from the text, lecture outlines, over 100 interactive molecular models, video clips of lecture demonstrations, and animations of difficult concepts in chemistry. The CD is available for both IBM and Macintosh platforms.

Laserdisc. The laserdisc provides 34 video clips of lecture demonstrations, line art from the text, and animations of difficult concepts in chemistry. Lecture manager software is available for IBM and Macintosh platforms. A print instructor's guide, complete with barcodes, frame references, and cross-references to the text is available.

Video Lecture Demonstrations, John Luoma, Cleveland State University; John J. Fortman and Rubin Battino, Wright State University; and Patricia L. Samuel, Boston University. This series of three videotapes (A, B, and C) contains 80 lecture demonstrations. Series C demonstrations appear on the laserdisc.

ACKNOWLEDGMENTS

The preparation of an introductory textbook, even a revision, is a complex project involving many people. The initial planning for this revision began with discussions with my then-sponsoring editor Richard Stratton. I have always enjoyed working with Richard and I wish to acknowledge his contributions to previous editions of *General Chemistry,* as well as to this one. During this initial planning phase, I was joined briefly by Kent Porter Hamann, who was actively involved in the development of the first edition of this book. Kent came up with a plan for the revision process, and I wish to thank her. Kathi Prancan, Houghton Mifflin's new chemistry editor, had the daunting task of pulling this project together in midstream, while immersing herself in all the chores of a sponsoring editor. My thanks to Kathi for a great job; I look forward to working with her on future projects.

In the manuscript phase, I was often on the phone with Susan Pashos, the developmental editor for this revision. During these phone bouts, she and I pored over text and art, sometimes for hours at a time. Susan's tremendous talent and devotion to the project had an enormous impact on the final book. Once we were in the production phase, I was on the phone daily with Peggy Flanagan, the project editor, who guided the manuscript and art through the production process. It is a process that requires enormous attention to detail, and Peggy has an eagle eye. It is also a process that seems fraught with minor crises, which, I am pleased to say, Peggy handled with aplomb. I thank her profusely for helping to turn stacks of paper into a bound book.

For this edition, we decided to completely revise all of the art. This monumental task was the work of many people. Jill Haber, production and design coordinator, had overall responsibility for the "look" of the book, which was designed by Ron Kosciak. Susan Pashos and Cynthia Maciel worked together in helping me with the specs for the new art. Art editors Charlotte Miller and Jessyca Broekman then helped turn these into finished line art, created electronically by Patrice Rossi and Illustrious. Naomi Kornhauser was the photography editor, researching new photographs, while coordinating the setup photography, which Ann Schroeder oversaw. Douglas Sawyer of Scottsdale Community College did the actual photography for the new setup photos for this edition. I wish to thank all of these people for a superb job.

Many professors of chemistry helped me in this revision. I want to thank the following for donating new problems: Wayne Jones (SUNY–Binghamton), Ronald Ragsdale (University of Utah), George Schenk (Wayne State University), and Ates Tanin (University of Toronto). Others helped in various capacities, as manuscript reviewers or as accuracy checkers of galleys, pages, art, and problem answers. I owe each of them a debt of gratitude. They were of enormous importance to me in developing this book. My thanks to these people:

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Finally, I want to thank my family and friends for the enormous help they have shown Jean and me during what has been a very difficult time for us. In January, 1994, just as I was trying to finish the final manuscript on another book so that I could begin this revision, Jean was stricken by a cerebellar hemorrhage. In the past, she contributed to this book in many ways, directly by sketching illustrations for me, and indirectly by her support. For this round, she needed the time for herself. I want to thank Jean for her past support, but mostly just for being here.

Darrell D. Ebbing

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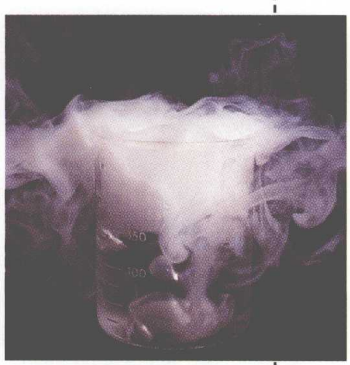

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