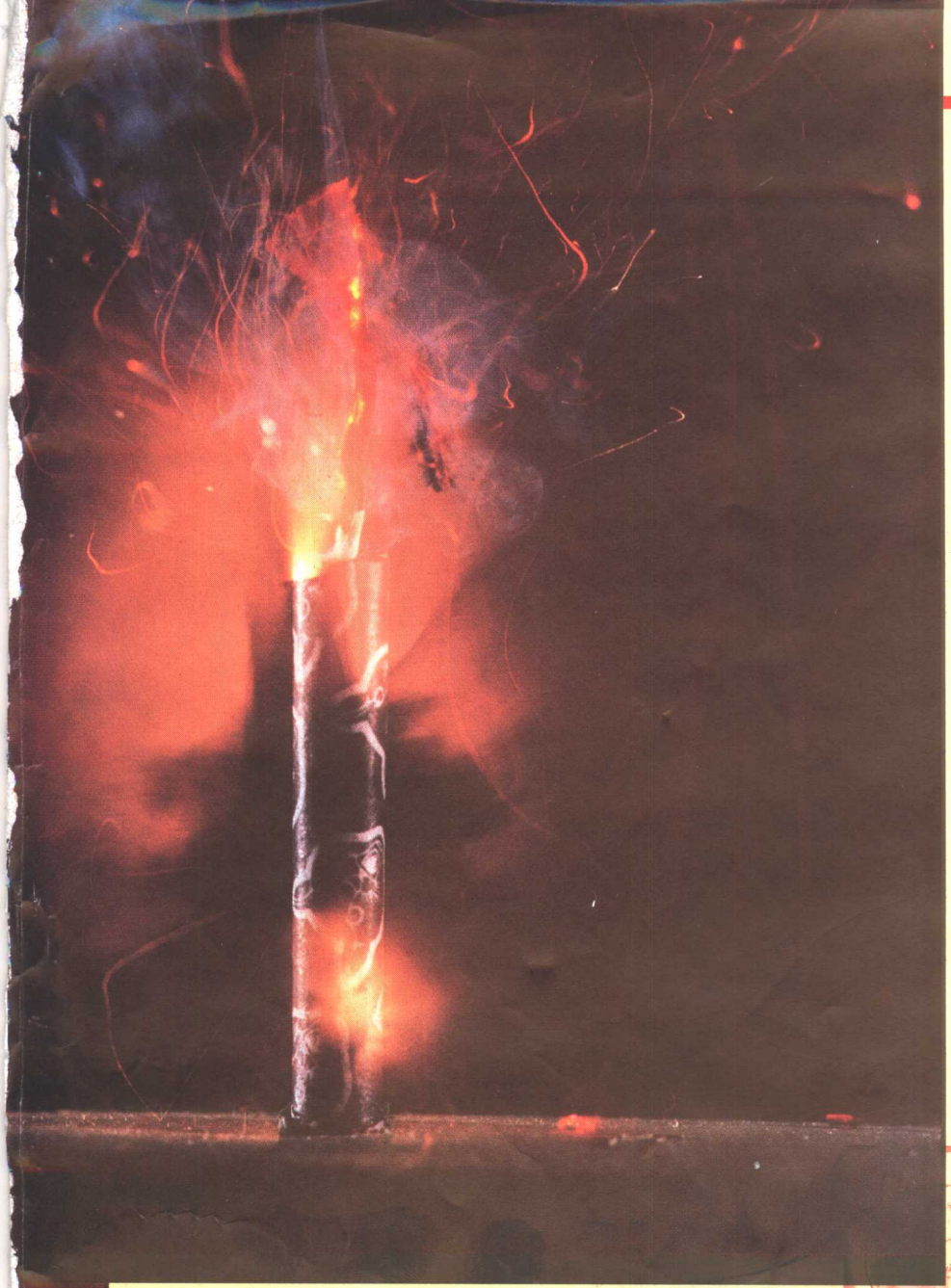
CHEMISTRY: SCIENCE OF CHANGE

OXTOBY • NACHTRIEB • FREEMAN



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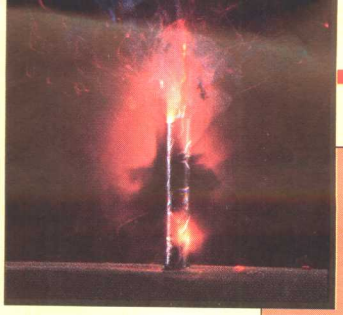
Fundamentals of General, Organic, and Biological Chemistry



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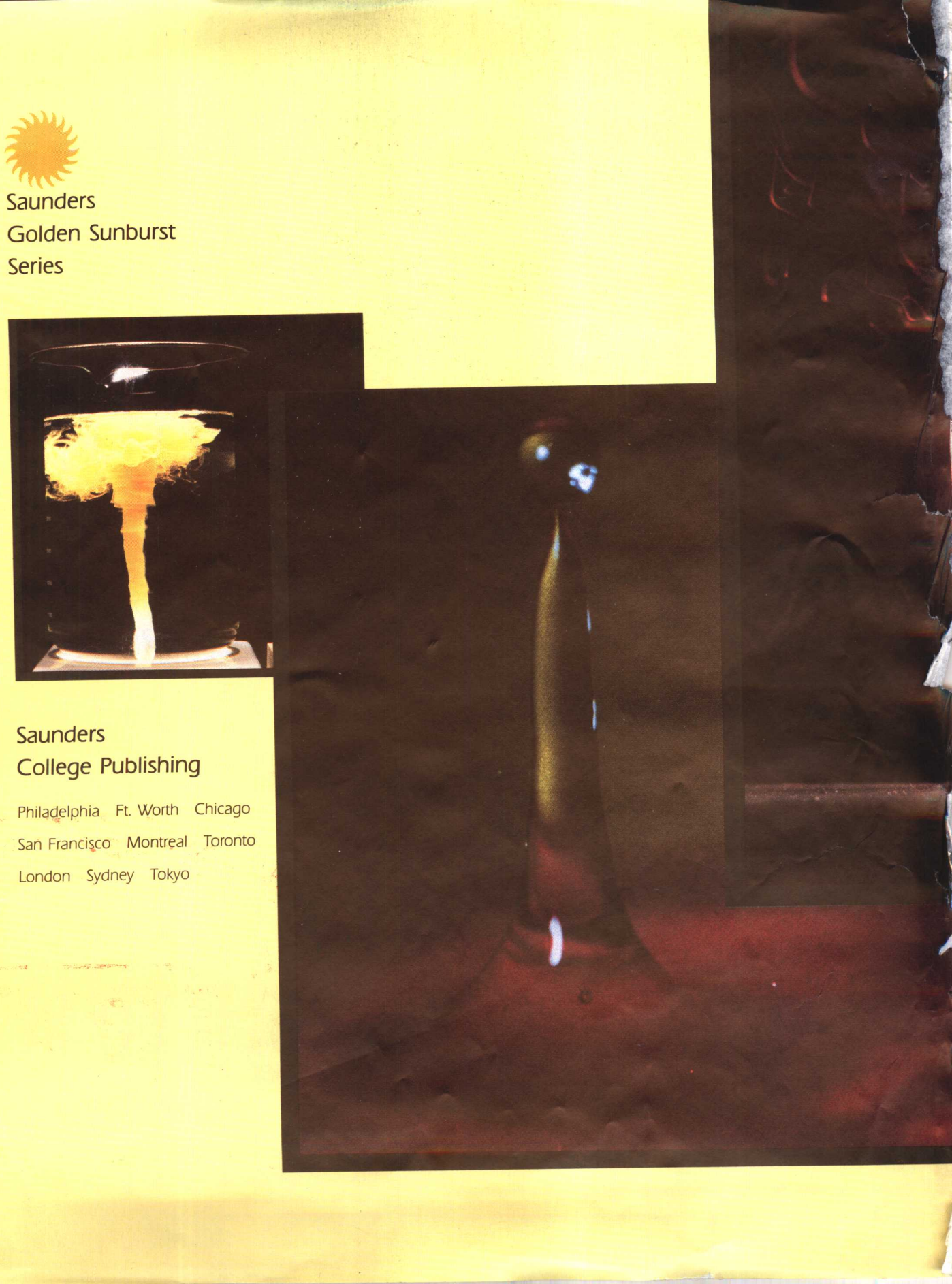

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Preface

Chemistry: Science of Change is intended for use as the text in introductory chemistry courses taken by students of biology, chemistry, geology, physics, engineering, and related subjects. The text builds on students' knowledge of algebra but does not require calculus. Although some background in high-school science is assumed, no specific knowledge of topics in chemistry is presupposed; this book is a self-contained presentation of the fundamentals of chemistry. Its aim is to convey to students the dynamic and changing aspects of chemistry in the modern world.

Organization

The underlying premise of this book is that chemistry is a science based on observations and measurements, from which deductions and principles can be derived. Our view is that the study of chemistry should start with the visible, tangible world of macroscopic experience and move from there toward the simple models that help to organize and rationalize daily experience. As students become comfortable with the chemist's way of viewing natural phenomena, the more fundamental (but also less evident) theoretical basis of the subject can be introduced gradually. It is our hope that students will come to look upon theory and experiment (or observation) as mutually reinforcing aspects of science. Each informs the other, and together they point the way to a deeper understanding of the workings of the real world. Our organization also allows students to begin meaningful laboratory work at an early stage.

Chapters 1 through 15 emphasize macroscopic aspects of chemistry. Chapters 1 and 2 begin with mass relationships in chemical reactions and from there demonstrate the origins of the atomic theory of matter. Chapter 3 is an introduction to the periodic table of the elements, the central organizing principle in chemistry. The Lewis electron dot model is also presented here, as a direct consequence of the group structure of the periodic table. Aspects of atomic structure such as orbital shapes and occupancies (the connection of which to chemical experiments is not direct, particularly at the elementary level) are treated later in the book. Chapter 4 is a qualitative introduction to the types of chemical reactions: dissolution and precipitation, acid-base, and oxidation-reduction. Chapters 5 through 7 discuss the states of matter and the phase equilibria among them: first gases, then liquids and solids, and finally solutions. Chapters 8 through 10 provide an introduction to chemical equilibrium, beginning with the gas phase and including extensive treatment of acid-base and solution equilibria. Chapters 11 and 12 introduce chemical thermodynamics: heat effects in chemistry and the nature of spontaneous change. Chapters 13 and

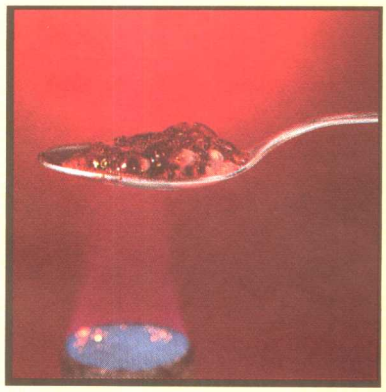
14 first discuss redox reactions and electrochemical cells and then treat the more quantitative aspects of cell voltages and concentration effects. Chapter 15 deals with the rates of chemical reactions, starting with experimental rate laws and reaction mechanisms and then discussing the gas-kinetic models that seek to account for the observed behavior.

In the next six chapters our emphasis shifts to a systematic development of the modern microscopic picture of the structure of matter. Chapter 16 begins the development appropriately with the building blocks of the atom—electrons, neutrons, and protons—and with the stability and reactivity of the nucleus. Chapter 17 then turns to one-electron atoms and the modern quantum theory, and Chapter 18 introduces many-electron atoms, returns to the periodic table from the quantum point of view, and treats the role of electrons in chemical bonding from that viewpoint as well. Chapter 19 continues this discussion and presents the rudiments of molecular spectroscopy and photochemistry. The coordination complexes considered in Chapter 20 serve as a bridge between the simple molecules of the earlier chapters and the extended structures of liquids and solids that are treated in Chapter 21.

Chapters 22 through 31 are short chapters that present an overview of chemical processes: industrial, atmospheric, geochemical, and biological. Our goal in these chapters is to show the ways in which reactions fit together into chemical processes, both in nature and in chemical industry. These chapters introduce no new principles; instead, they provide a useful, integrated review of the principles in the first 21 chapters, such as the tradeoffs between thermodynamics and kinetics in process design or the relationship between electronegativity and ceramic properties. Our presentation of industrial chemistry has a strong historical component, because the history of the chemical industry is an important subject in its own right and because the historical approach best illustrates the ways in which chemical processes are developed and improved. For the most part, these chapters are self-contained and can be included selectively if so desired, except that within this group Chapter 22 should be covered first; moreover, Chapter 27 should precede Chapter 28, and Chapter 29 should precede Chapters 30 and 31.

The place of "descriptive chemistry" in the chemistry curriculum is a popular subject for debate and discussion these days. This term encompasses several aspects: the chemistry of the periodic table, facts about chemicals in everyday life, and chemical processes. The approach we have followed in this book is to integrate the first two aspects into the text wherever possible to illustrate the natures of substances and the reactions they undergo. For example, we discuss metallurgy in the context of redox reactions; we combine the rather dry subject of the nomenclature of the oxides of nitrogen with a figure discussing their chemical properties; and we precede the treatment of the physical properties of gases with the chemical reactions that lead to gas production. On the other hand, chemical processes deserve systematic treatment such as we have provided in the last chapters. We find it artificial, for example, to present the Solvay process as an aspect of the chemistry of the alkali metal group when it is just as deeply grounded in acid-base chemistry. There is real value in concluding an introductory course with a broader look at chemistry in its "real-world" context, and that has been our goal in the final chapters.

Alternative Teaching Options



We have given the reasons for our choice of organization, but we recognize that some instructors may prefer a different order of presentation. We have therefore made the book flexible enough to accommodate many alternative organizations. For example, the material on atomic structure and chemical bonding in Section 16–1 and Chapters 17 through 19 could be introduced after Chapter 3 or after Chapter 10. Chapters 16 (except for the first section), 20, and 21 could be omitted or postponed until later in the course if time constraints are severe. Some instructors choose to split the coverage of thermodynamics into two parts. Those who wish to do so could cover Chapter 11 anytime after Chapter 5, while postponing Chapter 12 until later in the course.

A number of individual sections of chapters can be omitted without loss of continuity. For example, the last three sections of Chapter 10, while important for any course covering qualitative analysis of metal ions, are not essential to the material that follows them in the book. The material on nuclear chemistry in Chapter 16 (that is, all but Section 16–1) could also be omitted or postponed until later in the course.

As we have mentioned, instructors can be selective in their coverage of Chapters 22 through 31. These chapters can also be treated as "interchapters" and interwoven with other chapters in the book. All of them, however, rely on the basic principles of thermodynamics and should be held until after Chapter 12. For example, Chapters 22 and 23 could be covered after 12, Chapter 24 after 14, Chapter 25 after 15, Chapter 26 after 18, and Chapters 27 and 28 after 21. Chapters 29 through 31 provide a coherent introduction to organic chemistry (including polymers) and biochemistry at a level of detail appropriate to general chemistry and could be included after Chapter 19 or at the end of the course.

Appendices

The book contains seven appendices. Appendix A treats scientific notation, experimental uncertainty (including the distinction between precision and accuracy), and significant figures. Appendix B gives an overview of the SI system of units and shows how units are interconverted. Appendix C treats some mathematical operations used in general chemistry, including the drawing and reading of graphs, the solution of quadratic equations, and the use of logarithms. These three appendices are placed at the back of the book for easy reference, but the material in them can be used by the instructor at the appropriate points in the course. All three contain problems for students to work to test their understanding of the material.

Appendices D, E, and F consist of tables of thermodynamic, electrochemical, and physical data. Together with the tables inside the covers of the book, these provide quick access to data that are useful in solving problems in the text. Appendix G contains the answers to the odd-numbered problems at the end of each chapter.

Acknowledgments

This book has benefited greatly from many incisive comments and suggestions from chemists around the country who have reviewed the manuscript at various stages of development. Reviewers include

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David W. Oxtoby
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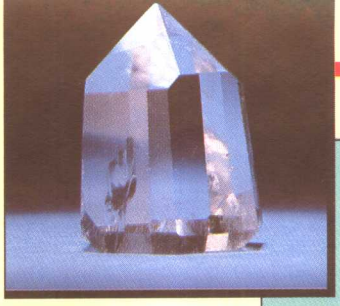


Supplements

Instructor's Manual by Wade A. Freeman. Included are lecture outlines, classroom demonstrations, and solutions to the even-numbered problems in the book.

Student Solutions Manual by William Pietro, University of Wisconsin, Madison. A manual of the odd-numbered problems in the book and their detailed solutions.

Student Study Guide by Richard Watts, University of California, Santa Barbara. Includes additional worked-out examples, as well as questions and practice examinations, to help students gauge their mastery of each chapter and to encourage them to think about important chemical concepts.

Overhead Transparencies. One hundred twenty-five full-color figures from the text.

Student Lecture Outline by Ronald Ragsdale, University of Utah. Helps students organize the class lectures and frees them from extensive note-taking.

Problems Book by Ronald Ragsdale. Used as a supplement, this book helps students master problem-solving in general chemistry.

Computerized Test Bank by William Snyder. A multiple-choice test bank with over 1000 test items for IBM PCs or compatible computers and Macintosh computers.

Printed Test Bank. A book of tests generated from the computerized test bank.

Laboratory Experiments for General Chemistry by Harold Hunt and Toby Block, Georgia Institute of Technology. A new laboratory manual with 42 experiments, designed with careful regard for safety in the laboratory. An instructor's manual is also available.

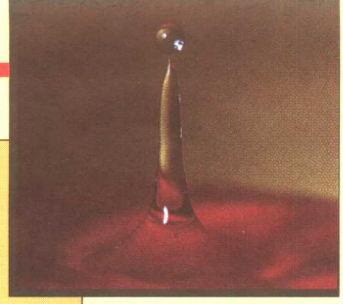
Qualitative Analysis and the Properties of Ions in Aqueous Solution by Emil Slowinski, Macalester College, and William Masterton, University of Connecticut. A paperback supplement on qualitative analysis, which encourages students to develop their own schemes of analysis.

Seraphim Periodic Table Videodisc. A visual database of information about applications, properties, and chemical reactivity of the elements.

Chemical Demonstration Videotapes by the University of Illinois, Urbana-Champaign. Schools using *Chemistry: Science of Change* may choose from a list of 35 available lecture/demonstration videotapes.

Audio-Tape Lessons and Workbook by B. Shakhashiri, R. Schreiner, and P. Meyer, University of Wisconsin, Madison. Tapes to help students learn general chemistry at their own pace. Students listen to the instructions on the tape and follow the examples in the workbook.

Tutorial Software. Wilkie computerized chemistry for Apple II and IBM computers. Covers 18 major topics in general chemistry.



To the Student

Chemistry is an immensely practical subject that, properly understood, furnishes answers to many important problems. Like all of the sciences, chemistry is an experimental discipline. Doing course work such as homework, quizzes, and examinations is very much like doing experiments. The difference is that someone else has asked the question (done the experiment) and collected the results in the form of data. What remains for you is to devise a strategy for converting the data to an answer. How well you answer the question depends on how well you have "sized up" the problem.

Understanding exactly what is wanted is the first step. Second, call to mind the principle(s) that underlie the desired result. What factors are involved? Decide whether the information provided is relevant and discard anything that is not. Plan a method of attack and carry it out. Once you have an answer, consider whether it "makes sense." Is it about the right size? Are its units correct? Was there another approach you might have taken to work the problem? If so, does it give the same answer? (Often there are several ways to solve a given problem.)

As you gain experience in problem-solving, you may find that your way of looking at new situations has changed. You may find yourself "looking for the facts," wondering what lies behind an occurrence, questioning the validity of a piece of information. Problem-solving is a *transferable skill* that applies not only to working chemistry problems (and getting good grades on exams), but to almost every activity in life.

As you are using this book, read thoughtfully for perhaps a page and then set the book aside. Reflect on what you've read. Is there a concept that might prove useful, a generalization that ties several ideas together, an analogy that is especially apt? Summarize it succinctly by making a note of it in your own words. The act of putting pen to paper is in itself a remarkable assist to the memory, and expressing the concept in your own words is a powerful study aid.

Another suggestion that often helps is to study with a classmate, taking turns instructing one another. There is no surer way to learn whether you understand a concept than to explain it to another person. Make up problems with which to test each other and, to overcome the "examination anxiety" that students sometimes experience, limit the time allotted to solve them. If you prefer, choose some of the odd-numbered problems at the end of the chapter you're studying. The answers are in Appendix G.

Above all, in your study of chemistry, develop a questioning, aggressive approach to what you read and hear. Ask for the evidence, and don't despair if you make mistakes. The wonderful edifice of science was built on trial and error, and persistence always wins!

About this Book

We have tried to make this a user-friendly book, and our principal concern has been to explain the subject in as clear and unambiguous a manner as possible. We have included a number of learning tools in this book to help you increase your understanding of chemistry. We hope these features will stimulate your interest in the subject.

Figures

The book makes extensive use of **figures** to aid in explaining concepts and to illustrate chemical behavior. These include color photographs, diagrams, and drawings of molecular structures. Especially in the first 15 chapters, we use molecular structures with their figure captions to present brief "capsule summaries" of the properties and uses of important simple compounds. In these structural diagrams, carbon is black, hydrogen is light gray, oxygen is red, nitrogen is blue, sulfur is orange, phosphorus is purple, fluorine is yellow, chlorine is green, bromine is reddish brown, iodine is reddish purple, boron is brown, and xenon is blue-green.

Examples and Exercises

Each chapter contains numerous **worked examples** to illustrate the principles that have been discussed. Each example is followed by a related **exercise** together with its answer.

Highlighted Text

Throughout each chapter **key terms** are printed in boldface where they first appear. Important statements and equations are screened in blue, and answers to examples are screened in tan. Acids are color coded in red and bases in blue; formal charges are shown in blue circles, while oxidation numbers appear in red.

Marginal Notes

The occasional **notes in the margin** serve several purposes: to emphasize or elaborate on a point, to provide a different perspective on a statement made in

the text, and to provide "signposts" directing you to other parts of the book where subjects have been or will be covered.

"Chemistry in Color" and "Chemistry in Progress"

Throughout the book we have included a number of **special boxed topics.** Those titled "Chemistry in Color" are built around the theme of the sources of color in the world and the relationship of color to chemistry. The boxes titled "Chemistry in Progress" show the ways in which chemistry contributes to and benefits from the stream of developments in science and technology that continuously change the shape of the modern world.

Chapter Summaries

Each chapter ends with a **summary** of the material presented in that chapter. The purpose of this is to place the new material in context and to review it. These summaries may be especially useful when you are studying for an examination.

Practice Exercises

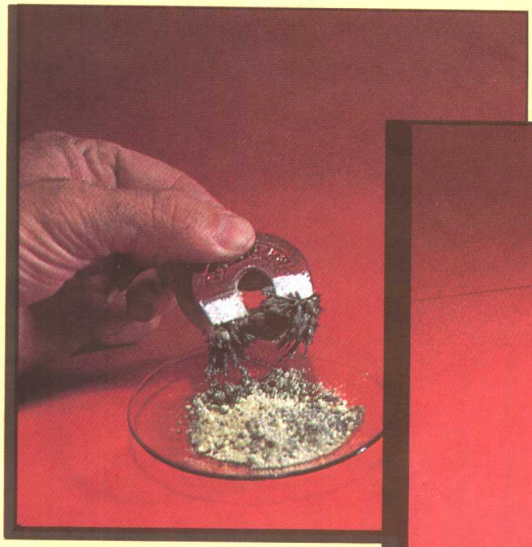
At the end of each of Chapters 1 through 21 there is a **practice exercise** that is built around a problem of chemical interest and draws on material from the entire chapter for its solution. Working through these exercises provides a useful review of material from the chapter, helps you to put principles into practice, and prepares you to solve the problems that follow.

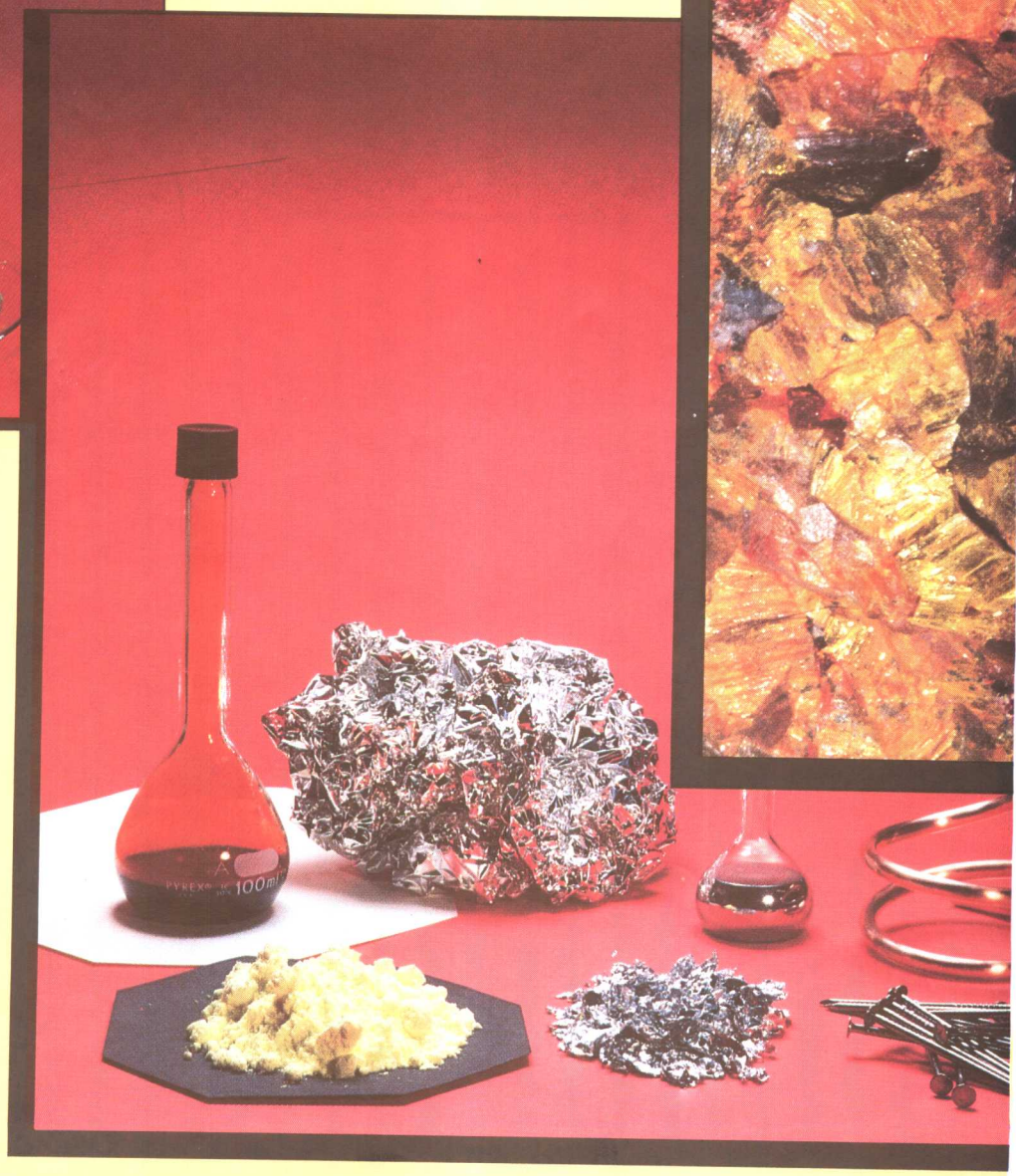
End-of-Chapter Problems

These **problems** are arranged in two groups. The first group consists of paired problems, placed in order of presentation of the topics in the chapter. The answer to the odd-numbered problem in the pair is given in Appendix G, allowing you to check the answer before undertaking the second problem, which parallels the first. These paired problems are followed by a group of additional problems, which may involve concepts from different parts of that chapter and which may draw on material from earlier chapters as well. More challenging problems are indicated with an asterisk.

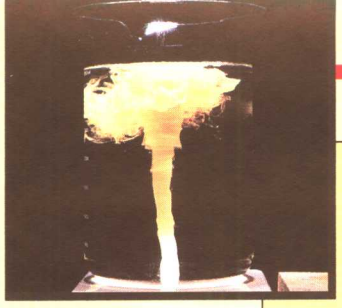
Index/Glossary

The **index/glossary** at the back of the book gives a brief definition of each term and a reference to the pages on which that term appears. You should get in the habit of consulting it when you encounter a term that you do not fully understand or one you have encountered earlier in the book and need to review.





(Left) A magnet can be used to separate the iron from a heterogeneous mixture of iron and sulfur. *(Center)* One-mole quantities of atoms of seven elements. Front row: sulfur, zinc, iron. Back row: bromine, aluminum, mercury, copper. *(Right)* The minerals orpiment (yellow, As_2S_3) and realgar (red, As_4S_4) exist next to each other in a single rock sample.



Contents Overview