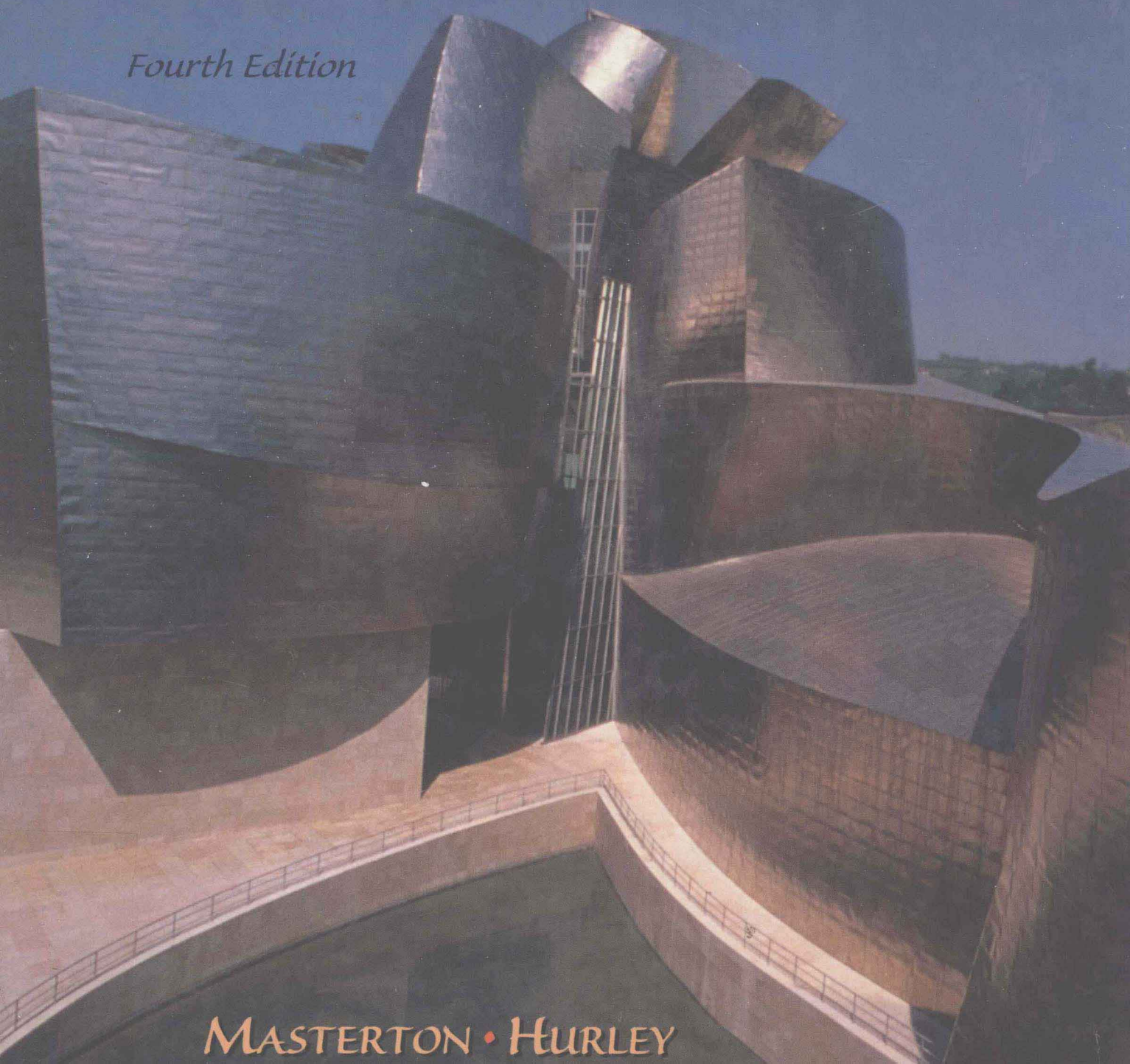
CHEMISTRY

PRINCIPLES AND REACTIONS

Fourth Edition



MASTERTON • HURLEY

CHEMISTRY

PRINCIPLES AND REACTIONS

Fourth Edition

A Core Text

WILLIAM L. MASTERTON
University of Connecticut

CECILE N. HURLEY
University of Connecticut

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Cover Designer: Jane Sanders

Cover Printer: Phoenix Color
Compositor: Progressive Information Technologies
Printer: R. R. Donnelley, Willard
Cover Image: The new Guggenheim Museum (designed by Frank O. Gehry) recently opened in Bilbao, Spain. Half-millimeter-thick "fish-scale" panels of titanium (a fourth-period transition metal) cover most of the building and are guaranteed to last one hundred years. The museum is a fine example of how chemical principles can contribute to a monumental work of art. *(Photo by Erika Barahona © FMGB Guggenheim Bilbao Museoa)*

Printed in the United States of America
4 5 6 7 05 04 03 02

Library of Congress Catalog Card Number: 99-069839
Chemistry: Principles and Reactions, Fourth Edition

ISBN: 0-03-026036-1

Asia
Thomson Learning
60 Albert Street, #15-01
Albert Complex
Singapore 189969

Australia
Nelson Thomson Learning
102 Dodds Street
South Melbourne, Victoria 3205
Australia

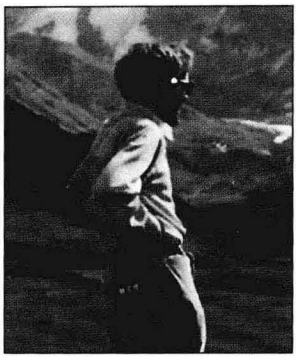
Canada
Nelson Thomson Learning
1120 Birchmount Road
Toronto, Ontario M1K 5G4
Canada

Europe/Middle East/Africa
Thomson Learning
Berkshire House
168-173 High Holborn
London WC1 V7AA
United Kingdom

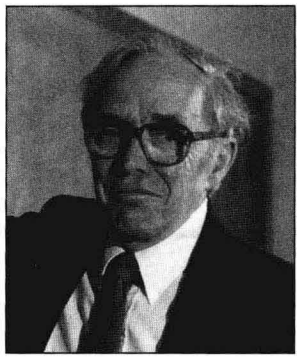
Latin America
Thomson Learning
Seneca, 53
Colonia Polanco
11560 Mexico D.F.
Mexico

Spain
Paraninfo Thomson Learning
Calle/Magallanes, 25
28015 Madrid, Spain

About the Authors



William L. Masterton received his Ph.D. in physical chemistry from the University of Illinois in 1953. Two years later, he arrived at the University of Connecticut, where he taught general chemistry and a graduate course in chemical thermodynamics. He received numerous teaching awards; the one of which he is most proud came from the Student Senate at UConn. Bill wrote, with co-author Emil Slowinski, the all-time best-selling general chemistry textbook, *Chemical Principles,* which sold well over one and a half million copies. Bill has also written a definitive account of the Lizzie Borden case entitled *Lizzie Didn't Do It,* published almost simultaneously with this book. Bill's field of research, solution thermodynamics, prepared him well for making maple syrup each March at the family farmhouse in New Hampshire.



Cecile Nespral Hurley received her M.S. at the University of California, Los Angeles. Since 1979, she has served as Lecturer and Coordinator of Freshman Chemistry at the University of Connecticut, where she directed a groundbreaking National Science Foundation–supported project on cooperative learning in general chemistry. She is one of a prestigious group of University Teaching Fellows, who are selected by their fellow faculty members as models of teaching excellence and dedication. In addition, she coordinates the High-School Cooperative Program in Chemistry, through which superior Connecticut high-school students take the University's general chemistry course at their schools. In her spare time, she roots for the UConn Women's Basketball Huskies and roots out weeds from her country garden, which she likes to imagine rivals Monet's at Giverny.

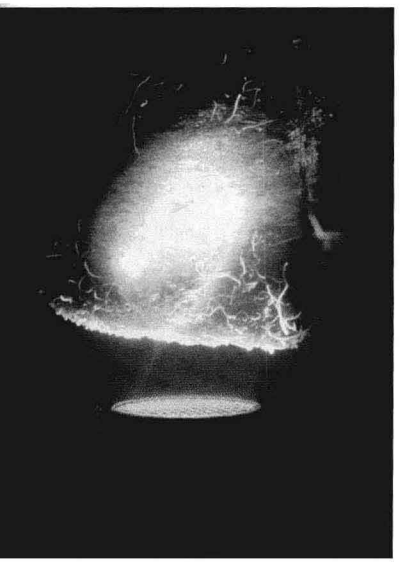
PREFACE

Chemistry: Principles and Reactions differs in mass and volume from other general chemistry texts.The typical text today runs anywhere from 1000 to 1300 pages and weighs 4 to 6 pounds. This book is several hundred pages shorter and at least a couple of pounds lighter.

An obvious advantage of a shorter text is the lower cost to the student (this book sells for much less than the $90 to $110 for the average general chemistry text). A further advantage is that this book can be covered in its entirety in a year course. With most of the general chemistry texts on the market, the instructor has to decide which chapters to omit. Frequently some of the most interesting topics are skipped, such as complex ions (Chapter 15 in this book) and nuclear chemistry (Chapter 19). Another casualty due to time restraints is often descriptive inorganic chemistry (Chapters 20 and 21 in this book).

You may be curious as to how we achieved this reduction in size. It was *not* done by lowering the level. Our criterion for including material was its importance and relevance to the student, not its difficulty. Beyond that, we have developed chemical principles slowly and carefully, devoting as much space to a topic as experience has shown to be necessary for student understanding.

How then did we arrive at a text at least 300 pages shorter than most general chemistry texts? For one thing, we have eliminated repetition and duplication wherever possible. For example, the book contains—



- one and only one method of balancing redox equations, the half-equation approach introduced in Chapter 4.
- one and only one way of working gas law problems, using the ideal gas law in all cases (Chapter 5).
- one and only one way of calculating ΔH (Chapter 8), using enthalpies of formation.
- one and only one equilibrium constant for gas phase reactions (Chapter 12), the thermodynamic constant K, often referred to as K_p. This simplifies not only the treatment of gaseous equilibrium but also the discussion of reaction spontaneity (Chapter 17) and electrochemistry (Chapter 18).

Certain topics ordinarily covered in texts of 1,000 or more pages have been deleted, abbreviated, or relegated to an appendix. Items in this category are—

- *biochemistry,* traditionally covered in the last chapter of general chemistry texts. Interesting as this material is, it requires a background in organic chemistry that first-year college students do not have. Our last chapter (Chapter 22) is devoted to the concepts of organic chemistry, including isomerism.
- *molecular orbital theory* (Appendix 5). Our experience has been that, important as this approach to chemical bonding is, it doesn't go over well with most general chemistry students.
- *nomenclature of complex ions and organic compounds* (Appendix 4). We believe this material is of questionable value in a beginning course.

- *qualitative analysis,* summarized in a few pages in Chapter 16. An extended discussion of the qual scheme and the chemistry behind it belongs in a lab manual, not a textbook.

Through three editions, this text has earned a reputation as being student-oriented. We have tried to continue and expand that tradition this time around. In evaluating reviewers' comments, we always ask the question, "Will this (recommended) change enhance the student's understanding or appreciation of chemistry?" All the changes we made in this fourth edition had that objective in mind.

Along these lines, it may be helpful to point out several unique features of this text. (These are described in more detail under "To the Student," page xvii)

- ***CD-ROM References*** appear in almost every chapter. These marginal callouts direct students to specific topic screens on the *Interactive General Chemistry CD-ROM* (Version 2.5). Additionally, for both the students' and professors' reference, a list of videos and animations from the CD-ROM that are appropriate to given sections of the text appears after the Table of Contents.
- In-text ***Examples*** start off with a **Strategy** section, which outlines the reasoning to be followed in the **Solution.** This helps to distinguish the "why" from the "how" of problem solving. About half of the examples end with a **Reality Check,** designed to convince the student that solving a problem begins the learning process rather than ending it. It encourages students to make sure that the answer is reasonable and/or relates directly to a chemical principle they have learned.
- ***Chapter Highlights,*** at the conclusion of each chapter, list the **Key Concepts, Key Equations,** and **Key Terms** covered. Included among the key terms are items, marked with a ■, introduced in earlier chapters. This section ends with a **Summary Problem,** which serves to tie together all of the concepts covered in a chapter. This helps the student to see the forest as well as the individual trees.
- End-of-chapter ***Questions & Problems*** are divided into four categories. Most are classified under special headings; problems of this type are arranged in matched pairs, only one of which is answered in Appendix 6. **Unclassified** questions and problems typically illustrate more than one concept. Then there are several **Conceptual Questions** of a qualitative nature designed to test how well the student understands chemical concepts. Finally, there are a few **Challenge Problems,** which we hope will pique the interest of student and instructor alike. As an aid for students, selected, fully worked-out solutions for selected problems from each chapter, identified by a WEB, are posted at:

http://www.brookscole.com/chemistry_d

The function of a chemistry teacher and hence of a textbook goes well beyond explaining chemical principles. Students must be convinced that chemistry is so relevant to their lives that it is worth devoting the time and effort required to master these principles. Real-life applications are emphasized throughout the exercises and problems in this text. They also appear in a special feature, **Chemistry: Beyond the Classroom,** found near the end of every chapter. New to this edition are discussions of amines and alkaloids (Chapter 4), automobile airbags (Chapter 5), polymers (Chapter 9), organic acids (Chapter 13), and cholesterol (Chapter 22).

Throughout the text we have presented short biographies of some of the pioneers in chemistry, ranging from Antoine Lavoisier (1748–1794) to Glenn Seaborg

(1912–1999). These sketches are referred to as **Chemistry: The Human Side;** they emphasize the personalities as well as the accomplishments of these individuals.

Ancillary Material

A large number of auxiliary materials have been developed for use with this text. These include:

For the Instructor

Instructor's Manual by William L. Masterton. Included are lecture outlines and lists of demonstrations for each chapter. Worked-out solutions are provided for all of the end-of-chapter problems that do not have answers in the appendix.

Printed Test Bank by David Treichel (Nebraska Wesleyan University). Features over 1,000 multiple-choice, five-part questions.

ExaMaster™ Computerized Test Bank is the software version of the printed Test Bank. Instructors can create thousands of questions in a multiple-choice format. A command reformats the multiple-choice question into a short-answer question. Adding or modifying existing problems, as well as incorporating graphics, can be done. ExaMaster™ also has gradebook capabilities for recording and graphing students' grades.

Overhead Transparencies set includes 142 full-color acetates with sizable labels for viewing in large lecture halls. The illustrations and tables chosen are those most often used in the classroom, and are marked with the icon OHT for easy identification.

Cooperative Learning Workbook by Cecile N. Hurley. A collection of worksheets (about three per chapter) that students work on in groups. Designed to stimulate group activity and discussion, the questions provided on each worksheet are equally conceptually oriented and quantitatively oriented. The booklet includes instructions for use, how to guide student discussion, and supporting data on the success of cooperative learning at University of Connecticut.

Chemical Principles in the Laboratory,* Seventh Edition,** by Emil Slowinski and Wayne Wolsey (both of Macalester College) and William Masterton provides detailed directions and advanced study assignments. This manual contains 43 experiments that have been selected with regard to cost and safety. All the experiments have been thoroughly class-tested. Alternatively, the ***Chemical Principles in the Laboratory with Qualitative Analysis,* Sixth Edition, *Alternate Version, is available, with eight experiments covering qualitative analysis. An **Instructor's Manual** is available for each version of *Chemical Principles in the Laboratory,* and each Instructor's Manual provides lists of equipment and chemicals needed for each experiment.

For the Student

Study Guide/Workbook by Cecile N. Hurley. Worked examples and problem-solving techniques help the student understand the principles of general chemistry. Each chapter is outlined for the student with fill-in-the-blanks, and exercises and self-tests allow the students to gauge their mastery of the chapter.

Student Solutions Manual by Cassandra T. Eagle and David G. Farrar (both of Appalachian State University). Complete solutions to all the problems answered in the text, including the Challenge Problems. References to the main text's sections and tables are provided as a guide for problem-solving techniques employed by the authors. Selected solutions from each chapter, identified by a WEB, are posted at:

http://www.brookscole.com/chemistry_d

Lecture Outline by Ronald O. Ragsdale (University of Utah). Organized to follow class lectures to free students from extensive note taking during lectures.

Chemistry Internet Resource Guide by Susan M. Young provides students with a tool to help understand the ways in which the Internet can assist their education. In addition to general information on chemistry Web sites, the Guide will help them to understand the learning aids offered on ChemSource, the Brooks/Cole general chemistry Web site.

Multimedia Ancillary Materials

Interactive General Chemistry CD-ROM **(Version 2.5) with Activ-Chemistry,** by John Kotz and William Vining and produced by Archipelago Productions. Considered the best general chemistry CD-ROM available by allowing the students to interact with the information presented. Divided into chapters, the CD-ROM allows one to watch a reaction in progress, change a variable in an experiment and experience the result, follow stepwise solutions to problems, explore the periodic table, and listen to tips and suggestions on problem solving and understanding concepts. The CD-ROM includes original graphics, over 100 video clips of chemical experiments, which are enhanced by sound and narration, and several hundred molecular models and animations. With ActivChemistry, students can also perform simulations of laboratory experiments.

The CD-ROM also includes molecular modeling software from Oxford Molecular Group that can be used to view hundreds of models, rotate the models for a fuller understanding of their structures, and measure bond lengths and bond angles.

The CD-ROM has been used by thousands of students worldwide since its introduction in 1996. It can be purchased as a package with the textbook or as a stand-alone product, and will run on either Windows™ or Macintosh® platforms.

The **2001 Chemistry Instructor's Resource CD-ROM** is a dynamic lecture tool containing imagery from all of the 2001 Brooks/Cole chemistry titles. It can be used in conjunction with commercial presentation software such as PowerPoint™, Persuasion™, and Podium™. The CD-ROM is for both Macintosh® and Windows™ platforms.

ChemSource World Wide Web Site at

http://www.brookscole.com/chemistry_d

PowerPoint™ files, selected movie clips and animations, quizzing and testing, real-world applications, molecular models, teaching tips, and more features give the instructor many tools to enhance the lecture presentation and to adjust the curriculum.

Lecture Outlines created with **PowerPoint**™ are also available for the professor. Relating to the text on a per chapter basis, Powerpoint™ users can edit the content with their own material or import material from our 2001 Chemistry Instructor's Resource CD-ROM.

CalTech Chemistry Animation Project (CAP) is a set of six video units of unmatched quality and clarity that cover the chemical topics of Atomic Orbitals, Valence Shell Electron Pair Repulsion Theory, Crystals and Unit Cells, Molecular Orbitals in Diatomic Molecules, Periodic Trends, and Hybridization and Resonance. Available to qualified adopters.

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. Also available in CD-ROM format through JCE:Software, Chemistry Department, University of Wisconsin, Madison, WI 53706, (800) 991-5534.

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

Brooks/Cole may provide complimentary instructional aids and supplements or supplemental packages to those adopters qualified under our adoption policy. Please contact your sales representative for more information. If, as an adopter or potential user, you receive supplements you do not need, please return them to your sales representative or send them to:

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Through the services of the Brooks/Cole Custom Publishing Group, portions of *Chemistry: Principles and Reactions,* Fourth Edition, can be packaged according to individual needs. Instructors who wish to augment *Chemistry: Principles and Reactions,* Fourth Edition, with their own material, make selected chapters available in courses with a different focus than that of the textbook as a whole, or package *Chemistry: Principles and Reactions,* Fourth Edition, with select chapters from other Brooks/Cole textbooks should contact their local sales representative.

ACKNOWLEDGMENTS

We are indebted to a great many people who have used this book, instructors and students alike, for suggestions as to how we might improve the fourth edition. Reviewers who have helped us include:

Steven Albrecht, *Oregon State University*
Charles W. Armbruster, *University of Missouri, St. Louis*
William H. Brown, *Beloit College*
John DeKorte, *Glendale Community College (Arizona)*
Harry A. Frank, *University of Connecticut, Storrs*
Dean F. Keeley, *The University of Southwestern Louisiana*
Don Kleinfelter, *University of Tennessee*
Tammy J. Melton, *Middle Tennessee State University*
Don Mencer, *Pennsylvania State University, Hazelton*

Kathy Nabona, *Austin Community College*
S. F. Pavkovic, *Loyola University of Chicago*
Richard Prigodich, *Trinity College*
Ronald Ragsdale, *University of Utah*
Thomas G. Richmond, *University of Utah*
Larry A. Scheich, *Saint Norbert College*
David Treichel, *Nebraska Wesleyan University*
Deborah Warnaar, *James Madison University*

We are particularly grateful to two members of the chemistry staff at the University of Connecticut. *Harry Frank* convinced us to revise the treatment of the solubility rules (Chapter 4) and kinetic theory (Chapter 5). *Bob Bohn* helped clarify the treatment of electronic structure (Chapter 6) and chemical bonding (Chapter 7). A former co-author and UConn chemistry professor, *Emil Slowinski* has given us valuable advice on this and previous editions. Although he retired from textbook writing more than ten years ago, Slow's philosophy and humor still permeate this book.

Reviewers of the first three editions include:

Linda Atwood, *California Polytechnic State University, San Luis Obispo*
Peter Baine, *California State University, Long Beach*
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Stanley M. Williamson, *University of California, Santa Cruz*
Sidney H. Young, *University of South Alabama*

John Vondeling, of Harcourt College Publishers, has contributed a great deal to this and previous editions, first as an editor and more recently as "publisher" (whatever that means). Our developmental editor, *Ed Dodd,* is new to this edition; he and *Mary Castellion* have devoted a great deal of time and effort to it. *Bonnie Boehme,* our project editor, has been a joy to work with. She combines unusual competence with a sparkling personality that has cheered us on numerous occasions.

William L. Masterton
Cecile N. Hurley
University of Connecticut
Storrs
March, 2000

To the Student

Over the next several months, you will probably receive a lot of advice from your instructor, teaching assistant, and fellow students about how to study chemistry. We hesitate to add our advice; experience as teachers and parents has taught us that students tend to do surprisingly well without it. We would, however, like to acquaint you with some of the learning tools in this text. They are described in the pages that follow.

Examples

In a typical chapter, you will find ten or more examples, each designed to illustrate a particular principle. These have answers, screened in color. More important, they contain a strategy statement, which describes the reasoning behind the solution. You will find it helpful to get into the habit of working all problems this way. First, spend a few moments deciding how the problem should be solved. Then, and only then, set up the arithmetic to solve it.

Many of the examples end with a **Reality Check,** which encourages you to check whether the answer makes sense. We hope you will get into the habit of doing this when you work problems on your own on quizzes and examinations.

CD-ROM References

These marginal callouts (identified by a ⊙ icon) refer to specific topic screens in the *Interactive General Chemistry CD-ROM* (Version 2.5) (available for purchase with this text). In addition, a list of animations and videos from the CD-ROM that are appropriate to given sections of the text appears after the Table of Contents.

Marginal Notes

Sprinkled throughout the text are a number of short notes that have been placed in the margin. Many of these are of the "now, hear this" variety; a few bring you up to date on current research in chemistry, in progress when the text was written. Some, probably fewer than we think, are humorous.

Chapter Highlights

At the end of each chapter, you will find a brief review of the material covered in that chapter. The "Chapter Highlights" include—

- the **Key Concepts** introduced in the chapter. These are indexed to the corresponding examples and end-of-chapter problems. If you have trouble working a

particular problem, it may help to go back and re-read the example that covers the same concept.

- the **Key Equations** and **Key Terms** in the chapter. If a particular term is unfamiliar to you, refer to the index at the back of the book. You will find the term defined in the glossary that is incorporated into the index.
- a **Summary Problem,** covering all or nearly all of the key concepts in the chapter. You can test your understanding of the chapter by working this problem; you may wish to do this as part of your preparation for examinations. A major advantage of a summary problem is that it ties together many different ideas, showing how they correlate with one another.

Questions & Problems

At the end of each chapter is a set of **Questions & Problems.** Most of these are classified, that is, grouped by type under a particular heading. The classified problems are in matched pairs. The second member of each pair illustrates the same principle as the first; it is numbered in color and answered in Appendix 6. Selected solutions for problems from each chapter, identified by a WEB icon, are posted at:

http://www.harcourtcollege.com/chem/general/masterton4/student/

Your instructor may assign unanswered problems as homework. After these problems have been discussed, you should work the corresponding answered problems to make sure you know what's going on.

Each chapter also contains a smaller number of **Unclassified, Conceptual,** and **Challenge Problems.** All of the challenge problems are answered in Appendix 6.

Mathematics Review

Appendix 3 touches on just about all the mathematical techniques you will use in general chemistry. Exponential notation and logarithms (natural and base 10) are emphasized.

List of Videos and Animations

On the following pages is a list of videos and animations that appear on the ***Interactive General Chemistry CD-ROM* (Version 2.5)** and illustrate discussions within the text. In the list below, the page numbers refer to the page in the text where the CD-ROM correlation appears.

Chapter 1: Matter and Measurements

Page 5, Screen 1.6, Compounds and Molecules.
Video: Frank DiSalvo Discusses the Value of the Periodic Table of Elements

Page 6, Screen 1.14, Separation of Mixtures.
Video: Separation of a Mixture of Sand and Potassium Chromate
Video: *Kitchen Chemistry:* Separation of Dyes

Page 9, Screen 1.10, Temperature.
Video: Transfer of Molecular Momentum

Chapter 2: Atoms, Molecules, and Ions

Page 30, Screen 2.5, The Dalton Atomic Theory.
Video: Magnesium Burns in Air, Producing Magnesium Oxide

Page 31, Screen 2.2, Introduction to Atoms.
Video: The Big Bang
Video: *A Closer Look:* Fuel for the Space Shuttle

Page 31, Screen 2.8, Electrons.
Animation: Deflection of Cathode Rays

Page 31, Screen 2.10, Protons.
Animation: Canal-Ray Experiment

Page 32, Screen 2.11, The Nucleus of the Atom.
Animation: Rutherford's α Particle Experiment

Page 34, Screen 2.7, Evidence of Subatomic Particles.
Animation: Separation of Radiation by an Electric Field

Page 37, Screen 2.17, Chemical Periodicity.
Video: Lithium in Water
Video: Sodium in Water
Video: Potassium in Water

Page 40, Screen 3.7, Ions—Cations and Anions.
Animation: Cation (Mg, 12 Protons, 12 Electrons)
Animation: Anion (F, 9 Protons, 9 Electrons)

Page 42, Screen 3.10, Ionic Compounds.
Video & Animation: The Reaction of Sodium and Chlorine (Yields Sodium Chloride)
Video & Animation: *A Closer Look:* The Ionic Crystal Lattice (KBr)

Chapter 3: Mass Relations in Chemistry; Stoichiometry

Page 64, Screen 3.18, Determining Empirical Formulas.
Video: $Zn(s) + S(s) \rightarrow ZnS(s)$

Page 65, Screen 5.8, Using Stoichiometry (2).
Animation: Carbon-Hydrogen Analysis Unit

Page 67, Screens 4.2, Chemical Equations, & 4.4, Balancing Chemical Equations.
Screen 4.2 Video: Bromine, $Br_2(l)$ and Aluminum, $Al(s)$ [$2Al(s) + 3Br(l) \rightarrow Al_2Br_6(s)$]
Screen 4.4 Video: Reactions That Form Oxides (Phosphorus, P_4, Reacts Vigorously with Oxygen to Give Tetraphosphorus Decaoxide)
Screen 4.4 Animation: Combustion Reactions (Reaction of Propane and Oxygen)

Page 69, Screens 5.2, Weight Relations in Chemical Reactions, & 5.3, Calculations in Stoichiometry.
Screen 5.2 Video & Animation: $P_4(s) + 6Cl_2(g) \rightarrow 4PCl_3(l)$
Screen 5.3 Video: Weight Relations in Chemical Reactions [$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$]

Page 70, Screen 5.4, Reactions Controlled by the Supply of One Reactant.
Video: Limiting Reactant [$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$]

Page 71, Screen 5.5, Limiting Reactants.
Video: Limiting Reactant: The Details (Zinc and Hydrochloric Acid Reacting to Form Zinc Chloride and Hydrogen Gas)

Page 74, Screen 3.14, Hydrated Compounds.
Video: Dehydration of Copper(II) Sulfate Pentahydrate

Chapter 4: Reactions in Aqueous Solution

Page 84, Screen 5.9, Solutions.
Video & Animation: $H_2O(l) + KMnO_4(s) \rightarrow KMnO_4(aq)$

Page 84, Screen 5.10, Solution Concentration.
Animation: *A Closer Look:* Ion Concentrations in Solution ($CaCl_2$ Dissolving in Water)

Page 85, Screen 5.11, Preparing Solutions of Known Concentrations (1).
Video: Direct Addition

Page 86, Screen 4.5, Compounds in Aqueous Solution.
Video: $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
Animation: Strong Electrolytes (HCl)
Animation: Weak Electrolytes (Acetic Acid)
Animation: Nonelectrolytes (Ethanol)

Page 88, Screens 4.11, Types of Reactions in Aqueous Solution, & 4.12, Precipitation Reactions.
Screen 4.11 Video: Precipitation Reactions [$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$]
Screen 4.12 Video: $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
Screen 4.12 Video: $Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$

Page 89, Screen 4.10, Equations for Reactions in Aqueous Solution—Net Ionic Equations.

Video: Net Ionic Equations: Reaction of Potassium Chromate and Lead Nitrate

Page 90, Screen 5.13, Stoichiometry of Reactions in Solution.
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