

MASTERTON & HURLEY

# CHEMISTRY

PRINCIPLES *and* REACTIONS

FIFTH EDITION

ENCLOSED FREE:  
GENERAL CHEMISTRY  
INTERACTIVE CD-ROM  
VERSION 3.0

# CHEMISTRY

## Principles and Reactions

*A Core Text*  
*Fifth Edition*

William L. Masterton

*University of Connecticut*

-Cecile N. Hurley

*University of Connecticut*

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*Cover Printer:* Transcontinental Printing/Interglobe  
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Library of Congress Control Number: 2002114532

Student Edition with InfoTrac College Edition: ISBN 0-534-40878-8  
 Student Edition without InfoTrac College Edition: ISBN 0-534-40877-X  
 Instructor's Edition: ISBN 0-534-40895-8

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Note: Atomic masses shown here are 1999 values, rounded to 4 digits.

# CHEMISTRY

## Principles and Reactions

*Fifth Edition*

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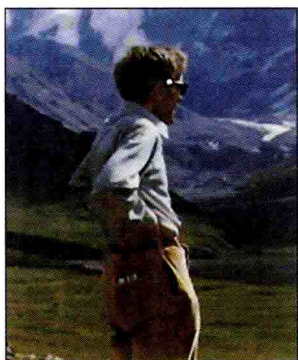


To

***Ruven and Trudy Smith***

*superb scientists, talented teachers, faithful friends  
whose generosity is beyond measure.*

# 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*. 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

In 1993, we made the bold and somewhat risky decision to pare down the size of our text to less than 700 pages (679 to be exact). We rejected the idea of publishing two different versions of the text (a “long” one and a “short” one), because we were—and remain to this day—fully committed to writing a text that would not break students’ backs or checkbooks.

You may be curious as to how we achieved this reduction in size. It was *not* done by lowering the level of the text. 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. With most general chemistry texts, the instructor has to decide which chapters to omit in order to make the book fit the year course. This frequently leads to some of the most interesting topics being skipped, such as complex ions (Chapter 15 in this book), nuclear chemistry (Chapter 19), and descriptive inorganic chemistry (Chapters 20 and 21). Our text, on the contrary, can be covered *in its entirety* in a year-long course. At the same time, due to its size, it is also suitable for one-semester or one-quarter courses.

How did we arrive at a text at least 300 pages shorter than the other general chemistry texts? For one thing, we eliminated repetition and duplication wherever possible. This book, like previous editions, 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 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 1000 or more pages have been deleted, abbreviated, or relegated to an appendix. Items in this category include—

- *biochemistry*, traditionally covered in the last chapter of general chemistry texts. While we have interspersed several biochemistry topics throughout the text (for example, the discussion of heme in Chapter 15), we do not devote an entire chapter to biochemistry. 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 to be of questionable value in a beginning course.

With each edition of this text, we have asked that it be judged on user-friendliness as well as content. We are very pleased with the responses we have received, from students as well as instructors. So, why another edition? This frequently asked



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question deserves an honest answer but seldom gets one, at least in print. Let's change the question slightly to inquire how this edition varies from its predecessors, particularly the fourth edition. The several paragraphs that follow respond to that question.

**1. This text, like the fourth edition, consists of 22 chapters, the titles of which are unchanged. We have, however, made significant changes in at least five chapters.** Mostly our objective has been to clarify discussions with which we were not satisfied. For example, the material in Chapter 6 dealing with quantum numbers and atomic orbitals (Sections 6.3 and 6.4) has been completely rewritten. In a couple of chapters, we have introduced new topics, notably fuel cells in Chapter 18.

**2. About 60% of the 200 in-text examples have been changed.** This allowed us to introduce **Conceptual Examples**, designed to prepare students for end-of-chapter conceptual problems. We have also introduced **Graded Examples**, in which successive parts (a, b, c) progress from the simple to the more complex. These are described in more detail in the section that follows this Preface entitled "To the Student."

**3. Of the more than 1500 end-of-chapter problems, about 30% are new.** Beyond that, **we have added several new Conceptual Problems.**

**4.** As in previous editions, each chapter contains a *Chemistry: Beyond the Classroom* feature designed to intrigue the student and stimulate his or her interest in chemistry. **Five of these are new to the fifth edition**, including discussions of **antacids (Chapter 4), allotropy (Chapter 9), and organic acids and bases (Chapter 13).** Several more have been revised and updated, including ozone (Chapter 11), acid rain (Chapter 14), and global warming (Chapter 17). Throughout the text we have again presented short biographies of some of the pioneers of 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.

**5.** One of the most popular features of previous editions has been the **Summary Problems**, which tie together all the concepts covered in a chapter, thereby helping the student see the forest as well as the trees. **All of the Summary Problems have been reworked for the fifth edition.**

**6.** Many figures in the art and photo program have been thoroughly revised for this edition. **The nanoscale views of atoms, molecules, and ions have been completely revised using molecular modeling software and an exacting three-dimensional style. One of the key elements of the revised photo program is to illustrate more clearly sequences of events in a reaction or a chemical analysis.**

**7.** Included with the text is a version of the **General Chemistry Interactive CD-ROM (Version 3.0)** specifically organized to match the topic order of *Chemistry: Principles and Reactions*, Fifth Edition. The marginal callouts found in the book, indicated by an icon (seen here in the margin) will direct students to specific topic screens on the CD-ROM. For the students' reference, a list of the interactive simulations, tutorials, and exercises found on the CD-ROM is provided on pages xxv–1. These modules are useful explorations and study tools that cover the main concepts for each chapter. Finally, a list of videos and animations from the CD-ROM, keyed to each section of the text, is available at the text's Web site (<http://www.brookscole.com/chemistry>).



Other unique features of this text, including a full description of the **Chapter Highlights, Summary Problems, and Questions & Problems** sections, are described in more detail under "To the Student," on page xxiii.



## ANCILLARY MATERIAL

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

### For the Instructor

*These ancillaries are available to qualified adopters. Please consult your local Thomson • Brooks/Cole sales representative for details.*

**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 of the text.

**Printed Test Bank** by David Treichel (Nebraska Wesleyan University). Features more than 1000 multiple-choice, five-part questions.

**ExamView® Computerized Testing (Windows/Macintosh)** The computerized version of the Test Bank allows instructors to create, deliver, and customize tests and study guides (both print and online) with this assessment and tutorial system. *Quick Test Wizard* and an *Online Test Wizard* easily guide you through the step-by-step process of creating tests that allows you to see the test you are creating on the screen exactly as it will print or display online. You can build tests of up to 250 questions, and using ExamView's complete word processing capabilities, you can enter an unlimited number of new questions or edit existing questions.

**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.

**Overhead Transparencies** set includes 150 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 in the text with a **OHT** icon for easy identification.

**Multimedia Manager CD-ROM (Windows/Macintosh)** The *Manager* is a digital library and presentation tool. Included is a library of resources valuable to instructors such as text art and tables. Electronic files are easily exported into other software packages so you can create your own materials. Also included in this package are all of the interactive simulations from the *General Chemistry Interactive CD-ROM (Version 3.0)*, along with over 100 QuickTime movies. The interactive images can be projected in a classroom environment.

**For the Laboratory:** A selection of laboratory manuals and materials are available from Brooks/Cole:

**Chemical Education Resources (CER)** (Catalog ISBN: 0-534-97709-X) allows you to customize a laboratory manual for your course from a wide range of more than 300 experiments. Contact your local Brooks/Cole representative or visit <http://www.textchoice.com>.

**Chemical Principles in the Laboratory, Seventh Edition** (ISBN: 0-03-031167-5) by Emil Slowinski, Wayne Wolsey, and William Masterton provides detailed directions and advance 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** (ISBN: 0-03-019234-X) is available, with eight additional 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

**Student Solutions Manual** (ISBN: 0-534-40882-6) by Cassandra T. Eagle (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** icon, are posted at the text's Web site (<http://www.brookscole.com/chemistry>).

**Study Guide/Workbook** (ISBN: 0-534-40881-8) 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.

**General Chemistry Interactive CD-ROM (Version 3.0)**, the multimedia companion included with this text, was originally designed by John Kotz (State University of New York, Oneonta) and William Vining (University of Massachusetts, Amherst). William Vining is the primary author of the newest version, and Patrick Harman, a design consultant, is now the co-author.

The CD-ROM is divided into chapters that closely follow the organization of *Chemistry: Principles and Reactions*, Fifth Edition. Instead of consisting solely of text and illustrations, however, the CD-ROM presents ideas and concepts with which the user can interact. One can watch a reaction in process, 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, more than 100 video clips of chemical experiments, which are enhanced by sound and narration, and several hundred molecular models and animations.

In addition to the descriptive material developed for the earlier versions, the new version of the CD-ROM includes Simulations, Tutorials, and Exercises in which the user can interact with chemical information. For example, the reactants and their concentrations can be changed in a reaction and the effect on reaction rate can be visualized. The user is led through a series of questions on the CD-ROM that lead to fuller understanding of the experiment. So that a student knows when the CD-ROM supports book material, marginal callouts found in the book (indicated by the icon seen here in the margin) will direct students to specific topic screens on the CD-ROM.

The CD-ROM also includes molecular modeling software from the CAChe/Fujitsu Group. This software 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. Additionally, the CD-ROM has a plotting tool, molar mass and molarity calculators, and an extensive database of compounds with their thermodynamic properties.

Earlier versions of the CD-ROM, used by thousands of students worldwide, were sold separately. The newest version is included in each copy of this textbook. The ISBN for the CD-ROM as a stand-alone product is 0-03-035319-X.

**InfoTrac® College Edition**—A FREE four-month subscription to this world-class online university library is enclosed with every new copy of this book, giving students and professors access to the latest news and research articles online—updated daily. (*This is available to college and university students only.*)

**OWL—Online Web-based Learning System** Learning chemistry takes practice, and that usually means completing homework assignments on various sections of the book. The Web-based OWL system presents the student with a series of questions on a given topic, and the student responds by indicating a numerical answer or selecting from a menu of choices. The questions are generated from a database of information, so each student in a course is given a different question each time he or she accesses an instructional unit. Extensive

feedback is available online for each question. Instructors can set up the system to deliver questions on certain dates, specify the number of tries, and specify the number of questions a student must answer successfully before the student is considered to have mastered the topic. Students find it an excellent way to review for examinations, and studies at the University of Massachusetts-Amherst show a strong correlation between the use of the OWL system and course performance.

Use the ISBN 0-534-26230-9 to order the textbook and OWL.

**WebTutor™ Advantage** offers real-time access to an array of study tools, including flash cards (with audio), practice quizzes, online tutorials, and Web links. Professors can use it to provide virtual office hours, post syllabi, set up threaded discussions, track student progress with quizzing material, and more. *WebTutor™ Advantage* extends the benefits of *WebTutor™* with additional enhancements that increase interactivity and bring topics to life, such as animations and videos. *WebTutor™ Advantage* is available as—

*WebTutor™ Advantage* on Blackboard (ISBN: 0-534-40883-4)

*WebTutor™ Advantage* on WebCT (ISBN: 0-534-40884-2)

**Essential Math for Chemistry Students** (ISBN: 0-314-09604-3) by David W. Ball (Cleveland State University) is a text for students who lack confidence and/or competency in the essential mathematical skills necessary to survive in general chemistry. Each chapter focuses on a specific type of skill and has worked-out examples to show how these skills translate to chemical problem solving.

## 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 it. Reviewers who helped us in the preparation of this edition include:

William H. Brown, *Beloit College*  
Cindy DeForest Hauser, *Oregon State University*  
Patricia Demko, *Ocean County College*  
Willetta Greene-Johnson, *Loyola University of Chicago*  
John W. Hartman, *Western Illinois University*  
Sharon Kapica, *County College of Morris*  
Richard Nafshun, *Oregon State University*  
George S. Patterson, *Suffolk University*  
Stephen F. Pavkovic, *Loyola University of Chicago*  
Nicholas C. Payne, *University of Western Ontario*  
Charles M. Wynn, *Eastern Connecticut State University*

We are particularly grateful to Professors Nafshun and Payne for detailed, thoughtful reviews that went far beyond what could reasonably be expected. To put it simply, they made this a better book.

Once again, we express our thanks to Emil Slowinski, who worked out all of the new in-text examples. Miracle of miracles, he obtained the same answers we did except for one case where he was right and we were wrong. Furthermore, Slow, belying his nickname, did all this well ahead of deadline without prodding from Bill Masterton, Cecile Hurley, or Ed Dodd. Jhenny Galan, Robielyn Ilagan, Neil Lim, and Maricar Tarun, talented teaching assistants at the University of Connecticut, checked the accuracy of the summary problems and the new end-of-chapter exercises. Without their help, the book's schedule would not have been met.

Two friends who helped us immeasurably with this edition were Ed Dodd, our developmental editor, and Bonnie Boehme, our project editor. Perhaps most important, they helped us maintain the continuity that suffered when John Vondeling, our multitalented publisher, passed away in January 2001.

William L. Masterton  
Cecile N. Hurley  
University of Connecticut  
Storrs  
November 2002



# 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 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. Most of them contain a **Strategy** statement, which describes the reasoning behind the **Solution**. You should 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 in quizzes and examinations.

Scattered throughout the text are about 20 **Graded Examples**. These consist of two to four parts (a, b, c, . . .), which build upon one another. A typical graded example might read as follows:

### EXAMPLE Graded

For the reaction



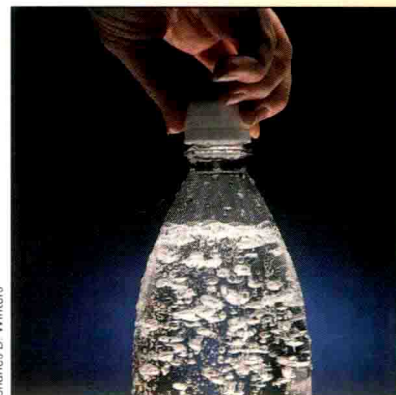
determine

- (a) the number of moles of A required to react with 5.0 mol of B.
- (b) the number of grams of A required to react with 5.0 g of B.
- (c) the volume of a 0.50 M solution of A required to react with 5.0 g of B.
- (d) the volume of a 0.50 M solution of A required to react with 25 mL of a solution that has a density of 1.2 g/mL and contains 32% by mass of B.

By working parts (a) through (d) in succession, you get to see how many different ways there are to ask questions about mass relations in a reaction, starting with a balanced equation. That should cushion the shock when you see only part (d) on an exam.

## CD-ROM References

These marginal callouts (identified by the icon seen here in the margin) refer to specific topic screens in the **General Chemistry Interactive CD-ROM (Version 3.0)** that is included with this text. A list of **Interactive Modules** from the CD follows these pages. Additionally, a **List of Animations and Videos** from the CD-ROM is available at the Web site for this text.



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## Margin 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; others make points that we forgot to put in the text. 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 supposed to be humorous. See, for example, the reference to skating on page 237; WLM *still* thinks that is uproariously funny.

## 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 reread 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.

## Summary Problem

Each chapter is summarized by a multistep problem that covers 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 so 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 and 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. 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. Selected solutions for problems from each chapter, identified by a **WEB** icon, are posted at:

**<http://www.brookscole.com/chemistry>**

(Select “General Chemistry” from the list of courses on the left navigational bar and then click on the cover for this text that appears on the screen.)

Each chapter also contains a smaller number of **Unclassified** and **Challenge Problems**. All of the Challenge problems are answered in Appendix 6. Chapters 1 through 19 contain a relatively small number of **Conceptual Problems**, which test your knowledge of basic concepts, usually in a nonmathematical way.

## 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.

# Interactive Modules

The included *General Chemistry Interactive CD-ROM (Version 3.0)* contains hundreds of interactive simulations, tutorials, and exercises. These modules are useful explorations and study tools that cover the main concepts for each chapter.

## CHAPTER 1: MATTER AND MEASUREMENTS

Screen 01.06, Identifying Pure Substances and Mixtures

*Exercise*

Screen 01.09, Temperature

*Tutorial*

Screen 01.10, Metric System Prefixes

*Tutorial*

Screen 01.11, Unit Conversion

*Tutorial*

Screen 01.11, Scientific Notation 1, Multiplication and Division

*Tutorial*

Screen 01.11, Scientific Notation 2, Raising to a Power

*Tutorial*

Screen 01.11, Scientific Notation 3, Square Roots

*Tutorial*

Screen 01.12, Physical Properties of Matter

*Exercise*

Screen 01.15, Density 1

*Tutorial*

Screen 01.15, Density 2

*Tutorial*

## CHAPTER 2: ATOMS, MOLECULES, AND IONS

Screen 02.06, Cathode Rays

*Exercise*

Screen 02.07, The Rutherford Experiment

*Exercise*

Screen 02.09, Summary of Atomic Composition

*Tutorial*

Screen 02.10, Radiation and Charge

*Exercise*

Screen 02.11, Periodic Table Organization

*Exercise*

Screen 02.15, Representing Compounds

*Tutorial*

Screen 02.15, Isomers

*Exercise*

Screen 02.16, Ions: Predicting Charge 1

*Tutorial*

Screen 02.16, Ions: Predicting Charge 2

*Tutorial*

Screen 02.17, Polyatomic Ions

*Tutorial*

Screen 02.18, Naming Ionic Compound Formulas

*Tutorial*

Screen 02.19, Naming Compounds of the Nonmetals

*Tutorial*

## CHAPTER 3: MASS RELATIONS IN CHEMISTRY; STOICHIOMETRY

Screen 03.02, Average Atomic Mass from Isotopic Abundance

*Tutorial*

Screen 03.03, Moles and Atoms Conversion

*Tutorial*

Screen 03.04, Compounds and Moles

*Simulation*

Screen 03.04, Determining Molar Mass

*Tutorial*

Screen 03.05, Using Molar Mass

*Tutorial*

Screen 03.05, Using Molar Mass

*Tutorial*

Screen 03.06, Percent Composition

*Tutorial*

Screen 03.07, Empirical Formulas

*Tutorial*

Screen 03.08, Molecular Formulas

*Tutorial*

Screen 03.10, The Law of Conservation of Matter

*Exercise*

Screen 03.10, The Law of Conservation of Matter

*Exercise*

Screen 03.11, Balancing Chemical Equations

*Tutorial*

Screen 03.12, Weight Relations in Chemical Reactions

*Exercise*

Screen 03.13, Stoichiometry: Theoretical Yield

*Tutorial*

Screen 03.15, Limiting Reactants: Redox Reactions

*Exercise*

Screen 03.15, Limiting Reactants

*Simulation*

Screen 03.16, Theoretical Yield

*Tutorial*

Screen 03.16, Percent Yield

*Tutorial*

## CHAPTER 4: REACTIONS IN AQUEOUS SOLUTION

Screen 04.03, Solution Concentration

*Tutorial*

Screen 04.03, Ion Concentration

*Tutorial*

Screen 04.04, Direct Addition

*Tutorial*

Screen 04.04, Dilution

*Tutorial*

Screen 04.04, Direct Addition Method

*Exercise*

Screen 04.04, Dilution Method

*Exercise*

Screen 04.06, Solubility of Ionic Compounds

*Simulation*

Screen 04.06, Solubility of Ionic Compounds

*Tutorial*