

Chemistry

Principles and Reactions

Sixth Edition

Masterton | Hurley

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CENGAGE Learning

SIXTH EDITION

Chemistry

Principles and Reactions

William L. Masterton

University of Connecticut

Cecile N. Hurley

University of Connecticut



BROOKS/COLE
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**Chemistry: Principles and Reactions,
Sixth Edition****William L. Masterton and Cecile N. Hurley**

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Cover Designer: Real Time Design/Dare Porter

Cover Image: © 2007 Chris Robinson,
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Library of Congress Control Number: 2007938694

ISBN-13: 978-0-495-12671-3

ISBN-10: 0-495-12671-3

Brooks/Cole Cengage Learning10 Davis Drive
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Periodic Table of the Elements

1 2 3 4 5 6 7 8 9

1 H 1.008

3 Li 6.941

4 Be 9.012

11 Na 22.99

12 Mg 24.30

19 K 39.10

20 Ca 40.08

21 Sc 44.96

22 Ti 47.87

23 V 50.94

24 Cr 52.00

25 Mn 54.94

26 Fe 55.85

27 Co 58.93

37 Rb 85.47

38 Sr 87.62

39 Y 88.91

40 Zr 91.22

41 Nb 92.91

42 Mo 95.94

43 Tc (97.91)

44 Ru 101.1

45 Rh 102.9

55 Cs 132.9

56 Ba 137.3

71 Lu 175.0

72 Hf 178.5

73 Ta 180.9

74 W 183.8

75 Re 186.2

76 Os 190.2

77 Ir 192.2

87 Fr (223.0)

88 Ra (226.0)

103 Lr (262.1)

104 Rf (261.1)

105 Db (262.1)

106 Sg (263.1)

107 Bh (264.1)

108 Hs (265.1)

109 Mt (266.1)

Metals Metalloids Nonmetals

Transition Metals

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

Lanthanides				
57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (144.9)

Actinides				
89 Ac (227.0)	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237.0)

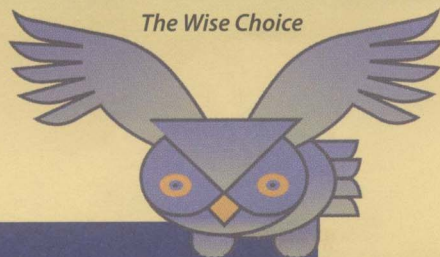
							17	18
							1 H 1.008	2 He 4.003
			13	14	15	16		
			5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
			13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
10	11	12						
28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209.0)	85 At (210.0)	86 Rn (222.0)
110 Ds (271)	111 Rg (272)	112 Uub (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)			

62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0
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94 Pu (244.1)	95 Am (243.1)	96 Cm (247.1)	97 Bk (247.1)	98 Cf (251.1)	99 Es (252.1)	100 Fm (257.1)	101 Md (258.1)	102 No (259.1)
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Students who used **OWL** scored significantly higher than those who used no online homework program.

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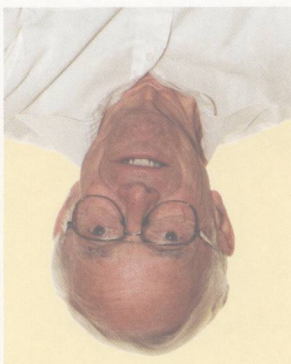
OWL students required far less out-of-class instruction to understand key concepts.

— St. Cloud State University Study

Dedication

To the memory of William Lewis Masterton

Teacher without peer
Expositor without parallel
Friend and mentor
You are missed.



1	Matter and Measurements	1
2	Atoms, Molecules, and Ions	24
3	Mass Relations in Chemistry, Stoichiometry	24
4	Reactions in Aqueous Solution	74
5	Gases	102
6	Electronic Structure and the Periodic Table	132
7	Covalent Bonding	161
8	Thermochemistry	196
9	Liquids and Solids	226
10	Solutions	268
11	Rate of Reaction	284
12	Gaseous Chemical Equilibrium	322
13	Acids and Bases	352
14	Equilibria in Acid-Base Solutions	382
15	Complex Ions	408
16	Precipitation Equilibria	430
17	Spontaneity of Reaction	450
18	Electrochemistry	480
19	Nuclear Reactions	512
20	Chemistry of the Metals	534
21	Chemistry of the Nonmetals	554
22	Organic Chemistry	578
23	Organic Polymers, Natural and Synthetic	610
Appendix 1	Units, Constants, and Reference Data	635
Appendix 2	Properties of the Elements	641
Appendix 3	Exponents and Logarithms	643
Appendix 4	Nomenclature of Complex Ions	648
Appendix 5	Molecular Orbitals	650
Appendix 6	Answers to Even-Numbered and Challenge Questions & Problems	656
	Credits	677
	Index/Glossary	681

Preface

The Preface of a textbook is one of the most difficult sections to write. In the past five editions, Bill Masterton and I would go for a long lunch and talk about the items we wished to include in the Preface. Lunch (always a cheeseburger and fries for Bill, unless there was mackerel and fried okra on the menu) always ended with Bill saying, "You write your outline of the Preface, and I will flesh it out." For this edition, there was no long lunch, no one to talk to, and no one to flesh out my outline. But I will try to flesh out the ideas that Bill and I talked about in one long phone call. These are the questions we tried to answer.

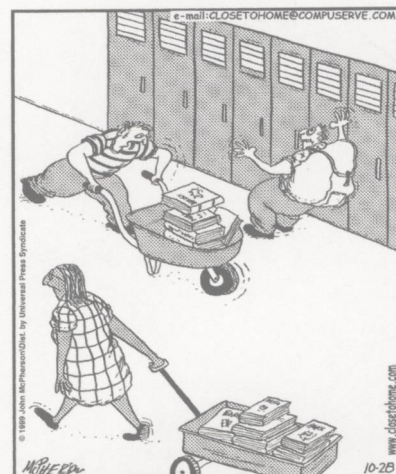
Why Do We Continue to Write a Short Book?

With rising tuition costs, depleted forests, and students' aching backs, the answer is obvious. The cartoon on this page illustrates one of our reasons. We remained steadfast in our belief that it should be possible to cover a text completely (or at least *almost* completely) in a two-semester course. The students justifiably ask why they have to pay for 1000-page books with "stuff" that is never covered in the course. We still do not have a good reason, so a 600-plus-page book was the aim for the sixth edition.

How Will We Write This Edition of a Short Book?

After we bemoaned the common perception that a short book is a low-level book, we reiterated our commitment to the principle that in treating general concepts in a concise way we would not sacrifice depth, rigor, or clarity. Our criteria for including material continue to be its importance and relevance to the student, not its difficulty. To achieve this, we decided on a three-pronged approach.

1. Eliminate repetition and duplication wherever possible. Like its earlier editions, this text uses:
 - Only one method for balancing redox reactions, the half-equation method introduced in Chapter 4.
 - Only one way of working gas-law problems, using the ideal gas law in all cases (Chapter 5).
 - Only one way of calculating ΔH (Chapter 8), using enthalpies of formation.
 - 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).
2. Relegate to the appendices or "Chemistry: Beyond the Classroom" essays topics ordinarily covered in texts of 1000 or more pages. Items in this category include:
 - MO (molecular orbital) theory (Appendix 5). Our experience has been (and continues to be) that although this approach is important to chemical bonding, most general chemistry students do not understand it but only memorize the principles discussed in the classroom.



With textbook loads ever increasing, many students are finding alternatives to backpacks.

- Nomenclature of complex ions and organic compounds. We believe that this material is of little value in a beginning course. The students promptly forget how to name a complex ion, because they have little chance to use the rules. The naming of organic compounds seems better left to a course in organic chemistry.
 - Qualitative analysis. This is summarized in a couple of pages in an essay in Chapter 16 in the “Chemistry: Beyond the Classroom” section. An extended discussion of the qual scheme and the chemistry behind it belongs in a lab manual, not a textbook.
 - Biochemistry. This material is traditionally covered in the last chapter of general chemistry texts. While we have included several biochemical topics in the text (among them a discussion of heme in Chapter 15 and carotenoids in Chapter 6), we do not see the value of an entire chapter on biochemistry. Interesting as this material is, it requires a background in organic chemistry that first-year students lack.
3. Avoid superfluous asides, applications to the real-world, or stories about scientists in the exposition of principles. We have incorporated many applications in the context of problems and some of the exposition of general principles. In general, however, we have stayed with a bare-bones approach. Students can easily be distracted by such interesting tidbits while they are striving hard to understand the concepts. We have put some of our favorite real-world applications and personal stories about scientists in separate sections, “Chemistry: Beyond the Classroom” and “Chemistry: The Human Side.” Our students tell us that they read these two sections first and that these sections are the parts of the book that they “really enjoy the most.” (Talk about faint praise!) They do admit to enjoying the marginal notes too.

How Will the Sixth Edition Differ from the Fifth Edition?

Although the principles of general chemistry do not change, there are always many ways to make a text better, more user-friendly, more interesting. It was our hope that if a student compared the fifth edition to the sixth edition, he or she would say, “The revision was worth having. It let me understand better.” (We doubted that students would be that forthcoming—but we hoped anyway!) The changes that we decided to make in pursuit of that hope are:

- Upgrading the in-text Examples. About 30% have been revised, to raise the rigor of the quantitative examples and deepen the conceptual understanding of the principles. Many students have admitted (because of the proverbial lack of time) that instead of solving problems at the end of the chapter, they did the Examples (because they had the solution right there to look at). They complained that some of those Examples were too simple to help them prepare for homework and exams.
- Adding new end-of-chapter questions and problems. There are almost 200 new end-of-chapter questions and problems, many of them conceptual.
- Continuing the process of updating static art to new balloon-caption art in which explanations previously presented in the text narrative or figure captions move into the art itself. We felt that today’s students are more likely to see and understand it with such placement.
- Updating and modernizing photographs and molecular models.
- Revising the style for presenting graphs to make them clearer.
- Inviting contributing authors to write essays about their current or recent research. There are four new essays for the end-of-chapter sections called “Chemistry: Beyond the Classroom.”
- Fully integrating, for the first time, *Chemistry: Principles and Reactions* with the OWL web-based chemistry learning system and assessment tool. Select end-of-chapter Questions and Problems from this edition are available in OWL with chemical and numeric parameterization, to provide students with a mastery learning environment and online graded homework. These problems are correlated to the Key Concepts summary list at the end of each chapter. OWL is described in more detail later in this Preface.



SUPPORT MATERIALS

A full complement of supporting materials to assist the instructor and student are available for use with this text.

For the Instructor

Supporting instructors' materials are available to qualified adopters. Please consult your local Cengage Learning, Brooks/Cole representative for details. Visit academic.cengage.com/chemistry/masterton to:

- See samples of materials.
- Request a desk copy.
- Locate your local representative.
- Download electronic files of the *Instructor's Manual*, the *Test Bank*, and other helpful materials for instructors and students.

Instructor's Manual by Cecile N. Hurley, University of Connecticut
ISBN-10: 0-495-38768-1; ISBN-13: 978-0-495-38768-8

This manual includes lecture outlines, lists of demonstrations for each chapter, and worked-out solutions for all of end-of-chapter Questions and Problems that do not have answers in Appendix 6 of the text (and the *Student Solutions Manual*). Electronic files of the *Instructor's Manual* are available on the PowerLecture CD-ROM and on the instructors' companion site at academic.cengage.com/chemistry/masterton.

Test Bank

ISBN-10: 0-495-38769-X; ISBN-13: 978-0-495-38769-5

This question bank features more than 1000 multiple-choice, five-part questions. Electronic files of the *Test Bank* are available on the PowerLecture CD-ROM. BlackBoard and WebCT formatted files for the *Test Bank* are also available on the instructor's companion site at academic.cengage.com/chemistry/masterton.

OWL: Online Web-based Learning by Roberta Day and Beatrice Botch of the University of Massachusetts, Amherst, and William Vining of the State University of New York at Oneonta

Used by more than 300 institutions and proven reliable for tens of thousands of students, OWL offers an online homework and quizzing system with unsurpassed ease of use, reliability, and dedicated training and service. OWL makes homework management a breeze and helps students improve their problem-solving skills and visualize concepts by providing instant analysis and feedback on a variety of homework problems, including tutors, simulations, and chemically and/or numerically parameterized short-answer questions. OWL is the only system specifically designed to support mastery learning, where students work as long as they need to master each chemical concept and skill. To view an OWL demo and for more information, visit academic.cengage.com/owl or contact your Brooks/Cole representative.

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For the sixth edition, approximately 20 end-of-chapter questions (marked in the text with ■) can be assigned in OWL.

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Learning Resources allow students to quickly access valuable help to master each homework question with integrated e-book readings, tutors, simulations, and exercises that accompany each question. Learning Resources are configurable by instructors.

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- Enhanced reports that give instant snapshots of your class progress.
- Easier grading access for quick report downloads.
- New Survey and Authoring features for creating your own content.
- Enhanced security to help you comply with FERPA regulations.

A fee-based access code is required for OWL. OWL is available only to North American adopters.

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- Electronic files for the *Instructor's Manual*, *Test Bank*, and *Cooperative Learning Worksheets*.
- Sample chapters from the *Student Solutions Manual* and *Study Guide*.
- ExamView® testing software, with all the test items from the printed *Test Bank* in electronic format, that enables you to create customized tests of up to 250 items in print or online.

Cooperative Learning Worksheets by Cecile N. Hurley, University of Connecticut

Available for download from the Instructor's Companion Site and on the PowerLecture CD-ROM.

This collection of worksheets (about three per chapter) is for students to use in collaborative groups. Designed to stimulate group activity and discussion, the questions provided on each worksheet are equally conceptually and quantitatively oriented. Also included are instructions for use, information on how to guide student discussion, and supporting data on the success of cooperative learning at the University of Connecticut.

For the Student

Visit the student companion website at academic.cengage.com/chemistry/masterton to see sample materials of selected student supplements. You can purchase any Brooks/Cole product at your local college bookstore or at our preferred online store www.ichapters.com.

Student Solutions Manual by Richard L. Nafshun, Oregon State University

ISBN-10: 0-495-38767-3; ISBN-13: 978-0-495-38767-1

This manual includes complete solutions to all end-of-chapter Questions and Problems answered in Appendix 6, including the Challenge Problems. The author includes references to textbook sections and tables to help guide students to use the problem-solving techniques employed by the authors. Selected solutions from each chapter, identified by the **WEB** icon, are on the student companion site at academic.cengage.com/chemistry/masterton.

Study Guide/Workbook by Cecile N. Hurley, University of Connecticut

ISBN-10: 0-495-38766-5; ISBN-13: 978-0-495-38766-4

This study aid contains additional worked examples and problem-solving techniques that complement and expand on those presented in the textbook. Each chapter also includes

an outline with fill-in-the-blanks for students to complete, exercises, and self-tests to help gauge mastery of the chapter. Sample chapters are available for review on the student companion website at academic.cengage.com/chemistry/masterton.

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CengageNOW's online self-assessment tools give you the choices and resources you need to study smarter. You can explore a variety of tutorials, exercises, and simulations (cross-referenced throughout the text by margin annotations) or take chapter-specific Pre-Tests and get a Personalized Study plan that directs you to specific interactive materials that can help you master areas where you need additional work. Access to CengageNOW for two semesters may be included with your new textbook, or can be purchased at www.ichapters.com using ISBN 0-495-39431-9.

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OWL for General Chemistry

See description of this online homework and quizzing system under Instructor's Support Materials.

Essential Algebra for Chemistry Students, second edition, by David W. Ball, Cleveland State University

ISBN-10: 0-495-01327-7; ISBN-13: 978-0-495-01327-3

This short book is intended 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.

Survival Guide for General Chemistry with Math Review, second edition, by Charles H. Atwood, University of Georgia

ISBN-10: 0-495-38751-7; ISBN-13: 978-0-495-38751-0

Intended to help you practice for exams, this "survival guide" shows you how to solve difficult general chemistry problems by dissecting them into manageable chunks. The guide includes three levels of proficiency questions—A, B, and minimal—to quickly build confidence as you master the knowledge you need to succeed in your course.

For the Laboratory

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ACKNOWLEDGMENTS

Many people who have used this book—instructors, teaching assistants, and students—have e-mailed, written, and called with suggestions on how to improve this book. Others just called to offer their condolences and encouragement on the loss of my co-author. I am grateful.

Reviewers who have helped in the preparation of this edition include:

Christopher Babb, Berry College
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Richard L. Nafshun, Oregon State University
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James A. Phillips, University of Wisconsin, Eau Claire
David Treichel, Nebraska Wesleyan University
Will Wickun, Montana State University, Billings

I am particularly grateful to Professors Fatma Selampinar (University of Connecticut) and David Shinn (University of Hawaii, Manoa) for their accuracy reviews. Their thoroughness and absolute attention to detail are incredible.

Professors Harry Frank (University of Connecticut), Steven Shaw (Montana State University), Greg Sotzing (University of Connecticut), and Leslie Sperling (Lehigh University) graciously consented to write essays on their research interests. Their essays are interesting and understandable to freshmen (no mean feat!).

Many people worked on the editorial and production team for this text. They took pages of manuscript, rough ideas, crude sketches, and long wish lists and put them together to create this edition. They prodded, cajoled, and set impossible deadlines, all with incredible patience. I couldn't have done it without them. They are: Lisa Lockwood, chemistry editor; Ashley Summers, assistant editor; Lisa Weber, technology project manager; Teresa Trego, content project manager; Amee Mosely, marketing manager; and Dan Fitzgerald, production editor at the production service Graphic World Publishing Services.

Missing from this list is Peter McGahey, my developmental editor, who deserves special thanks. He soothed frayed nerves and lifted sagging spirits with his positive, optimistic personality. His good humor provided an extra dose of energy. It also helped to get off topic once in a while to chat about tulip bulbs in the spring and perennials in the summer. Thanks, Peter. You were an oasis of calm on many days.

Two people who do not belong to any team deserve special recognition. To Joseph Hurley, best proofreader bar none, thanks for giving up your weekends to lend an extra pair of eyes. To Jim Hurley, who typed manuscript, read drafts through a nonchemist's (read mathematician's) eye, and listened to endless complaints, thank you for taking this journey with me.

Cecile N. Hurley
University of Connecticut
Storrs, CT
November 2007

To the Student

You've probably already heard a lot about your general chemistry course. Many think it is more difficult than other courses. There may be some justification for that opinion. Besides having its very own specialized vocabulary, chemistry is a quantitative science, which means that you need mathematics as a tool to help you understand the concepts. As a result, 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.

Learning Tools in *Chemistry: Principles and Reactions*, Sixth Edition

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 mathematics 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.

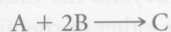
Graded Examples

Throughout the text, you will encounter special *Graded Examples*. A typical Graded Example looks 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.

There are two advantages to working a Graded Example.

1. By working parts (a) through (d) of this sample in succession, you can see how many different ways there are to ask a question about mass relations in a reaction. That should cushion the shock should you see only part (d) in an exam.

2. The parts of the Graded Example do not just progress from an easy mass relations question to a more difficult one. The value of the Graded Example is that the last question *assumes the ability to answer the earlier ones*. You may be able to answer parts (a) and (b) with a limited understanding of the material, but to answer part (d) you need to have mastered the material.

Use the graded example as you review for exams. Try to skip the earlier parts—in this case (a), (b), and (c)—and go directly to the last part, (d). If you can solve (d), you do not need to try (a), (b), and (c); you know how to do them. If you can't, then try (c) to see where you may have a problem. If you can't do (c), then try (b). As a last resort, start at (a) and work your way back through (d).

Marginal Notes

Sprinkled throughout the text are a number of short notes in the margin. Many of these are of the “now, hear this” variety, others are mnemonics, and still others make points that we forgot to put in the text. (These were contributed by your fellow students.) Some—probably fewer than we think—are supposed to be humorous. See, for example, the reference to ice skating on page 239; through five editions WLM thought it was uproariously funny.

OWL and CengageNOW

Two web-based resources accompany the text to aid your understanding of the concepts presented in each chapter:

CENGAGENOW™



- CengageNOW annotations appear throughout the text, directing you to tutorials, exercises, and simulations available online to help learn and reinforce the concepts presented in the text and your lecture. Each chapter is also supported by a diagnostic Pre-Test that directs you to those modules most likely to help you understand the topics where you need further work. More information about accessing CengageNOW is available in the Preface.
- For those courses using OWL (Online Web-based Learning), tutorials and end-of-chapter Questions and Problems from this book are available online as assigned by your instructor. OWL is described in more detail in the Preface.

Chemistry: The Human Side

Throughout the text, short biographies of some of the pioneers of chemistry appear in sections with this heading. They emphasize not only the accomplishments of these individuals but also their personalities.

Chemistry: Beyond the Classroom

Each chapter contains a “Chemistry: Beyond the Classroom” feature. It is a self-contained essay that illustrates a current example either of chemistry in use in the world or an area of chemical research. It does not intrude into the explanation of the concepts, so it won't distract you. But we promise that those essays—if you read them—will make you more scientifically literate.

Chapter Highlights

At the end of each chapter, you will find a brief review of its contents. A review is always helpful not only to refresh your memory of past material but also to organize your time and notes when preparing for an examination. The “Chapter Highlights” include:

- The *Key Terms* in the chapter. If a particular term is unfamiliar, refer to the index at the back of the book. You will find the term in the glossary that is incorporated in the index and also the pages in the text where it appears (if you need more explanation).

- The *Key Concepts* and *Key Equations* introduced in the chapter. These are indexed to the corresponding Examples and end-of-chapter problems. End-of-chapter problems available in OWL are also cross-referenced. If you have trouble working a particular problem here, it may help to go back and reread the Example that covers the same concept.
- Each chapter is summarized by a multi-step *Summary 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. A major advantage of the Summary Problems is that they tie together many different ideas, showing how they correlate with one another. An experienced general chemistry professor who uses the book always tells his class, "If you can answer the Summary Problem without help, you are ready for a test on its chapter."

Questions and Problems

At the end of each chapter is a set of Questions and Problems that your instructor may assign for homework. They are also helpful in testing the depth of your knowledge about the chapter. These sets include:

- Questions that test your knowledge of the specialized vocabulary that chemists use (e.g., write the names of formulas, write the chemical equation for a reaction that is described).
- **Quantitative problems** that require a calculator and some algebraic manipulations.
- **Classified problems** that start the set and are grouped by type under a particular heading that indicates the topic from the chapter that they address. The classified problems occur in matched pairs, so the second member illustrates the same principle as the first. This allows you more than one opportunity to test yourself. The second problem (even-numbered) is numbered in color and answered in Appendix 6. If your instructor assigns the odd problems without answers for homework, wait until the problem solution is discussed and solve the even problem to satisfy yourself that you understand how to solve the problem of that type.
- Each chapter also contains a smaller number of **unclassified problems**, which may involve more than one concept, including, perhaps, topics from a preceding chapter.
- **Conceptual questions** test your understanding of principles. A calculator is not (or should not be) necessary to answer these questions.
- The section of **challenge problems** presents problems that may require extra skill and/or insight and effort. They are all answered in Appendix 6.

Blue-numbered questions answered in Appendix 6 have fully worked solutions available in the *Student Solution Manual*. The *Student Solution Manual* is described in more detail in the Preface. To further aid your study, selected worked solutions for problems from each chapter, identified by the **WEB** icon, are posted on the book's companion website at academic.cengage.com/chemistry/masterton.

Appendices

The appendices at the end of the book provide not only the answers to the even-numbered problems but also additional materials you may find useful. Among them are:

- Appendix 1 includes a review of SI base units as well as tables of thermodynamic data and equilibrium constants.
- Appendix 3 contains a mathematical review touching on just about all the mathematics you need for general chemistry. Exponential notation and logarithms (natural and base 10) are emphasized.

Matter and Measurements

I have measured out my life with coffee spoons.

—T. S. Eliot

"The Love Song of J. Alfred Prufrock"

Chapter Outline

- 1.1 Types of Matter
- 1.2 Measurements
- 1.3 Properties of Substances

The flask shown in the painting is still part of glassware used in a modern chemist's laboratory.



"The Alchemist" by William F. Douglas © Victoria & Albert Museum, London/Art Resource, NY