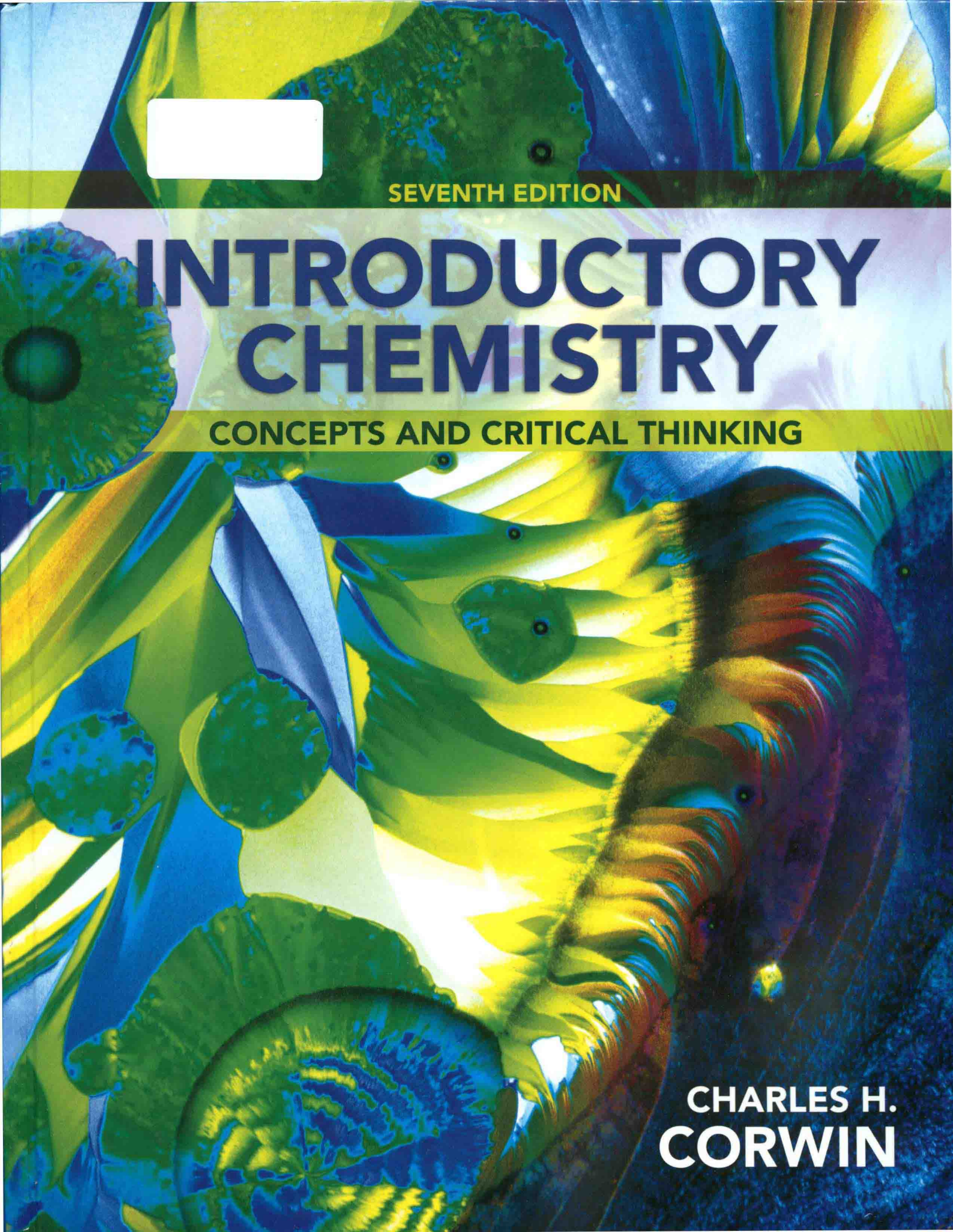
SEVENTH EDITION
INTRODUCTORY CHEMISTRY
CONCEPTS AND CRITICAL THINKING
CHARLES H. CORWIN

INTRODUCTORY CHEMISTRY

CONCEPTS AND CRITICAL THINKING

SEVENTH EDITION

Charles H. Corwin
American River College

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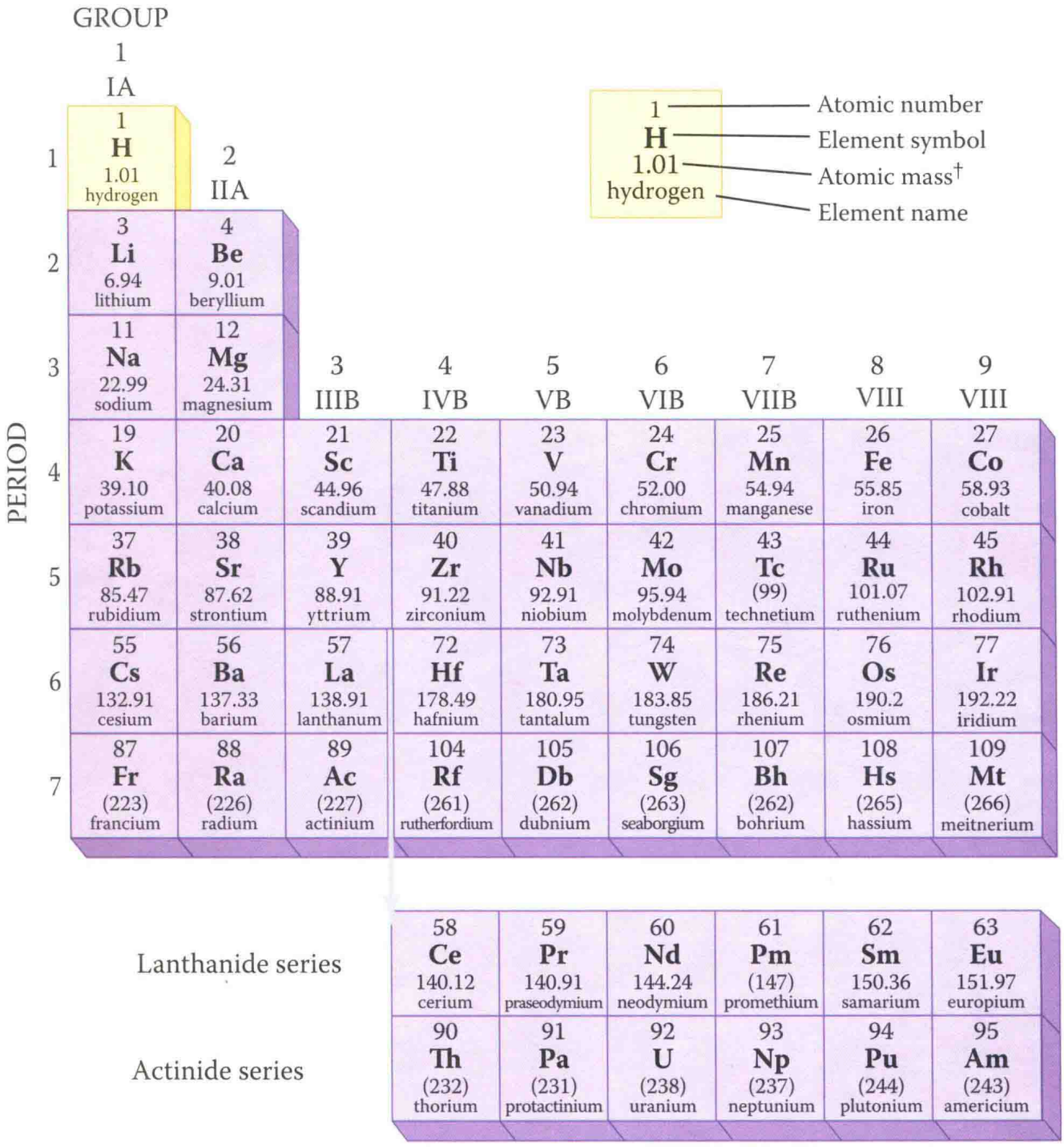
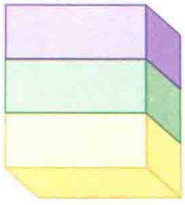
Periodic Table of the Elements



†The mass number of an important radioactive isotope—not the atomic mass—is shown in parenthesis for an element with no stable isotopes.



Metals
Semimetals
Nonmetals

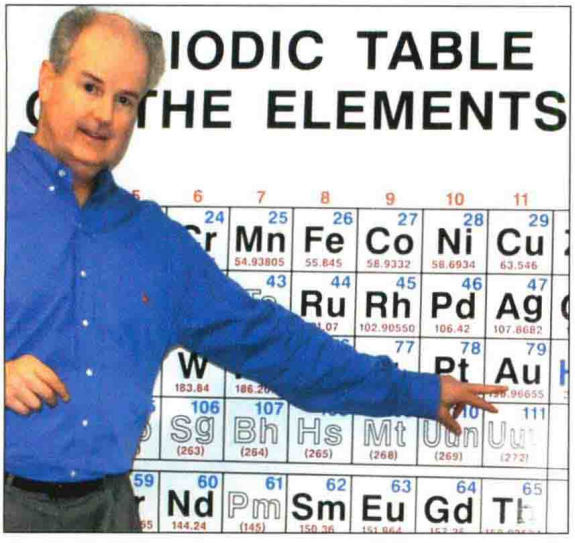
10 VIII	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
			5 **B** 10.81 boron	6 **C** 12.01 carbon	7 **N** 14.01 nitrogen	8 **O** 16.00 oxygen	9 **F** 19.00 fluorine	2 **He** 4.00 helium
			13 **Al** 26.98 aluminum	14 **Si** 28.09 silicon	15 **P** 30.97 phosphorus	16 **S** 32.07 sulfur	17 **Cl** 35.45 chlorine	10 **Ne** 20.18 neon
28 **Ni** 58.69 nickel	29 **Cu** 63.55 copper	30 **Zn** 65.39 zinc	31 **Ga** 69.72 gallium	32 **Ge** 72.61 germanium	33 **As** 74.92 arsenic	34 **Se** 78.96 selenium	35 **Br** 79.90 bromine	18 **Ar** 39.95 argon
46 **Pd** 106.42 palladium	47 **Ag** 107.87 silver	48 **Cd** 112.41 cadmium	49 **In** 114.82 indium	50 **Sn** 118.71 tin	51 **Sb** 121.75 antimony	52 **Te** 127.60 tellurium	53 **I** 126.90 iodine	36 **Kr** 83.80 krypton
78 **Pt** 195.08 platinum	79 **Au** 196.97 gold	80 **Hg** 200.59 mercury	81 **Tl** 204.38 thallium	82 **Pb** 207.2 lead	83 **Bi** 208.98 bismuth	84 **Po** (209) polonium	85 **At** (210) astatine	54 **Xe** 131.29 xenon
110 **Ds** (281) darmstadtium	111 **Rg** (280) roentgenium	112 **Cn** (285) copernicium	113 — (284)	114 **Fl** (289) flerovium	115 — (288)	116 **Lv** (292) livermorium	117* — (294)	86 **Rn** (222) radon

64 **Gd** 157.25 gadolinium	65 **Tb** 158.93 terbium	66 **Dy** 162.50 dysprosium	67 **Ho** 164.93 holmium	68 **Er** 167.26 erbium	69 **Tm** 168.93 thulium	70 **Yb** 173.04 ytterbium	71 **Lu** 174.97 lutetium
96 **Cm** (247) curium	97 **Bk** (247) berkelium	98 **Cf** (251) californium	99 **Es** (252) einsteinium	100 **Fm** (257) fermium	101 **Md** (258) mendelevium	102 **No** (259) nobelium	103 **Lr** (260) lawrencium

*Element 117 is currently under review by IUPAC.

INTRODUCTORY CHEMISTRY

About the Author



CHARLES H. CORWIN has instructed more than 10,000 students in both lecture and laboratory of introductory chemistry. He acknowledges the diversity of basic chemistry students and employs a variety of classroom pedagogies based on Bloom's taxonomy, Myers-Briggs inventory, critical thinking, and algorithmic versus conceptual heuristics. His teaching strategies include learning by objective, collaborative learning, web-based assignments, chemical demonstrations, and multimedia presentations.

The author was awarded degrees from San Jose State University, where he was a member of Tau Delta Phi honor society. He did graduate research at Stanford Research Institute on dialysis membranes, and attended the University of Akron, Institute of Polymer Science. He spent a sabbatical with the chemical education group at Purdue University studying a constructivist approach to cognitive development based on the work of Jean Piaget. Previously, he was visiting professor at Grand Valley State University on an NSF grant, and participated in a self-paced, mastery-learning study. He is currently interested in developing a hybrid online chemistry course with a laboratory component.

Professor Corwin has been recognized as teacher of the year at American River College, and has received a teaching award from Purdue University. In addition, he has been department chair, faculty mentor, academic senate representative, served on the ACS Examinations Committee, judged science projects at California state fairs, and for two decades was an examiner for the greater Sacramento region chemistry contest.

To the Student

A PERSONAL NOTE I have been with you in lecture and answered your questions. I have been with you in lab and given you encouragement. Perhaps I have not spoken to you personally, but I have had countless conversations with students who are trying to juggle college life, financial aid, employment hours, relationship issues, test anxiety, and stress in general. If you are a first-time student, or a reentry student, my advice is to maintain regular student and instructor contacts, and network with others who can help guide you toward your goals.

Introductory chemistry is a subject that builds systematically and culminates in a knowledge base for the physical sciences, life sciences, health sciences, and beyond. Therefore, it is essential that you set aside time each day to study chemistry, and avoid last-minute cramming for exams. On days when you lack motivation, open the textbook to the attractive art that illustrates the topic you are studying; or, go online to the textbook website and view one of the presentations in MasteringChemistry®.

The completion of a basic chemistry course begins to open doors to a rewarding career. A rewarding career is a source of personal satisfaction that spreads to all aspects of your life and helps you avoid making poor life choices. I know you can be successful in your chemistry class. I have seen others like you with different expressions on their faces at the end of the semester. It is a look of confidence after accepting the challenge, doing their best, and knowing they are better prepared for what lies ahead.

Preface

It is my goal not to repeat mistakes that I have made previously in the classroom and to improve my skill set each semester. Accordingly, I never leave campus without several Post-Its® for improving a presentation. I continually experiment with different topic organizations, employ multimedia and molecular models for visual concepts, and alternate quantitative and qualitative topics to provide a fresh edge.

It is all too obvious from reviewer comments that there is no consensus for the "right way" of presenting introductory chemistry. Each class situation varies with the course objectives and available facilities. In choosing an order of topic presentation in the *Seventh Edition*, I have weighed the arguments and made informed decisions.

Over a decade ago, many chemistry textbooks chose to move atomic theory and chemical bonding to later chapters. The genesis of this decision was based on Piagetian theory and the research evidence that conceptual topics are a higher cognitive task, which dictates descriptive and algorithmic topics be covered early as a foundation. Recently, some chemistry texts have reverted to an "atoms first" approach, which is influenced by innate student interest in the atomic and molecular world.

Experienced instructors may have found that a mathematically "soft" approach resonates with students. In an effort to cultivate student interest, we can first discuss physical and chemical properties and assign easy tasks such as learning the symbols of chemical elements. The downside to this approach is that students who woefully lack basic math skills, will later experience difficulty with calculations, and may not succeed in spite of our best efforts.

The *Seventh Edition* of *Introductory Chemistry: Concepts and Critical Thinking* allows instructors great latitude in choosing their topic presentation. This was mandated by reviewers who argued for the early placement of certain topics, whereas others argued for a later placement. Suggestions for the order of topic presentation were particularly diverse in the following areas: chemical bonding, molar volume, gas stoichiometry, and ionic equations.

We also asked reviewers to assess the rigor to which prerequisite science skills should be covered. The responses ranged from minimal to heavy emphasis; from relegation to an appendix to full chapter coverage. Obviously, a textbook cannot accommodate all views when there is such disparity. After weighing the alternatives, we opted for an interlude on *Prerequisite Science Skills* following Chapter 1. Students with a good preparation will find the material a simple review; whereas students with a weak preparation will find it helpful and improve their confidence.

A related area that was considered at some length was the depth of coverage for chemical calculations. In past editions, problem solving has received high marks by reviewers. Recently, some instructors have asked for more rigorous examples. We responded to this request in two ways: (1) challenge exercises have been added to the end of each chapter; and (2) a new chapter on *Advanced Problem Solving*, has been added that comprehensively covers a broad spectrum of problem-solving techniques.

NEW TO THIS EDITION

In this *Seventh Edition* of *Introductory Chemistry: Concepts and Critical Thinking*, there have been substantial changes including reorganization of chapters. In addition, the *Seventh Edition* includes the following.

- Interlude on **Prerequisite Science Skills** has been added following Chapter 1. The interlude helps students with weak math/science backgrounds prepare for chemical calculations. This brief interlude is an optional assignment at the discretion of the instructor.
- Chapter on **Advanced Problem Solving** has been added. Chapter 15 attacks problem solving comprehensively by applying diverse, proven strategies including: unit analysis, algebraic analysis, visualization, "ballpark" answers, and concept mapping. The new chapter also provides a section on multiconcept problems.

- Featured **Element in the Environment** begins each chapter to heighten student interest. For example, Chapter 5 shows native gold, gold ore, and states its occurrence in seawater. Chapter 9 shows copper and its recovery from an open-pit mine in Utah.
- **Challenge Exercises** have been added to each end-of-chapter exercise. These paired exercises offer questions at a higher level, and often require synthesis of more than one chemical concept.
- 

Online Exercises have been added to each end-of-chapter exercise. Web-based learning and incorporation of technology in teaching presentations has rapidly gained momentum. Accordingly, we have added online exercises that students will find both interesting and relevant to keep them engaged.
- A **Learning Objectives table** now appears at the end of each chapter. The learning objectives are correlated to sections and the end-of-chapter exercises for a greater connection between concepts and problems and for ease of assignment.

AN INTEGRATED LEARNING SYSTEM

More than a textbook, *Introductory Chemistry: Concepts and Critical Thinking, Seventh Edition* is a comprehensive learning system that offers print and media resources as well as an extensive website. Unlike other chemistry texts, all the materials are coherently integrated with the textbook by a single author, including the student solutions manual, laboratory manual, instructor's manual, and test item file. Moreover, the genesis of the package is based on considerable classroom experience, student feedback, instructor feedback, and multiple rounds of reviewer feedback from dozens of institutions across the country.

Students are presented with the same topics, in the same sequence, using the same vocabulary, consistently in the textbook and all the supplements. Instructors are presented with a tightly integrated package including an instructor's resource manual and a 3000-question test item file. The media resources include an Instructor Resource DVD, and the Pearson MasteringChemistry® online homework and tutorial system. The Mastering platform provides customizable and automatically graded assessments that provide individualized coaching, and responds to each student's progress.

PROBLEM SOLVING

An important objective of this text is to help students become effective problem solvers. This is accomplished by a walk-through discussion of each new topic, followed by an example exercise, practice exercise, concept exercise, and a problem-solving organizer at the end of each quantitative chapter.

Previous editions have received positive reviews for systematic problem solving. Inasmuch as basic chemistry students often have weak math skills, algebra has been scrupulously avoided in the early chapters in favor of the unit analysis method of problems solving. However, since many instructors prefer an algebraic approach to the gas laws, Chapter 10 offers both an algebraic and unit analysis approach to solving gas law problems.

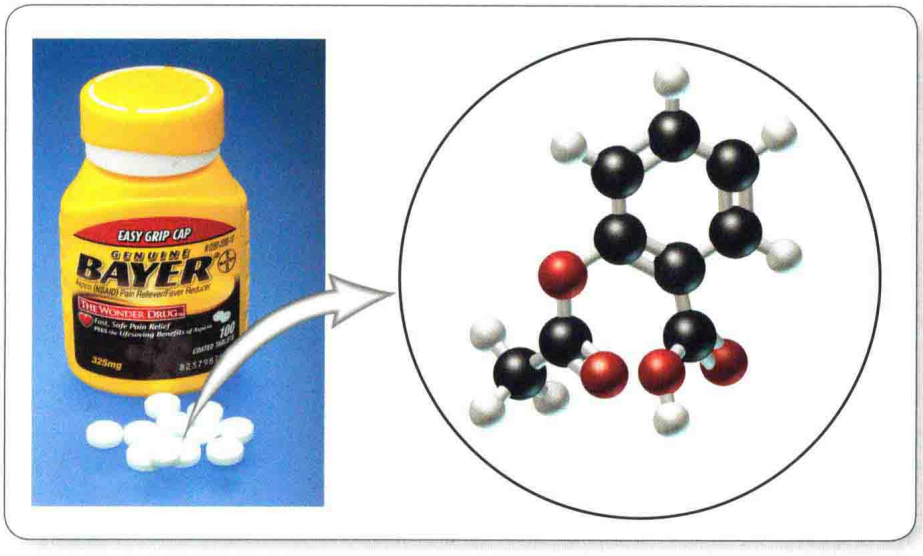
To assist underprepared students with a weak math/science background, the *Seventh Edition* offers a brief interlude on *Prerequisite Science Skills* that instructors can assign at their discretion.

The *Seventh Edition* offers numerous end-of-chapter exercises correlated to each chapter section, as well as the chapter learning objectives. New to the *Seventh Edition* are Challenge Exercises and Online Exercises. In addition, the *Seventh Edition* has a new chapter on *Advanced Problems Solving* that introduces a comprehensive range of problem-solving techniques.

LANGUAGE OF CHEMISTRY

Another important objective of this text is to help students learn the language of chemistry. To this end, each chapter has a unique matching exercise for all key terms that allows students to verify their definition in Appendix H. The *Study Guide & Student Solutions Manual* has a computer-generated crossword puzzle for each chapter with clues for *key terms* that provide a fun way to learn the language.

CONCEPTUAL LEARNING



An introductory chemistry student often requires motivation to learn this subject. To this end, in the *Seventh Edition* we have refined the palette of colors and style of rendering to achieve a new level of sophistication in illustrations and photographs. The molecular art program has been enhanced by providing molecular structures for chemical formulas and chemical reactions. Moreover, photographs are enhanced by providing macro/micro molecular art. This visual presentation not only enhances interest in the topics, but adds an effective pedagogical tool for understanding concepts that students find difficult to grasp.

CRITICAL THINKING

Cognitive scientists define *critical thinking* as mental activity associated with three types of thinking: applying reason, making decisions, and problem solving. In this text, critical thinking is introduced within the context of chemical principles. Critical thinking is undertaken specifically in the chapter vignettes and the end-of-chapter self-tests, and generally in problem solving.

In the *Seventh Edition*, we have introduced critical-thinking vignettes on topics ranging from the "World Trade Center" to "Aluminum or Aluminium?" In addition, each end-of-chapter self-test has questions on critical thinking.

FLEXIBLE CHAPTER SEQUENCE

For a variety of reasons, no two introductory chemistry classes present topics in the exact same order. Accordingly, the chapter sequence in *Introductory Chemistry: Concepts and Critical Thinking, Seventh Edition* is constructed in such a way so as to accommodate alternate sequences. For example, chemical bonding (Chapter 12) can immediately follow atomic theory and periodicity (Chapters 4 and 5); ionic equations can follow chemical reactions (Chapter 7); and gas stoichiometry can be deferred to the gas laws (Chapter 10).

ACKNOWLEDGMENTS

I would like to thank the reviewers, instructors, and students who have helped make this learning package so successful. I teach chemistry at a large community college (~40,000 students) with a high introductory chemistry enrollment. I am fortunate to have colleagues who are committed to our mission statement of empowering and preparing students to the full extent of their ability.

From the outset, this textbook has been shaped and honed by instructors who first class-tested the material in module form; and subsequently provided suggestions on a regular basis over six editions. I would be remiss not to specifically recognize my current colleagues: Kristin Casale, Darren Gottke, Ronald Grider, Tamilyn Hong, Jorge Jimenez, Greg Jorgensen, Michael Maddox, Dianne Meador, Chris Meadows, Edmund Niedzinski, Michael Payne, Karen Pesis, Deboleena Roy, Daniel Stewart, Brian Weissbart, Veronica Wheaton, and Linda Zarzana.

I also want to acknowledge a few select individuals for their contribution to the *Seventh Edition*. A most special thank you to Assistant Editor Lisa Pierce, who more than matched my perspicacity for detail and kept everything moving seamlessly and on schedule. Chemistry Editor-in-Chief Adam Jaworski gave broad direction to the *Seventh Edition* based on meetings with instructors around the country who brought issues to his attention. It was once again a pleasure to work with Eric Schrader, photo researcher, who demonstrated tenacity in acquiring high-quality photos to illustrate each topic. Project Manager Jenna Gray at PreMediaGlobal displayed laser focus on the four rounds of page proofs at the ftp website and coordinated the attractive layout and composition. To each of these individuals, singly and collectively, I extend my sincere appreciation.

REVIEWERS OF THE SEVENTH EDITION

The reviewers of this and previous editions of *Introductory Chemistry* continue to define that vague line between the simplifications that students require and the explanations that accuracy and detailed breadth of coverage demand. I thank them for working with me to make this a better learning resource.

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Marie Villarba
Glendale Community College
William H. Voige
James Madison University

Charles H. Corwin
Department of Chemistry
American River College
Sacramento, CA 95841
corwinc@arc.losrios.edu

Resources in Print and Online

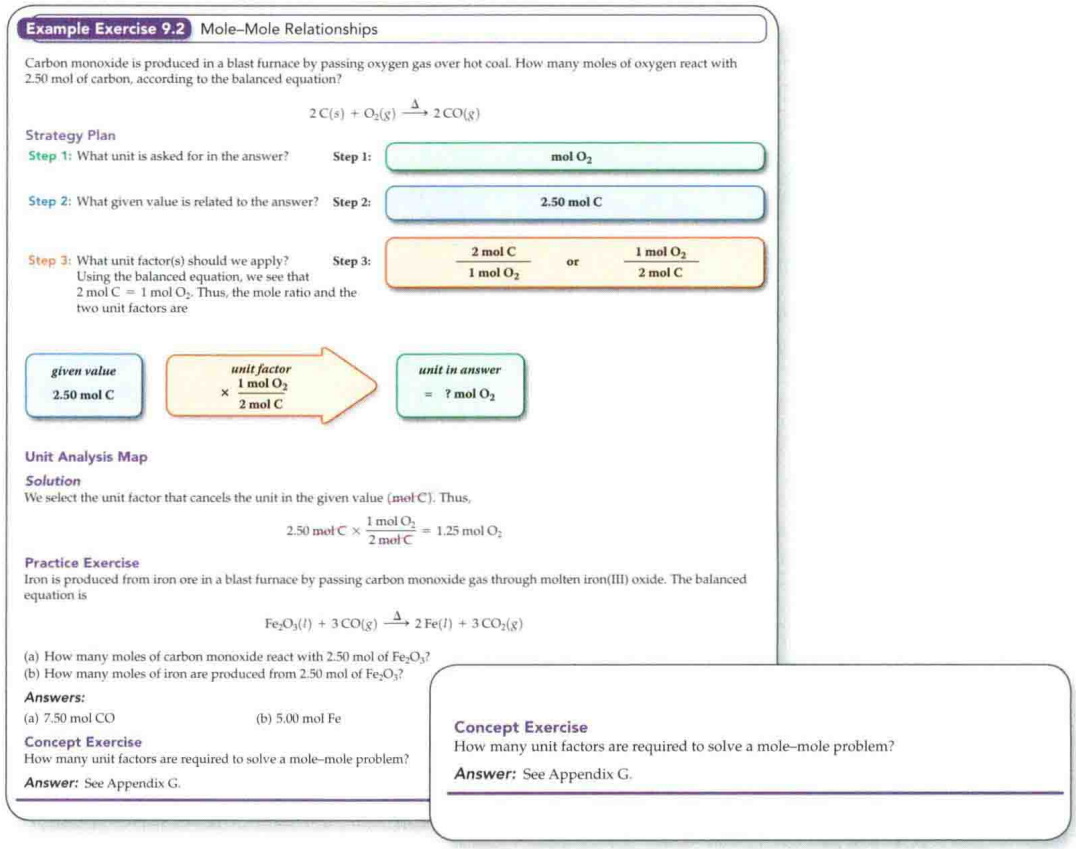
NAME OF SUPPLEMENT	AVAILABLE IN PRINT	AVAILABLE ONLINE	INSTRUCTOR OR STUDENT SUPPLEMENT	DESCRIPTION
MasteringChemistry®—for Introductory Chemistry: Concepts and Critical Thinking, 7/e 0321804597/ 9780321804594		✓	Supplement for Instructors and Students	The Mastering platform is the most effective and widely used online homework, tutorial, and assessment system for the sciences. It delivers self-paced tutorials that focus on your course objectives, provide individualized coaching, and respond to each student's progress. The Mastering system helps instructors maximize class time with easy-to-assign, customizable, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture or lab.
Study Guide & Selected Solutions Manual for Introductory Chemistry: Concepts and Critical Thinking, 7/e 0321808584/ 9780321808585	✓		Supplement for Students	Written by the author, Charles H. Corwin, this study aid includes diagnostic test questions for each topic covered in the text, crossword puzzles using key terms, and complete solutions to all odd-numbered exercises.
Instructor Manual and Test Bank for Introductory Chemistry: Concepts and Critical Thinking, 7/e 0321807669/ 9780321807663	✓	✓	Supplement for Instructors	The manual features a list of all chapter learning objectives and complete solutions to the even-numbered chapter exercises. This has been updated to reflect the revisions in this text and contains questions in a bank of more than 3000 multiple-choice questions.
Instructor's Resource DVD for Introductory Chemistry: Concepts and Critical Thinking, 7/e 0321821963/ 9780321821966		✓	Supplement for Instructors	This lecture resource contains all art and images from the textbook, three pre-built PowerPoint® presentations, animations, interactive activities, the Instructor's Manual in PDF format, the test item file in Word® format, and the TestGen computerized testing software.
Laboratory Manual for Introductory Chemistry: Concepts and Critical Thinking, 6/e 0321750942/ 9780321750945	✓		Supplement for Laboratory	Emphasizing environmental considerations, Corwin's acclaimed lab manual offers a proven format of a prelaboratory assignment, a stepwise procedure, and a postlaboratory assignment. More than 300,000 students to date in introductory chemistry, preparatory chemistry, and allied health chemistry have used these "bulletproof" experiments successfully. The *Sixth Edition* features environmental icons to alert students to recycle chemical waste, updated prelabs and postlabs, new experimental procedures, a new experiment (Experiment 25), and a new appendix on how to keep a laboratory notebook. Corwin's lab manual can be packaged with any Pearson intro prep chemistry book.
Catalyst: The Pearson Custom Laboratory Program for Chemistry		✓	Supplement for Laboratory	This program allows you to custom-build a chemistry lab manual that matches your content needs and course organization. You can either write your own labs using the Lab Authoring Kit tool or you can select from the hundreds of labs available at http://www.pearsonlearningsolutions.com/custom-library/catalyst. This program also allows you to add your own course notes, syllabi, or other materials.

Inspiring Students to Succeed in Chemistry

PROBLEM-SOLVING STUDY AIDS

Two-Column Example Exercises Using the unit analysis method, these exercises show students a logical way to apply the three-step problem-solving process in the worked-out example problems in each chapter.

Concept Exercises accompany each example exercise and practice exercise. The concept exercise serves to present the related topic at a higher level, whereas the example exercises and practice exercises are specific in nature.



Example Exercise 9.2 Mole–Mole Relationships

Carbon monoxide is produced in a blast furnace by passing oxygen gas over hot coal. How many moles of oxygen react with 2.50 mol of carbon, according to the balanced equation?

$$2\,C(s) + O_2(g) \xrightarrow{\Delta} 2\,CO(g)$$

Strategy Plan

Step 1: What unit is asked for in the answer? **Step 1:** mol O_2

Step 2: What given value is related to the answer? **Step 2:** 2.50 mol C

Step 3: What unit factor(s) should we apply? Using the balanced equation, we see that 2 mol C = 1 mol O_2. Thus, the mole ratio and the two unit factors are **Step 3:** $\frac{2\text{ mol C}}{1\text{ mol O}_2}$ or $\frac{1\text{ mol O}_2}{2\text{ mol C}}$

given value: 2.50 mol C × unit factor: $\frac{1\text{ mol O}_2}{2\text{ mol C}}$ = unit in answer: ? mol O_2

Unit Analysis Map

Solution

We select the unit factor that cancels the unit in the given value (mol C). Thus,

$$2.50\text{ mol C} \times \frac{1\text{ mol O}_2}{2\text{ mol C}} = 1.25\text{ mol O}_2$$

Practice Exercise

Iron is produced from iron ore in a blast furnace by passing carbon monoxide gas through molten iron(III) oxide. The balanced equation is

$$Fe_2O_3(l) + 3\,CO(g) \xrightarrow{\Delta} 2\,Fe(l) + 3\,CO_2(g)$$

(a) How many moles of carbon monoxide react with 2.50 mol of Fe_2O_3?
(b) How many moles of iron are produced from 2.50 mol of Fe_2O_3?

Answers:

(a) 7.50 mol CO (b) 5.00 mol Fe

Concept Exercise

How many unit factors are required to solve a mole–mole problem?

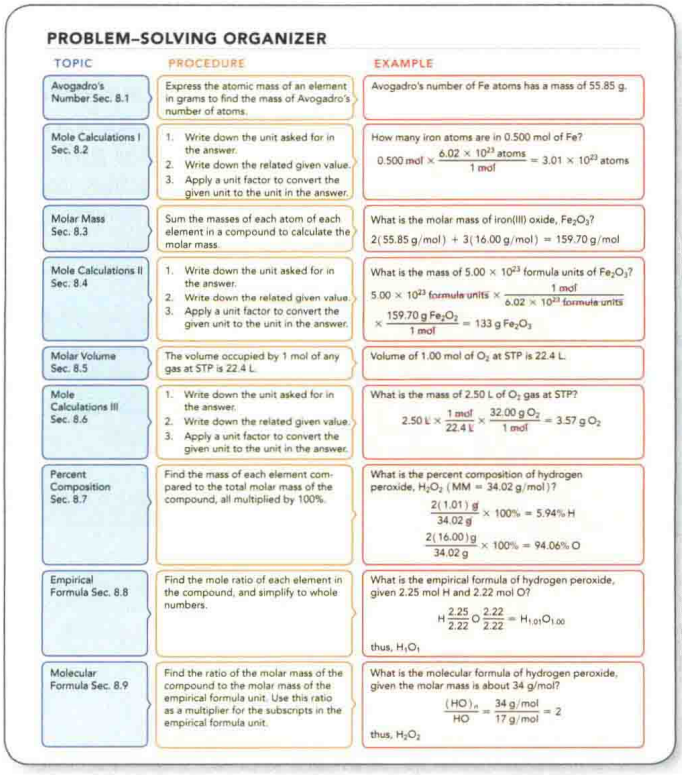
Answer: See Appendix G.

Concept Exercise

How many unit factors are required to solve a mole–mole problem?

Answer: See Appendix G.

Problem-Solving Organizers An important objective of this text is to help students become effective problem solvers. In the first column is a synopsis of the types of calculations in the chapter. In the second column is the correct procedure for solving each type of problem covered in the chapter. In the third column is an illustrated example of the problem type.



PROBLEM–SOLVING ORGANIZER

TOPIC	PROCEDURE	EXAMPLE
Avogadro's Number Sec. 8.1	Express the atomic mass of an element in grams to find the mass of Avogadro's number of atoms.	Avogadro's number of Fe atoms has a mass of 55.85 g.
Mole Calculations I Sec. 8.2	1. Write down the unit asked for in the answer. 2. Write down the related given value. 3. Apply a unit factor to convert the given unit to the unit in the answer.	How many iron atoms are in 0.500 mol of Fe? $0.500\text{ mol} \times \frac{6.02 \times 10^{23}\text{ atoms}}{1\text{ mol}} = 3.01 \times 10^{23}\text{ atoms}$
Molar Mass Sec. 8.3	Sum the masses of each atom of each element in a compound to calculate the molar mass.	What is the molar mass of iron(III) oxide, Fe_2O_3? $2(55.85\text{ g/mol}) + 3(16.00\text{ g/mol}) = 159.70\text{ g/mol}$
Mole Calculations II Sec. 8.4	1. Write down the unit asked for in the answer. 2. Write down the related given value. 3. Apply a unit factor to convert the given unit to the unit in the answer.	What is the mass of 5.00×10^{23} formula units of Fe_2O_3? $5.00 \times 10^{23}\text{ formula units} \times \frac{1\text{ mol}}{6.02 \times 10^{23}\text{ formula units}} \times \frac{159.70\text{ g } Fe_2O_3}{1\text{ mol}} = 133\text{ g } Fe_2O_3$
Molar Volume Sec. 8.5	The volume occupied by 1 mol of any gas at STP is 22.4 L.	Volume of 1.00 mol of O_2 at STP is 22.4 L.
Mole Calculations III Sec. 8.6	1. Write down the unit asked for in the answer. 2. Write down the related given value. 3. Apply a unit factor to convert the given unit to the unit in the answer.	What is the mass of 2.50 L of O_2 gas at STP? $2.50\text{ L} \times \frac{1\text{ mol}}{22.4\text{ L}} \times \frac{32.00\text{ g } O_2}{1\text{ mol}} = 3.57\text{ g } O_2$
Percent Composition Sec. 8.7	Find the mass of each element compared to the total molar mass of the compound, all multiplied by 100%.	What is the percent composition of hydrogen peroxide, H_2O_2 (MM = 34.02 g/mol)? $\frac{2(1.01)\text{ g}}{34.02\text{ g}} \times 100\% = 5.94\%\text{ H}$ $\frac{2(16.00)\text{ g}}{34.02\text{ g}} \times 100\% = 94.06\%\text{ O}$
Empirical Formula Sec. 8.8	Find the mole ratio of each element in the compound, and simplify to whole numbers.	What is the empirical formula of hydrogen peroxide, given 2.25 mol H and 2.22 mol O? $H\frac{2.25}{2.22}O\frac{2.22}{2.22} = H_{1.01}O_{1.00}$ thus, HO
Molecular Formula Sec. 8.9	Find the ratio of the molar mass of the compound to the molar mass of the empirical formula unit. Use this ratio as a multiplier for the subscripts in the empirical formula unit.	What is the molecular formula of hydrogen peroxide, given the molar mass is about 34 g/mol? $\frac{(HO)_n}{HO} = \frac{34\text{ g/mol}}{17\text{ g/mol}} = 2$ thus, H_2O_2