CHEMISTRY

The Molecular Nature of Matter and Change

Martin S. Silberberg

6e

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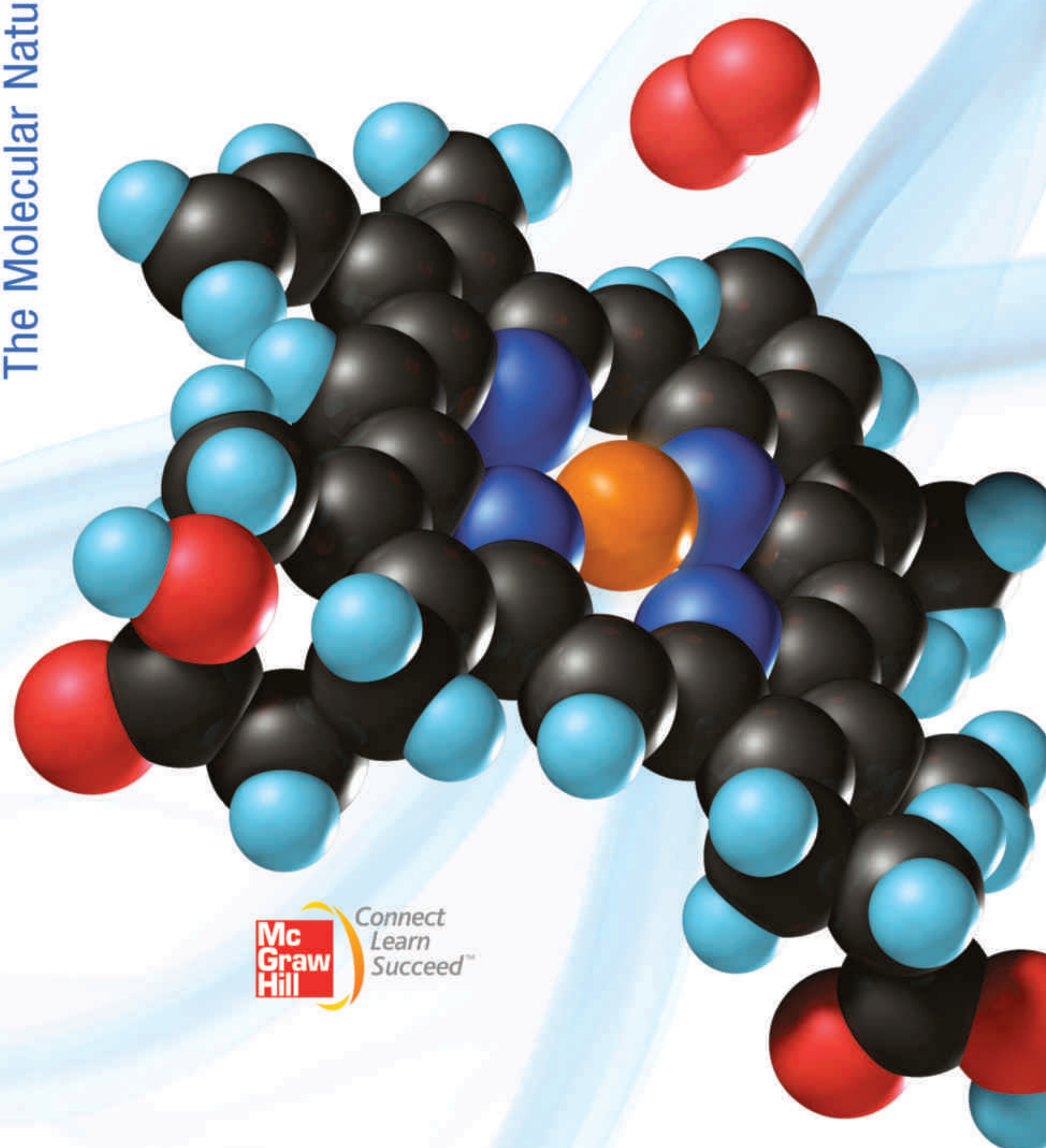

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CHEMISTRY: THE MOLECULAR NATURE OF MATTER AND CHANGE, SIXTH EDITION

This book is printed on acid-free paper.

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About the Author

Martin S. Silberberg received a B.S. in Chemistry from the City University of New York and a Ph.D. in Chemistry from the University of Oklahoma. He then accepted a position as research associate in analytical biochemistry at the Albert Einstein College of Medicine in New York City, where he developed methods to study neurotransmitter metabolism in Parkinson's disease and other neurological disorders. Following six years as research associate, Dr. Silberberg joined the faculty of Bard College at Simon's Rock, a liberal arts college known for its excellence in teaching small classes of highly motivated students. As head of the Natural Sciences Major and Director of Premedical Studies, he taught courses in general chemistry, organic chemistry, biochemistry, and liberal-arts chemistry. The small class size and close student contact afforded him insights into how students learn chemistry, where they have difficulties, and what strategies can help them succeed. Dr. Silberberg decided to apply these insights in a broader context and established a textbook writing, editing, and consulting company. Before writing his own texts, he worked as a consulting and development editor on chemistry, biochemistry, and physics texts for several major college publishers. He resides with his wife Ruth and son in the Pioneer Valley near Amherst, Massachusetts, where he enjoys the rich cultural and academic life of the area and relaxes by cooking and singing.

To Ruth and Daniel, with all my love,
and
In Memory of my Mother,
Gert Mazur,
Whose unfailing belief in me, I have finally come to realize,
has been a driving force in my life.

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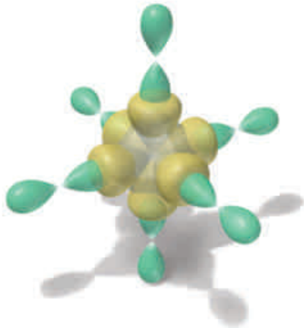

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Preface

At the core of natural science, chemistry is so crucial to an understanding of medicine, molecular biology, genetics, pharmacology, ecology, atmospheric science, engineering, nuclear studies, materials science, and many other fields that it has become a central requirement for an increasing number of academic majors. Furthermore, chemical principles are at the core of many key societal issues, including climate change, energy options, materials recycling, diet and nutrition, and medicine and disease.

WHAT SETS THIS BOOK APART

For five editions, *Chemistry: The Molecular Nature of Matter and Change* has been recognized for setting the standard among general chemistry textbooks. This sixth edition maintains that unparalleled reputation by keeping pace with the evolution of student learning. The text still contains the most accurate macroscopic-to-molecular illustrations, consistent step-by-step worked problems, and an extensive collection of end-of-chapter problems, with a wide range of difficulties and applications targeting student interests in engineering, medicine, materials, and environmental studies. Changes throughout the text have made it more succinct, the artwork more teachable and modern, and the design more open and inviting. And, while the content has certainly been updated to reflect chemistry's growing impact in the world, the mechanisms of the text—the teaching approaches that are so admired and emulated—have remained the same.

Visualizing Chemical Models

Chemistry deals with observable changes caused by unobservable atomic-scale events, requiring an understanding of a size gap of mind-boggling proportions. One of the text's goals coincides with that of so many teachers: to help the student visualize chemical events on the molecular scale. Thus, concepts are explained first at the macroscopic level and then from a molecular point of view, with the text's groundbreaking illustrations always placed next to the discussion to help today's visually oriented students.

Thinking Logically to Solve Problems

The problem-solving approach, based on the four-step method widely accepted by experts in chemical education, is introduced in Chapter 1 and employed *consistently* throughout the text. It encourages students to *plan* a logical approach to a problem, and only then proceed to *solve* it. Each sample problem includes a *check*. Finally, for *practice* and reinforcement, each sample problem is followed immediately by a similar follow-up problem, for which an abbreviated solution is given at the end of the chapter.

AN EVOLVING LEARNING SYSTEM

Just as the field of chemistry is addressing major changes in the world, the student learning experience is changing as well—different math and reading preparation, less time for traditional studying, electronic media as part of daily lectures and homework, and so on. To address these needs, a modern general chemistry text supported by a suite of robust electronic tools for teacher and student must continue to evolve. From first to second edition, a major emphasis was placed on creating more molecular art to help students visualize chemistry at that level. The third edition incorporated many revised sample problems and a plethora of new end-of-chapter problems. The fourth edition gave birth to molecular-scene sample problems to help students understand concepts through simple molecular depictions. Molecular scenes became so popular that the fifth edition tripled the number of sample problems and doubled the number of end-of-chapter problems using them. During these revisions, major content improvements took place in limiting-reactant stoichiometry, green chemistry, biomolecular structure, kinetics and equilibrium, entropy and free energy, and nuclear chemistry, among many other areas.

In preparation for the sixth edition, the author, together with key members of the editorial, sales, and marketing teams, consulted extensively with student and faculty users. From chapter reviews, focus groups, symposia, class tests, and one-on-one interviews with teachers, we were gratified to learn that everyone loved the pioneering, and still the most accurate, molecular art; the stepwise problem-solving approach, time-honored and consistent with decades of education research; the abundant mix of qualitative, basic quantitative, and applied end-of-chapter problems; and the student-friendly coverage of mainstream topics.

Based on this feedback, this edition focuses on "refining the standard" set earlier: distilling the writing to be concise and direct, opening up the overall appearance of pages, and improving illustrations by shortening legends and adding explanations into the art.

Content Changes to Individual Chapters

- Chapter 2 has a figure and table on molecular modeling.
- Discussion of empirical formulas has moved from Chapter 2 to Chapter 3 so it appears just before molecular formulas.
- Within Chapter 3, some sample problems have been segmented and seven new sample problems introduced to better focus problem-solving on distinct concepts.
- Chapter 3 contains more extensive use of stoichiometry reaction tables in limiting-reactant problems.
- Chapter 4 presents a new molecular-scene sample problem on depicting an ionic compound in aqueous solution.

- Chapter 5 includes a new subsection on how gas laws apply to breathing.
- Chapter 5 also contains new short discussions on the relevance of gas density. The coverage of reaction stoichiometry has been more logically grouped with other rearrangements of the ideal gas law.
- Chapter 5 contains new illustrations of diffusion and origin of pressure. It also uses the gas laws to explain why the troposphere has a uniform composition.
- Chapter 7 includes a new sample problem on using the Rydberg equation.
- Chapter 8 contains a new subsection covering electron configuration, chemical reactivity, and redox behavior.
- Chapter 9 contains a new discussion of carbon dioxide in global warming.
- Chapter 11 includes a new discussion of limitations to *d*-orbital hybridization.
- Chapter 12 presents new short discussions of everyday applications of surface tension, capillarity, and viscosity.
- Chapter 13 presents everyday applications of freezing point depression and osmotic pressure.
- The fifth edition's *Interchapter* has been deleted, but key figures have been placed in relevant locations within other chapters.
- Chapter 14 provides a thorough, focused survey of main-group descriptive chemistry.
- Chapter 15 contains new art for the molecular biology of protein synthesis and DNA replication.
- Chapter 16 incorporates two of the fifth edition's boxed features—on measuring reaction rates and on enzymes—into the chapter text.
- Chapter 17 makes consistent use of benchmarks for determining when an assumption is valid. It also incorporates the fifth edition's boxed feature on ammonia production into the text.
- Chapter 19 incorporates the fifth edition's boxed feature on cave formation into the chapter text.

Flexibility in Topic and Chapter Presentation

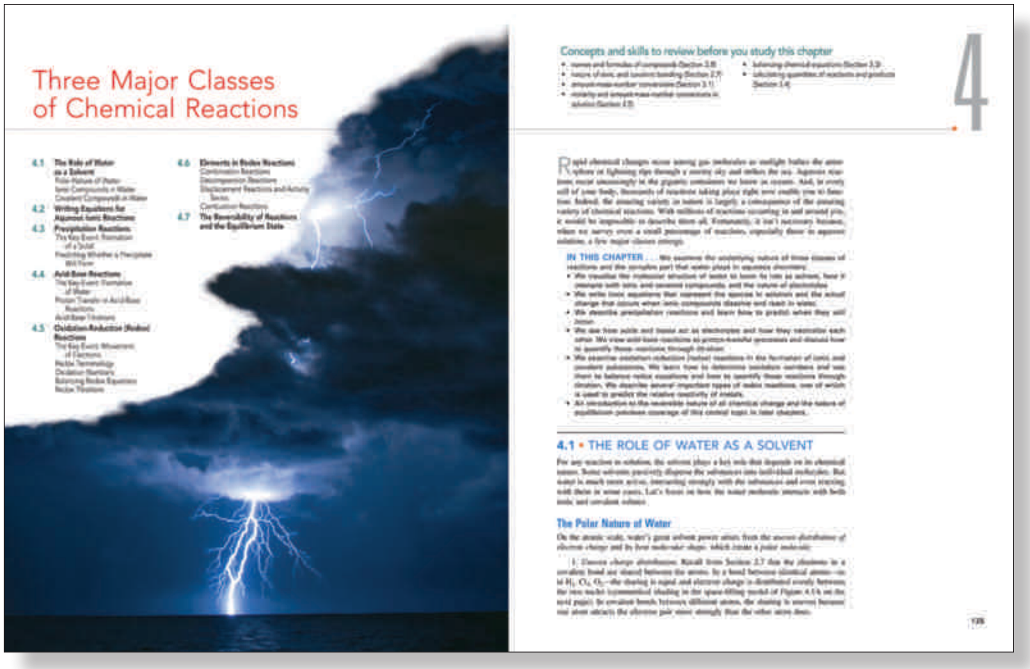
Chemistry: The Molecular Nature of Matter and Change has been revised to keep the mainstream topic sequence working optimally for teacher and student. But every course is unique, so flexibility has been built in: many section and subsection breaks allow topics to be rearranged with minimal loss of continuity. For example, redox balancing can be covered in Chapter 4, in Chapter 21, or, as done in the text. Likewise, several chapters can be taught in different orders. For instance, gases (Chapter 5) can be covered in sequence to explore the mathematical modeling of physical behavior or, with no loss of continuity, just before liquids and solids (Chapter 12) to show the effects of intermolecular forces on the three states of matter. In fact, feedback has indicated that many teachers move chapters, sections, and topics around, for example, covering descriptive chemistry (Chapter 14) and organic chemistry (Chapter 15) in the more traditional placement at the end of the course. Because the topic sequence is so flexible, any teacher can feel comfortable making such changes to suit his or her course.

THE SILBERBERG LEARNING SYSTEM

Many pedagogic tools are woven throughout the chapters to guide students on their learning journey.

Chapter Openers

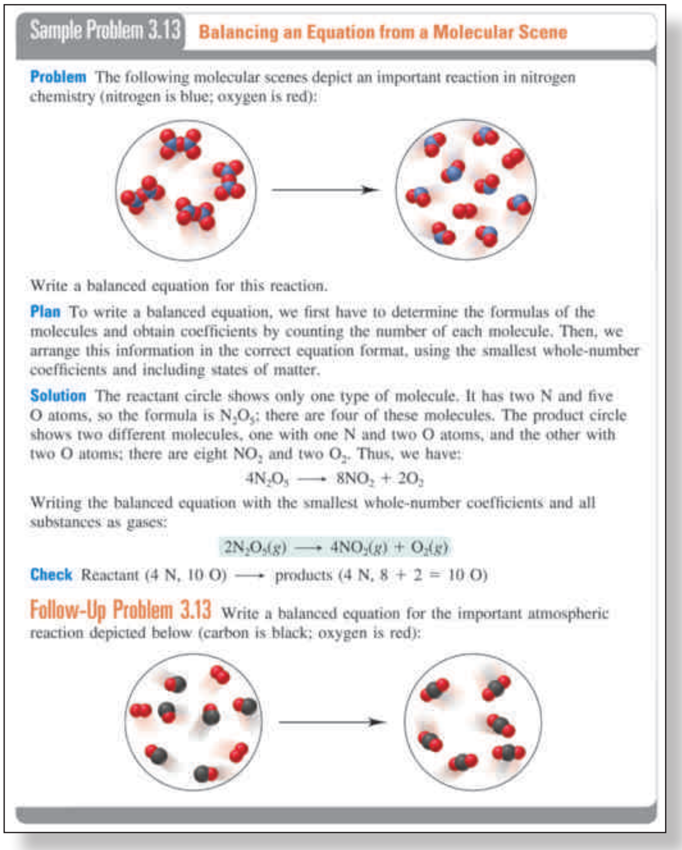
Each chapter introduces a familiar application and photo relating to the main topic of the chapter, followed by a bulleted list of main topics. The chapter outline shows the sequence of topics and subtopics. At the top of the opposite page, *Concepts and Skills to Review* lists key material from earlier chapters that students should understand before starting to read the current one.



Problem Solving

A worked-out *Sample Problem* appears whenever an important new concept or skill is introduced. The problem-solving step helps students think through chemistry problems logically and systematically. The universally accepted four-step approach of plan, solve, check, and practice is used consistently for every sample problem in the text. The steps are:

- **Plan** analyzes the problem so that students can use what is known to find what is unknown. This step develops the habit of thinking through the solution before performing calculations. Most quantitative problems are accompanied in the margin by a *Road Map*, a block diagram that is specific to the problem and leads students visually through the planned steps.
- **Solution** presents the calculation steps *in the same order* as they appear in the plan and in the road map.
- **Check** fosters the habit of going over one's work with a rough calculation to make sure the answer is both chemically and mathematically reasonable—a great way to avoid careless errors. In many cases, this step is followed by a *Comment* that identifies an additional insight, alternative approach, or common mistake to avoid.
- **Follow-Up Problem** presents a similar problem to provide immediate practice, with an abbreviated multistep solution appearing at the end of the chapter. Where appropriate in the first several chapters, students are asked to draw their own road map to solve the follow-up problem.


Sample Problem 3.13 **Balancing an Equation from a Molecular Scene**

Problem The following molecular scenes depict an important reaction in nitrogen chemistry (nitrogen is blue; oxygen is red):

Write a balanced equation for this reaction.

Plan To write a balanced equation, we first have to determine the formulas of the molecules and obtain coefficients by counting the number of each molecule. Then, we arrange this information in the correct equation format, using the smallest whole-number coefficients and including states of matter.

Solution The reactant circle shows only one type of molecule. It has two N and five O atoms, so the formula is N_2O_5; there are four of these molecules. The product circle shows two different molecules, one with one N and two O atoms, and the other with two O atoms; there are eight NO_2 and two O_2. Thus, we have:

$$4N_2O_5 \longrightarrow 8NO_2 + 2O_2$$

Writing the balanced equation with the smallest whole-number coefficients and all substances as gases:

$$2N_2O_5(g) \longrightarrow 4NO_2(g) + O_2(g)$$

Check Reactant (4 N, 10 O) $\longrightarrow$ products (4 N, 8 + 2 = 10 O)

Follow-Up Problem 3.13 Write a balanced equation for the important atmospheric reaction depicted below (carbon is black; oxygen is red):

Three-Level Illustrations

As the art that set the standard for chemistry textbooks, these illustrations connect the macroscopic and molecular levels of reality with the symbolic level in the form of a chemical equation.

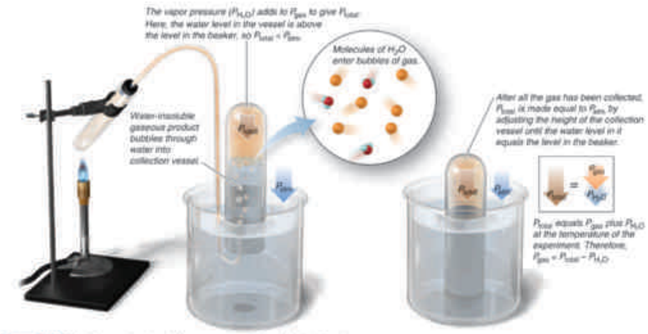
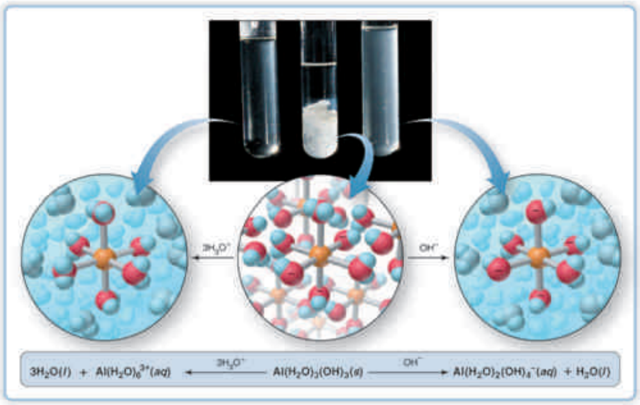


Figure 5.12 Collecting a water-insoluble gaseous product and determining its pressure.

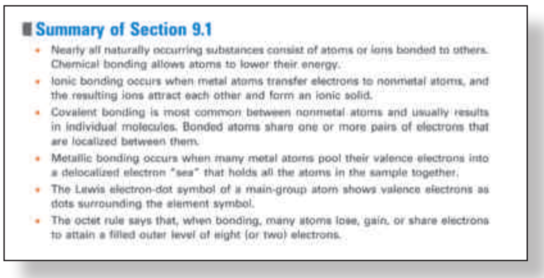
Annotated Figures

Modern, explanatory figures describe chemical processes through instructional labeling and realistic, three-dimensional art.



Section Summaries

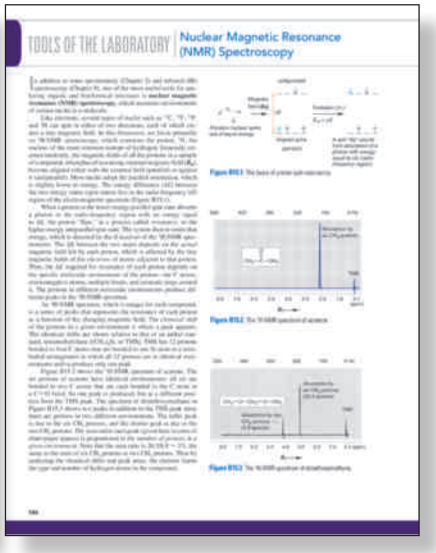
Concise, bulleted summary lists conclude each section, restating the major ideas just covered.


Summary of Section 9.1

- Nearly all naturally occurring substances consist of atoms or ions bonded to others. Chemical bonding allows atoms to lower their energy.
- Ionic bonding occurs when metal atoms transfer electrons to nonmetal atoms, and the resulting ions attract each other and form an ionic solid.
- Covalent bonding is most common between nonmetal atoms and usually results in individual molecules. Bonded atoms share one or more pairs of electrons that are localized between them.
- Metallic bonding occurs when many metal atoms pool their valence electrons into a delocalized electron "sea" that holds all the atoms in the sample together.
- The Lewis electron-dot symbol of a main-group atom shows valence electrons as dots surrounding the element symbol.
- The octet rule says that, when bonding, many atoms lose, gain, or share electrons to attain a filled outer level of eight (or two) electrons.

Applications

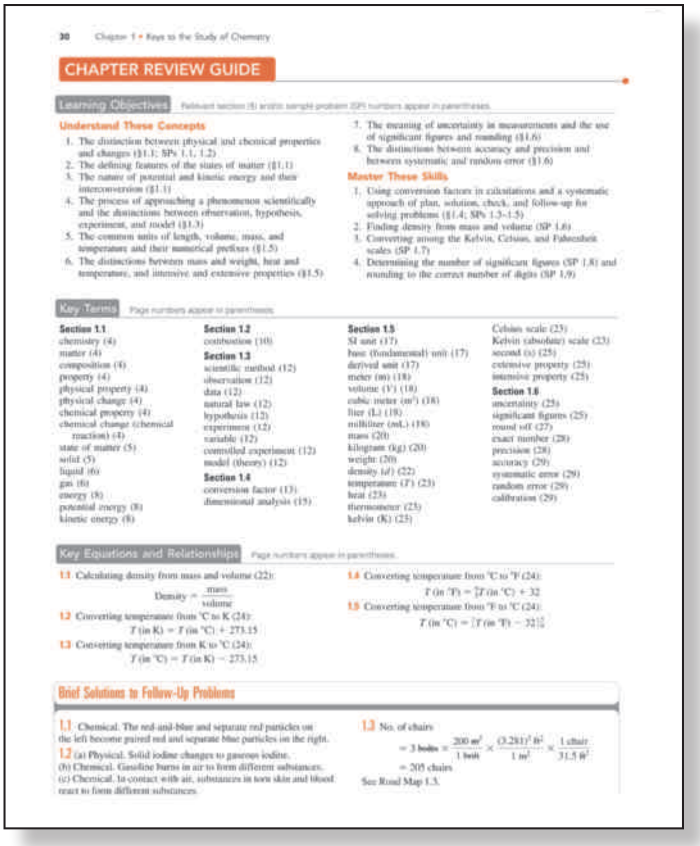
Chemical Connections essays show the interdisciplinary nature of chemistry by applying chemical principles directly to related scientific fields, including physiology, geology, biochemistry, engineering, and environmental science. *Tools of the Laboratory* essays describe the key instruments and techniques that chemists use in modern practice to obtain the data that underlie their theories. Both essay features now include several problems to enhance learning and relevance.



Chapter Review Guide

A rich catalog of study aids ends each chapter to help students review its content.

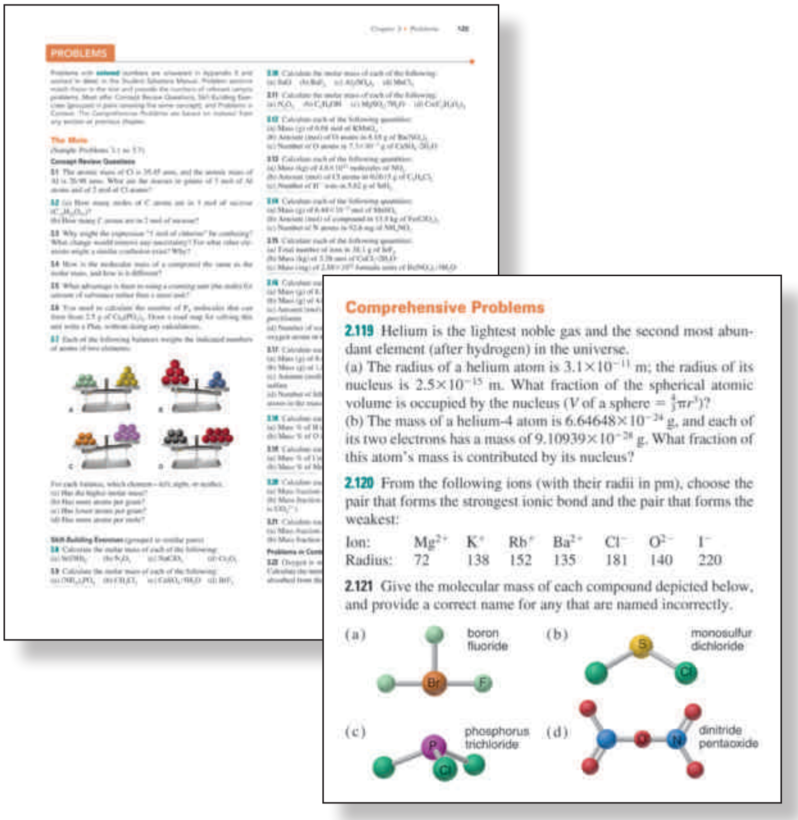
- **Learning Objectives,** with section and/or sample problem numbers, focus on key concepts and skills.
- **Key Terms** are boldfaced and defined within the chapter and listed here by section (with page numbers), as well as being defined again in the *Glossary*.
- **Key Equations and Relationships** are screened and numbered within the chapter and listed here with page numbers.
- **Brief Solutions to Follow-Up Problems** double the number of worked problems by providing multistep calculations at the ends of the chapters, rather than just a numerical answer at the back of the book. Road maps are supplied for those follow-up problems that ask students to prepare one in planning their solution.



End-of-Chapter Problems

An exceptionally large number of qualitative, quantitative, and molecular-scene homework problems end each chapter. Three types of problems are keyed by chapter section, with comprehensive problems following:

- **Concept Review Questions** test students' qualitative understanding of key ideas.
- **Skill-Building Exercises** are grouped in pairs that cover a similar idea, with one of each pair answered in the back of the book. These exercises begin with simple questions and increase in difficulty, gradually eliminating students' need for multistep directions.
- **Problems in Context** apply the skills learned in the skill-building exercises to interesting scenarios, including examples from industry, medicine, and the environment.
- **Comprehensive Problems,** most based on realistic applications, are more challenging and rely on concepts and skills from any section of the current chapter or from previous chapters.



PROBLEMS

Comprehensive Problems

2.119 Helium is the lightest noble gas and the second most abundant element (after hydrogen) in the universe.
(a) The radius of a helium atom is 3.1×10^{-11} m; the radius of its nucleus is 2.5×10^{-15} m. What fraction of the spherical atomic volume is occupied by the nucleus (V of a sphere $= \frac{4}{3}\pi r^3$)?
(b) The mass of a helium-4 atom is 6.64648×10^{-24} g, and each of its two electrons has a mass of 9.10939×10^{-28} g. What fraction of this atom's mass is contributed by its nucleus?

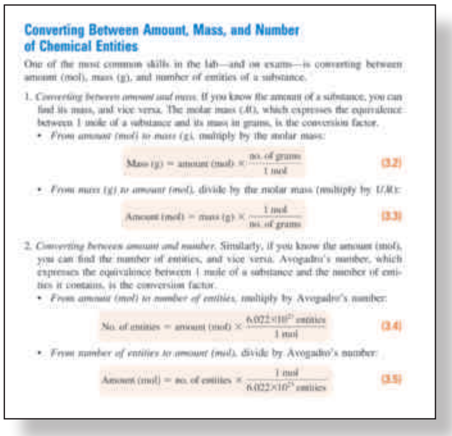
2.120 From the following ions (with their radii in pm), choose the pair that forms the strongest ionic bond and the pair that forms the weakest:

Ion:	Mg^{2+}	K^+	Rb^+	Ba^{2+}	Cl^-	O^{2-}	I^-
Radius:	72	138	152	135	181	140	220

2.121 Give the molecular mass of each compound depicted below, and provide a correct name for any that are named incorrectly.

Optimized Presentation

Text paragraphs have been made more concise, with presentation of content optimized through the use of subheads, numbered paragraphs, and lists. Main ideas are delineated, resulting in a more student-friendly study format.



Converting Between Amount, Mass, and Number of Chemical Entities

One of the most common skills in the lab—and on exams—is converting between amount (mol), mass (g), and number of entities of a substance.

1. *Converting between amount and mass.* If you know the amount of a substance, you can find its mass, and vice versa. The molar mass ($\mathcal{M}$), which expresses the equivalence between 1 mole of a substance and its mass in grams, is the conversion factor.
   - *From amount (mol) to mass (g),* multiply by the molar mass:

$$\text{Mass (g)} = \text{amount (mol)} \times \frac{\text{no. of grams}}{1\ \text{mol}} \quad (3.2)$$

   - *From mass (g) to amount (mol),* divide by the molar mass (multiply by $1/\mathcal{M}$):

$$\text{Amount (mol)} = \text{mass (g)} \times \frac{1\ \text{mol}}{\text{no. of grams}} \quad (3.3)$$

2. *Converting between amount and number.* Similarly, if you know the amount (mol), you can find the number of entities, and vice versa. Avogadro's number, which expresses the equivalence between 1 mole of a substance and the number of entities it contains, is the conversion factor.
   - *From amount (mol) to number of entities,* multiply by Avogadro's number:

$$\text{No. of entities} = \text{amount (mol)} \times \frac{6.022\times10^{23}\ \text{entities}}{1\ \text{mol}} \quad (3.4)$$

   - *From number of entities to amount (mol),* divide by Avogadro's number:

$$\text{Amount (mol)} = \text{no. of entities} \times \frac{1\ \text{mol}}{6.022\times10^{23}\ \text{entities}} \quad (3.5)$$

LEARNING SYSTEM RESOURCES FOR TEACHERS

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McGraw-Hill Connect is a web-based, interactive assignment and assessment platform that incorporates cognitive science principles to customize the learning process. The chemical drawing tool found within Connect: Chemistry is CambridgeSoft's ChemDraw, which is widely considered the "gold standard" of scientific drawing programs and the cornerstone application for drawing and annotating molecules, reactions, and pathways. This combination of Connect and ChemDraw is an easy-to-use, intuitive, and comprehensive course management and homework system with professional-grade drawing capabilities.

McGraw-Hill's ConnectPlus eBook takes digital texts beyond a simple PDF. With the same content as the printed book, but optimized for the screen, the ConnectPlus eBook has embedded media, including animations and videos, which bring concepts to life.

End-of-chapter problems from this textbook are available in Connect: Chemistry for teachers to build assignments that are automatically graded and tracked through reports that export easily to Excel. In addition to these questions, AP teachers have access to hundreds of AP-style multiple-choice and free-response questions adapted by AP teacher David Hostage, as well as two AP Practice Tests. Using Connect, teachers can edit existing problems and write entirely new problems; track individual student performance—by problem, assignment, concept, or in relation to the class overall—with automatic grading; provide instant feedback to students; and store detailed grade reports securely online. Within Connect, teachers can also create and share materials with colleagues. Contact your Glencoe/McGraw-Hill representative for pricing information.

Blackboard Course Management Integration

McGraw-Hill Blackboard Do More

McGraw-Hill Education and Blackboard, the Web-based course-management system, have teamed up to allow students and faculty to easily use online materials and activities to complement face-to-face teaching. Blackboard features exciting social learning and teaching tools that foster more logical, visually impactful, and active learning opportunities for students. This partnership allows teachers and students access to McGraw-Hill's Connect™ and Create™ from within Blackboard—with a single sign-on.

Teachers also get deep integration of McGraw-Hill content and content engines into Blackboard. Whether choosing a book for your course or building Connect™ assignments, all the tools you need are right where you want them—inside Blackboard. Gradebooks are also seamless. When a student completes an integrated Connect™ assignment, the grade for that assignment is automatically (and instantly) fed to the Blackboard grade center.

Online Learning Center On your textbook's Online Learning Center is an online digital library containing McGraw-Hill owned photos, artwork, animations, and other types of media that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials for classroom purposes. The visual and presentation resources in this collection include the following:

- **Art, Photos, and Tables** Full-color digital files of all illustrations in the book can be readily incorporated into lecture presentations, exams, or custom-made materials. The photo collection contains digital files of photographs from the text, which can be reproduced for multiple classroom uses. Additionally, every table that appears in the text has been saved in electronic form for use in classroom presentations and/or classroom materials.
- **Animations** Numerous full-color animations illustrating important processes are also provided. Harness the visual impact of concepts in motion by importing these files into classroom presentations or online course materials.
- **PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **PowerPoint Slides** For teachers who prefer to create their lectures from scratch, all illustrations, photos, sample problems, and tables have been inserted into blank PowerPoint slides, arranged by chapter.

The teacher side of your textbook's OLC includes a variety of AP-specific materials including an AP Teachers Manual.

AP Teacher's Manual To help AP teachers develop and teach their course, we provide an AP-specific teacher's manual. This manual, developed by AP teacher Marian DeWane, provides many useful tools to AP teachers.

Computerized Test Bank Prepared by Walter Orchard, Professor Emeritus of Tacoma Community College, over 2300 test questions to accompany *Chemistry: The Molecular Nature of Matter and Change* are available utilizing Brownstone's Diploma testing software. *Diploma's* software allows you to quickly create a customized test using McGraw-Hill's supplied questions or by authoring your own. *Diploma* allows you to create your tests without an Internet connection—just download the software and question files directly to your computer.

Instructor's Solutions Manual This supplement, prepared by Patricia Amateis of Virginia Tech, contains complete, worked-out solutions for *all* the end-of-chapter problems in the text. It can be found within the Instructors Resources, on the Connect: Chemistry site.

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Cooperative Chemistry Laboratory Manual Prepared by Melanie Cooper of Clemson University, this innovative manual features open-ended problems designed to simulate experience in a research lab. Working in groups, students investigate one problem over a period of several weeks, so they might complete three or four projects during the semester, rather than one preprogrammed experiment per class. The emphasis is on experimental design, analytic problem solving, and communication.

LEARNING SYSTEM RESOURCES FOR STUDENTS

McGraw Hill connect™ CHEMISTRY

With Connect: Chemistry, you can practice solving assigned homework problems using the Silberberg problem-solving methodology applied in the textbook. Algorithmic problems serve up multiple versions of similar problems for mastery of content, with hints and feedback to help you stay on track. Where appropriate, you engage in accurate, professional-grade chemical drawing through the use of CambridgeSoft's ChemDraw tool, which is implemented directly into homework problems. The AP-specific questions and AP Practice Tests available through Connect will help you prepare for the AP Exam.

McGraw Hill LearnSmart™

LearnSmart™ This adaptive diagnostic learning system, powered by Connect: Chemistry and based on artificial intelligence, constantly assesses your knowledge of the course material. As you work within the system, LearnSmart develops a personal learning path adapted to what you have actively learned and retained. This innovative study tool also has features to allow your teacher to see exactly what you have accomplished, with a built-in assessment tool for graded assignments.

Student Study Guide This study guide, prepared by Libby Bent Weberg, is designed to help you recognize your learning style; understand how to read, classify, and create a plan for solving a problem; and practice problem-solving skills. For each chapter section, the guide provides study objectives and a summary of the text. Following the summary are sample problems with detailed solutions. Each chapter has true-false questions and a self-test, with all answers provided at the end of the chapter.

Student Solutions Manual This supplement, prepared by Patricia Amateis of Virginia Tech, contains detailed solutions and explanations for all problems in the main text that have colored numbers.

Animations for MP3/iPod A number of animations are available for download to your MP3/iPod through the textbook's Connect website.

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Periodic Table of the Elements

- Metals (main-group)
- Metals (transition)
- Metals (inner transition)
- Metalloids
- Nonmetals

Period	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
	MAIN–GROUP ELEMENTS		TRANSITION ELEMENTS										MAIN–GROUP ELEMENTS					
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.41	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	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** (98)	44 **Ru** 101.1	45 **Rh** 102.9	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
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	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)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (263)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (267)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 (284)	114 (289)	115 (288)	116 (292)		118 (294)

As of late 2010, elements 113 through 116 and 118 had not been named.

INNER TRANSITION ELEMENTS

6	Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
7	Actinides	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (242)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

The Elements

Name	Symbol	Atomic Number	Atomic Mass*	Name	Symbol	Atomic Number	Atomic Mass*
Actinium	Ac	89	(227)	Mercury	Hg	80	200.6
Aluminum	Al	13	26.98	Molybdenum	Mo	42	95.94
Americium	Am	95	(243)	Neodymium	Nd	60	144.2
Antimony	Sb	51	121.8	Neon	Ne	10	20.18
Argon	Ar	18	39.95	Neptunium	Np	93	(244)
Arsenic	As	33	74.92	Nickel	Ni	28	58.70
Astatine	At	85	(210)	Niobium	Nb	41	92.91
Barium	Ba	56	137.3	Nitrogen	N	7	14.01
Berkelium	Bk	97	(247)	Nobelium	No	102	(253)
Beryllium	Be	4	9.012	Osmium	Os	76	190.2
Bismuth	Bi	83	209.0	Oxygen	O	8	16.00
Bohrium	Bh	107	(267)	Palladium	Pd	46	106.4
Boron	B	5	10.81	Phosphorus	P	15	30.97
Bromine	Br	35	79.90	Platinum	Pt	78	195.1
Cadmium	Cd	48	112.4	Plutonium	Pu	94	(242)
Calcium	Ca	20	40.08	Polonium	Po	84	(209)
Californium	Cf	98	(249)	Potassium	K	19	39.10
Carbon	C	6	12.01	Praseodymium	Pr	59	140.9
Cerium	Ce	58	140.1	Promethium	Pm	61	(145)
Cesium	Cs	55	132.9	Protactinium	Pa	91	(231)
Chlorine	Cl	17	35.45	Radium	Ra	88	(226)
Chromium	Cr	24	52.00	Radon	Rn	86	(222)
Cobalt	Co	27	58.93	Rhenium	Re	75	186.2
Copernicium	Cn	112	(285)	Rhodium	Rh	45	102.9
Copper	Cu	29	63.55	Roentgenium	Rg	111	(272)
Curium	Cm	96	(247)	Rubidium	Rb	37	85.47
Darmstadtium	Ds	110	(281)	Ruthenium	Ru	44	101.1
Dubnium	Db	105	(262)	Rutherfordium	Rf	104	(263)
Dysprosium	Dy	66	162.5	Samarium	Sm	62	150.4
Einsteinium	Es	99	(254)	Scandium	Sc	21	44.96
Erbium	Er	68	167.3	Seaborgium	Sg	106	(266)
Europium	Eu	63	152.0	Selenium	Se	34	78.96
Fermium	Fm	100	(253)	Silicon	Si	14	28.09
Fluorine	F	9	19.00	Silver	Ag	47	107.9
Francium	Fr	87	(223)	Sodium	Na	11	22.99
Gadolinium	Gd	64	157.3	Strontium	Sr	38	87.62
Gallium	Ga	31	69.72	Sulfur	S	16	32.07
Germanium	Ge	32	72.61	Tantalum	Ta	73	180.9
Gold	Au	79	197.0	Technetium	Tc	43	(98)
Hafnium	Hf	72	178.5	Tellurium	Te	52	127.6
Hassium	Hs	108	(277)	Terbium	Tb	65	158.9
Helium	He	2	4.003	Thallium	Tl	81	204.4
Holmium	Ho	67	164.9	Thorium	Th	90	232.0
Hydrogen	H	1	1.008	Thulium	Tm	69	168.9
Indium	In	49	114.8	Tin	Sn	50	118.7
Iodine	I	53	126.9	Titanium	Ti	22	47.88
Iridium	Ir	77	192.2	Tungsten	W	74	183.9
Iron	Fe	26	55.85	Uranium	U	92	238.0
Krypton	Kr	36	83.80	Vanadium	V	23	50.94
Lanthanum	La	57	138.9	Xenon	Xe	54	131.3
Lawrencium	Lr	103	(257)	Ytterbium	Yb	70	173.0
Lead	Pb	82	207.2	Yttrium	Y	39	88.91
Lithium	Li	3	6.941	Zinc	Zn	30	65.41
Lutetium	Lu	71	175.0	Zirconium	Zr	40	91.22
Magnesium	Mg	12	24.31			113**	(284)
Manganese	Mn	25	54.94			114	(289)
Meitnerium	Mt	109	(268)			115	(288)
Mendelevium	Md	101	(256)			116	(292)
						118	(294)

*All atomic masses are given to four significant figures. Values in parentheses represent the mass number of the most stable isotope.
**The names and symbols for elements 113 through 116 and 118 have not yet been chosen.

Fundamental Physical Constants (six significant figures)

Avogadro's number	N_A	$= 6.02214\times10^{23}$/mol
atomic mass unit	amu	$= 1.66054\times10^{-27}$ kg
charge of the electron (or proton)	e	$= 1.60218\times10^{-19}$ C
Faraday constant	F	$= 9.64853\times10^{4}$ C/mol
mass of the electron	m_e	$= 9.10939\times10^{-31}$ kg
mass of the neutron	m_n	$= 1.67493\times10^{-27}$ kg
mass of the proton	m_p	$= 1.67262\times10^{-27}$ kg
Planck's constant	h	$= 6.62607\times10^{-34}$ J·s
speed of light in a vacuum	c	$= 2.99792\times10^{8}$ m/s
standard acceleration of gravity	g	$= 9.80665$ m/s^2
universal gas constant	R	$= 8.31447$ J/(mol·K)
		$= 8.20578\times10^{-2}$ (atm·L)/(mol·K)

SI Unit Prefixes

p	n	μ	m	c	d	k	M	G
pico-	nano-	micro-	milli-	centi-	deci-	kilo-	mega-	giga-
10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^{3}	10^{6}	10^{9}

Conversions and Relationships

Length

SI unit: meter, m

1 km	= 1000 m
	= 0.62 mile (mi)
1 inch (in)	= 2.54 cm
1 m	= 1.094 yards (yd)
1 pm	$= 10^{-12}$ m = 0.01 Å

Volume

SI unit: cubic meter, m^3

1 dm^3	$= 10^{-3}$ m^3
	= 1 liter (L)
	= 1.057 quarts (qt)
1 cm^3	= 1 mL
1 m^3	= 35.3 ft^3

Pressure

SI unit: pascal, Pa

1 Pa	= 1 N/m^2
	= 1 kg/m·s^2
1 atm	$= 1.01325\times10^5$ Pa
	= 760 torr
1 bar	$= 1\times10^5$ Pa

Mass

SI unit: kilogram, kg

1 kg	$= 10^3$ g
	= 2.205 lb
1 metric ton (t)	$= 10^3$ kg

Energy

SI unit: joule, J

1 J	= 1 kg·m^2/s^2
	= 1 coulomb·volt (1 C·V)
1 cal	= 4.184 J
1 eV	$= 1.602\times10^{-19}$ J

Math relationships

π	= 3.1416
volume of sphere	$= \frac{4}{3}\pi r^3$
volume of cylinder	$= \pi r^2 h$

Temperature

SI unit: kelvin, K

0 K	= −273.15°C
mp of H_2O	= 0°C (273.15 K)
bp of H_2O	= 100°C (373.15 K)
T (K)	= T (°C) + 273.15
T (°C)	= [T (°F) − 32]$\frac{5}{9}$
T (°F)	= $\frac{9}{5}T$ (°C) + 32

Useful Data and Information

Atomic and Molecular Properties

Atomic radii	Figure 8.13, p. 309
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Bond lengths	Table 9.2, p. 340
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Properties of the Elements

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