

CHEMISTRY

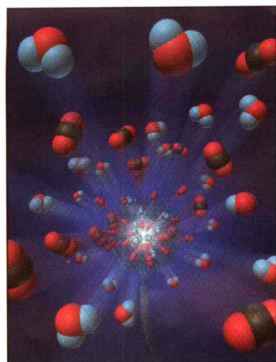
The Molecular Nature of Matter and Change



Second Edition



Silberberg



CHEMISTRY

The Molecular Nature of Matter and Change

Second Edition

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

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COVER IMAGE: On the molecular level, molecules of methane and oxygen react near the tip of a laboratory burner to form molecules of carbon dioxide and water. As in all chemical change, the number of each type of atom is the same before and after the change: one carbon dioxide and two waters form for every one methane and two oxygens that react.

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With love and gratitude

*To Ruth,
whose insight and experience
made this project possible*

and

*To Daniel,
whose optimism and creativity
make everything seem possible*

Preface

As we move through the turn of the millennium, everything seems to be changing. New medical imaging devices that peer into body parts to observe function join a family of new microscopes that peer at material surfaces to observe their atomic landscapes. Computer-aided design of new drugs is becoming routine, creating “cocktails” that arrest the progress of new diseases. And these will soon be surpassed by medicines borne from our complete analysis of the human genome. New electronic technologies are already redefining global communications, and we will soon be driving cars powered by new, cleaner energy sources. Alas, even our climate may be changing, as evidenced by the 1990s being proclaimed the hottest decade in recorded history.

Yet, in the face of all this change, certain things stay the same: the value of a good science course to teach logical thinking, the role of a good professor to inspire students and explain concepts—and the central importance of a good textbook that allows student and professor to realize their goals for the course.

To address current directions in the curriculum, *Chemistry: The Molecular Nature of Matter and Change* and its supplements have changed in some major ways, but the philosophy of the text, its student-oriented presentation, and its overall topic sequence have not. As in the first edition, my goal for the second edition was to write a teaching text, one with clear, lively explanations allied to realistic, pedagogic illustrations that help students learn chemistry with confidence—and maybe even a sense of awe!

Revising a textbook, especially one so well received in its first edition, is a challenge based on a simple mandate—listen to your readers to enhance the many aspects of the text that work well and strengthen the inevitable weak spots. This *Preface* and the illustrated *Guided Tour* that follows it highlight features introduced in the *First Edition* and some of the many specific ways that the *Second Edition* has changed to become an even more effective teaching tool.

Approach to Teaching Chemistry

The most important aspect of the text that has not changed (and never will!) is its three-pronged approach to teaching chemistry—visualizing chemical models, thinking through a quantitative problem, and demonstrating the tremendous relevance of chemistry to society.

Visualizing Chemical Models

Chemistry deals with changes that we observe in the world around us and with the atomic-scale events that cause them. Throughout the text, discussions team up with illustrations to bring home this central theme. Models are explained at the observable level and then from a close-up, molecular point of view. To bridge the mind-boggling size gap between these two levels of reality, the first edition broke new ground in chemical illustration with an art program that juxtaposed the macroscopic and atomic views, and, wherever meaningful, the symbolic view in the form of the balanced equation. The response from teachers and students was extremely positive, and it has been gratifying to see this approach attempted in the generation of texts that followed the first edition. Today's more visually oriented students will surely

benefit from this trend. The second edition expands this approach considerably and introduces further innovations.

New for the second edition are the following enhancements:

- To optimize comprehension of text and related art, every two-page spread has been designed to place a figure or table as near to its related text as possible, with many figures wrapped by the text so the student reads an explanation and sees it depicted simultaneously.
- To enrich the visualization of chemical events, many macro-to-molecular-to-equation figures have been added.
- To help students mentally translate line structures into molecular shapes, many molecular models have been added.
- To simultaneously depict both shape *and* polarity, a new type of model has been introduced that adapts the most advanced chemical modeling software.

In the *Guided Tour*, pages xx and xxi display the outstanding pedagogy of the new art program.

Thinking Logically to Solve Problems

Another innovation of the first edition that is enhanced in the second is the powerful problem-solving pedagogy, which is based on widely accepted modern principles of education. This approach encourages students to first plan a logical method for attacking a problem, and only then proceed to solve it quantitatively. For the more visually-oriented student, a block diagram *specific* for the problem appears alongside the plan whenever appropriate *throughout* the text. A step unique to this text fosters the habit of checking the reasonableness and magnitude of the answer, a habit universally recommended by professors. The check is followed immediately by practice with a similar type of problem.

New for the second edition are the following improvements:

- To help students develop a sound problem-solving strategy, every Sample Problem has been inspected for clarity and the adjacent block-diagram “roadmap” made more informative.
- To provide adequate practice for new ideas and skills, every set of chapter problems has been expanded, many with molecular art incorporated, and the problems have been classified by type.

In the *Guided Tour*, page xxii explains the approach in detail, and page xxiv shows the unique way that end-of-chapter problems are classified and sequenced.

Applying Ideas and Skills to the Real World

The influence of modern chemistry in everyday life is spreading enormously, informing global concerns about the environment, disease, energy resources, and countless other issues. In the process, many new hybrid fields are being spawned—biomaterials science, nanotechnology, enzyme engineering, planetary geochemistry, and the like. Today’s students will enter some of these fields and generate still newer ones in which the principles of chemistry have an ever greater impact.

As in the first edition, the relevance of chemistry is always presented to highlight or expand upon a principle being discussed. In addition to countless places in the main text, four key displayed features—Chemical Connections essays, Tools of the Chemistry Laboratory essays, Galleries, and Margin Notes—provide practical handles to what may seem abstract ideas.

New for the second edition are the following improvements:

- To maintain currency, text discussions and boxed essays have been updated with the latest government and industry data.

- To demonstrate the relevance of chemistry in everyday life, many new photos, Margin Notes, and Galleries have been added. In the *Guided Tour*, page xxiii demonstrates the relevance of these features.

Helping Students Learn Chemistry

My guiding principle throughout the conception, writing, and illustrating of both editions has been to create a “teaching” text, one that provides a clear path through the material with thorough explanations that foresee potential student confusion before it arises. To that end, each chapter has been designed with as many helpful learning aids as possible. Many first-edition users praised the usefulness of the Concepts and Skills to Review, Section Summaries, Chapter Perspectives, and the abundance of chapter endmatter for review.

New for the second edition are the following improvements and additions:

- To improve readability, every paragraph was examined line by line and revised, whenever necessary, for clarity and directness.
- To help orient the student to the upcoming flow of ideas, every chapter now opens with a *detailed* Chapter Outline of the content.
- To make the coverage as flexible as possible, every chapter now includes many more heads that subdivide the material.
- To better highlight concepts, every chapter now includes many more summarized lists of central points and italicized key ideas.
- To focus the student on major topics, every chapter now ends with a numbered list of learning objectives indicating section and/or sample problem.
- To provide an alternative means of review, certain figures/tables are highlighted and listed with other review material at the end of each chapter.

In the *Guided Tour*, pages xix and xxiv show examples of these features.

Innovative Treatments of Chapter Sequence and Content

The second edition of *Chemistry: The Molecular Nature of Matter and Change* retains the modern topic order suited to the great majority of today's general chemistry courses. At the same time, it provides the flexible chapter sequence that many professors desire for their own approach to the subject. Innovative treatments of the material appear in each chapter, including many topics geared toward students planning medical, scientific, and engineering careers, with some especially novel approaches to the chemistry of the elements, organic chemistry, and biochemistry.

Flexible Chapter Sequence

As the Detailed Contents shows, the main chapter order begins with coverage of basic concepts of matter and energy, including units and measurement, elements and compounds, stoichiometry, reaction classes, gas behavior, and thermochemistry (Chapters 1–6). It then moves on to a sequence of topics that build upon each other, from atomic structure and electron configuration to bonding and shape to the properties of liquids, solids, and solutions (Chapters 7–13). A unique treatment of the chemistry of the elements and organic and biochemistry (Interchapter and Chapters 14 and 15) is placed centrally but can be covered at many other places in the course. The central topics of physical chemistry are presented next, including one chapter on kinetics, three chapters on equilibrium, and two chapters on thermodynamics and its application to electrochemistry (Chapters 16–21). The text ends with selected topics in environmental and industrial chemistry, transition metal chemistry, and nuclear reactions (Chapters 22–24).

New for the second edition are the following key organizational changes:

- To clarify the distinctions among bonding models and facilitate molecular visualization, the discussion of Lewis structures was moved from the end of Chapter 9 to the beginning of Chapter 10. Thus, Chapter 9 now directly compares the three types of bonding (ionic, covalent, and metallic) on the atomic and macroscopic scales, and Chapter 10 focuses on depicting molecules, from Lewis structures to VSEPR shapes.
- To allow selected coverage of the more abstract aspects of covalent bonding, the discussions of valence-bond and molecular-orbital theories have been moved from the end of Chapter 10 to their own new Chapter 11.
- To apply the topics of physical chemistry immediately after they are discussed, the chapter on the elements in nature and industry has been moved from the end of the text to follow the chapter on electrochemistry, and the chapter on nuclear reactions now ends the text.

Integrated Chapter Content

What may not be immediately apparent from the Detailed Contents are the novel ways that many topics are presented. Of special note are the treatments of descriptive chemistry and organic chemistry. Rather than leaving these important topics for the end of the course, professors can elect to cover them immediately after Chapters 7–13. The Interchapter and Chapter 14 apply the principles from these chapters to *all* the main-group elements, emphasizing the *gradation* in element properties throughout the periodic table, rather than fostering misleading divisions between metals and nonmetals. Chapter 15 is a natural extension of descriptive chemistry, showing how the chemistry of organic and biological compounds arises from the atomic properties of carbon and its few bonding partners. Chapter 22 follows the example of Chapter 14 by applying the principles of kinetics, equilibrium, thermodynamics, and electrochemistry from Chapters 16–21 to the geochemistry, environmental chemistry, and industrial chemistry of the elements.

The text's devotion to biochemistry is unique. There is more coverage of this exciting field than in any other mainstream text, but it is integrated into discussions, margin notes, and boxed essays. Biopolymer structure and function forms a major portion of Chapter 15, while other discussions explore molecular shape in physiology, solubility factors in the structures of cell membranes and the action of antibiotics, principles of catalysis that apply to enzyme specificity and activity, principles of equilibrium that relate to metabolic control, electrochemical processes that produce and utilize ATP, and many more topics.

New for the second edition are countless small improvements to art and text in every chapter, including the following significant changes:

- Chapter 2 now includes a focus on organic structures and introduces Coulomb's law in an early discussion of ionic and covalent bonding that proves highly useful in Chapters 8 and 9.
- Chapter 4 is now completely revised to highlight precipitation, acid-base, and redox reactions. It also includes an introduction to the Brønsted-Lowry proton-transfer concept and a new section on the activity series of metals.
- Chapter 12 now includes a major new section highlighting the production and function of advanced materials—liquid crystals, electronic semiconductors, modern ceramics, and nanotechnological devices.
- Chapter 13 now introduces the concept of entropy for application to solution behavior and colligative properties.
- Chapters 15 and 23 now include an up-to-date and more visualizable treatment of isomers.

GUIDED TOUR

The pages in this Guided Tour to Chemistry: The Molecular Nature of Matter and Change, Second Edition, have been selected to walk you through the features of a chapter. As you examine them, note that a chapter begins by orienting you to the topic flow; the illustrations are placed very close to the related text; the art depicts a chemical reaction on several levels of reality simultaneously; the multipart sample problems help you plan, execute, and check the solution; the relevance of chemistry is clearly demonstrated; and the material at the end of the chapter provides many ways to review and practice the concepts and skills covered.

Displayed Topic Flow

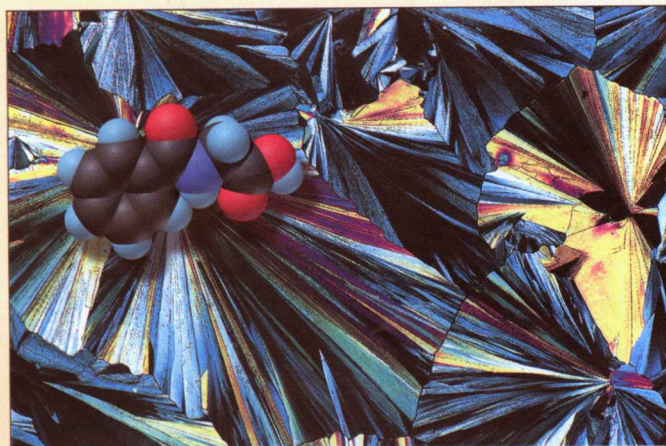
Orienting your focus on the content of the upcoming chapter—

Chapter Opener

The opener provides a thought-provoking figure and legend that relate to a main topic of the chapter.

Concepts and Skills to Review

This feature helps you prepare for the current chapter by listing important material from previous chapters that you should understand before you start reading.



15

Organic Compounds and the Atomic Properties of Carbon

Figure: Crystals of an organic compound. This color-enhanced micrograph of crystalline hippuric acid (with model hovering over it), a key amino-acid metabolite, shows one of the millions of organic compounds studied by chemists. Each of these substances either occurs in a living source, from which it is extracted and purified, or is synthesized in the laboratory. Whatever the origin, the behavior of organic compounds obeys the same chemical principles that govern all substances. Fuels, medicines, and polymers consist of organic compounds. In this chapter, you'll see that their physical and chemical properties depend on the properties of the carbon atom.

Chapter Outline

15.1 The Special Nature of Carbon and the Characteristics of Organic Molecules

- Structural Complexity
- Chemical Diversity
- 15.2 The Structures and Classes of Hydrocarbons**
 - Carbon Skeletons and Hydrogen Atoms
 - Alkanes
 - Constitutional Isomers
 - Optical Isomers
 - Alkenes and Geometric Isomers
 - Alkynes
 - Aromatic Hydrocarbons
 - Catenated Inorganic Hydrides
- 15.3 Some Important Classes of Organic Reactions**
 - Types of Organic Reactions
 - Organic Redox Reactions

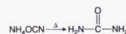
15.4 Properties and Reactivity of Common Functional Groups

- Single-Bonded Groups
- Double-Bonded Groups
- Single- and Double-Bonded Groups
- Triple-Bonded Groups
- 15.5 The Monomer-Polymer Theme I: Synthetic Macromolecules**
 - Addition Polymers
 - Condensation Polymers
- 15.6 The Monomer-Polymer Theme II: Biological Macromolecules**
 - Sugars and Polysaccharides
 - Amino Acids and Proteins
 - Nucleotides and Nucleic Acids

A living cell is a remarkable chemical system. Through elegantly controlled mechanisms, it oxidizes food for energy, maintains the concentrations of thousands of aqueous components, interacts continuously with its environment, synthesizes both simple and complex molecules for its survival and growth, and even reproduces itself. With all our technological prowess, no human-made system even approaches the cell for sheer artistry of function. This amazing chemical machine consumes, creates, and presents water, everything you put into or on your body—food, medicine, cosmetics, and clothing—consists of organic compounds. Organic fuels warm our homes, cook our meals, and power our society. Major industries are devoted to producing organic compounds, such as polymers, pharmaceuticals, and insecticides.

What is an organic compound? Dictionaries define it as “a compound of carbon,” but that definition would include carbonates, cyanides, carbides, cyanates, and other carbon-containing ionic compounds most chemists would classify as inorganic. Here is a practical, working definition: all **organic compounds** contain carbon, nearly always bonded to itself and to hydrogen, and often to other elements as well.

The word *organic* has a biological connotation arising from a major misconception that stifled research into the chemistry of living systems for many decades. In the early 19th century, many prominent thinkers believed that an unobservable spiritual energy, a “vital force,” existed within the compounds of living things, making them impossible to synthesize and fundamentally different from compounds of the mineral world. This idea of *vitalism* was challenged in 1828, when the young German chemist Friedrich Wöhler heated ammonium cyanate, a “mineral-world” compound, and produced urea, a “living-world” compound:



Although Wöhler did not appreciate the significance of this reaction—he was more interested by the fact that two compounds had the same molecular formula—his experiment is considered a key event in the origin of organic chemistry. Chemists soon synthesized methane, acetic acid, acetylene, and many other organic compounds from inorganic sources. ♦ Today we know that *the same chemical principles govern organic and inorganic systems* because the behavior of a compound arises from the properties of its elements, no matter how marvelous that behavior may be.

In this brief introduction to an enormous and ever-growing field, we continue the text's central theme—how the structure and reactivity of organic molecules emerge naturally from the properties of the component atoms, in this case carbon and its handful of bonding partners. First, we review the rather special atomic properties of carbon and see how they relate to organic molecules. We focus on hydrocarbons initially to give you a feel for writing and naming organic compounds. Then we classify the main types of organic reactions and, in the central portion of the chapter, apply them to the major families of organic compounds. Finally, we extend these ideas to the giant molecules of commerce and life—synthetic and natural polymers.

15.1 The Special Nature of Carbon and the Characteristics of Organic Molecules

Although there is nothing mystical about organic molecules, their indispensable role in biology and industry leads us to ask if carbon has some extraordinary attributes that give it a special chemical “personality.” Of course,

Concepts and Skills to Review

before you study this chapter

- naming simple alkanes (Section 2.3)
- electronegativity difference and bond polarity (Section 9.4)
- resonance structures (Section 10.1)
- VSEPR theory of molecular shape (Section 10.3)
- σ and π bonding; bond rotation (Section 11.2)
- types of intermolecular forces (Sections 12.3 and 13.1)
- properties of the Period 2 elements (Section 14.2)
- properties of the Group 4A(14) elements (Section 14.6)

Chapter Outline

The outline details the topic flow of the chapter by listing the major topics and the subtopics within them.

Introduction

The introduction points out the relevance of the topic, and the last paragraph corresponds to the sequence of topics in the Chapter Outline.

Integrated Text and Art

Using text *and* art to help you visualize chemical events and facilitate your study of the material—

Page Layout

Author and pager worked side by side to create a book of two-page spreads that place figures as close as possible to their related text. In some cases, art is even wrapped by text, so you can read concepts and see them depicted simultaneously.

Explanatory Legends

These rephrase the main text concept, so you can review much of the chapter content just by studying figures and legends. Especially significant pieces are highlighted with a red number on a yellow panel and are listed at the end of the chapter.

The Formation of Ionic Compounds

Ionic compounds are composed of **ions**, charged particles that form when an atom (or small group of atoms) gains or loses one or more electrons. The simplest type of ionic compound is a **binary ionic compound**, one composed of just two elements. It typically forms *when a metal reacts with a non-metal*. Each metal atom loses a certain number of its electrons and becomes a **cation**, a positively charged ion. At the same time, the nonmetal atoms gain the electrons lost by the metal atoms and become **anions**, negatively charged ions. The resulting cations and anions attract each other through electrostatic forces and form the ionic compound. A cation or anion derived from a single atom is called a **monatomic ion**; we'll discuss polyatomic ions, those derived from a small group of atoms, later.

The formation of the binary ionic compound sodium chloride, common table salt, is depicted in Figure 2.18, from the elements through the atomic-scale electron transfer to the compound. In the electron transfer, a sodium atom, which is neutral because it has the same number of protons as electrons, *loses* 1 electron and forms a sodium cation, Na^+ . (The charge on the ion is written as a *right superscript*.) A chlorine atom *gains* the electron and becomes a chloride anion, Cl^- . (The name change from the nonmetal atom to the ion is discussed in the next section.) Even the tiniest visible grain of

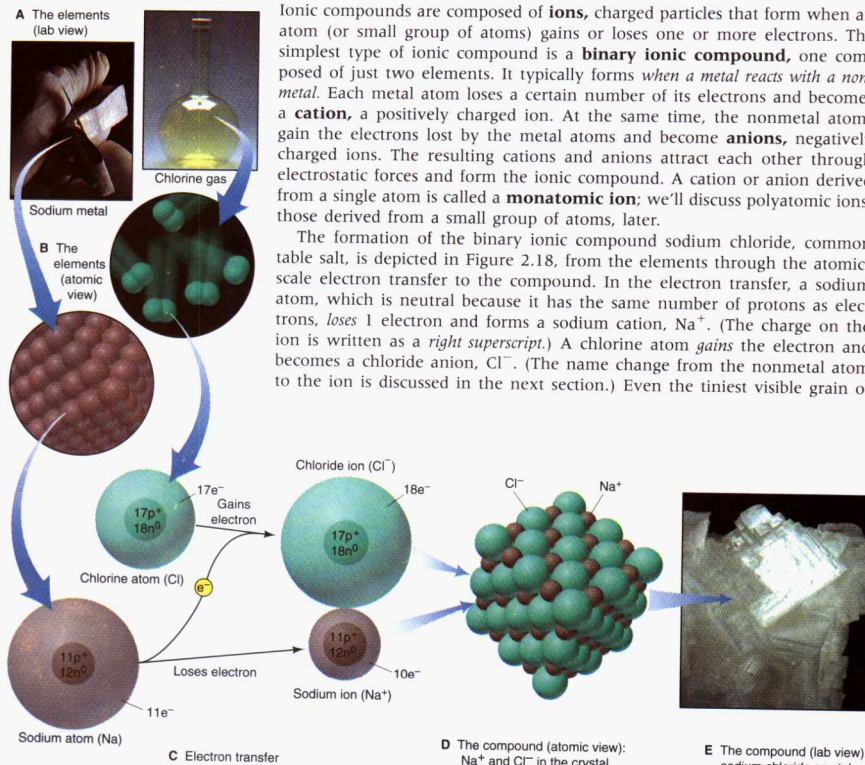


Figure 2.18 The formation of an ionic compound. A, The two elements as seen in the laboratory. B, The elements as they might appear on the atomic scale. C, The neutral sodium atom loses 1 electron to become a sodium cation (Na^+), and the chlorine atom gains 1 electron to become a chloride anion (Cl^-). (Note that when atoms lose electrons, they become smaller, and when they gain

D The compound (atomic view): Na^+ and Cl^- in the crystal

E The compound (lab view): sodium chloride crystal

electrons, they become larger.) D, Na^+ and Cl^- ions attract each other and lie in a three-dimensional crystalline array. E, This cubic array is reflected in the structure of crystalline NaCl , which occurs naturally as the mineral halite, hence the name *halogens* for the Group 7A(17) elements.

Three-Level Art

Innovated in the first edition, these provide macroscopic and molecular views of a process, so you learn to connect these two levels of reality with each other and with the chemical equation that describes the process in symbols.

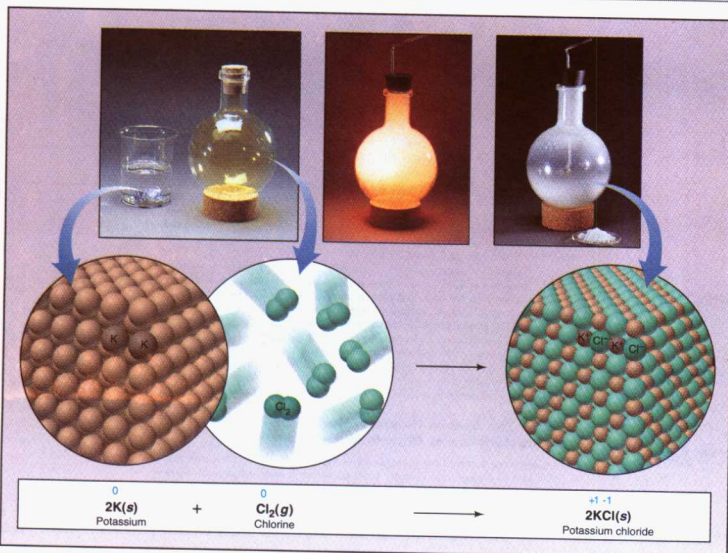
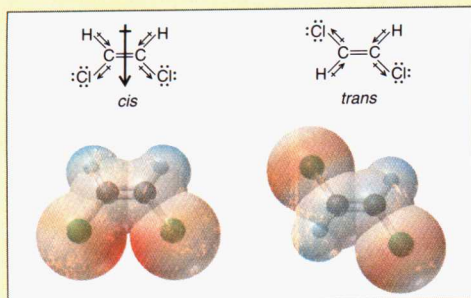


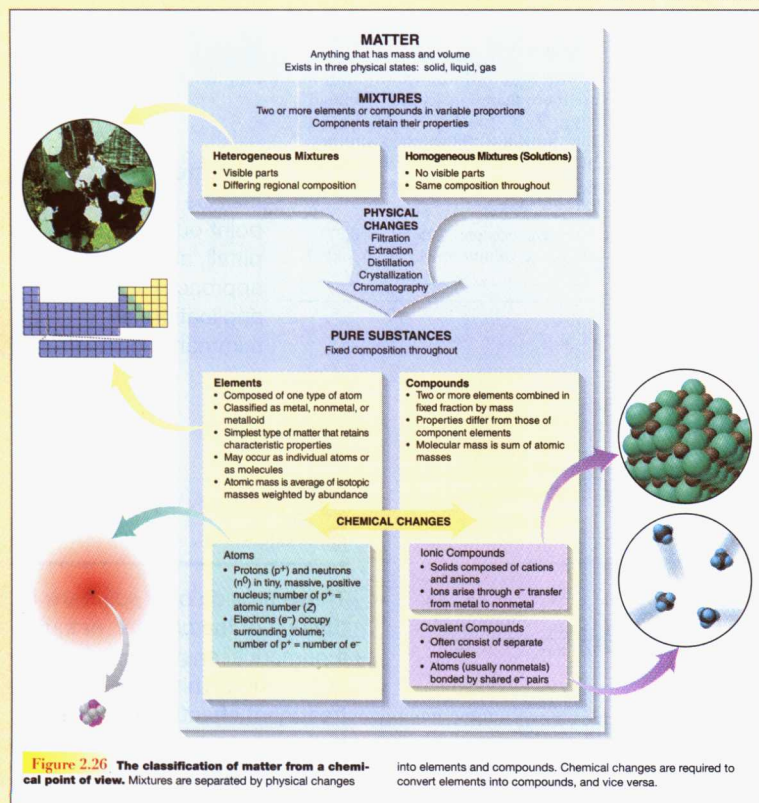
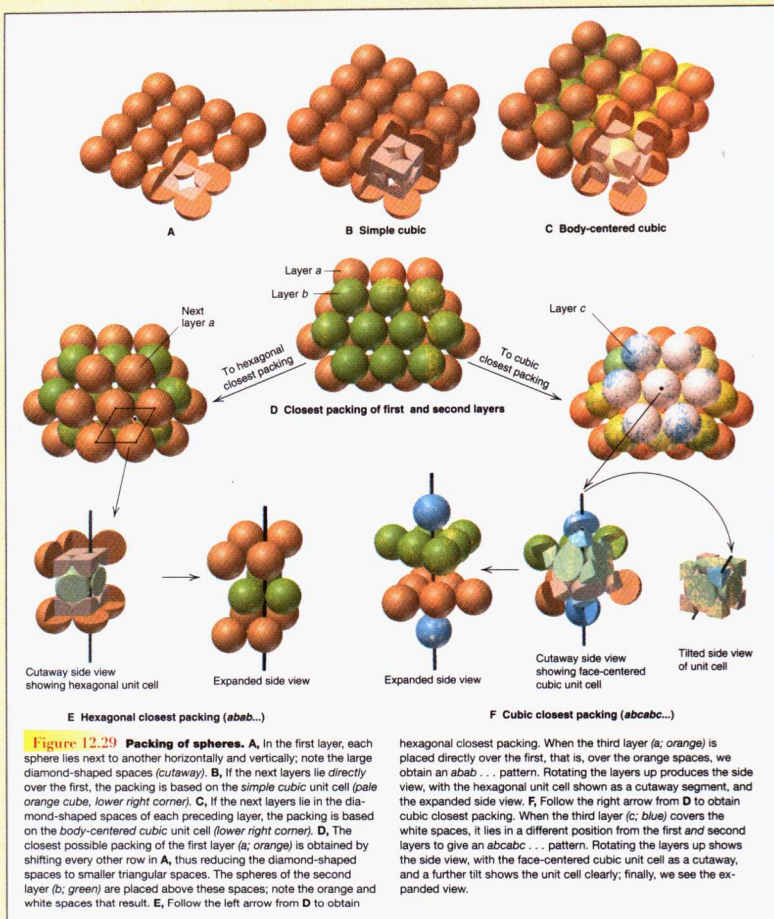
Figure 4.15 Three views of a combination reaction between elements. When the metal potassium and the nonmetal chlorine react, they form the solid ionic compound potassium chloride. The photos (top) present the view the chemist sees in the

laboratory. The blow-up arrows lead to an atomic-scale view (middle); the stoichiometry is indicated by the more darkly colored spheres. The balanced redox equation is shown with oxidation numbers (bottom).



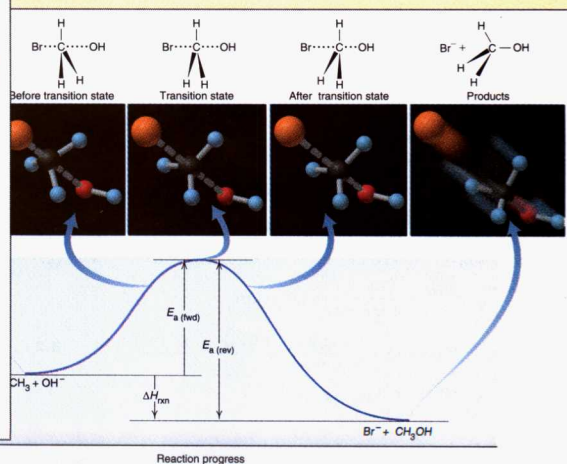
Cutting-Edge Molecular Models

Author and artist worked side by side and employed the most advanced computer-graphic software to provide accurate molecular models and vivid molecular-level scenes. This edition introduces electron density models, which depict shape, structure, and variations in electron charge within the same image.



Summary Diagrams

These illustrations show interconnections among many ideas to make your review more efficient.



Problem-Solving Method

Approaching chemistry problem solving with novel four-part Sample Problems that help you plan a strategy, solve the calculation, check the answer, and practice the new skill—

Sample Problem

A multipart worked-out problem appears when an important new concept or skill is introduced.

Plan

analyzes the steps needed to take what is known and find what is unknown. This approach helps you think through the solution *before* performing calculations.

Solution

shows the calculation steps in the same order as detailed in the Plan and Roadmap.

Check

fosters the habit of quickly going over your work to make sure the answer is chemically and mathematically reasonable—a great way to avoid careless errors on exams.

Follow-Up Problem

gives you immediate practice with the new skill by presenting a similar problem.

Sample Problem 5.2 Applying the Volume-Pressure Relationship

PROBLEM An apprentice of Boyle finds that the air trapped in a J tube occupies 24.8 cm^3 at 1.12 atm . By adding mercury to the tube, he increases the pressure on the trapped air to 2.64 atm . Assuming constant temperature, what is the new volume of air (in L)?

PLAN We must find the final volume (V_2) in liters, given the initial volume (V_1), initial pressure (P_1), and final pressure (P_2). The temperature and amount of gas are fixed. We convert the units of V_1 from cm^3 to mL and then to L, rearrange the ideal gas law to the appropriate form, and solve for V_2 . We can predict the direction of the change: since P increases, V will decrease; thus, $V_2 < V_1$. (Note the two-part roadmap.)

SOLUTION Summarizing the gas variables:

$$\begin{array}{lll} P_1 = 1.12 \text{ atm} & P_2 = 2.64 \text{ atm} & \\ V_1 = 24.8 \text{ cm}^3 \text{ (convert to L)} & V_2 = \text{unknown} & T \text{ and } n \text{ remain constant} \end{array}$$

Converting V_1 from cm^3 to L:

$$V_1 = 24.8 \text{ cm}^3 \times \frac{1 \text{ mL}}{1 \text{ cm}^3} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.0248 \text{ L}$$

Arranging the ideal gas law and solving for V_2 : At fixed n and T , we have

$$\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2} \quad \text{or} \quad P_1 V_1 = P_2 V_2$$

$$V_2 = V_1 \times \frac{P_1}{P_2} = 0.0248 \text{ L} \times \frac{1.12 \text{ atm}}{2.64 \text{ atm}} = \mathbf{0.0105 \text{ L}}$$

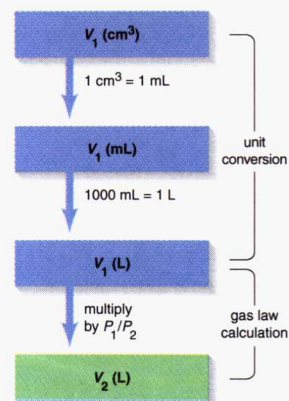
CHECK As we predicted, $V_2 < V_1$. The pressure more than doubled, so V_2 should be less than $\frac{1}{2}V_1$ ($0.0105/0.0248 < \frac{1}{2}$).

COMMENT Predicting the direction of the change provides another check on the problem setup: To make $V_2 < V_1$, we must multiply V_1 by a number *less than* 1. This means the ratio of pressures must be *less than* 1, so the larger pressure (P_2) must be in the denominator, P_1/P_2 .

Follow-up Problem 5.2 A sample of argon gas occupies 105 mL at 0.871 atm. If the temperature remains constant, what is the volume (in L) at 26.3 kPa?

Roadmap

is included in many Plans. It is a block diagram, *specific* to the problem, that visually leads you through the steps.



Comment

may be added to point out a common pitfall, alternative approach, modern application, or summarizing insight.

Answers to Follow-up Problems

$$\mathbf{5.1} \quad P_{\text{CO}_2} (\text{torr}) = (753.6 \text{ mmHg} - 174.0 \text{ mmHg})$$

$$\times \frac{1 \text{ torr}}{1 \text{ mmHg}} = 579.6 \text{ torr}$$

$$P_{\text{CO}_2} (\text{Pa}) = 579.6 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} \times \frac{1.01325 \times 10^5 \text{ Pa}}{1 \text{ atm}}$$

$$= 7.727 \times 10^4 \text{ Pa}$$

$$\begin{aligned} P_{\text{CO}_2} (\text{lb/in}^2) &= 579.6 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} \times \frac{14.7 \text{ lb/in}^2}{1 \text{ atm}} \\ &= 11.2 \text{ lb/in}^2 \end{aligned}$$

$$\mathbf{5.2} \quad P_2 (\text{atm}) = 26.3 \text{ kPa} \times \frac{1 \text{ atm}}{101.325 \text{ kPa}} = 0.260 \text{ atm}$$

$$V_2 (\text{L}) = 105 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.871 \text{ atm}}{0.260 \text{ atm}} = 0.352 \text{ L}$$

Answers to Follow-up Problems

These provide *brief solutions* at the end of the chapter, not just a numerical answer at the back of the book. This fuller treatment effectively doubles the number of worked-out problems and is an excellent way for you to reinforce skills.

Real-World Applications

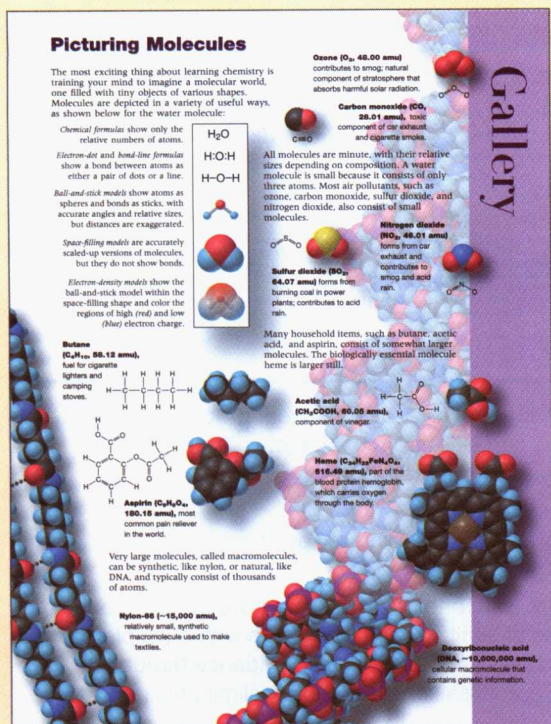
Seeing the relevance of text discussions with *concept-based* applications and four features that demonstrate how a principle affects your daily life and perhaps your future career—

Tools of the Chemistry Laboratory

These essays describe the key instruments and techniques that chemists use in modern practice to obtain the facts that underlie their theories.

Chemical Connections

These essays show the interdisciplinary nature of chemistry by applying chemical principles to related scientific fields, including physiology, geology, biochemistry, engineering, and environmental science.



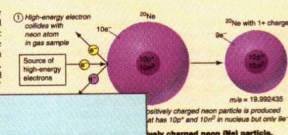
Galleries

These illustrated summaries of applications show how common and unusual substances and products relate to chemical principles. You'll learn how a ball-point pen works, why bubbles in a drink are round, why contact-lens rinse must have a certain concentration, how disposable and rechargeable batteries differ, and many other intriguing applications.

Tools of the Chemistry Laboratory

Mass Spectrometry

Mass spectrometry, the most powerful technique for measuring the mass and abundance of charged particles, is an outgrowth of electric and magnetic deflection studies on particles formed in cathode ray experiments. When a high-energy electron collides with an atom of neon-20, for example, one of the atom's electrons is knocked away and the resulting particle has one positive charge, Ne^+ .



Chemical Connections Chemistry in Physiology

Molecular Shape, Biological Receptors, and the Sense of Smell

In a very simple sense, a biological cell is a membrane-bound sack filled with molecular shapes interacting in an aqueous fluid. As a result of the magnificent internal organization of cells, many complex processes in an organism begin when a molecular "key" fits into a correspondingly shaped molecular "lock." The key can be a relatively small molecule circulating in a body fluid, whereas the lock is usually a large molecule, known as a biological receptor, that is often found embedded in a cell membrane. The receptor contains a precisely shaped cavity, or *receptor site*, that is exposed to the passing fluid. Thousands of molecules collide with this site, but when one with the correct shape (that is, the molecular key) lands on it, the receptor "grabs" it through intermolecular attractions, and the biological response begins.

Let's see how this fitting together of molecular shapes operates in the sense of smell (olfaction). A substance must have certain properties to have an odor. An odorous molecule travels through the air, so it must come from a gas or a volatile liquid or solid. To reach the receptor, it must be soluble, at least to a small extent, in the thin film of aqueous solution that lines the nasal passage. Most important, the odorous molecule, or a portion of it, must have a shape

that fits into one of the olfactory receptor sites that cover the nerve endings deep within the nasal passage (Figure 10.A). When this happens, the resulting nerve impulses travel from these endings to the brain, which interprets the impulses as a specific odor.

In the 1950s, the stereochemical theory of odor (*stereo* means "three-dimensional") was introduced to explain the relationship between odor and molecular shape. Its basic premise is that a molecule's shape (and sometimes its polarity, but not its composition, is the primary determinant of its odor). According to this theory, there are seven primary odors, each corresponding to one of seven different types of olfactory receptor sites. The seven odors are camphor-like, musky, floral, minty, ethereal, pungent, and putrid. (The last two odors depend on molecular polarity more than shape, and their receptors have partial charges opposite to those of the molecules landing there.) Figure 10.B shows the proposed shapes of three of the seven receptor sites, each occupied by a molecule having the associated odor.

Several predictions of this original version of the theory have been verified by experiment. If two substances fit the same receptor, they should have the same odor, even if

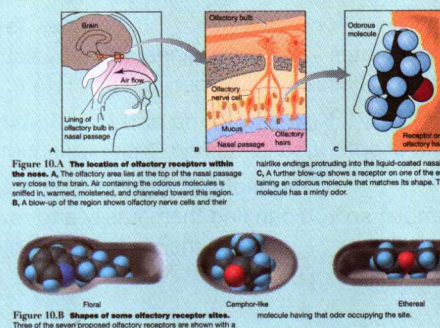


Figure 10.B. Shapes of some olfactory receptor sites. Three of the seven proposed olfactory receptors are shown with a molecule having that odor occupying the site.

Margin Notes

Over 145 short, lively explanations apply ideas in the related text. You'll explore how your body and the Earth control their temperatures, how crime labs track illegal drugs, how your lungs work, how fat-free chips and decaf coffee are made, the principle of a winning poker hand, the risks of nuclear radiation, handy tips for memorizing relationships, and much more.

Imagine an Earth Without Water Liquid water has an unusually high specific heat capacity of nearly $4.2 \text{ J/g} \cdot \text{K}$, about six times that of rock ($\sim 0.7 \text{ J/g} \cdot \text{K}$). If the Earth were devoid of oceans, the Sun's energy would heat a planet composed of rock. It would take only 0.7 J of energy to increase the temperature of each gram of rock by 1 K . Daytime temperatures would soar. The oceans also limit the temperature drop when the Sun sets, because the energy absorbed during the day is released at night. If the Earth had a rocky surface, temperatures would be frigid every night.

and Diamonds rainbow only if your back. Light surface of a water droplet and reflected. Since red light is less your eye from the sky, whereas in droplets that pass in a diamond's facets, which focus that dispersing incoming light, enough for the droplets to separate.

Review and Reinforcement

Reviewing key ideas and skills both during and after reading the main content—

Section Summary

These concise paragraphs conclude each section, immediately restating the major ideas just covered.

Chapter Perspective

With this introduction to chemical kinetics, we have begun to explore the dynamic inner workings of chemical change. Variations in reaction rate are observed through concentration and temperature changes, which operate on the molecular level through the frequency and energetics of particle collisions and the details of reactant structure. Kinetics allows us to speculate

about the molecular pathway of a reaction. Modern industry and biochemistry depend on its principles. However, speed and yield are very different aspects of a reaction. In Chapter 17, you'll see how opposing reaction rates give rise to the equilibrium state and examine how much product has formed once the net reaction has stopped.

The following learning objectives, with section and/or sample problem (SP) numbers in parentheses, can help focus your study:

Understand These Concepts

1. How reaction rate depends on concentration, particle size, and temperature (Section 16.1)
2. The meaning of reaction rate in terms of changing concentrations over time (Section 16.2)
3. How the rate can be expressed in terms of reactant or product concentrations (Section 16.2)
4. The distinction between average and instantaneous rate and why the instantaneous rate changes during the reaction (Section 16.2)
5. The interpretation of reaction rate in terms of reactant and product concentrations (Section 16.2)
6. The experimental basis of the rate law and the

17. How a reaction mechanism consists of several elementary steps, with the slowest step determining the overall rate (Section 16.7)
18. The criteria for a valid mechanism (Section 16.7)
19. How a catalyst speeds a reaction by lowering the activation energy (Section 16.8)
20. The distinction between homogeneous and heterogeneous catalysis (Section 16.8)

Master These Skills

1. Calculating instantaneous rate from the slope of a tangent to a concentration vs. time plot (Section 16.2)
2. Expressing rate in terms of changes in concentra-

Section Summary

An atom's electronegativity is related to its ability to pull bonded electrons toward it, which generates partial charges at the ends of the bond. Electronegativity increases across a period and decreases down a group, the reverse of the trend in size. The greater the ΔEN of the atoms in a bond, the more polar the bond is and the greater its ionic character. There is a gradation of bond type, from ionic to polar covalent to nonpolar covalent, which can be seen by combining a halogen with the other elements in its period.

Chapter Perspective and Learning Objectives

A brief overview at the end places the chapter in the context of previous and upcoming topics. Next, a numbered list, providing section and/or sample problem numbers, helps you focus on key concepts and skills.

Key Terms, Equations, and Figures

Key Terms

are boldfaced within the chapter. They are arranged here by section and defined again in the Glossary (with specific page reference).

Key Equations and Relationships

are numbered within the chapter and listed here with page number.

Highlighted Figures and Tables

are listed by page number, so you can find them easily and review their essential content.

For Review and Reference

Key Terms

stoichiometry
Section 3.1
mole (mol)
Avogadro's number
molar mass (M)
Section 3.2
combustion analysis

Section 3.3
chemical equation
reactant
product
balancing (stoichiometric)
coefficient

Section 3.4
overall (net) equation
limiting reactant
theoretical yield
side reaction
actual yield
percent yield (% yield)

Section 3.5
solute
solvent
concentration
molarity (M)

Key Equations and Relationships

3.1 Number of entities in one mole (p. 89):

1 mole contains 6.022×10^{23} entities (to 4 significant figures)

3.2 Converting amount (mol) to mass using M (p. 93):

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

3.3 Converting mass to amount (mol) using $\frac{1}{M}$ (p. 93):

$$\text{No. of moles} = \text{mass (g)} \times \frac{1 \text{ mol}}{\text{no. of grams}}$$

3.4 Converting amount (mol) to number of entities (p. 93):

$$\text{No. of entities} = \text{no. of moles} \times \frac{6.022 \times 10^{23} \text{ entities}}{1 \text{ mol}}$$

3.5 Converting number of entities to amount (mol) (p. 93):

$$\text{No. of moles} = \text{no. of entities} \times \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ entities}}$$

3.6 Calculating mass % (p. 96):

$$\text{Mass \% of element X} = \frac{\text{moles of X in formula} \times \text{molar mass of X (g/mol)}}{\text{mass of 1 mol of compound (g)}} \times 100$$

3.7 Calculating percent yield (p. 114):

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

3.8 Defining molarity (p. 116):

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{liters of solution}} \quad \text{or} \quad M = \frac{\text{mol solute}}{\text{L soln}}$$

3.9 Diluting a concentrated solution (p. 119):

$$M_{\text{dil}} \times V_{\text{dil}} = \text{number of moles} = M_{\text{conc}} \times V_{\text{conc}}$$

Highlighted Figures and Tables

These figures (F) and tables (T) provide a quick review of key ideas.

T2.1 Summary of mass terminology (p. 91)

T2.2 Information contained in a formula (p. 93)

F2.3 Summary of mass-mole-number relationships for elements and compounds (p. 94)

T2.8 Information contained in a balanced equation (p. 107)

F2.9 Summary of mass-mole-number relationships in a chemical reaction (p. 109)

F2.11 Summary of mass-mole-number-volume relationships in solution (p. 117)

F2.14 Overview of mole-mass-number relationships (p. 122)

End-of-Chapter Problems

An exceptionally large number of homework problems lets you practice the ideas and skills from the chapter. Three types of problems are keyed by chapter section.

Concept Review Questions

test your qualitative understanding of key ideas.

Skill-Building Exercises

are written in pairs, with one of each pair answered in the back of the book. A series of similar problems begins with a simple pair and increases in difficulty to build your confidence through a unique "weaning" process, which gradually eliminates multistep directions.

Problems in Context

apply the learned skills to interesting scenarios, with many examples from industry, medicine, and the environment.

Comprehensive Problems

follow the section-based problems. These more challenging problems rely on material from any section or earlier chapter.

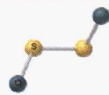


Figure P2.110



Figure P2.111

Mixtures: Classification and Separation

Concept Review Questions

2.112 To what main way is separating the components of a mixture different from separating the components of a compound?

2.113 What is the difference between a homogeneous and a heterogeneous mixture?

2.114 Is a solution a homogeneous or a heterogeneous mixture? Give an example of an aqueous solution.

Skill-Building Exercises (paired)

2.118 Classify each of the following as a compound, a homogeneous mixture, or a heterogeneous mixture: (a) distilled water; (b) gasoline; (c) beach sand; (d) wine; (e) air.

2.119 Classify each of the following as a compound, a homogeneous mixture, or a heterogeneous mixture: (a) orange juice; (b) vegetable soup; (c) cement; (d) calcium sulfate; (e) tea.

2.117 Name the technique(s) and briefly describe the procedure you would use to separate each of the following mixtures into two components: (a) table salt and pepper; (b) table sugar and sand; (c) drinking water contaminated with fuel oil; (d) vegetable oil and vinegar.

2.118 Name the technique(s) and briefly describe the procedure you would use to separate each of the following mixtures into two components: (a) crushed ice and crushed glass; (b) table sugar dissolved in ethanol; (c) iron and sulfur; (d) two pigments (chlorophyll *a* and chlorophyll *b*) from spinach leaves.

Problems in Context

2.119 Which separation method is operating in each of the following procedures?

(a) Pouring a mixture of cooked pasta and boiling water into a colander

(b) Removing colored impurities from raw sugar to make refined sugar

(c) Preparing coffee by pouring hot water through ground coffee beans

2.120 Illicit "street" drugs are often mixed with an inactive substance, such as ascorbic acid (vitamin C). After obtaining a sample of cocaine, government chemists separate the mixture into its component substances. By calculating the mass of vitamin C per gram of drug sample, they can track the drug's distribution. For example, if different samples of cocaine obtained on the streets of New York, Los Angeles, and Paris all contain 0.6384 g vitamin C per gram of sample, they very likely come from a common source. Is this street sam-

Comprehensive Problems

Problems with an asterisk (*) are more challenging.

2.121 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, and 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 6.646×10^{-24} g, and each of its two electrons has a mass of 9.109×10^{-28} g. What fraction of this atom's mass is contributed by its nucleus?

2.122 Before neutrons were discovered, Rutherford suggested that electrons resided both within the nucleus and around it. How could such a model give an atom with mass and charge similar to that of our current model?

2.123 Why is the atomic mass unit very close to the mass of a proton or of a neutron?

2.124 The scenes lettered A-I depict various types of matter on the atomic scale. Choose the correct scene(s) for each of the following:

(a) A mixture that fills its container

(b) A substance that cannot be broken down into any simpler substances

(c) An element with a very high resistance to flow

(d) A homogeneous mixture

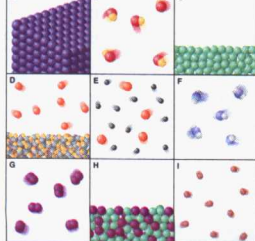
(e) An element that fills its container but displays a surface

(f) A gas consisting of diatomic particles

(g) A gas that can be broken down into simpler substances

(h) A substance with a 2:1 number ratio of its component atoms

(i) Matter that can be separated into its component substances by physical means



Learning the Chemistry of the Elements

The periodic table, the central organizing icon for the chemistry of the elements, is introduced in Chapter 2 and applied throughout the book. Helping you understand this rich, diverse material with two unique features—

Interchapter

This multipage, illustrated *Perspective on the Properties of the Elements* reviews the major points in Chapters 7–13 that deal with atomic properties and their resulting effects on element behavior.

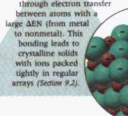
Characteristics of Chemical Bonding

Chemical bonds are the forces that hold atoms (or ions) together in an element or compound. The type of bonding, bond properties, nature of orbital overlap, and number of bonds determine physical and chemical behavior.

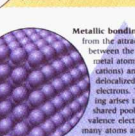
Types of Bonding

There are three idealized bonding models: ionic, covalent, and metallic.

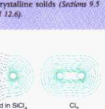
Ionic bonding results from the attraction between positive and negative ions. The ions arise through electron transfer between atoms with a large ΔEN (from metal to nonmetal). This bonding leads to crystalline solids with ions packed tightly in regular arrays (Section 9.2).



Covalent bonding results from the attraction between two nuclei and a localized electron pair. The bond arises through electron sharing between atoms with a small ΔEN (usually two nonmetals) and leads to discrete molecules with specific shapes or to extended networks (Section 9.3).



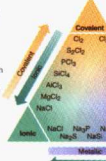
Metallic bonding results from the attraction between the nuclei of metal atoms (metal cations and their delocalized valence electrons). This bonding arises through the shared pooling of valence electrons from many atoms and leads to crystalline solids (Sections 9.5 and 12.6).



The actual bonding in real substances usually lies between these distinct models (Section 9.4). The electron density depictions show that electron clouds overlap slightly even in ionic bonding (NaCl). They overlap significantly in polar covalent bonding (an Si-Cl bond from SiCl₄) and completely in nonpolar covalent bonding (Cl₂).

The triangular diagram shows the continuum of bond types among all the Period 3 main-group elements.

Along the left leg of the triangle, compounds of each element with chlorine display a gradual change from ionic to covalent bonding and a decrease in bond polarity.



Along the right leg, the elements themselves display a gradual change from covalent to metallic bonding.

Along the base, compounds of each element with sodium display a gradual change from ionic to metallic bonding and, once again, a decrease in bond polarity.

TOPIC 2 Characteristics of Chemical Bonding

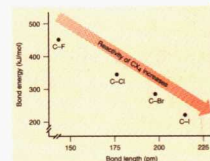
Bond Properties

There are two important properties of a covalent bond (Section 9.3).

Bond length is the distance between the nuclei of bonded atoms.

Bond energy (bond strength) is the enthalpy change required to break a given bond in 1 mol of gaseous molecules. Among similar compounds, these bond properties are related to each other and to reactivity, as shown in the graph for the carbon tetrahalides (CX₄). Note that

- As bond length increases, bond energy decreases. Shorter bonds are stronger bonds.
- As bond energy decreases, reactivity increases.



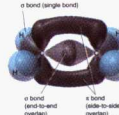
Nature of Orbital Overlap

In a covalent bond, the shared electrons reside in the entire region composed of the overlapping orbitals of the two atoms. The diagram depicts the bonding in ethylene (C₂H₄).

Bond order is one-half the number of electrons shared.

Bond orders of 1 (single bond) and 2 (double bond) are common; a bond order of 3 (triple bond) is much less common.

Fractional bond orders occur when there are resonance structures for species with adjacent single and double bonds (Sections 9.3 and 11.1).

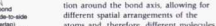
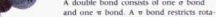


Orbitals overlap in two ways, which leads to two types of bonds (Section 11.2).

End-to-end overlap of s, p, and hybrid atomic orbitals leads to a sigma (σ) bond, one with electron density distributed above and below the bond axis.

Side-to-side overlap of p with p, or sometimes d, orbitals leads to a pi (π) bond, one with electron density distributed around the bond axis, allowing for different spatial arrangements of the atoms and, therefore, different molecules.

A double bond consists of one σ bond and one π bond. A π bond restricts rotation around the bond axis, allowing for different spatial arrangements of the atoms and, therefore, different molecules. Pi bonds are often sites of reactivity; for example,

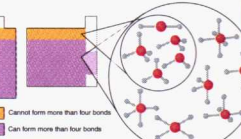


Number of Bonds and Molecular Shape

The shape of a molecule is defined by the positions of the nuclei of the bonded atoms. According to VSEPR theory (Section 10.3), the number of electron groups in the valence level of a central atom, which is based on the number of bonding and lone pairs, is the key factor that determines molecular shape. The small periodic table shows that

The elements in Period 2 cannot form more than four bonds because they have a maximum of four (one s and three p) valence orbitals. (Only carbon forms four bonds routinely.) Molecular shapes (small circle) are based on linear, trigonal planar, and tetrahedral electron-group arrangements.

Many elements in Period 3 or higher can form more than four bonds by including empty d orbitals and, thus, expanding their valence levels. Shapes include those above and others based on trigonal bipyramidal and octahedral electron-group arrangements (large circle).



Family Portrait Group 2A(2): The Alkaline Earth Metals

Key Atomic and Physical Properties

Atomic No.	Symbol	Atomic mass	Valence e ⁻ configuration	Common oxidation states
4	Be	9.012	2s ²	+2

12	Mg	24.30	3s ²	+2
20	Ca	40.08	4s ²	+2
38	Sr	87.62	5s ²	+2
86	Ba	137.3	6s ²	+2
88	Ra	(226)	7s ²	+2

Atomic Properties

Group electron configuration is ns² (filled or sub-levels). All members have the +2 oxidation state and, except for Be, form compounds with an ionic bond.

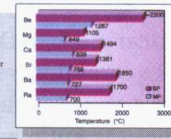
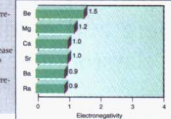
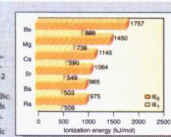
Atomic and ionic sizes increase down the group but are smaller than for the corresponding 1A(1) element.

IE and EN decrease down the group but are higher than for the corresponding 1A(1) element.

Physical Properties

Metallic bonding involves two valence e⁻. These metals are still relatively soft but are much harder than the 1A(1) metals.

Melting and boiling points generally decrease, and densities generally increase down the group. These values are much higher than for 1A(1), and the trend is not as regular.



Group 2A(2): The Alkaline Earth Metals Family Portrait

Some Reactions and Compounds

Important Reactions

The elements (E) act as reducing agents in reactions 1 to 5; note the similarity to reactions of Group 1A(1). Reaction 6 shows the general behavior of the oxides; reaction 7 shows the general insolubility of the carbonates at high temperature.

1. The metals reduce O₂ to form the oxide:
2E(s) + O₂(g) → 2E₂O(s)
Be also forms the peroxide, BeO₂.

2. The larger metals reduce water to form hydrogen gas:
E(s) + 2H₂O(l) → E²⁺(aq) + 2OH⁻(aq) + H₂(g)
(E = Ca, Sr, Ba)

Be and Mg form an adherent oxide coating that allows only slight reaction.

3. The metals reduce halogens to form ionic halides:
E(s) + X₂ → EX₂(s) (X = F, Cl, Br, I)

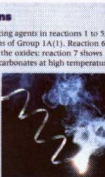
4. Most of the elements reduce hydrogen to form ionic hydrides:
E(s) + H₂(g) → EH₂(s) (E = all except Be)

5. Most of the elements reduce nitrogen to form ionic nitrides:
3E(s) + N₂(g) → E₃N₂(s) (E = all except Be)

6. Except for amphoteric BeO, the oxides are basic:
EO(s) + H₂O(l) → E²⁺(aq) + 2OH⁻(aq)
Ca(OH)₂ is a component of cement and mortar.

7. All carbonates undergo thermal decomposition to the oxide:
BCO₃(s) → BaO(s) + CO₂(g)

This reaction is used to produce CaO (lime) in huge amounts from naturally occurring limestone [see Margin Note, p. 550].



Magnesium ribbon burning

2. The larger metals reduce water to form hydrogen gas:
E(s) + 2H₂O(l) → E²⁺(aq) + 2OH⁻(aq) + H₂(g)
(E = Ca, Sr, Ba)

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E(s) + X₂ → EX₂(s) (X = F, Cl, Br, I)

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Important Compounds

1. Beryll, BeAl₂Si₂O₁₀. Beryl, the industrial source of Be, metal, also occurs as a gemstone with a variety of colors (see photo). It is chemically identical to emerald, except for the trace of Cr³⁺ that gives emerald its green color.

2. Magnesium oxide, MgO. Because of its high melting point (2852°C), MgO is used as a refractory material for furnace brick (see photo) and wire insulators.

3. Alkylmagnesium halides, RMgX (R = hydrocarbon group; X = halogen). These compounds, called Grignard reagents, are used to synthesize many organic compounds. Organosilicon agricultural fungicides are made by treating RMgX with SiCl₄.
3RMgCl + SiCl₄ → 3MgCl₂ + R₃SiCl

4. Calcium carbonate, CaCO₃. Occurs as enormous natural deposits of limestone, marble, chalk, and coral. Used as a building material, to make lime, and, in high purity, as a toothpaste abrasive and an antacid (see photo).

5. Calcium hydroxide, Ca(OH)₂. Used as a building material, to make lime, and, in high purity, as a toothpaste abrasive and an antacid (see photo).

6. Calcium oxide, CaO. Used as a building material, to make lime, and, in high purity, as a toothpaste abrasive and an antacid (see photo).

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A Complete Package of Supplements for Instructor and Student

Even though the written text remains at the core of the great majority of general chemistry courses, the modern presentation of concepts and the practice of skills now uses many other resources. Several excellent print and multimedia supplements have been prepared to accompany the text and make learning chemistry as meaningful and up-to-date as possible:

For the Instructor: *Print Supplements*

- **Instructor's Resource Manual** by Martin Silberberg
This manual, which is also available via the Silberberg On-Line Learning Center (www.mhhe.com/silberberg), contains discussions of chapter purpose and approach, alternative topic sequences, chapter outlines, strategies for incorporating descriptive chemistry, and recommended lab separates.
- **Instructor's Solutions Manual** by Alan Pribula, Frank Milio, and Thomas Berg, Towson University
This manual contains complete, worked-out solutions for all end-of-chapter problems in the text.
- **Test Bank** by S. Walter Orchard, University of Puget Sound
This valuable resource contains over 1,800 questions organized by chapter. Question types include multiple choice, true/false, and short answer.
- **Computerized Test Bank**
A computerized test generator is available in both Windows and Macintosh formats and enables instructors to generate tests from questions in the Test Bank.
- **Transparencies**
A boxed set of 300 full-color transparency acetates features images from the text selected by Martin Silberberg and modified to ensure maximum readability in both small and large classroom settings.

For the Instructor: *Media Supplements*

The Silberberg Visual Resource Library CD-ROM is an outstanding multimedia product that combines three exceptional resources:

- **McGraw-Hill Animation Library for General Chemistry**
This resource features over 50 high-quality animations of topics from throughout the course that can be used for classroom presentation.
- **Text Image Library**
This resource contains over 500 images from the text that can be used for stand-alone classroom presentation or inclusion into a PowerPoint presentation.
- **PowerPoint Lecture Presentation** by William Zoller, University of Washington
This fully editable presentation includes slides outlining the content from each chapter of the text. Where appropriate, illustrations from the Text Image Library have been included.

For the Student: *Print Supplements*

- **Student Study Guide** by Elizabeth Weberg
This excellent resource covers the most important points in every chapter of the text. Clearly formatted and illustrated, it develops concepts and skills in a friendly, relaxed style that forestalls student confusion. The guide contains numerous worked-out examples, key points to keep in mind, and a large number of additional problems (with answers) for self-test purposes.
- **Student Solutions Manual** by Deborah Wiegand, University of Washington, and Tris Samberg, Cascadia Community College
This manual contains complete worked-out solutions to all follow-up problems and the end-of-chapter problems designated with colored numbers. It presents solutions using the same problem-solving approach that is presented in the text.
- **Schaum's Outline of College Chemistry** by Jerome Rosenberg, Michigan State University, and Lawrence Epstein, University of Pittsburgh
This helpful study aid provides students with hundreds of solved and supplementary problems for the general chemistry course.

For the Student: *Media Supplements*

- **Silberberg 2/e On-Line Learning Center** www.mhhe.com/silberberg
Free to students and instructors using the text, the Silberberg On-Line Learning Center offers a variety of supplementary material to enhance the study of chemistry. A key feature of the Center is the over 1,800 interactive quiz questions (75 per chapter) that allow students to quiz themselves on the concepts presented in the text. The Center also offers additional activities for each chapter in the text, including Super Challenge exercises, ChemQuest web exercises, and molecular modeling exercises.
- **Chemistry Study Partner** by Martin Silberberg
Through the use of interactive problem solving and state-of-the-art animations that incorporate student-controlled simulations, this unique CD-ROM tutors students in many of the central ideas and skills from the course. Moreover, the CD-ROM links to the Silberberg On-Line Learning Center, so students can quiz themselves on concepts as they are presented.
- **Cyberchem**
This innovative CD-ROM provides a highly interactive study and tutorial package for the one-year general chemistry course. It contains 60 animations of concepts, 25 interactive lab simulations, and 25 movies focusing on real-world applications, along with interactive problem-solving and quizzing modules.
- **Molecules 3D: Molecular Modeling Software** by Molecular Arts Corporation
This powerful and innovative, yet inexpensive, software for Windows and Macintosh incorporates an expandable library of more than 100 structures to allow construction of virtually any molecule for 3D examination. It also allows conversion of Lewis structures to VSEPR-based molecular shapes at the click of a button.
- **Chem Skill Builder** by Electronic Homework Systems
This extremely useful CD-ROM generates questions for students for every topic in the general chemistry course. The questions are presented in a randomized fashion with a constant mix of variables so that no two students will receive the same questions. The application provides feedback for students when incorrect answers are entered, and the answers can be submitted to an instructor for grading.