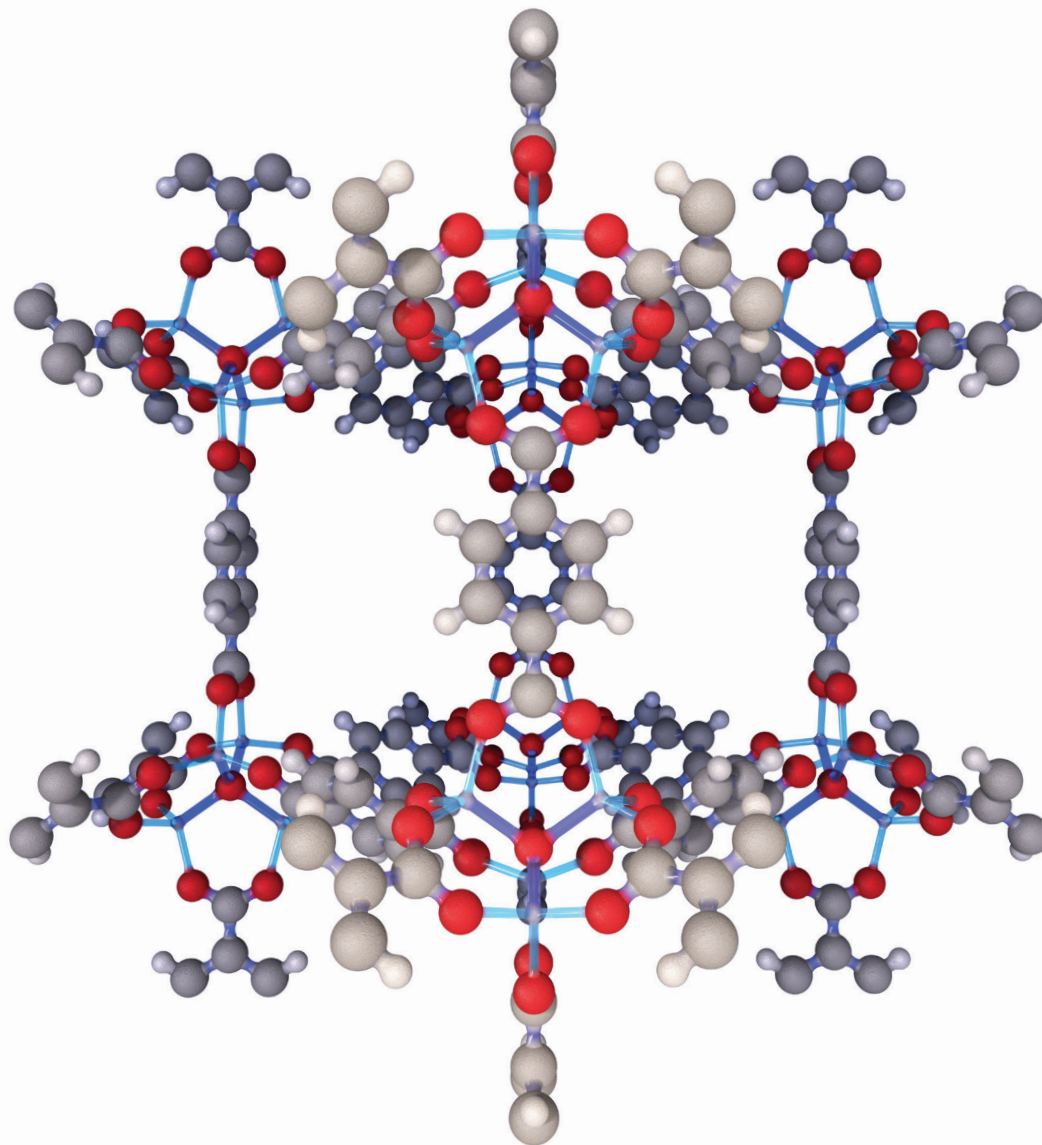


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Martin Silberberg Patricia Amateis



CHEMISTRY

The Molecular Nature of Matter and Change

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The Elements

Name	Symbol	Atomic Number	Atomic Mass*	Name	Symbol	Atomic Number	Atomic Mass*
Actinium	Ac	89	(227)	Mendelevium	Md	101	(258)
Aluminum	Al	13	26.98	Mercury	Hg	80	200.59
Americium	Am	95	(243)	Molybdenum	Mo	42	95.95
Antimony	Sb	51	121.76	Moscovium	Mc	115	(289)
Argon	Ar	18	39.79	Neodymium	Nd	60	144.24
Arsenic	As	33	74.92	Neon	Ne	10	20.18
Astatine	At	85	(210)	Neptunium	Np	93	(237)
Barium	Ba	56	137.33	Nickel	Ni	28	58.69
Berkelium	Bk	97	(249)	Nihonium	Nh	113	(285)
Beryllium	Be	4	9.012	Niobium	Nb	41	92.91
Bismuth	Bi	83	208.98	Nitrogen	N	7	14.01
Bohrium	Bh	107	(272)	Nobelium	No	102	(259)
Boron	B	5	10.81	Oganesson	Og	118	(294)
Bromine	Br	35	79.90	Osmium	Os	76	190.23
Cadmium	Cd	48	112.41	Oxygen	O	8	16.00
Calcium	Ca	20	40.08	Palladium	Pd	46	106.42
Californium	Cf	98	(252)	Phosphorus	P	15	30.97
Carbon	C	6	12.01	Platinum	Pt	78	195.08
Cerium	Ce	58	140.12	Plutonium	Pu	94	(239)
Cesium	Cs	55	132.91	Polonium	Po	84	(210)
Chlorine	Cl	17	35.45	Potassium	K	19	39.10
Chromium	Cr	24	52.00	Praseodymium	Pr	59	140.91
Cobalt	Co	27	58.93	Promethium	Pm	61	(145)
Copernicium	Cn	112	(285)	Protactinium	Pa	91	231.04
Copper	Cu	29	63.55	Radium	Ra	88	(226)
Curium	Cm	96	(247)	Radon	Rn	86	(222)
Darmstadtium	Ds	110	(281)	Rhenium	Re	75	186.21
Dubnium	Db	105	(262)	Rhodium	Rh	45	102.91
Dysprosium	Dy	66	162.5	Roentgenium	Rg	111	(280)
Einsteinium	Es	99	(252)	Rubidium	Rb	37	85.47
Erbium	Er	68	167.26	Ruthenium	Ru	44	101.07
Europium	Eu	63	151.96	Rutherfordium	Rf	104	(261)
Fermium	Fm	100	(257)	Samarium	Sm	62	150.36
Fleevorium	Fl	114	(287)	Scandium	Sc	21	44.96
Fluorine	F	9	19.00	Seaborgium	Sg	106	(266)
Francium	Fr	87	(223)	Selenium	Se	34	78.97
Gadolinium	Gd	64	157.25	Silicon	Si	14	28.08
Gallium	Ga	31	69.72	Silver	Ag	47	107.87
Germanium	Ge	32	72.63	Sodium	Na	11	22.99
Gold	Au	79	196.97	Strontium	Sr	38	87.62
Hafnium	Hf	72	178.49	Sulfur	S	16	32.06
Hassium	Hs	108	(277)	Tantalum	Ta	73	180.95
Helium	He	2	4.003	Technetium	Tc	43	(98)
Holmium	Ho	67	164.93	Tellurium	Te	52	127.6
Hydrogen	H	1	1.008	Tennessine	Ts	117	(293)
Indium	In	49	114.82	Terbium	Tb	65	158.93
Iodine	I	53	126.90	Thallium	Tl	81	204.38
Iridium	Ir	77	192.22	Thorium	Th	90	232.04
Iron	Fe	26	55.85	Thulium	Tm	69	168.93
Krypton	Kr	36	83.80	Tin	Sn	50	118.71
Lanthanum	La	57	138.91	Titanium	Ti	22	47.87
Lawrencium	Lr	103	(262)	Tungsten	W	74	183.84
Lead	Pb	82	207.2	Uranium	U	92	238.03
Lithium	Li	3	6.938	Vanadium	V	23	50.94
Livermorium	Lv	116	(291)	Xenon	Xe	54	131.29
Lutetium	Lu	71	174.97	Ytterbium	Yb	70	173.05
Magnesium	Mg	12	24.30	Yttrium	Y	39	88.91
Manganese	Mn	25	54.94	Zinc	Zn	30	65.38
Meitnerium	Mt	109	(276)	Zirconium	Zr	40	91.22

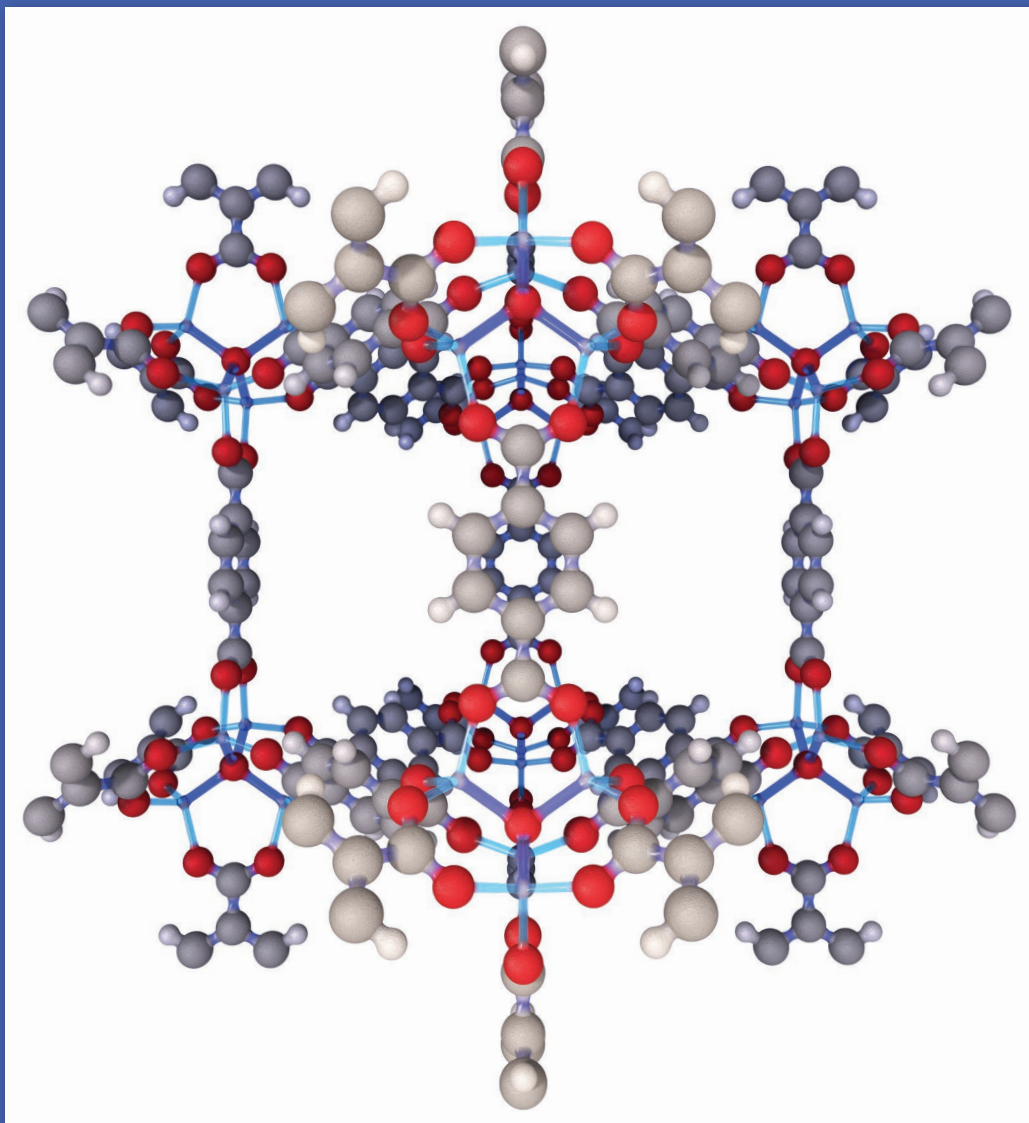
*Values in parentheses represent the mass number of the most stable isotope.

Martin Silberberg Patricia Amateis

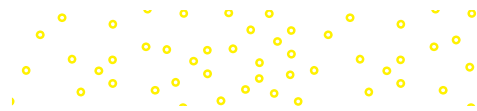
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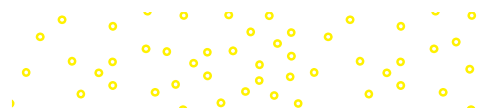
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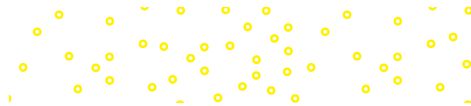
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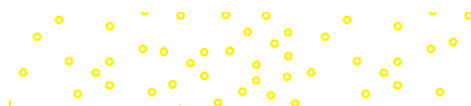


To Ruth and Daniel, with all my love and gratitude.

MSS

To my grandson Ben: I hope you love
chemistry one day!

PGA



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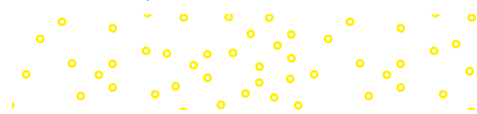
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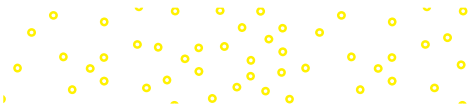
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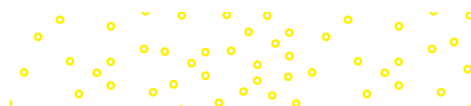
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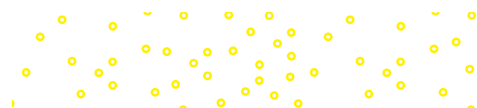
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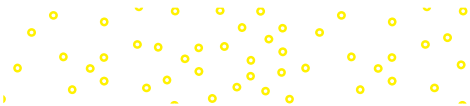
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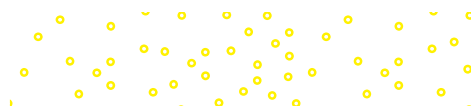
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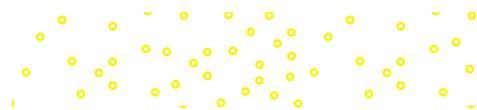
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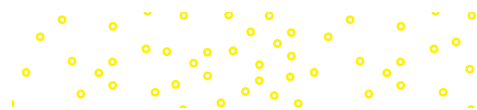
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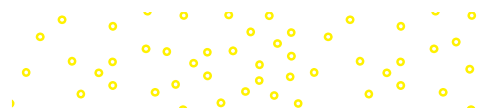
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ABOUT THE AUTHORS



Courtesy of Ruth Melnick

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Courtesy of Ralph L. Amateis

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PREFACE

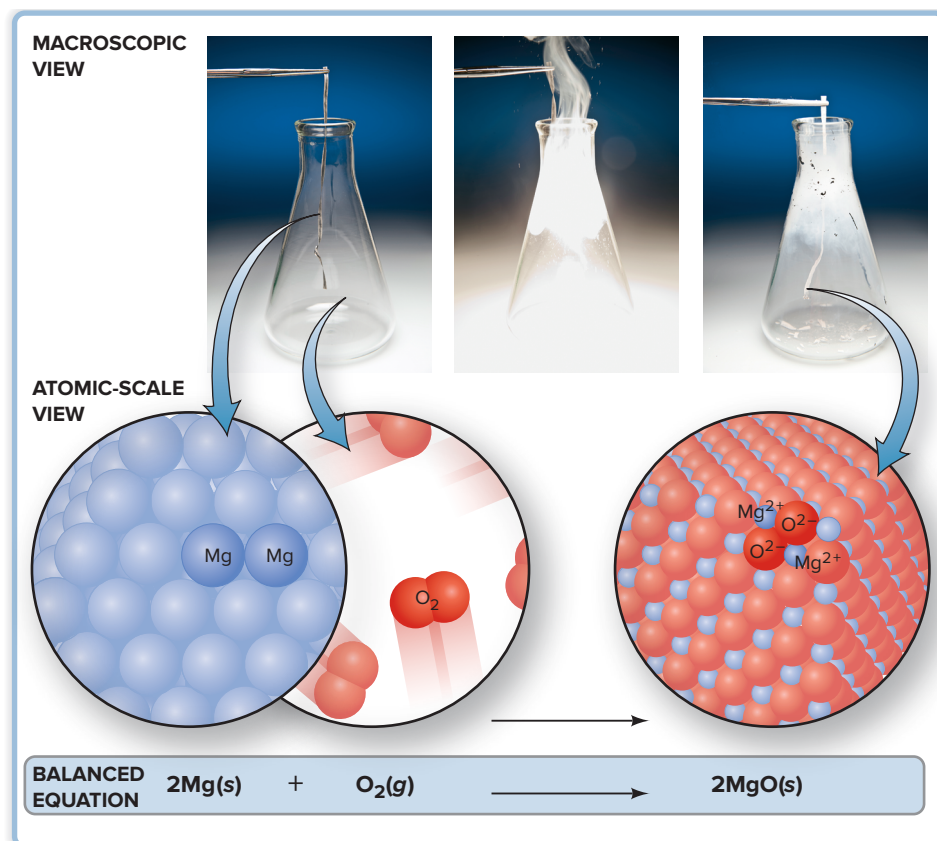
Chemistry is so crucial to an understanding of medicine and biology, environmental science, and many areas of engineering and industrial processing that it has become a requirement for an increasing number of academic majors. Furthermore, chemical principles lie at the core of some of the key societal issues we face in the 21st century—dealing with climate change, finding new energy options, and supplying nutrition and curing disease on an ever more populated planet.

SETTING THE STANDARD FOR A CHEMISTRY TEXT

The tenth edition of *Chemistry: The Molecular Nature of Matter and Change* maintains its standard-setting position among general chemistry textbooks by evolving further to meet the needs of professor and student. The text still contains the most accurate molecular illustrations, consistent step-by-step worked problems, and an extensive collection of end-of-chapter problems. And changes throughout this edition make the text more readable and succinct, the artwork more teachable and modern, and the design more focused and inviting. The three hallmarks that have made this text a market leader are now demonstrated in its pages more clearly than ever.

Visualizing Chemical Models—Macroscopic to Molecular

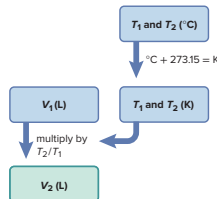
Chemistry deals with observable changes caused by unobservable atomic-scale events, requiring an appreciation of a size gap of mind-boggling proportions. One of the text's goals coincides with that of so many instructors: to help students visualize chemical events on the molecular scale. Thus, concepts are explained first at the macroscopic level and then from a molecular point of view, with pedagogic illustrations always placed next to the discussions to bring the point home for 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*, which fosters the habit of “thinking through” both the chemical and the quantitative reasonableness of the answer. Finally, for *practice* and reinforcement, each sample problem is followed immediately by *two* similar follow-up problems. And *Chemistry* marries problem solving to visualizing models with molecular-scene problems, which appear not only in homework sets, as in other texts, but also in the running text, where they are worked out stepwise.

Road Map



SAMPLE PROBLEM 5.3 | Applying the Volume-Temperature and Pressure-Temperature Relationships

Problem A balloon is filled with 1.95 L of air at 25°C and then placed in a car sitting in the sun. What is the volume of the balloon when the temperature in the car reaches 90°C?

Plan We know the initial volume (V_1) and the initial (T_1) and final (T_2) temperatures of the gas; we must find the final volume (V_2). The pressure of the gas is fixed, since the balloon is subjected to atmospheric pressure, and n is fixed, since air cannot escape or enter the balloon. We convert both T values to kelvins, rearrange the ideal gas law, and solve for V_2 (see the road map).

Solution Summarizing the gas variables:

$$\begin{array}{ll} V_1 = 1.95 \text{ L} & V_2 = \text{unknown} \\ T_1 = 25^\circ\text{C (convert to K)} & T_2 = 90^\circ\text{C (convert to K)} \\ P \text{ and } n \text{ remain constant} & \end{array}$$

Converting T from °C to K:

$$T_1 (\text{K}) = 25^\circ\text{C} + 273.15 = 298 \text{ K} \quad T_2 (\text{K}) = 90^\circ\text{C} + 273.15 = 363 \text{ K}$$

Rearranging the ideal gas law and solving for V_2 : at fixed n and P , we have

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

$$V_2 = V_1 \times \frac{T_2}{T_1} = 1.95 \text{ L} \times \frac{363 \text{ K}}{298 \text{ K}} = 2.38 \text{ L}$$

Check Let's predict the change to check the math: because $T_2 > T_1$, we expect $V_2 > V_1$. Thus, the temperature ratio should be greater than 1 (T_2 in the numerator). The T ratio is about 1.2 ($363/298$), so the V ratio should also be about 1.2 ($2.38/1.95 \approx 1.2$).

FOLLOW-UP PROBLEMS

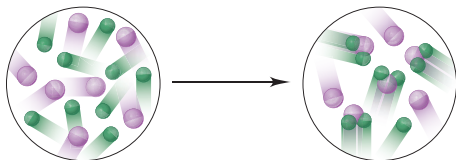
5.3A A steel tank used for fuel delivery is fitted with a safety valve that opens if the internal pressure exceeds 1.00×10^3 torr. The tank is filled with methane at 23°C and 0.991 atm and placed in boiling water at 100°C. What is the pressure in the heated tank? Will the safety valve open?

5.3B A sample of nitrogen occupies a volume of 32.5 L at 40°C. Assuming that the pressure remains constant, what temperature (in °C) will result in a decrease in the sample's volume to 28.6 L?

SOME SIMILAR PROBLEMS 5.26–5.29

SAMPLE PROBLEM 2.3 | Visualizing the Mass Laws

Problem The scenes below represent an atomic-scale view of a chemical reaction:



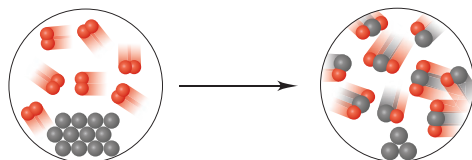
Which of the mass laws—mass conservation, definite composition, and/or multiple proportions—is (are) illustrated?

Plan From the depictions, we note the numbers, colors, and combinations of atoms (spheres) to see which mass laws pertain. If the numbers of each atom are the same before and after the reaction, the total mass did not change (mass conservation). If a compound forms that always has the same atom ratio, the elements are present in fixed parts by mass (definite composition). If the same elements form different compounds and the ratio of the atoms of one element that combine with one atom of the other element is a small whole number, the ratio of their masses is a small whole number as well (multiple proportions).

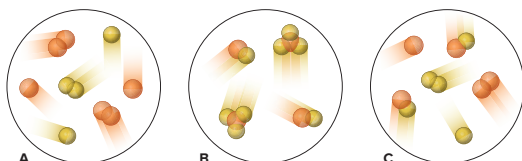
Solution There are seven purple and nine green atoms in each circle, so mass is conserved. The compound formed has one purple and two green atoms, so it has definite composition. Only one compound forms, so the law of multiple proportions does not pertain.

FOLLOW-UP PROBLEMS

2.3A The following scenes represent a chemical change. Which of the mass laws is (are) illustrated?



2.3B Which sample(s) best display(s) the fact that compounds of bromine (orange) and fluorine (yellow) exhibit the law of multiple proportions? Explain.



SOME SIMILAR PROBLEMS 2.22 and 2.23

SAMPLE PROBLEM 5.4 | Applying the Volume-Amount and Pressure-Amount Relationships

Problem A scale model of a blimp rises when it is filled with helium to a volume of 55.0 dm³. When 1.10 mol of He is added to the blimp, the volume is 26.2 dm³. How many more grams of He must be added to make it rise? Assume constant T and P .

Plan We are given the initial amount of helium (n_1), the initial volume of the blimp (V_1), and the volume needed for it to rise (V_2), and we need the additional mass of helium to make it rise. So, we first need to find n_2 . We rearrange the ideal gas law to the appropriate form, solve for n_2 , subtract n_1 to find the additional amount (n_{add}), and then convert moles to grams (see the road map).

Applying Ideas to the Real World

As the most practical science, chemistry should have a textbook that highlights its countless applications. Moreover, today's students may enter emerging chemistry-related hybrid fields, like biomaterials science or planetary geochemistry, and the text they use should point out the relevance of chemical concepts to such related sciences. The *Chemical Connections* and *Tools of the Laboratory* boxed essays (which include problems for added relevance), the more pedagogic margin notes, and the many applications woven into the chapter content are up-to-date, student-friendly features that are directly related to the neighboring content.

CHEMICAL CONNECTIONS TO ENVIRONMENTAL ENGINEERING

Most water destined for human use comes from lakes, rivers, reservoirs, or groundwater. Present in this essential resource may be soluble toxic organic compounds and high concentrations of NO_3^- and Fe^{2+} , colloidal clay and microbes, and suspended debris. Let's see how water is treated to remove these dissolved, dispersed, and suspended particles.

Water Treatment Plants

Treating water involves several steps (Figure B13.1):

Step 1. Screening and settling. As water enters the facility, screens remove debris, and settling removes sand and other particles.

Step 2. Coagulating. This step and the next two remove colloids. These particles have negative surfaces that repel each other. Added aluminum sulfate [cake alum; $\text{Al}_2(\text{SO}_4)_3$] or iron(III) chloride (FeCl_3), which supply Al^{3+} or Fe^{3+} ions that neutralize the charges, coagulates the particles through intermolecular forces.

Step 3. Flocculating and sedimenting. Mixing water and flocculating agents in large basins causes a fluffy *floc* to form. Added cationic polymers form long-chain bridges between floc particles, which grow bigger and flow into other basins, where they form a sediment and are removed. Some plants use *dissolved air flotation* (DAF) instead: bubbles forced through the water attach to the floc, and the floating mass is skimmed.

Step 4. Filtering. Various filters remove remaining particles. In *slow sand filters*, the water passes through sand and/or gravel of increasing particle size. In *rapid sand filters*, the sand is backwashed with water, and the colloidal mass is removed. Membrane filters (not shown) with pore sizes of 0.1–10 μm are thin tubes.

Solutions and Colloids in Water Purification

Step 5. Disinfecting. Water sources often contain harmful microorganisms that are killed by one of three agents:

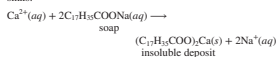
- Chlorine, as aqueous bleach (ClO^-) or Cl_2 , is most common, but carcinogenic chlorinated organic compounds can form.
- UV light emitted by high-intensity fluorescent tubes disinfects by disrupting microorganisms' DNA.
- Ozone (O_3) gas is a powerful oxidizing agent.

Sodium fluoride (NaF) is used to prevent tooth decay and phosphate salts to prevent leaching of lead from pipes may then be added.

Step 6 (not shown). Adsorbing onto granular activated carbon (GAC). Petroleum and other organic contaminants are removed by adsorption. GAC is a highly porous agent formed by "activating" wood, coal, or coconut shells with steam: 1 kg of GAC has a surface area of 275 m^2 !

Water Softening via Ion Exchange

Water with large amounts of 2+ ions, such as Ca^{2+} and Mg^{2+} , is called **hard water**. Combined with fatty-acid anions in soap, these cations form solid deposits on clothes, washing machines, and sinks:



When a large amount of HCO_3^- is present, the cations form *scale*, a carbonate deposit in boilers and hot-water pipes that interferes with the transfer of heat:

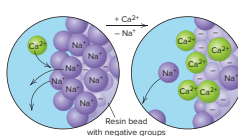


Figure B13.2 Ion exchange to remove hard-water cations.

anionic groups, such as $-\text{SO}_3^-$ or $-\text{COO}^-$, and Na^+ ions for charge balance (Figure B13.2). The hard-water cations displace the Na^+ ions and bind to the anionic groups. When all resin sites are occupied, the resin is regenerated with concentrated Na^+ solution that exchanges Na^+ ions for bound Ca^{2+} and Mg^{2+} .

Membrane Processes and Reverse Osmosis

Membranes with 0.0001–0.01 μm pores can remove unwanted ions from water. Recall that solutions of different concentrations separated by a semipermeable membrane create osmotic pressure. In **reverse osmosis**, a pressure *greater* than the osmotic pressure is *applied* to the more concentrated solution to force water back through the membrane and filter out ions. In homes, toxic *heavy-metal* ions, such as Pb^{2+} , Cd^{2+} , and Hg^{2+} , are removed this way. On a large scale, reverse osmosis is used for **desalination**, which can convert seawater (40,000 ppm of ions) to drinking water (400 ppm) (Figure B13.3). There are over 18,000 desalination units worldwide, providing water for 300 million people.

Wastewater Treatment

Wastewater, used domestic or industrial water, is treated in several ways before being returned to a natural source:

- In **primary** treatment, the water enters a settling basin to remove particles.
 - In **biological** treatment, bacteria metabolize organic compounds and are then removed by settling.
 - In **advanced** treatment, a process is tailored to remove a specific pollutant. For example, ammonia, which causes excessive growth of plants and algae, is removed in two steps:
 1. **Nitrification.** Certain bacteria oxidize ammonia (electron donor) with O_2 (electron acceptor) to form nitrate ion:

$$\text{NH}_4^+ + 2\text{O}_2 \rightarrow \text{NO}_3^- + 2\text{H}^+ + \text{H}_2\text{O}$$
 2. **Denitrification.** Other bacteria oxidize an added compound, like methanol (CH_3OH), using the NO_3^- :

$$5\text{CH}_3\text{OH} + 6\text{NO}_3^- \rightarrow 3\text{N}_2 + 5\text{CO}_2 + 7\text{H}_2\text{O} + 6\text{OH}^-$$
- Thus, the process converts NH_3 in wastewater to N_2 , which is released to the atmosphere.

Problems

- B13.1.** Briefly answer each of the following:
- Why is cake alum [$\text{Al}_2(\text{SO}_4)_3$] added during water purification?
 - Why is water that contains large amounts of Ca^{2+} and Mg^{2+} difficult to use for cleaning?
 - What is the meaning of *reverse* in reverse osmosis?
 - Why might a water treatment plant use ozone as a disinfectant instead of chlorine?
 - How does passing a saturated NaCl solution through a "spent" ion-exchange resin regenerate the resin?
- B13.2.** Wastewater discharged into a stream by a sugar refinery contains 3.55 g of sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) per liter. A government-sponsored study is testing the feasibility of removing the sugar by reverse osmosis. What pressure must be applied to the wastewater solution at 20.°C to produce pure water?

TOOLS OF THE LABORATORY

Nuclear Magnetic Resonance (NMR) Spectroscopy

In addition to mass spectrometry (Chapter 2) and infrared (IR) spectroscopy (Chapter 9), one of the most useful tools for analyzing organic and biochemical structures is **nuclear magnetic resonance (NMR) spectroscopy**, which measures the molecular environments of certain nuclei in a molecule.

Like electrons, several types of nuclei, such as ^{13}C , ^{19}F , ^3H , and ^1H , act as if they spin in either of two directions, each of which creates a tiny magnetic field. In this discussion, we focus primarily on ^1H -NMR spectroscopy, which measures changes in the nuclei of the most common isotope of hydrogen. Oriented randomly, the magnetic fields of all the ^1H nuclei in a sample of compound, when placed in a strong external magnetic field (B_0), become aligned either *with* the external field (parallel) or *against* it (antiparallel). Most nuclei adopt the parallel orientation, which is slightly lower in energy. The energy difference (ΔE) between the two energy states (spin states) lies in the radio-frequency (rf) region of the electromagnetic spectrum (Figure B15.1).

When an ^1H (blue arrow) in the lower energy (parallel) spin state absorbs a photon in the radio-frequency region with an energy equal to ΔE , it "flips" in a process called **resonance**, to the higher energy (antiparallel) spin state. The system then re-emits that energy, which is detected by the rf receiver of the ^1H -NMR spectrometer. The ΔE between the two states depends on the *actual* magnetic field acting on each ^1H nucleus, which is affected by the tiny magnetic fields of the *electrons* of atoms adjacent to that nucleus. Thus, the ΔE required for resonance of each ^1H nucleus depends on its specific molecular environment—the C atoms, electronegative atoms, multiple bonds, and aromatic rings around it. ^1H nuclei in different molecular environments produce different peaks in the ^1H -NMR spectrum.

An ^1H -NMR spectrum, which is unique for each compound, is a series of peaks that represents the resonance as a function of the changing magnetic field. The **chemical shift** of the ^1H nuclei in a given environment is where a peak appears. Chemical shifts are shown relative to that of an added standard, tetramethylsilane [$(\text{CH}_3)_4\text{Si}$, or TMS]. TMS has 12 ^1H nuclei bonded to four C atoms that are bonded to one Si atom in a tetrahedral arrangement, so all 12 are in identical environments and produce only one peak.

Figure B15.2 shows the ^1H -NMR spectrum of acetone. The six ^1H nuclei of acetone have identical environments: all six are bonded to two C atoms that are each bonded to the C atom involved in the $\text{C}=\text{O}$ bond. So one peak is produced, but at a different position from the TMS peak. The spectrum of dimethylmethane in Figure B15.3 shows two peaks in addition to the TMS peak, since the ^1H nuclei have two different environments. The taller peak is due to the six ^1H nuclei in the two CH_3 groups, and the shorter peak is due to the two ^1H nuclei in the CH_2 group. The area under each peak (given as a number of chart-paper grid spaces) is proportional to the *number of ^1H nuclei in a given environment*. Note that the area ratio is $20.3/6.8 \approx 3/1$, the same as the ratio of six nuclei in the CH_3 groups to two in the CH_2 group. Thus, by analyzing the chemical shifts and peak areas, the chemist learns the type and number of hydrogen atoms in the compound.

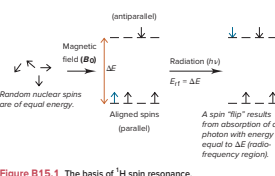


Figure B15.1 The basis of ^1H spin resonance.

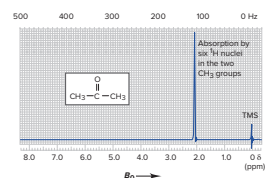
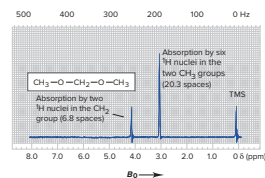


Figure B15.2 The ^1H -NMR spectrum of acetone.



(continued) Figure B15.3 The ^1H -NMR spectrum of dimethylmethane.

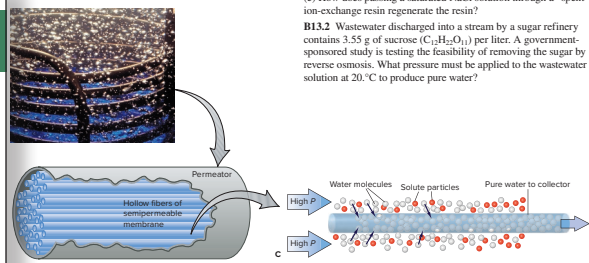
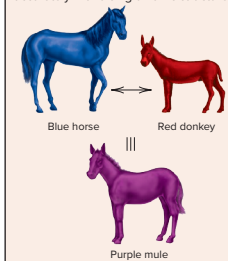


Figure B13.3 Reverse osmosis to remove ions. **A**, Part of a reverse-osmosis permeator. **B**, Each permeator contains a bundle of hollow fibers of semipermeable membrane. **C**, Pumping seawater at high pressure removes ions, and pure water enters the fibers and is collected. Source: (A) Robert Eysel/NY/The Image Bank/Getty Images

A Purple Mule, Not a Blue Horse and a Red Donkey

A mule is a genetic mix, a hybrid, of a horse and a donkey; it is not a horse one instant and a donkey the next. Similarly, the color purple is a mix of red and blue, not red one instant and blue the next. In the same sense, a resonance hybrid is one molecular species, not one resonance structure the instant and another resonance structure the next. The problem is that we cannot depict the actual species, the hybrid, accurately with a single Lewis structure.



Reinforcing through Review and Practice

A favorite feature, the section summaries that conclude every section restate the major ideas concisely and immediately (rather than postponing such review until the end of the chapter).

A rich catalog of study aids ends each chapter to help students review the content:

- **Learning Objectives**, with section and/or sample problem numbers, focus on the concepts to understand and the skills to master.
- **Key Terms**, boldfaced and defined within the chapter, are listed here by section (with page numbers), as well as being defined in the *Glossary*.
- **Key Equations and Relationships** are highlighted and numbered within the chapter and listed here with page numbers.
- **Chapter Practice Test** is a new feature in the tenth edition. Students can test their knowledge of each chapter's topics with a ten-question multiple-choice practice test. The Practice Test questions thoroughly cover the concepts in each chapter. Answers are provided at the end of the test and complete solutions are available in the electronic textbook.
- **Brief Solutions to Follow-up Problems** triple the number of worked problems by providing multistep calculations at the end of the chapter, rather than just numerical answers at the back of the book.

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.

CHAPTER REVIEW GUIDE		
Learning Objectives	Relevant section (S) and/or sample problem (SP) numbers appear in parentheses.	
Understand These Concepts	Master These Skills	
1. The defining characteristics of the three types of matter—element, compound, and mixture—on the macroscopic and atomic levels, and of the particles within them—atoms, molecules, and ions (§2.1)	1. Distinguishing elements, compounds, and mixtures at the atomic scale (SP 2.1)	
2. The types of mixtures and their properties (§2.1)	2. Using the mass ratio of element to compound to find the mass of an element in a compound (SP 2.2)	
3. The significance of the three mass laws—mass conservation, definite composition, and multiple proportions (§2.2)	3. Visualizing the mass laws (SP 2.3)	
4. The postulates of Dalton's atomic theory and how it explains the mass laws (§2.2)	4. Determining the numbers of subatomic particles in the isotopes of an element (SP 2.4)	
5. The major contribution of experiments by Thomson, Millikan, and Rutherford to our understanding of atomic structure (§2.3)	5. Calculating an atomic mass from isotopic composition (SP 2.5)	
6. The structure of the atom, the main features of the subatomic particles, and the importance of isotopes in determining atomic mass (§2.4)	6. Identifying an element from its Z value (SP 2.6)	
7. The format of the periodic table and the general location and characteristics of metals, metalloids, and nonmetals (§2.5)	7. Predicting the ion an element forms (SP 2.7)	
8. The essential features of ionic and covalent compounds and the distinction between them (§2.6)	8. Naming and writing the formula of an ionic compound formed from the ions in Tables 2.4–2.6 (SPs 2.8–2.11, 2.16)	
	9. Naming and writing the formula of an acid and its anion (SP 2.12)	
	10. Naming and writing the formula of a binary covalent compound (SPs 2.13, 2.14, 2.16)	
	11. Calculating the molecular or formula mass of a compound (SP 2.15, 2.16)	
Key Terms	Page numbers appear in parentheses.	
anion (64)	covalent compound (64)	ion (64)
atom (42)	crystallization (44)	monatomic ion (65)
atomic mass (59)	Dalton (Da) (58)	neutron (n^0) (55)
atomic mass unit (amu) (58)	distillation (44)	nonmetal (62)
atomic number (Z) (56)	electron (e^-) (55)	nucleus (55)
atomic symbol (57)	element (42)	oxoanion (71)
binary covalent compound (74)	filtration (44)	percent by mass (mass percent, mass %) (47)
binary ionic compound (64)	formula mass (76)	period (61)
cathode ray (52)	formula unit (76)	periodic table of the elements (61)
cation (64)	fraction by mass (mass fraction) (47)	polyatomic ion (67)
chemical bond (64)	group (61)	proton (p^+) (55)
chemical formula (68)	heterogeneous mixture (43)	substance (41)
chromatography (44)	homogeneous mixture (solution) (43)	volatility (44)
compound (42)	hydrate (71)	molecular mass (76)
covalent bond (66)		molecule (42)
Key Equations and Relationships	Page numbers appear in parentheses.	
2.1 Finding the mass of an element in a given mass of compound (48):	2.3 Calculating the average atomic mass of the isotopes of an element (59):	
Mass of element in sample = mass of compound in sample \times $\frac{\text{mass of element in compound}}{\text{mass of compound}}$	Atomic mass = \sum (isotopic mass)(fractional abundance of isotope)	
2.2 Calculating the number of neutrons in an atom (57):	2.4 Determining the molecular mass of a formula unit of a compound (76):	
Number of neutrons = mass number – atomic number or, $N = A - Z$	Molecular mass or formula mass = sum of atomic masses	

CHAPTER PRACTICE TEST

The answers to the Practice Test problems are shown below and the full solutions can be found in the e-book.

1. Which of the following two statements are *not* correct? Select both answers.

- (a) The atomic number gives the number of electrons in a neutral atom.
 (b) SrF_2 is an ionic compound.
 (c) Group 16 nonmetals have a charge of 2– in binary ionic compounds.
 (d) The inner transition elements are all metals.
 (e) In the compound carbon tetrachloride, carbon forms ions with a 4+ charge.

(f) Mixtures and compounds can be separated into their pure component substances by physical means.

2. How many protons, neutrons, and electrons does $^{90}\text{Zr}^{3+}$ have?

- (a) 50 protons, 40 neutrons, and 47 electrons
 (b) 40 protons, 50 neutrons, and 40 electrons
 (c) 50 protons, 50 neutrons, and 53 electrons
 (d) 40 protons, 50 neutrons, and 43 electrons
 (e) 40 protons, 50 neutrons, and 37 electrons
 (f) 43 protons, 90 neutrons, and 40 electrons

3. What is the formula of cobalt(III) sulfite?

- (a) CoSO_4 (b) Co_2S_3 (c) $\text{Co}_2(\text{SO}_3)_2$
 (d) $\text{Co}_2(\text{SO}_4)_2$ (e) $\text{Co}_2(\text{SO}_3)_3$ (f) Co_2S_3

4. A metallic element forms an ionic compound with bromine, having the formula XBBr_2 . This ion of element X has 70 electrons. What is the identity of the element?

- (a) Yb (b) Hf (c) Pb (d) Ho (e) W

5. Which is the correct formula for the compound formed between the 6th period alkali metal and the hypobromite ion?

- (a) Rb_2BrO (b) $\text{Sr}(\text{BrO})_2$ (c) Cs_2BrO
 (d) RbBrO (e) $\text{Ba}(\text{BrO})_2$ (f) CsBrO

6. Two of the following compounds are incorrectly named. Select both compounds that are incorrectly named.

- (a) CuF_2 copper(II) fluoride
 (b) As_2O_5 tetraarsenic pentoxide
 (c) AlCl_3 aluminum chlorite
 (d) K_3PO_4 potassium phosphide
 (e) H_2SO_3 sulfurous acid

7. A compound is composed of carbon, hydrogen, and oxygen. If a sample of the compound has a mass of 171.2 g and the compound is 42.1% carbon and 51.4% oxygen, what is the mass of hydrogen in the sample?

- (a) 6.50 g (b) 11.1 g (c) 18.7 g
 (d) 21.4 g (e) 26.3 g

8. Calcium has five stable isotopes: ^{40}Ca (39.96 amu), ^{42}Ca (41.96 amu), ^{44}Ca (42.96 amu), ^{46}Ca (43.96 amu), and ^{48}Ca (45.96 amu). Which one of these isotopes is the most abundant?

- (a) ^{40}Ca (b) ^{42}Ca (c) ^{44}Ca (d) ^{46}Ca (e) ^{48}Ca

9. The element antimony has two naturally occurring isotopes: ^{121}Sb and ^{123}Sb . Given that the isotopic masses of these two isotopes are 120.9038 amu and 122.9042 amu, respectively, and the average atomic mass of antimony is 121.76 amu, calculate the percent abundance of ^{121}Sb .

- (a) 42.80% (b) 57.20% (c) 32.12% (d) 66.54% (e) 61.42%

10. A sample of a compound contains 2.04 kg of aluminum and 1.81 kg of oxygen. What mass of aluminum is in a 7.11 kg sample of the compound?

- (a) 3.56 kg (b) 3.14 kg (c) 3.77 kg
 (d) 4.11 kg (e) 5.02 kg

Answers: 1. c, f; 2. c; 3. c; 4. e; 5. f; 6. c, d; 7. b; 8. a; 9. b; 10. c

BRIEF SOLUTIONS TO FOLLOW-UP PROBLEMS

2.1A (a) There is only one type of atom (blue) present, so this is an element. (b) Two different atoms (orange and green) appear in a fixed ratio of 1/1, so this is a compound. (c) These molecules consist of one type of atom (orange), so this is an element.

2.1B There are two types of particles reacting (left circle), one with two blue atoms and the other with two orange; the depiction shows a mixture of two elements. In the product (right circle), all the particles have one blue atom and one orange; this is a compound.

2.2A Mass (g) of fool's gold

$$= 86.2 \text{ g fool's gold} \times \frac{110.0 \text{ g fool's gold}}{51.2 \text{ g fool's gold}}$$

$$= 185 \text{ g fool's gold}$$

Mass (g) of sulfur = 185 g fool's gold – 86.2 g iron

$$= 98.8 \text{ g sulfur}$$

2.2B Mass (g) of silver

$$= 3.57 \text{ g silver bromide} \times \frac{15.4 \text{ g silver}}{26.8 \text{ g silver bromide}}$$

$$= 2.05 \text{ g silver}$$

Mass (g) of bromine = 3.57 g silver bromide – 2.05 g silver

$$= 1.52 \text{ g bromine}$$

2.3A There are 12 black atoms and 14 red atoms in each circle (mass conservation). In the right circle, there are molecules of two compounds—one compound has one black and one red atom, and the other has one black and two red atoms (multiple proportions). Each compound has a fixed ratio of black-to-red atoms (definite composition).

2.3B Sample B. Two bromine-fluorine compounds appear. In one, there are three fluorine atoms for each bromine; in the other, there is one fluorine for each bromine. Therefore, the masses of fluorine that combine with a given mass of bromine are in a 3/1 ratio.

Finally, an exceptionally large number of qualitative, quantitative, and molecular-scene problems end each chapter. Four types of problems are presented—three by chapter section, with comprehensive problems following:

- **Concept Review Questions** test qualitative understanding of key ideas.
- **Skill-Building Exercises** are grouped in similar pairs, with one of each pair answered in the back of the book. A group of similar exercises may begin with explicit steps and increase in difficulty, gradually weaning the student from the need for multistep directions.
- **Problems in Context** apply the skills learned in the skill-building exercises to interesting scenarios, including realistic examples dealing with industry, medicine, and the environment.
- **Comprehensive Problems**, mostly based on realistic applications, are more challenging and rely on material from any section of the current chapter or any previous chapter.

PROBLEMS

Problems with **colored** numbers are answered in Appendix E and worked in detail in the Student Solutions Manual. Problem sections match those in the text and give the numbers of relevant sample problems. Most offer Concept Review Questions, Skill-Building Exercises (grouped in pairs covering the same concept), and Problems in Context. The Comprehensive Problems are based on material from any section or previous chapter.

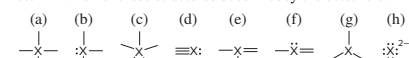
Depicting Molecules and Ions with Lewis Structures (Sample Problems 10.1 to 10.5)

Concept Review Questions

10.1 Which of these atoms *cannot* serve as a central atom in a Lewis structure: (a) O; (b) He; (c) F; (d) H; (e) P? Explain.

10.2 When is a resonance hybrid needed to adequately depict the bonding in a molecule? Using NO_2 as an example, explain how a resonance hybrid is consistent with the actual bond length, bond strength, and bond order.

10.3 In which of these structures does X obey the octet rule?



10.4 What is required for an atom to expand its valence shell? Which of the following atoms can expand its valence shell: F, S, H, Al, Se, Cl?

Skill-Building Exercises (grouped in similar pairs)

10.5 Draw a Lewis structure for (a) SiF_4 ; (b) SeCl_2 ; (c) COF_2 (C is the central atom).

10.6 Draw a Lewis structure for (a) PH_4^+ ; (b) C_2F_4 ; (c) SbH_3 .

10.7 Draw a Lewis structure for (a) PF_3 ; (b) H_2CO_3 (both H atoms are attached to O atoms); (c) CS_2 .

10.8 Draw a Lewis structure for (a) CH_4S ; (b) S_2Cl_2 ; (c) CHCl_3 .

10.9 Draw Lewis structures of all the important resonance forms of (a) NO_2^+ ; (b) NO_2F (N is central).

10.10 Draw Lewis structures of all the important resonance forms of (a) HNO_3 (atom sequence: HONO_2); (b) HAsO_4^{2-} (atom sequence: HOAsO_3^{2-}).

10.11 Draw Lewis structures of all the important resonance forms of (a) N_5^+ ; (b) NO_2^- .

10.12 Draw Lewis structures of all the important resonance forms of (a) HCO_2^- (H is attached to C); (b) HBrO_4 (HOBrO_3).

10.13 Draw the Lewis structure with lowest formal charges, and determine the charge of each atom in (a) IF_5 ; (b) AlH_4^- .

10.14 Draw the Lewis structure with lowest formal charges, and determine the charge of each atom in (a) $\text{S}_2\text{O}_3^{2-}$; (b) NO .

10.15 Draw the Lewis structure with lowest formal charges, and determine the charge of each atom in (a) CN^- ; (b) ClO^- .

10.16 Draw the Lewis structure with lowest formal charges, and determine the charge of each atom in (a) ClF_2^+ ; (b) ClNO .

10.17 Draw a Lewis structure for a resonance form of each ion with the lowest possible formal charges, show the charges, and give oxidation numbers of the atoms: (a) BrO_3^- ; (b) SO_3^{2-} .

10.18 Draw a Lewis structure for a resonance form of each ion with the lowest possible formal charges, show the charges, and give oxidation numbers of the atoms: (a) AsO_4^{3-} ; (b) ClO_2^- .

10.19 These species do not obey the octet rule. Draw a Lewis structure for each, and state the type of octet-rule exception: (a) BH_3 (b) AsF_4^- (c) SeCl_4

10.20 These species do not obey the octet rule. Draw a Lewis structure for each, and state the type of octet-rule exception: (a) PF_6^- (b) ClO_3 (c) H_3PO_3 (one P—H bond)

10.21 These species do not obey the octet rule. Draw a Lewis structure for each, and state the type of octet-rule exception: (a) BrF_3 (b) ICl_2^- (c) BeF_2

10.22 These species do not obey the octet rule. Draw a Lewis structure for each, and state the type of octet-rule exception: (a) O_3^- (b) XeF_2 (c) SbF_4^-

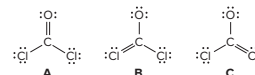
Problems in Context

10.23 Molten beryllium chloride reacts with chloride ion from molten NaCl to form the BeCl_4^{2-} ion, in which the Be atom attains an octet. Show the net ionic reaction with Lewis structures.

10.24 Despite many attempts, the perbromate ion (BrO_7^-) was not prepared in the laboratory until about 1970. (In fact, articles were published explaining theoretically why it could never be prepared!) Draw a Lewis structure for BrO_7^- in which all atoms have lowest formal charges.

10.25 Cryolite (Na_3AlF_6) is an indispensable component in the electrochemical production of aluminum. Draw a Lewis structure for the AlF_6^- ion.

10.26 Phosgene is a colorless, highly toxic gas that was employed against troops in World War I and is used today as a key reactant in organic syntheses. From the following resonance structures, select the one with the lowest formal charges:



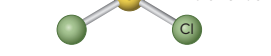
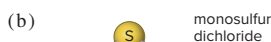
Comprehensive Problems

2.116 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?

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



2.118 Polyatomic ions are named by patterns that apply to elements in a given group. Using the periodic table and Table 2.6, give the name of each of the following: (a) SeO_4^{2-} ; (b) AsO_4^{3-} ;

OPTIMIZING THE TEXT

The modern chemistry student's learning experience is changing dramatically. To address the changes that students face, a modern text partnered with a suite of robust digital tools must continue to evolve. With each edition, students and instructors alike have been involved in refining this text. From one-on-one interviews, focus groups, and symposia, as well as extensive chapter reviews and class tests, we learned that everyone praises the pioneering molecular art; the stepwise problem-solving approach; the abundant mix of qualitative, quantitative, and applied end-of-chapter problems; and the rigorous *and* student-friendly coverage of mainstream topics.

Global Changes to Every Chapter

Making the concepts clearer through digital learning resources. Students will be able to access digital learning resources throughout this text's eBook. These learning resources present summaries of concepts and worked examples, including videos of chemistry instructors solving problems or modeling concepts that students can view over and over again. Thus, students can have an "office hour" moment at any time.

Student Hot Spots We are very pleased to incorporate real student data points and input, derived from thousands of our users, to help guide our revision. With these data, we were able to both hone our text content when needed and, for particularly challenging concepts, point students to the learning resource videos that can elucidate and reinforce those concepts. You'll see these marginal features throughout the text. Students should log into ALEKS and view the resources through our eBook.

Applying ideas with enhanced problems throughout the chapters. The much admired four-part problem-solving format (plan, solution, check, follow-up) is retained in the tenth edition, in both data-based and molecular-scene *Sample Problems*. Two *Follow-up Problems* are included with each sample problem, as well as a list of *Similar Problems* within the end-of-chapter problem set. *Brief Solutions* for all of the follow-up problems appear at the end of each chapter (rather than providing just a numerical answer in a distant end-of-book appendix, as is typical). The tenth edition has over 250 sample problems and over 500 follow-up problems. In many chapters, several sample and follow-up problems (and their brief solutions) were revised in this edition with two goals in mind. We sought to provide students with a variety of problems that would clearly elucidate concepts and demonstrate problem-solving techniques, while giving students the opportunity to be challenged and gain competence. We also included more intermediate steps in the solutions to both sample and follow-up problems so that students could more easily follow the solutions, and we have included Road Maps with even more sample problems to show students how to plan their solutions.

Re-learning ideas with annotated illustrations. The innovative three-level figures and other art that raised the bar for molecular visualization in chemistry textbooks is still present. Several existing figures have been revised and several new ones added to create an even better teaching tool. We continue to streamline figure legends by placing their content into clarifying annotations with the figures themselves.

Solution Finding the mass (kg) of uranium in 102 kg of pitchblende:

$$\text{Mass (kg) of uranium} = \text{mass (kg) of pitchblende} \times \frac{\text{mass (kg) of uranium in pitchblende}}{\text{mass (kg) of pitchblende}}$$

$$= 102 \text{ kg pitchblende} \times \frac{71.4 \text{ kg uranium}}{84.2 \text{ kg pitchblende}} = 86.5 \text{ kg uranium}$$

Converting the mass of uranium from kg to g:

$$\text{Mass (g) of uranium} = 86.5 \text{ kg uranium} \times \frac{1000 \text{ g}}{1 \text{ kg}} = 8.65 \times 10^4 \text{ g uranium}$$

Finding the mass (in kg) of oxygen in 102 kg of pitchblende:

$$\text{Mass (kg) of oxygen} = \text{mass (kg) of pitchblende} - \text{mass (kg) of uranium}$$

$$= 102 \text{ kg} - 86.5 \text{ kg} = 15.5 \text{ kg oxygen}$$

Converting the mass of oxygen from kg to g:

$$\text{Mass (g) of oxygen} = 15.5 \text{ kg oxygen} \times \frac{1000 \text{ g}}{1 \text{ kg}} = 1.55 \times 10^4 \text{ g oxygen}$$

Check The analysis showed that most of the mass of pitchblende is due to uranium, so the large mass of uranium makes sense. Rounding off to check the math gives

$$\sim 100 \text{ kg pitchblende} \times \frac{70}{85} = 82 \text{ kg uranium}$$

FOLLOW-UP PROBLEMS

2.2A The mineral "fool's gold" does not contain any gold; instead, it is a compound composed only of the elements iron and sulfur. A 110.0-g sample of fool's gold contains 51.2 g of iron. What mass of sulfur is in a sample of fool's gold that contains 86.2 g of iron?

2.2B Silver bromide is the light-sensitive compound coated onto black-and-white film. A 26.8-g sample contains 15.4 g of silver, with bromine as the only other element. How many grams of each element are on a roll of film that contains 3.57 g of silver bromide?

SOME SIMILAR PROBLEMS 2.30–2.33

Student Hot Spot

Student data indicate that you may struggle with using mass fraction to calculate the mass of an element in a compound. Access the eBook to view an additional Learning Resource video on this topic.

Mastering the content with abundant end-of-chapter problem sets. New problems were added to several chapter problem sets, providing students and teachers with abundant choices in a wide range of difficulty and real-life scenarios. The problem sets are more extensive than in most other texts.

Checking knowledge with chapter practice tests. Brand new to this tenth edition is a ten-question multiple-choice practice test at the end of each chapter. The questions on the practice test thoroughly cover the concepts in each chapter, giving students a low-stakes opportunity to check their mastery of the chapter topics. Answers are provided at the end of the test and complete solutions are available in the electronic textbook.

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- Strengthening art guidelines to improve accessibility by ensuring that meaningful text and images are distinguishable and perceivable by users with limited color vision and moderately low vision.

Content Changes to Individual Chapters

In addition to the general optimization of concept explanations and problem solutions throughout the text, specific improvements were made to most chapters:

- **Chapter 1** has been reorganized to introduce the topics of significant figures, accuracy, and precision before students begin to perform calculations. There is a new table summarizing the rules for determining significant figures, and the section on dimensional analysis has been rewritten for more clarity.
- **Chapter 2** includes a new figure that illustrates the classification of matter, two new follow-up problems, a revised discussion of mass fraction, mass percentage, and Law of Definite Composition, and a significantly revised section on compound nomenclature. The chapter was reorganized

to collect all discussion of mixtures in one section instead of splitting that discussion between sections.

- **Chapter 3** features new road maps in two sample problems, revised follow-up problems, and a streamlined discussion on empirical, molecular, and structural formulas.
- **Chapter 4** incorporates a new table summarizing redox reaction terms and two revised sample problems. The section on acid-base reactions was heavily revised and simplified. The discussion on molarity is now the first topic in the chapter.
- **Chapter 5** has a new sample problem on partial pressure; the sections on gas laws and kinetic-molecular theory were heavily revised to present these topics with more clarity.
- **Chapter 6** has three sample problems that were revised, with new road maps added; two follow-up problems were revised as well. The Chemical Connections essay on energy use has been updated.
- **Chapter 7** now includes the discussion of all four quantum numbers as the discussion on the spin quantum number was moved from Chapter 8. There is a new figure illustrating blackbody radiation, a revised sample problem, and revised discussions on the electromagnetic spectrum and on Bohr's model of the atom.
- **Chapter 8** includes a revised sample problem on electron configurations as well as a stream-lined discussion about electron configurations of main-group ions.
- **Chapter 9** features a new figure illustrating Coulomb's law and ionic bonding, a revised sample problem on bond length and strength, and revised discussions on bond breaking/formation, polar covalent bonds, and heat released from food, fuels, and explosives. Bond energy values were updated.
- **Chapter 10** presents drawing Lewis structures step by step in a new table format and there is a revised sample problem on resonance structures and formal charges.
- **Chapter 11** features a revised follow-up problem, a modified figure illustrating molecular orbitals that arise from combinations of $2p$ orbitals, and a revision of the discussion on MO theory.
- **Chapter 12** has been reorganized by placing the discussion on intermolecular forces first. There is a new table comparing the properties and features of the three phases of matter and a new figure illustrating the difference between intermolecular versus intramolecular forces.
- **Chapter 13** includes a new figure that shows students how to determine the type of intermolecular forces occurring between solute and solvent, a new figure that illustrates gas solubility versus temperature, and two revised figures that more clearly describes the energy changes that occur in exothermic and endothermic processes. The discussion of intermolecular forces in proteins, DNA, and lipids was moved to Chapter 15, and a discussion of the effect of intermolecular forces on solubility of pesticides was added to this chapter.

- **Chapter 14** incorporates a discussion on the isotopes of hydrogen, including a new table comparing them. This information-packed chapter was streamlined through the removal of a few minor topics.
- **Chapter 15** features three new figures on the types of hydrocarbons, types of amines, and the polypeptide chains in proteins. The section on classes of organic reactions was rewritten for clarity.
- **Chapter 16** includes a new figure illustrating reaction rate and a new figure on enzyme catalysis. The integrated rate law for first-order reaction was presented in a more simplified way.
- **Chapter 17** includes a revision to the discussion of K_p versus K_c , and the discussion on solving equilibrium calculations has been revised for focus and clarity.
- **Chapter 18** incorporates a new table summarizing pH, pOH, $[H_3O^+]$, and $[OH^-]$ for acidic, basic, and neutral solutions. There is a new follow-up problem on K_a calculation, and the section on the acid-base properties of salt solutions was completely rewritten. Updated K_a and K_b values were incorporated into this chapter.
- **Chapter 19** features a new section and sample problem on the common-ion effect. Updated K_{sp} values were added and the sample problem on writing K_{sp} expression has been revised.
- **Chapter 20** includes updated values of standard thermodynamic quantities.
- **Chapter 21** features a new sample problem on balancing redox reactions in acidic solution and streamlined discussions on several topics.
- **Chapter 24** includes a revised discussion of modes of radioactive decay and updated discussions on nuclear reactors and on fusion.

Innovative Topic and Chapter Presentation

Although the topic sequence coincides with that used in most mainstream courses, built-in flexibility allows a wide range of differing course structures:

For courses that follow their own topic sequence, the general presentation, with its many section and subsection breaks and bulleted lists, allows topics to be rearranged, or even deleted, with minimal loss of continuity.

For courses that present several chapters, or topics within chapters, in different orders:

- Redox balancing by the half-reaction method is covered with electrochemistry in Chapter 21, but it can easily be taught with Chapter 4.
- 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.

For courses that use an atoms-first approach for some of the material, Chapters 7 through 13 move smoothly from quantum theory (7) through electron configuration (8), bonding models (9), molecular shape (10), VB and MO bonding theories (11), intermolecular forces in liquids and solids (12), and solutions (13). Immediate applications of these concepts appear in the discussions of periodic patterns in main-group chemistry (Chapter 14) and in the survey of organic chemistry (Chapter 15). Some instructors have also brought forward the coverage of transition elements and coordination compounds (23) as further applications of bonding concepts. (Of course, Chapters 14, 15, and 23 can just as easily remain in their more traditional placement later in the course.)

For courses that emphasize biological/medical applications, many chapters highlight these topics, including the chemistry of polysaccharides, proteins, and nucleic acids (including protein synthesis, DNA replication, and DNA sequencing) (15), as well as introductions to enzyme catalysis (16), biochemical pathways (17), and trace elements in protein function (23).

For courses that stress engineering applications of physical chemistry topics, Chapters 16 through 21 cover kinetics (16), equilibrium in gases (17), acids and bases (18), and aqueous ionic systems (19) and entropy and free energy (20) as they apply to electrochemical systems (21), all in preparation for coverage of the elements in geochemical cycles, metallurgy, and industry in Chapter 22.



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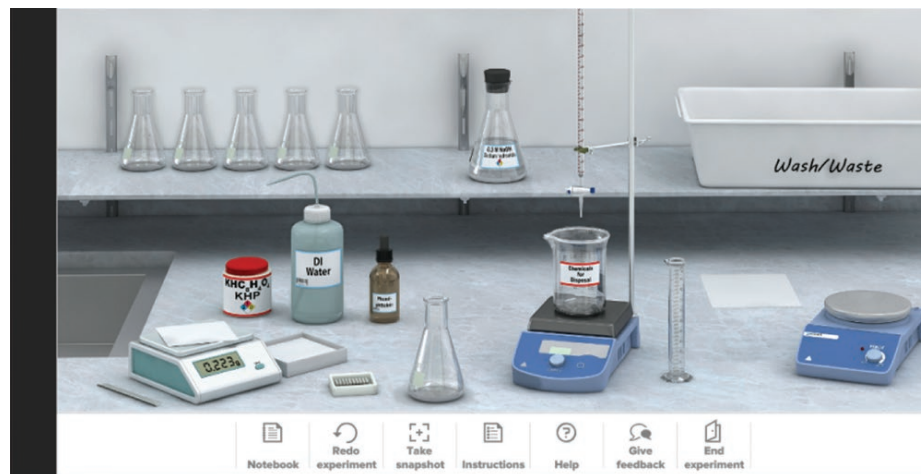
- **Art** Full-color digital files of all illustrations, photos, and tables in the book can be readily incorporated into lecture presentations, exams, or custom-made classroom materials. In addition, all files have been inserted into PowerPoint slides for ease of lecture preparation.
- **Animations** 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.
- **Accessible PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **Computerized Test Bank** Also among the instructor resources is a computerized test bank. The testing software TestGen[®] can be used to create customized exams quickly. Hundreds of text-specific, open-ended, and multiple-choice questions are included in the question bank.
- **Instructor's Solutions Manual** This supplement, prepared by Patricia Amateis, contains complete, worked-out solutions for *all* the end-of-chapter problems in the text.



ALEKS (Assessment and LEarning in Knowledge Spaces) is a web-based system for individualized assessment and learning available 24/7 over the Internet. ALEKS uses artificial intelligence to accurately determine a student's knowledge and then guides them to the material that they are most ready to learn. ALEKS offers immediate feedback and access to ALEKSPedia—an interactive text that contains concise entries on chemistry topics. ALEKS is also a full-featured course management system with rich reporting features that allow instructors to monitor individual and class performance, set student goals, assign/grade online quizzes, and more. ALEKS allows instructors to spend more time on concepts while ALEKS teaches students practical problem-solving skills. And with ALEKS 360, your student also has access to this text's eBook. Learn more at www.aleks.com/highered/science



McGraw Hill Virtual Labs is a must-see, outcomes-based lab simulation. It assesses a student's knowledge and adaptively corrects deficiencies, allowing the student to learn faster and retain more knowledge with greater success. First, a student's knowledge is adaptively leveled on core learning outcomes: Questioning reveals knowledge deficiencies that are corrected by the delivery of content that is conditional on a student's response. Then, a simulated lab experience requires the student to think and act like a scientist: recording, interpreting, and analyzing



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Prepared by Melanie Cooper of Michigan State 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, analytical problem solving, and communication.

STUDENT SOLUTIONS MANUAL

This supplement contains detailed solutions and explanations for all problems in the main text that have colored numbers.

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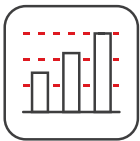
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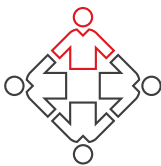


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CEPIEC

1

Keys to Studying Chemistry: Definitions, Units, and Problem Solving

1.1 Some Fundamental Definitions

States of Matter
Properties of Matter and Its Changes
Central Theme in Chemistry
Importance of Energy

1.2 The Scientific Approach: Developing a Model

1.3 Units of Measurement

Features of SI Units

SI Units in Chemistry
Temperature Scales

1.4 Uncertainty in Measurement: Significant Figures

Determining Significant Digits
Calculations and Rounding Off
Precision, Accuracy, and Instrument Calibration

1.5 Units and Conversion Factors in Calculations

Constructing and Choosing Conversion Factors
Converting Between Unit Systems
Systematic Problem-Solving Approach
Extensive and Intensive Properties



Source: (coral reef) Igor Borisov/IBorisoff/iStock/Getty Images; (green carrots field) Aleksandar Milutinovic/Shutterstock; (solar panel) Filip Fuxa/fyletto/123RF; (drinking water) Science Photo/Shutterstock

- › exponential (scientific) notation (Appendix A)

You are embarking on the study of chemistry, a fascinating science that is fundamental to understanding other natural sciences and one that has a tremendous impact on all of society. Scientists use chemistry as they work on solutions to tough problems such as reducing greenhouse gas emissions to mitigate climate change, tackling the issue of ocean acidification that threatens marine ecosystems, producing drought- and disease-resistant crops to maintain a sufficient world food supply, finding treatments and cures for diseases such as malaria, cancer, and Alzheimer’s disease, ending pandemics, producing better batteries and solar cells, promoting renewable energy sources, and providing clean drinking water for people all over the world. There are transformative discoveries to be made in chemistry every day!

A basic understanding of chemistry is crucial for anyone who wants to study biochemistry, geochemistry, food chemistry, agricultural chemistry, forensic chemistry, environmental chemistry, engineering, medicine, or nanotechnology, just to name a few of the many fields that intersect with chemistry. You’re going to learn some amazing things in your chemistry course as you begin to view a hidden reality, one filled with incredibly minute particles moving at fantastic speeds and interacting in ways that determine how all matter behaves. This chapter holds the keys to unlock and enter this new world, so let’s get started!

IN THIS CHAPTER . . . *We discuss some central ideas about matter and energy, the process of science, units of measurement, and how scientists handle data.*

- › We begin with fundamental concepts about matter and energy and their changes.
- › We take a look at how scientists build models to study nature.
- › We examine modern units for mass, length, volume, density, and temperature.
- › We see that data collection always includes some uncertainty and examine the distinction between accuracy and precision.
- › We apply systematic chemical problem solving to unit conversions.

1.1 SOME FUNDAMENTAL DEFINITIONS

A good place to begin our exploration of chemistry is by defining it and a few central concepts. **Chemistry** is *the scientific study of matter and its properties, the changes that matter undergoes, and the energy associated with those changes*. **Matter** is the “stuff” of the universe: air, glass, planets, students—*anything that has mass and volume*. Chemists want to know the **composition** of matter, *the types and amounts of simpler substances that make it up*. A *substance* is a type of matter that has a defined, fixed composition.

The States of Matter

Matter occurs commonly in *three physical forms* called **states**: solid, liquid, and gas. On the macroscopic scale, each state of matter is defined by the way the sample fills a container (Figure 1.1, *flasks at top*):

- A **solid** has a fixed shape that does not conform to the container shape. Solids are *not* defined by rigidity or hardness: solid iron is rigid and hard, but solid lead is flexible, and solid wax is soft.
- A **liquid** has a varying shape that conforms to the container shape, but only to the extent of the liquid’s volume; that is, a liquid has *an upper surface*.
- A **gas** also has a varying shape that conforms to the container shape, but it fills the entire container and, thus, does *not* have a surface.

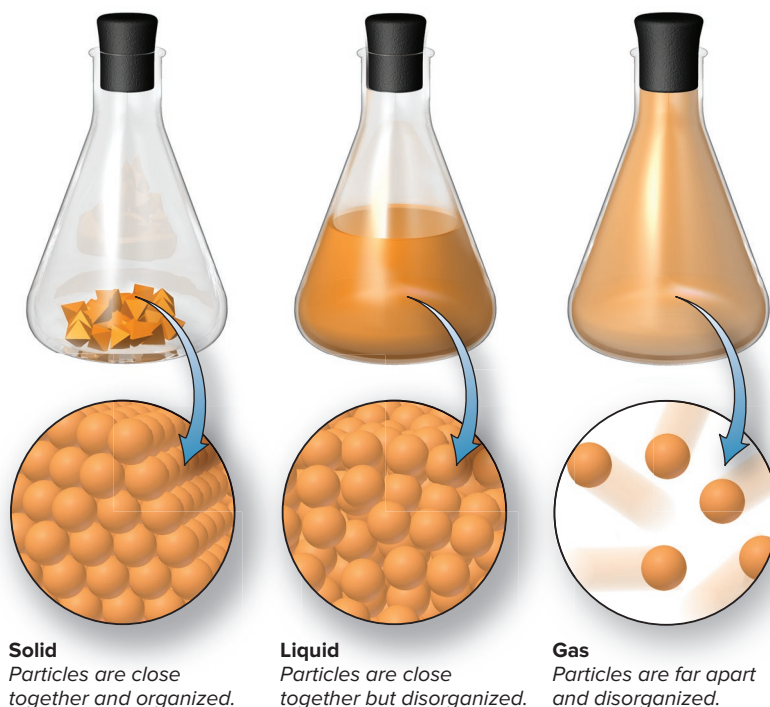


Figure 1.1 The physical states of matter.

On the atomic scale, each state is defined by the relative positions of its particles (Figure 1.1, *circles at bottom*):

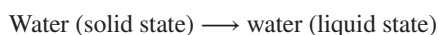
- In a *solid*, the particles lie next to each other in a regular, three-dimensional pattern, or *array*.
- In a *liquid*, the particles also lie close together but move randomly around each other.
- In a *gas*, the particles have large distances between them and move randomly throughout the container.

The Properties of Matter and Its Changes

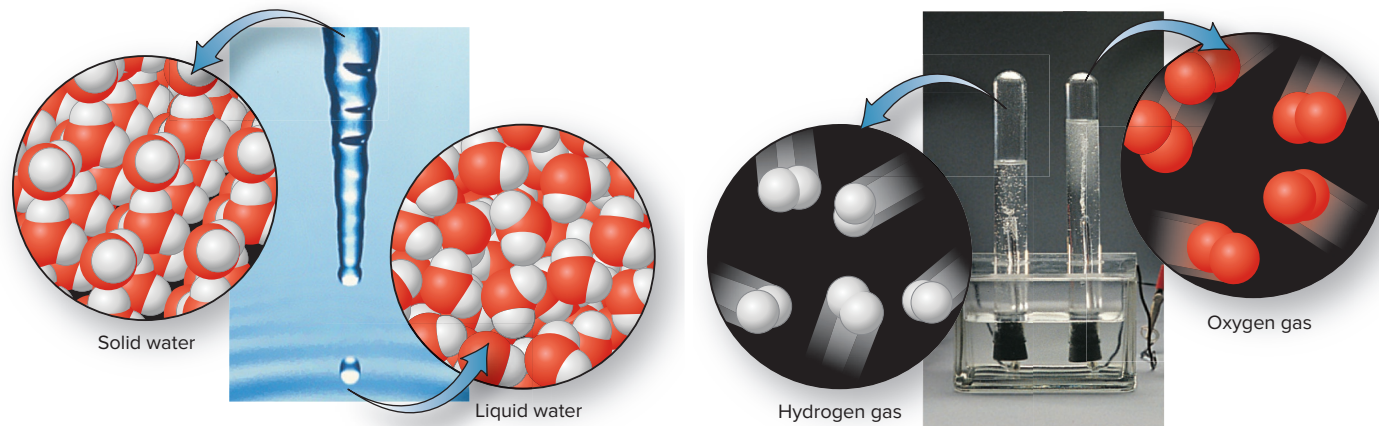
We learn about matter by observing its **properties**, *the characteristics that give each substance its unique identity*. To identify a person, we might observe height, weight, hair and eye color, fingerprints, and, now, even DNA pattern, until we arrive at a unique identification. To identify a substance, we observe two types of properties, physical and chemical, which are closely related to two types of change that matter undergoes.

Physical Change: No Change in Composition **Physical properties** are characteristics a substance shows *by itself, without changing into or interacting with another substance*. These properties include color, melting point, electrical conductivity, and density. A **physical change** occurs when a substance *alters its physical properties, not its composition*. For example, when ice melts, several physical properties change, such as hardness, density, and ability to flow. But the composition of the sample does *not* change: it is still water. The photograph in Figure 1.2A shows what this change looks like in everyday life. The “blow-up” circles depict a magnified view of the particles making up the sample. In the icicle, the particles lie in the repeating pattern characteristic of a solid, whereas they are jumbled in the liquid droplet; however, *the particles are the same* in both states of water.

Physical change (same substance before and after):



All changes of state of matter are physical changes.

**A Physical change:**

Solid state of water becomes liquid state.
 Particles before and after remain the same,
 which means composition did **not** change.

B Chemical change:

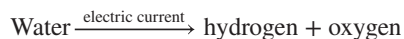
Electric current decomposes water into different substances
 (hydrogen and oxygen). Particles before and after are different,
 which means composition **did** change.

Figure 1.2 The distinction between physical and chemical change.

Source: (A) Paul Morrell/The Image Bank/Getty Images; (B) Stephen Frisch/McGraw Hill

Chemical Change: A Change in Composition Chemical properties are characteristics a substance shows as it changes into or interacts with another substance (or substances). Chemical properties include flammability, corrosiveness, and reactivity with acids. A **chemical change**, also called a **chemical reaction**, occurs when one or more substances are converted into one or more substances with different composition and properties. Figure 1.2B shows the chemical change (reaction) that occurs when you pass an electric current through water: the water decomposes (breaks down) into two other substances, hydrogen and oxygen, that bubble into the tubes. The composition has changed: the final sample is no longer water.

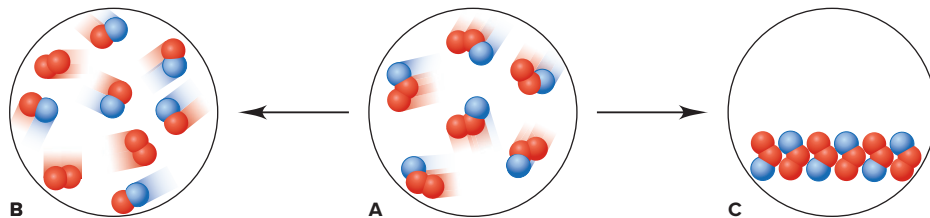
Chemical change (different substances before and after):



Let's work through a sample problem that uses atomic-scale scenes to distinguish between physical and chemical change.

SAMPLE PROBLEM 1.1 | Visualizing Change on the Atomic Scale

Problem The scenes below represent an atomic-scale view of a sample of matter, A, undergoing two different changes, left to B and right to C:



Decide whether each depiction shows a physical or a chemical change.

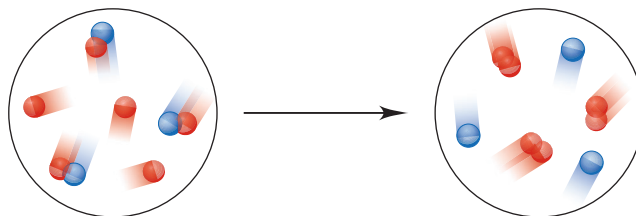
Plan Given depictions of two changes, we have to determine whether each represents a physical or a chemical change. The number and colors of the little spheres that make up each particle tell its “composition.” Samples with particles of the *same* composition but in a different arrangement depict a *physical* change, whereas samples with particles of a *different* composition depict a *chemical* change.

Solution In A, each particle consists of one blue and two red spheres. The particles in A change into two types in B, one made of red and blue spheres and the other made of two red spheres; therefore, they have undergone a **chemical change** to form different particles. The particles in C are the same as those in A, but they are closer together and arranged in a regular pattern; therefore, they have undergone a **physical change**.

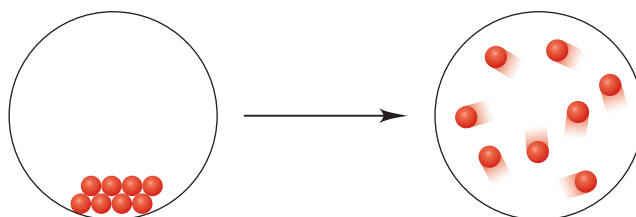
FOLLOW-UP PROBLEMS

Brief Solutions for all Follow-up Problems appear at the end of the chapter.

1.1A Is the following change chemical or physical?



1.1B Is the following change chemical or physical?



SOME SIMILAR PROBLEMS 1.1 and 1.80

Table 1.1 illustrates some of the unique physical and chemical properties of the common substance copper.

Table 1.1 | Some Characteristic Properties of Copper

Physical Properties

Easily hammered into sheets (malleable) and drawn into wires (ductile)



Can be melted and mixed with zinc to form brass



Density = 8.95 g/cm^3
Melting point = 1083°C
Boiling point = 2570°C

Chemical Properties

Slowly forms a blue-green carbonate in moist air



Reacts with nitric or sulfuric acid

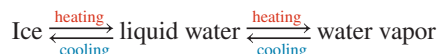


Slowly forms deep-blue solution in aqueous ammonia



Source: (copper) Stephen Frisch/McGraw Hill; (copper wire) dgstudiodg/iStockphoto/Getty Images; (candlestick) Willard/iStock/Getty Images; (copper carbonate, copper reacting with acid, copper and ammonia) Stephen Frisch/McGraw Hill

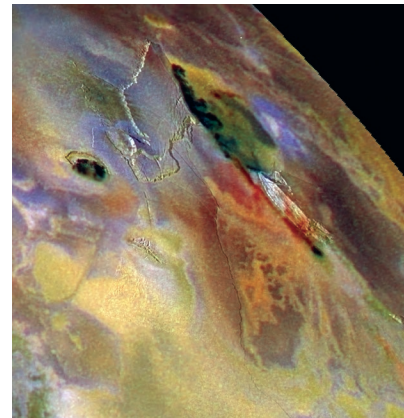
Temperature and Changes in Matter Depending on the temperature and pressure of the surroundings, many substances can exist in each of the three physical states and undergo changes in state as well. For example, as the temperature increases, solid water melts to liquid water, which boils to gaseous water (also called *water vapor*). Similarly, as the temperature drops, water vapor condenses to liquid water, and with further cooling, the liquid freezes to ice:



In a steel plant, solid iron melts to liquid (molten) iron and then cools to the solid again. And, far beyond the confines of a laboratory or steel plant, lakes of molten sulfur (a solid on Earth at room temperature) lie on Jupiter's moon Io (*see photo*), which is capped by poles of frozen hydrogen sulfide, a gas on Earth.

The main point is that *a physical change caused by heating can generally be reversed by cooling*. This is *not* generally true for a chemical change. For example, heating iron in moist air causes a chemical reaction that yields the brown, crumbly substance known as rust. Cooling does not reverse this change; rather, another chemical change (or series of them) is required.

The following sample problem provides practice in distinguishing some familiar examples of physical and chemical change.



Many substances that are common on Earth occur in unusual states on other worlds.

Source: NASA-JPL

SAMPLE PROBLEM 1.2

Distinguishing Between Physical and Chemical Change

Problem Decide whether each of the following processes is primarily a physical or a chemical change, and explain briefly:

- (a) Frost forms as the temperature drops on a humid winter night.
- (b) A cornstalk grows from a seed that is watered and fertilized.
- (c) A match ignites to form ash and a mixture of gases.
- (d) Perspiration evaporates when you relax after jogging.
- (e) A silver fork tarnishes slowly in air.

Plan The basic question we ask to decide whether a change is chemical or physical is, “Does the substance change composition or just change form?”

Solution (a) Frost forming is a **physical change**: the drop in temperature changes water vapor (gaseous water) in humid air to ice crystals (solid water).
 (b) A seed growing involves **chemical change**: the seed uses water, substances from air, fertilizer, soil, and energy from sunlight to make complex changes in composition.
 (c) The match burning is a **chemical change**: the combustible substances in the match head are converted into other substances.
 (d) Perspiration evaporating is a **physical change**: the water in sweat changes its state, from liquid to gas, but not its composition.
 (e) Tarnishing is a **chemical change**: silver changes to silver sulfide by reacting with sulfur-containing substances in the air.

FOLLOW-UP PROBLEMS

1.2A Decide whether each of the following processes is primarily a physical or a chemical change, and explain briefly:

- (a) Purple iodine vapor appears when solid iodine is warmed.
- (b) Gasoline fumes are ignited by a spark in an automobile engine's cylinder.
- (c) A scab forms over an open cut.

1.2B Decide whether each of the following processes is primarily a physical or a chemical change, and explain briefly:

- (a) Clouds form in the sky.
- (b) Old milk turns sour.
- (c) Butter is melted to use on popcorn.

SOME SIMILAR PROBLEMS 1.6 and 1.7

The Central Theme in Chemistry

Understanding the properties of a substance and the changes it undergoes leads to the central theme in chemistry: *macroscopic-scale* properties and behavior, those we can see, are the results of *atomic-scale* properties and behavior that we cannot see. The distinction between chemical and physical change is defined by composition, which we study macroscopically. But composition ultimately depends on the makeup of substances at the atomic scale. Similarly, macroscopic properties of substances in any of the three states arise from atomic-scale behavior of their particles. Picturing a chemical event on the molecular scale, even one as common as the flame of a laboratory burner, helps clarify what is taking place. What is happening when water boils or copper melts? What events occur in the invisible world of minute particles that cause a seed to grow, a neon light to glow, or a nail to rust? Throughout the text, we return to this central idea:

*We study **observable** changes in matter to understand their **unobservable** causes.*

The Importance of Energy in the Study of Matter

Physical and chemical changes are accompanied by energy changes. **Energy** is often defined as *the ability to do work*. Essentially, all work involves moving something. Work is done when your arm lifts a book, when a car's engine moves the wheels, or when a falling rock moves the ground as it lands. The object doing the work (arm, engine, rock) transfers some of the energy it possesses to the object on which the work is done (book, wheels, ground).

The total energy an object possesses is the sum of its potential energy and its kinetic energy.

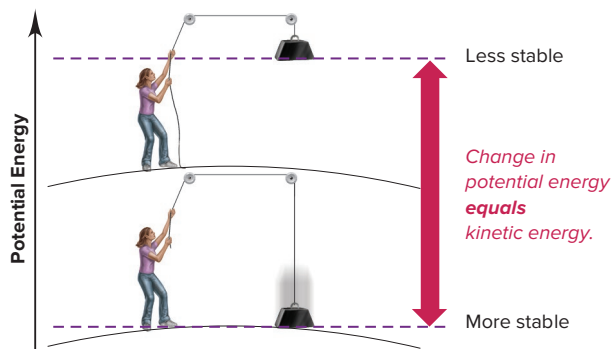
- **Potential energy** is the energy due to the **position** of the object relative to other objects.
- **Kinetic energy** is the energy due to the **motion** of the object.

Let's examine four systems that illustrate the relationship between these two forms of energy: a weight raised above the ground, two balls attached by a spring, two electrically charged particles, and a fuel and its waste products. Two concepts central to all these cases are

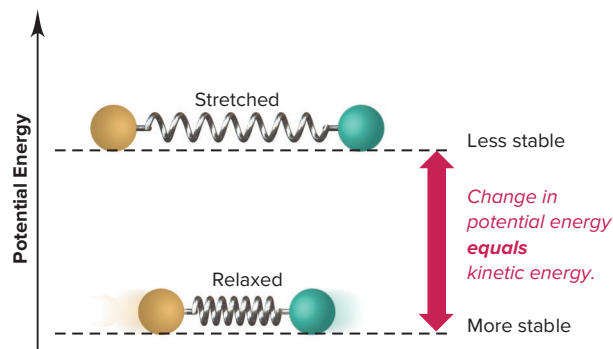
1. *When energy is converted from one form to the other, it is conserved, not destroyed.*
2. *Situations of lower energy are more stable and are favored over situations of higher energy, which are less stable.*

The four cases are

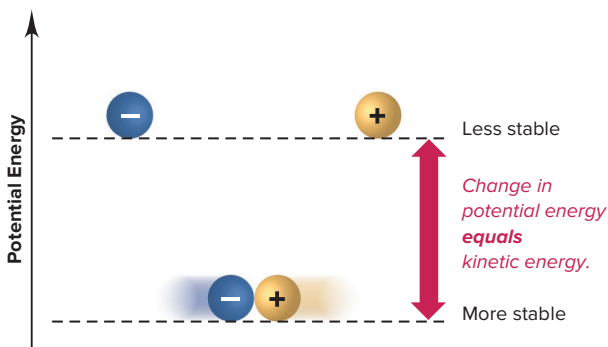
- *A weight raised above the ground* (Figure 1.3A). The energy you exert to lift a weight against gravity increases the weight's potential energy (energy due to its position). When you drop the weight, that additional potential energy is converted to kinetic energy (energy due to motion). The situation with the weight elevated and higher in potential energy is *less stable*, so the weight will fall when released, resulting in a situation that is lower in potential energy and *more stable*.
- *Two balls attached by a spring* (Figure 1.3B). When you pull the balls apart, the energy you exert to stretch the relaxed spring increases the system's potential energy. This change in potential energy is converted to kinetic energy when you release the balls. The system of balls and spring is less stable (has more potential energy) when the spring is stretched than when it is relaxed.
- *Two electrically charged particles* (Figure 1.3C). Due to interactions known as *electrostatic forces*, *opposite charges attract each other, and like charges repel each other*. When energy is exerted to move a positive particle away from a negative one, the potential energy of the system increases, and that increase is converted to kinetic energy when the particles are pulled together by the electrostatic attraction. Similarly, when energy is used to move two positive (or two negative) particles together, their potential energy increases and changes to kinetic energy when they are pushed apart by the electrostatic repulsion. Charged particles move naturally to a more stable situation (lower energy).
- *A fuel and its waste products* (Figure 1.3D). Matter is composed of positively and negatively charged particles. *The chemical potential energy of a substance results*



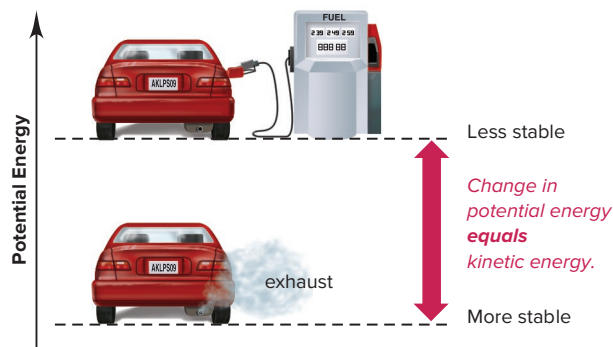
A A gravitational system. Potential energy is gained when a weight is lifted. It is converted to kinetic energy as the weight falls.



B A system of two balls attached by a spring. Potential energy is gained when the spring is stretched. It is converted to the kinetic energy of the moving balls as the spring relaxes.



C A system of oppositely charged particles. Potential energy is gained when the charges are separated. It is converted to kinetic energy as the attraction pulls the charges together.



D A system of fuel and exhaust. A fuel is higher in chemical potential energy than the exhaust. As the fuel burns, some of its potential energy is converted to the kinetic energy of the moving car.

from the relative positions of its particles and the attractions and repulsions among them. Some substances are higher in potential energy than others. For example, gasoline and oxygen have more chemical potential energy than the exhaust gases they form. This difference is converted into kinetic energy, which moves the car, heats the interior, makes the lights shine, and so on. Similarly, the difference in potential energy between the food and air we take in and the wastes we excrete enables us to move, grow, keep warm, study chemistry, and so on.

Figure 1.3 Potential energy is converted to kinetic energy. The dashed horizontal lines indicate the potential energy of each system before and after the change.

› Summary of Section 1.1

- › Chemists study the composition and properties of matter and how they change.
- › Matter exists in three physical states—solid, liquid, and gas. The behavior of each state is due to the arrangement of the particles.
- › Each substance has a unique set of *physical* properties (attributes of the substance itself) and *chemical* properties (attributes of the substance as it interacts with or changes to other substances). Changes in matter can be *physical* (different form of the same substance) or *chemical* (different substance).
- › A physical change caused by heating may be reversed by cooling. But a chemical change caused by heating can be reversed only by other chemical changes.
- › Macroscopic changes result from submicroscopic changes.
- › Changes in matter are accompanied by changes in energy.
- › An object's potential energy is due to its position; an object's kinetic energy is due to its motion. Energy used to lift a weight, stretch a spring, or separate opposite charges increases the system's potential energy, which is converted to kinetic energy as the system returns to its original condition. Energy changes form but is conserved.
- › Chemical potential energy arises from the positions and interactions of a substance's particles. When a higher energy (less stable) substance is converted into a more stable (lower energy) substance, some potential energy is converted into kinetic energy.