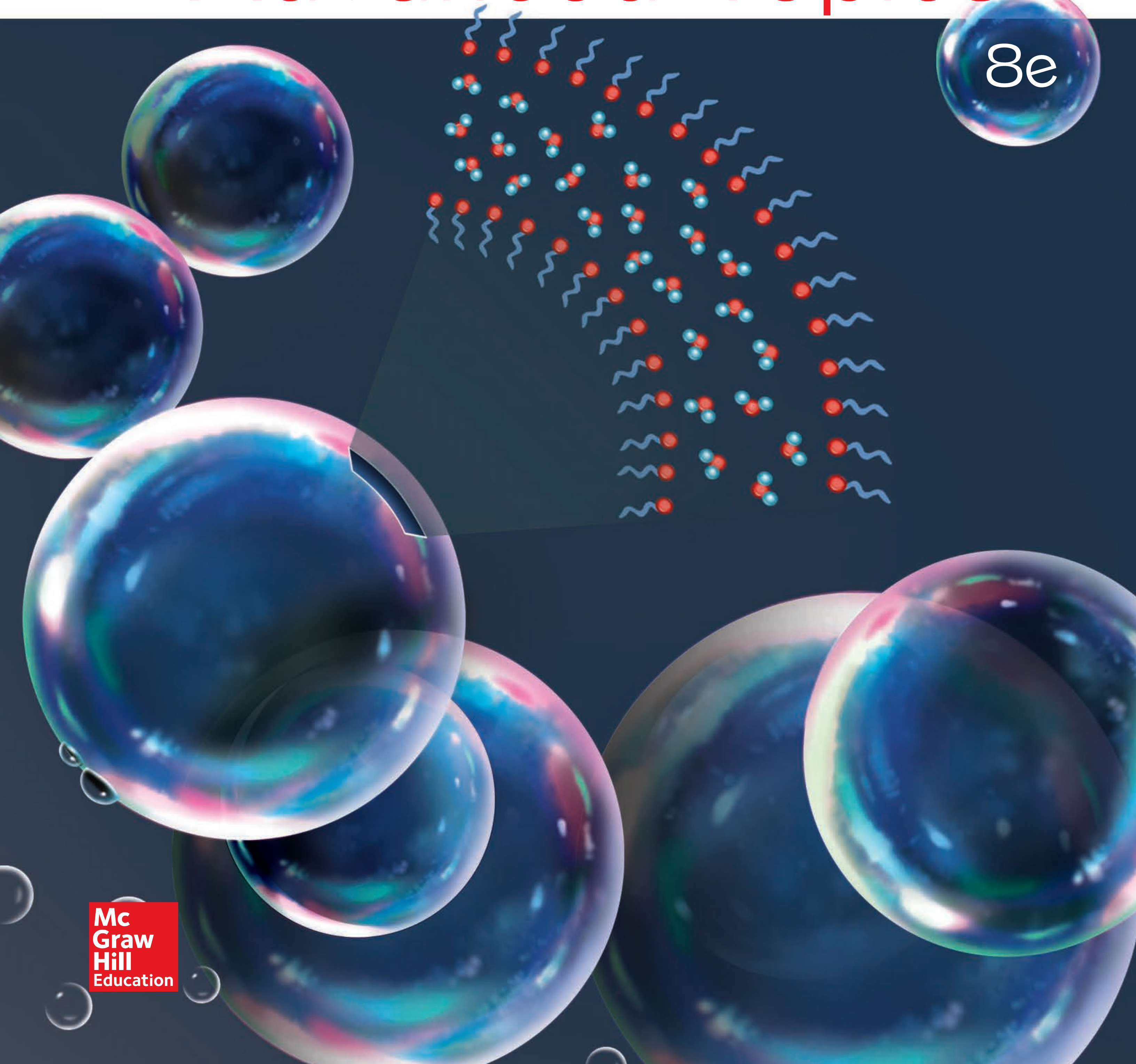
Silberberg ~ Amateis

CHEMISTRY

The Molecular Nature of Matter and Change

Advanced Topics

8e



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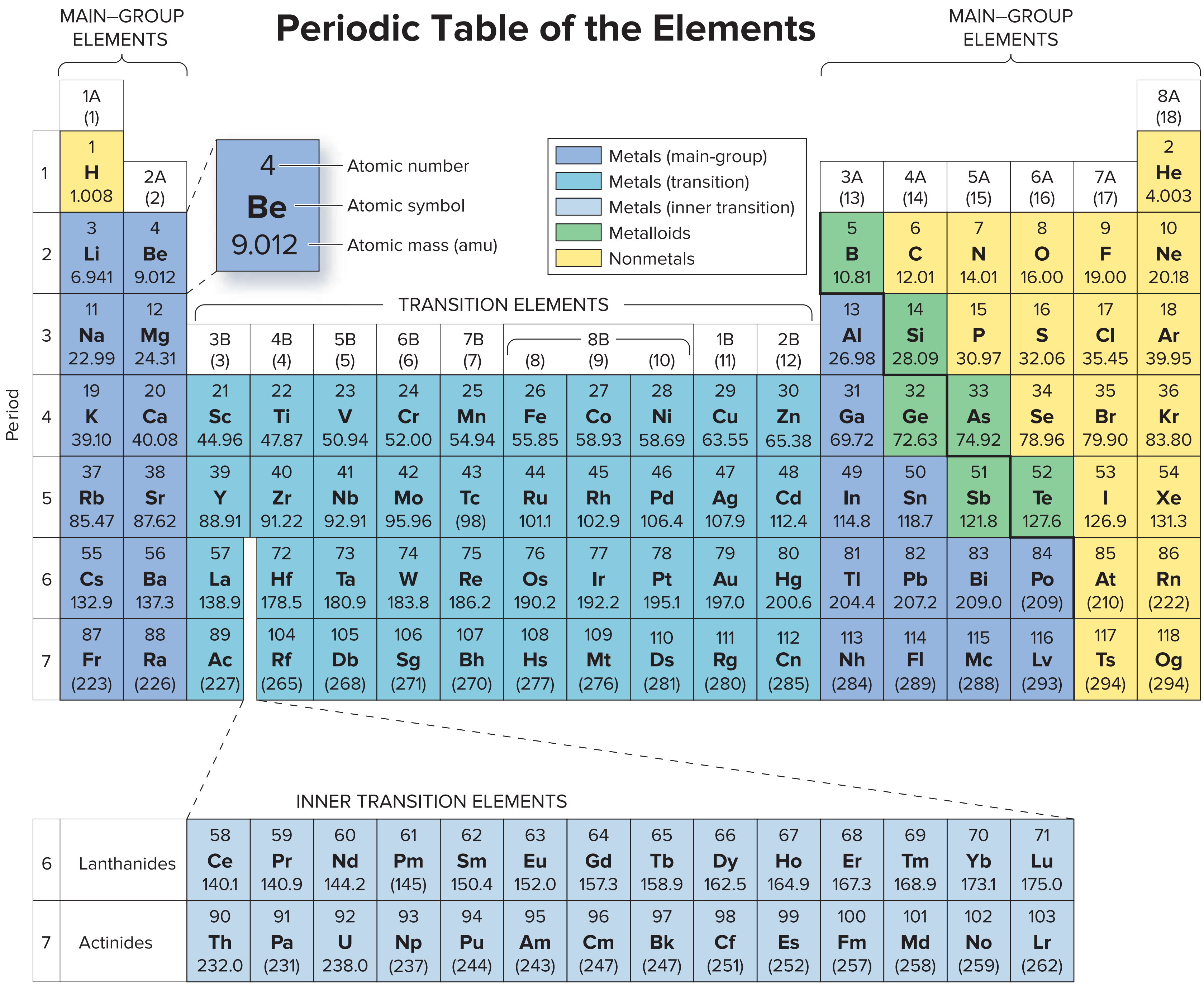
Periodic Table of the Elements



🟦	Metals (main-group)
🟦	Metals (transition)
🟦	Metals (inner transition)
🟩	Metalloids
🟨	Nonmetals

Period	1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (265)	105 **Db** (268)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 **Nh** (284)	114 **Fl** (289)	115 **Mc** (288)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

INNER TRANSITION ELEMENTS

6	Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.1	71 **Lu** 175.0
7	Actinides	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

The Elements

Name	Symbol	Atomic Number	Atomic Mass*
Actinium	Ac	89	(227)
Aluminum	Al	13	26.98
Americium	Am	95	(243)
Antimony	Sb	51	121.8
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	(210)
Barium	Ba	56	137.3
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.012
Bismuth	Bi	83	209.0
Bohrium	Bh	107	(267)
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.4
Calcium	Ca	20	40.08
Californium	Cf	98	(249)
Carbon	C	6	12.01
Cerium	Ce	58	140.1
Cesium	Cs	55	132.9
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Copernicium	Cn	112	(285)
Copper	Cu	29	63.55
Curium	Cm	96	(247)
Darmstadtium	Ds	110	(281)
Dubnium	Db	105	(262)
Dysprosium	Dy	66	162.5
Einsteinium	Es	99	(254)
Erbium	Er	68	167.3
Europium	Eu	63	152.0
Fermium	Fm	100	(253)
Flevorium	Fl	114	(289)
Fluorine	F	9	19.00
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.3
Gallium	Ga	31	69.72
Germanium	Ge	32	72.61
Gold	Au	79	197.0
Hafnium	Hf	72	178.5
Hassium	Hs	108	(277)
Helium	He	2	4.003
Holmium	Ho	67	164.9
Hydrogen	H	1	1.008
Indium	In	49	114.8
Iodine	I	53	126.9
Iridium	Ir	77	192.2
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.9
Lawrencium	Lr	103	(257)
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Livermorium	Lv	116	(293)
Lutetium	Lu	71	175.0
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Meitnerium	Mt	109	(268)
Mendelevium	Md	101	(256)
Mercury	Hg	80	200.6
Molybdenum	Mo	42	95.94
Moscovium	Mc	115	(288)
Neodymium	Nd	60	144.2
Neon	Ne	10	20.18
Neptunium	Np	93	(244)
Nickel	Ni	28	58.70
Nihonium	Nh	113	(284)
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	(253)
Oganesson	Og	118	(294)
Osmium	Os	76	190.2
Oxygen	O	8	16.00
Palladium	Pd	46	106.4
Phosphorus	P	15	30.97
Platinum	Pt	78	195.1
Plutonium	Pu	94	(242)
Polonium	Po	84	(209)
Potassium	K	19	39.10
Praseodymium	Pr	59	140.9
Promethium	Pm	61	(145)
Protactinium	Pa	91	(231)
Radium	Ra	88	(226)
Radon	Rn	86	(222)
Rhenium	Re	75	186.2
Rhodium	Rh	45	102.9
Roentgenium	Rg	111	(272)
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.1
Rutherfordium	Rf	104	(263)
Samarium	Sm	62	150.4
Scandium	Sc	21	44.96
Seaborgium	Sg	106	(266)
Selenium	Se	34	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.9
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulfur	S	16	32.07
Tantalum	Ta	73	180.9
Technetium	Tc	43	(98)
Tellurium	Te	52	127.6
Tennessine	Ts	117	(294)
Terbium	Tb	65	158.9
Thallium	Tl	81	204.4
Thorium	Th	90	232.0
Thulium	Tm	69	168.9
Tin	Sn	50	118.7
Titanium	Ti	22	47.88
Tungsten	W	74	183.9
Uranium	U	92	238.0
Vanadium	V	23	50.94
Xenon	Xe	54	131.3
Ytterbium	Yb	70	173.0
Yttrium	Y	39	88.91
Zinc	Zn	30	65.41
Zirconium	Zr	40	91.22

*All atomic masses are given to four significant figures. Values in parentheses represent the mass number of the most stable isotope.

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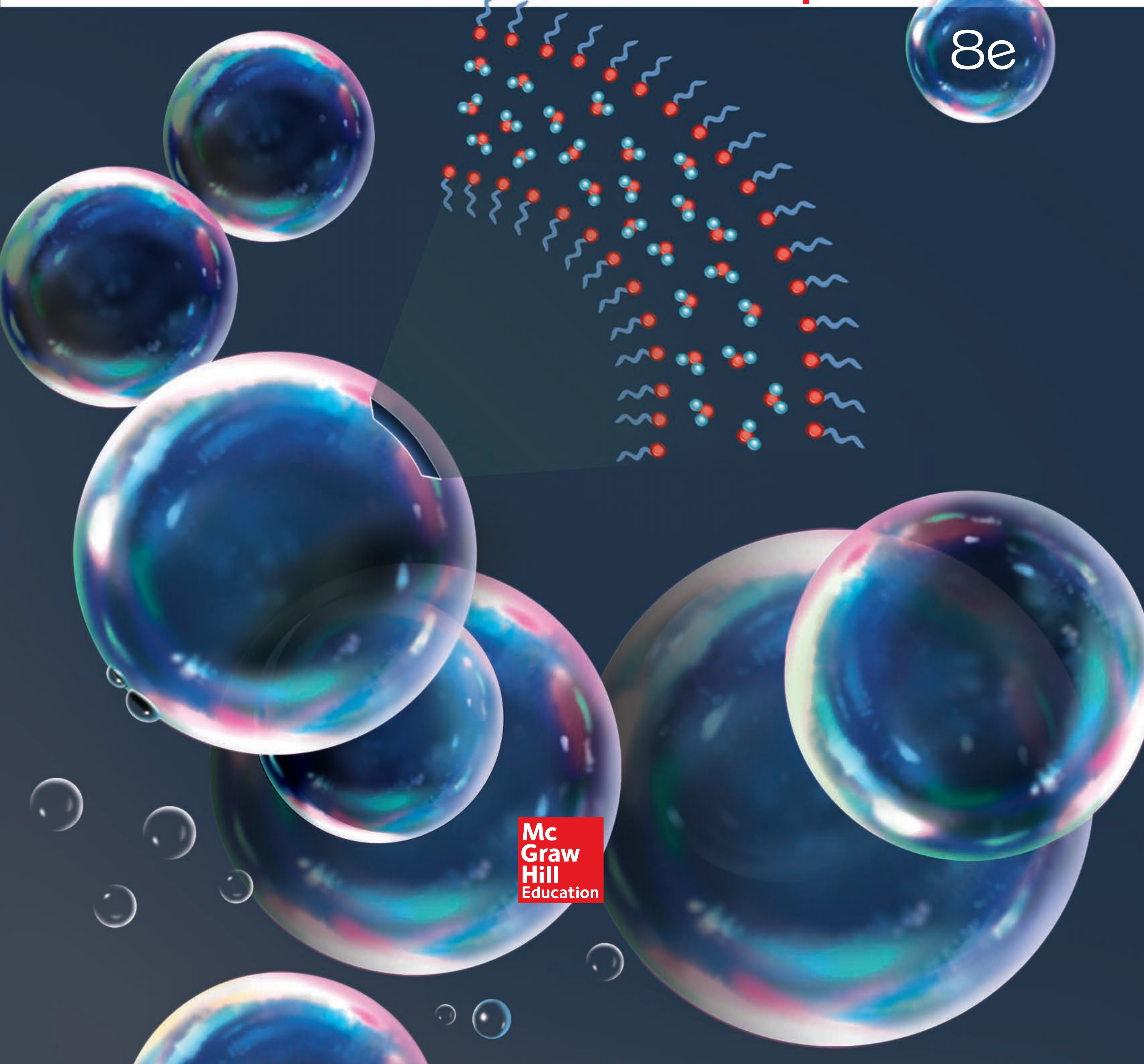

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To Ruth and Daniel, with all my love and gratitude.
MSS

To Ralph, Eric, Samantha, and Lindsay:
you bring me much joy.
PGA

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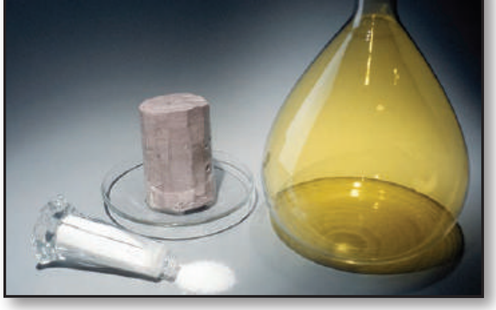

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LIST OF SAMPLE PROBLEMS *(Molecular-scene problems are shown in color.)*

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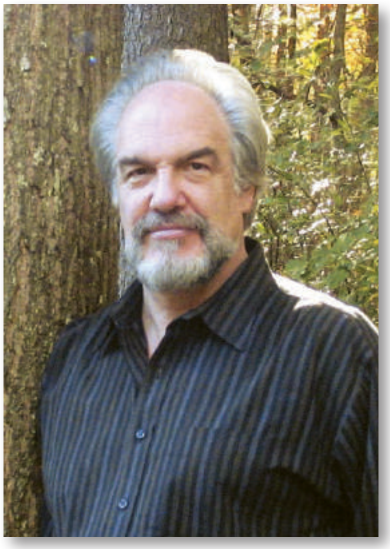
ABOUT THE AUTHORS



Courtesy of Martin S. Silberberg

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

Courtesy of Patricia G. Amateis

Patricia G. Amateis graduated with a B.S. in Chemistry Education from Concord University in West Virginia and a Ph.D. in Analytical Chemistry from Virginia Tech. She has been on the faculty of the Chemistry Department at Virginia Tech for 31 years, teaching General Chemistry and Analytical Chemistry. For the past 16 years, she has served as Director of General Chemistry, responsible for the oversight of both the lecture and lab portions of the large General Chemistry program. She has taught thousands of students during her career and has been awarded the University Sporn Award for Introductory Teaching, the Alumni Teaching Award, and the William E. Wine Award for a history of university teaching excellence. She and her husband live in Blacksburg, Virginia and are the parents of three adult children. In her free time, she enjoys biking, hiking, competing in the occasional sprint triathlon, and playing the double second in Panjammers, Blacksburg's steel drum band.

PREFACE

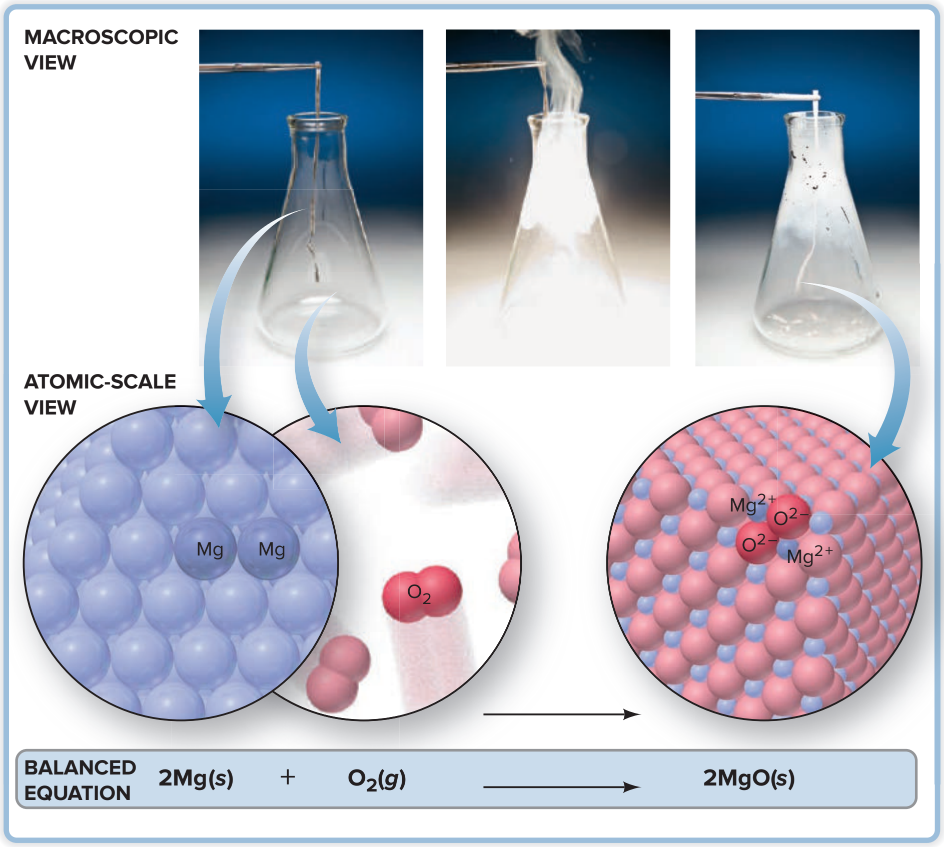
Chemistry is so crucial to an understanding of medicine and biology, environmental science, and many areas of engineering and industrial processing that it has become a requirement for an increasing number of academic majors. Furthermore, chemical principles lie at the core of some of the key societal 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 eighth 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.



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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.

SAMPLE PROBLEM 3.9 Determining an Empirical Formula from Masses of Elements

Problem Analysis of a sample of an ionic compound yields 2.82 g of Na, 4.35 g of Cl, and 7.83 g of O. What are the empirical formula and the name of the compound?

Plan This problem is similar to Sample Problem 3.8, except that we are given element *masses* that we must convert into integer subscripts. We first divide each mass by the element's molar mass to find the amount (mol). Then we construct a preliminary formula and convert the amounts (mol) to integers.

Solution Finding amount (mol) of each element:

$$\text{Amount (mol) of Na} = 2.82\ \cancel{\text{g Na}} \times \frac{1\ \text{mol Na}}{22.99\ \cancel{\text{g Na}}} = 0.123\ \text{mol Na}$$

$$\text{Amount (mol) of Cl} = 4.35\ \cancel{\text{g Cl}} \times \frac{1\ \text{mol Cl}}{35.45\ \cancel{\text{g Cl}}} = 0.123\ \text{mol Cl}$$

$$\text{Amount (mol) of O} = 7.83\ \cancel{\text{g O}} \times \frac{1\ \text{mol O}}{16.00\ \cancel{\text{g O}}} = 0.489\ \text{mol O}$$

Constructing a preliminary formula: $Na_{0.123}Cl_{0.123}O_{0.489}$

Converting to integer subscripts (dividing all by the smallest subscript):

$$Na_{\frac{0.123}{0.123}}Cl_{\frac{0.123}{0.123}}O_{\frac{0.489}{0.123}} \longrightarrow Na_{1.00}Cl_{1.00}O_{3.98} \approx Na_1Cl_1O_4, \quad \text{or} \quad NaClO_4$$

The empirical formula is $NaClO_4$; the name is sodium perchlorate.

Check The numbers of moles seem correct because the masses of Na and Cl are slightly more than 0.1 of their molar masses. The mass of O is greatest and its molar mass is smallest, so it should have the greatest number of moles. The ratio of subscripts, 1/1/4, is the same as the ratio of moles, 0.123/0.123/0.489 (within rounding).

FOLLOW-UP PROBLEMS

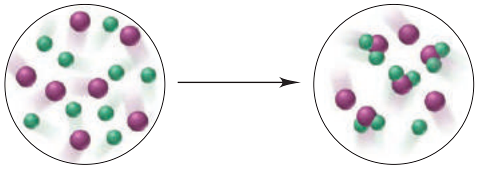
of an unknown compound is found to contain 1.23 g of H, 12.64 g of of O. What is the empirical formula and the name of the compound?

wn metal M reacts with sulfur to form a compound with the formula of M reacts with 2.88 g of S, what are the names of M and M_2S_3? [*Hint:* mount (mol) of S, and use the formula to find the amount (mol) of M.]

PROBLEMS 3.42(b), 3.43(b), 3.46, and 3.47

SAMPLE PROBLEM 2.3 Visualizing the Mass Laws

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



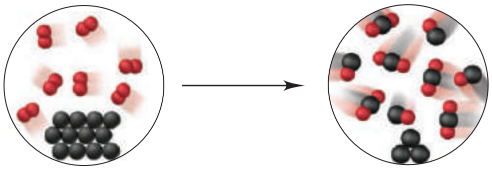
Which of the mass laws—mass conservation, definite composition, and/or multiple proportions—is (are) illustrated?

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).

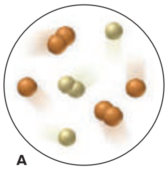
Solution There are seven purple and nine green atoms in each circle, so mass is conserved. The compound formed has one purple and two green atoms, so it has definite composition. Only one compound forms, so the law of multiple proportions does not pertain.

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.



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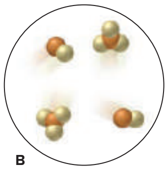
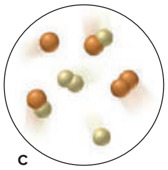


B

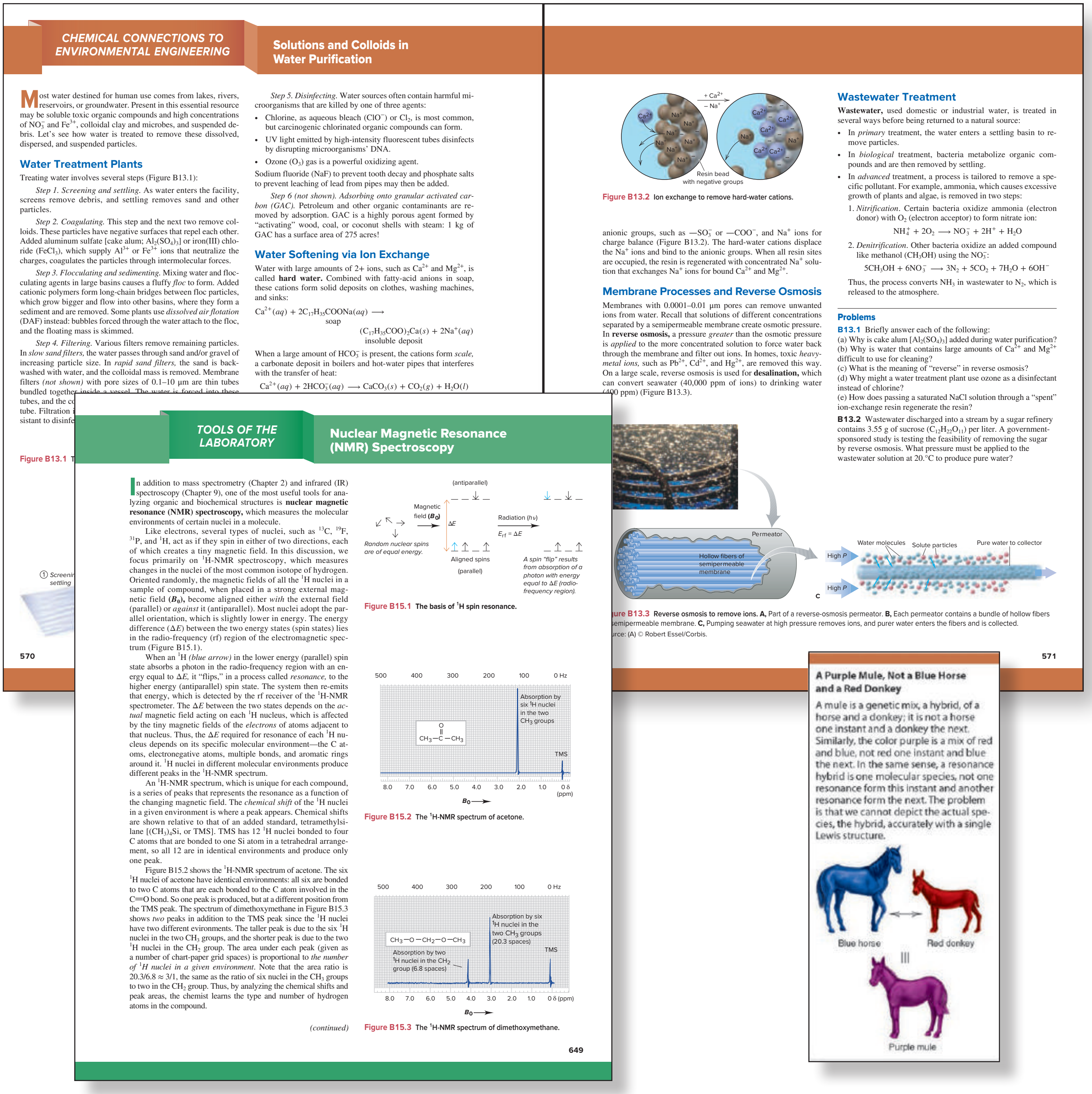


C

SOME SIMILAR PROBLEMS 2.14 and 2.15

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

Solutions and Colloids in Water Purification

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^{3+}, 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; $Al_2(SO_4)_3$] 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 bundled together inside a vessel. The water is forced into these tubes, and the c
tube. Filtration i
sistant to disinfe

Figure B13.1 T

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) 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 acres!

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:

$$Ca^{2+}(aq) + \underset{\text{soap}}{2C_{17}H_{35}COONa(aq)} \longrightarrow \underset{\text{insoluble deposit}}{(C_{17}H_{35}COO)_2Ca(s)} + 2Na^+(aq)$$

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:

$$Ca^{2+}(aq) + 2HCO_3^-(aq) \longrightarrow CaCO_3(s) + CO_2(g) + H_2O(l)$$

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

anionic groups, such as $—SO_3^-$ or $—COO^-$, 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).

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:
  $$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$
  2. *Denitrification.* Other bacteria oxidize an added compound like methanol (CH_3OH) using the NO_3^-:
  $$5CH_3OH + 6NO_3^- \longrightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

  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:
(a) Why is cake alum [$Al_2(SO_4)_3$] added during water purification?
(b) Why is water that contains large amounts of Ca^{2+} and Mg^{2+} difficult to use for cleaning?
(c) What is the meaning of "reverse" in reverse osmosis?
(d) Why might a water treatment plant use ozone as a disinfectant instead of chlorine?
(e) 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 ($C_{12}H_{22}O_{11}$) 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?

ure B13.3 Reverse osmosis to remove ions. **A,** Part of a reverse-osmosis permeator. **B,** Each permeator contains a bundle of hollow fibers semipermeable membrane. **C,** Pumping seawater at high pressure removes ions, and purer water enters the fibers and is collected.

urce: (A) © Robert Essel/Corbis.

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, ^{31}P, 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 **($\boldsymbol{B_0}$),** 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 [$(CH_3)_4Si$, 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 C═O bond. So one peak is produced, but at a different position from the TMS peak. The spectrum of dimethoxymethane in Figure B15.3 shows *two* peaks in addition to the TMS peak since the ^1H nuclei have two different evironments. 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.

(continued)

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

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

Figure B15.3 The ^1H-NMR spectrum of dimethoxymethane.

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 form this instant and another resonance form 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

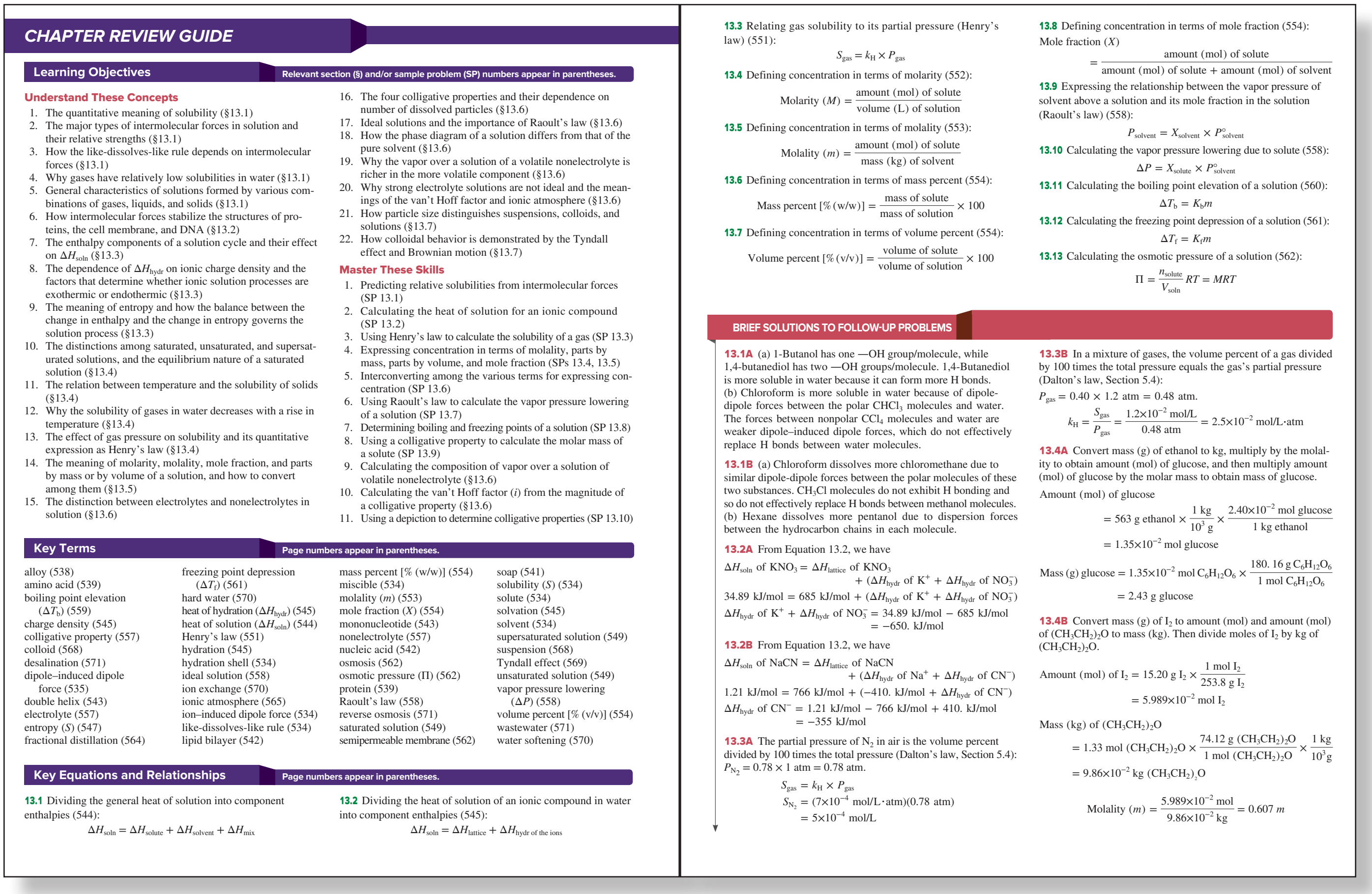
A favorite feature, the section summaries that conclude every section restate the major ideas concisely and immediately (rather than postponing such review until the end of the chapter).

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.
- **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 (§) and/or sample problem (SP) numbers appear in parentheses.

Understand These Concepts

1. The quantitative meaning of solubility (§13.1)
2. The major types of intermolecular forces in solution and their relative strengths (§13.1)
3. How the like-dissolves-like rule depends on intermolecular forces (§13.1)
4. Why gases have relatively low solubilities in water (§13.1)
5. General characteristics of solutions formed by various combinations of gases, liquids, and solids (§13.1)
6. How intermolecular forces stabilize the structures of proteins, the cell membrane, and DNA (§13.2)
7. The enthalpy components of a solution cycle and their effect on ΔH_{soln} (§13.3)
8. The dependence of ΔH_{hydr} on ionic charge density and the factors that determine whether ionic solution processes are exothermic or endothermic (§13.3)
9. The meaning of entropy and how the balance between the change in enthalpy and the change in entropy governs the solution process (§13.3)
10. The distinctions among saturated, unsaturated, and supersaturated solutions, and the equilibrium nature of a saturated solution (§13.4)
11. The relation between temperature and the solubility of solids (§13.4)
12. Why the solubility of gases in water decreases with a rise in temperature (§13.4)
13. The effect of gas pressure on solubility and its quantitative expression as Henry's law (§13.4)
14. The meaning of molarity, molality, mole fraction, and parts by mass or by volume of a solution, and how to convert among them (§13.5)
15. The distinction between electrolytes and nonelectrolytes in solution (§13.6)
16. The four colligative properties and their dependence on number of dissolved particles (§13.6)
17. Ideal solutions and the importance of Raoult's law (§13.6)
18. How the phase diagram of a solution differs from that of the pure solvent (§13.6)
19. Why the vapor over a solution of a volatile nonelectrolyte is richer in the more volatile component (§13.6)
20. Why strong electrolyte solutions are not ideal and the meanings of the van't Hoff factor and ionic atmosphere (§13.6)
21. How particle size distinguishes suspensions, colloids, and solutions (§13.7)
22. How colloidal behavior is demonstrated by the Tyndall effect and Brownian motion (§13.7)

Master These Skills

1. Predicting relative solubilities from intermolecular forces (SP 13.1)
2. Calculating the heat of solution for an ionic compound (SP 13.2)
3. Using Henry's law to calculate the solubility of a gas (SP 13.3)
4. Expressing concentration in terms of molality, parts by mass, parts by volume, and mole fraction (SPs 13.4, 13.5)
5. Interconverting among the various terms for expressing concentration (SP 13.6)
6. Using Raoult's law to calculate the vapor pressure lowering of a solution (SP 13.7)
7. Determining boiling and freezing points of a solution (SP 13.8)
8. Using a colligative property to calculate the molar mass of a solute (SP 13.9)
9. Calculating the composition of vapor over a solution of volatile nonelectrolyte (§13.6)
10. Calculating the van't Hoff factor (*i*) from the magnitude of a colligative property (§13.6)
11. Using a depiction to determine colligative properties (SP 13.10)

Key Terms Page numbers appear in parentheses.

alloy (538)
amino acid (539)
boiling point elevation (ΔT_b) (559)
charge density (545)
colligative property (557)
colloid (568)
desalination (571)
dipole–induced dipole force (535)
double helix (543)
electrolyte (557)
entropy (*S*) (547)
fractional distillation (564)
freezing point depression (ΔT_f) (561)
hard water (570)
heat of hydration (ΔH_{hydr}) (545)
heat of solution (ΔH_{soln}) (544)
Henry's law (551)
hydration (545)
hydration shell (534)
ideal solution (558)
ion exchange (570)
ionic atmosphere (565)
ion–induced dipole force (534)
like-dissolves-like rule (534)
lipid bilayer (542)
mass percent [% (w/w)] (554)
miscible (534)
molality (*m*) (553)
mole fraction (*X*) (554)
mononucleotide (543)
nonelectrolyte (557)
nucleic acid (542)
osmosis (562)
osmotic pressure (Π) (562)
protein (539)
Raoult's law (558)
reverse osmosis (571)
saturated solution (549)
semipermeable membrane (562)
soap (541)
solubility (*S*) (534)
solute (534)
solvation (545)
solvent (534)
supersaturated solution (549)
suspension (568)
Tyndall effect (569)
unsaturated solution (549)
vapor pressure lowering (ΔP) (558)
volume percent [% (v/v)] (554)
wastewater (571)
water softening (570)

Key Equations and Relationships Page numbers appear in parentheses.

13.1 Dividing the general heat of solution into component enthalpies (544):

$$\Delta H_{soln} = \Delta H_{solute} + \Delta H_{solvent} + \Delta H_{mix}$$

13.2 Dividing the heat of solution of an ionic compound in water into component enthalpies (545):

$$\Delta H_{soln} = \Delta H_{lattice} + \Delta H_{\text{hydr of the ions}}$$

13.3 Relating gas solubility to its partial pressure (Henry's law) (551):

$$S_{gas} = k_H \times P_{gas}$$

13.4 Defining concentration in terms of molarity (552):

$$\text{Molarity } (M) = \frac{\text{amount (mol) of solute}}{\text{volume (L) of solution}}$$

13.5 Defining concentration in terms of molality (553):

$$\text{Molality } (m) = \frac{\text{amount (mol) of solute}}{\text{mass (kg) of solvent}}$$

13.6 Defining concentration in terms of mass percent (554):

$$\text{Mass percent } [\%\,(\text{w/w})] = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100$$

13.7 Defining concentration in terms of volume percent (554):

$$\text{Volume percent } [\%\,(\text{v/v})] = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100$$

13.8 Defining concentration in terms of mole fraction (554):

$$\text{Mole fraction } (X) = \frac{\text{amount (mol) of solute}}{\text{amount (mol) of solute} + \text{amount (mol) of solvent}}$$

13.9 Expressing the relationship between the vapor pressure of solvent above a solution and its mole fraction in the solution (Raoult's law) (558):

$$P_{solvent} = X_{solvent} \times P^{\circ}_{solvent}$$

13.10 Calculating the vapor pressure lowering due to solute (558):

$$\Delta P = X_{solute} \times P^{\circ}_{solvent}$$

13.11 Calculating the boiling point elevation of a solution (560):

$$\Delta T_b = K_b m$$

13.12 Calculating the freezing point depression of a solution (561):

$$\Delta T_f = K_f m$$

13.13 Calculating the osmotic pressure of a solution (562):

$$\Pi = \frac{n_{solute}}{V_{soln}} RT = MRT$$

BRIEF SOLUTIONS TO FOLLOW-UP PROBLEMS

13.1A (a) 1-Butanol has one —OH group/molecule, while 1,4-butanediol has two —OH groups/molecule. 1,4-Butanediol is more soluble in water because it can form more H bonds.
(b) Chloroform is more soluble in water because of dipole-dipole forces between the polar $CHCl_3$ molecules and water. The forces between nonpolar CCl_4 molecules and water are weaker dipole–induced dipole forces, which do not effectively replace H bonds between water molecules.

13.1B (a) Chloroform dissolves more chloromethane due to similar dipole-dipole forces between the polar molecules of these two substances. CH_3Cl molecules do not exhibit H bonding and so do not effectively replace H bonds between methanol molecules.
(b) Hexane dissolves more pentanol due to dispersion forces between the hydrocarbon chains in each molecule.

13.2A From Equation 13.2, we have

$$\begin{aligned}\Delta H_{soln} \text{ of } KNO_3 &= \Delta H_{lattice} \text{ of } KNO_3 + (\Delta H_{hydr} \text{ of } K^+ + \Delta H_{hydr} \text{ of } NO_3^-)\\ 34.89 \text{ kJ/mol} &= 685 \text{ kJ/mol} + (\Delta H_{hydr} \text{ of } K^+ + \Delta H_{hydr} \text{ of } NO_3^-)\\ \Delta H_{hydr} \text{ of } K^+ + \Delta H_{hydr} \text{ of } NO_3^- &= 34.89 \text{ kJ/mol} - 685 \text{ kJ/mol}\\ &= -650. \text{ kJ/mol}\end{aligned}$$

13.2B From Equation 13.2, we have

$$\begin{aligned}\Delta H_{soln} \text{ of NaCN} &= \Delta H_{lattice} \text{ of NaCN} + (\Delta H_{hydr} \text{ of } Na^+ + \Delta H_{hydr} \text{ of } CN^-)\\ 1.21 \text{ kJ/mol} &= 766 \text{ kJ/mol} + (-410. \text{ kJ/mol} + \Delta H_{hydr} \text{ of } CN^-)\\ \Delta H_{hydr} \text{ of } CN^- &= 1.21 \text{ kJ/mol} - 766 \text{ kJ/mol} + 410. \text{ kJ/mol}\\ &= -355 \text{ kJ/mol}\end{aligned}$$

13.3A The partial pressure of N_2 in air is the volume percent divided by 100 times the total pressure (Dalton's law, Section 5.4): $P_{N_2} = 0.78 \times 1 \text{ atm} = 0.78 \text{ atm}$.

$$\begin{aligned}S_{gas} &= k_H \times P_{gas}\\ S_{N_2} &= (7{\times}10^{-4} \text{ mol/L·atm})(0.78 \text{ atm})\\ &= 5{\times}10^{-4} \text{ mol/L}\end{aligned}$$

13.3B In a mixture of gases, the volume percent of a gas divided by 100 times the total pressure equals the gas's partial pressure (Dalton's law, Section 5.4):

$P_{gas} = 0.40 \times 1.2 \text{ atm} = 0.48 \text{ atm}$.

$$k_H = \frac{S_{gas}}{P_{gas}} = \frac{1.2{\times}10^{-2} \text{ mol/L}}{0.48 \text{ atm}} = 2.5{\times}10^{-2} \text{ mol/L·atm}$$

13.4A Convert mass (g) of ethanol to kg, multiply by the molality to obtain amount (mol) of glucose, and then multiply amount (mol) of glucose by the molar mass to obtain mass of glucose.

$$\begin{aligned}\text{Amount (mol) of glucose} &= 563 \text{ g ethanol} \times \frac{1 \text{ kg}}{10^3 \text{ g}} \times \frac{2.40{\times}10^{-2} \text{ mol glucose}}{1 \text{ kg ethanol}}\\ &= 1.35{\times}10^{-2} \text{ mol glucose}\end{aligned}$$

$$\begin{aligned}\text{Mass (g) glucose} &= 1.35{\times}10^{-2} \text{ mol } C_6H_{12}O_6 \times \frac{180.16 \text{ g } C_6H_{12}O_6}{1 \text{ mol } C_6H_{12}O_6}\\ &= 2.43 \text{ g glucose}\end{aligned}$$

13.4B Convert mass (g) of I_2 to amount (mol) and amount (mol) of $(CH_3CH_2)_2O$ to mass (kg). Then divide moles of I_2 by kg of $(CH_3CH_2)_2O$.

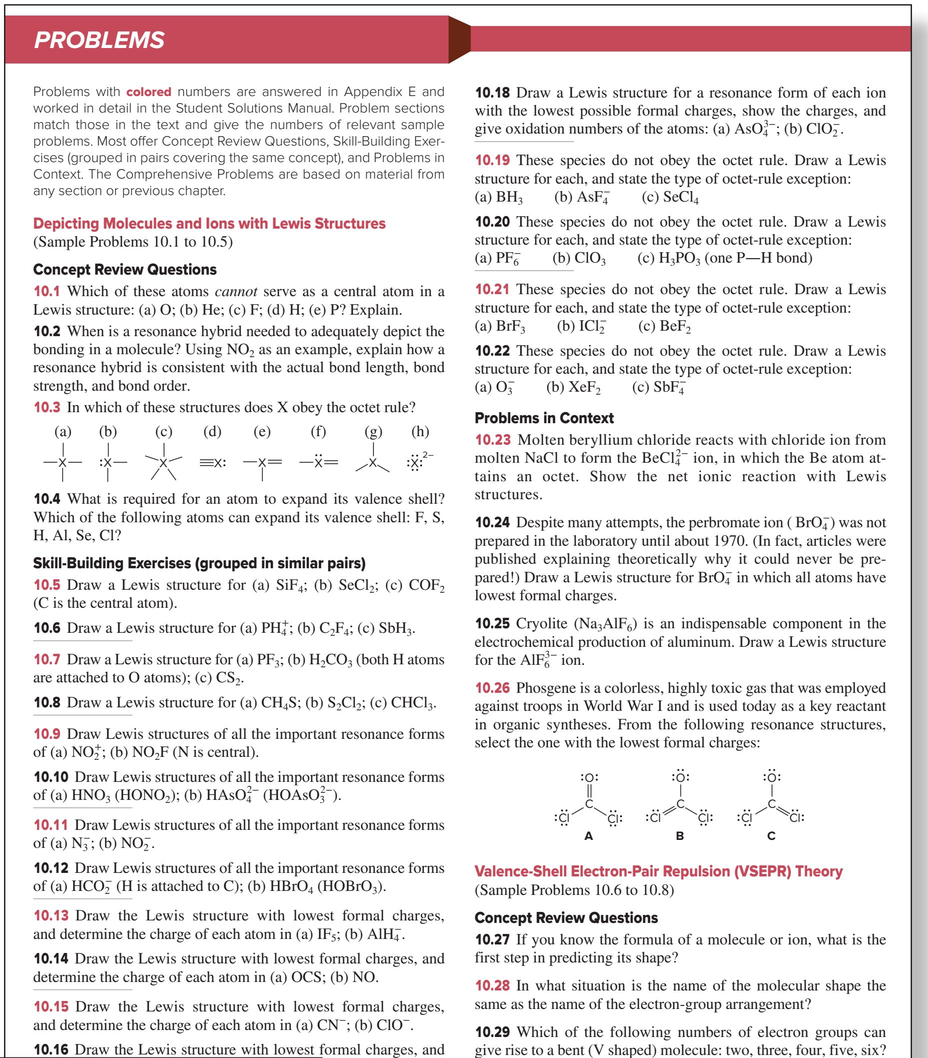
$$\begin{aligned}\text{Amount (mol) of } I_2 &= 15.20 \text{ g } I_2 \times \frac{1 \text{ mol } I_2}{253.8 \text{ g } I_2}\\ &= 5.989{\times}10^{-2} \text{ mol } I_2\end{aligned}$$

$$\begin{aligned}\text{Mass (kg) of } (CH_3CH_2)_2O &= 1.33 \text{ mol } (CH_3CH_2)_2O \times \frac{74.12 \text{ g } (CH_3CH_2)_2O}{1 \text{ mol } (CH_3CH_2)_2O} \times \frac{1 \text{ kg}}{10^3 \text{ g}}\\ &= 9.86{\times}10^{-2} \text{ kg } (CH_3CH_2)_2O\end{aligned}$$

$$\text{Molality } (m) = \frac{5.989{\times}10^{-2} \text{ mol}}{9.86{\times}10^{-2} \text{ kg}} = 0.607\ m$$

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?

(a) (b) (c) (d) (e) (f) (g) (h)

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 ($HONO_2$); (b) $HAsO_4^{2-}$ ($HOAsO_3^{2-}$).

10.11 Draw Lewis structures of all the important resonance forms of (a) N_3^-; (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) OCS; (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

; (b) ClNO.

e form of each ion

w the charges, and

; (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_4^-) 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_4^- 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^{3-} 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:

A B C

Valence-Shell Electron-Pair Repulsion (VSEPR) Theory

(Sample Problems 10.6 to 10.8)

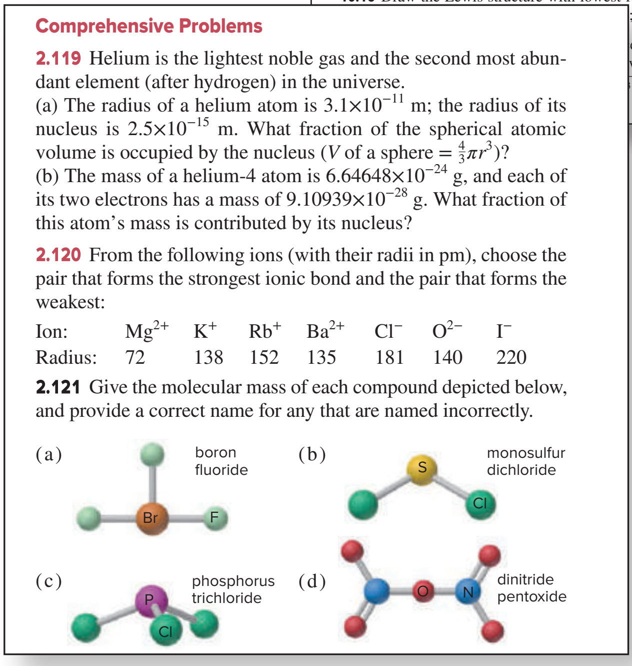
Concept Review Questions

10.27 If you know the formula of a molecule or ion, what is the first step in predicting its shape?

10.28 In what situation is the name of the molecular shape the same as the name of the electron-group arrangement?

10.29 Which of the following numbers of electron groups can give rise to a bent (V shaped) molecule: two, three, four, five, six? Draw an example for each case, showing the shape classification (AX_mE_n) and the ideal bond angle.

10.30 Name all the molecular shapes that have a tetrahedral electron-group arrangement.



Comprehensive Problems

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

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

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

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

(a) boron fluoride
(b) monosulfur dichloride
(c) phosphorus trichloride
(d) dinitride pentoxide

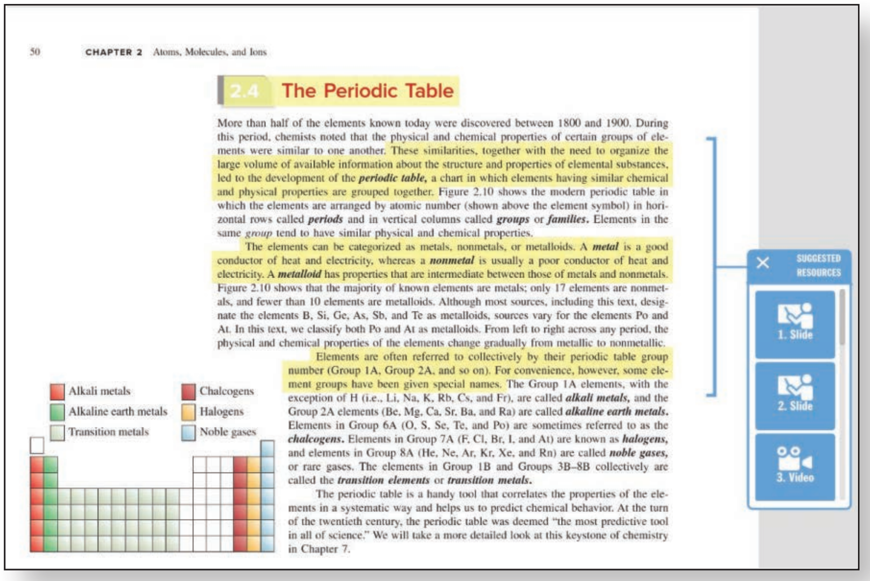
OPTIMIZING THE TEXT

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

Our revision for the eighth edition focused on continued optimization of the text. To aid us in this process, we were able to use data from literally thousands of student responses to questions in LearnSmart, the adaptive learning system that assesses student knowledge of course content. The data, such as average time spent answering each question and the percentage of students who correctly answered the question on the first attempt, revealed the learning objectives that students found particularly difficult. We utilized several approaches to present these difficult concepts in a clearer, more straightforward way in the eighth edition of *Chemistry: The Molecular Nature of Matter and Change.*

Making the concepts clearer through digital learning resources. Students will be able to access over 2,000 digital learning resources throughout this text's SmartBook. These learning resources present summaries of concepts and worked examples, including over 400 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.



50 CHAPTER 2 Atoms, Molecules, and Ions

2.4 The Periodic Table

More than half of the elements known today were discovered between 1800 and 1900. During this period, chemists noted that the physical and chemical properties of certain groups of elements were similar to one another. These similarities, together with the need to organize the large volume of available information about the structure and properties of elemental substances, led to the development of the ***periodic table,*** a chart in which elements having similar chemical and physical properties are grouped together. Figure 2.10 shows the modern periodic table in which the elements are arranged by atomic number (shown above the element symbol) in horizontal rows called ***periods*** and in vertical columns called ***groups*** or ***families.*** Elements in the same *group* tend to have similar physical and chemical properties.

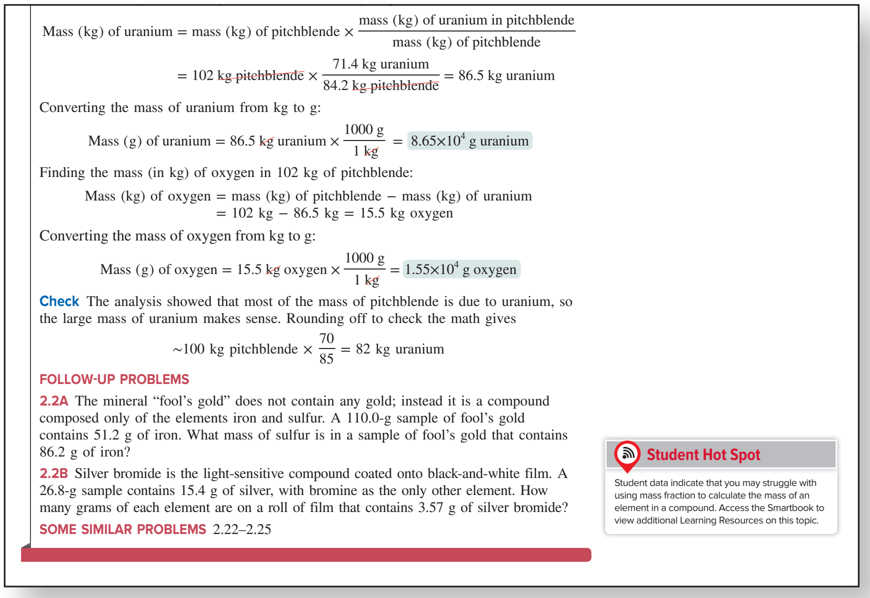
The elements can be categorized as metals, nonmetals, or metalloids. A ***metal*** is a good conductor of heat and electricity, whereas a ***nonmetal*** is usually a poor conductor of heat and electricity. A ***metalloid*** has properties that are intermediate between those of metals and nonmetals. Figure 2.10 shows that the majority of known elements are metals; only 17 elements are nonmetals, and fewer than 10 elements are metalloids. Although most sources, including this text, designate the elements B, Si, Ge, As, Sb, and Te as metalloids, sources vary for the elements Po and At. In this text, we classify both Po and At as metalloids. From left to right across any period, the physical and chemical properties of the elements change gradually from metallic to nonmetallic.

Elements are often referred to collectively by their periodic table group number (Group 1A, Group 2A, and so on). For convenience, however, some element groups have been given special names. The Group 1A elements, with the exception of H (i.e., Li, Na, K, Rb, Cs, and Fr), are called ***alkali metals,*** and the Group 2A elements (Be, Mg, Ca, Sr, Ba, and Ra) are called ***alkaline earth metals.*** Elements in Group 6A (O, S, Se, Te, and Po) are sometimes referred to as the ***chalcogens.*** Elements in Group 7A (F, Cl, Br, I, and At) are known as ***halogens,*** and elements in Group 8A (He, Ne, Ar, Kr, Xe, and Rn) are called ***noble gases,*** or rare gases. The elements in Group 1B and Groups 3B–8B collectively are called the ***transition elements*** or ***transition metals.***

The periodic table is a handy tool that correlates the properties of the elements in a systematic way and helps us to predict chemical behavior. At the turn of the twentieth century, the periodic table was deemed "the most predictive tool in all of science." We will take a more detailed look at this keystone of chemistry in Chapter 7.

NEW! Student Hot Spot

We are very pleased to incorporate real student data points and input, derived from thousands of our LearnSmart users, to help guide our revision. LearnSmart Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content. With these data, we were able to both hone our text content when needed and, for particularly challenging concepts, point students to the learning resources that can elucidate and reinforce those concepts. You'll see these marginal features throughout the text. Students should log into Connect and view the resources through our SmartBook.



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

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

Converting the mass of uranium from kg to g:

$$\text{Mass (g) of uranium} = 86.5\ \cancel{\text{kg}}\ \text{uranium} \times \frac{1000\ \text{g}}{1\ \cancel{\text{kg}}} = 8.65\times10^4\ \text{g uranium}$$

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

$$\begin{aligned}\text{Mass (kg) of oxygen} &= \text{mass (kg) of pitchblende} - \text{mass (kg) of uranium}\\ &= 102\ \text{kg} - 86.5\ \text{kg} = 15.5\ \text{kg oxygen}\end{aligned}$$

Converting the mass of oxygen from kg to g:

$$\text{Mass (g) of oxygen} = 15.5\ \cancel{\text{kg}}\ \text{oxygen} \times \frac{1000\ \text{g}}{1\ \cancel{\text{kg}}} = 1.55\times10^4\ \text{g oxygen}$$

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 2.22–2.25

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 Smartbook to view additional Learning Resources on this topic.

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 eighth 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 eighth edition has over 250 sample problems and over 500 follow-up problems. In almost every chapter, 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.

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.

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.

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 a revised table of decimal prefixes and SI units to make conversion among SI units clearer, a revised discussion on intensive and extensive properties, and a revised sample problem on density.
- **Chapter 2** includes revised sample problems on mass percent and naming of compounds.
- **Chapter 3** has several new end-of-chapter problems: one new problem on the determination of a molecular formula, two new problems on writing a balanced reaction and determining the limiting reactant from molecular scenes, and two new stoichiometric problems involving limiting reactants.
- **Chapter 4** includes a new figure illustrating the activity series of the halogens. Sample problems on stoichiometry in precipitation and acid-base reactions were revised to include reactions that do not have 1:1 mole ratios.
- **Chapter 5** has two revised sample problems that provide students with additional opportunities for pressure unit conversions and stoichiometry calculations for gas reactions.
- **Chapter 6** has a clearer and more detailed discussion on pressure-volume work and a revised sample problem on the calorimetric determination of heat of combustion. Also included are new end-of-chapter problems on the calculation of enthalpy change for an aqueous reaction and determination of heat of combustion with bomb calorimetry.
- **Chapter 7** contains a new table summarizing the relationships between the quantum numbers and orbitals for the first four main energy levels.
- **Chapter 8** contains a new figure on electron spin; orbital diagrams have been added to the solutions of several sample problems.
- **Chapter 9** has improvements to several figures, a more detailed discussion of relationship between difference in electronegativity and ionic character, and some new follow-up problems.
- **Chapter 10** includes more detailed examples of depicting molecules with double bonds and ions with Lewis structures. Sample and follow-up problems have been revised to provide more opportunities to calculate formal charges and use those to evaluate resonance structures.
- **Chapter 11** has new art to illustrate formation of sigma and pi bonds and a new figure to show the placement of lone pairs in hybrid orbitals.
- **Chapter 12** includes additional information about viscosity and intermolecular forces.
- **Chapter 13** includes a more challenging sample problem on Henry's law, as well as revisions to several follow-up problems. There are new problems on the calculation of molar mass from freezing point depression.
- **Chapter 15** incorporates new art to make nomenclature clearer and a revised figure to show the key stages in protein synthesis.
- **Chapter 16** has a revised sample problem using the first-order integrated rate law, a revised figure on reaction mechanisms, and a new molecular scene problem on first-order reactions.
- **Chapter 17** contains a revised table on concentration ratios in an equilibrium system and two new sample problems, one on finding the equilibrium constant for an overall reaction, and the other on converting between K_p and K_c.
- **Chapter 18** has a new table on magnitude of K_a and percent dissociation and two revised sample problems.
- **Chapter 19** has a revised sample problem on buffer pH that reflects a more realistic lab procedure, a new molecular scene problem involving buffer solutions, a clearer presentation of pH calculations during acid-base titrations, and revised figures of pH titration curves. The section on acid-base indicators has been expanded, including the addition of a new figure about choosing an indicator for each type of acid-base titration. The discussion of aqueous solutions of metal sulfides was simplified.
- **Chapter 20** incorporates a new table that summarizes Q, K, ΔG, and reaction spontaneity.
- **Chapter 21** has several revised follow-up problems.
- **Chapter 23** has a new figure illustrating chelate complex ions and several revised figures. A new equation for calculating the charge of the metal ion in a complex ion has been added.

- **Chapter 24** has a new table summarizing changes in mass and atomic numbers during radioactive decay; a table on stability of even vs. odd numbers of nucleons has been revised. The discussion about mode of decay and neutron/proton ratio has been expanded.

Addition of Advanced Topics

In this special version of the 8th edition, advanced topics have been added to three chapters for use in classes in which a deeper and more rigorous level of discussion is appropriate. Problems on these advanced topics have been added to the end-of-chapter problem sets and to the online homework question bank.

- **Chapter 7** includes an expanded discussion on the development of the Schrödinger equation and the particle-in-a-box model. A new sample problem gives students an opportunity to apply the particle-in-a-box model to electron transitions.
- **Chapter 16** incorporates the calculus involved in the derivation of the integrated rate laws for zero-, first-, and second-order reactions. Also now included are discussions of pseudo-first-order reactions, steady-state approximation, and the Michaelis-Menten equation for enzyme kinetics.
- **Chapter 20** has a significantly expanded section on entropy. The calculations of entropy changes during isothermal gas expansion or contraction, phase changes, and changes in temperature have been added to enhance the current content; three new sample problems demonstrating these entropy change calculations are included.

Innovative Topic and Chapter Presentation

While 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 oxidation-number method (formerly covered in Chapter 4) has been removed from the text, and 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 role of intermolecular forces in biomolecular structure (12), 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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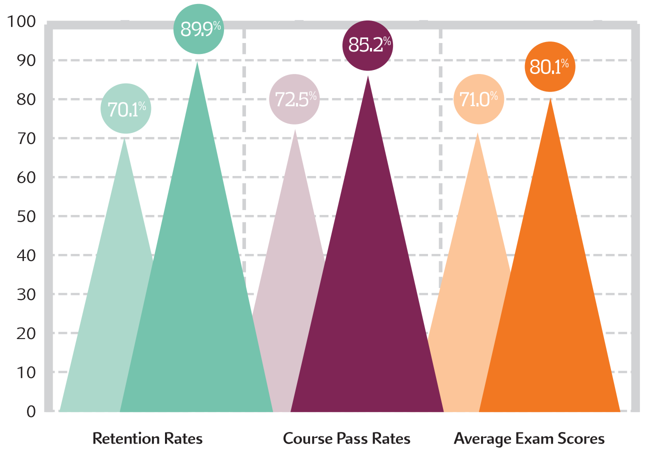

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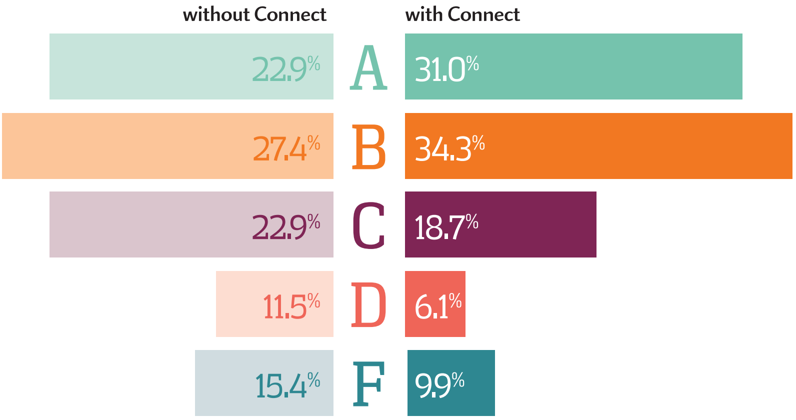

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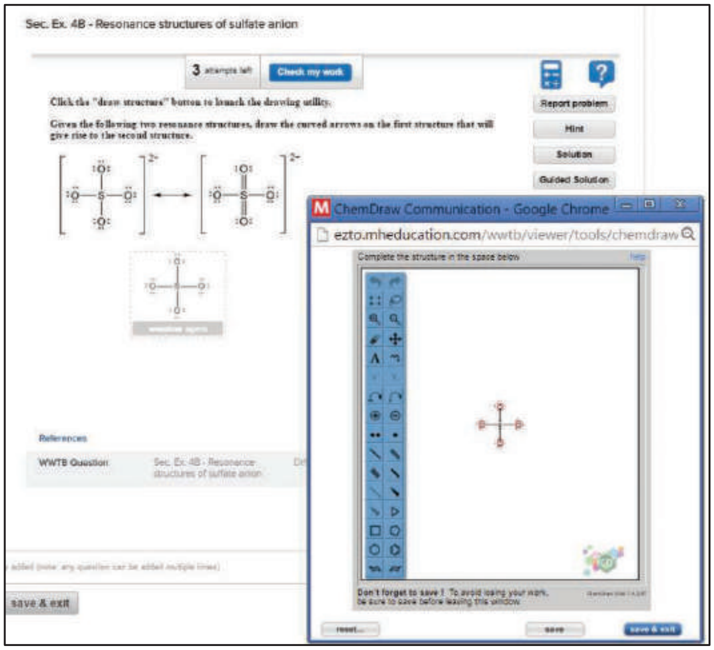

Sec. Ex. 4B - Resonance structures of sulfate anion

Click the "draw structure" button to launch the drawing utility.

Given the following two resonance structures, draw the curved arrows on the first structure that will give rise to the second structure.

ChemDraw Communication - Google Chrome
ezto.mheducation.com/wwtb/viewer/tools/chemdraw

Complete the structure in the space below

References
WWTB Question Sec. Ex. 4B - Resonance structures of sulfate anion

Don't forget to save! To avoid losing your work, be sure to save before leaving this window.

Instructors have access to the following instructor resources through Connect.

- **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.
- **PowerPoint Lecture Outlines** Ready-made presentations that combine art and lecture notes are provided for each chapter of the text.
- **Computerized Test Bank** Over 2300 test questions that accompany *Chemistry: The Molecular Nature of Matter and Change* are available utilizing the industry-leading test generation software TestGen. These same questions are also available and assignable through Connect for online tests.
- **Instructor's Solutions Manual** This supplement, prepared by Mara Vorachek-Warren of St. Charles Community College, contains complete, worked-out solutions for *all* the end-of-chapter problems in the text.

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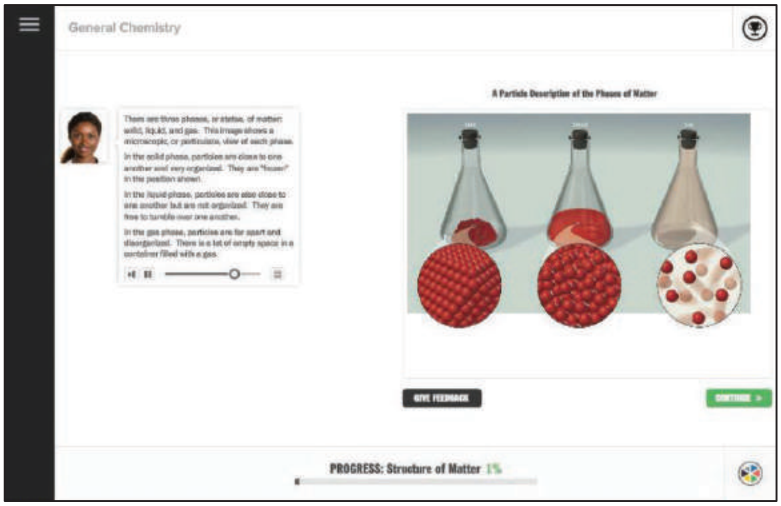
Fueled by LearnSmart—the most widely used and intelligent adaptive learning resource—**LearnSmart Prep** is designed to get students ready for a forthcoming course by quickly and effectively addressing gaps in prerequisite knowledge that may cause problems down the road. By distinguishing what students know from what they don't, and honing in on concepts they are most likely to forget, LearnSmart Prep maintains a continuously adapting learning path individualized for each student, and tailors content to focus on what the student needs to master in order to have a successful start in the new class.



General Chemistry

A Particle Description of the Phases of Matter

PROGRESS: Structure of Matter 1%

THE VIRTUAL LAB EXPERIENCE

Based on the same world-class, superbly adaptive technology as LearnSmart, **McGraw-Hill LearnSmart 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 data using simulated equipment found in labs and clinics. The student is allowed to make mistakes—a powerful part of the learning experience! A virtual coach provides subtle hints when needed, asks questions about the student's choices, and allows the student to reflect on and correct those mistakes. Whether your need is to overcome the logistical challenges of a traditional lab, provide better lab prep, improve student performance, or make students' online experience one that rivals the real world, LearnSmart Labs accomplishes it all.

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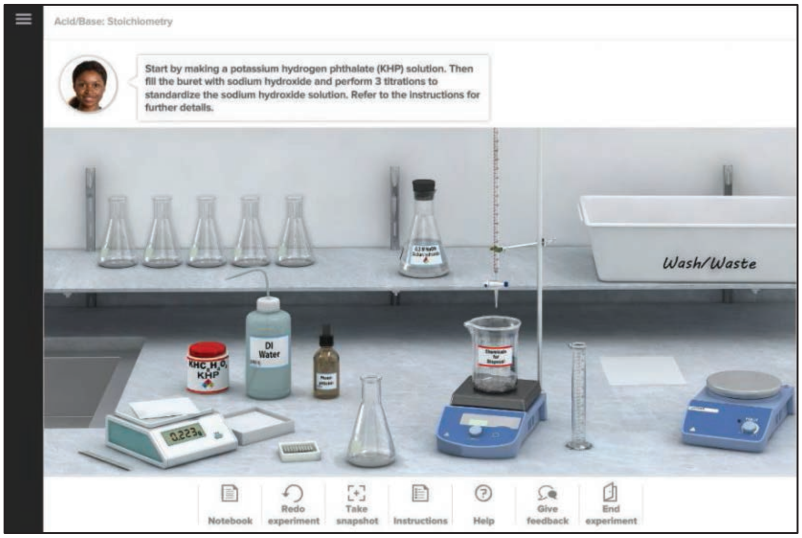


Start by making a potassium hydrogen phthalate (KHP) solution. Then fill the buret with sodium hydroxide and perform 3 titrations to standardize the sodium hydroxide solution. Refer to the instructions for further details.

COOPERATIVE CHEMISTRY LABORATORY MANUAL

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

STUDENT SOLUTIONS MANUAL

This supplement, prepared by Mara Vorachek-Warren of St. Charles Community College, contains detailed solutions and explanations for all problems in the main text that have colored numbers.

ACKNOWLEDGMENTS

It would be nearly impossible to put together a more professional, talented, and supportive publishing team than our colleagues at McGraw-Hill Education: Managing Director Thomas Timp, Director of Chemistry David Spurgeon, Ph.D., Associate Director of Digital Content Robin Reed, Program Manager Lora Neyens, Content Project Manager Laura Bies, Designer David Hash, Marketing Manager Matthew Garcia, and Director of Digital Content Shirley Hino. It is a pleasure to work with them; their leadership, knowledge, and encouragement have helped to make this latest edition a reality.

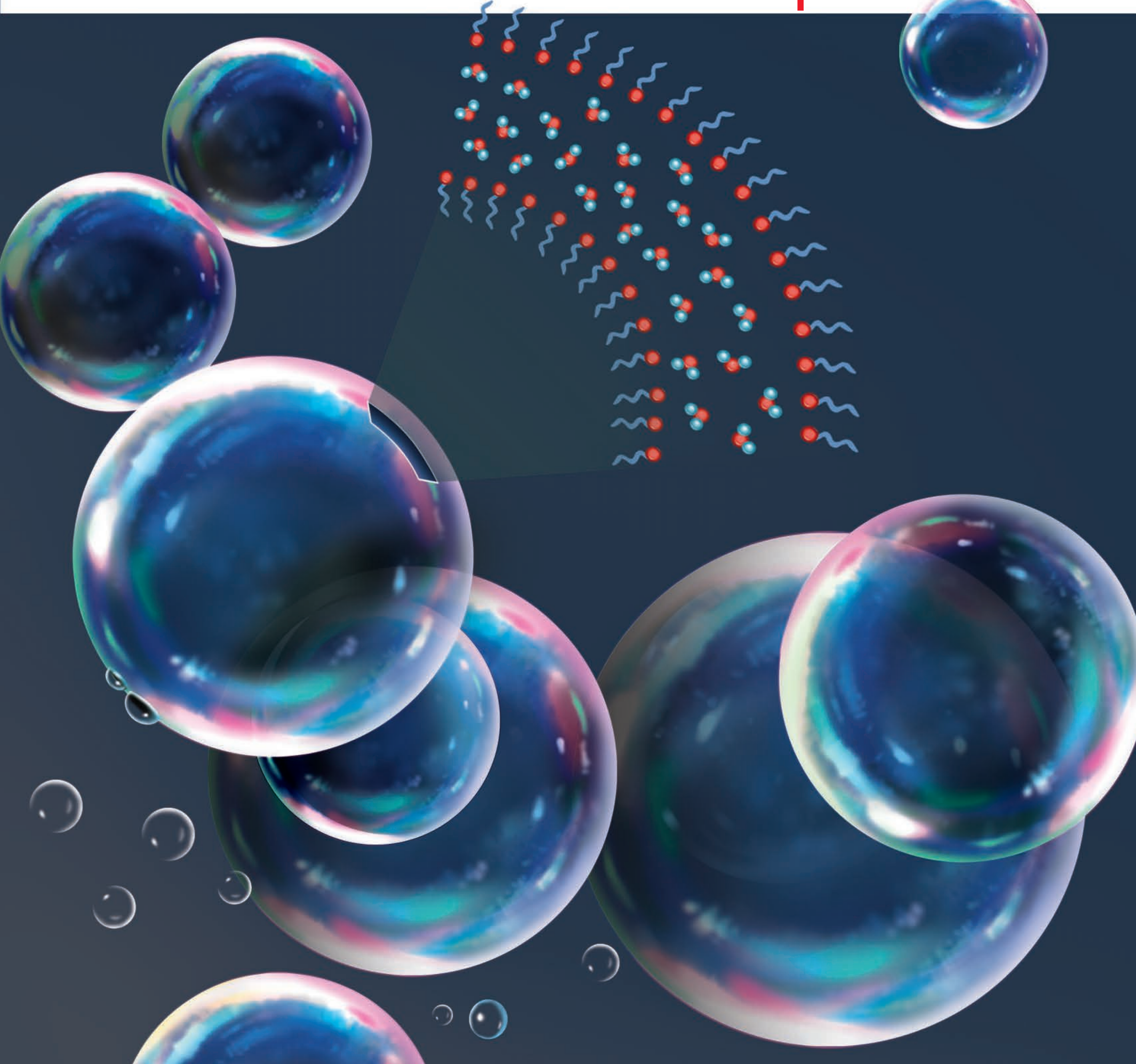
Mara Vorachek-Warren of St. Charles Community College provided a thorough accuracy check of all the new sample problems, follow-up problems, and end-of-chapter problems as part of her superb preparation of both the Student and Instructor's Solutions Manuals.

The following individuals helped write and review learning goal-oriented content for **LearnSmart for General Chemistry:** Margaret Ruth Leslie, Kent State University and Adam I. Keller, Columbus State Community College.

Several expert freelancers contributed as well. Jane Hoover did her usual excellent job in copyediting the text, and Lauren Timmer and Louis Poncz followed with meticulous proofreading. And many thanks to Jerry Marshall, who patiently researched new stock and studio photos.

CHEMISTRY

Advanced Topics



1

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

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Concepts and Skills to Review Before You Study This Chapter

- exponential (scientific) notation (Appendix A)

Maybe you're taking this course because chemistry is fundamental to understanding other natural sciences. Maybe it's required for your medical or engineering major. Or maybe you just want to learn more about the impact of chemistry on society or even on your everyday life. For example, does the following morning routine (described in chemical terms) sound familiar? You are awakened by the buzzing of your alarm clock, a sound created when molecules align in the liquid-crystal display of your clock and electrons flow to create a noise. You throw off a thermal insulator of manufactured polymer (blanket) and jump in the shower to emulsify fatty substances on your skin and hair with purified water and formulated detergents. Next you adorn yourself in an array of pleasant-smelling pigmented gels, dyed polymeric fibers, synthetic footwear, and metal-alloy jewelry. After a breakfast of nutrient-enriched, spoilage-retarded carbohydrates (cereal) in a white emulsion of fats, proteins, and monosaccharides (milk) and a cup of hot aqueous extract containing a stimulating alkaloid (coffee), you abrade your teeth with a colloidal dispersion of artificially flavored, dental-hardening agents (toothpaste), grab your portable electronic device containing ultrathin, microetched semiconductor layers powered by a series of voltaic cells (laptop), collect some objects made from processed cellulose and plastic, electronically printed with light- and oxygen-resistant inks (books), hop in your hydrocarbon-fueled, metal-vinyl-ceramic vehicle, electrically ignite a synchronized series of controlled gaseous explosions (start your car), and take off for class!

But the true impact of chemistry extends much farther than the commercial products of daily life. The truth is that the most profound biological and environmental questions ultimately have chemical answers: How does an organism reproduce, grow, and age? What are the underlying explanations for health and disease? How can we sustain a planetary ecosystem in which plant, animal, and human populations thrive? Is there life on other worlds?

So, no matter what your reason for studying chemistry, you're going to learn some amazing things. And, this course comes with a bonus for developing two mental skills. The first, common to all science courses, is the ability to solve problems systematically. The second is specific to chemistry, for as you comprehend its ideas, you begin to view a hidden reality, one filled with incredibly minute particles moving at fantastic speeds, colliding billions of times a second, and interacting in ways that allow your brain to translate fluxes of electric charge into thoughts and that determine how all the matter inside and outside of you behaves. This chapter holds the keys to unlock and enter this new world.

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.
- A brief discussion of chemistry's origins, including some major missteps, leads to an overview of how scientists build models to study nature.
- We examine modern units for mass, length, volume, density, and temperature and apply systematic chemical problem solving to unit conversions.
- We see that data collection always includes some uncertainty and examine the distinction between accuracy and precision.

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.* (In Section 1.4, we discuss the meanings of mass and volume in terms of how they are measured.) 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.

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.

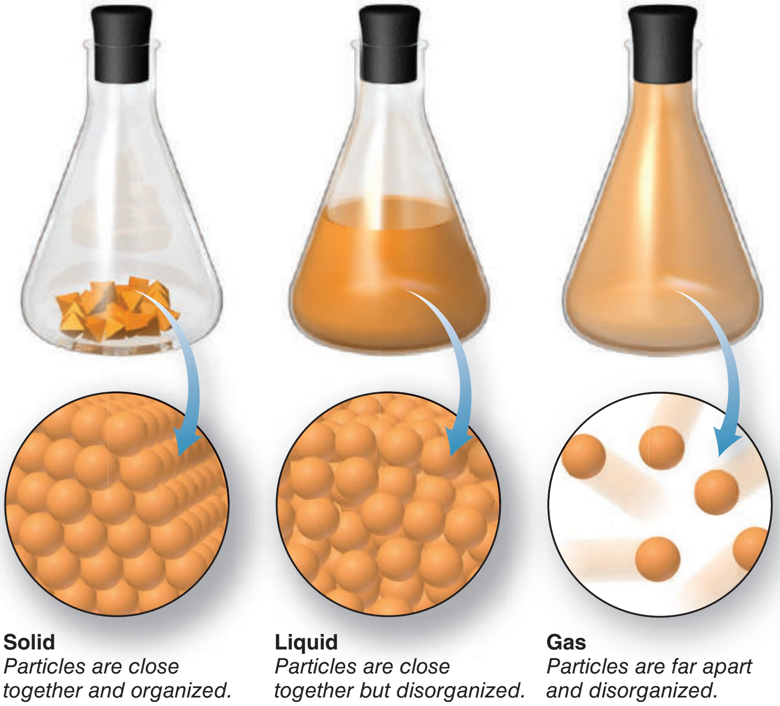


Figure 1.1 The physical states of matter.

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):

$$\text{Water (solid state)} \longrightarrow \text{water (liquid state)}$$

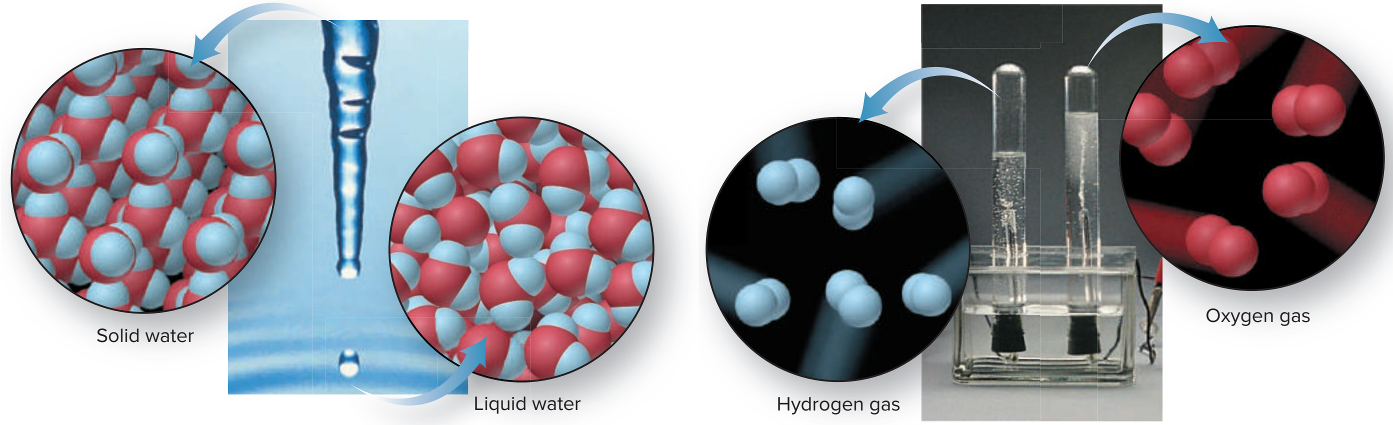
All changes of state of matter are physical changes.

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):

$$\text{Water} \xrightarrow{\text{electric current}} \text{hydrogen} + \text{oxygen}$$

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



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

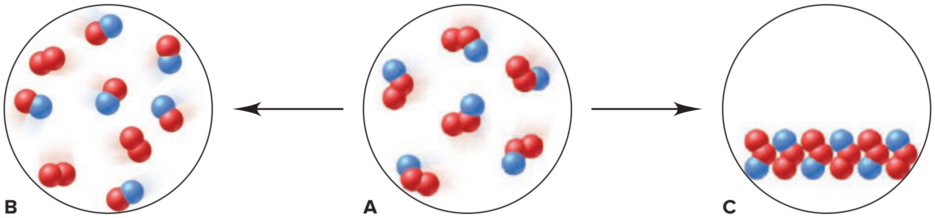
B Chemical change:
Electric current decomposes water into different substances (hydrogen and oxygen). Particles before and after are different, which means composition ***did*** *change.*

Figure 1.2 The distinction between physical and chemical change.

Source: (A) © Paul Morrell/Stone/Getty Images; (B) © McGraw-Hill Education/Stephen Frisch, photographer

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.

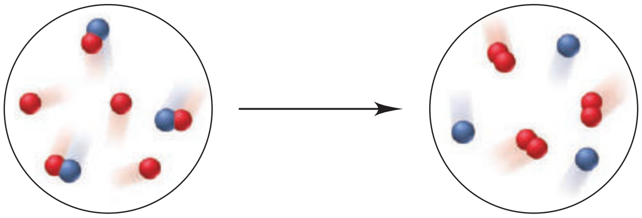
Plan Given depictions of two changes, we have to determine whether each represents a physical or a chemical change. The number and colors of the little spheres that make up each particle tell its "composition." Samples with particles of the *same* composition but in a different arrangement depict a *physical*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

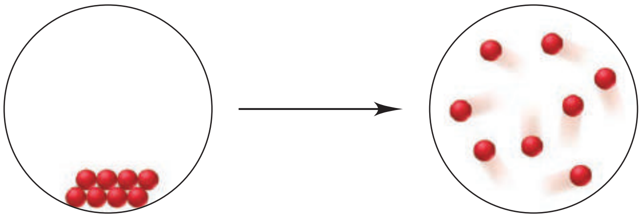
FOLLOW-UP PROBLEMS

*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 1.84

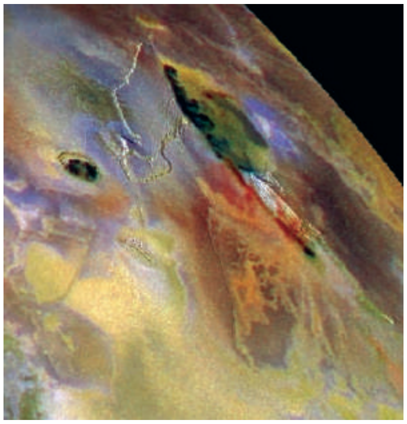
Like water, hydrogen, oxygen, or any other real substance, copper is also identified by *its own set* of physical and chemical properties (Table 1.1).

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*).

Table 1.1 Some Characteristic Properties of Copper

Physical Properties	Chemical Properties
Easily hammered into sheets (malleable) and drawn into wires (ductile) 	Slowly forms a blue-green carbonate in moist air 
Can be melted and mixed with zinc to form brass 	Reacts with nitric or sulfuric acid 
Density = 8.95 g/cm^3 Melting point = 1083°C Boiling point = 2570°C	Slowly forms deep-blue solution in aqueous ammonia 

Source: (copper) © McGraw-Hill Education/Mark Dierker, photographer; (candlestick) © Ruth Melnick; (copper carbonate, copper reacting with acid, copper and ammonia) © McGraw-Hill Education/Stephen Frisch, photographer



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

Source: JPL-NASA

Similarly, as the temperature drops, water vapor condenses to liquid water, and with further cooling, the liquid freezes to ice:

$$\text{Ice} \xrightarrow{\textit{heating}} \text{Liquid water} \xrightarrow{\textit{heating}} \text{Water vapor}$$

$$\text{Ice} \xleftarrow{\textit{cooling}} \text{Liquid water} \xleftarrow{\textit{cooling}} \text{Water vapor}$$

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.

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, and 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.

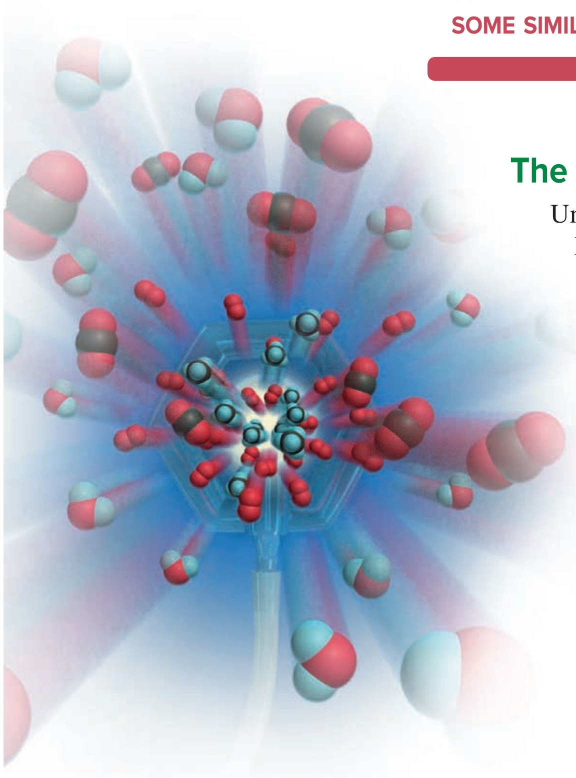
1.2B Decide whether each of the following processes is primarily a physical or a chemical change, and explain briefly:
(a) Clouds form in the sky.
(b) Old milk turns sour.
(c) Butter is melted to use on popcorn.

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 *(see margin),* 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.*


Methane and oxygen form carbon dioxide and water in the flame of a lab burner. (Carbon is black, oxygen red, and hydrogen blue.)

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.

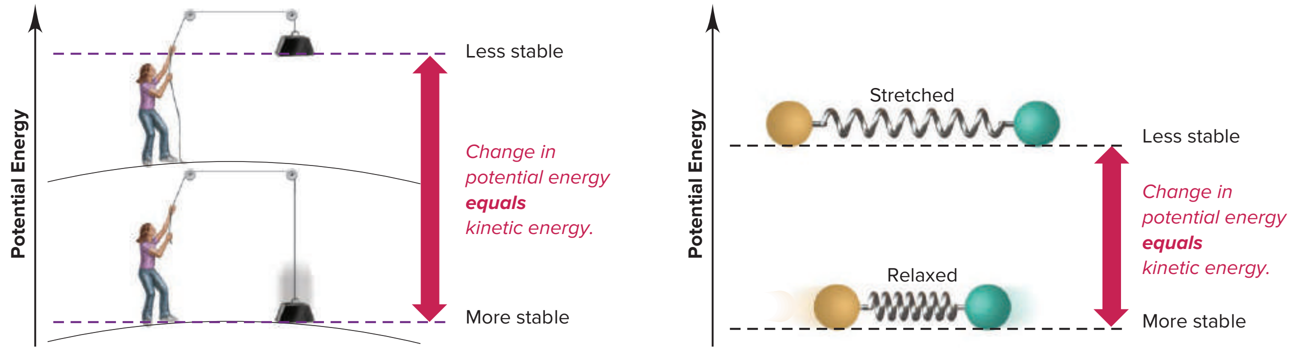
- **Potential energy** is *the energy due to the **position** of the object relative to other objects.*
- **Kinetic energy** is *the energy due to the **motion** of the object.*

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.*

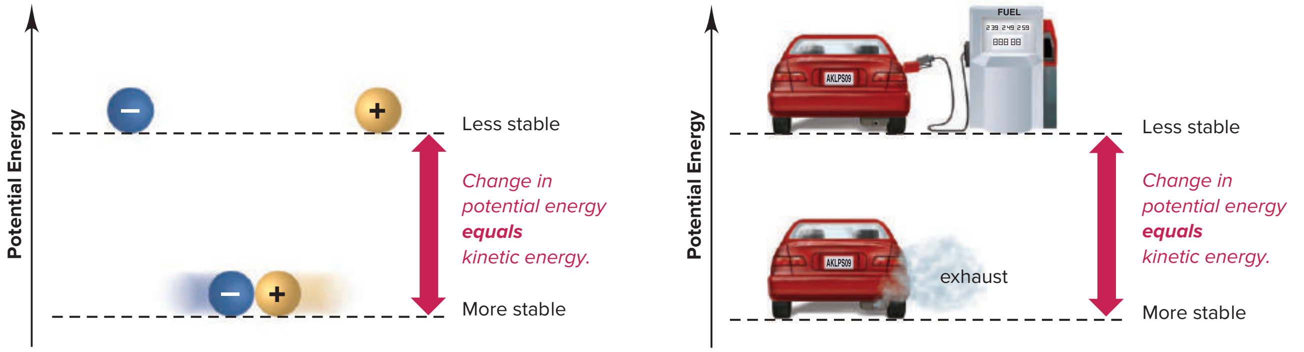
The four cases are

- *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



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.*

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.