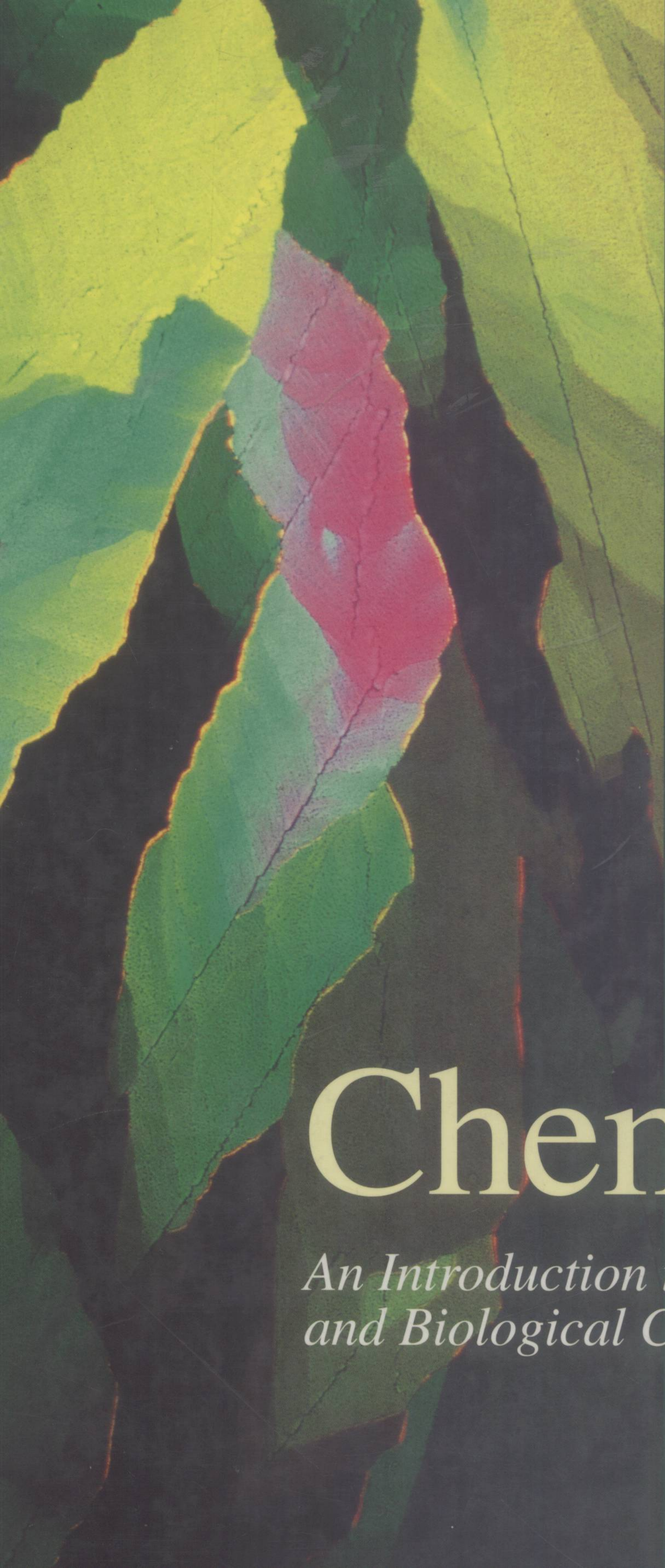
Sixth Edition



Chemistry

An Introduction to General, Organic, and Biological Chemistry

Karen C. Timberlake

Sixth Edition

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An Introduction to General, Organic, and Biological Chemistry

Karen C. Timberlake
Los Angeles Valley College

HarperCollinsCollegePublishers

This book is dedicated

to all my family who support my work and share my hopes and dreams, to my friend Susan who taught me to persevere in the joy of life, and to you, the student, and the realization of your endeavors.

The whole art of teaching is only the art of awakening the natural curiosity of young minds.—ANATOLE FRANCE

One must learn by doing the thing; though you think you know it, you have no certainty until you try.—SOPHOCLES

Discovery consists of seeing what everybody has seen and thinking what nobody has thought.—ALBERT SZENT-GYORGI

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Front and back cover photo: Photomicrograph of sulphur crystals

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Periodic Table of the Elements

Representative elements

Group ↓ Alkali metals (1, 1A); Alkaline earth metals ↓ (2, 2A); Transition metals (B) (3–12); Halogens ↓ (17, 7A); Noble gases ↓ (18, 8A)

Nonmetals

Metals

Period number	1 1A	2 2A	3	4	5	6	7	8	9	10	11	12	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
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** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **Ba** 137.3	57* **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226	89† **Ac** (227)	104 **Db** (261)	105 **Jl** (262)	106 **Rf** (263)	107 **Bh** (262)	108 **Hn** (265)	109 **Mt** (266)	110 (269)	111 (272)							

*Lanthanides	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
†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** (260)

Atomic Weights of the Elements (Based on Carbon-12)

Name	Symbol	Atomic Number	Atomic Weight[a]
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
Blismuth	Bi	83	209.0
Bohrium[b]	Bh	107	(262)
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.4
Calcium	Ca	20	40.08
Californium	Cf	98	(251)
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
Copper	Cu	29	63.55
Curium	Cm	96	(247)
Dubnium[b]	Db	104	(261)
Dysprosium	Dy	66	162.5
Einsteinium	Es	99	(252)
Erbium	Er	68	167.3
Europium	Eu	63	152.0
Fermium	Fm	100	(257)
Fluorine	F	9	19.00
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.3
Gallium	Ga	31	69.72
Germanium	Ge	32	72.59
Gold	Au	79	197.0
Hafnium	Hf	72	178.5
Hahnium[b]	Hn	108	(265)
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
Joliotium[b]	Jl	105	(262)
Krypton	Kr	36	83.80
Lanthanum	La	57	138.9
Lawrencium[b]	Lr	103	(260)
Lead	Pb	82	207.2
Lithium	Li	3	6.941
Lutetium	Lu	71	175.0
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Mendelevium[b]	Md	101	(258)

Name	Symbol	Atomic Number	Atomic Weight
Mercury	Hg	80	200.6
Molybdenum	Mo	42	95.94
Meitnerium[b]	Mt	109	(266)
Neodymium	Nd	60	144.2
Neon	Ne	10	20.18
Neptunium	Np	93	(237)
Nickle	Ni	28	58.69
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium[b]	No	102	(259)
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	(244)
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
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.1
Rutherfordium[b]	Rf	106	(263)
Samarium	Sm	62	150.4
Scandium	Sc	21	44.96
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	32.06
Tantalum	Ta	73	180.9
Technetium	Tc	43	(98)
Tellurium	Te	52	127.6
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	65.38
Zirconium	Zr	40	91.22
—[c]	—	110	(269)
—[c]	—	111	(272)

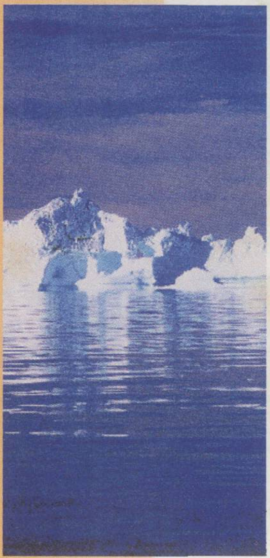
[a]The atomic weights in parentheses are the mass numbers of the longest lived isotopes.
[b]Recommended element names by International Union of Pure & Applied Commission (IUPAC) on Nomenclature of Inorganic Chemistry.
[c]Element 110 was first produced Nov. 9, 1994 and Element 111 was first produced Dec. 8, 1994 both in Darmstadt, Germany.

A Visual Guide to the Book

Each chapter opens with an overview of the material called **Looking Ahead.** The **Learning Goals** show what concepts are covered in each text section.

Chapter 2

Energy and Matter



The three states of matter for water are ice, liquid, and gas.

Looking Ahead

Learning Goals

2.1 Describe some forms of energy.
2.2 Given a temperature, calculate a corresponding temperature on another scale.
2.3 Given the mass of a sample, and the temperature change, calculate the heat lost or gained.
2.4 Calculate the energy of a sample using calorimetry data.
2.5 Identify the physical state of a substance as a solid, liquid, or gas.
2.6 Draw a diagram that represents the changes of state for matter.
2.7 Calculate the heat absorbed or released by a sample of water during a change of state.

Questions to Think About show the connections between chemistry and everyday life.

QUESTIONS TO THINK ABOUT

1. How does the body regulate increases or decreases in body temperature?
2. What are some forms of energy in your room?
3. Why is it important that energy can change form?
4. What objects in your home change energy from one form to another?
5. What are some states of matter you can see around you?
6. What is meant by the statement "150 Calories per serving" on a food nutrition label?

An object at rest requires energy to make it move. An object that is moving needs energy to make it stop. We say that energy makes it possible to do work. You use energy to do the work of running, playing tennis, studying, and breathing. You obtain that energy from the foods you eat. Energy takes many forms, but you are probably most familiar with heat or thermal energy. In your home, you use thermal energy to cook food, heat water, warm the room, and dry your hair.

Matter is everything around us that has mass and occupies space. Matter can be a solid, liquid, or gas. For example, the water in an ice cube, an ice rink, or an iceberg is solid. The water running out of a faucet or in a pool is a liquid. Water becomes a gas when it evaporates from wet clothes or boils away in a pan on the stove. Many gases are invisible to us, but some are detected by a characteristic odor or color. For example, you know when a bottle of perfume or ammonia is opened because you smell the gas as it fills the room.

The state of matter can be changed by adding or removing heat. When you heat water in a tea kettle, the water gets hotter. Perhaps it boils and changes to a gas. You make ice cubes by using a freezer to remove heat from the water in an ice cube tray.

2.1 Energy

Learning Goal
Describe some forms of energy.

When you are running, walking, dancing, or thinking, you are using energy to do **work**. In fact, **energy** is defined as the ability to do work. Suppose you are climbing a steep hill. Perhaps you become too tired to go on. We could say that you do not have sufficient energy to do any more work. Now, suppose you sit down and have lunch. In a while you will have obtained some energy from the food, and you will be able to do more work and complete the climb.

Potential and Kinetic Energy

All energy is potential or kinetic. **Potential energy** is stored energy, whereas **kinetic energy** is the energy of motion. A boulder resting on top of a mountain has potential energy because of its location. If the boulder rolls down the mountain, the potential energy becomes kinetic energy. Water stored in a reservoir has potential energy. When the water goes over the dam, the stored energy becomes kinetic energy. Even the food you eat has potential energy. When you digest food, you convert its stored energy to kinetic energy to do biological work.

39

Sample Problems appear throughout the book to reinforce chemical concepts and help students develop problem-solving skills and critical thinking. **Study Checks** below the problems challenge students to immediately apply the ideas they just learned. **Answers to Study Checks** appear at the end of the chapter.

Sample Problem 1.9
Problem Solving Using Conversion Factors

On a recent bicycle trip, Maria averaged 35 miles per day. How many days did it take her to cover 175 miles?

Solution

Step 1 Identify the given quantity in the question.

Given: 175 miles

Step 2 Write a unit plan.

Unit plan: miles → days   Unit for answer

Step 3 Identify relationships needed and write conversion factor(s).

Relationship (from Problem): 35 miles = 1 day

Conversion Factors: $\frac{1\text{ day}}{35\text{ miles}}$ and $\frac{35\text{ miles}}{1\text{ day}}$

Step 4 Set up the problem starting with the given, cancel units, and carry out calculations. The answer is given with two significant figures.

Problem Setup:

Unit for answer goes here

$$175\text{ miles} \times \frac{1\text{ day}}{35\text{ miles}} = 5.0\text{ days}$$

3 SFs   2 SFs   2 SFs

(175 ÷ 35 = 5.0)

Suppose the problem were set up in the following way. If the units do not cancel, you know there is an error in the setup.

$$175\text{ miles} \times \frac{35\text{ miles}}{\text{day}} = 6215\ \textbf{miles}^2\textbf{/day}$$ Wrong units!

Study Check
A recipe for shark fin soup calls for 3.0 quarts of chicken broth. If 1 quart contains 4 cups, how many cups of broth are needed?

Problem Solving Using Metric Factors

The metric conversion factors from Table 1.6 are used to change from one metric unit to another, as seen in the following Sample Problem.

Steps for Writing Electron-Dot Structures

Step 1 Determine the total number of valence electrons in all of the atoms.

Step 2 Place single bonds between each set of atoms. Each single bond uses two of the available valence electrons.

Step 3 Subtract the electrons used to bond the atoms, and arrange the remaining valence electrons to give each atom an octet. Hydrogen needs only a single bond, or two electrons.

Step 4 If octets of all the atoms cannot be completed using the remaining electrons, rearrange some of the electrons so that another pair or two are shared between two of the atoms as a double or triple bond. Check that all of the atoms have octets.

Sample Problem 4.16
Drawing Electron-Dot Structures Having Multiple Bonds

Draw the electron-dot structure of the compound CO_2. (Carbon is the central atom.)

O C O

Solution
Oxygen has six valence electrons, and carbon has four. Each oxygen atom needs two electrons, and the carbon atom needs four electrons.

Step 1 Using group numbers, calculate the total number of valence electrons available:

O C O

$6\,e^- + 4\,e^- + 6\,e^- = 16$ valence electrons

Step 2 Connect the atoms by single bonds:

O:C:O

Uses 2 e^- Uses 2 e^-

Step 3 Arrange the remaining valence electrons to satisfy octets:

:O:C:O:

Not octets

Step 4 Because octets cannot be completed using the remaining 12 electrons, double bonds are needed instead of single bonds between atoms. Rearrange the electrons, placing them between atoms to form double bonds to give octets to all the atoms.

Rearranging electron dots   Octets

:Ö:C:Ö: ⟶ :Ö::C::Ö:

Study Check
Determine the number of valence electrons and arrange them in the electron-dot structure of the HCN molecule.

Art and text complement the text discussion by giving both a written description and a visual interpretation of concepts like calculating nutritional content or balancing chemical equations.

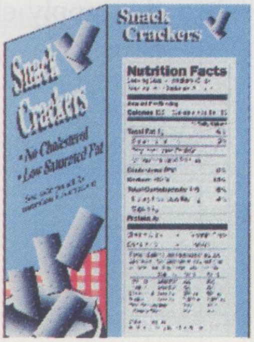


Figure 2.5
The nutritional facts on the label of a food package lists the Calories and the grams of each food type per serving.

The caloric content of a food is listed in the nutritional information on the package, usually in terms of the number of Calories in a serving, as shown in Figure 2.5. The general composition and caloric content of some foods are given in Table 2.5.

Table 2.5 *General Composition and Caloric Content of Some Foods*

Food	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal[a])
Banana, 1 medium	1	trace	26	110
Beans, red kidney, 1 cup	15	1	42	240
Beef, lean, 3 oz	22	5	trace	130
Carrots, raw, 1 cup	1	trace	11	50
Chicken, no skin, 3 oz	20	3	0	110
Egg, 1 large	6	6	trace	80
Milk, 4% fat, 1 cup	9	9	12	165
Milk, nonfat, 1 cup	9	trace	12	85
Oil, olive, 1 tbs.	0	14	0	130
Potato, baked	3	trace	23	105
Salmon, 3 oz	17	5	0	115
Steak, 3 oz	20	27	0	320
Yogurt, lowfat, 1 cup	8	4	13	

[a] Kcal values are rounded to nearest five.

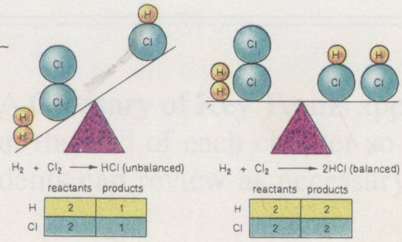


Figure 5.7
Unbalanced and balanced equations.

coefficients to balance an equation. Because each compound in the equation is represented by its correct formula, none of the subscripts can be changed when you are balancing an equation.

$$H_2 + Cl_2 \longrightarrow 2HCl \quad \text{Balanced}$$

This time when we count the atoms in the equation, we find they are balanced.

Reactant Side	*Product Side*
2 H	~~1 H~~ 2 H
2 Cl	~~1 Cl~~ 2 Cl

Figure 5.7 illustrates the unbalanced and the balanced equation.

Some hints for balancing equations are given in Table 5.5. Remember, they are only hints. Balancing equations in this way is largely a matter of trial and error.

Table 5.5 *Hints for Balancing Chemical Equations*

Step 1 Count the number of atoms of each element on the reactant side and on the product side.

Step 2 Detemine which atoms need to be balanced.

Step 3 Start balancing, one element at a time, by placing coefficients in front of the formula containing that element. A typical starting place is with the elements in a formula with subscripts.

Step 4 Recheck the atoms on the reactant side and on the product side to see if the equation is completely balanced. Sometimes, balancing one element will undo the balance of another. If this happens, repeat the process.

There is a rich array of **Health Notes** and **Environmental Notes** that apply chemical topics to real issues.

HEALTH NOTE *Polyatomic Ions in Bone and Teeth*

Bone structure consists of two parts: a solid mineral material, and a second phase made up primarily of collagen proteins. The mineral substance is a compound called hydroxyapatite, a solid formed from calcium ions, phosphate ions, and hydroxide ions. This material is deposited in the web of collagen to form a very durable bone material. (See Figure 4.10).

$Ca_{10}(PO_4)_6(OH)_2$
Hydroxyapatite

In most individuals, bone material is continuously being absorbed and re-formed. After age 40, more bone material may be lost than formed, a condition called osteoporosis. Bone mass reduction occurs at a faster rate in women than in men, and at different rates in different parts of the body skeleton. The reduction in bone mass can be as much as 50% over a period of 30 to 40 years. It is recommended that persons over 35, especially women, include a daily calcium supplement in their diet.

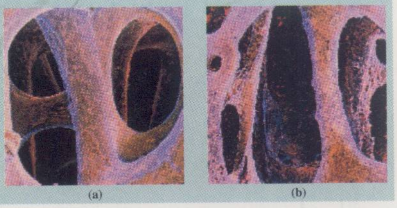


Figure 4.10
Scanning electron micrographs (SEM) of (a) normal bone and (b) bone in osteoporosis due to calcium loss.

Sample Problem 4.9
Writing Formulas Having Polyatomic Ions

Write the formula for a compound containing aluminum ions and bicarbonate ions.

Solution

The positive ion in the compound is the aluminum ion, Al^{3+}, and the negative ion is the bicarbonate ion, HCO_3^-, which is a polyatomic ion.

Al^{3+} (Aluminum ion) HCO_3^- (Bicarbonate ion)

Three HCO_3^- ions are required to balance the Al^{3+} charge.

Al^{3+} HCO_3^-
HCO_3^-
HCO_3^-

$(3+) + 3 \times (1-) = 0$

ENVIRONMENTAL NOTE *Acid Rain*

Rain typically has a pH of 6.2. It is slightly acidic because the carbon dioxide in the air combines with water to form carbonic acid. However, in many parts of the world, rain has become considerably more acidic, with pH values as low as 3 being reported. One cause of acid rain is the sulfur dioxide (SO_2) gas produced when coal that contains sulfur is burned.

In the air, the SO_2 gas reacts with oxygen to produce SO_3, which then combines with water to form sulfuric acid, H_2SO_4, a strong acid.

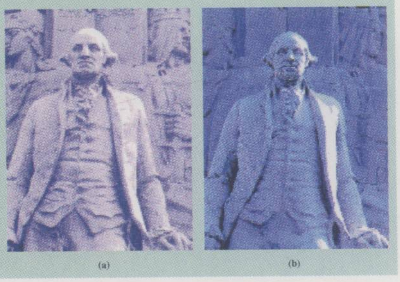
$$S + O_2 \longrightarrow SO_2$$
$$2SO_2 + O_2 \longrightarrow 2SO_3$$
$$SO_3 + H_2O \longrightarrow H_2SO_4$$

In parts of the United States, acid rain has made lakes so acidic they are no longer able to support fish and plant life. Limestone ($CaCO_3$) is sometimes added to these lakes to neutralize the acid. In Eastern Europe, acid rain has brought about an environmental disaster. Nearly 40% of the forests in Poland have been severely damaged, and some parts of the land are so acidic that crops will not grow. Throughout Europe, monuments made of marble (a form of $CaCO_3$) are deteriorating as acid rain dissolves the marble. See Figure 9.10.

$$2H^+ + CaCO_3 \longrightarrow Ca^{2+} + H_2O + CO_2$$

Efforts to slow or stop the damaging effects of acid rain include the reduction of sulfur emissions. This will require installation of expensive equipment in coal-burning plants to absorb more of the SO_2 gases before they are emitted. In some outdated plants, this may be impossible, and they will need to be closed. It is a difficult problem for engineers and scientists, but one that must be solved.

Figure 9.10
(a) Detail of the marble that is part of the Washington Square Arch in Washington Square Park completed on July 17, 1935.
(b) The destructive effect of acid rain on the same marble, June, 1994.



9.8 Buffers

Learning Goal
Describe the role of buffers in maintaining the pH of a solution.

When an acid or base is added to pure water, the pH changes drastically. However, if a solution is buffered, there is little change in pH when small amounts of acid or base are added. A **buffer solution** resists a change in pH when small amounts of acid or base are added. For example, blood is a buffer

Chapter Summaries emphasize the main ideas in each section of the chapter. Pertinent chapters include summaries of reactions.

Chapter Summary 385

Summary of Addition Reactions of Alkenes

Hydrogenation

$\text{Alkene} + H_2 \xrightarrow{Pt} \text{alkane}$

$CH_2{=}CH{-}CH_3 + H_2 \xrightarrow{Pt} CH_3{-}CH_2{-}CH_3$

Halogenation

$\text{Alkene} + Cl_2 \text{ (or } Br_2) \longrightarrow \text{dihaloalkane}$

$CH_2{=}CH{-}CH_3 + Cl_2 \longrightarrow CH_2(Cl){-}CH(Cl){-}CH_3$

Hydrohalogenation

$\text{Alkene} + HX \longrightarrow \text{haloalkane}$

$CH_2{=}CH{-}CH_3 + HCl \longrightarrow CH_3{-}CH(Cl){-}CH_3$ Markovnikov's rule

Hydration of Alkenes

$\text{Alkene} + H{-}OH \xrightarrow{H^+} \text{alcohol}$

$CH_2{=}CH{-}CH_3 + H{-}OH \xrightarrow{H^+} CH_3{-}CH(OH){-}CH_3$ Markovnikov's rule

Chapter Summary

11.1 Alkenes
Alkenes are unsaturated hydrocarbons that contain at least one double bond ($C{=}C$) as the functional group.

11.2 Naming Alkenes
Alkenes and cycloalkenes use IUPAC rules similar to the alkanes but use an *ene* ending. In alkenes, the longest carbon chain containing the double bond is numbered from the end nearest the double bond. If there are any substituents on a cycloalkene, the double bond is assigned the positions of 1 and 2, and the ring numbered to give the next lower numbers to the substituents.

11.3 Cis±Trans Isomers
Geometric isomers of alkenes occur when the carbon atoms in the double bond are connected to different atoms or groups. In the cis isomer, the attached groups are on the same side of the double bond, whereas in the trans isomer, they are connected on the opposite sides of the double bond.

11.4 Addition of Hydrogen and Halogens
The addition of small molecules to the double bond is a characteristic reaction of alkenes. H[...]rogenation adds hydrogen atoms to the double [...] of an alkene to yield an alkane. [...]genation adds bromine or chlorine atoms to [...]uce dihaloalkanes.

11.5 Addition of Hydrogen Halides and Water
Hydrogen halides and water can also add to a double bond. When there are a different number of groups attached to the carbons in the double bond, Markovnikov's rule tells us to add the H from the adding reactant (HX or $H{-}OH$) to the carbon with the greater number of hydrogen atoms.

11.6 Alkynes
The alkynes are a family of unsaturated hydrocarbons that contain at least one triple bond. They use naming rules similar to the alkenes, but the parent chain ends with *yne*.

11.7 Aromatic Hydrocarbons
Most aromatic compounds contain benzene, a cyclic structure containing six CH units. The structure of benzene is represented as a hexagon with a circle in the center. The names of many aromatic compounds use the parent name benzene, although many common names were retained as IUPAC names, such as toluene, phenol, and aniline. The benzene ring is numbered and the branches are listed in alphabetical order. For two branches, the positions are often shown by the prefixes *ortho* (1,2-), *meta* (1,3-), and *para* (1,4-).

Chemistry at Home 177

5.8 Calculations Using Equations
When the number of moles is given for one substance in an equation, a mole±mole factor can be used to convert to moles of another substance, reactant, or product. When grams of one or both substances are given or desired, their molar masses are used to change grams to moles, or moles to grams.

Glossary of Key Terms

activation energy The energy needed upon collision to break apart the bonds of the colliding molecules.
Avogadro's number The number of items in a mole, equal to 6.02×10^{23}.
catalyst A substance that increases the rate of a reaction by lowering the energy of activation.
chemical change The formation of a new substance with a different composition and properties than the initial substance.
chemical equation A shorthand way to represent a chemical reaction using chemical formulas to indicate the reactants and products.
chemical reaction The process by which a chemical change takes place.
coef/Æcients Whole numbers placed in front of the formulas in an equation to balance the number of atoms or moles of atoms of each element in an equation.
endothermic reaction A reaction that requires heat; the energy level of the products is higher than the reactants.
exothermic reaction A reaction that releases heat; the energy level of the products is lower than the reactants.
formula weight The sum of the atomic weights of all the atoms in a formula.
heat of reaction The energy released or absorbed during a chemical reaction equal to the energy difference between the reactants and products.
law of conservation of matter A law that states that atoms are neither created nor destroyed in a chemical reaction but are only rearranged.
molar mass The mass of one mole of an element or compound equal to the formula weight expressed in grams.
mole (mol) A group of atoms, molecules, or formula units that contains 6.02×10^{23} of these items.
mole conversion factor A conversion factor that relates the number of moles of two compounds in an equation derived from their coefficients.
physical change A change in which the physical properties change but not the chemical composition of the substance.
products The substances formed as a result of a chemical reaction.
rate of reaction The speed at which reactants are used up to form product.
reactants The initial substances that undergo change in a chemical reaction.

A **Glossary of Key Terms** appears at the end of each chapter so students can review as necessary.

Chemistry at Home

1. Place 1/2 cup of vinegar in a glass. Add a teaspoon of baking soda and observe. What evidence of a chemical reaction do you see?
2. Obtain three matching glasses. Half fill one with hot water, one with room temperature water, and one with cold water. Add a few drops of food coloring or ink to each sample. Do not disturb. How does the temperature of the water affect the rate at which the color spread through the water?
3. Place 1 cup of water in a glass and measure the temperature of the water with a candy thermometer. Add a tablespoon of baking soda and stir. What happens to the temperature? Is the reaction exothermic or endothermic?
4. Freshly cut surfaces of fruits discolor when exposed to oxygen in the air. Cut slices of apple, potato, avocado, or banana. Wrap one slice in plastic wrap. Place another in the refrigerator. Dip one in lemon juice and leave out. Leave one unwrapped on the kitchen counter. What changes occur after 1±2 hours? What were the effects of wrapping, refrigerating, and dipping in lemon juice on the rate of reaction? Explain.

Chemistry at Home describes activities that can be done with household items to observe chemical changes.

Answers to Study Checks in the Sample Problems appear at the end of the chapter so students get immediate feedback on their work.

Problems at the end of each chapter encourage students to apply chemistry concepts to problem solving. Each problem is keyed to a Learning Goal so students can refer back to the corresponding text section for help using a Sample Problem. Each Learning Goal has duplicate problems for homework assignments.

Challenge Problems ask students to think critically and incorporate ideas from other chapters.

Problems 213

scan The image of a site in the body created by the detection of radiation from radioactive isotopes that have accumulated in that site.
shielding Materials used to provide protection from radioactive sources.
transmutation The formation of a radioactive isotope by bombarding a stable nucleus with fast-moving particles.

Chemistry at Home

1. Read the label of contents on a smoke detector. What isotope is used? What are the products of radioactive decay for the isotope? (*Hint:* Use a chemistry handbook.) What type of radiation is emitted? Why would this be used in a home? How does the alarm detect smoke? What is the activity of the isotope? How often should it be replaced? Why?
2. Visit a radiology laboratory in a local hospital or clinic.
3. Ask your dentist about dental X rays. What amount of radiation is used? How are you and the x-ray technician protected?
4. How is radon measured in the home? What is in the home kits for radon detection?

Answers to Study Checks

6.1 β or ${}^{0}_{-1}e$
6.2 Limiting the time one spends near a radioactive source and staying as far away as possible will reduce exposure to radiation.
6.3 ${}^{214}_{84}Po \longrightarrow {}^{210}_{82}Pb + {}^{4}_{2}He$
6.4 ${}^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e$
6.5 ${}^{27}_{13}Al + {}^{4}_{2}He \longrightarrow {}^{30}_{15}P + {}^{1}_{0}n$
6.6 ${}^{14}_{7}N$
6.7 9.3×10^{9} iodine-131 atoms
6.8 0.50 g
6.9 17,190 years
6.10 fusion

Problems

Natural Radioactivity *(Goal 6.1)*

6.1 a. How are an alpha particle and a helium nucleus similar? different?
b. What symbols are used for alpha particles?
6.2 a. How are a beta particle and an electron similar? different?
b. What symbols are used for beta particles?
6.3 Naturally occurring potassium consists of three isotopes, potassium-39, potassium-40, and radioactive potassium-41.
a. Write the nuclear symbols for each isotope.
b. In what ways are the isotopes similar, and in what ways do they differ?
6.4 Naturally occurring iodine is iodine-127. Medically radioactive isotopes of iodine-125 and iodine-130 are used.
a. Write the nuclear symbols for each isotope.
b. In what ways are the isotopes similar, and in what ways do they differ?
6.5 Supply the missing information in the following table:

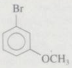
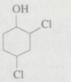
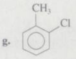
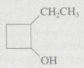
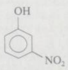
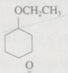
Medical Use	Nuclear Symbol	Mass Number	Number of Protons	Number of Neutrons
Spleen imaging	${}^{51}_{24}Cr$			
Malignancies		60	27	
Blood volume			26	33
Hyperthyroidism	${}^{131}_{53}I$			
Leukemia treatment		32		17

Chapter 12 Alcohols, Phenols, Ethers, Aldehydes, and Ketones

b. $CH_3-C(=O)-CH_3$ or $CH_3-CH(OH)-CH_3$
12.37 Indicate the compound in each of the following pairs that will form a brick-red precipitate with Benedict's reagent:
a. pentane or pentanal
b. propanone or propionaldehyde
c. cyclopentanone or cyclopentanal
12.38 Indicate the compound in each of the following pairs that will form a silver mirror in the Tollens' test:
a. hexanone or hexanal
b. butane or butyraldehyde
c. 1-pentanol or pentanal
12.39 Give the condensed structural formula of the organic product formed when each of the following is reduced by hydrogen in the presence of a nickel catalyst:
a. butyraldehyde
b. acetone
c. 3-bromohexanal
d. 2-methyl-3-pentanone
12.40 Give the condensed structural formula of the organic product formed when each of the following is reduced by hydrogen in the presence of a nickel catalyst:
a. ethyl propyl ketone
b. formaldehyde
c. 3-chlorocyclopentanone
d. 2-pentanone

Challenge Problems

The following groups of problems include functional groups, physical and chemical properties, and reactions from all of the organic chapters.

12.41 Give the IUPAC and common names (if any) for each of the following compounds:
a. $CH_3C(CH_3)_2CH_2CH_2CH(CH_3)CH_3$ (printed as $CH_3CCH_2CH_2CHCH_3$ with CH_3 groups)
b. $CH_3CH(Br)CH_2CH(OH)CH_2CH_3$
c. $CH_3CH_2CH(=O)$
d. $CH_3(H)C=C(H)CH_2CH_3$
e.

f.

g.

12.42 Give the IUPAC and common names (if any) for each of the following compounds:
a. $CH_3-O-CH_2CH_2CH_3$
b. $CH_3-CH_2-CH(SH)-CH_2-CH_3$
c.

d. $CH_3CH_2-C\equiv C-CH_3$
e.

f.

g. $CH_3C(=O)CH_2CH_2CH_2CH_2CH_2CH_3$
12.43 Draw the condensed structural formula of each of the following:
a. 3-methylcyclopentanone
b. *p*-dichlorobenzene
c. β-chloropropionaldehyde
d. *m*-bromophenol
e. diethyl ether
12.44. Draw the structural formula of each of the following:
a. methanethiol
b. β-chlorobutyraldehyde
c. 3-methyl-1-butanol
d. 3-methoxypentanal
e. *m*-bromotoluene
12.45 Which of the following compounds are soluble in water?
a. $CH_3CH_2CH_2CH_2CH_3$
b. CH_3OH
c. $CH_3CH_2-O-CH_2CH_3$

Preface

Welcome to the Sixth Edition of *Chemistry: An Introduction to General, Organic, and Biological Chemistry.* It is my hope that the reshaping of this text over six editions has resulted in a text that makes teaching and learning chemistry an enthusiastic and positive experience for both the instructor and student. It remains my goal to assist students in their development of critical thinking, understanding of scientific concepts, and problem-solving techniques. These skills will be needed to make decisions about major issues in our lives concerning our environment, medicine, and health.

This textbook is written for students with no previous background in chemistry who are preparing for health-related careers or wish to take a preliminary course in chemistry. Over the years I have found that chemistry is less formidable when concepts are associated with applications to the health and environmental sciences. Connections made between chemistry and the real world help students recognize how chemistry impacts their lives and future careers. I have found discussions of applications of chemistry valuable in increasing student interest, motivation, concentration, and performance in class.

New to This Edition

In response to the needs of students and suggestions of instructors and reviewers, many improvements have been made in this Sixth Edition. Each chapter begins with a new preview section that contains *Learning Goals, Questions To Think About,* and *Looking Ahead.* This preview section gives students an overview of the content of the chapter and ways that the chemical concepts impact their lives. Throughout each chapter, a large number of sample problems, all with complete solutions and study checks, challenge the student to participate actively in problem solving. In each chapter, the *Health Notes* and *Environmental Notes* connect the chemical principles to real-life issues of health, medicine, and the environment.

New in this edition are the *Chapter Summaries* to review and emphasize the major topics in each chapter section. Also new in this edition is *Chemistry At Home* to challenge and excite students about the chemistry that takes place in the common materials around them. All of the problem sets have been rewritten with duplicate exercises to give more problems that engage the student in problem solving with a greater range of difficulty. In this Sixth Edition, the answers to the odd-number chapter problems are given in an appendix to give instructors the option of quiz, group, or homework assignments. Also new are the *Challenge Problems* that require students to use critical thinking that is more complex and related to concepts in other chapters.

In this text, more difficult topics that may be time consuming are placed at the end of chapters. Depending on the time limitations, these topics can be covered or omitted without affecting the flow of learning from one chapter to another.

Features of the Learning Program

This textbook has been designed with many instructional features to enhance your students' learning.

1. **Looking Ahead:** Each chapter begins with an outline of topics, Health Notes, and Environmental Notes.
2. **Learning Goals:** Each chapter contains a set of learning goals that specify the concepts to be covered. This gives students an overview of the material in each chapter and prepares them for what they are expected to accomplish.
3. **Questions to Think About:** These are intended to stimulate students to think about ways that chemistry impacts their daily lives. The preview questions enhance learning by relating students experiences with the chemical concepts and topics to be presented in the chapter. The preview questions stimulate critical thinking early, rather than waiting until the end of the chapter.
4. **Sample Problems:** Sample problems with complete solutions throughout the text reinforce the concepts in each chapter. This format continually involves students with the material through active participation in the patterns of problem solving. A completely worked-out solution and explanation in each sample provides a model of the problem solving and calculations that students must do to answer the question successfully.
5. **Study Checks and Answers to Study Checks:** With every sample problem, there is a *Study Check* that challenges students to apply the information and methods in a similar type of problem, but without the solution. Students can interact with the subject matter by immediately applying the problem solving in the sample problem. Immediate feedback is available by looking in the *Answers to Study Checks* at the end of the chapter.
6. **Health Notes and Environmental Notes:** In every chapter, boxed notes relate and apply chemical principles to real issues and concerns that students may have about health, medicine, and the environment. Clinical examples interest and motivate students interested in careers in the health sciences. All of the Health Notes and Environmental Notes are listed in the table of contents and include discussions about global warming, radon in our homes, loss and gain of weight, ozone depletion, acid rain, cholesterol, anabolic steroids, pheromones, hyperbaric chambers, kidney stones, alcohol, recycling of plastics,

alkaloids, blood types, genetic diseases, ketone bodies, recombinant DNA, viruses, AIDS, and cancer. Many of the notes are updated with current information.

7. **Chapter Summaries:** At the end of each chapter, a chapter summary reviews major topics and emphasizes the main ideas in each section.
8. **Glossary of Key Terms:** A glossary of key terms at the end of each chapter defines terms in the chapter so that you can review new vocabulary.
9. **Chemistry at Home:** These projects can be done at home to apply what students have learned or can also be used for extra credit work. The extension of chemistry into real life can stimulate thinking and increase your students' interest in science.
10. **End-of-Chapter Problems:** There are a large number of problems to work at the end of each chapter. Problems are keyed to the section heads and learning goals, allowing instructors to select appropriate problems for any section. A full range of problems are now structured into duplicate sets, with each problem followed by a similar type of problem (duplicate problem). Students may compare their answers to the odd-number problems with the answers given in the appendix. The duplicate problems can be used by instructors for classroom quizzes, homework, group problem solving, or other problem-solving exercises where answers are not available. Each problem set concludes with a group of *Challenge Problems* that engage students in solving problems with a greater range of difficulty. These problems are more complex mathematically, require more critical thinking and material from other chapters, and have real-life relationships.
11. **Appendices:** Several appendices provide additional reference materials for your students' learning needs. These appendices review common conversion factors, scientific notations, using percent in calculations, and some basic operations with the calculator including changing signs and recognizing scientific notation. The answers to the odd-number problems are also in the appendices.
12. **Art Program:** Throughout the text full color is used to highlight major ideas. Photographs and new graphics are used to increase understanding and enhance learning. The wider margins include figures, diagrams, tables, and photographs that illustrate the concepts.

Content Changes in Each Chapter

In Chapter 1, the section on conversion factors now precedes significant figures. The section on metric and SI prefixes has been combined with equalities. Chapter 2 begins with the topics of energy and its measurement, food energy, states of matter, and calculations of heat energy. New material includes equilibrium of solid–liquid and liquid–vapor states.

In Chapter 3, the discussion on subshells and orbitals appears at the end of the chapter, making it optional. In Chapter 4, the cations of transition elements are discussed along with the ions of representative elements. The section on naming ionic compounds now includes the naming of compounds containing polyatomic ions. Bond polarity and bond types now appears at the end of the chapter.

In Chapter 5, the topic of chemical equations is now covered in one section, which is followed by a new section that discusses energy changes, heats, and rates of reactions. New in this chapter is the effect of catalysts on the energy of activation (moved from enzymes), energy diagrams for exothermic and endothermic reactions, and a new Health Note on hot packs and cold packs. The material on moles, molar mass, and equations has been rewritten. Writing conversion factors for the mole relationships in equations is carefully explained and then utilized in calculating quantities in reactions.

In Chapter 6, the material on producing radioactive isotopes now follows nuclear equations and the biological effect of ionizing radiation is now a Health Note. A new Health Note combines maximum permissible dose, radiation sickness, and lethal dose. The table on average annual radiation per person is updated to include radon, and global fallout is deleted.

In Chapter 7, Gases, new graphics illustrate the gas relationships more clearly and a new Health Note on blood pressure has been added. All of the discussions of gas laws have been rewritten to clarify concepts. The Environmental Note on ozone depletion was moved to Chapter 12 to be included with the discussion of chlorofluorohydrocarbons.

Chapter 8 begins with a discussion on hydrogen bonding in water and leads into solution formation. Factors affecting rates of solution now include nature of solute and solvent, saturation, temperature effect on solubility of solids and gases in liquids, and solubility rules (moved from Chapter 9 in the last edition).

Chapter 9 begins with a rewritten section on electrolytes and equivalents. Acids and bases are now defined by both the Arrhenius and Brønsted–Lowry concepts and the term *hydronium ion* is used more consistently. The strengths of acids and bases is now a separate section and the neutralization of acids and bases now precedes the ionization of water. The reverse reaction in weak electrolytes, weak acids, and bases introduces the idea of equilibrium between molecules and ions. The concentrations of ions in water has been simplified to 1×10^{-7} M. The relationship between H_3O^+ and OH^- is now more conceptual (increase/decrease) and less calculator work is required. The discussion of pH includes an explanation of the mathematical meaning of pH and logs. Instructions have been added to calculate pH using a calculator. Buffers are now defined as solutions that resist changes in pH when small amounts of acid or base are added. Acid–base titration is now the last section in the chapter.

Chapter 10 introduces organic chemistry by discussing the hydrocarbons and the components in crude oil. The comparison of organic and inorganic compounds is now between butane and sodium chloride, compounds of similar masses. Structural isomers now follow complete structural formulas. The sections on nomenclature have been rewritten for clarity. New figures contain more three-dimensional drawings of the ball-and-stick models. A new Health Note on the cycloalkanes and haloalkanes currently used as anesthetics, an area of interest to allied health majors, is added to the section on cycloalkanes. The Environmental Note on haloalkanes now includes a photo of spraying with pesticides and the note on ozone depletion has been moved into this section.

Chapter 11 has a more descriptive title. The nature of the alkene family and the names of alkenes are now two separate sections. The rules for naming alkenes now appear in a series of steps to allow a clearer explanation. The sections on naming and on cis–trans isomers stand alone and can be omitted by instructors who do not include those topics. The addition reactions are now in two sections, one for the addition of X_2 reagents, and the other for the addition of HX and HOH. This section also includes a clearer explanation of Markovnikov's rule. The polymerization of alkenes has been rewritten and now includes notes and a photo on biopolymers. The last section in the chapter on benzene has been reworked. A new Health Note on aromatic compounds in health and medicine has been added. In Chapter 12, phenols are now introduced with alcohols in the first section. The Health Note on alcohols now includes levels of ethanol intoxication, behavior, and dangers. A discussion on thiols is included in the alcohol section, but the discussion on disulfides has been moved to Chapter 16 (on proteins). The properties of solubility of alcohols and ionization of phenol have been retained, but lists of boiling points have been deleted. The reactions of alcohols, dehydration, and oxidation, are now in the same section for easy reference. The note on biological oxidation now includes the Breathalyzer test for drunk drivers. In Chapter 13, the naming of acids is explained more carefully. A new Health Note on α-hydroxy acids and their current use in skin care products has been added. Another new note discusses plastics and recycling identification codes. The naming of amines and amides has been reworked and the note on amines in health and medicine has been expanded. There is a new Health Note on heterocyclic amines and their physiological activity. A new note was added on the Alar controversy, in which hormones were sprayed on apples.

The biomolecules section begins with a rewritten Chapter 14 on carbohydrates. A new explanation of chirality of sugars emphasizes nonsuperimposable mirror images, introduces the term *enantiomers,* and deletes the use of symmetry. A Health Note on chiral compounds is expanded to include more examples such as thalidomide and L-ibuprofen as well as the development of *chiral technology*. After describing the open-chain structures of the monosaccharides, hemiacetal and hemiketal formation is used to introduce their cyclic structures. In the structures of disaccharides, the α-1,4-glycosidic bond is now drawn as a single line. New Health Notes on the sweetness of sugars and the role of carbohydrates in blood typing and new figures for fiber and polysaccharides found in nature have been added. The number of tests to identify carbohydrates has been reduced. Projects for Chemistry at Home include photosynthesis, hydrolysis of starch, solubility of carbohydrates, and tests for starch with iodine.

The classes of lipids now introduce Chapter 15 to give an overview followed by some ways a fatty acid can be written. Monounsaturated fatty acids are now defined separately from polyunsaturated fatty acids, and palmitoleic acid has been added to the list of fatty acids. A new figure depicting the fit of saturated compared with unsaturated fatty acids has been added as well as a figure comparing the percentage of saturated, monounsaturated, and polyuunsaturated fatty acids in some typical fats and oils. The section on phospholipids and glycolipids now includes a description of cell membranes. Fat-soluble vitamins, steroid hormones, and anabolic steroids are now included in this chapter.

Chapter 16 combines two chapters from the last edition on proteins and enzymes. Amino acid structures are described and the zwitterion form used more extensively throughout the chapter. The discussion on peptide bonds has been rewritten and hydrolysis added. The sections on protein structure have been rewritten and the discussion on denaturation shortened. With the earlier discussion of catalysts in Chapter 5, the discussion of enzymes describes enzyme action and inhibition, and now includes a discussion of the induced-fit model. The old section on digestion enzymes has been moved to Chapter 18. Water-soluble vitamins are discussed as coenzymes in this chapter.

In Chapter 17, the components of nucleic acids have been combined into one figure. The section on replication has been rewritten to emphasize the role of complementary base pairing. The process of protein synthesis is followed by a discussion on genetic mutations. The last section reviews the cellular regulation of protein synthesis. A Health Note on viruses has been expanded to include the HIV virus.

In Chapter 18, metabolism and energy production describe ATP, catabolic reactions, and anabolic reactions. It has been completely rewritten beginning with digestion of foods (moved from enzymes) to the production of ATP from the oxidation products of the food molecules. The process of energy production now starts with glycolysis and carbohydrate degradation, acetyl coenzyme A, citric acid cycle, and the electron transport chain. The anion form of the carboxylic acids is used consistently and throughout the discussion, the types of oxidation and their coenzymes are emphasized. The discussion of the electron transport chain has been rewritten to emphasize the transfer of electrons and includes the chemiosmotic theory for energy production. Finally, the total ATP is calculated for the complete oxidation of glucose. Fatty acid synthesis is used as an example of an anabolic pathway, and the connection of amino acids to the citric acid intermediates and urea is shown.

The Supplement Package to Accompany the Text

For the Student

Laboratory Manual

The early experiments in the ***Laboratory Manual*** introduce students to basic laboratory skills. Students carry out laboratory investigations, develop the skills of manipulating laboratory equipment, gather and report data, solve problems, calculate, and draw conclusions. In this edition, as in the past, there is an emphasis on safety in the laboratory. Hazardous chemicals and procedures considered dangerous have been omitted. For each experiment, there is a report page and a set of questions that relate the laboratory to the corresponding information in the text. Some questions require essay-type answers to promote writing skills in science.