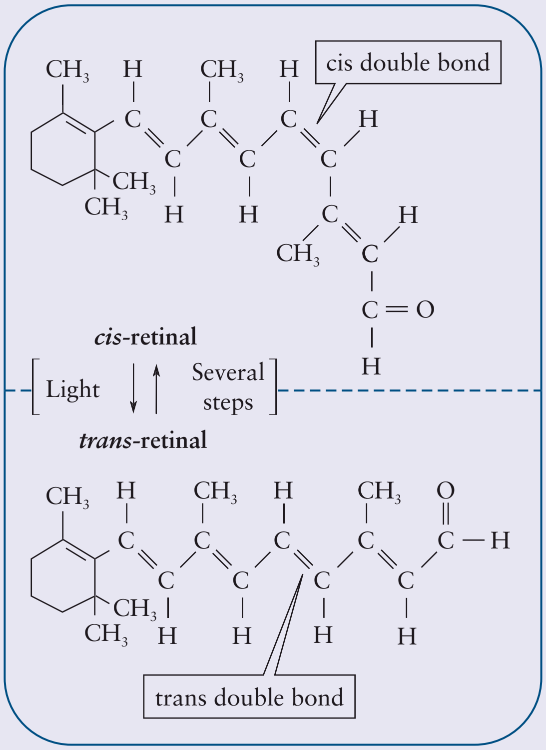
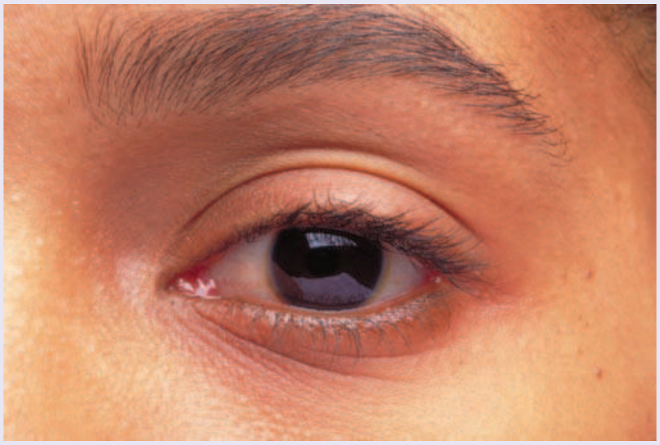
Chemistry Around Us 12.2

Seeing the Light

Cis-trans isomerism is important in several biological processes, one of which is vision. When light strikes the retina, a cis double bond in the compound *retinal* (structurally related to vitamin A) is converted to a trans double bond. The conversion triggers a chain of events that finally results in our being able to see.



In a series of steps, *trans*-retinal is enzymatically converted back to *cis*-retinal so that the cycle can be repeated. Bright light temporarily destroys our ability to see in dim light because large quantities of *cis*-retinal are rapidly converted to the trans isomer by the bright light. It takes time for conversion of the *trans*-retinal back to *cis*-retinal. This difference in conversion rates between the *cis* and *trans* forms of retinal enables our eyes to adjust automatically to variations in light levels.



The vision process depends on a cis-trans reaction.

In addition to geometry, alkenes also differ from open-chain alkanes in that the double bonds prevent the relatively free rotation that is characteristic of carbon atoms bonded by single bonds. As a result, alkenes can exhibit geometric isomerism, the same type of stereoisomerism seen earlier for the cycloalkanes (Section 11.9). There are two geometric isomers of 2-butene:

cis-2-butene   *trans*-2-butene

Once again, the prefix *cis*- is used for the isomer in which the two similar or identical groups are on the same side of the double bond and *trans*- for the one in which they are on opposite sides. The two isomers *cis*- and *trans*-2-butene represent distinctly different compounds with different physical properties (see Table 12.1).

Not all double-bonded compounds show cis-trans stereoisomerism. Cis-trans stereoisomerism is found only in alkenes that have two different groups attached to each

Table 12.1 Physical Properties of a Pair of Geometric Isomers

Isomer	Melting Point (°C)	Boiling Point (°C)	Density (g/mL)
cis-2-butene	−139.9	3.7	0.62
trans-2-butene	−105.6	0.9	0.60

double-bonded carbon atom. In 2-butene, the two different groups are a methyl and a hydrogen for each double-bonded carbon:

cis-2-butene

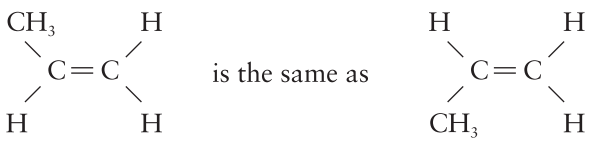
trans-2-butene

If either double-bonded carbon is attached to identical groups, no cis-trans isomers are possible. Thus, there are no geometric isomers of ethene or propene:

ethene

propene

To see why this is so, let's try to draw geometric isomers of propene:



(A)

(B)

Notice that structure (B) can be converted into (A) by just flipping it over. Thus, they are identical and not isomers.

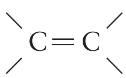
Example 12.3

Determine which of the following molecules can exhibit geometric isomerism, and draw structural formulas to illustrate your conclusions:

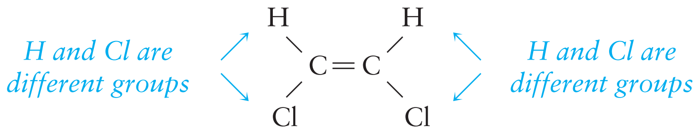
a. $Cl-CH=CH-Cl$
b. $CH_2=CH-Cl$
c. $Cl-CH=CH-CH_3$

Solution

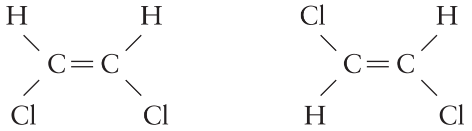
a. Begin by drawing the carbon–carbon double bond with bond angles of 120° about each carbon atom:



Next, complete the structure and analyze each carbon of the double bond to see if it is attached to two different groups:

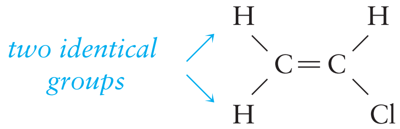


In this case, each carbon is attached to two different groups and geometric isomers are possible:

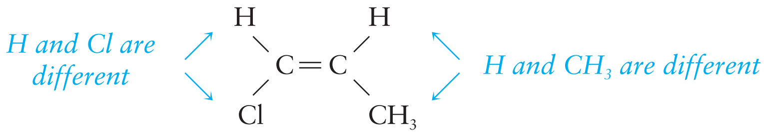


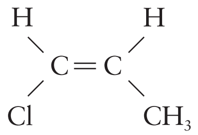
cis　　　　trans

b. No geometric isomers are possible because one carbon contains two identical groups:

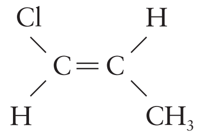


c. Geometric isomers are possible because there are two different groups on each carbon:



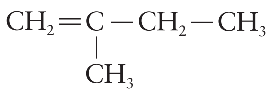


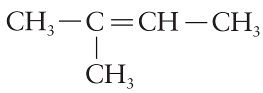
cis-1-chloropropene

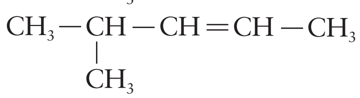


trans-1-chloropropene

Learning Check 12.3 Determine which of the following can exhibit geometric isomerism, and draw structural formulas for the *cis* and *trans* isomers of those that can:

a. 

c. 

b. 

12.3 Properties of Alkenes

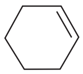
Learning Objective

5. Write equations for addition reactions of alkenes, and use Markovnikov's rule to predict the major products of certain reactions.

Physical Properties

The alkenes are similar to the alkanes in physical properties—they are nonpolar compounds that are insoluble in water, soluble in nonpolar solvents, and less dense than water

Table 12.2 Physical Properties of some Alkenes

IUPAC Name	Structural Formula	Boiling Point (°C)	Melting Point (°C)	Density (g/mL)
ethene	$CH_2{=}CH_2$	−104	−169	0.38
propene	$CH_2{=}CHCH_3$	−47	−185	0.52
1-butene	$CH_2{=}CHCH_2CH_3$	−6	−185	0.60
1-pentene	$CH_2{=}CHCH_2CH_2CH_3$	30	−138	0.64
1-hexene	$CH_2{=}CHCH_2CH_2CH_2CH_3$	63	−140	0.67
cyclohexene		83	−104	0.81

(see Table 12.2). Alkenes containing 4 carbon atoms or fewer are gases under ordinary conditions. Those containing 5 to 17 carbon atoms are liquids, and those with 18 or more carbon atoms are solids. Low molecular weight alkenes have somewhat unpleasant, gasoline-like odors.

Chemical Properties

In contrast to alkanes, which are inert to almost all chemical reagents (Section 11.11), alkenes are quite reactive chemically. Since the only difference between an alkane and an alkene is the double bond, it is not surprising to learn that most of the reactions of alkenes take place at the double bond. These reactions follow the pattern:

$$>C{=}C< \; + \; A{-}B \longrightarrow -\overset{A}{\underset{|}{\overset{|}{C}}}-\overset{B}{\underset{|}{\overset{|}{C}}}- \qquad (12.1)$$

They are called **addition reactions** because a substance is added to the double bond. Addition reactions are characterized by two reactants that combine to form one product.

addition reaction A reaction in which a compound adds to a multiple bond.

Halogenation is one of the most common addition reactions. For example, when bromine, a halogen, is added to an alkene, the double bond reacts, and only a carbon–carbon single bond remains in the product. Without a double bond present, the product is referred to as a **haloalkane** or **alkyl halide.** Reaction 12.2 gives the general reaction, and Reaction 12.3 is a specific example, the bromination of 1-butene.

haloalkane or alkyl halide A derivative of an alkane in which one or more hydrogens are replaced by halogens.

General reaction:

$$>C{=}C< \; + \; Br{-}Br \longrightarrow -\underset{Br}{\underset{|}{\overset{|}{C}}}-\underset{Br}{\underset{|}{\overset{|}{C}}}- \qquad (12.2)$$

Specific example:

$$\underset{\text{1-butene}}{CH_3{-}CH_2{-}CH{=}CH_2} + Br{-}Br \longrightarrow \underset{\text{1,2-dibromobutane}}{CH_3{-}CH_2{-}\underset{Br}{\underset{|}{CH}}{-}\underset{Br}{\underset{|}{CH_2}}} \qquad (12.3)$$

The addition of Br_2 to double bonds provides a simple laboratory test for unsaturation (see Active Figure 12.5). As the addition takes place, the characteristic red-brown color of the added bromine fades as it is used up, and the colorless dibromoalkane product forms.

Active Figure 12.5 The reaction of bromine with an unsaturated hydrocarbon. **Go to www.cengage.com/chemistry/seager or OWL to explore an interactive version of this figure.**

© Joel Gordon

1 Dilute bromine solution added to 1-hexene loses its red-brown color immediately.

© Joel Gordon

2 The remainder of the bromine solution is added. The last drops react as quickly as the first.

The addition of halogens is also used to quantitatively determine the degree of unsaturation in vegetable oils, margarines, and shortenings (Section 18.4). Chlorine reacts with alkenes to give dichloro products in an addition reaction similar to that of bromine. However, it is not used as a test for unsaturation because it is difficult to see the pale green color of chlorine in solution.

Learning Check 12.4 Write the structural formula for the product of each of the following reactions:

a. $CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}}=CH_2 + Br_2 \longrightarrow$

b.  $+ \; Cl_2 \longrightarrow$

In the presence of an appropriate catalyst (such as platinum, palladium, or nickel), hydrogen adds to alkenes and converts them into the corresponding alkanes. This reaction, which is called **hydrogenation,** is illustrated in Reactions 12.4 and 12.5.

hydrogenation A reaction in which the addition of hydrogen takes place.

General reaction:

$$\begin{matrix} \diagdown & & \diagup \\ & C=C & \\ \diagup & & \diagdown \end{matrix} + H-H \xrightarrow{Pt} -\underset{\displaystyle H}{\underset{|}{\overset{|}{C}}}-\underset{\displaystyle H}{\underset{|}{\overset{|}{C}}}- \qquad (12.4)$$

an alkane

Specific example:

$$CH_3CH=CHCH_3 + H-H \xrightarrow{Pt} CH_3\underset{\displaystyle H}{\underset{|}{C}}H-\underset{\displaystyle H}{\underset{|}{C}}HCH_3 \qquad (12.5)$$

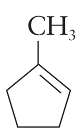
2-butene butane

The hydrogenation of vegetable oils is a very important commercial process. Vegetable oils, such as soybean and cottonseed oil, are composed of long-chain organic molecules that contain many alkene bonds. The high degree of unsaturation characteristic of these oils gave rise to the term **polyunsaturated.** Upon hydrogenation, the melting point of the oils is raised, and the oils become low-melting-point solids. These products are used in the form of margarine and shortening.

polyunsaturated A term usually applied to molecules with several double bonds.

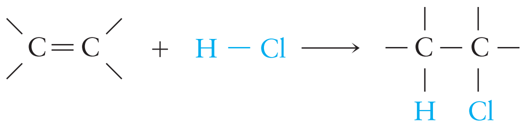
Learning Check 12.5 Write the structural formula for the product of each of the following reactions:

a. $CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}}=CH-CH_3 + H_2 \xrightarrow{Pt}$

b.  $+ \; H_2 \xrightarrow{Pt}$

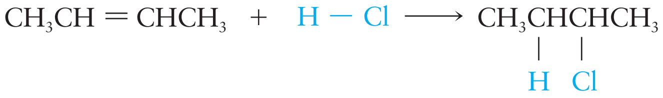
A number of acidic compounds, such as the hydrogen halides—HF, HCl, HBr, and HI—also add to alkenes to give the corresponding alkyl halide. The reaction with HCl is illustrated as follows:

General reaction:



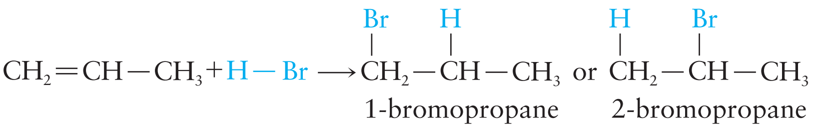
(12.6)

Specific example:



(12.7)

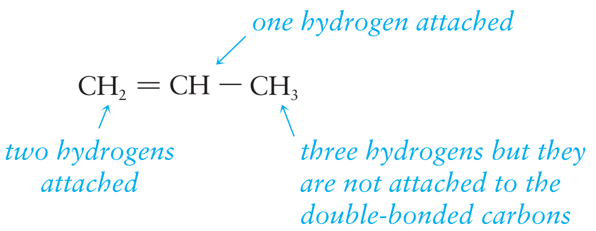
The addition reactions involving H_2, Cl_2, and Br_2 yield only one product because the same group (H and H or Br and Br) adds to each double-bonded carbon. However, with H—X, a different group adds to each carbon, and for certain alkenes, there are two possible products. For example, in the reaction of HBr with propene, two products might be expected: 1-bromopropane or 2-bromopropane,



(12.8)

It turns out that only one product, 2-bromopropane, is formed in significant amounts. This fact, first reported in 1869 by Russian chemist Vladimir Markovnikov, gave rise to a rule for predicting which product will be exclusively or predominantly formed. According to **Markovnikov's rule,** when a molecule of the form H—X adds to an alkene, the hydrogen becomes attached to a double-bonded carbon atom that is already bonded to the greatest number of hydrogens. A phrase to help you remember this rule is "the rich get richer." Applying this rule to propene, we find:

Markovnikov's rule In the addition of H—X to an alkene, the hydrogen becomes attached to the carbon atom that is already bonded to more hydrogens.

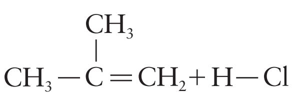


Therefore, H attaches to the end carbon of the double bond, Br attaches to the second carbon, and 2-bromopropane is the major product.

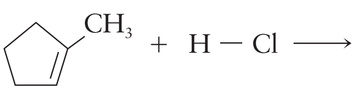
Example 12.4

Use Markovnikov's rule to predict the major product in the following reactions:

a.

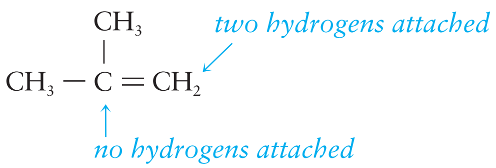


b.

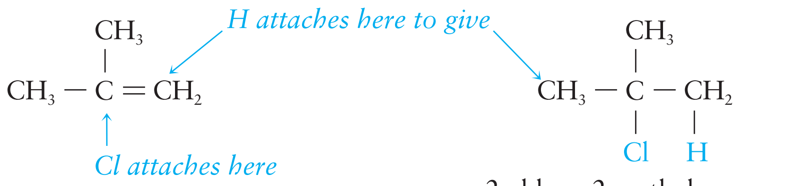


Solution

a. Analyze the C═C to see which carbon atom has more hydrogens attached:

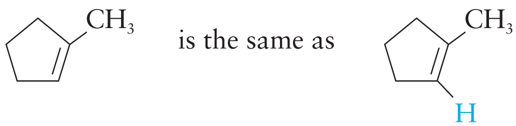


The H of H—Cl will attach to the position that has more hydrogens. Thus, 2-chloro-2-methylpropane is the major product:

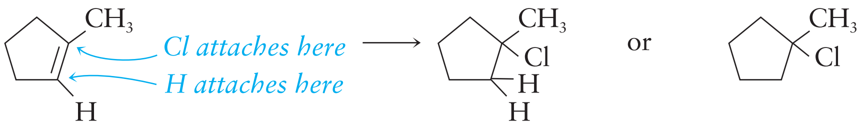


2-chloro-2-methylpropane

b. The challenge with a cyclic alkene is to remember that the hydrogens are not shown. Thus,



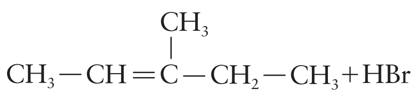
As before, the H of H—Cl will attach to the double-bonded carbon that has more hydrogens:



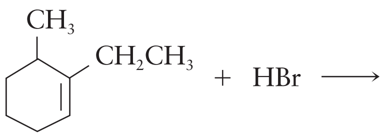
Learning Check 12.6

Use Markovnikov's rule to predict the major product in the following reactions:

a.



b.



Study Skills 12.1 Keeping a Reaction Card File

Remembering organic reactions for exams is challenging for most students. Because the number of reactions being studied increases rapidly, it is a good idea to develop a systematic way to organize them for easy and effective review.

One way to do this is to focus on the functional group concept. When an exam question asks you to complete a reaction by identifying the product, your first step should be to identify the functional group of the reactant. Usually, only the functional group portion of a molecule undergoes reaction. In addition, a particular functional group usually undergoes the same characteristic reactions regardless of the other features of the organic molecule to which it is bound. Thus, by remembering the behavior of a functional group under specific conditions, you can predict the reactions of many compounds, no matter how complex the structures look, as long as they contain the same functional group. For example, any structure containing a C═C will undergo reactions typical of alkenes. Other functional groups will be introduced in later chapters.

Keeping a reaction card file based on the functional group concept is a good way to organize reactions for review. Write the structures and names of the reactants on one side of an index card with an arrow showing any catalyst or special conditions. Write the product structure and name on the back of the card. We recommend that you do this for the general reaction (like those in the Key Reactions section at the end of most chapters) and for a specific example. Review your cards every day (this can even be done while waiting for a bus, etc.), and add to them as new reactions are studied. As an exam approaches, put aside the reactions you know well, and concentrate on the others in what should be a dwindling deck. This is an effective way to focus on learning what you don't know.

In the absence of a catalyst, water does not react with alkenes. But, if an acid catalyst such as sulfuric acid is added, water adds to carbon–carbon double bonds to give alcohols. In this reaction, which is called **hydration,** a water molecule is split in such a way that —H attaches to one carbon of the double bond, and —OH attaches to the other carbon. In Reactions 12.9–12.11, H_2O is written H—OH to emphasize the portions that add to the double bond. Notice that the addition follows Markovnikov's rule:

hydration The addition of water to a multiple bond.

$$\mathrm{>C=C<} + \mathrm{H-OH} \xrightarrow{H_2SO_4} \mathrm{-\underset{H}{\underset{|}{\overset{|}{C}}}-\underset{OH}{\underset{|}{\overset{|}{C}}}-} \qquad (12.9)$$

an alcohol

$$\underset{\text{2-butene}}{\mathrm{CH_3CH=CHCH_3}} + \mathrm{H-OH} \xrightarrow{H_2SO_4} \underset{\text{2-butanol}}{\mathrm{CH_3\underset{H}{\underset{|}{C}H}-\underset{OH}{\underset{|}{C}H}CH_3}} \qquad (12.10)$$

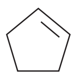
$$\underset{\text{propene}}{\mathrm{CH_3CH=CH_2}} + \mathrm{H-OH} \xrightarrow{H_2SO_4} \underset{\text{2-propanol}}{\mathrm{CH_3\underset{OH}{\underset{|}{C}H}-\underset{H}{\underset{|}{C}H_2}}} \qquad (12.11)$$

The hydration of alkenes provides a convenient method for preparing alcohols on a large scale. The reaction is also important in living organisms, but the catalyst is an enzyme rather than sulfuric acid. For example, one of the steps in the body's utilization of carbohydrates for energy involves the hydration of fumaric acid, which is catalyzed by the enzyme fumarase:

$$\underset{\text{fumaric acid}}{\mathrm{HO-\overset{O}{\overset{\|}{C}}-CH=CH-\overset{O}{\overset{\|}{C}}-OH}} + H_2O \xrightarrow{\text{fumarase}} \underset{\text{malic acid}}{\mathrm{HO-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{C}H}-\overset{OH}{\overset{|}{C}H}-\overset{O}{\overset{\|}{C}}-OH}} \qquad (12.12)$$

Learning Check 12.7 Draw structural formulas for the major organic product of each of the following reactions:

a. $CH_3CH_2CH_2CH{=}CH_2 + H_2O \xrightarrow{H_2SO_4}$

b.  $+ \; H_2O \xrightarrow{H_2SO_4}$

12.4 Addition Polymers

Learning Objective

6. Write equations for addition polymerization, and list uses for addition polymers.

Certain alkenes undergo a very important reaction in the presence of specific catalysts. In this reaction, alkene molecules undergo an addition reaction with one another. The double bonds of the reacting alkenes are converted to single bonds as hundreds or

Figure 12.6 Gore-Tex® is a thin, membranous material made by stretching Teflon fibers. Fabrics layered with Gore-Tex repel wind and rain but allow body perspiration to escape, making it an excellent fabric for sportswear.

polymerization A reaction that produces a polymer.

polymer A very large molecule made up of repeating units.

addition polymer A polymer formed by the linking together of many alkene molecules through addition reactions.

monomer The starting material that becomes the repeating units of polymers.

thousands of molecules bond and form long chains. For example, several ethylene molecules react as follows:

$$\underset{\text{ethylene molecules}}{CH_2{=}CH_2 + CH_2{=}CH_2 + CH_2{=}CH_2 + CH_2{=}CH_2} \xrightarrow[\text{catalysts}]{\text{Heat, pressure,}} \tag{12.13}$$

$$\underset{\text{polyethylene}}{-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-}$$

The product is commonly called polyethylene even though there are no longer any double bonds present. The newly formed bonds in this long chain are shown in color. This type of reaction is called a **polymerization,** and the long-chain product made up of repeating units is a **polymer** (*poly* = many, *mer* = parts). The trade names of many polymers such as Orlon®, Plexiglas®, Lucite®, and Teflon® are familiar (see Figure 12.6). These products are referred to as **addition polymers** because of the addition reaction between double-bonded compounds that is used to produce them. The starting materials that make up the repeating units of polymers are called **monomers** (*mono* = one, *mer* = part). Quite often, common names are used for both the polymer and the monomer.

It is not possible to give an exact formula for a polymer produced by a polymerization reaction because the individual polymer molecules vary in size. We could represent polymerization reactions as in Reaction 12.13. However, since this type of reaction is inconvenient, we adopt a commonly used approach: The polymer is represented by a simple repeating unit based on the monomer. For polyethylene, the unit is $\text{+}CH_2{-}CH_2\text{+}$. The large number of units making up the polymer is denoted by *n,* a whole number that varies from several hundred to several thousand. The polymerization reaction of ethylene is then written as:

$$\underset{\text{ethylene}}{nCH_2{=}CH_2} \xrightarrow[\text{catalysts}]{\text{Heat, pressure,}} \underset{\text{polyethylene}}{\text{+}CH_2-CH_2\text{+}_n} \tag{12.14}$$

The lowercase *n* in Reaction 12.14 represents a large, unspecified number. From this reaction, we see that polyethylene is essentially a very long chain alkane. As a result, it has the chemical inertness of alkanes, a characteristic that makes polyethylene suitable for food storage containers, garbage bags, eating utensils, laboratory apparatus, and hospital equipment (see Figure 12.7). Polymer characteristics are modified by using alkenes with different

A Packaging materials from polyethylene

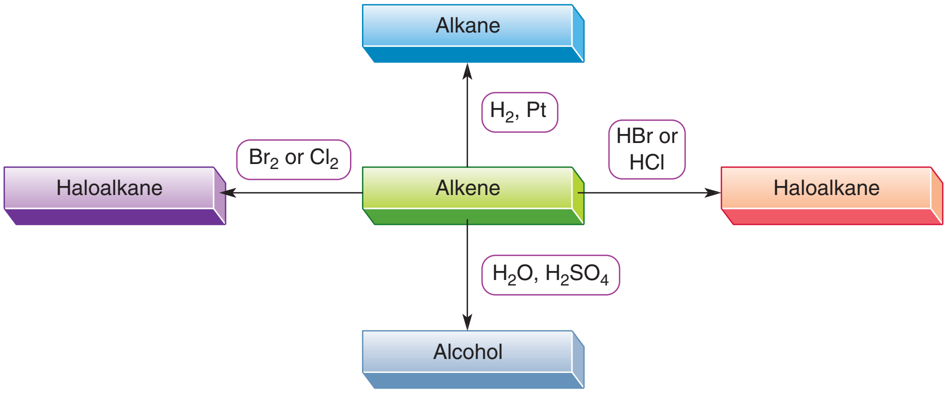
B Polystyrene

C Polyvinyl chloride

Figure 12.7 Common polymer-based consumer products.

Study Skills 12.2 A Reaction Map for Alkenes

A diagram may help you visualize and remember the four common addition reactions in this section. In each case, the alkene double bond reacts, and an alkane or alkane derivative is produced. The specific reagent determines the outcome of the reaction.



groups attached to either or both of the double-bonded carbons. For example, the polymerization of vinyl chloride gives the polymer poly (vinyl chloride), PVC (Reaction 12.15):

$$\underset{\text{vinyl chloride}}{n\mathrm{CH_2{=}\overset{Cl}{\overset{|}{C}}H}} \xrightarrow[\text{catalysts}]{\text{Heat,}} \underset{\text{poly (vinyl chloride)}}{\left(\mathrm{CH_2-\overset{Cl}{\overset{|}{C}}H}\right)_n} \qquad (12.15)$$

The commercial product Saran Wrap is an example of a **copolymer,** which is a polymer made up of two different monomers (Reaction 12.16):

copolymer An addition polymer formed by the reaction of two different monomers.

$$\underset{\text{vinyl chloride}}{n\mathrm{CH_2=\underset{\underset{Cl}{|}}{CH}}} + \underset{\text{vinylidene chloride}}{n\mathrm{CH_2=\overset{Cl}{\overset{|}{\underset{\underset{Cl}{|}}{C}}}}} \xrightarrow{\text{Catalyst}} \underset{\text{Saran Wrap}}{\left(\mathrm{CH_2-\underset{\underset{Cl}{|}}{CH}-CH_2-\overset{Cl}{\overset{|}{\underset{\underset{Cl}{|}}{C}}}}\right)_n} \qquad (12.16)$$

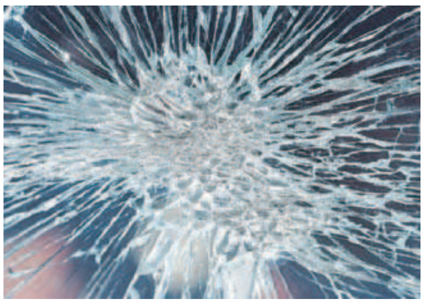
A number of the more important addition polymers are shown in Table 12.3. As you can tell by looking at some of the typical uses, addition polymers have become nearly indispensable in modern life (see Figure 12.8).

Learning Check 12.8 Draw the structural formula of a portion of polypropylene containing four repeating units of the monomer propylene,

$$\mathrm{CH_2=\overset{CH_3}{\overset{|}{C}}H}$$

Table 12.3 Common Addition Polymers

Chemical Name and Trade Name(s)	Monomer	Polymer	Typical Uses
polyethylene	$CH_2{=}CH_2$	$-\!\!\!+ CH_2-CH_2 +\!\!\!-_n$	Bottles, plastic bags, film
polypropylene	$CH_2{=}CH(CH_3)$	$-\!\!\!+ CH_2-CH(CH_3) +\!\!\!-_n$	Carpet fiber, pipes, bottles, artificial turf
poly (vinyl chloride) (PVC)	$CH_2{=}CH(Cl)$	$-\!\!\!+ CH_2-CH(Cl) +\!\!\!-_n$	Synthetic leather, floor tiles, garden hoses, water pipe
polytetrafluoroethylene (Teflon®)	$CF_2{=}CF_2$	$-\!\!\!+ CF_2-CF_2 +\!\!\!-_n$	Pan coatings, plumbers' tape, heart valves, fabrics
poly (methyl methacrylate) (Lucite®, Plexiglas®)	$CH_2{=}C(CH_3)-C(=O)-O-CH_3$	$-\!\!\!+ CH_2-C(CH_3)(C(=O)-O-CH_3) +\!\!\!-_n$	Airplane windows, paint, contact lenses, fiber optics
poly (vinyl acetate)	$CH_2{=}CH-O-C(=O)-CH_3$	$-\!\!\!+ CH_2-CH(O-C(=O)-CH_3) +\!\!\!-_n$	Adhesives, latex paint, chewing gum
polyacrylonitrile (Orlon®, Acrilan®)	$CH_2{=}CH(CN)$	$-\!\!\!+ CH_2-CH(CN) +\!\!\!-_n$	Carpets, fabrics
polystyrene (Styrofoam®)	$CH_2{=}CH(C_6H_5)$	$-\!\!\!+ CH_2-CH(C_6H_5) +\!\!\!-_n$	Food coolers, drinking cups, insulation



Frank Cezus

1 Automobile safety glass contains a sheet of polyvinyl polymer layered between two sheets of glass to prevent the formation of sharp fragments.

Richard Hutchings/Digital Light Source/ Peter Arnold Inc.

2 The elasticity of bubble gum comes from a copolymer of styrene and 1,3-butadiene.

Figure 12.8 Two uses of addition polymers. What properties of addition polymers are exhibited in both of these products?

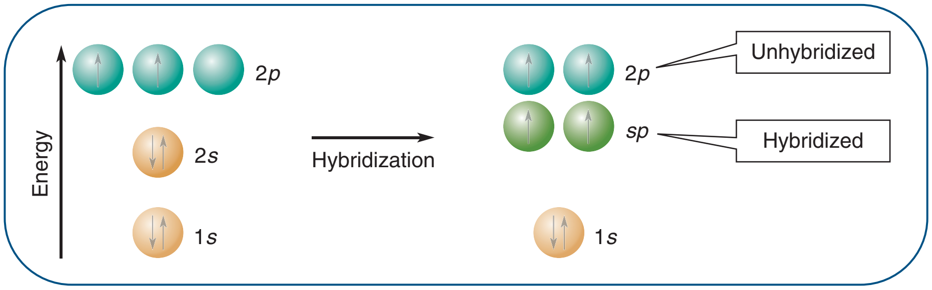


Figure 12.9 *sp* hybridization occurs when one of the 2*p* orbitals of carbon mixes with the 2*s* orbital. Two 2*p* orbitals remain unhybridized.

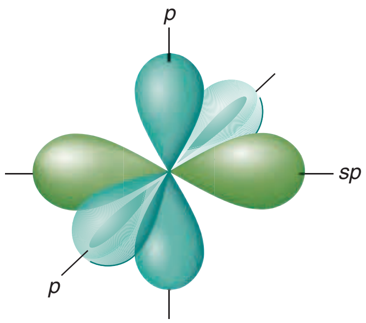


Figure 12.10 The unhybridized *p* orbitals are perpendicular to the two *sp* hybridized orbitals.

12.5 Alkynes

Learning Objective

7. Write the IUPAC names of alkynes from their molecular structures.

The characteristic feature of alkynes is the presence of a triple bond between carbon atoms. Thus, alkynes are also unsaturated hydrocarbons. Only a few compounds containing the carbon–carbon triple bond are found in nature. The simplest and most important compound of this series is ethyne, more commonly called acetylene (C_2H_2):

$$H-C\equiv C-H$$

acetylene

Acetylene is used in torches for welding steel and in making plastics and synthetic fibers.

Once again, orbital hybridization provides an explanation for the bonding of the carbon atoms. Structurally, the hydrogen and carbon atoms of acetylene molecules lie in a straight line. This same linearity of the triple bond and the two atoms attached to the triple-bonded carbons is found in all alkynes. These characteristics are explained by mixing a 2*s* and a single 2*p* orbital of each carbon to form a pair of *sp* hybrid orbitals. Two of the 2*p* orbitals of each carbon are unhybridized (see Figures 12.9 and 12.10).

A carbon–carbon sigma bond in acetylene forms by the overlap of one *sp* hybrid orbital of each carbon. The other *sp* hybrid orbital of each carbon overlaps with a 1*s* orbital of a hydrogen to form a carbon–hydrogen sigma bond. The remaining pair of unhybridized *p* orbitals of each carbon overlap sideways to form a pair of pi bonds between the carbon atoms. Thus, each acetylene molecule contains three sigma bonds (two carbon–hydrogen and one carbon–carbon) and two pi bonds (both are carbon–carbon). This is shown in Figure 12.11.

Alkynes are named in exactly the same ways as alkenes, except the ending *-yne* is used:

1-butyne 3-methyl-1-butyne

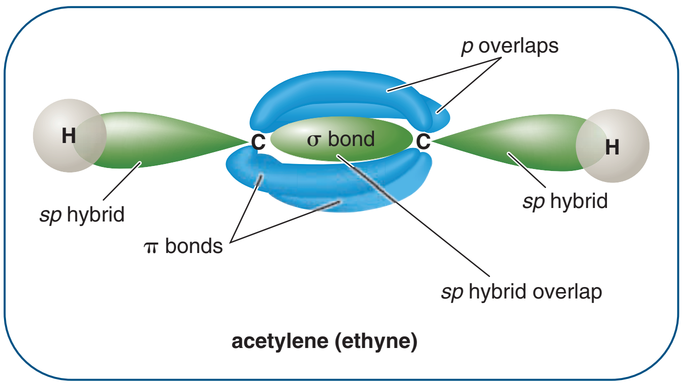
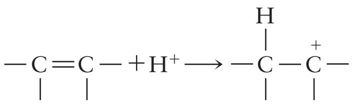


Figure 12.11 The shape of acetylene is explained by sigma bonding between *sp* hybrid orbitals and pi bonding between unhybridized *p* orbitals.

HOW REACTIONS OCCUR 12.1 The Hydration of Alkenes: An Addition Reaction

The mechanism for the hydration of alkenes is believed to begin when H^+ from the acid catalyst is attracted to the electrons of the carbon–carbon double bond. The H^+ becomes bonded to one of the carbons by a sharing of electrons:

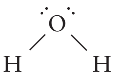
Step 1.



a carbocation

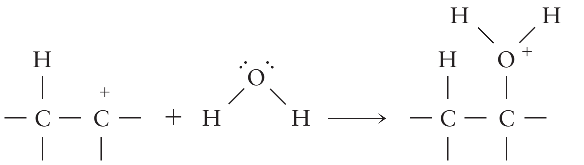
This process leaves the second carbon with only three bonds about it and thus a positive charge. Such ions, referred to as **carbocations,** are extremely reactive.

As soon as it forms, the positive carbocation attracts any species that has readily available nonbonding electrons, whether it is an anion or a neutral molecule. In the case of water, the oxygen atom has two unshared pairs of electrons:



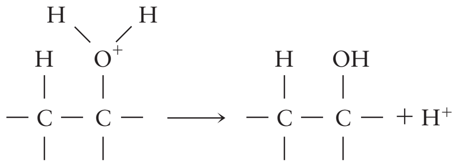
One pair of oxygen electrons forms a covalent bond with the carbocation:

Step 2.



In the third step, H^+ is lost to produce the alcohol:

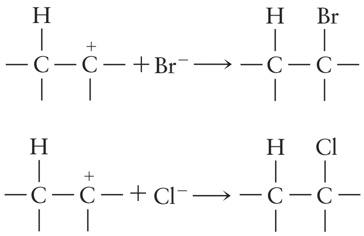
Step 3.

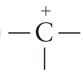


an alcohol

Notice that the acid catalyst, H^+, which initiated the reaction, is recovered unchanged in the final step of the mechanism.

By applying Step 2 of the mechanism for hydration, we can understand how HCl and HBr react with alkenes:



carbocation An ion of the form 

Learning Check 12.9 Give the IUPAC name for each of the following:

a. $CH_3-CH_2-C\equiv C-CH_3$

b. $CH_3-CH(CH_3)-CH_2-C\equiv C-CH_3$

The physical properties of the alkynes are nearly the same as those of the corresponding alkenes and alkanes: They are insoluble in water, less dense than water, and have relatively low melting and boiling points. Alkynes also resemble alkenes in their addition reactions. The same substances (Br_2, H_2, HCl, etc.) that add to double bonds also add to triple bonds. The one significant difference is that alkynes consume twice as many moles of addition reagent as alkenes in addition reactions that go on to completion.

12.6 Aromatic Compounds and the Benzene Structure

Learning Objective

8. Classify organic compounds as aliphatic or aromatic.

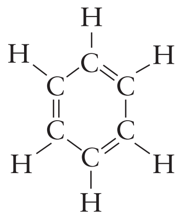
Some of the early researchers in organic chemistry became intrigued by fragrant oils that could be extracted from certain plants. Oil of wintergreen and the flavor component of the vanilla bean are examples. The compounds responsible for the aromas had similar chemical properties. As a result, they were grouped together and called aromatic compounds.

As more and more aromatic compounds were isolated and studied, chemists gradually realized that aromatics contained at least six carbon atoms, had low hydrogen-to-carbon ratios (relative to other organic hydrocarbons), and were related to benzene (C_6H_6). For example, toluene, an aromatic compound from the bark of the South American tolu tree, has the formula C_7H_8.

Chemists also learned that the term *aromatic* was not always accurate. Many compounds that belong to the class because of chemical properties and structures are not at all fragrant. Conversely, there are many fragrant compounds that do not have aromatic compound properties or structures. Today, the old class name is used but with a different meaning. Aromatic compounds are those that contain the characteristic benzene ring or its structural relatives. Compounds that do not contain this structure (non-aromatic compounds) are referred to as **aliphatic compounds.** Alkanes, alkenes, and alkynes are, therefore, aliphatic compounds.

aliphatic compound Any organic compound that is not aromatic.

The molecular structure of benzene presented chemists with an intriguing puzzle after the compound was discovered in 1825 by Michael Faraday. The formula C_6H_6 indicated that the molecule was highly unsaturated. However, the compound did not show the typical reactivity of unsaturated hydrocarbons. Benzene underwent relatively few reactions, and these proceeded slowly and often required heat and catalysts. This was in marked contrast to alkenes, which reacted rapidly with many reagents, in some cases almost instantaneously. This apparent discrepancy between structure and reactivity plagued chemists until 1865, when Friedrich August Kekulé von Stradonitz (see Figure 12.12), a German chemist, suggested that the benzene molecule might be represented by a ring arrangement of carbon atoms with alternating single and double bonds between the carbon atoms:



or

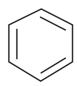
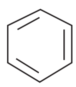
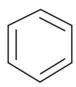


Figure 12.12 Friedrich August Kekulé (1829–1896).

He later suggested that the double bonds alternate in their positions between carbon atoms to give two equivalent structures:



and

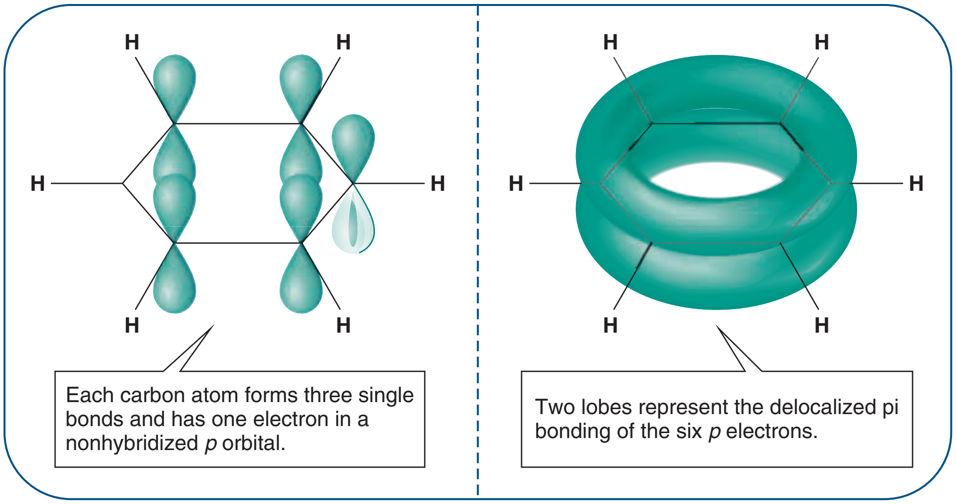


Kekulé structures

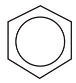
A modern interpretation of the benzene structure based on hybridization enables chemists to better understand and explain the chemical properties of benzene and other aromatic compounds. Each carbon atom in a benzene ring has three sp^2 hybrid orbitals and one unhybridized *p* orbital.

A single sigma bond between carbons of the benzene ring is formed by the overlap of two sp^2 orbitals, one from each of the double-bonded carbons. Because each carbon forms two single bonds, two of the sp^2 hybrid orbitals of each carbon are involved. The third sp^2 hybrid orbital of each carbon forms a single sigma bond with a hydrogen by overlapping with a 1*s* orbital of hydrogen. The unhybridized *p* orbitals of each carbon overlap sideways above and below the plane of the carbon ring to form two delocalized pi lobes that run completely around the ring in the shape of a double torus. The first torus represents the blended and overlapping orbital area of the six pi lobes that point up, and the torus underneath it represents the blending and overlapping orbital area of the six pi lobes that point down (see Figure 12.13).

Figure 12.13 A hybrid orbital view of the benzene structure.

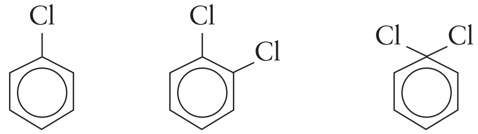


This interpretation leads to the conclusion that six bonding electrons move freely around the double ring structure formed by the overlapping delocalized pi lobes. Because of this, the benzene structure is often represented by the symbol:



with the circle representing the evenly distributed electrons in the pi lobes. All six carbon and six hydrogen atoms in benzene molecules lie in the same plane (see Figure 12.13). Therefore, substituted aromatic compounds do not exhibit cis-trans isomerism.

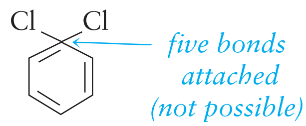
As you draw the structure of aromatic compounds, remember that only one hydrogen atom or group can be attached to a particular position on the benzene ring. For example, compounds (A) and (B) below exist, but (C) does not. Examination of the Kekulé structure of compound (C) shows that the carbon has five bonds attached to it in violation of the octet rule:



(A) exists

(B) exists

(C) does not exist



Kekulé structure

12.7 The Nomenclature of Benzene Derivatives

Learning Objective

9. Name and draw structural formulas for aromatic compounds.

The chemistry of the aromatic compounds developed somewhat haphazardly for many years before systematic nomenclature schemes were developed. Some of the common names used earlier have acquired historical respectability and are used today; some have even been incorporated into the modern systematic nomenclature system.

The following guidelines are all based on the IUPAC aromatic nomenclature system. They are not complete, and you will not be able to name all aromatic compounds by using them. However, you will be able to name and recognize those used in this book.

Chemistry and Your Health 12.1

Beautiful, Brown ... and Overdone

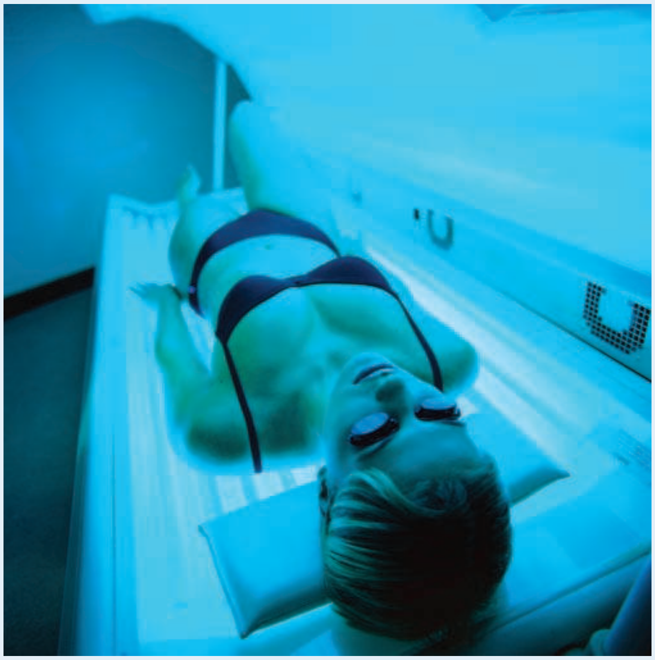
For many people, a well-tanned skin is considered to be very attractive. However, the methods used to achieve this stylish appearance sometimes have some serious health drawbacks.

The body protects itself from ultraviolet (UV) radiation by producing a skin pigment called melanin. The accumulation of melanin in the skin leads to the characteristic tan color and protects the skin from burning and other damage caused by UV radiation. Melanin takes 3 to 5 days to form after initial exposure to the sun. Melanin then helps the skin to gradually tan if the exposed time is kept within reasonable bounds.

Teens are particularly susceptible to the risk of overexposure because they are still experiencing tremendous growth at the cellular level. However, people run the risk of developing skin cancer if they are exposed to the sun or to artificial sunlight in tanning salons too often or for long times.

Anyone using the facilities of a tanning salon should find out the recommended exposure times for each bed. At the beginning of developing a tan, an individual should not tan more than every other day. As the tan develops, it is wise to cut back tanning sessions to no more than twice a week. Many salon owners allow individuals to tan for greater periods of time than is safely recommended. Every tanning bed has a chart indicating what frequency and duration are approved by safety standards. If the beds in a salon do not have such charts, the salon is not following safety guidelines, and it would be a good idea to leave.

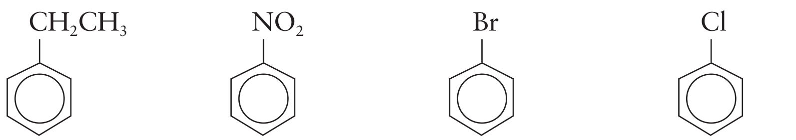
Exposure to UV rays is known to stimulate addictive behavior that results in increasing tanning frequency and duration. Although a tan is commonly thought to be beautiful, skin cancer certainly is not. Be a conscientious and perceptive consumer.



Masterfile (Royalty-Free Div.)

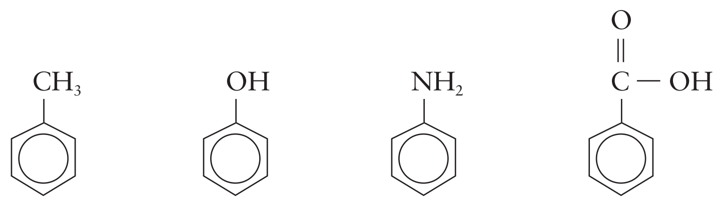
According to the Food and Drug Administration, the use of artificial tanning devices is not recommended for anyone.

Guideline 1. When a single hydrogen of the benzene ring is replaced, the compound can be named as a derivative of benzene:



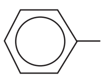
ethylbenzene nitrobenzene bromobenzene chlorobenzene

Guideline 2. A number of benzene derivatives are known by common names that are also IUPAC-accepted and are used preferentially over other possibilities. Thus, toluene is favored over methylbenzene, and aniline is used rather than aminobenzene:



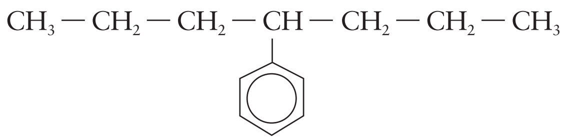
toluene phenol aniline benzoic acid

Guideline 3. Compounds formed by replacing a hydrogen of benzene with a more complex hydrocarbon group can be named by designating the benzene ring as the group. This is shown as the benzene ring, C_6H_5—, which is also

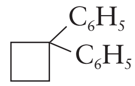


phenyl group A benzene ring with one hydrogen absent, C_6H_5—.

called a **phenyl group:**



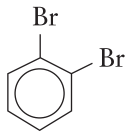
4-phenylheptane



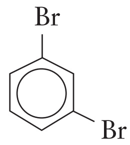
1,1-diphenylcyclobutane

It's easy to confuse the words *phenyl* and *phenol.* The key to keeping them straight is the ending: *-ol* means an alcohol (C_6H_5—OH), and *-yl* means a group (C_6H_5—).

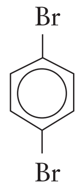
Guideline 4. When two groups are attached to a benzene ring, three isomeric structures are possible. They can be designated by the prefixes *ortho (o), meta (m),* and *para (p):*



o-dibromobenzene

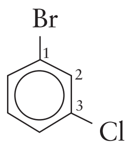


m-dibromobenzene

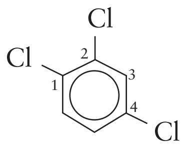


p-dibromobenzene

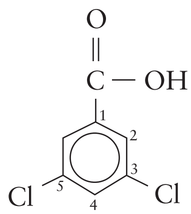
Guideline 5. When two or more groups are attached to a benzene ring, their positions can be indicated by numbering the carbon atoms of the ring so as to obtain the lowest possible numbers for the attachment positions. Groups are arranged in alphabetical order. If there is a choice of identical sets of numbers, the group that comes first in alphabetical order is given the lower number. IUPAC-acceptable common names may be used:



m-bromochlorobenzene
or 1-bromo-3-chlorobenzene



1,2,4-trichlorobenzene

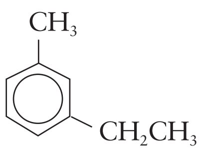


3,5-dichlorobenzoic acid

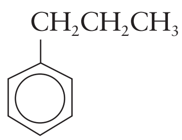
Example 12.5

Name each of the following aromatic compounds:

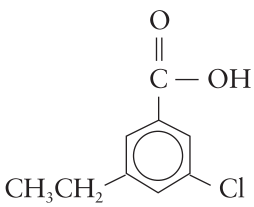
a.



b.



c.



Solution

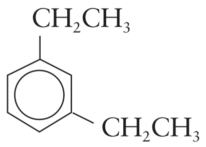
a. This compound is named as a substituted toluene. Both of the following are correct: 3-ethyltoluene and *m*-ethyltoluene. Note that in 3-ethyltoluene the methyl group, which is a part of the toluene structure, must be assigned to position number one.

b. This compound may be named as a substituted benzene or a substituted propane: propylbenzene, 1-phenylpropane.

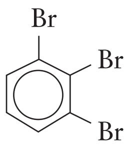
c. When three groups are involved, the ring-numbering approach must be used: 3-chloro-5-ethylbenzoic acid.

Learning Check 12.10 Name the following aromatic compounds:

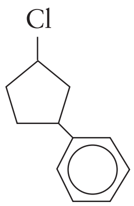
a.



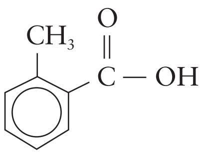
c.



b.



d.



12.8 Properties and Uses of Aromatic Compounds

Learning Objective

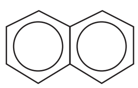
10. Recognize uses for specific aromatic compounds.

The physical properties of benzene and other aromatic hydrocarbons are similar to those of alkanes and alkenes. They are nonpolar and thus insoluble in water. This hydrophobic characteristic plays an important role in the chemistry of some proteins (Chapter 19).

Aromatic rings are relatively stable chemically. Because of this, benzene often reacts in such a way that the aromatic ring remains intact. Thus, benzene does not undergo the addition reactions that are characteristic of alkenes and alkynes. The predominant type of reaction of aromatic molecules is substitution, in which one of the ring hydrogens is replaced by some other group. Such aromatic reactions are of lesser importance for our purposes and are not shown here.

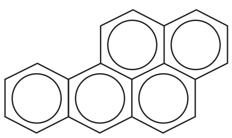
All aromatic compounds discussed to this point contain a single benzene ring. There are also substances called **polycyclic aromatic compounds,** which contain two or more benzene rings sharing a common side, or "fused" together. The simplest of these compounds, naphthalene, is the original active ingredient in mothballs:

polycyclic aromatic compound A derivative of benzene in which carbon atoms are shared between two or more benzene rings.

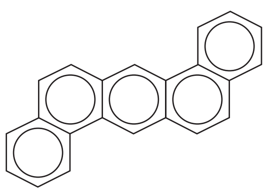


naphthalene

A number of more complex polycyclic aromatic compounds are known to be carcinogens—chemicals that cause cancer. Two of these compounds are:



a benzopyrene



a dibenzanthracene

At the Counter 12.1

Smoking: It's Quitting Time

Smoking is a difficult habit to break, especially if the attempt is made by stopping abruptly—going "cold turkey." Mark Twain described the more reasonable gradual approach when he said, "Habit is habit, and not to be flung out of the window by any man, but coaxed downstairs a step at a time." Smokers do not have to go "cold turkey" because there are several OTC aids available, as well as some new prescription products to help them gradually overcome the strong urge to smoke—and eventually quit.

The transdermal (absorbed through the skin) nicotine patch is available over the counter in doses of 7–22 mg. When used as directed, this method delivers a steady supply of nicotine to the bloodstream and helps minimize withdrawal symptoms. Nicotine gum helps reduce withdrawal symptoms when used correctly. The gum should be chewed briefly and then held next to the cheek, allowing the lining of the mouth to absorb the nicotine.

With a prescription, smokers can also obtain a nasal spray that provides a small dose of nicotine each time it is used. This product, called Nicotrol NS®, was approved by the FDA even though inhaling the nicotine poses a small risk that smokers will become as dependent on the mist as they are on cigarettes. The nicotine from the nasal spray gets into the bloodstream faster than nicotine from the gum or patch, providing immediate relief from cigarette craving. A squirt into each nostril gives a smoker 1 mg of nicotine, but it is not supposed to be used more than five times per hour.

The Nicotrol nicotine inhalation system has also received FDA approval. This inhaler, available only by prescription, consists of a plastic cylinder about the size of a cigarette that encloses a cartridge containing nicotine. When a smoker "puffs" on the device, nicotine vapors are absorbed through the lining of the mouth and throat. It takes about 80 puffs to deliver the amount of nicotine obtained from a single cigarette. An advantage of using the system is that a smoker still mimics the hand-to-mouth behavior of smoking, a part of the smoking habit that will be easier to break once nicotine withdrawal symptoms subside.

One of the newest prescription products designed to help break the smoking habit does not contain any nicotine. It is an antidepressant called bupropion that has been shown to be effective in the treatment of nicotine addiction. It is believed that bupropion mimics some of the action of nicotine by releasing the brain chemicals norepinephrine and dopamine, but it is not completely understood how it works. During treatment, a bupropion tablet (marketed as Zyban®) is taken once a day for 3 days and then twice daily during the week before smoking is stopped. Usually, the treatment is continued for the next 6 to 12 weeks to help curb the craving for cigarettes.

If a smoker truly wants to quit, these aids alone will not do it. A smoker must have some kind of support from a formal program, or at least informal support from family and friends. A smoker should also get rid of all tobacco products and avoid smoking triggers, such as other smokers, stress, and alcohol. Exercise can also be a distraction from smoking and can minimize the weight gain that sometimes accompanies giving up smoking.

Eric Nelson/Custom Medical Stock Photo

Nicotine replacement therapy is used to help stop smoking by delivering nicotine to the body in a low controlled dose.

© Robert Vanden Brugge/BELGA/epa/Corbis

Zyban is a nicotine-free anti-smoking pill.

These cancer-producing compounds are often formed as a result of heating organic materials to high temperatures. They are present in tobacco smoke (see Figure 12.14), automobile exhaust, and sometimes in burned or heavily browned food. Such compounds are believed to be at least partially responsible for the high incidence of lung and lip cancer among cigarette smokers. Those who smoke heavily face an increased risk of getting cancer. Chemists have identified more than 4000 compounds in cigarette smoke, including 43 known carcinogens. The Environmental Protection Agency (EPA) considers tobacco smoke a Class A carcinogen.

The major sources of aromatic compounds are petroleum and coal tar, a sticky, dark-colored material derived from coal. As with many classes of organic compounds, the simplest structures are the most important commercial materials.

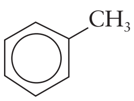
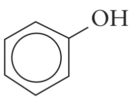
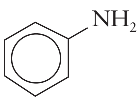
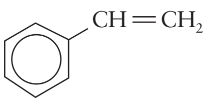
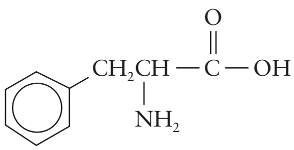
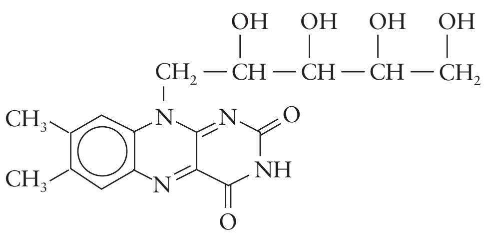
Benzene and toluene are excellent laboratory and industrial solvents. In addition, they are the starting materials for the synthesis of hundreds of other valuable aromatic compounds that are intermediates in the manufacture of a wide variety of commercial products, including the important polymers Bakelite® and polystyrene (see Table 12.4).

A number of aromatic compounds are important in another respect: They must be present in our diet for proper nutrition. Unlike plants, which have the ability to synthesize the benzene ring from simpler materials, humans must obtain any necessary aromatic rings from their diet. This helps explain why certain amino acids, the building blocks of proteins, and some **vitamins** are dietary essentials (Table 12.4).

Figure 12.14 Cigarette smoke contains carcinogenic polycyclic aromatic compounds.

vitamin An organic nutrient that the body cannot produce in the small amounts needed for good health.

Table 12.4 Some Important Aromatic Compounds

Name	Structural Formula	Use
benzene		Industrial solvent and raw material
toluene		Industrial solvent and raw material
phenol		Manufacture of Bakelite® and Formica®
aniline		Manufacture of drugs and dyes
styrene		Preparation of polystyrene products
phenylalanine		An essential amino acid
riboflavin		Vitamin B_2

Concept Summary

The Nomenclature of Alkenes. Compounds containing double or triple bonds between carbon atoms are said to be unsaturated. The alkenes contain double bonds, alkynes contain triple bonds, and aromatics contain a six-membered ring with three double bonds. **Objective 1, Exercise 12.2.** In the IUPAC nomenclature system, alkene names end in *-ene,* and alkynes end in *-yne.*

Objective 2, Exercise 12.4

The Geometry of Alkenes. In alkenes, the double-bonded carbons and the four groups attached to these carbons lie in the same plane. Because rotation about the double bond is restricted, alkenes may exist as geometric, or cis-trans, isomers. This type of stereoisomerism is possible when each double-bonded carbon is attached to two different groups. **Objective 3, Exercise 12.18** IUPAC names of stereoisomers contain the prefixes *cis-* or *trans-*.

Objective 4, Assessment Exercise 12.20

Properties of Alkenes. The physical properties of alkenes are very similar to those of the alkanes. They are nonpolar, insoluble in water, less dense than water, and soluble in nonpolar solvents. Alkenes are quite reactive, and their characteristic reaction is addition to the double bond. Three important addition reactions are bromination (an example of halogenation) to give a dibrominated alkane, hydration to produce an alcohol, and the reaction with H—X to give an alkyl halide. The addition of H_2O and H—X are governed by Markovnikov's rule.

Objective 5, Exercise 12.26

Addition Polymers. Addition polymers are formed from alkene monomers that undergo repeated addition reactions with each other. Many familiar and widely used materials, such as fibers and plastics, are addition polymers.

Objective 6, Exercise 12.36

Alkynes. The alkynes contain triple bonds and possess a linear geometry of the two carbons and the two attached groups. Alkyne names end in *-yne.* **Objective 7, Exercise 12.44** The physical and chemical properties of alkynes are very similar to those of the alkenes.

Aromatic Compounds and the Benzene Structure. Benzene, the simplest aromatic compound, and other members of the aromatic class contain a six-membered ring with three double bonds. This aromatic ring is often drawn as a hexagon containing a circle, which represents the six electrons of the double bonds that move freely around the ring. All organic compounds that do not contain an aromatic ring are called aliphatic compounds.

Objective 8, Exercise 12.48

The Nomenclature of Benzene Derivatives. Several acceptable IUPAC names are possible for many benzene compounds. Some IUPAC names are based on widely used common names such as toluene and aniline. Other compounds are named as derivatives of benzene or by designating the benzene ring as a phenyl group.

Objective 9, Exercises 12.52 and 12.54

Properties and Uses of Aromatic Compounds. Aromatic hydrocarbons are nonpolar and have physical properties similar to those of the alkanes and alkenes. Benzene resists addition reactions typical of alkenes. Benzene and toluene are key industrial chemicals. Other important aromatics include phenol, aniline, and styrene.

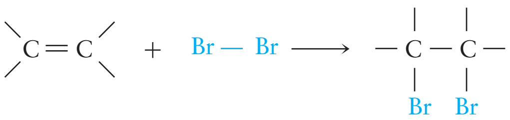
Objective 10, Exercise 12.66

Key Terms and Concepts

Addition polymer (12.4)
Addition reaction (12.3)
Aliphatic compound (12.6)
Alkene (Introduction)
Alkyne (Introduction)
Aromatic hydrocarbon (Introduction)
Carbocation (12.5)
Copolymer (12.4)
Haloalkane or alkyl halide (12.3)
Hydration (12.3)
Hydrogenation (12.3)
Markovnikov's rule (12.3)
Monomer (12.4)
Phenyl group (12.7)
Polycyclic aromatic compound (12.8)
Polymer (12.4)
Polymerization (12.4)
Polyunsaturated (12.3)
Unsaturated hydrocarbon (Introduction)
Vitamin (12.8)

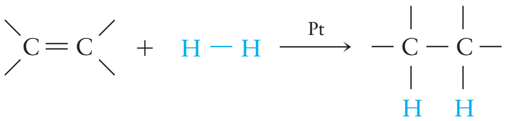
Key Reactions

1. Halogenation of an alkene (Section 12.3):

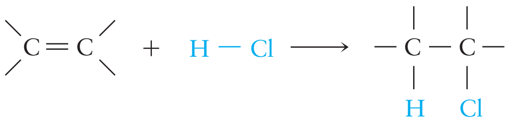


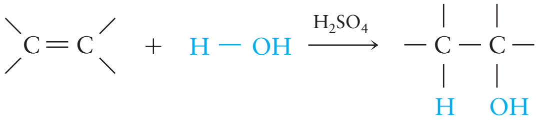
Reaction 12.2

2. Hydrogenation of an alkene (Section 12.3):



Reaction 12.4

3. Addition of H—X to an alkene (Section 12.3):  Reaction 12.6

4. Hydration of an alkene (Section 12.3):  Reaction 12.9

5. Addition polymerization of an alkene (Section 12.4): $n\mathrm{CH_2{=}CH_2} \xrightarrow[\text{catalysts}]{\text{Heat, pressure}} \mathrm{-\!(CH_2-CH_2)\!-}_n$ Reaction 12.14

Exercises

OWL Interactive versions of these problems are assignable in OWL.

Even-numbered exercises are answered in Appendix B.

Blue-numbered exercises are more challenging.

The Nomenclature of Alkenes (Section 12.1) and Alkynes (Section 12.5)

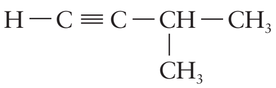
12.1 What is the definition of an unsaturated hydrocarbon?

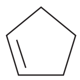
12.2 Define the terms alkene, alkyne, and aromatic hydrocarbon.

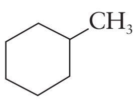
12.3 Select those compounds that can be correctly called *unsaturated* and classify each one as an *alkene* or an *alkyne:*

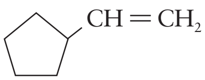
a. $CH_3-CH_2-CH_3$

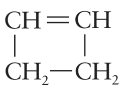
b. $CH_3CH=CHCH_3$

c. 

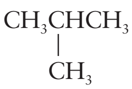
d. 

e. 

f. 

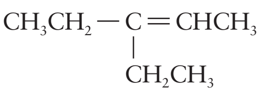
g. 

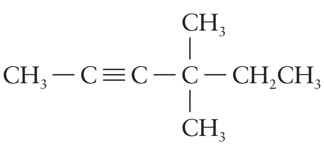
h. $CH_2=CHCH_2CH_3$

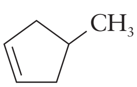
i. 

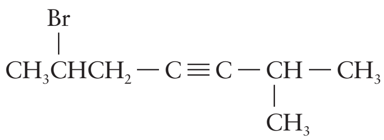
12.4 Give the IUPAC name for the following compounds:

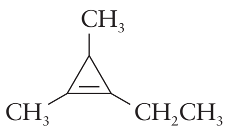
a. $CH_3CH=CHCH_3$

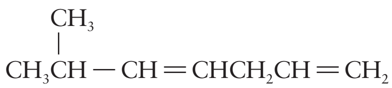
b. 

c. 

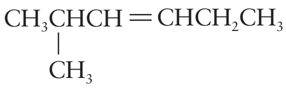
d. 

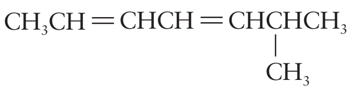
e. 

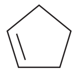
f. 

g. 

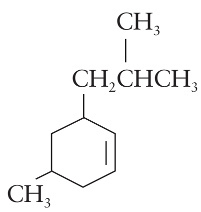
12.5 Give the IUPAC name for the following compounds:

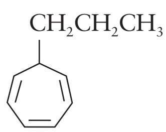
a. 

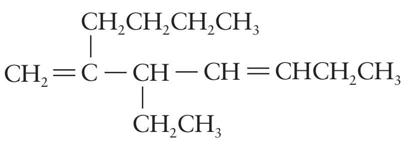
b. 

c. 

d. $CH_3-C\equiv C-CH_2CH_3$

e. 

f. 

g. 

12.6 Draw structural formulas for the following compounds:

a. 4-methyl-2-hexene

b. 4,4-dimethyl-1-pentyne

c. 1,3-butadiene

d. 1-ethyl-3-methylcyclopentene

e. 1,6-dimethylcyclohexene

12.7 Draw structural formulas for the following compounds:

a. 4,4,5-trimethyl-2-heptyne

b. 1,3-cyclohexadiene

c. 2-*t*-butyl-4,4-dimethyl-1-pentene

d. 4-isopropyl-3,3-dimethyl-1,5-octadiene

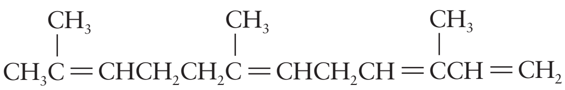
e. 2-methyl-1,3-cyclopentadiene

f. 3-*sec*-butyl-3-*t*-butyl-1-heptyne

12.8 A compound has the molecular formula C_5H_8. Draw a structural formula for a compound with this formula that would be classified as (a) an alkyne, (b) a diene, and (c) a cyclic alkene. Give the IUPAC name for each compound.

12.9 Draw structural formulas and give IUPAC names for the 13 alkene isomers of C_6H_{12}. Ignore geometric isomers and cyclic structures.

12.10 α-Farnesene is a constituent of the natural wax found on apples. Given that a 12-carbon chain is named as a dodecane, what is the IUPAC name of α-farnesene?



α-farnesene

12.11 Each of the following names is wrong. Give the structure and correct name for each compound.

a. 3-pentene

b. 3-methyl-2-butene

c. 2-ethyl-3-pentyne

12.12 Each of the following names is wrong. Give the structure and correct name for each compound.

a. 2-methyl-4-hexene

b. 3,5-heptadiene

c. 4-methylcyclobutene

The Geometry of Alkenes (Section 12.2)

12.13 What type of hybridized orbital is present on carbon atoms bonded by a double bond? How many of these hybrid orbitals are on each carbon atom?

12.14 What type of orbital overlaps to form a pi bond in an alkene? What symbol is used to represent a pi bond? How many electrons are in a pi bond?

12.15 Describe the geometry of the carbon–carbon double bond and the two atoms attached to each of the double-bonded carbon atoms.

12.16 Explain the difference between geometric and structural isomers of alkenes.

12.17 Draw structural formulas and give IUPAC names for all the isomeric pentenes (C_5H_{10}) that are:

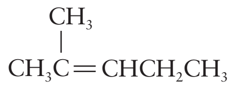
a. Alkenes that do not show geometric isomerism. There are four compounds.

b. Alkenes that do show geometric isomerism. There is one cis and one trans compound.

12.18 Which of the following alkenes can exist as cis-trans isomers? Draw structural formulas and name the cis and trans isomers.

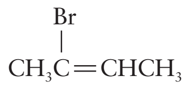
a. $CH_3CH_2CH_2CH_2CH{=}CH_2$

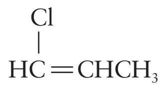
b. $CH_3CH_2CH{=}CHCH_2CH_3$

c. 

12.19 Which of the following alkenes can exist as cis-trans isomers? Draw structural formulas and name the cis and trans isomers.

a. $H_2C{=}CH{-}CH_3$

b. 

c. 

12.20 Draw structural formulas for the following:

a. *trans*-2-pentene

b. *cis*-2-hexene

12.21 Draw structural formulas for the following:

a. *trans*-3,4-dibromo-3-heptene

b. *cis*-1,4-dichloro-2-methyl-2-butene

Properties of Alkenes (Section 12.3)

12.22 In what ways are the physical properties of alkenes similar to those of alkanes?

12.23 Which of the following reactions is an addition reaction?

a. $A_2 + C_3H_6 \rightarrow C_3H_6A_2$

b. $A_2 + C_6H_6 \rightarrow C_6H_5A + HA$

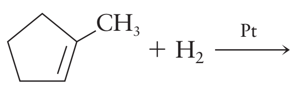
c. $HA + C_4H_8 \rightarrow C_4H_9A$

d. $3O_2 + C_2H_4 \rightarrow 2CO_2 + 2H_2O$

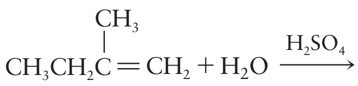
e. $C_7H_{16} \rightarrow C_7H_8 + 4H_2$

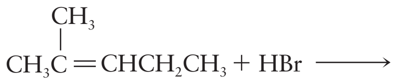
12.24 State Markovnikov's rule, and write a reaction that illustrates its application.

12.25 Complete the following reactions. Where more than one product is possible, show only the one expected according to Markovnikov's rule.

a. 

b. $CH_3CH_2CH{=}CH_2 + Cl_2 \longrightarrow$

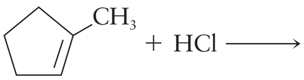
c. 

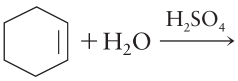
d. 

12.26 Complete the following reactions. Where more than one product is possible, show only the one expected according to Markovnikov's rule.

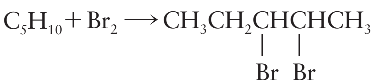
a. $CH_2{=}CHCH_2CH_3 + H_2 \xrightarrow{Pt}$

b. $CH_2{=}CHCH_2CH_3 + Br_2 \longrightarrow$

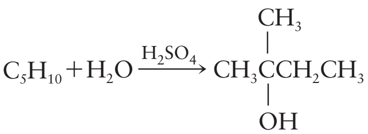
c. 

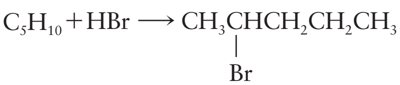
d. 

12.27 Draw the structural formula for the alkenes with molecular formula C_5H_{10} that will react to give the following products. Show all correct structures if more than one starting material will react as shown.

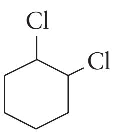
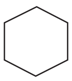
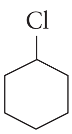
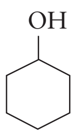
a. 

b. $C_5H_{10} + H_2 \xrightarrow{Pt} CH_3CH_2CH_2CH_2CH_3$

c. 

d. 

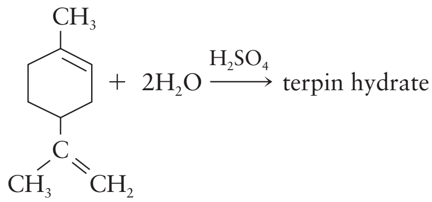
12.28 What reagents would you use to prepare each of the following from cyclohexene?

a.  b.  c.  d. 

12.29 What is an important commercial application of hydrogenation?

12.30 Cyclohexane and 2-hexene both have the molecular formula C_6H_{12}. Describe a simple chemical test that would distinguish one from the other.

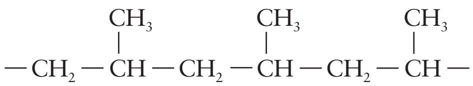
12.31 Terpin hydrate is used medicinally as an expectorant for coughs. It is prepared by the following addition reaction. What is the structure of terpin hydrate?



Addition Polymers (Section 12.4)

12.32 Explain what is meant by each of the following terms: *monomer, polymer, addition polymer,* and *copolymer.*

12.33 A section of polypropylene containing three units of monomer can be shown as:



Draw structural formulas for comparable three-unit sections of:

a. Teflon

b. Orlon

c. Lucite

12.34 Identify a structural feature characteristic of all monomers listed in Table 12.3.

12.35 Rubber cement contains a polymer of 2-methylpropene (isobutylene) called polyisobutylene. Write an equation for the polymerization reaction.

12.36 Much of today's plumbing in newly built homes is made from a plastic called poly (vinyl chloride), or PVC. Using Table 12.3, write a reaction for the formation of poly (vinyl chloride).

12.37 Identify a major use for each of the following addition polymers:

a. Styrofoam

b. Acrilan

c. Plexiglas

d. PVC

e. polypropylene

Alkynes (Section 12.5)

12.38 What type of hybridized orbital is present on carbon atoms bonded by a triple bond? How many of these hybrid orbitals are on each carbon atom?

12.39 How many sigma bonds and how many pi bonds make up the triple bond of an alkyne?

12.40 Describe the geometry in an alkyne of the carbon–carbon triple bond and the two attached atoms.

12.41 Explain why geometric isomerism is not possible in alkynes.

12.42 Give the common name and major uses of the simplest alkyne.

12.43 Describe the physical and chemical properties of alkynes.

12.44 Write the structural formulas and IUPAC names for all the isomeric alkynes with the formula C_5H_8.

Aromatic Compounds and the Benzene Structure (Section 12.6)

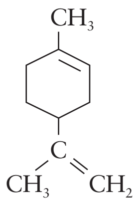
12.45 What type of hybridized orbital is present on the carbon atoms of a benzene ring? How many sigma bonds are formed by each carbon atom in a benzene ring?

12.46 What type of orbital overlaps to form the pi bonding in a benzene ring?

12.47 What does the circle within the hexagon represent in the structural formula for benzene?

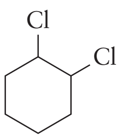
12.48 Define the terms *aromatic* and *aliphatic*.

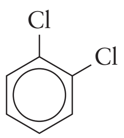
12.49 Limonene, which is present in citrus peelings, has a very pleasant lemonlike fragrance. However, it is not classified as an aromatic compound. Explain.



limonene

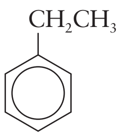
12.50 A disubstituted cycloalkane such as (a) exhibits cis-trans isomerism, whereas a disubstituted benzene (b) does not. Explain.

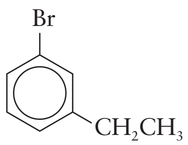
a. 

b. 

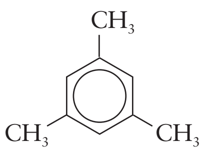
The Nomenclature of Benzene Derivatives (Section 12.7)

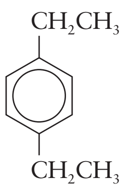
12.51 Give an IUPAC name for each of the following hydrocarbons as a derivative of benzene:

a. 

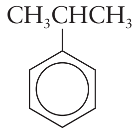
b. 

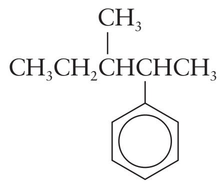
12.52 Give an IUPAC name for each of the following hydrocarbons as a derivative of benzene:

a. 

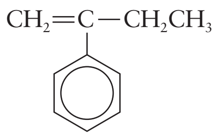
b. 

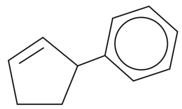
12.53 Give an IUPAC name for the following as hydrocarbons with the benzene ring as a substituent:

a. 

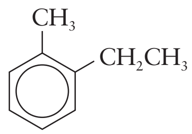
b. 

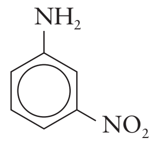
12.54 Give an IUPAC name for the following as hydrocarbons with the benzene ring as a substituent:

a. 

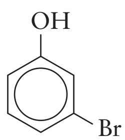
b. 

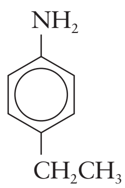
12.55 Name the following compounds, using the prefixed abbreviations for *ortho, meta,* and *para* and assigning IUPAC-acceptable common names:

a. 

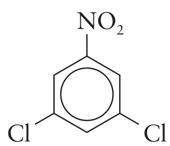
b. 

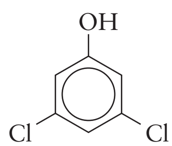
12.56 Name the following compounds, using the prefixed abbreviations for *ortho, meta,* and *para* and assigning IUPAC-acceptable common names:

a. 

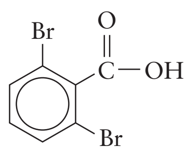
b. 

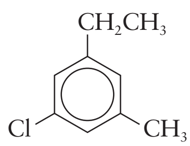
12.57 Name the following by numbering the benzene ring. IUPAC-acceptable common names may be used where appropriate:

a. 

b. 

12.58 Name the following by numbering the benzene ring. IUPAC-acceptable common names may be used where appropriate:

a. 

b. 

12.59 Draw structural formulas for the following:

a. 2,4-diethylaniline

b. 4-ethyltoluene

c. *p*-ethyltoluene

12.60 Write structural formulas for the following:

a. *p*-propylphenol

b. *o*-bromobenzoic acid

c. 3-methyl-2-phenylbutane

12.61 There are three bromonitrobenzene derivatives. Draw their structures and give an IUPAC name for each one.

Properties and Uses of Aromatic Compounds (Section 12.8)

12.62 Describe the chief physical properties of aromatic hydrocarbons.

12.63 Why does benzene not readily undergo addition reactions characteristic of other unsaturated compounds?

12.64 Compare the chemical behavior of benzene and cyclohexene.

12.65 For each of the following uses, list an appropriate aromatic compound:

a. A solvent

b. A vitamin

c. An essential amino acid

d. Starting material for dyes

12.66 For each of the following uses, list an appropriate aromatic compound:

a. Used in the production of Formica

b. A starting material for polystyrene

c. Used to manufacture drugs

d. A starting material for Bakelite

Additional Exercises

12.67 In general, alkynes have slightly higher boiling points and densities than structurally equivalent alkanes. What interparticle force would this be attributable to?

12.68 In Reaction 12.14, heat, pressure, and catalysts are needed to convert ethylene gas to polyethylene. Explain the effects of each of the three conditions (heat, pressure, catalysts) in terms of factors that affect reaction rates.

12.69 Propene reacts with a diatomic molecule whose atoms have the electronic configuration of $1s^22s^22p^63s^23p^5$. Draw the structure of the product formed and give its IUPAC name.

12.70 Draw a generalized energy diagram for the following reaction. Is the reaction endothermic or exothermic?

$$\text{alkene} + \text{water} \xrightarrow{H_2SO_4} \text{alcohol} + 10\ \text{kcal/mol}$$

12.71 What will be the limiting reactant when 25.0 g of 2-butene reacts with 25.0 g of iodine to produce 2,3-diiodobutane? How many moles of product could be produced?

$$CH_3CH{=}CHCH_3 + I_2 \longrightarrow CH_3\overset{\overset{I}{|}}{C}H\overset{\overset{I}{|}}{C}HCH_3$$

Allied Health Exam Connection

The following questions are from these sources:

1. *Nursing School Entrance Exam* © 2005, Learning Express, LLC.

2. *McGraw-Hill's Nursing School Entrance Exams* by Thomas A. Evangelist, Tamara B. Orr and Judy Unrein © 2009, The McGraw-Hill Companies, Inc.

3. *NSEE Nursing School Entrance Exams,* 3rd Edition © 2009, Kaplan Publishing.

4. *Cliffs Test Prep: Nursing School Entrance Exams* by Fred N. Grayson © 2004, Wiley Publishing, Inc.

5. *Peterson's Master the Nursing School and Allied Health Entrance Exams,* 18th Edition by Marion F. Gooding © 2008, Peterson's, a Nelnet Company.

12.72 Which of the following are aromatic compounds?

a. benzene

b. ethyl alcohol

c. methane

d. phenol

12.73 Identify which of the following general formulas would be used to characterize (1) an alkane, (2) an alkene with one C=C bond, and (3) an alkyne with one C≡C bond.

a. C_nH_{2n}

b. C_nH_{2n+2}

c. C_nH_{2n-2}

12.74. The compound $CH_2{=}CH{-}CH_2{-}CH_2{-}CH_3$ is an example of:

a. a pentane

b. a hexene

c. an alkene

d. organic macromolecule

12.75 The correct structural formula for ethyne is:

a. H—C=C—H

b. H—C=C=H

c. H—C≡C—H

d. H=C=C=H

12.76 Protection of the skin from the harmful effects of ultraviolet light is provided by the pigment __________, which is produced by specialized cells within the stratum germinativum.

a. carotene

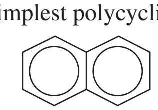
b. melanin

c. keratin

d. hemoglobin

Chemistry for Thought

12.77 Napthalene is the simplest polycyclic aromatic compound:



Draw a Kekulé structure for this compound like that shown for benzene in Section 12.6.

12.78 Why does propene not exhibit geometric isomerism?

12.79 Limonene is present in the rind of lemons and oranges. Based on its structure (see Exercise 12.49), would you consider it to be a solid, liquid, or gas at room temperature?

12.80 If the average molecular weight of polyethylene is 5.0×10^4 u, how many ethylene monomers ($CH_2{=}CH_2$) are contained in a molecule of the polymer?

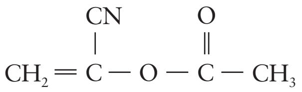
12.81 Reactions to synthesize the benzene ring of aromatic compounds do not occur within the human body, and yet many essential body components involve the benzene structure. How does the human body get its supply of aromatic compounds?

12.82 Answer the question in the caption to Figure 12.8 pertaining to addition polymers.

12.83 Why can't alkanes undergo addition polymerization?

12.84 Some polymers produce toxic fumes when they are burning. Which polymer in Table 12.3 produces hydrogen cyanide, HCN? Which produces hydrogen chloride, HCl?

12.85 "Super glue" is an addition polymer of the following monomer. Draw a structural formula for a three-unit section of super glue.



12.86 One of the fragrant components in mint plants is menthene, a compound whose IUPAC name is 1-isopropyl-4-methylcyclohexene. Draw a structural formula for menthene.

The International System of Measurements

APPENDIX A

The International System of Units (SI units) was established in 1960 by the International Bureau of Weights and Measures. The system was established in an attempt to streamline the metric system, which included certain traditional units that had historical origins but that were not logically related to other metric units. The International System established fundamental units to represent seven basic physical quantities. These quantities and the fundamental units used to express them are given in Table A.1.

Table A.1 Fundamental SI Units

Physical Quantity	SI Unit	Abbreviation
Length	meter	m
Mass	kilogram	kg
Temperature	kelvin	K
Amount of substance	mole	mol
Electrical current	ampere	A
Time	second	s
Luminous intensity	candela	cd

All other SI units are derived from the seven fundamental units. Prefixes are used to indicate multiples or fractions of the fundamental units (Table 1.2). In some cases, it has been found convenient to give derived units specific names. For example, the derived unit for force is kg m/s^2, which has been given the name newton (abbreviated N) in honor of Sir Isaac Newton (1642–1726). Some examples of derived units are given in Table A.2.

Table A.2 Examples of Derived SI Units

Physical Quantity	Definition in Fundamental Units	Specific Name	Abbreviation
Volume	m^3 (see NOTE below)	—	—
Force	kg m/s^2	newton	N
Energy	kg m^2/s^3 = N m	joule	J
Power	kg m^2/s^3 = J/s	watt	W
Pressure	kg/m s^2 = N/m^2	pascal	Pa
Electrical charge	A s	coulomb	C
Electrical potential	kg m^2/A s^3 = W/A	volt	V
Electrical resistance	kg m^2/A^2 s^3 = V/A	Ohm	Ω
Frequency	1/s	hertz	Hz

NOTE: The liter (L), a popular volume unit of the metric system, has been redefined in terms of SI units as 1 dm^3 or 1/1000 m^3. It and its fractions (mL, μL, etc.) are still widely used to express volume.

Answers to Even-Numbered End-of-Chapter Exercises

APPENDIX B

CHAPTER 1

1.2 Mass is a measurement of the amount of matter in an object. Weight is a measurement of the gravitational force acting on an object.

1.4 **a.** The distance the ball could be thrown on the moon would be greater. Although the throwing force would be the same, the smaller gravitational force pulling the ball downward would allow the ball to travel farther before hitting the surface of the moon.

b. The rolling distance would be the same in both locations because gravity does not influence rolling motion on a smooth surface.

1.6 The gravitational force is greater the closer an object is to the center of Earth. Thus, a person would weigh more at the poles (closer to the center) and less at the equator.

1.8 **a.** Physical: Both pieces of the stick are still made of the same substance.

b. Chemical: The smoke is a new substance.

c. Physical: Each smaller piece is still the substance salt.

d. Chemical: The change in color indicates a change in the substances present.

1.10 **a.** Physical: The state of a substance (solid, liquid, or gas) can be changed without changing the identity of the substance.

b. Chemical: The word *reacts* indicates a chemical change.

c. Physical: Freezing is a physical change, so the temperature at which it occurs is a physical property.

d. Chemical: Because rusting is a chemical change (rust is a different substance from the metal), the ability to rust or not to rust is a chemical property.

e. Physical: Color is a physical property because it can be observed without trying to change the substance into another substance.

1.12 **a.** Yes: The change in melting point indicates a different substance has been formed. Also, the evolved gas is a different substance.

b. No: It must be different because its melting point is different from that of succinic acid.

c. The succinic acid molecules must be larger because the atoms of the succinic acid were divided between the molecules of the new solid and the molecules of the evolved gas.

d. Heteroatomic: Because the succinic acid changed into two different substances, molecules of succinic acid must contain at least two different kinds of atoms.

1.14 Heteroatomic: Because only a single substance is formed, its molecules must contain at least one atom from each of the two reacting substances.

1.16 Heteroatomic: The molecules of the products hydrogen and oxygen contain hydrogen atoms and oxygen atoms, respectively. The two different kinds of atoms must have come from the water.

1.18 **a.** A is a compound because compounds are made up of heteroatomic molecules.

b. D is an element because elements are made up of homoatomic molecules.

c. E is a compound because it can be changed into the simpler substances G and J. The simpler substances G and J cannot be classified without conducting further tests on them to see if they can be changed into still other simpler substances.

1.20 **a.** R cannot be classified as an element or a compound. Even though none of the tests changed it into a simpler substance, all possible tests were not done on it, and some test might exist that would change it.

b. T can be classified as a compound because it was changed into simpler substances.

c. The remaining solid cannot be classified because no tests were done to see if it could be changed into simpler substances.

1.22 **a.** homogeneous

b. homogeneous

c. heterogeneous

d. heterogeneous

e. homogeneous

f. heterogeneous

g. homogeneous

1.24 **a.** pure substance

b. solution

e. solution

g. solution

1.26 In a modern society, quantities must be expressed with precision. Goods, services, time, and so on must be clearly expressed as quantities in order for trade, purchases, salaries, and the like to be carried out or determined.

1.28 The stone would be useful for expressing relatively large quantities such as the weights of people, cows, or bags of grain. It is likely that originally "one stone" was equal to the weight of some field stone that had been accepted as a standard.

1.30 **a.** metric

b. metric

c. nonmetric

d. metric

e. nonmetric

f. metric

1.32 **c.** meters
e. liters

1.34 **a.** 1 million microliters
b. 75 thousand watts
c. 15 million hertz
d. 200×10^{-12} meters

1.36 0.240 L, 240 cm^3

1.38 8.8 lb

1.40 **a.** About 3 in.
b. 65 K
c. About 2 kg

1.42 **a.** 0.001 kg, or 1 g
b. About 68 fl oz
c. 333 mg, or about 300 mg

1.44 97.0°F in the morning and 99.0°F at bedtime

1.46 **a.** Incorrect: No zero should precede the first number in the nonexponential number. 2.7×10^{-3} is correct.
b. Correct
c. Incorrect: The decimal is not in the standard position in the nonexponential number. 7.19×10^{-5} is correct.
d. Incorrect: No nonexponential number is given. 1×10^3 is correct.
e. Incorrect: The decimal is not in the standard position in the nonexponential number. 4.05×10^{-4} is correct.
f. Incorrect: No exponent is used, and the decimal is not in the standard position in the nonexponential number. 1.19×10^{-1} is correct.

1.48 **a.** 1.4×10^4
b. 3.65×10^2
c. 2.04×10^{-3}
d. 4.618×10^2
e. 1.00×10^{-3}
f. 9.11×10^2

1.50 1.86×10^5 mi/s; 1.100×10^9 km/h

1.52 0.000 000 000 000 000 000 000 105

1.54 **a.** 9.0×10^{-5}
b. 1.4×10^7
c. 7.6×10^{-2}
d. 1.9×10^1
e. 2.6×10^{12}

1.56 **a.** $(1.44 \times 10^2)(8.76 \times 10^{-2}) = 1.26 \times 10^1$
b. $(7.51 \times 10^2)(1.06 \times 10^2) = 7.96 \times 10^4$
c. $(4.22 \times 10^{-2})(1.19 \times 10^{-3}) = 5.02 \times 10^{-5}$
d. $(1.28000 \times 10^5)(3.16 \times 10^{-5}) = 4.04 \times 10^0$

1.58 **a.** 2.6×10^{-5}
b. 2.2×10^2
c. 6.4×10^{-4}
d. 7.25×10^{-4}
e. 3.1×10^{-2}

1.60 **a.** 1.7×10^{-1}
b. 1.0×10^{-9}
c. 2.6×10^6
d. 2.3×10^0
e. 1.5×10^7

1.62 **a.** 0.01 cm
b. 0.01 mm
c. 0.1°
d. 0.1 lb/in.^{2}

1.64 **a.** 6.00 mL
b. 37.0°C
c. 9.00 s
d. 15.5°

1.66 **a.** Measured: 5.06 lb; exact: 16 potatoes; 0.316 lb/potato
b. Measured: the individual percentages; exact: the 5 players; 71.34%/player. Note that the sum of the five percentages has four significant figures, so the calculated average must have four.

1.68 **a.** 3
b. 3
c. 4
d. 2
e. 4
f. 5

1.70 **a.** 5.2
b. 0.104
c. 0.518
d. 1.0×10^2
e. 2.52×10^{-18}

1.72 **a.** 6.2
b. 230
c. 0.589
d. 0.58
e. 27.75
f. 21.64

1.74 **a.** 4.48×10^{-3}
b. 2.208
c. 2.65
d. −13
e. 3
f. 0.81

1.76 **a.** Black rectangle: Area = 124.8 cm^2; perimeter = 44.80 cm

Red rectangle: Area = 48.9 cm^2; perimeter = 45.24 cm

Green rectangle: Area = 8.11 cm^2; perimeter = 11.46 cm

Orange rectangle: Area = 9.0 cm^2; perimeter = 27.80 cm

b. Black rectangle: Area = 0.01248 m^2; perimeter = 0.4480 m

Red rectangle: Area = 0.00489 m^2; perimeter = 0.4524 m

Green rectangle: Area = 0.000811 m^2; perimeter = 0.1146 m

Orange rectangle: Area = 0.00090 m^2; perimeter = 0.2780 m

c. No

1.78 **a.** $\frac{0.015 \text{ grain}}{1 \text{ mg}}$

b. $\frac{0.0338 \text{ fl oz}}{1 \text{ mL}}$

c. $\frac{1 \text{ L}}{1.057 \text{ qt}}$

d. $\frac{1 \text{ m}}{1.094 \text{ yd}}$

1.80 The factor is $\frac{1 \text{ km}}{0.621 \text{ mi}}$. The race is about 42 km long.

1.82 1.06 cups or 1 cup

1.84 39.6 lb; your baggage is not overweight.

1.86 1.31 g/L

1.88 7.701%

1.90 71%

1.92 IgG = 75.09%; IgA = 16.23%; IgM = 7.58%; IgD = 1.10%; IgE = 0.008%

1.94 **a.** 0.792 g/mL

b. 1.03 g/mL

c. 1.98 g/L

d. 8.90 g/cm^3

1.96 Volume = 63.0 cm^3; density = 11.4 g/cm^3

1.98 380 mL

1.100 **a.** 4.5×10^6 mm

b. 6.0×10^3 g

c. 9.86×10^{12} km

d. 1.91×10^2 mg

e. 5.0×10^{-6} mg

1.102 54 days

1.104 955 mg

1.106 b

1.108 b

1.110 d

1.112 d

1.114 b

1.116 d

1.118 c

1.120 b

1.122 d

1.124 c

1.126 d

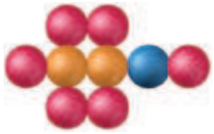
CHAPTER 2

2.2 **a.**

b.

c.

d.



2.4 **a.** H_2O

b. H_2O_2

c. H_2SO_4

d. C_2H_6O

2.6 **a.** One sulfur (S), two oxygen (O)

b. Four carbon (C), ten hydrogen (H)

c. One hydrogen (H), one chlorine (Cl), two oxygen (O)

d. One boron (B), three fluorine (F)

2.8 **a.** The two hydrogen atoms should be denoted by a subscript: H_2S

b. The letter L of chlorine should be lowercase: $HClO_2$

c. The coefficient 2 should not be used to indicate the number of atoms in the molecule. Subscripts should be used instead: H_2N_4

d. The numbers in the formula should be written as subscripts: C_2H_6

2.10 **a.** Charge = 5+; mass = 11 u

b. Charge = 11+; mass = 21 u

c. Charge = 36+; mass = 86 u

d. Charge = 50+; mass = 118 u

2.12 **a.** 5

b. 11

c. 36

d. 50

2.14 **a.** 14 electrons, 14 protons

b. 50 electrons, 50 protons

c. 74 electrons, 74 protons

2.16 **a.** 12 protons, 13 neutrons, 12 electrons

b. 28 protons, 30 neutrons, 28 electrons

c. 48 protons, 71 neutrons, 48 electrons

2.18 **a.** $^{28}_{14}Si$

b. $^{40}_{18}Ar$

c. $^{88}_{38}Sr$

2.20 **a.** Atomic number = 5; mass number = 11; $^{11}_{5}B$

b. Atomic number = 11; mass number = 21; $^{21}_{11}Na$

c. Atomic number = 36; mass number = 86; $^{86}_{36}Kr$

d. Atomic number = 50; mass number = 118; $^{118}_{50}Sn$

2.22 **a.** $^{37}_{17}Cl$

b. $^{65}_{29}Cu$

c. $^{66}_{30}Zn$

2.24 Atomic weights rounded to nearest whole number give He = 4.0 u and C = 12 u. Three He total 12 u, which will balance one C, which also totals 12 u.

2.26 Ca, calcium

2.28 N, nitrogen

2.30 **a.** 46.01 u

b. 17.03 u

c. 180.16 u

d. 48.00 u

e. 62.07 u

2.32 Ethylene, C_2H_4

2.34 $y = 3$

2.36 **a.** 14 neutrons

b. 27.0 u

2.38 Calculated value = 69.72 u

Periodic table value = 69.72 u

2.40 Calculated value = 63.55 u

Periodic table value = 63.55 u

2.42 1.90 g F

2.44 **a.** 1 mol P atoms = 6.02×10^{23} P atoms

6.02×10^{23} P atoms = 30.97 g P

1 mol P atoms = 30.97 g P

b. 1 mol Al atoms = 6.02×10^{23} Al atoms

6.02×10^{23} Al atoms = 26.98 g Al

1 mol Al atoms = 26.98 g Al

c. 1 mol Kr atoms = 6.02×10^{23} Kr atoms

6.02×10^{23} Kr atoms = 83.80 g Kr

1 mol Kr atoms = 83.80 g Kr

2.46 **a.** 5.14×10^{-23} g P

b. 44.52 g Al

c. 20.95 g Kr

2.48 Molecular weight BF_3 = 67.8 u

Molecular weight H_2S = 34.1 u

0.68 g BF_3

2.50 **a.** 1. 2 $C_4H_{10}O$ molecules contain 8 C atoms, 20 H atoms, and 2 O atoms.

2. 10 $C_4H_{10}O$ molecules contain 40 C atoms, 100 H atoms, and 10 O atoms.

3. 100 $C_4H_{10}O$ molecules contain 400 C atoms, 1000 H atoms, and 100 O atoms.

4. 6.02×10^{23} $C_4H_{10}O$ molecules contain 24.08×10^{23} C atoms, 60.2×10^{23} H atoms, and 6.02×10^{23} O atoms.

5. 1 mol of $C_4H_{10}O$ molecules contains 4 mol of C atoms, 10 mol of H atoms, and 1 mol of O atoms.

6. 74.12 g $C_4H_{10}O$ contain 48.04 g of C, 10.08 g of H, and 16.00 g of O.

b. 1. 2 $C_2H_3O_2F$ molecules contain 4 C atoms, 6 H atoms, 4 O atoms, and 2 F atoms.

2. 10 $C_2H_3O_2F$ molecules contain 20 C atoms, 30 H atoms, 20 O atoms, and 10 F atoms.

3. 100 $C_2H_3O_2F$ molecules contain 200 C atoms, 300 H atoms, 200 O atoms, and 100 F atoms.

4. 6.02×10^{23} $C_2H_3O_2F$ molecules contain 12.04×10^{23} C atoms, 18.06×10^{23} H atoms, 12.04×10^{23} O atoms, and 6.02×10^{23} F atoms.

5. 1 mol of $C_2H_3O_2F$ molecules contains 2 mol of C atoms, 3 mol of H atoms, 2 mol of O atoms, and 1 mol of F atoms.

6. 78.04 g of $C_2H_3O_2F$ contain 24.02 g of C, 3.02 g of H, 32.00 g of O, and 19.00 g of F.

c. 1. 2 C_6H_7N molecules contain 12 C atoms, 14 H atoms, and 2 N atoms.

2. 10 C_6H_7N molecules contain 60 C atoms, 70 H atoms, and 10 N atoms.

3. 100 C_6H_7N molecules contain 600 C atoms, 700 H atoms, and 100 N atoms.

4. 6.02×10^{23} C_6H_7N molecules contain 36.12×10^{23} C atoms, 42.14×10^{23} H atoms, and 6.02×10^{23} N atoms.

5. 1 mol of C_6H_7N molecules contains 6 mol of C atoms, 7 mol of H atoms, and 1 mol of N atoms.

6. 93.13 g of C_6H_7N contain 72.06 g of C, 7.06 g of H, and 14.01 g of N.

2.52 **a.** 5.0 mol H atoms

b. 3.01×10^{23} C atoms

c. 14.1 g H

2.54 34.6 g C_2H_6O

2.56 In CO, mass % O = 57.12%.

In CO_2, mass % O = 72.71%.

2.58 Statements 4–6 are:

4. 6.02×10^{23} $C_6H_{12}O_6$ molecules contain 36.1×10^{23} C atoms, 72.2×10^{23} H atoms, and 36.1×10^{23} O atoms.

5. 1 mol of $C_6H_{12}O_6$ molecules contains 6 mol of C atoms, 12 mol of H atoms, and 6 mol of O atoms.

6. 180.16 g of $C_6H_{12}O_6$ contain 72.06 g of C, 12.10 g of H, and 96.00 g of O.

a. 23.18 g of O

b. 18.0 mol of H atoms

c. 4.50×10^{23} C atoms

2.60 Magnetite = 72.36% Fe; hematite = 69.94% Fe. Magnetite has the higher % Fe by mass.

2.62 U-238 would have a greater density because each U-238 nucleus would contain 3 more neutrons than a U-235 nucleus and thus have a greater mass. However, the size (volume) of each atom (measured from the nucleus to the outer electrons) would be the same, so one cm^3 of each isotope would contain the same number of atoms.

2.64 2.32×10^{-23} g

2.66 The density would increase tremendously because many more of the smaller atoms (measured from the nucleus to the outer electrons) would fit into a cm^3. Each of the smaller atoms would have the same mass as the larger atoms, so the density (mass/volume) would be much greater.

2.68 b

2.70 a

2.72 b

2.74 b

2.76 a

2.78 d

2.80 b

2.82 c

2.84 a

2.86 b

CHAPTER 3

3.2 **a.** Group VIIIB (9), period 4

b. Group IVA (14), period 6

c. Group VA (15), period 4

d. Group IIA (2), period 6

3.4 **a.** Kr, krypton

b. Sn, tin

c. Mo, molybdenum

d. Nd, neodymium

3.6 **a.** 5

b. 16

c. 32

3.8 **a.** period

b. period

c. group

d. group

3.10 protons

3.12 **a.** 2

b. 6

c. 8

3.14 Sixteen orbitals; one 4*s*, three 4*p*, five 4*d*, and seven 4*f* orbitals.

3.16 Seven orbitals in the subshell can contain a maximum of 14 electrons.

3.18 **a.** 8

b. 5

c. 4

d. 4

3.20 Cesium, Cs, has chemical properties most like sodium, Na. Both elements have one valence-shell electron.

3.22 An ore deposit that contained copper might also be expected to contain gold and silver because all three elements belong to group IB (11) of the periodic table and thus have similar chemical properties.

3.24 **a.** $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^1$; one electron is unpaired.

b. $1s^22s^22p^63s^23p^2$; two electrons are unpaired.

c. $1s^22s^22p^63s^23p^64s^23d^2$; two electrons are unpaired.

d. $1s^22s^22p^63s^23p^6$; no electrons are unpaired.

3.26 **a.** $1s^22s^22p^63s^2$; six *s* electrons.

b. $1s^22s^22p^3$; three unpaired electrons.

c. $1s^22s^22p^63s^23p^1$; four subshells are filled.

3.28 **a.** C, carbon

b. Na, sodium

c. Si, silicon, and S, sulfur

d. Nb, niobium

e. V, vanadium, and Co, cobalt

3.30 **a.** $[Ar]4s^23d^{10}4p^4$

b. $[Ar]4s^23d^3$

c. $[Ar]4s^2$

d. $[He]2s^22p^2$

3.32 Na: $[Ne]3s^1$

Mg: $[Ne]3s^2$

Al: $[Ne]3s^23p^1$

Si: $[Ne]3s^23p^2$

P: $[Ne]3s^23p^3$

S: $[Ne]3s^23p^4$

Cl: $[Ne]3s^23p^5$

Ar: $[Ne]3s^23p^6$

3.34 **a.** *d* area

b. *s* area

c. *p* area

d. *f* area

3.36 **a.** transition
b. representative
c. inner-transition
d. noble gas
e. representative

3.38 **a.** metalloid
b. nonmetal
c. metal
d. nonmetal
e. metal

3.40 **a.** Na
b. Pb
c. Ba
d. Cs

3.42 **a.** Ga
b. Sb
c. C
d. Te

3.44 **a.** K
b. Sn
c. Mg
d. Li

3.46 The chemical properties would be the same because chemical properties depend on the number of valence electrons in the atom. The number of valence electrons in isotopes of the same element is identical.

3.48 8.0 mg

3.50 The element has an atomic weight of 40.0, and so is calcium (Ca). It is a representative element and will conduct electricity because it is a metal.

3.52 a

3.54 d

3.56 a

3.58 b

3.60 b

3.62 b

3.64 d

3.66 d

3.68 a

3.70 b

CHAPTER 4

4.2 **a.** $\cdot\underset{\cdot}{\overset{\cdot\cdot}{\mathrm{As}}}\cdot$
b. $\cdot\underset{\cdot}{\overset{\cdot}{\mathrm{Si}}}\cdot$
c. $\cdot\underset{\cdot}{\overset{\cdot}{\mathrm{Pb}}}\cdot$
d. $\overset{\cdot}{\mathrm{Ba}}\cdot$

4.4 **a.** $[\mathrm{Kr}]5s^2 4d^{10} 5p^2$
b. $[\mathrm{Ar}]4s^2 3d^{10} 4p^4$
c. $[\mathrm{Xe}]6s^1$
d. $[\mathrm{Kr}]5s^2 4d^{10} 5p^5$

4.6 **a.** $\cdot\underset{\cdot}{\overset{\cdot}{\mathrm{Sn}}}\cdot$
b. $\mathrm{Cs}\cdot$
c. $\underset{\cdot}{\overset{\cdot}{\mathrm{In}}}\cdot$
d. $\overset{\cdot}{\mathrm{Sr}}\cdot$

4.8 **a.** $\cdot\overset{\cdot}{\mathrm{E}}\cdot$
b. $\cdot\underset{\cdot}{\overset{\cdot\cdot}{\mathrm{E}}}:$

4.10 **a.** Add 4 or lose 14
b. Add 2 or lose 16
c. Add 31 or lose 1
d. Add 1 or lose 17

4.12 **a.** Lose 1: $Cs \rightarrow Cs^+ + e^-$
b. Add 2: $O + 2e^- \rightarrow O^{2-}$
c. Add 3: $N + 3e^- \rightarrow N^{3-}$
d. Add 1: $I + e^- \rightarrow I^-$

4.14 **a.** Se^{2-}
b. Rb^+
c. Al^{3+}

4.16 **a.** sulfur, S
b. aluminum, Al
c. sodium, Na
d. chlorine, Cl

4.18 **a.** helium, He
b. xenon, Xe
c. argon, Ar
d. krypton, Kr

4.20 **a.** $Ba \rightarrow Ba^{2+} + 2e^-$; $F + e^- \rightarrow F^-$
Formula is BaF_2
b. $K \rightarrow K^+ + e^-$; $Br + e^- \rightarrow Br^-$
Formula is KBr
c. $Al \rightarrow Al^{3+} + 3e^-$; $Br + e^- \rightarrow Br^-$
Formula is $AlBr_3$

4.22 **a.** BaTe
b. Ba_3N_2
c. BaF_2
d. Ba_3P_2

4.24 **a.** binary
b. binary
c. not binary
d. binary
e. not binary

4.26 **a.** lithium ion
b. magnesium ion
c. barium ion
d. cesium ion

4.28 **a.** bromide ion
b. oxide ion
c. phosphide ion
d. telluride ion

4.30 **a.** magnesium oxide
b. calcium sulfide
c. zinc oxide
d. aluminum chloride
e. sodium nitride

4.32 **a.** tin (II) sulfide and tin (IV) sulfide
b. iron (II) chloride and iron (III) chloride
c. copper (I) oxide and copper (II) oxide
d. gold (I) chloride and gold (III) chloride

4.34 **a.** stannous sulfide and stannic sulfide
b. ferrous chloride and ferric chloride
c. cuprous oxide and cupric oxide
d. aurus chloride and auric chloride

4.36 **a.** Hg_2O
b. PbO
c. PtI_4
d. Cu_3N
e. CoS

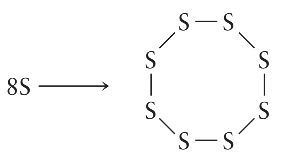
4.38 **a.** 58.10 u
b. 55.06 u
c. 51.79 u
d. 143.10 u

4.40 **a.** Na^+ and Br^-
b. Ca^{2+} and F^-
c. Cu^+ and S^{2-}
d. Li^+ and N^{3-}

4.42 **a.** 22.99 g of Na^+ and 79.90 g of Br^-
b. 40.08 g of Ca^{2+} and 38.00 g of F^-
c. 127.10 g of Cu^+ and 32.06 g of S^{2-}
d. 20.82 g of Li^+ and 14.01 g of N^{3-}

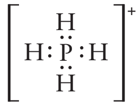
4.44 **a.** 6.02×10^{23} Na^+ ions and 6.02×10^{23} Br^- ions
b. 6.02×10^{23} Ca^{2+} ions and 12.04×10^{23} F^- ions
c. 12.04×10^{23} Cu^+ ions and 6.02×10^{23} S^{2-} ions
d. 18.06×10^{23} Li^+ ions and 6.02×10^{23} N^{3-} ions

4.46

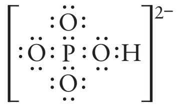


4.48 **a.** H:S̤̈:H or H—S—H
b. :C̤̈l:F̤̈: or Cl—F
c. H:B̤̈r: or H—Br
d. :C̤̈l:Ö̤:H or Cl—O—H

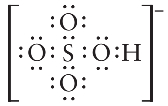
4.50 **a.**

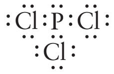
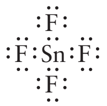


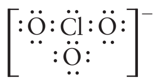
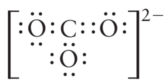
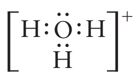
b.

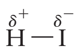
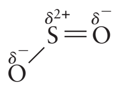
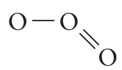


c.



4.52 **a.** H:S̤̈:H — Bent
b.  Triangular pyramid with P at the top
c. :F̤̈:Ö̤:F̤̈: — Bent
d.  Tetrahedral with Sn in center

4.54 **a.**  Bent
b.  Triangular pyramid with Cl at the top
c.  Flat triangle with C in the center
d.  Triangular pyramid with O at the top

4.56 **a.** 
b. 
c. Nonpolarized 

4.58 **a.** Polar covalent
b. Polar covalent
c. Polar covalent
d. Ionic
e. Polar covalent

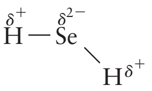
4.60 **a.** Polar
b. Polar
c. Nonpolar

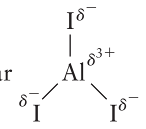
4.62 **a.** Polar covalent

b. Ionic

c. Polar covalent

4.64 **a.** Polar $\overset{\delta+}{C}\equiv\overset{\delta-}{O}$

b. Polar 

c. Nonpolar 

4.66 **a.** nitrogen trichloride

b. tetraphosphorus hexoxide

c. bromine monochloride

d. sulfur tetrafluoride

e. chlorine dioxide

4.68 **a.** SeF_4

b. OF_2

c. N_2O

d. PCl_3

4.70 **a.** $Ca(ClO)_2$, calcium hypochlorite

b. $CsNO_2$, cesium nitrite

c. $MgSO_3$, magnesium sulfite

d. $K_2Cr_2O_7$, potassium dichromate

4.72 **a.** $Mg(OH)_2$

b. $CaSO_3$

c. $(NH_4)_3PO_4$

d. $NaHCO_3$

e. $BaSO_4$

4.74 **a.** M_2SO_3

b. $MC_2H_3O_2$

c. MCr_2O_7

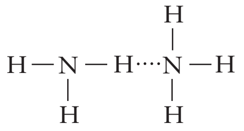
d. MPO_4

e. $M(NO_3)_3$

4.76 The stronger the attractive forces between molecules, the higher the melting and boiling points. Thus, we can conclude that the forces attracting dimethyl ether molecules to one another are weaker than the forces attracting ethyl alcohol molecules to one another. Because both compounds are covalently bonded, it is likely that the attractive forces are polar forces, and we might conclude that ethyl alcohol is more polar than dimethyl ether.

4.78 The predominant forces that exist between molecules of noble gases are dispersion forces because noble gas molecules are nonpolar. Dispersion forces increase with increasing mass of the particles involved, so the boiling points of the noble gases would increase in the order of He, Ne, Ar, Kr, Xe, and Rn.

4.80 The relatively high melting point indicates that it is unlikely that weak dispersion forces are the predominant forces present. Dipolar forces are also quite weak and therefore are also unlikely to be the forces present.

4.82 NH_3 

4.84 8.06 g

4.86 N_2O, covalent, dinitrogen monoxide

4.88 a

4.90 a

4.92 c

4.94 b

4.96 b

4.98 c

4.100 c

4.102 a

4.104 a

4.106 b

CHAPTER 5

5.2

	Reactants	*Products*
a.	H_2, Cl_2	HCl
b.	$KClO_3$	KCl, O_2
c.	magnesium oxide, carbon	magnesium, carbon monoxide
d.	ethane, oxygen	carbon dioxide, water

5.4 **a.** Not consistent: The number of O atoms is not the same on both sides.

b. Consistent

c. Not consistent: The masses of reactants and products are not equal.

d. Consistent

5.6

	Left side	*Right side*	*Classification*
a.	4Ag, 2O	2Ag, 2O	Unbalanced
b.	1Al, 2O	2Al, 3O	Unbalanced
c.	2Ag, 2N, 2K, 1S, 10 O	2Ag, 2N, 2K, 1S, 10 O	Balanced
d.	1S, 4O	1S, 3O	Unbalanced

5.8 **a.** $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(\ell)$

b. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

c. $2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(\ell)$

d. $S(s) + O_2(g) \rightarrow SO_2(g)$

e. $Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + CaCO_3(s)$

f. $2NaBr(aq) + Cl_2(aq) \rightarrow 2NaCl(aq) + Br_2(aq)$

g. $2Ag_2CO_3(s) \rightarrow 4Ag(s) + 2CO_2(g) + O_2(g)$

h. $H_2O_2(aq) + H_2S(aq) \rightarrow 2H_2O(\ell) + S(s)$

5.10 **a.** +5

b. +6

c. +5

d. +1

e. +7

f. +3

5.12 **a.** Cr (+6)

b. S (+2)

c. N (+5)

d. P (+5)

e. Cl (+7)

f. Cl (+3)

5.14 **a.** oxidized

b. neither

c. reduced

d. oxidized

e. oxidized

5.16 **a.** $\underset{0}{2Cu(s)} + \underset{0}{O_2(g)} \rightarrow 2\underset{+2\ -2}{CuO(s)}$

Oxidizing agent: O_2

Reducing agent: Cu

b. $\underset{0}{Cl_2(g)} + 2\underset{+1\ -1}{KI(aq)} \rightarrow 2\underset{+1\ -1}{KCl(aq)} + \underset{0}{I_2(aq)}$

Oxidizing agent: Cl_2

Reducing agent: KI (I)

c. $3\underset{+4\ -2}{MnO_2(s)} + 4\underset{0}{Al(s)} \rightarrow 2\underset{+3\ -2}{Al_2O_3(s)} + 3\underset{0}{Mn(s)}$

Oxidizing agent: MnO_2 (Mn)

Reducing agent: Al

d. $2\underset{+1}{H^+(aq)} + 3\underset{+4\ -2}{SO_3^{2-}(aq)} + 2\underset{+5\ -2}{NO_3^-(aq)} \rightarrow$
$2\underset{+2\ -2}{NO(g)} + \underset{+1\ -2}{H_2O(\ell)} + 3\underset{+6\ -2}{SO_4^{2-}(aq)}$

Oxidizing agent: NO_3^- (N)

Reducing agent: SO_3^{2-} (S)

e. $\underset{0}{Mg(s)} + 2\underset{+1\ -1}{HCl(aq)} \rightarrow \underset{+2\ -1}{MgCl_2(aq)} + \underset{0}{H_2(g)}$

Oxidizing agent: HCl (H^+)

Reducing agent: Mg

f. $4\underset{+4\ -2}{NO_2(g)} + \underset{0}{O_2(g)} \rightarrow 2\underset{+5\ -2}{N_2O_5(g)}$

Oxidizing agent: O_2

Reducing agent: NO_2 (N)

5.18 Oxidizing agent: NaOH (H)

Reducing agent: Al

5.20 **a.** Nonredox, decomposition

b. Redox, single replacement

c. Nonredox, double replacement

d. Nonredox, combination

e. Redox, combination

f. Redox, combination

5.22 Nonredox, decomposition

5.24 Redox

5.26 Redox

5.28 **a.** Li^+, NO_3^-

b. Na^+, HPO_4^{2-}

c. Ca^{2+}, ClO_3^-

d. K^+, OH^-

e. Mg^{2+}, Br^-

f. NH_4^+, SO_4^{2-}

5.30 **a.** Total ionic: $Cl_2(aq) + 2Na^+(aq) + 2I^-(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + I_2(aq)$

Spectator ion: Na^+

Net ionic: $Cl_2(aq) + 2I^-(aq) \rightarrow 2Cl^-(aq) + I_2(aq)$

b. Total ionic: $Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$

Spectator ions: Na^+ and NO_3^-

Net ionic: $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

c. Total ionic: $Zn(s) + 2H^+(aq) + 2Cl^-(aq) \rightarrow Zn^{2+}(aq) + 2Cl^-(aq) + H_2(g)$

Spectator ion: Cl^-

Net ionic: $Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$

d. Total ionic: $Ba^{2+}(aq) + 2Cl^-(aq) + 2H^+(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + 2H^+(aq) + 2Cl^-(aq)$

Spectator ions: H^+ and Cl^-

Net ionic: $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

e. Total ionic: $SO_3(aq) + H_2O(\ell) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$

Spectator ions: none

Net ionic: $SO_3(aq) + H_2O(\ell) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$

f. Total ionic: $2Na^+(aq) + 2I^-(aq) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow I_2(aq) + SO_2(aq) + 2Na^+(aq) + SO_4^{2-}(aq) + 2H_2O(\ell)$

Spectator ions: Na^+ and one SO_4^{2-} from right side

Net ionic: $2I^-(aq) + 4H^+(aq) + SO_4^{2-}(aq) \rightarrow I_2(aq) + SO_2(aq) + 2H_2O(\ell)$

5.32 **a.** $H^+(aq) + NO_3^-(aq) + K^+(aq) + OH^-(aq) \rightarrow K^+(aq) + NO_3^-(aq) + H_2O(\ell)$

Spectator ions: K^+, NO_3^-

Net ionic: $H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell)$

b. $3H^+(aq) + PO_4^{3-}(aq) + 3NH_4^+(aq) + 3OH^-(aq) \rightarrow 3NH_4^+(aq) + PO_4^{3-}(aq) + 3H_2O(\ell)$

Spectator ions: NH_4^+, PO_4^{3-}

Net ionic: $3H^+(aq) + 3OH^-(aq) \rightarrow 3H_2O(\ell)$

c. $H^+(aq) + I^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow Na^+(aq) + I^-(aq) + H_2O(\ell)$

Spectator ions: Na^+, I^-

Net ionic: $H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell)$

In every net ionic reaction, H^+ reacts with OH^- to form H_2O

5.34 Exothermic: Heat is a product of the reaction.

5.36 The insulation around the ice slows its rate of melting by preventing it from absorbing heat. However, this prevents the ice from performing its cooling function in the cooler. For the cooler to work properly, heat must move from the warmer food to the cooler ice, where it is absorbed as the ice melts.

5.38 **a.** $Ca(s) + 2H_2O(\ell) \rightarrow H_2(g) + Ca(OH)_2(s)$

2. 1 mol Ca + 2 mol $H_2O \rightarrow$ 1 mol H_2 + 1 mol $Ca(OH)_2$
3. 6.02×10^{23} Ca atoms + $2(6.02 \times 10^{23})$ H_2O molecules $\rightarrow 6.02 \times 10^{23}$ H_2 molecules + 6.02×10^{23} $Ca(OH)_2$ molecules (or formula units)
4. 40.1 g Ca + 36.0 g $H_2O \rightarrow$ 2.02 g H_2 + 74.1 g $Ca(OH)_2$

b. $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

2. 2 mol NO + 1 mol $O_2 \rightarrow$ 2 mol NO_2
3. $2(6.02 \times 10^{23})$NO molecules + 6.02×10^{23} O_2 molecules $\rightarrow 2(6.02 \times 10^{23})$ NO_2 molecules
4. 60.0 g NO + 32.0 g $O_2 \rightarrow$ 92.0 g NO_2

c. $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(\ell)$

2. 2 mol C_2H_6 + 7 mol $O_2 \rightarrow$ 4 mol CO_2 + 6 mol H_2O
3. $2(6.02 \times 10^{23})$ C_2H_6 molecules + $7(6.02 \times 10^{23})$ O_2 molecules $\rightarrow 4(6.02 \times 10^{23})$ CO_2 molecules + $6(6.02 \times 10^{23})$ H_2O molecules
4. 60.1 g C_2H_6 + 224 g $O_2 \rightarrow$ 176 g CO_2 + 108 g H_2O

d. $Zn(s) + 2AgNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + 2Ag(s)$

2. 1 mol Zn + 2 mol $AgNO_3 \rightarrow$ 1 mol $Zn(NO_3)_2$ + 2 mol Ag
3. 6.02×10^{23} Zn atoms + $2(6.02 \times 10^{23})$ $AgNO_3$ molecules (or formula units) $\rightarrow$ 6.02×10^{23} $Zn(NO_3)_2$ molecules (or formula units) + $2(6.02 \times 10^{23})$ Ag Atoms
4. 65.4 g Zn + 340 g $AgNO_3 \rightarrow$ 189 g $Zn(NO_3)_2$ + 216 g Ag

e. $2HCl(aq) + Mg(OH)_2(s) \rightarrow MgCl_2(aq) + 2H_2O(\ell)$

2. 2 mol HCl + 1 mol $Mg(OH)_2 \rightarrow$ 1 mol $MgCl_2$ + 2 mol H_2O
3. $2(6.02 \times 10^{23})$ HCl molecules + 6.02×10^{23} $Mg(OH)_2$ molecules (or formula units) $\rightarrow$ 6.02×10^{23} $MgCl_2$ molecules (or formula units) + $2(6.02 \times 10^{23})$ H_2O molecules
4. 72.9 g HCl + 58.3 g $Mg(OH)_2 \rightarrow$ 95.2 g $MgCl_2$ + 36.0 g H_2O

5.40 $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$

1. 2 SO_2 molecules + 1 O_2 molecule $\rightarrow$ 2 SO_3 molecules
4. 12.0×10^{23} SO_2 molecules + 6.02×10^{23} O_2 molecules $\rightarrow 12.0 \times 10^{23}$ SO_3 molecules
5. 2 mol SO_2 + 1 mol $O_2 \rightarrow$ 2 mol SO_3
6. 128 g SO_2 + 32.0 g $O_2 \rightarrow$ 160 g SO_3

Factors:

$\frac{12.0 \times 10^{23}\ SO_2\ \text{molecules}}{6.02 \times 10^{23}\ O_2\ \text{molecules}}$; $\frac{12.0 \times 10^{23}\ SO_3\ \text{molecules}}{12.0 \times 10^{23}\ SO_2\ \text{molecules}}$;

$\frac{32.0\ g\ O_2}{128\ g\ SO_2}$; $\frac{128\ g\ SO_2}{160\ g\ SO_3}$; $\frac{32.0\ g\ O_2}{160\ g\ SO_3}$; $\frac{128\ SO_2}{32.0\ g\ O_2}$;

$\frac{2\ mol\ SO_2}{1\ mol\ O_2}$; $\frac{2\ mol\ SO_3}{2\ mol\ SO_2}$; $\frac{1\ mol\ O_2}{2\ mol\ SO_3}$; $\frac{1\ mol\ O_2}{2\ mol\ SO_2}$; $\frac{2\ mol\ SO_3}{32.0\ g\ O_2}$;

$\frac{128\ g\ SO_2}{2\ mol\ SO_2}$; $\frac{2\ mol\ SO_2}{32.0\ g\ O_2}$; $\frac{2\ mol\ SO_3}{1\ mol\ O_2}$; $\frac{160\ g\ SO_3}{32.0\ g\ O_2}$; $\frac{32.0\ g\ O_2}{1\ mol\ O_2}$

This list does not include all possible factors.

5.42 892 g

5.44 445 g

5.46 495 g

5.48 1.02×10^3 g

5.50 256 g

5.52 **a.** O_2 is the limiting reactant.

b. 71.9 g NO_2

5.54 144 g

5.56 76.5%

5.58 72.5%

5.60 89.0%

5.62 $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow 2NaCl(aq) + BaSO_4(s)$

Net ionic: $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

5.64 7.502 g

5.66 c

5.68 c

5.70 b

5.72 b

5.74 c

5.76 a

5.78 b

5.80 a

5.82 d

5.84 b

5.86 c

5.88 d

CHAPTER 6

6.2 **a.** 121 mL

b. 158 mL

c. 67.9 mL

6.4 2 mL

6.6 **a.** The density will decrease because density is equal to mass/volume, and the volume of carbon dioxide will increase on heating while the mass remains unchanged.

b. 1.67 g/L

6.8 As the ball travels upward and slows, more and more of its kinetic energy is converted into potential energy. At the maximum height, when the ball stops before starting to fall, all the energy is in the form of potential energy. As the ball falls faster and faster, more and more of the potential energy is converted back into kinetic energy. If there were no energy losses from air resistance, the ball would gain back as much kinetic energy as it had when it was initially thrown.

6.10 Each type of molecule has the same kinetic energy of 3.18×10^{10} u cm^2/s^2.

6.12 **a.** Particles (molecules) in a liquid move freely and therefore assume the container shape, but the cohesive forces between the particles prevent them from separating completely from each other and filling the container.

b. There is very little space between the particles (molecules) of liquids and solids. As a result, increased pressure cannot push the particles closer together and will have little influence on their volumes.

c. Gas molecules move around essentially unrestricted, and on average, equal numbers collide with each of the walls of a container in a given amount of time. The collisions cause the pressure on the walls, so the pressure on all the walls is the same.

6.14 Heat must be added to a substance to convert it from the solid to the liquid state, and then from the liquid to the gaseous state. If the added heat causes no temperature difference between the two states, as when a solid melts to a liquid at the melting point, then the added heat increases the potential energy of the particles of the substance. Thus, at the melting point, the particles of both solid and liquid forms of a substance will have the same kinetic energy because they are at the same temperature. However, particles of the liquid will have more potential energy, corresponding to the energy that had to be added to change the solid to a liquid. Similar arguments apply for a comparison of the liquid and gaseous states of a substance.

6.16 **a.** gaseous

b. solid

c. gaseous

d. gaseous

6.18 **a.** 0.957 atm

b. 727 torr

c. 14.1 psi

d. 0.966 bar

6.20 **a.** 14.3 atm

b. 14.4 bar

c. 1.09×10^4 mmHg

d. 427 in. Hg

6.22 **a.** 337 K

b. −258.9°C

c. 4 K

6.24 Column A: $P_f = 1.50$ atm; Column B: $V_f = 4.49$ L; Column C: $T_f = 221$ K

6.26 138 mL

6.28 3.7 atm

6.30 31.6 L

6.32 691 mL

6.34 4.5 L

6.36 1.9 L

6.38 125 atm

6.40 1.4×10^4 ft^3

6.42 884 mL

6.44 3.75 g/L

6.46 **a.** 0.0130 mol

b. 7.41 atm

c. 9.91 L

6.48 5.12 atm

6.50 8.31 g

6.52 2.7 mol

6.54 46.0 g/mol

6.56 44.1 g/mol; the gas is most likely CO_2

6.58 240 torr

6.60 O_2 mass/H_2 mass = 16 according to Graham's law. From the periodic table, O_2 mass/H_2 mass = 32 u/2 u = 16. The agreement is very good.

6.62 The helium-filled balloon would appear to go flat first because helium molecules diffuse through the rubber balloon faster than do nitrogen molecules. The rates of diffusion according to Graham's law would be He rate/N_2 rate = $\sqrt{28.0 \text{ u}/4.00 \text{ u}} = 2.6$. Thus, He would be expected to escape through the balloon 2.6 times as fast as nitrogen.

6.64 **a.** exothermic

b. exothermic

c. endothermic

6.66 A change in state refers to a process in which a substance changes from one of the three states of matter—solid, liquid, or gas—to another of the three states.

6.68 Liquid methylene chloride evaporates very rapidly, and when it evaporates, it absorbs heat. Thus, the liquid acted to cool and temporarily anesthetize any tissue on which it was sprayed.

6.70 The boiling points of the two liquids are different. Thus, a measurement of the temperature of each boiling liquid would differentiate between them. The ethylene glycol would have the higher boiling point of the two.

6.72 The temperature of boiling water is influenced by the atmospheric pressure on the water. On top of Mount Everest the atmospheric pressure is quite low, so water boils at a temperature significantly lower than the normal boiling point of 100°C. The temperature of the burning campfire would not be influenced by the altitude. Thus, the potato would cook faster if it were put into the campfire.

6.74 Since sand does not sublime, heat the mixture and lead the hot iodine vapor out of the hot chamber and to a cool surface. The pure iodine vapor will condense to a solid on the cool surface, and can be scraped off and collected.

6.76 **a.** 3.6×10^2 cal

b. 7×10^3 cal

c. 2.4×10^3 cal

6.78 **a.** 4.07×10^7 cal

b. 7.07×10^7 cal

c. 5.71×10^7 cal

6.80 7.72×10^4 cal

6.82 1.78×10^{-3} g/mL

6.84 1.16 L The reaction is a combination reaction.

6.86 The air of the atmosphere contains about 21 volume percent oxygen at any altitude. However, the pressure of the atmosphere at high altitudes is less than the pressure at lower altitudes. If the air at a higher altitude is at the same temperature as at a lower altitude, and since $P = nRT/V$, the same volume (V) of a lung full of air at a higher altitude and lower pressure (P) contains fewer moles of gas (n), and so fewer moles of oxygen. So, from the point of view of the number of molecules of oxygen, the higher altitude air has less oxygen, but from a percentage point of view it still contains 21% oxygen.

6.88 a

6.90 c

6.92 a

6.94 d

6.96 a

6.98 c

6.100 a

6.102 b

6.104 a

6.106 a

6.108 d

6.110 a

6.112 d

6.114 d

6.116 b

CHAPTER 7

7.2 **a.** Solvent: water; solute: sodium hypochlorite

b. Solvent: isopropyl alcohol; solute: water

c. Solvent: water; solute: hydrogen peroxide

d. Solvent: SD alcohol; solutes: water, glycerin, fragrance, menthol, benzophenone, coloring

7.4 **a.** Not a solution because it is not homogeneous. It is cloudy rather than clear.

b. Solution; solvent: water; solutes: all dissolved components.

c. Not a solution because it is not homogeneous. Bits of pulp can be seen.

d. Solution if prepared carefully with a tea bag or good strainer; solvent: water; solutes: all dissolved components.

e. Not a solution because it is not homogeneous.

7.6 **a.** The oil and vinegar are immiscible.

b. The alcohol is soluble in the water.

c. The tar is soluble in the chloroform.

7.8 **a.** unsaturated

b. supersaturated

c. saturated

7.10 The solution could be carefully cooled to a temperature lower than room temperature. Another method would be to allow some of the solvent to evaporate.

7.12 **a.** soluble

b. insoluble

c. slightly soluble

d. very soluble

e. slightly soluble

7.14 Add pure water to the mixture. The $BaCl_2$ is soluble and will dissolve in the water. The liquid that contains the dissolved $BaCl_2$ can then be poured off carefully, leaving behind the insoluble solid $BaSO_4$.

7.16 **a.** Soluble in benzene

b. Soluble in benzene

c. Soluble in water

d. Soluble in benzene

7.18 The structure indicates that Freon-114 is a nonpolar material. Grease is also nonpolar, as indicated by its insolubility in water. Thus, grease would dissolve readily in Freon-114.

7.20 **a.** 0.196 M

b. 0.755 M

c. 0.670 M

7.22 **a.** 1.00 M

b. 0.150 M

c. 0.50 M

7.24 **a.** 0.338 mol

b. 0.0370 mol

c. 0.442 L or 442 mL

7.26 **a.** 0.820 g

b. 0.130 L

c. 0.516 L

7.28 **a.** 6.1%

b. 6.1%

c. 6.1%

7.30 **a.** 7.41%

b. 15.3%

c. 54.5%

d. 44.1%

7.32 **a.** 11.1%

b. 10.7%

c. 7.48%

7.34 **a.** 7.5%

b. 7.5%

c. 3.0%

d. 43.0%

7.36 0.025 L or 25 mL

7.38 a. 4.00%

b. 4.00%

c. 7.83%

7.40 About 40%

7.42 **a.** Put 0.0250 mol (3.55 g) of solid Na_2SO_4 into a 100-mL volumetric flask and add enough pure water to fill the flask to the mark after the solid dissolves.

b. Put 0.055 mol (9.47 g) of solid $Zn(NO_3)_2$ into a 500-mL volumetric flask and add enough pure water to fill the flask to the mark after the solid dissolves.

c. Mix together 6.25 g of solid NaCl and 244 g (244 mL) of pure water. Allow the NaCl to dissolve.

d. Put 0.55 g of solid KCl into a 100-mL volumetric flask and add enough pure water to fill the flask to the mark after the solid dissolves.

7.44 %(w/w) = 25.0; %(w/v) = 23.8

7.46 **a.** 92.4 g

b. 0.600 mol

c. 21.6 mL

d. 0.630 g

7.48 **a.** Add 1.67 L of 18.0 M H_2SO_4 solution to enough water to give 5.00 L of solution. The 18.0 M acid should be added to water, and not the water to the acid. One way to make the desired solution is to add the 1.67 L of 18.0 M acid to about 3 L of pure water. Stir the resulting solution, then add enough additional water to bring the total volume to 5.00 L.

b. Put 41.7 mL of 3.00 M $CaCl_2$ solution into a 250 mL volumetric flask and add enough pure water to fill the flask to the mark when the contents are well mixed.

c. Put 30.0 mL of a 10.0% solution into a calibrated volumetric container (such as a volumetric flask or large volumetric cylinder) and add enough pure water to bring the total volume of well-mixed solution to 200 mL.

d. Put 100 mL of a 50.0% solution into a calibrated volumetric container and add enough pure water to bring the total volume of well-mixed solution to 500 mL.

7.50 **a.** 0.00650 M

b. 0.0488 M

c. 0.0195 M

d. 0.0139 M

7.52 16.6 g

7.54 20.0 mL

7.56 44.3 mL

7.58 42.3 mL

7.60 1.3 g

7.62 Because ice cream is essentially a solution of substances dissolved in water, the freezing point of the solution is lower than that of pure water. The temperature of a mixture of ice and pure water is the same as the freezing point of pure water. Thus, a mixture of ice and water has a temperature higher than the freezing point of the ice cream solution. A mixture of ice, salt, and water has a temperature (freezing point) lower than that of pure water. If enough salt is added to the ice and water mixture, the temperature can be made lower than the freezing point of the ice cream solution, and it will freeze.

7.64 **a.** Boiling point = 101.6°C; freezing point = −5.58°C

b. Boiling point = 100.78°C; freezing point = −2.79°C

c. Boiling point = 102.3°C; freezing point = −8.37°C

d. Boiling point = 103.1°C; freezing point = −11.2°C

7.66 **a.** Boiling point = 100.26°C; freezing point = −0.93°C

b. Boiling point = 100.39°C; freezing point = −1.40°C

c. Boiling point = 103.35°C; freezing point = −12.0°C

7.68 **a.** Osmolarity = 0.15

b. Osmolarity = 0.45

c. Osmolarity = 1.19

7.70 $\pi = 5.58 \times 10^3$ torr $= 5.58 \times 10^3$ mmHg = 7.34 atm

7.72 $\pi = 1.12 \times 10^4$ torr $= 1.12 \times 10^4$ mmHg = 14.7 atm

7.74 $\pi = 1.08 \times 10^5$ torr $= 1.08 \times 10^5$ mmHg = 143 atm

7.76 $\pi = 3.5 \times 10^3$ torr $= 3.5 \times 10^3$ mmHg = 4.6 atm

7.78 $\pi = 9.95 \times 10^3$ torr $= 9.95 \times 10^3$ mmHg = 13.1 atm

7.80 Water will flow from the 5.00% solution into the 10.0% solution. The 10.0% solution will become diluted as osmosis takes place.

7.82 Much of the soiling material to be removed by washing consists of fats and oils, which are nonpolar and will not dissolve in water. The soaps or detergents act as emulsifying agents, which allow the nonpolar materials to be suspended in water and removed from the material being washed.

7.84 **a.** Na^+ and Cl^-

b. urea molecules

c. K^+, Cl^- and glucose molecules

7.86 1.07 g/mL

7.88 10.2 mL

7.90 a

7.92 c

7.94 b

7.96 c

7.98 b

7.100 b

7.102 b

7.104 b

7.106 a

7.108 d

7.110 a

7.112 d

7.114 c

CHAPTER 8

8.2 **a.** Nonspontaneous: The rocket engines of the shuttle must operate continuously to push the shuttle into an orbit.

b. Spontaneous: Once ignited, the fuel continues to burn without additional input of energy.

c. Nonspontaneous: Heat must be supplied continuously to keep the water boiling.

d. Nonspontaneous: The only way to raise the temperature of a substance is to supply heat.

e. Nonspontaneous: To make your room orderly, someone must provide some work to move the clothing, etc., around. The work done represents an input of energy to the room.

8.4 **a.** Exergonic: The person doing the pushing is giving up energy to the automobile.

b. Endergonic: The ice must gain energy in the form of heat in order to melt.

c. Exergonic: The surroundings lose heat to the ice in order for the ice to melt.

d. Exergonic: In order to condense, the steam must give up some energy in the form of heat.

e. Endergonic: The heat given up by the steam as it condenses is accepted by the surroundings.

8.6 **a.** Both the energy and the entropy of the water decrease when water freezes. The process is spontaneous if the temperature of the surroundings is lower than 0°C.

b. The energy of the water decreases while the entropy stays essentially constant. The process is spontaneous.

c. The energy of the perfume increases slightly as energy is absorbed during evaporation. The entropy of the perfume increases a great deal as the molecules evaporate from the liquid and disperse throughout the room. The process is spontaneous.

8.8 **a.** Entropy is highest at the end of the play because the players are in a more mixed-up state as compared to just before the play began.

b. The answer is the 10% copper/gold alloy or the 2% alloy, depending on the atoms discussed. A lower concentration of copper atoms allows more disorder among the copper atoms, but more order among the gold atoms. A higher concentration of copper allows less disorder for the copper atoms, but increases the disorder of the gold atoms.

c. Entropy is highest with the purse on the ground and the contents scattered.

d. The mixture characteristic of coins in a piggy bank would have the highest entropy of the choices.

e. The mixture of loose pearls in a box would have the highest entropy of the choices.

8.10 The answers are subjective and depend on the meaning given to the terms *very slow, slow,* and *fast.*

a. very slow

b. slow

c. very slow

d. slow

e. fast

8.12 **a.** Any of the following could be measured at different times: the weight of the block, the weight or volume of the water produced by the melting block, and the physical dimensions of the melting block.

b. Either of the following could be measured at different times: the distance a weighted object penetrates into a sample, and the force required to break a specific-sized piece.

c. Either of the following could be measured at different times: the length of the unburned candle and the weight of the candle.

8.14 **a.** Rate = 0.0330 M/min

b. Rate = 0.0194 M/min

8.16 Rate = 1.54×10^{-4} M/min

8.18 Rate = 1.51×10^{-6} M/s

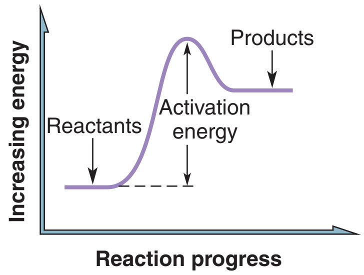
8.20 **a.** Assumption #1 is being violated. According to assumption #1, decreasing the concentrations of reactants would decrease the number of collisions and so decrease the rate at which the molecules would react.

b. Assumption #2 is being violated. According to assumption #2, molecules must collide with a certain minimum energy in order to react. At a lower temperature, fewer molecules would have the necessary minimum energy, so the reaction should go slower, not faster.

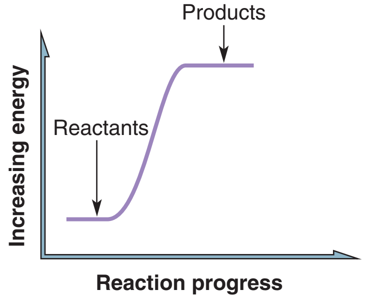
c. Assumption #1 is being violated. According to assumption #1, increasing the concentration of either of the reactants should increase the number of collisions and so increase the rate of the reaction.

8.22 An increase in temperature increases the speeds of the molecules involved in a reaction. The increased speed acts to increase the reaction rate in two ways. First, it causes more collisions to occur between molecules in a given amount of time. Second, it causes the energy of the colliding molecules to be greater so that more of the collisions will involve molecules that have at least the minimum energy needed for a reaction to take place.

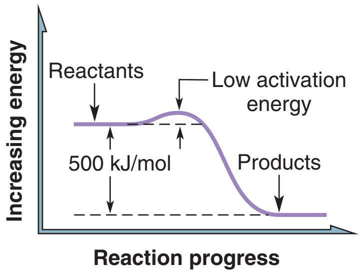
8.24 **a.**



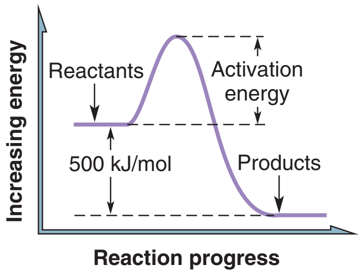
b.



8.26



AT ROOM TEMP.



AT 150° C

Both reactions are exothermic and the products have 500 kJ/mol less energy than the reactants, so both reactions give up 500 kJ/mol. The reaction that takes place at room temperature has a smaller activation energy than the reaction that must be heated to 150°C.

8.28 **a.** Slow to rapid, depending on the state of division of the solid. If large lumps of CaO were exposed to gaseous HCl, the reaction would be slow, since only the CaO on the surface of the lumps would be available. If the CaO were divided into dust-size particles and blown into the gaseous HCl, the reaction would go quite rapidly.

b. Slow. This reaction involves only solids, so only the material at the surface where two solid particles come into contact can react. As in part a, dividing the solids into a fine powder before mixing would speed the reaction significantly.

c. Won't react. The particles of both reactants carry a negative electrical charge, so the particles will repel each other, and collisions between them are highly unlikely.

d. Rapid. The particles of both reactants are in solution, where collisions occur frequently. Also, even though one of the particles is electrically charged, the other is not, so the charge will not diminish or enhance the chances for collisions between reactants.

8.30 Heat the reaction mixture, add a catalyst, or increase the concentration of one or more of the reactants.

8.32 About 0.93 hours or 56 minutes

8.34 Catalysts provide reaction pathways with lower activation energy. They may do this by reacting to form an intermediate structure that yields products when it breaks up or by providing a surface on which the reactants react.

8.36 **a.** Equilibrium would be indicated when the intensity of the violet color of the reaction mixture remained constant with time.

b. Equilibrium would be indicated when the amount of undissolved sugar remained constant with time.

c. Equilibrium would be indicated when either the intensity of the red-brown color of the reaction mixture remained constant with time or the total pressure of the reaction mixture remained constant with time.

8.38 The concentrations of H_2 and Br_2 would decrease, and the concentration of HBr would increase. The intensity of the red-brown color of the mixture would stop decreasing and would become constant when equilibrium was established.

8.40 **a.** $K = \dfrac{[CO_2][H_2O]^2}{[CH_4][O_2]^2}$

b. $K = \dfrac{[O_2]^3}{[O_3]^2}$

c. $K = \dfrac{[H_2O][CO]}{[H_2][CO_2]}$

d. $K = \dfrac{[NO_2]^4[H_2O]^6}{[NH_3]^4[O_2]^7}$

8.42 **a.** $K = \dfrac{[Au(CN)_2^-]}{[Au^+][CN^-]^2}$

b. $K = \dfrac{[Pt\,Cl_4^{2-}]}{[Pt^{2+}][Cl^-]^4}$

c. $K = \dfrac{[Co(NH_3)_6^{2+}]}{[Co^{2+}][NH_3]^6}$

8.44 **a.** $2CO + O_2 \rightleftharpoons 2CO_2$

b. $CO + Cl_2 \rightleftharpoons COCl_2$

c. $2H_2 + O_2 \rightleftharpoons 2H_2O$

d. $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

8.46 K = 0.47

8.48 K = 0.099

8.50 **a.** The concentration of products will be smaller than the concentration of reactants.

b. The concentration of products will be larger than the concentration of reactants.

c. The concentration of products will be larger than the concentration of reactants.

d. The concentration of products will be smaller than the concentration of reactants.

8.52 **a.** Shift right

b. Shift left

c. Shift right

8.54 **a.** Shift right: The color will become less blue and more purple.

b. Shift right: The amount of solid $PbCl_2$ will increase.

c. Shift right: The intensity of the violet color of the mixture will decrease.

d. Shift right: The intensity of the violet color of the mixture will decrease.

e. Shift left: The intensity of the brown color of the mixture will increase.

8.56 **a.** The amount of solid LiOH will increase, the amount of solid $LiHCO_3$ will decrease, and the concentration of CO_2 gas will be decreased.

b. The amount of solid $NaHCO_3$ will increase, the amount of solid Na_2O will decrease, and the concentration of CO_2 gas and H_2O gas will decrease.

c. The amount of solid $CaCO_3$ will increase, the amount of solid CaO will decrease, and the concentration of CO_2 gas will decrease.

8.58 **a.** Shift left

b. Shift right

c. Shift left

d. Shift left

e. No shift will occur

f. Shift left

8.60 Apply pressure to the balloon and decrease its volume. This would increase the concentrations of the gaseous reactants A and B inside the balloon and speed up the reaction.

8.62 **a.** Criterion 2

b. Criterion 3

c. Criterion 2

d. Criterion 3

e. Criterion 3

8.64 a

8.66 a

8.68 c

8.70 b

8.72 a

8.74 a

8.76 a

8.78 a

8.80 a

8.82 c

8.84 d

CHAPTER 9

9.2 **a.** $HF(aq) \rightarrow H^+(aq) + F^-(aq)$

b. $HClO_3(aq) \rightarrow H^+(aq) + ClO_3^-(aq)$

c. $H_3BO_3(aq) \rightarrow H^+(aq) + H_2BO_3^-(aq)$

d. $HSe^-(aq) \rightarrow H^+(aq) + Se^{2-}(aq)$

9.4 **a.** Not an Arrhenius base

b. Arrhenius base: $RbOH(aq) \rightarrow Rb^+(aq) + OH^-(aq)$

c. Not an Arrhenius base

d. Arrhenius base: $Ba(OH)_2(aq) \rightarrow Ba^{2+}(aq) + 2OH^-(aq)$

9.6 **a.** Acids: H_2O and HOCl
Bases: OCl^- and OH^-

b. Acids: $H_2C_2O_4$ and H_3O^+
Bases: H_2O and $HC_2O_4^-$

c. Acids: HPO_4^{2-} and H_3O^+
Bases: H_2O and PO_4^{3-}

d. Acids: H_2O and $HC_2O_4^-$
Bases: $C_2O_4^{2-}$ and OH^-

e. Acids: H_3AsO_4 and H_3O^+
Bases: H_2O and $H_2AsO_4^-$

9.8

	Acid	*Conjugate base*	*Base*	*Conjugate acid*
a.	$HC_2O_4^-$	$C_2O_4^{2-}$	H_2O	H_3O^+
b.	HNO_2	NO_2^-	H_2O	H_3O^+
c.	H_2O	OH^-	PO_4^{3-}	HPO_4^{2-}
d.	H_2SO_3	HSO_3^-	H_2O	H_3O^+
e.	H_2O	OH^-	F^-	HF

9.10 **a.** $HF + H_2O \rightleftarrows H_3O^+ + F^-$

b. $HClO_3 + H_2O \rightleftarrows H_3O^+ + ClO_3^-$

c. $HClO + H_2O \rightleftarrows H_3O^+ + ClO^-$

d. $HS^- + H_2O \rightleftarrows H_3O^+ + S^{2-}$

9.12 **a.** HBO_3^{2-}

b. $C_6H_5NH_2$

c. S^{2-}

d. $C_2O_4^{2-}$

e. ClO_4^-

9.14 **a.** $C_6H_5NH_3^+$

b. $HS_2O_3^-$

c. HCN

d. $H_2AsO_4^-$

e. HF

9. 16 The substance added to complete each equation appears in blue.

a. $H_2AsO_4^-(aq) + NH_3(aq) \rightarrow NH_4^+(aq) + HAsO_4^{2-}(aq)$

b. $C_6H_5NH_2(aq) + H_2O(\ell) \rightarrow C_6H_5NH_3^+(aq) + OH^-(aq)$

c. $S^{2-}(aq) + H_2O(\ell) \rightarrow HS^-(aq) + OH^-(aq)$

d. $(CH_3)_2NH(aq) + HBr(aq) \rightarrow (CH_3)_2NH_2^+(aq) + Br^-(aq)$

e. $CH_3NH_2(aq) + HCl(aq) \rightarrow CH_3NH_3^+(aq) + Cl^-(aq)$

9.18 **a.** $H_3O^+(aq) + NH_2^-(aq) \rightarrow H_2O(\ell) + NH_3(aq)$

b. $H_2PO_4^-(aq) + NH_3(aq) \rightarrow HPO_4^{2-}(aq) + NH_4^+(aq)$

c. $HS_2O_3^-(aq) + OCl^-(aq) \rightarrow S_2O_3^{2-}(aq) + HOCl(aq)$

d. $H_2O(\ell) + ClO_4^-(aq) \rightarrow OH^-(aq) + HClO_4(aq)$

e. $H_2O(\ell) + NH_3(aq) \rightarrow OH^-(aq) + NH_4^+(aq)$

9.20 hydrocyanic acid

9.22 **a.** hydrotelluric acid

b. hypochlorous acid

c. sulfurous acid

d. nitrous acid

9.24 succinic acid

9.26 $HMnO_4$

9.28 **a.** 8.3×10^{-10} M

b. 3.7×10^{-14} M

c. 3.2×10^{-13} M

d. 2.8×10^{-6} M

e. 1.9×10^{-13} M

9.30 **a.** 1.4×10^{-12} M

b. 2.4×10^{-11} M

c. 3.6×10^{-15} M

d. 1.3×10^{-5} M

e. 1.1×10^{-9} M

9.32 In Exercise 9.28: (a) acidic, (b) acidic, (c) acidic, (d) basic, (e) acidic

In Exercise 9.30: (a) basic, (b) basic, (c) basic, (d) basic, (e) acidic

9.34 **a.** acidic

b. basic

c. acidic

d. basic

9.36 **a.** 7.52, basic

b. 11.84, basic

c. 6.50, acidic

d. 3.90, acidic

e. 1.30, acidic

9.38 **a.** 5.41, acidic

b. 2.21, acidic

c. 10.75, basic

d. 5.67, acidic

e. 10.92, basic

9.40 **a.** 6.5×10^{-9} M

b. 1.9×10^{-4} M

c. 2.6×10^{-12} M

9.42 **a.** $[H^+] = 1.0 \times 10^{-5}$ M; $[OH^-] = 1.0 \times 10^{-9}$ M

b. $[H^+] = 1.3 \times 10^{-3}$ M; $[OH^-] = 7.6 \times 10^{-12}$ M

c. $[H^+] = 1.6 \times 10^{-11}$ M; $[OH^-] = 6.2 \times 10^{-4}$ M

9.44 **a.** 8.9×10^{-9} M, basic

b. 1.2×10^{-4} M, acidic

c. 4.2×10^{-8} M, basic

d. 4.0×10^{-8} M, basic

e. 5.9×10^{-7} M, acidic

9.46 **a.** 1.2×10^{-3} M, acidic

b. 7.8×10^{-5} M, acidic

c. 4.8×10^{-3} M, acidic

d. 8.5×10^{-4} M, acidic

9.48 **a.** Add 1.0 L of dilute (6 M) HNO_3 to 1.0 L of pure water and mix well.

b. Add 50 mL of concentrated (15 M) NH_3 to 450 mL of pure water and mix well.

c. Add 83 mL of concentrated (12 M) HCl to 4.9 L of pure water and mix well.

9.50 **a.** $H_2SO_4(aq) + 2H_2O(\ell) \rightarrow 2H_3O^+(aq) + SO_4^{2-}(aq)$

b. $H_2SO_4(aq) + CaO(s) \rightarrow CaSO_4(aq) + H_2O(\ell)$

c. $H_2SO_4(aq) + Mg(OH)_2(s) \rightarrow MgSO_4(aq) + 2H_2O(\ell)$

d. $H_2SO_4(aq) + CuCO_3(s) \rightarrow CuSO_4(aq) + CO_2(g) + H_2O(\ell)$

e. $H_2SO_4(aq) + 2KHCO_3(s) \rightarrow K_2SO_4(aq) + 2CO_2(g) + 2H_2O(\ell)$

f. $H_2SO_4(aq) + Mg(s) \rightarrow MgSO_4(aq) + H_2(g)$

9.52 **a.** Total ionic: $2H^+(aq) + SO_4^{2-}(aq) + 2H_2O(\ell) \rightarrow 2H_3O^+(aq) + SO_4^{2-}(aq)$

Net ionic: $2H^+(aq) + 2H_2O(\ell) \rightarrow 2H_3O^+(aq)$

Simplified net ionic: $H^+(aq) + H_2O(\ell) \rightarrow H_3O^+(aq)$

b. Total ionic: $2H^+(aq) + SO_4^{2-}(aq) + CaO(s) \rightarrow Ca^{2+}(aq) + SO_4^{2-}(aq) + H_2O(\ell)$

Net ionic: $2H^+(aq) + CaO(s) \rightarrow Ca^{2+}(aq) + H_2O(\ell)$

c. Total ionic: $2H^+(aq) + SO_4^{2-}(aq) + Mg(OH)_2(s) \rightarrow Mg^{2+}(aq) + SO_4^{2-}(aq) + 2H_2O(\ell)$

Net ionic: $2H^+(aq) + Mg(OH)_2(s) \rightarrow Mg^{2+}(aq) + 2H_2O(\ell)$

d. Total ionic: $2H^+(aq) + SO_4^{2-}(aq) + CuCO_3(s) \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq) + CO_2(g) + H_2O(\ell)$

Net ionic: $2H^+(aq) + CuCO_3(s) \rightarrow Cu^{2+}(aq) + CO_2(g) + H_2O(\ell)$

e. Total ionic: $2H^+(aq) + SO_4^{2-}(aq) + 2KHCO_3(s) \rightarrow 2K^+(aq) + SO_4^{2-}(aq) + 2CO_2(g) + 2H_2O(\ell)$

Net ionic: $2H^+(aq) + 2KHCO_3(s) \rightarrow 2K^+(aq) + 2CO_2(g) + 2H_2O(\ell)$

Simplified net ionic: $H^+(aq) + KHCO_3(s) \rightarrow K^+(aq) + CO_2(g) + H_2O(\ell)$

f. Total ionic: $2H^+(aq) + SO_4^{2-}(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + SO_4^{2-}(aq) + H_2(g)$

Net ionic: $2H^+(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + H_2(g)$

9.54 $2HCl(aq) + SrO(s) \rightarrow SrCl_2(aq) + H_2O(\ell)$

$2HCl(aq) + Sr(OH)_2(s) \rightarrow SrCl_2(aq) + 2H_2O(\ell)$

$2HCl(aq) + SrCO_3(s) \rightarrow SrCl_2(aq) + H_2O(\ell) + CO_2(g)$

$2HCl(aq) + Sr(HCO_3)_2(s) \rightarrow SrCl_2(aq) + 2H_2O(\ell) + 2CO_2(g)$

$2HCl(aq) + Sr(s) \rightarrow SrCl_2(aq) + H_2(g)$

9.56 **a.** Molecular: $Sn(s) + H_2SO_3(aq) \rightarrow SnSO_3(aq) + H_2(g)$

Total ionic: $Sn(s) + 2H^+(aq) + SO_3^{2-}(aq) \rightarrow Sn^{2+}(aq) + SO_3^{2-}(aq) + H_2(g)$

Net ionic: $Sn(s) + 2H^+(aq) \rightarrow Sn^{2+}(aq) + H_2(g)$

b. Molecular: $3Mg(s) + 2H_3PO_4(aq) \rightarrow Mg_3(PO_4)_2(s) + 3H_2(g)$

Total ionic: $3Mg(s) + 6H^+(aq) + 2PO_4^{3-}(aq) \rightarrow Mg_3(PO_4)_2(s) + 3H_2(g)$

Net ionic: $3Mg(s) + 6H^+(aq) + 2PO_4^{3-}(aq) \rightarrow Mg_3(PO_4)_2(s) + 3H_2(g)$

c. Molecular: $Ca(s) + HBr(aq) \rightarrow CaBr_2(aq) + H_2(g)$

Total ionic: $Ca(s) + 2H^+(aq) + 2Br^-(aq) \rightarrow Ca^{2+}(aq) + 2Br^-(aq) + H_2(g)$

Net ionic: $Ca(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2(g)$

9.58 **a.** Molecular: $3\ RbOH(aq) + H_3PO_4(aq) \rightarrow Rb_3PO_4(aq) + 3H_2O(\ell)$

Total ionic: $3Rb^+(aq) + 3OH^-(aq) + 3H^+(aq) + PO_4^{3-}(aq) \rightarrow 3Rb^+(aq) + PO_4^{3-}(aq) + 3H_2O(\ell)$

Net ionic: $3OH^-(aq) + 3H^+(aq) \rightarrow 3H_2O(\ell)$

Simplified net ionic: $OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

b. Molecular: $2RbOH(aq) + H_2C_2O_4(aq) \rightarrow Rb_2C_2O_4(aq) + 2H_2O(\ell)$

Total ionic: $2Rb^+(aq) + 2OH^-(aq) + 2H^+(aq) + C_2O_4^{2-}(aq) \rightarrow 2Rb^+(aq) + C_2O_4^{2-}(aq) + 2H_2O(\ell)$

Net ionic: $2OH^-(aq) + 2H^+(aq) \rightarrow 2H_2O(\ell)$

Simplified net ionic: $OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

c. Molecular: $RbOH(aq) + HC_2H_3O_2(aq) \rightarrow RbC_2H_3O_2(aq) + H_2O(\ell)$

Total ionic: $Rb^+(aq) + OH^-(aq) + H^+(aq) + C_2H_3O_2^-(aq) \rightarrow Rb^+(aq) + C_2H_3O_2^-(aq) + H_2O(\ell)$

Net ionic: $OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

9.60 **a.** Molecular: $2KOH(aq) + H_3PO_4(aq) \rightarrow K_2HPO_4(aq) + 2H_2O(\ell)$

Total ionic:
$2K^+(aq) + 2OH^-(aq) + 2H^+(aq) + HPO_4^{2-}(aq) \rightarrow 2K^+(aq) + HPO_4^{2-}(aq) + 2H_2O(\ell)$

Net ionic: $2OH^-(aq) + 2H^+(aq) \rightarrow 2H_2O(\ell)$

Simplified net ionic: $OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

b. Molecular: $3KOH(aq) + H_3PO_4 \rightarrow K_3PO_4(aq) + 3H_2O(\ell)$

Total ionic:
$3K^+(aq) + 3OH^-(aq) + 3H^+(aq) + PO_4^{3-}(aq) \rightarrow 3K^+(aq) + PO_4^{3-}(aq) + 3H_2O(\ell)$

Net ionic: $3OH^-(aq) + 3H^+(aq) \rightarrow 3H_2O(\ell)$

Simplified net ionic: $OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

c. Molecular: $KOH(aq) + H_2C_2O_4(aq) \rightarrow KHC_2O_4(aq) + H_2O(\ell)$

Total ionic:
$K^+(aq) + OH^-(aq) + H^+(aq) + HC_2O_4^-(aq) \rightarrow K^+(aq) + HC_2O_4^-(aq) + H_2O(\ell)$

Net ionic: $OH^-(aq) + H^+(aq) \rightarrow H_2O(\ell)$

9.62 **a.** Cation: NH_4^+; anion: NO_3^-

b. Cation: Ca^{2+}; anion: Cl^-

c. Cation: Mg^{2+}; anion: HCO_3^-

d. Cation: K^+; anion: $C_2H_3O_2^-$

e. Cation: Li^+; anion: HSO_3^-

9.64 **a.** Acid: HCl; base: $Cu(OH)_2$

b. Acid: H_2SO_4; base: NH_3 or NH_4OH

c. Acid: H_3PO_4; base: LiOH

d. Acid: H_2CO_3; base: $Mg(OH)_2$

e. Acid: $HC_2H_3O_2$; base: $Ca(OH)_2$

f. Acid: HNO_3; base: KOH

9.66 **a.** 1.3×10^2 g; the product would be $MgSO_4$

b. 1.8×10^2 g; the product would be $Na_2B_4O_7$

9.68 **a.** Acid: HNO_3; solid: $KHCO_3$

b. Acid: HCl; solid: Zn

c. Acid: HBr; solid Li_2O

9.70 **a.** $2HNO_3(aq) + MgCO_3(s) \rightarrow Mg(NO_3)_2(aq) + H_2O(\ell) + CO_2(g)$

b. $2HCl(aq) + CaO(s) \rightarrow CaCl_2(aq) + H_2O(\ell)$

c. $H_2SO_4(aq) + 2RbHCO_3(s) \rightarrow Rb_2SO_4(aq) + 2H_2O(\ell) + 2CO_2(g)$

9.72 **a.** 1/2 mol

b. 1/2 mol

c. 1/3 mol

9.74 **a.** 0.44 eq; 4.4×10^2 meq

b. 0.45 eq; 4.5×10^2 meq

c. 6.24×10^{-2} eq; 62.4 meq

9.76 **a.** 3.50×10^{-2} eq; 35.0 meq

b. 4.01×10^{-2} eq; 40.1 meq

c. 1.35×10^{-1} eq; 135 meq

d. 4.17×10^{-2} eq; 41.7 meq

9.78 9.98×10^{-3} mol, 1.74 g

9.80 B, A, C, D

9.82 **a.** Acid order is B, A, C, D.

b. Conjugate base order is D, C, A, B.

9.84 **a.** $HSe^-(aq) \rightleftarrows H^+(aq) + Se^{2-}(aq)$

$$K_a = \frac{[H^+][Se^{2-}]}{[HSe^-]}$$

b. $H_2BO_3^-(aq) \rightleftarrows H^+(aq) + HBO_3^{2-}(aq)$

$$K_a = \frac{[H^+][HBO_3^{2-}]}{[H_2BO_3^-]}$$

c. $HBO_3^{2-}(aq) \rightleftharpoons H^+(aq) + BO_3^{3-}(aq)$

$$K_a = \frac{[H^+][BO_3^{3-}]}{[HBO_3^{2-}]}$$

d. $HAsO_4^{2-}(aq) \rightleftharpoons H^+(aq) + AsO_4^{3-}(aq)$

$$K_a = \frac{[H^+][AsO_4^{3-}]}{[HAsO_4^{2-}]}$$

e. $HClO(aq) \rightleftharpoons H^+(aq) + ClO^-(aq)$

$$K_a = \frac{[H^+][ClO^-]}{[HClO]}$$

9.86 According to the definitions given in the chapter, the person should be given the 20% acetic acid solution. If the other solution were the one desired, the term *dilute* should have been used rather than *weak.*

9.88 Titrations are done in order to analyze acids or bases. The amount of acid or base contained in a titrated sample can be determined from the volume of titrant added and the concentration of the titrant.

9.90 **a.** The endpoint and equivalence point will be the same if the chosen indicator changes color at the same pH as the pH of the salt solution produced by the reaction of the acid and base involved in the titration.

b. The endpoint and equivalence point will not be the same if the chosen indicator changes color at a pH that is different from the pH of the salt solution produced by the reaction of the acid and base involved in the titration.

9.92 **a.** 0.150 mol

b. 0.300 mol

9.94 **a.** $NaOH(aq) + HC_2O_2Cl_3(aq) \rightarrow NaC_2O_2Cl_3(aq) + H_2O(\ell)$

b. $2NaOH(aq) + H_2S_2O_6(aq) \rightarrow Na_2S_2O_6(aq) + 2H_2O(\ell)$

c. $4NaOH(aq) + H_4P_2O_6(aq) \rightarrow Na_4P_2O_6(aq) + 4H_2O(\ell)$

9.96 **a.** $2HCl(aq) + Zn(OH)_2(aq) \rightarrow ZnCl_2(aq) + 2H_2O(\ell)$

b. $3HCl(aq) + Tl(OH)_3(aq) \rightarrow TlCl_3(aq) + 3H_2O(\ell)$

c. $HCl(aq) + CsOH(aq) \rightarrow CsCl(aq) + H_2O(\ell)$

9.98 0.0278 M

9.100 **a.** 33.3 mL

b. 41.7 mL

c. 100 mL

d. 120 mL

e. 85.0 mL

f. 83.3 mL

9.102 **a.** 3.50 M

b. 0.891 M

c. 12.4 M

9.104 122.0 g/mol

9.106 The ions produced when Na_3PO_4 dissolves in water are Na^+ and PO_4^{3-}. The Na^+ ion is the conjugate acid of the strong base NaOH and therefore is a very weak Brønsted acid. The PO_4^{3-} ion is the conjugate base of the weak acid HPO_4^{2-} and therefore will act as a base in a hydrolysis reaction with water and will contribute to the pH of the solution. The reaction is:

$$PO_4^{3-}(aq) + H_2O(\ell) \rightarrow HPO_4^{2-}(aq) + OH^-(aq)$$

Thus, we see that the hydrolysis reaction contributes OH^- ions to the solution, causing it to have a pH greater than 7.

9.108 **a.** pH greater than 7. The ions produced when the salt dissolves in water are Na^+ and OCl^-. The Na^+ is the conjugate acid of a strong base (NaOH). It will be a weak acid and will not undergo a significant hydrolysis reaction. The OCl^- ion is the conjugate base of a weak acid (HOCl) and will therefore undergo a significant hydrolysis reaction that will contribute to the pH of the solution. The reaction is:

$$OCl^-(aq) + H_2O(\ell) \rightarrow HOCl(aq) + OH^-$$

The OH^- ions produced by this reaction will cause the pH of the solution to be greater than 7.

b. pH greater than 7. The explanation is the same as in part a. The hydrolysis reaction of the CHO_2^- ion is:

$$CHO_2^-(aq) + H_2O(\ell) \rightarrow HCHO_2(aq) + OH^-(aq)$$

c. pH equal to 7. The ions produced when the salt dissolves in water are K^+ and NO_3^-. The K^+ is the conjugate acid of the strong base KOH, and the NO_3^- is the conjugate base of the strong acid HNO_3. Since both ions come from strong sources, they are both weak in their respective behaviors as a conjugate acid or base. As a result, neither of them will undergo a significant hydrolysis reaction that will influence the solution pH.

d. pH greater than 7. The explanation is the same as in part a. The hydrolysis reaction of the PO_4^{3-} ion is:

$$PO_4^{3-}(aq) + H_2O(\ell) \rightarrow HPO_4^{2-}(aq) + OH^-(aq)$$

9.110 Different salts will hydrolyze to different extents in water solution and produce solutions of different pH. In titrations, the pH at the equivalence point is the pH characteristic of a solution of the salt produced by the reaction of the acid and base involved in the titration. Different acids and bases will produce different salts and possibly different solution pH values at the equivalence point. Thus, an indicator must be chosen that will change color at a pH as near as possible to the pH of the salt solution resulting from the titration.

9.112 The buffering anions present in the solution of the two salts are HPO_4^{2-} and $H_2PO_4^-$. When acid is added to the solution, the buffering reaction (like Equation 9.48) is:

$$HPO_4^{2-}(aq) + H^+(aq) \rightleftharpoons H_2PO_4^-(aq)$$

When base is added, the buffering reaction (like Equation 9.49) is:

$$H_2PO_4^-(aq) + OH^-(aq) \rightleftharpoons HPO_4^-(aq) + H_2O(\ell)$$

9.114 $HCO_3^-(aq) + H^+(aq) \rightleftharpoons H_2CO_3(aq)$

9.116 **a.** pH = 3.85

b. pH = 3.85

c. The difference is that the buffer of part b would have a greater buffer capacity; that is, it could buffer against larger added amounts of acid or base.

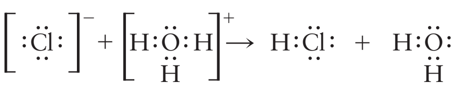
9.118 **a.** pH = 4.54

b. pH = 7.81

c. pH = 6.12

9.120 $[HPO_4^{2-}]/[H_2PO_4^-] = 2.75$

9.122 $Cl^-(aq) + H_3O^+(aq)HCl(aq) + H_2O(\ell)$



base acid acid base

A base donates a pair of electrons to form a covalent bond, while an acid accepts a pair.

9.124 pH = 6.63

9.126 a

9.128 c

9.130 c

9.132 c

9.134 c

9.136 a

9.138 d

9.140 d

9.142 b

9.144 c

9.146 c

CHAPTER 10

10.2 **a.** Beta, gamma, and positron

b. Alpha and positron

c. Gamma and neutron

10.4 **a.** A beta particle is identical with an electron.

b. An alpha particle is made up of two protons and two neutrons.

c. A positron is a positively charged electron.

10.6 **a.** The mass number is reduced by 4, and the atomic number is reduced by 2.

b. The mass number is unchanged, and the atomic number is increased by 1.

c. The mass number is unchanged, and the atomic number is reduced by 1.

d. The mass number and atomic number are both unchanged.

e. The mass number is unchanged, and the atomic number is reduced by 1.

10.8 **a.** ${}^{96}_{41}\text{Nb}$

b. ${}^{80}_{37}\text{Rb}$

c. ${}^{38}_{20}\text{Ca}$

10.10 The quantity added to complete each equation appears in blue.

a. ${}^{204}_{82}\text{Pb} \rightarrow {}^{200}_{80}\text{Hg} + {}^{4}_{2}\alpha$

b. ${}^{84}_{35}\text{Br} \rightarrow {}^{84}_{36}\text{Kr} + {}^{0}_{-1}\beta$

c. ${}^{41}_{20}\text{Ca} + {}^{0}_{-1}\text{e} \rightarrow {}^{41}_{19}\text{K}$

d. ${}^{149}_{62}\text{Sm} \rightarrow {}^{145}_{60}\text{Nd} + {}^{4}_{2}\alpha$

e. ${}^{34}_{14}\text{Si} \rightarrow {}^{34}_{15}\text{P} + {}^{0}_{-1}\beta$

f. ${}^{15}_{8}\text{O} \rightarrow {}^{0}_{-1}\beta + {}^{15}_{7}\text{N}$

10.12 **a.** ${}^{192}_{78}\text{Pt} \rightarrow {}^{4}_{2}\alpha + {}^{188}_{76}\text{Os}$

b. ${}^{10}_{4}\text{Be} \rightarrow {}^{0}_{-1}\beta + {}^{10}_{5}\text{B}$

c. ${}^{19}_{8}\text{O} \rightarrow {}^{0}_{-1}\beta + {}^{19}_{9}\text{F}$

d. ${}^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\alpha + {}^{234}_{90}\text{Th}$

e. ${}^{108}_{50}\text{Sn} + {}^{0}_{-1}\text{e} \rightarrow {}^{108}_{49}\text{In}$

f. ${}^{72}_{31}\text{Ga} \rightarrow {}^{0}_{-1}\beta + {}^{72}_{32}\text{Ge}$

10.14 The half-life of a dozen cookies would be the time it takes for the number to be reduced to 6. The half-life of a $500 checking account would be the time it takes to reduce the amount in the account to $250.

10.16 0.19 ng remains

10.18 2.24×10^4 years old

10.20 1.68×10^4 years old

10.22 Long-term exposure to low-level radiation is more likely to cause changes to genetic material in cells. Such changes might result in genetic mutations, cancer, or other serious consequences. Short-term exposure to intense radiation destroys tissue rapidly and causes radiation sickness, which can lead to death, depending on the dose of radiation received.

10.24 A physical unit of radiation, such as a curie, indicates the activity of a source of radiation in terms of the number of nuclear decays that occur per minute. A biological unit of radiation, such as a rem, indicates the damage caused by radiation in living tissue.

10.26 2.9 R of X-rays

10.28 1.2×10^5 disintegrations/s

10.30 Hot spots are concentrations of radioisotope in tissue. Cold spots are areas of tissue that reject or keep out radioactive tracers.

10.32 ${}^{51}_{24}\text{Cr} + {}^{0}_{-1}\text{e} \rightarrow {}^{51}_{23}\text{V}$. The daughter is vanadium-51.

10.34 Use a radioactive isotope of oxygen to make water by burning hydrogen in it. Mix the radioactive water with hydrogen peroxide. Add the catalyst and collect the oxygen gas given off. If the gas is radioactive, it came from the water; if it is not radioactive, it came from the hydrogen peroxide.

10.36 Use a Geiger-Müller tube to measure the radioactivity of a gallon of water that contains the radioisotope. Pour that water into the pool and allow time for it to become completely and uniformly mixed with the water in the pool. Then, remove a gallon of the pool water and measure its radioactivity. For example, if the pool water has a radioactivity one ten-thousandth that of the original tracer-containing water, it means the original gallon of water has been diluted by a factor of 10,000, and therefore the pool contains 10,000 gal of water. Thus, the pool's volume is equal to the factor by which the radioactivity has been reduced.

10.38 ${}^{24}_{12}\text{Mg} + {}^{4}_{2}\alpha \rightarrow {}^{1}_{0}\text{n} + {}^{27}_{14}\text{Si}$

10.40 ${}^{238}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{239}_{94}\text{Pu} + 2\ {}^{0}_{-1}\beta$

10.42 A moderator slows neutrons so that their chances of being captured and interacting with a target nucleus are greater.

10.44 ${}^{66}_{30}\text{Zn} + {}^{1}_{1}p \rightarrow {}^{67}_{31}\text{Ga}$

10.46 $2\,{}^{1}_{1}\text{H} \rightarrow {}^{2}_{1}\text{H} + {}^{0}_{1}\beta$

10.48 Nuclear fission is a process in which heavy nuclei split into smaller nuclei when they are hit by a neutron. Energy is released by the process. An example is:

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{139}_{54}\text{Xe} + {}^{95}_{38}\text{Sr} + 2{}^{1}_{0}\text{n}$$

When nuclear fusion occurs, small nuclei fuse together and form heavier nuclei. Energy is released by the process. An example is: $^{1}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + \gamma$

10.50 $^{235}_{94}\text{Pu} \rightarrow {}^{4}_{2}\alpha + {}^{234}_{92}\text{U}$

10.52 The positive nuclei of the reacting hydrogen atoms naturally repel each other. In order to overcome this repulsion and get close enough together to fuse, the nuclei must have very high speeds (kinetic energy). The necessary high kinetic energy can only be obtained by the nuclei at very high temperatures. Remember, temperature is a measurement of the average kinetic energy of particles in matter.

10.54 3.5×10^{20} counts/minute $= 1.6 \times 10^{8}$ Ci

10.56 a

10.58 a

10.60 d

10.62 c

10.64 b

10.66 b

10.68 a

10.70 b

10.72 c

10.74 c

10.76 b

10.78 b

10.80 d

CHAPTER 11

11.2 Hair, skin, clothing, paper, plastic, carpet

11.4 They all contain carbon.

11.6 Covalent

11.8 **a.** Organic; most organic compounds are flammable.

b. Inorganic; a high-melting solid is typical of ionic compounds.

c. Organic; many organic compounds are insoluble in water.

d. Organic; most organic compounds can undergo combustion.

e. Organic; a low-melting solid is characteristic of covalent materials, which are usually organic.

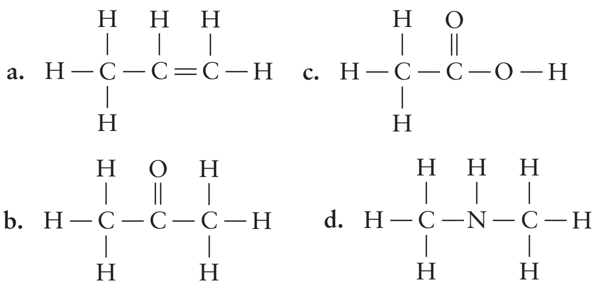
11.10 Organic compounds do not readily accept electrons to transport them, thus making the flow of electrical current impossible.

11.12 The ability of carbon to bond to itself repeatedly; isomerism.

11.14 The *s* orbital of the hydrogen overlaps with the sp^3 orbital of carbon.

11.16 A *p* orbital and an sp^3 orbital both have a two-lobed shape. A *p* orbital has equal-sized lobes, whereas an sp^3 orbital has different-sized lobes.

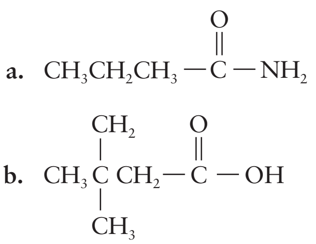
11.18



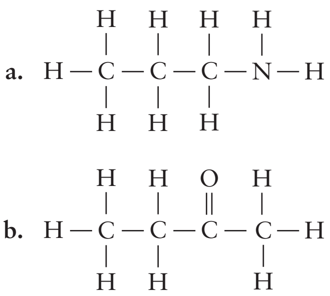
11.20 b, d, e

11.22 Two structures (a and d) are correct. In structure b, the second carbon atom has only three bonds. In structure c, carbon atoms 2 and 3 have too many bonds. In structure e, the second carbon atom from the right has only three bonds.

11.24



11.26



11.28 **a.** normal

b. normal

c. branched

d. branched

e. normal

f. branched

11.30 **a.** same

b. isomers

c. same

d. isomers

11.32 **a.** 6

b. 5

c. 7

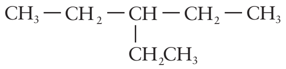
11.34 **a.** 3-ethylhexane

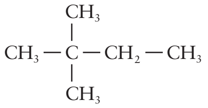
b. 3-ethyl-4-methylhexane

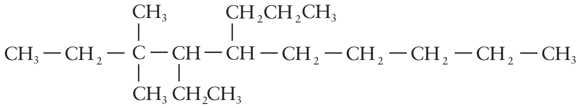
c. 4-t-butyl-5-isopropyloctane

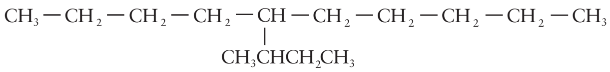
d. 5-isopropyl-2-methyloctane

e. 4-isopropyl-4-propylheptane

11.36 **a.** 

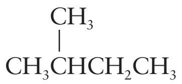
b. 

c. 

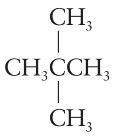
d. 

11.38

$CH_3CH_2CH_2CH_2CH_3$
pentane

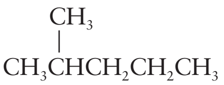


2-methylbutane

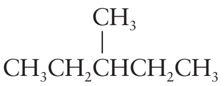


2,2-dimethylpropane

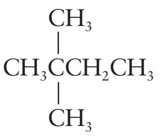
11.40 $CH_3CH_2CH_2CH_2CH_2CH_3$ hexane



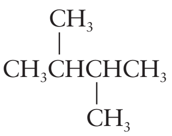
2-methylpentane



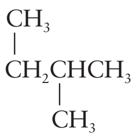
3-methylpentane



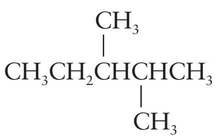
2,2-dimethylbutane



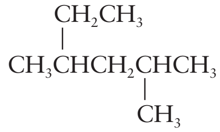
2,3-dimethylbutane

11.42 **a.** 

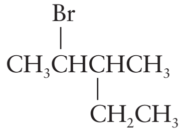
The longest carbon chain is four carbon atoms rather than three. The correct name is 2-methylbutane.

b. 

The chain should be numbered from the right to give 2,3-dimethylpentane.

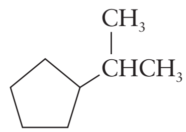
c. 

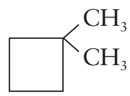
The longest carbon chain is six carbon atoms and should be numbered from the right to give 2,4-dimethylhexane.

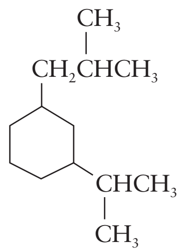
d. 

The longest carbon chain is five carbon atoms rather than four. The correct name is 2-bromo-3-methylpentane.

11.44 **a.** cyclopentane
b. 1,2-dimethylcyclobutane
c. 1,1-dimethylcyclohexane
d. 1,2,3-trimethylcyclobutane

11.46 **a.** 

b. 

c. 

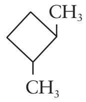
11.48 b, c, and d

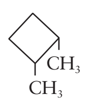
11.50 So that the carbon atoms with attached hydrogens can assume a tetrahedral shape.

11.52

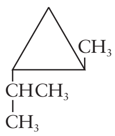
a. none

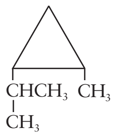
b. none





c. *trans*-1,2-dimethylcyclobutane *cis*-1,2-dimethylcyclobutane





d. *trans*-1-isopropyl-2-methylcyclopropane *cis*-1-isopropyl-2-methylcyclopropane

11.54 a. *trans*-1-ethyl-2-methylcyclopropane

b. *cis*-1-bromo-2-chlorocyclopentane

c. *trans*-1-methyl-2-propylcyclobutane

d. *trans*-1,3-dimethylcyclohexane

11.56 a. liquid

b. no

c. yes

d. less dense

11.58 2-methylheptane

11.60 a. $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

b. $C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

c. $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$

11.62 $2C_6H_{14} + 13O_2 \rightarrow 12CO + 14H_2O$

11.64 Because of the rigid structure of cycloalkanes, stronger dispersion forces can develop between molecules. This increase of intermolecular attraction causes an increase in boiling point.

11.66 pentane: 414.5 torr; hexane: 113.9 torr; heptane: 37.2 torr

11.68 13 L of air

11.70 a. C_3H_8 $CH_3—CH_2—CH_3$

b. C_8H_{18}
$CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3$

c. C_4H_{10} $CH_3—CH_2—CH_2—CH_3$

11.72 a. C_2H_6

11.74 d. CO_2 and H_2O

11.76 c. high affinity for hemoglobin

CHAPTER 12

12.2 An alkene contains one or more C═C bonds.

An alkyne contains one or more C≡C bonds.

An aromatic hydrocarbon contains the characteristic benzene ring or similar feature.

12.4 a. 2-butene

b. 3-ethyl-2-pentene

c. 4,4-dimethyl-2-hexyne

d. 4-methylcyclopentene

e. 6-bromo-2-methyl-3-heptyne

f. 1-ethyl-2,3-dimethylcyclopropene

g. 6-methyl-1,4-heptadiene

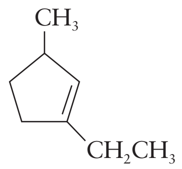
12.6

a. $CH_3CH{=}CHCH(CH_3)CH_2CH_3$ (CH₃ branch on the fourth carbon)

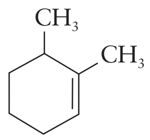
b. $CH{\equiv}CCH_2C(CH_3)_2CH_3$

c. $CH_2{=}CH{-}CH{=}CH_2$

d.



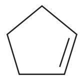
e.



12.8 Several possibilities exist including these:

$CH{\equiv}CCH_2CH_2CH_3$ 1-pentyne

$CH_2{=}CHCH{=}CHCH_3$ 1,3-pentadiene



cyclopentene

12.10 3,7,11-trimethyl-1,3,6,10-dodecatetraene

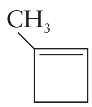
12.12 a. $CH_3CH(CH_3){-}CH_2CH{=}CHCH_3$

5-methyl-2-hexene

b. $CH_3CH_2CH{=}CHCH{=}CHCH_3$

2,4-heptadiene

c.



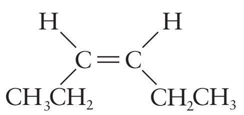
1-methylcyclobutene

12.14 The overlap of two *p* orbitals forms a π (pi) bond containing two electrons.

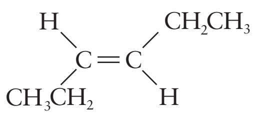
12.16 Structural isomers have a different order of linkage of atoms. Geometric isomers have the same order of linkage of atoms but different three-dimensional arrangements of their atoms in space.

12.18 a. and **c.** cannot have cis- and trans-isomers.

b.

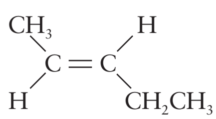


cis-3-hexene

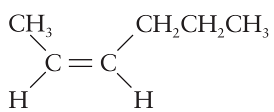


trans-3-hexene

12.20 a.



b.



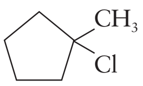
12.22 Both alkanes and alkenes are nonpolar compounds that are insoluble in water, less dense than water, and soluble in nonpolar solvents.

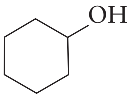
12.24 When H—X adds to an alkene, the hydrogen becomes attached to the carbon atom that is already bonded to more hydrogens.

$$CH_2=CH-CH_3 + HCl \longrightarrow CH_3\overset{\overset{\displaystyle Cl}{|}}{C}HCH_3$$

12.26 **a.** $CH_3CH_2CH_2CH_3$

b. $Br-CH_2\overset{\overset{\displaystyle Br}{|}}{C}HCH_2CH_3$

c. 

d. 

12.28 **a.** Cl_2

b. H_2 with Pt catalyst

c. HCl

d. H_2O with H_2SO_4 catalyst

12.30 The addition of Br_2 to these samples will cause the cyclohexane solution to become light orange with unreacted Br_2, whereas the 2-hexene will react with the Br_2 and remain colorless.

12.32 A monomer is a starting material used in the preparation of polymers, long-chain molecules made up of many repeating units. Addition polymers are long-chain molecules prepared from alkene monomers through numerous addition reactions. A copolymer is prepared from two monomer starting materials.

12.34 A carbon–carbon double bond

12.36 $$nCH_2=\underset{\underset{\displaystyle Cl}{|}}{C}H \xrightarrow{\text{catalyst}} \left(CH_2-\underset{\underset{\displaystyle Cl}{|}}{C}H\right)_n$$

12.38 *sp*; two

12.40 Linear

12.42 Acetylene is a fuel used by welding torches and in the synthesis of monomers for plastics and fibers.

12.44 $H-C\equiv C-CH_2CH_2CH_3$
1-pentyne

$CH_3-C\equiv C-CH_2CH_3$
2-pentyne

$$CH_3\overset{\overset{\displaystyle CH_3}{|}}{C}H-C\equiv C-H$$
3-methyl-1-butyne

12.46 Unhydridized *p* orbitals

12.48 Aromatic refers to compounds containing the benzene ring. Aliphatic substances do not contain a benzene ring.

12.50 In cyclohexane, attached groups are located above and below the plane of the ring. In benzene, attached groups are located in the same plane as the ring.

12.52 **a.** 1,3,5-trimethylbenzene

b. 1,4-diethylbenzene

12.54 **a.** 2-phenyl-1-butene

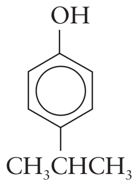
b. 3-phenylcyclopentene

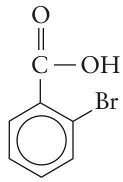
12.56 **a.** *m*-bromophenol

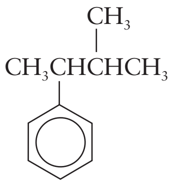
b. *p*-ethylaniline

12.58 **a.** 2,6-dibromobenzoic acid

b. 3-chloro-5-ethyltouene

12.60 **a.** 

b. 

c. 

12.62 Nonpolar and insoluble in water

12.64 Cyclohexene readily undergoes addition reactions. Benzene resists addition reactions and favors substitution reactions. Both undergo combustion.

12.66 **a.** phenol

b. styrene

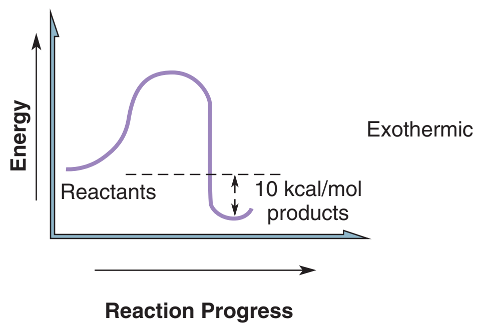
c. aniline

d. phenol

12.68 Heat increases the kinetic energy of the ethylene molecules and increases the number of molecules having the required activation energy.

Pressure on a gas increases the temperature and concentration of the gas.

Catalysts lower the activation energy requirements.

12.70 

12.72 a and d

12.74 c, an alkene

12.76 b, melanin

Solutions to Learning Checks

APPENDIX C

CHAPTER 1

1.1 A change is chemical if new substances are formed and physical if no new substances are formed.

a. Chemical: The changes in taste and odor indicate that new substances form.

b. Physical: The handkerchief doesn't change, and the evaporated water is still water.

c. Chemical: The changes in color and taste indicate that new substances form.

d. Chemical: The gases and smoke released indicate that new substances form.

e. Physical: The air is still air, as indicated by appearance, odor, and so on.

f. Physical: On being condensed, the steam forms water, which is the same substance present before the change.

1.2 **a.** Triatomic and heteroatomic: The three atoms of two kinds (oxygen and hydrogen) make it both triatomic (three atoms) and heteroatomic (two or more kinds of atoms).

b. Triatomic and homoatomic: The three atoms make it triatomic, but all three atoms are the same (oxygen).

c. Polyatomic and heteroatomic: The total of five atoms makes it polyatomic, and the two different kinds of atoms (carbon and hydrogen) make it heteroatomic.

1.3 Molecules of elements can be diatomic, triatomic, or polyatomic, but all atoms will be identical and will be represented by the same color. Molecules of compounds must be diatomic, triatomic, or polyatomic (more than one atom), and the atoms will not all be identical.

a. Compound: polyatomic and heteroatomic

b. Element: diatomic and homoatomic

c. Element: polyatomic and homoatomic

d. Compound: polyatomic and heteroatomic

1.4 The product would have to be a compound because it would be polyatomic (more than one atom because two substances were used) and heteroatomic (different atoms from the two different substances).

1.5 Substitute the given radius and π values into the equation:

$A = \pi r^2 = (3.14)(3.5\text{ cm})^2 = (3.14)(12.25\text{ cm}^2) = 38\text{ cm}^2$

1.6 The volume of a rectangular object is equal to the product of the three sides.

$$V = (30.0\text{ cm})(20.0\text{ cm})(15.0\text{ cm}) = 9000\text{ cm}^3, \text{ or } (9.00 \times 10^3\text{ cm}^3)$$

$1\text{ cm}^3 = 1\text{ mL}$, so the volume is 9.00×10^3 mL. A liter is equal to 1000 mL, so 9000 mL = 9 L. The correct answers are 9.00×10^3 mL and 9.00 L.

1.7 Because 1 kg = 1000 g,

$$0.819\ \cancel{\text{kg}} \times \frac{1000\text{ g}}{1\ \cancel{\text{kg}}} = 819\text{ g}$$

1.8 Use Equation 1.4 and the fact that 77°F = 25°C, as shown in Example 1.7.

$$\text{K} = °\text{C} + 273 = 25°\text{C} + 273 = 298\text{ K}$$

1.9 **a.** Scientific notation is used. In nonscientific notation, the number is written 588.

b. Scientific notation is not used. In scientific notation, the number is written 4.39×10^{-4}.

c. Scientific notation is used. In nonscientific notation, the number is written 0.0003915.

d. Scientific notation is not used. In scientific notation, the number is written 9.870×10^3.

e. Scientific notation is not used. In scientific notation, the number is written 3.677×10^1.

f. Scientific notation is not used. In scientific notation, the number is written 1.02×10^{-1}.

1.10 The two important things to note are the placement of the decimal in the standard position and the correct value of the exponent.

a. Written incorrectly: The decimal is not in standard position. Move the decimal 1 place to the left and increase the exponent by 1 to account for moving the decimal: 6.25×10^5.

b. Written incorrectly: The decimal is not in the standard position, and no exponent is used. Move the decimal 3 places to the right and use −3 for the exponent to account for moving the decimal: 9.8×10^{-3}.

c. Written incorrectly: The decimal is not in the standard position. Move the decimal 3 places to the right and reduce the exponent by 3 to account for moving the decimal: 4.1×10^{-6}.

d. Written correctly.

1.11 Perform multiplications and divisions separately for the nonexponential and exponential terms, then combine the results into the final answer.

a. $(2.4 \times 10^3)(1.5 \times 10^4) = (2.4 \times 1.5)(10^3 \times 10^4) = (3.6)(10^{3+4}) = 3.6 \times 10^7$

b. $(3.5 \times 10^2)(2.0 \times 10^{-3}) = (3.5 \times 2.0)(10^2 \times 10^{-3}) = (7.0)(10^{2+(-3)}) = 7.0 \times 10^{-1}$

c. $\dfrac{6.3 \times 10^5}{2.1 \times 10^3} = \left(\dfrac{6.3}{2.1}\right)\left(\dfrac{10^5}{10^3}\right) = (3.0)(10^{5-3})$

$= 3.0 \times 10^2$

d. $\dfrac{4.4 \times 10^{-2}}{8.8 \times 10^{-3}} = \left(\dfrac{4.4}{8.8}\right)\left(\dfrac{10^{-2}}{10^{-3}}\right) = (.50)(10^{-2-(-3)})$

$= .50 \times 10^1 = 5.0 \times 10^0$, or 5.0

1.12 The primary challenge is to interpret correctly the significance of zeros. Leading zeros to the left of nonzero numbers are not significant; all other zeros, including trailing zeros, are significant.

a. 3, trailing zero is significant.

b. 4

c. 3, leading zeros are not significant.

d. 2

e. 1, leading zeros are not significant.

f. 4, trailing zero is significant.

1.13 **a.** 3 significant figures; original decimal position is 2 places to the right of standard position, so exponent is +2.
1.01×10^2 m.

b. 4 significant figures; original decimal position is 3 places to the right of standard position, so exponent is +3.
1.200×10^3 g.

c. 3 significant figures; original decimal position is 3 places to the left of standard position, so exponent is −3.
2.30×10^{-3} kg.

d. 4 significant figures; original decimal position is 3 places to the right of standard position, so exponent is +3.
1.296×10^3°C.

e. 4 significant figures; original decimal position is 1 place to the right of standard position, so exponent is +1.
2.165×10^1 mL.

f. 2 significant figures; original decimal position is 2 places to the left of standard position, so exponent is −2.
1.5×10^{-2} km.

1.14 **a.** Answer will be rounded to 2 significant figures to match 0.0019.

$$(0.0019)(21.39) = 0.04064 = 4.1 \times 10^{-2}$$

b. Answer will be rounded to 2 significant figures to match 4.1.

$$\frac{8.321}{4.1} = 2.0295 = 2.0$$

c. Answer will be rounded to 3 significant figures to match 0.0911 and 3.22.

$$\frac{(0.0911)(3.22)}{(1.379)} = 0.21272 = 0.213, \text{ or } 2.13 \times 10^{-1}$$

1.15 In each case, the sum or difference is rounded to have the same number of places to the right of the decimal as the least number of places in the terms added or subtracted.

a. Answer will be rounded to have one place to the right of the decimal to match 3.2.

$$8.01 + 3.2 = 11.21 = 11.2$$

b. Answer will be rounded to have no places to the right of the decimal to match 3000.

$$3000 + 20.3 + 0.009 = 3020.309 = 3020$$

c. Answer will be rounded to have two places to the right of the decimal to match both 4.33 and 3.12.

$$4.33 - 3.12 = 1.21$$

d. Answer will be rounded to have two places to the right of the decimal to match 2.42.

$$6.023 - 2.42 = 3.603 = 3.60$$

1.16 Two factors result from the relationship 1 g = 1000 mg. The factors are:

$$\frac{1\text{ g}}{1000\text{ mg}} \quad \text{and} \quad \frac{1000\text{ mg}}{1\text{ g}}$$

The first factor is used because it cancels the mg unit and generates the g unit:

Step 1. 1.1 mg

Step 2. 1.1 mg = g

Step 3. $1.1\ \cancel{\text{mg}} \times \dfrac{1\text{ g}}{1000\ \cancel{\text{mg}}} = \text{g}$

Step 4. $\dfrac{(1.1)(1\text{ g})}{(1000)} = 0.0011\text{ g} = 1.1 \times 10^{-3}\text{ g}$

The number of significant figures matches the number in 1.1 because the 1 and 1000 are exact numbers.

1.17 Two factors, 1 km/1000 m and 0.621 mi/1 km, are used to convert meters to miles, and two factors, 60 s/1 min and 60 min/1 h, are used to convert seconds in the denominator to hours.

$$10.0\frac{\cancel{\text{m}}}{\cancel{\text{s}}} \times \frac{1\ \cancel{\text{km}}}{1000\ \cancel{\text{m}}} \times \frac{0.621\text{ mi}}{1\ \cancel{\text{km}}} \times \frac{60\ \cancel{\text{s}}}{1\ \cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{1\text{ h}} = 22.356\text{ mi/h}$$

Rounding to 3 significant figures gives 22.4 mi/h.

1.18 **a.** $\% = \dfrac{\text{part}}{\text{total}} \times 100; \% = \dfrac{\$988}{\$1200} \times 100 = 82.3\%$

b. $\% = \dfrac{\text{part}}{\text{total}} \times 100$

$$90.4\% = \frac{\text{part}}{83} \times 100$$

$$\frac{(90.4\%)(83)}{100} = \text{part}$$

= no. voting to not take final

= 75.0

Number voting to take exam = 83 − 75 = 8.

1.19 The value of the density gives two factors that may be used to solve problems of this type:

$$\frac{2.7\text{ g}}{1.0\text{ cm}^3} \quad \text{and} \quad \frac{1.0\text{ cm}^3}{2.7\text{ g}}$$

a. The sample volume is 60.0 cm^3, and we wish to use a factor that will convert this to grams. The first factor given above will work.

$$60.0\ \cancel{\text{cm}^3} \times \frac{2.7\text{ g}}{1.0\ \cancel{\text{cm}^3}} = 162\text{ g (calculator answer)}$$

$$= 1.6 \times 10^2\text{ g (properly rounded answer)}$$

b. The sample mass is 98.5 g, and we wish to convert this to cm^3. The second factor given above will work.

$$98.5\ \cancel{g} \times \frac{1.0\ cm^3}{2.7\ \cancel{g}} = 36.48\ cm^3\ \text{(calculator answer)}$$

$$= 3.6 \times 10^1\ cm^3\ \text{(properly rounded answer)}$$

1.20 **a.** The sample mass is equal to the difference between the mass of the container with the sample inside and the mass of the empty container:

$$m = 64.93\ g - 51.22\ g = 13.71\ g$$

The density of the sample is equal to the sample mass divided by the sample volume:

$$d = \frac{m}{V} = \frac{13.71\ g}{10.00\ mL}$$

$$= 1.371\ g/mL\ \text{(properly rounded answer)}$$

b. The identity can be determined by calculating the density of the sample from the data and comparing the density with the known densities of the two possible metals. The volume of the sample is equal to the difference between the cylinder readings with the sample present and with the sample absent:

$$V = 25.2\ mL - 21.2\ mL = 4.0\ mL$$

According to Table 1.3, 1 mL = 1 cm^3, so the sample volume is equal to 4.0 cm^3. The density of the sample is equal to the sample mass divided by the sample volume:

$$d = \frac{m}{V} = \frac{35.66\ g}{4.0\ cm^3}$$

$$= 8.9\ g/cm^3\ \text{(properly rounded answer)}$$

A comparison with the known densities of nickel and chromium allows the metal to be identified as nickel.

CHAPTER 2

2.1 The number of atoms in each molecule is represented by a subscript in the formula.

a. H_3PO_4 **b.** SO_3 **c.** $C_6H_{12}O_6$

2.2 **a.** The atomic number, Z, equals the number of protons: $Z = 4$. The mass number, A, equals the sum of the number of protons and the number of neutrons: $A = 4 + 5 = 9$. According to the periodic table, the element with an atomic number of 4 is beryllium, with the symbol Be. The isotope symbol is ^9_4Be.

b. According to the periodic table, chlorine has the symbol Cl and an atomic number, Z, of 17. The mass number, 37, is equal to the sum of the number of protons and neutrons: $A = \#p + \#n$. Therefore, the number of neutrons is equal to the mass number, A, minus the number of protons: $\#n = A - 17 = 37 - 17 = 20$.

c. According to the periodic table, the element with the symbol Si is silicon, which has an atomic number of 14. Therefore, the atom contains 14 protons. Since $A = \#p + \#n$, we see that $\#n, = A - \#p = 28 - 14 = 14$.

2.3 **a.** Nitrogen atoms have a periodic table weight of 14.01 u, which rounds to 14 u. Iron atoms have a periodic table weight of 55.85 u, which rounds to 56 u. Thus, four nitrogen atoms (4×14 u = 56 u) will balance one iron atom.

b. Carbon atoms have a periodic table weight of 12.01 u, which rounds to 12 u. Helium atoms have a periodic table weight of 4.00 u, which rounds to 4 u. Thus, two carbon atoms (2×12 u = 24 u) will balance six helium atoms (6×4 u = 24 u).

c. Calcium atoms have a periodic table weight of 40.08 u, which rounds to 40 u. Argon atoms have a periodic table weight of 39.95 u, which rounds to 40 u. Thus, two calcium atoms (2×40 u = 80 u) will balance two argon atoms (2×40 u = 80 u).

2.4 Molecular weights are obtained by adding the atomic weights of the atoms in molecules. We have used four significant figures in atomic weights.

a. H_2SO_4; molecular weight = 2(at. wt. H) + (at. wt. S) + 4(at. wt. O)

$$MW = 2(1.008\ u) + 32.06\ u + 4(16.00\ u)$$

$$= 2.016\ u + 32.06\ u + 64.00\ u$$

$$= 98.08\ u$$

b. C_3H_8O; molecular weight = 3(at. wt. C) + 8(at. wt. H) + (at. wt. O)

$$MW = 3(12.01\ u) + 8(1.008\ u) + 16.00\ u$$

$$= 36.03\ u + 8.064\ u + 16.00\ u$$

$$= 60.09\ u$$

2.5 **a.** Because naturally occuring fluorine consists of only a single isotope, the equation for calculating atomic weight becomes:

$$\text{At. wt.} = \frac{(\%\ \text{fluorine-19})(\text{mass fluorine-19})}{100}$$

$$= \frac{(100)(19.00\ u)}{100} = 19.00\ u$$

The calculated value is the same as the periodic table value.

b.

$$\text{At. wt.} = \frac{(\%\ \text{Mg-24})(\text{mass Mg-24})}{100}$$

$$+ \frac{(\%\ \text{Mg-25})(\text{mass Mg-25}) + (\%\ \text{Mg-26})(\text{mass Mg-26})}{100}$$

$$= \frac{(78.70)(23.99\ u) + (10.13)(24.99\ u)}{100}$$

$$\frac{+ (11.17)(25.98\ u)}{100}$$

$$= 24.31\ u$$

Once again, the calculated value is the same as the periodic table value.

2.6 The mass ratio is obtained by dividing the mass of the magnesium sample by the mass of the carbon sample:

$$\frac{\text{Mg mass}}{\text{C mass}} = \frac{13.66\ g}{6.748\ g} = 2.024$$

The number of atoms in each sample is calculated using the factors obtained earlier from the mass of one atom of each element:

$$13.66\ \cancel{g\ Mg} \times \frac{1\ \text{Mg atom}}{4.037 \times 10^{-23}\ \cancel{g\ Mg}}$$

$$= 3.384 \times 10^{23}\ \text{Mg atoms}$$

$$6.748 \text{ g C} \times \frac{1 \text{ C atom}}{1.994 \times 10^{-23} \text{ g C}} = 3.384 \times 10^{23} \text{ C atoms}$$

2.7 The known quantity is one O atom, and the unit of the unknown is grams of O. The factor comes from the relationship 6.02×10^{23} O atoms = 16.00 g O. This relationship provides two factors:

$$\frac{6.02 \times 10^{23} \text{ O atoms}}{16.00 \text{ g O}} \quad \text{and} \quad \frac{16.00 \text{ g O}}{6.02 \times 10^{23} \text{ O atoms}}$$

The second factor is the one used:

$$(1 \text{ O atom})\left(\frac{16.00 \text{ g O}}{6.02 \times 10^{23} \text{ O atoms}}\right) = 2.66 \times 10^{-23} \text{ g O}$$

The ratio of this mass to the mass of a carbon atom is:

$$\frac{2.66 \times 10^{-23} \text{ g O}}{1.994 \times 10^{-23} \text{ g C}} = 1.33 \text{ (properly rounded answer)}$$

The ratio of the atomic weights of oxygen and carbon is:

$$\frac{16.00 \text{ u}}{12.01 \text{ u}} = 1.33 \text{ (rounded to 3 significant figures)}$$

The two ratios are the same to 3 significant figures.

2.8 MW = 1(At. wt. C) + 1(At. wt. O) = 1(12.0 u) + 1(16.0 u) = 28.0 u

Application of the mole concept to CO molecules gives the following relationships:

$$1 \text{ mol CO molecules} = 6.02 \times 10^{23} \text{ CO molecules} = 28.0 \text{ g CO}$$

The calculation of the mass of one CO molecule is done as follows: The known quantity is 1 CO molecule, and the unit of the unknown is g CO. The factor comes from the relationship 6.02×10^{23} CO molecules = 28.0 g CO.

$$(1 \text{ CO molecule})\left(\frac{28.0 \text{ g CO}}{6.02 \times 10^{23} \text{ CO molecules}}\right) = 4.65 \times 10^{-23} \text{ g CO}$$

Comparing the mass of a CO molecule to the mass of a CO_2 molecule gives:

$$\frac{\text{mass of 1 CO molecule}}{\text{mass of 1 CO}_2 \text{ molecule}} = \frac{4.65 \times 10^{-23} \text{ g}}{7.31 \times 10^{-23} \text{ g}} = 0.636$$

Comparing the molecular weight of CO to the molecular weight of CO_2 gives:

$$\frac{\text{MW CO}}{\text{MW CO}_2} = \frac{28.0 \text{ u}}{44.0 \text{ u}} = 0.636$$

It is seen that the ratio of the actual masses of the molecules is identical to the ratio of their relative masses (their molecular weights).

2.9 The relationships between moles of atoms in 1 mol of molecules is given by the subscripts of the atoms. Thus, 1 mol of glucose molecules would contain 6 mol of C atoms, 12 mol of H atoms, and 6 mol of O atoms. One-half mol of glucose molecules would contain half as many moles of each atom, or 3 mol of C atoms, 6 mol of H atoms, and 3 mol of O atoms.

2.10 $\% = \frac{\text{part}}{\text{total}} \times 100$

In each compound, the part will be the mass of carbon associated with some mass of compound (the total). The mass relationships are easily obtained by assuming a sample size equal to 1.00 mol of each compound.

CO_2: 1.00 mol CO_2 molecules = 1.00 mol C atoms + 2.00 mol O atoms or, using atomic weights,

$$44.01 \text{ g CO}_2 = 12.01 \text{ g C} + 32.00 \text{ g O}$$

$$\% \text{ C} = \frac{(12.01 \text{ g C}) \times 100}{(44.01 \text{ g CO}_2)} = 27.29\% \text{ C}$$

CO: 1.00 mol CO molecules = 1.00 mol C atoms + 1.00 mol O atoms

$$28.01 \text{ g CO} = 12.01 \text{ g C} + 16.00 \text{ g O}$$

$$\% \text{ C} = \frac{(12.01 \text{ g C})}{(28.01 \text{ g CO})} \times 100 = 42.88\% \text{ C}$$

CHAPTER 3

3.1 Each element is found at the intersection of the given group (vertical columns) and period (horizontal rows).

a. Ge **b.** Re

3.2 **a.** Period 1 has 2 elements, H and He.

b. Group IIB(12) has 4 elements, Zn, Cd, Hg, and element 112.

3.3 **a.** The maximum number of electrons that can be found in any orbital, including a 4*p* orbital, is 2.

b. All *d* subshells, including the 5*d*, contain 5 orbitals with a capacity of 2 electrons each. Thus, the 5*d* subshell can contain a maximum of 10 electrons.

c. Shell number 1 contains only a single *s* orbital, the 1*s* orbital, and so can contain a maximum of 2 electrons.

3.4 The valence shell is the last shell with electrons. According to Table 3.2, group VA(15) elements all have 5 electrons in the valence shell. Group VIA(16) elements have 6, group VIIA(17) have 7, and the noble gases VIIIA(18) have 8.

3.5 **a.** Strontium (Sr) is in group IIA(2) and so contains 2 electrons in its valence shell.

b. Once again, the roman numeral of the group heading gives the number of valence-shell electrons. The element is Ge, and because it is in group IVA(14), it has 4 electrons in the valence shell.

c. The fifteenth element in period 4 is As, which is in group VA(15) and therefore has 5 electrons in the valence shell.

3.6 The subshell filling order is obtained from Figure 3.7 or Figure 3.8. All subshells except the last one are filled to their capacities as follows: *s* subshells—filled with 2, *p* subshells—filled with 6, *d* subshells—filled with 10, and *f* subshells—filled with 14. The last subshell has only enough electrons added to bring the total number of electrons to the desired value.

a. Element 9 requires 9 electrons: $1s^2 2s^2 2p^5$; 1 unpaired

b. Mg is element 12 and so needs 12 electrons:

$1s^2 2s^2 2p^6 3s^2$; 0 unpaired

c. The element in group VIA(16) and period 3 is S, which is element 16. Therefore, it needs 16 electrons:

$1s^2 2s^2 2p^6 3s^2 3p^4$; 2 unpaired

d. An atom with 23 protons needs 23 electrons:

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$; 3 unpaired

3.7 **a.** From Learning Check 3.6, the electronic configuration of element number 9 is $1s^22s^22p^5$. The $1s^2$ electrons represent the configuration of helium. So, we can write the configuration as $[He]2s^22p^5$.

b. The configuration of Mg is $1s^22s^22p^63s^2$. The first 10 electrons represent the configuration of neon: $[Ne]3s^2$.

c. The configuration of S is $1s^22s^22p^63s^23p^4$. Once again, the first 10 electrons represent the configuration of neon: $[Ne]3s^23p^4$.

d. The 23 electrons are represented by $1s^22s^22p^63s^23p^64s^2\,3d^3$. The first 18 electrons represent the configuration of argon: $[Ar]4s^23d^3$.

3.8 **a.** On the basis of the location of each element in Figure 3.9, the distinguishing electrons are of the following types: element 38(Sr): *s*; element 47(Ag): *d*; element 50(Sn): *p*; element 86(Rn): *p*.

b. Their classifications based on Figure 3.10 are element 38(Sr): representative element; element 47(Ag): transition element; element 50(Sn): representative element; element 86(Rn): noble gas.

3.9 The periodic table and Figure 3.12 are used.

a. Xe: nonmetal

b. As: metalloid

c. Hg: metal

d. Ba: metal

e. Th: metal

3.10 **a.** The slowest reaction involves Li, and the fastest involves K.

Li
Na
K

b. The rate of the reaction increases coming down the group, and according to Table 3.3, the ionization energy decreases coming down the group.

c. The decrease in ionization energy coming down the group means less energy is required to remove electrons from atoms of the elements located farther down the group. The reactions in Figure 3.17 involve the removal of an electron from atoms of the metals, so the easier it is to remove electrons (less energy required), the faster the reaction should go. This trend in speed is what is observed.

CHAPTER 4

4.1 The subshell filling order is obtained from Figure 3.7 or Figure 3.8.

F; 9 electrons: $1s^22s^22p^5$

K; 19 electrons: $1s^22s^22p^63s^23p^64s^1$

The configuration of F can be changed to that of He ($1s^2$) by giving up 7 electrons or to that of Ne ($1s^22s^22p^6$) by accepting 1 electron. The configuration of K can be changed to that of Ar ($1s^22s^22p^63s^23p^6$) by giving up 1 electron or to that of Kr ($1s^22s^22p^63s^23p^64s^23d^{10}4p^6$) by accepting 17 electrons.

4.2 **a.** Element number 9 is fluorine, which is in group VIIA(17) and so has 7 valence-shell electrons. The Lewis structure is $:\ddot{\underset{\cdot\cdot}{F}}\cdot$.

b. Magnesium is in group IIA(2) and so has 2 valence-shell electrons. The Lewis structure is $\dot{Mg}\cdot$.

c. Sulfur is in group VIA(16) and so has 6 valence-shell electrons. The Lewis structure is $:\ddot{\underset{\cdot}{S}}\cdot$.

d. Krypton is a noble gas and so has 8 valence-shell electrons. The Lewis structure is $:\ddot{\underset{\cdot\cdot}{Kr}}:$.

4.3 **a.** Lithium contains 3 electrons, with one of them classified as a valence-shell electron: $[He]2s^1$ and Li·.

b. Bromine contains 35 electrons, with 7 of them classified as valence-shell electrons: $[Ar]4s^23d^{10}4p^5$ and $:\ddot{\underset{\cdot\cdot}{Br}}\cdot$.

c. Strontium contains 38 electrons, with 2 classified as valence-shell electrons: $[Kr]5s^2$ and $\dot{Sr}\cdot$.

d. Sulfur contains 16 electrons, with 6 classified as valence-shell electrons: $[Ne]3s^23p^4$ and $:\ddot{\underset{\cdot}{S}}\cdot$.

4.4 The change that will actually take place is the one that involves the fewest electrons. Thus, F will gain 1 electron rather than give up 7, and K will give up 1 electron rather than gain 17:

$$F + 1e^- \rightarrow F^-$$

$$K \rightarrow K^+ + 1e^-$$

4.5 **a.** Element number 34 is a nonmetal. It is in group VIA(16) and will, when treated using the rules for nonmetals, accept 8 − 6 or 2 electrons during ionic bond formation:

$$Se + 2e^- \rightarrow Se^{2-}$$

b. Rb, a metal in group IA(1), will lose 1 electron during ionic bond formation:

$$Rb \rightarrow Rb^+ + 1e^-$$

c. Element 18 is a nonmetallic noble gas. It will not react to form ionic bonds.

d. In, a metal in group IIIA(13), will lose 3 electrons during ionic bond formation:

$$In \rightarrow In^{3+} + 3e^-$$

4.6 **a.** Mg, a metal in group IIA(2), will lose 2 electrons:

$$Mg \rightarrow Mg^{2+} + 2e^-$$

O, a nonmetal in group VIA(16), will gain 2 electrons:

$$O + 2e^- \rightarrow O^{2-}$$

The positive and negative ions are combined in the lowest numbers possible to give the compound formula. The combining requirement is that the total number of positive charges from the positive ion must equal the total number of negative charges from the negative ion. In the case of Mg^{2+} and O^{2-}, one of each ion satisfies the requirement, and the formula is MgO.

b. K, a group IA(1) metal, will lose 1 electron:

$$K \rightarrow K^+ + 1e^-$$

S, a group VIA(16) nonmetal, will gain 2 electrons:

$$S + 2e^- \rightarrow S^{2-}$$

In the formula, $2K^+$ will be needed for each S^{2-}. Thus, the compound formula is K_2S.

c. Ca, a group IIA(2) metal, will lose 2 electrons:

$$Ca \rightarrow Ca^{2+} + 2e^-$$

Br, a group VIIA(17) nonmetal, will gain 1 electron:

$$Br + 1e^- \rightarrow Br^-$$

In the formula, $2Br^-$ will combine with each Ca^{2+}: $CaBr_2$

4.7 **a.** magnesium oxide

b. potassium sulfide

c. calcium bromide

4.8 **a.** Charge balance requires that $2Br^-$ combine with each Co^{2+}: $CoBr_2$. Names are cobalt(II) bromide and cobaltous bromide.

b. Charge balance requires that $3Br^-$ combine with each Co^{3+}: $CoBr_3$. Names are cobalt(III) bromide and cobaltic bromide.

4.9 **a.** For H_2S, the molecular weight is the sum of the atomic weights of the atoms in the formula:

$$\text{MW} = (2)(\text{at. wt. H}) + (1)(\text{at. wt. S})$$
$$= (2)(1.01\ \text{u}) + (1)(32.1\ \text{u})$$
$$\text{MW} = 34.1\ \text{u}$$

For CaO, the formula weight is also equal to the sum of the atomic weights of the atoms in the formula:

$$\text{FW} = (1)(\text{at. wt. Ca}) + (1)(\text{at. wt. O})$$
$$= (1)(40.1\ \text{u}) + (1)(16.0\ \text{u})$$
$$\text{FW} = 56.1\ \text{u}$$

b. According to Section 2.6, 1.00 mol of a molecular compound has a mass in grams equal to the molecular weight of the compound. Thus, 1.00 mol H_2S = 34.1 g H_2S. For ionic compounds, 1.00 mol of compound has a mass in grams equal to the formula weight of the compound. Thus, 1.00 mol CaO = 56.1 g CaO.

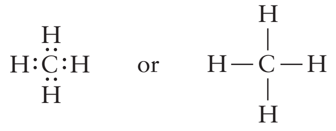
c. In Section 2.6, we learned that 1.00 mol of a molecular compound contains Avogadro's number of molecules. Thus, 1.00 mol $H_2S = 6.02 \times 10^{23}$ molecules of H_2S. In the case of ionic compounds, 1.00 mol of compound contains Avogadro's number of formula units. That is, 1.00 mol of calcium oxide contains Avogadro's number of CaO units, where each unit represents one Ca^{2+} ion and one O^{2-} ion. Thus:

$$1.00\ \text{mol CaO} = 6.02 \times 10^{23}\ \text{CaO units} \quad \text{or}$$
$$1.00\ \text{mol CaO} = 6.02 \times 10^{23}\ Ca^{2+}\ \text{ions} + 6.02 \times 10^{23}\ O^{2-}\ \text{ions}$$

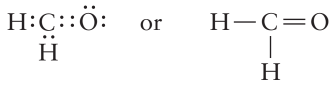
4.10 **a.** N is in group VA(15) and therefore has 5 valence-shell electrons. Two N atoms will provide 10 total electrons to satisfy the octets. At least 2 electrons are needed to bond the atoms. This leaves only 8 electrons to satisfy the remaining octet requirements of both atoms. This deficiency of electrons means some multiple bonds will be needed between the atoms:

b. Br is in group VIIA(17) and therefore has 7 valence-shell electrons. Two atoms will provide 14 electrons, and the bonding is readily shown:

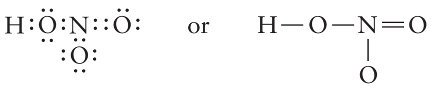
4.11 **a.** Each C contributes 4 valence-shell electrons, and each H contributes 1. The total available is 8:



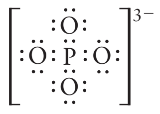
b. Each H contributes 1 electron, the C contributes 4, and the O contributes 6. The total of 12 electrons cannot satisfy all octets unless two pair are shared between the C and O atoms:



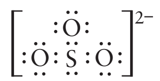
c. Each H contributes 1 electron, each O contributes 6, and the N contributes 5. The 24 total electrons can satisfy all octets only if two pair are shared between the N and one of the O atoms:



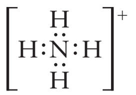
4.12 **a.** The P provides 5 electrons, each O provides 6, and the 3− charge indicates an additional 3 electrons. The total number of electrons is therefore 32, which is enough to satisfy all octets without any multiple bonds:



b. The S provides 6 electrons, each O provides 6, and the 2− charge indicates an additional 2 electrons. The total number of electrons is therefore 26, which is enough to satisfy all octets without any multiple bonds:

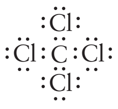


c. The N provides 5 electrons, each H provides 1, and the + charge indicates that 1 must be subtracted. The total number of electrons is therefore 8, which is enough to satisfy the octet of N, and each H requirement of 2 electrons without any multiple bonds:



4.13 **a.** The 3 electron pairs around the B atom will arrange themselves in a flat triangle around the B. Therefore, the molecule will be flat (planar) with the F atoms forming a triangle around the B.

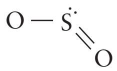
b. The Lewis structure is:



The 4 electron pairs around the C atom will arrange themselves in a tetrahedral orientation. Thus, the molecule will be tetrahedral with C in the center and a Cl atom at each of the corners of the tetrahedron around the C.

c. The Lewis structure is:

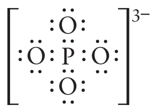
The 3 electron pairs around the S will occupy the corners of a triangle around the S. This will give rise to a bent molecule



d. The Lewis structure is:

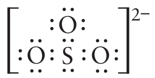
Each double bond on the central C atom is treated like a single pair of electrons when VSEPR theory is used. Thus, the double bonds are treated like 2 pairs and will arrange themselves to be on opposite sides of the C atom. A linear molecule results: S=C=S.

4.14 **a.** The Lewis structure from Learning Check 4.12 is:



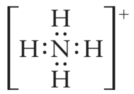
We see that phosphorus is the central atom, and it has four electron pairs around it. The four pairs will be located at the corners of a tetrahedron with the P in the middle. The four O atoms will occupy the corners of the tetrahedron, giving the same shape as that of the SO_4^{2-} ion of Example 4.14a.

b. The Lewis structure from Learning Check 4.12 is:



We see that sulfur is the central atom, and it has four electron pairs around it. The four pairs will be located at the corners of a tetrahedron with the S in the middle. The shape of the ion is determined by the location of the oxygen atoms and the S atom. The O atoms will occupy three of the corners of the tetrahedron, and one pair of electrons will occupy the fourth. Thus, the shape of the ion will be a triangular-based pyramid with the O atoms at the three corners of the base and the S atom at the top.

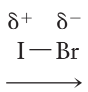
c. The Lewis structure from Learning Check 4.12 is:



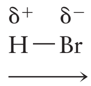
We see that nitrogen is the central atom, and it has four electron pairs around it. The four pairs will be located at the corners of a tetrahedron with the N in the middle. The four H atoms will thus be located at the corners of the tetrahedron with the N in the middle, giving a tetrahedral-shaped ion like the SO_4^{2-} ion of Example 4.14a.

4.15 **a.** No polarization because bound atoms are identical.

b. Br is located higher in the group and so is more electronegative than I:



c. Br is farther toward the right in the periodic table and so is more electronegative than H:



4.16 The values of ΔEN are used.

a. ΔEN = 4.0 − 0.8 = 3.2. Bond is classified as ionic.

b. ΔEN = 3.5 − 3.0 = 0.5. Bond is classified as polar covalent.

c. ΔEN = 3.0 − 1.5 = 1.5. Bond is classified as polar covalent.

d. ΔEN = 3.5 − 0.8 = 2.7. Bond is classified as ionic.

4.17 **a.** sulfur trioxide

b. boron trifluoride

c. disulfur heptoxide

d. carbon tetrachloride

4.18 **a.** Ca is a group IIA(2) metal and so forms Ca^{2+} ions. Formula: $CaHPO_4$; name: calcium hydrogen phosphate.

b. Mg is a group IIA(2) metal and so forms Mg^{2+} ions. Formula: $Mg_3(PO_4)_2$; name: magnesium phosphate.

c. K is a group IA(1) metal and so forms K^+ ions. Formula: $KMnO_4$; name: potassium permanganate.

d. The ammonium ion, NH_4^+, acts as the positive ion in this compound. Formula: $(NH_4)_2Cr_2O_7$; name: ammonium dichromate.

4.19 Assuming that dispersion forces are significant in establishing the melting and boiling points of these elements leads to the conclusion that, in each pair, the element with the higher atomic weight would have the higher melting and boiling points.

a. Se **b.** Sb **c.** Ne

CHAPTER 5

5.1 Both subscripts and coefficients are used.

N_2 : 2 atoms—on the basis of subscript.

$3H_2$: 6 atoms—on the basis of subscript and coefficient.

$2NH_3$: 2 N atoms (on the basis of coefficient) and 6 H atoms (on the basis of subscript and coefficient).

5.2 $2SO_2 + O_2 \rightarrow 2SO_3$

5.3 **a.** Oxygen is −2 (Rule 5).

Sulfur is +6 (Rule 6).

b. Calcium is +2 (Rule 3).

Oxygen is −2 (Rule 5).

Chlorine is +5 (Rule 6).

c. Oxygen is −2 (Rule 5).

Chlorine is +7 (Rule 7).

5.4 **a.** Zn = 0 (Rule 1), H^+ = +1 (Rule 2), Zn^{2+} = +2 (Rule 2), H_2 = 0 (Rule 1).

Zn is oxidized, so it is the reducing agent.

H^+ is reduced, so it is the oxidizing agent.

b. In KI: K = +1 (Rule 3), I = −1 (Rule 6).

Cl_2 = 0 (Rule 1).

In KCl: K = +1 (Rule 3), Cl = −1 (Rule 6).

$I_2 = 0$ (Rule 1).

I in KI is oxidized, so KI is the reducing agent.

Cl_2 is reduced, so Cl_2 is the oxidizing agent.

c. In IO_3^-: O = −2 (Rule 5), I = +5 (Rule 7).

In HSO_3^-: H = +1 (Rule 4), O = −2 (Rule 5), S = +4 (Rule 7).

$I^- = -1$ (Rule 2).

In HSO_4^-: H = +1 (Rule 4), O = −2 (Rule 5), S = +6 (Rule 7).

S in HSO_3^- is oxidized, so HSO_3^- is the reducing agent.

I in IO_3^- is reduced, so IO_3^- is the oxidizing agent.

5.5 **a.** The O.N. of H changes from +1 to 0, and the O.N. of I changes from −1 to 0. Reaction is redox. Because one substance changes into two substances, the reaction is a decomposition.

b. The O.N. of H does not change. The O.N. of O changes from −1 (in a peroxide) to −2 (in water) and 0 (in O_2). This is an example in which the same element is both oxidized and reduced. The reaction is redox. Because one substance changes into two substances, the reaction is a decomposition.

c. No oxidation numbers change. The reaction is nonredox. This is a double-replacement (metathesis) reaction.

d. The O.N. of P changes from 0 to +5, and the O.N. of O changes from 0 to −2. The reaction is redox. Because two substances combine to form a single substance, the reaction is a combination.

e. The O.N. of Na does not change. The O.N. of I changes from −1 to 0, and the O.N. of Cl changes from 0 to −1. The reaction is redox. Because the Cl simply replaces the I in the compound, this is a single-replacement reaction.

5.6 **a.** Total ionic: $2Na^+(aq) + 2I^-(aq) + Cl_2(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + I_2(aq)$

Na^+ is a spectator ion.

Net ionic: $2I^-(aq) + Cl_2(aq) \rightarrow 2Cl^-(aq) + I_2(aq)$

b. Total ionic: $Ca^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + CO_3^{2-}(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + CaCO_3(s)$

Na^+ and Cl^- are spectator ions.

Net ionic: $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

c. Total ionic: $Ba^{2+}(aq) + 2OH^-(aq) + 2H^+(aq) + SO_4^{2-}(aq) \rightarrow 2H_2O(\ell) + BaSO_4(s)$

There are no spectator ions, so the net ionic reaction is the same as the total ionic reaction.

5.7 **a.** 2. $1 \text{ mol } N_2(g) + 3 \text{ mol } H_2(g) \longrightarrow 2 \text{ mol } NH_3(g)$

3. 6.02×10^{23} N_2 molecules + $3(6.02 \times 10^{23})$ H_2 molecules $\longrightarrow 2(6.02 \times 10^{23})$ NH_3 molecules

4. $28.0 \text{ g } N_2 + 3(2.00)\text{g } H_2 \longrightarrow 2(17.0)\text{g } NH_3$

b. **Step 1.** 2.11 mol H_2

Step 2. 2.11 mol H_2 = mol NH_3

Step 3. $2.11 \cancel{\text{mol } H_2} \times \dfrac{2 \text{ mol } NH_3}{3 \cancel{\text{mol } H_2}} = \text{mol } NH_3$

Step 4. $2.11 \times \dfrac{2 \text{ mol } NH_3}{3} = 1.406 \text{ mol } NH_3 = 1.41 \text{ mol } NH_3$

The answer was rounded to 3 significant figures to match the three in 2.11. The 2 and 3 are exact counting numbers.

c. **Step 1.** 9.47 g H_2

Step 2. 9.47 g H_2 = g N_2

Step 3. $9.47 \cancel{\text{g } H_2} \times \dfrac{28.0 \text{ g } N_2}{6.00 \cancel{\text{g } H_2}} = \text{g } N_2$

Step 4. $9.47 \times \dfrac{28.0 \text{ g } N_2}{6.00} = 44.19 \text{ g } N_2 = 44.2 \text{ g } N_2$

The answer was rounded to 3 significant figures to match the three in 9.47, 28.0 g N_2 and 6.00.

5.8 The mass of NH_3 possible from each reactant is calculated. The reactant giving the smallest mass of NH_3 is the limiting reactant, and the mass of NH_3 calculated for the limiting reactant is the amount that will be produced:

$$2.00 \cancel{\text{mol } H_2} \times \frac{34.0 \text{ g } NH_3}{3 \cancel{\text{mol } H_2}} = 22.7 \text{ g } NH_3$$

$$15.5 \cancel{\text{g } N_2} \times \frac{34.0 \text{ g } NH_3}{28.0 \cancel{\text{g } N_2}} = 18.8 \text{ g } NH_3$$

The results show the limiting reactant to be the 15.5 g of N_2, and the amount of NH_3 produced will be 18.8 g.

5.9 **a.**
$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{17.43 \text{ g}}{21.34 \text{ g}} \times 100 = 81.68\%$$

b. The theoretical yield must be calculated.

$$510 \cancel{\text{g } CaCO_3} \times \frac{56.08 \text{ g } CaO}{100.1 \cancel{\text{g } CaCO_3}} = 285.722 \text{ g } CaO = 286 \text{ g } CaO$$

The % yield is then calculated using this theoretical yield:

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 = \frac{235 \text{ g}}{286 \text{ g}} \times 100 = 82.2\%$$

CHAPTER 6

6.1 **a.**
$$d = \frac{\text{mass}}{\text{volume}}$$

$$\text{copper: } d = \frac{114.2 \text{ g}}{12.8 \text{ mL}} = 8.92 \text{ g/mL}$$

$$\text{glycerin: } d = \frac{63.0 \text{ g}}{50.0 \text{ mL}} = 1.26 \text{ g/mL}$$

$$\text{helium: } d = \frac{0.286 \text{ g}}{1500 \text{ mL}} = 1.91 \times 10^{-4} \text{ g/mL}$$

b. Copper: Doubling the pressure will not influence the volume, mass, or density of a solid.

Glycerin: Doubling the pressure will not significantly influence the volume and will not influence the mass or density of a liquid.

Helium: The increased pressure will cause the volume to decrease. The mass will not be changed, so the density will increase.

6.2 $d = \frac{m}{V}$, so $m = Vd$

$$m = (1200\ \text{mL})(1.18 \times 10^{-3}\ \text{g/mL})$$
$$= 1.42\ \text{g}$$

6.3 $\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}(3.00\ \text{g})(10.0\ \text{cm/s})^2 = 1.50 \times 10^2\ \text{g cm}^2/\text{s}^2$

$\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}(3.00\ \text{g})(20.0\ \text{cm/s})^2 = 6.00 \times 10^2\ \text{g cm}^2/\text{s}^2$

6.4 The factors used come from the information in Table 6.3.

a. $670\ \text{torr} \times \frac{1\ \text{atm}}{760\ \text{torr}} = 0.882\ \text{atm}$

b. $670\ \text{torr} \times \frac{14.7\ \text{psi}}{760\ \text{torr}} = 13.0\ \text{psi}$

6.5 **a.** K = °C + 273 = 27 + 273 = 300 K

b. K = °C + 273 = 0 + 273 = 273 K

c. °C = K − 273 = 0 − 273 = − 273°C

d. °C = K − 273 = 100 − 273 = − 173°C

6.6 **a.** Equation 6.8 is used. Temperatures must be converted to kelvins:

$P_i = 1.90$ atm $\quad P_f = 1.00$ atm

$V_i = 10.0$ L $\quad V_f = ?$

$T_i = 30°\text{C} = 303$ K $\quad T_f = -10.2°\text{C} = 262.8$ K

$$\frac{P_iV_i}{T_i} = \frac{P_fV_f}{T_f}$$

$$\frac{(1.90\ \text{atm})(10.0\ \text{L})}{303\ \text{K}} = \frac{(1.00\ \text{atm})(V_f)}{262.8\ K}$$

Solve for V_f:

$$V_f = \frac{(1.90\ \text{atm})(10.0\ \text{L})(262.8\ \text{K})}{(1.00\ \text{atm})(303\ \text{K})} = 16.5\ \text{L}$$

b. $P_i = 800$ torr $\quad P_f = 900$ torr

$V_i = 500$ mL $\quad V_f = 250$ mL

$T_i = 300$ K $\quad T_f = ?$

$$\frac{P_iV_i}{T_i} = \frac{P_fV_f}{T_f}$$

$$\frac{(800\ \text{torr})(500\ \text{mL})}{300\ \text{K}} = \frac{(900\ \text{torr})(250\ \text{mL})}{T_f}$$

Invert both sides and solve for T_f:

$$T_f = \frac{(300\ \text{K})(900\ \text{torr})(250\ \text{mL})}{(800\ \text{torr})(500\ \text{mL})} = 169\ \text{K}$$

$$°\text{C} = \text{K} - 273 = 169\ \text{K} - 273 = -104°\text{C}$$

6.7 To use the ideal gas law, all quantities must have units to match those of R. The only unit that needs to be changed is the temperature:

$$\text{K} = °\text{C} + 273 = 30°\text{C} + 273 = 303\ \text{K}$$
$$PV = nRT$$

Solve for P:

$$P = \frac{nRT}{V}$$
$$= \frac{(2.15\ \text{mol})\left(0.0821\ \frac{\text{L atm}}{\text{mol K}}\right)(303\ \text{K})}{(12.6\ \text{L})}$$
$$= 4.24\ \text{atm}$$

6.8 The ideal gas law in the form $PV = mRT/MW$ is solved for MW:

$$\text{MW} = \frac{mRT}{PV}$$

The temperature must be converted to kelvins:

$$\text{K} = 27°\text{C} + 273 = 300\ \text{K}$$

$$\text{MW} = \frac{(3.35\ \text{g})\left(0.0821\ \frac{\text{L atm}}{\text{mol K}}\right)(300\ \text{K})}{(1.21\ \text{atm})(2.00\ \text{L})}$$
$$= 34.1\ \text{g/mol}$$

This matches the molecular weight of H_2S.

6.9 $P_{\text{total}} = P_{\text{He}} + P_{N_2} + P_{O_2}$

The partial pressures of N_2 and O_2 are changed to torr before adding. The factors used come from information in Table 6.3.

P_{N_2}: $0.200\ \text{atm} \times \frac{760\ \text{torr}}{1\ \text{atm}} = 152\ \text{torr}$

P_{O_2}: $7.35\ \text{psi} \times \frac{760\ \text{torr}}{14.7\ \text{psi}} = 380\ \text{torr}$

$P_{\text{total}} = P_{\text{He}} + P_{N_2} + P_{O_2} = 310\ \text{torr} + 152\ \text{torr} + 380\ \text{torr} = 842\ \text{torr}$

6.10 The lighter (least massive) helium molecules will diffuse faster than the neon molecules. The relationship between the diffusion rates is given by Graham's law.

$$\frac{\text{Rate of He}}{\text{Rate of Ne}} = \sqrt{\frac{\text{mass of Ne}}{\text{mass of He}}} = \sqrt{\frac{20.18}{4.003}}$$
$$= \sqrt{5.041} = 2.25$$

Thus, rate of He = (2.25) rate of Ne. So, helium is seen to diffuse at a rate more than twice that of neon.

6.11 **a.** Evaporation is endothermic.

b. Freezing is exothermic.

c. Melting is endothermic.

6.12 The lower the forces between particles, the higher will be the vapor pressure.

a. Both substances form hydrogen bonds, but dispersion forces are stronger in propyl alcohol. Thus, methyl alcohol has the higher vapor pressure.

b. The only forces acting between the molecules in each case are dispersion forces. These are stronger between the heavier nitrogen molecules, so helium has the higher vapor pressure.

c. Molecules of HF form strong hydrogen bonds with one another, whereas the only forces between neon molecules are weak dispersion forces. Thus, neon has the higher vapor pressure.

6.13 Heat absorbed = (mass)(specific heat)(temp. change). The specific heat of helium is obtained from Table 6.8.

$$\text{Heat absorbed} = (1000\text{ g})(1.25\text{ cal/g }°\text{C})(700°\text{C} - 25°\text{C}) = 8.44 \times 10^5\text{ cal}$$

6.14 Heat absorbed = (mass)(heat of vaporization). The heat of vaporization for water was given in the text.

$$\text{Heat absorbed} = (5000\text{ g})(540\text{ cal/g}) = 2.70 \times 10^6\text{ cal}$$

CHAPTER 7

7.1 **a.** Solvent is gold; solutes are copper, zinc, and nickel.

b. Solvent is nitrogen; solutes are oxygen, argon, and the other gases.

7.2 At 80°C, a saturated solution of KNO_3 contains about 181 g of solute/100 g of H_2O, and a saturated solution of NaBr contains about 118 g of solute per 100 g H_2O. At 50°C both solutions are still saturated, but the KNO_3 solution contains only about 102 g of solute per 100 g H_2O, while the NaBr solution contains about 117 g of solute per 100 g H_2O. Thus, the solubility of KNO_3 is seen to be much more temperature dependent than the solubility of NaBr.

7.3 **a.** The solubility of nitrates and lack of solubility of sulfates and carbonates of barium makes barium nitrate, $Ba(NO_3)_2$, the salt to use. More of it would dissolve and would release more Ba^{2+} ions.

b. Like dissolves like, so oil will dissolve best in oily solvents such as light mineral oil or gasoline. Light mineral oil is the solvent used because it leaves a residue that is similar to the natural oily secretions found on the bird feathers. Gasoline would be hazardous to use (flammable) and leaves no such useful residue.

7.4 **a.** The data may be substituted directly into Equation 7.5:

$$M = \frac{1.25\text{ mol solute}}{2.50\text{ L solution}} = 0.500\,\frac{\text{mol solute}}{\text{L solution}}$$

The solution is 0.500 molar, or 0.500 M.

b. In this problem, the volume of solution must be converted to liters before the data are substituted into Equation 7.5:

$$(225\text{ }\cancel{\text{mL}}\text{ solution})\left(\frac{1\text{ L}}{1000\text{ }\cancel{\text{mL}}}\right) = 0.225\text{ L solution}$$

$$M = \frac{0.486\text{ mol solute}}{0.225\text{ L solution}} = 2.16\,\frac{\text{mol solute}}{\text{L solution}}$$

The solution is 2.16 molar, or 2.16 M.

c. In this problem, the volume of solution must be converted to liters and the mass of solute must be converted to moles before the data can be substituted into Equation 7.5:

$$(100\text{ }\cancel{\text{mL}}\text{ solution})\left(\frac{1\text{ L}}{1000\text{ }\cancel{\text{mL}}}\right) = 0.100\text{ L solution}$$

$$(2.60\text{ }\cancel{\text{g NaCl}})\left(\frac{1\text{ mol NaCl}}{58.44\text{ }\cancel{\text{g NaCl}}}\right) = 0.0445\text{ mol NaCl}$$

In the last calculation, the factor $\frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}}$ comes from the calculated formula weight of 58.44 u for NaCl. The data are now substituted into Equation 7.5:

$$M = \frac{0.0445\text{ mol NaCl}}{0.100\text{ L solution}} = 0.445\,\frac{\text{mol NaCl}}{\text{L solution}}$$

The solution is 0.445 molar, or 0.445 M.

7.5 **a.** To calculate %(w/w), the mass of solute contained in a specific mass of solution is needed. The mass of solute is 0.900 g, and the mass of solution is equal to the solvent mass (100 g) plus the solute mass (0.900 g):

$$\%(\text{w/w}) = \frac{\text{solute mass}}{\text{solution mass}} \times 100 = \frac{0.900\text{ }\cancel{\text{g}}}{100.9\text{ }\cancel{\text{g}}} \times 100 = 0.892\ \%(\text{w/w})$$

To calculate %(w/v), the number of grams of solute must be known along with the number of milliliters of solution. The mass of solute is 0.900 g, and the solution volume is 100 mL:

$$\%(\text{w/v}) = \frac{\text{g of solute}}{\text{mL of solution}} \times 100 = \frac{0.900\text{ g}}{100\text{ mL}} \times 100 = 0.900\ \%(\text{w/v})$$

b. The given quantity is 30 mL of beverage, and the desired quantity is milliliters of pure alcohol. The %(v/v) provides the necessary factor:

$$30\text{ }\cancel{\text{mL beverage}} \times \frac{45\text{ mL alcohol}}{100\text{ }\cancel{\text{mL beverage}}} = 14\text{ mL alcohol}$$

7.6 **a.** $M = \dfrac{\text{mol of solute}}{\text{liters of solution}}$

$$\begin{aligned}\text{mol of solute} &= (M)(\text{liters of solution})\\ &= (1.00\text{ M})(0.500\text{ L})\\ &= 0.500\text{ mol of solute}\end{aligned}$$

The solute is $MgCl_2$, which has a formula weight of 95.2 u. The formula weight provides the factor in the following calculation:

$$0.500\text{ }\cancel{\text{mol MgCl}_2} \times \frac{95.2\text{ g MgCl}_2}{1\text{ }\cancel{\text{mol MgCl}_2}} = 47.6\text{ g MgCl}_2$$

The solution is prepared by putting 47.6 g of $MgCl_2$ into a 500-mL flask and adding pure water to the mark, making certain all the solid solute dissolves and the resulting solution is well mixed.

b. $$\%(\text{w/v}) = \frac{\text{g of solute}}{\text{mL of solution}} \times 100$$

$$\begin{aligned}\text{g of solute} &= \frac{\%(\text{w/v})(\text{mL of solution})}{100}\\ &= \frac{(12.0\%)(100\text{ mL})}{100} = 12.0\text{ g}\end{aligned}$$

The solution is prepared by putting 12.0 g of $MgCl_2$ into a 100-mL flask and adding pure water to the mark, making certain all the solid solute dissolves and the resulting solution is well mixed.

c. $$\%(\text{v/v}) = \frac{\text{solute volume}}{\text{solution volume}} \times 100$$

$$\begin{aligned}\text{solute volume} &= \frac{\%(\text{v/v})(\text{solution volume})}{100}\\ &= \frac{(20.0\%)(1.00\text{ L})}{100} = 0.200\text{ L}\\ &= 200\text{ mL}\end{aligned}$$

The solution is prepared by putting 200 mL of ethylene glycol into a 1.00-L flask and adding pure water to the mark, making certain the two liquids are completely mixed to form the final solution.

7.7 Equation 7.9 is used to calculate the volume of 6.00 M NaOH solution needed.

$$(C_c)(V_c) = (C_d)(V_d)$$
$$(6.00\ \text{M})(V_c) = (0.250\ M)(500\ mL)$$
$$V_c = \frac{(0.250\ \cancel{M})(500\ \text{mL})}{(6.00\ \cancel{M})} = 20.8\ \text{mL}$$

The solution is prepared by putting 20.8 mL of 6.00 M NaOH solution into a 500-mL flask, adding pure water to the mark, and making certain the resulting solution is well mixed.

7.8 **a.** Because $CaCl_2$ is a strong electrolyte, it dissociates completely:

$CaCl_2 \rightarrow Ca^{2+} + 2Cl^-$. Thus, $n = 3$.

$$\Delta t_b = nK_b\text{M} = (3)(0.52°\text{C}/\cancel{M})(0.100\ \cancel{M}) = 0.16°\text{C}$$

Because the boiling point of a solution is higher than the boiling point of the pure solvent, Δt_b is added to the boiling point of the pure solvent.

Solution B.P. = 100.00°C + 0.16°C = 100.16°C

$$\Delta t_f = nK_f\text{M} = (3)(1.86°\text{C}/\cancel{M})(0.100\ \cancel{M}) = 0.558°\text{C}$$

Because the freezing point of a solution is lower than the freezing point of the pure solvent, Δt_f is subtracted from the freezing point of the solvent.

Solution F.P. = 0.00°C − 0.558°C = −0.558°C = −0.56°C

$$\pi = nMRT$$
$$= (3)(0.100\ \cancel{\text{mol}}/\cancel{L})(62.4\ \cancel{L}\ \text{torr}/\cancel{K}\ \cancel{\text{mol}})(300\ \cancel{K})$$
$$= 5.62 \times 10^3\ \text{torr} = 7.39\ \text{atm}$$

b. Because ethylene glycol does not dissociate in solution, $n = 1$.

$$\Delta t_b = nK_b\text{M} = (1)(0.52°\text{C}/\cancel{M})(0.100\ \cancel{M}) = 0.052°\text{C}$$

Solution B.P. = 100.00°C + 0.052°C = 100.05°C

$$\Delta t_f = nK_f\text{M} = (1)(1.86°\text{C}/\cancel{M})(0.100\ \cancel{M}) = 0.186°\text{C}$$

Solution F.P. = 0.00°C − 0.186°C = −0.186°C
= −0.19°C

$$\pi = nMRT$$
$$= (1)(0.100\ \cancel{\text{mol}}/\cancel{L})(62.4\ \cancel{L}\ \text{torr}/\cancel{K}\ \cancel{\text{mol}})(300\ \cancel{K})$$
$$= 1.87 \times 10^3\ \text{torr} = 2.46\ \text{atm}$$

CHAPTER 8

8.1 Because only Ce^{4+} and Fe^{2+} are mixed, the initial concentration of Ce^{3+} is 0.

$$\text{Rate} = \frac{C_t - C_0}{\Delta t} = \frac{1.50 \times 10^{-5}\ \text{mol/L} - 0\ \text{mol/L}}{75.0\ \text{s}}$$
$$= 2.00 \times 10^{-7}\ \frac{\text{mol/L}}{\text{s}}$$

8.2 **a.** $K = \dfrac{[NO_2]^2}{[N_2O_4]}$

b. $K = \dfrac{[N_2O][NO_2]}{[NO]^3}$

8.3 **a.** $K = \dfrac{[IBr]^2}{[Br_2][I_2]}$

$$= \frac{(1.96 \times 10^{-2})^2}{(1.50 \times 10^{-1})(5.00 \times 10^{-2})}$$
$$= 5.12 \times 10^{-2}$$

The small value of K indicates the equilibrium position is toward the left.

b. $K = \dfrac{[NH_3]^2}{[N_2][H_2]^3}$

$$= \frac{(9.00)^2}{(9.23 \times 10^{-3})(2.77 \times 10^{-2})^3}$$
$$= 4.13 \times 10^8$$

The large K value indicates the equilibrium position is toward the right.

8.4 **a.** Heat + $NH_4NO_3(s) \rightleftarrows NH_4^+(aq) + NO_3^-(aq)$

The equilibrium will shift to the right when heat is added in an attempt to use up the added heat. This shift corresponds to dissolving more of the solid at the higher temperature. The solubility is higher at a higher temperature.

b. $2SO_2(g) + O_2(g) \rightleftarrows 2SO_3(g)$

If O_2 were removed from an equilibrium mixture, the equilibrium would shift left in an attempt to replenish the removed O_2. This shift would reduce the amount of SO_3 present at equilibrium, which means the concentration of SO_3 would be lower than it was in the initial equilibrium.

CHAPTER 9

9.1 **a.** $HC_2H_3O_2 + H_2O \rightleftarrows H_3O^+ + C_2H_3O_2^-$

acid — base — acid — base

conjugate pair (H_2O / H_3O^+)
conjugate pair ($HC_2H_3O_2$ / $C_2H_3O_2^-$)

b. $NO_2^- + H_2O \rightleftarrows OH^- + HNO_2$

base — acid — base — acid

conjugate pair (H_2O / OH^-)
conjugate pair (NO_2^- / HNO_2)

c. $HS^- + H_2O \rightleftarrows H_3O^+ + S^{2-}$

acid — base — acid — base

conjugate pair (H_2O / H_3O^+)
conjugate pair (HS^- / S^{2-})

9.2 **a.** The anhydrous compound is called hydrogen iodide. The name of the water solution is obtained by dropping *hydrogen* from the anhydrous compound name and adding the prefix *hydro-* to the stem *iod*. The *-ide* suffix on the *iod* stem is replaced by the suffix *-ic* to give the name *hydroiodic*. The word *acid* is added, giving the final name *hydroiodic acid* for the water solution.

b. The anhydrous compound is called hydrogen bromide. The name of the water solution is obtained the same way it was for HI(aq) in part a, using the stem *brom* in place of *iod*. The resulting name for the water solution is *hydrobromic acid.*

9.3 The removal of the two H^+ ions leaves behind the CO_3^{2-} polyatomic ion. From Table 4.6, this ion is the carbonate ion. According to rules 1-4, the *-ate* suffix is replaced by the *-ic* suffix to give the name *carbonic acid*.

9.4 **a.** Solution is basic because $[OH^-]$ is greater than 1.0×10^{-7} mol/L:

$$[H_3O^+] = \frac{1.0 \times 10^{-14}(\text{mol/L})^2}{[OH^-]} = \frac{1.0 \times 10^{-14}(\text{mol/L})^2}{1.0 \times 10^{-5}\ \text{mol/L}}$$
$$= 1.0 \times 10^{-9}\ \text{mol/L}$$

b. Solution is basic because $[H_3O^+]$ is less than 1.0×10^{-7} mol/L:

$$[OH^-] = \frac{1.0 \times 10^{-14}(\text{mol/L})^2}{[H_3O^+]} = \frac{1.0 \times 10^{-14}(\text{mol/L})^2}{1.0 \times 10^{-9}\ \text{mol/L}}$$
$$= 1.0 \times 10^{-5}\ \text{mol/L}$$

This solution has the same $[H_3O^+]$ and $[OH^-]$ as the solution in part a.

c. Solution is acidic because $[H_3O^+]$ is greater than 1.0×10^{-7} mol/L:

$$[OH^-] = \frac{1.0 \times 10^{-14}(\text{mol/L})^2}{[H_3O^+]} = \frac{1.0 \times 10^{-14}(\text{mol/L})^2}{1.0 \times 10^{-2}\ \text{mol/L}}$$
$$= 1.0 \times 10^{-12}\ \text{mol/L}$$

9.5 **a.** $[H^+] = 1 \times 10^{-14}$ mol/L. pH is the negative of the exponent used to express $[H^+]$, so pH $= -(-14) = 14.0$.

b. $[OH^-] = 1.0$ mol/L. The value of $[H^+]$ is calculated:

$$[H^+] = \frac{1 \times 10^{-14}(\text{mol/L})^2}{[OH^-]} = \frac{1 \times 10^{-14}(\text{mol/L})^2}{1.0\ \text{mol/L}}$$
$$= 1 \times 10^{-14}\ \text{mol/L}$$

pH is the negative of the exponent used to express $[H^+]$, so pH $= -(-14) = 14.0$.

c. $[OH^-] = 1 \times 10^{-8}$ mol/L. The value of $[H^+]$ is calculated:

$$[H^+] = \frac{1 \times 10^{-14}(\text{mol/L})^2}{[OH^-]} = \frac{1 \times 10^{-14}(\text{mol/L})^2}{1 \times 10^{-8}\ \text{mol/L}}$$
$$= 1 \times 10^{-6}\ \text{mol/L}$$

pH is the negative of the exponent used to express $[H^+]$, so pH $= -(-6) = 6.0$.

9.6 **a.** pH $= 10.0$, and

$$[H^+] = 1 \times 10^{-\text{pH}} = 1 \times 10^{-10}\ \text{mol/L}$$
$$[OH^-] = \frac{K_w}{[H^+]} = \frac{1 \times 10^{-14}\ (\text{mol/L})^2}{1 \times 10^{-10}\ \text{mol/L}} = 1 \times 10^{-4}\ \text{mol/L}$$

b. pH $= 4.0$, and $[H^+] = 1 \times 10^{-\text{pH}} = 1 \times 10^{-4}$

$$[OH^-] = \frac{K_w}{[H^+]} = \frac{1 \times 10^{-14}\ (\text{mol/L})^2}{1 \times 10^{-4}\ \text{mol/L}} = 1 \times 10^{-10}\ \text{mol/L}$$

c. pH $= 5.0$, and $[H^+] = 1 \times 10^{-\text{pH}} = 1 \times 10^{-5}$

$$[OH^-] = \frac{K_w}{[H^+]} = \frac{1 \times 10^{-14}\ (\text{mol/L})^2}{1 \times 10^{-5}\ \text{mol/L}} = 1 \times 10^{-9}\ \text{mol/L}$$

9.7 **a.** The calculator answer is 4.3768. The correctly rounded value is 4.38.

b. The calculator answer is 8.0915. The correctly rounded value is 8.09.

9.8 **a.** The calculator answer is 0.0017783, or 1.7783×10^{-3}. The correctly rounded value should have two significant figures to match the two figures to the right of the decimal in the pH value. The answer is 1.8×10^{-3} mol/L.

b. The calculator answer is 4.6774×10^{-9}. The correctly rounded answer is 4.7×10^{-9} mol/L.

9.9 According to Table 9.4, concentrated NH_3 stock solution is 15 M. Equation 7.9 is used to determine the amount of this solution needed.

$$C_cV_c = C_dV_d$$
$$(15\ \text{M})(V_c) = (3.0\ \text{M})(500\ \text{mL})$$
$$V_c = \frac{(3.0\ \cancel{\text{M}})(500\ \text{mL})}{(15\ \cancel{\text{M}})}$$
$$= 100\ \text{mL}$$

Because the resulting solution molarity is given using only two significant figures, the volumes can be measured using graduated cylinders. Measure 100 mL of stock (15 M) aqueous ammonia, put it into a container and add 400 mL of distilled water. Mix the resulting solution well.

9.10 $2HCl(aq) + Sr(HCO_3)_2(s) \rightarrow SrCl_2(aq) + 2CO_2(g) + 2H_2O(\ell)$

Total Ionic: $2H^+(aq) + 2Cl^-(aq) + Sr(HCO_3)_2(s) \rightarrow Sr^{2+}(aq) + 2Cl^-(aq) + 2CO_2(g) + 2H_2O(\ell)$
Cl^- is a spectator ion.

Net Ionic: $2H^+(aq) + Sr(HCO_3)_2(s) \rightarrow Sr^{2+}(aq) + 2CO_2(g) + 2H_2O(\ell)$

9.11 **a.** Molecular: $Ca(s) + 2H_2O(\ell) \rightarrow H_2(g) + Ca(OH)_2(s)$

Total Ionic: $Ca(s) + 2H_2O(\ell) \rightarrow H_2(g) + Ca(OH)_2(s)$

Net Ionic: $Ca(s) + 2H_2O(\ell) \rightarrow H_2(g) + Ca(OH)_2(s)$

All three equations are the same because none of the reactants or products form ions in solution.

b. Molecular: $Mg(s) + H_2SO_4(aq) \rightarrow H_2(g) + MgSO_4(aq)$

Total Ionic: $Mg(s) + 2H^+(aq) + SO_4^{2-}(aq) \rightarrow H_2(g) + Mg^{2+}(aq) + SO_4^{2-}(aq)$
The SO_4^{2-} is a spectator ion.

Net Ionic: $Mg(s) + 2H^+(aq) \rightarrow H_2(g) + Mg^{2+}(aq)$

9.12 **a.** Molecular: $HNO_3(aq) + NaOH(aq) \rightarrow H_2O(\ell) + NaNO_3(aq)$

Total Ionic: $H^+(aq) + NO_3^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow H_2O(\ell) + Na^+(aq) + NO_3^-(aq)$
Na^+ and NO_3^- are spectator ions.

Net Ionic: $H^+(aq) + OH^-(aq) \rightarrow H_2O(\ell)$

b. Molecular: $H_2SO_4(aq) + 2KOH(aq) \rightarrow 2H_2O(\ell) + K_2SO_4(aq)$

Total Ionic:
$2H^+(aq) + SO_4^{2-}(aq) + 2K^+(aq) + 2OH^-(aq) \rightarrow 2H_2O(\ell) + 2K^+(aq) + SO_4^{2-}(aq)$
K^+ and SO_4^{2-} are spectator ions.

Net Ionic: $2H^+(aq) + 2OH^-(aq) \rightarrow 2H_2O(\ell)$

9.13 $6HCl(aq) + 2Al(s) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

$6HCl(aq) + Al_2O_3(s) \rightarrow 2AlCl_3(aq) + 3H_2O(\ell)$

$3HCl(aq) + Al(OH)_3(s) \rightarrow AlCl_3(aq) + 3H_2O(\ell)$

$6HCl(aq) + Al_2(CO_3)_3(s) \rightarrow 2AlCl_3(aq) + 3H_2O(\ell) + 3CO_2(g)$

$3HCl(aq) + Al(HCO_3)_3(s) \rightarrow AlCl_3(aq) + 3H_2O(\ell) + 3CO_2(g)$

9.14 **a.** The dissociation reaction is $NaCl(aq) \rightarrow Na^+(aq) + Cl^-(aq)$. Thus, 1 mol of NaCl produces 1 mol of Na^+ or 1 mol of positive charges. Thus, 1 mol NaCl = 1 eq NaCl. Therefore,

$$0.10\ \cancel{\text{mol NaCl}} \times \frac{1\ \text{eq NaCl}}{1\ \cancel{\text{mol NaCl}}} = 0.10\ \text{eq NaCl}$$

Also, because 1 eq = 1000 meq,

$$0.10\ \cancel{\text{eq}} \times \frac{1000\ \text{meq}}{1\ \cancel{\text{eq}}} = 1.0 \times 10^2\ \text{meq}$$

b. The dissociation reaction is $Mg(NO_3)_2(aq) \rightarrow Mg^{2+}(aq) + 2NO_3^-(aq)$. Thus, 1 mol of $Mg(NO_3)_2$ produces 1 mol of Mg^{2+} or 2 mol of positive charges. Thus, 1 mol $Mg(NO_3)_2$ = 2 eq $Mg(NO_3)_2$. Therefore,

$$0.10\ \cancel{\text{mol Mg(NO}_3)_2} \times \frac{2\ \text{eq Mg(NO}_3)_2}{1\ \cancel{\text{mol Mg(NO}_3)_2}} = 0.20\ \text{eq Mg(NO}_3)_2$$

Also, because 1 eq = 1000 meq,

$$0.20\ \cancel{\text{eq}} \times \frac{1000\ \text{meq}}{1\ \cancel{\text{eq}}} = 2.0 \times 10^2\ \text{meq}$$

9.15 The Cl^- ion has a single charge, so we may write:

$$1.00\ \text{mol NaCl} = 1.00\ \text{mol Cl}^- = 1.00\ \text{eq Cl}^- = 1.00\ \text{eq NaCl}$$

As in Example 9.11, the pattern for the calculation is liters solution $A \rightarrow$ eq A, and the pathway is liters Cl^- solution $\rightarrow$ eq Cl^-. The conversion factor comes from the concentration of 0.103 eq/L given in the problem:

$$(0.250\ \cancel{\text{L}}\ \text{Cl}^-\ \cancel{\text{solution}})\left(\frac{0.103\ \text{eq Cl}^-}{1.00\ \cancel{\text{L solution}}}\right) = 0.0258\ \text{eq Cl}^-$$

The equivalents of Cl^- are converted to the quantities asked for by using factors from the relationships given above and the formula weight for NaCl, 58.44 u:

$$(0.0258\ \cancel{\text{eq Cl}^-})\left(\frac{1.00\ \text{eq NaCl}}{1.00\ \cancel{\text{eq Cl}^-}}\right) = 0.0258\ \text{eq NaCl}$$

$$(0.0258\ \cancel{\text{eq NaCl}})\left(\frac{1.00\ \text{mol NaCl}}{1.00\ \cancel{\text{eq NaCl}}}\right) = 0.0258\ \text{mol NaCl}$$

$$(0.0258\ \cancel{\text{mol NaCl}})\left(\frac{58.44\ \text{g NaCl}}{1.00\ \cancel{\text{mol NaCl}}}\right) = 1.51\ \text{g NaCl}$$

9.16 **a.** $HPO_4^{2-} \rightleftarrows H^+ + PO_4^{3-}$

$$K_a = \frac{[H^+][PO_4^{3-}]}{[HPO_4^{2-}]}$$

b. $HNO_2 \rightleftarrows H^+ + NO_2^-$

$$K_a = \frac{[H^+][NO_2^-]}{[HNO_2]}$$

c. $HF \rightleftarrows H^+ + F^-$

$$K_a = \frac{[H^+][F^-]}{[HF]}$$

9.17 **a.** In a series of similar oxyacids, acid strength increases with increases in the number of oxygens: $HClO_3$, $HClO_2$, HClO.

b. The anion from the weakest acid will be the strongest base. HNO_3 is a stronger acid than HNO_2, so NO_2^- is a stronger base than NO_3^-.

c. The anion of an acid behaves as a weaker acid than the acid from which it came. The anion actually behaves as a base in this case, so $HC_2H_3O_2$ is a stronger acid than $C_2H_3O_2^-$.

9.18 The pattern is liters solution $A \rightarrow$ mol B, and the pathway is liters NaOH solution $\rightarrow$ mol NaOH $\rightarrow$ mol H_3PO_4. In combined form, the steps in the factor-unit method are:

Step 1. 0.0141 L NaOH solution

Step 2. 0.0141 L NaOH solution = mol H_3PO_4

Step 3. $$0.0141\ \cancel{\text{L NaOH solution}} \times \frac{0.250\ \cancel{\text{mol NaOH}}}{1\ \cancel{\text{L NaOH solution}}} \times \frac{1\ \text{mol H}_3\text{PO}_4}{3\ \cancel{\text{mol NaOH}}} = \text{mol H}_3\text{PO}_4$$

Step 4. $$(0.0141)\left(\frac{0.250}{1}\right)\left(\frac{1\ \text{mol H}_3\text{PO}_4}{3}\right) = 0.00118\ \text{mol H}_3\text{PO}_4$$

The molarity of the H_3PO_4 solution is calculated:

$$\begin{aligned} M &= \frac{\text{mol H}_3\text{PO}_4}{\text{L H}_3\text{PO}_4\ \text{solution}} \\ &= \frac{0.00118\ \text{mol H}_3\text{PO}_4}{0.0250\ \text{L H}_3\text{PO}_4\ \text{solution}} \\ &= \frac{0.0472\ \text{mol H}_3\text{PO}_4}{\text{L H}_3\text{PO}_4\ \text{solution}} = 0.0472\ M \end{aligned}$$

9.19 **a.** The ions resulting from dissociation are Na^+ and NO_3^-. Na^+ is the cation of a strong base, and NO_3^- is the anion of a strong acid. Neither ion will hydrolyze significantly in water, so the solution pH will be about 7.

b. The ions resulting from dissociation are Na^+ and NO_2^-. Na^+ is the cation of a strong base and will not hydrolyze significantly. NO_2^- is the anion of a weak acid and will behave as a base in the hydrolysis reaction. The solution will therefore be basic, and the pH will be higher than 7.

c. The ions resulting from dissociation are K^+ and BO_3^{3-}. K^+ is the cation of a strong base and will not hydrolyze significantly. BO_3^{3-} is the anion of a weak acid and will behave as a base in the hydrolysis reaction. The solution will therefore be basic, and the pH will be higher than 7.

9.20 **a.** Because the acid (HCOOH) and conjugate base ($HCOO^-$) concentrations are the same, the pH will equal pK_a for the acid. This is shown by the following calculation:

$$\begin{aligned} \text{pH} &= pK_a + \log\frac{[B^-]}{[HB]} \\ &= 3.74 + \log\frac{[HCOO^-]}{[HCOOH]} \\ &= 3.74 + \log\frac{0.22\ \text{mol/L}}{0.22\ \text{mol/L}} \\ &= 3.74 + \log 1 \\ &= 3.74 + 0 = 3.74 \end{aligned}$$

b. The acid is H_2SO_3, and the conjugate base is HSO_3^- (produced when the $NaHSO_3$ salt dissociates).

$$\begin{aligned} \text{pH} &= pK_a + \log\frac{[B^-]}{[HB]} \\ &= 1.82 + \log\frac{(0.10\ \text{mol/L})}{(0.25\ \text{mol/L})} \\ &= 1.82 + \log 0.40 \\ &= 1.82 - 0.40 \\ &= 1.42 \end{aligned}$$

c. The acid is H_2CO_3 and the conjugate base is HCO_3^-. The desired pH is 7.40. Substitution into Equation 9.54 gives:

$$\text{pH} = \text{p}K_a + \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

$$7.40 = 6.37 + \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

$$7.40 - 6.37 = \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

$$1.03 = \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

We now know the log of the desired ratio. Use Step 3 in Table 9.3 to get the antilog of 1.03. The correctly rounded value is 11. Thus, the concentration of HCO_3^- must be 11 times the concentration of H_2CO_3 in the blood to maintain the desired pH.

CHAPTER 10

10.1 **a.** $^{131}_{53}\text{I}$ **b.** $^{0}_{-1}\beta$ **c.** $^{4}_{4}X$ **d.** $^{0}_{-4}X$

10.2 $^{234}_{90}\text{Th} \rightarrow {}^{0}_{-1}\beta + {}^{234}_{91}\text{Pa}$

In general: $^{A}_{Z}X \rightarrow {}^{0}_{-1}\beta + {}_{Z+1}^{A}Y$

When a β particle is emitted, the daughter has the same mass number and an atomic number higher by 1 than that of the decaying nucleus.

10.3 $^{A}_{Z}X \rightarrow {}^{0}_{1}\beta + {}_{Z-1}^{A}Y$

The atomic number of the daughter is 1 less than that of the decaying nucleus.

10.4 $^{A}_{Z}X + {}^{0}_{-1}e \rightarrow {}_{Z-1}^{A}Y$

The atomic number of the daughter is 1 less than that of the decaying nucleus.

10.5 **a.** $^{50}_{25}\text{Mn} \rightarrow {}^{0}_{1}\beta + {}^{50}_{24}\text{Cr}$

b. $^{54}_{25}\text{Mn} + {}^{0}_{-1}e \rightarrow {}^{54}_{24}\text{Cr}$

c. $^{56}_{25}\text{Mn} \rightarrow {}^{0}_{-1}\beta + {}^{56}_{26}\text{Fe}$

d. $^{224}_{88}\text{Ra} \rightarrow {}^{4}_{2}\alpha + {}^{220}_{86}\text{Rn}$

10.6 During the first half-life, the original 200.00 mg will be reduced to 100.00 mg. This will be reduced to 50.00 mg during the second half-life and to 25.00 mg during the third. Thus, 3 half-lives or 3(7.7 min) = 23.1 min will be required.

10.7 The elapsed time of 79.8 hours is 6 half-lives (79.8/13.3 = 6). The fraction remaining is 1/2 × 1/2 × 1/2 × 1/2 × 1/2 × 1/2 = 1/64 of the original diagnostic dose.

10.8 Equation 10.2 is used: $\frac{I_x}{I_y} = \frac{d_y^2}{d_x^2}$

$$\frac{10.0 \text{ units}}{I_5} = \frac{(5 \text{ ft})^2}{(25 \text{ ft})^2}$$

$$I_5 = \frac{(10.0 \text{ units})(25 \text{ ft})^2}{(5 \text{ ft})^2} = 250 \text{ units}$$

10.9 $^{55}_{25}\text{Mn} + {}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{55}_{26}\text{Fe}$

The product is iron-55.

CHAPTER 11

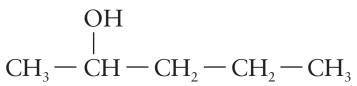
11.1 Look for the presence of carbon atoms.

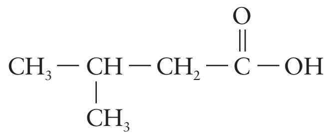
a. inorganic **d.** inorganic
b. organic **e.** organic
c. organic **f.** inorganic

11.2 Refer to Table 11.1 for help.

a. organic
b. organic
c. inorganic

11.3 Compound (a) is a structural isomer because it has the same molecular formula but a different structural formula.

11.4 **a.**


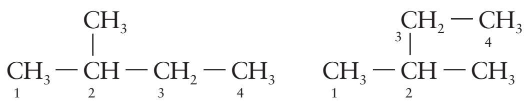
b.


11.5 **a.** The number of hydrogen atoms is twice the carbon atoms plus two: C_8H_{18}.

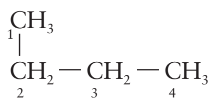
b. $CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3$

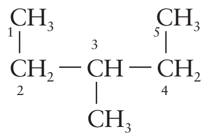
11.6 **a.** Same molecule: In both molecules, the five carbons are bonded in a continuous chain.

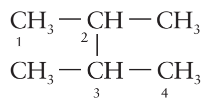
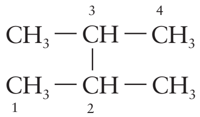
b. Same molecule: In both molecules, there is a continuous chain of four carbons with a branch at position 2.

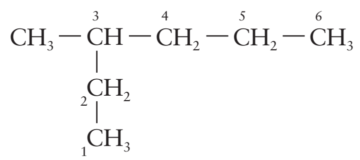


c. Structural isomers: Both molecules have a continuous chain of five carbons, but the branch is located at different positions.

11.7 **a.**

a butane

b.

a pentane

c.

or

a butane

11.8 **a.**


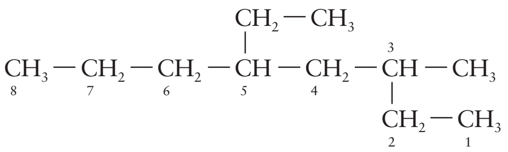
A CH_3 group is located at position 3. If the chain had been numbered beginning at the right, the CH_3 group would have been at position 4.

b. Numbering from the left, groups are located at positions 5, 5, 7. From the right, the groups are at positions 2, 4, 4. The first difference occurs with the first number, so numbering from the right (2, 4, 4) is correct.

11.9 Proceeding from the left, the groups are methyl, propyl, isopropyl, *sec*-butyl, and ethyl.

11.10 a. The chain is numbered from the right to give 2-methylhexane.

b.

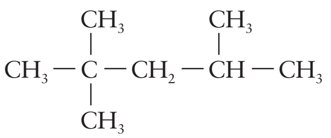


The chain is numbered from the right to give 5-ethyl-3-methyloctane.

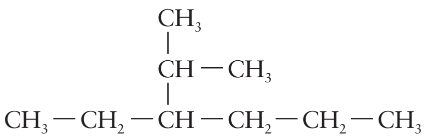
c. The chain is numbered from the right to give 4-isopropyl-2,3-dimethylheptane.

11.11

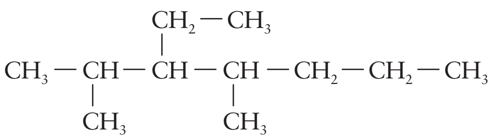
a.



b.



c.



11.12 a. 1,4-dimethylcyclohexane

b. The correct name is ethylcyclopropane. When only one group is attached to a ring, the position is not designated.

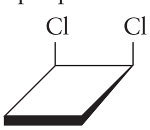
c. The name 1-ethyl-2-methylcyclopentane is correct, whereas 2-ethyl-1-methylcyclopentane is incorrect because the ring numbering begins with the carbon attached to the first group alphabetically.

11.13 a. (1) *Trans* because the two Br's are on opposite sides of the ring.

(2) *Cis*; both Cl's are on the same side.

(3) *Cis*; the two groups are on the same side.

b. In showing geometric isomers of ring compounds, it helps to draw the ring in perspective:



CHAPTER 12

12.1 In each of these alkenes, the double-bonded carbons occur at positions 1 and 2.

a. 3-bromo-1-propene

b. 2-ethyl-1-pentene

c. 3,4-dimethylcyclohexene

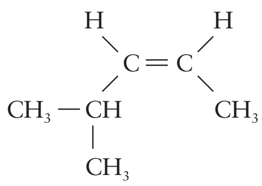
12.2 a. The chain is correctly numbered from the right to give 2-methyl-1,3-butadiene.

b. The chain is correctly numbered from the left to give 2-methyl-1,3,6-octatriene.

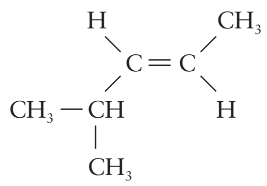
c. 7-bromo-1,3,5-cycloheptatriene

12.3 a. This structure does not exhibit geometric isomerism because there are two H's attached to the carbon at position 1.

b.



cis

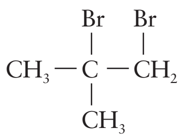


trans

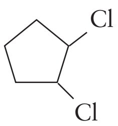
c. This structure does not exhibit geometric isomerism because there are two methyl groups attached to the left double-bonded carbon.

12.4

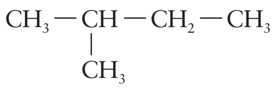
a.



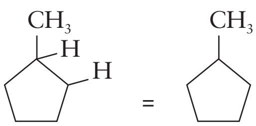
b.



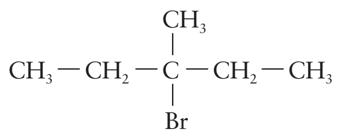
12.5 a.



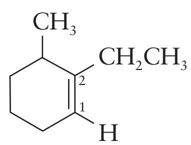
b.



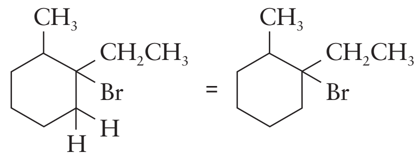
12.6 a. The major product will be the one where H attaches to the CH carbon:



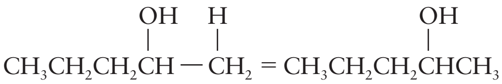
b. Position 1 on the ring has an attached hydrogen, whereas position 2 does not have any attached hydrogens:



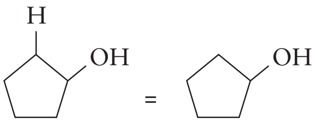
Thus, H attaches at position 1 to give:



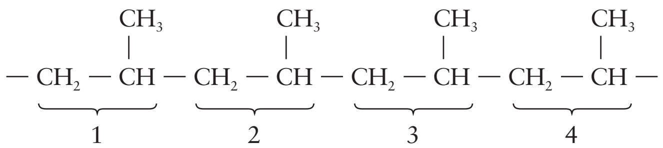
12.7 **a.** Markovnikov's rule predicts that H will attach at position 1 to give:



b.



12.8 The double bond becomes a single bond:



12.9 Each chain is correctly numbered from the right.

a. 2-pentyne **b.** 5-methyl-2-hexyne

12.10 **a.** Numbers or the term *meta* may be used:

1,3-diethylbenzene or *m*-diethylbenzene

b. The compound must be named as a derivative of cyclopentane. The correct name is 1-chloro-3-phenylcyclopentane.

c. Numbers must be used when there are three groups: 1,2,3-tribromobenzene.

d. If the compound is named as a derivative of benzoic acid, then the methyl group is at position 2. The name is 2-methylbenzoic acid.

Glossary

absolute zero The temperature at which all motion stops; a value of 0 on the Kelvin scale.

acid dissociation constant The ratio of product molarities (H^+ and acid anion) multiplied together and divided by the molarity of undissociated acid. All molarities are measured at equilibrium.

acidic solution A solution in which the concentration of H_3O^+ is greater than the concentration of OH^-; also, a solution in which pH is less than 7.

activation energy Energy needed to start some spontaneous processes. Once started, the processes continue without further stimulus or energy from an outside source.

activity series A tabular representation of the tendencies of metals to react with H^+.

acute radiation syndrome A condition following short-term exposure to intense radiation.

addition polymer A polymer formed by the linking together of many alkene molecules through addition reactions.

addition reaction A reaction in which a compound adds to a multiple bond.

aliphatic compound Any organic compound that is not aromatic.

alkaline solution See **basic solution**.

alkane A hydrocarbon that contains only single bonds.

alkene A hydrocarbon that contains one or more double bonds.

alkyl group A group differing by one hydrogen from an alkane.

alkyl halide See **haloalkane**.

alkyne A hydrocarbon that contains one or more triple bonds.

alpha particle The particle that makes up alpha rays; identical to the helium nucleus and composed of two protons and two neutrons.

anion A negatively charged ion.

aromatic hydrocarbon Any organic compound that contains the characteristic benzene ring or similar feature.

Arrhenius acid Any substance that provides H^+ ions when dissolved in water.

Arrhenius base Any substance that provides OH^- ions when dissolved in water.

atom The limit of chemical subdivision for matter.

atomic mass unit (u) A unit used to express the relative masses of atoms. One u is equal to $\frac{1}{12}$ the mass of an atom of carbon-12.

atomic number of an atom A number equal to the number of protons in the nucleus of an atom. Symbolically it is represented by Z.

atomic orbital A volume of space around atomic nuclei in which electrons of the same energy move. Groups of orbitals with the same *n* values form subshells.

atomic weight The mass of an average atom of an element expressed in atomic mass units.

Avogadro's law Equal volumes of gases measured at the same temperature and pressure contain equal numbers of molecules.

balanced equation An equation in which the number of atoms of each element in the reactants is the same as the number of atoms of that same element in the products.

basic solution A solution in which the concentration of OH^- is greater than the concentration of H_3O^+; also, a solution in which pH is greater than 7; also called alkaline solution.

basic unit of measurement A specific unit from which other units for the same quantity are obtained by multiplication or division.

becquerel A physical unit of radiation measurement corresponding to one nuclear disintegration per second.

beta particle The particle that makes up beta rays; identical to an electron but produced in the nucleus when a neutron is changed into a proton and an electron.

binary compound A compound made up of two different elements.

biological unit of radiation A radiation measurement unit that indicates the damage caused by radiation in living tissue.

boiling point The temperature at which the vapor pressure of a liquid is equal to the prevailing atmospheric pressure.

bond polarization A result of the attraction of shared electrons to the more electronegative atom of a bonded pair of atoms.

Boyle's law A gas law that describes the pressure and volume behavior of a gas sample kept at constant temperature. Mathematically, it is $PV = k$.

branched alkane An alkane in which at least one carbon atom is not part of a continuous chain.

branching chain reaction See **expanding chain reaction**.

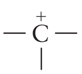
breeder reaction A nuclear reaction in which isotopes that will not undergo spontaneous fission are changed into isotopes that will.

Brønsted acid Any hydrogen-containing substance that is capable of donating a proton (H^+) to another substance.

Brønsted base Any substance capable of accepting a proton from another substance.

buffer A solution with the ability to resist changing pH when acids (H^+) or bases (OH^-) are added.

buffer capacity The amount of acid (H^+) or base (OH^-) that can be absorbed by a buffer without causing a significant change in pH.

carbocation An ion of the form .

catalyst A substance that changes (usually increases) reaction rates without being used up in the reaction.

cation A positively charged ion.

chain reaction A nuclear reaction in which the products of one reaction cause a repeat of the reaction to take place.

Charles's law A gas law that describes the temperature and volume behavior of a gas sample kept at constant pressure. Mathematically, it is $V/T = k'$.

chemical change A change matter undergoes that involves changes in composition.

chemical property A property matter demonstrates when attempts are made to change it into new substances.

cis- On the same side (as applied to geometric isomers).

cohesive force The attractive force between particles; it is associated with potential energy.

cold spot Tissue from which a radioactive tracer is excluded or rejected.

colligative property A solution property that depends only on the concentration of solute particles in solution.

colloid A homogeneous mixture of two or more substances in which the dispersed substances are present as larger particles than are found in solutions.

combination reaction A chemical reaction in which two or more substances react to form a single substance.

combined gas law A gas law that describes the pressure, volume, and temperature behavior of a gas sample. Mathematically, it is $PV/T = k''$.

compound A pure substance consisting of two or more kinds of atoms in the form of heteroatomic molecules or individual atoms.

compound formula A symbol for the molecule of a compound, consisting of the symbols of the atoms found in the molecule. Atoms present in numbers higher than 1 have the number indicated by a subscript.

compressibility The change in volume of a sample resulting from a pressure change acting on the sample.

concentration The amount of solute contained in a specific amount of solution.

condensation An exothermic process in which a gas or vapor is changed to a liquid or solid.

condensed structural formula A structural molecular formula showing the general arrangement of atoms but without showing all the covalent bonds.

conformations The different arrangements of atoms in space achieved by rotation about single bonds.

conjugate acid–base pair A Brønsted acid and its conjugate base.

conjugate base The species remaining when a Brønsted acid donates a proton.

copolymer An addition polymer formed by the reaction of two different monomers.

covalent bond The attractive force that results between two atoms that are both attracted to a shared pair of electrons.

critical mass The minimum amount of fissionable material needed to sustain a critical chain reaction at a constant rate.

critical reaction A constant-rate chain reaction.

crystal lattice A rigid three-dimensional arrangement of particles.

curie A physical unit of radiation measurement corresponding to 3.7×10^{10} nuclear disintegrations per second.

cycloalkane An alkane in which carbon atoms form a ring.

cyclotron A cyclic particle accelerator that works by changing electrical polarities as charged particles cross a gap. The particles are kept in a spiral path by a strong magnetic field.

Dalton's law of partial pressures The total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of the gases in the mixture.

daughter nuclei The new nuclei produced when unstable nuclei undergo radioactive decay.

decomposition A change in chemical composition that can result from heating.

decomposition reaction A chemical reaction in which a single substance reacts to form two or more simpler substances.

density The number given when the mass of a sample of a substance is divided by the volume of the same sample.

derived unit of measurement A unit obtained by multiplication or division of one or more basic units.

dialysis A process in which solvent molecules, other small molecules, and hydrated ions pass from a solution through a membrane.

dialyzing membrane A semipermeable membrane with pores large enough to allow solvent molecules, other small molecules, and hydrated ions to pass through.

diatomic molecule A molecule that contains two atoms.

diffusion A process that causes gases to spontaneously intermingle when they are brought together.

dipolar force The attractive force that exists between the positive end of one polar molecule and the negative end of another.

diprotic acid An acid that gives up two protons (H^+) per molecule when dissolved.

dispersed phase The substance present in a colloidal dispersion in amounts less than the amount of dispersing medium.

dispersing medium The substance present in a collodial dispersion in the largest amount.

dispersion force A very weak attraction force acting between the particles of all matter; results from momentary nonsymmetric electron distributions in molecules or atoms.

disruptive force The force resulting from particle motion; associated with kinetic energy.

dissolving A term used to describe the process of solution formation when the solvent and solutes form a homogeneous mixture.

distinguishing electron The last or highest-energy electron found in an element.

double bond The bond resulting from the sharing of two pairs of electrons.

double-replacement reaction A chemical reaction in which two compounds react and exchange partners to form two new compounds.

effective collision A collision that causes a reaction to occur between colliding molecules.

effusion A process in which a gas escapes from a container through a small hole.

electrolyte A solute that when dissolved in water forms a solution that conducts electricity.

electron capture A mode of radioactive decay for some unstable nuclei in which an electron from outside the nucleus is drawn into the nucleus, where it combines with a proton to form a neutron.

electronegativity The tendency of an atom to attract shared electrons of a covalent bond.

electronic configurations The detailed arrangements of electrons indicated by a specific notation, $1s^2 2s^2 2p^4$, and so on.

element A pure substance consisting of only one kind of atom in the form of homoatomic molecules or individual atoms.

elemental symbol A symbol assigned to an element that is based on the name of the element and consists of one capital letter or a capital letter followed by a lowercase letter.

emulsifying agent (stabilizing agent) A substance that when added to colloids prevents them from coalescing and settling.

endergonic process A process that gains or accepts energy as it takes place.

endothermic reaction A reaction that absorbs heat.

endpoint of a titration The point at which the titration is stopped on the basis of an indicator color change or pH meter reading.

entropy A measurement or indication of the disorder or randomness of a system; the more disorderly a system, the higher its entropy.

equilibrium concentration The unchanging concentration of reactants and products in a reaction system that is in a state of equilibrium.

equilibrium constant A constant that relates the equilibrium concentrations of products to those of reactants, each being raised to exponents obtained from stoichiometric coefficients.

equilibrium expression An equation relating the equilibrium constant and reactant and product concentrations.

equivalence point of a titration The point at which the unknown solution has exactly reacted with the known solution. Neither is in excess.

equivalent of salt The amount that will produce 1 mol of positive charges on dissolving and dissociating into ions.

evaporation An endothermic process in which a liquid is changed to a gas; also called vaporization.

exact numbers Numbers that have no uncertainty; numbers from defined relationships, counting numbers, and numbers that are part of reduced simple fractions.

exergonic process A process that gives up energy as it takes place.

exothermic reaction A reaction that liberates heat.

expanded structural formula A structural molecular formula showing all the covalent bonds.

expanding chain reaction A reaction in which the products of one reaction cause more than one more reaction to occur; also called branching chain reaction.

factors used in the factor-unit method Fractions obtained from fixed relationships between quantities.

family of the periodic table See **Group of the periodic table**.

first ionization energy The energy required to remove the first electron from a neutral atom.

formula weight The sum of the atomic weights of the atoms shown in the formula of an ionic compound.

functional group A unique reactive combination of atoms that differentiates molecules of organic compounds of one class from those of another.

gamma ray A high-energy ray that is like an X ray but with a higher energy.

gas law A mathematical relationship that describes the behavior of gases as they are mixed, subjected to pressure or temperature changes, or allowed to diffuse.

Geiger-Müller tube A radiation-detection device operating on the principle that ions form when radiation passes through a tube filled with low-pressure gas.

genome A summation of all the genetic material (chromosomes) of a cell; a person's genetic blueprint.

geometric isomers Molecules that differ in the three-dimensional arrangements of their atoms in space and not in the order of linkage of atoms.

Graham's law A mathematical expression that relates rates of effusion or diffusion of two gases to the masses of the molecules of the two gases.

gray A biological unit of radiation measurement that corresponds to the transfer of 1 J of energy to 1 kg of tissue.

group of the periodic table A vertical column of elements that have similar chemical properties; also called family of the periodic table.

half-life The time required for one-half the unstable nuclei in a sample to undergo radioactive decay.

haloalkane A derivative of an alkane in which one or more hydrogens are replaced by halogens; also called alkyl halide.

heat of fusion The amount of heat energy required to melt exactly 1 g of a solid substance at constant temperature.

heat of vaporization The amount of heat energy required to vaporize exactly 1 g of a liquid substance at constant temperature.

Henderson-Hasselbalch equation A relationship between the pH of a buffer, pK_a, and the concentrations of acid and salt in the buffer.

heteroatomic molecule A molecule that contains two or more kinds of atoms.

heterogeneous matter Matter with properties that are not the same throughout the sample.

heterogeneous catalyst A catalytic substance normally used in the form of a solid with a large surface area on which reactions take place; also called surface catalyst.

homeostasis A condition of chemical balance in the body.

homoatomic molecule A molecule that contains only one kind of atom.

homogeneous catalyst A catalytic substance that is distributed uniformly throughout the reaction mixture.

homogeneous matter Matter that has the same properties throughout the sample.

homologous series Compounds of the same functional class that differ by a $—CH_2—$ group.

hot spot Tissue in which a radioactive tracer concentrates.

Hund's rule A statement of the behavior of electrons when they occupy orbitals: Electrons will not join other electrons in an orbital if an empty orbital of the same energy is available for occupancy.

hybrid orbital An orbital produced from the combination of two or more nonequivalent orbitals of an atom.

hydrate A salt that contains specific numbers of water molecules as part of the solid crystalline structure.

hydrated ion An ion in solution that is surrounded by water molecules.

hydration The addition of water to a multiple bond.

hydrocarbon An organic compound that contains only carbon and hydrogen.

hydrogen bonding The result of attractive dipolar forces between molecules in which hydrogen atoms are covalently bonded to very electronegative elements (O, N, or F).

hydrogenation A reaction in which the addition of hydrogen takes place.

hydrolysis reaction Any reaction with water; for salts, a reaction of the acidic cation and/or basic anion of the salt with water.

hydrophobic Characterizing molecules or parts of molecules that repel (are insoluble in) water.

ideal gas law A gas law that relates the pressure, volume, temperature, and number of moles in a gas sample. The equation is $PV = nRT$.

immiscible A term used to describe liquids that are insoluble in each other.

inhibitor A substance that decreases reaction rates.

inner-transition element An element in which the distinguishing electron is found in an *f subshell.*

inorganic chemistry The study of the elements and all noncarbon compounds.

insoluble substance A substance that does not dissolve to a significant extent in the solvent.

internal energy The energy associated with vibrations within molecules.

International Unit (IU) A measure of vitamin activity, determined by biological methods.

inverse square law of radiation A mathematical way of saying that the intensity of radiation is inversely proportional to the square of the distance from the source of the radiation.

ionic bond The attractive force that holds together ions of opposite charge.

ion product of water The equilibrium constant for the dissociation of pure water into H_3O^+ and OH^-.

isoelectronic A term meaning "same electronic," used to describe atoms or ions that have identical electronic configurations.

isomerism A property in which two or more compounds have the same molecular formula but different arrangements of atoms.

isotopes Atoms having the same atomic number but different mass numbers; that is, they are atoms of the same element that contain different numbers of neutrons in their nuclei.

kinetic energy The energy a particle has as a result of its motion. Mathematically, it is $KE = \frac{1}{2}mv^2$.

lattice site The individual location occupied by a particle in a crystal lattice.

law of conservation of matter Atoms are neither created nor destroyed in chemical reactions.

Le Châtelier's principle The position of equilibrium will shift to compensate for changes made that upset a system at equilibrium.

Lewis structure A representation of an atom or ion in which the elemental symbol represents the atomic nucleus and all but the valence-shell electrons. The valence-shell electrons are represented by dots arranged around the elemental symbol.

limiting reactant The reactant present in a reaction in the least amount based on its reaction coefficients and molecular weight. The limiting reactant determines the maximum amount of product that can be formed.

limiting-reactant principle The maximum amount of product possible from a reaction is determined by the amount of reactant present in the least amount, based on its reaction coefficient and molecular weight.

linear accelerator A particle accelerator that works by changing electrical polarities as charged particles cross gaps between segments of a long tube.

Markovnikov's rule In the addition of H—X to an alkene, the hydrogen becomes attached to the carbon atom that is already bonded to more hydrogens.

mass A measurement of the amount of matter in an object.

mass number of an atom A number equal to the sum of the number of protons and neutrons in the nucleus of an atom. Symbolically, it is represented by A.

matter Anything that has mass and occupies space.

melting point The temperature at which a solid changes to a liquid; the solid and liquid have the same vapor pressure.

metal An element found in the left two-thirds of the periodic table. Most have the following properties: high thermal and electrical conductivities, high malleability and ductility, and a metallic luster.

metallic bond An attractive force responsible for holding solid metals together, originating from the attraction between positively charged atomic kernels that occupy the lattice sites and mobile electrons that move freely through the lattice.

metalloids Elements that form a narrow diagonal band in the periodic table between the metals and nonmetals; they have properties somewhat between those of metals and nonmetals.

mixture A physical blend of matter that can be physically separated into two or more components.

moderator A material capable of slowing down neutrons that pass through it.

molarity A solution concentration that is expressed in terms of the number of moles of solute contained in 1 L of solution.

mole The number of particles (atoms or molecules) contained in a sample of element or compound with a mass in grams equal to the atomic or molecular weight, respectively.

molecular equation An equation written with each compound represented by its un-ionized formula.

molecular weight The relative mass of a molecule expressed in atomic mass units and calculated by adding the atomic weights of the atoms in the molecule.

molecule The smallest particle of a pure substance that has the properties of that substance.

monomer The starting material that becomes the repeating unit of polymers.

monoprotic acid An acid that gives up only one proton (H^+) per molecule when dissolved.

net ionic equation An equation that contains only un-ionized or insoluble materials and ions that undergo changes as the reaction proceeds. All spectator ions are eliminated.

network solid A solid in which the lattice sites are occupied by atoms that are covalently bonded to each other.

neutral A term used to describe any water solution in which the concentrations of H_3O^+ and OH^- are equal; also, a water solution with $pH = 7$.

neutralization reaction A reaction in which an acid and base react completely, leaving a solution that contains only a salt and water.

noble gas configuration An electronic configuration in which the last eight electrons occupy and fill the *s* and *p* subshells of the highest-occupied shell.

nonelectrolyte A solute that when dissolved in water forms a solution that does not conduct electricity.

nonmetal An element found in the right one-third of the periodic table. Most occur as brittle, powdery solids or gases and have properties generally opposite those of metals.

nonpolar covalent bond A covalent bond in which the bonding pair of electrons is shared equally by the bonded atoms.

nonpolar molecule A molecule that contains no polarized bonds, or a molecule containing polarized bonds in which the resulting charges are distributed symmetrically throughout the molecule.

normal alkane Any alkane in which all the carbon atoms are aligned in a continuous chain.

normal boiling point The temperature at which the vapor pressure of a liquid is equal to one standard atmosphere (760 torr); also called standard boiling point.

nuclear fission A process in which large nuclei split into smaller, approximately equal-sized nuclei when bombarded by neutrons.

nuclear fusion A process in which small nuclei combine or fuse to form larger nuclei.

nucleus The central core of atoms that contains protons, neutrons, and most of the mass of atoms.

octet rule A rule for predicting electron behavior in reacting atoms: Atoms will gain or lose sufficient electrons to achieve an outer electron arrangement identical to that of a noble gas. This arrangement usually consists of eight electrons in the valence shell.

organic chemistry The study of carbon-containing compounds.

organic compound A compound that contains the element carbon.

osmolarity The product of *n* and M in the equation $\pi = nMRT$.

osmosis The process in which solvent flows through a semipermeable membrane into a solution.

osmotic pressure The hydrostatic pressure required to prevent the net flow of solvent through a semipermeable membrane into a solution.

oxidation Originally, a process involving a reaction with oxygen. Today it means a number of things, including a process in which electrons are given up, hydrogen is lost, or an oxidation number increases.

oxidation number A positive or negative number assigned to the elements in chemical formulas according to a specific set of rules; also called oxidation state.

oxidation state See **oxidation number**.

oxidizing agent The substance that contains an element that is reduced during a chemical reaction.

partial pressure The pressure an individual gas of a mixture would exert if it were in the container alone at the same temperature as the mixture.

Pauli exclusion principle A statement of the behavior of electrons when they occupy orbitals: Only electrons spinning in opposite directions can simultaneously occupy the same orbital.

percent A solution concentration that expresses the amount of solute in 100 parts of solution.

percentage yield The percentage of the theoretical amount of product actually produced by a reaction.

periodic law A statement about the behavior of the elements when they are arranged in a specific order. In its present form, it is stated as follows: Elements with similar chemical properties occur at regular (periodic) intervals when the elements are arranged in order of increasing atomic numbers.

period of the periodic table A horizontal row of elements.

pH The negative logarithm of the molar concentration of H^+ (H_3O^+) in a solution.

phenyl group A benzene ring with one hydrogen absent, C_6H_5—.

physical change A change matter undergoes without changing composition.

physical property A property of matter that can be observed or measured without trying to change the composition of the matter being studied.

physical unit of radiation A radiation measurement unit that indicates the activity of the source of the radiation; for example, the number of nuclear decays per minute.

pK_a The negative logarithm of K_a.

polar covalent bond A covalent bond that shows bond polarization; that is, the bonding electrons are shared unequally.

polar molecule A molecule that contains polarized bonds and in which the resulting charges are distributed asymmetrically throughout the molecule.

polyatomic ion A covalently bonded group of atoms that carries a net electrical charge.

polyatomic molecule A molecule that contains three or more atoms.

polycyclic aromatic compound A derivative of benzene in which carbon atoms are shared between two or more benzene rings.

polymer A very large molecule made up of repeating units.

polymerization A reaction that produces a polymer.

polyunsaturated A term usually applied to molecules with several double bonds.

position of equilibrium An indication of the relative amounts of reactants and products present at equilibrium.

positron A positively charged electron.

potential energy The energy a particle has as a result of attractive or repulsive forces acting on it.

pressure A force per unit area of surface on which the force acts. In measurements and calculations involving gases, it is often expressed in units related to measurements of atmospheric pressure.

product of a reaction A substance produced as a result of a chemical reaction; written on the right side of the equation representing the reaction.

pure substance Matter that has a constant composition and fixed properties.

rad A biological unit of radiation measurement that corresponds to the transfer of 1×10^{-2} J or 2.4×10^{-3} cal of energy to 1 kg of tissue.

radical An electron-deficient particle that is very reactive; also called free radical.

radioactive dating A process for determining the age of artifacts and rocks, based on the amount and half-life of radioisotopes contained in the object.

radioactive decay A process in which an unstable nucleus changes energy states and in the process emits radiation.

radioactive nuclei Nuclei that undergo spontaneous changes and emit energy in the form of radiation.

radioisotope An isotope of an element that emits nuclear radiation.

reactant of a reaction A substance that undergoes chemical change during a reaction; written on the left side of the equation representing the reaction.

reaction mechanism A detailed explanation of how a reaction actually takes place.

reaction rate The speed at which a chemical reaction takes place.

reducing agent The substance that contains an element that is oxidized during a chemical reaction.

reduction Originally, a process in which oxygen was lost. Today it means a number of things, including a process in which electrons are gained, hydrogen is accepted, or an oxidation number decreases.

rem A biological unit of radiation measurement that corresponds to the health effect produced by one roentgen of gamma rays or X rays regardless of the type of radiation involved.

representative element An element in which the distinguishing electron is found in an *s* or a *p* subshell.

retrovirus A virus in which RNA directs the synthesis of DNA.

roentgen A biological unit of radiation measurement used with X rays and gamma rays; the quantity of radiation that generates 2.1×10^{9} ion pairs per cubic centimeter of dry air or 1.8×10^{12} ion pairs per gram of tissue.

salt A solid crystalline ionic compound at room temperature that contains the cation of a base and the anion of an acid.

saturated hydrocarbon Another name for an alkane.

saturated solution A solution that contains the maximum amount possible of dissolved solute in a stable situation under the prevailing conditions of temperature and pressure.

scientific models Explanations for observed behavior in nature.

scientific notation A way of representing numbers consisting of a product between a nonexponential number and 10 raised to a whole-number exponent that may be positive or negative.

scintillation counter A radiation-detection device that works on the principle that phosphors give off light when struck by radiation.

shape Shape depends on the physical state of matter.

shell A location and energy of electrons around a nucleus that is designated by a value for n, where $n = 1, 2, 3$, etc.

side reaction A reaction that does not give the desired product of a reaction.

significant figures The numbers in a measurement that represent the certainty of the measurement, plus one number representing an estimate.

simple ion An atom that has acquired a net positive or negative charge by losing or gaining electrons.

single-replacement reaction A chemical reaction in which an element reacts with a compound and displaces another element from the compound.

solubility The maximum amount of solute that can be dissolved in a specific amount of solvent under specific conditions of temperature and pressure.

soluble substance A substance that dissolves to a significant extent in the solvent.

solute One or more substances present in a solution in amounts less than that of the solvent.

solution A homogeneous mixture of two or more pure substances.

solvent The substance present in a solution in the largest amount.

specific heat The amount of heat energy required to raise the temperature of exactly 1 g of a substance by exactly 1°C.

spectator ion An ion in a total ionic reaction that is not changed as the reaction proceeds. It appears in identical forms on the left and right sides of the equation.

spontaneous process A process that takes place naturally with no apparent cause or stimulus.

stable substance A substance that does not undergo spontaneous changes under the surrounding conditions.

standard atmosphere The pressure needed to support a 760-mm column of mercury in a barometer tube.

standard boiling point See **normal boiling point**.

standard conditions A set of specific temperature and pressure values used for gas measurements.

standard position for a decimal In scientific notation, the position to the right of the first nonzero digit in the nonexponential number.

state of equilibrium A condition in a reaction system in which the rates of the forward and reverse reactions are equal.

stereoisomers Compounds with the same structural formula but different spatial arrangements of atoms.

stoichiometry The study of mass relationships in chemical reactions.

strong acid or base An acid or base that dissociates (ionizes) essentially completely when dissolved to form a solution.

structural isomers Compounds that have the same molecular formula but in which the atoms bond in different patterns.

sublimation The endothermic process in which a solid is changed directly to a gas without first becoming a liquid.

subshell A component of a shell that is designated by a letter from the group *s, p, d,* and *f.*

supercritical mass The minimum amount of fissionable material that must be present to cause a branching chain reaction to occur.

supercritical reaction A branching chain reaction.

supersaturated solution An unstable solution that contains an amount of solute greater than the solute solubility under the prevailing conditions of temperature and pressure.

surface catalyst See **heterogeneous catalyst**.

thermal expansion A change in volume of a sample resulting from a change in temperature of the sample.

thermonuclear reaction A nuclear fusion reaction that requires a very high temperature to start.

titration An analytical procedure in which one solution (often a base) of known concentration is slowly added to a measured volume of an unknown solution (often an acid). The volume of the added solution is measured with a buret.

torr The pressure needed to support a 1-mm column of mercury in a barometer tube.

total ionic equation An equation written with all soluble ionic substances represented by the ions they form in solution.

tracer A radioisotope used medically because its progress through the body or localization in specific organs can be followed.

trans- On opposite sides (as applied to geometric isomers).

transition element An element in which the distinguishing electron is found in a *d* subshell.

transuranium element A synthetic element with atomic number greater than that of uranium.

triatomic molecule A molecule that contains three atoms.

triple bond The bond resulting from the sharing of three pairs of electrons.

triprotic acid An acid that gives up three protons (H^+) per molecule when dissolved.

Tyndall effect A property of colloids in which the path of a beam of light through the colloid is visible because the light is scattered.

universal gas constant The constant that relates pressure, volume, temperature, and the number of moles of gas in the ideal gas law.

unsaturated hydrocarbon A hydrocarbon containing one or more multiple bonds.

valence shell The outermost (highest-energy) shell that contains electrons.

vaporization See **evaporation**.

vapor pressure The pressure exerted by vapor that is in equilibrium with its liquid.

virus An infectious particle composed of only proteins and DNA or RNA.

vitamin An organic nutrient that the body cannot produce in the small amounts needed for good health.

volume/volume percent A concentration that expresses the volume of liquid solute contained in 100 volumes of solution.

VSEPR theory A theory based on the mutual repulsion of electron pairs; used to predict molecular shapes.

water of hydration Water retained as a part of the solid crystalline structure of some salts.

weak (or moderately weak) acid or base An acid or base that dissociates (ionizes) less than completely when dissolved to form a solution.

weight A measurement of the gravitational force acting on an object.

weight/volume percent A concentration that expresses the grams of solute contained in 100 mL of solution.

weight/weight percent A concentration that expresses the mass of solute contained in 100 mass units of solution.

Index

C

D

E

F

O

P

R

S

T

U

V

This page intentionally left blank

PERIODIC TABLE OF THE ELEMENTS

KEY

79 **Au** Gold 197.0	Atomic number Symbol Name Atomic weight (rounded to four significant figures)

- Metals
- Metalloids
- Nonmetals, noble gases

Group number, IUPAC system — (1)
Group number, U.S. system — IA
Group designation — (2) IIA
Period number — 2

Period	(1) IA	(2) IIA	(3) IIIB	(4) IVB	(5) VB	(6) VIB	(7) VIIB	(8) VIIIB	(9) VIIIB	(10) VIIIB	(11) IB	(12) IIB	(13) IIIA	(14) IVA	(15) VA	(16) VIA	(17) VIIA	Noble Gases (18) VIIIA	Period
1	1 **H** Hydrogen 1.008																	2 **He** Helium 4.003	1
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012											5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18	2
3	11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.31											13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.06	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95	3
4	19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.87	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.41	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.64	33 **As** Arsenic 74.92	34 **Se** Selenium 78.96	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80	4
5	37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.1	45 **Rh** Rhodium 102.9	46 **Pd** Palladium 106.4	47 **Ag** Silver 107.9	48 **Cd** Cadmium 112.4	49 **In** Indium 114.8	50 **Sn** Tin 118.7	51 **Sb** Antimony 121.8	52 **Te** Tellurium 127.6	53 **I** Iodine 126.9	54 **Xe** Xenon 131.3	5
6	55 **Cs** Cesium 132.9	56 **Ba** Barium 137.3	57 **La** Lanthanum 138.9	72 **Hf** Hafnium 178.5	73 **Ta** Tantalum 180.9	74 **W** Tungsten 183.9	75 **Re** Rhenium 186.2	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.2	78 **Pt** Platinum 195.1	79 **Au** Gold 197.0	80 **Hg** Mercury 200.6	81 **Tl** Thallium 204.4	82 **Pb** Lead 207.2	83 **Bi** Bismuth 209.0	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)	6
7	87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (263)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (267)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (276)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (280)	112 **—** — (285)	113 **—** — (284)	114 **—** — (289)	115 **—** — (288)			118 **—** — (294)	7

Mass numbers in parentheses are the most stable radioactive isotope.

Period															Period
6	58 **Ce** Cerium 140.1	59 **Pr** Praseodymium 140.9	60 **Nd** Neodymium 144.2	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.4	63 **Eu** Europium 152.0	64 **Gd** Gadolium 157.3	65 **Tb** Terbium 158.9	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 164.9	68 **Er** Erbium 167.3	69 **Tm** Thulium 168.9	70 **Yb** Ytterbium 173.0	71 **Lu** Lutetium 175.0	6
7	90 **Th** Thorium (232)	91 **Pa** Protactinium (231)	92 **U** Uranium (238)	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)	7

OWL Online Web Learning

UMassAmherst

The results are in–and they prove that **OWL** will help you **study smarter and succeed** in chemistry!

OWL for General, Organic, and Biochemistry

The Chemist's Choice. The Student's Solution.

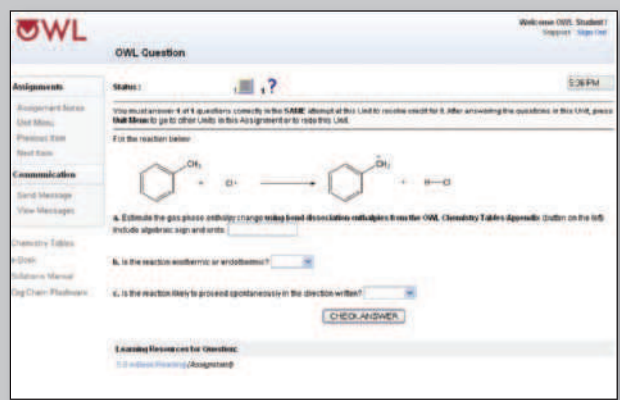
Strengthen your understanding with **OWL, the #1 online learning system for chemistry!**

Developed *by* chemistry instructors, **OWL** has already helped hundreds of thousands of students master chemistry through tutorials, interactive simulations, and algorithmically generated homework questions that provide instant answer-specific feedback.

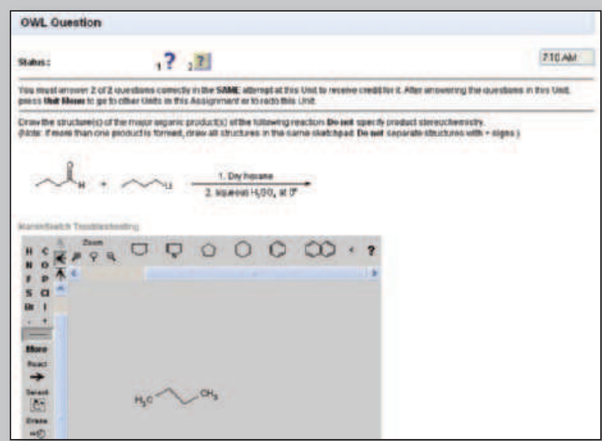
OWL now features a modern, intuitive interface and is the only system specifically designed to support **mastery learning**, where you can work as long as you need to master each chemical concept and skill.

The newest version of **OWL for General, Organic, and Biochemistry** offers:

- **A wide range of assignment types**—tutorials, interactive simulations, short answer questions, and algorithmically generated homework questions that provide instant, answer-specific feedback, including ***end-of-chapter questions from your textbook***



- **MarvinSketch**, an advanced molecular drawing program for drawing gradable structures



In addition, **OWL** also offers:

- **e-Books**, fully integrated electronic textbooks correlated to OWL questions
- **Jmol**, a molecular visualization program for rotating molecules and measuring bond distances and angles.

"I attribute my good grade in this course largely to **OWL.**"

Student, Michigan

"I liked the **step-by-step tutorials** and having all the charts (periodic table, etc.) a click away."

Student, Texas

To learn more, visit us online at: **www.cengage.com/OWL**

Features within the Text

Chemistry Around Us

Chemistry and Your Health

At the Counter

Study Skills

How Reactions Occur

Table of Atomic Weights and Numbers

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	(227)	Mendelevium	Md	101	(260)
Aluminum	Al	13	26.98	Mercury	Hg	80	200.6
Americium	Am	95	(243)	Molybdenum	Mo	42	95.94
Antimony	Sb	51	121.8	Neodymium	Nd	60	144.2
Argon	Ar	18	39.95	Neon	Ne	10	20.18
Arsenic	As	33	74.92	Neptunium	Np	93	(237)
Astatine	At	85	(210)	Nickel	Ni	28	58.69
Barium	Ba	56	137.3	Niobium	Nb	41	92.91
Berkelium	Bk	97	(247)	Nitrogen	N	7	14.01
Beryllium	Be	4	9.012	Nobelium	No	102	(259)
Bismuth	Bi	83	209.0	Osmium	Os	76	190.2
Bohrium	Bh	107	(267)	Oxygen	O	8	16.00
Boron	B	5	10.81	Palladium	Pd	46	106.4
Bromine	Br	35	79.90	Phosphorus	P	15	30.97
Cadmium	Cd	48	112.4	Platinum	Pt	78	195.1
Calcium	Ca	20	40.08	Plutonium	Pu	94	(244)
Californium	Cf	98	(251)	Polonium	Po	84	(209)
Carbon	C	6	12.01	Potassium	K	19	39.10
Cerium	Ce	58	140.1	Praseodymium	Pr	59	140.9
Cesium	Cs	55	132.9	Promethium	Pm	61	(145)
Chlorine	Cl	17	35.45	Protactinium	Pa	91	(231)
Chromium	Cr	24	52.00	Radium	Ra	88	(226)
Cobalt	Co	27	58.93	Radon	Rn	86	(222)
Copper	Cu	29	63.55	Rhenium	Re	75	186.2
Curium	Cm	96	(247)	Rhodium	Rh	45	102.9
Darmstadtium	Ds	110	(281)	Roentgenium	Rg	111	(280)
Dubnium	Db	105	(262)	Rubidium	Rb	37	85.47
Dysprosium	Dy	66	162.5	Ruthenium	Ru	44	101.1
Einsteinium	Es	99	(252)	Rutherfordium	Rf	104	(263)
Erbium	Er	68	167.3	Samarium	Sm	62	150.4
Europium	Eu	63	152.0	Scandium	Sc	21	44.96
Fermium	Fm	100	(257)	Seaborgium	Sg	106	(266)
Fluorine	F	9	19.00	Selenium	Se	34	78.96
Francium	Fr	87	(223)	Silicon	Si	14	28.09
Gadolinium	Gd	64	157.3	Silver	Ag	47	107.9
Gallium	Ga	31	69.72	Sodium	Na	11	22.99
Germanium	Ge	32	72.64	Strontium	Sr	38	87.62
Gold	Au	79	197.0	Sulfur	S	16	32.07
Hafnium	Hf	72	178.5	Tantalum	Ta	73	180.9
Hassium	Hs	108	(277)	Technetium	Tc	43	(98)
Helium	He	2	4.003	Tellurium	Te	52	127.6
Holmium	Ho	67	164.9	Terbium	Tb	65	158.9
Hydrogen	H	1	1.008	Thallium	Tl	81	204.4
Indium	In	49	114.8	Thorium	Th	90	(232)
Iodine	I	53	126.9	Thulium	Tm	69	168.9
Iridium	Ir	77	192.2	Tin	Sn	50	118.7
Iron	Fe	26	55.85	Titanium	Ti	22	47.87
Krypton	Kr	36	83.80	Tungsten	W	74	183.9
Lanthanum	La	57	138.9	Uranium	U	92	(238)
Lawrencium	Lr	103	(262)	Vanadium	V	23	50.94
Lead	Pb	82	207.2	Xenon	Xe	54	131.3
Lithium	Li	3	6.941	Ytterbium	Yb	70	173.0
Lutetium	Lu	71	175.0	Yttrium	Y	39	88.91
Magnesium	Mg	12	24.31	Zinc	Zn	30	65.41
Manganese	Mn	25	54.94	Zirconium	Zr	40	91.22
Meitnerium	Mt	109	(276)				

A value in parentheses is the mass number of the isotope of longest half-life for radioactive elements.