

Other Organic Compounds



Organic compounds are used to make many of the products we use every day.

Functional Groups and Classes of Organic Compounds

A functional group is an atom or group of atoms that is responsible for the specific properties of an organic compound; the bonds within functional groups are often the site of chemical reactivity. A given functional group undergoes the same types of chemical reactions in every molecule in which it is found. Therefore, all compounds that contain the same functional group have similar properties and can be classified together.

Alcohols

Alcohols are organic compounds that contain one or more hydroxyl groups. The general formula for a class of organic compounds consists of the functional group and the letter *R*, which stands for the rest of the molecule. The general formula for alcohols is $R-OH$. Systematic names of organic compounds indicate which functional groups are present in a molecule. The rules for naming simple alcohols are as follows.

Alcohol Nomenclature

- 1. Name the parent compound.** Locate the longest continuous chain of carbon atoms *that contains the hydroxyl group*. If there is only one hydroxyl group, change the final *-e* in the name of the corresponding alkane to *-ol*. If there is more than one hydroxyl group, use the full name of the corresponding alkane and add the suffix modified to indicate the number of hydroxyl groups. For example, *-diol* = 2, *-triol* = 3, and so on.
- 2. Number the carbon atoms in the parent chain.** Number the carbon atoms in the chain so that the hydroxyl groups have the lowest numbers possible.
- 3. Insert position numbers.** Place the hydroxyl position number or numbers immediately before the name of the parent alcohol.
- 4. Punctuate the name.** Separate the position numbers from the name with a hyphen. If there is more than one position number, separate the position numbers with commas.

SECTION 21-1

OBJECTIVES

- Define *functional group*, and explain why functional groups are important.
- Identify alcohols, alkyl halides, and ethers based on the functional group present in each.
- Classify alcohols, alkyl halides, and ethers from names and structural formulas.
- Relate properties of alcohols, alkyl halides, and ethers to their structures. Describe how these properties influence the uses of specific organic compounds.

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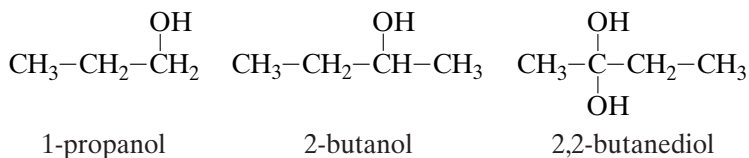
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TOPIC: Alcohols
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TABLE 21-1 Boiling Points of Some Alcohols and Alkanes

Compound	Molecular formula	Molar mass (g/mol)	Boiling point (°C)
methanol	CH ₃ OH	32	64.7
ethane	C ₂ H ₆	30	−88
ethanol	C ₂ H ₅ OH	46	78.3
propane	C ₃ H ₈	44	−42.1
1-propanol	C ₃ H ₇ OH	60	97.2
butane	C ₄ H ₁₀	58	−0.50

Following are three examples of correctly named alcohols.



Properties and Uses of Alcohols

As shown in Table 21-1, the boiling points of alcohols tend to be higher than those of alkanes of comparable molar mass. For example, the molar mass of ethanol, 46 g/mol, is close to that of propane, 44 g/mol. However, their boiling points are very different. The boiling point of ethanol is 78.3°C, while the boiling point of propane is −42.1°C. In addition, boiling points increase as the number of hydroxyl groups in the molecule increases. This trend can be seen in Table 21-2, which shows the boiling points for alcohols with one, two, and three hydroxyl groups.

The boiling point trends shown in Tables 21-1 and 21-2 can be explained by hydrogen bonding, which was discussed in Chapter 6. Compared to alkanes, extra energy is required to break hydrogen bonds between alcohol molecules before conversion from a liquid to a gas. When more than one hydroxyl group is present, an alcohol molecule may form multiple hydrogen bonds. In this case, even more energy is required to break the hydrogen bonds before the liquid is converted to a gas.

TABLE 21-2 Multiple Hydroxyl Groups and Boiling Points

Alcohol	Number of hydroxyl groups	Boiling point (°C)
ethanol	1	78.3
1,2-ethanediol	2	197.3
1-propanol	1	97.2
1,2-propanediol	2	188
1,2,3-propanetriol	3	258–260

TABLE 21-3 Solubility of Some Alcohols in Water

Alcohol	Molecular formula	Solubility (g/100. g of water)
methanol	CH_3OH	∞ (completely soluble)
1-butanol	$\text{C}_4\text{H}_9\text{OH}$	7.4
1-pentanol	$\text{C}_5\text{H}_{11}\text{OH}$	2.7
1-octanol	$\text{C}_8\text{H}_{17}\text{OH}$	0.06

As explained in Chapter 13, alcohols are soluble in water because of hydrogen bonding. However, the solubility of alcohols in water tends to decrease with an increase in the size of the molecule. The longer the hydrocarbon chain in an alcohol, the larger the nonpolar, insoluble portion of the molecule. Table 21-3 illustrates this trend.

Hydrogen bonding in alcohols can also explain other properties and uses of alcohols. Cold creams, lipsticks, body lotions, and similar products generally include 1,2,3-propanetriol, commonly called glycerol, to keep them moist. A model for glycerol is shown in Figure 21-1. Multiple hydroxyl groups allow glycerol to form many hydrogen bonds with water molecules in the air or in the surrounding material.

Alcohols are sometimes used today as alternative fuels and as octane enhancers in fuel for automobiles. Ethanol is combined with gasoline, for example, in a one-to-nine ratio to produce gasohol. Some experts have promoted the use of gasohol as a fuel for automobiles because it burns more cleanly, helps save valuable petroleum reserves, and reduces our nation's dependence on foreign imports of petroleum. However, there are also disadvantages. The combustion of ethanol produces only 60% as much energy per gram as does the combustion of gasoline. The presence of ethanol also causes increased water absorption in the fuel.

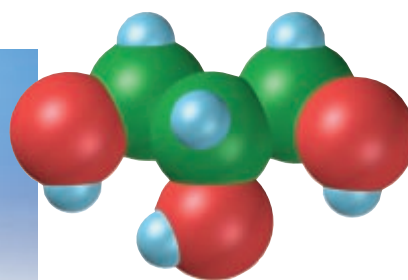


FIGURE 21-1 Glycerol contains three hydroxyl groups. This structure allows it to form multiple hydrogen bonds with water. Glycerol is added as a moisturizer to skin products.

All simple alcohols are poisonous to some extent. When ethanol is consumed, it is broken down by the enzyme alcohol dehydrogenase. This enzyme rapidly converts ethanol to an oxidized form known as acetaldehyde, which is then converted to acetic acid. Acetic acid, a component of household vinegar, is relatively harmless to the human body. However, consuming large amounts of ethanol can be fatal. The lethal dose varies for different individuals. The amount of ethanol found in a liter of hard liquor, 400 mL, is usually fatal.

Other simple alcohols are attacked by alcohol dehydrogenase more slowly, making these alcohols more toxic than ethanol. For example, methanol, or wood alcohol, is converted to formaldehyde and formic acid, both of which are toxic. A great deal of damage can be done to cells before these chemicals are completely metabolized by the body. Methanol is about 10 times more toxic than is ethanol. Toxic effects of methanol include damage to the optic nerve, coma, and death.





TOPIC: Alkyl halides
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Alkyl Halides

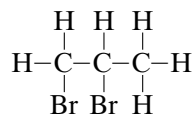
Alkyl halides are organic compounds in which one or more halogen atoms—fluorine, chlorine, bromine, or iodine—are substituted for one or more hydrogen atoms in a hydrocarbon. Because $-X$ is often used to represent any halogen, an alkyl halide may be represented by the general formula $R-X$. The rules for naming simple alkyl halides in the IUPAC system are as follows.

Alkyl Halide Nomenclature

- 1. Name the parent compound.** Locate the longest continuous chain of carbon atoms. Add the prefixes for the attached halogen atoms to the name of the alkane corresponding to the number of carbon atoms in this chain. The prefixes to use are *fluoro-* for fluorine, *chloro-* for chlorine, *bromo-* for bromine, and *iodo-* for iodine. If more than one kind of halogen atom is present, add the halogen prefixes in alphabetical order. If there is more than one atom of the same halogen, add the appropriate prefix (*di-*, *tri-*, and so on) after the prefixes are arranged in alphabetical order.
- 2. Number the carbon atoms in the parent chain.** Number the carbon-atom chain so that the lowest number is in the name. If there are different halogen atoms in equivalent positions, give the lower number to the one that comes first in alphabetical order.
- 3. Insert position numbers.** Place the halogen position number or numbers immediately before the halogen prefixes.
- 4. Punctuate the name.** Separate the position numbers from the name with hyphens. If there is more than one position number, separate the position numbers with commas.

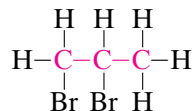
SAMPLE PROBLEM 21-1

Name the alkyl halide shown.



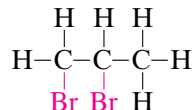
SOLUTION

1. Locate the longest continuous chain of carbon atoms that contains the halogen.



The chain has three carbon atoms, so the name of the chain is *propane*.

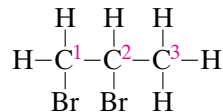
2. Identify and name the halogen atoms attached to the chain.



Bromine atoms are attached to the chain. Add the prefix *bromo-* in front of *propane*. Add the prefix *di-* to show that there are two bromine atoms present.

dibromopropane

3. Number the carbon-atom chain so that the sum of the halogen numbers is as low as possible.



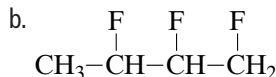
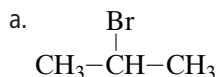
4. The bromine atoms are on carbons numbered 1 and 2. Place these numbers immediately before the halogen prefix. Separate the numbers from the prefix with a hyphen. Separate the numbers with a comma.

1,2-dibromopropane

The complete name is 1,2-dibromopropane.

PRACTICE

1. Name each of the following alkyl halides:



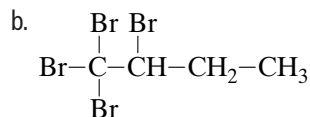
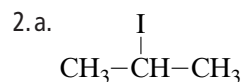
Answer

1. a. 2-bromopropane
b. 1,2,3-trifluorobutane

2. Draw condensed structures for each of the following alkyl halides:

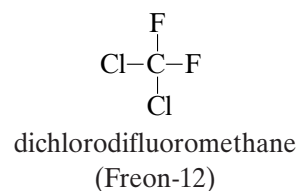
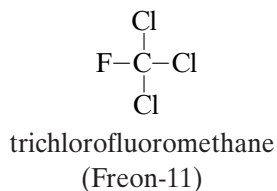
a. 2-iodopropane

b. 1,1,1,2-tetrabromobutane



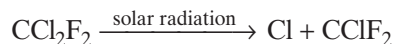
Properties and Uses of Alkyl Halides

Alkyl halides are some of the most widely used organic chemicals. A family of alkyl halides that has received widespread attention in recent years is the chlorofluorocarbons, or CFCs. CFCs are alkyl halides that contain both chlorine and fluorine. The formulas for two widely used CFCs, Freon-11 and Freon-12, are shown below.



CFC-11 and CFC-12 are odorless, nontoxic, nonflammable, and very stable. They also easily change physical states. These properties make them useful in a number of commercial operations. They have been used in the manufacture of plastic foam and as liquid refrigerants in commercial refrigerators. At the height of their production, in 1985, more than 700 million kilograms of CFC-11 and CFC-12 were manufactured worldwide.

However, CFCs contribute to the destruction of ozone in the upper atmosphere, as shown in Figure 21-2. When released into the atmosphere, CFCs can break down and release free chlorine atoms.



The released chlorine atoms attack molecules of ozone (O_3) found in the upper atmosphere. The ozone is converted to diatomic oxygen.

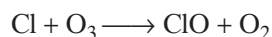
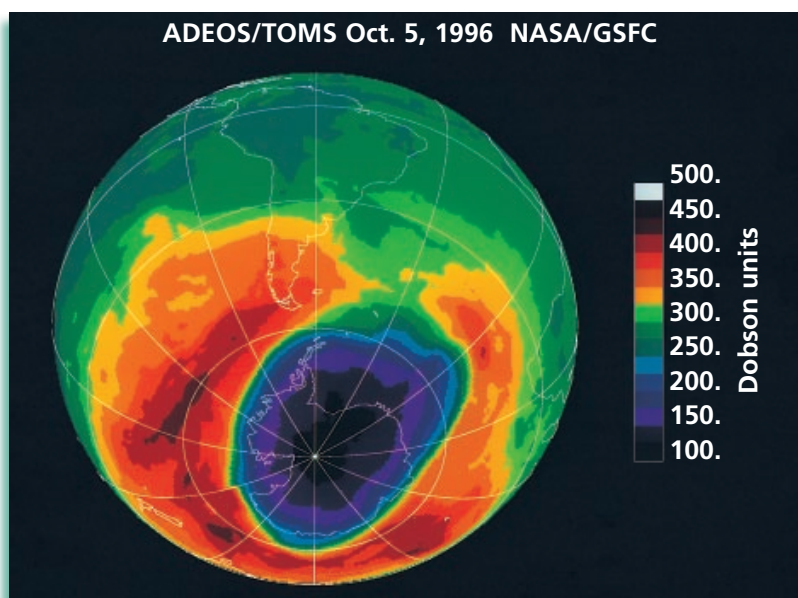


FIGURE 21-2 The depletion of ozone in the upper atmosphere above Antarctica has produced an area of very low ozone concentration, called the ozone hole. The black region over Antarctica shows the area of greatest ozone depletion.



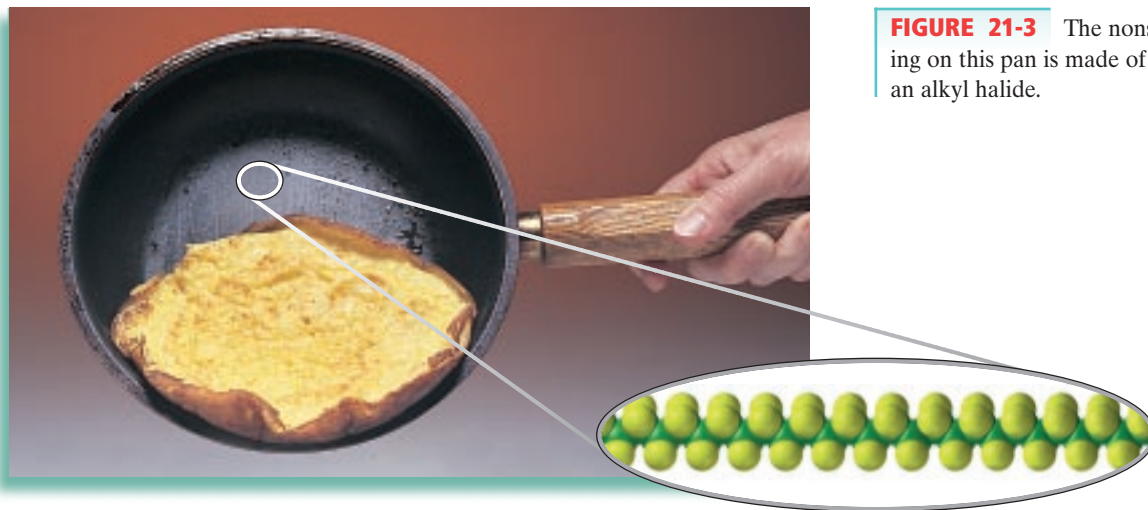


FIGURE 21-3 The nonstick coating on this pan is made of Teflon, an alkyl halide.

Chlorine atoms are eventually regenerated.



This makes it possible for a single chlorine atom to destroy thousands of ozone molecules.

The depletion of ozone in the upper atmosphere has produced an area of very low concentration, called an ozone hole, over Antarctica. Ozone molecules absorb ultraviolet radiation from sunlight, preventing most of that radiation from reaching Earth. Ultraviolet radiation is known to cause skin cancer in humans, to kill some forms of microscopic life, to damage plant tissue, and to cause other harmful effects in plants and animals. Because CFCs are a major cause of ozone depletion, more than 100 nations signed an agreement in 1987 to reduce the amount of CFCs produced.

Another alkyl halide is tetrafluoroethene, C_2F_4 . It is joined in long chains to make a material with the trade name Teflon. Because of the unreactive carbon-fluorine bond, Teflon is inactive and stable to about 325°C . It also has a low coefficient of friction, which means that other objects slide smoothly over its surface. These properties enable Teflon to be used in heat-resistant machine parts that cannot be lubricated. It is also used in making utensils with “nonstick” surfaces, such as the frying pan in Figure 21-3.

Ethers

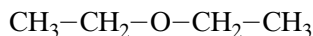
Ethers are organic compounds in which two hydrocarbon groups are bonded to the same atom of oxygen. They can be represented by the general formula $R-\text{O}-R'$. In this formula, R' may be the same hydrocarbon group as R or a different one. One set of rules for naming simple ethers are as follows.

Ether Nomenclature

- 1. Name the parent compound.** The word *ether* will come at the end of the name.
- 2. Add the names of the alkyl groups.** If there are two different alkyl groups, arrange the names in alphabetical order in front of the word *ether*. If both alkyl groups are the same, the prefix *di-* is added to the name of the alkyl group in front of the word *ether*.
- 3. Leave appropriate spaces in the name.** There should be spaces between the names of the alkyl groups and between the alkyl groups and the word *ether*.

SAMPLE PROBLEM 21-2

Name the ether shown below.

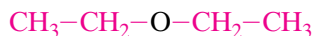


SOLUTION

1. The word *ether* will come at the end of the name.

ether

2. Identify and name the two alkyl groups joined to the oxygen atom.



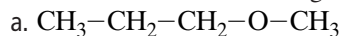
They are both ethyl groups. Add the prefix *di-* to show that there are two ethyl groups present. Place *diethyl* in front of *ether*, separated by a space.

diethyl ether

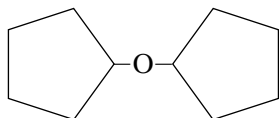
The full name is diethyl ether. Diethyl ether is the most common ether and is also known as ethyl ether, or just ether.

PRACTICE

1. Name each of the following ethers:



b.

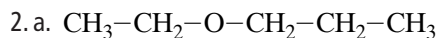


2. Draw condensed structures for the following ethers:

- ethyl propyl ether
- dicyclohexyl ether
- butyl methyl ether

Answer

- a. methyl propyl ether
b. dicyclopentyl ether
c. methyl pentyl ether



b.

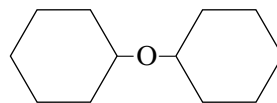


TABLE 21-4 Comparison of the Boiling Points of an Ether, Alkane, and Alcohol

Compound	Molar mass	Boiling point (°C)
diethyl ether	74	34.6
pentane	72	36.1
1-butanol	74	117.7

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TOPIC: Ethers
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Properties and Uses of Ethers

The solubilities of ethers and alcohols in water are similar. For example, diethyl ether and 1-butanol have the same molar mass. They also have approximately the same solubility, 6 g/100 g of water for diethyl ether and 7.4 g/100 g of water for 1-butanol. This similarity can be explained by the fact that ethers, like alcohols, can form hydrogen bonds with water molecules.

In comparison, the boiling points of ethers are much lower than those of alcohols of similar molar mass. But, they are about the same as those of alkanes of similar molar mass. This trend is clear from the comparison in Table 21-4. This trend can also be explained by hydrogen bonding. Unlike alcohols, ethers cannot form hydrogen bonds with each other because they do not have a hydrogen atom bonded to a highly electronegative atom. Therefore, no extra energy is needed to break hydrogen bonds for ethers to boil.

Like alkanes, ethers are not very reactive compounds. This property explains their most common uses as solvents. In many organic reactions in which water cannot be used as a solvent, an ether is used instead.

Methyl-*tertiary*-butyl ether (MTBE) is the most widely used ether. It is another gasoline octane enhancer. At one time, tetraethyl lead, $(\text{C}_2\text{H}_5)_4\text{Pb}$, was widely used for this purpose. However, concerns about the release of lead into the environment have increased, so tetraethyl lead has been replaced by MTBE and other octane enhancers.

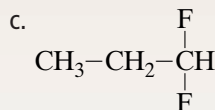
SECTION REVIEW

1. Give the general formula and class of organic compounds for each of the following:

- $\text{CH}_3\text{—OH}$
- $\text{CH}_3\text{—O—CH}_3$
- $\text{Br—CH}_2\text{—CH}_2\text{—CH}_3$

2. Give the name of each of the following:

- $\begin{array}{c} \text{OH} \\ | \\ \text{CH}_3\text{—CH—CH}_3 \end{array}$
- $\text{CH}_3\text{—O—CH}_3$



- Compare the boiling points of alcohols, ethers, and alkanes, and explain one reason for the differences.
- Draw condensed structures for each of the following:
 - 1,2-propanediol
 - ethyl methyl ether
 - dichloromethane

OBJECTIVES

- Identify aldehydes, ketones, carboxylic acids, esters, and amines based on the functional group present in each.
- Classify aldehydes, ketones, carboxylic acids, esters, and amines from names and structural formulas.
- Relate properties of aldehydes, ketones, carboxylic acids, esters, and amines to their structures. Describe how these properties influence the uses of specific organic compounds.

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TOPIC: Aldehydes/ketones
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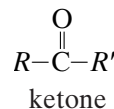
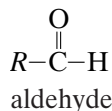
More Classes of Organic Compounds

Aldehydes and Ketones

Aldehydes and ketones contain the *carbonyl group*, shown below.



The difference between aldehydes and ketones is the location of the carbonyl group. **Aldehydes** are organic compounds in which the carbonyl group is attached to a carbon atom at the end of a carbon-atom chain. **Ketones** are organic compounds in which the carbonyl group is attached to carbon atoms within the chain. These differences can be seen in their general formulas, shown below.

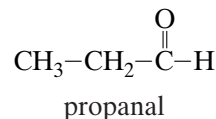
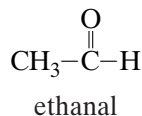
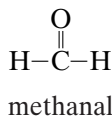


The IUPAC rules for naming simple aldehydes and ketones are as follows.

Aldehyde Nomenclature

Name the parent compound. Locate the longest continuous chain that contains the carbonyl group. Change the final *-e* in the name of the corresponding alkane to *-al*.

Following are three examples of correctly named aldehydes.

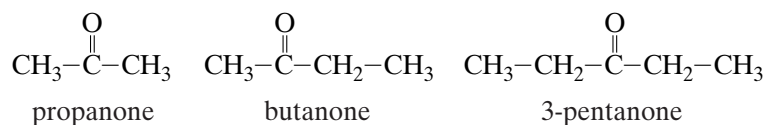


Ketone Nomenclature

1. Name the parent compound. Locate the longest continuous chain that contains the carbonyl group. Change the final *-e* in the name of the corresponding alkane to *-one*.

- 2. Number the carbon atoms in the parent chain.** Number the carbon atoms in the chain so that the carbon atom in the carbonyl group has the lowest possible number.
- 3. Insert position numbers.** Place the carbonyl position number in front of the name.
- 4. Punctuate the name.** Separate the position number from the name with a hyphen.

Following are three examples of correctly named ketones.



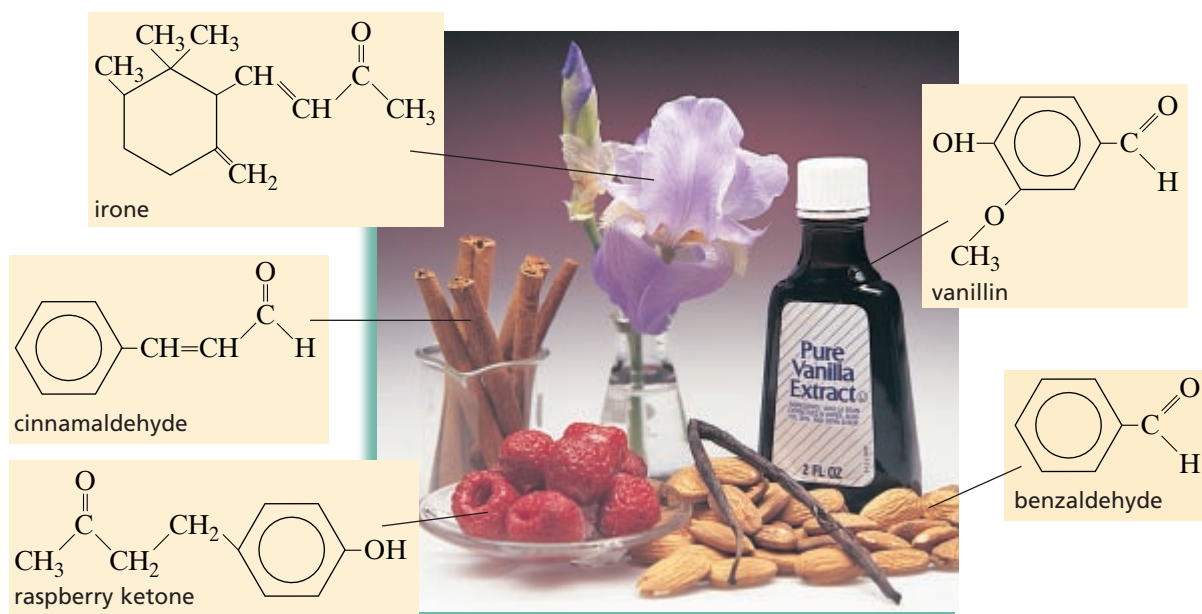
Properties and Uses of Aldehydes and Ketones

The simplest aldehyde is methanal, also known as formaldehyde. It was once commonly used in biology laboratories as a preservative for dead animals. Its most important commercial use, however, is in the production of plastics. One of the first commercial plastics, bakelite, was made by combining phenol and formaldehyde in a long chain.

The simplest ketone is propanone, whose common name is acetone. Acetone is found in some nail-polish removers because it dissolves the organic substances in nail polish. However, artificial fingernails are made of plastics that are also dissolved by acetone. Today other solvents are being used more frequently as nail-polish removers.

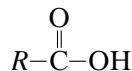
Aldehydes and ketones are often responsible for odors and flavors. For example, cinnamaldehyde contributes to the odor and flavor of cinnamon. Figure 21-4 gives some examples of odors and flavors that come from aldehydes and ketones.

FIGURE 21-4 Many common odors and flavors come from aldehydes and ketones.



Carboxylic Acids

Carboxylic acids are organic compounds that contain the carboxyl functional group. The carboxyl group always comes at the end of a carbon-atom chain. A member of this class of organic compounds can be represented by the general formula shown below.

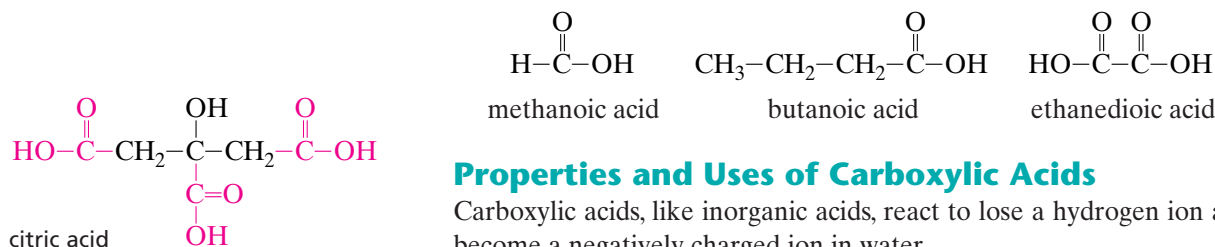


The rules for naming simple carboxylic acids are as follows.

Carboxylic Acid Nomenclature

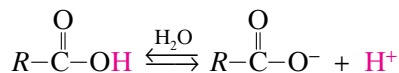
Name the parent compound. Locate the longest continuous chain *that contains the carboxyl group*. If there is only one carboxyl group, change the final -e in the name of the corresponding alkane to -*oic acid*. If there is more than one carboxyl group, use the full name of the corresponding alkane, and add the suffix modified to indicate the number of carboxyl groups. For example, -*dioic acid* = 2, -*trioic acid* = 3, and so on.

Following are three examples of correctly named carboxylic acids.



Properties and Uses of Carboxylic Acids

Carboxylic acids, like inorganic acids, react to lose a hydrogen ion and become a negatively charged ion in water.



Carboxylic acids are much weaker than many inorganic acids, such as hydrochloric, sulfuric, and nitric acids. Acetic acid, the weak acid in vinegar, is a carboxylic acid. The IUPAC name for acetic acid is ethanoic acid.

A number of carboxylic acids occur naturally in plants and animals. For example, citrus fruits, shown in Figure 21-5, contain citric acid. Table 21-5 lists more examples. Carboxylic acids are also used as food additives. For example, ethanoic and citric acids are used in foods to give them a tart or acidic flavor. Benzoic, propanoic, and sorbic acids are used as preservatives. All three acids kill microorganisms that cause foods to spoil.

The most widely used carboxylic acids are methanoic and ethanoic acids. Because they can be made inexpensively, they are the starting material for many chemical processes. For example, ethanoic acid is used in the production of polyvinyl acetate, PVA. PVA is used in latex paint, adhesives, and textile coatings.



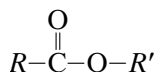
FIGURE 21-5 Citric acid, found in citrus fruits, contains three carboxylic acid groups shown in red on the structural formula.

TABLE 21-5 Some Carboxylic Acids and Their Natural Sources

Carboxylic acid	Structural formula	Source
methanoic acid	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}-\text{C}-\text{OH} \end{array}$	ants
butanoic acid	$\text{CH}_3-\text{CH}_2-\text{CH}_2-\begin{array}{c} \text{O} \\ \parallel \\ \text{C}-\text{OH} \end{array}$	rancid butter
hexanoic acid	$\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\begin{array}{c} \text{O} \\ \parallel \\ \text{C}-\text{OH} \end{array}$	milk fats, coconut oil, palm oil
lactic acid	$\begin{array}{c} \text{OH} \quad \text{O} \\ \quad \parallel \\ \text{CH}_3-\text{CH}-\text{C}-\text{OH} \end{array}$	sour milk, blood, and muscle fluid
malic acid	$\begin{array}{c} \text{O} \quad \quad \text{OH} \quad \text{O} \\ \parallel \quad \quad \quad \parallel \\ \text{HO}-\text{C}-\text{CH}_2-\text{CH}-\text{C}-\text{OH} \end{array}$	apples
oxalic acid	$\begin{array}{c} \text{O} \quad \text{O} \\ \parallel \quad \parallel \\ \text{HO}-\text{C}-\text{C}-\text{OH} \end{array}$	rhubarb

Esters

Esters are organic compounds with carboxylic acid groups in which the hydrogen of the hydroxyl group has been replaced by an alkyl group. The general formula for an ester is given below.



The IUPAC system for naming simple esters is as follows.

Ester Nomenclature

- 1. Name the parent compound.** Name the carboxylic acid from which the ester was formed (see page 674). Change the *-oic acid* ending in the name of this acid to *-oate*. This gives the second half of the ester's name.
- 2. Add the name of the alkyl group.** Identify and name the alkyl group that has replaced the hydrogen of the hydroxyl group. Add the name of the alkyl group to the front of the name.
- 3. Leave appropriate spaces in the name.** There should be a space between the name of the alkyl group and the name of the parent compound.

Following are two examples of correctly named esters.

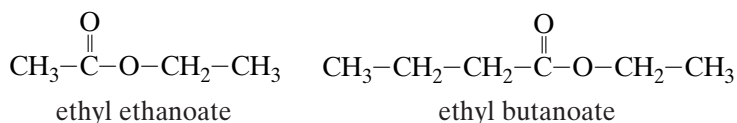
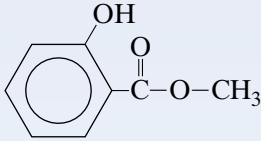
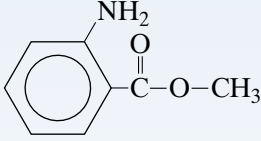


TABLE 21-6 Common Flavors and Odors Produced by Esters

Ester	Structural formula	Flavor or odor
ethyl butanoate	$\text{CH}_3\text{---CH}_2\text{---CH}_2\text{---}\overset{\text{O}}{\parallel}\text{C}\text{---O---CH}_2\text{---CH}_3$	pineapple
methyl salicylate		wintergreen oil
geraniol formate	$\text{H}\overset{\text{O}}{\parallel}\text{C}\text{---O---CH}_2\text{---CH=}\overset{\text{CH}_3}{\underset{ }{\text{C}}}\text{---CH}_2\text{---CH}_2\text{---CH=}\overset{\text{CH}_3}{\underset{ }{\text{C}}}\text{---CH}_3$	rose
methyl anthranilate		grape juice and jasmine
linalyl acetate	$\text{CH}_3\text{---}\overset{\text{O}}{\parallel}\text{C}\text{---O---}\overset{\text{CH}_3}{\underset{\text{CH=CH}_2}{\underset{ }{\text{C}}}}\text{---CH}_2\text{---CH}_2\text{---CH=}\overset{\text{CH}_3}{\underset{ }{\text{C}}}\text{---CH}_3$	lavender

Properties and Uses of Esters

Esters are common in plants and are responsible for some distinctive flavors and odors. Table 21-6 lists some of these esters and the flavors and odors with which they are associated. At one time, compounds such as those listed in the table were obtained only from natural materials. But chemists have learned how to synthesize these and many other naturally occurring compounds for use as food additives. Figure 21-6 shows the structure of isoamyl acetate, which is found in bananas and is also used as an artificial flavoring.

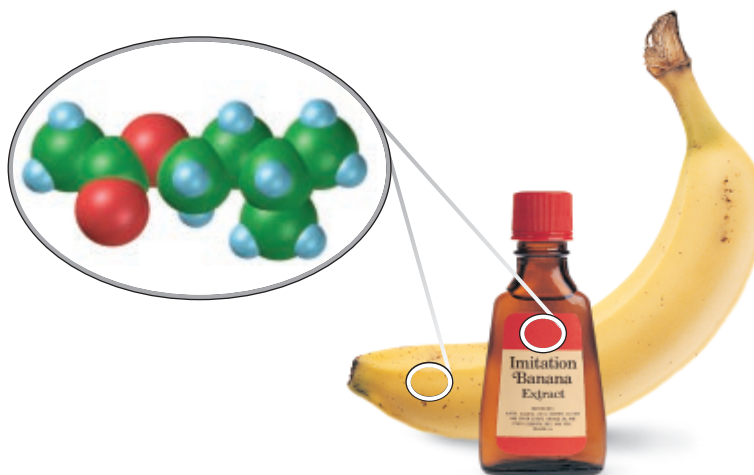
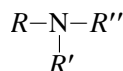


FIGURE 21-6 The ester in bananas can be synthesized and used as a flavoring.

Amines

Amines are organic compounds that can be considered to be derivatives of ammonia, NH_3 . They can be represented by the following general formula. Note that the functional group does *not* contain oxygen.

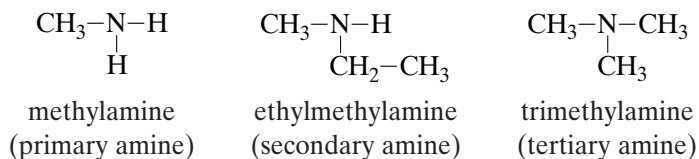


Amines are often named by a common system rather than the IUPAC system. The steps in naming a simple amine by the common system are as follows.

Amine Nomenclature

- 1. Name the parent compound.** The end of the name will be *-amine*.
- 2. Add the names of the alkyl groups.** Arrange the names of the alkyl groups attached to the nitrogen atom in alphabetical order. Add the prefixes *di-* or *tri-* in front of the group name if two or three, respectively, of the same kind are included in the amine. Combine these names in front of *-amine* to form one word.

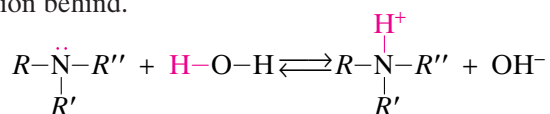
Following are three examples of correctly named amines.



Amines are categorized as primary, secondary, or tertiary, depending on the number of hydrogen atoms of the ammonia molecule that have been replaced. As shown in the structures above, *in a primary amine, one hydrogen atom of an ammonia molecule has been replaced by an alkyl group. In a secondary amine, two hydrogen atoms of an ammonia molecule have been replaced by alkyl groups. In a tertiary amine, all three hydrogen atoms of an ammonia molecule have been replaced by alkyl groups.*

Properties and Uses of Amines

The chemical properties of the amines depend largely on the electronic structure of the nitrogen atom, which has an unshared pair of electrons. This region of negative charge makes amines weak bases in aqueous solutions. The unshared pair of electrons on the amine molecule attracts a positive hydrogen atom in a water molecule. The hydrogen atom bonds with the amine, forming a positively charged ion and leaving the hydroxide ion behind.



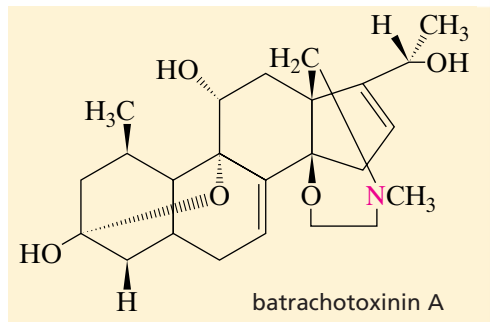


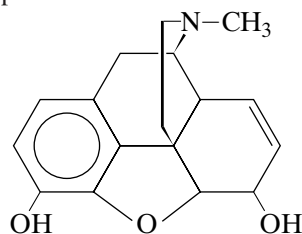
FIGURE 21-7 The poison dart frog produces toxic amines, one of which is batrachotoxinin A, that kill nerve cells. The nitrogen atom of the amine is shown in red.



An interesting example of this reaction involves two naturally occurring and toxic amines known as batrachotoxin and batrachotoxinin A. These compounds are produced by the poison dart frog, shown in Figure 21-7, which lives in the rain forests of Colombia. In water solution, both of these amines gain protons and become positively charged ions. Because these two amines carry the same charge as sodium ions found in the nervous system, they behave in much the same way. Both batrachotoxin ions can move through the openings in nerve cells, called sodium channels. These ions are much larger than sodium ions, however. They force the sodium channels to remain in the “open” position, and sodium ions are allowed to flood a nerve cell. This causes the nerve cell to continuously transmit nerve impulses, resulting in rapid death of the cell.

Amines are common in nature. They are often formed during the breakdown of proteins in animal cells. Two such amines are putrescine and cadaverine. Their names reflect their foul odors and presence in decaying bodies. Another amine, methylamine, has the unpleasant odor associated with dead fish. Yet a fourth amine, skatole, is found in feces and contributes to their odor.

The class of organic compounds known as alkaloids also consists of amines. *Alkaloids* are naturally occurring amine products of plants that have physiological effects on animals. Examples of alkaloids include caffeine, nicotine, morphine, and coniine (found in poisonous hemlock). Alkaloids tend to have complex chemical structures, as illustrated by the structure for morphine.



morphine (a tertiary amine)

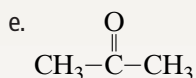
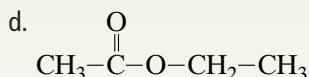
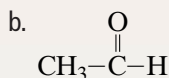
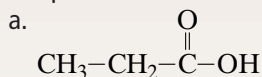
Table 21-7 summarizes the functional groups and the general formulas of the classes of organic compounds discussed in Sections 21-1 and 21-2.

TABLE 21-7 *Classes of Organic Compounds*

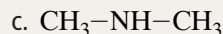
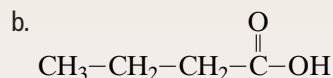
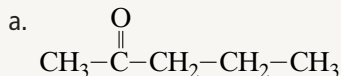
Class	Functional group	General formula
alcohol	$-\text{OH}$	$R-\text{OH}$
alkyl halide	$-\text{X}$ ($\text{X} = \text{F}, \text{Cl}, \text{Br}, \text{I}$)	$R-\text{X}$
ether	$-\text{O}-$	$R-\text{O}-R'$
aldehyde	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{H} \end{array}$	$\begin{array}{c} \text{O} \\ \parallel \\ R-\text{C}-\text{H} \end{array}$
ketone	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}- \end{array}$	$\begin{array}{c} \text{O} \\ \parallel \\ R-\text{C}-R' \end{array}$
carboxylic acid	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{OH} \end{array}$	$\begin{array}{c} \text{O} \\ \parallel \\ R-\text{C}-\text{OH} \end{array}$
ester	$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{O}- \end{array}$	$\begin{array}{c} \text{O} \\ \parallel \\ R-\text{C}-\text{O}-R' \end{array}$
amine	$\begin{array}{c} -\text{N}- \\ \end{array}$	$\begin{array}{c} R-\text{N}-R'' \\ \\ R' \end{array}$

SECTION REVIEW

1. Give the general formula and class of organic compounds for each of the following:



2. Give the name of each of the following:



3. Draw condensed structures for each of the following:

a. ethyl ethanoate

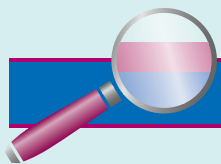
b. triethylamine

c. butanal

4. How are aldehydes and ketones alike? How do they differ from each other?

5. How do the strengths of organic acids compare with the strengths of most inorganic acids?

6. Show the reaction that occurs when amines are dissolved in water.



Unraveling the Mystery of DNA

HISTORICAL PERSPECTIVE

Today genetic engineers can identify, modify, and even transplant genes, but virtually nothing was known about the chemical mechanism of heredity at the beginning of the twentieth century. The term gene was coined in 1909 to describe a molecule that existed only in theory at the time. By the century's midpoint, however, scientists were poised to discover the molecular structure of the gene and explain the biochemical process that is the foundation of modern genetics.

The Chemical Nature of the Gene

By the early part of the twentieth century, scientists knew that genes were one of two types of organic macromolecules: proteins or nucleic acids. Most researchers believed genes to be the former until 1944, when it was shown that hereditary information could be transmitted from one bacterial cell to another by DNA alone.

An Important New Technique

One problem early researchers encountered was the inability to directly observe the minuscule genes. The development of a relatively new crystallographic technique proved vital to the elucidation of the structures of DNA and other biological macromolecules.

The technique was called X-ray diffraction and involved shining X rays onto crystallized molecular samples to take “snapshots” of their structure. Until the 1950s, most X-ray crystallography was focused on proteins. But in 1951, James D. Watson realized the



X-ray diffraction patterns of DNA taken by Rosalind Franklin were used to determine the structure of DNA.

potential value of X-ray diffraction in determining a model for DNA. That year, he accepted a position at Cambridge University's Cavendish Laboratory to learn more about the procedure.

A Fateful Union

At Cavendish, Watson befriended Francis Crick, a theoretical

biophysicist. Crick did not know how to perform X-ray diffraction either, but he was adept at analyzing the images that resulted from it. Fortunately, Cavendish was also home to two experts on X-ray crystallography of DNA: Maurice Wilkins and Rosalind Franklin. With the help of these two experimentalists, Watson and Crick set out to solve the riddle of DNA.

A Big Leap

One of the team's biggest clues was the result of an investigation into proteins by Linus Pauling, the eminent chemist at the California Institute of Technology. Pauling determined the basic shape of a polypeptide chain, or protein strand, to be an α -helix, a large molecule of repeating units that twist around a central axis.

This discovery inspired Watson and Crick to look for a similar but more complex structure in DNA.

Watson wrote:

In the α -helix, a single polypeptide . . . chain folds up into a helical arrangement held

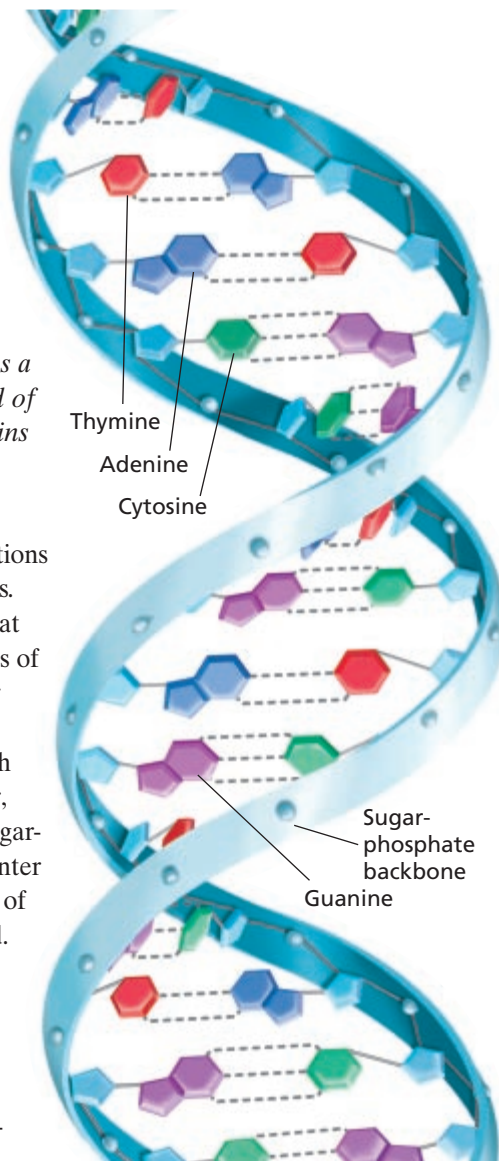
together by hydrogen bonds between groups on the same chain. Maurice told Francis, however, that the diameter of the DNA molecule was thicker than would be the case if only one polynucleotide (DNA strand) were present. This made him think that the DNA molecule was a compound helix composed of several polynucleotide chains twisted about each other.

Watson and Crick began contemplating DNA configurations with two, three, and four helices. They correctly hypothesized that the sugar and phosphate groups of DNA's basic repeating units, or nucleotides, alternated to form the molecular backbone of each helix in the molecule. However, they mistakenly situated the sugar-phosphate backbones in the center of the molecule, with the bases of the nucleotides jutting outward.

The DNA Solution

Redirected by new X-ray diffraction data obtained by Franklin, Watson began considering models with the sugar-phosphate chains on the outside of the DNA molecule and the bases pointing inward. After reviewing a titration study of DNA indicating that many, if not all, of the molecule's bases formed hydrogen bonds with each other, he speculated:

Conceivably the crux of the matter was a rule governing



The Watson-and-Crick model of DNA contains opposing adenine-thymine and guanine-cytosine bases on a double-helical sugar-phosphate backbone.

hydrogen bonding between bases. . . I thus started wondering whether each DNA molecule consisted of two chains with identical base sequences held together by

hydrogen bonds between pairs of identical bases.

Crick immediately observed that this like-with-like double-stranded model did not satisfy the symmetry requirements of the X-ray data. When Watson began exploring models pairing different bases, he uncovered the final clue to the DNA mystery:

. . . an adenine-thymine pair held together by two hydrogen bonds was identical in shape to a guanine-cytosine pair held together by at least two hydrogen bonds.

Fitting the opposing adenine-thymine and guanine-cytosine bases inside the double-helical sugar-phosphate backbones resulted in the first correct molecular model of DNA, for which they were awarded a Nobel Prize in 1962.

A Long-Standing Theory

The model of DNA discovered by James Watson and Francis Crick has continued to be the basis of biochemical genetics. The model has enabled scientists to explain genetic mutations, to predict or correct certain genetic disorders, and to genetically engineer organisms to have desirable traits.

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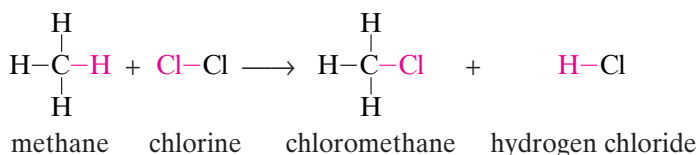
Organic Reactions

OBJECTIVES

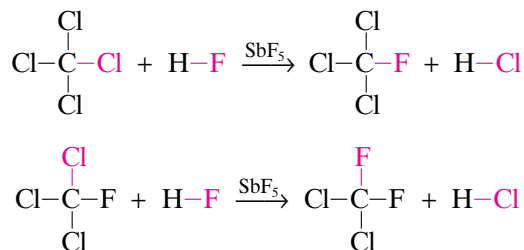
- Describe and distinguish between the organic reactions: substitution, addition, condensation, and elimination.
- Relate some functional groups to some characteristic reactions.

Substitution Reactions

A **substitution reaction** is one in which one or more atoms replace another atom or group of atoms in a molecule. The reaction between an alkane, such as methane, and a halogen, such as chlorine, to form an alkyl halide is an example of a substitution reaction. Notice that in this reaction, a chlorine atom replaces a hydrogen atom on the methane molecule.



Additional compounds can be formed by replacing the other hydrogen atoms remaining in the methane molecule. The products are dichloromethane, trichloromethane, and tetrachloromethane. Trichloromethane is also known as chloroform, and tetrachloromethane is also known as carbon tetrachloride. CFCs are formed by further substitution reactions between chloroalkanes and HF.



Addition Reactions

An **addition reaction** is one in which an atom or molecule is added to an unsaturated molecule and increases the saturation of the molecule. A common type of addition reaction is hydrogenation. In *hydrogenation*, one or more hydrogen atoms are added to an unsaturated molecule. Vegetable oils contain unsaturated fatty acids, long chains of carbon atoms with many double bonds. The following equation shows just one portion of an oil molecule. When hydrogen gas is blown through an oil, hydrogen atoms may add to the double bonds in the oil molecule.

CHEMISTRY



Module 7: Equilibrium

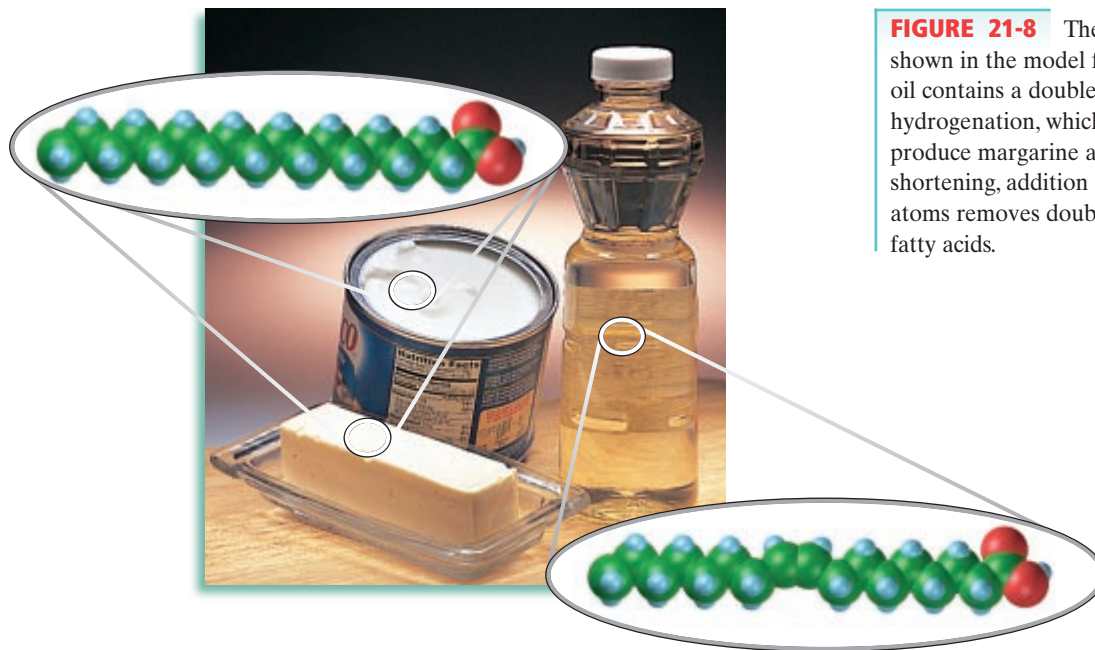
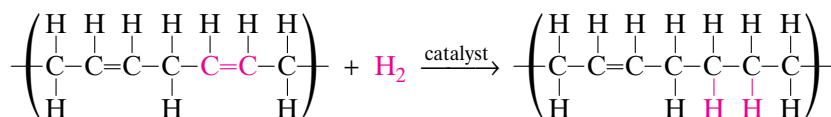


FIGURE 21-8 The fatty acid shown in the model for vegetable oil contains a double bond. During hydrogenation, which is used to produce margarine and vegetable shortening, addition of hydrogen atoms removes double bonds from fatty acids.



The molecule still consists of long chains of carbon atoms, but it contains far fewer double bonds. The conversion of these double bonds to single bonds changes the material from an oil, which is a liquid, into a fat, which is a solid. When you see the word *hydrogenated* on a food product, you know that an oil has been converted to a fat by this process. Examples of an oil and hydrogenated fats are shown in Figure 21-8.

Condensation Reactions

A **condensation reaction** is one in which two molecules or parts of the same molecule combine. A small molecule, such as water, is usually removed during the reaction. An example is the reaction between two amino acids, which contain both amine and carboxyl groups. One hydrogen from the amine group of one amino acid combines with the hydroxyl from the carboxyl group of the other amino acid to form a molecule of water. When repeated many times, this reaction forms a protein molecule.

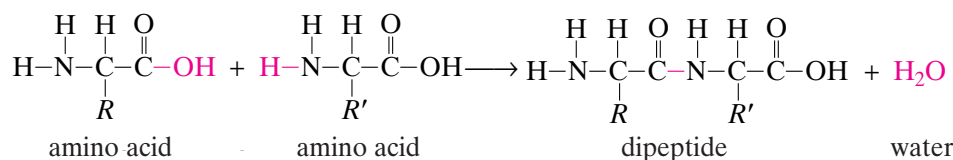
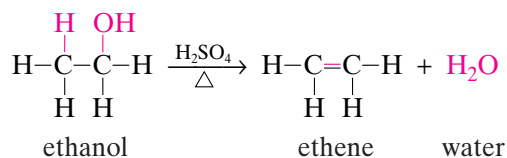




FIGURE 21-9 Sucrose is dehydrated when it reacts with concentrated sulfuric acid. Elimination of water produces a compound that is mostly carbon.

Elimination Reactions

An **elimination reaction** is one in which a simple molecule, such as water or ammonia, is removed from adjacent carbon atoms of a larger molecule. A simple example of an elimination reaction is the heating of ethanol in the presence of concentrated sulfuric acid. Under these conditions, a hydrogen atom bonded to one carbon atom and a hydroxyl group bonded to the second carbon atom are removed from the ethanol molecule. The hydrogen atom and hydroxyl group combine to form a molecule of water.



Another example of an elimination reaction is the dehydration of sucrose with concentrated sulfuric acid, shown in Figure 21-9.

SECTION REVIEW

1. Can an addition reaction occur between chlorine and ethane? Why or why not?
2. Does an addition reaction increase or decrease the saturation of a molecule?
3. What functional groups does the molecule of water come from in the condensation reaction between two amino acids?
4. Explain how elimination reactions could be considered the opposite of addition reactions.

Polymers

SECTION 21-4

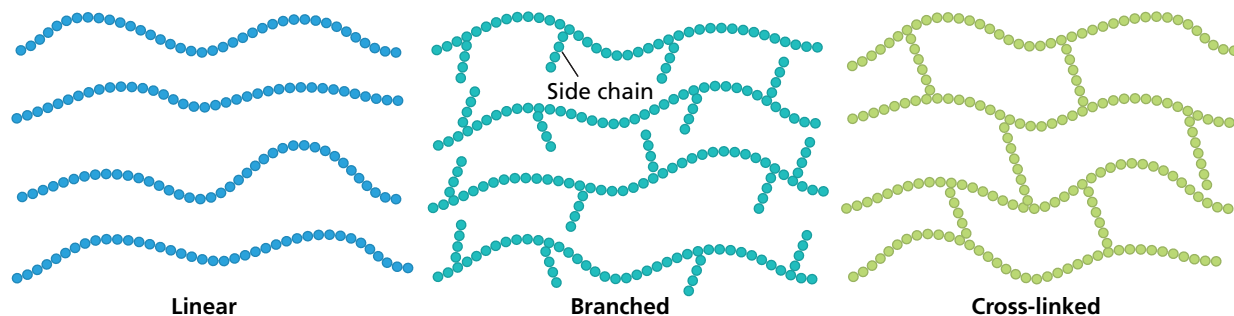
OBJECTIVES

- Explain the relationship between monomers and polymers.
- Describe how the differences in the general structures of linear, branched, and cross-linked polymers contribute to their properties.
- Identify the two main types of polymers and the basic reaction mechanisms by which they are made.
- Relate the structures of specific polymers to their properties and uses.

Polymer Thermal Properties and Structure

Polymers can be classified by the way they behave when heated. A **thermoplastic polymer** melts when heated and can be reshaped many times. A **thermosetting polymer** does not melt when heated but keeps its original shape. The thermal properties of polymers can be explained by whether their structure is linear, branched, or cross-linked, as shown in Figure 21-10.

The molecules of a *linear polymer* are free to move. They slide back and forth against each other easily when heated. So, linear polymers are thermoplastic. The molecules of a *branched polymer* contain side chains that prevent the molecules from sliding across each other easily. However, branched polymers are still likely to be thermoplastic. In *cross-linked polymers*, adjacent molecules in the polymer have formed bonds with each other. Individual molecules are not able to slide past each other when heated. Cross-linked polymers retain their shape when heated and are thermosetting polymers.



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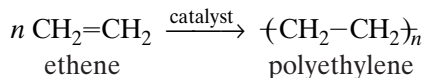
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FIGURE 21-10 Compare structures of the three types of polymers. Linear polymers are free to slide. Branched and cross-linked polymers are inhibited.

Addition Polymers

An **addition polymer** is a polymer formed by chain addition reactions between monomers that contain a double bond. For example, molecules of ethene can polymerize with each other to form polyethene, commonly called polyethylene.



The letter n shows that the addition reaction can be repeated multiple times to form a polymer n monomers long. In fact, this reaction can be repeated hundreds or thousands of times.

Forms of Polyethylene and Related Polymers

Various forms of polyethylene, shown in Figure 21-11, have different molecular structures. High-density polyethylene (HDPE) is a linear polymer. It has a high density because linear molecules can pack together closely. One use of HDPE is in plastic containers such as milk and juice bottles because HDPE tends to remain stiff and rigid.

FIGURE 21-11 Properties of the different forms of polyethylene are reflected in their uses. Linear molecules of polyethylene can pack together very closely as shown in the model of HDPE. The branches of branched polyethylene keep the molecules from packing tightly as shown in the LDPE structure. The cross-links of cPE make it very strong.



TABLE 21-8 *Some Addition Polymers*

Monomer structure	Monomer name	Polymer name	Typical use
$\text{CH}_2=\text{CH}-\text{CH}_3$	propylene	polypropylene	plastic bottles
$\text{CH}_2=\text{CH}-\text{Cl}$	vinyl chloride	polyvinyl chloride (PVC)	pipng
$\text{CH}_2=\text{CH}-\text{CN}$	acrylonitrile	polyacrylonitrile	fabrics
$\text{CH}_2=\text{CH}-\text{C}_6\text{H}_5$	styrene	polystyrene	insulation
$\text{CH}_2=\text{CH}-\text{O}-\overset{\text{O}}{\parallel}{\text{C}}-\text{CH}_3$	vinyl acetate	polyvinyl acetate	adhesives, paints

If ethylene is heated to about 200°C at pressures above 200 atmospheres, random branching of the molecule chains may occur during polymerization. Branches form when hydrogen atoms are removed from the molecule and ethylene molecules add at these locations. Branched-chain molecules are not able to cluster as closely together as are linear molecules. Thus, the density of branched-chain polyethylene is less than that of linear polyethylene. The branched-chain form of polyethylene is known as low-density polyethylene (LDPE). LDPE tends to be less rigid than HDPE and is used, for example, in plastic bags.

When hydrogen atoms are removed from polyethylene molecules, two adjacent molecule chains may bond with each other. This forms a cross-link between the two molecules. Cross-linked polyethylene (sometimes called cPE) is even tougher and more rigid than HDPE. It is used for objects that need to be very strong.

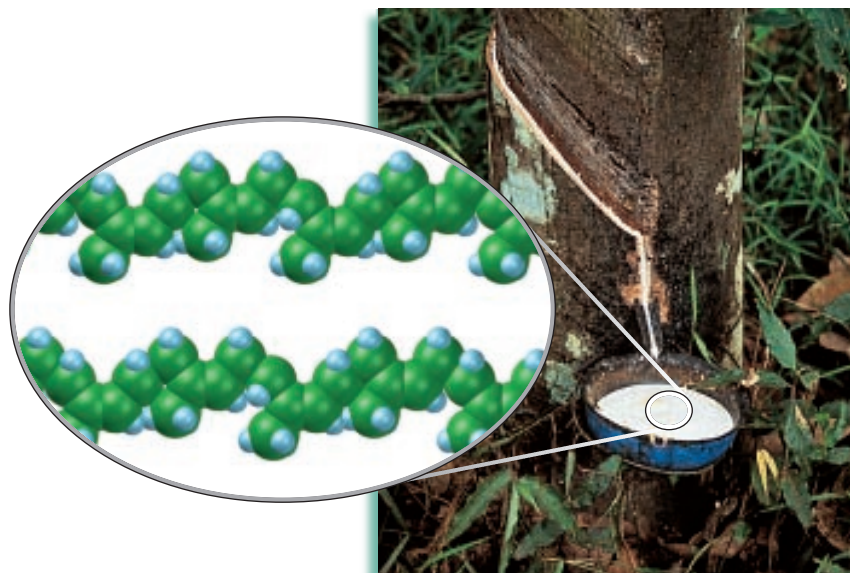
Addition polymers similar to polyethylene can be made by substituting an atom or group of atoms for a hydrogen atom in ethene to form the monomer. Table 21-8 lists examples of these addition polymers.

Polystyrene, a polymer found in this table, is another example of a polymer whose properties can be altered. Pure polystyrene can be melted and molded for use in clear plastic cold-drink cups. Or it can be formed into tiny beads and then soaked in a low-boiling-point liquid, such as pentane. When this mixture is heated, the liquid vaporizes, expands, and forms tiny bubbles within the polystyrene. The product of this reaction is an opaque white material used to make hot-drink cups. Figure 21-12 shows the two types of polystyrene cups.



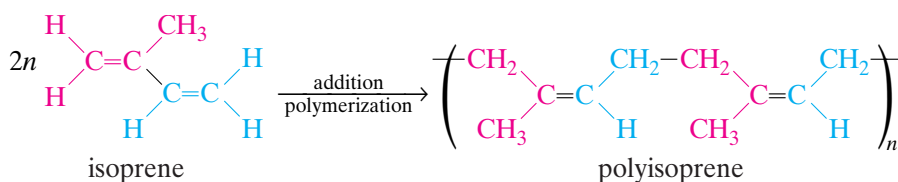
FIGURE 21-12 Both of these cups are made of polystyrene. Depending on how it is processed, polystyrene can be either flexible or rigid and brittle.

FIGURE 21-13 A rubber tree secretes latex, which is a suspension of rubber particles in water. When the rubber particles are precipitated, a gooey, sticky mass forms. An idealized model of natural rubber is shown in this figure.



Natural and Synthetic Rubber

Natural rubber is produced by the rubber tree, *Hevea brasiliensis*, shown in Figure 21-13. It is formed as the result of an addition reaction. The monomer in this reaction is 2-methyl-1,3-butadiene, commonly called isoprene.



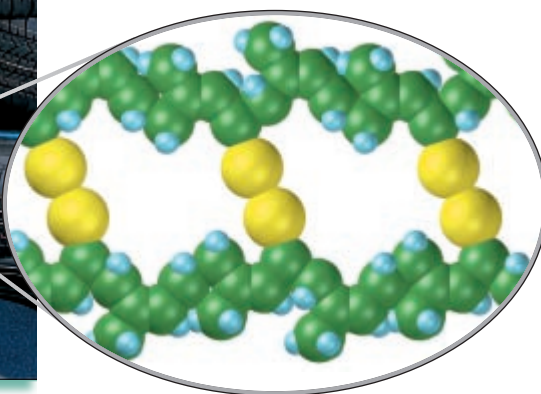
Natural rubber has relatively few practical applications. When warmed, individual molecules of polyisoprene slide easily back and forth past each other. The rubber gets soft and gooey, making it useless for many purposes.

A process for converting natural rubber into a useful commercial product was accidentally discovered by Charles Goodyear in 1839. Goodyear found that the addition of sulfur to molten rubber produces a material that remains very hard and tough when cooled. He called this process vulcanization. **Vulcanization** is a cross-linking process between adjacent polyisoprene molecules that occurs when the molecules are heated with sulfur atoms. Sulfur atoms bond to a carbon atom in one molecule and a second carbon atom in a second molecule, forming a cross-link between the two molecules. This is shown in the model in Figure 21-14. Vulcanization enabled rubber to be used in a wide variety of products, such as hoses, rainwear, and tires.

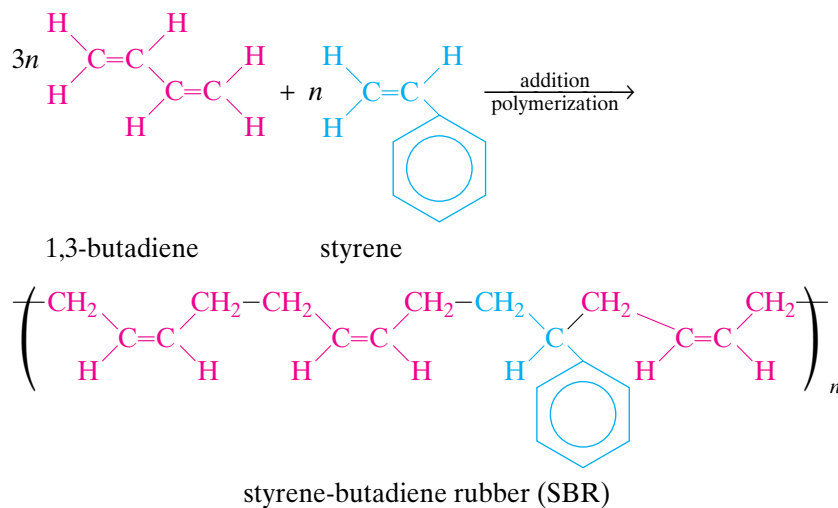
In the first year of World War II, Japan controlled large portions of Southeast Asia, where most of the world's natural rubber is obtained. The United States and other Allied nations were forced to develop



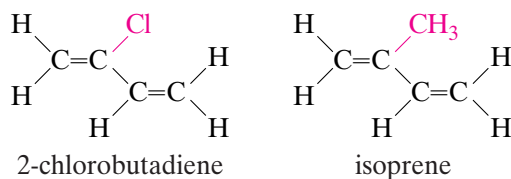
FIGURE 21-14 An idealized model of vulcanized rubber, in which rubber molecules are cross-linked by sulfur atoms, is shown in this figure. Vulcanized rubber is used in tires.



synthetic substitutes for natural rubber. Some synthetic rubbers have superior properties to natural rubber. Styrene-butadiene rubber, SBR, is a copolymer made in the reaction between styrene and butadiene, as shown below. SBR is used primarily in tires.



Another substitute, neoprene, is formed during the polymerization of 2-chlorobutadiene. Notice that 2-chlorobutadiene is identical to isoprene, the monomer of natural rubber, except for the presence of a chlorine atom in place of a methyl group on the number 2 carbon atom.

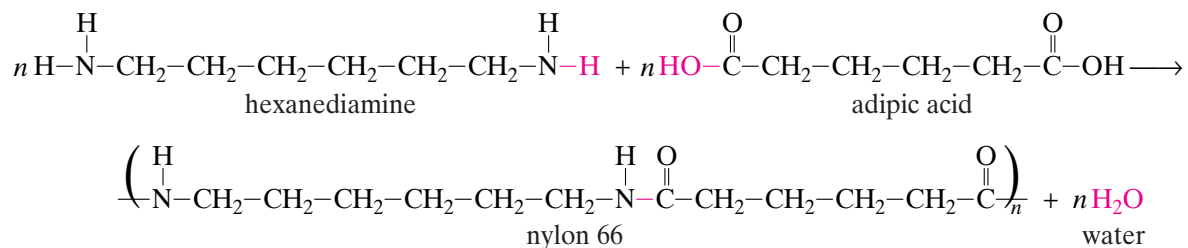


Condensation Polymers

A **condensation polymer** is a polymer formed by condensation reactions. Monomers of condensation polymers must contain two functional groups. This allows each monomer to link with two other monomers by condensation reactions. Condensation polymers are usually copolymers with two monomers in an alternating order.

Nylon and the Polyamides

One example of a condensation polymer is shown below. A carboxylic acid with two carboxyl groups, adipic acid, and an amine with two amine groups, hexanediamine, react with each other through the elimination of a molecule of water.

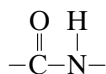


This reaction is shown in Figure 21-15. The product contains two kinds of monomers, the adipic acid monomer and the hexanediamine monomer. This copolymer is known as nylon 66 because each of the monomers contains six carbon atoms. Nylon 66 was invented by Dr. Wallace Carothers in 1935 and is one of the most widely used of all synthetic polymers.



FIGURE 21-15 Nylon 66, shown here being wound onto a stirring rod, is produced from the polymerization of adipic acid (the top layer) and hexanediamine (the bottom layer).

Nylon 66 is an example of a polyamide polymer. The word *polyamide* comes from the presence of the amide group in the polymer. The structure of the amide group is shown below.



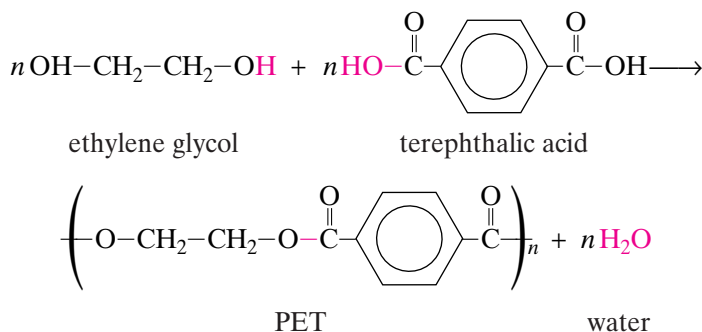
Polyamides have become commercial successes because they can be fabricated into so many different forms. For example, they can be knitted and woven, like natural fibers, to make stockings and other types of clothing. When polyamides are treated with radiation, extensive cross-linking occurs and the final product becomes very rigid and strong. One product made in this way, Kevlar, is so strong that it is used in the manufacture of bullet-proof vests used by police officers.



FIGURE 21-16 This thread is made from polyester.

Polyester

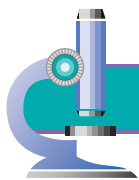
Polyesters are another common type of condensation polymer. Polyethylene terephthalate, PET, is a polyester formed when terephthalic acid reacts with ethylene glycol.



PET has a vast range of uses, such as in tires, photographic film, food packaging, and bottles. Its best known use may be as a fiber called polyester, which is widely used in permanent-press clothing. Polyester fabric is made wrinkle resistant by the cross-linking of its polymer strands. Polyester thread is shown in Figure 21-16.

SECTION REVIEW

1. Would the handles of cookware more likely be made of a thermosetting polymer or a thermoplastic polymer? Why?
2. Would it be possible to have an addition polymer synthesized from a monomer that has only single bonds? Why or why not?
3. Make a simple diagram showing how the structure of a soft, pliable polyethylene differs from the structure of the form that is the most rigid and stiff.
4. Why can a molecule with only one functional group *not* undergo a condensation reaction to form a polymer?



High-Barrier Plastics

Flat-tasting soda? Technology comes to the rescue. No matter how tightly the cap is sealed on a bottle, soda loses fizz over time. Because of the nature of plastic, the carbon dioxide gas actually escapes through the bottle. Benny Freeman, an associate professor of chemical engineering at North Carolina State University, has discovered how to stop this problem with a special kind of plastic called a liquid crystalline polymer.

According to Freeman, the long molecules that make up plastics do not fit together tightly. Instead, the plastic molecules are constantly moving and opening gaps between them similar to the spaces between noodles in a bowl of cooked spaghetti. Gas molecules can pass through these gaps. In a soda bottle, the carbon dioxide in the soft drink dissolves into the plastic and escapes into the air outside the bottle. Conversely, plastic containers also allow oxygen to seep inside them, which can spoil the food they hold.

Liquid crystal polymers, or LCPs, are made up of long molecules, like other plastics are. But, says Freeman, the molecules in an LCP are much straighter, and they all point in the same general direction. Instead of looking like a bowl of cooked pasta, LCP molecules more closely resemble a box of uncooked spaghetti packed tightly together. Because



The LCP layer (white) of this power cable makes the cable waterproof.

it is much more difficult for gas molecules to squeeze through them, LCPs make an ideal material for manufacturing containers.

Aside from keeping soft drinks fresh, these high-barrier plastics could also replace glass packaging for foods that easily become stale or spoiled from contact with oxygen. That would result in much lighter, unbreakable containers. Gas tanks made from LCPs would better prevent harmful fumes from leaking out and polluting the environment. The liquid crystal polymer could also be used as a protectant to line underground electrical cables, making them virtually waterproof and corrosion-free. LCPs are currently used to line the breathing system of NASA's new spacesuits.

Liquid crystal polymers have not yet made it into the packaging of everyday products because they are several times more expensive than regular plastics. Freeman thinks that this problem could be solved by creating what he calls a composite structure: a combination of regular plastic and the liquid crystal polymer. By sandwiching a thin LCP layer between two pieces of regular plastic, manufacturers could keep their costs down and still keep your soda fizzy.

"We are," says Freeman, "at the beginning of really understanding where you can start to manipulate structure and actually control properties in these materials. There's still a lot of uncharted territory in the science of these materials."

CHAPTER 21 REVIEW

CHAPTER SUMMARY

- 21-1**
- A functional group is an atom or group of atoms responsible for the properties of the organic compound which contains the functional group.
 - Systematic names of organic compounds indicate the type and position of functional groups present.
 - Alcohols contain the hydroxyl functional group. Their tendency to form hydrogen bonds affects their properties and uses.
 - In alkyl halides, one or more hydrogen atoms of an alkane have been replaced by one or more

halogen atoms. One class of alkyl halides, the CFCs, has many important industrial uses but may cause serious environmental problems.

- Two alkyl groups are joined to an oxygen atom in ethers. Generally unreactive, they are widely used as solvents.
- The physical and chemical properties of organic classes often reflect the ability or inability of molecules in each class to form hydrogen bonds.

Vocabulary

alcohols (663)

alkyl halides (666)

ethers (669)

functional group (663)

- 21-2**
- Aldehydes and ketones both contain the carbonyl group and are responsible for some odors and flavors. In aldehydes, the carbonyl group is attached to the first carbon atom of a carbon-atom chain. In ketones, it is in the middle of a carbon-atom chain.
 - Carboxylic acids contain carboxyl groups. They act as weak acids in aqueous solutions.
 - In esters, the hydrogen atom of a carboxylic acid group has been replaced with an alkyl group. Natural and synthetic esters give many foods their flavors and odors.
 - Amines are derivatives of ammonia in which one or more hydrogen atoms are replaced by one or more alkyl groups. They behave as weak bases in aqueous solutions.

Vocabulary

aldehydes (672)

carboxylic acids (674)

ketones (672)

secondary amine (677)

amines (677)

esters (675)

primary amine (677)

tertiary amine (677)

- 21-3**
- Both addition and substitution reactions add atoms to a molecule. In substitution reactions, an atom or group of atoms is replaced. In addition reactions, an atom or group of atoms is added to a double or triple bond.
 - A small molecule is usually removed during both condensation reactions and elimination

reactions. In a condensation reaction, two molecules or parts of the same molecule combine. In an elimination reaction, a large molecule eliminates a small molecule.

Vocabulary

addition reaction (682)

condensation reaction (683)

elimination reaction (684)

substitution reaction (682)

CHAPTER SUMMARY *continued*

- 21-4**
- Polymers are large molecules made of many repeating units called monomers. A copolymer consists of two or more different monomers.
 - Thermosetting polymers cannot be melted once they are formed. Thermoplastic polymers can be melted more than once.
 - The physical properties of polymers are strongly influenced by the presence or absence of branching and cross-linking among polymer chains.
 - Addition reactions require that the monomers contain a double bond. Polyethylene and related polymers as well as natural and synthetic rubbers involve addition polymerization.
 - Monomers of condensation polymers must contain two functional groups. Nylon 66, other polyamides, and polyesters are condensation polymers.

Vocabulary

addition polymer (686)

copolymer (685)

polymers (685)

thermosetting polymer (685)

condensation polymer (690)

monomers (685)

thermoplastic polymer (685)

vulcanization (688)

REVIEWING CONCEPTS

- Write the general formula for each of the following:
 - alcohol
 - ether
 - alkyl halide (21-1)
- Based on the boiling points of water and methanol, in which would you expect to observe a greater degree of hydrogen bonding? Explain your answer. (21-1)
- Why is glycerol used in moisturizing skin lotions?
 - How does this relate to the chemical structure of glycerol? (21-1)
- State two advantages and one disadvantage of using gasohol as an automotive fuel. (21-1)
- Why are CFCs regarded as an environmental hazard? (21-1)
- Alcohols and ethers are both organic compounds that contain oxygen. Explain how their chemical structures differ. (22-1)
- What is the important chemical property of ethers that leads to their most common use? (21-1)
- Write the general formula for each of the following:
 - aldehyde
 - ketone
 - carboxylic acid (21-2)
 - ester
 - amine
- Aldehydes and ketones both contain the same functional group. Why are they classified as separate classes of organic compounds? (21-2)
- Cinnamaldehyde is responsible for what odor?
 - The IUPAC name for cinnamaldehyde is 3-phenyl-2-propenal. Based on its names, to which class of compounds does it belong? (21-2)
- Why can a carboxyl group not be in the middle of a carbon-atom chain? (21-2)
- Show the reaction that occurs when carboxylic acids are dissolved in water.
 - What property of carboxylic acids does this reaction illustrate? (21-2)
- How are esters related to carboxylic acids? (21-2)
- What element do amines contain besides carbon and hydrogen? (21-2)
- Explain why an amine acts as a base. (21-2)
- Show the reaction that occurs when aqueous solutions of carboxylic acids and amines are mixed. (21-2)

17. Name five classes of organic compounds that are often responsible for odors and flavors. (21-2)
18. What classes of organic compounds contain oxygen? (21-1 and 21-2)
19. What type of chemical reaction would you expect to occur between 2-octene and hydrogen bromide, HBr? (21-3)
20. How many molecules of chlorine, Cl_2 , can be added to a molecule of 1-propene? a molecule of 1-propyne? (21-3)
21. Compare substitution and addition reactions. (21-3)
22. What problems would you expect to encounter in trying to hydrogenate hexane, C_6H_{14} ? (21-3)
23. In a chemical reaction, two small molecules are joined and a water molecule is produced. What type of reaction took place? (21-3)
24. Do elimination reactions increase or decrease the saturation of a molecule? (21-3)
25. Name three common natural products and three synthetic products made of polymers. (21-4)
26. Some automobile engine parts are made of polymers. Do you think these polymers are thermosetting or thermoplastic? Explain your answer. (21-4)
27. Classify each of the following as thermosetting or thermoplastic:
 - a. linear polymer
 - b. branched polymer
 - c. cross-linked polymer (21-4)
28. What are two reactions by which polymers can be formed? (21-4)
29. What is the structural requirement for a molecule to be a monomer in an addition polymer? (21-4)
30. Explain the structural molecular differences between the following three types of polyethylene: HDPE, LDPE, and cPE. (21-4)
31. What is the primary structural difference between polyethylene and polystyrene? (21-4)
32. Give a molecular explanation for the fact that natural rubber melts when it is heated but vulcanized rubber does not. (21-4)
33. How is the molecular structure of neoprene different from that of natural rubber? (21-4)
34. Could ethanoic acid be used as a monomer in a condensation polymer? Why or why not? (21-4)
35. Draw the structural formula for the amide group. (21-4)
36. Why is polyester wrinkle resistant? (21-4)

PROBLEMS

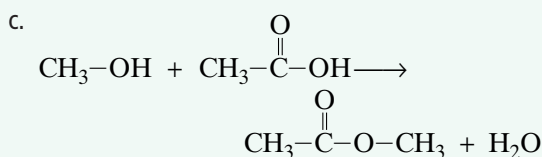
Organic Compound Nomenclature

37. Name the following alcohols:
 - a. $\text{CH}_3\text{—OH}$
 - b. $\begin{array}{c} \text{OH} \\ | \\ \text{CH}_3\text{—CH—CH}_2\text{—OH} \end{array}$
 - c. $\begin{array}{c} \text{OH} \\ | \\ \text{CH}_3\text{—CH—CH}_2\text{—CH}_3 \end{array}$
 - d. $\begin{array}{c} \text{OH} \\ | \\ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH—CH}_3 \end{array}$
38. Draw condensed structures for each of the following alcohols:
 - a. 2,3-pentanediol
 - b. 1-pentanol
 - c. 1,2,3-propanetriol
 - d. ethanol
39. Name the following alkyl halides. (Hint: See Sample Problem 21-1.)
 - a. $\text{CH}_3\text{—I}$
 - b. $\text{Cl—CH}_2\text{—CH}_2\text{—Cl}$
 - c. $\begin{array}{c} \text{I} \quad \text{Br} \\ | \quad | \\ \text{CH}_3\text{—C—C—CH}_3 \\ | \quad | \\ \text{I} \quad \text{Br} \end{array}$
 - d. $\begin{array}{c} \text{Br} \\ | \\ \text{CH}_3\text{—CH}_2\text{—C—Br} \\ | \\ \text{Br} \end{array}$
40. Draw condensed structures for each of the following alkyl halides:
 - a. 2,3,4-trichloropentane
 - b. 1,1-diiodopropane
 - c. 1-fluorohexane
 - d. 2,2-dichloro-1,1-difluoropropane
41. Name the following ethers. (Hint: See Sample Problem 21-2.)
 - a. $\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—O—CH}_2\text{—CH}_2\text{—CH}_3$

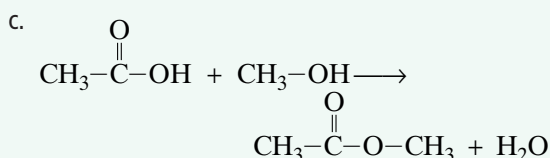
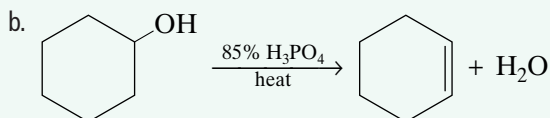
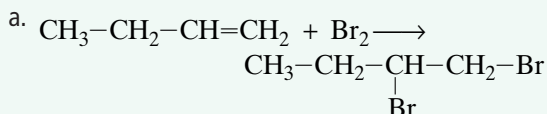
- b. $\text{CH}_3\text{—O—CH}_2\text{—CH}_3$
 c. $\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—O—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$
 d. $\text{CH}_3\text{—CH}_2\text{—O—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3$
- 42.** Draw condensed structures for each of the following ethers:
 a. dimethyl ether c. butyl propyl ether
 b. methyl propyl ether d. ethyl heptyl ether
- 43.** Name the following aldehydes:
 a. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—C—H} \end{array}$
 b. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—C—H} \end{array}$
 c. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—C—H} \end{array}$
 d. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—C—H} \end{array}$
- 44.** Draw condensed structures for each of the following aldehydes:
 a. methanal c. octanal
 b. hexanal d. ethanal
- 45.** Name the following ketones:
 a. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—C—CH}_3 \end{array}$
 b. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—C—CH}_3 \end{array}$
 c. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—C—CH}_3 \end{array}$
 d. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—C—CH}_2\text{—CH}_3 \end{array}$
- 46.** Draw condensed structures for each of the following ketones:
 a. 3-hexanone c. 2-octanone
 b. 2-pentanone d. 2-hexanone
- 47.** Name the following carboxylic acids:
 a. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—C—OH} \end{array}$
 b. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—C—OH} \end{array}$
- c. $\begin{array}{c} \text{O} \\ \parallel \\ \text{H—C—OH} \end{array}$
 d. $\begin{array}{c} \text{O} \qquad \qquad \text{O} \\ \parallel \qquad \qquad \parallel \\ \text{HO—C—CH}_2\text{—CH}_2\text{—C—OH} \end{array}$
- 48.** Draw condensed structures for each of the following carboxylic acids:
 a. butanoic acid c. hexanedioic acid
 b. hexanoic acid d. heptanoic acid
- 49.** Name the following esters:
 a. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—C—O—CH}_3 \end{array}$
 b. $\begin{array}{c} \text{O} \\ \parallel \\ \text{H—C—O—CH}_3 \end{array}$
 c. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—C—O—CH}_2\text{—CH}_3 \end{array}$
 d. $\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—C—O—CH}_2\text{—CH}_3 \end{array}$
- 50.** Draw condensed structures for each of the following esters:
 a. butyl ethanoate c. propyl propanoate
 b. ethyl methanoate d. methyl butanoate
- 51.** Name the following amines:
 a. $\text{CH}_3\text{—NH}_2$
 b. $\text{CH}_3\text{—CH}_2\text{—NH—CH}_2\text{—CH}_3$
 c. $\text{CH}_3\text{—CH}_2\text{—NH—CH}_3$
 d. $\begin{array}{c} \text{CH}_3\text{—N—CH}_3 \\ | \\ \text{CH}_3 \end{array}$
- 52.** Draw condensed structures for each of the following amines:
 a. butylmethylamine c. diethylmethylamine
 b. ethylamine d. ethylpropylamine

Organic Reactions

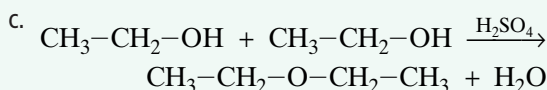
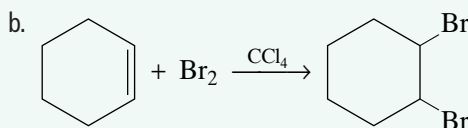
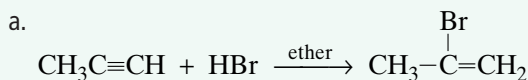
- 53.** Which of the following reactions is a substitution reaction?
 a. $\text{CH}_2=\text{CH}_2 + \text{Cl}_2 \longrightarrow \text{Cl—CH}_2\text{—CH}_2\text{—Cl}$
 b. $\text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH}_3 + \text{Cl}_2 \longrightarrow \text{Cl—CH}_2\text{—CH}_2\text{—CH}_2\text{—CH}_3 + \text{HCl}$



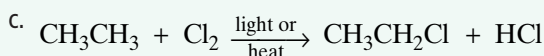
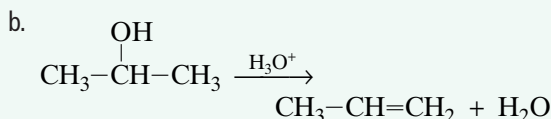
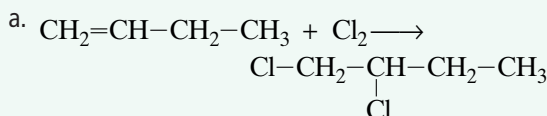
54. Which of the following reactions is an addition reaction?



55. Which of the following reactions is a condensation reaction?



56. Which of the following reactions is an elimination reaction?



Calculations with Organic Compounds

57. Calculate the molecular mass of trichlorofluoromethane.

58. A compound is found to contain 54.5% carbon, 9.1% hydrogen, and 36.4% oxygen.

a. Determine the simplest formula.

b. The molecular mass of this compound is 88.1 g. What is the molecular formula?

59. The hydronium ion concentration in 0.05 M acetic acid is 9.4×10^{-4} mol/L. What is the pH of the solution?

60. What volume of ethanol must be diluted with water to prepare 500. mL of 0.750 M solution? The density of ethanol is given as 0.789 g/mL.

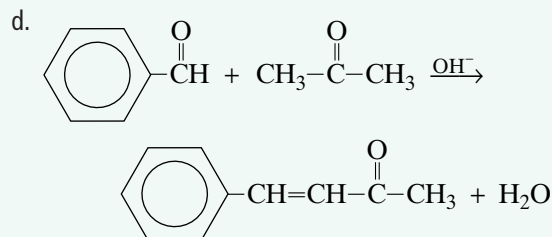
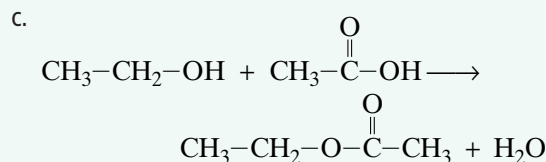
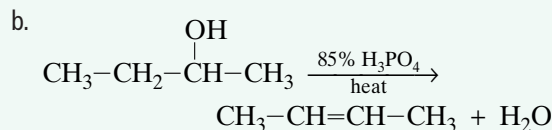
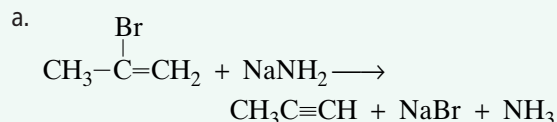
61. 1,2-ethanediol, also called ethylene glycol, is commonly used as an antifreeze. The density of ethylene glycol is 1.432 g/mL.

a. Calculate the theoretical freezing point of the water in a 50% (by volume) solution of ethylene glycol.

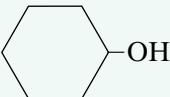
b. The actual freezing point of such a solution is about -37°C . Account for any difference between this and the value you calculated.

MIXED REVIEW

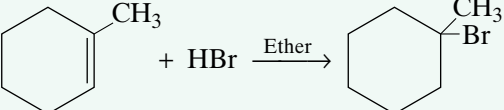
62. Classify each of the following reactions as an elimination reaction or a condensation reaction:



63. Name the following compounds:

- $$\text{CH}_3-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\parallel}{\text{C}}-\text{CH}_2-\text{CH}_3$$
- $$\text{CH}_3-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_2-\text{CH}_2-\text{CH}_3$$
- $$\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_2 \\ | \\ \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} \end{array}$$
- $$\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_3-\text{N}-\text{CH}_2-\text{CH}_3 \end{array}$$
- $$\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\parallel}{\text{C}}-\text{H}$$
- $$\text{CH}_3-\text{CH}_2-\text{O}-\text{CH}_2-\text{CH}_2-\text{CH}_3$$
- $$\begin{array}{c} \text{Cl} \\ | \\ \text{CH}_3-\text{CH}-\text{CH}_2-\text{CH} \\ | \quad \quad | \\ \text{Br} \quad \quad \text{Cl} \end{array}$$
- 

64. Classify each of the following reactions as a substitution reaction or an addition reaction:

- $$\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{OH} + \text{HCl} \xrightarrow[\text{heat}]{\text{ZnCl}_2} \text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{Cl} + \text{H}_2\text{O}$$
- $$\text{CH}_2=\text{CH}_2 + \text{HBr} \xrightarrow[25^\circ\text{C}]{\text{Ether}} \text{CH}_3-\text{CH}_2-\text{Br}$$
- $$\text{CH}\equiv\text{CH} + \text{HCl} \xrightarrow{\text{HgCl}_2} \text{CH}_2=\text{CH}-\text{Cl}$$
- 

65. Draw structural formulas for each of the following compounds:

- 1,2,3-trichloropropane
- 1-butanol
- ethyl methyl ether
- propanoic acid
- methyl propanoate
- trimethylamine

66. For each of the following, determine if the compound is named correctly. If it is not, give the correct name.

- $$\text{CH}_3-\text{CH}_2-\overset{\text{OH}}{\text{CH}}-\text{CH}_3$$

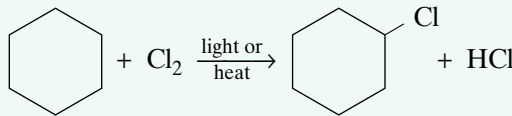
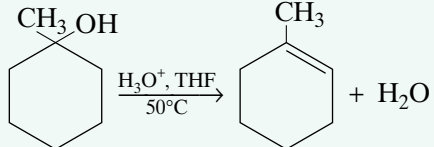
2-butanol
- $$\text{CH}_3-\text{CH}_2-\text{CH}_2-\overset{\text{Br}}{\underset{\text{Br}}{\text{C}}}-\text{CH}_3$$

4-dibromopentane
- $$\text{CH}_3-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$$

ethyl pentanoate
- $$\text{CH}_3-\text{NH}-\text{CH}_2-\text{CH}_2-\text{CH}_3$$

methylpropylamine

67. Identify each of the following reactions as an addition, substitution, elimination, or condensation reaction:

- $$\text{CH}_3-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH} + \text{CH}_3-\overset{\text{OH}}{\text{CH}}-\text{CH}_3 \longrightarrow \text{CH}_3-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\overset{\text{CH}_3}{\text{CH}}-\text{CH}_3 + \text{H}_2\text{O}$$
- $$\text{CH}_2=\text{CH}-\text{CH}_3 + \text{Cl}_2 \longrightarrow \text{Cl}-\text{CH}_2-\underset{\text{Cl}}{\text{CH}}-\text{CH}_3$$
- 
- 

CRITICAL THINKING

68. **Applying Ideas** How does ethylene glycol protect radiator fluid in an automobile from both freezing in the winter and boiling over in the summer?

69. **Predicting Outcomes** Would a collection of 1,2-ethanediol molecules be likely to form twice as many hydrogen bonds as an equal number of ethanol molecules? Why or why not?



TECHNOLOGY & LEARNING

70. Graphing Calculator Predict the Freezing Point

The graphing calculator can run a program that predicts the freezing point of ethylene glycol solutions, given the concentration. Begin by creating a table of data. Use the program to carry out the predictions.

Go to Appendix C. If you are using a TI 83 Plus, you can download the program and data and run the application as directed. If you are using another calculator, your teacher will provide you with keystrokes and data sets to use. Remember that after creating your lists, you will need to name the program and check the display, as explained in Appendix C. You will then be ready to run the program. After you have graphed the data, answer these questions.

- What is the approximate freezing point of the solution with a molality of 5.00m?
- What is the approximate freezing point of the solution with a molality of 10.00m?
- What is the approximate freezing point of the solution with a molality of 13.00m?

RESEARCH & WRITING

- A class of CFCs known as hydrochlorofluorocarbons (HCFCs) has been suggested as a substitute for CFCs in many applications. How does the chemical structure of an HCFC differ from that of a CFC? Why are the HCFCs more acceptable environmentally than other CFCs?
- At one time, a group of compounds known as the PCBs were very popular for a number of

industrial applications. Find out the general structural formula for these compounds and the properties that made them so popular. Also find out why the PCBs were eventually banned for most industrial uses.

- The widespread use of synthetic polymers in modern society has created a number of new environmental problems. Find out what some of these problems are and what can be done to reduce them.

ALTERNATIVE ASSESSMENT

- Performance** Devise a set of experiments to study how well biodegradable plastics break down. If your teacher approves your plan, conduct a class experiment to test the procedure on products labeled “biodegradable.”
- Performance** Your teacher will make available unlabeled samples of benzoic acid, ethyl alcohol, and hexanediamine. Develop an experiment to identify each. If your teacher approves your plan, identify the unknown substances.
- Keep a list of the food you consume in a single day. Compare the content labels from those foods, and then list the most commonly used chemicals in them. With the aid of your teacher and some reference books, try to classify the organic chemicals by their functional groups.
- As a class or small group, research the preservatives used in various foods. Examine their chemical structure. Determine a way to test for organic functional groups of possibly hazardous preservatives.