

Substituted Hydrocarbons and Their Reactions

BIG Idea The substitution of different functional groups for hydrogen atoms in hydrocarbons results in a diverse group of organic compounds.

22.1 Alkyl Halides and Aryl Halides

MAIN Idea A halogen atom can replace a hydrogen atom in some hydrocarbons.

22.2 Alcohols, Ethers, and Amines

MAIN Idea Oxygen and nitrogen are two of the most-common atoms found in organic functional groups.

22.3 Carbonyl Compounds

MAIN Idea Carbonyl compounds contain a double-bonded oxygen in the functional group.

22.4 Other Reactions of Organic Compounds

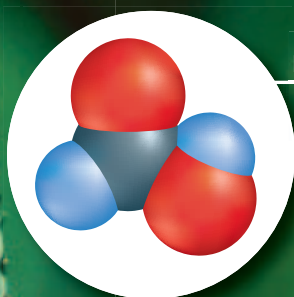
MAIN Idea Classifying the chemical reactions of organic compounds makes predicting products of reactions much easier.

22.5 Polymers

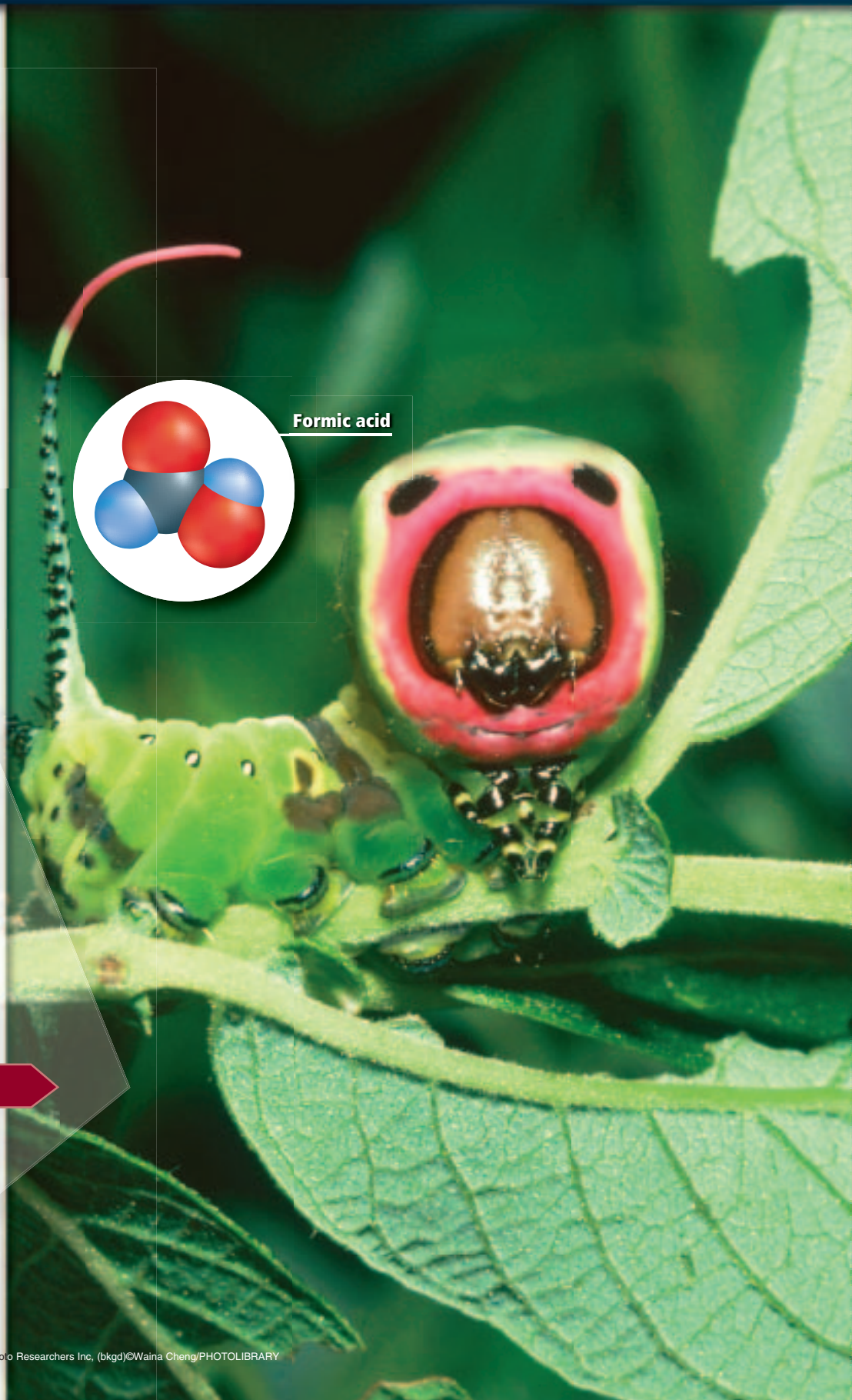
MAIN Idea Synthetic polymers are large organic molecules made up of repeating units linked together by addition or condensation reactions.

ChemFacts

- The larva of the *Cerura vinula* moth squirts formic acid when threatened.
- The feathery antennae of the adult moth contains chemoreceptors for detecting organic compounds.



Formic acid



Start-Up Activities

LAUNCH Lab

How do you make slime?

In addition to carbon and hydrogen, most organic substances contain other elements that give the substances unique properties. How do the properties of substances change when groups form bonds called cross-links between the chains?



Procedure

1. Read and complete the lab safety form.
2. Use a **graduated cylinder** to measure 20 mL of 4% **polyvinyl alcohol solution**. Pour the solution into a small **disposable plastic cup**. Note the viscosity of the solution as you stir it with a **stirring rod**.
3. While stirring, add 6 mL of 4% **sodium tetraborate solution** to the polyvinyl alcohol solution. Continue to stir until there is no further change in the consistency of the product.
4. Use a gloved hand to scoop the material out of the cup. Knead and stretch the polymer.

Analysis

1. **Compare and contrast** the physical properties of the product and the reactants.
2. **Explain** how the crosslinking of the molecular chains affected the viscosity of the solution.

Inquiry What is the ratio of sodium tetraborate solution to polyvinyl alcohol solution? What would you create if the ratio was changed?

FOLDABLES™ Study Organizer

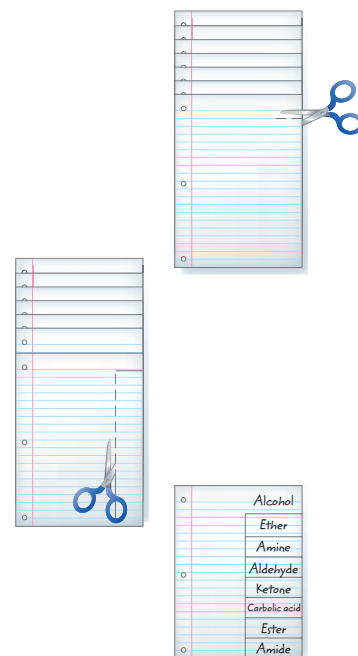
Functional Groups Make the following Foldable to organize information about the functional groups of organic compounds.

STEP 1 Layer seven sheets of paper as shown.

STEP 2 Make a 3-cm horizontal cut through all seven sheets on about the sixth line from the top.

STEP 3 Make a vertical cut from the bottom to meet the horizontal cut.

STEP 4 Place a full sheet at the bottom of the cut sheets. Align the tops and sides of all sheets. Staple the Foldable or place in a notebook. Label the tabs as shown.



FOLDABLES Use this Foldable with Sections 22.1, 22.2, 22.3, and 22.4. As you read these sections, summarize what you learn about the classes of organic compounds. Include their structures, and give examples.

Chemistry Online

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- ▶ find the Try at Home Lab, Modeling Basic Organic Compounds

Section 22.1

Objectives

- Define functional group, and give examples.
- Compare and contrast alkyl and aryl halide structures.
- Evaluate the boiling points of organic halides.

Review Vocabulary

aliphatic compound: a nonaromatic hydrocarbon, such as an alkane, an alkene, or an alkyne

New Vocabulary

functional group
halocarbon
alkyl halide
aryl halide
plastic
substitution reaction
halogenation

Alkyl Halides and Aryl Halides

MAIN Idea A halogen atom can replace a hydrogen atom in some hydrocarbons.

Real-World Reading Link If you have ever played on a sports team, were individual players substituted during the game? For example, a player who is rested might substitute for a player who is tired. After the substitution, the characteristics of the team change.

Functional Groups

You read in Chapter 21 that in hydrocarbons, carbon atoms are linked only to other carbon atoms or hydrogen atoms. But carbon atoms can also form strong covalent bonds with other elements, the most common of which are oxygen, nitrogen, fluorine, chlorine, bromine, iodine, sulfur, and phosphorus.

Atoms of these elements occur in organic substances as parts of functional groups. In an organic molecule, a **functional group** is an atom or group of atoms that always reacts in a certain way. The addition of a functional group to a hydrocarbon structure always produces a substance with physical and chemical properties that differ from those of the parent hydrocarbon. All the items—natural and synthetic—in **Figure 22.1** contain functional groups that give them their individual characteristics, such as smell. Organic compounds containing several important functional groups are shown in **Table 22.1**. The symbols R and R' represent carbon chains or rings bonded to the functional group. An * represents a hydrogen atom, carbon chain, or carbon ring.

Keep in mind that double and triple bonds between two carbon atoms are considered functional groups even though only carbon and hydrogen atoms are involved. By learning the properties associated with a given functional group, you can predict the properties of organic compounds for which you know the structure, even if you have never studied them.

■ **Figure 22.1** All of these items contain at least one of the functional groups that you will study in this chapter. For example, the fruit and flowers have sweet-smelling aromas that are due to ester molecules.



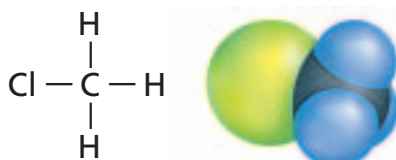
Table 22.1

Organic Compounds and Their Functional Groups

Compound Type	General Formula	Functional Group
Halocarbon	$R-X$ ($X = F, Cl, Br, I$)	Halogen
Alcohol	$R-OH$	Hydroxyl
Ether	$R-OH-R'$	Ether
Amine	$R-NH_2$	Amino
Aldehyde	$\begin{array}{c} O \\ \\ * - C - H \end{array}$	Carbonyl
Ketone	$\begin{array}{c} O \\ \\ R - C - R' \end{array}$	Carbonyl
Carboxylic acid	$\begin{array}{c} O \\ \\ * - C - OH \end{array}$	Carboxyl
Ester	$\begin{array}{c} O \\ \\ * - C - O - R \end{array}$	Ester
Amide	$\begin{array}{c} O \quad H \\ \quad \\ * - C - N - R \end{array}$	Amide

Organic Compounds Containing Halogens

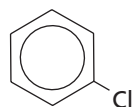
The most simple functional groups can be thought of as substituent groups attached to a hydrocarbon. Recall that a substituent group is a side branch attached to a parent chain. The elements in group 17 of the periodic table—fluorine, chlorine, bromine, and iodine—are the halogens. Any organic compound that contains a halogen substituent is called a **halocarbon**. If you replace any of the hydrogen atoms in an alkane with a halogen atom, you form an alkyl halide. An **alkyl halide** is an organic compound containing a halogen atom covalently bonded to an aliphatic carbon atom. The first four halogens—fluorine, chlorine, bromine, and iodine—are found in many organic compounds. For example, chloromethane is the alkyl halide formed when a chlorine atom replaces one of methane's four carbon atoms, as shown in **Figure 22.2**.



Chloromethane

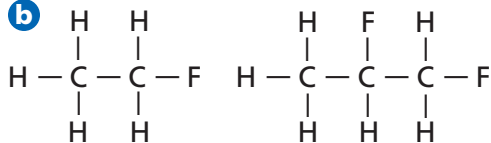
■ **Figure 22.2** Chloromethane is an alkyl halide that is used in the manufacturing process for silicone products, such as window and door sealants.

a



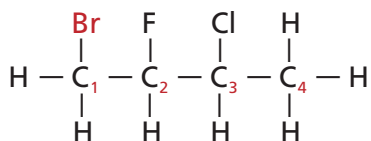
Chlorobenzene

b



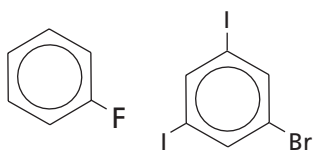
Fluoroethane and 1, 2-Difluoropropane

c



1-Bromo-3-chloro-2-fluorobutane

d



Fluorobenzene and 1-Bromo-3,5-diiodobenzene

■ **Figure 22.3** Organic molecules containing functional groups are named based on their main-chain alkane structure using IUPAC conventions.

An **aryl halide** is an organic compound containing a halogen atom bonded to a benzene ring or other aromatic group. The structural formula for an aryl halide is created by first drawing the aromatic structure and then replacing its hydrogen atoms with the halogen atoms specified, as shown in **Figure 22.3a**.

Connection to Earth Science

Alkyl halides are widely used as refrigerants. Until the late 1980s, alkyl halides called chlorofluorocarbons (CFCs) were widely used in refrigerators and air-conditioning systems. Recall from Chapter 1 how CFCs affect the ozone layer. CFCs have been replaced by HFCs (hydrofluorocarbons), which contain only hydrogen and fluorine atoms bonded to carbon. One of the more common HFCs is 1,1,2-trifluoroethane, also called R134a.

Naming halocarbons Organic molecules containing functional groups are given IUPAC names based on their main-chain alkane structures. For the alkyl halides, a prefix indicates which halogen is present. The prefixes are formed by changing the *-ine* at the end of each halogen name to *-o*. Thus, the prefix for fluorine is *fluoro-*, chlorine is *chloro-*, bromine is *bromo-*, and iodine is *iodo-*, as shown in **Figure 22.3b**.

If more than one kind of halogen atom is present in the same molecule, the atoms are listed alphabetically in the name. The chain also must be numbered in a way that gives the lowest position number to the substituent that comes first in the alphabet. Note how the alkyl halide in **Figure 22.3c** is named.

Similarly, the benzene ring in an aryl halide is numbered to give each substituent the lowest position number possible, as shown in **Figure 22.3d**.



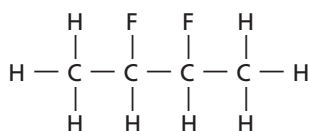
Reading Check Infer why the lowest possible position number is used to name an aryl halide instead of using a randomly chosen position number.

PRACTICE Problems

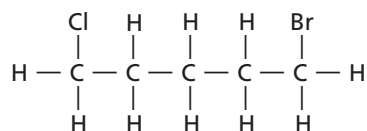
Extra Practice Page 991 and glencoe.com

Name the alkyl or aryl halide whose structure is shown.

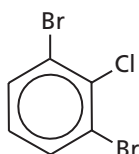
1.



2.




3.




Structure	Name	Boiling Point (°C)	Density (g/mL) in Liquid State
CH ₄	methane	-162	0.423 at -162°C (boiling point)
CH ₃ Cl	chloromethane	-24	0.911 at 25°C (under pressure)
CH ₃ CH ₂ CH ₂ CH ₂ CH ₃	pentane	36	0.626
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ F	1-fluoropentane	62.8	0.791
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ Cl	1-chloropentane	108 <i>Increases</i>	0.882 <i>Increases</i>
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ Br	1-bromopentane	130	1.218
CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ I	1-iodopentane	155	1.516

Properties and uses of halocarbons It is easiest to talk about properties of organic compounds containing functional groups by comparing those compounds with alkanes, whose properties were discussed in Chapter 21. **Table 22.2** lists some of the physical properties of certain alkanes and alkyl halides.

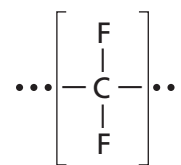
Note that each alkyl chloride has a higher boiling point and a higher density than the alkane with the same number of carbon atoms. Note also that the boiling points and densities increase as the halogen changes from fluorine to chlorine, bromine, and iodine. This trend occurs primarily because the halogens from fluorine to iodine have increasing numbers of electrons that lie farther from the halogen nucleus. These electrons shift position easily and, as a result, the halogen-substituted hydrocarbons have an increasing tendency to form temporary dipoles. Because the dipoles attract each other, the energy needed to separate the molecules also increases. Thus, the boiling points of halogen-substituted alkanes increase as the size of the halogen atom increases.

 **Reading Check** Explain the relationship between the number of electrons in the halogen and the boiling point.

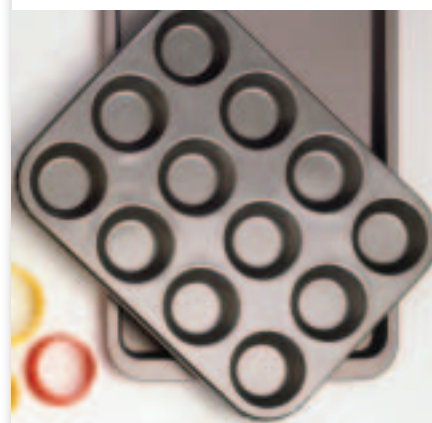
Organic halides are seldom found in nature, although human thyroid hormones are organic iodides. Halogen atoms bonded to carbon atoms are more reactive than the hydrogen atoms they replace. For this reason, alkyl halides are often used as starting materials in the chemical industry. Alkyl halides are also used as solvents and cleaning agents because they readily dissolve nonpolar molecules, such as greases. **Figure 22.4** shows an application of polytetrafluoroethene (PTFE), a plastic made from gaseous tetrafluoroethylene. A **plastic** is a polymer that can be heated and molded while relatively soft. Another plastic commonly called *vinyl* is polyvinyl chloride (PVC). It can be manufactured soft or hard, as thin sheets, or molded into objects.

 **Reading Check** Explain why alkyl halides are often used in the chemical industry as starting materials instead of alkanes.

■ **Figure 22.4** Polytetrafluoroethene (PTFE) is made up of hundreds of units. PTFE provides a nonstick surface for many kitchen items, including bakeware.



PTFE



PTFE Application

Table 22.3 Substitution Reactions

Generic Substitution Reaction $\text{R-CH}_3 + \text{X}_2 \rightarrow \text{R-CH}_2\text{X} + \text{HX}$ <p>where X is fluorine, chlorine, or bromine</p>	Example of General Substitution Reaction (Halogenation) $\text{C}_2\text{H}_6 + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{HCl}$ <p>Ethane Chloroethane</p>
General Alkyl Halide-Alcohol Reaction $\text{R-X} + \text{OH}^- \rightarrow \text{R-OH} + \text{X}^-$ <p>Alkyl halide Alcohol</p>	Example of an Alkyl Halide-Alcohol Reaction $\text{CH}_3\text{CH}_2\text{Cl} + \text{OH}^- \rightarrow \text{CH}_3\text{CH}_2\text{OH} + \text{Cl}^-$ <p>Chloroethane Ethanol</p>
General Alkyl Halide-Ammonia Reaction $\text{R-X} + \text{NH}_3 \rightarrow \text{R-NH}_2 + \text{HX}$ <p>Alkyl halide Amine</p>	Example of an Alkyl Halide-Ammonia Reaction $\text{CH}_3(\text{CH}_2)_6\text{CH}_2\text{Br} + \text{NH}_3 \rightarrow \text{CH}_3(\text{CH}_2)_6\text{CH}_2\text{NH}_2 + \text{HBr}$ <p>1-Bromooctane Octaneamine</p>

Substitution Reactions

From where does the immense variety of organic compounds come? Amazingly enough, the ultimate source of nearly all synthetic organic compounds is petroleum. The oil-field workers shown in **Figure 22.5** are drilling for petroleum, which is a fossil fuel that consists almost entirely of hydrocarbons, especially alkanes. How can alkanes be converted into compounds as different as alkyl halides, alcohols, and amines?

One way is to introduce a functional group through substitution, as shown in **Table 22.3**. A **substitution reaction** is one in which one atom or a group of atoms in a molecule is replaced by another atom or group of atoms. With alkanes, hydrogen atoms can be replaced by atoms of halogens, typically chlorine or bromine, in a process called **halogenation**. One example of a halogenation reaction, shown in **Table 22.3**, is the substitution of a chlorine atom for one of ethane's hydrogen atoms. **Figure 22.6** shows another halogenated hydrocarbon commonly called halothane (2-bromo-2-chloro-1,1,1-trifluoroethane), which was first used as a general anesthetic in the 1950s.

Equations for organic reactions are sometimes shown in generic form. **Table 22.3** shows the generic form of a substitution reaction. In this reaction, X can be fluorine, chlorine, or bromine, but not iodine. Iodine does not react well with alkanes.



Reading Check Draw the molecular structure of halothane.

■ **Figure 22.5** These oil-field workers are drilling for petroleum. A single oil well can extract more than 100 barrels per day.

Explain the relationship between petroleum and synthetic organic compounds.





■ **Figure 22.6** Halothane was introduced into medicine in the 1950s as a general anesthetic for patients undergoing surgery.

Further substitution Once an alkane has been halogenated, the resulting alkyl halide can undergo other types of substitution reactions in which the halogen atom is replaced by another atom or group of atoms. For example, reacting an alkyl halide with a basic solution results in the replacement of the halogen atom by an $-OH$ group, forming an alcohol. An example of an alkyl halide-alcohol reaction is shown in **Table 22.3**. The generic form of the alkyl halide-alcohol reaction is also shown in **Table 22.3**.

Reacting an alkyl halide with ammonia (NH_3) replaces the halogen atom with an amino group ($-NH_2$), forming an alkyl amine, also shown in **Table 22.3**. The alkyl amine is one of the products produced in this reaction. Some of the newly formed amines continue to react, resulting in a mixture of amines.

FOLDABLES

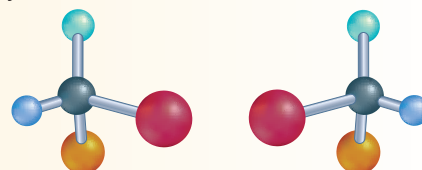
Incorporate information from this section into your Foldable.

Section 22.1 Assessment

Section Summary

- The substitution of functional groups for hydrogen in hydrocarbons creates a wide variety of organic compounds.
- An alkyl halide is an organic compound that has one or more halogen atoms bonded to a carbon atom in an aliphatic compound.

4. **MAIN Idea** Compare and contrast alkyl halides and aryl halides.
5. **Draw** structures for the following molecules.
 - a. 2-chlorobutane
 - b. 1,3-difluorohexane
 - c. 1,1,1-trichloroethane
 - d. 4-bromo-1-chlorobenzene
6. **Define** *functional group* and name the group present in each of the following structures. Name the type of organic compound each substance represents.
 - a. $CH_3CH_2CH_2OH$
 - b. CH_3CH_2F
 - c. $CH_3CH_2NH_2$
 - d.
$$\begin{array}{c} O \\ || \\ CH_3C - OH \end{array}$$
7. **Evaluate** How would you expect the boiling points of propane and 1-chloropropane to compare? Explain your answer.
8. **Interpret Scientific Illustrations** Examine the pair of substituted hydrocarbons illustrated at right, and decide whether it represents a pair of optical isomers. Explain your answer.



Section 22.2

Objectives

- ▶ **Identify** the functional groups that characterize alcohols, ethers, and amines.
- ▶ **Draw** the structures of alcohols, ethers, and amines.
- ▶ **Discuss** the properties and uses of alcohols, ethers, and amines.

Review Vocabulary

miscible: describes two liquids that are soluble in each other

New Vocabulary

hydroxyl group
alcohol
denatured alcohol
ether
amine

Alcohols, Ethers, and Amines

MAIN Idea Oxygen and nitrogen are two of the most-common atoms found in organic functional groups.

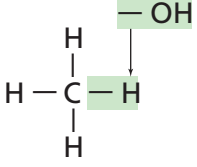
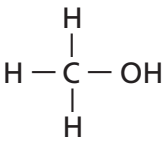
Real-World Reading Link The last time you had a vaccination, the nurse probably disinfected your skin with an alcohol wipe before giving you the injection. Did you know that the nurse was using a substituted hydrocarbon?

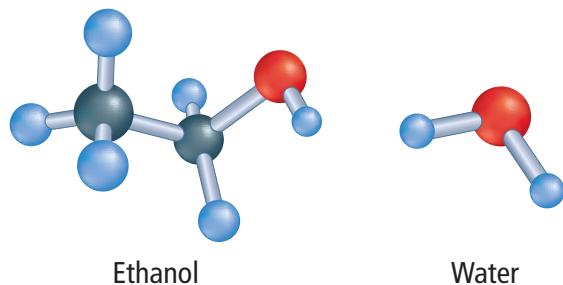
Alcohols

Many organic compounds contain oxygen atoms bonded to carbon atoms. Because an oxygen atom has six valence electrons, it commonly forms two covalent bonds to gain a stable octet. An oxygen atom can form a double bond with a carbon atom, replacing two hydrogen atoms, or it can form one single bond with a carbon atom and another single bond with another atom, such as hydrogen. An oxygen-hydrogen group covalently bonded to a carbon atom is called a **hydroxyl group** ($-\text{OH}$). An organic compound in which a hydroxyl group replaces a hydrogen atom of a hydrocarbon is called an **alcohol**. As shown in **Table 22.4**, the general formula for an alcohol is ROH . **Table 22.4** also illustrates the relationship of the simplest alkane, methane, to the simplest alcohol, methanol.

Ethanol and carbon dioxide are produced by yeasts when they ferment sugars, such as those in grapes and bread dough. Ethanol is found in alcoholic beverages and medicinal products. Because it is an effective antiseptic, ethanol can be used to swab skin before an injection is given. It is also a gasoline additive and an important starting material for the synthesis of more complex organic compounds.

Figure 22.7 shows a model of an ethanol molecule and a model of a water molecule. As you compare the models, notice that the covalent bonds from the oxygen in ethanol are at roughly the same angle as the bonds around the oxygen in the water molecule. Therefore, the hydroxyl groups of alcohol molecules are moderately polar, as with water, and are able to form hydrogen bonds with the hydroxyl groups of other alcohol molecules. Due to this hydrogen bonding, alcohols have much higher boiling points than hydrocarbons of similar shape and size.

Table 22.4		Alcohols	
General Formula	Simple Alcohol and Simple Hydrocarbon		
ROH R represents carbon chains or rings bonded to the functional group	 Methane (CH_4) Alkane	 Methanol (CH_3OH) Alcohol	



■ **Figure 22.7** The covalent bonds from oxygen have approximately the same bonding angle in ethanol and water.

Also, because of polarity and hydrogen bonding, ethanol is completely miscible with water. In fact, once they are mixed, it is difficult to separate water and ethanol completely. Distillation is used to remove ethanol from water, but even after that process is complete, about 5% water remains in the ethanol-water mixture.

On the shelves of drugstores, you can find bottles of ethanol labeled *denatured alcohol*. **Denatured alcohol** is ethanol to which small amounts of noxious materials, such as aviation gasoline or other organic solvents, have been added. Ethanol is denatured in order to make it unfit to drink. Because of their polar hydroxyl groups, alcohols make good solvents for other polar organic substances. For example, methanol, the smallest alcohol, is a common industrial solvent found in some paint strippers, and 2-butanol is found in some stains and varnishes.

Note that the names of alcohols are based on alkane names, like the names of alkyl halides. For example, CH_4 is methane and CH_3OH is methanol; CH_3CH_3 is ethane and $\text{CH}_3\text{CH}_2\text{OH}$ is ethanol. When naming a simple alcohol based on an alkane carbon chain, the IUPAC rules call for naming the parent carbon chain or ring first and then changing the *-e* at the end of the name to *-ol* to indicate the presence of a hydroxyl group. In alcohols of three or more carbon atoms, the hydroxyl group can be at two or more positions. To indicate the position, a number is added, as shown in **Figure 22.8a** and **22.8b**.

✓ **Reading Check** Explain why the names *3-butanol* and *4-butanol* cannot represent real substances.

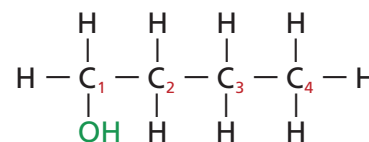
Now look at **Figure 22.8c**. The compound's ring structure contains six carbons with only single bonds, so you know that the parent hydrocarbon is cyclohexane. Because an $-\text{OH}$ group is bonded to a carbon, it is an alcohol and the name will end in *-ol*. No number is necessary because all carbons in the ring are equivalent. This compound is called cyclohexanol. It is a poisonous compound used as a solvent for certain plastics and in the manufacture of insecticides.

A carbon chain can also have more than one hydroxyl group. To name these compounds, prefixes such as *di-*, *tri-*, and *tetra-* are used before the *-ol* to indicate the number of hydroxyl groups present. The full alkane name, including *-ane*, is used before the prefix.

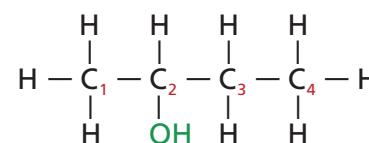
Figure 22.8d shows the molecule 1,2,3-propanetriol, commonly called glycerol. It is another alcohol containing more than one hydroxyl group. Glycerol is often used as an antifreeze and as an airplane deicing fluid.

✓ **Reading Check** Explain why numbers are not used to name the compound shown in **Figure 22.8c**.

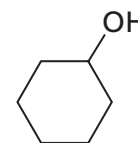
■ **Figure 22.8** The names of alcohols are based on alkane names.



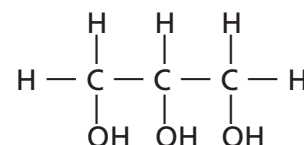
a. 1-Butanol



b. 2-Butanol



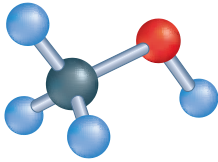
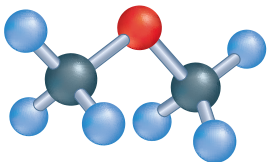
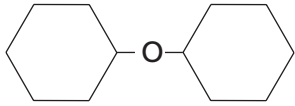
c. Cyclohexanol



d. 1,2,3-Propanetriol (glycerol)

Table 22.5

Ethers

General Formula	Methanol and Methyl ether	
ROR' where R and R' represent carbon chains or rings bonded to functional groups	 Methanol bp = 65°C	 Methyl ether bp = -25°C
Examples of Ethers		
 Cyclohexyl ether	$CH_3CH_2CH_2 - O - CH_2CH_2CH_3$ Propyl ether	
$CH_3CH_2 - O - CH_2CH_2CH_2CH_3$ Butylethyl ether	$CH_3CH_2 - O - CH_3$ Ethylmethyl ether	

VOCABULARY

ACADEMIC VOCABULARY

Bond

to connect, bind, or join

An oxygen atom bonds to two carbon atoms in an ether.

FOLDABLES

Incorporate information from this section into your Foldable.

Ethers

Ethers are another group of organic compounds in which oxygen is bonded to carbon. An **ether** is an organic compound containing an oxygen atom bonded to two carbon atoms. Ethers have the general formula ROR' , as shown in **Table 22.5**. The simplest ether is one in which oxygen is bonded to two methyl groups. Note the similarity between methanol and methyl ether shown in **Table 22.5**.

The term *ether* was first used in chemistry as a name for ethyl ether, the volatile, highly flammable substance that was commonly used as an anesthetic in surgery from 1842 until the twentieth century. As time passed, the term *ether* was applied to other organic substances having two hydrocarbon chains attached to the same oxygen atom.

Because ethers have no hydrogen atoms bonded to the oxygen atom, their molecules cannot form hydrogen bonds with each other. Therefore, ethers are generally more volatile and have much lower boiling points than alcohols of similar size and mass. Ethers are much less soluble in water than alcohols because they have no hydrogen to donate to a hydrogen bond. However, the oxygen atom can act as a receptor for the hydrogen atoms of water molecules.



Reading Check Infer why ethyl ether is undesirable as an anesthetic.

When naming ethers that have two identical alkyl chains bonded to oxygen, first name the alkyl group and then add the word *ether*. **Table 22.5** shows the structures and names of two of these symmetrical ethers, propyl ether and cyclohexyl ether. If the two alkyl groups are different, the groups are listed in alphabetical order and then followed by the word *ether*. **Table 22.5** contains two examples of these asymmetrical ethers, butylethyl ether and ethylmethyl ether.

Amines

Amines contain nitrogen atoms bonded to carbon atoms in aliphatic chains or aromatic rings and have the general formula RNH_2 , as shown in **Table 22.6**.

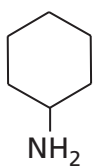
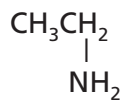

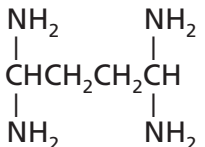
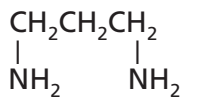
Chemists consider amines derivatives of ammonia (NH_3). Amines are considered primary, secondary, or tertiary amines depending on whether one, two, or three of the hydrogens in ammonia have been replaced by organic groups.

When naming amines, the $-\text{NH}_2$ (amino) group is indicated by the suffix *-amine*. When necessary, the position of the amino group is designated by a number, as shown in the examples in **Table 22.6**. If more than one amino group is present, the prefixes *di-*, *tri-*, *tetra-*, and so on are used to indicate the number of groups.

The amine aniline is used in the production of dyes with deep shades of color. The common name *aniline* is derived from the plant in which it was historically obtained. Cyclohexylamine and ethylamine are important in the manufacture of pesticides, plastics, pharmaceuticals, and rubber that is used to make tires.

All volatile amines have odors that humans find offensive, and amines are responsible for many of the odors characteristic of dead, decaying organisms. Two amines found in decaying human remains are putrescine and cadaverine. Specially trained dogs are used to locate human remains using these distinctive odors. Sniffer dogs are often used after catastrophic events, such as tsunamis, hurricanes, and earthquakes. They are also used in forensic investigations.

Table 22.6 Amines

General Formula		
RNH_2		
where R represents a carbon chain or ring bonded to the functional group		
Examples of Amines		
 Cyclohexylamine	 Ethylamine	 Aniline
 1,1,4,4-Butanetetraamine	 1,3-Propanediamine	

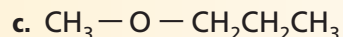
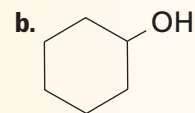
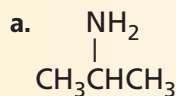
Section 22.2 Assessment

Section Summary

- Alcohols, ethers, and amines are formed when specific functional groups substitute for hydrogen in hydrocarbons.
- Because they readily form hydrogen bonds, alcohols have higher boiling points and higher water solubilities than other organic compounds.

9. **MAIN Idea** Identify two elements that are commonly found in functional groups.

10. **Identify** the functional group present in each of the following structures. Name the substance represented by each structure.



11. **Draw** the structure for each molecule.

a. 1-propanol

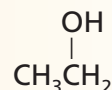
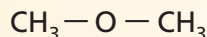
c. propyl ether

b. 1,3-cyclopentanediol

d. 1,2-propanediamine

12. **Discuss** the properties of alcohols, ethers, and amines, and give one use of each.

13. **Analyze** Based on the molecular structures below, which compound would you expect to be more soluble in water? Explain your reasoning.



Section 22.3

Objectives

- Identify the structures of carbonyl compounds, including aldehydes, ketones, carboxylic acids, esters, and amides.
- Discuss the properties of compounds containing the carbonyl group.

Review Vocabulary

electronegative: indicates the relative ability of an element's atoms to attract electrons in a chemical bond

New Vocabulary

carbonyl group
aldehyde
ketone
carboxylic acid
carboxyl group
ester
amide
condensation reaction

Carbonyl Compounds

MAIN Idea Carbonyl compounds contain a double-bonded oxygen in the functional group.

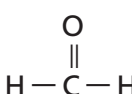
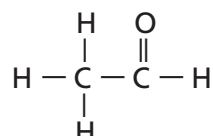

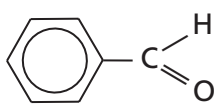
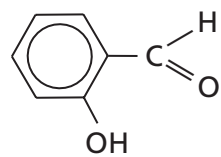
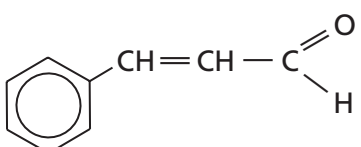
Real-World Reading Link Have you ever eaten a piece of fruit-flavored candy that tasted like real fruit? Many natural fruits, such as strawberries, contain dozens of organic molecules that combine to give the distinctive aroma and flavor of fruits. The carbonyl group is found in many common types of artificial flavorings.

Organic Compounds Containing the Carbonyl Group

The arrangement in which an oxygen atom is double-bonded to a carbon atom is called a **carbonyl group**. This group is the functional group in organic compounds known as aldehydes and ketones.

Aldehydes An **aldehyde** is an organic compound in which a carbonyl group located at the end of a carbon chain is bonded to a carbon atom on one side and a hydrogen atom on the other. Aldehydes have the general formula $*\text{CHO}$, where $*$ represents an alkyl group or a hydrogen atom, as shown in **Table 22.7**.

Aldehydes are formally named by changing the final $-e$ of the name of the alkane with the same number of carbon atoms to the suffix $-al$. Thus, the formal name of the compound methanal, shown in **Table 22.7**, is based on the one-carbon alkane methane. Because the carbonyl group in an aldehyde always occurs at the end of a carbon chain, no numbers are used in the name unless branches or additional functional groups are present. Methanal is also commonly called formaldehyde. Ethanal has the common name *acetaldehyde*. Scientists often use the common names of organic compounds because they are familiar to chemists.

Table 22.7	Aldehydes		
General Formula	Examples of Aldehydes		
$*\text{CHO}$ *represents an alkyl group or a hydrogen atom	 Methanal (formaldehyde)	 Ethanal (acetaldehyde)	
 Carbonyl group	 Benzaldehyde	 Salicylaldehyde	 Cinnamaldehyde

An aldehyde molecule contains a polar, reactive structure. However, like ethers, aldehyde molecules cannot form hydrogen bonds among themselves because the molecules have no hydrogen atoms bonded to an oxygen atom. Therefore, aldehydes have lower boiling points than alcohols with the same number of carbon atoms. Water molecules can form hydrogen bonds with the oxygen atom of aldehydes, so aldehydes are more soluble in water than alkanes but not as soluble as alcohols or amines.

Formaldehyde has been used for preservation for many years, as shown in **Figure 22.9**. Industrially, large quantities of formaldehyde are reacted with urea to manufacture a type of grease-resistant, hard plastic used to make buttons, appliance and automotive parts, and electrical outlets, as well as the glue that holds the layers of plywood together. Benzaldehyde and salicylaldehyde, shown in **Table 22.7**, are two components that give almonds their natural flavor. The aroma and flavor of cinnamon, a spice that comes from the bark of a tropical tree, are produced largely by cinnamaldehyde, also shown in **Table 22.7**.

 **Reading Check Identify** two uses for aldehydes.

Ketones A carbonyl group can also be located within a carbon chain rather than at the end. A **ketone** is an organic compound in which the carbon of the carbonyl group is bonded to two other carbon atoms. Ketones have the general formula shown in **Table 22.8**. The carbon atoms on either side of the carbonyl group are bonded to other atoms. The simplest ketone, commonly known as acetone, has only hydrogen atoms bonded to the side carbons, as shown in **Table 22.8**.

Ketones are formally named by changing the *-e* at the end of the alkane name to *-one*, and including a number before the name to indicate the position of the ketone group. In the previous example, the alkane name propane is changed to propanone. The carbonyl group can be located only in the center, but the prefix 2- is usually added to the name for clarity, as shown in **Table 22.8**.

Ketones and aldehydes share many chemical and physical properties because their structures are similar. Ketones are polar molecules and are less reactive than aldehydes. For this reason, ketones are popular solvents for other moderately polar substances, including waxes, plastics, paints, lacquers, varnishes, and glues. Like aldehydes, ketone molecules cannot form hydrogen bonds with each other but can form hydrogen bonds with water molecules. Therefore, ketones are somewhat soluble in water. Acetone is completely miscible with water.



■ **Figure 22.9** A water solution of formaldehyde was used in the past to preserve biological specimens. However, formaldehyde's use has been restricted in recent years because studies indicate it might cause cancer.

Table 22.8		Ketones	
General Formula	Examples of Ketones		
$\text{R} - \overset{\text{O}}{\parallel} \text{C} - \text{R}'$ <p>where R and R' represent carbon chains or rings bonded to functional groups</p>	$\begin{array}{c} \text{H} & \text{O} & \text{H} \\ & & \\ \text{H} - \text{C} - & \text{C} & - \text{C} - \text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$ <p>2-Propanone (acetone)</p>	$\begin{array}{c} \text{H} & \text{O} & \text{H} & \text{H} \\ & & & \\ \text{H} - \text{C} - & \text{C} & - \text{C} - & \text{C} - \text{H} \\ & & & \\ \text{H} & & \text{H} & \text{H} \end{array}$ <p>2-Butanone (methyl ethyl ketone)</p>	

Table 22.9

Carboxylic Acids


General Formula	Examples of Carboxylic Acids
$*-\overset{\text{O}}{\parallel}{\text{C}}-\text{OH}$ <p>where R represents carbon chains or rings bonded to functional groups</p>	<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> $\begin{array}{c} \text{H} \quad \text{O} \\ \quad \parallel \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$ <p>Ethanoic acid (acetic acid)</p> </div> <div style="text-align: center;"> $\begin{array}{c} \text{O} \\ // \\ \text{H}-\text{C} \\ \backslash \\ \text{O}-\text{H} \end{array}$ <p>Methanoic acid (formic acid)</p> </div> </div>

Carboxylic Acids

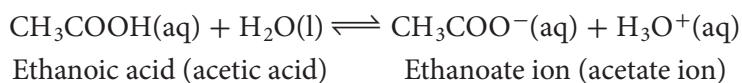
A **carboxylic acid** is an organic compound that has a carboxyl group. A **carboxyl group** consists of a carbonyl group bonded to a hydroxyl group. Thus, carboxylic acids have the general formula shown in **Table 22.9**. One diagram shown in **Table 22.9** is the structure of a familiar carboxylic acid—acetic acid, the acid found in vinegar.

Although many carboxylic acids have common names, the formal name is formed by changing the *-ane* of the parent alkane to *-anoic acid*. Thus, the formal name of acetic acid is ethanoic acid.

A carboxyl group is usually represented in condensed form by writing $-\text{COOH}$. For example, ethanoic acid can be written as CH_3COOH . The simplest carboxylic acid consists of a carboxyl group bonded to a single hydrogen atom, HCOOH , shown in **Table 22.9**. Its formal name is methanoic acid, but it is more commonly known as formic acid. Some insects produce formic acid as a defense mechanism, as shown in **Figure 22.10**.


 **Reading Check Explain** how the name *ethanoic acid* is derived.

Carboxylic acids are polar and reactive. Those that dissolve in water ionize weakly to produce hydronium ions, the anion of the acid in equilibrium with water, and the unionized acid. The ionization of ethanoic acid is an example.



Carboxylic acids can ionize in water solution because the two oxygen atoms are highly electronegative and attract electrons away from the hydrogen atom in the $-\text{OH}$ group. As a result, the hydrogen proton can transfer to another atom that has a pair of electrons not involved in bonding, such as the oxygen atom of a water molecule. Because they ionize in water, soluble carboxylic acids turn blue litmus paper red and have a sour taste.

Some important carboxylic acids, such as oxalic acid and adipic acid, have two or more carboxyl groups. An acid with two carboxyl groups is called a dicarboxylic acid. Others have additional functional groups such as hydroxyl groups, as in the lactic acid found in yogurt. Typically, these acids are more soluble in water and often more acidic than acids with only a carboxyl group.

 **Reading Check Evaluate** Using the information above, explain why carboxylic acids are classified as acids.

■ **Figure 22.10** Stinging ants defend themselves with a venom that contains formic acid.

Identify another name for formic acid.



Table 22.10 Esters	
General Formula	Example of an Ester
$\begin{array}{c} \text{O} \\ \parallel \\ -\text{C}-\text{O}-\text{R} \end{array}$ <p>Ester group</p>	$\begin{array}{c} \text{Ethanoate group} \quad \text{Propyl group} \\ \text{CH}_3-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{CH}_2\text{CH}_2\text{CH}_3 \\ \text{Ester group} \end{array}$ <p>Propyl ethanoate (propyl acetate)</p>

Organic Compounds Derived from Carboxylic Acids

Several classes of organic compounds have structures in which the hydrogen or the hydroxyl group of a carboxylic acid is replaced by a different atom or group of atoms. The two most common classes are esters and amides.

Esters An **ester** is any organic compound with a carboxyl group in which the hydrogen of the hydroxyl group has been replaced by an alkyl group, producing the arrangement shown in **Table 22.10**. The name of an ester is formed by writing the name of the alkyl group followed by the name of the acid with the *-ic acid* ending replaced by *-ate*, as illustrated by the example shown in **Table 22.10**. Note how the name *propyl* results from the structural formula. The name shown in parentheses is based on the name *acetic acid*, the common name for ethanoic acid.

Esters are polar molecules and many are volatile and sweet-smelling. Many kinds of esters are found in the natural fragrances and flavors of flowers and fruits, as shown in **Figure 22.11**. Natural flavors, such as apple or banana, result from mixtures of many different organic molecules, including esters, but some of these flavors can be imitated by a single ester structure. Consequently, esters are manufactured for use as flavors in many foods and beverages and as fragrances in candles, perfumes, and other scented items.

VOCABULARY

SCIENCE USAGE V. COMMON USAGE

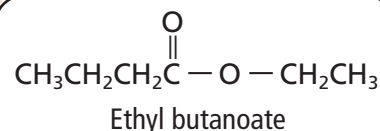
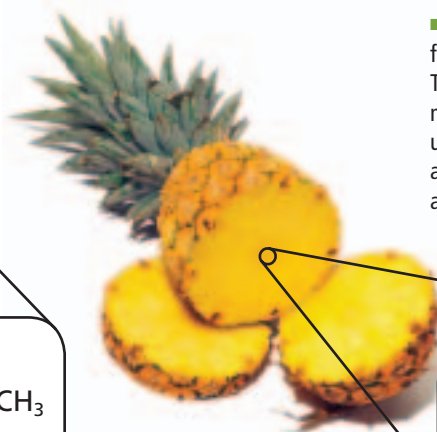
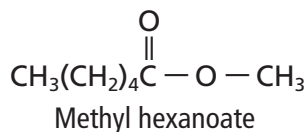
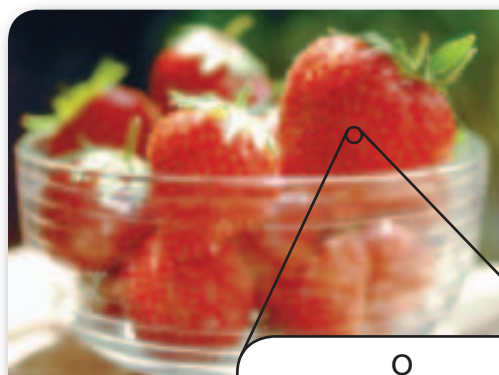
Class

Science usage: a group, set, or kind that share common traits

Esters are a class of organic molecules.

Common usage: a group of students that meet at regular intervals to study the same subject

Students meet for chemistry class during fourth period.



■ **Figure 22.11** Esters are responsible for the flavors and aromas of many fruits. The aroma of strawberries is due in part to methyl hexanoate. Ethyl butanoate contributes to the aroma of pineapple. Most natural aromas and flavors are mixtures of esters, aldehydes, and alcohols.

Make an Ester

How can you recognize an ester?

Procedure 

1. Read and complete the lab safety form.
2. Prepare a hot-water bath by pouring 150 mL of **tap water** into a **250-mL beaker**. Place the beaker on a **hot plate** set to medium.
3. Use a **balance** and **weighing paper** to measure 1.5 g of **salicylic acid**. Place the salicylic acid in a **small test tube** and add 3 mL of **distilled water**. Use a **10-mL graduated cylinder** to measure the water. Then add 3 mL of **methanol**. Use a **Beral pipette** to add 3 drops of **concentrated sulfuric acid** to the test tube. **WARNING: Concentrated sulfuric acid can cause burns. Methanol fumes are explosive—keep away from open flame. Handle chemicals with care.**
4. When the water is hot but not boiling, place the test tube in the bath for 5 min. Use a **test-tube clamp** to remove the test tube from the bath and place in a **test-tube holder** until needed.
5. Place a **cotton ball** in a **petri dish half**. Pour the contents of the test tube onto the cotton ball. Record your observation of the odor of the product.

Analysis

1. **Name** The common name of the ester that you produced is *oil of wintergreen*. Name some products that you think could contain the ester.
2. **Evaluate** the advantages and disadvantages of using synthetic esters in consumer products as compared to using natural esters.

Amides An **amide** is an organic compound in which the $-OH$ group of a carboxylic acid is replaced by a nitrogen atom bonded to other atoms. The general structure of an amide is shown in **Table 22.11**. Amides are named by writing the name of the alkane with the same number of carbon atoms, and then replacing the final $-e$ with $-amide$. Thus, the amide shown in **Table 22.11** is called ethanamide, but it can also be named acetamide from its common name, acetic acid.

 **Reading Check Name** three foods that contain acetic acid.

The amide functional group is found repeated many times in natural proteins and some synthetic materials. For example, you might have used a non-aspirin pain reliever containing acetaminophen. In the acetaminophen structure shown in **Table 22.11**, notice that the amide ($-NH-$) group connects a carbonyl group and an aromatic group.

One important amide is **caramide** (NH_2CONH_2), or **urea**, as it is commonly known. Urea is an end product in the metabolic breakdown of proteins in mammals. It is found in the blood, bile, milk, and perspiration of mammals. When proteins are broken down, amino groups (NH_2) are removed from the amino acids. The amino groups are then converted to ammonia (NH_3) that are toxic to the body. The toxic ammonia is converted to nontoxic urea in the liver. The urea is filtered out of the blood in the kidneys and passed from the body in urine.

Because of the high nitrogen content of urea and because it is easily converted to ammonia in the soil, urea is a common commercial fertilizer. Urea is also used as a protein supplement for ruminant animals, such as cattle and sheep. These animals use urea to produce proteins in their bodies.


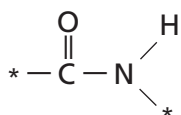
 **Reading Check Identify** an amide that is found in the human body.

Table 22.11

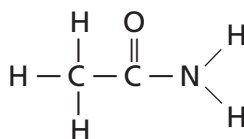
Amides

General Formula

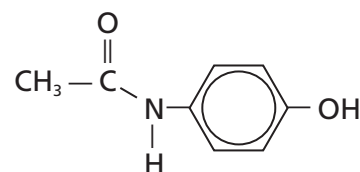


Amide group

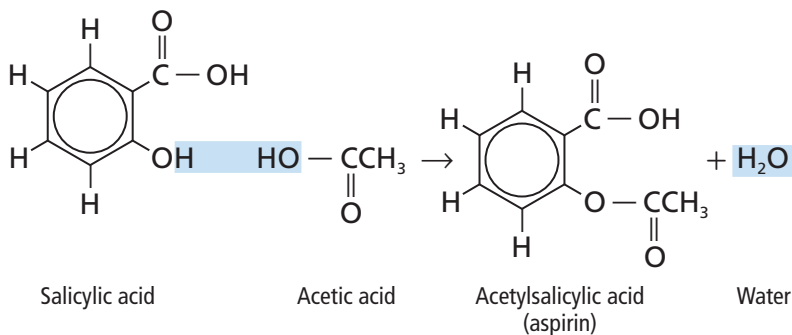
Examples of Amides



Ethanamide (acetamide)



Acetaminophen



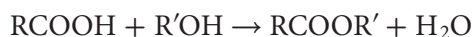
■ **Figure 22.12** To synthesize aspirin, two organic molecules are combined in a condensation reaction to form a larger molecule.

Condensation Reactions

Many laboratory syntheses and industrial processes involve the reaction of two organic reactants to form a larger organic product, such as the aspirin shown in **Figure 22.12**. This type of reaction is known as a condensation reaction.

In a **condensation reaction**, two smaller organic molecules combine to form a more complex molecule, accompanied by the loss of a small molecule such as water. Typically, the molecule lost is formed from one particle from each of the reactant molecules. In essence, a condensation reaction is an elimination reaction in which a bond is formed between two atoms not previously bonded to each other.

The most common condensation reactions involve the combining of carboxylic acids with other organic molecules. A common way to synthesize an ester is by a condensation reaction between a carboxylic acid and an alcohol. Such a reaction can be represented by the following general equation.



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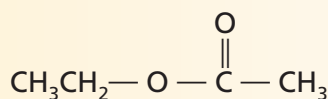
Section 22.3 Assessment

Section Summary

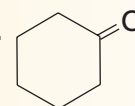
- Carbonyl compounds are organic compounds that contain the C=O group.
- Five important classes of organic compounds containing carbonyl compounds are aldehydes, ketones, carboxylic acids, esters, and amides.

14. **MAIN Idea** **Classify** each of the carbonyl compounds as one of the types of organic substances you have studied in this section.

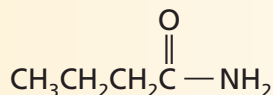
a.



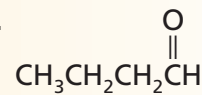
c.



b.



d.



15. **Describe** the products of a condensation reaction between a carboxylic acid and an alcohol.
16. **Determine** The general formula for alkanes is $\text{C}_n\text{H}_{2n+2}$. Derive a general formula to represent an aldehyde, a ketone, and a carboxylic acid.
17. **Infer** why water-soluble organic compounds with carboxyl groups exhibit acidic properties in solutions, whereas similar compounds with aldehyde structures do not exhibit these properties.

Section 22.4

Objectives

- **Classify** an organic reaction into one of five categories: substitution, addition, elimination, oxidation-reduction, or condensation.
- **Use** structural formulas to write equations for reactions of organic compounds.
- **Predict** the products of common types of organic reactions.

Review Vocabulary

catalyst: a substance that increases the rate of a chemical reaction by lowering activation energies but is not consumed in the reaction

New Vocabulary

elimination reaction
dehydrogenation reaction
dehydration reaction
addition reaction
hydration reaction
hydrogenation reaction

Other Reactions of Organic Compounds

MAIN Idea Classifying the chemical reactions of organic compounds makes predicting products of reactions much easier.

Real-World Reading Link As you eat lunch, the oxidation of organic compounds is probably not on your mind. However, that is exactly what is about to occur as your cells break down the food that you eat to obtain energy for your body.

Classifying Reactions of Organic Substances

Organic chemists have discovered thousands of reactions by which organic compounds can be changed into different organic compounds. By using combinations of these reactions, chemical industries convert simple molecules from petroleum and natural gas into the large, complex organic molecules found in many useful products—including lifesaving drugs and many other consumer products as shown in **Figure 22.13**.

You have already read about substitution and condensation reactions in Sections 22.1 and 22.3. Two other important types of organic reactions are elimination and addition.

Elimination reactions One way to change an alkane into a chemically reactive substance is to form a second covalent bond between two carbon atoms, producing an alkene. The formation of alkenes from alkanes is an **elimination reaction**, a reaction in which a combination of atoms is removed from two adjacent carbon atoms, forming an additional bond between the carbon atoms. The atoms that are eliminated usually form stable molecules, such as H_2O , HCl , or H_2 .

Reading Check Define *elimination reaction* in your own words.

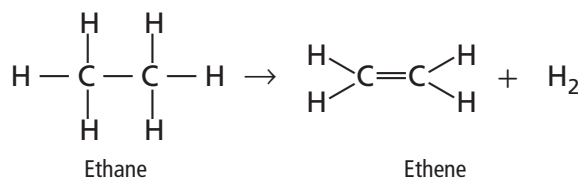
■ **Figure 22.13** Many consumer products, such as plastic containers, fibers in ropes and clothing, and oils and waxes in cosmetics, are made from petroleum and natural gas.



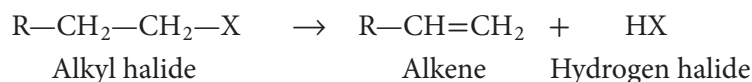


■ **Figure 22.14** Low density polyethylene (LDPE) is made from gaseous ethene under high pressure in the presence of a catalyst. LDPE is used for playground equipment because it is easy to mold into various shapes, it is easy to dye into many colors, and it is durable.

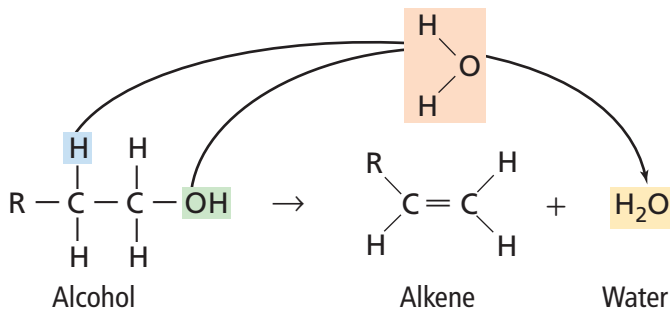
Ethene, the starting material for the playground equipment shown in **Figure 22.14**, is produced by the elimination of two hydrogen atoms from ethane. A reaction that eliminates two hydrogen atoms is called a **dehydrogenation reaction**. Note that the two hydrogen atoms form a molecule of hydrogen gas.



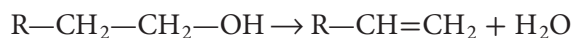
Alkyl halides can undergo elimination reactions to produce an alkene and a hydrogen halide, as shown here.



Likewise, alcohols can also undergo elimination reactions by losing a hydrogen atom and a hydroxyl group to form water, as shown below. An elimination reaction in which the atoms removed form water is called a **dehydration reaction**. In the dehydration reaction, the alcohol is broken down into an alkene and water.



The generic form of this dehydration reaction can be written as follows.



Chemistry  **Online**
Personal Tutor For help identifying organic reactions, visit glencoe.com.

Table 22.12

Summary of Addition Reactions

Reactant Alkene	Addition Reactant	Product
$ \begin{array}{c} \text{R} \quad \text{H} \\ \diagdown \quad / \\ \text{C} = \text{C} \\ / \quad \diagdown \\ \text{H} \quad \text{H} \end{array} $	Water (hydration)	Alcohol
	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{O} \end{array} $	$ \begin{array}{c} \text{H} \quad \text{OH} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $
	Hydrogen (hydrogenation)	Alkane
	$ \text{H}-\text{H} $	$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $
Hydrogen halide	Alkyl halide	
$ \text{H}-\text{X} $	$ \begin{array}{c} \text{H} \quad \text{X} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	
Halogen	Alkyl dihalide	
$ \text{X}-\text{X} $	$ \begin{array}{c} \text{X} \quad \text{X} \\ \quad \\ \text{R}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	

Addition reactions Another type of organic reaction appears to be an elimination reaction in reverse. An **addition reaction** results when other atoms bond to each of two atoms bonded by double or triple covalent bonds. Addition reactions typically involve double-bonded carbon atoms in alkenes or triple-bonded carbon atoms in alkynes. Addition reactions occur because double and triple bonds have a rich concentration of electrons. Therefore, molecules and ions that attract electrons tend to form bonds that use some of the electrons from the multiple bonds. The most common addition reactions are those in which H_2O , H_2 , HX , or X_2 add to an alkene, as shown in **Table 22.12**.

A **hydration reaction**, also shown in **Table 22.12**, is an addition reaction in which a hydrogen atom and a hydroxyl group from a water molecule add to a double or triple bond. The generic equation shown in **Table 22.12** shows that a hydration reaction is the opposite of a dehydration reaction.

A reaction that involves the addition of hydrogen to atoms in a double or triple bond is called a **hydrogenation reaction**. One molecule of H_2 reacts to fully hydrogenate each double bond in a molecule. When H_2 adds to the double bond of an alkene, the alkene is converted to an alkane.

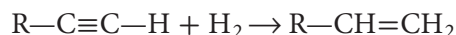


Reading Check Identify the reaction that is the reverse of a hydrogenation reaction.

Catalysts are usually needed in the hydrogenation of alkenes because the reaction's activation energy is too large without them. Catalysts such as powdered platinum or palladium provide a surface that absorbs the reactants and makes their electrons more available to bond to other atoms.

Hydrogenation reactions are commonly used to convert the liquid unsaturated fats found in oils from plants such as soybean, corn, and peanuts into saturated fats that are solid at room temperature. These hydrogenated fats are then used to make margarine and solid shortening.

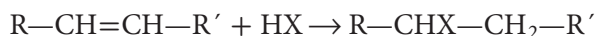
Alkynes can also be hydrogenated to produce alkenes or alkanes. One molecule of H_2 must be added to each triple bond in order to convert an alkyne to an alkene, as shown here.



After the first molecule of H_2 is added, the alkyne is converted to an alkene. A second molecule of H_2 follows the hydrogenation reaction.



In a similar mechanism, the addition of hydrogen halides to alkenes is an addition reaction useful to industry for the production of alkyl halides. The generic equation for this reaction is shown below.



DATA ANALYSIS LAB

Based on Real Data*

Interpret Data

What are the optimal conditions to hydrogenate canola oil? Edible vegetable oil is hydrogenated to preserve its flavor and to alter its melting properties. Because evidence suggests that *trans*-fatty acids are associated with increased risk of heart disease and cancer, the minimum amount of *trans*-fatty acids and the maximum amount of *cis*-oleic acid are desired.

Computer models were used to simulate processing conditions and to alter eight variables to optimize the output of the desirable oil. Multiple optimal operating conditions were determined. A small-scale industrial plant was used to confirm the results of the computer simulation.

Data and Observations

The table at right shows some of the data from this investigation.

Think Critically

1. Calculate the percent yield for each of the trials shown in the table.

Data for Canadian Canola Oil

Trial Run	Computer Simulation		Experimental	
	<i>trans</i> -Fatty Acids (wt. %)	<i>cis</i> -Oleic Acid (wt. %)	<i>trans</i> -Fatty Acids (wt. %)	<i>cis</i> -Oleic Acid (wt. %)
1	4.90	69.10	5.80	70.00
2	4.79	63.75	4.61	64.00
3	4.04	68.96	4.61	67.00
4	5.99	62.80	7.10	65.00
5	4.60	68.10	5.38	66.50

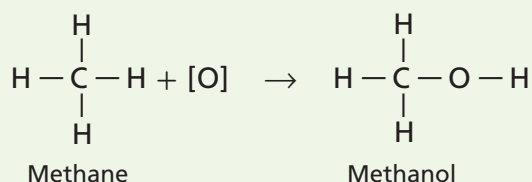
Data obtained from Izadifar, M. 2005. Application of genetic algorithm for optimization of vegetable oil hydrogenation process. *Journal of Food Engineering*. 78 (2007) 1-8.

2. Evaluate Which trial(s) produced the highest yield of *cis*-oleic acid and the lowest yield of *trans*-fatty acids?

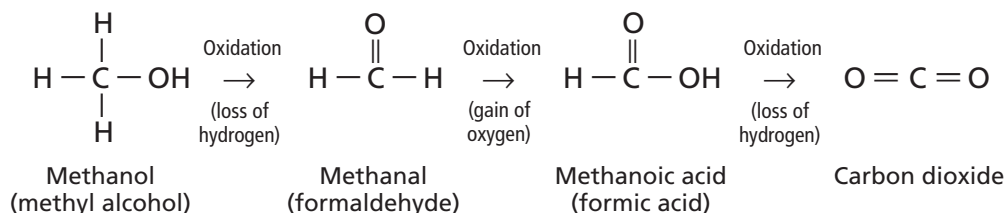
3. Explain why the techniques used in this investigation are useful in manufacturing processes.

Table 22.13 Oxidation-Reduction Reactions

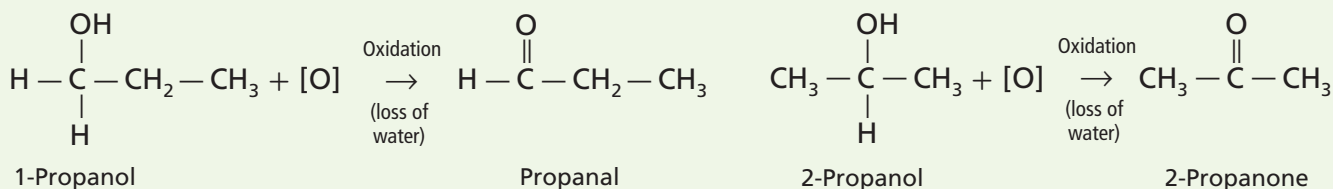
The conversion of methane to methanol



Producing an aldehyde



Further oxidation of the reaction



Oxidation-reduction reactions Many organic compounds can be converted to other compounds by oxidation and reduction reactions. For example, suppose you want to convert methane, the main constituent of natural gas, to methanol, a common industrial solvent and raw material for making formaldehyde and methyl esters. The conversion of methane to methanol can be represented by the equation shown in **Table 22.13**, in which [O] represents oxygen from an agent such as copper(II) oxide, potassium dichromate, or sulfuric acid.


What happens to methane in this reaction? Before answering, it might be helpful to review the definitions of oxidation and reduction. Oxidation is the loss of electrons, and a substance is oxidized when it gains oxygen or loses hydrogen. Reduction is the gain of electrons, and a substance is reduced when it loses oxygen or gains hydrogen. Thus, methane is oxidized as it gains oxygen and is converted to methanol. Of course, every redox reaction involves both an oxidation and a reduction; however, organic redox reactions are described based on the change in the organic compound.

Oxidizing the methanol shown in **Table 22.13** is the first step in the sequence of reactions that can be used to produce an aldehyde, which are also shown in **Table 22.13**. For clarity, oxidizing agents are omitted. Preparing an aldehyde by this method is not always a simple task because the oxidation might continue, forming the carboxylic acid.

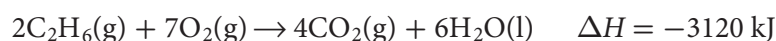


Reading Check Identify Use **Table 22.13** to identify two possible products that are produced when the aldehyde is further oxidized.

However, not all alcohols can be oxidized to aldehydes and, subsequently, carboxylic acids. To understand why, compare the oxidations of 1-propanol and 2-propanol, shown in **Table 22.13**. Note that oxidizing 2-propanol yields a ketone, not an aldehyde. Unlike aldehydes, ketones resist further oxidation to carboxylic acids. Thus, while the propanal formed by oxidizing 1-propanol easily oxidizes to form propanoic acid, the 2-propanone formed by oxidizing 2-propanol does not react to form a carboxylic acid.

 **Reading Check Write** the equation using molecular structures like those in **Table 22.13** for the formation of propanoic acid.

How important are organic oxidations and reductions? You have seen that oxidation and reduction reactions can change one functional group into another. That ability enables chemists to use organic redox reactions, in conjunction with the substitution and addition reactions you read about earlier in the chapter, to synthesize a tremendous variety of useful products. On a personal note, all living systems—including you—depend on the energy released by oxidation reactions. Of course, some of the most dramatic oxidation-reduction reactions are combustion reactions. All organic compounds that contain carbon and hydrogen burn in excess oxygen to produce carbon dioxide and water. For example, the highly exothermic combustion of ethane is described by the following thermochemical equation.



As you read in Chapter 9, much of the world relies on the combustion of hydrocarbons as a primary source of energy. Our reliance on the energy from organic oxidation reactions is illustrated in **Figures 22.15**.

Predicting Products of Organic Reactions

The generic equations representing the different types of organic reactions you have learned—substitution, elimination, addition, oxidation-reduction, and condensation—can be used to predict the products of other organic reactions of the same types. For example, suppose you were asked to predict the product of an elimination reaction in which 1-butanol is a reactant. You know that a common elimination reaction involving an alcohol is a dehydration reaction.



Real-World Chemistry Polycyclic Aromatic Hydrocarbons (PAHs)



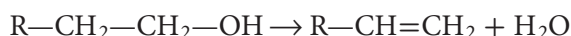
Biological molecules

Hydrocarbons composed of multiple aromatic rings are called PAHs. They have been found in meteorites and identified in the material surrounding dying stars. Scientists simulated conditions in space and found that about 10% of the PAHs were converted to alcohols, ketones, and esters. These molecules can be used to form compounds that are important in biological systems.

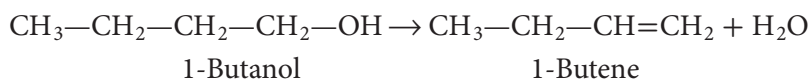
■ **Figure 22.15** People around the world depend on the oxidation of hydrocarbons to get to work and to transport products.

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from this section into
your Foldable.

The generic equation for the dehydration of an alcohol is as follows.



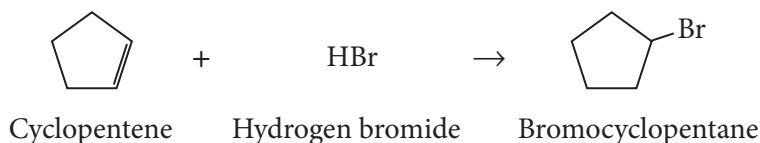
To determine the actual product, first draw the structure of 1-butanol. Then use the generic equation as a model to see how 1-butanol would react. The generic reaction shows that the $-\text{OH}$ and a $\text{H}-$ are removed from the carbon chain. Finally, draw the structure of the likely products, as shown in the following equation.



As another example, suppose that you wish to predict the product of the reaction between cyclopentene and hydrogen bromide. Recall that the generic equation for an addition reaction between an alkene and an alkyl halide is as follows.



First, draw the structure for cyclopentene, the organic reactant, and add the formula for hydrogen bromide, the other reactant. From the generic equation, you can see that a hydrogen atom and a halide atom add across the double bond to form an alkyl halide. Finally, draw the formula for the likely product. If you are correct, you have written the following equation.

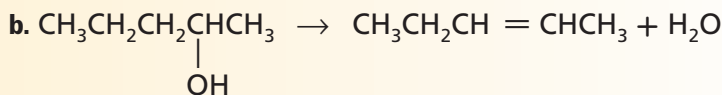
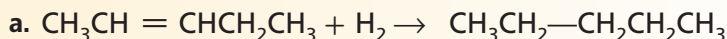


Section 22.4 Assessment

Section Summary

- Most reactions of organic compounds can be classified into one of five categories: substitution, elimination, addition, oxidation-reduction, and condensation.
- Knowing the types of organic compounds reacting can enable you to predict the reaction products.

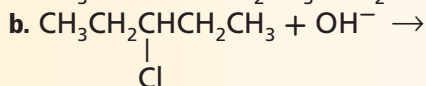
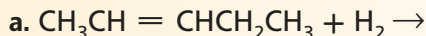
18. MAIN Idea Classify each reaction as substitution, elimination, addition, or condensation.



19. Identify the type of organic reaction that would best accomplish each conversion.

- a. alkyl halide \rightarrow alkene c. alcohol + carboxylic acid \rightarrow ester
 b. alkene \rightarrow alcohol d. alkene \rightarrow alkyl dihalide

20. Complete each equation by writing the condensed structural formula for the product that is most likely to form.



21. Predicting Products Explain why the hydration reaction involving 1-butene might yield two distinct products, whereas the hydration of 2-butene yields only one product.

Section 22.5

Objectives

- ▶ **Diagram** the relationship between a polymer and the monomers from which it forms.
- ▶ **Classify** polymerization reactions as addition or condensation.
- ▶ **Predict** polymer properties based on their molecular structures and the presence of functional groups.

Review Vocabulary

molecular mass: the mass of one molecule of a substance

New Vocabulary

polymer
monomer
polymerization reaction
addition polymerization
condensation polymerization
thermoplastic
thermosetting

Polymers

MAIN Idea Synthetic polymers are large organic molecules made up of repeating units that are linked together by addition or condensation reactions.

Real-World Reading Link Think how different your life would be without plastic sandwich bags, plastic foam cups, nylon and polyester fabrics, vinyl siding on buildings, foam cushions, and a variety of other synthetic materials. These products all have at least one thing in common—they are made of polymers.

The Age of Polymers

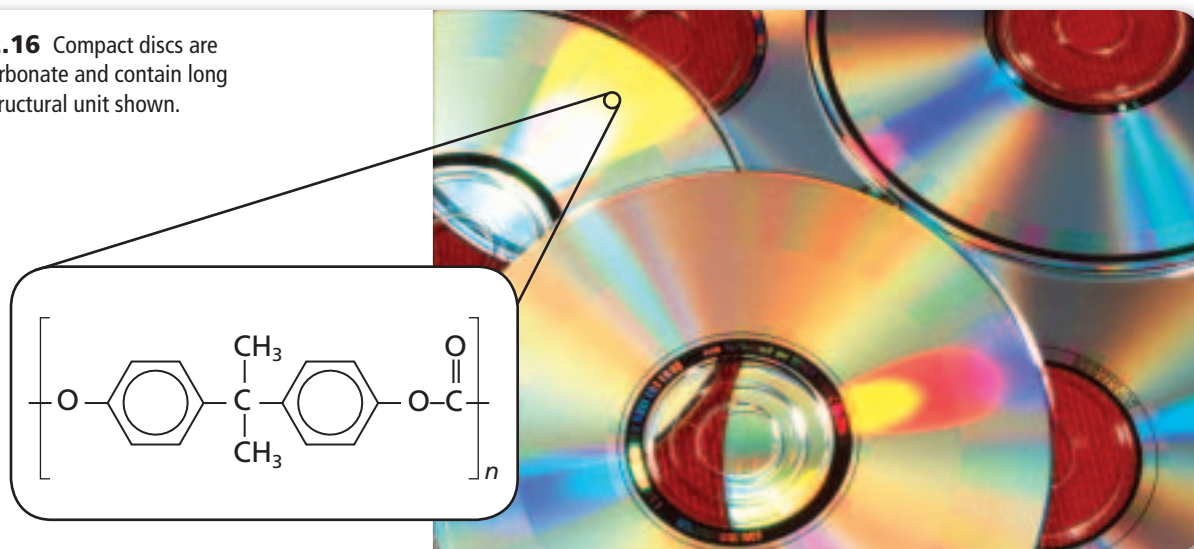
The compact discs shown in **Figure 22.16** contain polycarbonate, which is made of extremely long molecules with groups of atoms that repeat in a regular pattern. This molecule is an example of a synthetic polymer.

Polymers are large molecules consisting of many repeating structural units. In **Figure 22.16**, the letter n beside the structural unit of polycarbonate represents the number of structural units in the polymer chain. Because polymer n values vary widely, molecular masses of polymers range from less than 10,000 amu to more than 1,000,000 amu. A typical chain in nonstick coating on skillets has about 400 units, giving it a molecular mass of around 40,000 amu.

Before the development of synthetic polymers, people were limited to using natural substances such as stone, wood, metals, wool, and cotton. By the turn of the twentieth century, a few chemically treated natural polymers such as rubber and the first plastic, celluloid, had become available. Celluloid is made by treating cellulose from cotton or wood fiber with nitric acid.

The first synthetic polymer, synthesized in 1909, was a hard, brittle plastic called Bakelite. Because of its resistance to heat, it is still used today in stove-top appliances. Since 1909, hundreds of other synthetic polymers have been developed. Because of the widespread use of polymers, people might refer to this time as the Age of Polymers.

■ **Figure 22.16** Compact discs are made of polycarbonate and contain long chains of the structural unit shown.





■ **Figure 22.17** Polyethylene is a nontoxic, unbreakable polymer that is used to make toys for children.

Reactions Used to Make Polymers

Polymers are relatively easy to manufacture. Polymers can usually be synthesized in one step in which the major reactant is a substance consisting of small, simple organic molecules called monomers. A **monomer** is a molecule from which a polymer is made.

When a polymer is made, monomers bond together one after another in a rapid series of steps. A catalyst is usually required for the reaction to take place at a reasonable pace. With some polymers, such as polyester fabric and nylon, two or more kinds of monomers bond to each other in an alternating sequence. A reaction in which monomer units are bonded together to form a polymer is called a **polymerization reaction**. The repeating group of atoms formed by the bonding of the monomers is called the structural unit of the polymer. The structural unit of a polymer made from two different monomers has the components of both monomers.

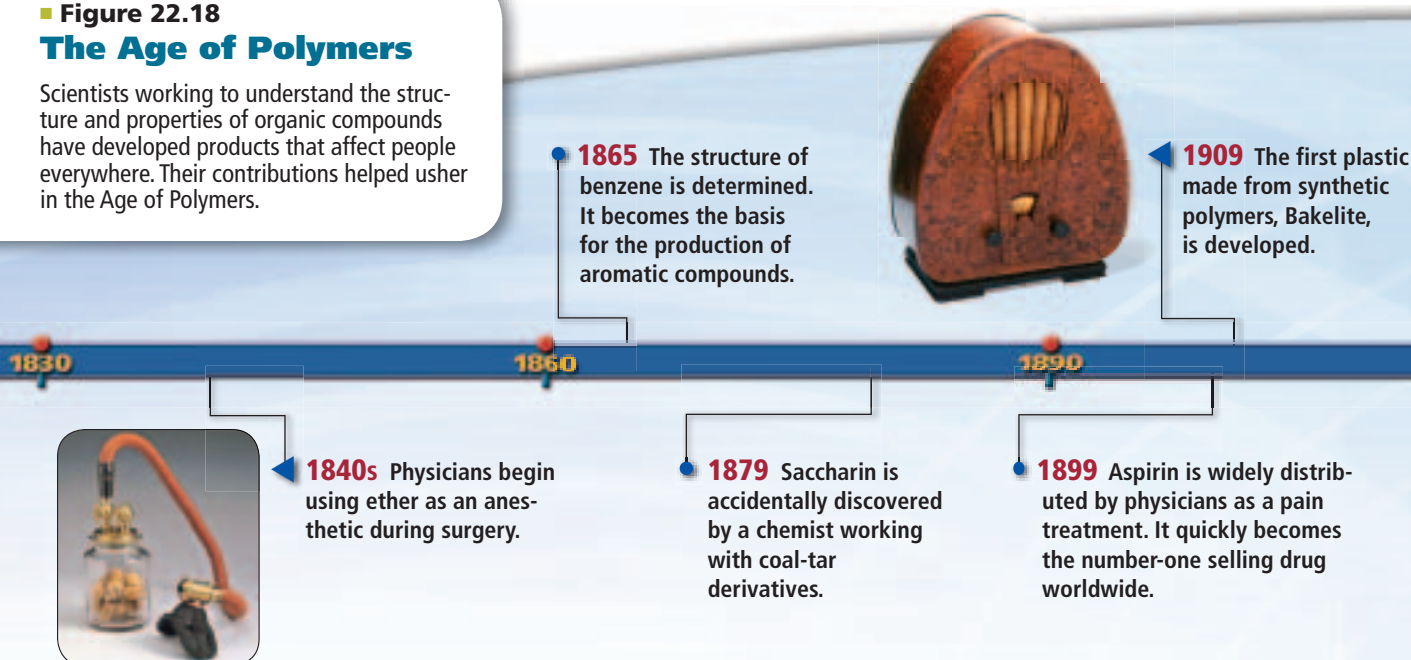
Figure 22.17 shows unbreakable children's toys that are made of low-density polyethylene (LDPE), which is synthesized by polymerizing ethene under pressure. Ethene is also the starting product for polyethylene terephthalate (PETE), a plastic that is used to make bottles. When made into fiber, it is called polyester fiber.

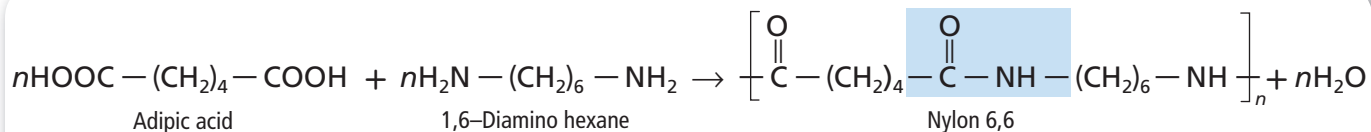
Figure 22.18 shows milestones leading to the Age of Polymers and highlights of polymer development. Although the first synthetic polymer was developed in 1909, the industry did not flourish until after World War II.

✓ **Reading Check** Compare and contrast a monomer and a structural unit of a polymer.

■ Figure 22.18 The Age of Polymers

Scientists working to understand the structure and properties of organic compounds have developed products that affect people everywhere. Their contributions helped usher in the Age of Polymers.





■ **Figure 22.19** Nylon is a polymer consisting of thin strands that resemble silk.

Addition polymerization In **addition polymerization**, all of the atoms present in the monomers are retained in the polymer product. When the monomer is ethene, an addition polymerization results in the polymer polyethylene. Unsaturated bonds are broken in addition polymerization, just as they are in addition reactions. The difference is that the molecule added is a second molecule of the same substance, ethene. Note that the addition polymers in **Table 22.14** on the next page are similar in structure to polyethylene. That is, the molecular structure of each is equivalent to polyethylene in which other atoms or groups of atoms are attached to the chain in place of hydrogen atoms. All of these polymers are made by addition polymerization.

Condensation polymerization **Condensation polymerization** takes place when monomers containing at least two functional groups combine with the loss of a small by-product, usually water. Nylon and a type of bulletproof fabric are made this way. Nylon was first synthesized in 1931 and soon became popular because it is strong and can be drawn into thin strands resembling silk. Nylon 6,6 is the name of one type of nylon that is synthesized. One monomer is a chain, with the end carbon atoms being part of carboxyl groups, as shown in **Figure 22.19**. The other monomer is a chain having amino groups at both ends. These monomers undergo a condensation polymerization that forms amide groups linking the subunits of the polymer, as shown by the tinted box in **Figure 22.19**. Note that one water molecule is released for every new amide bond formed.



1939–1945 During World War II, nylon is allocated solely for military items such as parachutes, as shown in the photo, tents, and ponchos.

1959 Spandex, an elastic fiber, is commercially produced.

2006 Researchers develop a paper-thin, radiation-resistant, liquid-crystal polymer in which electronic circuits can be imbedded, making it useful in space applications.

1946 Products with nonstick coating (PTFE), including bearings, bushings, gears, and cookware, become commercially available.







1988 The world's first polymer banknote is issued by the Reserve Bank of Australia. By 1996, all Australians use plastic money.

Concepts in Motion

Interactive Time Line To learn more about these discoveries and others, visit glencoe.com.



**Table
22.14**
Common Polymers

Polymer	Applications	Structural Unit
Polyvinyl chloride (PVC)	Plastic pipes, meat wrap, upholstery, rainwear, house siding, garden hose 	$\cdots - \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{---C---C---} \\ \quad \\ \text{Cl} \quad \text{H} \end{array} \left[\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{---C---C---} \\ \quad \\ \text{Cl} \quad \text{H} \end{array} \right]_n \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{---C---C---} \\ \quad \\ \text{Cl} \quad \text{H} \end{array} \cdots$ Polyvinyl chloride
Polyacrylonitrile	Fabrics for clothing and upholstery, carpet	$\left[\text{CH}_2 - \underset{\begin{array}{c} \\ \text{C} \equiv \text{N} \end{array}}{\text{CH}} \right]_n$
Polyvinylidene chloride	Food wrap, fabrics 	$\left[\text{CH}_2 - \underset{\begin{array}{c} \\ \text{Cl} \\ \\ \text{Cl} \end{array}}{\text{C}} \right]_n$
Polymethyl methacrylate	"Nonbreakable" (acrylic glass) windows, inexpensive lenses, art objects 	$\left[\text{CH}_2 - \underset{\begin{array}{c} \\ \text{C}(\text{O}-\text{CH}_3) \\ \\ \text{CH}_3 \end{array}}{\text{C}} \right]_n$
Polypropylene (PP)	Beverage containers, rope, netting, kitchen appliances	$\left[\text{CH}_2 - \underset{\begin{array}{c} \\ \text{CH}_3 \end{array}}{\text{CH}} \right]_n$
Polystyrene (PS) and styrene plastic	Foam packing and insulation, plant pots, disposable food containers, model kits 	$\left[\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{---C---C---} \\ \quad \\ \text{C}_6\text{H}_5 \quad \text{H} \end{array} \right]_n$
Polyethylene terephthalate (PETE)	Soft-drink bottles, tire cord, clothing, recording tape, replacements for blood vessels	$\left[\text{O} - \overset{\text{O}}{\parallel}{\text{C}} - \text{C}_6\text{H}_4 - \overset{\text{O}}{\parallel}{\text{C}} - \text{O} - \underset{\begin{array}{c} \quad \\ \text{H} \quad \text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}}{\text{C} - \text{C}} \right]_n$
Polyurethane	Foam furniture cushions, waterproof coatings, parts of shoes	$\left[\overset{\text{O}}{\parallel}{\text{C}} - \text{NH} - \text{CH}_2 - \text{CH}_2 - \text{NH} - \overset{\text{O}}{\parallel}{\text{C}} - \text{O} - \text{CH}_2 - \text{CH}_2 - \text{O} \right]_n$



■ **Figure 22.20** Plastic lumber is made from recycled plastic, such as used soft-drink bottles, milk jugs, and other polyethylene waste.


Properties and Recycling of Polymers

Why do we use so many different polymers today? One reason is that they are easy to synthesize. Another reason is that the starting materials used to make them are inexpensive. Still another, more important, reason is that polymers have a wide range of properties. Some polymers can be drawn into fine fibers that are softer than silk, while others are as strong as steel. Polymers do not rust like steel does, and many polymers are more durable than natural materials such as wood. Fencing and decking materials made of plastic, like those shown in **Figure 22.20**, do not decay and do not need to be repainted.

Properties of polymers Another reason why polymers are in such great demand is that it is easy to mold them into different shapes or to draw them into thin fibers. It is not easy to do this with metals and other natural materials because they must be heated either to high temperatures, do not melt at all, or are too weak to be used to form small, thin items.

As with all substances, polymers have properties that result directly from their molecular structure. For example, polyethylene is a long-chain alkane. Thus, it has a waxy feel, does not dissolve in water, is non-reactive, and is a poor electrical conductor. These properties make it ideal for use in food and beverage containers and as an insulator in electrical wire and TV cable.

Polymers fall into two different categories, based on their melting characteristics. A **thermoplastic** polymer is one that can be melted and molded repeatedly into shapes that are retained when cooled. Polyethylene and nylon are examples of thermoplastic polymers. A **thermosetting** polymer is one that can be molded when it is first prepared, but after it cools, it cannot be remelted. This property is explained by the fact that thermosetting polymers begin to form networks of bonds in many directions when they are synthesized. By the time they have cooled, thermosetting polymers have become, in essence, a single large molecule. Bakelite is an example of a thermosetting polymer. Instead of melting, Bakelite decomposes when overheated.

 **Reading Check** Compare and contrast thermoplastic and thermosetting polymers.

CAREERS IN CHEMISTRY

Polymer Chemist Does the thought of developing new and better polymers sound inspiring and challenging to you? Polymer chemists develop new polymers and create uses or manufacturing processes for older ones. For more information on chemistry careers, visit glencoe.com.

VOCABULARY

WORD ORIGIN

Thermoplastic

thermo- comes from the Greek word *thermē* which means heat; *plastic* comes from the Greek word *plastikos* which means to mold or form



1
PETE
Polyethylene
terephthalate



2
HDPE
High-density
polyethylene



3
V
Vinyl



4
LDPE
Low-density
polyethylene



5
PP
Polypropylene



6
PS
Polystyrene



7
OTHER
All other
plastics

■ **Figure 22.21** Codes on plastic products aid in recycling because they identify the composition of the plastic.

Recycling polymers The starting materials for the synthesis of most polymers are derived from fossil fuels. As the supply of fossil fuels becomes depleted, recycling plastics becomes more important. Recycling and buying goods made from recycled plastics decreases the amount of fossil fuels used, which conserves fossil fuels.

Currently, about 5% of the plastics used in the United States are recycled. Plastics recycling is somewhat difficult due to the large variety of different polymers found in products. Usually, the plastics must be sorted according to polymer composition before they can be reused. Thermosetting polymers are more difficult to recycle than thermoplastic polymers because only thermoplastic materials can be melted and remolded repeatedly. The task of separating plastics can be time-consuming and expensive. This is why the plastics industry and the government have tried to improve the process by providing standardized codes that indicate the composition of each plastic product. The standardized codes for plastics are shown in **Figure 22.21**. These codes provide a quick way for recyclers to sort plastics.

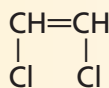
Section 22.5 Assessment

Section Summary

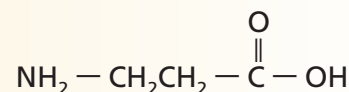
- ▶ Polymers are large molecules formed by combining smaller molecules called monomers.
- ▶ Polymers are synthesized through addition or condensation reactions.
- ▶ The functional groups present in polymers can be used to predict polymer properties.

22. **MAIN Idea** Draw the structure for the polymer that could be produced from each of the following monomers by the method stated.

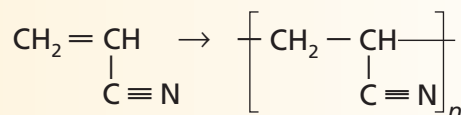
a. Addition



b. Condensation

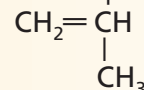


23. **Label** the following polymerization reaction as *addition* or *condensation*. Explain your answer.



24. **Identify** Synthetic polymers often replace stone, wood, metals, wool, and cotton in many applications. Identify some advantages and disadvantages of using synthetic materials instead of natural materials.

25. **Predict** the physical properties of the polymer that is made from the following monomer. Mention solubility in water, electrical conductivity, texture, and chemical reactivity. Do you think it will be thermoplastic or thermosetting? Give reasons for your predictions.



Everyday Chemistry

Garlic: Pleasure and Pain

Did you know that the flavors of fresh and roasted garlic are very different? Fresh garlic, shown in **Figure 1**, contains substances that cause a burning sensation in your mouth. However, roasted garlic does not produce this sensation. These sensations, pleasure or pain, are because of chemical reactions.

When raw garlic is bruised, cut, or crushed, it produces a chemical called allicin, as shown in **Figure 2**. The production of allicin is a chemical defense mechanism for the garlic plant against other organisms. Allicin is an unstable compound and is converted to other compounds over time or when garlic is heated or roasted, which explains why roasted garlic does not cause the burning sensation in your mouth.

Sensing temperature and pain Temperature and pain are sensed by neurons embedded in the skin, including the skin inside your mouth. These neurons have temperature-detecting molecules on their surfaces that are called transient receptor potential (TRP) ion channels. Different TRP channels are activated by different temperature ranges. For example, when a person touches something hot, some of the TRP ion channels open and allow charged calcium ions to enter the nerve cell. This increases the charge within the nerve cell. When the charge increases enough, an electrical signal is sent to the brain, where it is interpreted as a hot sensation.



Figure 1 Fresh garlic contains a pain-producing chemical as a defense against predators.

Allicin also activates neurons. Allicin apparently acts on a pair of ion channel proteins called TRPA1 and TRPV1. When the chemical allicin is present, these channels allow ions to enter the nerve cell. The additional electric charge in the nerve cell signals the brain, where the signal is interpreted by the brain as a burning sensation.

Probing pain receptors While it is interesting to know why tasting raw garlic is painful, the understanding of how allicin causes that pain sensation is even more interesting and useful. Researchers hope that a further understanding of how these receptors work will lead to new methods for controlling chronic pain in patients.

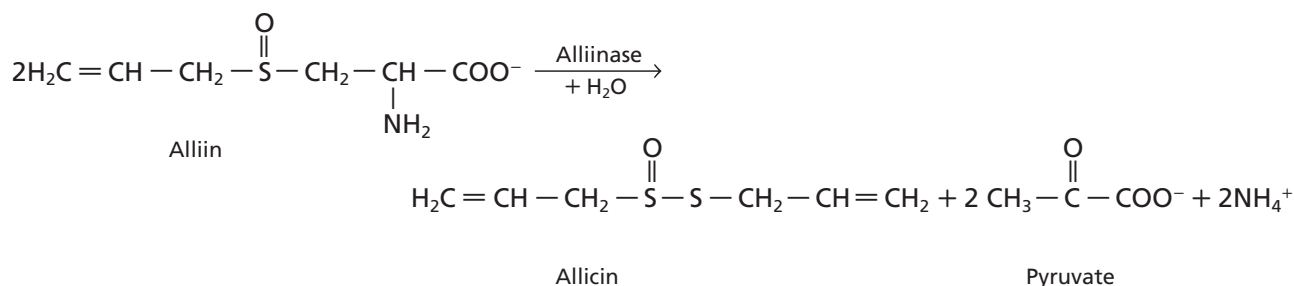


Figure 2 When garlic is bruised or damaged, alliin and the enzyme alliinase produce allicin. When you taste fresh garlic, neurons embedded in your mouth cause an electrical signal to be sent to your brain. The brain interprets the electrical signal as a burning sensation.

WRITING in Chemistry

Research and prepare a poster that shows other chemical reactions in plants. For more information, visit www.glencoe.com.

INTERNET: OBSERVE PROPERTIES OF ALCOHOLS

Background: Alcohols are organic compounds that contain the $-OH$ functional group. How fast various alcohols evaporate indicates the strength of intermolecular forces in alcohols. The evaporation of a liquid is an endothermic process, absorbing energy from the surroundings. This means that the temperature will decrease as evaporation occurs.

Question: How do intermolecular forces differ in three alcohols?

Materials

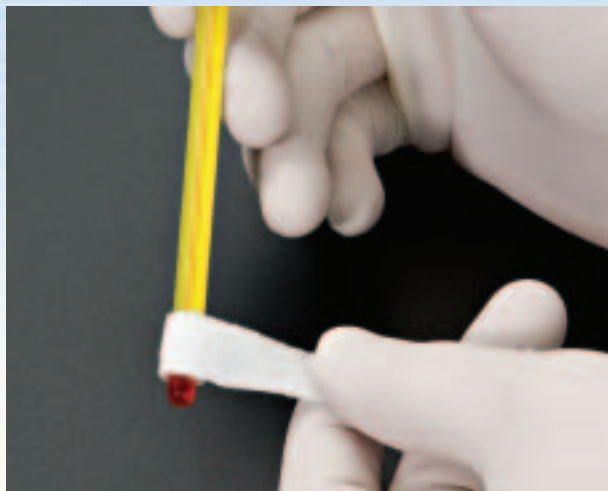
nonmercury thermometer	ethanol (95%)
stopwatch	2-propanol (99%)
facial tissue	wire twist tie or small rubber band
cloth towel	piece of cardboard for use as a fan
Beral pipettes (5)	
methanol	

Safety Precautions

WARNING: Alcohols are flammable. Keep liquids and vapors away from open flames and sparks.

Procedure

1. Read and complete the lab safety form.
2. Prepare data tables for recording data.
3. Cut five 2-cm by 6-cm strips of tissue.
4. Place a thermometer on a folded towel lying on a flat table so that the bulb of the thermometer extends over the edge of the table. Make sure the thermometer cannot roll off the table.
5. Wrap a strip of tissue around the bulb of the thermometer. Secure the tissue with a wire twist tie placed above the bulb of the thermometer.
6. Choose one person to control the stopwatch and read the temperature on the thermometer. A second person will put a small amount of the liquid to be tested into a Beral pipette.
7. When both people are ready, squeeze enough liquid onto the tissue to completely saturate it. At the same time, the other person starts the stopwatch, reads the temperature, and records it in the data table.
8. Fan the tissue-covered thermometer bulb with a piece of cardboard or other stiff paper. After 1 min, read and record the final temperature in the data table. Remove the tissue and wipe the bulb dry.



9. Repeat Steps 5 through 8 for each of the three alcohols: methanol, ethanol, and 2-propanol.
10. Obtain the classroom temperature and humidity data from your teacher.
11. **Cleanup and Disposal** Place the used tissues in the trash. Pipettes can be reused.

Analyze and Conclude

1. **Observe and Infer** What can you conclude about the relationship between heat transfer and the differences in the temperature changes you observed?
2. **Evaluate** Molar enthalpies of vaporization (kJ/mol) for the three alcohols at 25°C are: methanol, 37.4; ethanol, 42.3; and 2-propanol, 45.4. What can you conclude about the relative strength of intermolecular forces existing in the three alcohols?
3. **Compare** Make a general statement comparing the molecular size of an alcohol in terms of the number of carbons in the carbon chain to the rate of evaporation of that alcohol.
4. **Observe and Infer** Post your data on the Internet at glencoe.com. Infer why there are differences between your data and those of other students.
5. **Error Analysis** Determine where errors might have been introduced in your procedure.

INQUIRY EXTENSION

Design an Experiment Suggest a way to make this experiment more quantitative and controlled. Design an experiment using your new method.



BIG Idea The substitution of different functional groups for hydrogen atoms in hydrocarbons results in a diverse group of organic compounds.

Section 22.1 Alkyl Halides and Aryl Halides

MAIN Idea A halogen atom can replace a hydrogen atom in some hydrocarbons.

Vocabulary

- alkyl halide (p. 787)
- aryl halide (p. 788)
- functional group (p. 786)
- halocarbon (p. 787)
- halogenation (p. 790)
- plastic (p. 789)
- substitution reaction (p. 790)

Key Concepts

- The substitution of functional groups for hydrogen in hydrocarbons creates a wide variety of organic compounds.
- An alkyl halide is an organic compound that has one or more halogen atoms bonded to a carbon atom in an aliphatic compound.

Section 22.2 Alcohols, Ethers, and Amines

MAIN Idea Oxygen and nitrogen are two of the most-common atoms found in organic functional groups.

Vocabulary

- alcohol (p. 792)
- amine (p. 795)
- denatured alcohol (p. 793)
- ether (p. 794)
- hydroxyl group (p. 792)

Key Concepts

- Alcohols, ethers, and amines are formed when specific functional groups substitute for hydrogen in hydrocarbons.
- Because they readily form hydrogen bonds, alcohols have higher boiling points and higher water solubilities than other organic compounds.

Section 22.3 Carbonyl Compounds

MAIN Idea Carbonyl compounds contain a double-bonded oxygen in the functional group.

Vocabulary

- aldehyde (p. 796)
- amide (p. 800)
- carbonyl group (p. 796)
- carboxyl group (p. 798)
- carboxylic acid (p. 798)
- condensation reaction (p. 801)
- ester (p. 799)
- ketone (p. 797)

Key Concepts

- Carbonyl compounds are organic compounds that contain the C=O group.
- Five important classes of organic compounds containing carbonyl compounds are aldehydes, ketones, carboxylic acids, esters, and amides.

Section 22.4 Other Reactions of Organic Compounds

MAIN Idea Classifying the chemical reactions of organic compounds makes predicting products of reactions much easier.

Vocabulary

- addition reaction (p. 804)
- dehydration reaction (p. 803)
- dehydrogenation reaction (p. 803)
- elimination reaction (p. 802)
- hydrogenation reaction (p. 804)
- hydration reaction (p. 804)

Key Concepts

- Most reactions of organic compounds can be classified into one of five categories: substitution, elimination, addition, oxidation-reduction, and condensation.
- Knowing the types of organic compounds reacting can enable you to predict the reaction products.

Section 22.5 Polymers

MAIN Idea Synthetic polymers are large organic molecules made up of repeating units linked together by addition or condensation reactions.

Vocabulary

- addition polymerization (p. 811)
- condensation polymerization (p. 810)
- monomer (p. 810)
- polymer (p. 809)
- polymerization reaction (p. 810)
- thermoplastic (p. 813)
- thermosetting (p. 813)

Key Concepts

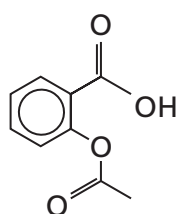
- Polymers are large molecules formed by combining smaller molecules called monomers.
- Polymers are synthesized through addition or condensation reactions.
- The functional groups present in polymers can be used to predict polymer properties.

Section 22.1

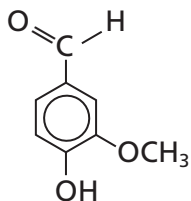
Mastering Concepts

- What is a functional group?
- Describe and compare the structures of alkyl halides and aryl halides.
- What reactant would you use to convert methane to bromomethane?
- Name the amines represented by each of the condensed formulas.
 - $\text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{NH}_2$
 - $\text{CH}_3(\text{CH}_2)_5\text{CH}_2\text{NH}_2$
 - $\text{CH}_3(\text{CH}_2)_2\text{CH}(\text{NH}_2)\text{CH}_3$
 - $\text{CH}_3(\text{CH}_2)_8\text{CH}_2\text{NH}_2$
- Explain why the boiling points of alkyl halides increase in order going down the column of halides in the periodic table, from fluorine through iodine.

Mastering Problems



a Acetylsalicylic acid



b Vanillin

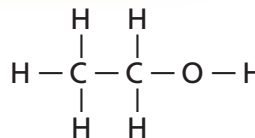
■ Figure 22.22

- Circle and name each of the functional groups circled in the structures shown in Figure 22.22.
- Draw structures for these alkyl and aryl halides.
 - chlorobenzene
 - 1-bromo-4-chlorohexane
 - 1,2-difluoro-3-iodocyclohexane
 - 1,3-dibromobenzene
 - 1,1,2,2-tetrafluoroethane
- For 1-bromo-2-chloropropane:
 - Draw the structure.
 - Does the compound have optical isomers?
 - If the compound has optical isomers, identify the chiral carbon atom.
- Draw and name all of the structural isomers possible for an alkyl halide with no branches and the molecular formula $\text{C}_5\text{H}_{10}\text{Br}_2$.
- Name one structural isomer created by changing the position of one or more halogen atoms in each alkyl halide.

a. 2-chloropentane	c. 1,3-dibromocyclopentane
b. 1,1-difluoropropane	d. 1-bromo-2-chloroethane

Section 22.2

Mastering Concepts



■ Figure 22.23

- How is the compound shown in Figure 22.23 denatured? What is the name of the compound?
- Practical Applications** Name one alcohol, amine, or ether that is used for each of the following purposes.

a. antiseptic	c. antifreeze
b. solvent in paint strippers	d. anesthetic
	e. dye production
- Explain why an alcohol molecule will always have a higher solubility in water than an ether molecule having an identical molecular mass.
- Explain why ethanol has a much higher boiling point than aminoethane, even though their molecular masses are nearly equal.

Mastering Problems

- Name one ether that is a structural isomer of each alcohol.

a. 1-butanol	b. 2-hexanol
--------------	--------------
- Draw structures for the following alcohol, amine, and ether molecules.

a. 1,2-butanediol	e. butyl pentyl ether
b. 5-aminohexane	f. cyclobutyl methyl ether
c. isopropyl ether	g. 1,3-diaminobutane
d. 2-methyl-1-butanol	h. cyclopentanol

Section 22.3

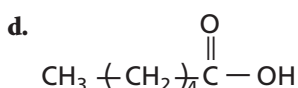
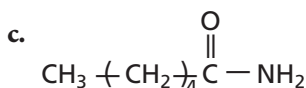
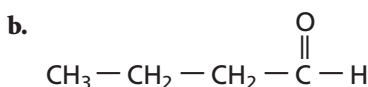
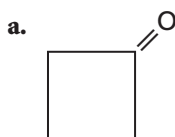
Mastering Concepts

- Draw the general structure for each of the following classes of organic compounds.

a. aldehyde	d. ester
b. ketone	e. amide
c. carboxylic acid	
- Common Uses** Name an aldehyde, ketone, carboxylic acid, ester, or amide used for each of the following purposes.
 - preserving biological specimens
 - solvent in fingernail polish
 - acid in vinegar
 - flavoring in foods and beverages
- What type of reaction is used to produce aspirin from salicylic acid and acetic acid?

Mastering Problems

45. Draw structures for each of the following carbonyl compounds.
- 2,2-dichloro-3-pentanone
 - 4-methylpentanal
 - isopropyl hexanoate
 - octanoamide
 - 3-fluoro-2-methylbutanoic acid
 - cyclopentanal
 - hexyl methanoate
46. Name each of the following carbonyl compounds.



Section 22.4

Mastering Concepts

47. **Synthetic Organic Compounds** What is the starting material for making most synthetic organic compounds?
48. Explain the importance of classifying reactions.
49. List the type of organic reaction needed to perform each of the following transformations.
- alkene \rightarrow alkane
 - alkyl halide \rightarrow alcohol
 - alkyl halide \rightarrow alkene
 - amine + carboxylic acid \rightarrow amide
 - alcohol \rightarrow alkyl halide
 - alkene \rightarrow alcohol

Mastering Problems

50. Classify each of the following organic reactions as substitution, addition, oxidation-reduction elimination, or condensation.
- 2-butene + hydrogen \rightarrow butane
 - propane + fluorine \rightarrow 2-fluoropropane + hydrogen fluoride
 - 2-propanol \rightarrow propene + water
 - cyclobutene + water \rightarrow cyclobutanol

51. Use structural formulas to write equations for the following reactions.
- the substitution reaction between 2-chloropropane and water yielding 2-propanol and hydrogen chloride
 - the addition reaction between 3-hexene and chlorine yielding 3,4-dichlorohexane
52. What type of reaction converts an alcohol into each of the following types of compounds?
- ester
 - alkyl halide
 - alkene
 - aldehyde
53. Use structural formulas to write the equation for the condensation reaction between ethanol and propanoic acid.

Section 22.5

Mastering Concepts

54. Explain the difference between addition polymerization and condensation polymerization.
55. Which type of polymer is easier to recycle, thermosetting or thermoplastic? Explain your answer.

Mastering Problems

56. **Manufacturing Polymers** What monomers react to make each polymer?
- polyethylene
 - polyethylene terephthalate
 - polytetrafluoroethylene
57. Name the polymers made from the following monomers.
- $\text{CF}_2 = \text{CF}_2$
 - $\text{CH}_2 = \text{CCl}_2$
58. Choose the polymer of each pair that you expect to have the higher water solubility.
- | | |
|---|--|
| $\begin{array}{c} \text{CH}_3 \\ \\ \text{[CH - CH}_2\text{]}_n \end{array}$ <p>I</p> | $\begin{array}{c} \text{OH} \\ \\ \text{C=O} \\ \\ \text{[CH}_2 - \text{C - CH}_2\text{]}_n \end{array}$ <p>II</p> |
|---|--|
 - | | |
|--|--|
| $\text{[CH}_2 - \text{CH}_2\text{]}_n$ | $\begin{array}{c} \text{[CH}_2 - \text{CH]}_n \\ \\ \text{OH} \end{array}$ |
|--|--|

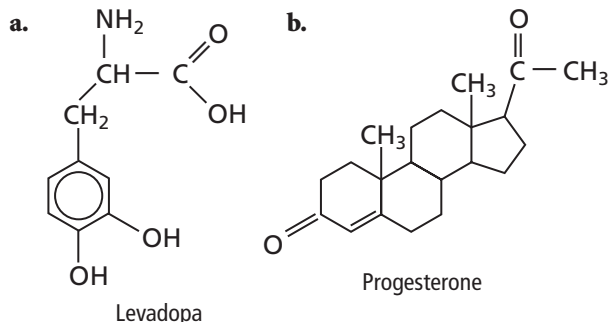
59. Examine the structures of the following polymers in Table 22.14. Decide whether each is made by addition or condensation polymerization.
- nylon
 - polyacrylonitrile
 - polyurethane
 - polypropylene
60. **Human Hormones** Which halogen is found in hormones made by a normal human thyroid gland?

Mixed Review

61. Describe the properties of carboxylic acids.
62. Draw structures of the following compounds.
- butanone
 - propanal
 - hexanoic acid
 - heptanoamide
63. Name the type of organic compound formed by each of the following reactions.
- elimination from an alcohol
 - addition of hydrogen chloride to an alkene
 - addition of water to an alkene
 - substitution of a hydroxyl group for a halogen atom
64. List two uses for each of the following polymers.
- polypropylene
 - polyurethane
 - polytetrafluoroethylene
 - polyvinyl chloride
65. Draw structures of and supply names for the organic compounds produced by reacting ethene with each of the following substances.
- water
 - hydrogen
 - hydrogen chloride
 - fluorine
66. **Environmentally-Safe Propellants** Hydrofluoroalkanes (HFAs) are replacing chlorofluorocarbons in hand-held asthma inhalers, because of CFC damage to the ozone layer. Draw the structures of the HFAs listed below.
- 1,1,1,2,3,3,3-heptafluoropropane
 - 1,1,1,2,-tetrafluoroethane

Think Critically

67. **Interpret Scientific Illustrations** List all the functional groups present in each of the following complex organic molecules.



68. **Evaluate** Ethanoic acid (acetic acid) is very soluble in water. However, naturally occurring long-chain carboxylic acids, such as palmitic acid ($\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$), are insoluble in water. Explain.
69. **Communicate** Write structural formulas for all structural isomers of molecules having the following formulas. Name each isomer.
- $\text{C}_3\text{H}_8\text{O}$
 - $\text{C}_2\text{H}_4\text{Cl}_2$

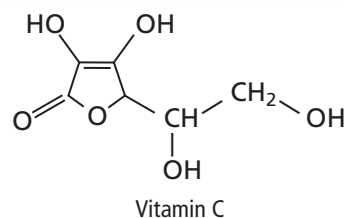


Figure 22.24

70. **Interpret Scientific Illustrations** Human cells require vitamin C to properly synthesize materials that make up connective tissue such as that found in ligaments. List the functional groups present in the Vitamin C molecule shown in Figure 22.24.
71. **Identify** Draw the structure of an example of an organic molecule that has four carbons and falls into each of the compound types listed.
- ester
 - aldehyde
 - ether
 - alcohol
72. **Predict** A monohalogenation reaction describes a substitution reaction in which a single hydrogen atom is replaced by a halogen. A dihalogenation reaction is a reaction in which two hydrogen atoms are replaced by two halogen atoms.
- Draw the structures of all the possible monohalogenation products that can form when pentane reacts with Cl_2 .
 - Draw the structures of all the possible dihalogenation products that can form when pentane reacts with Cl_2 .

Table 22.15 Alcohol Solubility in Water (mol/100 g H_2O)

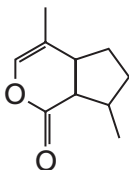
Name	Alcohol	Solubility
Methanol	CH_3OH	infinite
Ethanol	$\text{C}_2\text{H}_5\text{OH}$	infinite
Propanol	$\text{C}_3\text{H}_7\text{OH}$	infinite
Butanol	$\text{C}_4\text{H}_9\text{OH}$	0.11
Pentanol	$\text{C}_5\text{H}_{11}\text{OH}$	0.030
Hexanol	$\text{C}_6\text{H}_{13}\text{OH}$	0.0058
Heptanol	$\text{C}_7\text{H}_{15}\text{OH}$	0.0008

73. **Evaluate** Examine Table 22.15 comparing some alcohols and their solubility in water. Use the table to answer the following questions.
- What type of bond forms between the $-\text{OH}$ group of alcohols and water?
 - State a relationship between water solubility and alcohol size from the data in the table.
 - Provide an explanation for the relationship you stated in Part b.

- 74. Recognize** Most useful organic molecules are made from raw materials using several steps. This is called a multistep synthesis pathway. Label the types of reaction or process taking place in each step of the multistep synthesis pathway below.

petroleum → ethane → chloroethane → ethene → ethanol → ethanoic (acetic) acid

Challenge Problem



■ Figure 22.25

- 75. Animal Pheromones** Catnip contains an organic chemical known as *nepetalactone*, shown in **Figure 22.25**, that is thought to mimic feline sex pheromones. Cats will rub in it, roll over it, paw at it, chew it, lick it, leap about, then purr loudly, growl, and meow for several minutes before losing interest. It takes up to two hours for the cat to “reset” and then have the same response to the catnip.

- What type of organic compound is nepetalactone?
- Draw the structural formula for nepetalactone on a sheet of paper and then draw in all the missing hydrogen atoms. Remember that carbon atoms must have four bonds to be stable.
- Write the molecular formula for nepetalactone.

Cumulative Review

- 76.** Explain why the concentration of ozone over Antarctica decreases at about the same time every year. (*Chapter 1*)
- 77.** Why do the following characteristics apply to transition metals? (*Chapter 6*)
- Ions vary in charge.
 - Many of their solids are colored.
 - Many are hard solids.
- 78.** Determine the number of atoms in each of the following. (*Chapter 10*)
- 56.1 g Al
 - 2 moles C
- 79.** What is a rate-determining step? (*Chapter 16*)
- 80.** According to Le Châtelier’s principle, how would increasing the volume of the reaction vessel affect the equilibrium $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$? (*Chapter 17*)
- 81.** Compare and contrast saturated and unsaturated hydrocarbons. (*Chapter 21*)

Additional Assessment

WRITING in Chemistry

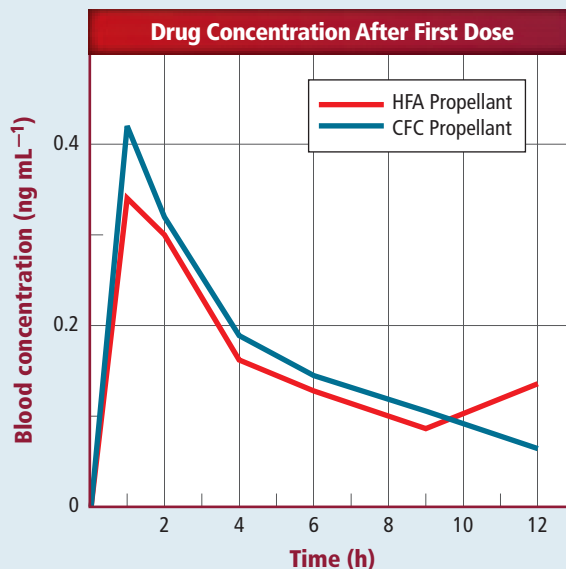
- 82. Historical Perspective** Write a short story describing how your life would differ if you lived in the 1800s, before the development of synthetic polymers.

DBQ Document-Based Questions

Pharmaceutical Propellants Many inhaled medications used to treat asthma contained chlorofluorocarbon (CFC). However, the Montreal Protocol called for a ban of CFCs as a propellant in pharmaceutical products by 2008. Two hydrofluoroalkanes (HFAs) appear to be effective in delivering asthma medications to the lungs. However, the medication dosage had to be cut in half with the new HFA propellants.

Figure 22.26 shows the concentration after one dose of the drug beclomethasone in the blood of volunteers using a CFC or an HFA propellant in the inhaler.

Data obtained from: Anderson, P.J. 2006. *Chest: The Cardiopulmonary and Critical Care Journal*. 120:89–93



■ Figure 22.26

- 83.** After one dose of the drug beclomethasone was given, which propellant resulted in the highest concentration of medication in the blood, HFA or CFC?
- 84.** When does the drug reach its peak concentration?
- 85.** Only one-half the amount of medication is needed with the HFA propellant when compared to the CFC propellant to achieve a similar blood-concentration level. Infer the advantages of using a lower dose of medication to get similar results.

Standardized Test Practice

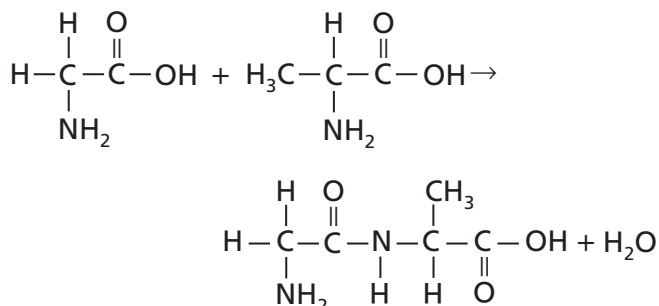
Multiple Choice

1. What are the products of this reaction?

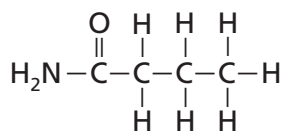


- A. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2\text{Br}$ and H_2
 B. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3$ and Br_2
 C. $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ and HBr
 D. $\text{CH}_3\text{CH}_2\text{CH}_3$ and NH_2Br

2. What kind of reaction is this?



- A. substitution
 B. condensation
 C. addition
 D. elimination
3. What are the oxidation numbers of the elements in CuSO_4 ?
- A. $\text{Cu} = +2, \text{S} = +6, \text{O} = -2$
 B. $\text{Cu} = +3, \text{S} = +5, \text{O} = -2$
 C. $\text{Cu} = +2, \text{S} = +2, \text{O} = -1$
 D. $\text{Cu} = +2, \text{S} = 0, \text{O} = -2$
4. The corrosion, or rusting, of iron is an example of a naturally occurring voltaic cell. To prevent corrosion, sacrificial anodes are sometimes attached to rust-susceptible iron. Sacrificial anodes must
- A. be more likely to be reduced than iron.
 B. have a higher reduction potential than iron.
 C. be more porous and abraded than iron.
 D. lose electrons more easily than iron.
5. What type of compound does this molecule represent?

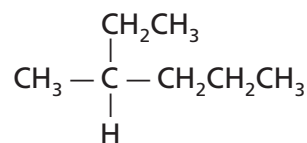


- A. amine
 B. amide
 C. ester
 D. ether

6. Diprotic succinic acid (
- $\text{H}_2\text{C}_4\text{H}_4\text{O}_4$
-) is an important part of the process that converts glucose to energy in the human body. What is the
- K_a
- expression for the second ionization of succinic acid?

- A. $K_a = [\text{H}_3\text{O}^+][\text{HC}_4\text{H}_4\text{O}_4^-] / [\text{H}_2\text{C}_4\text{H}_4\text{O}_4]$
 B. $K_a = [\text{H}_3\text{O}^+][\text{HC}_4\text{H}_4\text{O}_4^{2-}] / [\text{HC}_4\text{H}_4\text{O}_4^-]$
 C. $K_a = [\text{H}_2\text{C}_4\text{H}_4\text{O}_4] / [\text{H}_3\text{O}^+][\text{HC}_4\text{H}_4\text{O}_4^-]$
 D. $K_a = [\text{H}_2\text{C}_4\text{H}_4\text{O}_4] / [\text{H}_3\text{O}^+][\text{C}_4\text{H}_4\text{O}_4^{2-}]$

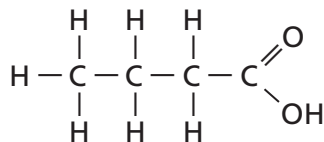
Use the figure below to answer Question 7.



7. Which is the correct name for this compound?
- A. 3-methyl hexane
 B. 2-ethyl pentane
 C. 2-propyl butane
 D. 1-ethyl 1-methyl butane
8. A strip of metal X is immersed in a 1M solution of X^+ ions. When this half-cell is connected to a standard hydrogen electrode, a voltmeter reads a positive reduction potential. Which is true of the X electrode?
- A. It accepts electrons more readily than H^+ ions.
 B. It is undergoing oxidation.
 C. It is adding positive X^+ ions to its solution.
 D. It acts as the anode in the cell.
9. What is the mass of one molecule of barium hexafluorosilicate (BaSiF_6)?
- A. 4.64×10^{-22} g
 B. 1.68×10^{26} g
 C. 2.16×10^{21} g
 D. 6.02×10^{-23} g
10. Which type of compound accepts H^+ ions?
- A. an Arrhenius acid
 B. an Arrhenius base
 C. a Brønsted-Lowry acid
 D. a Brønsted-Lowry base
11. Which substituted hydrocarbon has the general formula $\text{R}-\text{OH}$?
- A. alcohol
 B. amine
 C. ketone
 D. carboxylic acid

Short Answer

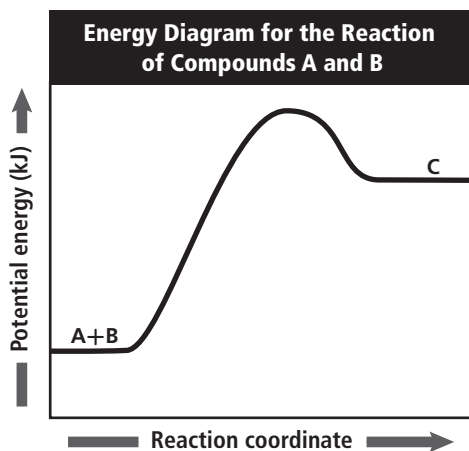
Use the figure below to answer Questions 12 and 13.



12. What is the functional group present in this compound?
13. Give the name for this compound.

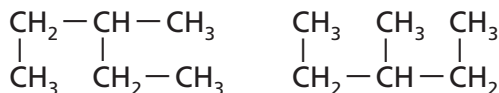
Extended Response

Use the graph below to answer Question 14.



14. Discuss the reaction that results in the shape of the energy graph shown.

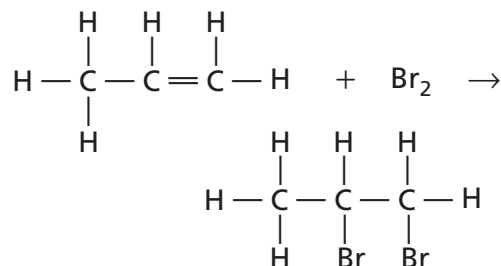
Use the figure below to answer Question 15.



15. The two structures above both have the molecular formula C_6H_{14} . Are they isomers of one another? Explain how you can tell.

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16. To electroplate an iron fork with silver,
- the silver electrode must have more mass than the fork.
 - the iron fork must act as the anode in the cell.
 - electric current must be applied to the iron fork.
 - iron ions must be present in the cell solution.
 - the electric current must be pulsed.
17. Which type of reaction is shown below?



- condensation
- dehydration
- polymerization
- halogenation
- hydration

Use the table below to answer Question 18.

Experimental Data for $\text{A} + \text{B} \rightarrow \text{C}$			
Time	$[\text{A}]/M$	$[\text{B}]/M$	$[\text{C}]/M$
0.00 sec	0.35	0.50	0.00
5.00 sec	0.15	0.30	0.40

18. Which is the rate of this reaction in terms of moles of product per second?
- 0.40 mol/s
 - 0.85 mol/s
 - 0.08 mol/s
 - 0.17 mol/s
 - 0.93 mol/s

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Review Section . . .	22.4	22.4	19.1	20.1	22.2	18.2	21.2	20.1	10.3	18.1	22.2	22.1	22.3	16.1	21.4	20.1	22.4	16.3