



# CHAPTER 17

## AN INTRODUCTION TO ORGANIC CHEMISTRY, BIOCHEMISTRY, AND SYNTHETIC POLYMERS

It's Friday night, and you don't feel like cooking so you head for your favorite eatery, the local 1950s-style diner. There you spend an hour talking and laughing with friends while downing a double hamburger, two orders of fries, and the thickest milkshake in town. After the food has disappeared, you're ready to dance the night away at a nearby club.

What's in the food that gives you the energy to talk, laugh, and dance? How do these substances get from your mouth to the rest of your body, and what happens to them once they get there? The branch of chemistry that answers these questions and many more is called **biochemistry**, the chemistry of biological systems. Because the scope of biochemistry is huge, we will attempt no more than a glimpse of it here by tracing some of the chemical and physical changes that food undergoes in your body. You will be introduced to the kinds of questions that biochemists ask and will see some of the answers that they provide. Because chemicals that are important to biological systems are often organic, or carbon-based, compounds, we start this chapter with an introduction to organic chemistry.

It's not always apparent to the naked eye, but the structures of many plastics and synthetic fabrics are similar to the structures of biological substances. In fact, nylon was purposely developed to mimic the structural characteristics of protein. The last section in this chapter shows you how these substances are similar, and how synthetic polymers are made and used.

17.1 Organic Compounds

17.2 Important Substances in Foods

17.3 Digestion

17.4 Synthetic Polymers



How does the body manage to benefit from the nutrients in the food we eat?

### Review Skills

The presentation of information in this chapter assumes that you can already perform the tasks listed below. You can test your readiness to proceed by answering the Review Questions at the end of the chapter. This might also be a good time to read the Chapter Objectives, which precede the Review Questions.

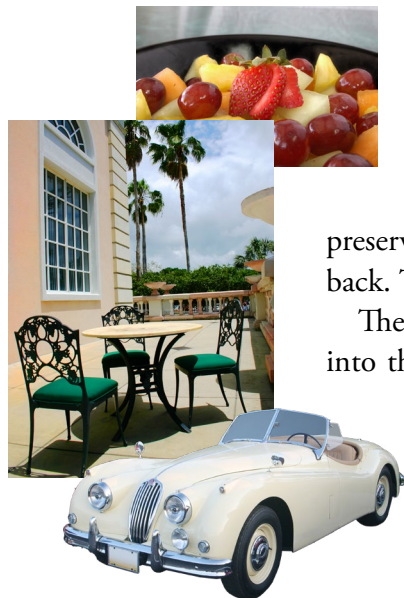
- Give a general description of the information provided in a Lewis structure. (Section 3.3.)
- Describe the information given by a space-filling model, a ball-and-stick model, and a geometric sketch. (Section 3.3)
- Given a Lewis structure or enough information to write one, draw a geometric sketch of the molecule, including bond angles (or approximate bond angles). (Section 12.4)

## 17.1 Organic Compounds

Two co-workers at a pharmaceutical company, John and Stuart, jump into John's car at noon to drive four blocks to get some lunch. The gasoline that fuels the car is composed of many different organic compounds, including some belonging to the category of organic compounds called alkanes and a fuel additive called methyl t-butyl ether (MTBE). When they get to the restaurant, Stuart orders a spinach and fruit salad. The spinach contains a carboxylic acid called oxalic acid, and the odor from the orange and pineapple slices is due, in part, to the aldehyde 3-methylbutanal and the ester ethyl butanoate. The salad dressing is preserved with BHT, which is an example of an arene. John orders fish, but he sends it back. The smell of the amine called trimethylamine let him know that it was spoiled.

The number of natural and synthetic organic, or carbon-based, compounds runs into the millions. Fortunately, the task of studying them is not so daunting as their number would suggest, because organic compounds can be categorized according to structural similarities that lead to similarities in the compounds' important properties. For example, you discovered in Section 3.3 that alcohols are organic compounds possessing one or more  $-OH$  groups attached to a hydrocarbon group (a group that contains only carbon and hydrogen). Because of this structural similarity, all alcohols share certain chemical characteristics. Chemists are therefore able to describe the properties of alcohols in general, which is simpler than describing each substance individually.

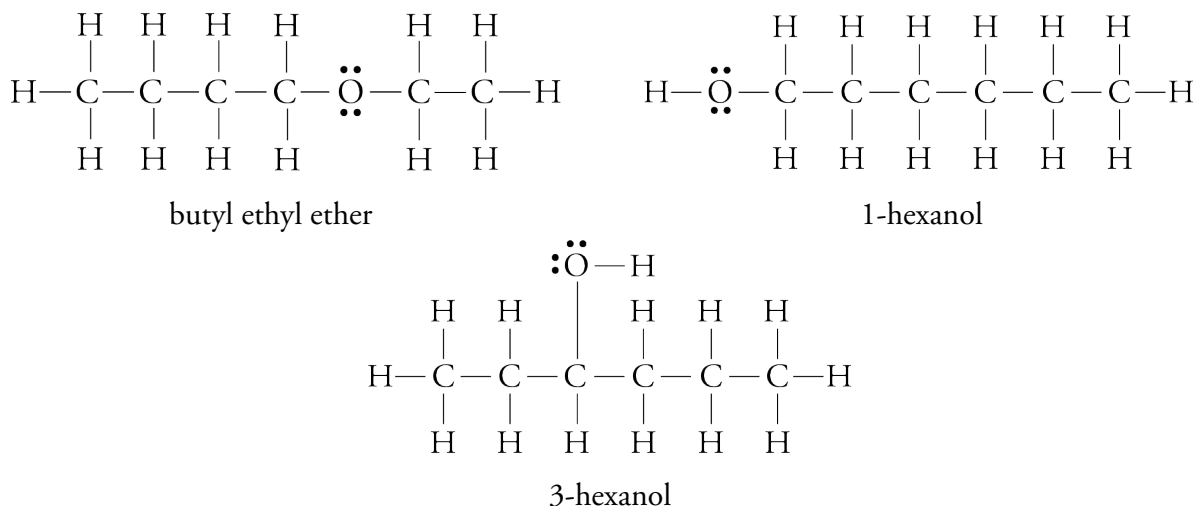
After reading this section, you too will know how to recognize and describe alkanes, ethers, carboxylic acids, aldehydes, esters, arenes, amines, and other types of organic compounds.



John and Stuart are surrounded by many different types of organic compounds, including alkanes and ether in their gas tank and carboxylic acid, aldehyde, ester, and arene in their lunch.

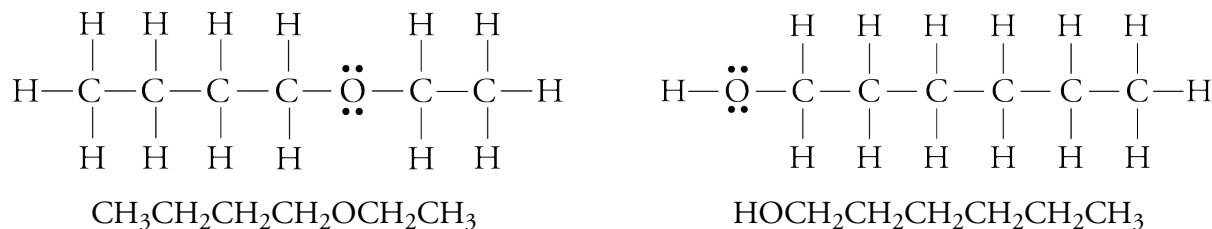
### Formulas for Organic Compounds

Organic (carbon-based) compounds are often much more complex than inorganic compounds, so it is more difficult to deduce their structures from their chemical formulas. Moreover, many organic formulas represent two or more isomers, each with a Lewis structure of its own (Section 12.2). The formula  $C_6H_{14}O$ , for example, has numerous isomers, including



Chemists have developed ways of writing organic formulas so as to describe their structures as well. For example, the formula for butyl ethyl ether can be written  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$ , and the formula for 1-hexanol can be written  $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$  to show the order of the atoms in the structure.

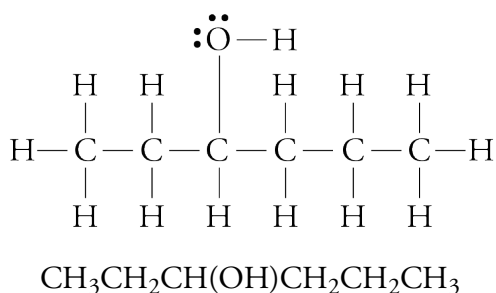
## OBJECTIVE 2



Formulas such as these that serve as a collapsed or condensed version of a Lewis structure are often called condensed formulas (even though they are longer than the molecular formulas). To simplify these formulas, the repeating  $-\text{CH}_2-$  groups can be represented by  $\text{CH}_2$  in parentheses followed by a subscript indicating the number of times it is repeated. In this convention, butyl ethyl ether becomes  $\text{CH}_3(\text{CH}_2)_3\text{OCH}_2\text{CH}_3$ , and 1-hexanol becomes  $\text{HOCH}_2(\text{CH}_2)_4\text{CH}_3$ .

## OBJECTIVE 2

The position of the  $-\text{OH}$  group in 3-hexanol can be shown with the condensed formula  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{CH}_2\text{CH}_3$ . The parentheses, which are often left out, indicate the location at which the  $-\text{OH}$  group comes off the chain of carbon atoms. According to this convention, the group in parentheses is attached to the carbon that precedes it in the condensed formula.



Although Lewis structures are useful for describing the bonding within molecules, they can be time consuming to draw, and they do not show the spatial relationships of the atoms well. For example, the Lewis structure of butyl ethyl ether seems to indicate that the bond angles around each carbon atom are either  $90^\circ$  or  $180^\circ$  and that the carbon atoms lie in a straight line. In contrast, the ball-and-stick and space-filling models in Figure 17.1 on the next page show that the angles are actually about  $109^\circ$  and that the carbons are in a zigzag arrangement. The highly simplified depiction known as a line drawing, introduced in Chapter 15, shows an organic structure's geometry better than a Lewis structure does and takes much less time to draw. Remember that in a line drawing, each corner represents a carbon, each line represents a bond (a double line is a double bond), and an end of a line without another symbol attached also represents a carbon. We assume that there are enough hydrogen atoms attached to each carbon to yield four bonds total.

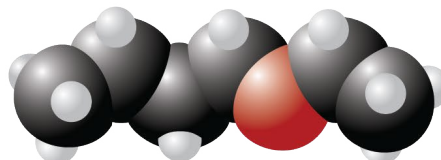
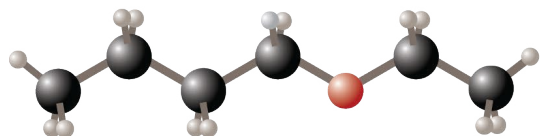
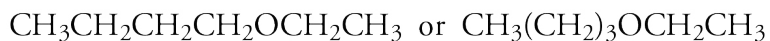
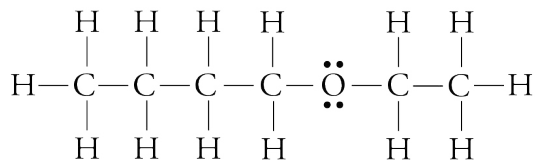
## OBJECTIVE 2

Study Figures 17.1, 17.2, and 17.3 and then practice converting Lewis structures into condensed formulas and line drawings, and vice versa.

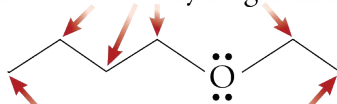
**Figure 17.1**

Ways to Describe Butyl Ethyl Ether

OBJECTIVE 2



Carbon atoms with two hydrogen atoms attached

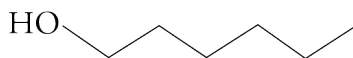
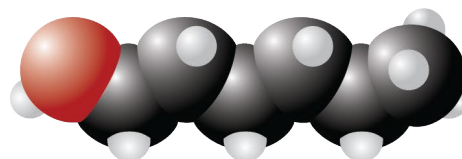
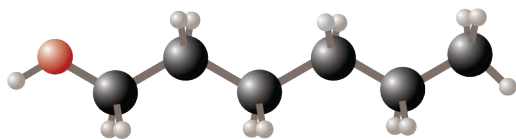
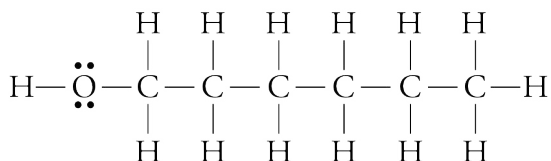


Carbon atoms with three hydrogen atoms attached

**Figure 17.2**

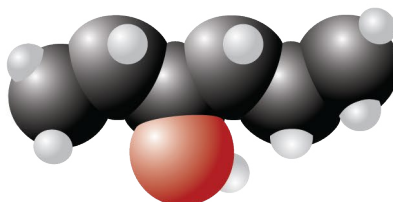
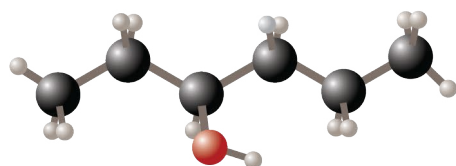
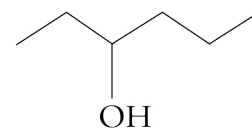
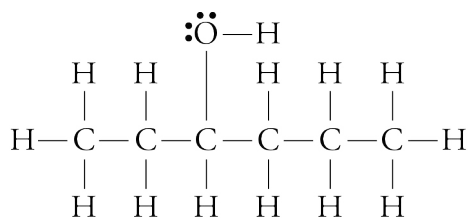
Ways to Describe 1-Hexanol

OBJECTIVE 2

**Figure 17.3**

Ways to Describe 3-Hexanol

OBJECTIVE 2



The remainder of this section lays a foundation for your future study of organic chemistry by providing brief descriptions of some of the most important families of organic compounds. Table 17.1 at the end of this section provides a summary of these descriptions.

This is not the place to describe the process of naming organic compounds, which is much more complex than for inorganic compounds, except to say that many of the better known organic substances have both a systematic and a common name. In the examples that follow, the first name presented is the one that follows the rules set up by the International Union of Pure and Applied Chemistry (IUPAC). Any alternative names will be presented in parentheses. Thereafter, we will refer to the compound by whichever name is more frequently used by chemists.

## Alkanes

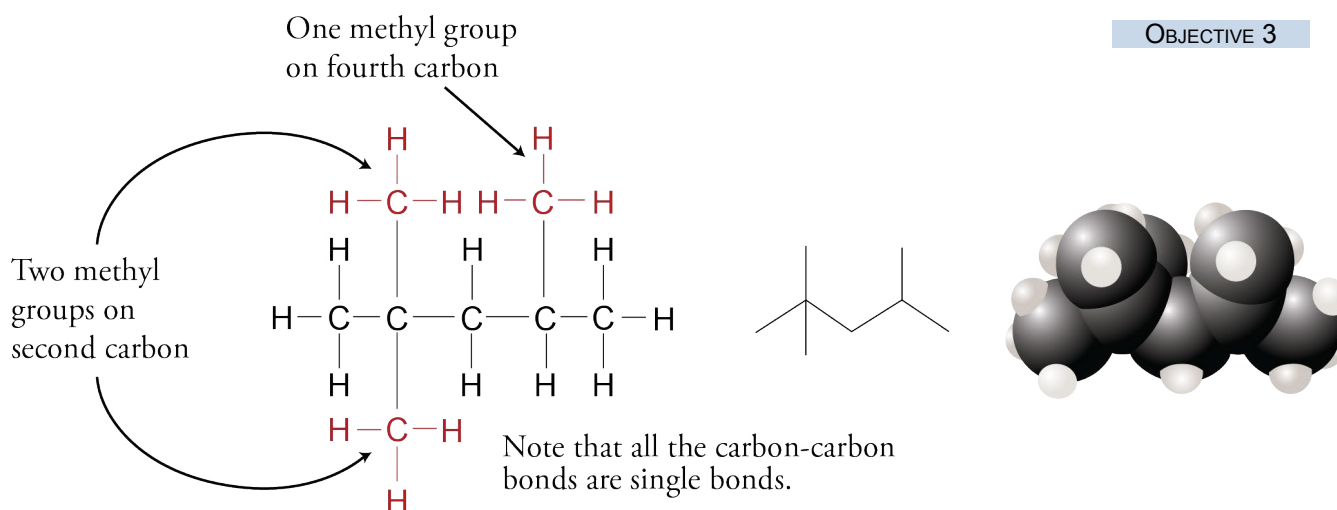
Hydrocarbons (compounds composed of carbon and hydrogen) in which all of the carbon-carbon bonds are single bonds are called **alkanes**. An example is 2,2,4-trimethylpentane (or isooctane), depicted in Figure 17.4. To show that two methyl groups,  $-\text{CH}_3$ , come off the second carbon atom and another comes off the fourth carbon atom, its formula can be described as  $\text{CH}_3\text{C}(\text{CH}_3)_2\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_3$  or  $(\text{CH}_3)_3\text{CCH}_2\text{CH}(\text{CH}_3)_2$ .

OBJECTIVE 3

**Figure 17.4**

The Alkane Isooctane, or 2,2,4-Trimethylpentane

OBJECTIVE 3



Isooctane is used as a standard of comparison in the rating of gasoline. The “octane rating” you see at the gas pump is an average of a “research octane” value, R, determined under laboratory conditions and a “motor octane” value, M, based on actual road operation. Gasoline that has a research octane rating of 100 runs a test engine as efficiently as a fuel that is 100% isooctane. A gasoline that runs a test engine as efficiently (or, rather, inefficiently) as 100% heptane,  $\text{CH}_3(\text{CH}_2)_5\text{CH}_3$ , has a zero research octane rating. A gasoline that has a research octane rating of 80 runs a test engine as efficiently as a mixture of 80% isooctane and 20% heptane.



This gasoline pump shows the octane rating for the gasoline it pumps.

## Alkenes

### OBJECTIVE 3

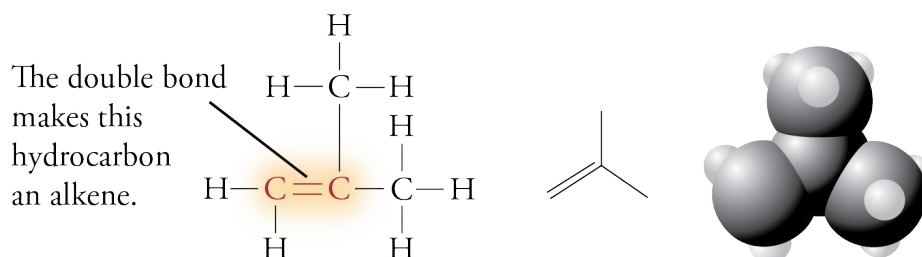
Hydrocarbons that have one or more carbon-carbon double bonds are called **alkenes**. The alkene 2-methylpropene (isobutene),  $\text{CH}_2\text{C}(\text{CH}_3)\text{CH}_3$  or  $\text{CH}_2\text{C}(\text{CH}_3)_2$ , is used to make many other substances, including the gasoline additive MTBE and the antioxidant BHT (Figure 17.5).

All alkenes have very similar chemical and physical properties, primarily determined by the carbon-carbon double bond. When a small section of an organic molecule is largely responsible for the molecule's chemical and physical characteristics, that section is called a **functional group**.

**Figure 17.5**

The Alkene 2-Methylpropene (Isobutene)

### OBJECTIVE 3



## Alkynes

Hydrocarbons that have one or more carbon-carbon triple bonds are called **alkynes**. The most common alkyne is ethyne (acetylene),  $\text{C}_2\text{H}_2$  (Figure 17.6). It is the gas used in oxyacetylene torches.



The energy necessary to weld metals with an oxyacetylene torch comes from the combustion of acetylene.

**Figure 17.6**

The Alkyne Acetylene (or Ethyne)

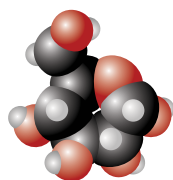
### OBJECTIVE 3

The triple bond makes this hydrocarbon an alkyne.

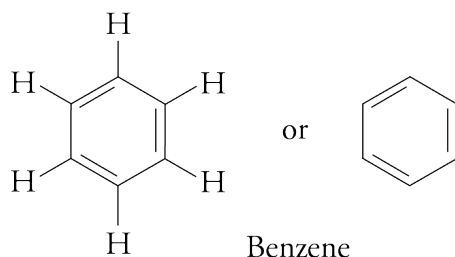


## Arenes (Aromatics)

Benzene,  $\text{C}_6\text{H}_6$ , has six carbon atoms arranged in a ring.



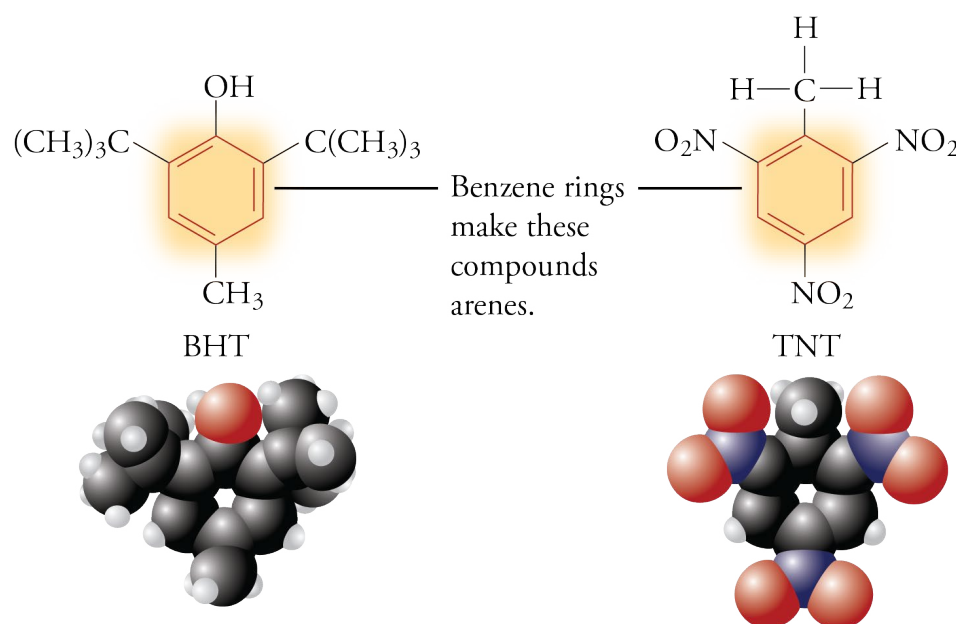
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### OBJECTIVE 3

Compounds that contain the benzene ring are called **arenes** or **aromatics**. There are many important arenes, including butylated hydroxytoluene (BHT), which is a common antioxidant added to food containing fats and oils, and trinitrotoluene

(TNT), the explosive (Figure 17.7).



**Figure 17.7**

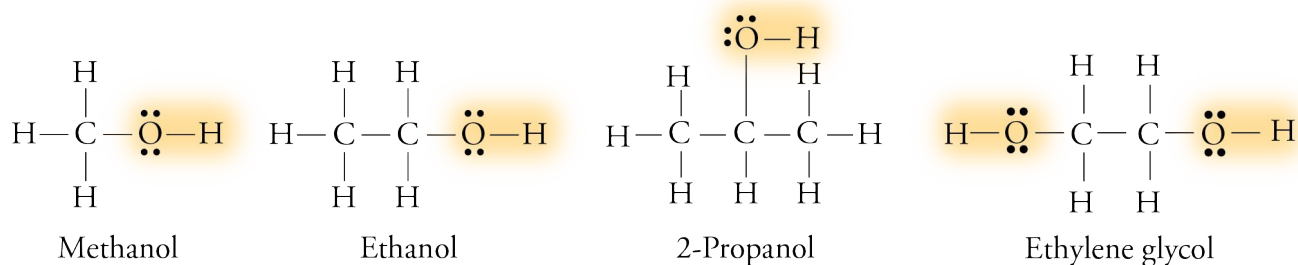
The Arenes Butylated Hydroxytoluene, BHT, and Trinitrotoluene, TNT

OBJECTIVE 3

## Alcohols

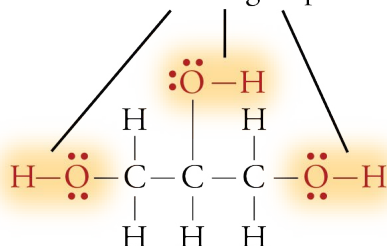
As you learned in Chapter 3, **alcohols** are compounds with one or more  $\text{-OH}$  groups attached to a hydrocarbon group, that is, to a group consisting of only carbon and hydrogen atoms. We have encountered methanol (methyl alcohol),  $\text{CH}_3\text{OH}$ , and ethanol (ethyl alcohol),  $\text{C}_2\text{H}_5\text{OH}$ , in earlier chapters; 2-propanol (isopropyl alcohol),  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ , is a common rubbing alcohol, and 1,2-ethanediol (ethylene glycol),  $\text{HOCH}_2\text{CH}_2\text{OH}$ , is a common coolant and antifreeze.

OBJECTIVE 3



The alcohol 1,2,3-propanetriol (glycerol or glycerin),  $\text{HOCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$ , is used as an emollient (smoother) and demulcent (softener) in cosmetics and as an antidrying agent in toothpaste and tobacco (Figure 17.8).

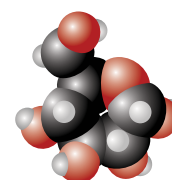
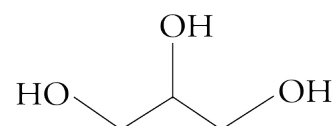
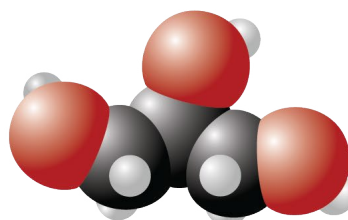
Alcohols have one or more  $\text{O-H}$  functional groups.



OBJECTIVE 3

**Figure 17.8**

Glycerol, an Alcohol

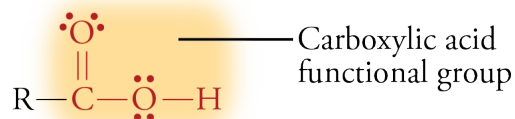


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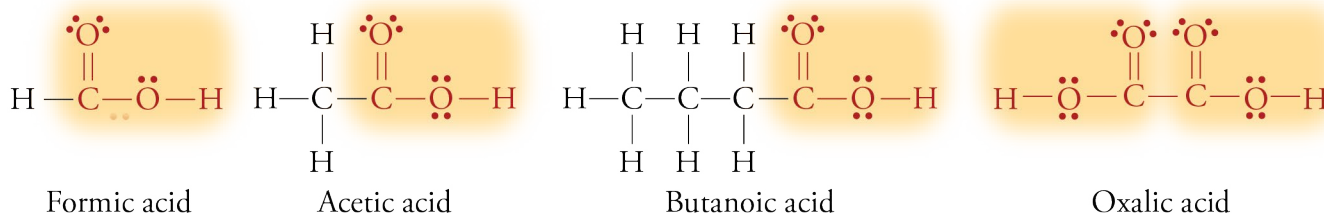
## Carboxylic Acids

### OBJECTIVE 3

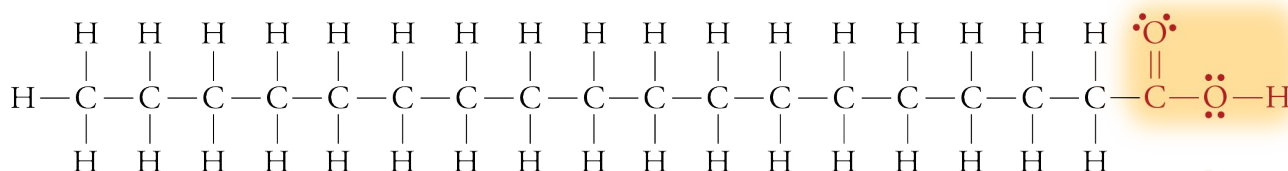
**Carboxylic acids** are organic compounds that have the general formula



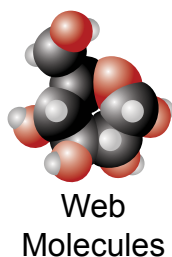
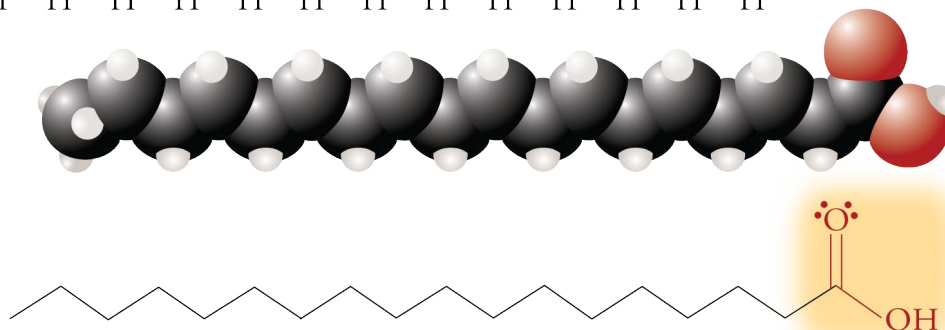
in which R represents either a hydrocarbon group (with all carbon and hydrogen atoms) or a hydrogen atom. The carboxylic acid functional group can be written as  $-\text{COOH}$  or  $-\text{CO}_2\text{H}$ . Methanoic acid (formic acid),  $\text{HCOOH}$  or  $\text{HCO}_2\text{H}$ , is the substance that causes ant bites to sting and itch. Ethanoic acid (acetic acid), written as  $\text{CH}_3\text{COOH}$ ,  $\text{CH}_3\text{CO}_2\text{H}$ , or  $\text{HC}_2\text{H}_3\text{O}_2$ , is the substance that gives vinegar its sour taste. Butanoic acid (butyric acid),  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$  or  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$ , is the substance that gives rancid butter its awful smell. Oxalic acid,  $\text{HOOC}\text{COOH}$  or  $\text{HO}_2\text{CCO}_2\text{H}$ , which has two carboxylic acid functional groups, is found in leafy green plants such as spinach. Stearic acid,  $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$  or  $\text{CH}_3(\text{CH}_2)_{16}\text{CO}_2\text{H}$ , is a natural fatty acid found in beef fat (Figure 17.9).



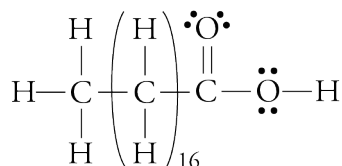
**Figure 17.9**  
Stearic Acid, a Carboxylic Acid



### OBJECTIVE 3



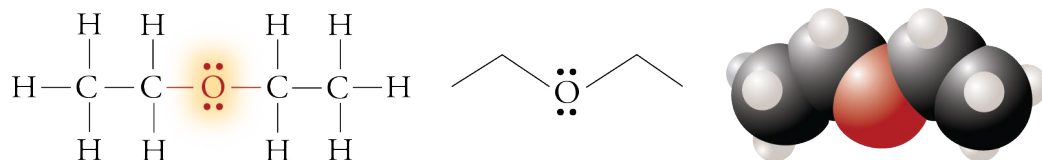
The Lewis structure for stearic acid can be condensed to





## Ethers

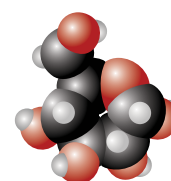
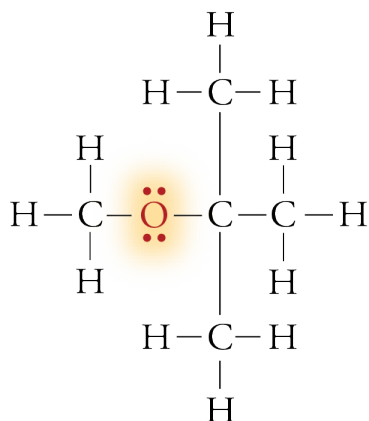
**Ethers** consist of two hydrocarbon groups surrounding an oxygen atom. One important ether is diethyl ether,  $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$ , used as an anesthetic. A group with a condensed formula of  $\text{CH}_3\text{CH}_2-$  is called an ethyl group and is often described as  $\text{C}_2\text{H}_5-$ , so the formula of diethyl ether can also be  $\text{C}_2\text{H}_5\text{OC}_2\text{H}_5$  or  $(\text{C}_2\text{H}_5)_2\text{O}$  (Figure 17.10).



**Figure 17.10**  
Diethyl Ether

OBJECTIVE 3

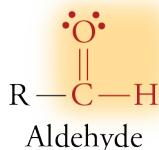
The ether tert-butyl methyl ether (methyl t-butyl ether or MTBE),  $\text{CH}_3\text{OC}(\text{CH}_3)_3$ , can be added to gasoline to boost its octane rating.



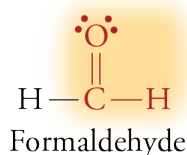
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## Aldehydes

Compounds called **aldehydes** have the general structure

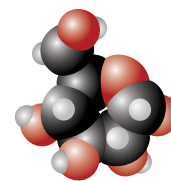


R can be a hydrogen atom or a hydrocarbon group. An aldehyde's functional group is usually represented by  $-\text{CHO}$  in condensed formulas. The simplest aldehyde is formaldehyde,  $\text{HCHO}$ , which has many uses, including the manufacture of polymeric resins.



Natural aldehydes contribute to the pleasant odors of food. For example, 3-methylbutanal (isovaleraldehyde),  $(\text{CH}_3)_2\text{CHCH}_2\text{CHO}$ , is found in oranges, lemons, and peppermint. In the line drawing for aldehydes, it is customary to show

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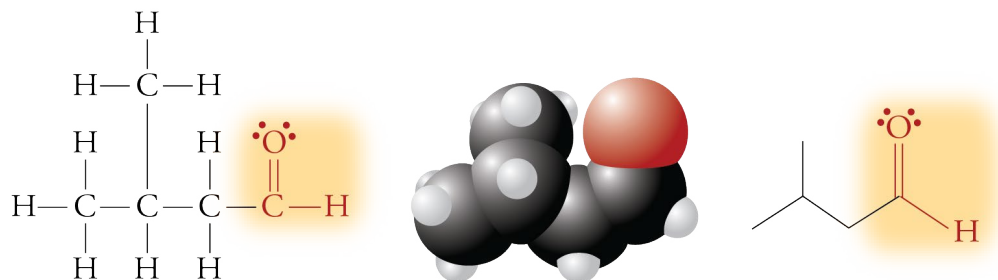


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the hydrogen in the aldehyde functional group (Figure 17.11).

**Figure 17.11**  
Isovaleraldehyde, or  
3-Methylbutanal

OBJECTIVE 3



## Ketones

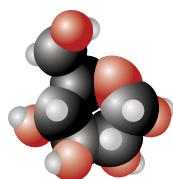
**Ketones** have the general formula

OBJECTIVE 3

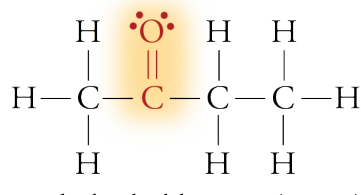


Ketone

The hydrocarbon groups represented by R and R' can be identical or different. The most common ketones are 2-propanone (acetone),  $\text{CH}_3\text{COCH}_3$ , and 2-butanone (methyl ethyl ketone or MEK),  $\text{CH}_3\text{COCH}_2\text{CH}_3$ . Both compounds are solvents frequently used in nail polish removers (Figure 17.12).

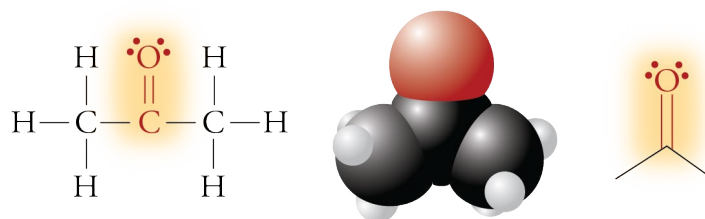


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**Figure 17.12**  
Acetone, a Ketone

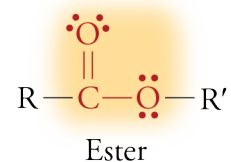
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## Esters

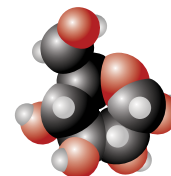
**Esters** are pleasant smelling substances whose general formula is

OBJECTIVE 3

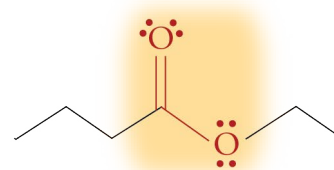
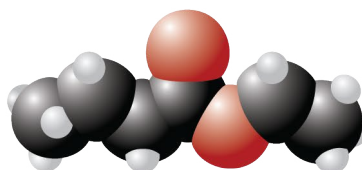
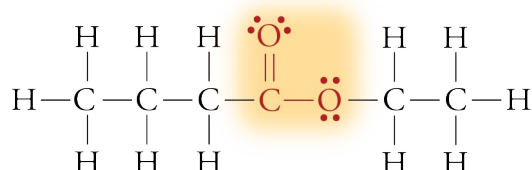


with R representing either a hydrocarbon group or a hydrogen atom, and R'

representing a hydrocarbon group. In condensed formulas, the ester functional group is indicated by either  $-\text{COO}-$  or  $-\text{CO}_2-$ . Ethyl butanoate (or ethyl butyrate),  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOCH}_2\text{CH}_3$  or  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{CH}_2\text{CH}_3$ , is an ester that contributes to pineapples' characteristic odor (Figure 17.13).



Web  
Molecules

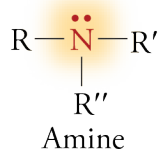


OBJECTIVE 3

**Figure 17.13**  
Ethyl Butanoate, an Ester

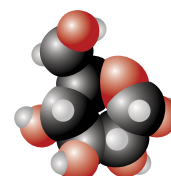
## Amines

**Amines** have the general formula

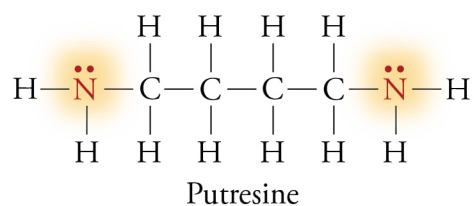
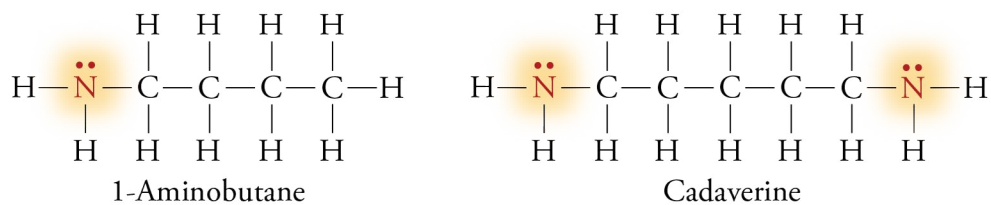


OBJECTIVE 3

in which the R's represent hydrocarbon groups or hydrogen atoms (but at least one of the groups must be a hydrocarbon group). The amine 1-aminobutane (or n-butylamine),  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$ , is an intermediate that can be converted into pharmaceuticals, dyes, and insecticides. Amines can have more than one amine functional group. Amines often have distinctive and unpleasant odors. For example, 1,5-diaminopentane (cadaverine),  $\text{H}_2\text{N}(\text{CH}_2)_5\text{NH}_2$ , and 1,4-diaminobutane (putrescine),  $\text{H}_2\text{N}(\text{CH}_2)_4\text{NH}_2$ , form part of the odor of rotting flesh and in much smaller quantities, bad breath.



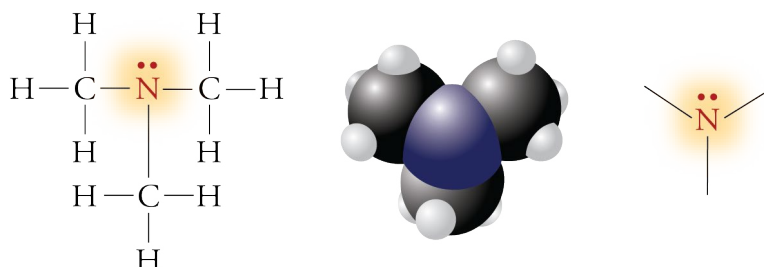
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Trimethylamine,  $(\text{CH}_3)_3\text{N}$ , is partly responsible for the smell of spoiled fish (Figure 17.14).

**Figure 17.14**  
Trimethylamine, an  
Amine

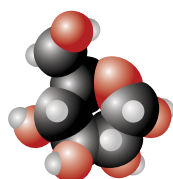
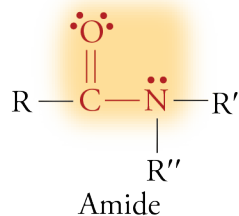
OBJECTIVE 3



## Amides

OBJECTIVE 3

**Amides** have the following general formula

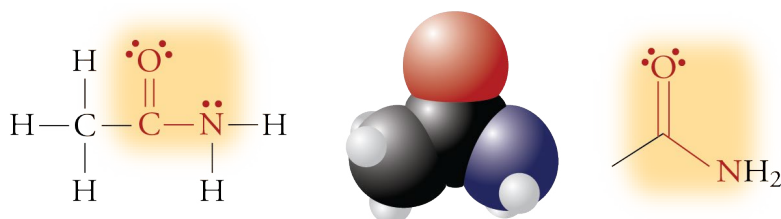


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with the R's representing hydrocarbon groups or hydrogen atoms. In condensed formulas, the amide functional group is indicated by  $-\text{CON}-$ . The amide ethanamide (acetamide),  $\text{CH}_3\text{CONH}_2$ , has many uses, including the production of explosives (Figure 17.15).

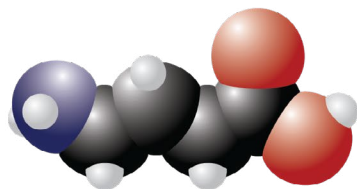
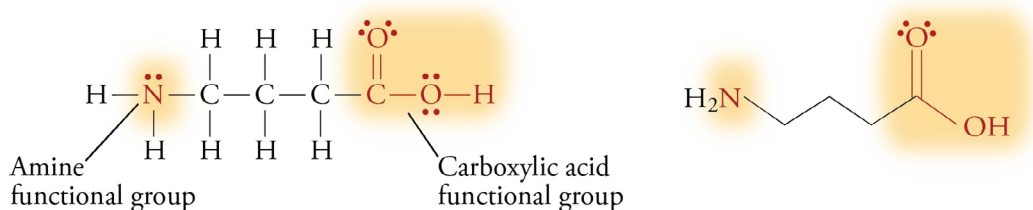
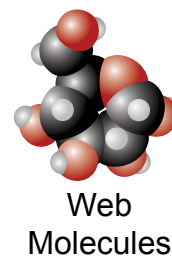
**Figure 17.15**  
Acetamide, an Amide

OBJECTIVE 3



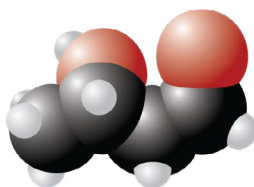
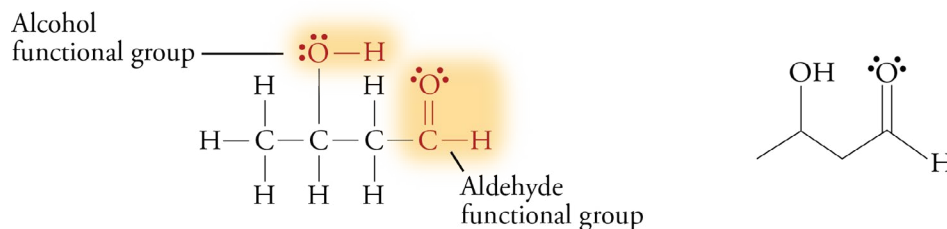
## Organic Compounds with More Than One Functional Group

Many organic compounds have more than one functional group. For example, 4-aminobutanoic acid (more often called gamma aminobutanoic acid, gamma aminobutyric acid, or GABA),  $\text{H}_2\text{N}(\text{CH}_2)_3\text{COOH}$ , has an amine functional group on one end and a carboxylic acid functional group on the other (Figure 17.16). GABA inhibits nerve cell activity in the body, as described in Special Topic 3.1: *Molecular Shapes, Intoxicating Liquids, and the Brain*.



**Figure 17.16**  
GABA, Both an Amine and a Carboxylic Acid

The compound 3-hydroxybutanal (aldol),  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CHO}$ , contains both an alcohol and an aldehyde functional group. Aldol is used to make perfumes, fungicides, and dyes (Figure 17.17).



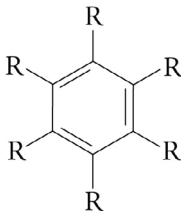
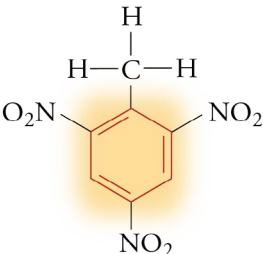
**Figure 17.17**  
Aldol, Both an Alcohol and an Aldehyde

Table 17.1, on the next page, summarizes the ways in which you can recognize organic compounds.

Table 17.1

## OBJECTIVE 3

Types of Organic Compounds (Unless stated otherwise, R represents either a hydrocarbon group or a hydrogen atom.)

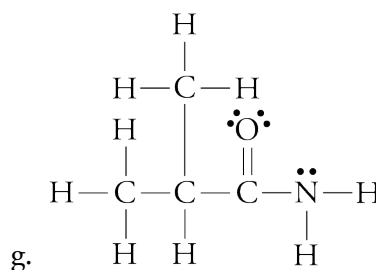
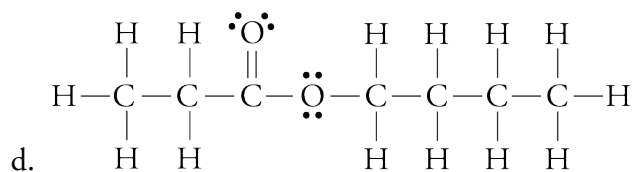
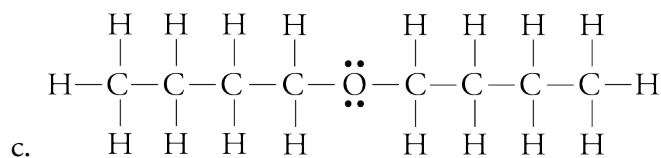
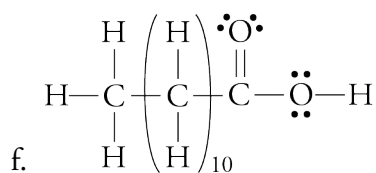
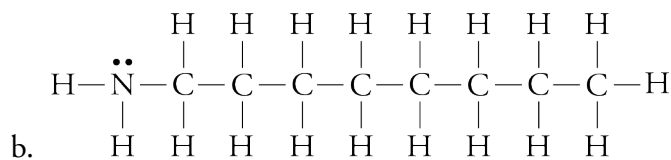
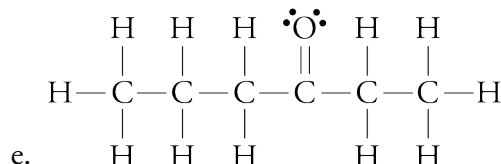
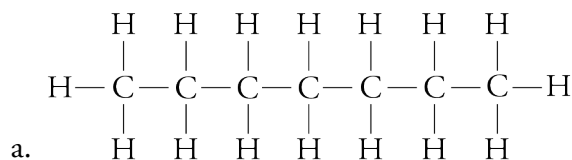
Type of Compound	General Structure	General Condensed Formula	Example
Alkane	$\begin{array}{c} \text{R} \quad \text{R} \\   \quad   \\ \text{R}-\text{C}-\text{C}-\text{R} \\   \quad   \\ \text{R} \quad \text{R} \end{array}$	$\text{CR}_3\text{CR}_3$	Propane, $\text{CH}_3\text{CH}_2\text{CH}_3$ , in liquid petroleum (LP) gas $\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
Alkene	$\begin{array}{c} \text{R} \quad \text{R} \\   \quad   \\ \text{R}-\text{C}=\text{C}-\text{R} \\   \quad   \\ \text{R} \quad \text{R} \end{array}$	$\text{CR}_2\text{CR}_2$	2-Methylpropene (isobutene), $\text{CH}_2\text{C}(\text{CH}_3)_2$ used to make butyl rubber, BHT (an antioxidant), and MTBE (a gasoline additive) $\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{H} \\   \\ \text{H}-\text{C}=\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$
Alkyne	$\text{R}-\text{C}\equiv\text{C}-\text{R}$	$\text{CRCR}$	Ethyne (acetylene), $\text{C}_2\text{H}_2$ used in oxyacetylene torches $\text{H}-\text{C}\equiv\text{C}-\text{H}$
Arene (aromatic)		$\text{C}_6\text{R}_6$	Trinitrotoluene (TNT), $\text{CH}_3\text{C}_6\text{H}_2(\text{NO}_2)_3$ , an explosive 
Alcohols	$\begin{array}{c} \text{R}-\ddot{\text{O}}-\text{H} \\   \\ \text{R} \neq \text{H} \end{array}$	$\text{ROH}$	Ethanol (ethyl alcohol), $\text{C}_2\text{H}_5\text{OH}$ in intoxicating beverages $\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\ddot{\text{O}}-\text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$
Carboxylic acids	$\begin{array}{c} \ddot{\text{O}} \\    \\ \text{R}-\text{C}-\ddot{\text{O}}-\text{H} \end{array}$	$\text{RCOOH}$ or $\text{RCO}_2\text{H}$	Ethanoic acid (acetic acid), $\text{CH}_3\text{COOH}$ in vinegar $\begin{array}{c} \text{H} \quad \ddot{\text{O}} \\   \quad    \\ \text{H}-\text{C}-\text{C}-\ddot{\text{O}}-\text{H} \\   \\ \text{H} \end{array}$
Ethers	$\begin{array}{c} \text{R}-\ddot{\text{O}}-\text{R}' \\   \\ \text{R}' \neq \text{H} \end{array}$	$\text{ROR}$	Diethyl ether, $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$ , an anesthetic $\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\ddot{\text{O}}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$
Aldehyde	$\begin{array}{c} \ddot{\text{O}} \\    \\ \text{R}-\text{C}-\text{H} \end{array}$	$\text{RCHO}$	Ethanal (acetaldehyde), $\text{CH}_3\text{CHO}$ used to make acetic acid; created from ethanol in the human body $\begin{array}{c} \text{H} \quad \ddot{\text{O}} \\   \quad    \\ \text{H}-\text{C}-\text{C}-\text{H} \\   \\ \text{H} \end{array}$
Ketone	$\begin{array}{c} \ddot{\text{O}} \\    \\ \text{R}-\text{C}-\text{R}' \\   \\ \text{R}' \neq \text{H} \end{array}$	$\text{RCOR}$	2-Propanone (acetone), $\text{CH}_3\text{COCH}_3$ , a solvent $\begin{array}{c} \text{H} \quad \ddot{\text{O}} \quad \text{H} \\   \quad    \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$

Ester	$\begin{array}{c} \cdot\cdot \\ \text{O} \\ \parallel \\ \text{R}-\text{C}-\ddot{\text{O}}-\text{R}' \\ \text{R}' \neq \text{H} \end{array}$	RCOOR or RCO <sub>2</sub> R	Ethyl butanoate (ethyl butyrate), CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> COOCH <sub>2</sub> CH <sub>3</sub> smells like pineapples; used in artificial flavorings	
Amine	$\begin{array}{c} \cdot\cdot \\ \text{N} \\   \\ \text{R}-\text{N}-\text{R}' \\   \\ \text{R}'' \end{array}$ <p>At least one R is a hydrocarbon group.</p>	R <sub>3</sub> N	1-Aminobutane (n-butyl amine), NH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub> intermediate in the production of pharmaceuticals, dyes, and insecticides	
Amide	$\begin{array}{c} \cdot\cdot \\ \text{O} \\ \parallel \\ \text{R}-\text{C}-\ddot{\text{N}}-\text{R}' \\   \\ \text{R}'' \end{array}$	RCONR <sub>2</sub>	Ethanamide (acetamide), CH <sub>3</sub> CONH <sub>2</sub> used to make explosives	

### EXERCISE 17.1 - Organic Compounds

Identify each of these structures as representing an alkane, alkene, alkyne, arene (aromatic), alcohol, carboxylic acid, ether, aldehyde, ketone, ester, amine, or amide.

OBJECTIVE 3







## SPECIAL TOPIC 17.1 Rehabilitation of Old Drugs and Development of New Ones

Imagine that you are a research chemist hired by a large pharmaceutical company to develop a new drug for treating AIDS. How are you going to do it? Modern approaches to drug development fall into four general categories.

**Old Drug, New Use** One approach is to do a computer search of all of the drugs that have been used in the past to try to find one that can be put to a new use. For example, imagine you want to develop a drug for combating the lesions seen in Kaposi's sarcoma, an AIDS related condition. These lesions are caused by the abnormal proliferation of small blood vessels. A list of all of the drugs that are thought to inhibit the growth of blood vessels might include some that are effective in treating Kaposi's sarcoma.

One of the drugs on that list is thalidomide, originally developed as a sedative by the German pharmaceutical company Chemie Gruenthal in the 1950s. Thalidomide was considered a safe alternative to other sedatives, which are lethal in large doses; but when it was also used to reduce the nausea associated with pregnant women's "morning sickness," it caused birth defects in the babies they were carrying. Thalidomide never did receive approval in the United States, and it was removed from the European market in the 1960s. About 10,000 children were born with incompletely formed arms and legs owing to thalidomide's effects.

Thalidomide is thought to inhibit the formation of limbs in the fetus by slowing the formation of blood vessels, but what can be disastrous for unborn children can be lifesaving for others. Today the drug is being used as a treatment for Kaposi's sarcoma and may be helpful in treating AIDS related weight loss and brain cancer as well.

**Old Drug, New Design** Another approach to drug development is to take a chemical already known to have a certain desirable effect and alter it slightly in hopes of enhancing its potency. The chemists at the Celgene Corporation have taken this approach with thalidomide. They have developed a number of new drugs similar in structure to thalidomide that appear to be 400 to 500 times more potent.

**Rational Drug Design** In a third, more direct, approach, often called rational drug design, the researcher first tries to determine what chemicals in the body are leading to the trouble. Often these chemicals are enzymes, large molecules that contain an active site in their structure where other molecules must fit to cause a change in the body. Once the offending enzyme is identified, isolated, and purified,

it is "photographed" by x-ray crystallography, which in combination with sophisticated computer analysis reveals the enzyme's three-dimensional structure, including the shape of the active site. The next step is to design a molecule that will fit into the active site and deactivate the enzyme. If the enzyme is important for the replication of viruses like the AIDS virus or a flu virus, the reproduction of the virus will be slowed.

**Combinatorial Chemistry** The process of making a single new chemical, isolating it, and purifying it in quantities large enough for testing is time-consuming and expensive. If the chemical fails to work, all you can do is start again and hope for success with the next. Thus chemists are always looking for ways to make and test more new chemicals faster. A new approach to the production of chemicals, called combinatorial chemistry, holds great promise for doing just that.

Instead of making one new chemical at a time, the strategy of combinatorial chemistry is to make and test thousands of similar chemicals at the same time. It therefore requires highly efficient techniques for isolating and identifying different compounds. One way of easily separating the various products from the solution in which they form is to run the reaction on the surface of tiny polymer beads that can be filtered from the reaction mixture after the reaction takes place. The beads need to be tagged in some way, so the researcher can identify which ones contain which new substance. One of the more novel ways of doing this is to cause the reaction to take place inside a tiny capsule from which a microchip sends out an identifying signal.

After a library of new chemicals has been produced, the thousands of compounds need to be tested to see which have desirable properties. Unfortunately, the procedures for testing large numbers of chemicals are often less than precise. One approach is to test them each in rapid succession for one characteristic that suggests a desired activity. A secondary library is then made with a range of structures similar to the structure of any substance that has that characteristic, and these new chemicals are also tested. In this way, the chemist can zero in on the chemicals that are most likely to have therapeutic properties. The most likely candidates are then made in larger quantities, purified more carefully, and tested in more traditional ways. Combinatorial chemistry has shown promise for producing pharmaceuticals of many types including anticancer drugs and drugs to combat AIDS.

## 17.2 Important Substances in Food

*Organic chemistry is the chemistry of carbon compounds. Biochemistry is the study of carbon compounds that crawl.*

Mike Adams, Science Writer

Let's take a closer look at the fast food dinner described in the chapter introduction. Our food is a mixture of many different kinds of substances, but the energy we need to run our bodies comes from three of them: digestible carbohydrates (the source of 40%-50% of our energy), protein (11%-14%), and fat (the rest). Table 17.2 shows typical mass and energy values for a burger, a serving of fries, and a milkshake. In order to understand what happens to these substances when we eat them, you need to know a little bit more about their composition.

**Table 17.2**

Fast Food Dinner (According to the USDA Nutrient Database for Standard Reference)

	Energy, calories	Energy, kJ	Total Mass	Protein mass	Carbohydrate mass	Fat mass
Large double hamburger with condiment	540.2	2260	226.0 g	34.3 g	40.3 g	26.6 g
Fried potatoes	663.0	2774	255.0 g	7.2 g	76.9 g	38.1 g
Chocolate milkshake	355.6	1488	300.0 g	9.2 g	63.5 g	8.1 g

### Carbohydrates

#### OBJECTIVE 4

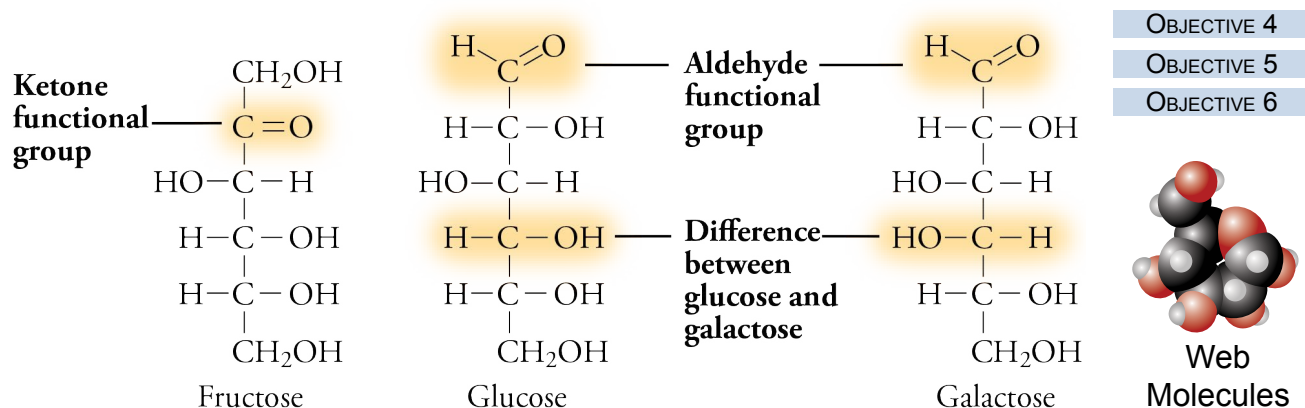
**Carbohydrate** is a general name for sugars, starches, and cellulose. The name derives from an earlier belief that these substances were hydrates of carbon, because many of them have the general formula  $(\text{CH}_2\text{O})_n$ . Today, chemists also refer to carbohydrates as **saccharides** after the smaller units from which they are built. Sugars are monosaccharides and disaccharides. Starches and cellulose are polysaccharides. Carbohydrates serve many different functions in nature. For example, sugar and starch are important for energy storage and production in both plants and animals, and cellulose provides the support structure of woody plants.

#### OBJECTIVE 5

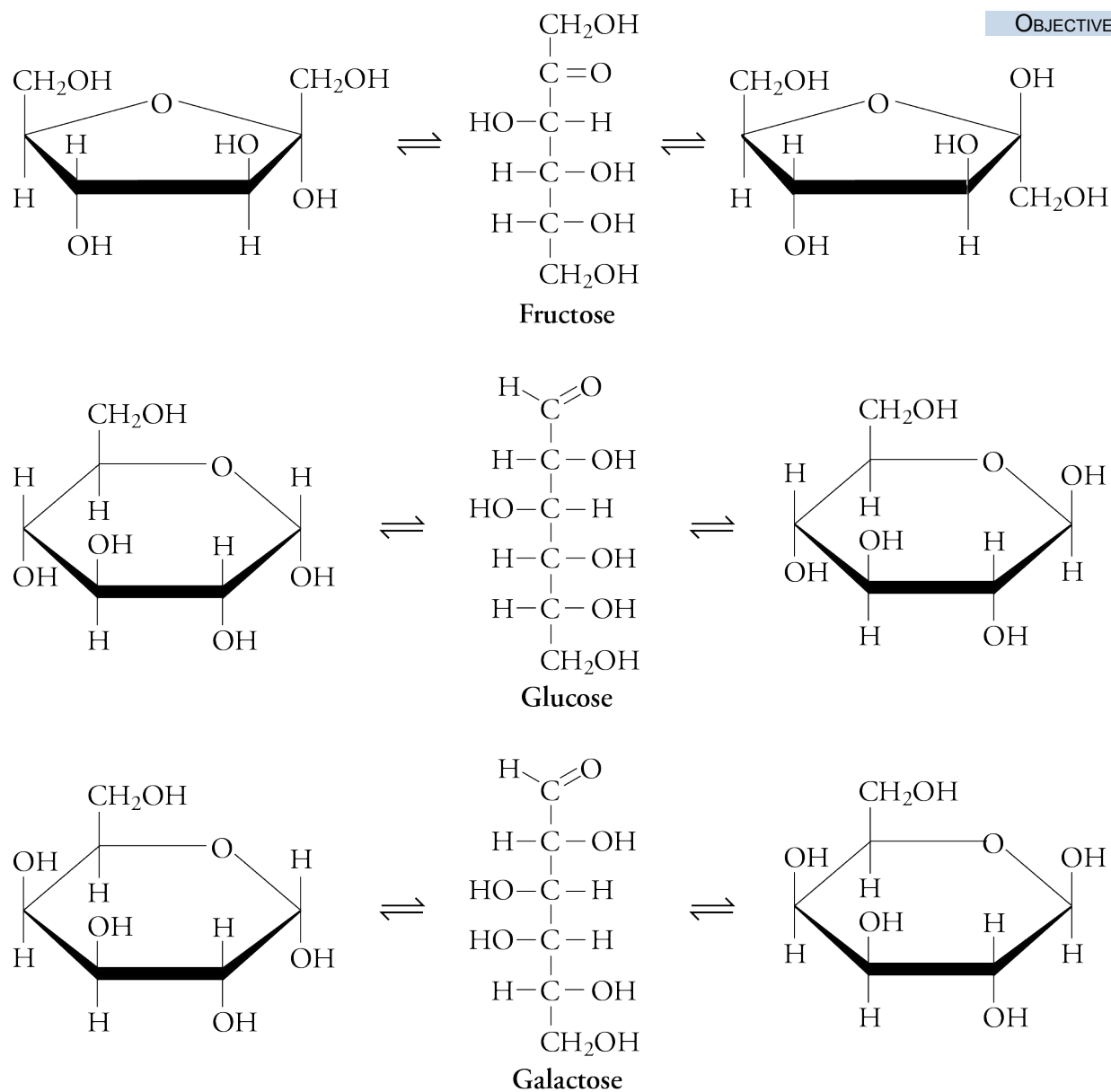
#### OBJECTIVE 6

The most important **monosaccharides** are the sugars glucose, fructose, and galactose, isomers with the general formula  $\text{C}_6\text{H}_{12}\text{O}_6$ . Each of these sugars can exist in either of two ring forms or in an open-chain form (Figures 17.18 and 17.19). In solution, they are constantly shifting from one to another. Note that glucose and galactose have aldehyde functional groups in the open-chain form, and fructose has a ketone functional group. Glucose and galactose differ only in the relative position of the  $-\text{H}$  and  $-\text{OH}$  groups on one of the carbon atoms.

**Figure 17.18**  
Open-chain Form of Three Monosaccharides



**Figure 17.19**  
Fructose, Glucose, and Galactose



## OBJECTIVE 5

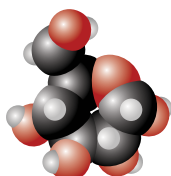
**Disaccharides** are composed of two monosaccharide units. Maltose, a disaccharide consisting of two glucose units, is formed in the brewing of beer from barley in a process called malting. Lactose, or milk sugar, is a disaccharide consisting of galactose and glucose; sucrose is a disaccharide that contains glucose and fructose (Figure 17.20).

## OBJECTIVE 7

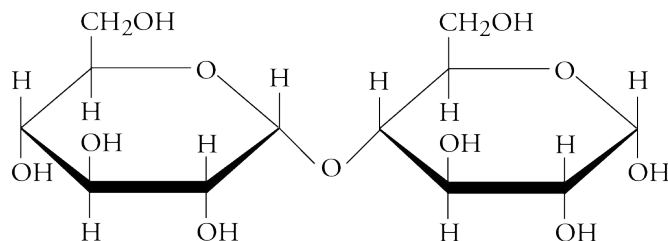
**Figure 17.20**

Three Disaccharides:  
Maltose, Lactose, and  
Sucrose

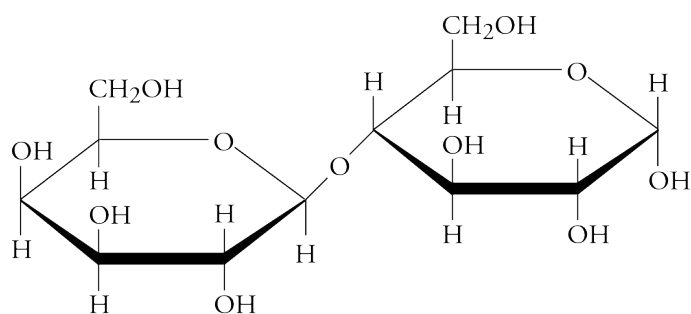
## OBJECTIVE 7



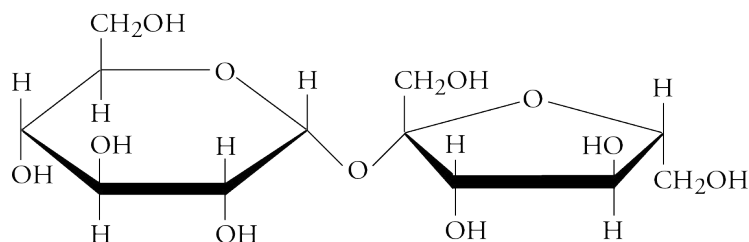
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Maltose (glucose and glucose)



Lactose (galactose and glucose)



Sucrose (glucose and fructose)

## OBJECTIVE 5

**Polysaccharides** consist of many saccharide units linked together to form long chains. The most common polysaccharides are starch, glycogen (sometimes called animal starch), and cellulose. All of these are composed of repeating glucose units, but they differ in the way the glucose units are attached.

## OBJECTIVE 8

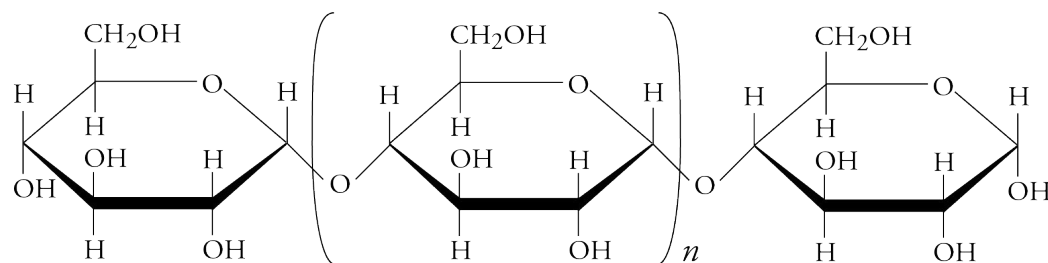
Almost every kind of plant cell has energy stored in the form of starch. Plant starch itself has two general forms, amylose and amylopectin. Amylose molecules are long, unbranched chains. Amylopectin molecules are long chains that branch (Figure 17.21). Glycogen is similar to amylopectin, but its branches are usually shorter and more numerous. Glycogen molecules are stored in liver and muscle cells of animals, where they can be converted into glucose molecules and be used as a source of energy. All the polysaccharides are **polymers**, a general name for large molecules composed of repeating units, called **monomers**.

## OBJECTIVE 8

Cellulose is the primary structural material in plants. Like starch, it is composed of large numbers of glucose molecules linked together; but in cellulose the manner of linking produces very organized chains that can pack together closely, allowing strong attractions to form (Figure 17.21). The strong structures that result provide support and protection for plants. Our digestive enzymes are able to break the linkages in starch

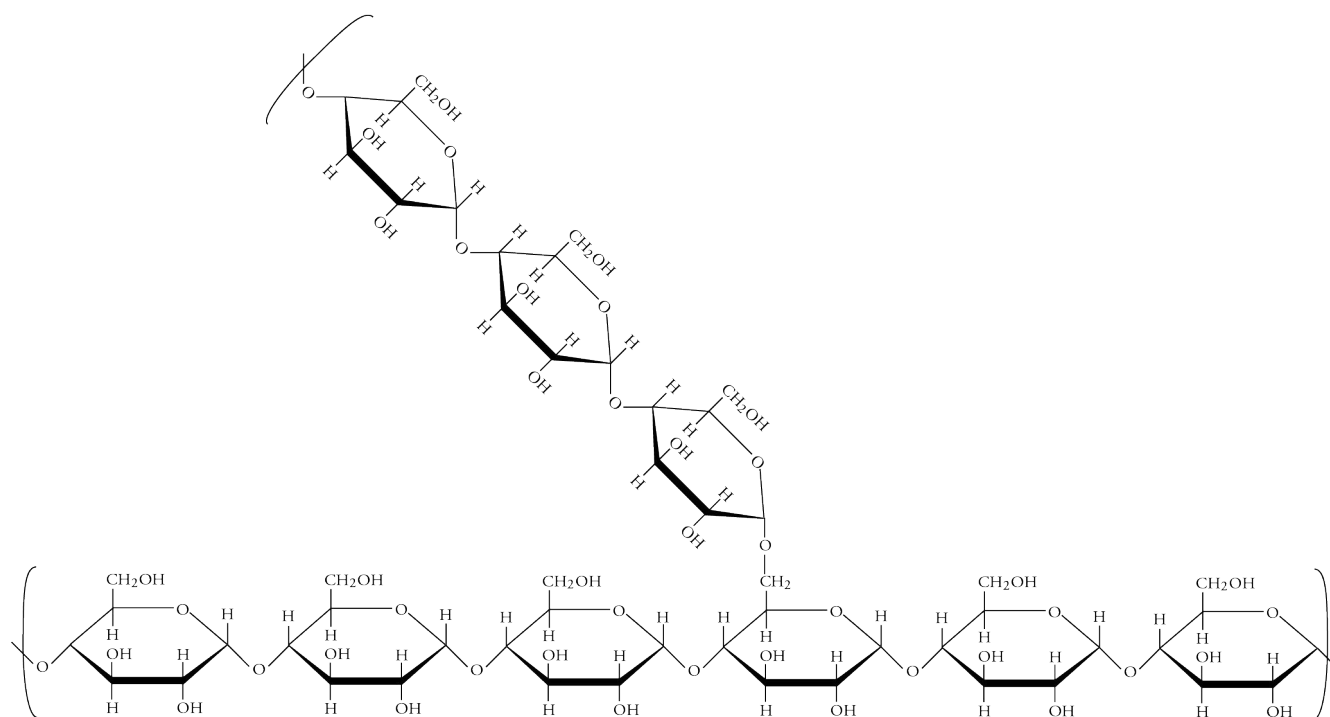
## OBJECTIVE 9

to release energy producing glucose, but they are unable to liberate glucose molecules from cellulose because they cannot break the linkages there. Cellulose passes through our digestive tract unchanged.

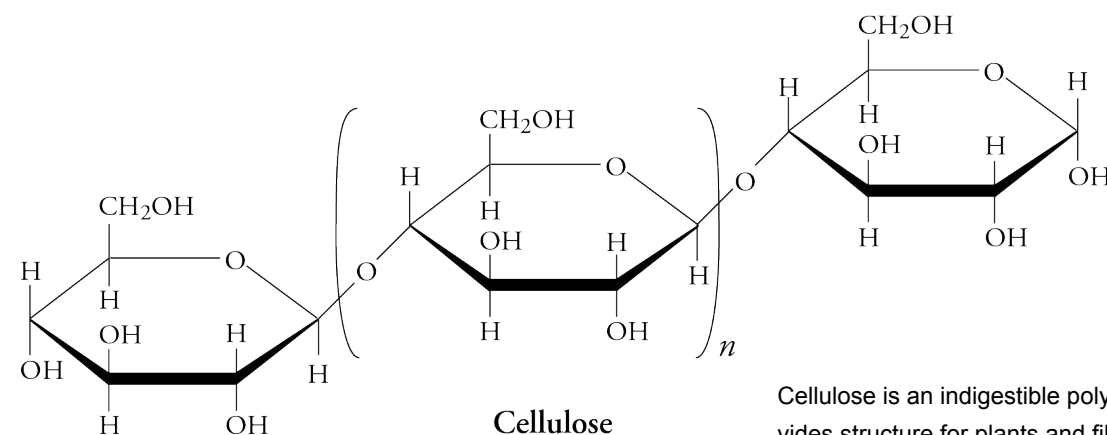


**Amylose**

Starch provides energy both for plants and for animals that eat the plants.



**Amylopectin**

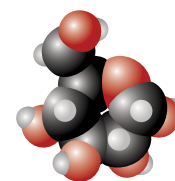


**Cellulose**

Cellulose is an indigestible polysaccharide that provides structure for plants and fiber in animal diets.

**Figure 17.21**  
Polysaccharides

OBJECTIVE 8

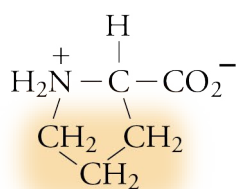


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Molecules

OBJECTIVE 8

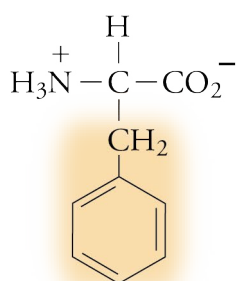


## Cyclic amino acid

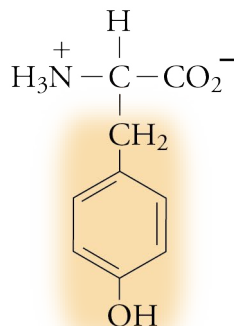


Proline, Pro (P)

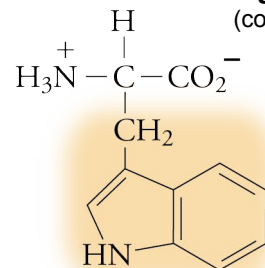
## Aromatic amino acids



Phenylalanine, Phe (F)



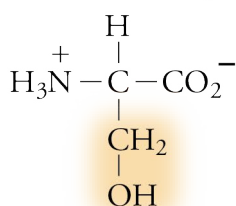
Tyrosine, Tyr (Y)



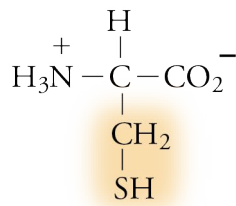
Tryptophan, Trp (W)

Figure 17.22  
(continued)

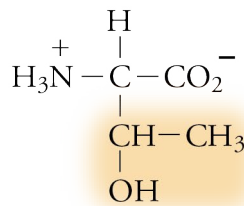
## Amino acids with hydroxyl- or sulfur-containing side chains



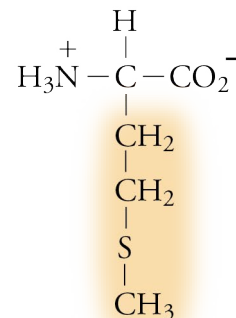
Serine, Ser (S)



Cysteine, Cys (C)

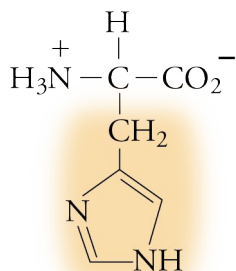


Threonine, Thr (T)

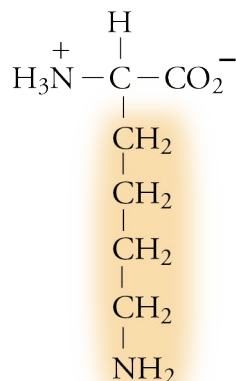


Methionine, Met (M)

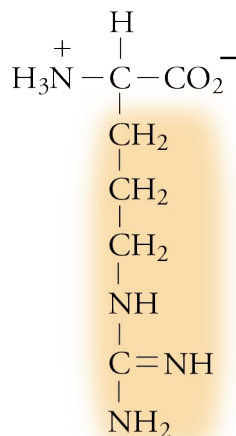
## Basic amino acids



Histidine, His (H)

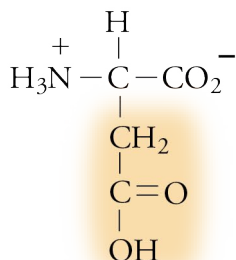


Lysine, Lys (K)

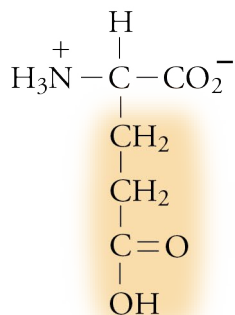


Arginine, Arg (R)

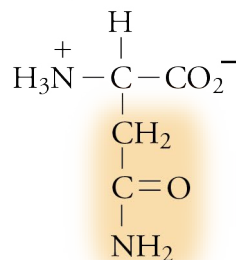
## Acidic amino acids and amino acids with amide functional groups



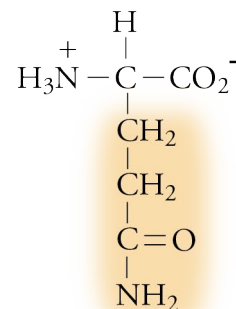
Aspartic acid, Asp (D)



Glutamic acid, Glu (E)



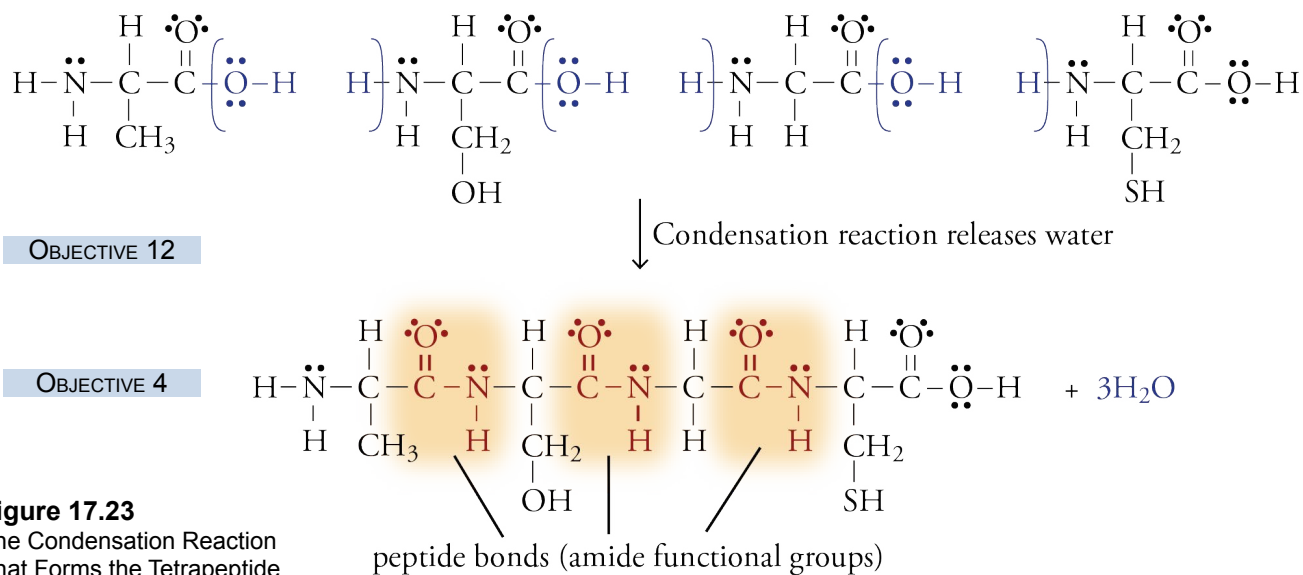
Asparagine, Asn (N)



Glutamine, Gln (Q)

## OBJECTIVE 12

Amino acids are linked together by a **peptide bond**, created when the carboxylic acid group of one amino acid reacts with the amine group of another amino acid to form an amide functional group. The product is called a **peptide**. Although the language used to describe peptides is not consistent among scientists, small peptides are often called oligopeptides, and large peptides are called polypeptides. Figure 17.23 shows how alanine, serine, glycine, and cysteine can be linked to form a structure called a tetrapeptide (a peptide made from four amino acids). Because the reaction that links amino acids produces water as a by-product, it is an example of a **condensation reaction**, a chemical change in which a larger molecule is made from two smaller molecules accompanied by the release of water or another small molecule.



**Figure 17.23**  
The Condensation Reaction  
That Forms the Tetrapeptide  
Ala-Ser-Gly-Cys

## OBJECTIVE 13

All protein molecules are polypeptides. At first glance, many of them look like shapeless blobs of atoms. In fact, each protein has a definite form that is determined by the order of the amino acids in the peptide chain and the interactions between them. To illustrate the general principles of protein structure, let's look at one of the most thoroughly studied of all proteins, a relatively small one called bovine pancreatic trypsin inhibitor (BPTI).

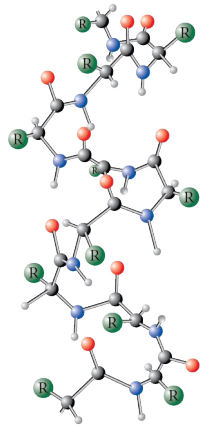
Protein molecules are described in terms of their primary, secondary, and tertiary structures. The **primary structure** of a protein is the linear sequence of its amino acids. The primary structure for BPTI is

Arg-Pro-Asp-Phe-Cys-Leu-Glu-Pro-Pro-Tyr-Thr-Gly-Pro-Cys-Lys-Ala-Arg-Ile-Ile-Arg-Tyr-Phe-Tyr-Asn-Ala-Lys-Ala-Gly-Leu-Cys-Gln-Thr-Phe-Val-Tyr-Gly-Gly-Cys-Arg-Ala-Lys-Arg-Asn-Asn-Phe-Lys-Ser-Ala-Glu-Asp-Cys-Leu-Arg-Thr-Cys-Gly-Gly-Ala

The arrangement of atoms that are close to each other in the polypeptide chain is called the **secondary structure** of the protein. Images of two such arrangements, an  $\alpha$ -helix and a  $\beta$ -sheet, are shown in Figures 17.24 and 17.25.



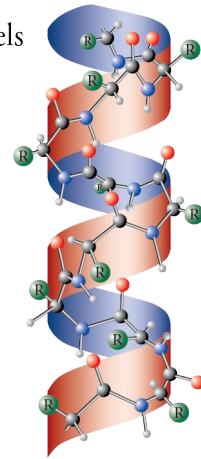
Ball-and-stick model of a portion of the  $\alpha$ -helical secondary structure of a protein molecule



This ribbon model shows the general arrangement of atoms in a portion of the  $\alpha$ -helical secondary structure of a protein molecule.



The two models superimposed

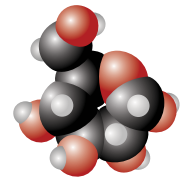
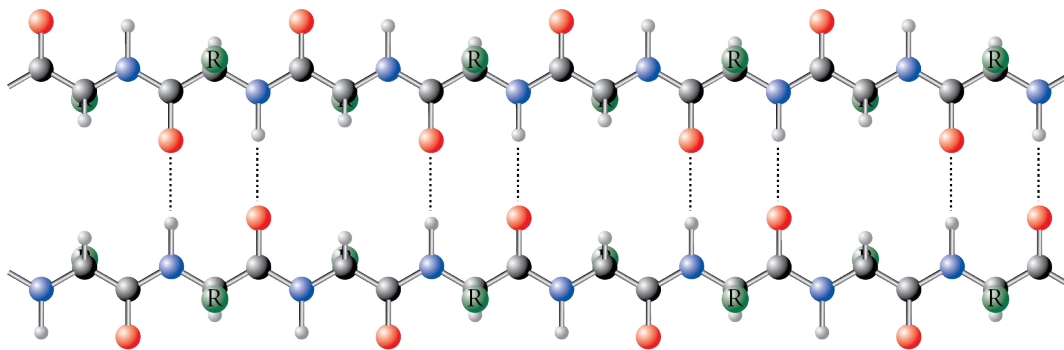


OBJECTIVE 13

**Figure 17.24**  
 $\alpha$ -Helix

OBJECTIVE 13

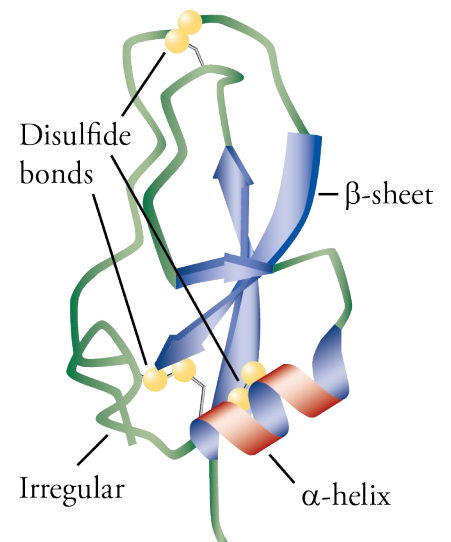
**Figure 17.25**  
 $\beta$ -Sheet



Web  
Molecules

BPTI contains both  $\alpha$ -helix and  $\beta$ -sheet secondary structures, separated by less regular arrangements of amino acids. Because of the complexity of protein molecules, simplified conventions are used in drawing them to clarify their secondary and tertiary structures. Figure 17.26 shows the ribbon convention, in which  $\alpha$ -helices are depicted by coiled ribbons and  $\beta$ -sheets are represented by flat ribbons.

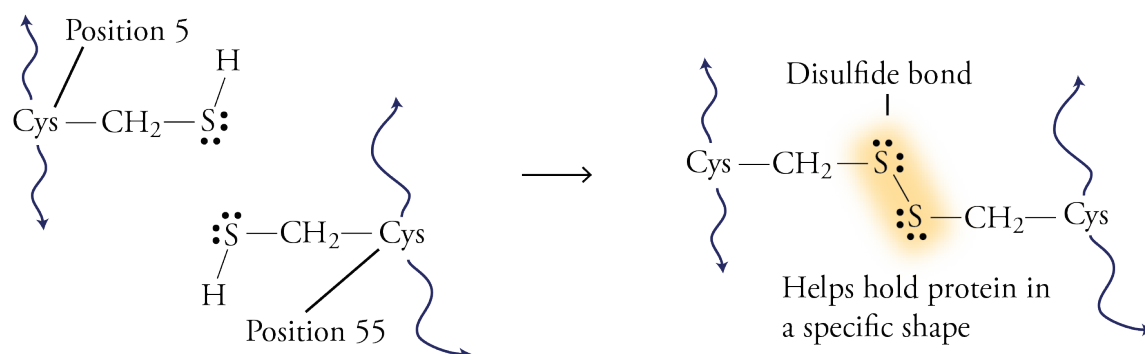
When the long chains of amino acids link to form protein structures, not only do they arrange themselves into secondary structures, but the whole chain also arranges itself into a very specific overall shape called the **tertiary structure** of the protein. The protein chain is held in its tertiary structure by attractions between the side-chains of its amino acids. For example, covalent bonds that form between sulfur atoms in different parts of the chain help create and hold the



**Figure 17.26**  
The Ribbon Structure of the Protein BPTI

OBJECTIVE 14

BPTI molecule's specific shape. These bonds, called **disulfide bonds**, can form between two cysteine amino acids (Figure 17.27).



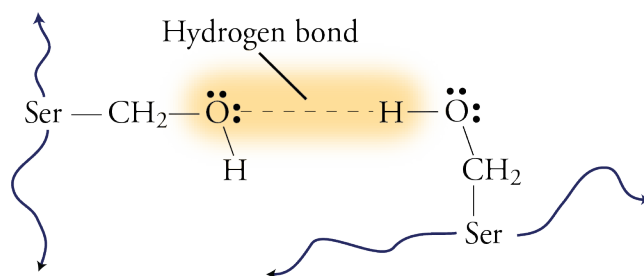
**Figure 17.27**  
Disulfide Bonds Between Cysteine Amino Acid Side-Chains in a Protein Molecule

OBJECTIVE 14

OBJECTIVE 14

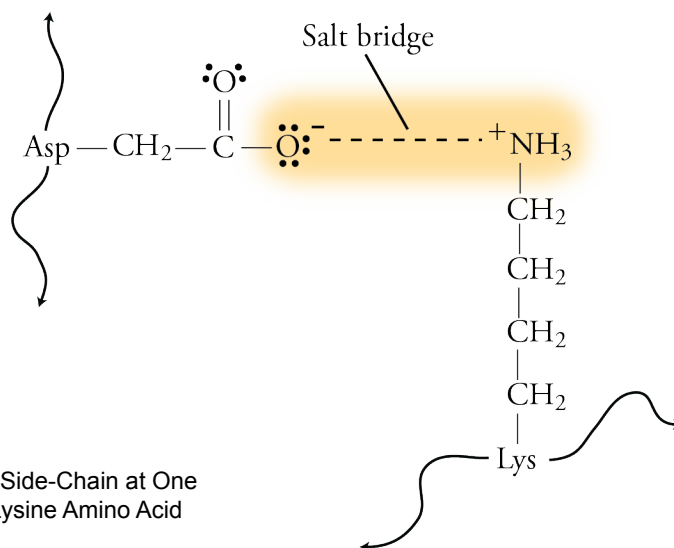
Hydrogen bonds can also help hold protein molecules in their specific tertiary shape. For example, the possibility of hydrogen bonding between their  $-OH$  groups will cause two serine amino acids in a protein chain to be attracted to each other (Figure 17.28).

**Figure 17.28**  
Hydrogen Bonding Between Two Serine Amino Acids in a Protein Molecule



OBJECTIVE 14

The tertiary structure is also determined by the creation of **salt bridges**, which consist of negatively charged side-chains attracted to positively charged side-chains (Figure 17.29).

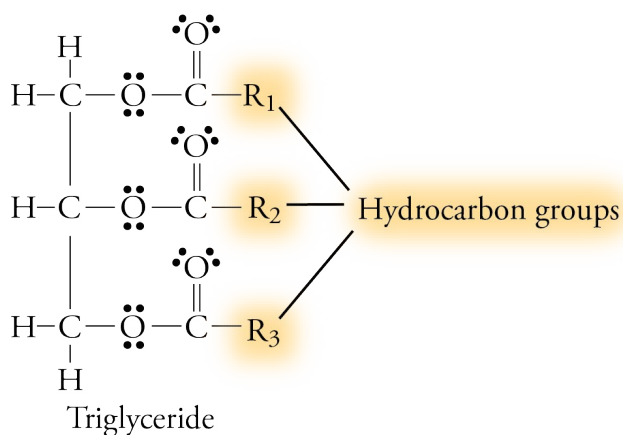


**Figure 17.29**  
Salt Bridge Between an Aspartic Acid Side-Chain at One Position in a Protein Molecule and a Lysine Amino Acid Side-Chain in Another Position

## Fat

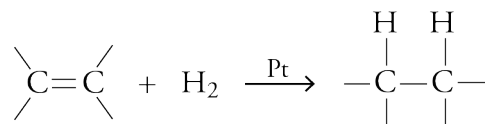
The fat stored in our bodies is our primary long-term energy source. A typical 70-kg human has fuel reserves of about 400,000 kJ in fat, 100,000 kJ in protein (mostly muscle protein), 2500 kJ in glycogen, and 170 kJ in total glucose. One of the reasons why it is more efficient to store energy as fat than as carbohydrate or protein is that fat produces 37 kJ/g, whereas carbohydrate and protein produce only 17 kJ/g.

As you discovered in Section 15.2, animal fats and vegetable oils are made up of **triglycerides**, which have many different structures but the same general design: long-chain hydrocarbon groups attached to a three-carbon backbone.



We saw that the hydrocarbon groups in triglycerides can differ in the length of the carbon chain and in the frequency of double bonds between their carbon atoms. The liquid triglycerides in vegetable oils have more carbon-carbon double bonds than the solid triglycerides in animal fats. The more carbon-carbon double bonds a triglyceride molecule has, the more likely it is to be liquid at room temperature.

A process called **hydrogenation** converts liquid triglycerides to solid triglycerides by adding hydrogen atoms to the double bonds and so converting them to single bonds. For example, the addition of hydrogen in the presence of a platinum catalyst changes corn oil into margarine.



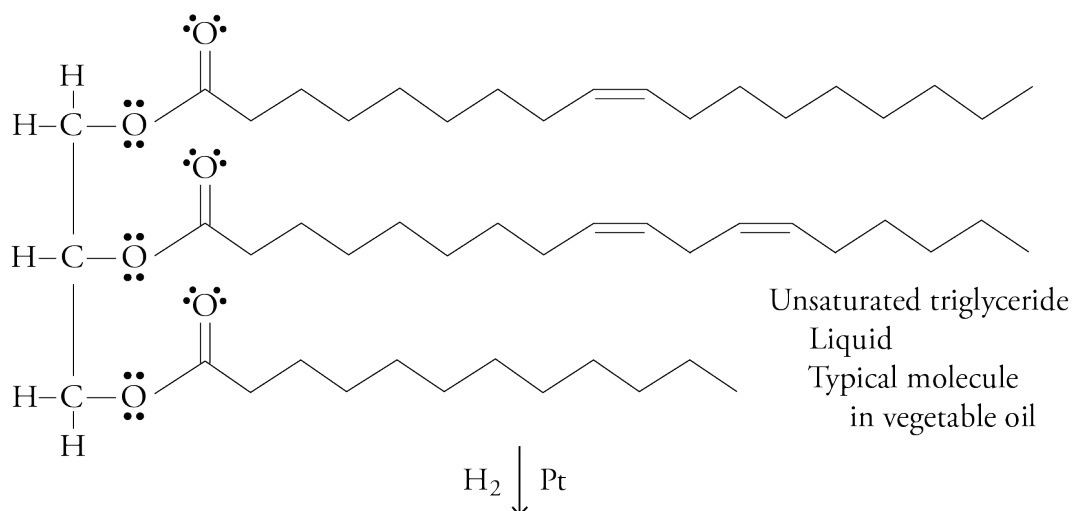
When enough hydrogen atoms are added to a triglyceride to convert all double bonds to single bonds, we call it a **saturated triglyceride** (or fat). It is saturated with hydrogen atoms. A triglyceride that still has one or more carbon-carbon double bonds is an **unsaturated triglyceride**. If enough hydrogen is added to an unsaturated triglyceride to convert some but not all of the carbon-carbon double bonds to single bonds, we say it has been partially hydrogenated. Margarine is often described as being made with partially hydrogenated vegetable oils. There is an example of a hydrogenation reaction on the next page.

OBJECTIVE 15

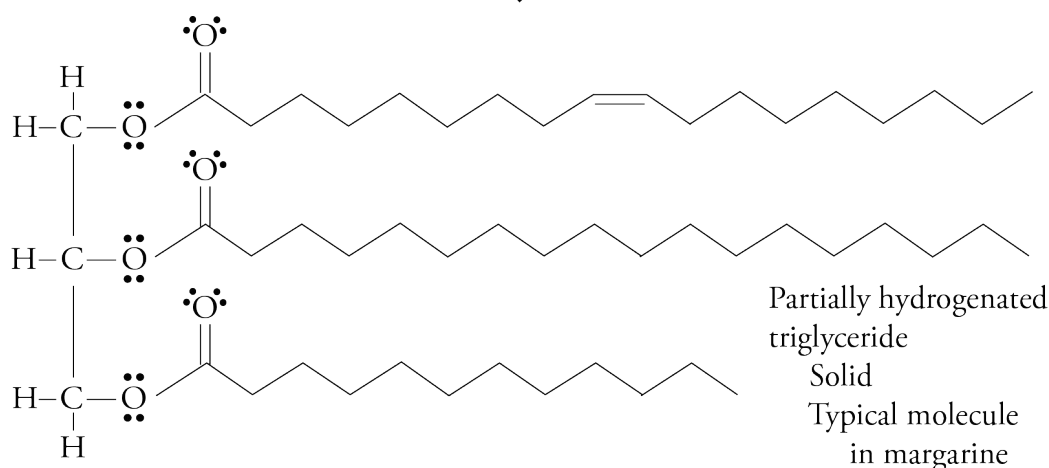
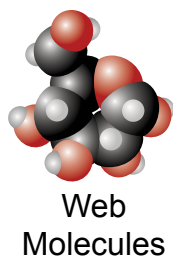
OBJECTIVE 16

OBJECTIVE 17

OBJECTIVE 18



## OBJECTIVE 19



## SPECIAL TOPIC 17.2 Olestra and Low-Fat Potato Chips

Should you eat less fat? Scientists doing medical research think you probably should; they recommend no more than 30% fat in our diets, but the average American diet is estimated to contain 34% fat. So, maybe you're convinced that you should cut down on fatty foods, but you can't imagine watching the Super Bowl without a big bag of chips at your side. The chemists at Proctor & Gamble have been trying to solve your dilemma by developing an edible substance with the rich taste and smooth texture of fat molecules but without the calories. Olestra seems to meet these criteria.

Fat digestion is an enzyme-mediated process that breaks fat molecules into glycerol and fatty acids, which are then able to enter the blood stream. Olestra is a hexa-, hepta-, or octa-ester of fatty acids (derived from vegetable oil, such as soybean oil or cottonseed oil) and sucrose. Because the body contains no digestive enzymes that can convert Olestra's fat-like molecules into their smaller

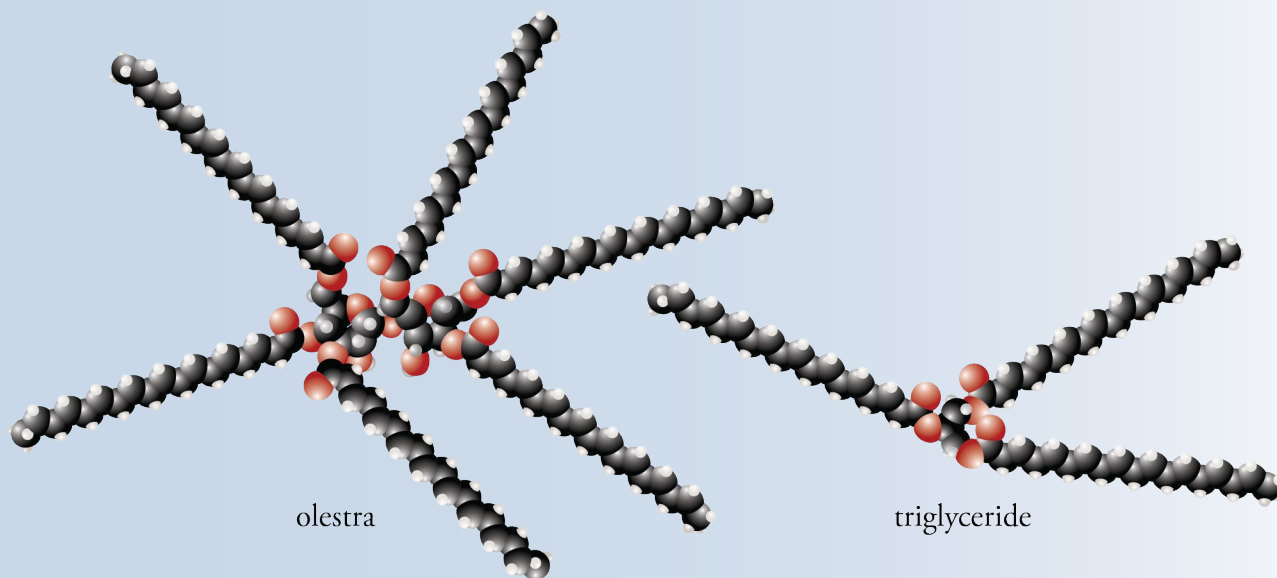
components of sucrose and fatty acids, and because Olestra is too large to enter the bloodstream undigested, the compound passes through our systems unchanged.

Olestra is stable at high temperature, and can be used in fried or baked foods, such as potato chips. A one-ounce serving of potato chips made with olestra has 0 g fat and 70 Cal, comparing favorably with the 10 g fat and 160 Cal of normal chips. But, there are also drawbacks associated with olestra. Studies have shown that it can cause gastrointestinal distress and prevent the adsorption of the fat soluble vitamins (A, D, E, and K) and carotenoids (members of a group of nutrients that includes beta carotene). Because of these findings, foods with olestra originally carried the following warning: "Olestra may cause abdominal cramping and loose stools. Olestra inhibits the adsorption of some vitamins and other nutrients. Vitamins A, D, E, and K have been added." Adding vitamins to foods containing olestra keeps Olestra

from blocking the absorption of the fat-soluble vitamins in our other foods. The decrease in absorption of beta-carotene is only a problem when foods with olestra are eaten along with other foods that are rich in carotene, such as carrots.

Scientists will continue to study the pros and cons

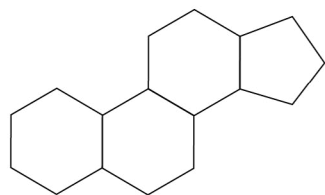
of olestra-containing foods, but in the end, it will be up to you to decide whether the benefits of lower fat, lower calorie food products outweigh the potential problems associated with their consumption.



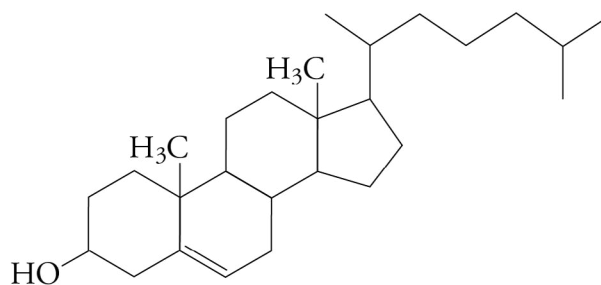
## Steroids

In today's world, many people's first thought when they hear the word steroid is of the controversies over substances banned in sports. In fact, steroids are important hormones produced in our bodies that help control inflammation, regulate our immune system, help maintain salt and water balance, and control the development of sexual characteristics. **Steroids** are derivatives of the four-ring structure below. One important member of this group of biomolecules is cholesterol.

### OBJECTIVE 4



General four-ring structure of steroids

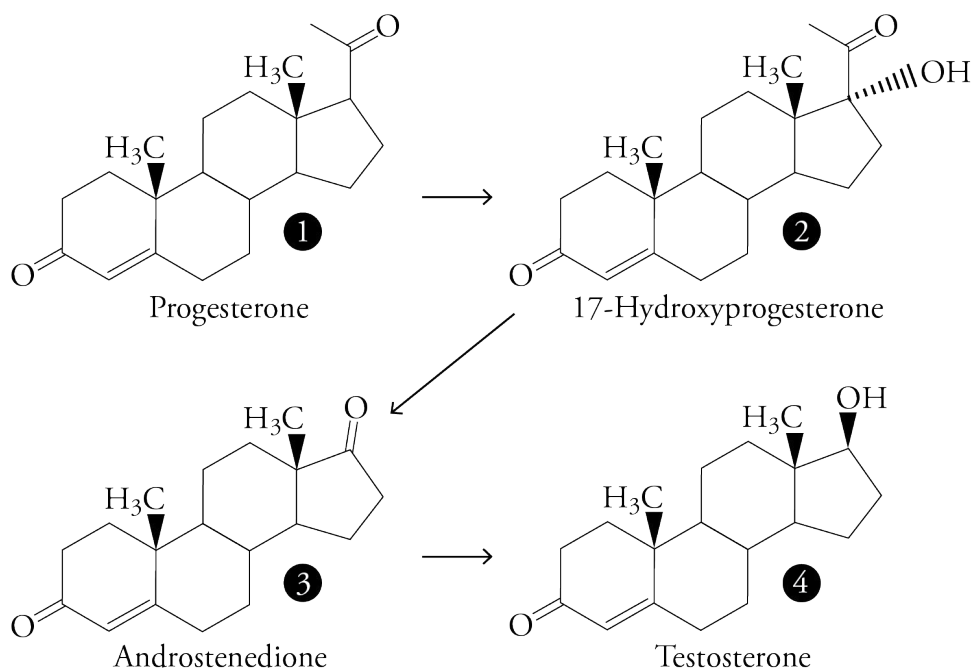
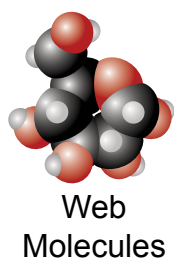


Cholesterol

Because cholesterol plays a role in the development of atherosclerosis, or hardening of the arteries, it too has gotten a bad reputation. The general public is largely unaware that as the starting material for the production of many important body chemicals, including hormones (compounds that help regulate chemical changes in the body),

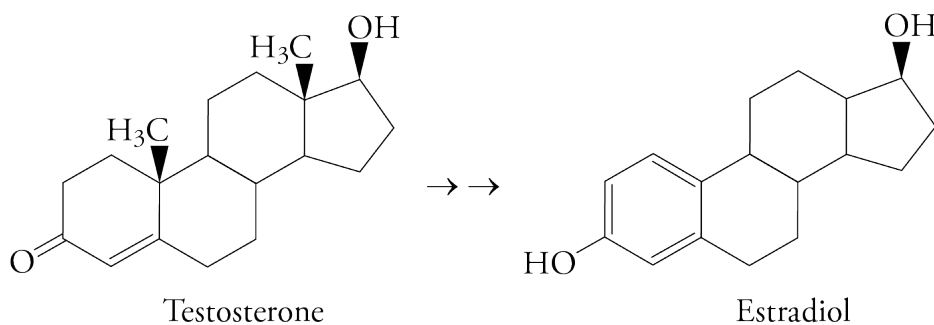
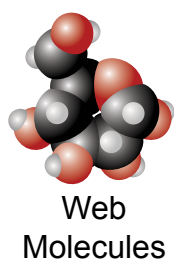
cholesterol is necessary for normal, healthy functioning of our bodies. For example, cholesterol is converted into the hormone progesterone, which is then converted into other hormones, such as the male hormone testosterone (Figure 17.30).

**Figure 17.30**  
Formation of Testosterone from Progesterone



Estradiol, an important female hormone, is synthesized from testosterone. Estradiol and progesterone together regulate the monthly changes in the uterus and ovaries that are described collectively as the menstrual cycle (Figure 17.31).

**Figure 17.31**  
Formation of the Female Sex Hormone Estradiol From Testosterone



## SPECIAL TOPIC 17.3 Harmless Dietary Supplements or Dangerous Drugs?

*Despite the testimonials to muscle size and strength, there is no evidence that andro, creatine or any other substance enhances athletic performances over what could be attained by practice, training and proper nutrition.*

Todd B. Nippoldt, M.D.  
An endocrinologist at the Mayo Clinic

When serious athletes hear of natural substances that build muscles and provide energy, they are bound to wonder whether supplementing their diets with these substances could improve their athletic performance. The 1998 baseball season drew attention to two substances that some ballplayers were believed to be taking at the time: the steroid androstenedione (“andro”) and creatine, a compound found in the muscle tissue of vertebrates.

Should these substances be classified as dietary supplements or as drugs? This is a legal distinction with wide-ranging repercussions. Because both andro and creatine were classified as dietary supplements under the Dietary Supplement and Health Act of 1994, they could be sold over the counter to anyone, without first being subjected to the extensive scientific testing necessary for substances classified as drugs. Before you start seasoning your steaks with andro and creatine, however, several important questions should be answered.

*Are they safe?* Although small amounts of androstenedione and testosterone in the body are essential to good health, introducing larger than normal amounts into one’s system has potentially serious side effects, including gland cancer, hair loss, impotence, and acne. Increased testosterone levels in women can lead to a deeper voice and facial hair.

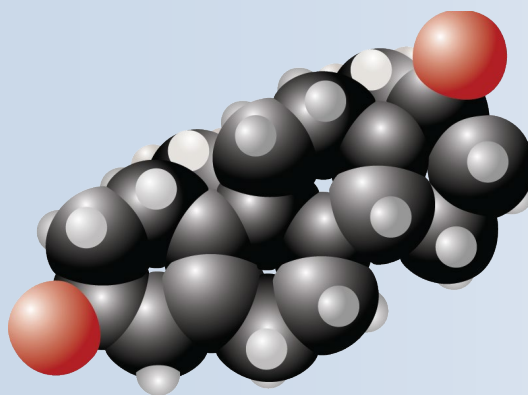
*Are they effective?* It has been found that when a typical

100 mg dose of androstenedione is consumed, all but a small percentage is destroyed in the liver, and what is left boosts testosterone levels only temporarily. It is not clear whether this has a significant effect on muscle building. According to the National Strength and Conditioning Association (a professional society for athletic trainers, sports medicine physicians and researchers, professional coaches, and physical therapists), there is no reliable evidence that andro improves athletic performance.

Research suggests that taking creatine does lead to a small improvement in some physical tasks, but there is still doubt whether supplemental amounts have any significant value. Meat contains creatine. Assuming adequate amounts of meat are eaten, one’s liver will normally produce about 2 g of the substance per day. The creatine is stored in the muscles, but any excess is promptly removed by the kidneys.

*Are they legal?* In 1998, andro was banned in the NFL, Olympics, and NCAA, but it was still permitted in baseball and basketball, which only banned illegal drugs. For this reason, baseball players could take it, but shot putter Randy Barnes, the 1996 Olympic gold medalist and world record holder, was banned from Olympic competition for life for doing so. (Barnes claimed that he was not told about the ban, and he appealed the decision.)

Do andro and creatine make a significant difference in a ballplayer’s ability to hit home runs? Edward R. Laskowski, M.D., co-director of the Sports Medicine Center at the Mayo Clinic in Rochester, Minnesota, says, “[A home run hitter] has all the tools within himself to do what he [does]. If you ask elite athletes in any sport what they did to get to the top, they often break it down to the basics—training, conditioning and practice.”



Androstenedione

## 17.3 Digestion

### OBJECTIVE 20



This food will be digested to form the substances listed in Table 17.3.

Let's go back to that burger, fries, and milkshake again and see what happens when the carbohydrate, protein, and fat molecules they contain are digested. **Digestion** is the process of converting large molecules into small molecules capable of passing into the bloodstream to be carried throughout the body and used for many different purposes. Disaccharides are broken down into monosaccharides (glucose, galactose, and fructose), polysaccharides into glucose, protein into amino acids, and fat into glycerol and fatty acids (Table 17.3).

**Table 17.3** Products of Digestion

### OBJECTIVE 20

Substance in Food	Breakdown Products
Disaccharides (maltose, lactose, sucrose)	Monosaccharides (glucose, galactose, and fructose)
Polysaccharides (starch)	Glucose
Protein	Amino acids
Fats and oils	Glycerol and fatty acids

When you eat a fast food dinner, its digestion begins in a minor way in your mouth. It then passes from your mouth through your esophagus to your stomach, where the first stages of protein digestion turn it into a pasty material called chyme. The chyme then travels to the small intestine, where most of the digestive process takes place. Because the purpose of this chapter is to give just a glimpse of biochemistry rather than a complete description, only protein digestion is described here.

### Digestive Enzymes

The digestion process is regulated by **enzymes**, which not only increase the speed of chemical changes (by huge amounts) but do so at the mild temperatures and, except in the stomach, close to neutral pH inside the body. Table 17.4 lists the sources of some of the more important digestive enzymes, what substance they digest, and the products that result from the digestion.

**Table 17.4** Sources and Activities of Major Digestive Enzymes

Organ	What digests	Enzyme	Products
mouth	starch	amylase	maltose
stomach	protein	pepsin	shorter polypeptides
small intestine	starch	pancreatic amylase	maltose, maltriose, and short polysaccharides
	polypeptides	trypsin, chymotrypsin, carboxypeptidase	amino acids, dipeptides, and tripeptides
	triglycerides	pancreatic lipase	fatty acids and monoglycerides
	maltose	maltase	glucose
	sucrose	sucrase	glucose and fructose
	lactose	lactase	glucose and galactose
	polypeptides	aminopeptidase	amino acids, dipeptides, and tripeptides

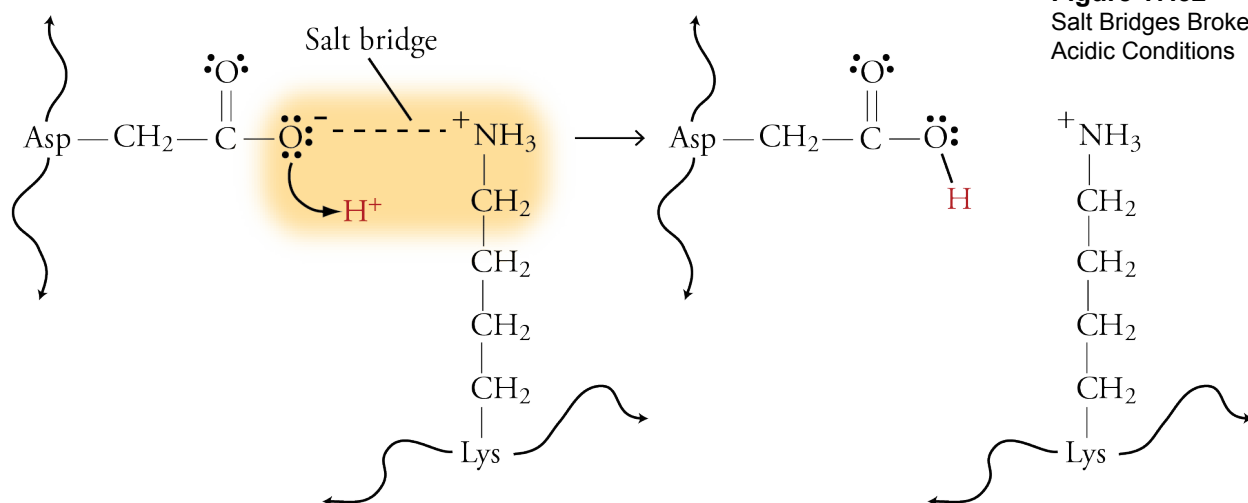


## Digestion of Protein

Certain undigested proteins can move from the digestive tract of babies into their blood (allowing newborns to get antibodies from their mother's first milk), but with rare exceptions, only amino acids (not proteins) move into an adult's bloodstream. For our cells to obtain the raw materials necessary for building the proteins of the human body, the proteins in our food must first be converted into amino acids.

The digestion of proteins begins in the stomach. The acidic conditions there weaken the links that maintain the protein molecules' tertiary structure. This process is called **denaturation**, because the loss of tertiary structure causes a corresponding loss of the protein's "natural" function. One of the reactions responsible for denaturation is shown in Figure 17.32. The  $H^+$  ions in the stomach juices disrupt salt bridges within the protein molecules by binding to the negatively charged aspartic acid side-chains.

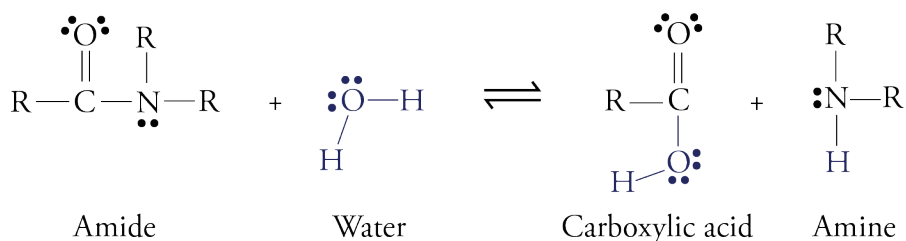
### OBJECTIVE 21



**Figure 17.32**  
Salt Bridges Broken by  
Acidic Conditions

Although an enzyme called pepsin begins to digest protein molecules while they are in our stomach, most of the digestion of protein takes place after the food leaves the stomach and moves into the small intestines. Here enzymes such as trypsin, chymotrypsin, elastase, carboxypeptidase, and aminopeptidase convert protein molecules into amino acids, dipeptides, and tripeptides. The dipeptides and tripeptides are converted to amino acids by other enzymes. Once the amino acids are free, they can move into the blood stream and circulate throughout our body.

In all forms of digestion (whether of proteins, carbohydrates, or fats), larger molecules are broken down into smaller molecules by a reaction with water in which a water molecule is split in two, each part joining a different product molecule. This type of reaction is called **hydrolysis**. Remember that proteins are long chains of amino acids linked together by amide functional groups called peptide bonds. When protein molecules are digested, a series of hydrolysis reactions convert them into separate amino acids.



In the laboratory, the hydrolysis of amides is very slow unless a strong acid catalyst is added to the mixture, yet in the small intestines, where the conditions are essentially neutral rather than acidic, most of the hydrolysis of proteins takes place rather quickly. The reason, as we have seen, is the presence of enzymes.

**OBJECTIVE 22**

For an enzyme-mediated reaction to take place, the reacting molecule or molecules, which are called **substrates**, must fit into a specific section of the enzyme's structure called the **active site**. A frequently used analogy for the relationship of substrate to active site is the way a key must fit into a lock in order to do its job. Each active site has (1) a shape that fits a specific substrate or substrates only, (2) side-chains that attract the enzyme's particular substrate(s), and (3) side-chains specifically positioned to speed the reaction. Therefore, each enzyme will only act on a specific molecule or a specific type of molecule, and in a specific way. For example, chymotrypsin's one enzymatic function is to accelerate the breaking of peptide bonds that link an amino acid that has a nonpolar side-chain, such as phenylalanine, to another amino acid on the interior of polypeptide chains.

You will find a proposed mechanism for how chymotrypsin catalyzes the hydrolysis of certain peptide bonds in protein molecules at the textbook's Web site.

## 17.4 Synthetic Polymers

Political events of the 1930s created an interesting crisis in fashion. Women wanted sheer stockings, but with the growing unrest in the world, manufacturers were having an increasingly difficult time obtaining the silk necessary to make them. Chemistry came to the rescue.



Nylon was designed by scientists to approximate the qualities of silk.

If you were a chemist trying to develop a substitute for silk, your first step would be to find out as much as you could about its chemical structure. Silk is a polyamide (polypeptide), a long chain molecule (polymer) composed of amino acids linked together by amide functional groups (peptide bonds). Silk molecules contain 44% glycine (the simplest of the amino acids, with a hydrogen for its distinguishing side-chain) and 40% alanine (another very simple amino acid, with a  $-\text{CH}_3$  side-chain). Having acquired this information, you might decide to try synthesizing a simple polypeptide of your own.

The next step in your project would be to plan a process for making the new polymer, perhaps using the process of protein formation in living organisms as a guide. We saw in Section 17.1 that polypeptides form in nature when the carboxylic acid group of one amino acid reacts with the amine group of another amino acid to form an amide functional group called a peptide bond. The reason amino acids are able to form long chains in this way is that amino acids are difunctional. Each amino acid possesses both an amine functional group and a carboxylic acid functional group. After two amino acids are linked by a peptide bond, each of them still has either a carboxylic acid group or an amine group free to link to yet another amino acid (Figure 17.23).

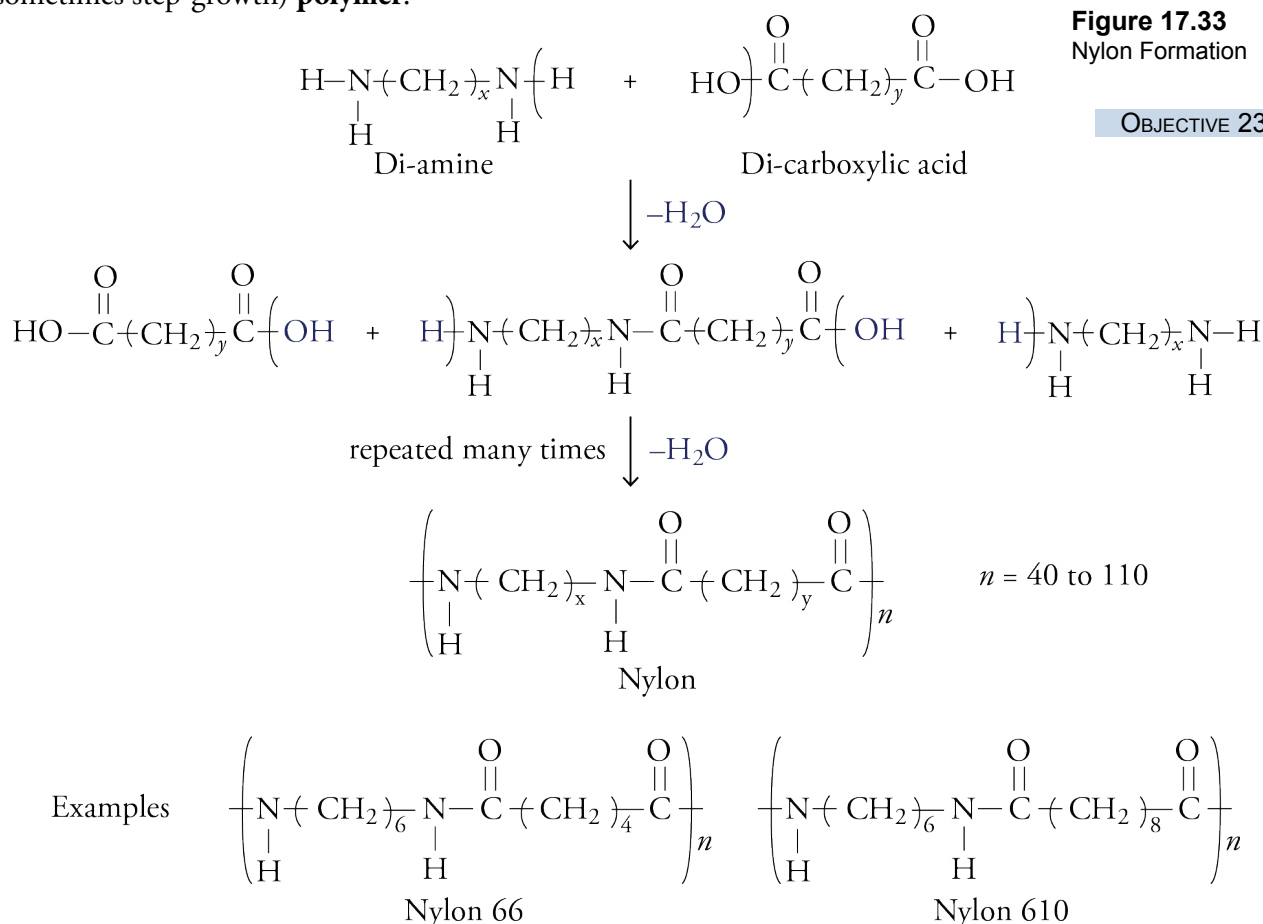
**OBJECTIVE 23**

## Nylon, a Synthetic Polypeptide

W. H. Carothers, working for E.I. Du Pont de Nemours and Company, developed the first synthetic polyamide. He found a way to react adipic acid (a di-carboxylic acid) with hexamethylene diamine (which has two amine functional groups) to form long-chain polyamide molecules called Nylon 66. (The first “6” in the “66” indicates the number of carbon atoms in each portion of the polymer chain that are contributed by the diamine, and the second “6” shows the number of carbon atoms in each portion that are contributed by the di-carboxylic acid.) The reactants are linked together by condensation reactions in which an  $-OH$  group removed from a carboxylic acid functional group combines with a  $-H$  from an amine group to form water, and an amide linkage forms between the reacting molecules (Figure 17.33). When small molecules, such as water, are released in the formation of a polymer, the polymer is called a **condensation** (or sometimes step-growth) **polymer**.



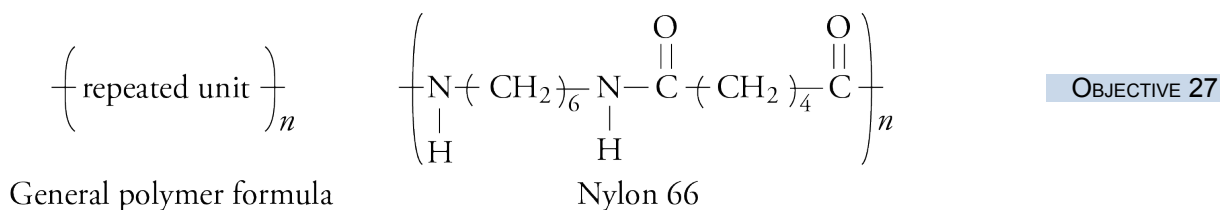
Camping equipment is often made of nylon.



**Figure 17.33**  
Nylon Formation

OBJECTIVE 23

Chemists write chemical formulas for polymers by enclosing the repeating unit in parentheses followed by a subscript  $n$  to indicate that the unit is repeated many times:



OBJECTIVE 27

Nylon 66 was first made in 1935 and went into commercial production in 1940. Its fibers were strong, elastic, abrasion resistant, lustrous, and easy to wash. With these qualities, nylon became more than just a good substitute for silk in stockings. Today it is used in a multitude of products, including carpeting, upholstery fabrics, automobile tires, and turf for athletic fields.

**OBJECTIVE 24**

One of the reasons for nylon's exceptional strength is the attraction between amide functional groups. The higher the percentage of amide functional groups in nylon's polymer structure, the stronger the attraction between the chains. Thus changing the number of carbon atoms in the diamine ( $x$  in Figure 17.33) and in the di-carboxylic acid ( $y$  in Figure 17.33) changes the nylon's properties. For example, Nylon 610, which has four more carbon atoms in its di-carboxylic acid molecules than are found in Nylon 66, is somewhat weaker than Nylon 66 and has a lower melting point. Nylon 610 is used for bristles in paintbrushes.



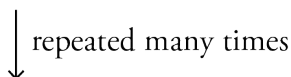
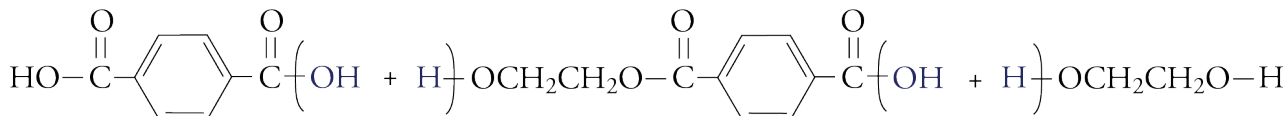
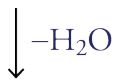
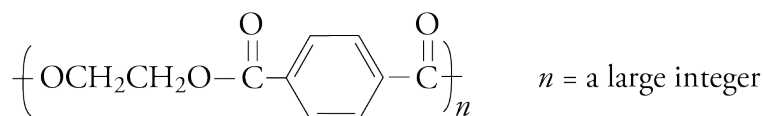
The uniforms worn by baseball players are made of polyester.

**Polyesters**

You've got a big day planned in the city: an afternoon at the ballpark watching your favorite player belt home runs, followed by dinner and disco dancing at a "retro" club called Saturday Night Fever. The player's uniform and your own disco outfit are almost certainly made from polyester, which is a condensation polymer similar to nylon. Polyesters are made from the reaction of a diol (a compound with two alcohol functional groups) with a di-carboxylic acid. Figure 17.34 shows the steps for the formation of poly(ethylene terephthalate) from ethylene glycol and terephthalic acid.

**Figure 17.34**

Polyester Formation

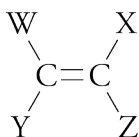
**OBJECTIVE 25****OBJECTIVE 27**

Poly(ethylene terephthalate)

The transparency of polyester makes it a popular choice for photographic film and projection slides. Mylar, which is used to make long-lasting balloons, is a polyester, as is the polymer used for making eyeglass lenses. Polyesters have been used for fabrics that would once have been made from cotton, whose fundamental structure consists of the polymer cellulose. Polyester fibers, such as the fibers of Dacron and Fortrel—made from poly(ethylene terephthalate)—are about three times as strong as cellulose fibers, so polyester fabrics or blends that include polyester last longer than fabrics made from pure cotton. The strength and elasticity of polyesters make them ideal for sports uniforms.

### Addition Polymers

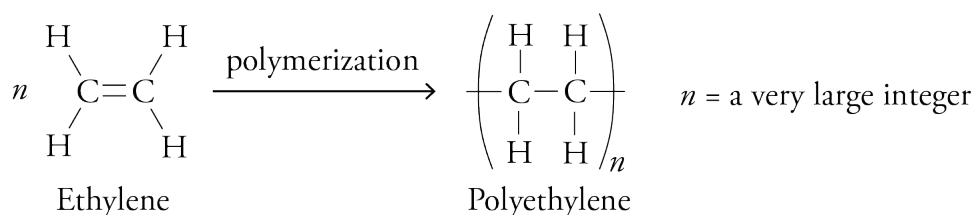
Unlike condensation (step-growth) polymers, which release small molecules, such as water, as they form, the reactions that lead to **addition**, or chain-growth, **polymers** incorporate all of the reactants' atoms into the final product. Addition polymers are usually made from molecules that have the following general structure:



Different W, X, Y, and Z groups distinguish one addition polymer from another.

Visit the text's Web site to see one way in which addition polymers can be made.

If all of the atoms attached to the carbons of the monomer's double bond are hydrogen atoms, the initial reactant is ethylene, and the polymer it forms is polyethylene.



Polyethylene molecules can be made using different techniques. One process leads to branches that keep the molecules from fitting closely together. Other techniques have been developed to make polyethylene molecules with very few branches. These straight-chain molecules fit together more efficiently, yielding a high-density polyethylene, HDPE, that is more opaque, harder, and stronger than the low-density polyethylene, LDPE. HDPE is used for containers, such as milk bottles, and LDPE is used for filmier products, such as sandwich bags.

Table 17.5 shows other addition polymers that can be made using monomers with different groups attached to the carbons in the monomer's double bond.

Table 17.5 Addition (Chain-Growth) Polymers

OBJECTIVE 27

Initial reactant	Polymer	Examples of uses
$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C}=\text{C} \\ & / & \diagdown \\ \text{H} & & \text{H} \end{array}$ Ethylene	$\left( \begin{array}{c} \text{H} & \text{H} \\   &   \\ -\text{C} & - & \text{C}- \\   &   \\ \text{H} & \text{H} \end{array} \right)_n$ Polyethylene	packaging, beverage containers, food containers, toys, detergent bottles, plastic buckets, mixing bowls, oil bottles, plastic bags, drapes, squeeze bottles, wire, and cable insulation
$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C}=\text{C} \\ & / & \diagdown \\ \text{H} & & \text{CH}_3 \end{array}$ Propylene	$\left( \begin{array}{c} \text{H} & \text{H} \\   &   \\ -\text{C} & - & \text{C}- \\   &   \\ \text{H} & \text{CH}_3 \end{array} \right)_n$ Polypropylene	clothing, home furnishings, indoor-outdoor carpeting, rope, automobile interior trim, battery cases, margarine and yogurt containers, grocery bags, caps for containers, carpet fiber, food wrap, plastic chairs, and luggage
$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C}=\text{C} \\ & / & \diagdown \\ \text{H} & & \text{Cl} \end{array}$ Vinyl chloride	$\left( \begin{array}{c} \text{H} & \text{H} \\   &   \\ -\text{C} & - & \text{C}- \\   &   \\ \text{H} & \text{Cl} \end{array} \right)_n$ Poly(vinyl chloride) or PVC	“vinyl” seats in automobiles, “vinyl” siding for houses, rigid pipes, food wrap, vegetable oil bottles, blister packaging, rain coats, shower curtains, and flooring
$\begin{array}{c} \text{H} & & \text{H} \\ & \diagdown & / \\ & \text{C}=\text{C} \\ & / & \diagdown \\ \text{H} & & \text{C}_6\text{H}_5 \end{array}$ Styrene	$\left( \begin{array}{c} \text{H} & \text{H} \\   &   \\ -\text{C} & - & \text{C}- \\   &   \\ \text{H} & \text{C}_6\text{H}_5 \end{array} \right)_n$ Polystyrene	foam insulation and packing (Styrofoam <sup>®</sup> ), plastic utensils, rigid, transparent salad containers, clothes hangers, foam cups, and plates

## SPECIAL TOPIC 17.4 Recycling Synthetic Polymers

You finish off the last of the milk. What are you going to do with the empty bottle? If you toss it into the trash, it will almost certainly go into a landfill, taking up space and serving no useful purpose. If you put it in the recycle bin, it's likely to be melted down to produce something new.








Between 50 and 60 billion pounds of synthetic polymers are manufactured each year in the United States—over 200 pounds per person. A large percentage of these polymers are tossed into our landfills after use. This represents a serious waste of precious raw materials (the petroleum products from which synthetic polymers are made), and exacerbates concerns that the landfills are quickly filling up. These factors give the recycling of polymers a high priority among our nation's concerns.

Some synthetic polymers can be recycled and some cannot. So-called thermoplastic polymers, usually composed of linear or only slightly branched molecules, can be heated and formed and then reheated and reformed. Therefore, they can be recycled. On the other hand, thermosetting polymers, which consist of molecules with extensive three-dimensional cross-linking, decompose when heated, so they cannot be reheated and reformed. This makes them more difficult to recycle.

In 1988, the Plastic Bottling Institute suggested a system in which numbers embossed on objects made of polymers tell the recycling companies what type of polymer was used in the object's construction (Table 17.6).

**Table 17.6** Recyclable Thermoplastics

OBJECTIVE 28

Symbol and Abbreviation	Name of Polymer	Examples of Uses for Virgin Polymer	Examples of Uses for Recycled Polymer
 1 PET	poly(ethylene terephthalate)	beverage containers, boil in food pouches	detergent bottles, carpet fibers, fleece jackets
 2 HDPE	high density polyethylene	milk bottles, detergent bottles, mixing bowls, toys, plastic bags	compost bins, detergent bottles, curbside recycling bins
 3 PVC	poly(vinyl chloride)	food wrap, vegetable oil bottles, blister packaging, plastic pipes	detergent bottles, tiles, plumbing pipe fittings
 4 LDPE	low density polyethylene	shrink-wrap, plastic sandwich bags, squeeze bottles	films for industry and general packaging
 5 PP	polypropylene	yogurt containers, grocery bags, carpet fiber, food wrap, luggage	compost bins, curbside recycling bins
 6 PS	polystyrene	plastic utensils, clothes hangers, foam cups and plates	coat hangers, office accessories, video/CD boxes
 7 OTHER	includes nylon	other	-----

**Biochemistry** The chemistry of biological systems.

**Alkanes** Hydrocarbons (compounds composed of carbon and hydrogen) in which all of the carbon-carbon bonds are single bonds.

**Alkenes** Hydrocarbons that have one or more carbon-carbon double bonds.

**Functional group** A small section of an organic molecule that to a large extent determines the chemical and physical characteristics of the molecule.

**Alkynes** Hydrocarbons that have one or more carbon-carbon triple bonds.

**Arenes or Aromatics** Compounds that contain the benzene ring.

**Alcohols** Compounds with one or more  $-OH$  groups attached to a hydrocarbon group.

**Carboxylic acids** Compounds that have a hydrogen atom or a hydrocarbon group connected to a  $-COOH$  (or  $-CO_2H$ ) group.

**Ethers** Compounds with two hydrocarbon groups surrounding an oxygen atom.

**Aldehydes** Compounds that have a hydrogen atom or a hydrocarbon group connected to a  $-CHO$  group.

**Ketones** Compounds that have the  $-CO-$  functional group surrounded by hydrocarbon groups.

**Esters** Compounds that have the following general formula,  $RCO_2R'$ , where R can be a hydrogen atom or a hydrocarbon group and  $R'$  is a hydrocarbon group.

**Amines** Compounds with the general formula  $R_3N$ , in which R represents a hydrogen atom or a hydrocarbon group (and at least one R group being a hydrocarbon group).

**Amides** Compounds with the general formula  $RCONR$ , in which each R represents hydrogen atoms or hydrocarbon groups.

**Carbohydrates** Sugar, starch, and cellulose. Also called saccharides.

**Saccharides** Sugar, starch, and cellulose. Also called carbohydrates.

**Monosaccharides** Sugar molecules with one saccharide unit.

**Disaccharides** Sugar molecules composed of two monosaccharide units.

**Polysaccharides** Molecules with many saccharide units.

**Polymer** A large molecule composed of repeating units.

**Monomer** The repeating unit in a polymer.

**Protein** Natural polypeptides.

**Amino acid** The monomer that forms the protein polymers. They contain an amine functional group and a carboxylic acid group separated by a carbon.

**Peptide bond** An amide functional group that forms when the carboxylic acid group on one amino acid reacts with the amine group of another amino acid.

**Peptide** A substance that contains two or more amino acids linked together by peptide bonds.

**Condensation reaction** A chemical reaction in which two substances combine to form a larger molecule with the release of a small molecule, such as water.

**Primary structure of proteins** The sequence of amino acids in a protein molecule.

**Secondary protein structure** The arrangement of atoms that are close to each other in a polypeptide chain. Examples of secondary structures are  $\alpha$ -helix and  $\beta$ -sheet.

**Tertiary protein structure** The overall arrangement of atoms in a protein molecule.

**Disulfide bond** A covalent bond between two sulfur atoms on cysteine amino acids in a protein structure.

**Salt bridge** A link in a protein structure between a negatively charged side-chain and a positively charged side-chain.

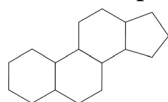
**Triglyceride** A compound with three hydrocarbon groups attached to a three carbon backbone by ester functional groups.

**Hydrogenation** A process by which hydrogen is added to an unsaturated triglyceride to convert double bonds to single bonds. This can be done by combining the unsaturated triglyceride with hydrogen gas and a platinum catalyst.

**Saturated triglyceride** A triglyceride with single bonds between all of the carbon atoms.

**Unsaturated triglyceride** A triglyceride that has one or more carbon-carbon double bonds.

**Steroids** Compounds containing the four-ring structure below.



**Digestion** The process of converting large molecules into small molecules that can move into the blood stream to be carried throughout the body.

**Enzyme** A naturally occurring catalyst.

**Denature** To change the tertiary structure of a protein, causing it to lose its natural function.

**Hydrolysis** A chemical reaction in which larger molecules are broken down into smaller molecules by a reaction with water in which a water molecule is split in two, each part joining a different product molecule.

**Substrate** A molecule that an enzyme causes to react.



**Active site** A specific section of the protein structure of an enzyme in which the substrate fits and reacts.

**Condensation (or step-growth) polymer** A polymer formed in a reaction that releases small molecules, such as water. This category includes nylon and polyester.

**Addition (or chain-growth) polymer** A polymer that contains all of the atoms of the original reactant in its structure. This category includes polyethylene, polypropylene, and poly(vinyl chloride).

You can test yourself on the glossary terms at the textbook's Web site.

The goal of this chapter is to teach you to do the following.

1. Define all of the terms in the Chapter Glossary.

### Section 17.1 Organic Compounds

2. Given a Lewis structure of an organic molecule, draw its condensed formula and line drawing.
3. Given a Lewis structure, a condensed formula, or a line drawing for an organic compound, identify it as representing an alkane, alkene, alkyne, arene (aromatic), alcohol, carboxylic acid, ether, aldehyde, ketone, ester, amine, or amide.

### Section 17.2 Important Substances in Food

4. Given a structure for a biomolecule, identify it as a carbohydrate, amino acid, peptide, triglyceride, or steroid.
5. Given a structure for a carbohydrate molecule, identify it as a monosaccharide, disaccharide, or polysaccharide.
6. Describe the general differences between glucose, galactose, and fructose.
7. Identify the saccharide units that form the disaccharides maltose, lactose, and sucrose.
8. Describe the similarities and differences between amylose, amylopectin, glycogen, and cellulose.
9. Explain why starch can be digested in our digestive tract and why cellulose cannot.
10. Describe the general structure of amino acids.
11. Explain why amino acid molecules in our bodies usually have a positive end and a negative end.
12. Describe how amino acids are linked to form peptides.
13. Identify descriptions of the primary, secondary, and tertiary structure of proteins.
14. Describe how disulfide bonds, hydrogen bonds, and salt bridges help hold protein molecules together in specific tertiary structures.
15. Explain why it is more efficient to store energy in the body as fat rather than carbohydrate or protein.
16. Write or identify a description of the general structure of a triglyceride molecule.
17. Given the chemical formulas for two triglycerides with a different number of carbon-carbon double bonds, identify the one that is more likely to be a solid at room temperature and which one is more likely to be a liquid.
18. Given the chemical formula for a triglyceride, identify it as saturated or unsaturated.

19. Given the chemical formula for an unsaturated triglyceride, draw the structure for the product of its complete hydrogenation.

### Section 17.3 Digestion

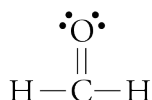
20. Identify the digestion products of disaccharides, polysaccharides, protein, and triglycerides.
21. Describe how the digestion of protein molecules is facilitated by changes in the stomach.
22. Explain why each enzyme only acts on a specific molecule or a specific type of molecule.

### Section 17.4 Synthetic Polymers

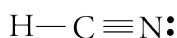
23. Describe how Nylon 66 is made.
24. Explain why Nylon 66 is stronger than Nylon 610.
25. Describe how polyesters are made.
26. Describe the similarities and differences between the molecular structures of low-density polyethylene (LDPE) and high-density polyethylene (HDPE).
27. Given a structure for a polymer, identify it as representing nylon, polyester, polyethylene, poly(vinyl chloride), polypropylene, or polystyrene.
28. Given the recycling code for an object, identify the polymer used to make the object.

## Review Questions

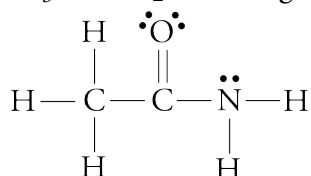
1. Draw a Lewis structure, a geometric sketch, a ball-and-stick model, and a space-filling model for methane,  $\text{CH}_4$ .
2. Draw a Lewis structure, a geometric sketch, a ball-and-stick model, and a space-filling model for ammonia,  $\text{NH}_3$ .
3. Draw a Lewis structure, a geometric sketch, a ball-and-stick model, and a space-filling model for water,  $\text{H}_2\text{O}$ .
4. Draw a Lewis structure, a geometric sketch, a ball-and-stick model, and a space-filling model for methanol,  $\text{CH}_3\text{OH}$ .
5. The following Lewis structure represents a molecule of formaldehyde,  $\text{CH}_2\text{O}$ . Draw a geometric sketch, a ball-and-stick model, and a space-filling model for this molecule.



6. The following Lewis structure represents a molecule of hydrogen cyanide,  $\text{HCN}$ . Draw a geometric sketch, a ball-and-stick model, and a space-filling model for this molecule.



7. The following Lewis structure represents a molecule of ethanamide,  $\text{CH}_3\text{CONH}_2$ . Draw a geometric sketch for this molecule.



Complete the following statements by writing one of these words or phrases in each blank.

17 kJ/g	large
37 kJ/g	linear sequence
acidic	liver
active site	long-term
addition	monomers
amide	monosaccharide
amino acids	monosaccharides
amylopectin	muscle cells
amylose	<i>n</i>
benzene ring	-OH
carbon-carbon	overall shape
cellulose	peptide
cholesterol	parentheses
close to each other	partially
condensation	polysaccharides
denaturation	protein
diol	proteins in our food
disaccharides	repeating units
double bonds	shape
energy	single
fatty acids	single bonds
fructose	small
galactose	small section
glucose	split in two
glucose units	starches
glycerol	step-growth
glycogen	substrates
hydrocarbon groups	sugars
hydrocarbons	water
hydrogenation	

8. Hydrocarbons (compounds composed of carbon and hydrogen) in which all of the carbon-carbon bonds are \_\_\_\_\_ bonds are called alkanes.
9. Hydrocarbons that have one or more \_\_\_\_\_ double bonds are called alkenes.
10. When a(n) \_\_\_\_\_ of an organic molecule is largely responsible for the molecule's chemical and physical characteristics, that section is called a functional group.
11. \_\_\_\_\_ that have one or more carbon-carbon triple bonds are called alkynes.
12. Compounds that contain the \_\_\_\_\_ are called arenes or aromatics.

13. Alcohols are compounds with one or more \_\_\_\_\_ groups attached to a hydrocarbon group, that is, to a group consisting of only carbon and hydrogen atoms.
14. Ethers consist of two \_\_\_\_\_ surrounding an oxygen atom.
15. Carbohydrate is a general name for \_\_\_\_\_, \_\_\_\_\_, and cellulose.
16. Sugars are monosaccharides and \_\_\_\_\_. Starches and cellulose are \_\_\_\_\_.
17. Disaccharides are composed of two \_\_\_\_\_ units.
18. Maltose is a disaccharide consisting of two \_\_\_\_\_ units.
19. Lactose, or milk sugar, is a disaccharide consisting of \_\_\_\_\_ and glucose.
20. Sucrose is a disaccharide that contains glucose and \_\_\_\_\_.
21. The most common polysaccharides are starch, \_\_\_\_\_ (sometimes called animal starch), and cellulose. All of these are composed of repeating \_\_\_\_\_, but they differ in the way the units are connected.
22. Almost every kind of plant cell has \_\_\_\_\_ stored in the form of starch. Starch itself has two general forms, \_\_\_\_\_ and \_\_\_\_\_.
23. Glycogen molecules are stored in \_\_\_\_\_ and \_\_\_\_\_ of animals, where they can be converted into glucose molecules and be used as a source of energy.
24. All the polysaccharides are polymers, a general name for large molecules composed of \_\_\_\_\_, called monomers.
25. Our digestive enzymes are able to break the linkages in starch to release energy producing glucose, but they are unable to liberate glucose molecules from \_\_\_\_\_ because they cannot break the linkages there.
26. Protein molecules are polymers composed of \_\_\_\_\_ called \_\_\_\_\_.
27. Amino acids are linked together by a(n) \_\_\_\_\_ bond, created when the carboxylic acid group of one amino acid reacts with the amine group of another amino acid to form a(n) \_\_\_\_\_ functional group.
28. Condensation is a chemical reaction in which two substances combine to form a larger molecule with the release of a small molecule, such as \_\_\_\_\_.
29. The primary structure of a protein is the \_\_\_\_\_ of its amino acids.
30. The arrangement of atoms that are \_\_\_\_\_ in the polypeptide chain is called the secondary structure of the protein.
31. The tertiary structure of a protein is its very specific \_\_\_\_\_.
32. The fat stored in our bodies is our primary \_\_\_\_\_ energy source.
33. One of the reasons why it is more efficient to store energy as fat than as carbohydrate or protein is that fat produces \_\_\_\_\_, whereas carbohydrate and protein produce only \_\_\_\_\_.
34. A process called \_\_\_\_\_ converts liquid triglycerides to solid triglycerides by adding hydrogen atoms to the double bonds and so converting them to single bonds.
35. When enough hydrogen atoms are added to a triglyceride to convert all double bonds to \_\_\_\_\_, we call it a saturated triglyceride (or fat). It is saturated with hydrogen atoms.

36. A triglyceride that has one or more carbon-carbon \_\_\_\_\_ is an unsaturated triglyceride.
37. If enough hydrogen is added to an unsaturated triglyceride to convert some but not all of the carbon-carbon double bonds to single bonds, we say it has been \_\_\_\_\_ hydrogenated.
38. As the starting material for the production of many important body chemicals, including hormones (compounds that help regulate chemical changes in the body), the steroid \_\_\_\_\_ is necessary for normal, healthy functioning of our bodies.
39. Digestion is the process of converting \_\_\_\_\_ molecules into \_\_\_\_\_ molecules capable of passing into the bloodstream to be carried throughout the body and used for many different purposes.
40. In digestion, disaccharides are broken down into \_\_\_\_\_ (glucose, galactose, and fructose), polysaccharides into glucose, \_\_\_\_\_ into amino acids, and fat into \_\_\_\_\_ and \_\_\_\_\_.
41. For our cells to obtain the raw materials necessary for building the proteins of the human body, the \_\_\_\_\_ must first be converted into amino acids.
42. The digestion of proteins begins in the stomach. The \_\_\_\_\_ conditions there weaken the links that maintain the protein molecules' tertiary structure. This process is called \_\_\_\_\_, because the loss of tertiary structure causes a corresponding loss of the protein's "natural" function.
43. In all forms of digestion (whether of proteins, carbohydrates, or fats), larger molecules are broken down into smaller molecules by a reaction with water in which a water molecule is \_\_\_\_\_, each part joining a different product molecule. This type of reaction is called hydrolysis.
44. For an enzyme-mediated reaction to take place, the reacting molecule or molecules, which are called \_\_\_\_\_, must fit into a specific section of the enzyme's structure called the \_\_\_\_\_. A frequently used analogy for the relationship of substrate to active site is the way a key must fit into a lock in order to do its job. Each active site has (1) a(n) \_\_\_\_\_ that fits a specific substrate or substrates only, (2) side-chains that attract the enzyme's particular substrate(s), and (3) side-chains specifically positioned to speed the reaction.
45. The reactants that form nylon are linked together by \_\_\_\_\_ reactions in which an  $-OH$  group removed from a carboxylic functional group combines with a  $-H$  from an amine group to form water, and an amide linkage forms between the reacting molecules.
46. When small molecules, such as water, are released in the formation of a polymer, the polymer is called a condensation (or sometimes \_\_\_\_\_) polymer.
47. Chemists write chemical formulas for polymers by enclosing the repeating unit in \_\_\_\_\_ followed by a subscript \_\_\_\_\_ to indicate that the unit is repeated many times.
48. Polyesters are made from the reaction of a(n) \_\_\_\_\_ (a compound with two alcohol functional groups) with a di-carboxylic acid.
49. The reactions that lead to \_\_\_\_\_, or chain-growth, polymers incorporate all of the reactants' atoms into the final product.

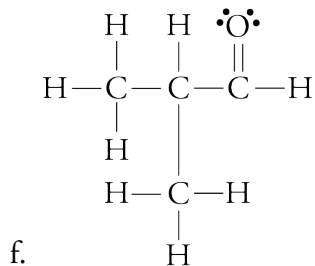
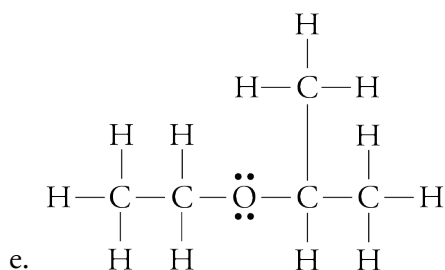
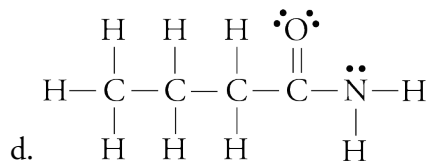
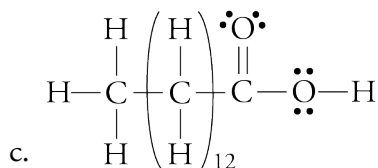
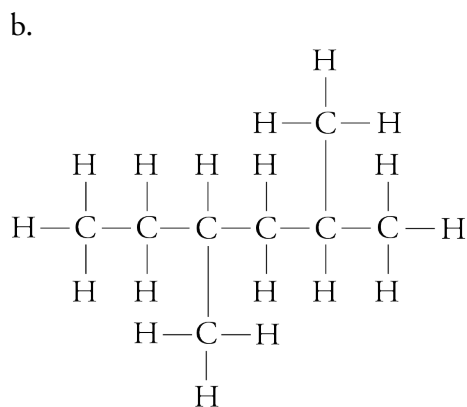
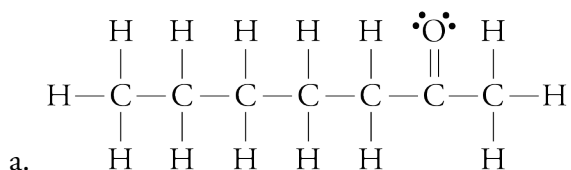
## Chapter Problems

### Section 17.1 Organic Compounds

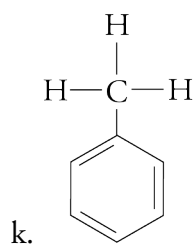
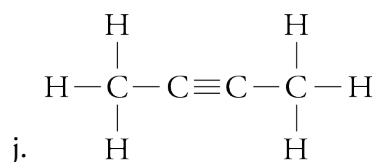
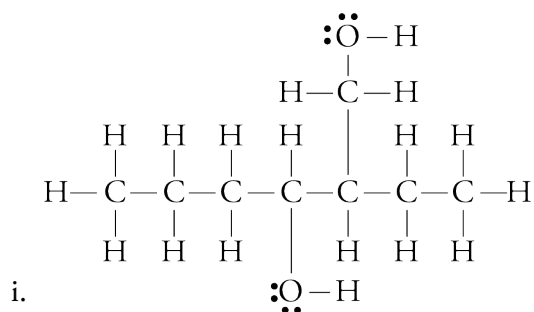
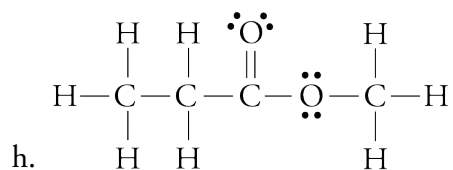
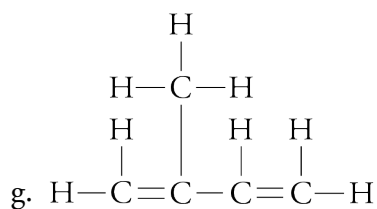
50. Classify each of the following as organic or inorganic (not organic) compounds.
- sodium chloride, NaCl, in table salt
  - hexane, C<sub>6</sub>H<sub>14</sub>, in gasoline
  - ethyl butanoate, CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CO<sub>2</sub>CH<sub>2</sub>CH<sub>3</sub>, in a pineapple
  - water, H<sub>2</sub>O, in your body
51. Classify each of the following as organic or inorganic (not organic) compounds.
- an oil molecule, C<sub>57</sub>H<sub>102</sub>O<sub>6</sub>, in corn oil
  - silicon dioxide, SiO<sub>2</sub>, in beach sand
  - aluminum oxide, Al<sub>2</sub>O<sub>3</sub>, in a ruby
  - sucrose, C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>, in a piece of hard candy

#### OBJECTIVE 3

52. Identify each of these Lewis structures as representing either an alkane, alkene, alkyne, arene (aromatic), alcohol, carboxylic acid, aldehyde, ketone, ether, ester, amine, or amide.

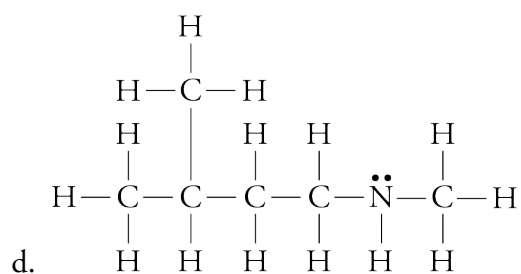
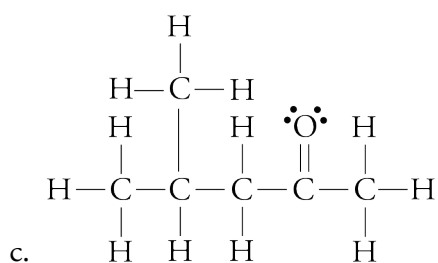
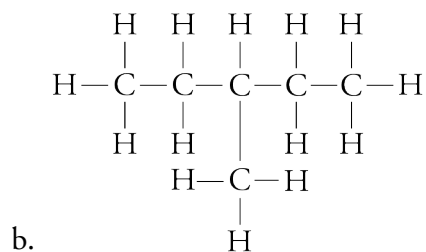
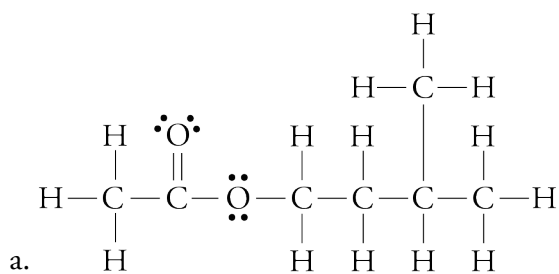


52. (continued)

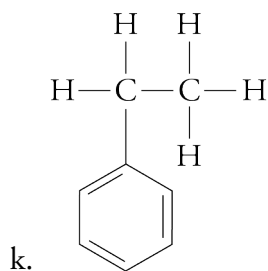
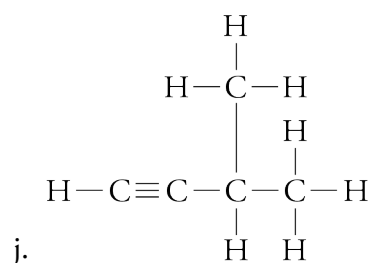
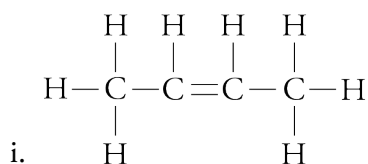
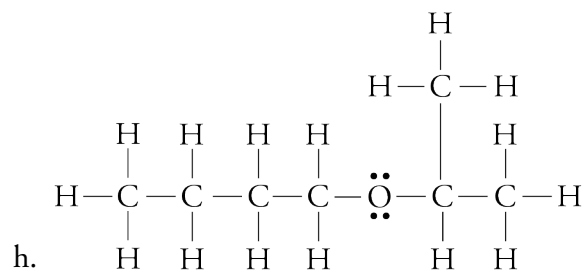
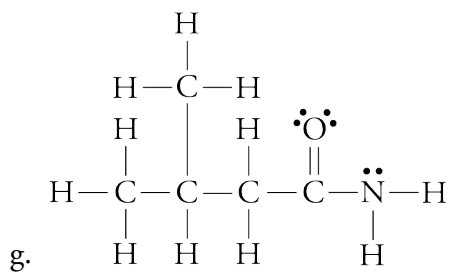
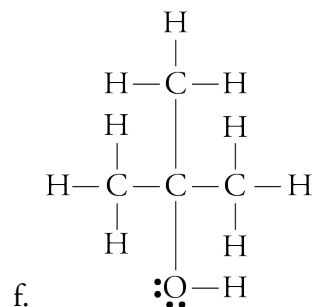
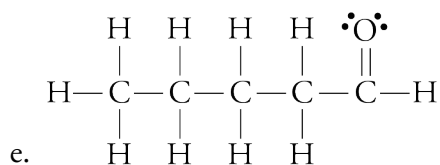


53. Identify each of these Lewis structures as representing either an alkane, alkene, alkyne, arene (aromatic), alcohol, carboxylic acid, aldehyde, ketone, ether, ester, amine, or amide.

OBJECTIVE 3



53. (continued)



## OBJECTIVE 2

54. Write condensed chemical formulas to represent the Lewis structures in parts (a) through (j) of problem 52. (For example, 2-propanol can be described as  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ .)

## OBJECTIVE 2

55. Write condensed chemical formulas to represent the Lewis structures in parts (a) through (j) of problem 53. (For example, 2-propanol can be described as  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ .)

## OBJECTIVE 2

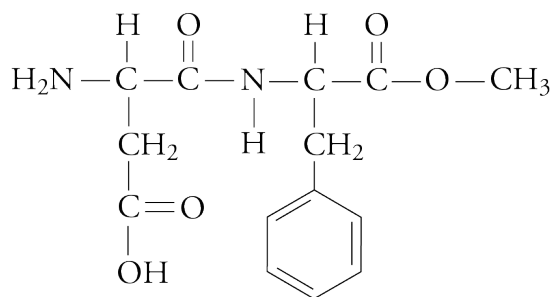
56. Write line drawings to represent the Lewis structures in parts (a) through (i) of problem 52.

## OBJECTIVE 2

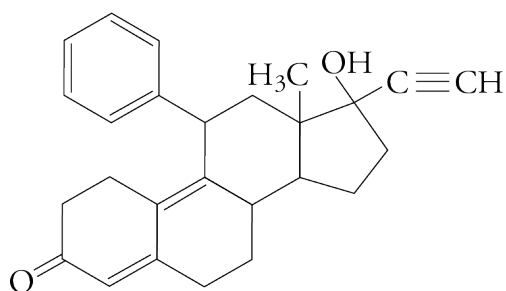
57. Write line drawings to represent the Lewis structures in parts (a) through (i) of problem 53.



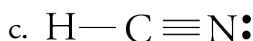
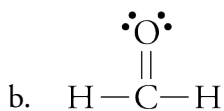
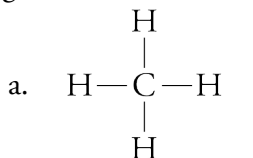
58. The chemical structure of the artificial sweetener aspartame is below. Identify all of the organic functional groups that it contains.



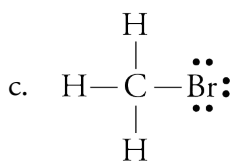
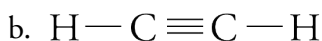
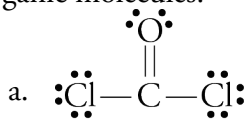
59. Mifepristone (often called RU-486) is a controversial morning after contraceptive pill. Identify all of the organic functional groups that it contains.



60. Draw geometric sketches, including bond angles, for each of the following organic molecules.



61. Draw geometric sketches, including bond angles, for each of the following organic molecules.



62. The four smallest alkanes have the following formulas:  $\text{CH}_4$ ,  $\text{C}_2\text{H}_6$ ,  $\text{C}_3\text{H}_8$ , and  $\text{C}_4\text{H}_{10}$ . Note the trend for the relationship between the number of carbon atoms and the number of hydrogen atoms. Based on this trend, what would the formula be for the alkane with 22 carbons?

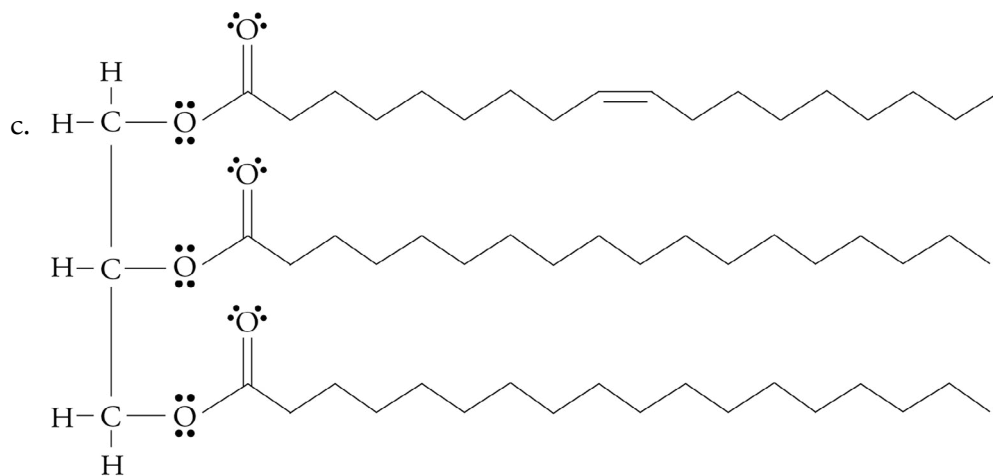
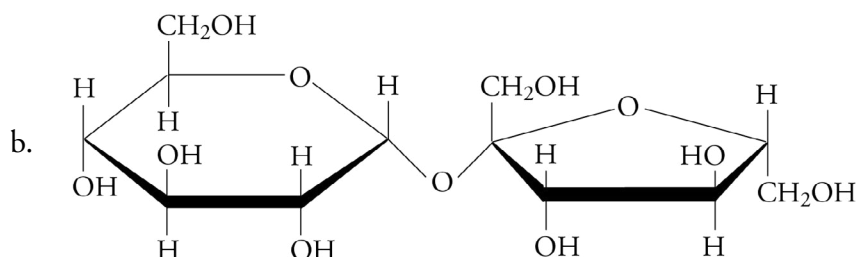
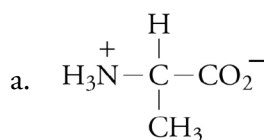


65. Draw line drawings for three isomers of  $C_5H_{12}$ .
66. Draw line drawings for three isomers of  $C_4H_8$ . (Draw each isomer with one double bond.)
67. Two of the three isomers of  $C_3H_8O$  are alcohols and one is an ether. Draw condensed structures for these three isomers.
68. Draw the condensed structure for an isomer of  $C_3H_6O_2$  that is a carboxylic acid, and draw another condensed structure for an isomer of  $C_3H_6O_2$  that is an ester.
69. Draw a Lewis structure for an isomer of  $C_2H_5NO$  that is an amide, and draw a second Lewis structure for a second isomer of  $C_2H_5NO$  that has both an amine functional group and an aldehyde functional group.
70. Draw the Lewis structure for an isomer of  $C_3H_6O$  that is a ketone, and draw another Lewis structure for an isomer of  $C_3H_6O$  that is an aldehyde.
71. Ketones, aldehydes, carboxylic acids, esters, and amides all have a carbon-oxygen double bond (often called a carbonyl group). Explain how these classifications of organic compounds are different from each other.

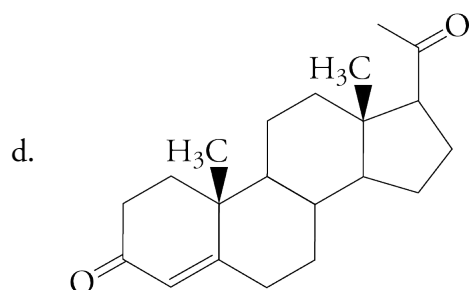
### Section 17.2 Important Substances in Food

72. Identify each of the following structures as representing a carbohydrate, amino acid, peptide, triglyceride, or steroid.

OBJECTIVE 4

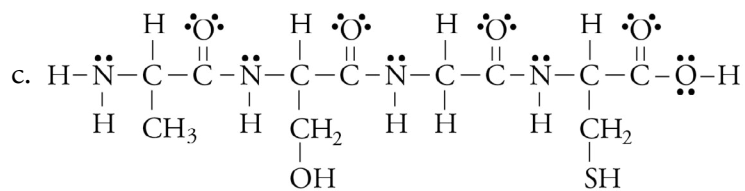
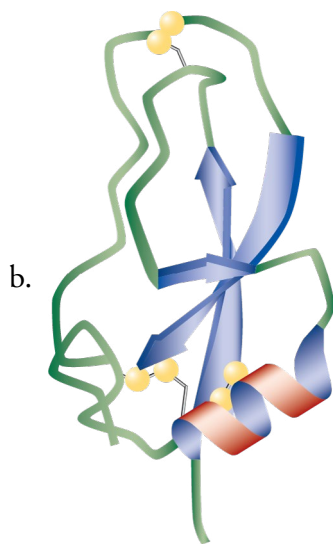
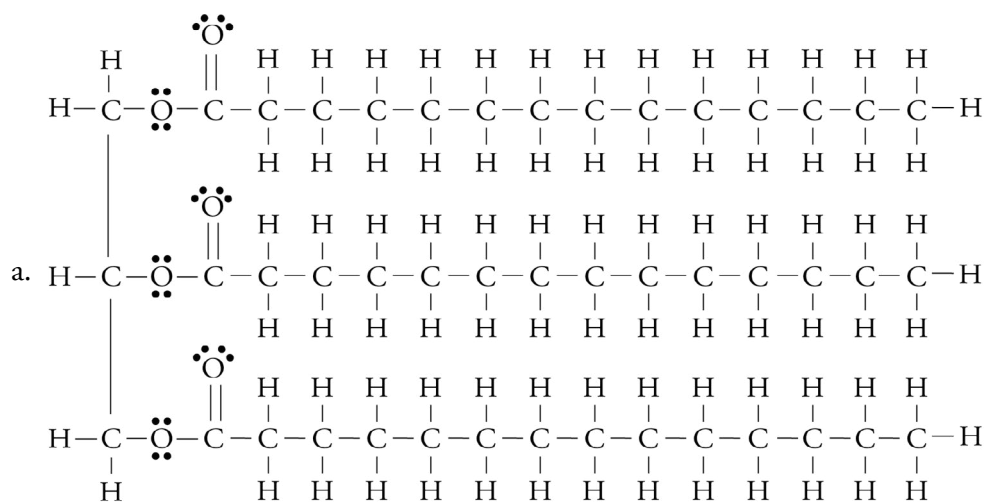


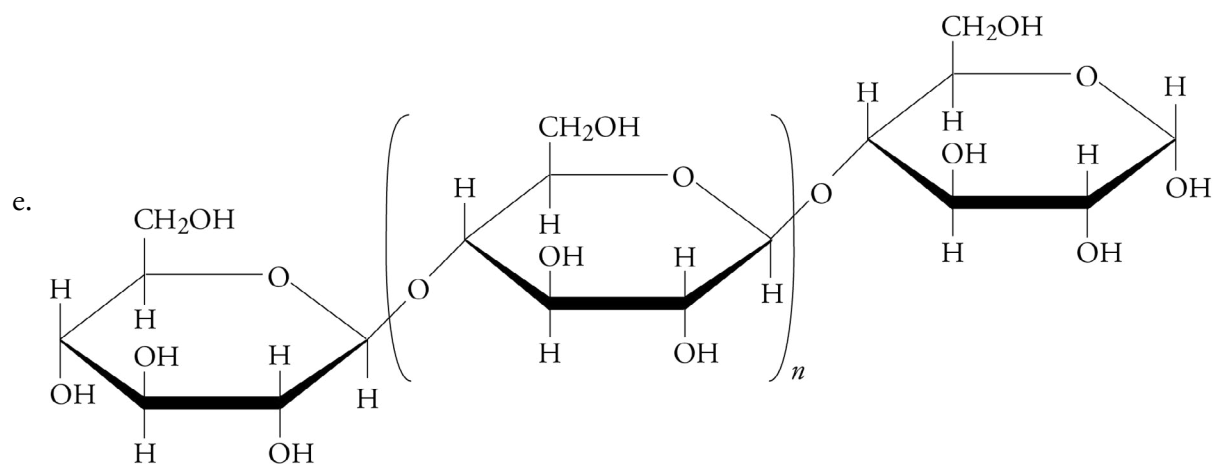
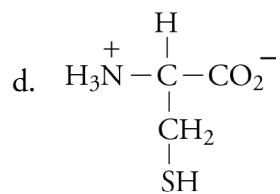
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72. *Continued*

## OBJECTIVE 4

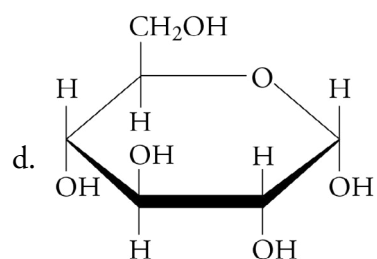
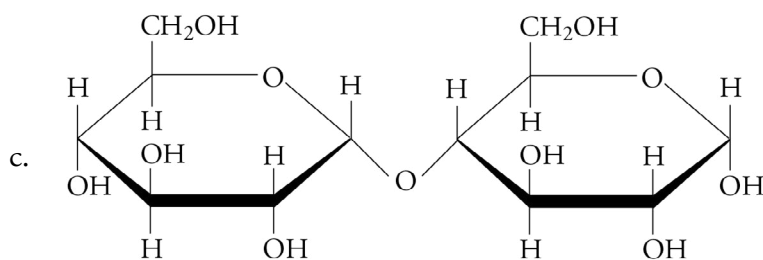
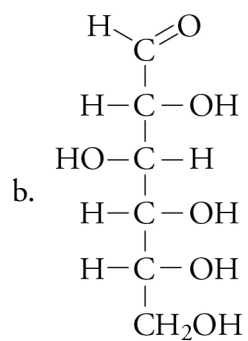
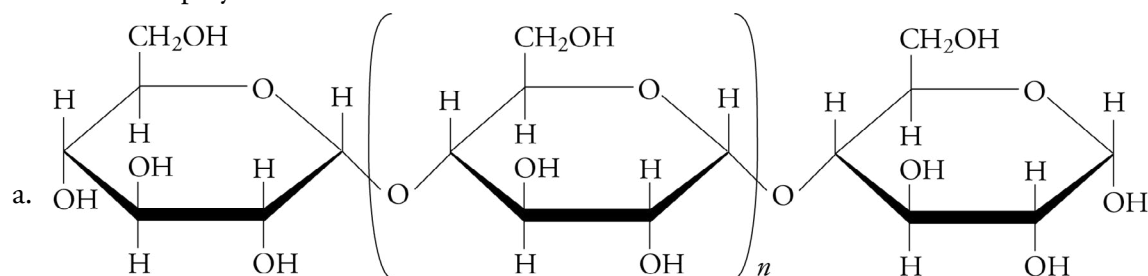
73. Identify each of the following structures as representing a carbohydrate, amino acid, peptide, triglyceride, or steroid.





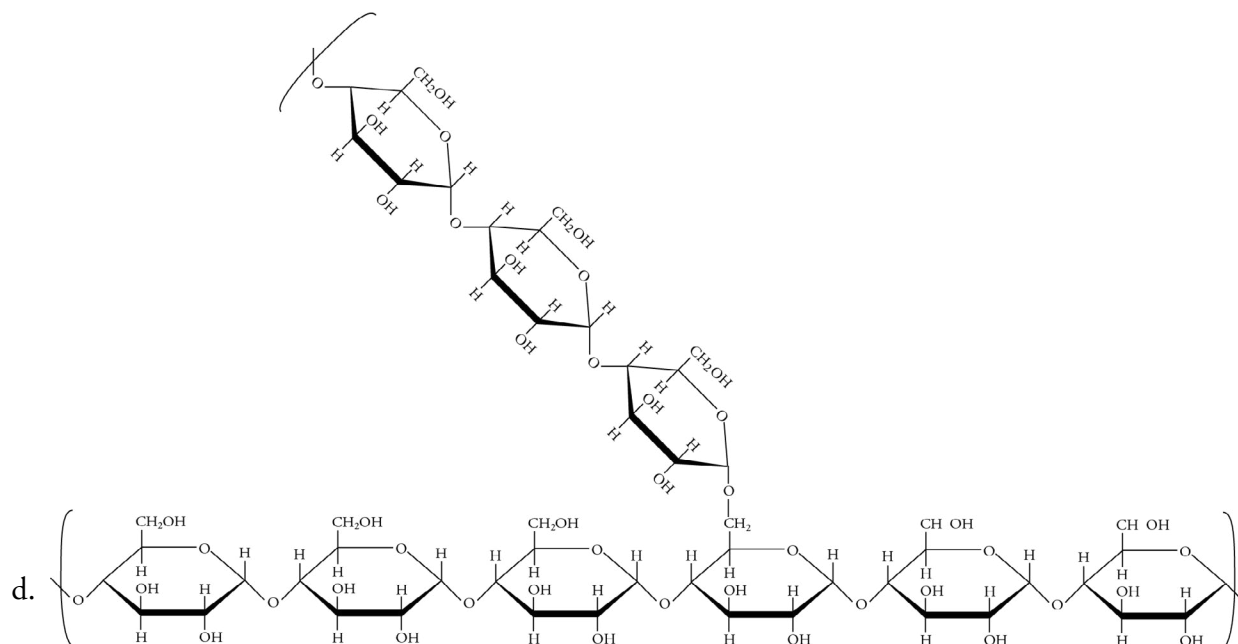
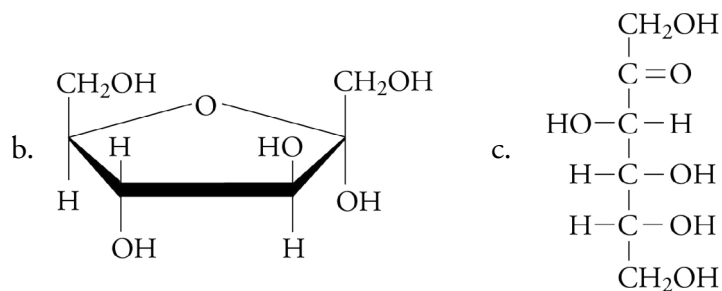
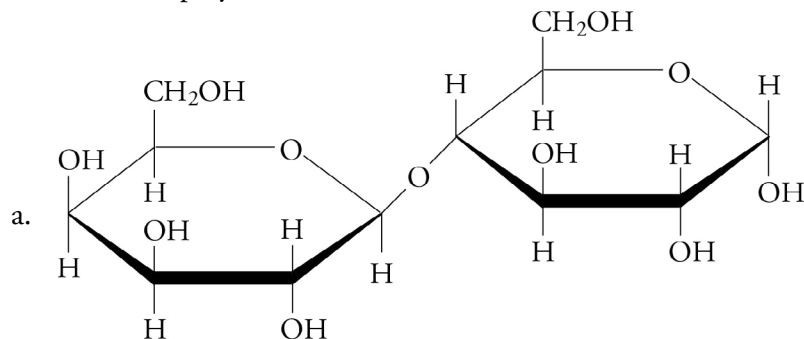
74. Identify each of the following structures as representing a monosaccharide, disaccharide, or polysaccharide.

OBJECTIVE 5



## OBJECTIVE 5

75. Identify each of the following structures as representing a monosaccharide, disaccharide, or polysaccharide.



76. Identify each of the following as a monosaccharide, disaccharide, or polysaccharide.

a. maltose    b. fructose    c. amylose    d. cellulose

77. Identify each of the following as a monosaccharide, disaccharide, or polysaccharide.

a. amylopectin    b. glucose    c. lactose    d. galactose

## OBJECTIVE 6

78. Describe the general difference between glucose and galactose.

## OBJECTIVE 6

79. Describe the general differences between glucose and fructose.

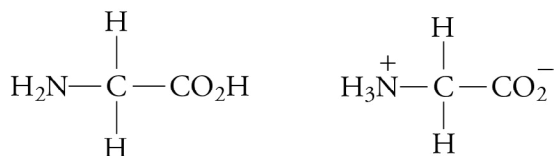
## OBJECTIVE 7

80. What saccharide units form maltose, lactose, and sucrose?

## OBJECTIVE 8

81. Describe the similarities and differences between amylose, amylopectin, and glycogen.

82. Describe the similarities and differences between starches (such as amylose, amylopectin, and glycogen) and cellulose.
83. Explain why the starch molecules found in a potato can be digested in our digestive tract and why the cellulose in the same potato cannot.
84. Explain why glycine amino acid molecules in our bodies are usually found in the second form below rather than the first.



OBJECTIVE 8

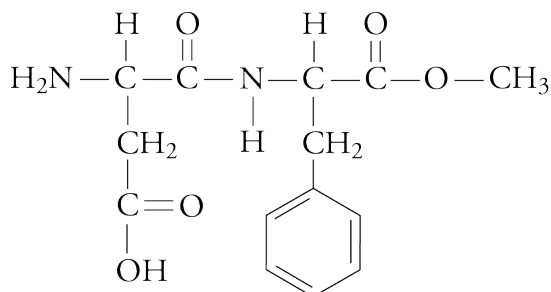
OBJECTIVE 9

OBJECTIVE 11

85. Using Figure 17.22, draw the Lewis structure of the dipeptide that has alanine combined with serine. Circle the peptide bond in your structure.
86. Using Figure 17.22, draw the Lewis structure of the dipeptide that has cysteine combined with glycine. Circle the peptide bond in your structure.
87. Show how the amino acids leucine, phenylalanine, and threonine can be linked together to form the tripeptide leu-phe-thr.
88. Show how the amino acids tryptophan, aspartic acid, and asparagine can be linked together to form the tripeptide try-asp-asn.
89. When the artificial sweetener aspartame is digested, it yields methanol as well as the amino acids aspartic acid and phenylalanine. Although methanol is toxic, the extremely low levels introduced into the body by eating aspartame are not considered dangerous, but for people who suffer from phenylketonuria (PKU), the phenylalanine can cause severe mental retardation. Babies are tested for this disorder at birth, and when it is detected, they are placed on diets that are low in phenylalanine. Using Figure 17.22, identify the portions of aspartame's structure that yield aspartic acid, phenylalanine, and methanol.

OBJECTIVE 12

OBJECTIVE 12



90. Describe the differences between the primary, secondary, and tertiary structures of proteins.
91. Describe how disulfide bonds, hydrogen bonds, and salt bridges help hold protein molecules together in specific tertiary structures.
92. Explain why it is more efficient to store energy in the body as fat rather than carbohydrate or protein.

OBJECTIVE 13

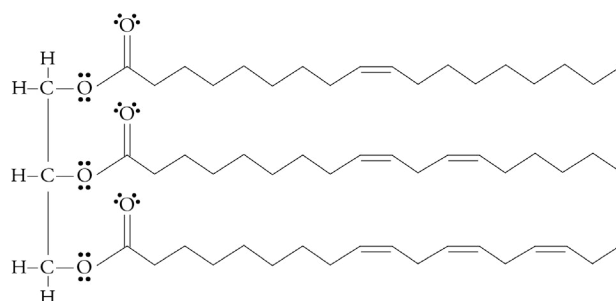
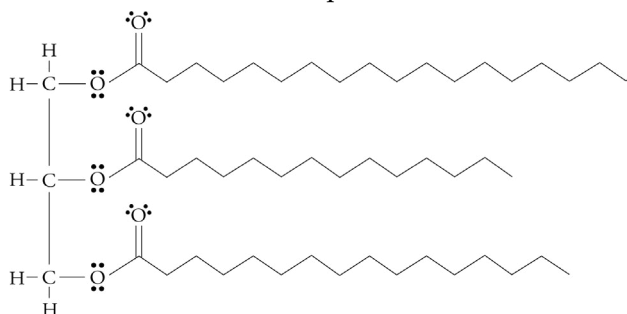
OBJECTIVE 14

OBJECTIVE 15

OBJECTIVE 17

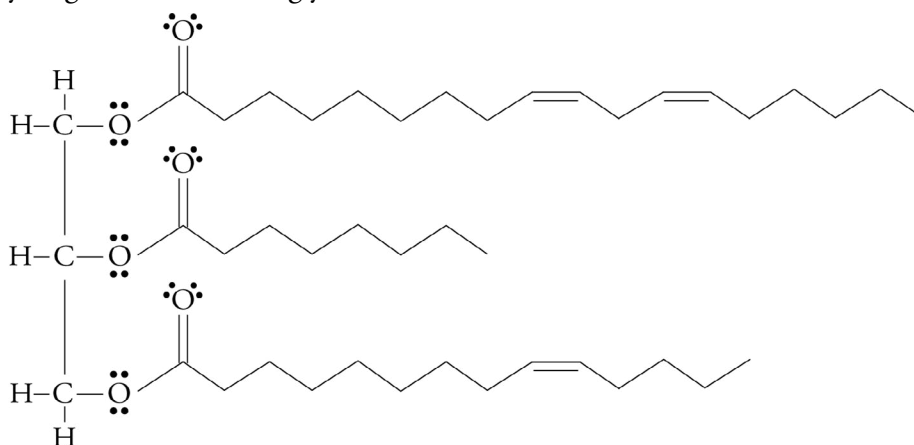
93. Identify each of the following triglycerides as saturated or unsaturated. Which is more likely to be a solid at room temperature and which one is more likely to be a liquid?

OBJECTIVE 18



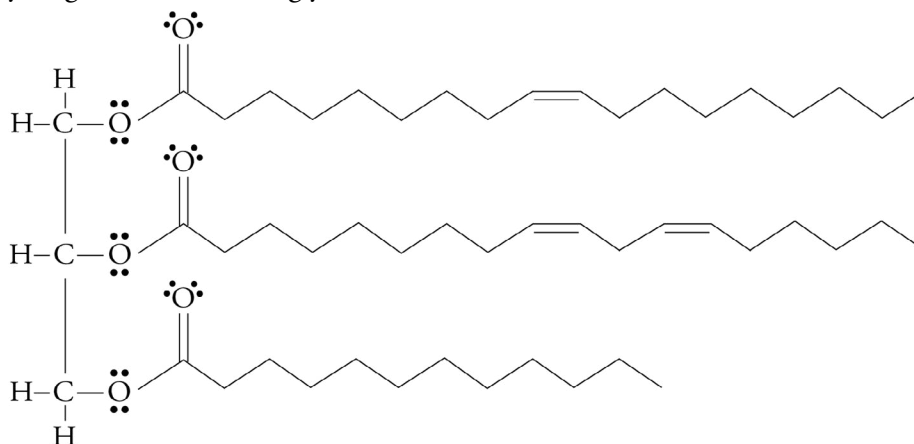
OBJECTIVE 19

94. Draw the structure of the triglyceride that would form from the complete hydrogenation of the triglyceride below.



OBJECTIVE 19

95. Draw the structure of the triglyceride that would form from the complete hydrogenation of the triglyceride below.



### Section 17.3 Digestion

OBJECTIVE 20

96. When you wash some fried potatoes down with a glass of milk, you deliver a lot of different nutritive substances to your digestive tract, including lactose (a disaccharide), protein, and fat from the milk and starch from the potatoes. What are the digestion products of disaccharides, polysaccharides, protein, and fat?

OBJECTIVE 21

97. Describe how the digestion of protein molecules is facilitated by conditions in the stomach.



98. Explain why each enzyme only acts on a specific molecule or a specific type of molecule.

OBJECTIVE 22

### Section 17.4 Synthetic Polymers

99. Describe how Nylon 66 is made.
100. Explain why Nylon 66 is stronger than Nylon 610.
101. Describe how polyesters are made.
102. Describe the similarities and differences between the molecular structures of low density polyethylene (LDPE) and high density polyethylene (HDPE).
103. Identify each of the following as representing nylon, polyester, polyethylene, poly(vinyl chloride), polypropylene, or polystyrene. (In each case, the “ $n$ ” represents some large integer.)

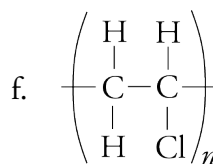
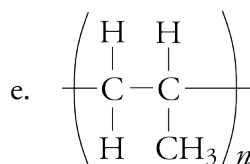
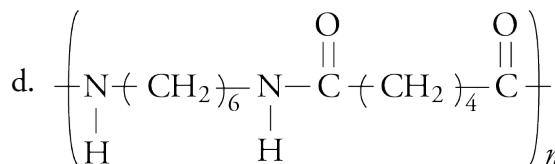
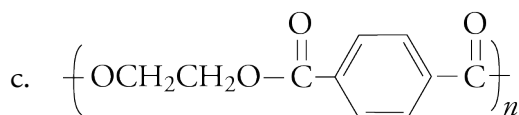
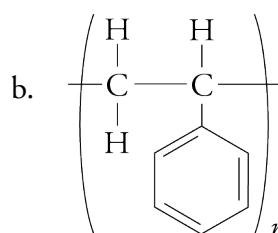
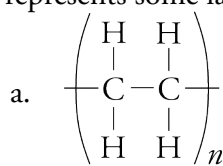
OBJECTIVE 23

OBJECTIVE 24

OBJECTIVE 25

OBJECTIVE 26

OBJECTIVE 27



104. Both ethylene and polyethylene are composed of nonpolar molecules. Explain why ethylene is a gas at room temperature while polyethylene is a solid at the same temperature.
105. Find three plastic objects in your home that are labeled with a recycling code of 1. From what substance are these objects made? Are objects of this type recycled in your town?
106. Find three objects in your home that are labeled with a recycling code of 2. From what substance are these objects made? Are objects of this type recycled in your town?
107. Find one object representing each of the recycling codes 3, 4, 5, 6. From what substance is each object made? Can these objects be recycled in your town?

OBJECTIVE 28

OBJECTIVE 28

OBJECTIVE 28

### Discussion Questions

108. Cyclopropane,  $\text{C}_3\text{H}_6$ , is a potent anesthetic that can be dangerous because it is very flammable. Develop a theory for why it is so reactive. Hints: Draw a Lewis structure for it that has all single bonds (notice the “cyclo” portion of the name). Predict the bond angles between the carbon atoms in the structure based on the number of electron groups around each carbon. Compare this angle to the bond angles between carbon atoms that cyclopropane must have based on the shape that you have drawn.