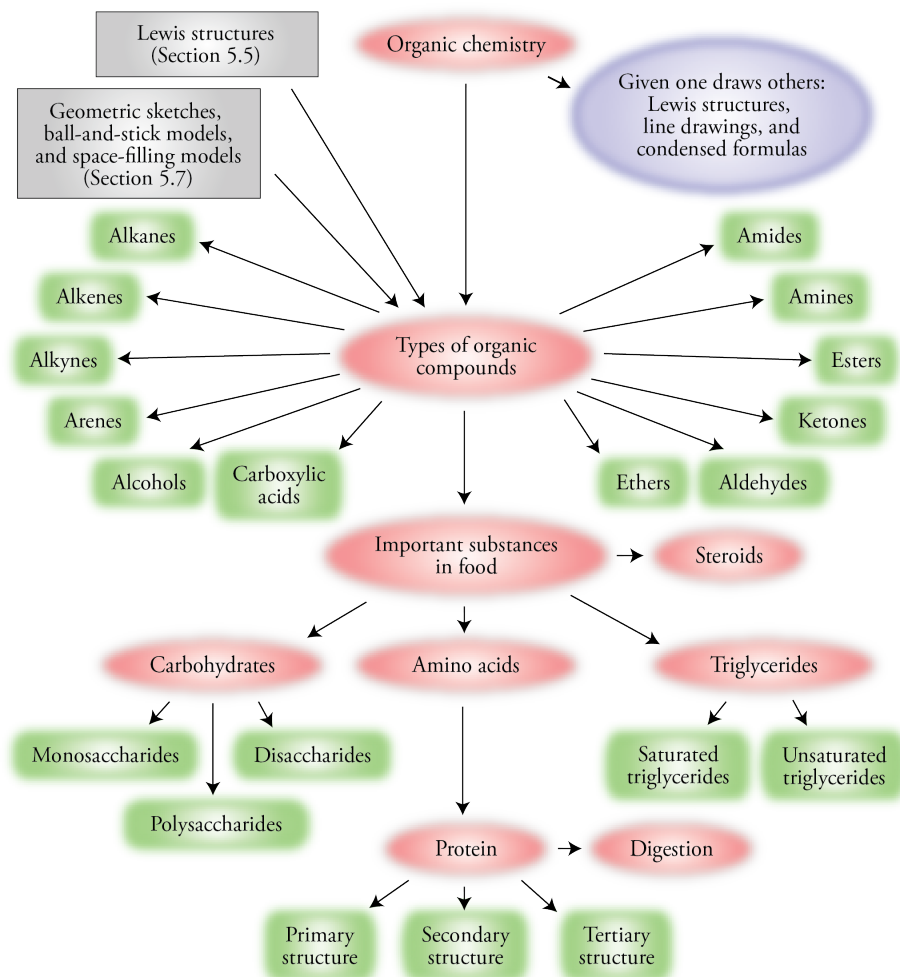


# Chapter 15

An Introduction to Organic Chemistry,  
Biochemistry, and Synthetic Polymers

***An Introduction to Chemistry***  
by Mark Bishop

# Chapter Map

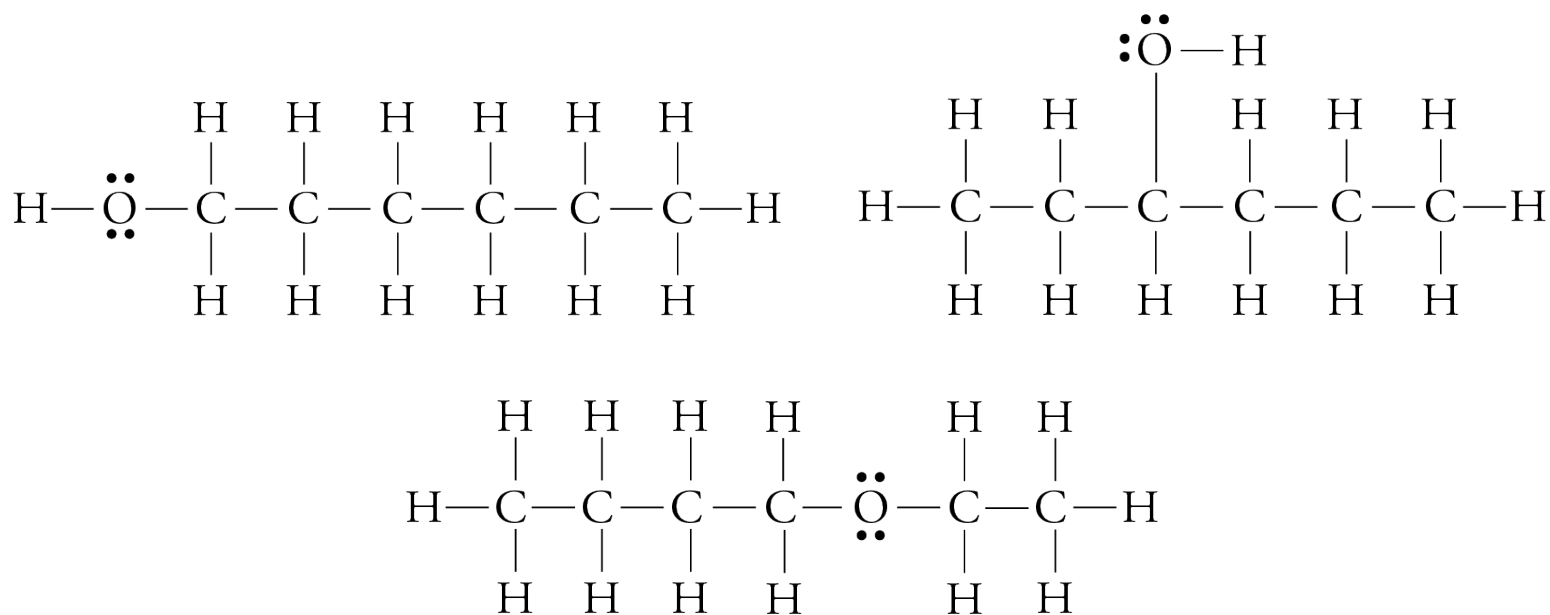


# Organic Chemistry



- **Organic chemistry** is the chemistry of carbon-based compounds.
- There are two reasons why there are millions of organic chemicals.
  - Carbon atoms can form strong bonds to other carbon atoms and still form bonds to atoms of other elements.
  - There are many different ways to arrange the same atoms in carbon-based compounds.

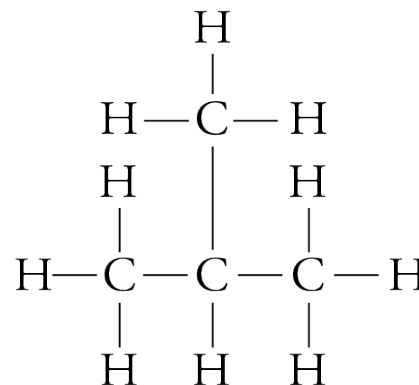
# Isomers



- **Isomers** are molecules with the same atoms (same molecular formula) but a different arrangement of the atoms in space (different structural formula).

# Ways to Describe Organic Compounds (Methylpropane)

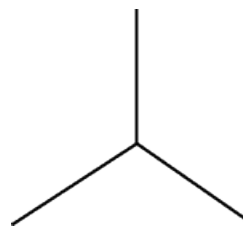
- Lewis structures



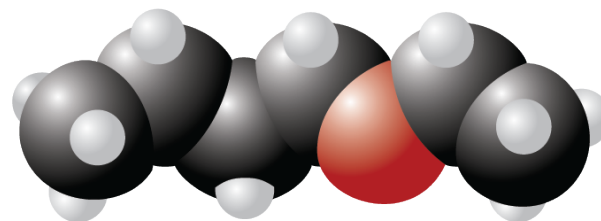
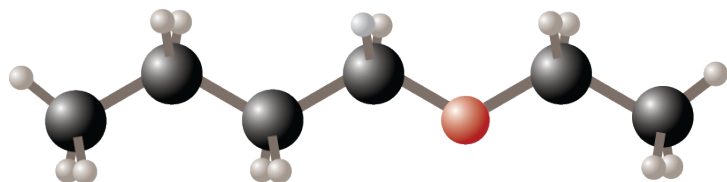
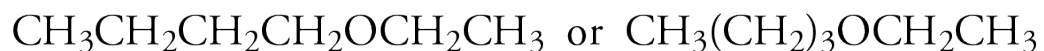
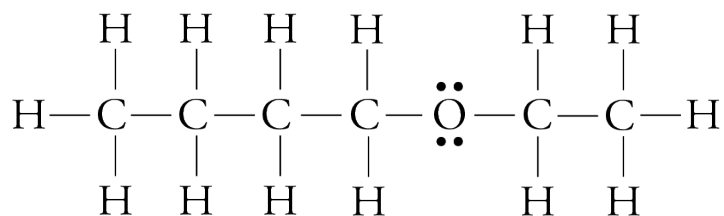
- Condensed formulas



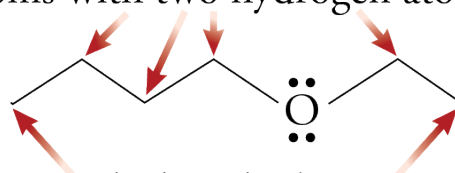
- Line drawings



# Ways to Describe Organic Compounds (butyl ethyl ether)

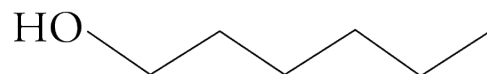
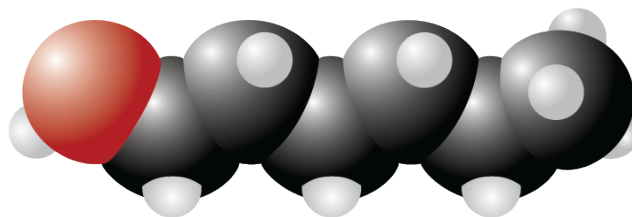
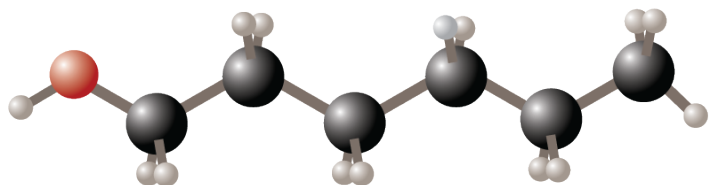
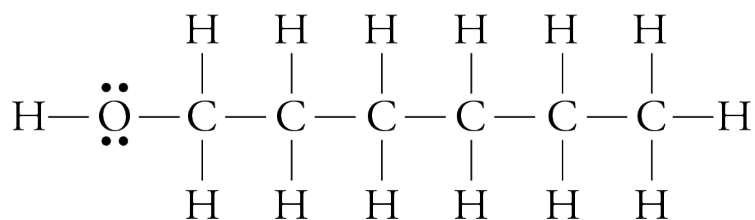


Carbon atoms with two hydrogen atoms attached

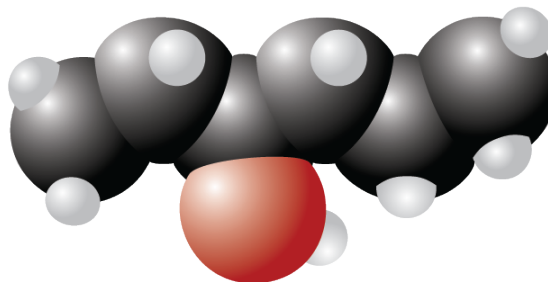
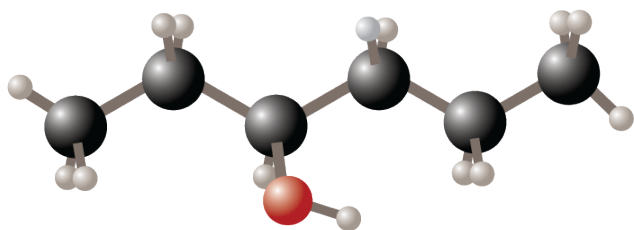
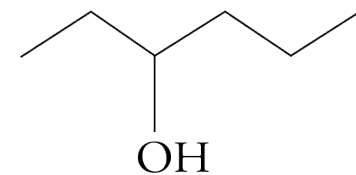
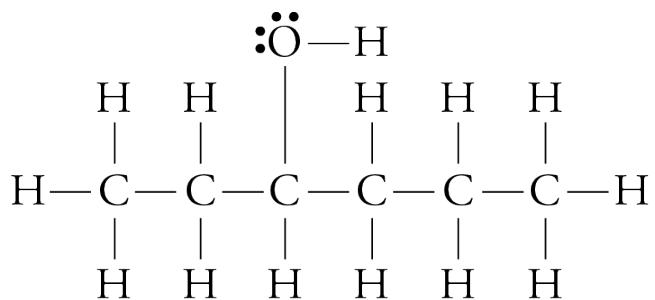


Carbon atoms with three hydrogen atoms attached

# Ways to Describe Organic Compounds (1-hexanol)



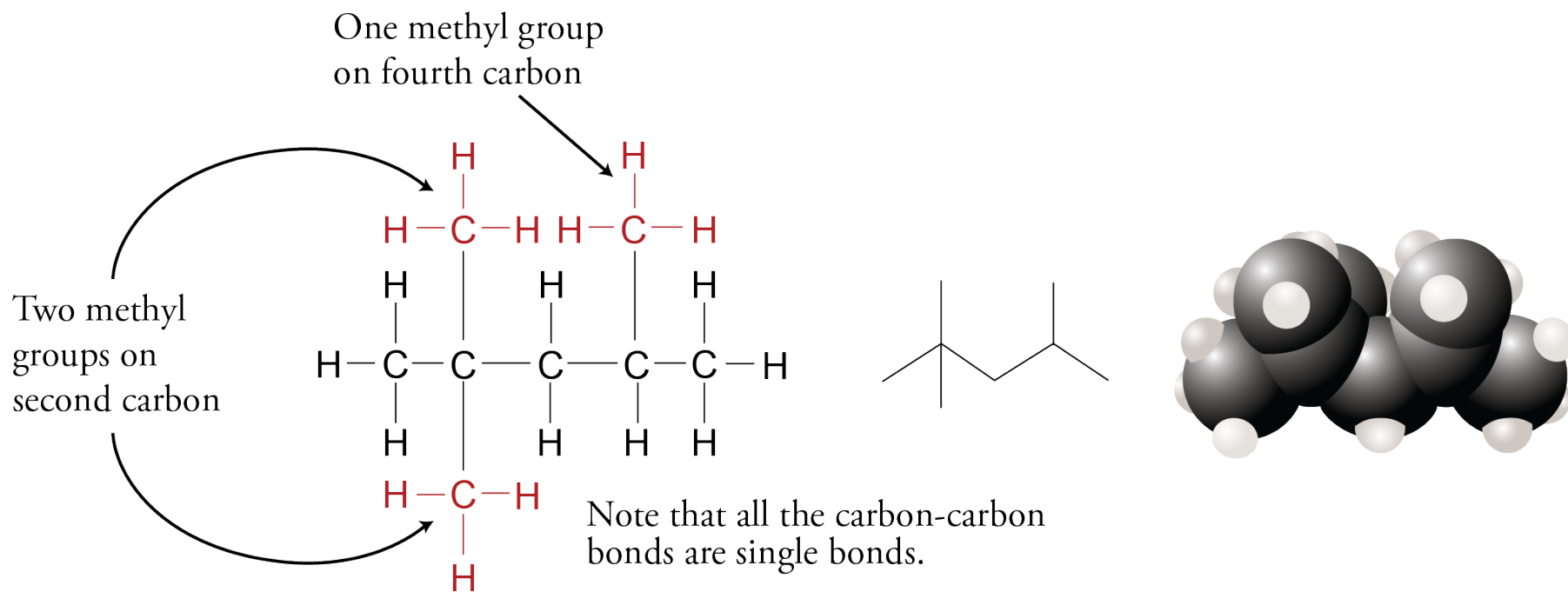
# Ways to Describe Organic Compounds (3-hexanol)





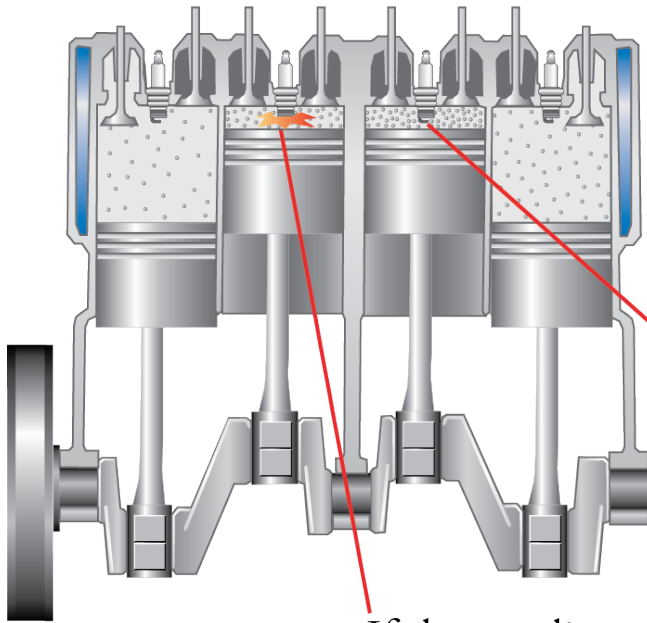
# Alkanes

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



2,2,4-trimethylpentane,  $\text{CH}_3\text{C}(\text{CH}_3)_2\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_3$

# Pre-ignition Knock and Octane Rating

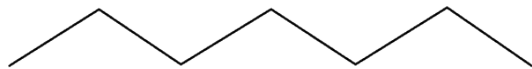


If the gasoline-air mixture reacts too soon, before the peak of the stroke of the piston, the piston pushes the crankshaft in the opposite direction, causing a vibration or "pre-ignition knock".

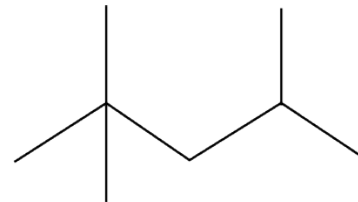
If the gasoline-air mixture ignites at (or just past) the peak of the stroke of the piston, the crankshaft is turned, which ultimately turns the wheels.

Straight-chain hydrocarbons, such as heptane, are more likely to react early, so a gasoline that has a higher percentage of straight-chain hydrocarbons has a greater tendency toward pre-ignition knock.

Branched-chain hydrocarbons, such as 2,2,4-trimethylpentane, are less likely to react early, so a gasoline that has a higher percentage of branched-chain hydrocarbons has a lower tendency toward pre-ignition knock.



Heptane



2,2,4-trimethylpentane

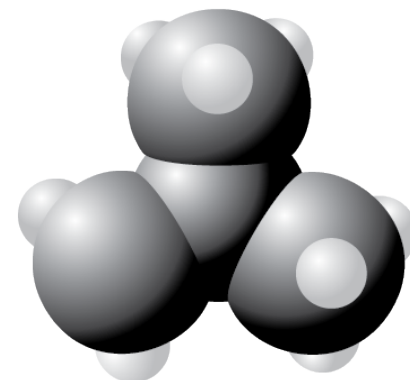
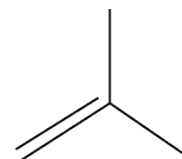
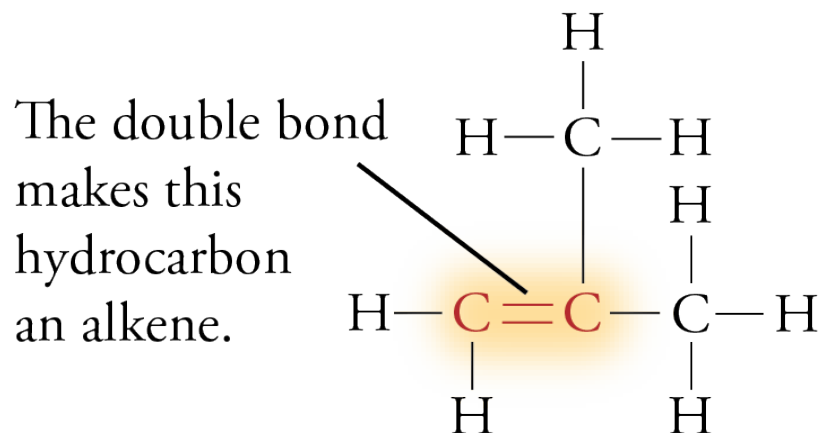
# Steps to Octane Rating



- Measure efficiency and degree of vibration for a test engine running on various percentages of heptane (a straight-chain hydrocarbon) and 2,2,4-trimethylpentane (a branched-chain hydrocarbon).
- Run the same test engine with the gasoline to be tested, and measure its efficiency and degree of vibration.
- Assign an octane rating to the gasoline based on comparison of the efficiency and degree of vibration of the test engine with the gasoline and the various percentages of 2,2,4-trimethylpentane (octane or isooctane) and heptane. For example, if the gasoline runs the test engine as efficiently as 91% 2,2,4-trimethylpentane (octane or isooctane) and 9% heptane, it gets an octane rating of 91.

# Alkenes

Hydrocarbons that have one or more carbon-carbon double bonds

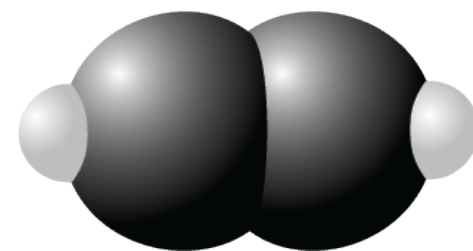
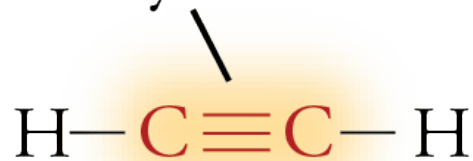


2-methylpropene (isobutene),  $\text{CH}_2\text{C}(\text{CH}_3)\text{CH}_3$

# Alkynes

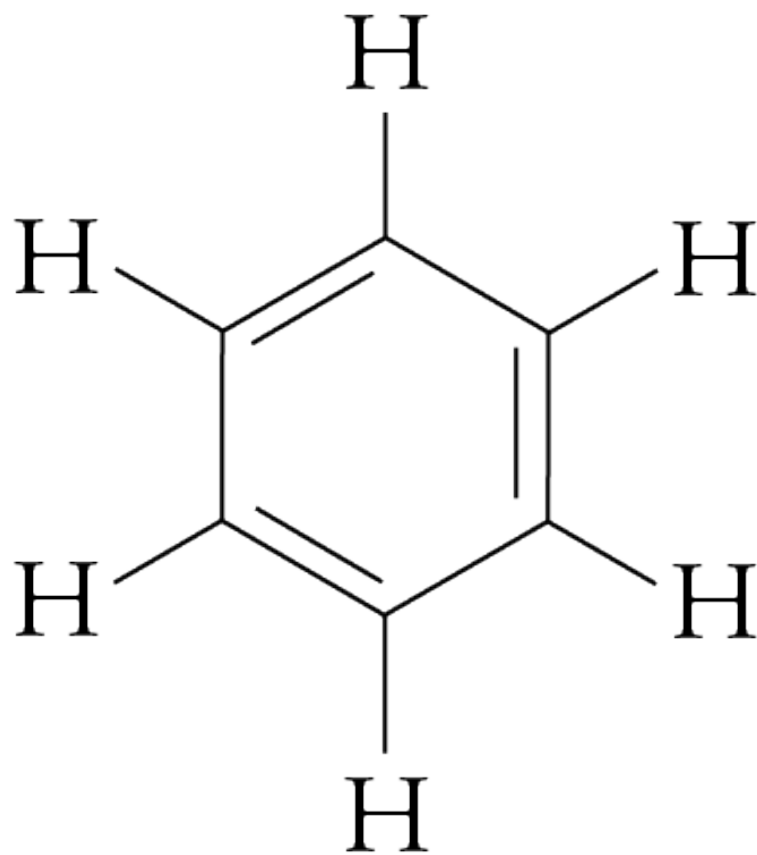
Hydrocarbons that have one or more carbon-carbon triple bonds

The triple bond makes  
this hydrocarbon an alkyne.

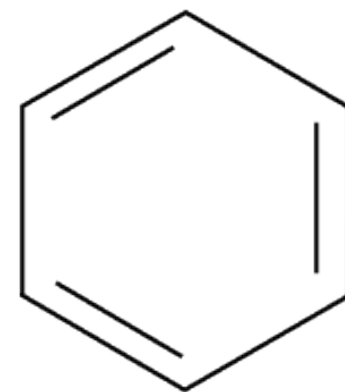


Ethyne (acetylene), HCCH

# Benzene

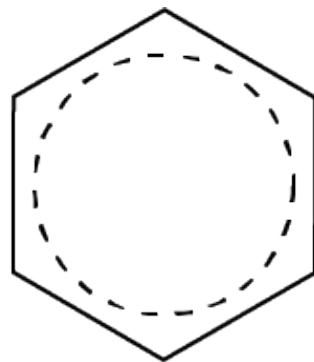
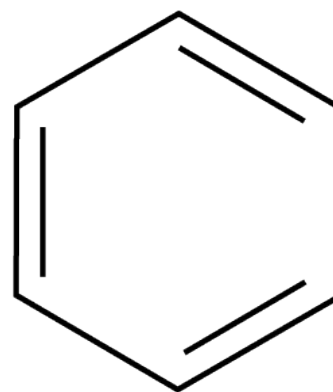
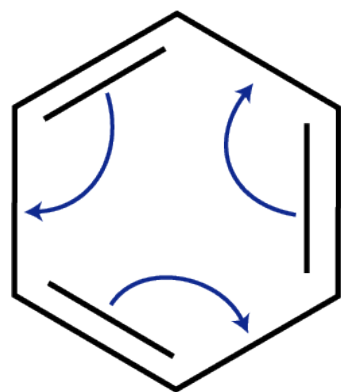


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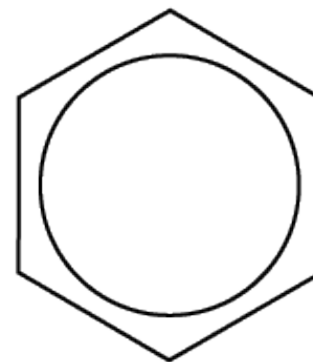


Benzene

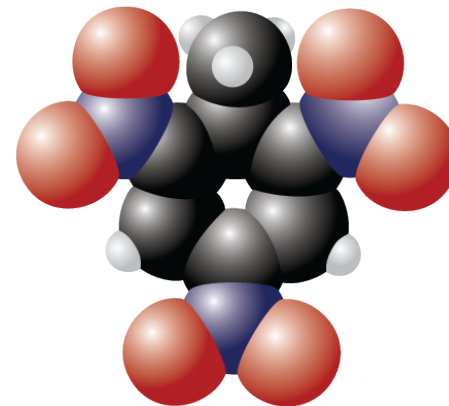
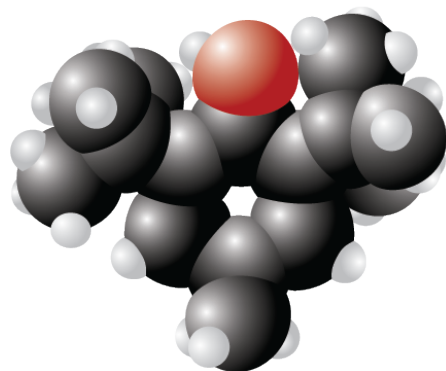
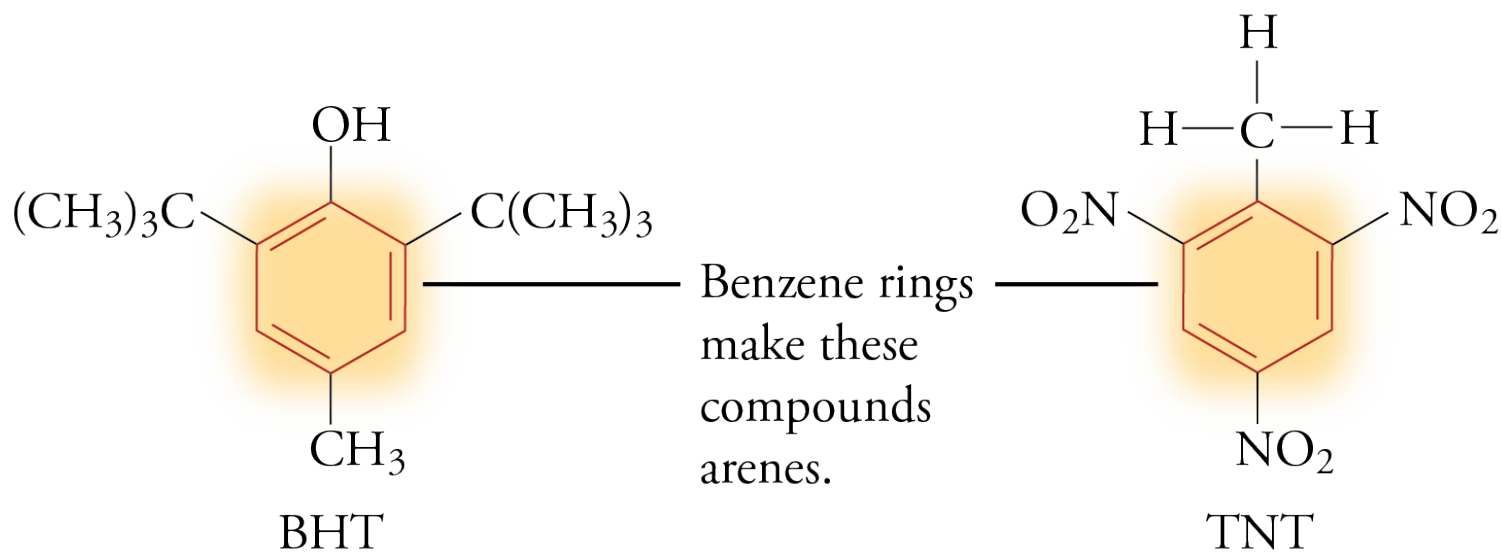
# Benzene



or



# Arenes (or Aromatics) - Compounds that contain the benzene ring

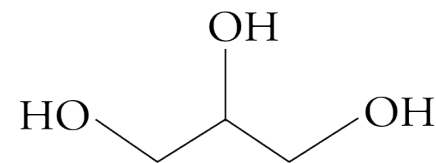
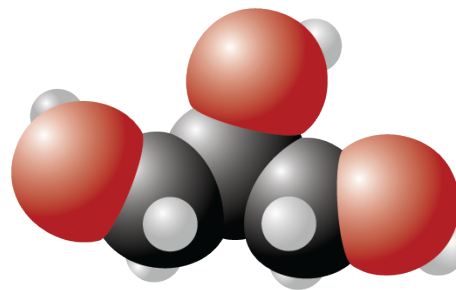
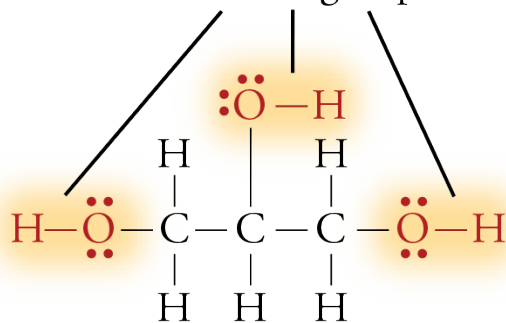




# Alcohols

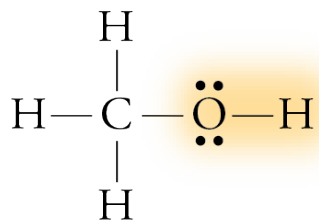
Compounds with one or more -OH groups attached to a hydrocarbon group

Alcohols have one or more O-H functional groups.

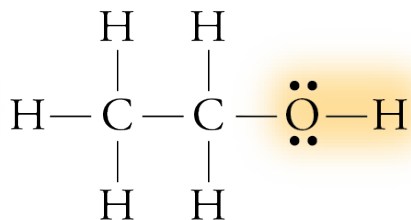


Glycerol,  $\text{HOCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$

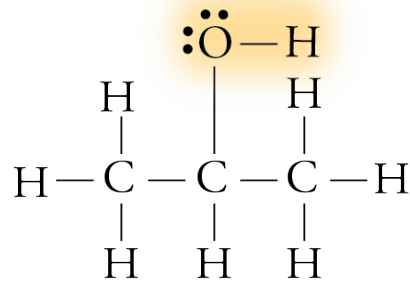
# Other Common Alcohols



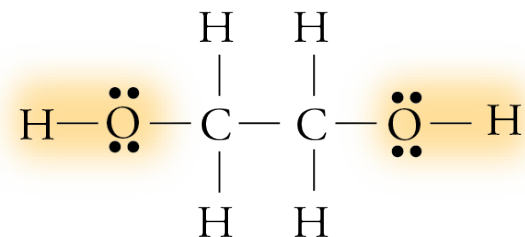
Methanol



Ethanol

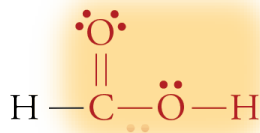


2-Propanol

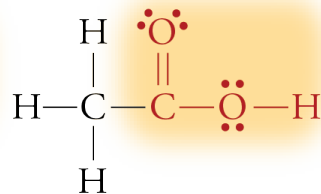


Ethylene glycol

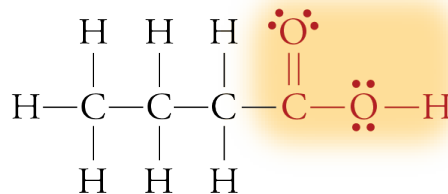
# Carboxylic Acids



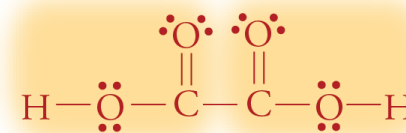
Formic acid



Acetic acid



Butanoic acid

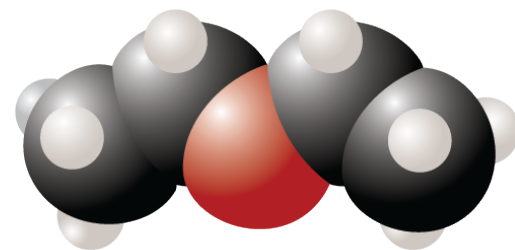
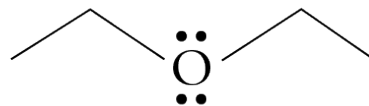
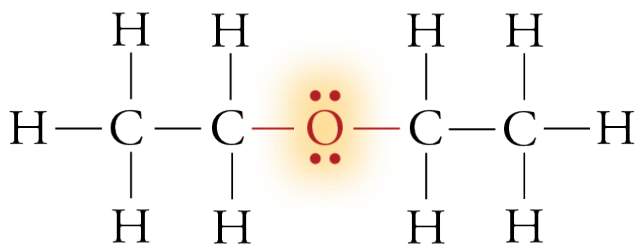


Oxalic acid



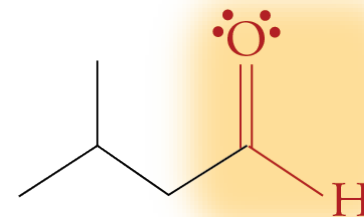
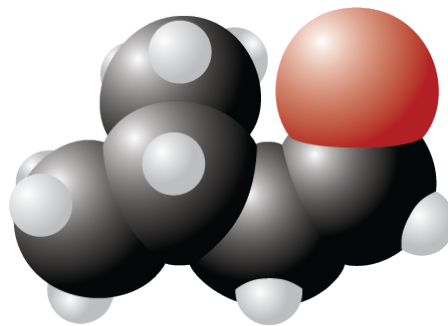
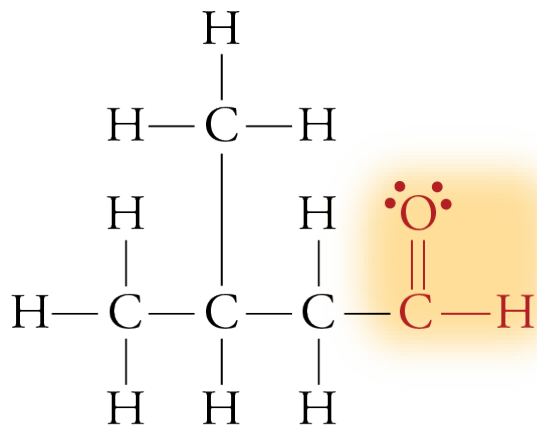
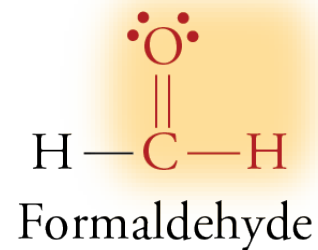
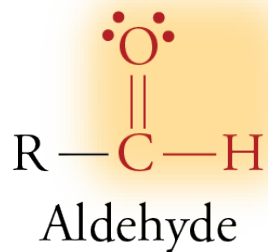
# Ethers

Two hydrocarbon groups surrounding an oxygen atom



Diethyl ether,  $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$

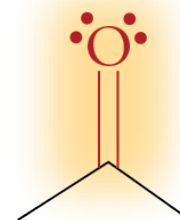
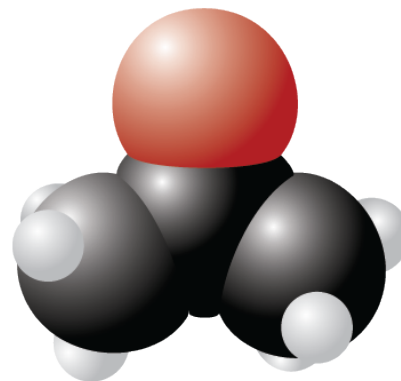
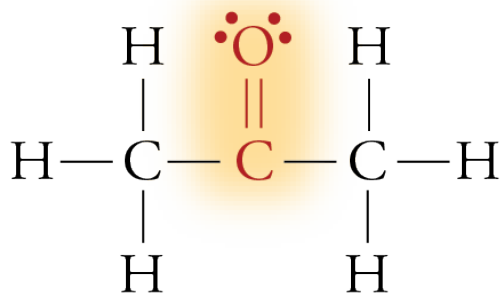
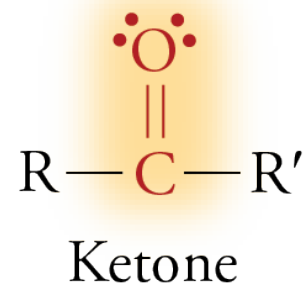
# Aldehyde



2-methylbutanal,  $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{CHO}$

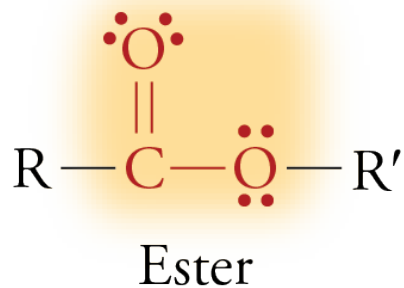
# Ketones

The R' s must be hydrocarbon groups. They cannot be hydrogen atoms.

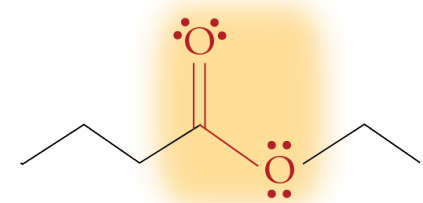
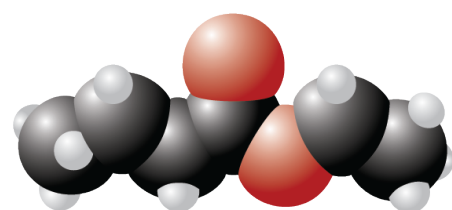
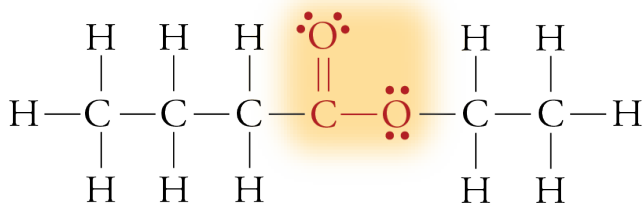


2-propanone (acetone),  $\text{CH}_3\text{COCH}_3$

# Esters



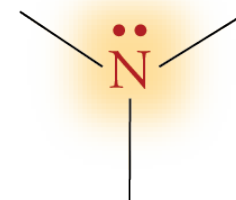
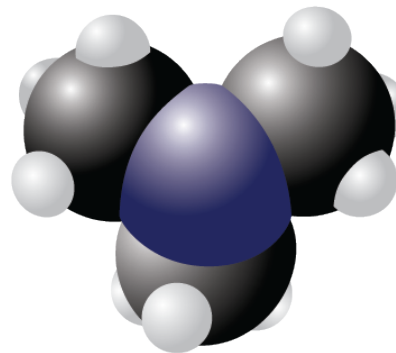
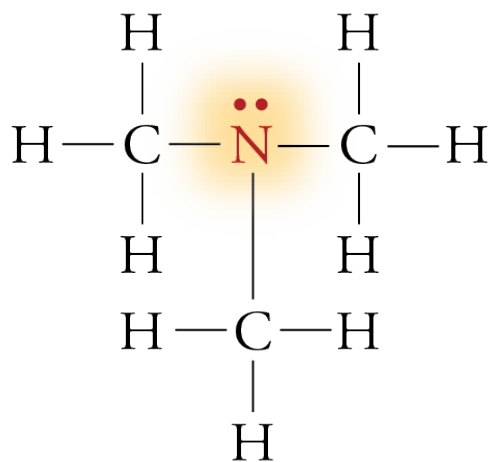
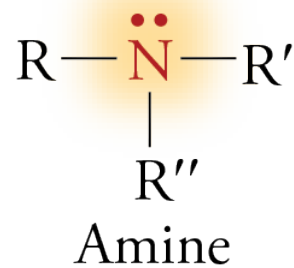
The R' must be a hydrocarbon group. It cannot be a hydrogen atom.



Ethyl butanoate,  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{CH}_2\text{CH}_3$

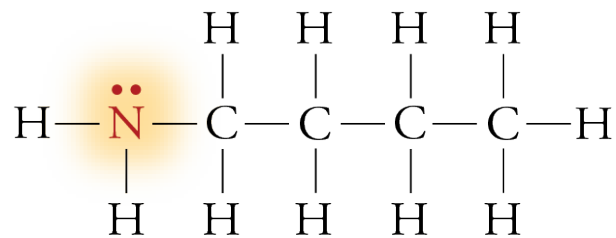


# Amine

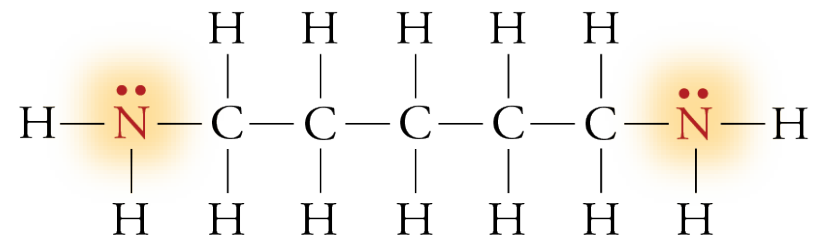


Trimethylamine,  $(\text{CH}_3)_3\text{N}$

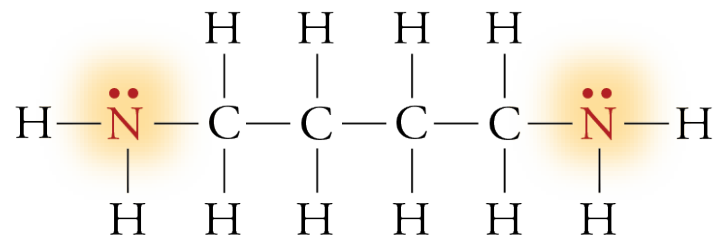
# More Amines



1-Aminobutane

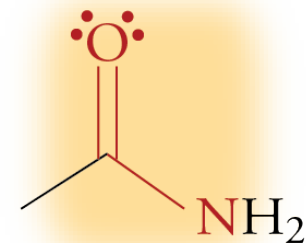
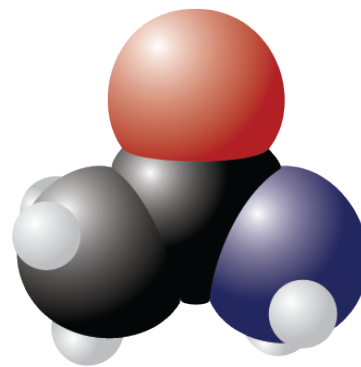
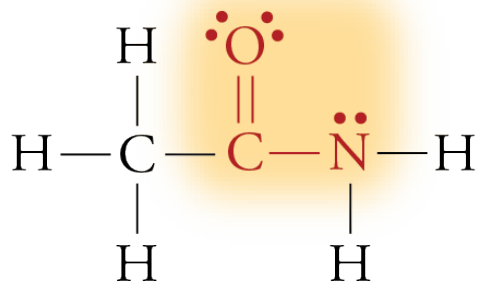
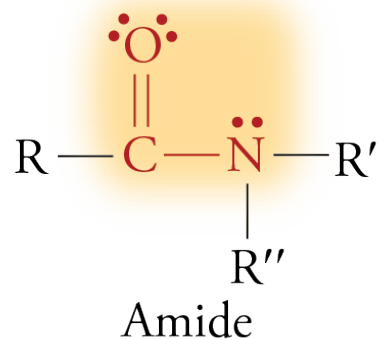


Cadaverine



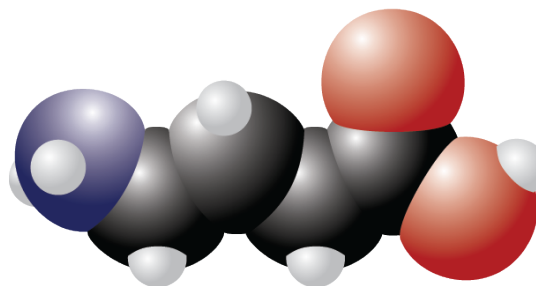
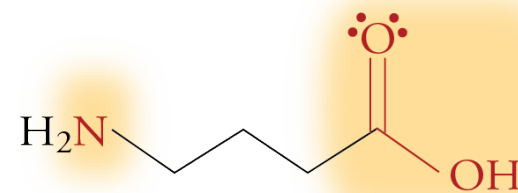
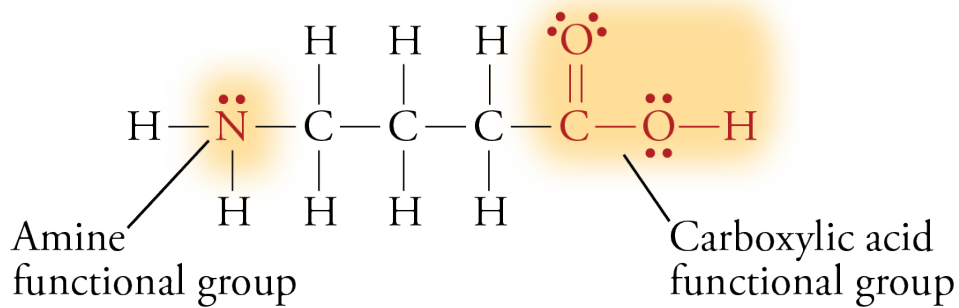
Putresine

# Amides

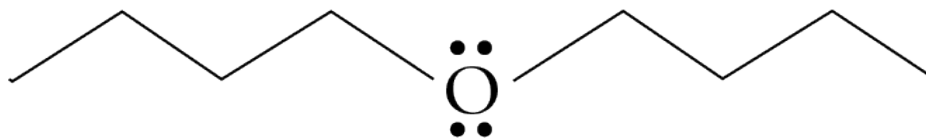
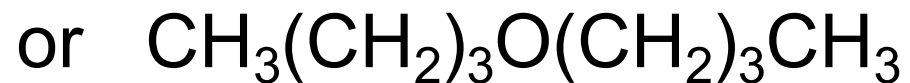
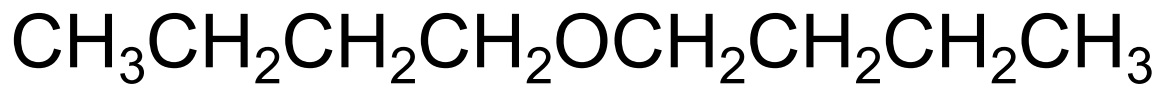
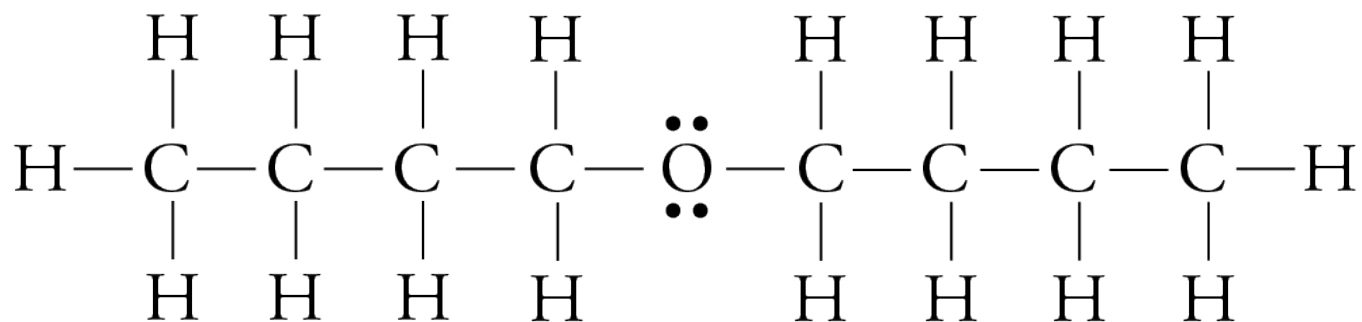


Ethanamide (acetamide),  $\text{CH}_3\text{CONH}_2$

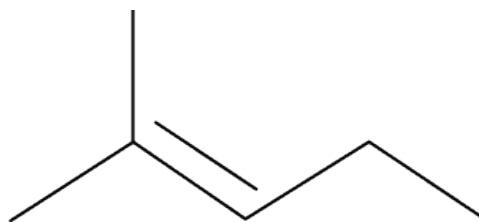
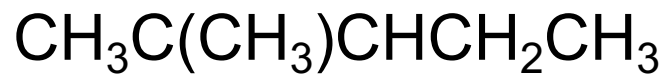
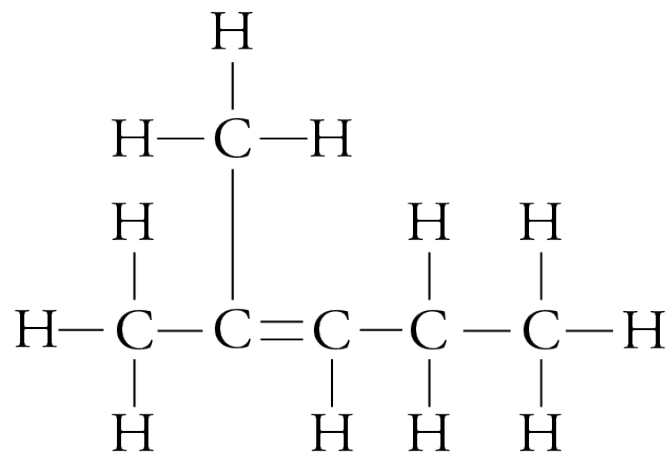
# Difunctional Compounds - GABA



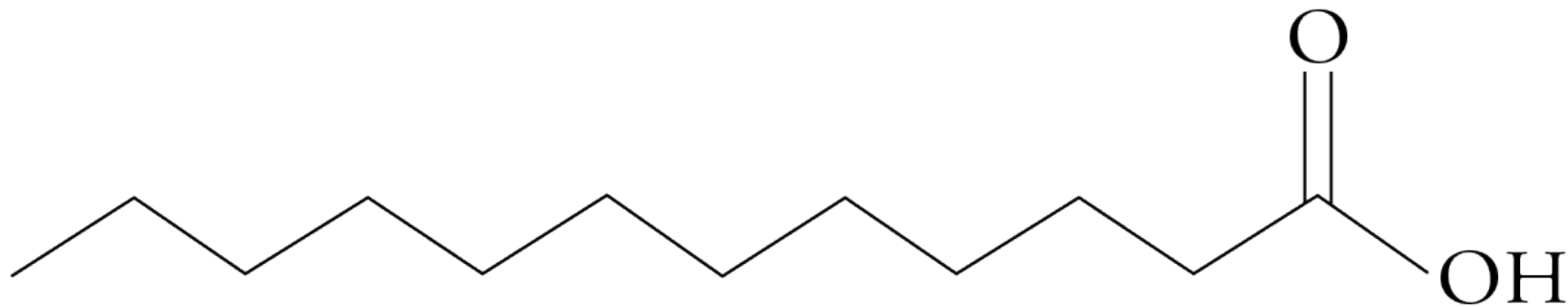
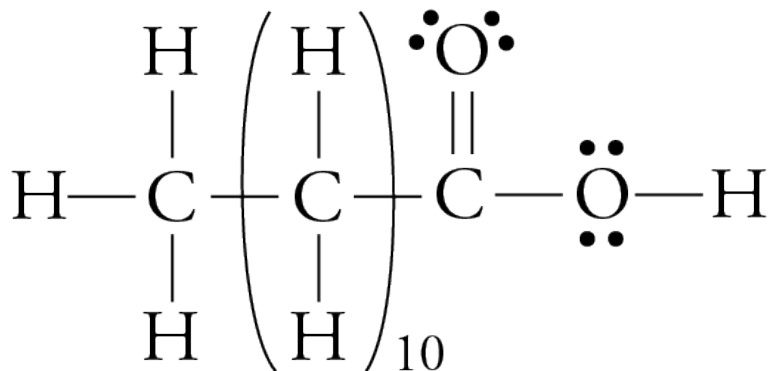
# Example 1



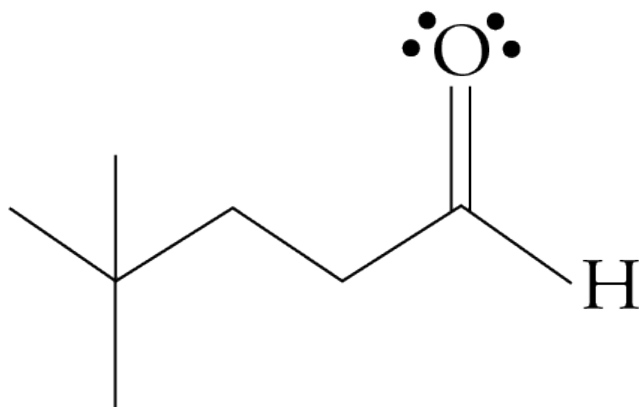
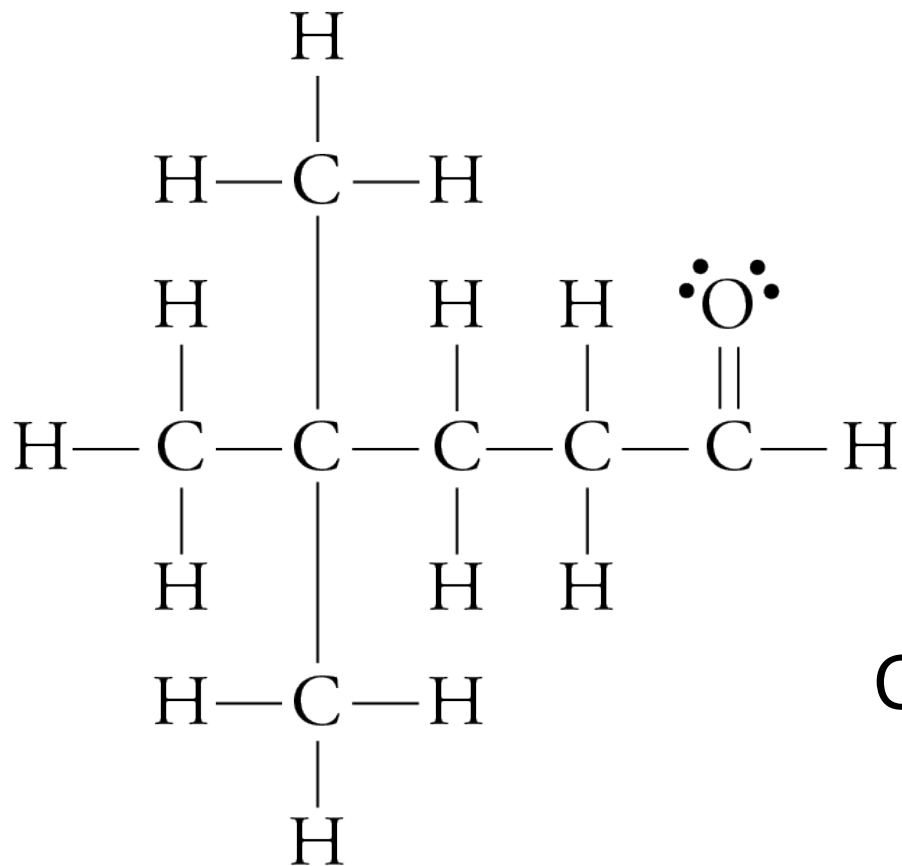
# Example 2



## Example 3



## Example 4





# Types of Biomolecules



- **Carbohydrates**
  - Monosaccharides (glucose and fructose)
  - Disaccharides (maltose, lactose, and sucrose)
  - Polysaccharides (starch and cellulose)
- **Amino Acids and Proteins**
- **Triglycerides**
- **Steroids**

# Substances in Food



- 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 triglycerides (the rest).

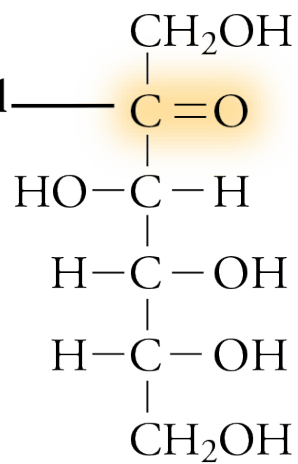
# Carbohydrates



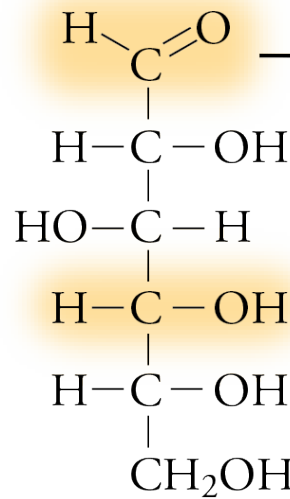
- Carbohydrate is a general name for sugars, starches, and cellulose.
- They are also be called saccharides.
- Sugars are monosaccharides or disaccharides, and starches and cellulose are polysaccharides.
- The most common monosaccharides are glucose, fructose, and galactose, which are isomers with the formula  $C_6H_{12}O_6$ .

# Monosaccharides

**Ketone  
functional  
group**

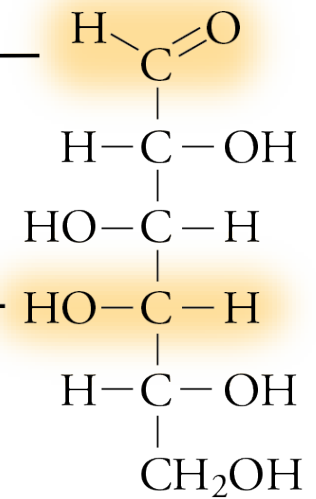


Fructose



Glucose

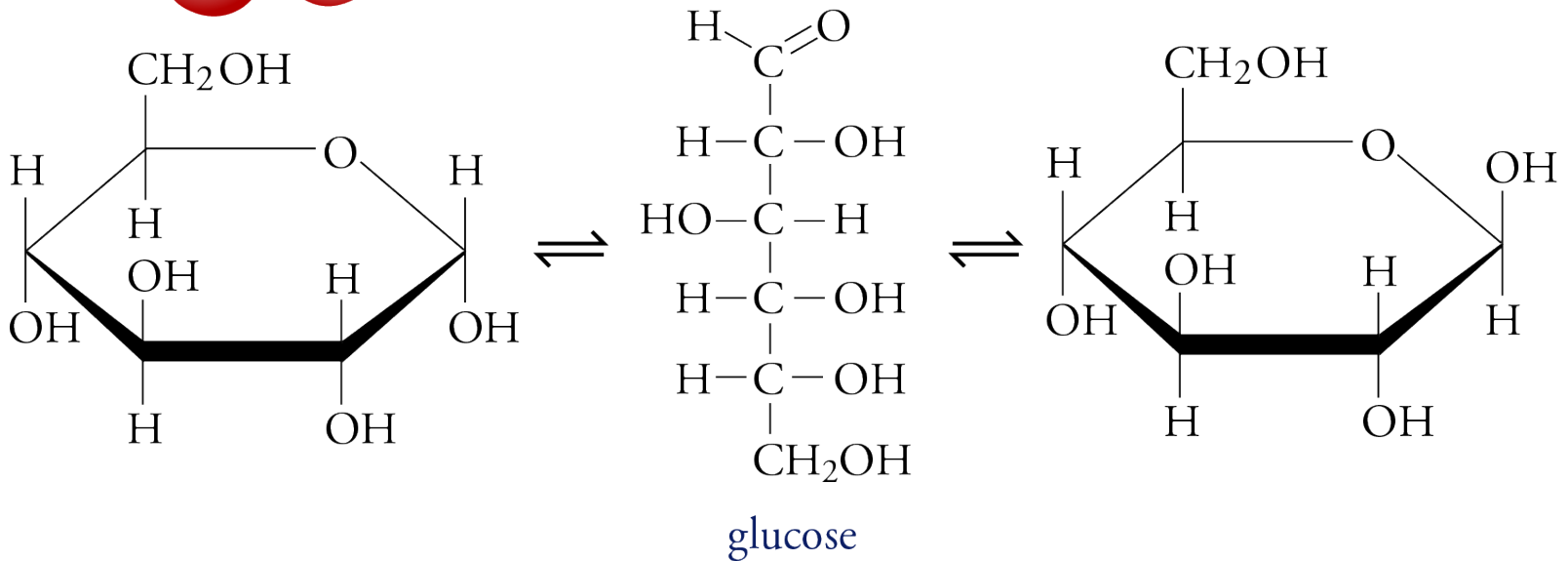
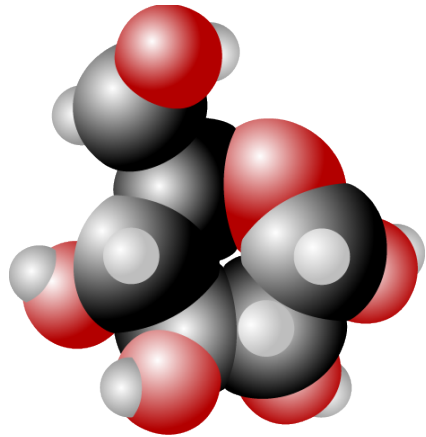
**Aldehyde  
functional  
group**



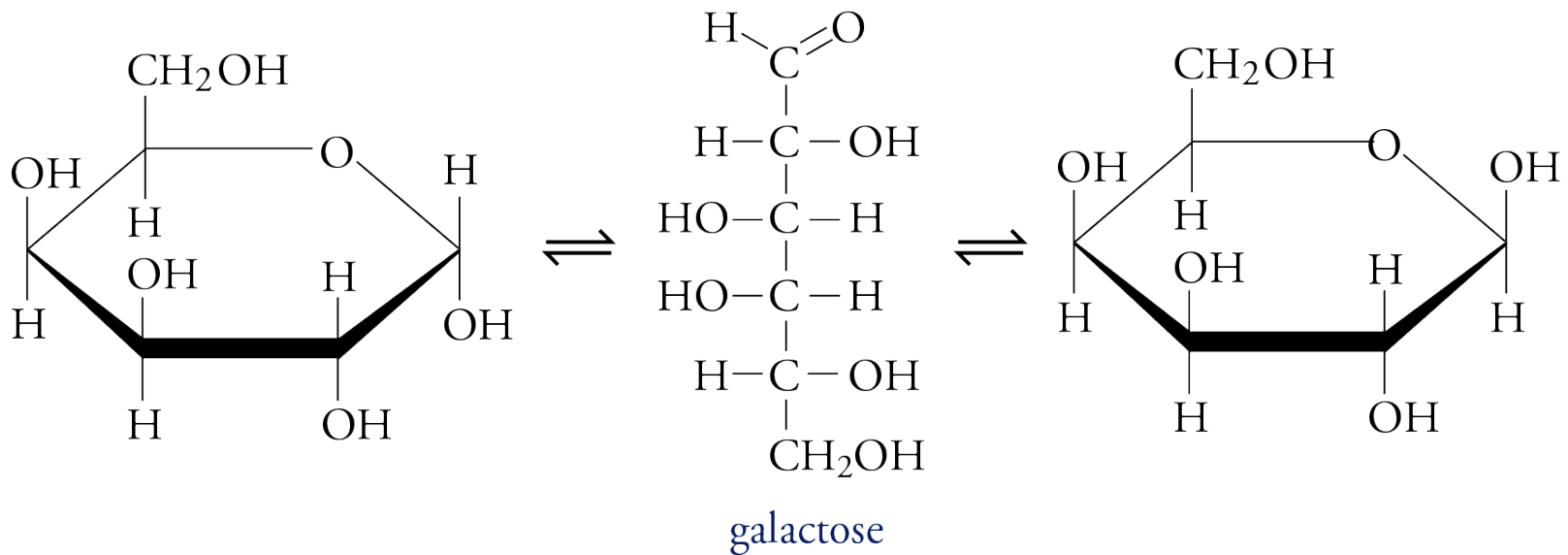
Galactose

**Difference  
between  
glucose and  
galactose**

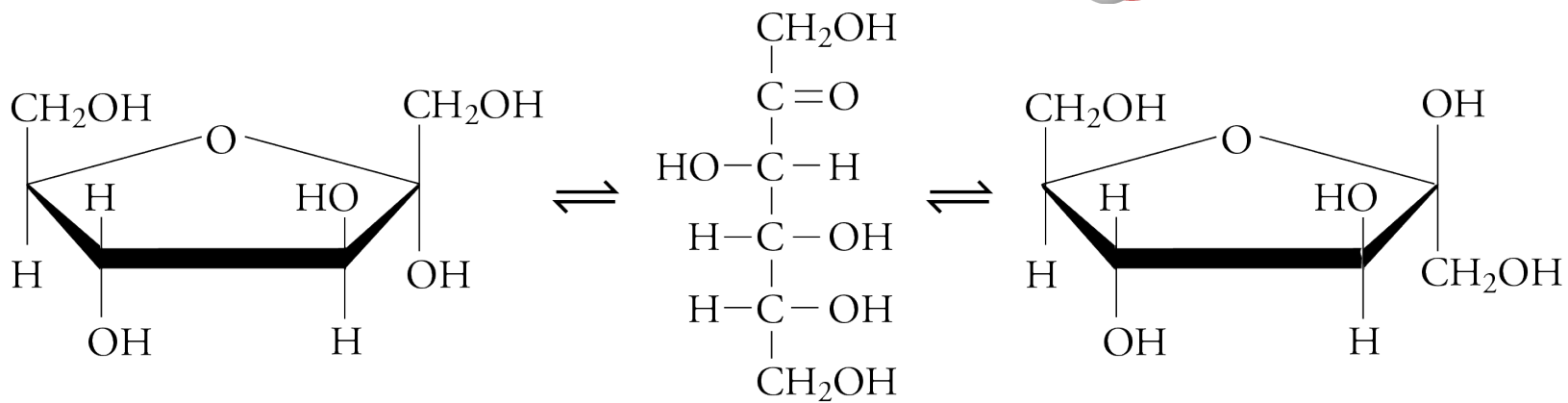
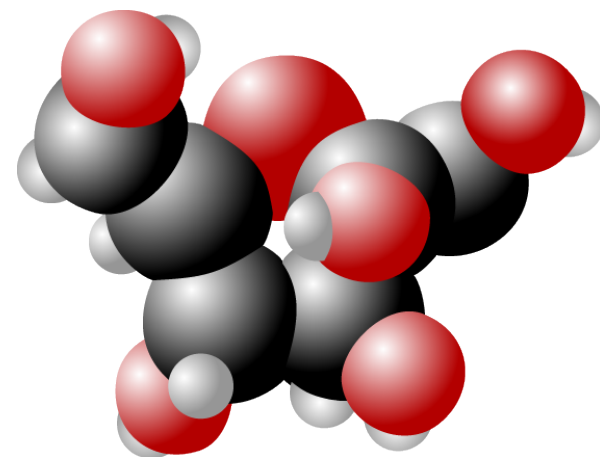
# Glucose



# Galactose

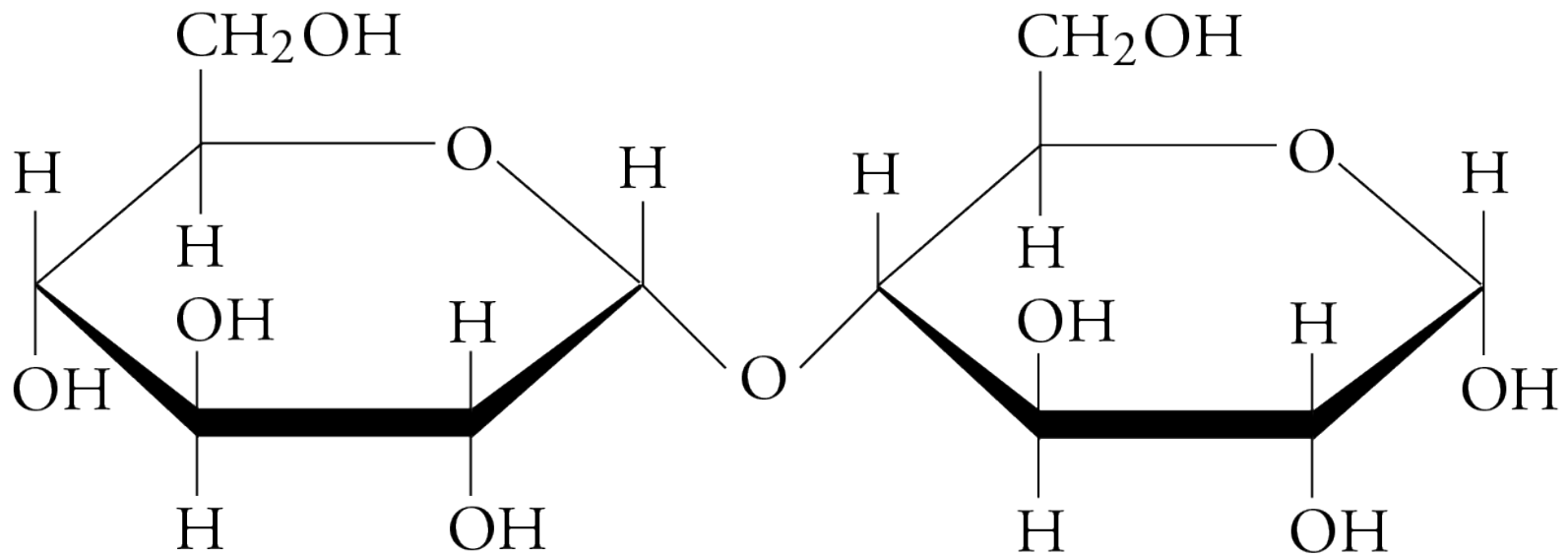


# Fructose



Fructose

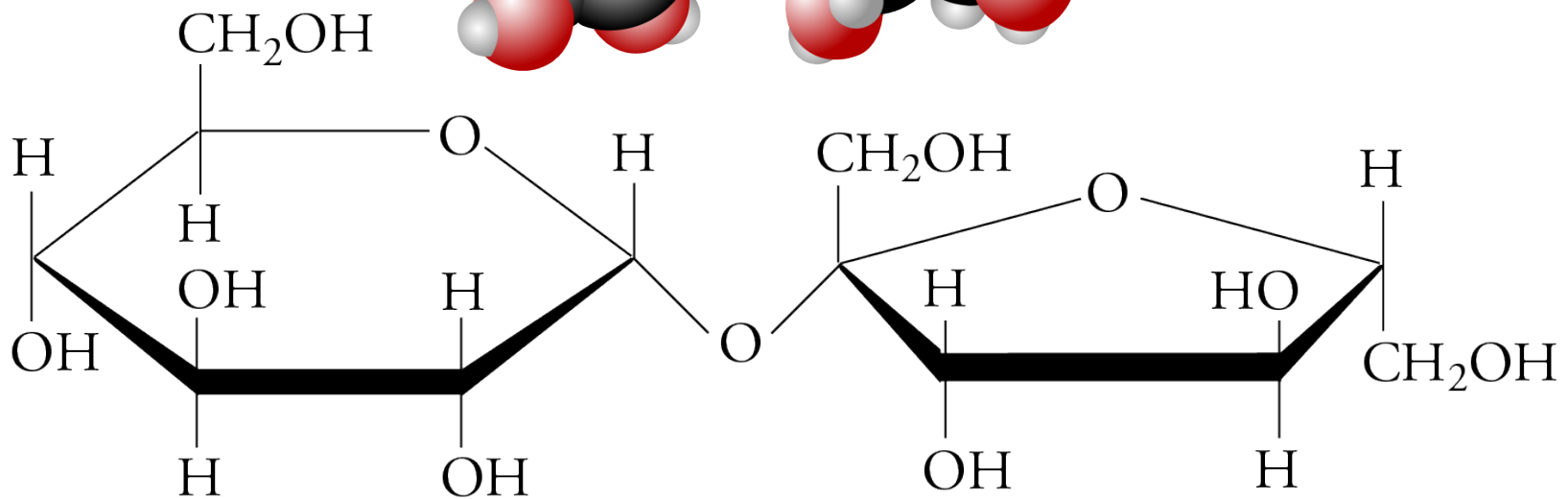
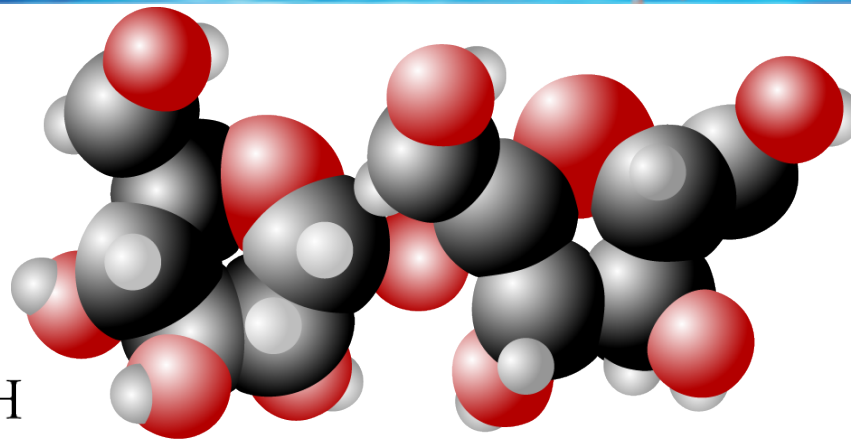
# Maltose



Maltose (glucose and glucose)

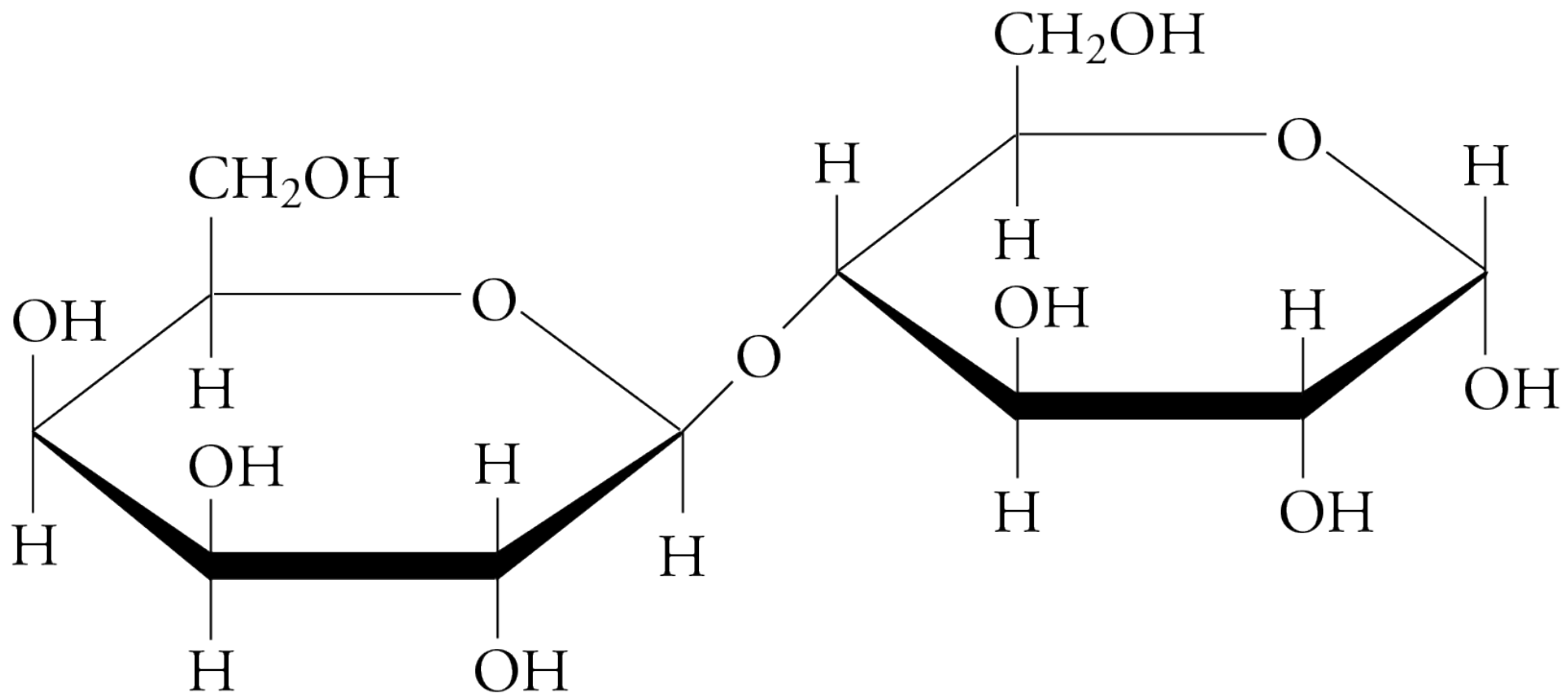


# Sucrose



Sucrose (glucose and fructose)

# Lactose



Lactose (galactose and glucose)

# Polysaccharides



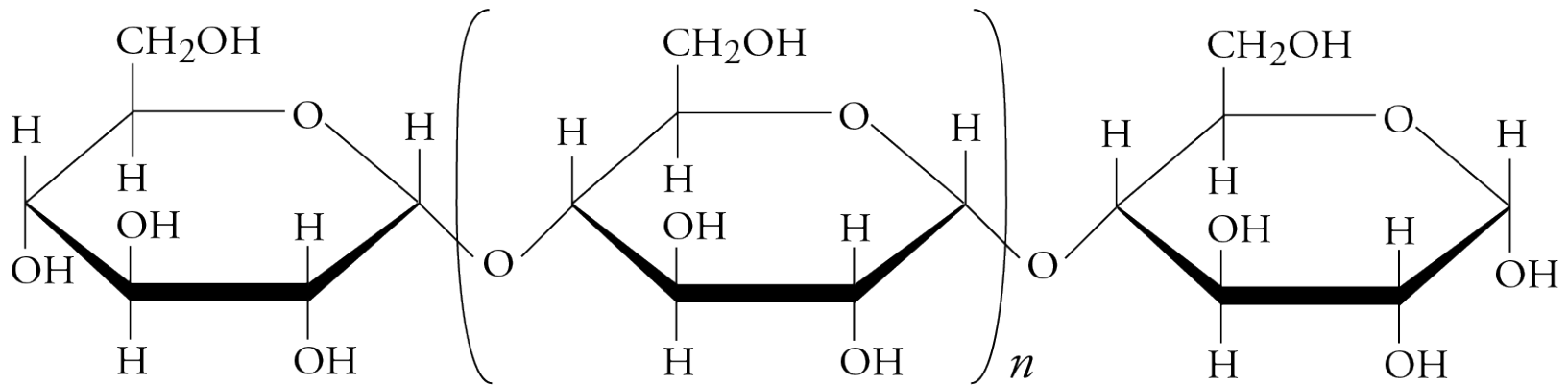
- Starches are polysaccharides (polymers) composed of long chains of glucose molecules (monomers) linked together by alpha linkages.
  - **Polymers** are large molecules composed of simpler repeating units called **monomers**.
- Cellulose is a polysaccharide composed of long chains of glucose molecules linked together by beta linkages.

# Plant and Animal Starches



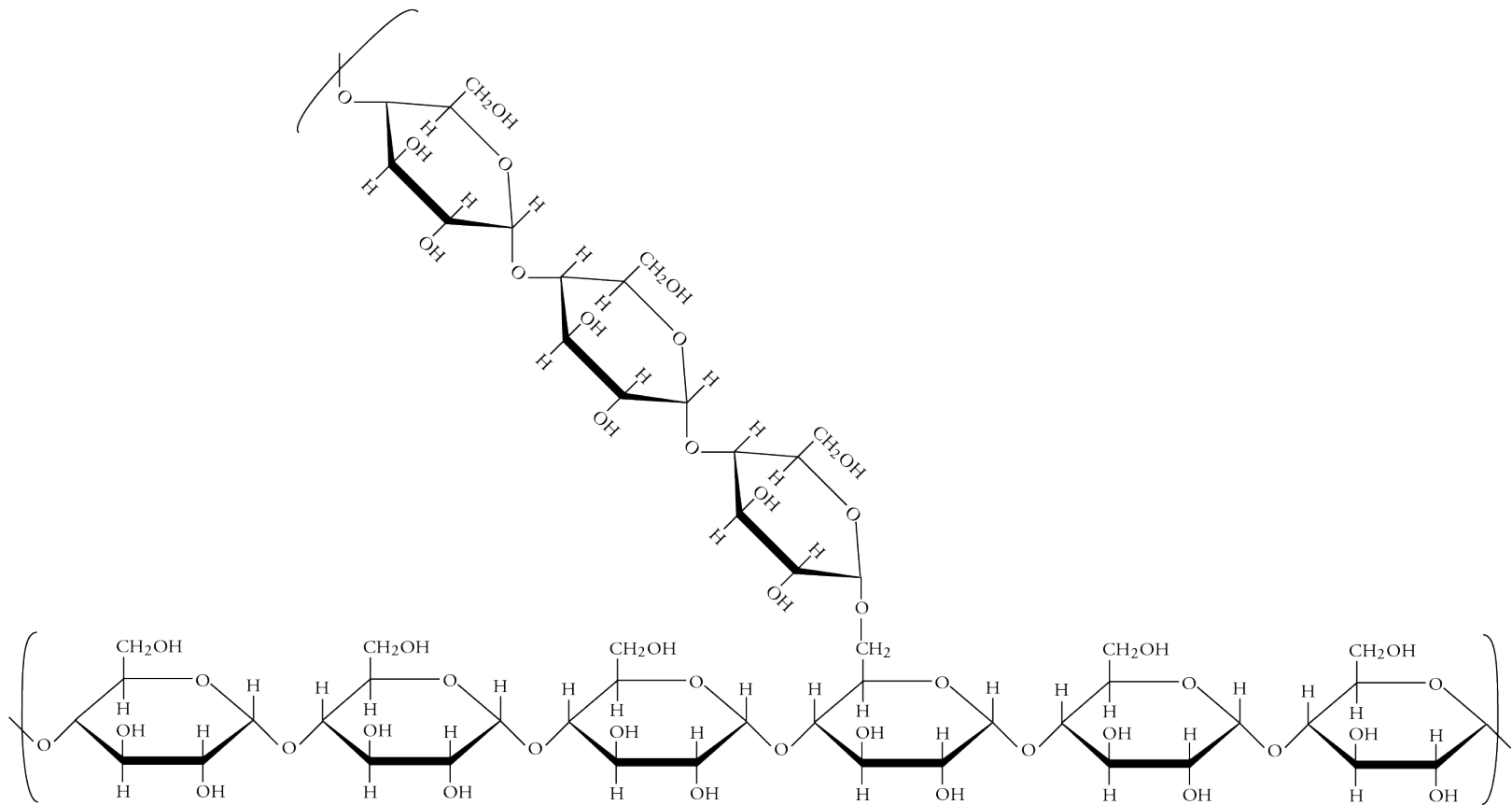
- Plant Starch
  - Amylose with long straight chains of glucose molecules.
  - Amylopectin with long chains of glucose molecules with periodic chains of glucose molecules coming off as branches from the straight chains.
- Animal Starch (Glycogen)
  - Similar to amylopectin but with generally shorter and more frequent branches.

# Amylose



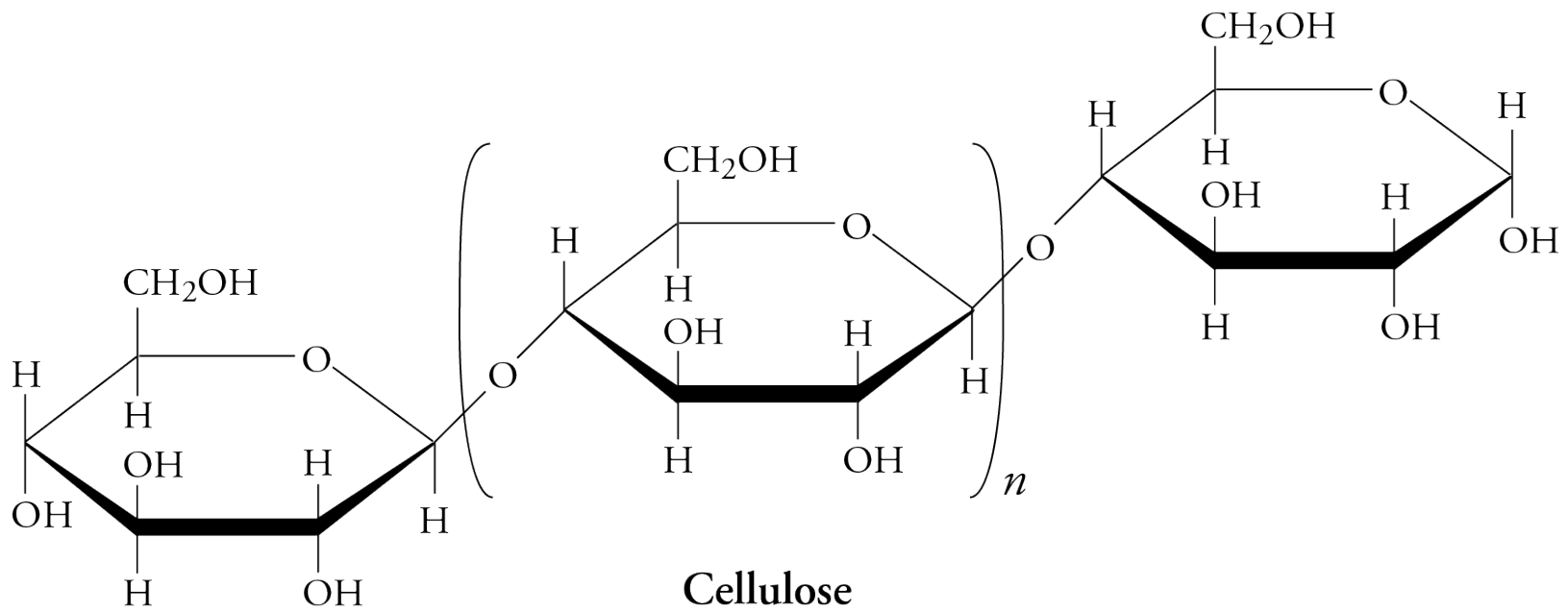
Amylose

# Amylopectin or Glycogen



Amylopectin

# Cellulose



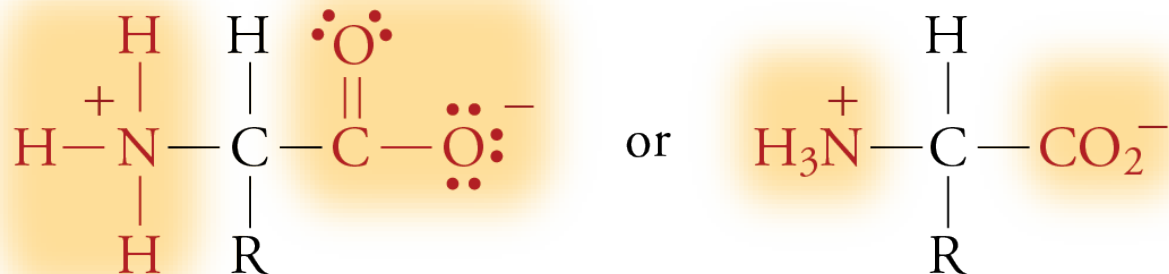
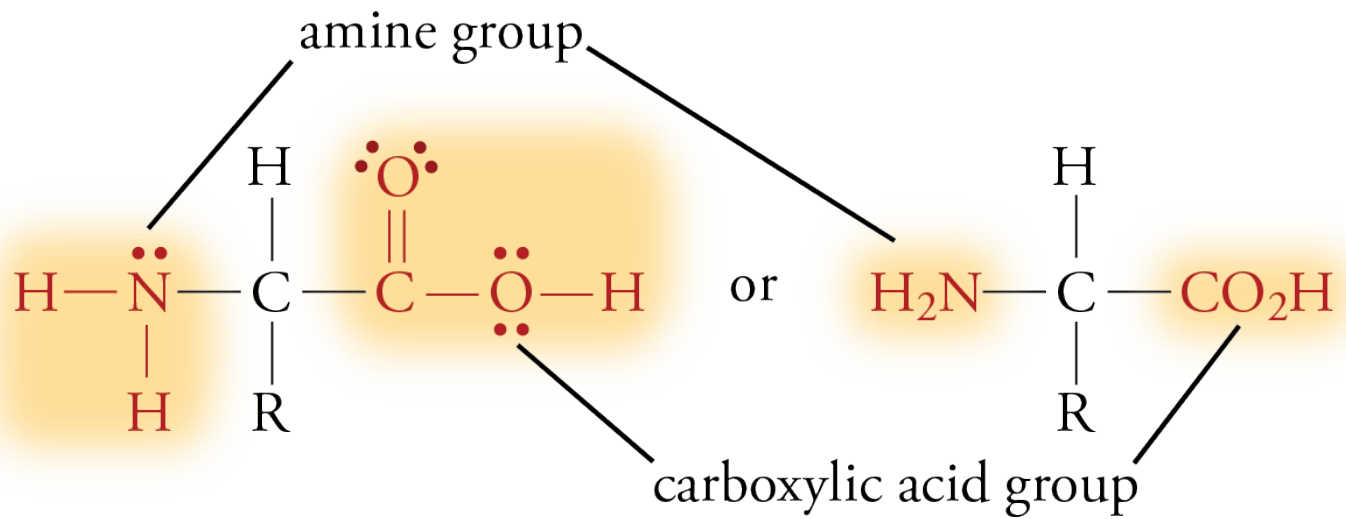
# Amino Acids



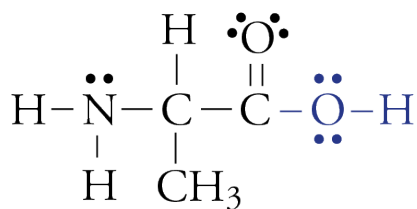
- Amino acids are the building blocks of proteins.
- There are hundreds of amino acids in nature, but only 20 of them are important for producing proteins.
- Each amino acid has an amine group and a carboxylic acid group separated by a carbon.
- One amino acid differs from another by a side chain connected to the central carbon.



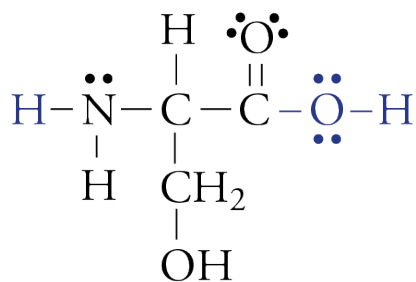
# Amino Acids



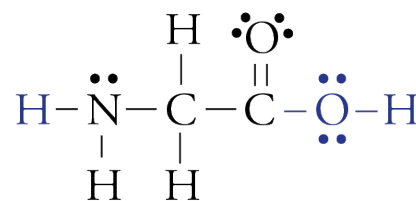
# Alanine, Serine, Glycine, and Cysteine



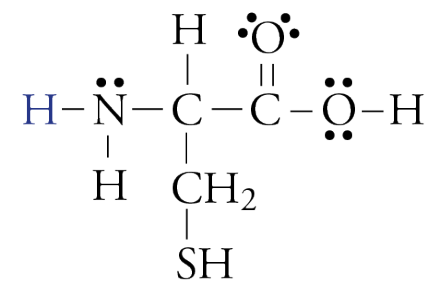
Alanine (Ala)



Serine (Ser)



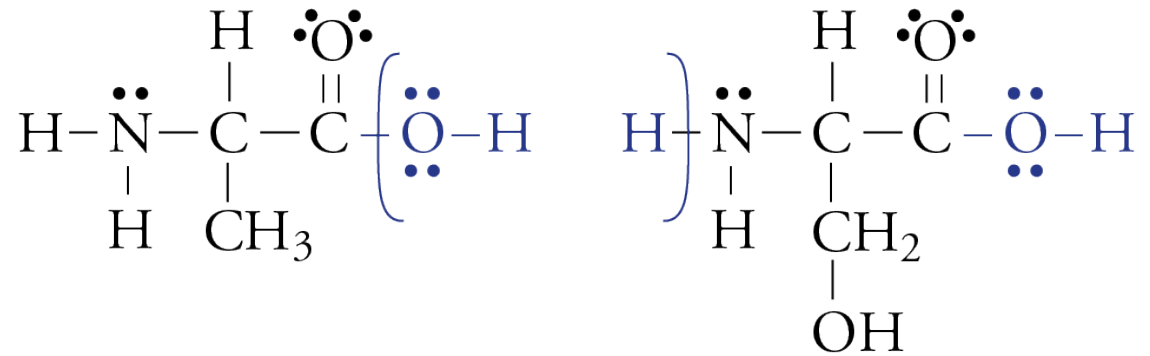
Glycine (Gly)



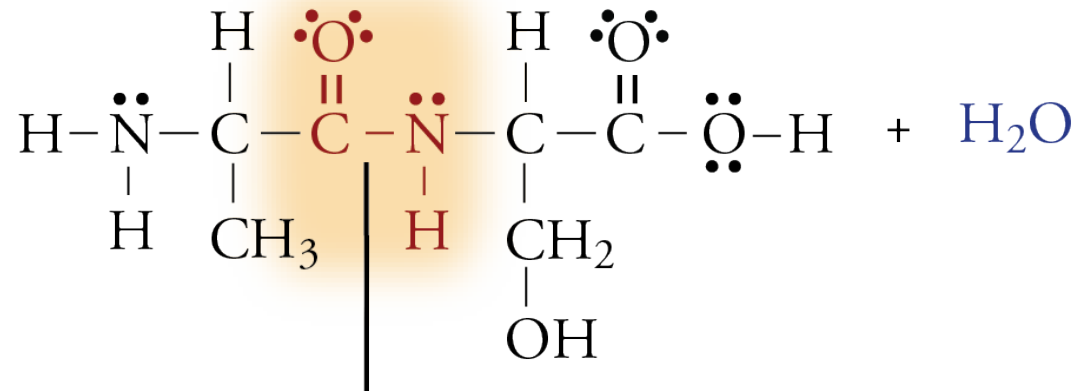
Cysteine (Cys)

# Protein Formation

- The amine group of one amino acid can react with the carboxylic group of another amino acid to form an amide group and link the amino acids together.
- In proteins, this amide linkage is called a peptide bond.

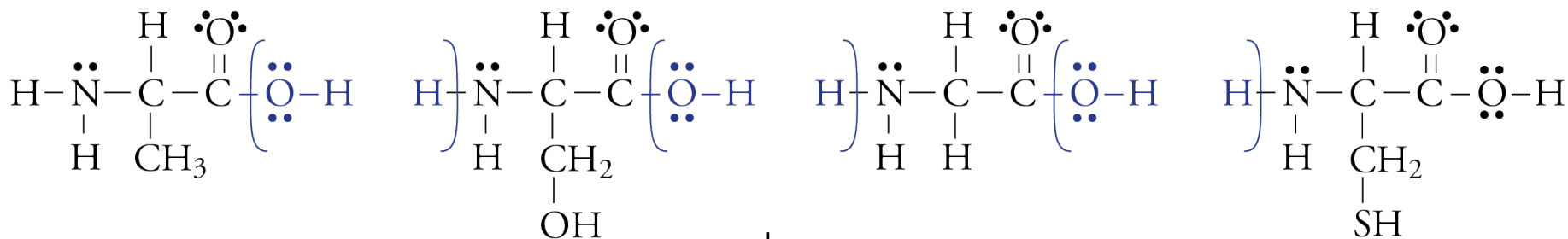


↓ Condensation reaction releases water

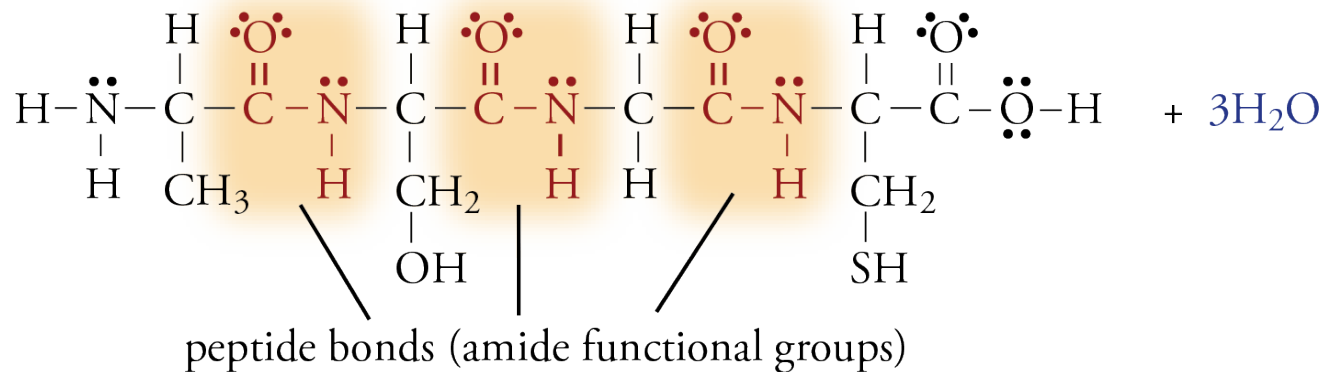


peptide bond (amide functional group)


# Formation of Ala-Ser-Gly-Cys



↓ Condensation reaction releases water



# Polypeptides and Proteins



- A chain of amino acids linked by peptide bonds would be called a **polypeptide** or often just a peptide.
- If the polypeptide has more than about 50 amino acids, we called it a **protein**.

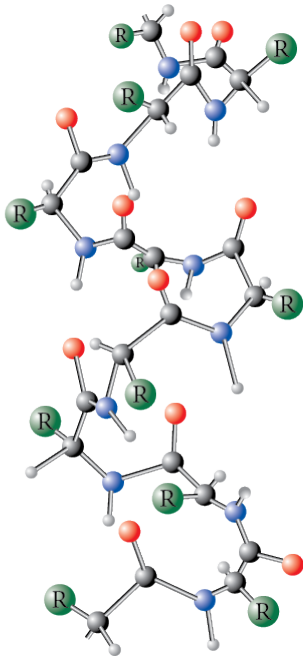
# Primary and Secondary Protein Structures



- **Primary Structure** = the sequence of amino acids in the protein
- The arrangement of atoms that are close to each other in the polypeptide chain is called the **secondary structure** of protein.
  - Three types
    - $\alpha$ -helix
    - $\beta$ -sheet
    - irregular

# $\alpha$ -helix – Secondary Structure

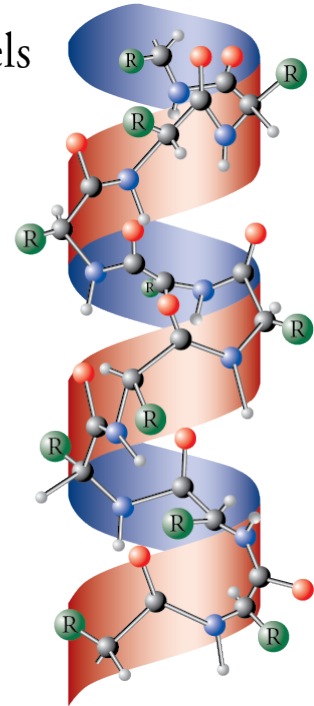
Ball-and-stick model of a portion of the  $\alpha$ -helical secondary structure of a protein molecule



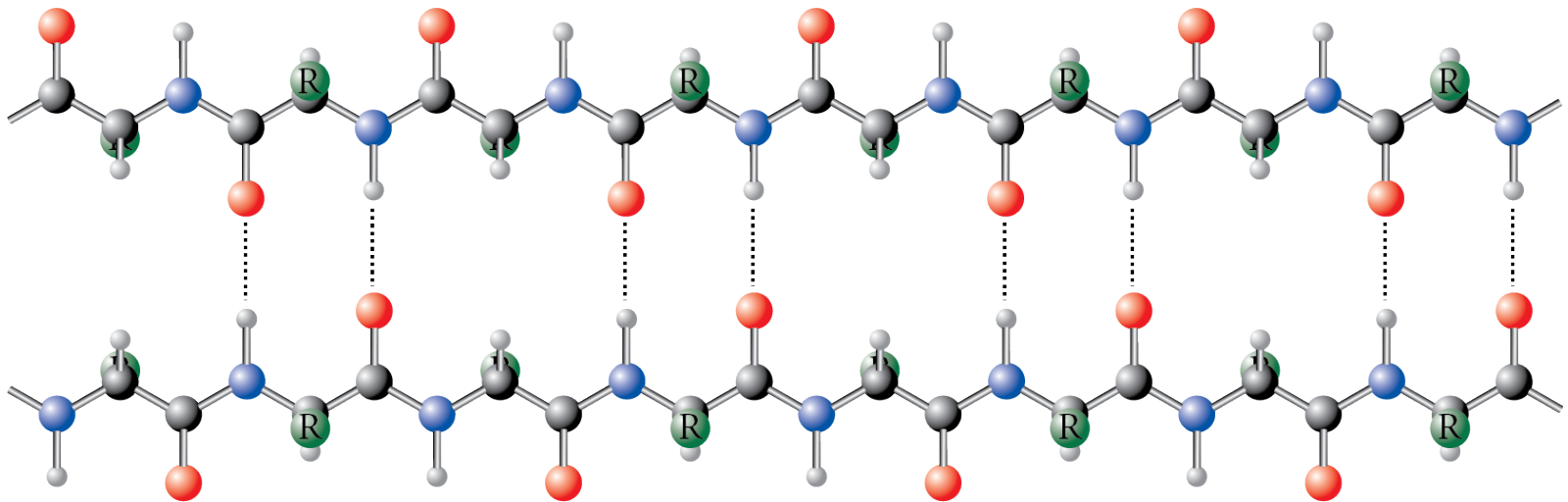
This ribbon model shows the general arrangement of atoms in a portion of the  $\alpha$ -helical secondary structure of a protein molecule.



The two models superimposed

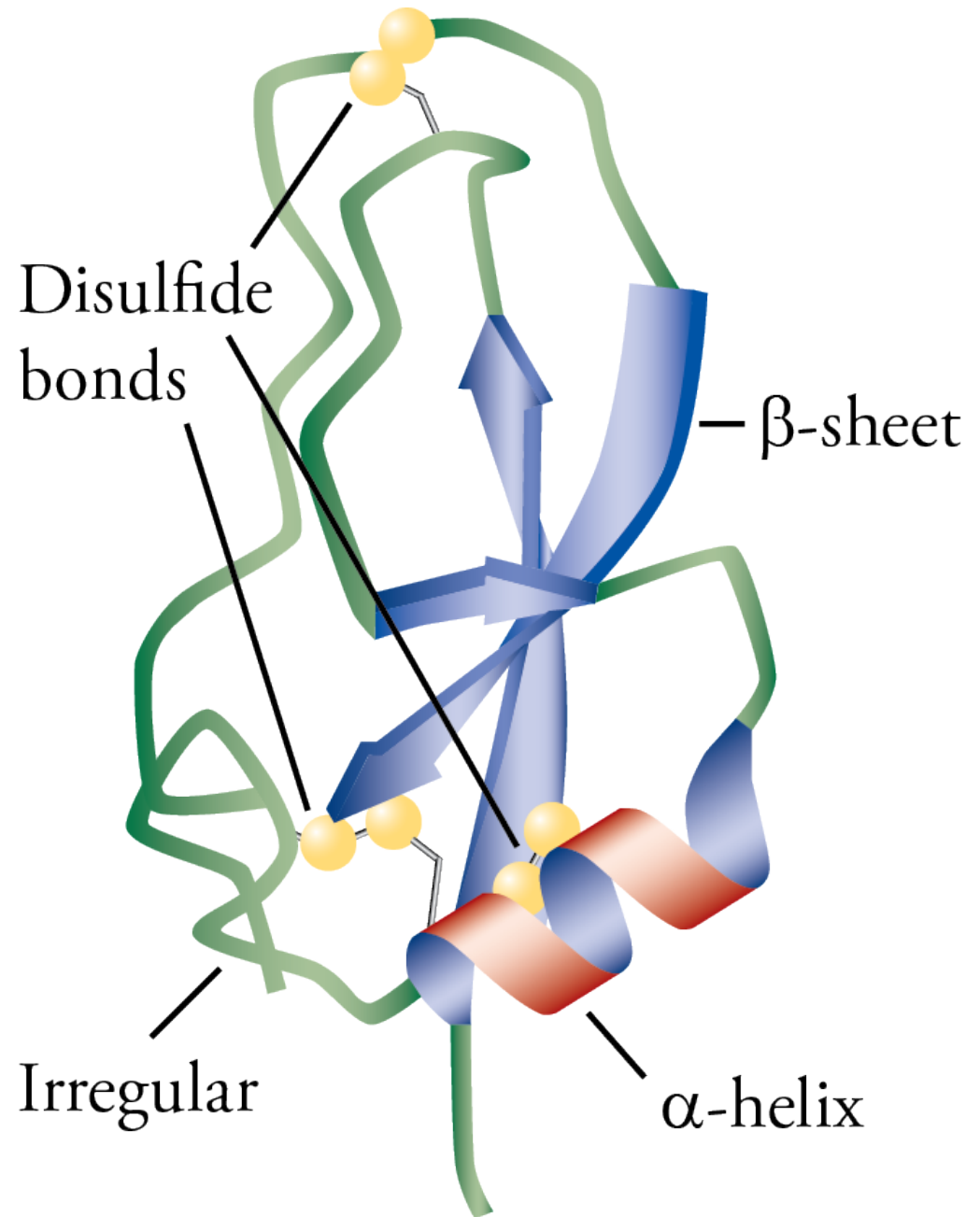


# $\beta$ -Sheet Secondary Structure





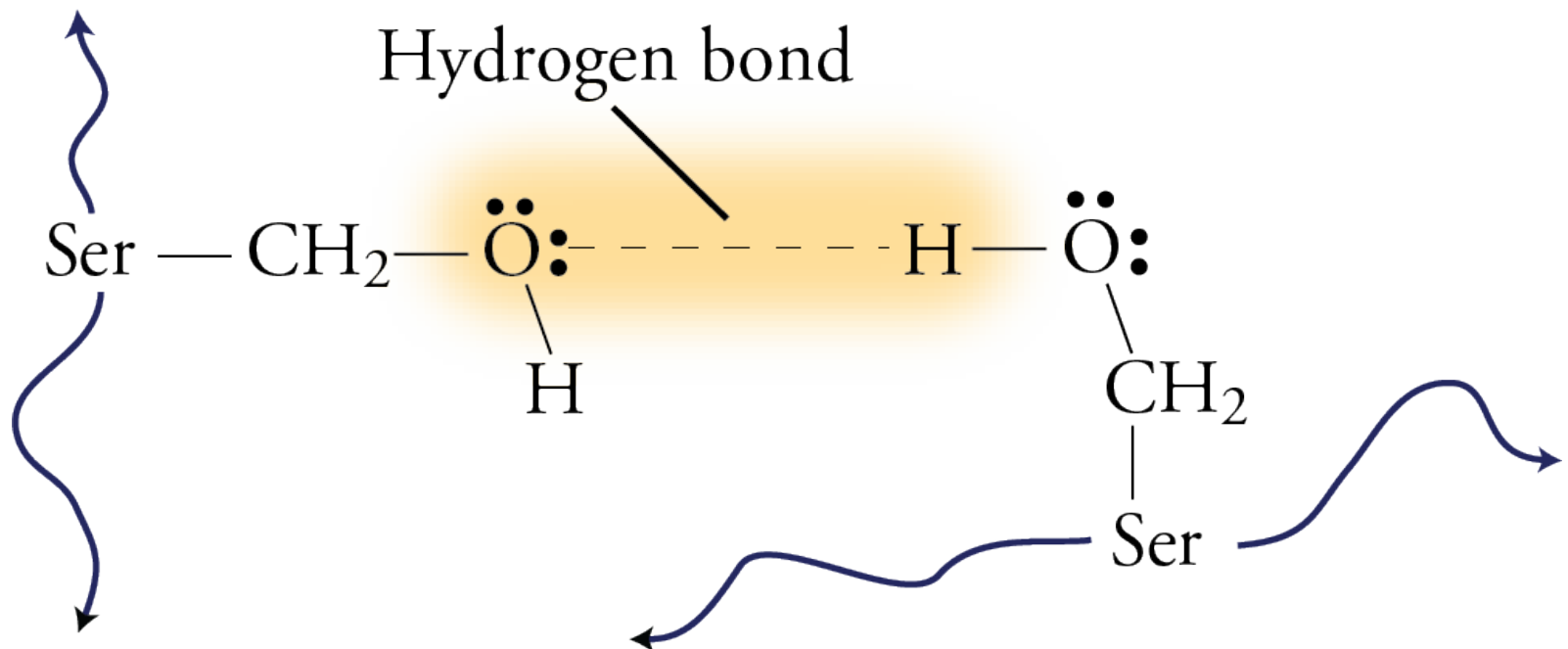
# The Ribbon Structure of the Protein BPTI



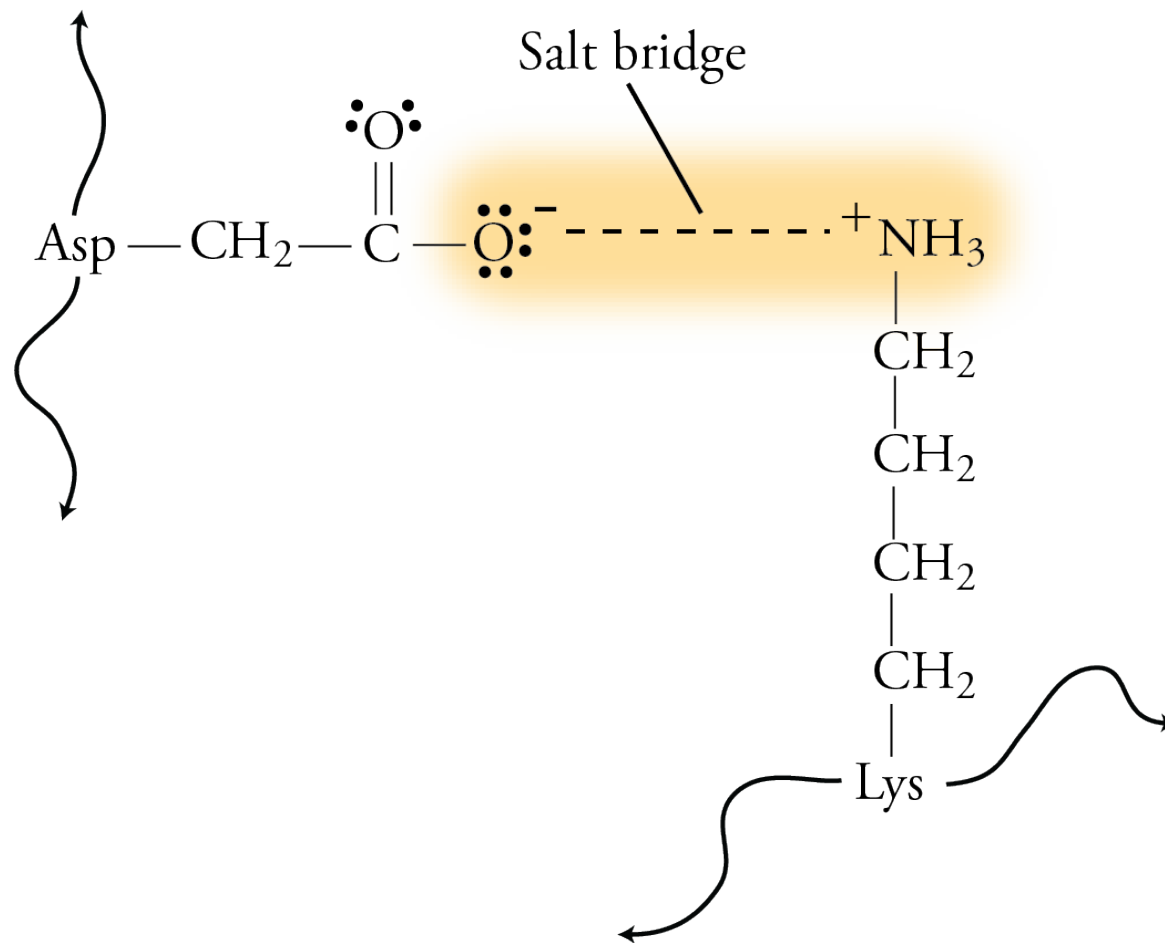
# Tertiary Protein Structure

- The very specific overall shape of the protein called its ***tertiary structure***.
- The protein chain is held in its tertiary structure by interactions between the side chains of its amino acids.
  - Hydrogen bonds
  - Salt bridges
  - Disulfide bonds

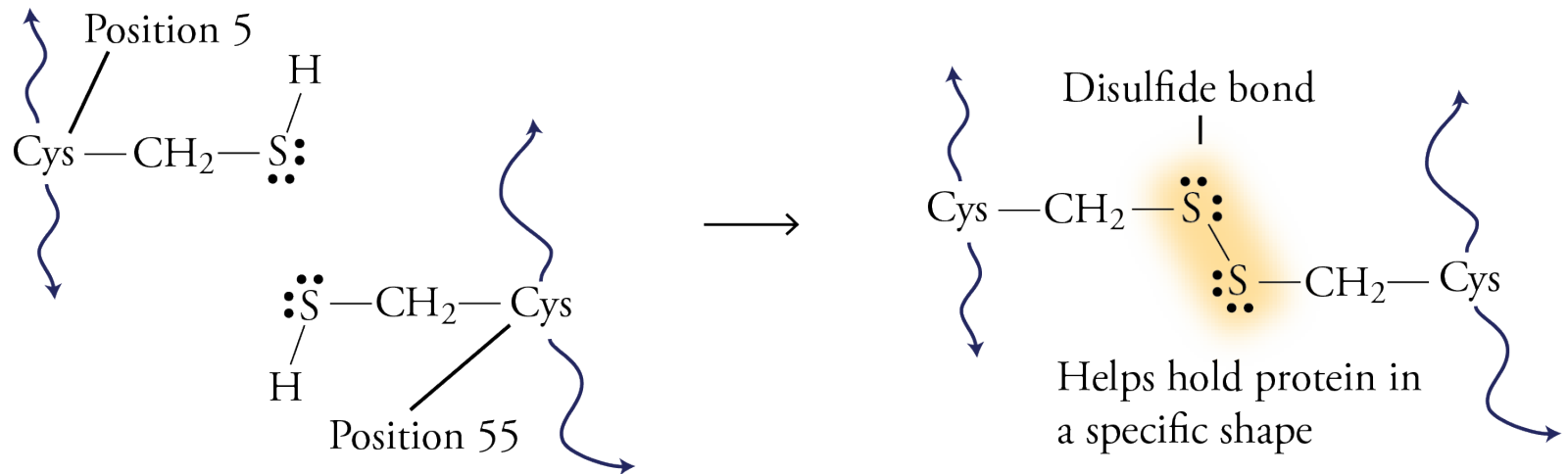
# Hydrogen Bonding in Proteins



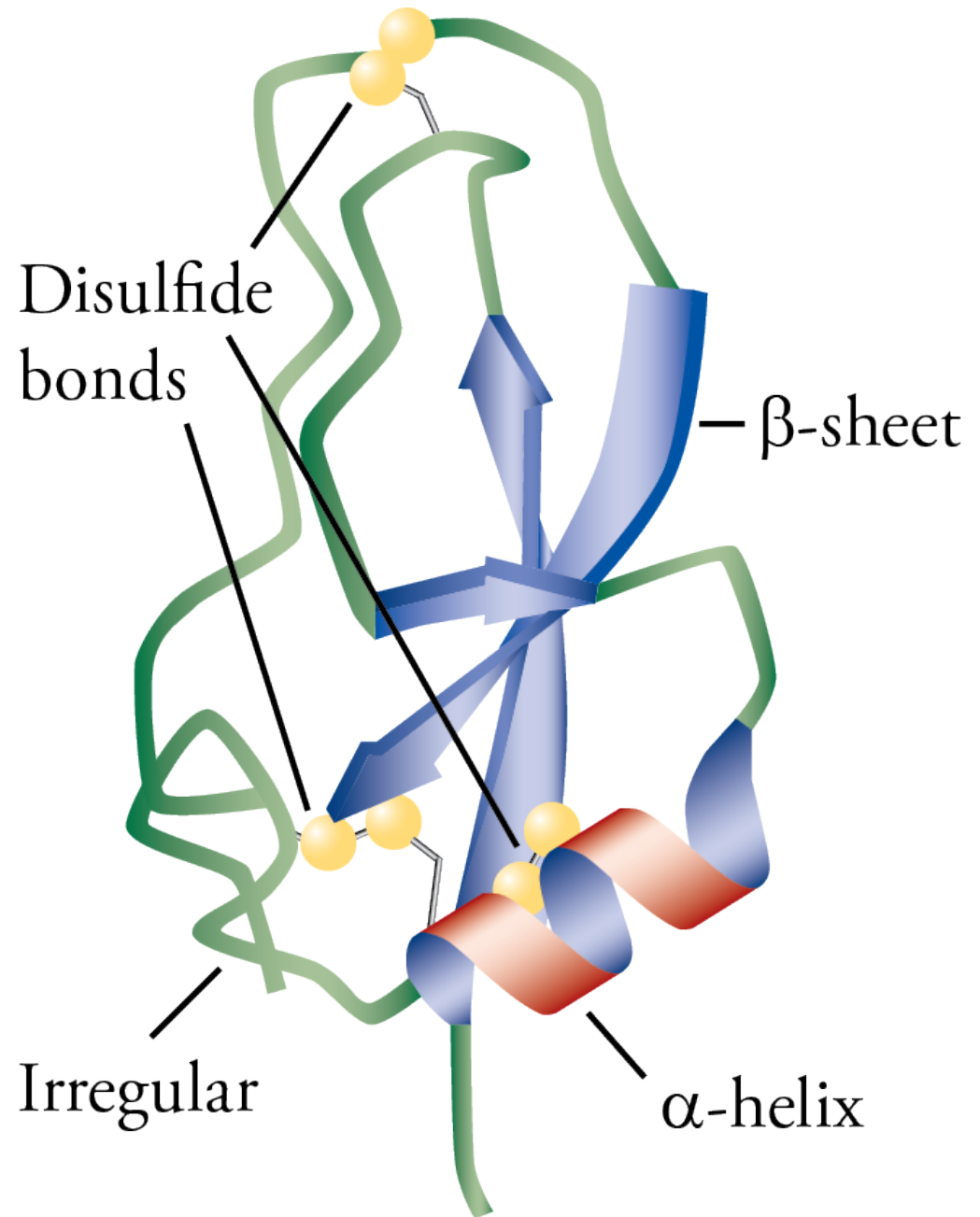
# Salt Bridge in Proteins



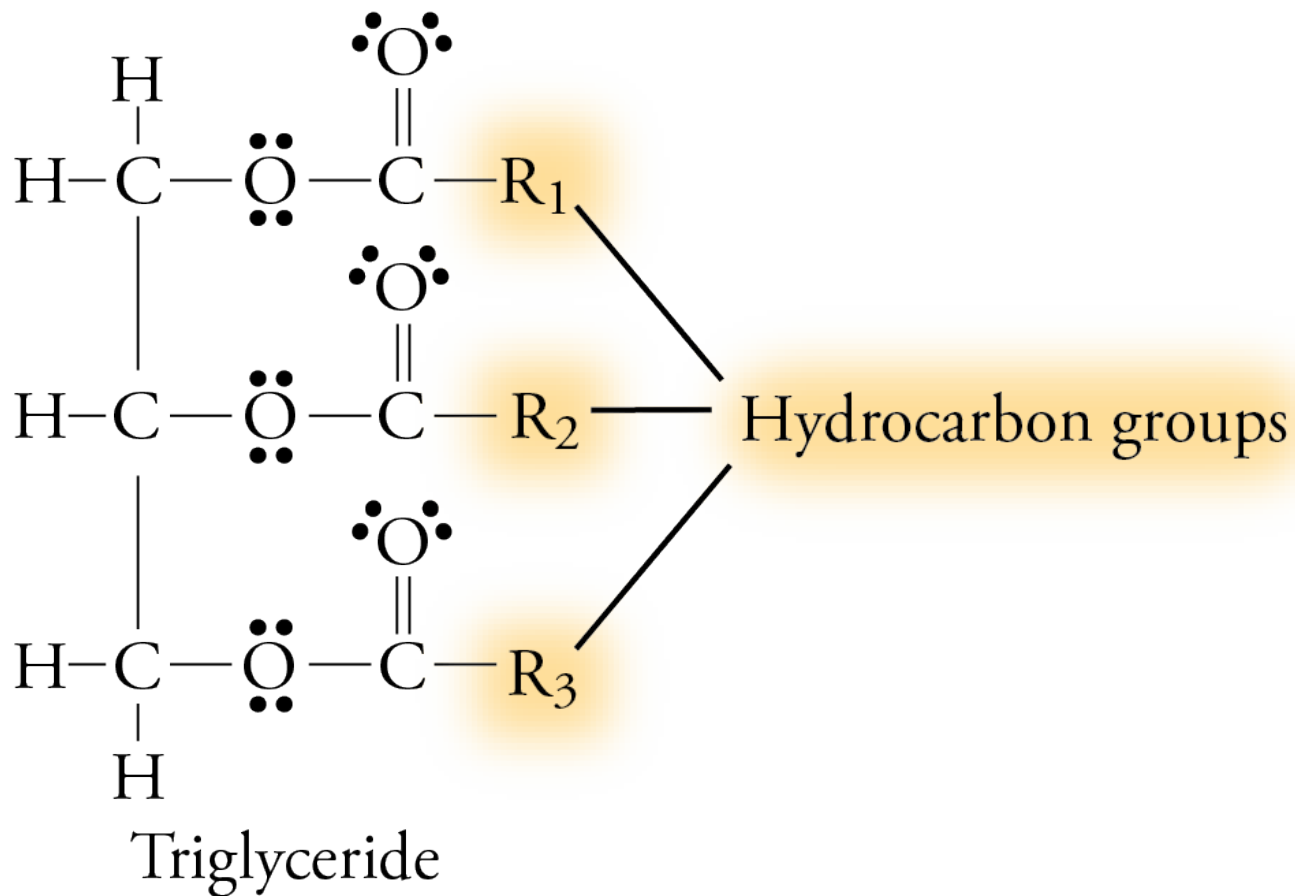
# Disulfide Bonds in Proteins



# The Ribbon Structure of the Protein BPTI



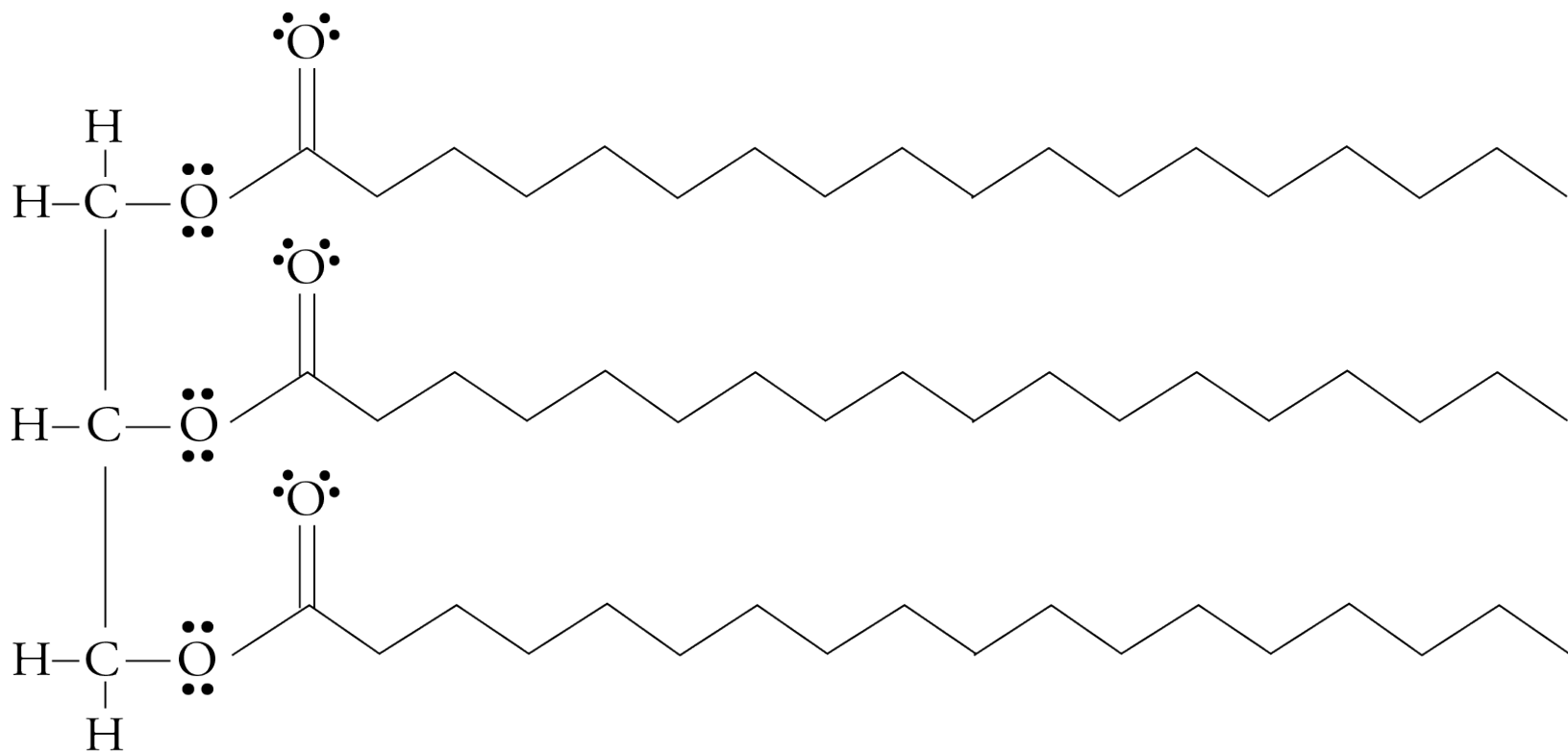
# Triglycerides (Fats and Oils)





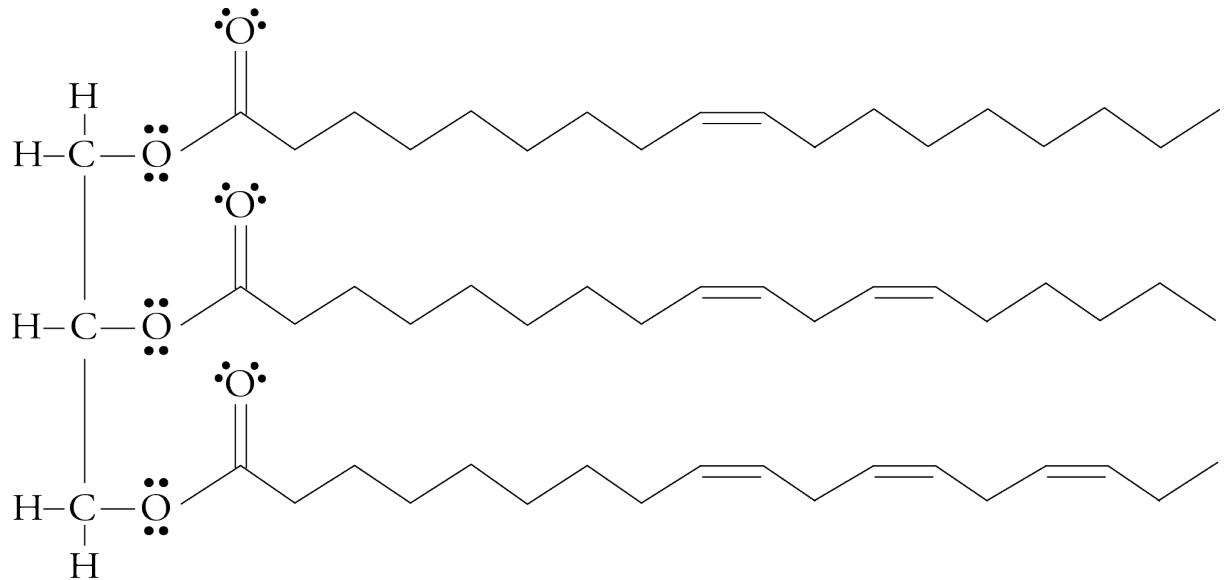


# Tristearin – Line Drawing



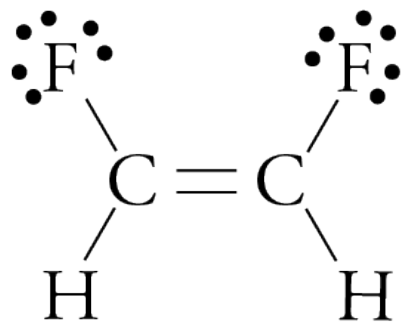
# Unsaturated Triglyceride

Liquid triglycerides are rich in carbon-carbon double bonds.

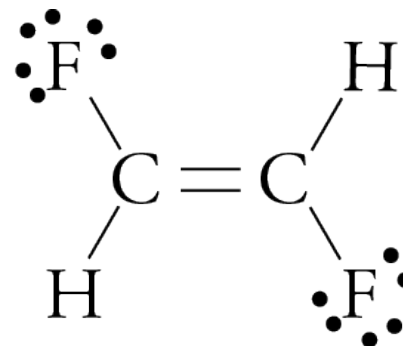


# Cis and Trans

- When there is a double bond between two carbon atoms and when like groups are on different carbon atoms and the same side of the double bond, the arrangement is called ***cis***.
- When the like groups are on opposite sides of the double bond the arrangement is called ***trans***.

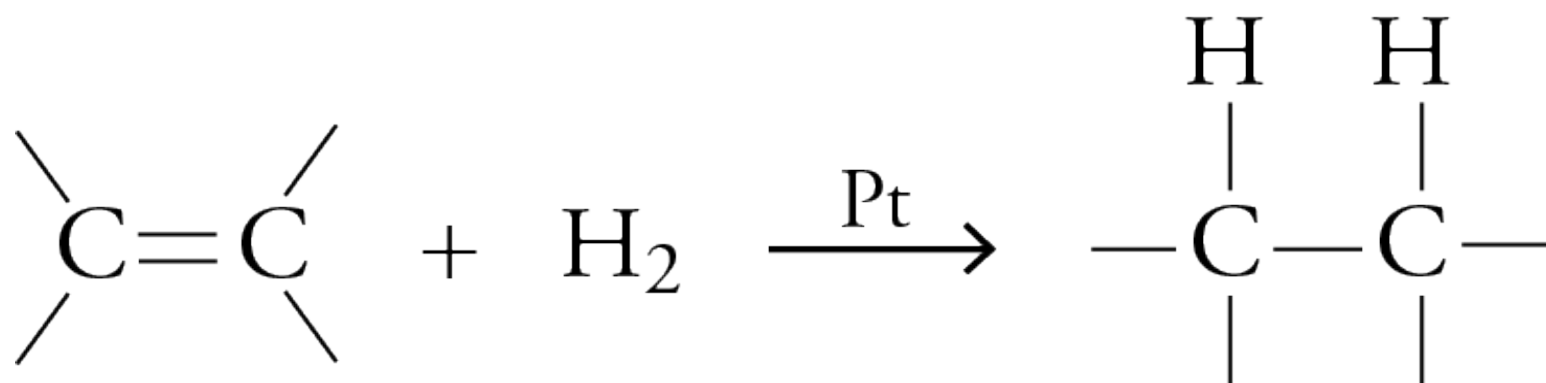


cis-1,2-difluoroethene

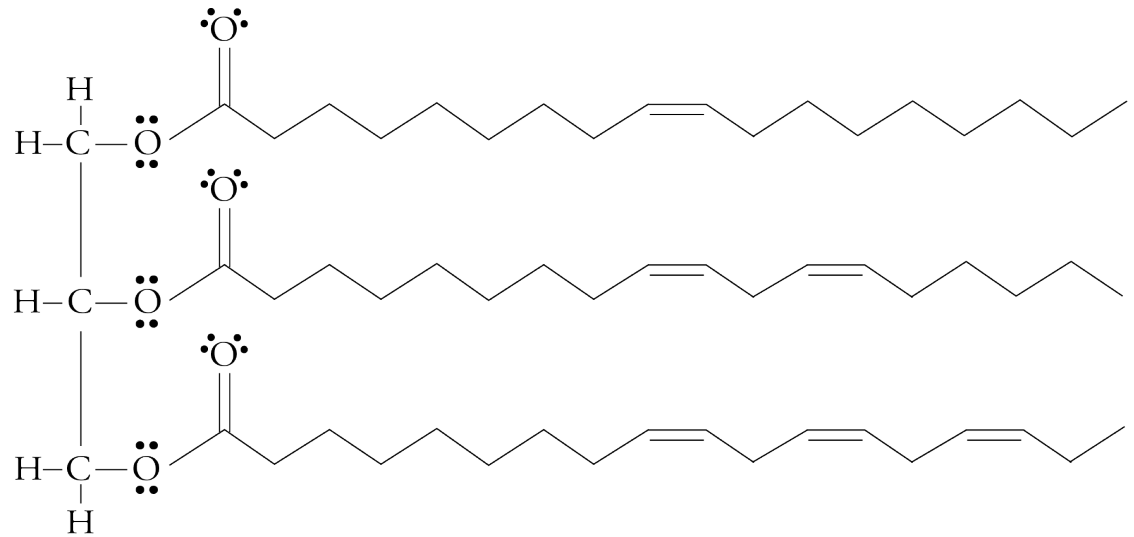


trans-1,2-difluoroethene

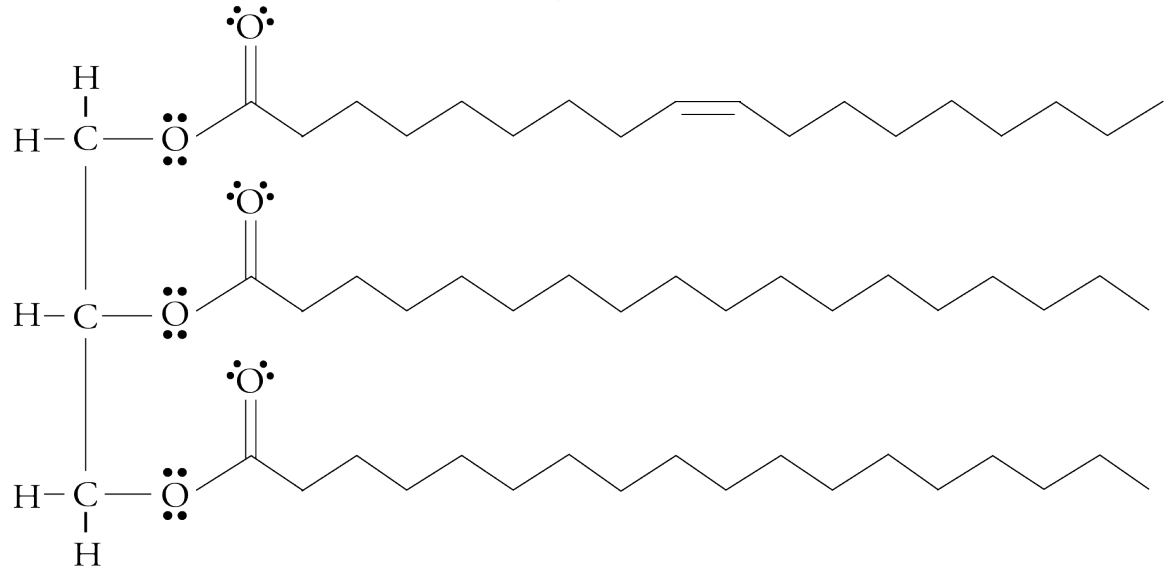
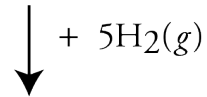
# Hydrogenation



# Hydrogenation - Example



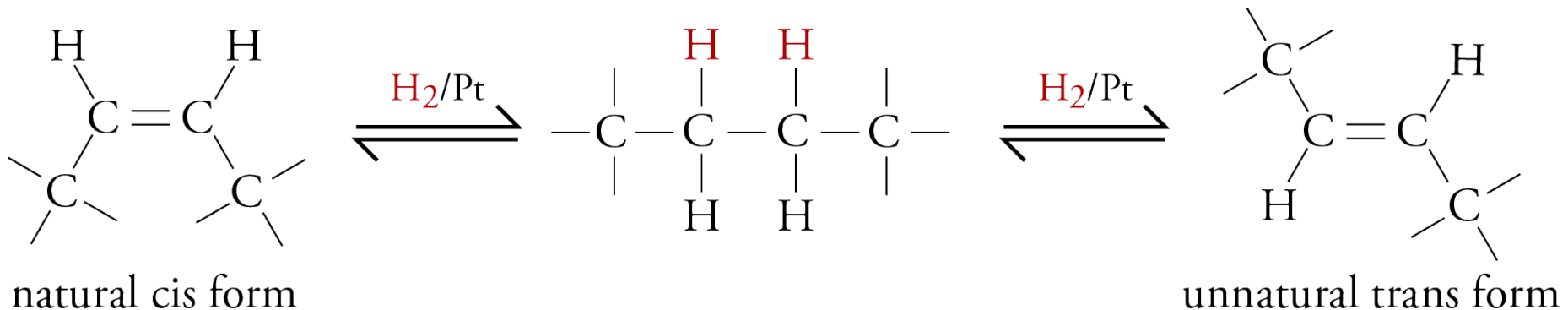
Typical vegetable oil molecule - liquid unsaturated triglyceride



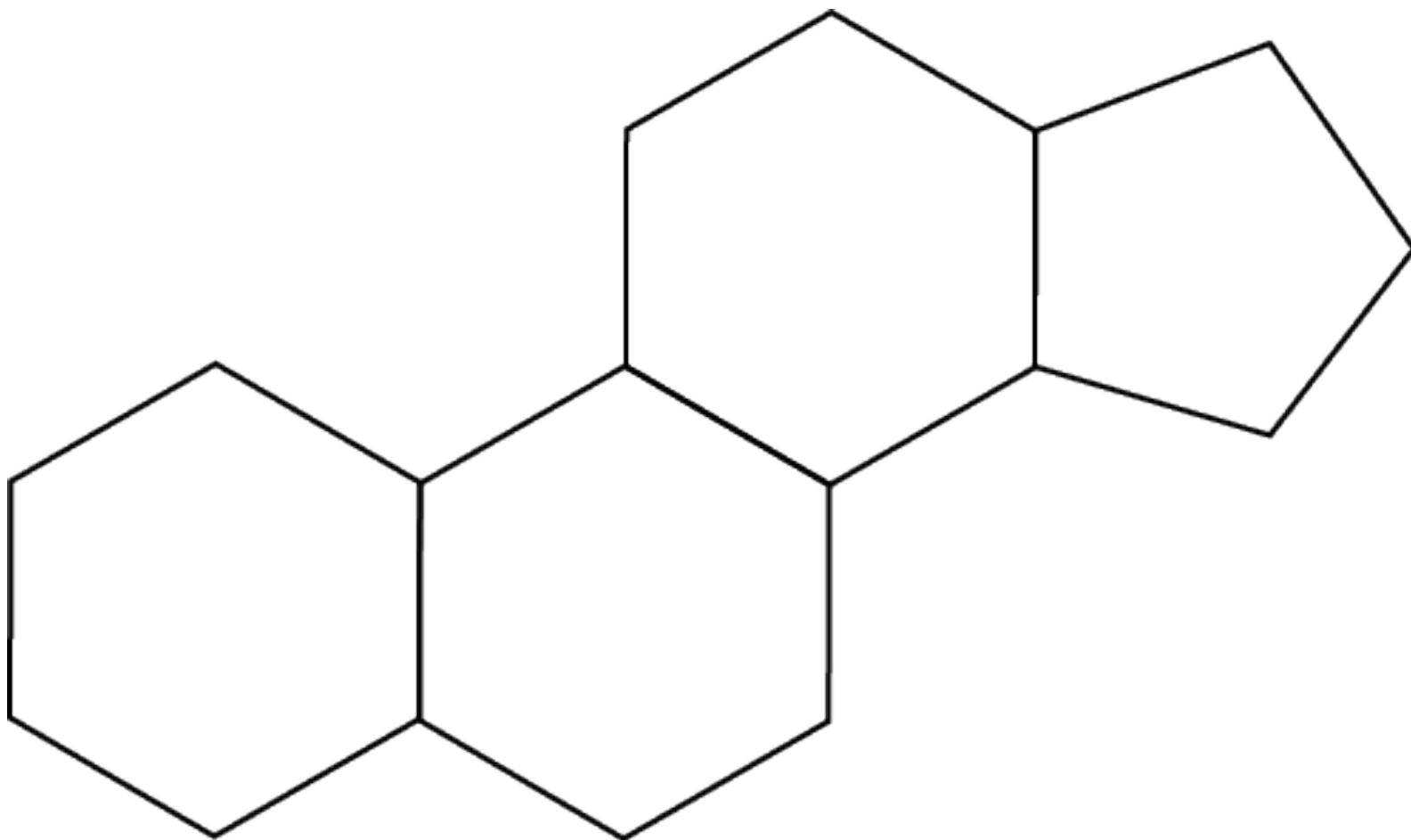
Typical molecule in margarine - solid partially hydrogenated triglyceride

# Trans Fats

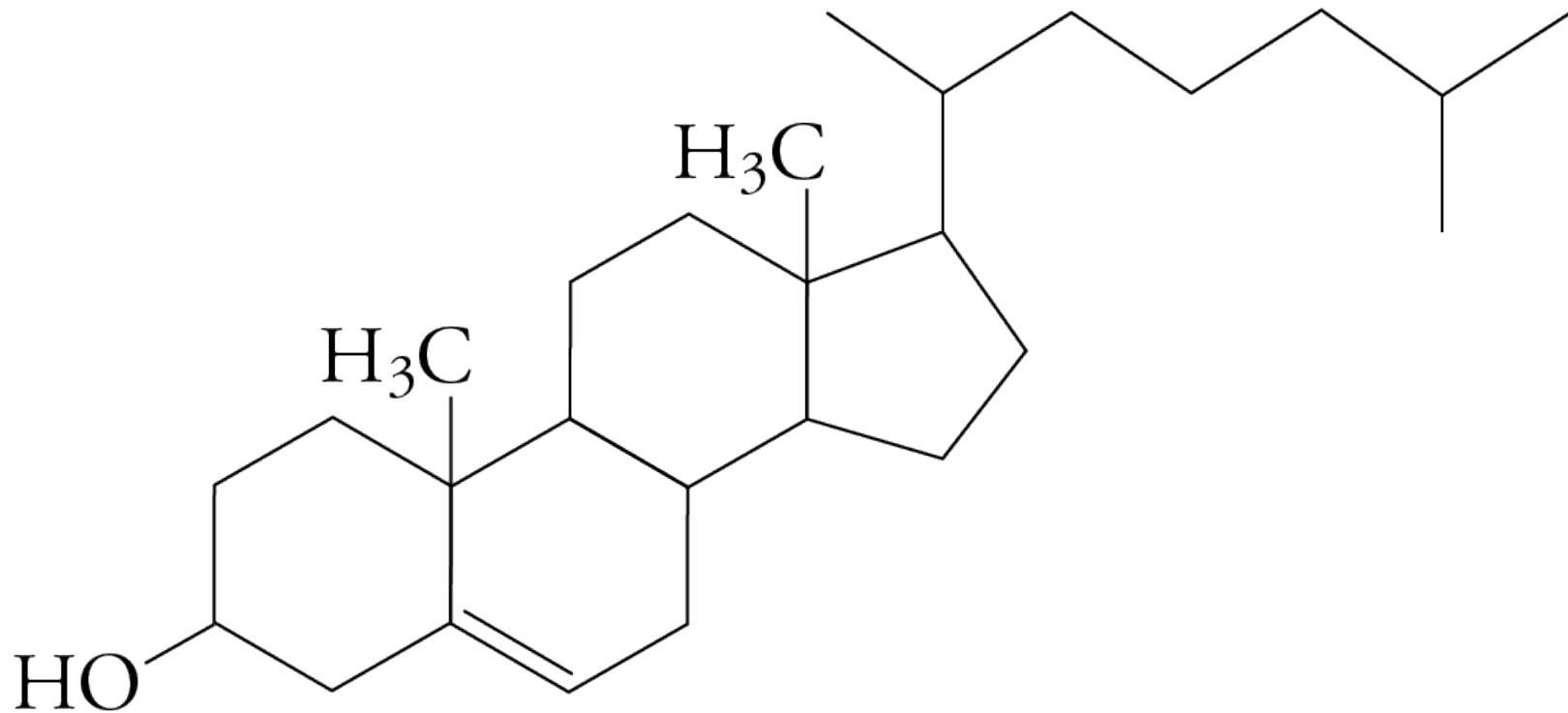
- Natural unsaturated triglycerides have the groups attached to the double-bonded carbon atoms in the cis arrangement.
- Hydrogenation is reversible.
- When the double bond is reformed, it is more likely to form the more stable trans form than the less stable cis form.
- Therefore, partially hydrogenated vegetable oils contain trans fats, which are considered to be damaging to your health.



# Steroid Skeleton



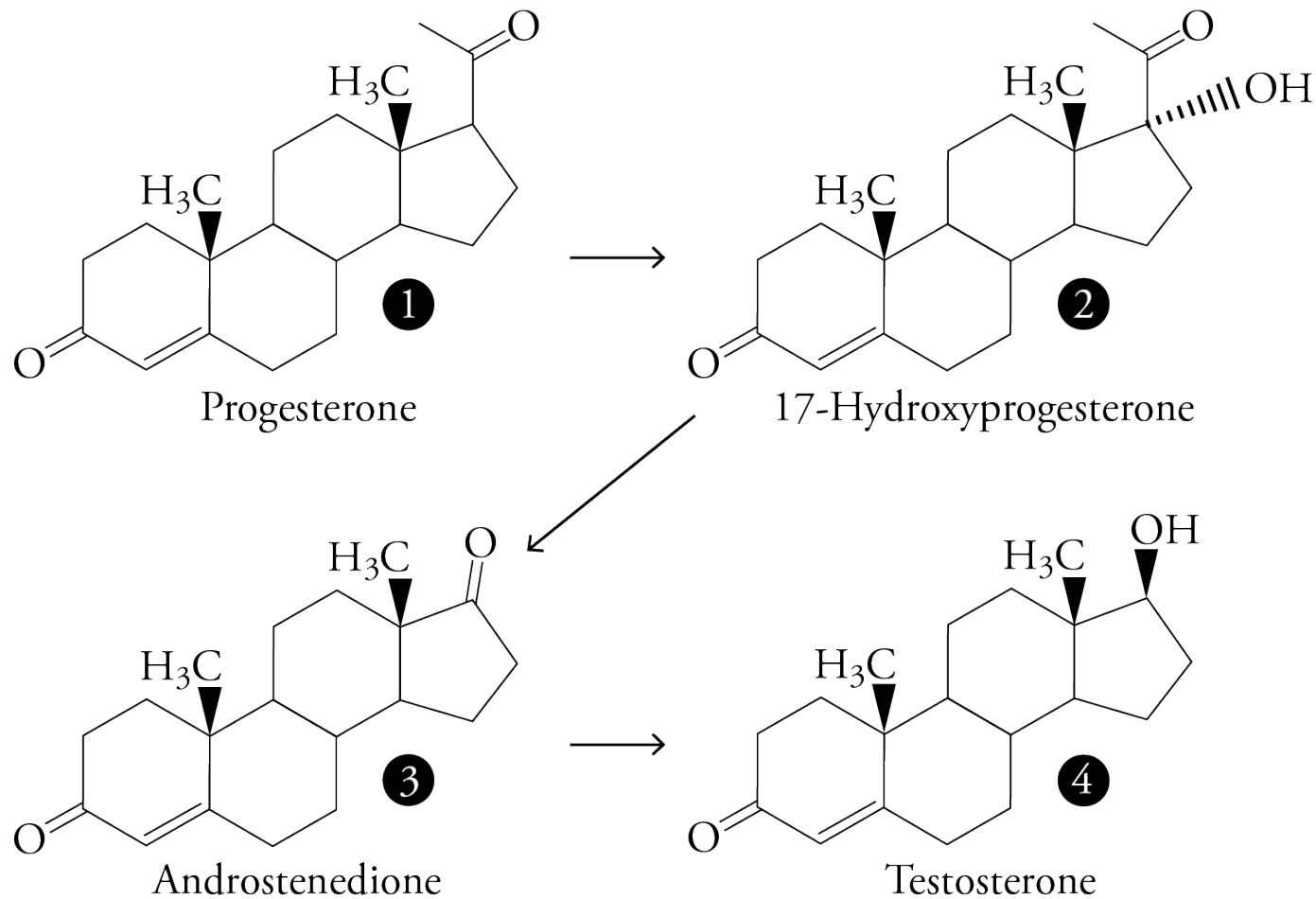
# Cholesterol



cholesterol



# Testosterone Formation

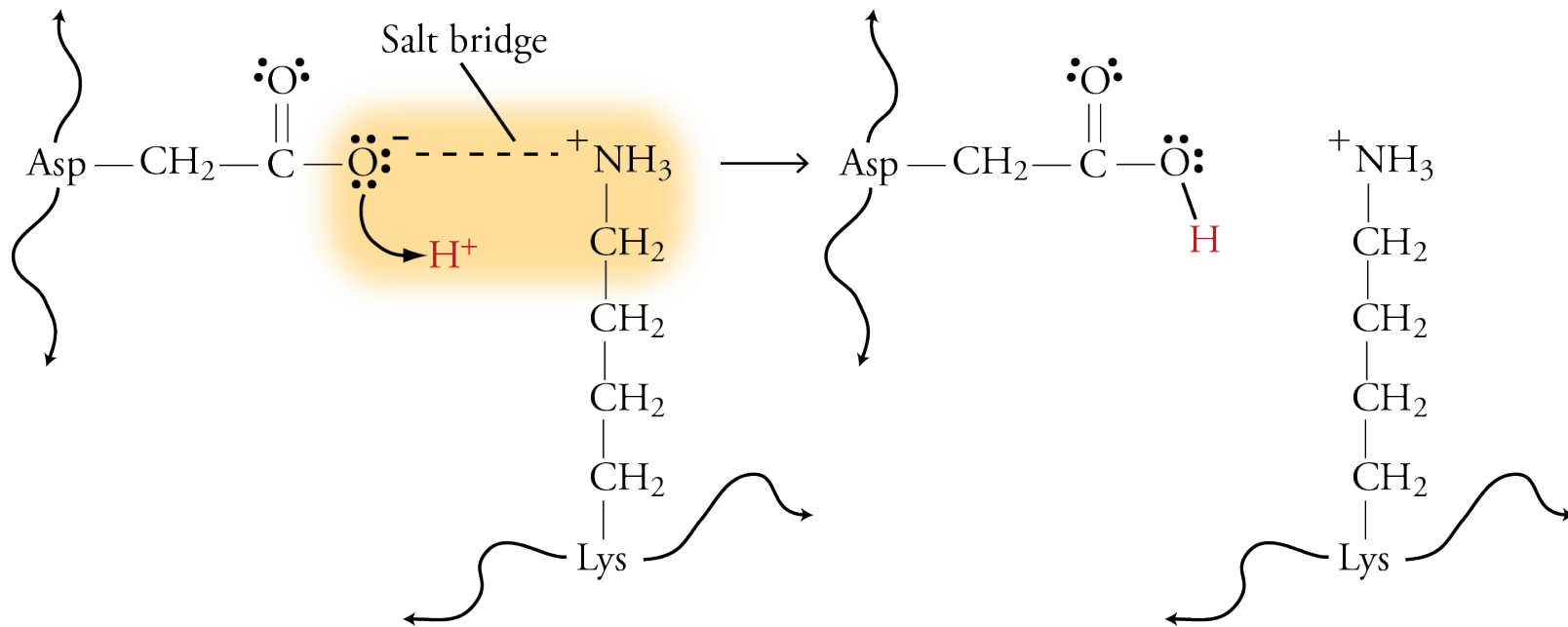


# Digestion

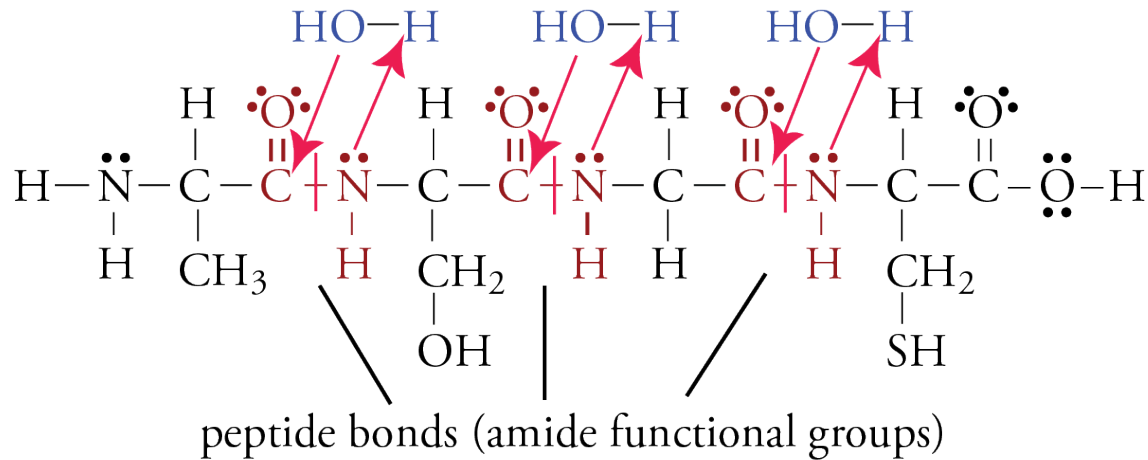


- **Digestion** is the process of converting large molecules into small molecules capable of passing into the bloodstream to be carried throughout the body and used for many different purposes.
- In one part of the digestion process, enzymes in your small intestines convert large water-insoluble molecules into small water-soluble molecules that can migrate through the lining of the intestines and dissolve in the blood, which is about 92% water.

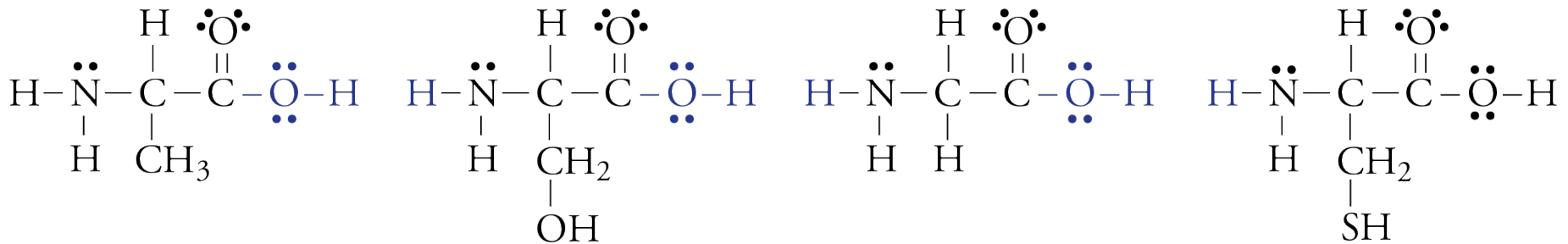
# Disruption of Salt Bridge



# Protein Hydrolysis



↓ Hydrolysis

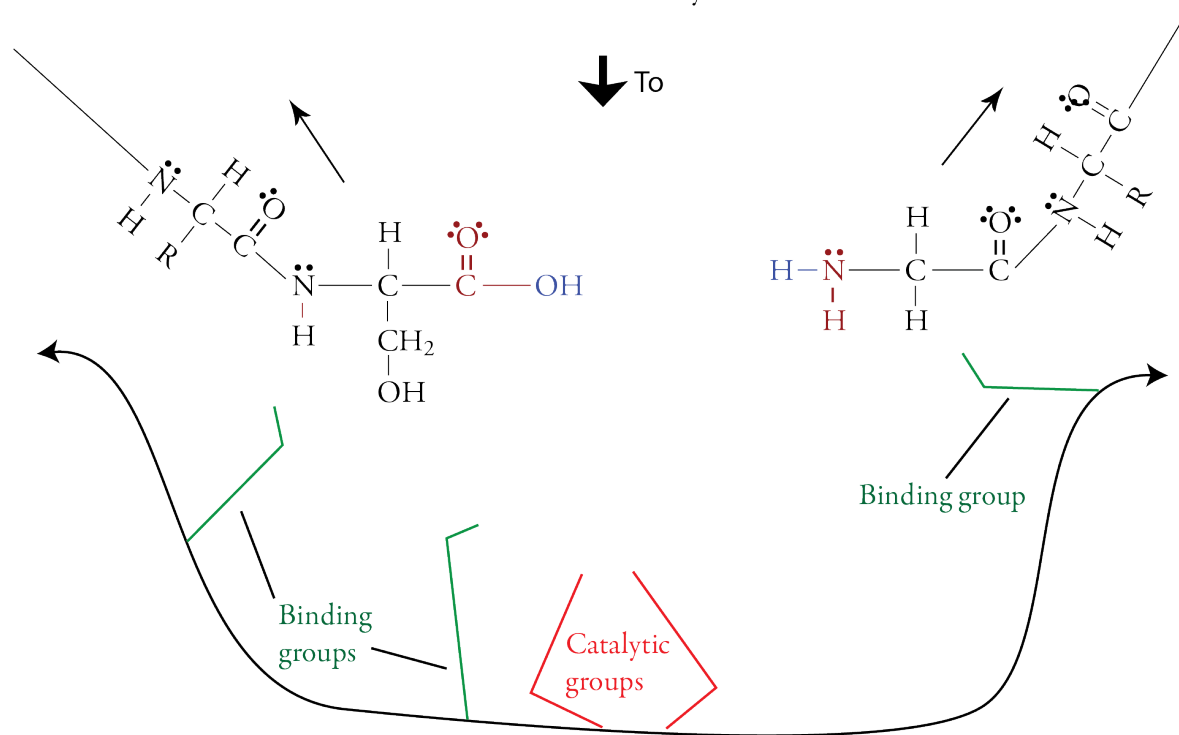
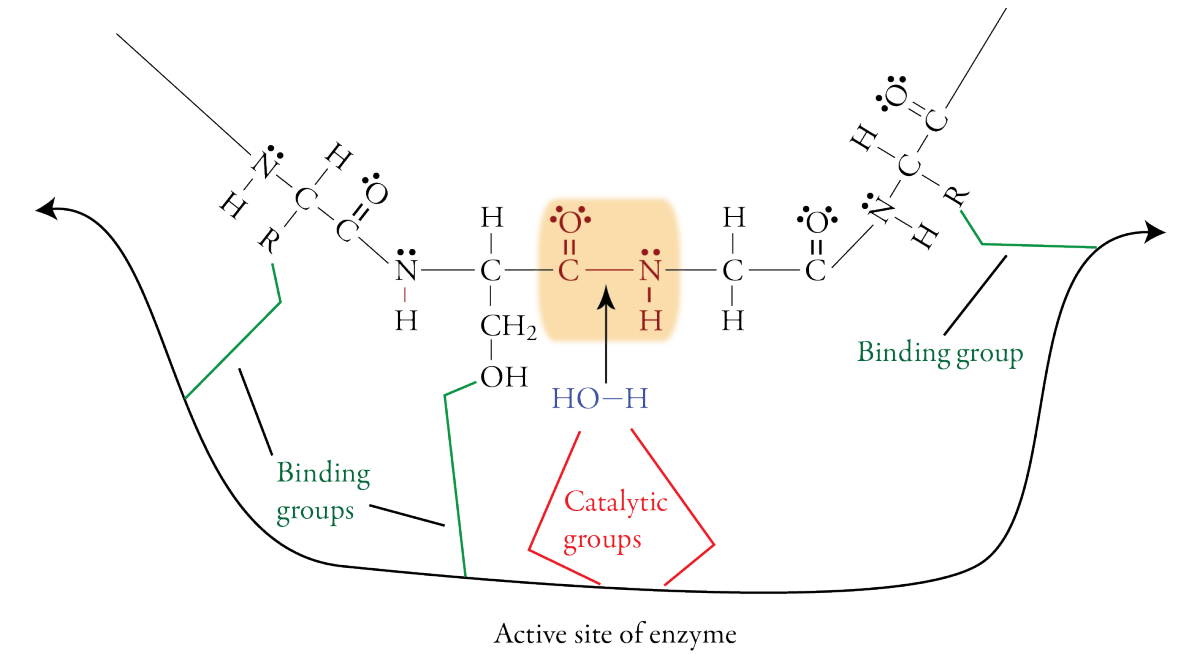


# Enzymes



- ***Catalysts*** speed chemical changes without being permanently altered themselves.
- ***Enzymes*** are naturally occurring catalysts.
- The chemicals that they act on are called ***substrates***.

# Protein Active Site



# Enzymes



- Very specific due to
  - Shape – “Lock and Key”
  - Positions of binding groups, which attract substrates to the active site, the portion of the enzyme where the reaction occurs.
  - Positions of the catalytic groups that speed the reaction.

# Enzymes Speed Chemical Reactions



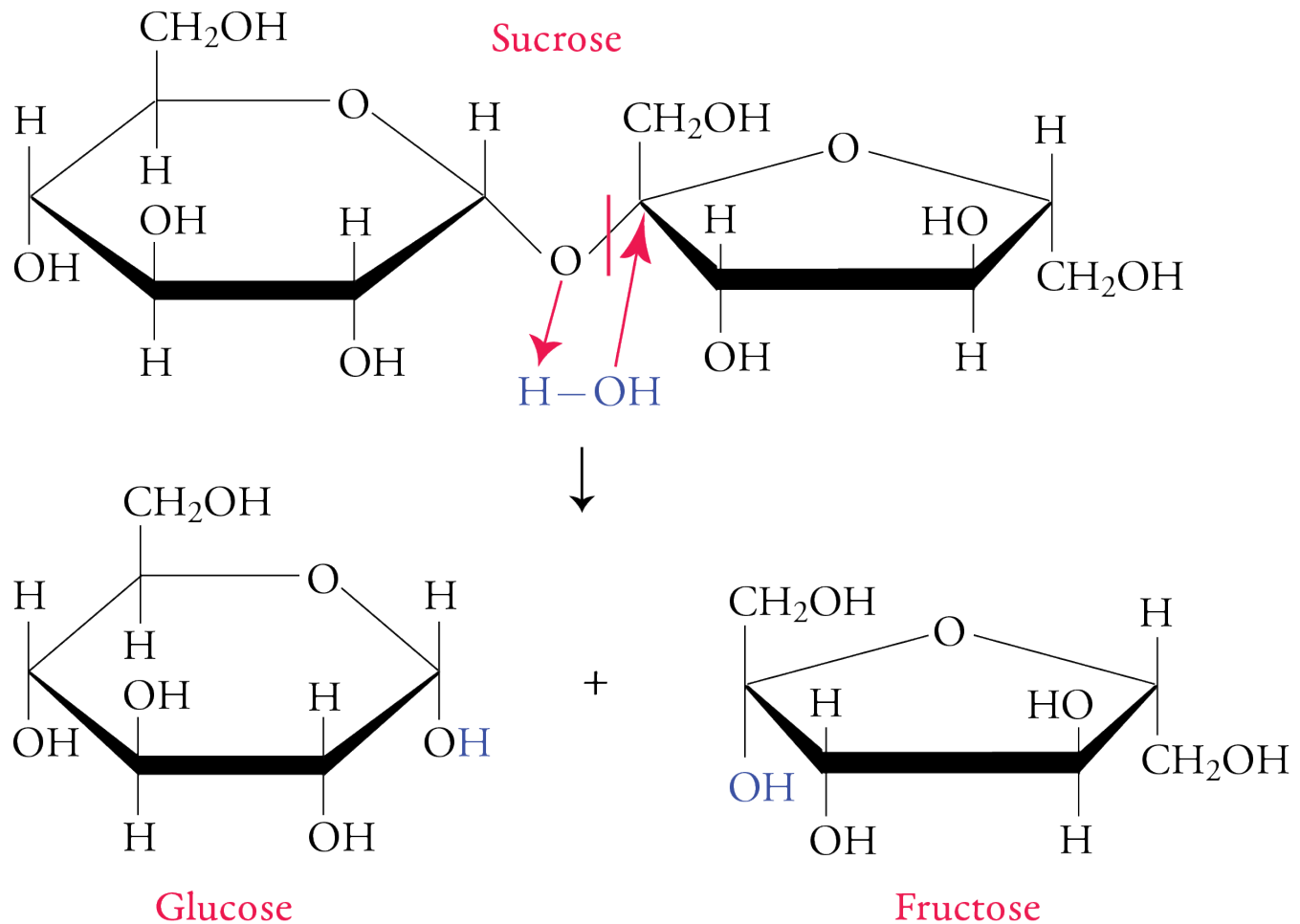
- Provide a different path to products that has more stable intermediates and therefore requires less energy.
- Give the correct orientation every time.



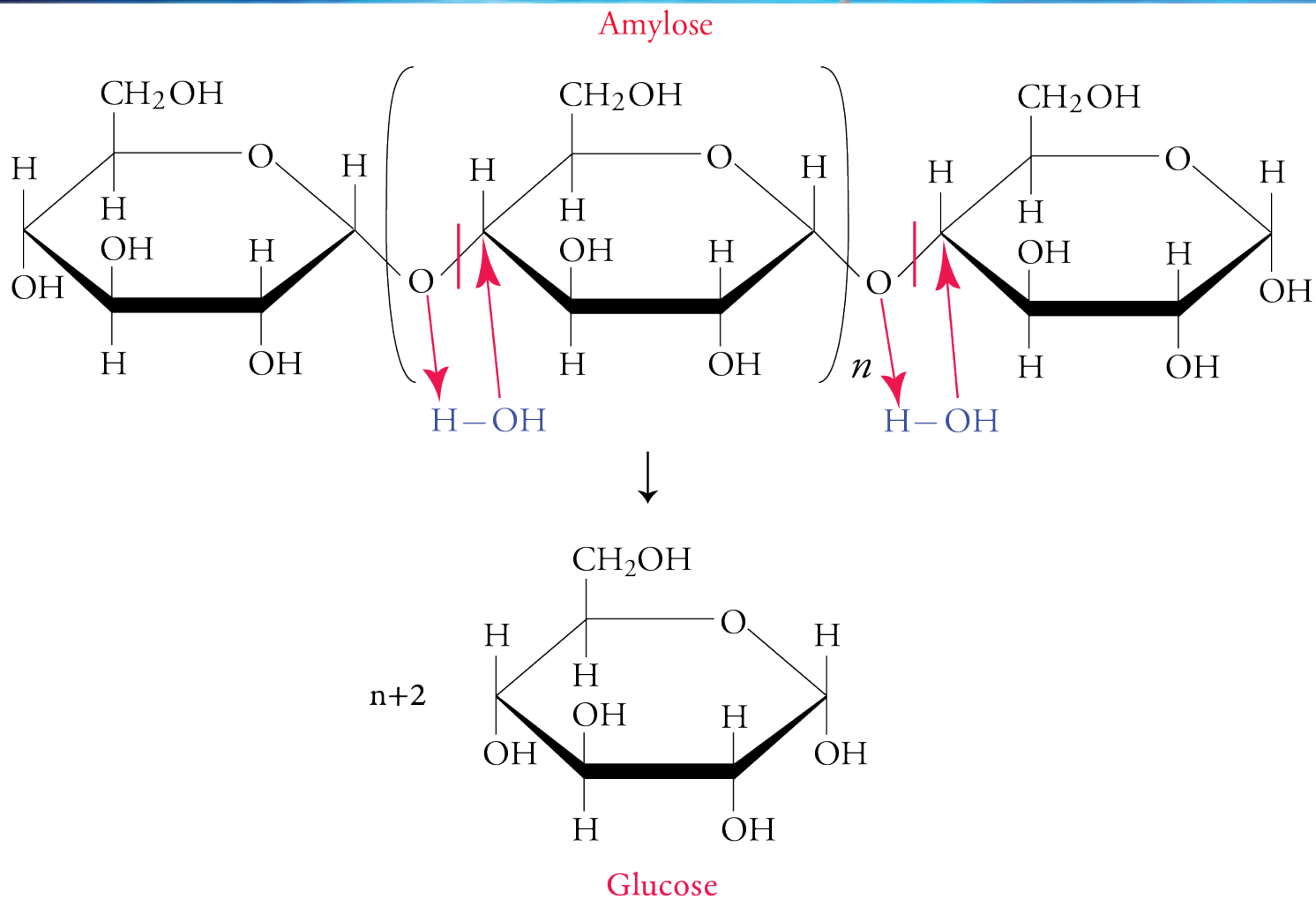
# Digestion Products

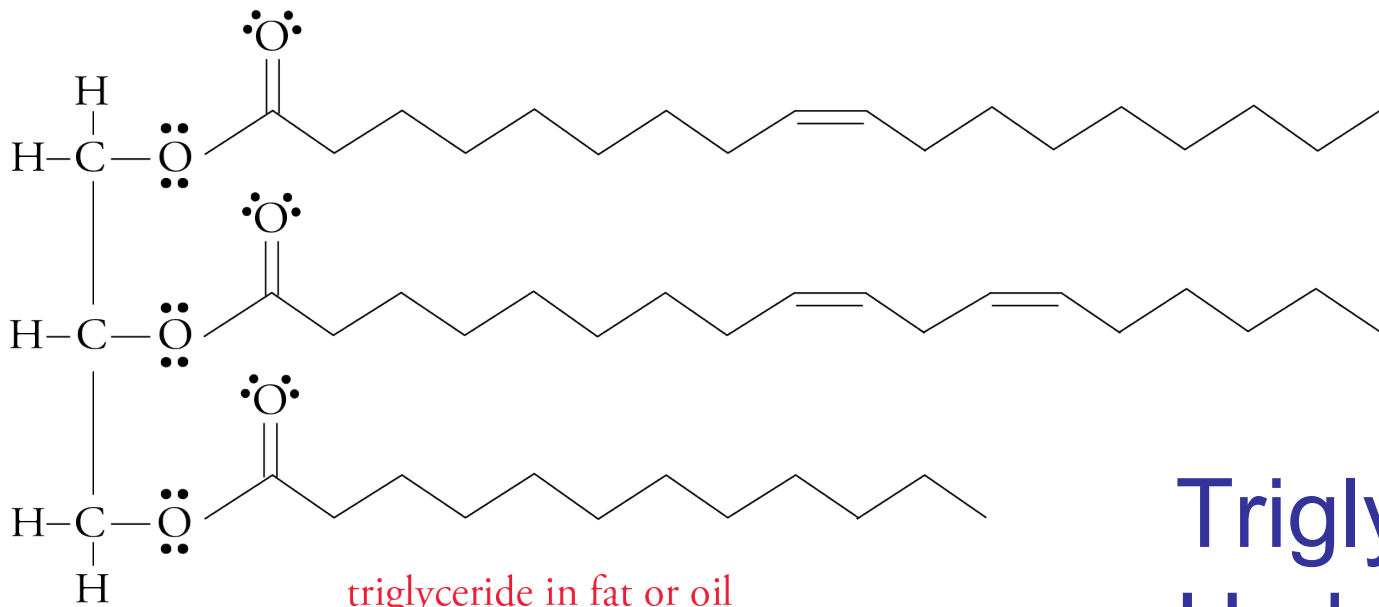
<b>Substance in Food</b>	<b>Products of Digestion</b>
disaccharides	monosaccharides
polysaccharides	glucose
protein	amino acids
Triglycerides (fats and oils)	glycerol and fatty acids

# Sucrose Hydrolysis

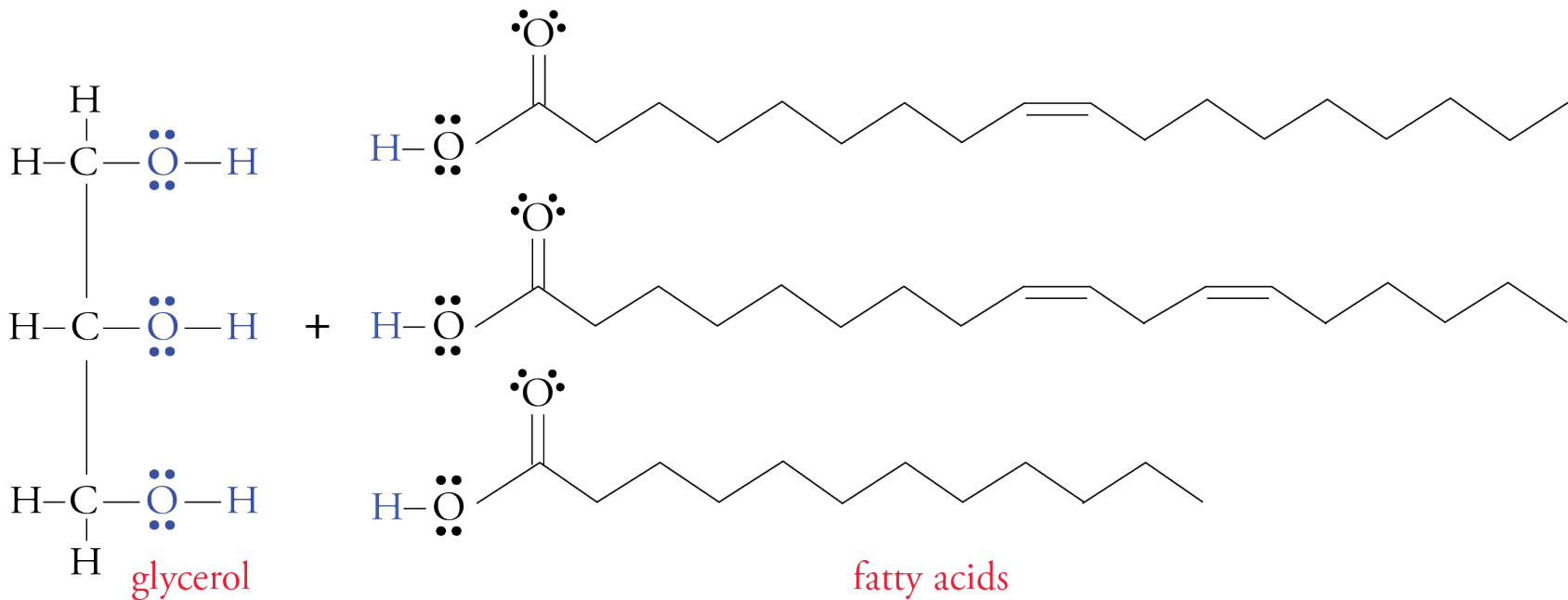


# Amylose Hydrolysis



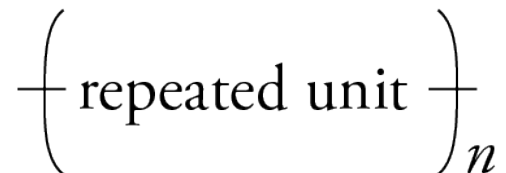


# Triglyceride Hydrolysis



# Polymers

- A **polymer** is a large molecule with simple repeating units.
- The simple repeating units are called **monomers**.
- Polymer formulas are described with the formula for the monomer in parentheses with an  $n$  as a subscript to indicate some large integer number. The  $n$  varies even for a sample of the same polymer.



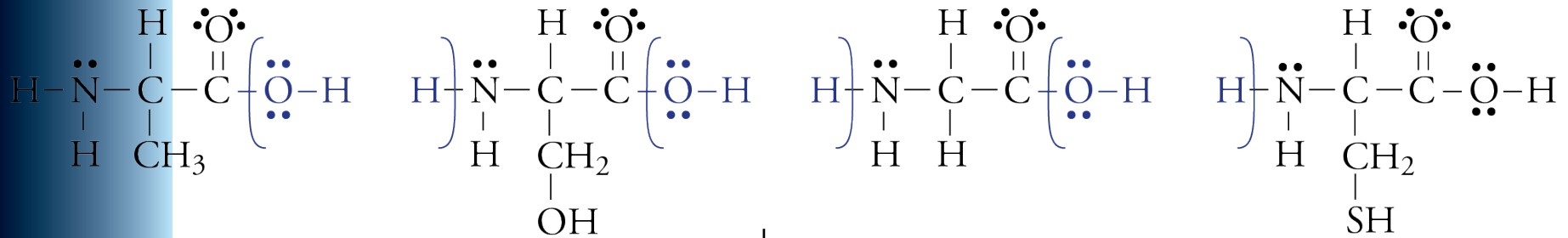
General polymer formula

# Natural and Synthetic Polymers

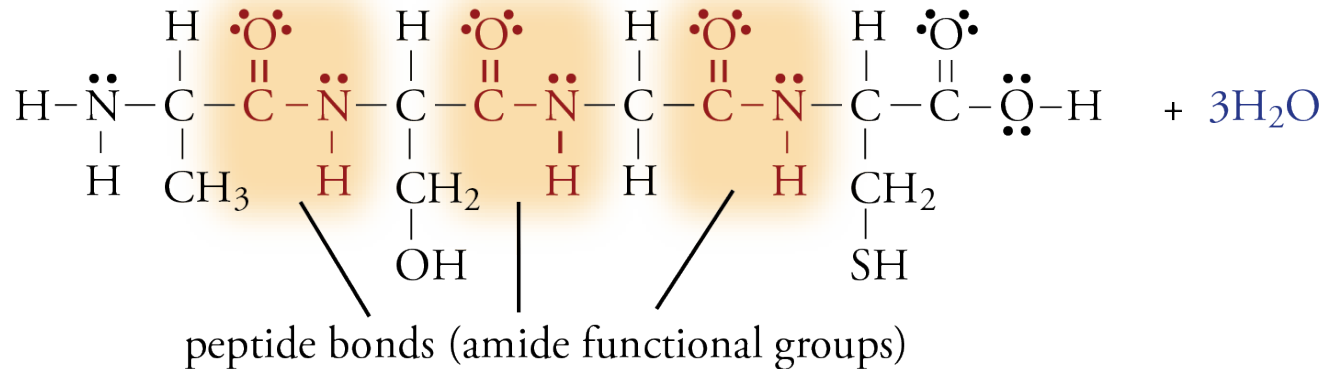


- Natural polymers include
  - Starches with glucose monomers
  - Proteins with amino acid monomers
- Synthetic polymers are produced by chemists. Examples include, nylon, polyester, polyethylene, poly(vinyl chloride), polypropylene, and polystyrene.

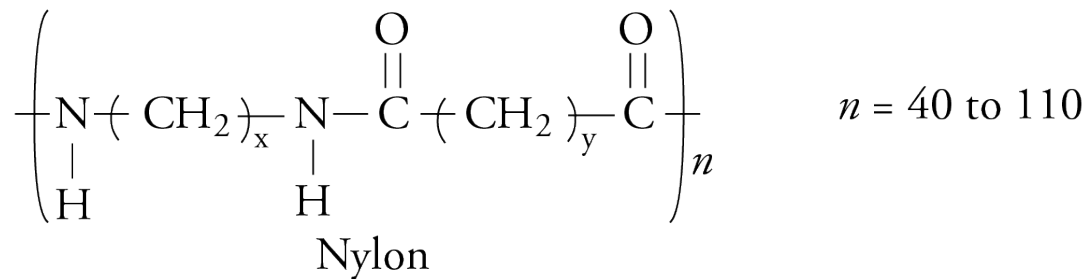
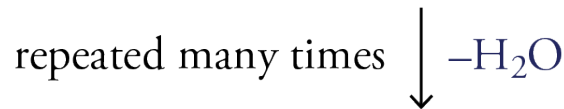
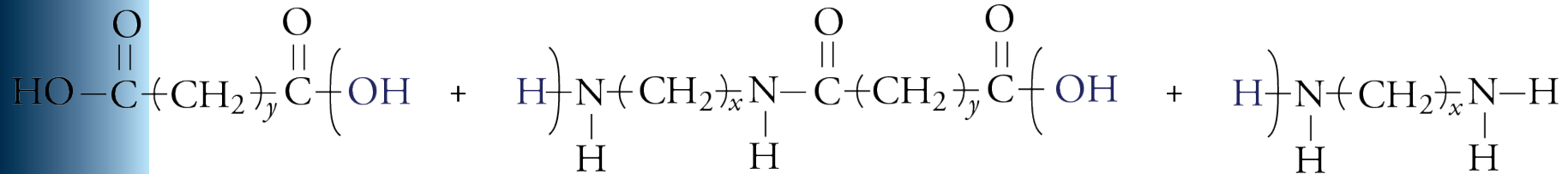
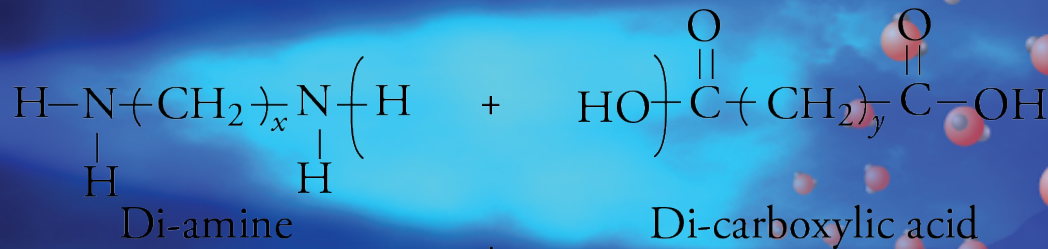
# Formation of Ala-Ser-Gly-Cys



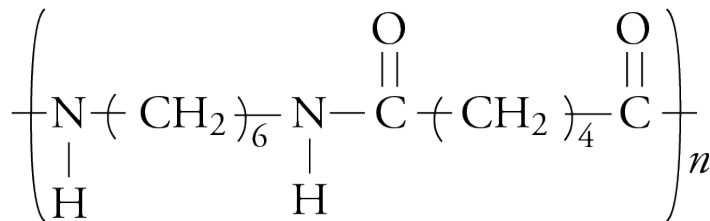
↓ Condensation reaction releases water



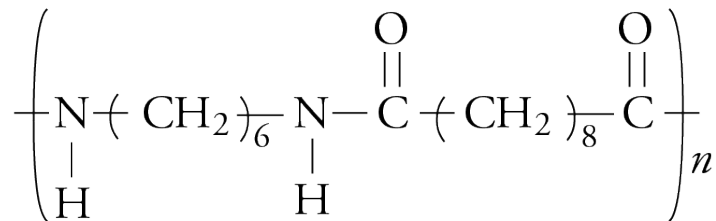
# Nylon Formation



Examples



Nylon 66



Nylon 610

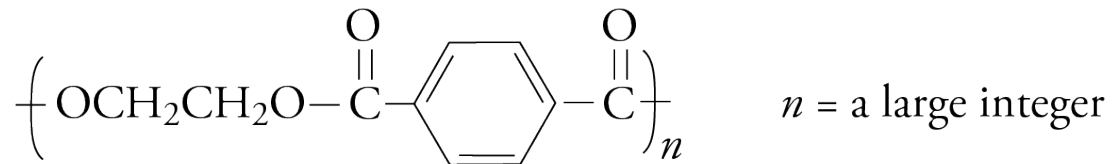
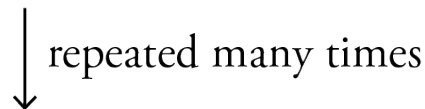
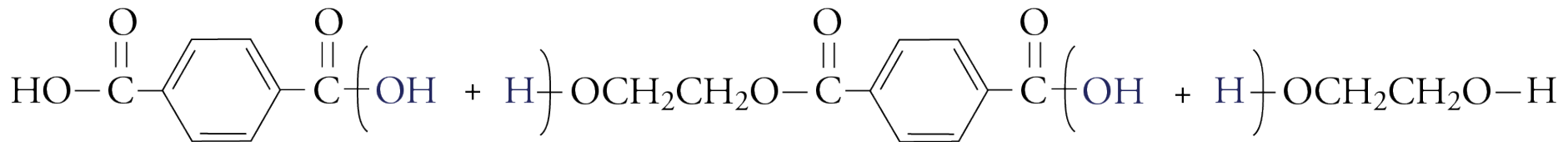
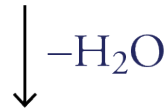


# Condensation Polymers



- **Condensation polymers** are polymers that are formed by condensation reactions in which two molecules are joined and a small molecule, such as water, is released.

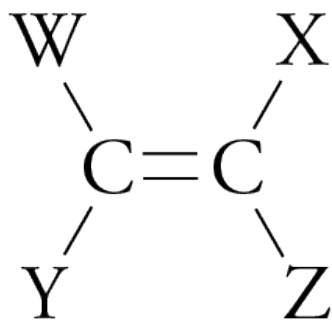
# Polyester Formation

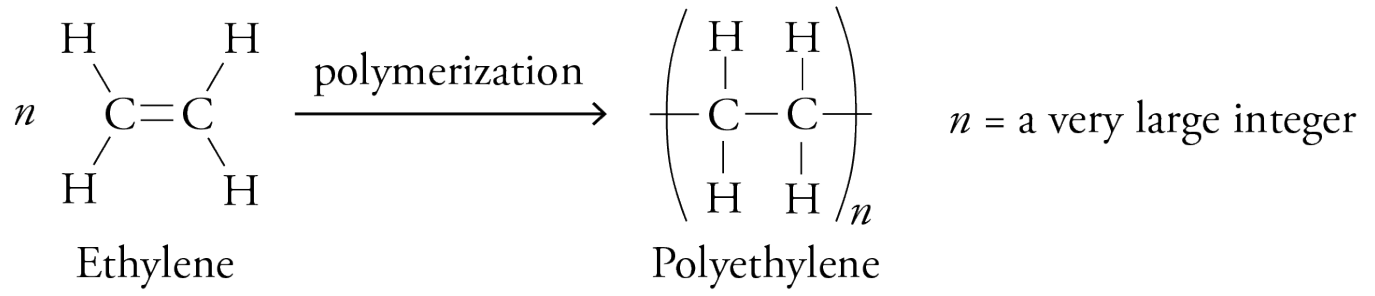


Poly(ethylene terephthalate)

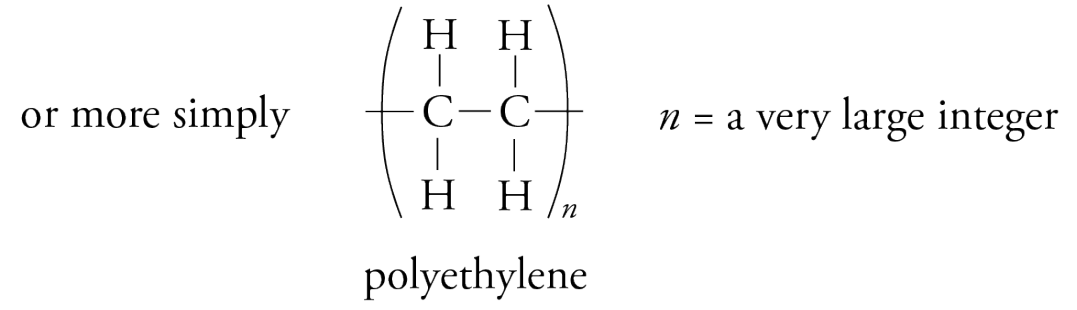
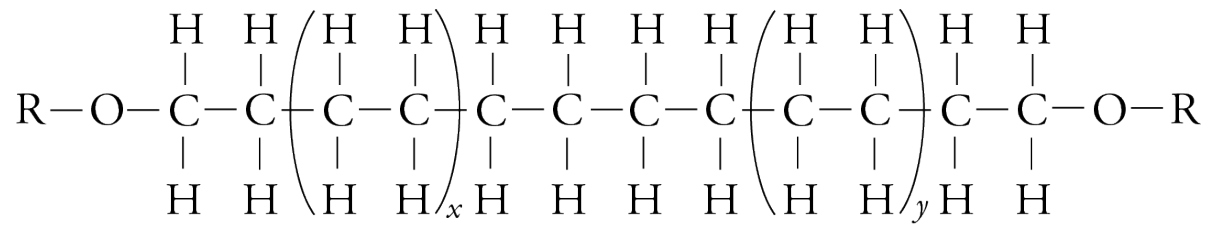
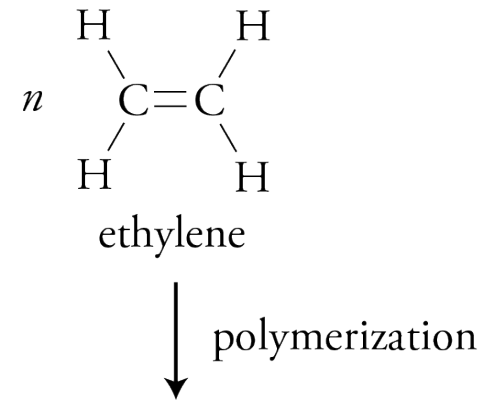
# Addition Polymers

- Addition polymers are made from molecules that have the following general formula.






# Polyethylene Formation

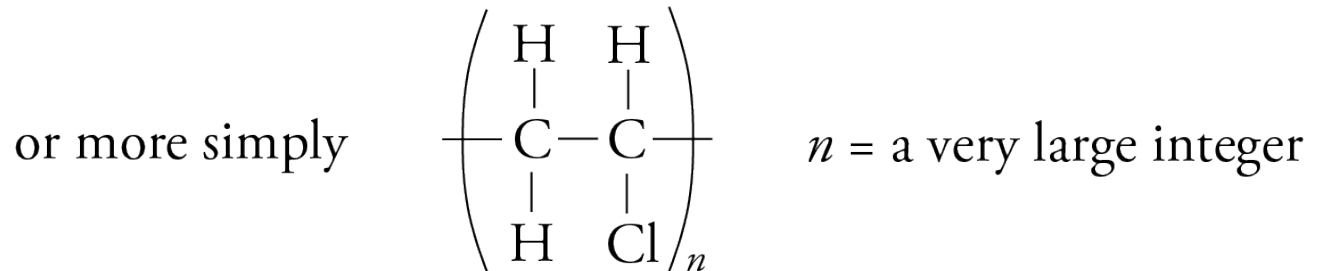
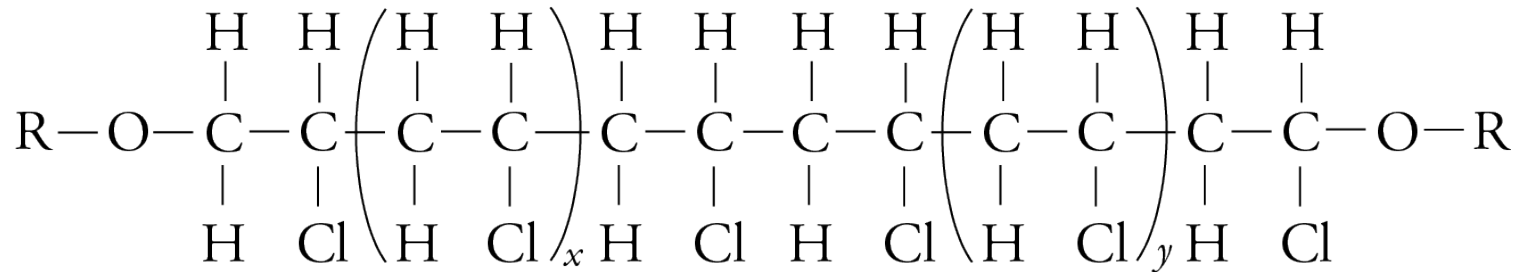
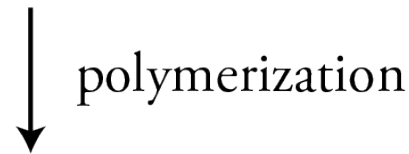
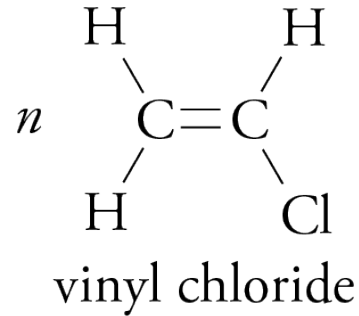


# High- and Low-Density Polyethylene



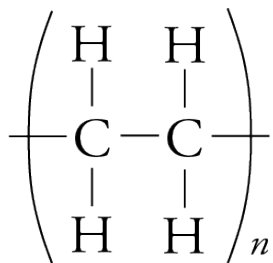
- If polyethylene is made under conditions that lead to mostly unbranched chains, the chains are able to pack together tightly forming high-density polyethylene, which is described by the acronym HDPE or sometimes PE-HD.
- If the polyethylene is made in a way that encourages branches, the molecules do not pack together as tightly, forming low-density polyethylene, which is described by the acronym LDPE or sometimes PE-LD.

# Poly(vinyl chloride) or PVC

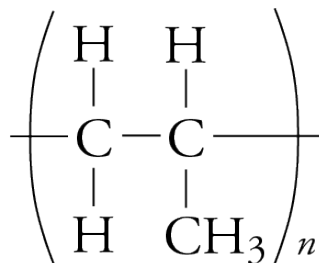


poly(vinyl chloride) or PVC

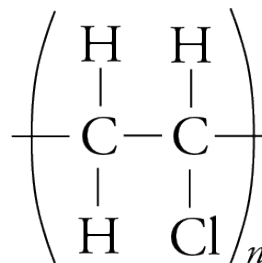
# Addition Polymers



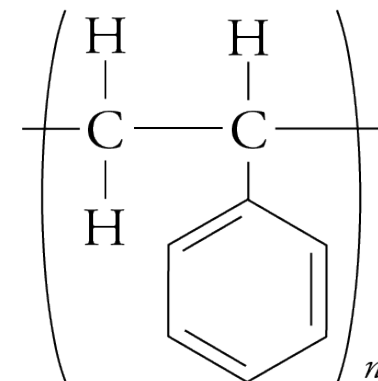
Polyethylene  
(HDPE or  
LDPE)



Polypropylene  
(PP)



Poly(vinyl chloride)  
(PVC)



Polystyrene  
(PS)

# Recycling Codes



PET  
(or PETE)



HDPE  
(or PE-HD)



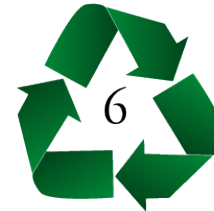
PVC  
(or V)



LDPE  
(or PE-LD)



PP



PS



OTHER