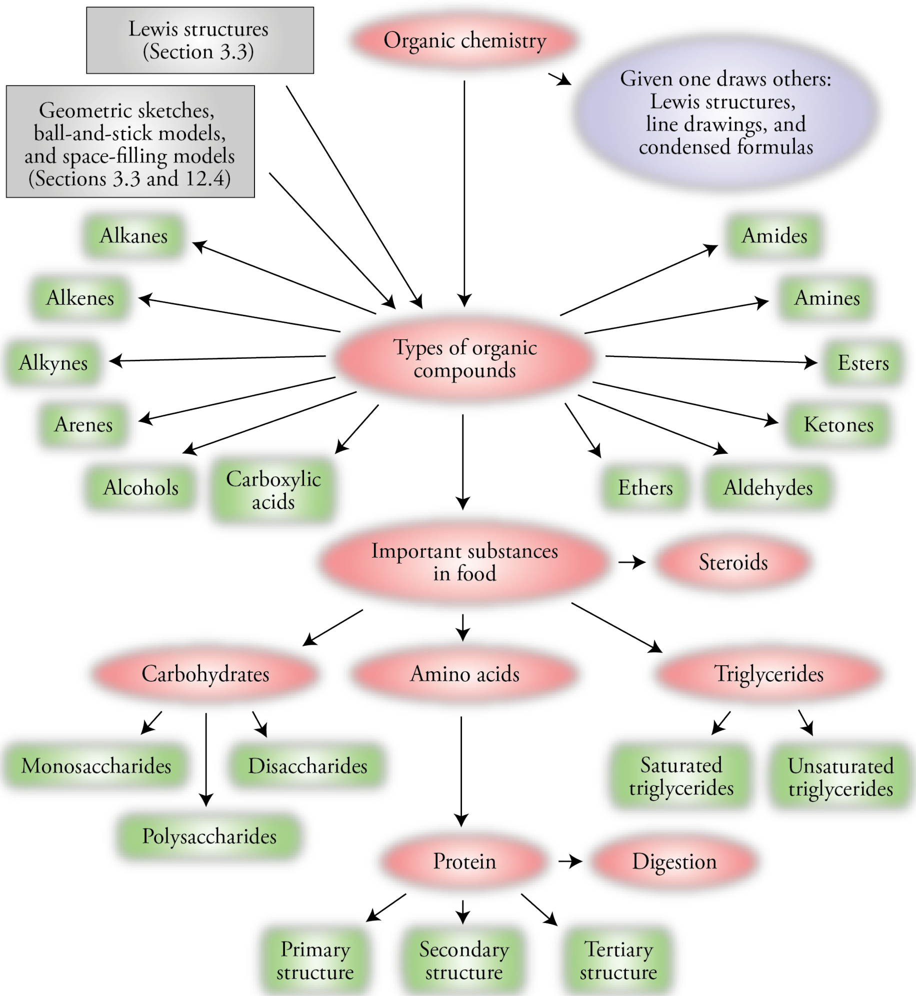
Chapter 17
An Introduction to Organic Chemistry, Biochemistry, and Synthetic Polymers

An Introduction to Chemistry

by Mark Bishop

Chapter Map

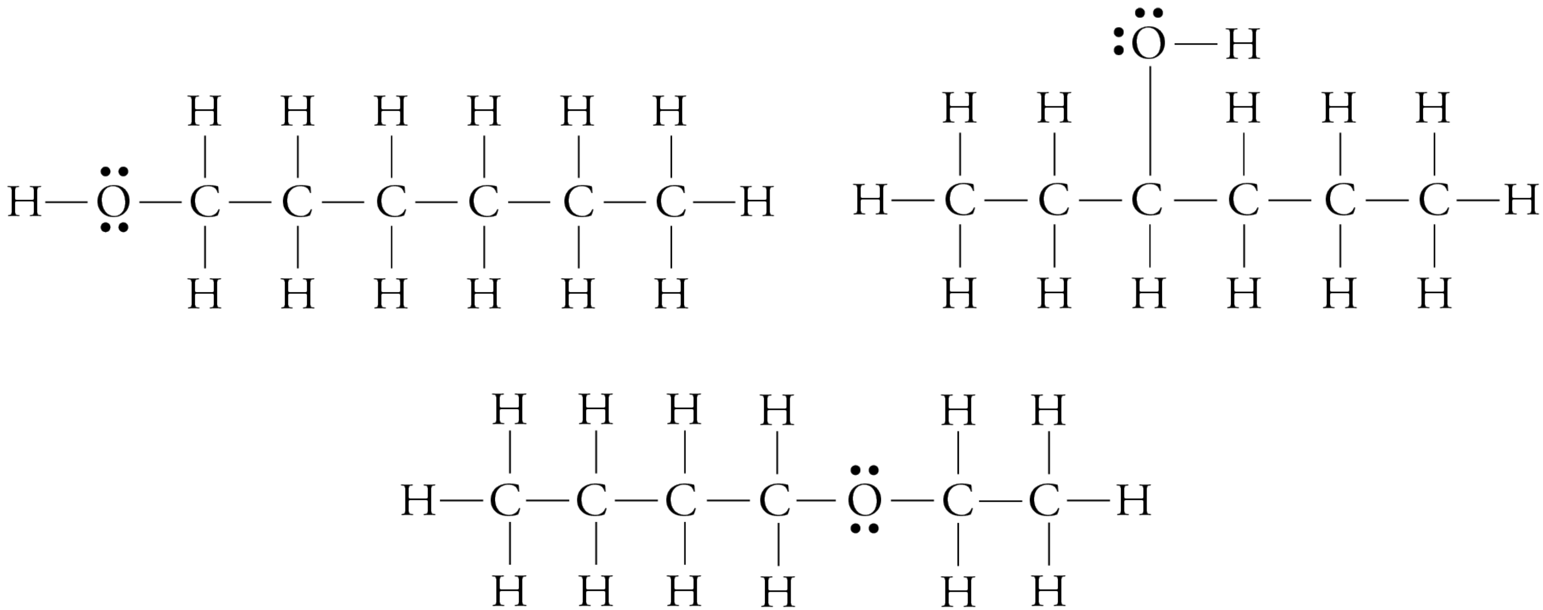


Lewis structures (Section 3.3)
Organic chemistry
Geometric sketches, ball-and-stick models, and space-filling models (Sections 3.3 and 12.4)
Given one draws others: Lewis structures, line drawings, and condensed formulas
Alkanes
Amides
Alkenes
Amines
Types of organic compounds
Alkynes
Esters
Arenes
Ketones
Alcohols
Carboxylic acids
Ethers
Aldehydes
Important substances in food
Steroids
Carbohydrates
Amino acids
Triglycerides
Monosaccharides
Disaccharides
Saturated triglycerides
Unsaturated triglycerides
Polysaccharides
Protein
Digestion
Primary structure
Secondary structure
Tertiary structure

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.

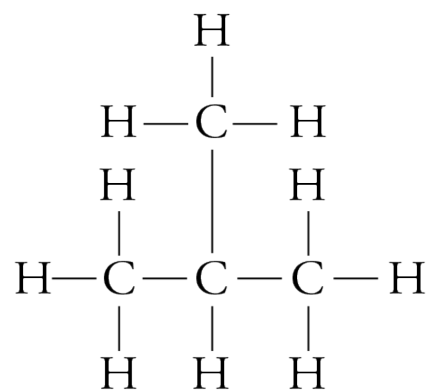
Isomers



- **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)

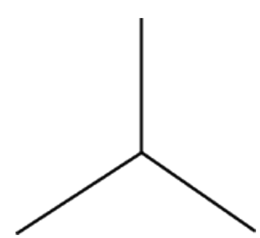
- Lewis structures



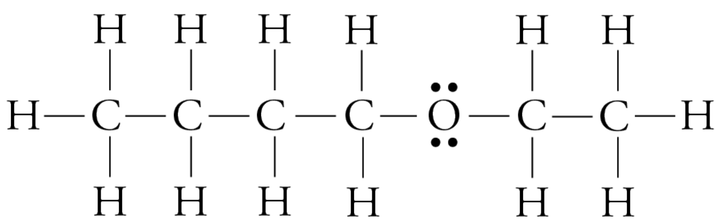
- Condensed formulas

  $CH_3CH(CH_3)CH_3$

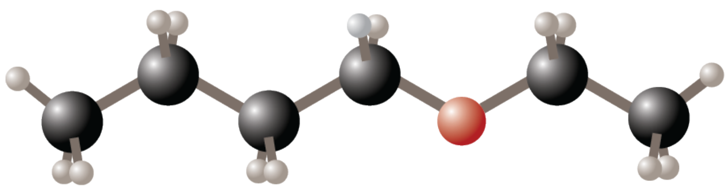
- Line drawings

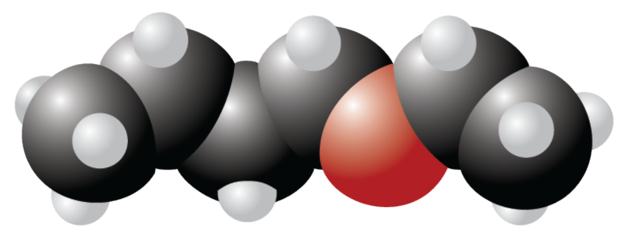


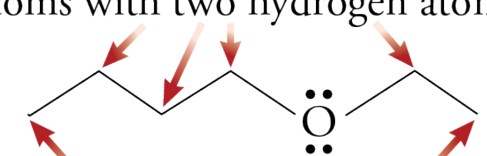
Ways to Describe Organic Compounds (butyl ethyl ether)



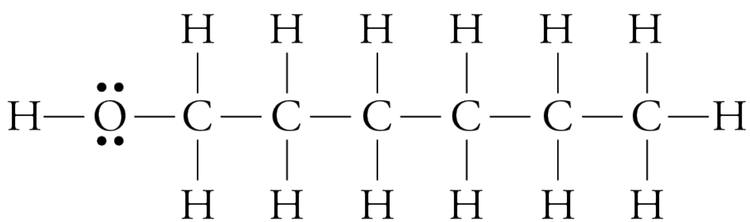
$CH_3CH_2CH_2CH_2OCH_2CH_3$ or $CH_3(CH_2)_3OCH_2CH_3$



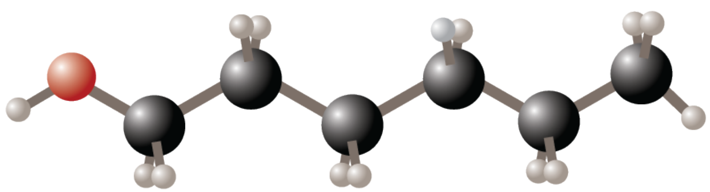


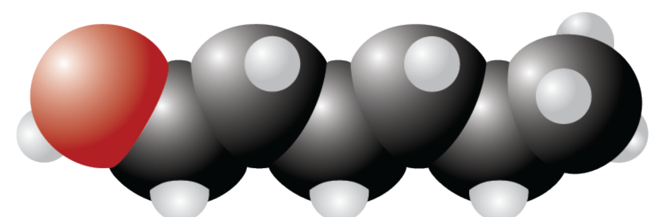


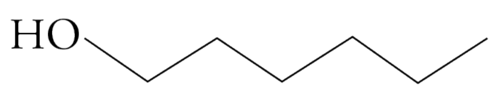
Ways to Describe Organic Compounds (1-hexanol)



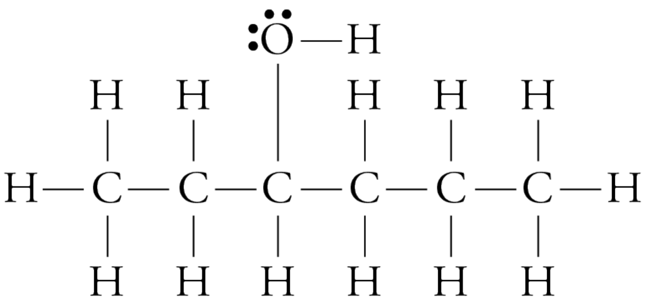
$HOCH_2CH_2CH_2CH_2CH_2CH_3$ or $HOCH_2(CH_2)_4CH_3$



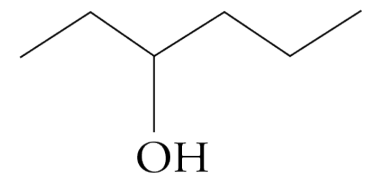


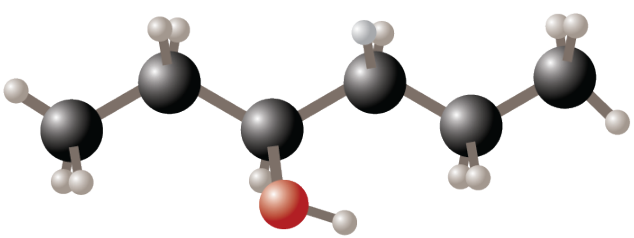


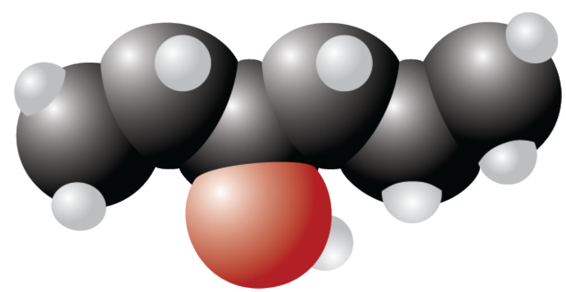
Ways to Describe Organic Compounds (3-hexanol)



$CH_3CH_2CH(OH)CH_2CH_2CH_3$

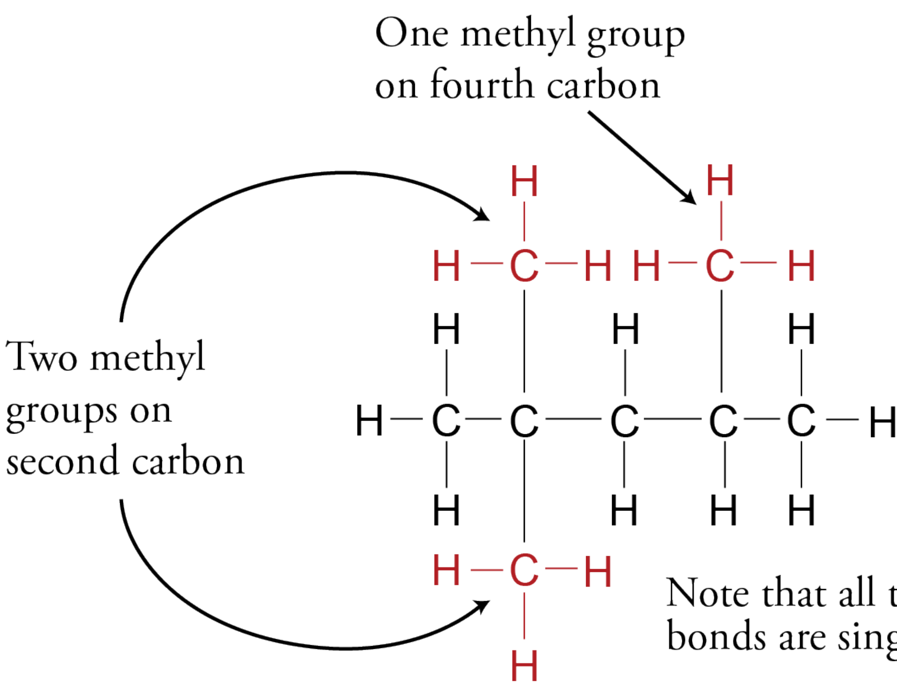


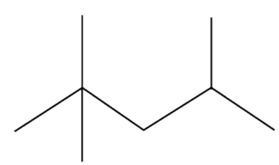


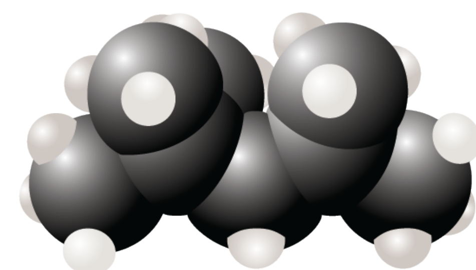


Alkanes

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

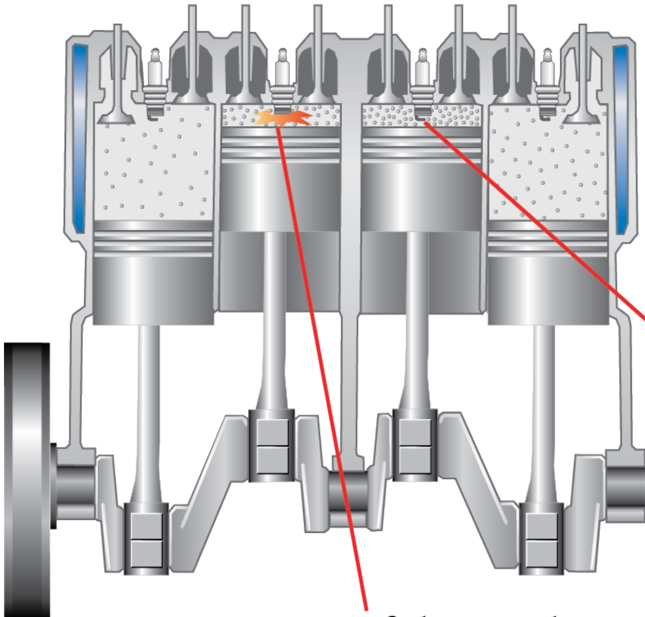






2,2,4-trimethylpentane, $CH_3C(CH_3)_2CH_2CH(CH_3)CH_3$

Pre-ignition Knock and Octane Rating

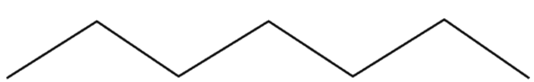


If the gasoline-air mixture reacts too soon, before the peak of the stroke of the piston, the piston pushes the crankshaft in the opposite direction, causing a vibration or "pre-ignition knock".

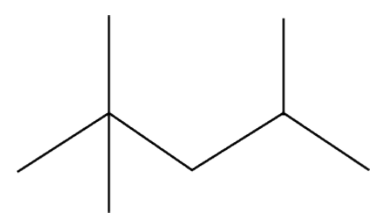
If the gasoline-air mixture ignites at (or just past) the peak of the stroke of the piston, the crankshaft is turned, which ultimately turns the wheels.

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



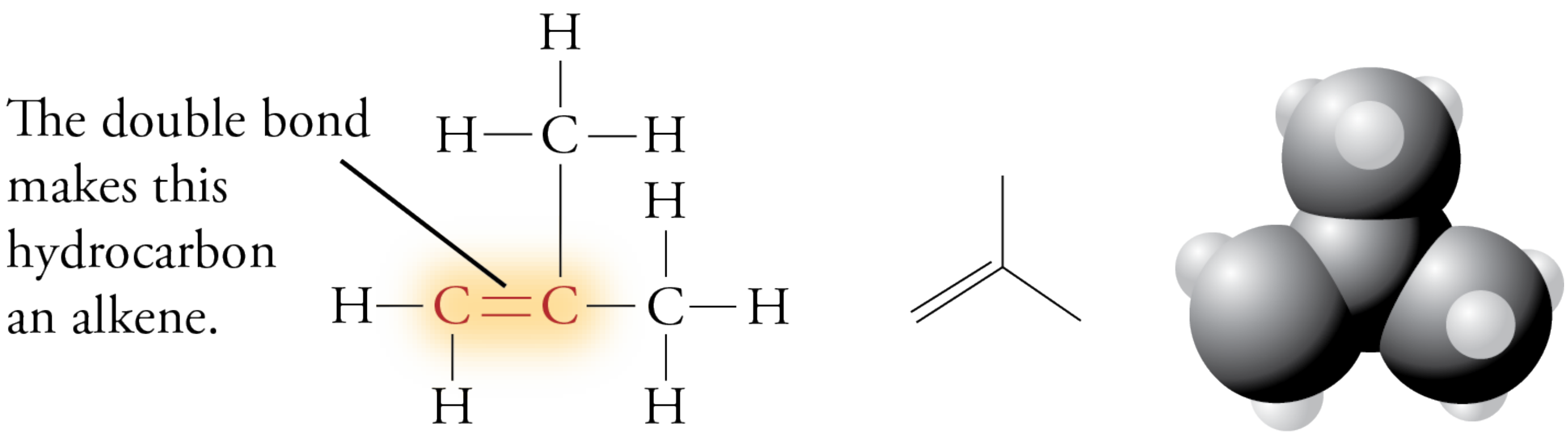
2,2,4-trimethylpentane

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

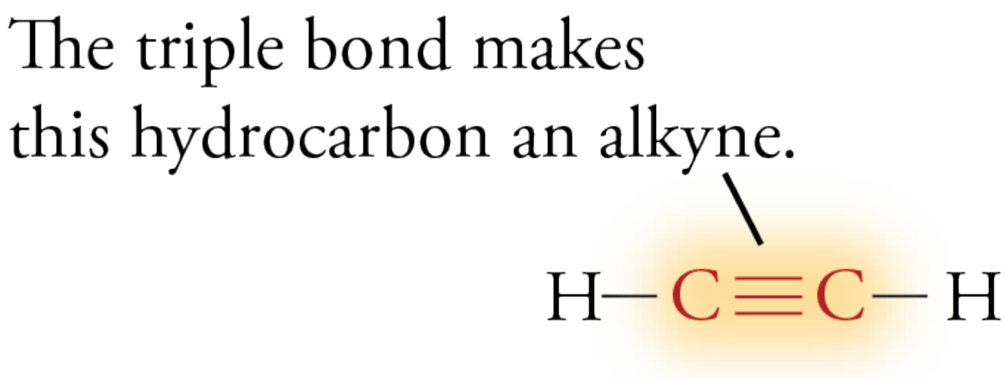
Hydrocarbons that have one or more carbon-carbon double bonds

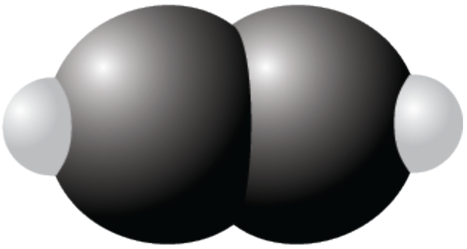


2-methylpropene (isobutene), $CH_2C(CH_3)CH_3$

Alkynes

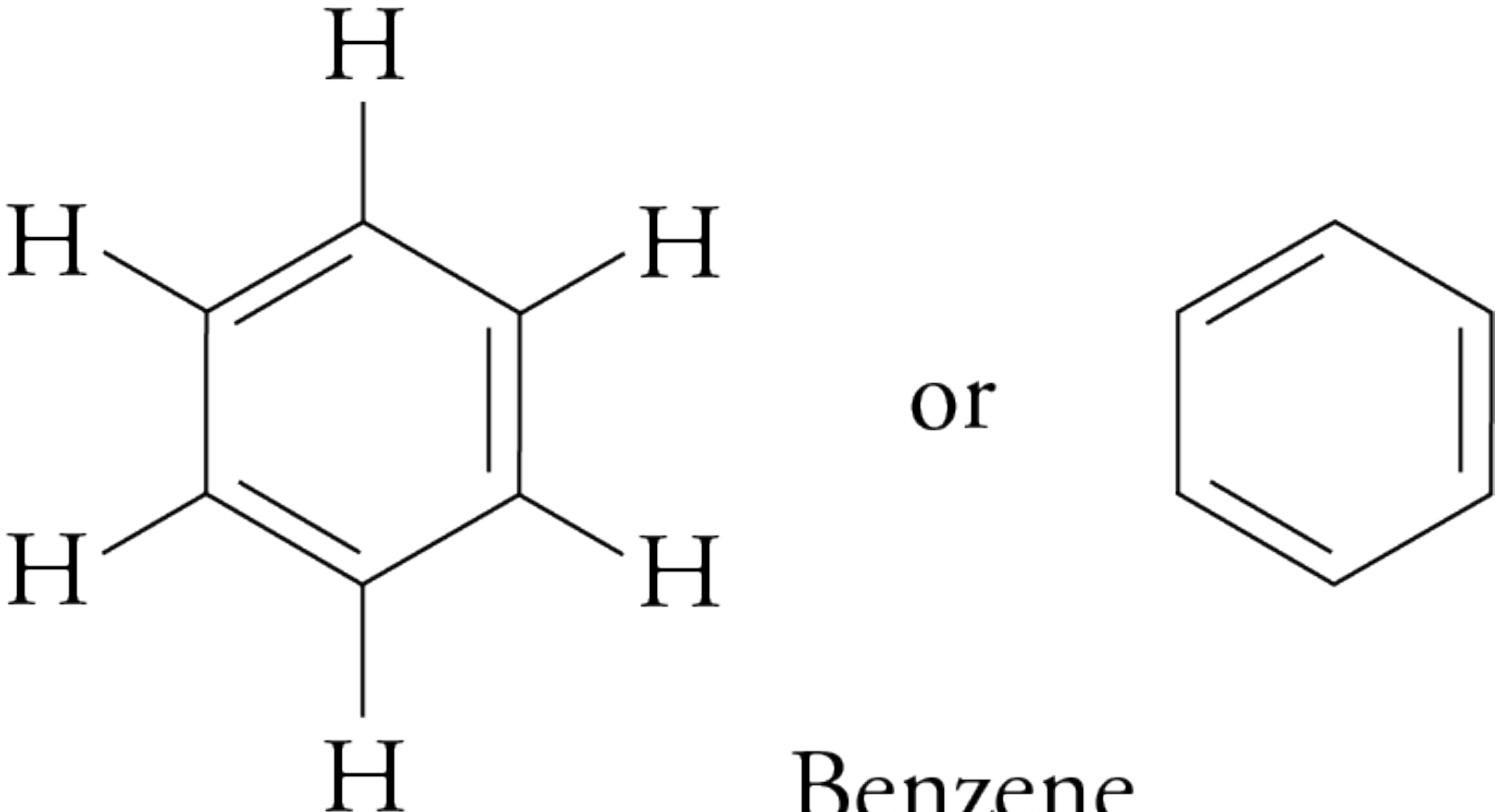
Hydrocarbons that have one or more carbon-carbon triple bonds





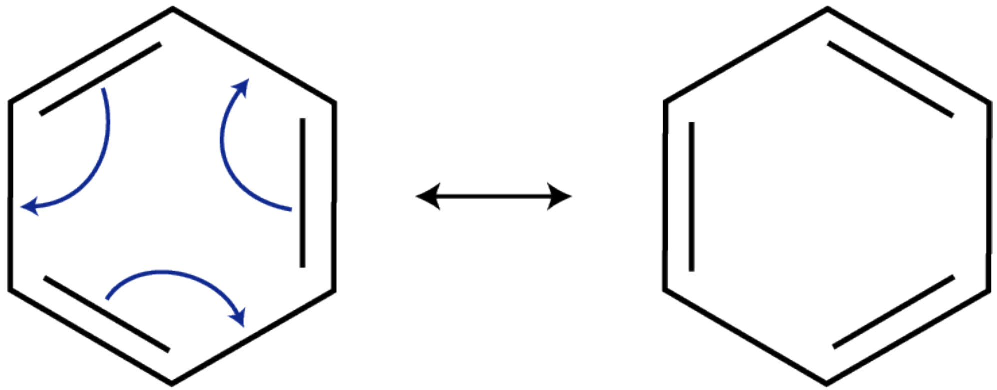
Ethyne (acetylene), HCCH

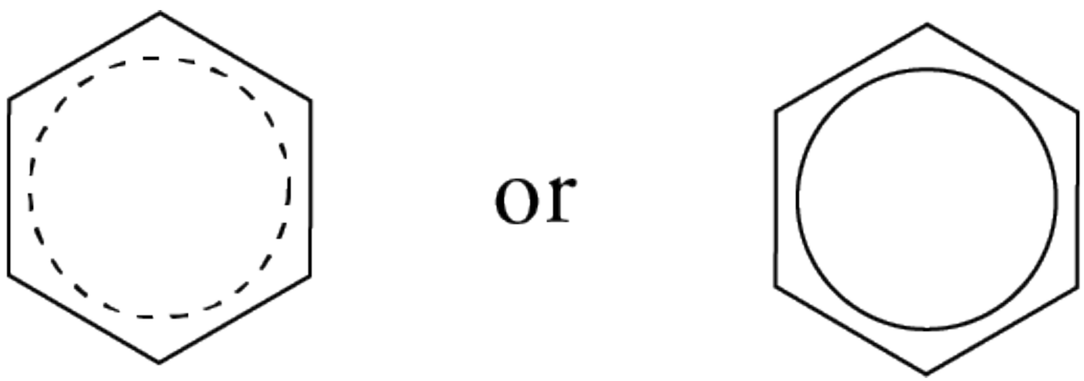
Benzene



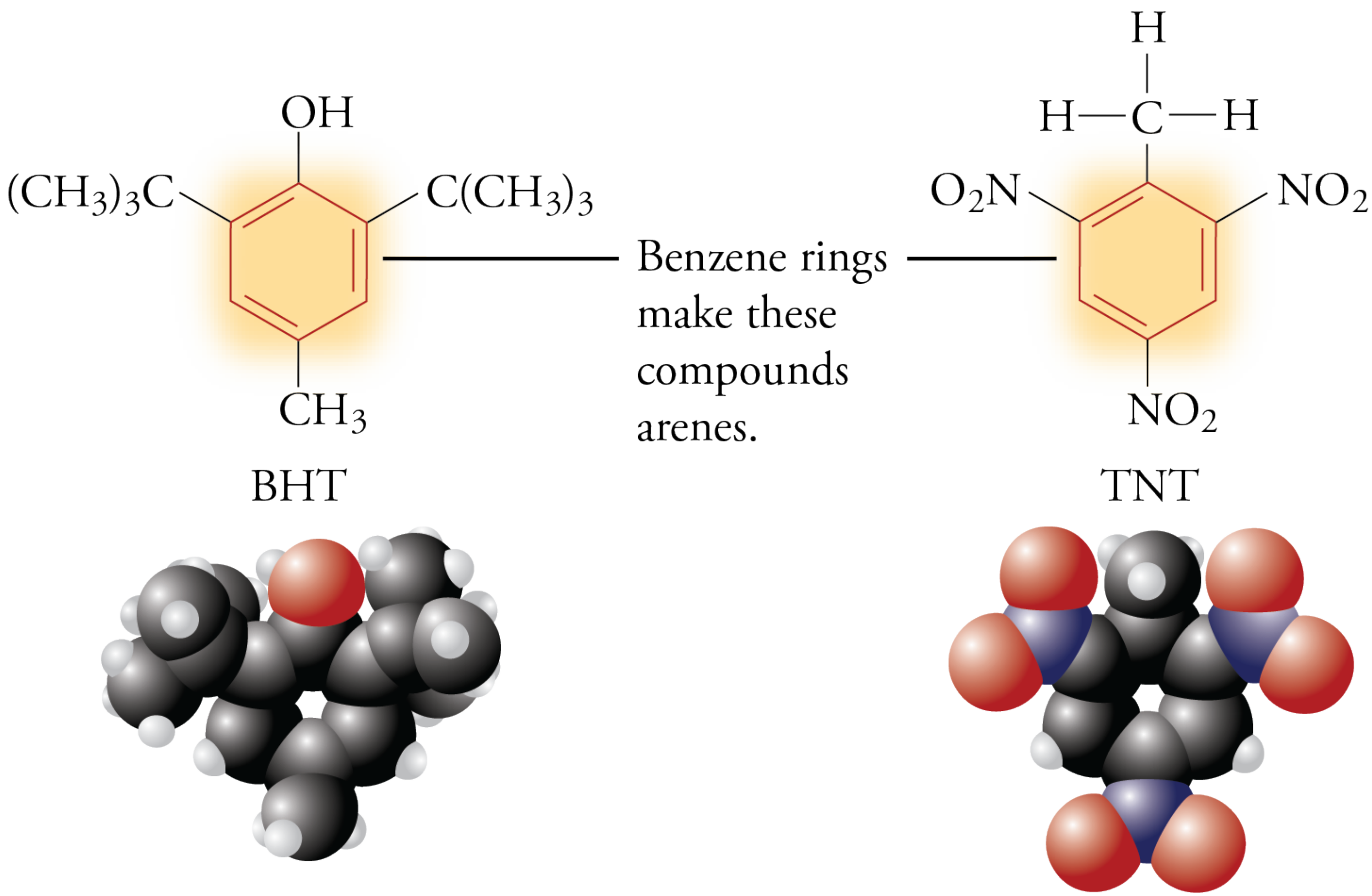
Benzene

Benzene



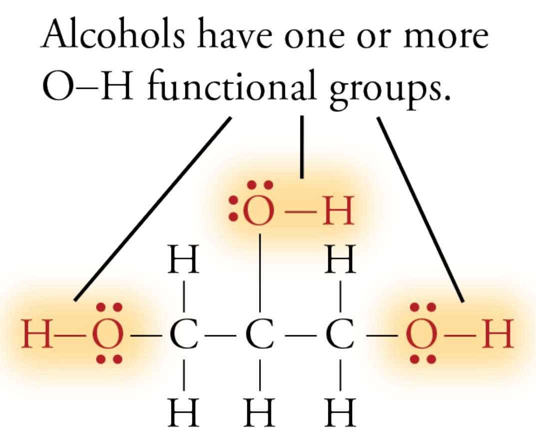


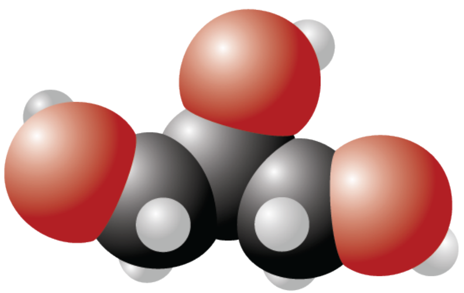
Arenes (or Aromatics) - Compounds that contain the benzene ring

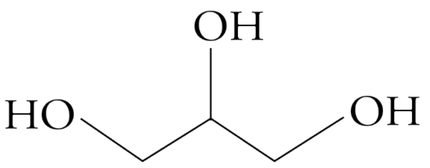


Alcohols

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

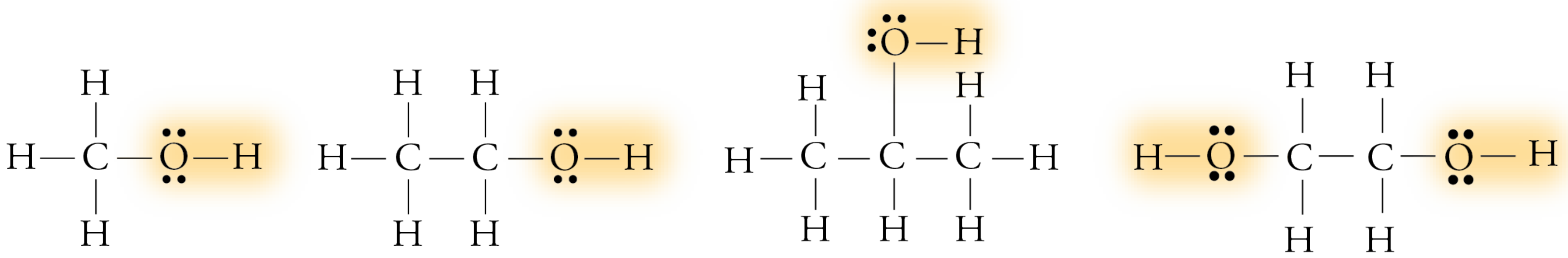






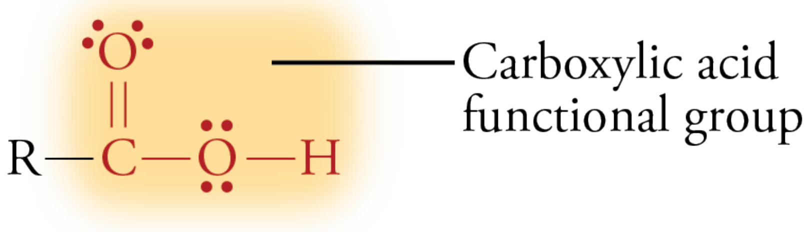
Glycerol, $HOCH_2CH(OH)CH_2OH$

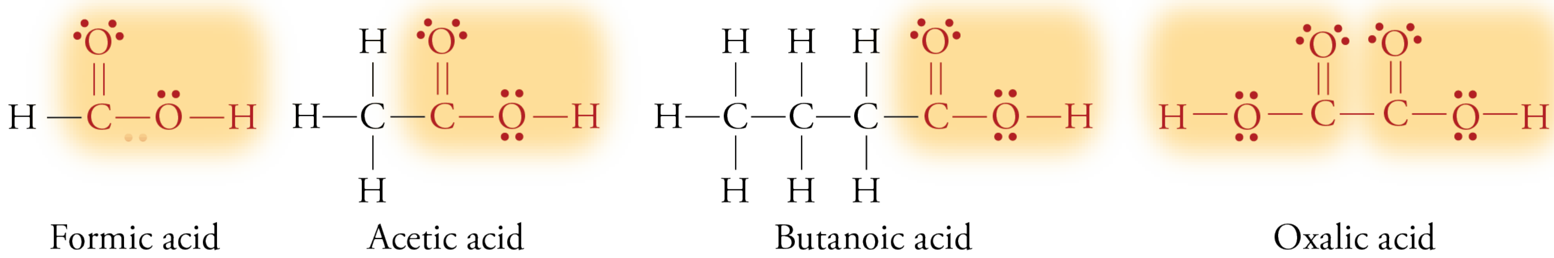
Other Common Alcohols



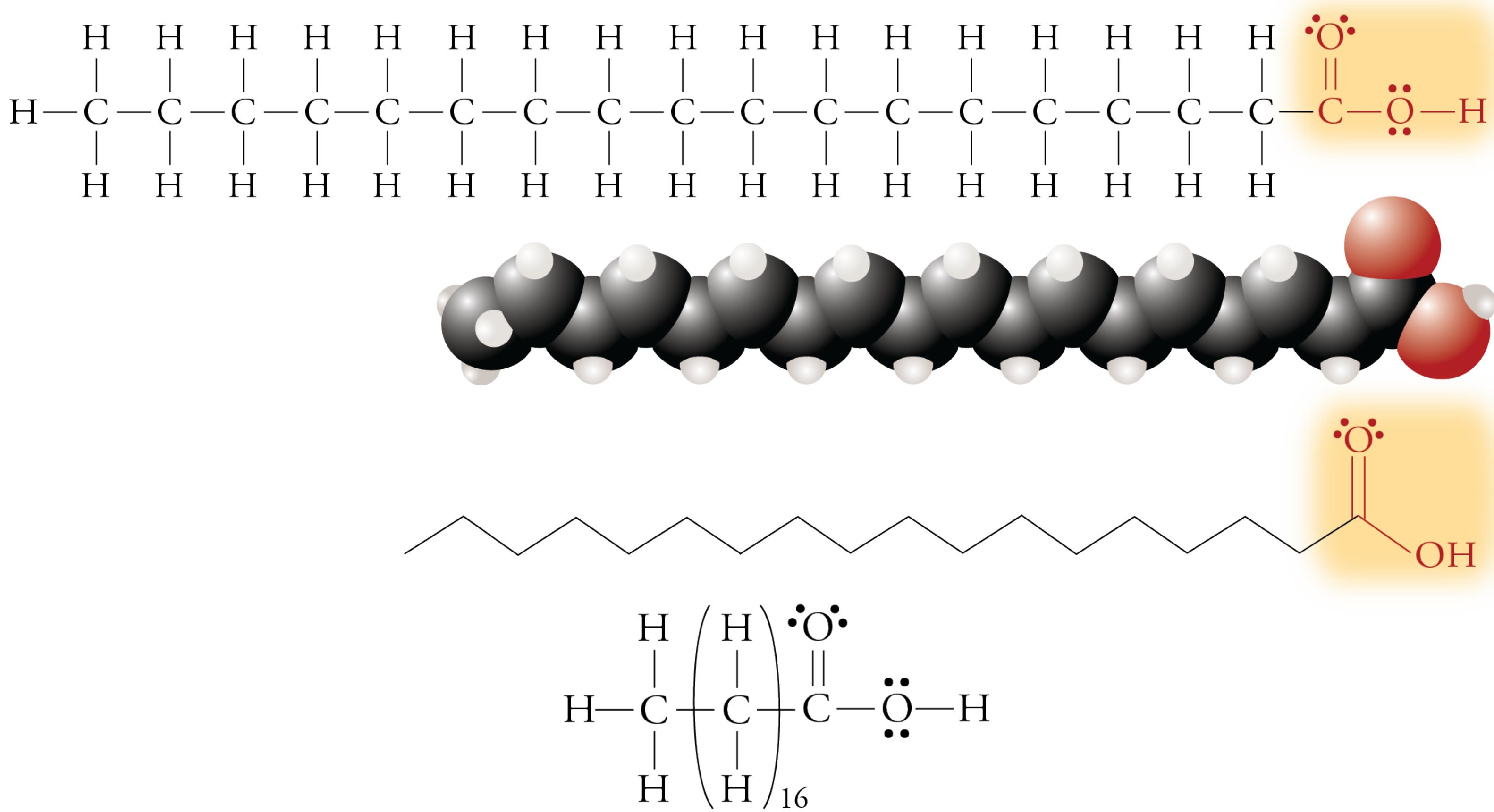
Methanol Ethanol 2-Propanol Ethylene glycol

Carboxylic Acids





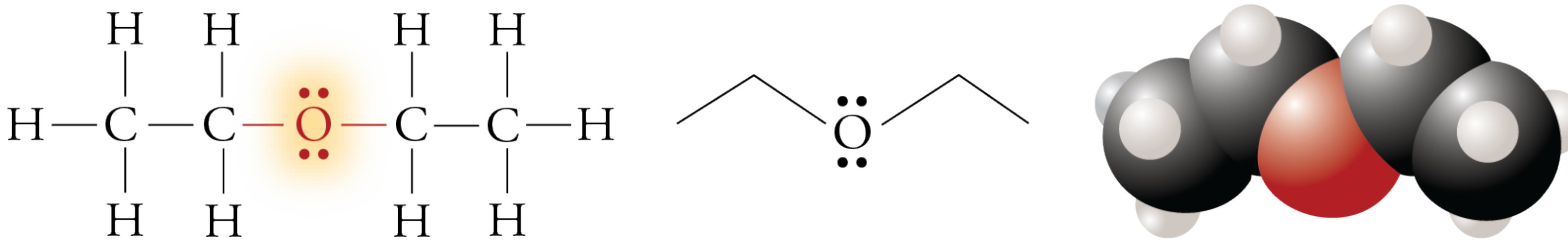
Fatty Acids



Stearic acid, $CH_3(CH_2)_{16}CO_2H$

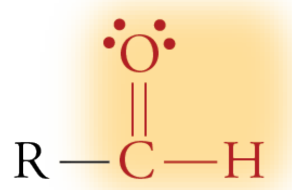
Ethers

Two hydrocarbon groups surrounding an oxygen atom

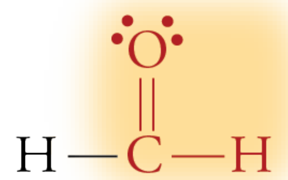


Diethyl ether, $CH_3CH_2OCH_2CH_3$

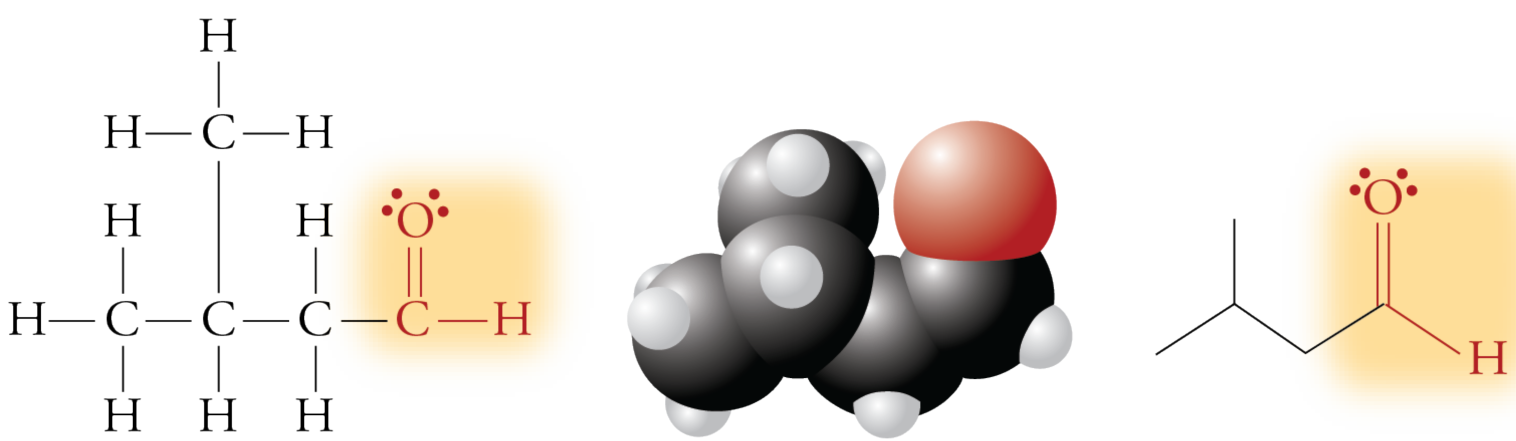
Aldehyde



Aldehyde



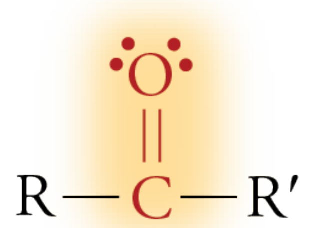
Formaldehyde



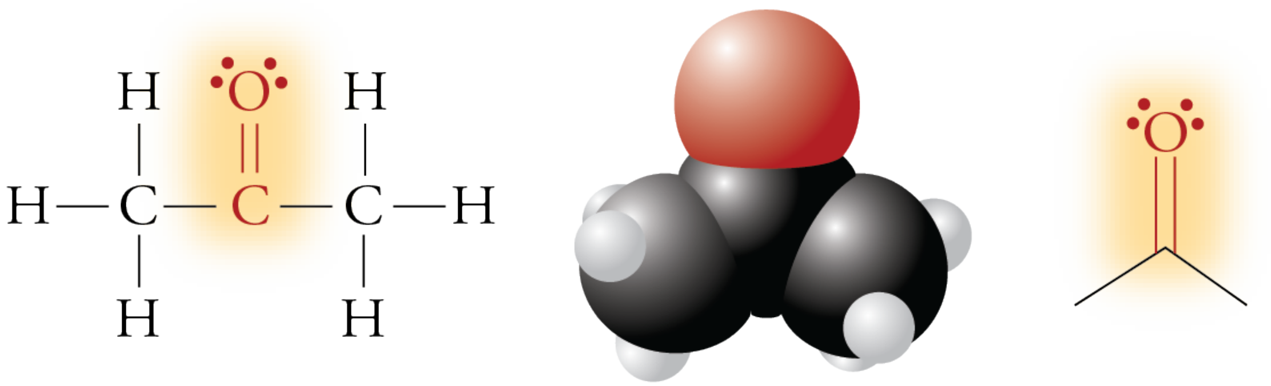
2-methylbutanal, $CH_3CH(CH_3)CH_2CHO$

Ketones

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

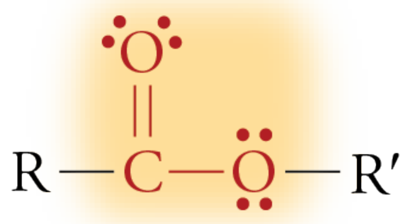


Ketone



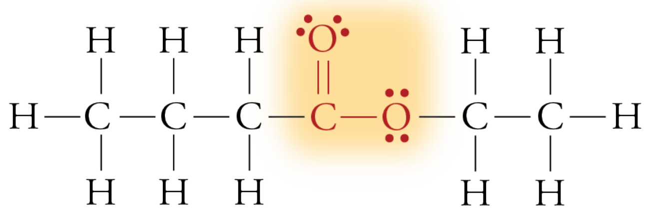
2-propanone (acetone), CH_3COCH_3

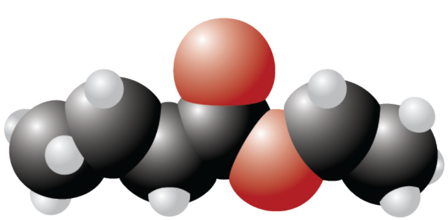
Esters

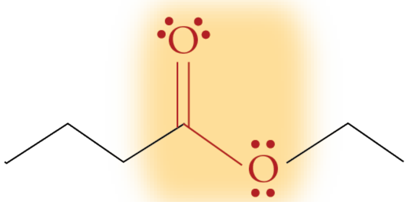


Ester

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

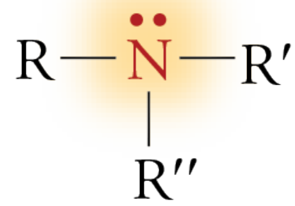




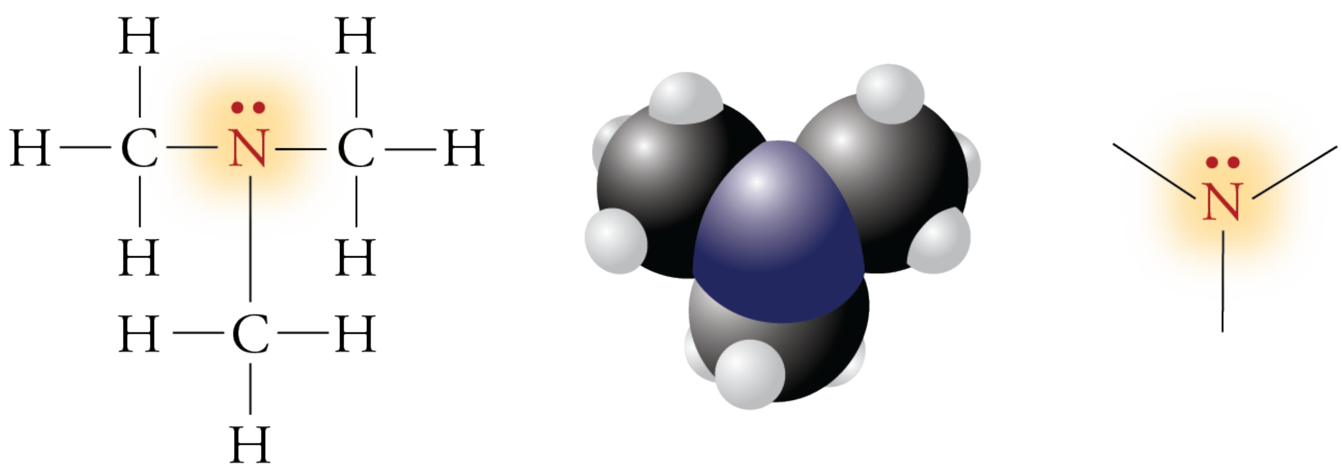


Ethyl butanoate, $CH_3CH_2CH_2CO_2CH_2CH_3$

Amine

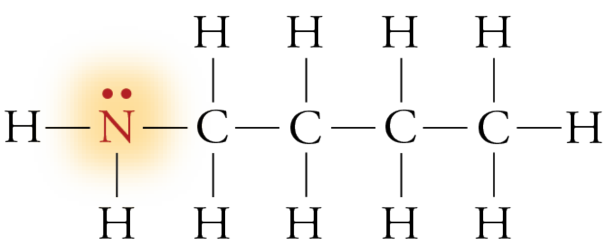


Amine

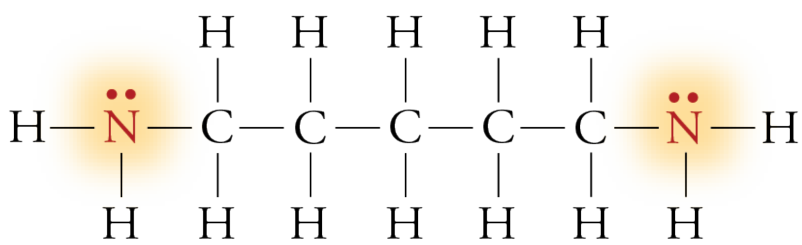


Trimethylamine, $(CH_3)_3N$

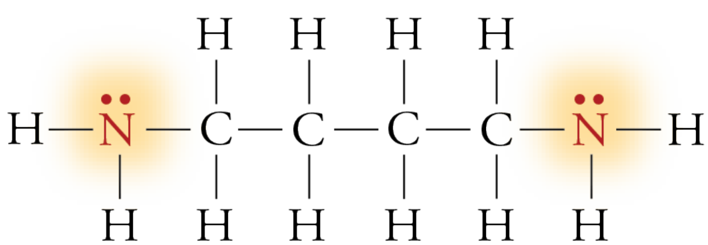
More Amines



1-Aminobutane

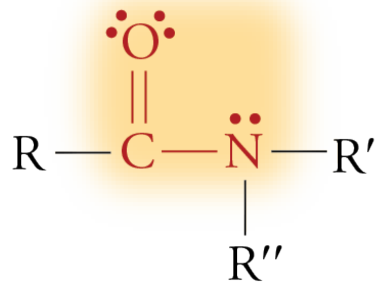


Cadaverine

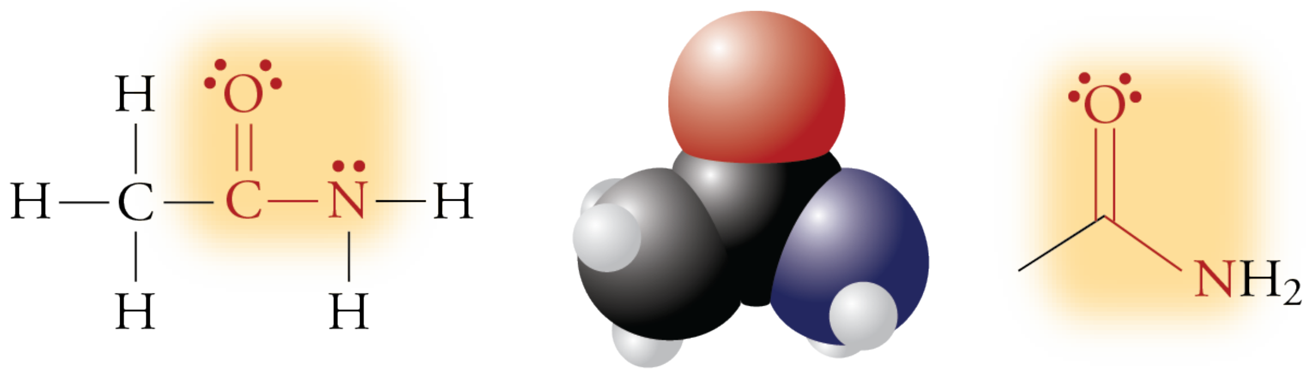


Putresine

Amides

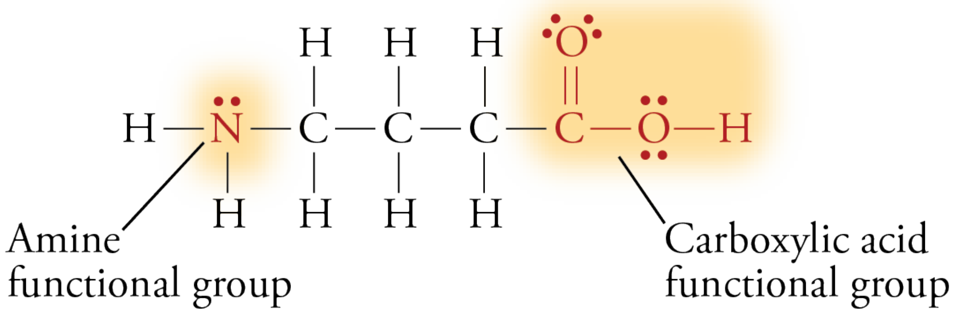


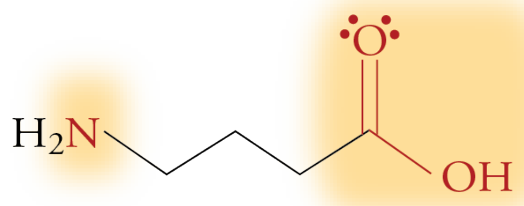
Amide

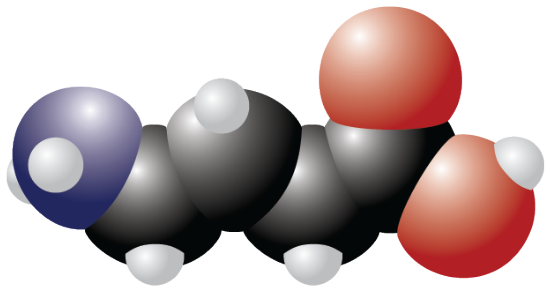


Ethanamide (acetamide), CH_3CONH_2

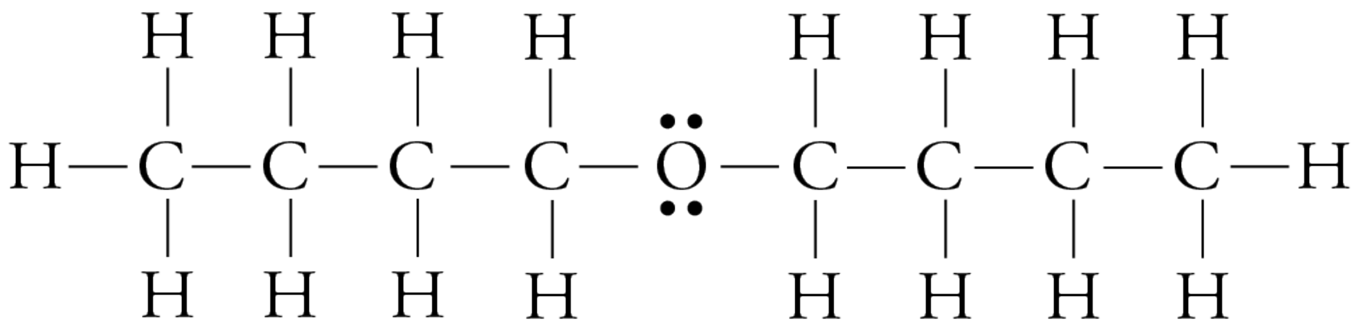
Difunctional Compounds - GABA





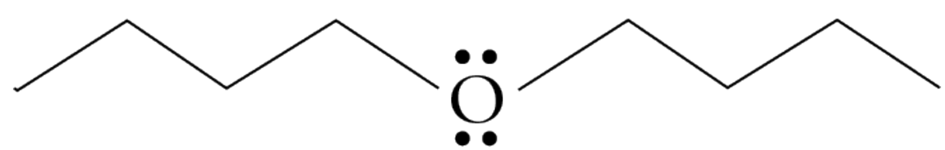


Example 1

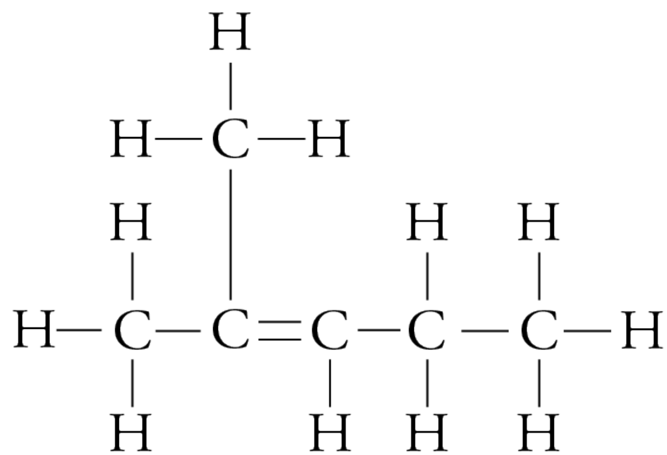


$CH_3CH_2CH_2CH_2OCH_2CH_2CH_2CH_3$

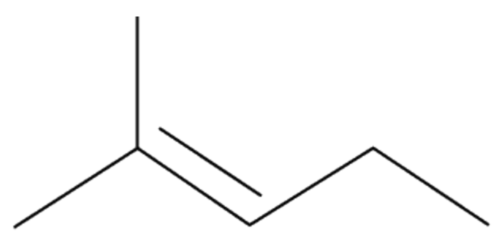
or $CH_3(CH_2)_3O(CH_2)_3CH_3$



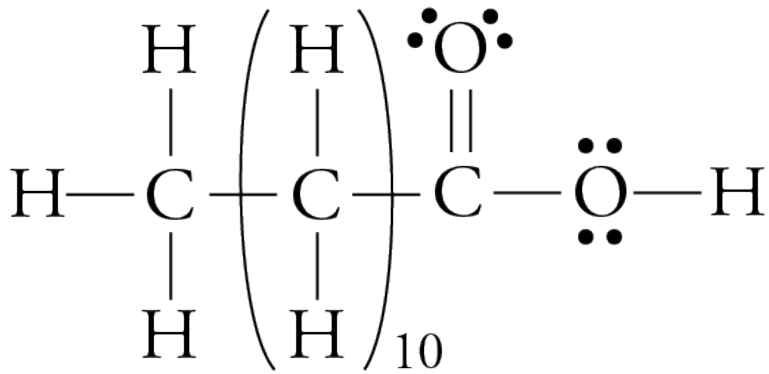
Example 2



$CH_3C(CH_3)CHCH_2CH_3$



Example 3

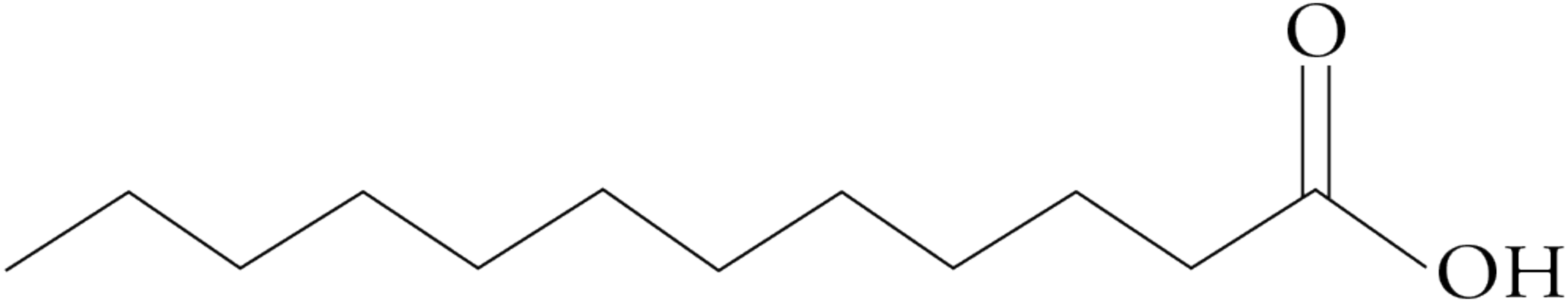


$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CO_2H$

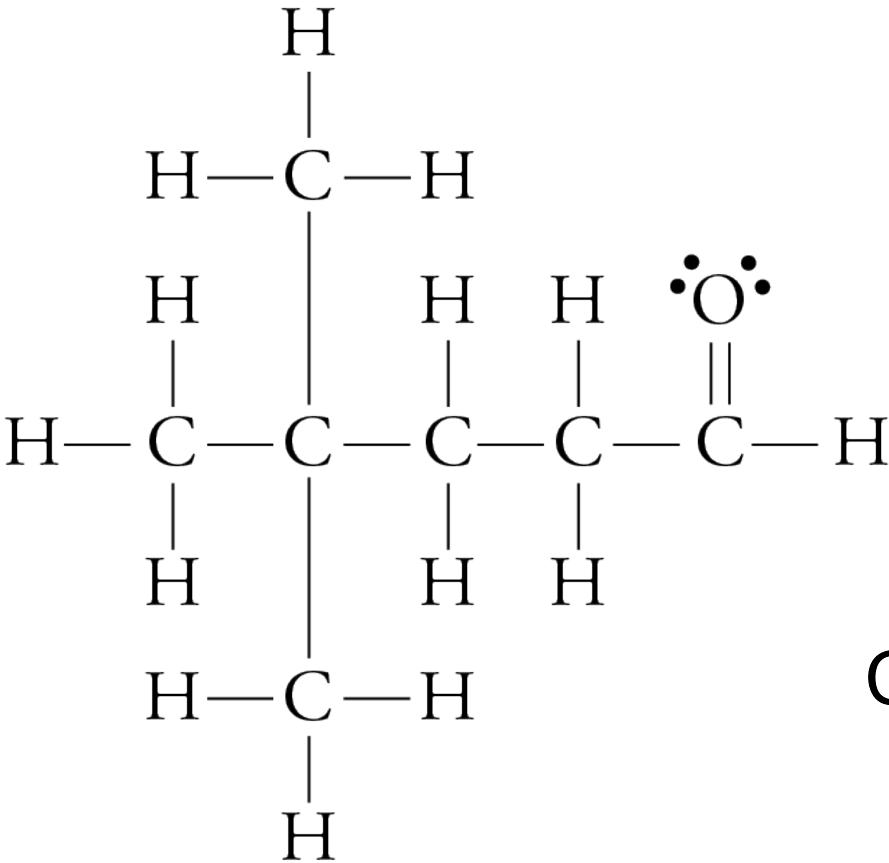
or $CH_3(CH_2)_{10}CO_2H$

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2COOH$

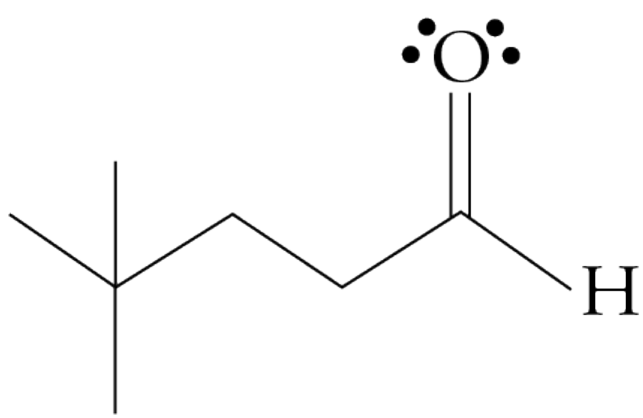
or $CH_3(CH_2)_{10}COOH$



Example 4



$CH_3C(CH_3)_2CH_2CH_2CHO$



Types of Biomolecules

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

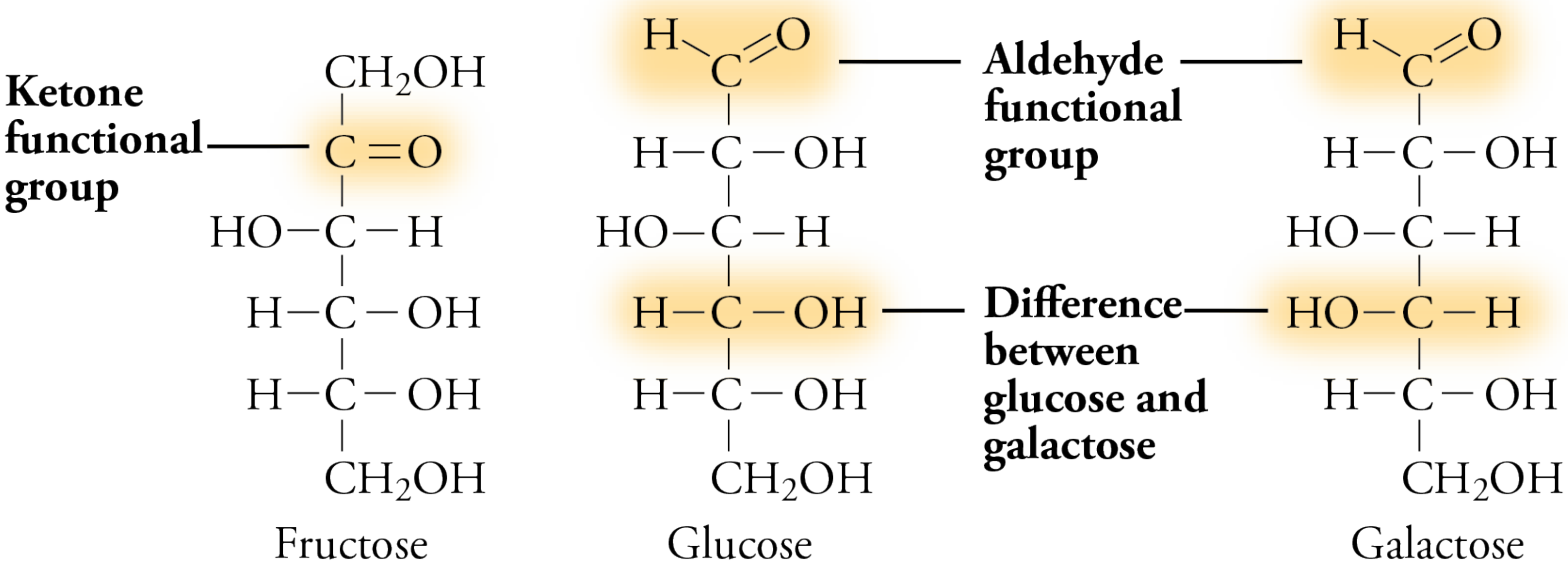
Substances in Food

- 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).

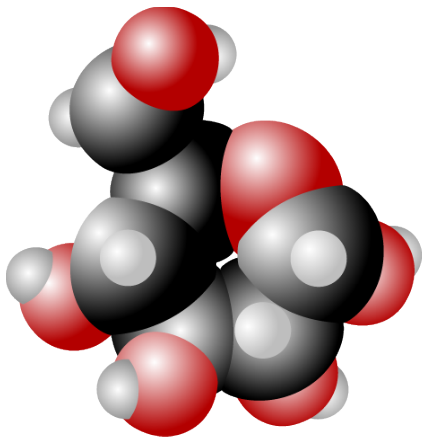
Carbohydrates

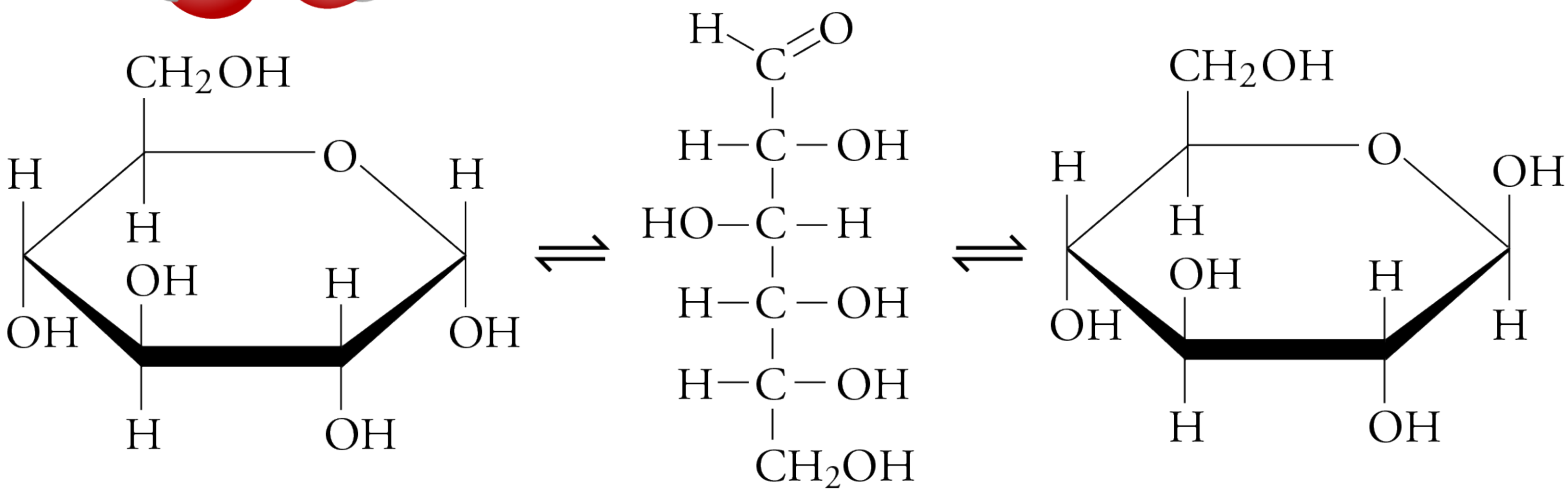
- Carbohydrate is a general name for sugars, starches, and cellulose.
- They are also be called saccharides.
- Sugars are monosaccharides or disaccharides, and starches and cellulose are polysaccharides.
- The most common monosaccharides are glucose, fructose, and galactose, which are isomers with the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

Monosaccharides



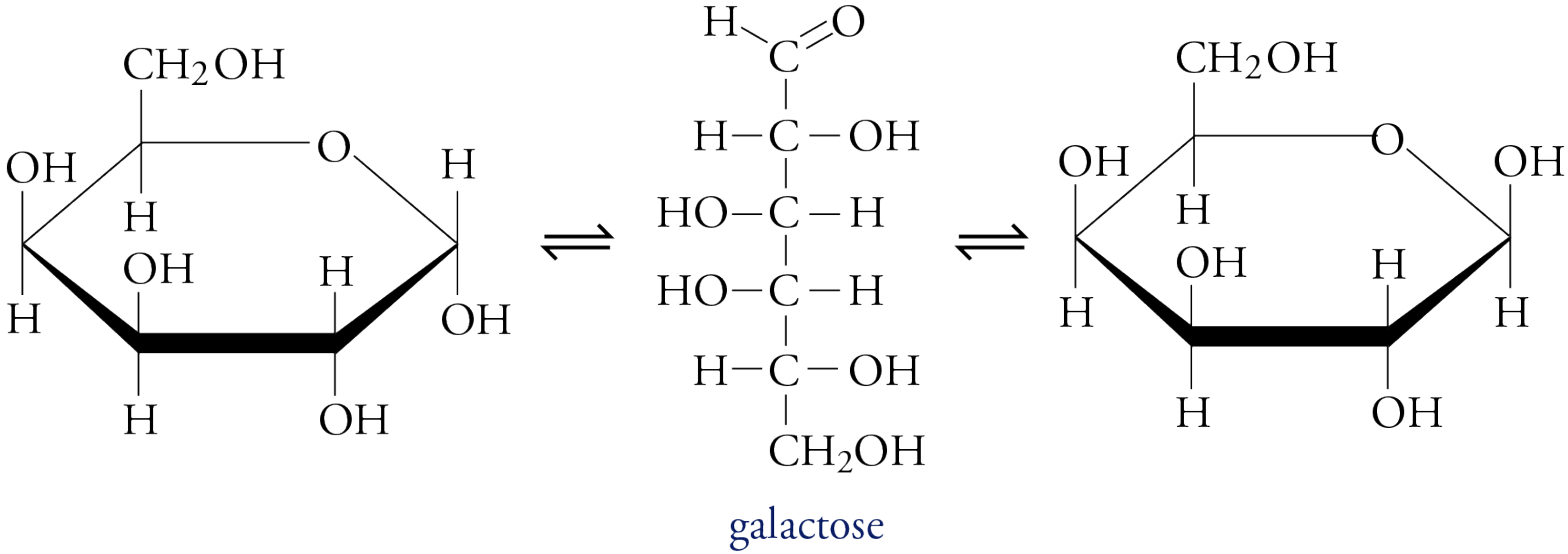
Glucose



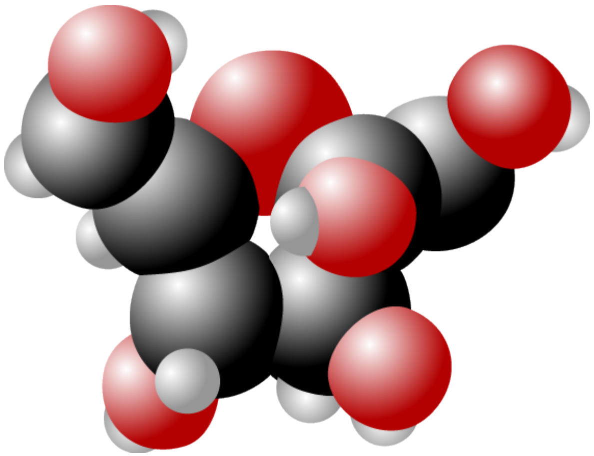


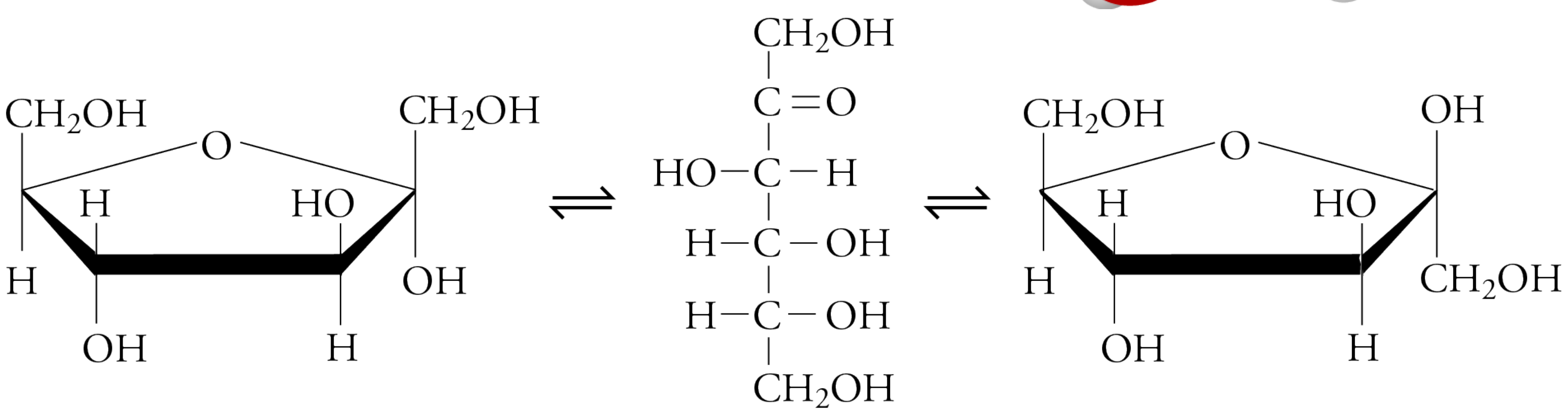
glucose

Galactose


CH2OH
O
OH
H
OH
H
OH
H
H
OH
H
OH
H—C—OH
HO—C—H
HO—C—H
H—C—OH
CH2OH
galactose

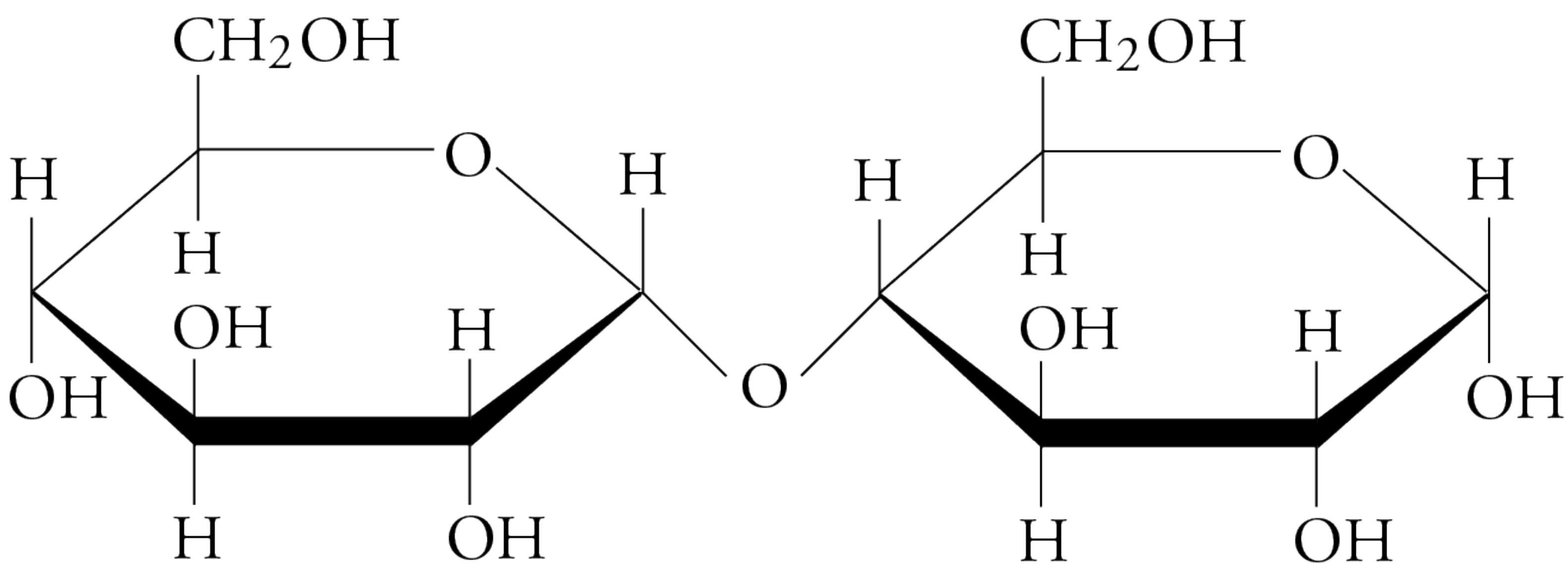
Fructose





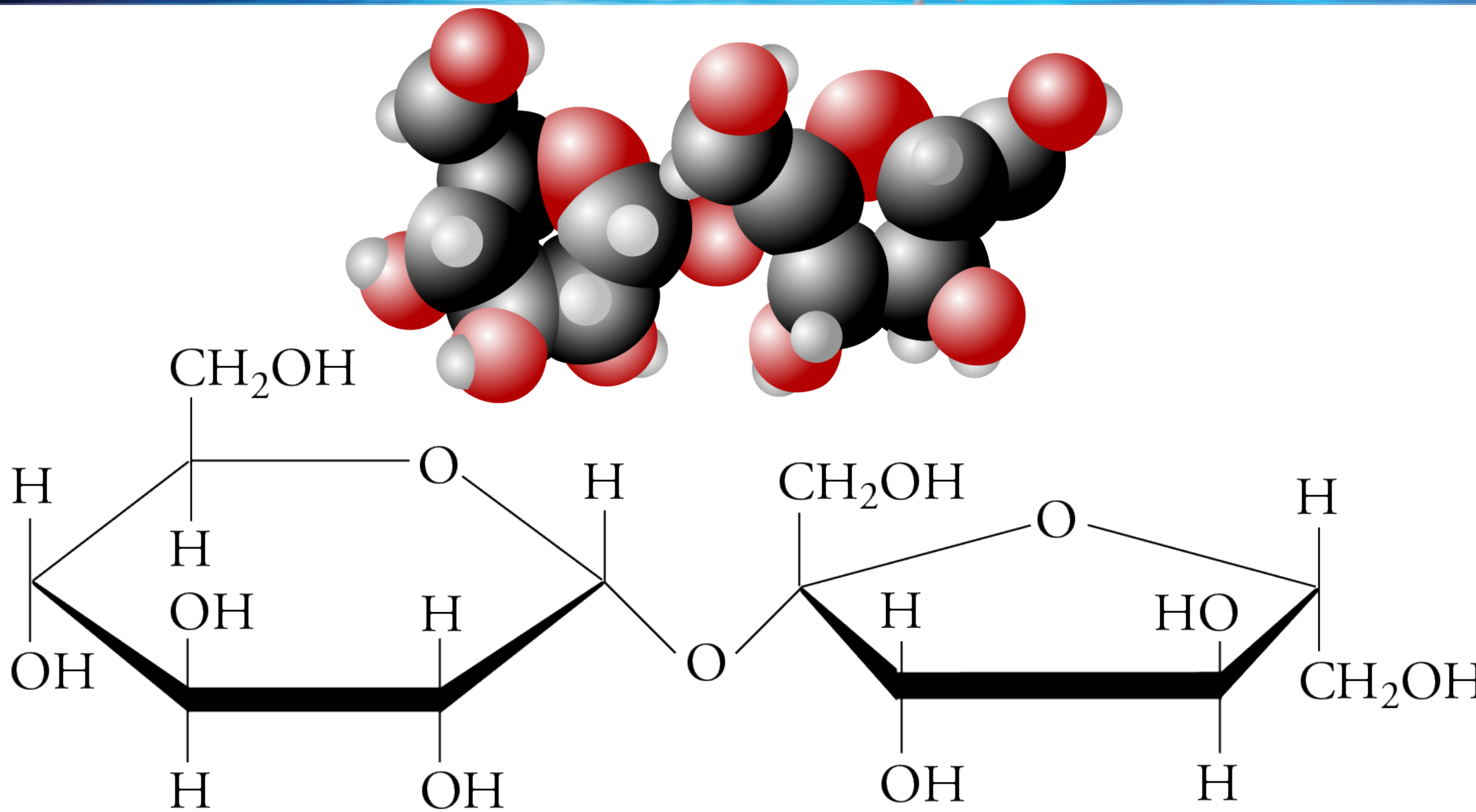
Fructose

Maltose



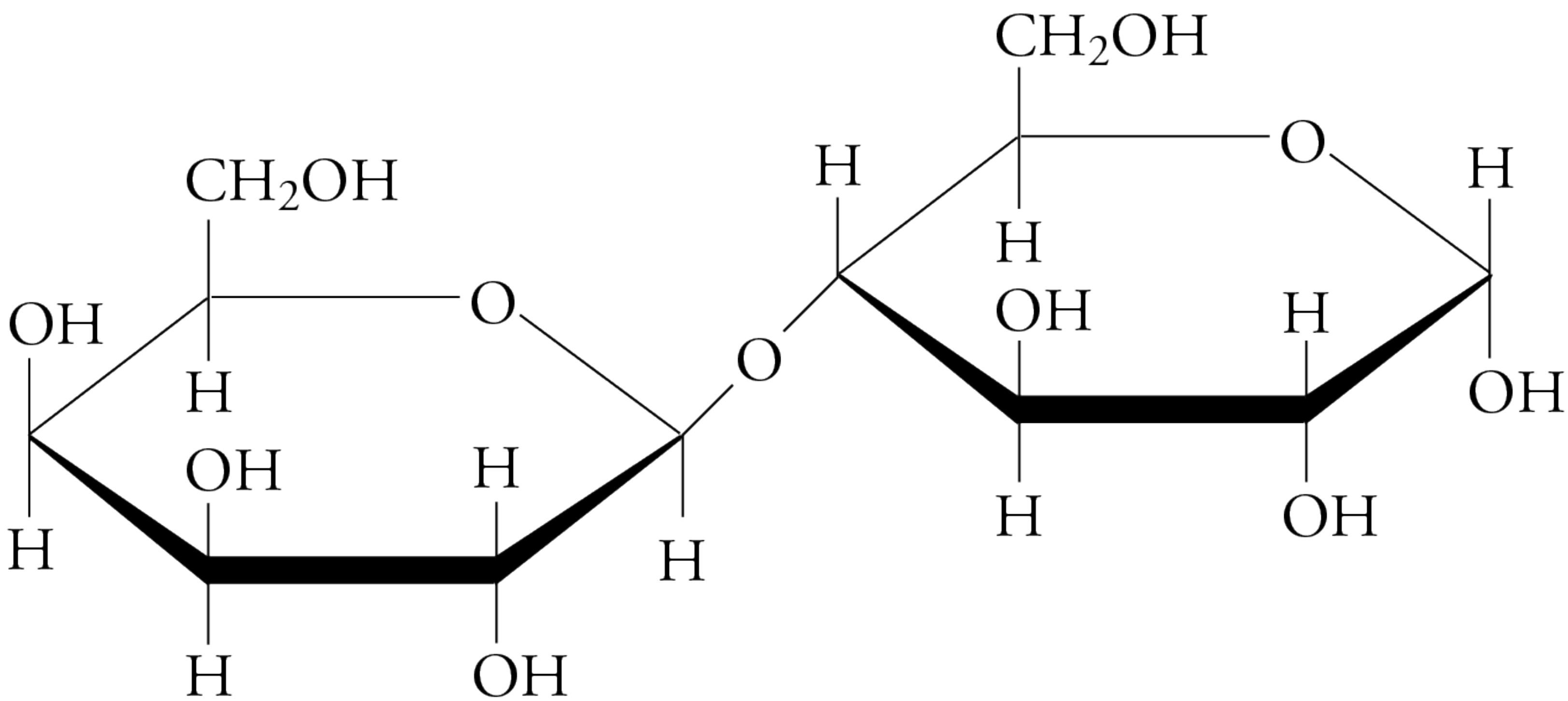
Maltose (glucose and glucose)

Sucrose



Sucrose (glucose and fructose)

Lactose



Lactose (galactose and glucose)

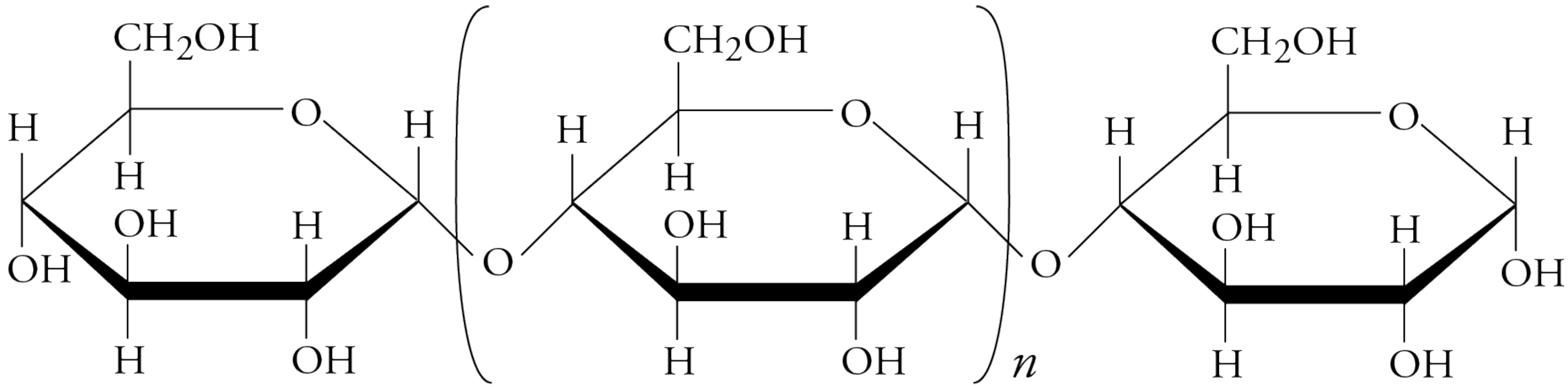
Polysaccharides

- 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

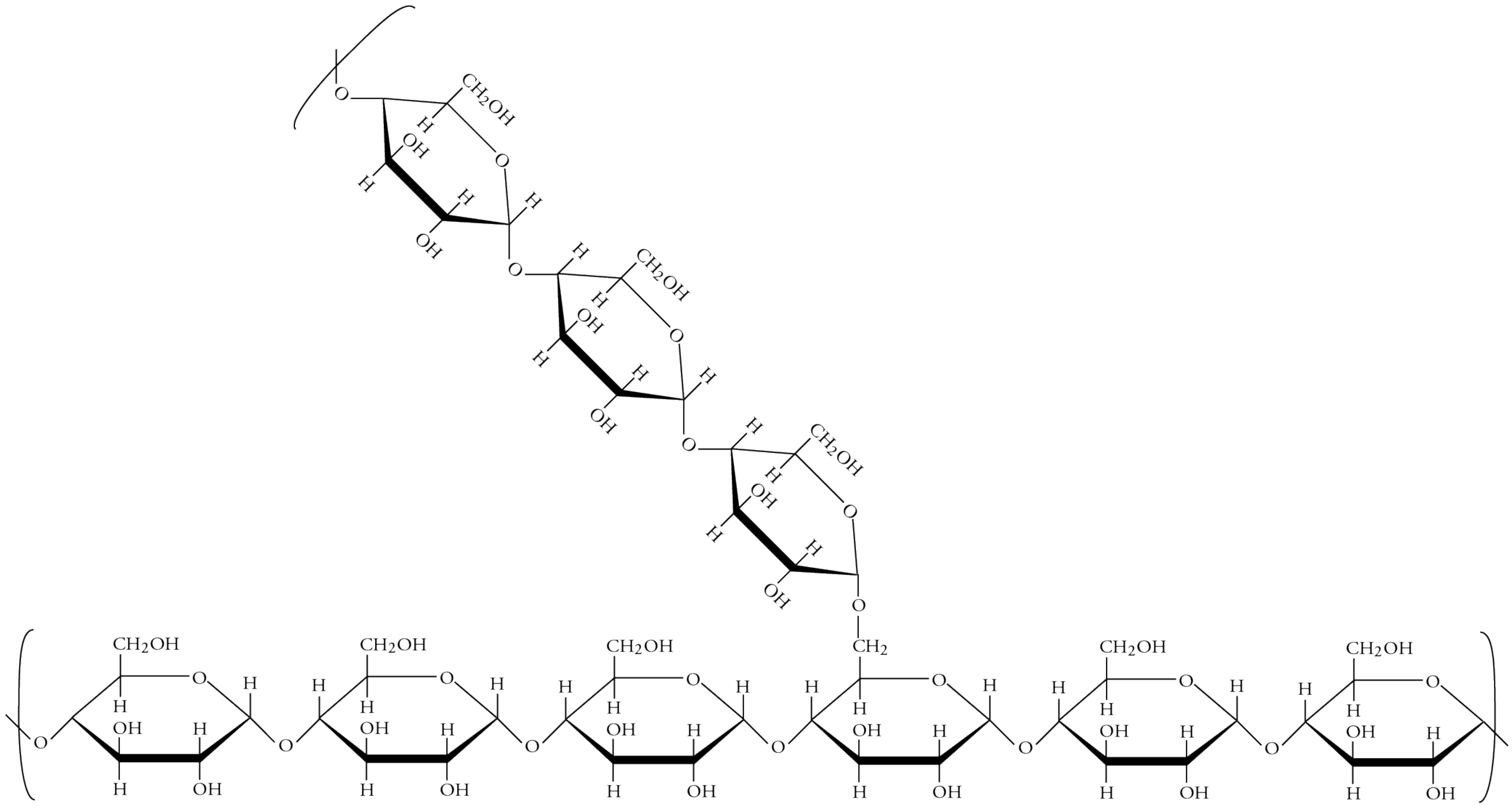
- Plant Starch
  - Amylose with long straight chains of glucose molecules.
  - Amylopectin with long chains of glucose molecules with periodic chains of glucose molecules coming off as branches from the straight chains.
- Animal Starch (Glycogen)
  - Similar to amylopectin but with generally shorter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

Amylose



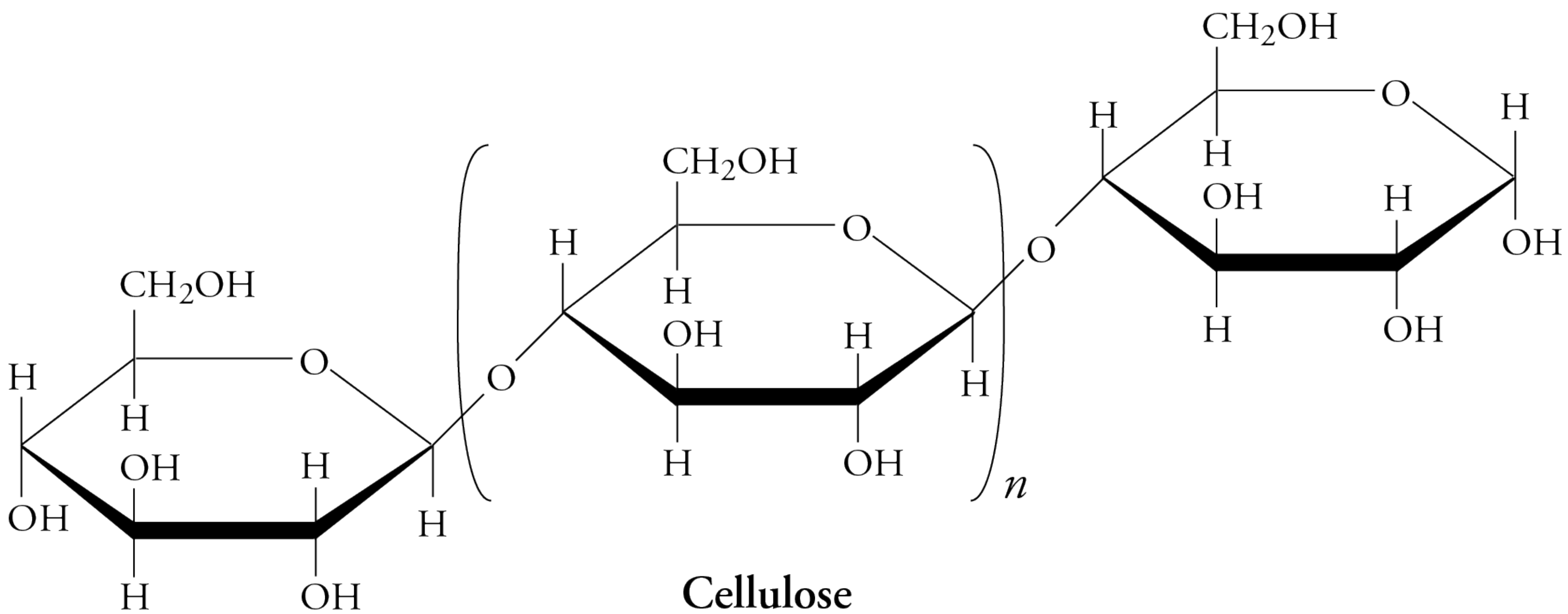
Amylose

Amylopectin or Glycogen



Amylopectin

Cellulose

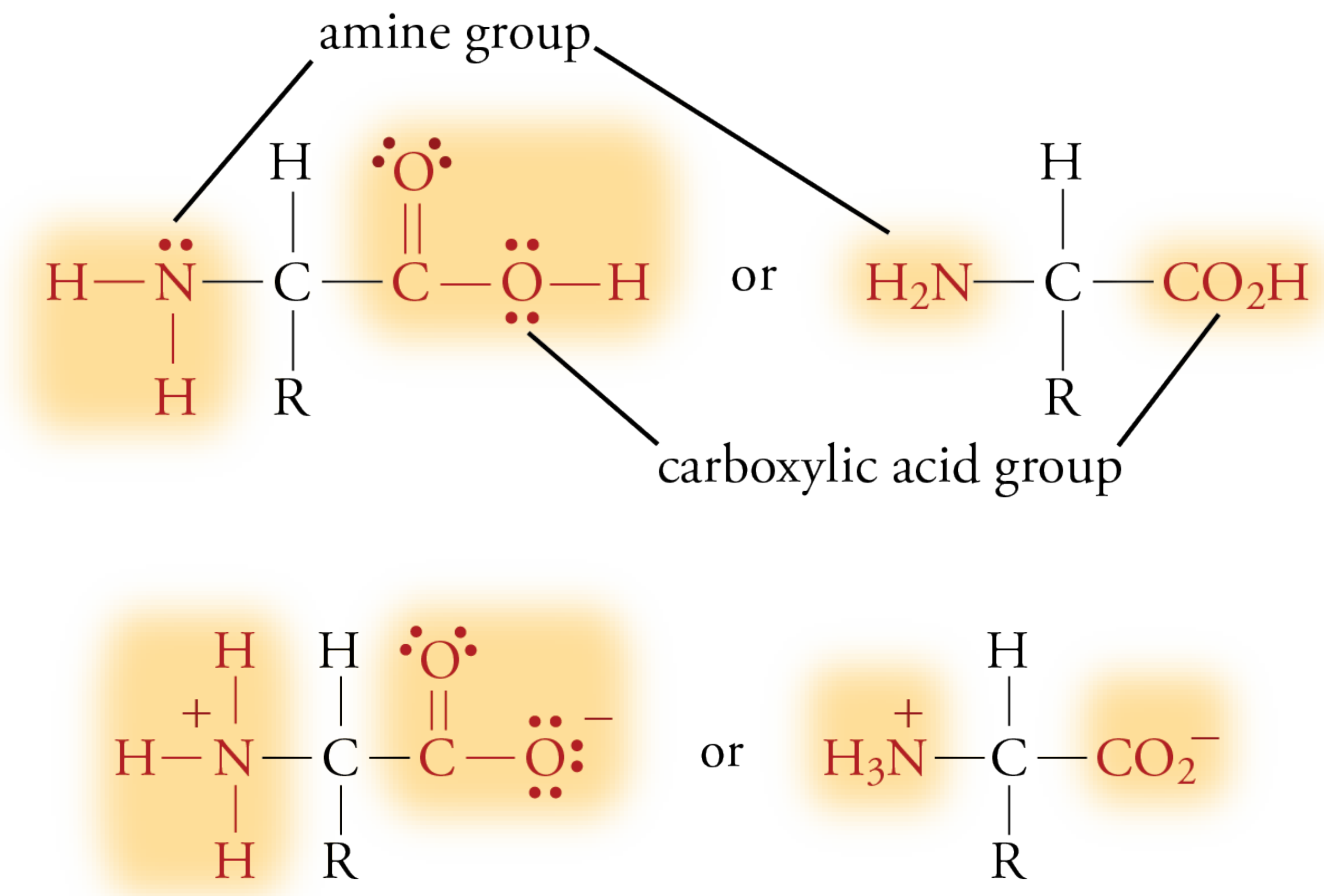


Cellulose

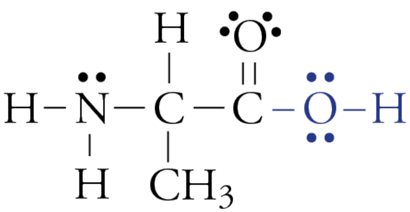
Amino Acids

- 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.

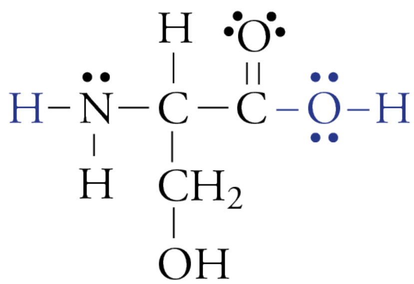
Amino Acids



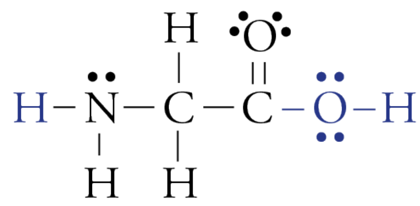
Alanine, Serine, Glycine, and Cysteine



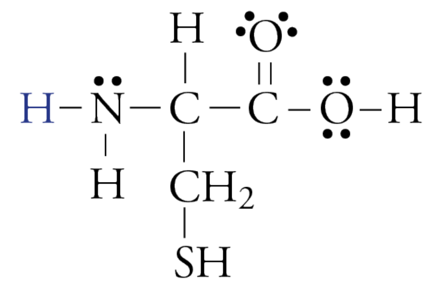
Alanine (Ala)



Serine (Ser)



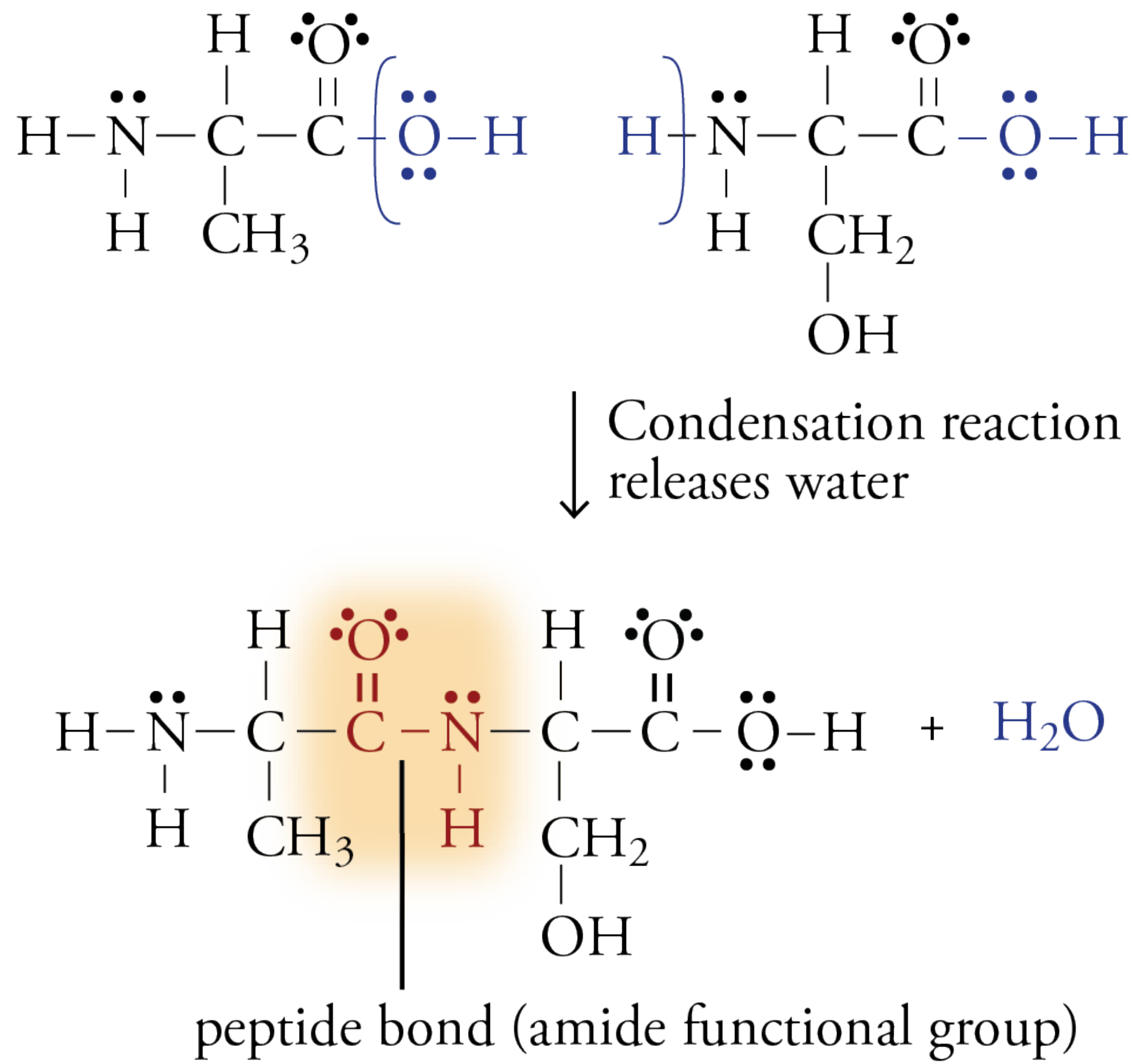
Glycine (Gly)



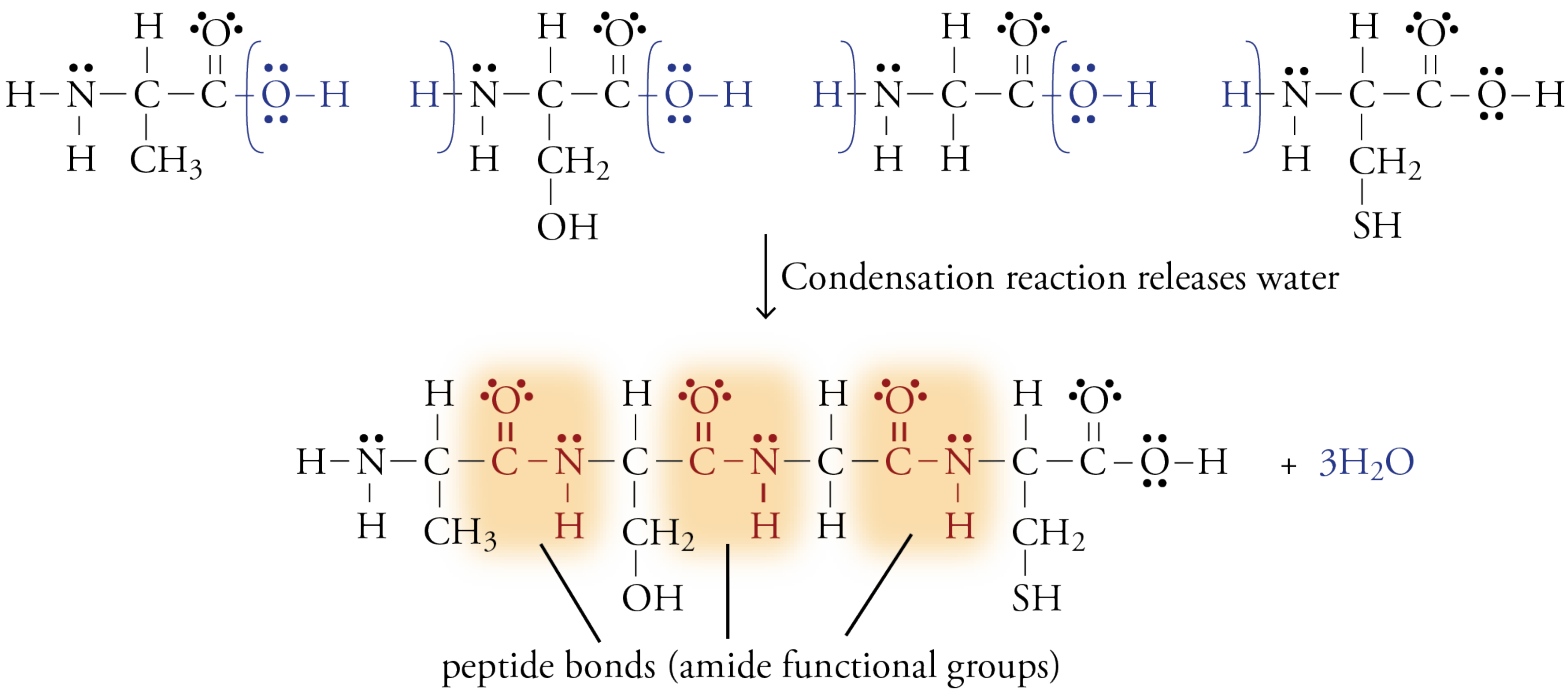
Cysteine (Cys)

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.



Formation of Ala-Ser-Gly-Cys



Polypeptides and Proteins

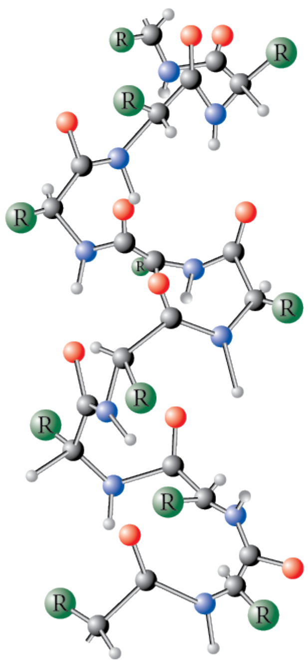
- A chain of amino acids linked by peptide bonds would be called a **polypeptide** or often just a peptide.
- If the polypeptide has more than about 50 amino acids, we called it a **protein**.

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
    - α-helix
    - β-sheet
    - irregular

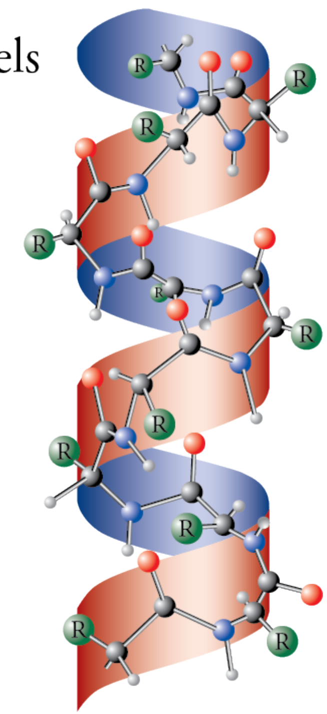
α-helix – Secondary Structure

Ball-and-stick model of a portion of the α-helical secondary structure of a protein molecule

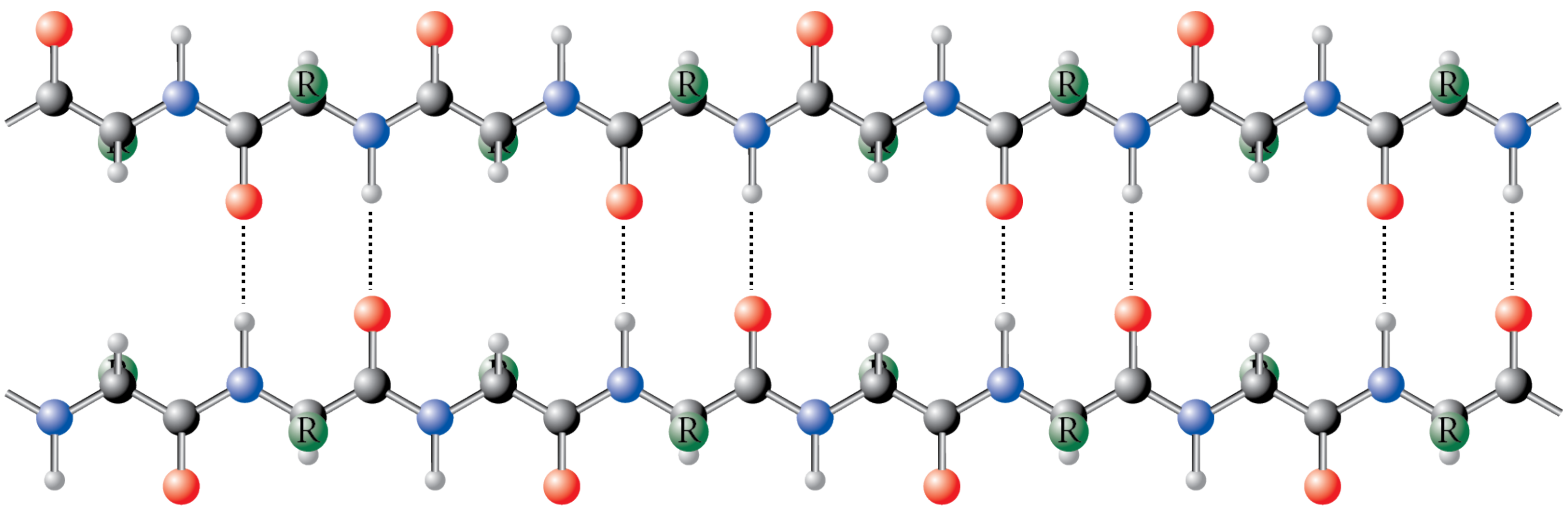


This ribbon model shows the general arrangement of atoms in a portion of the α-helical secondary structure of a protein molecule.

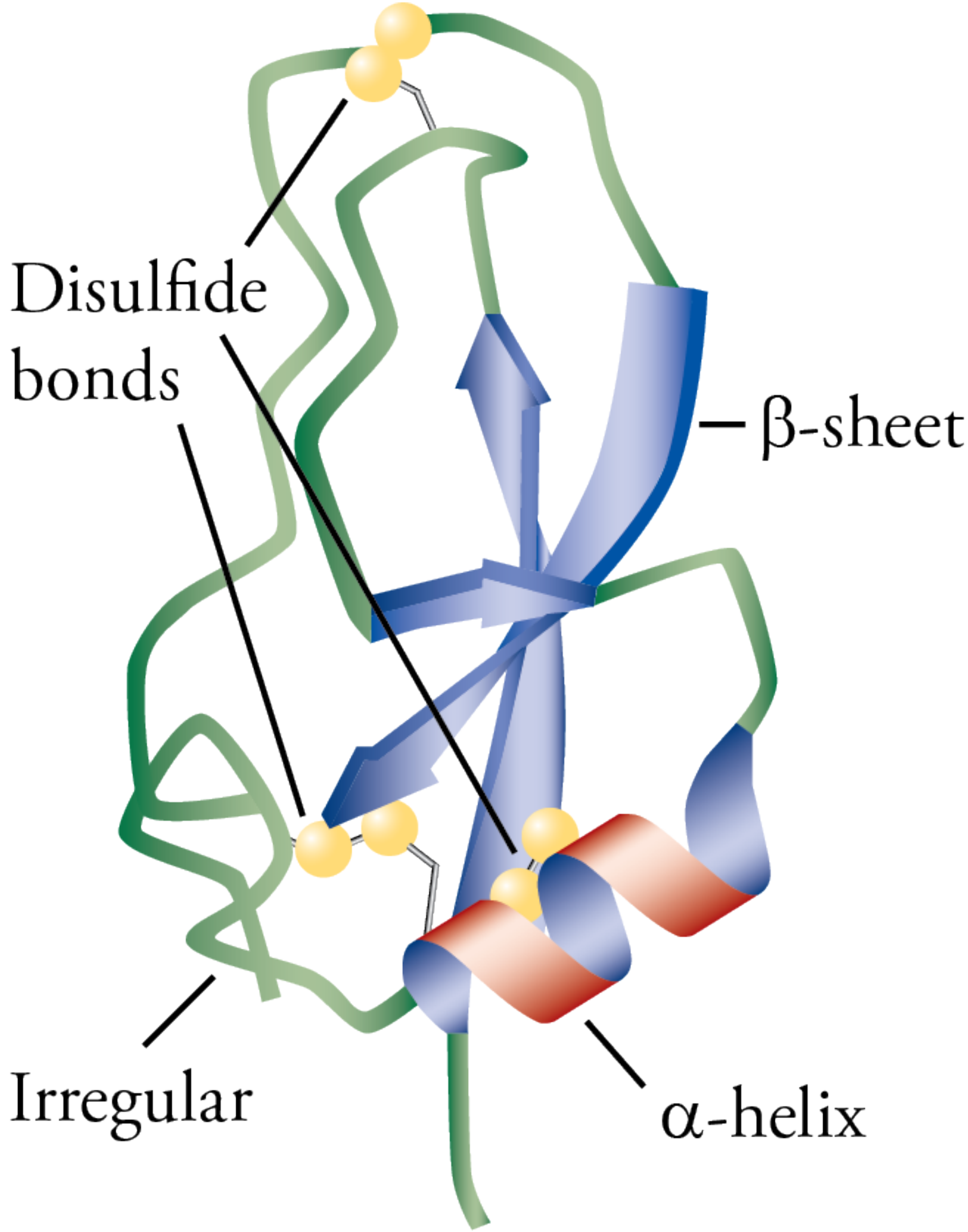
The two models superimposed



β-Sheet
Secondary Structure



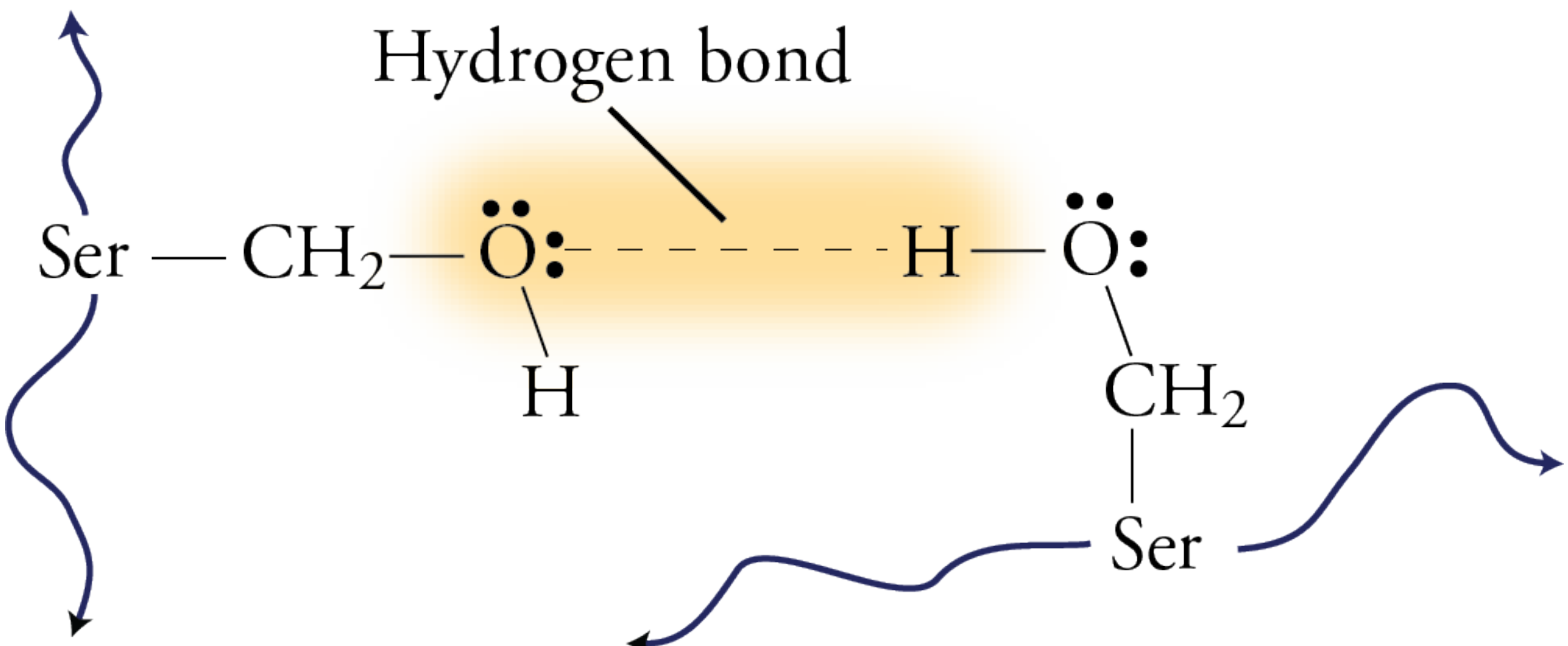
The Ribbon Structure of the Protein BPTI



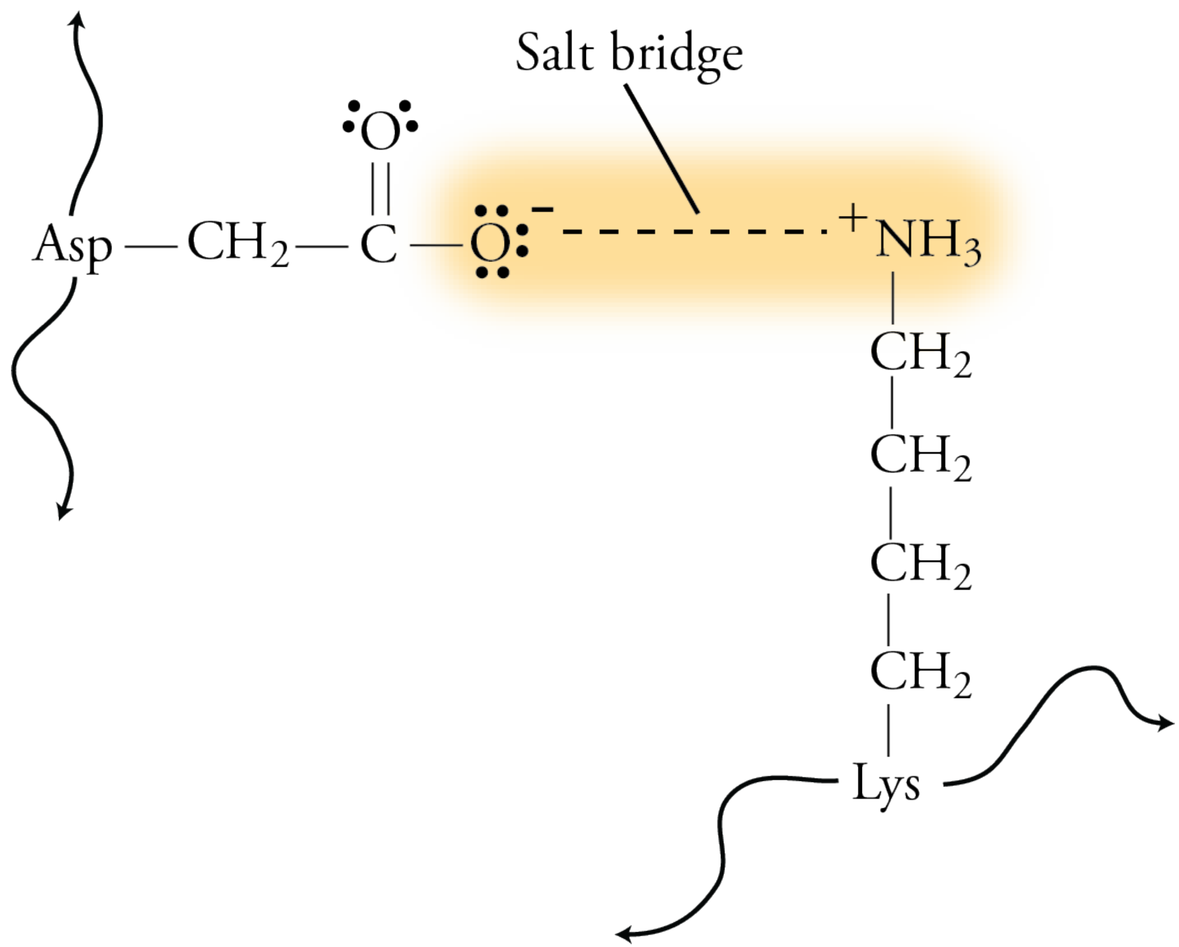
Tertiary Protein Structure

- 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

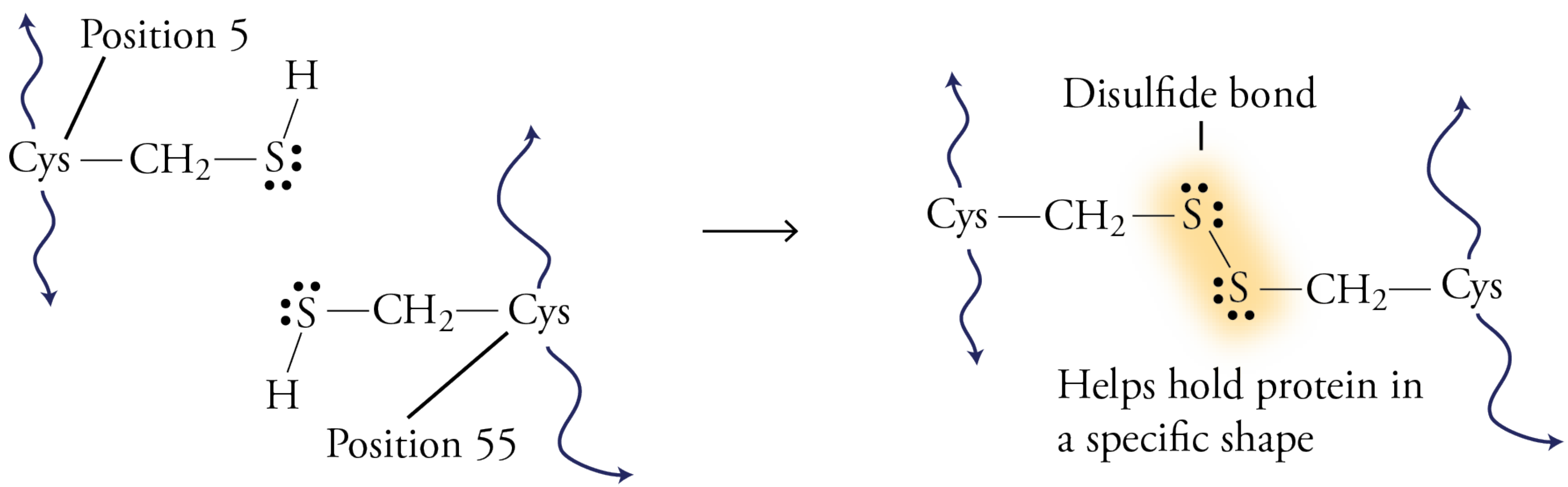
Hydrogen Bonding in Proteins



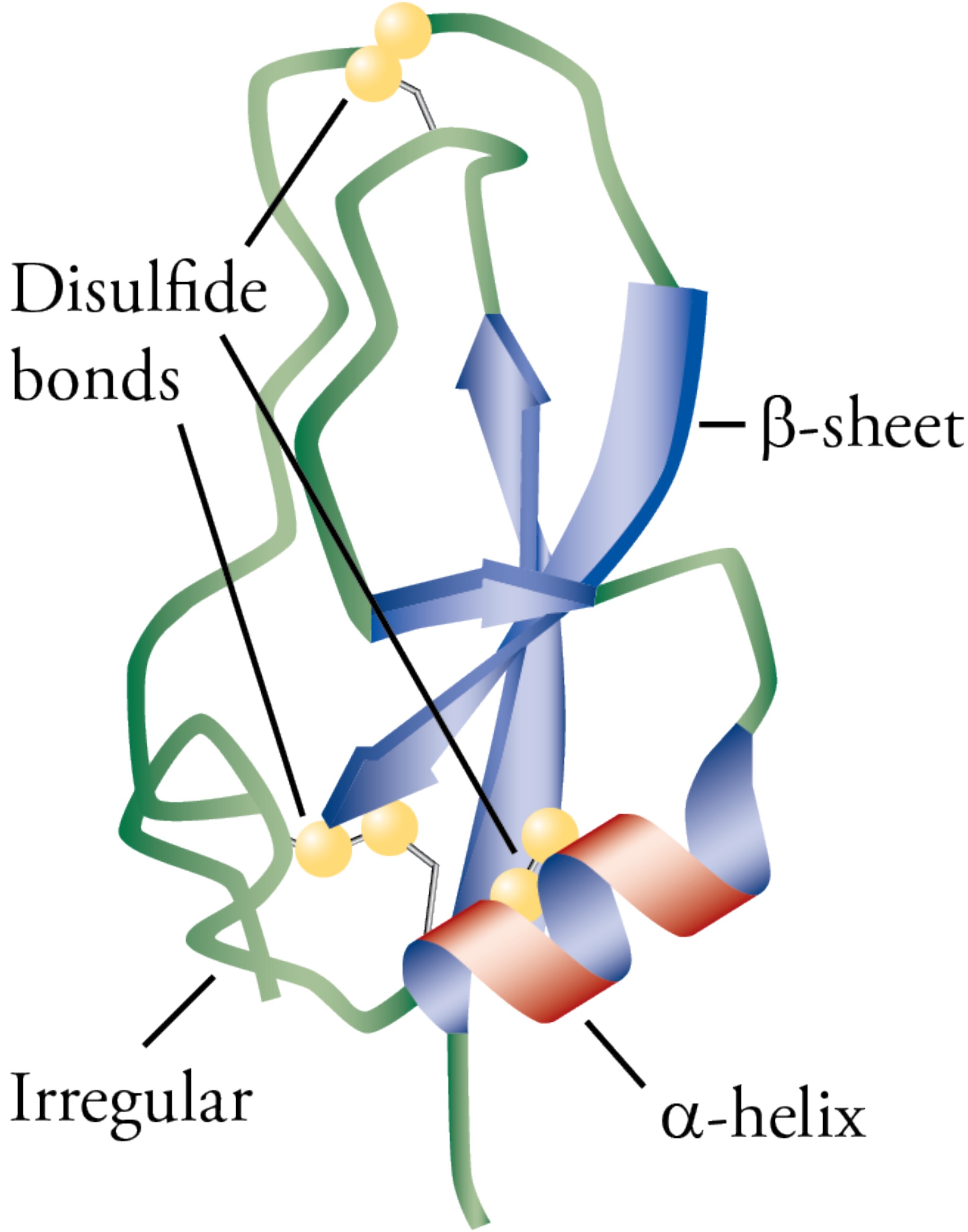
Salt Bridge in Proteins



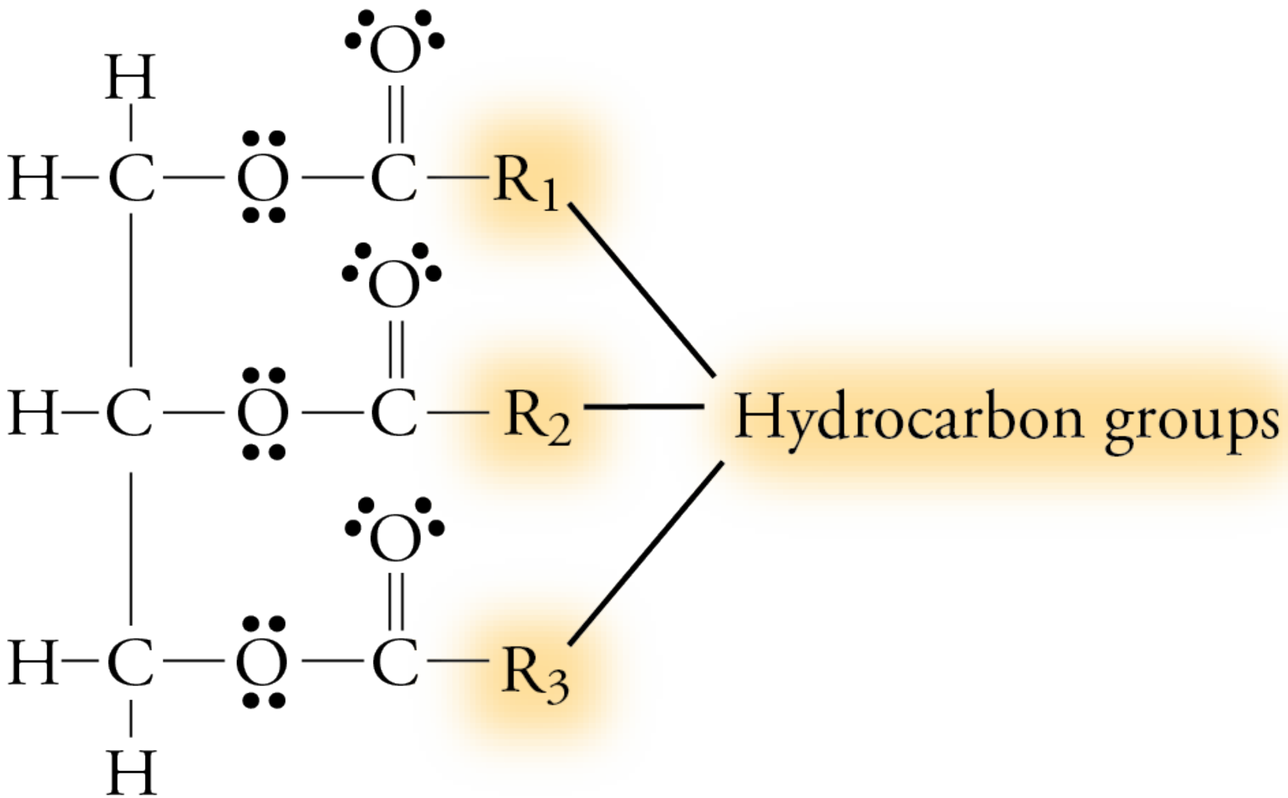
Disulfide Bonds in Proteins



The Ribbon Structure of the Protein BPTI

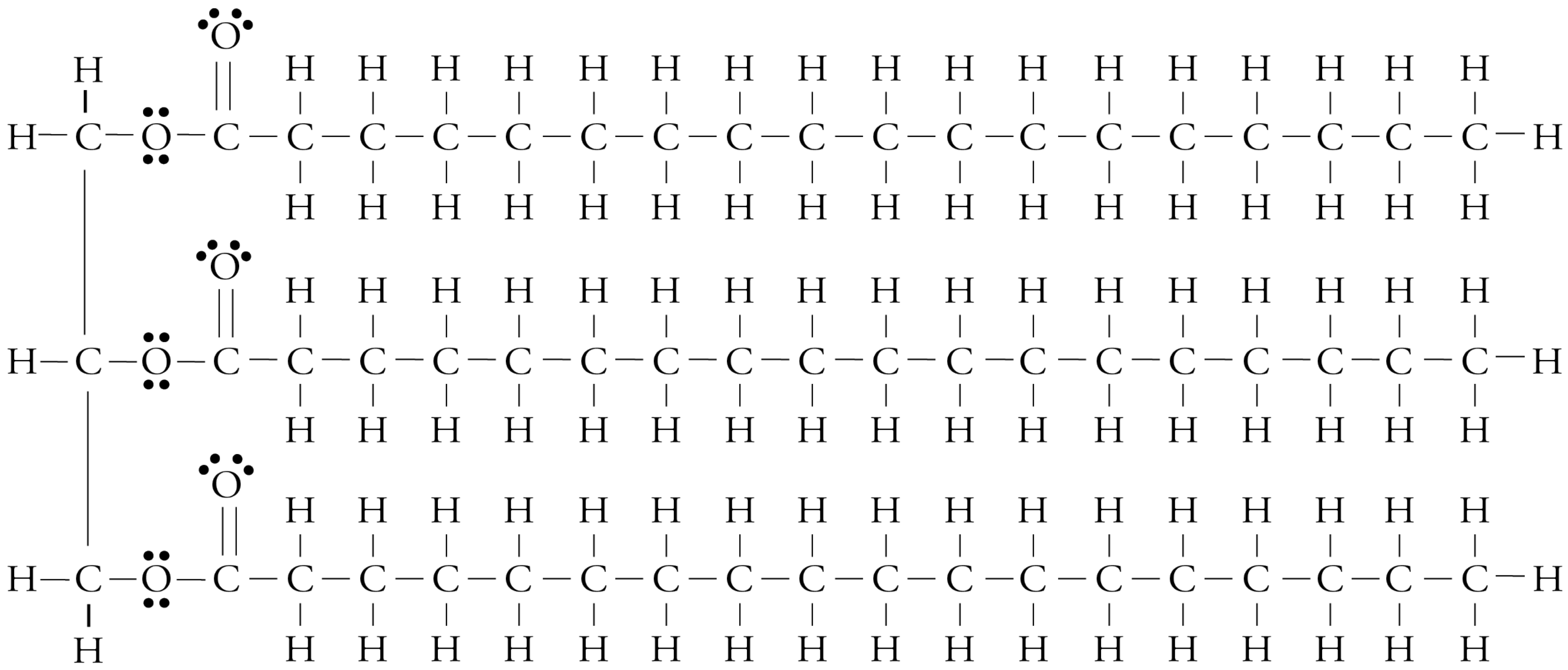


Triglycerides (Fats and Oils)

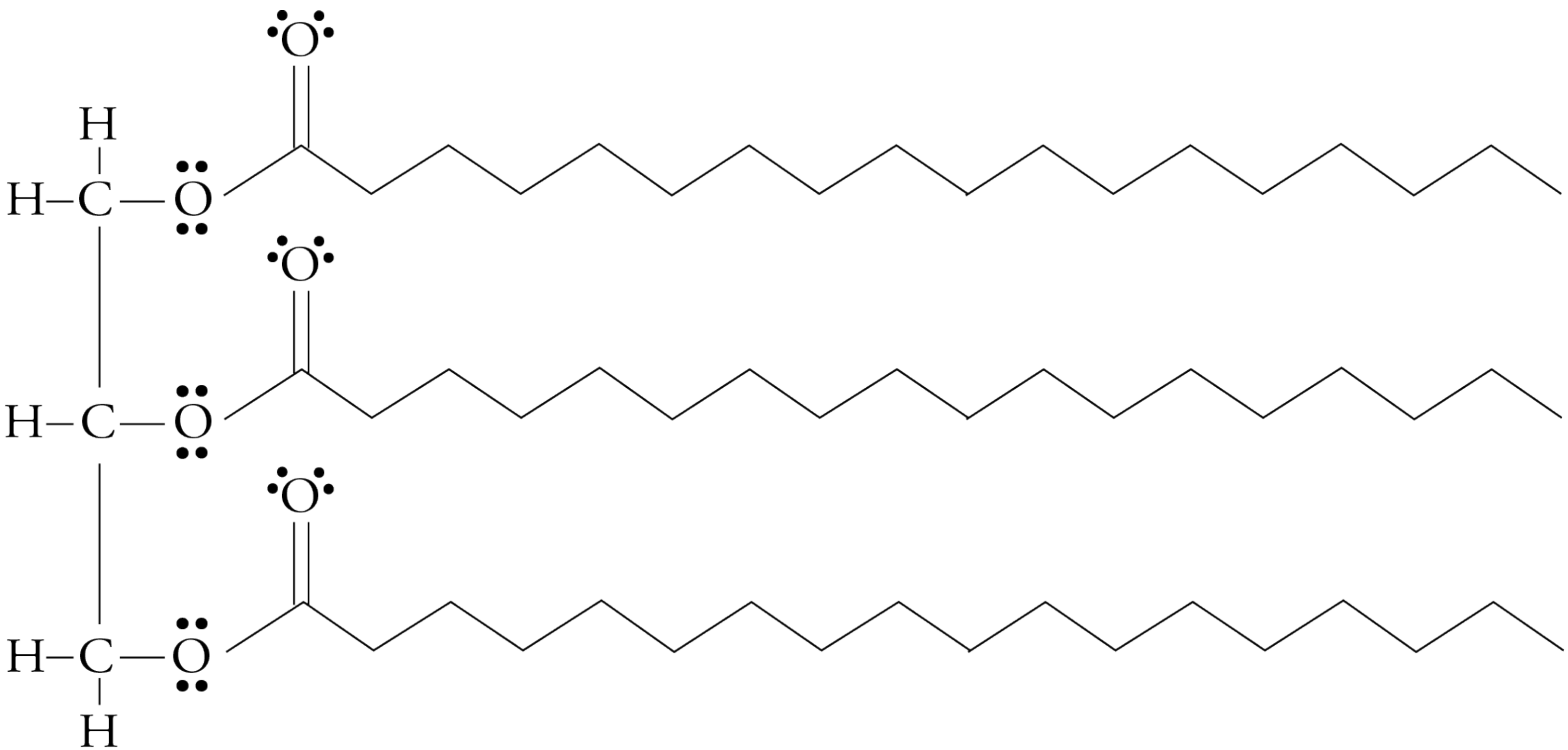


Triglyceride

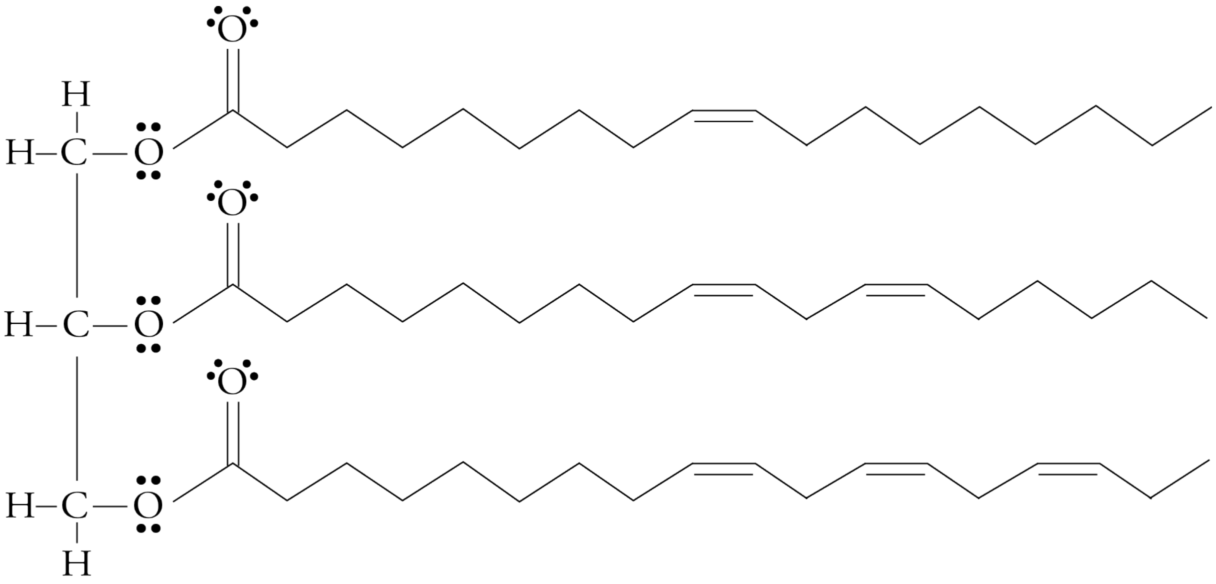
Saturated Triglyceride - Tristearin



Tristearin – Line Drawing



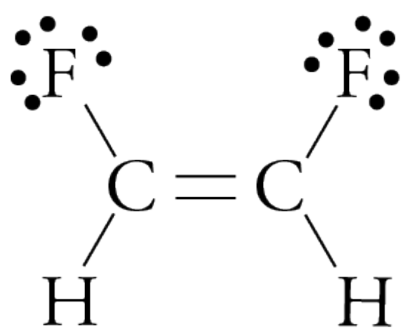
Unsaturated Triglyceride



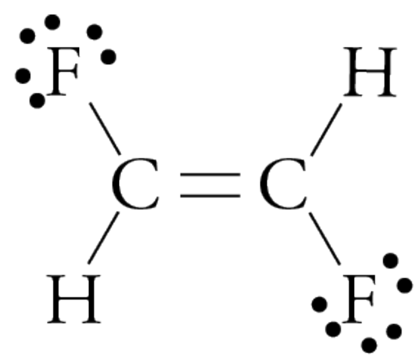
Liquid triglycerides are rich in carbon-carbon double bonds.

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***.

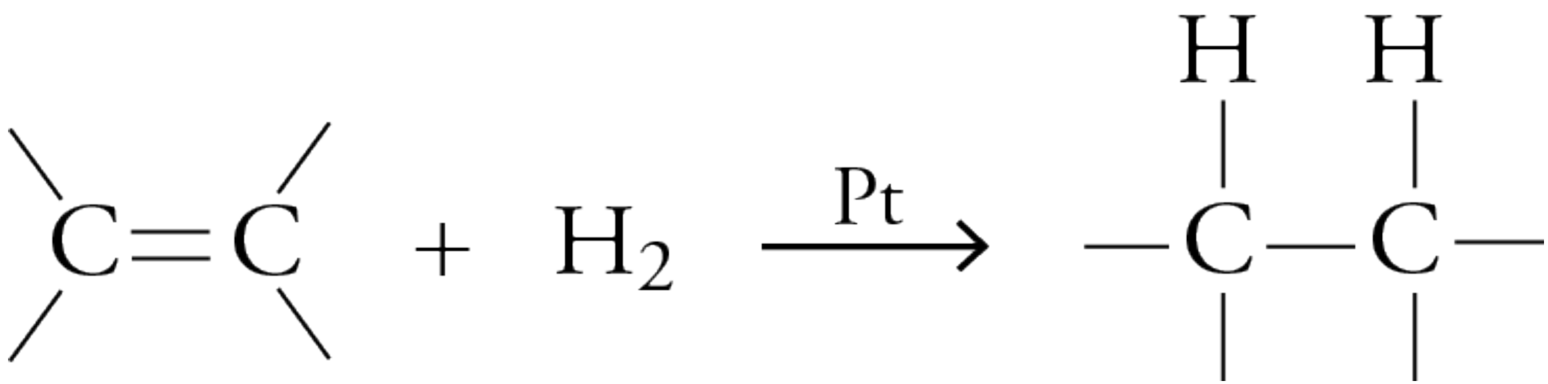


cis-1,2-difluoroethene

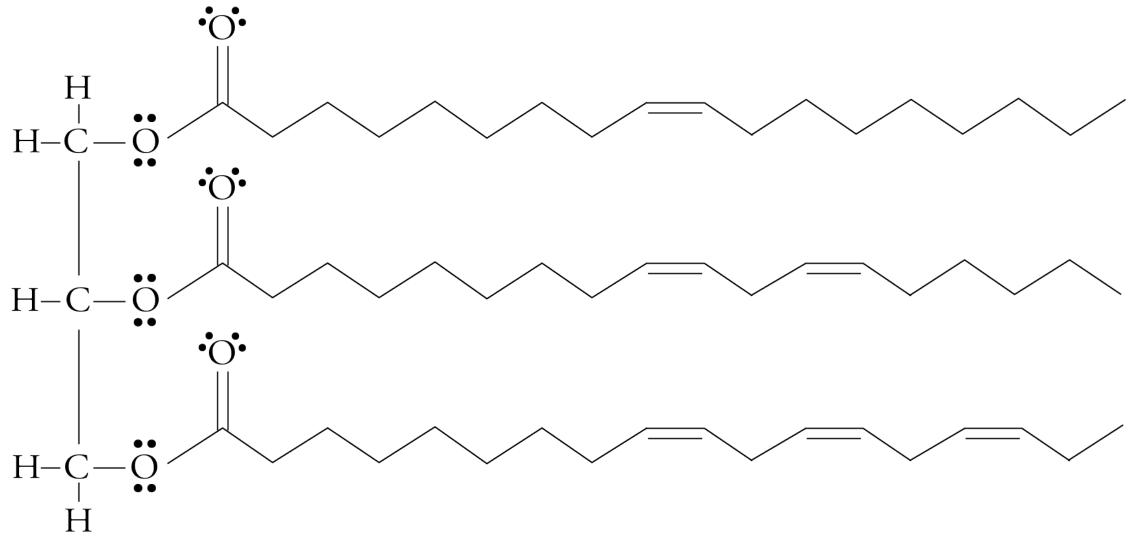


trans-1,2-difluoroethene

Hydrogenation

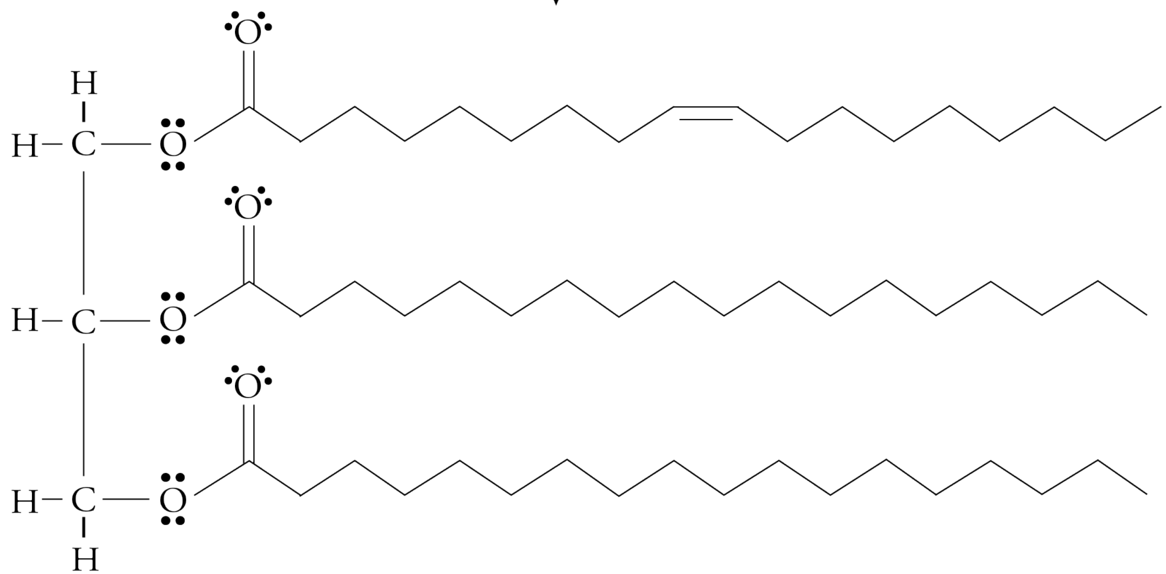


Hydrogenation - Example



Typical vegetable oil molecule - liquid unsaturated triglyceride

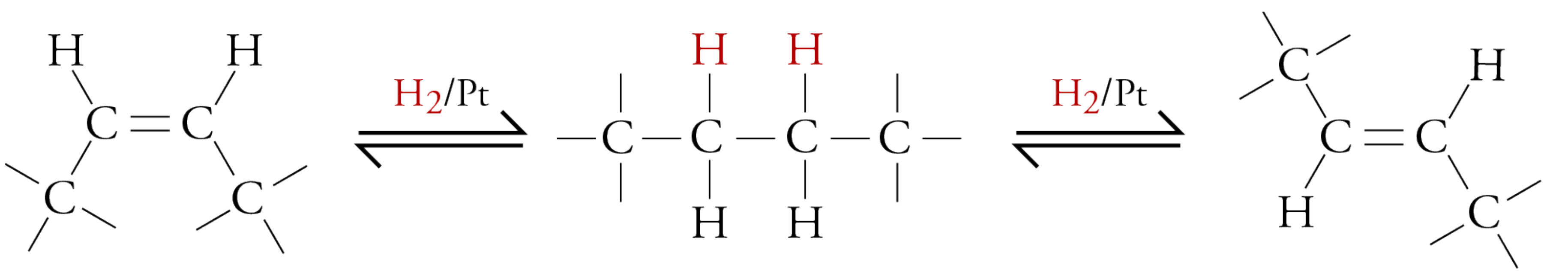
$\downarrow + 5H_2(g)$



Typical molecule in margarine - solid partially hydrogenated triglyceride

Trans Fats

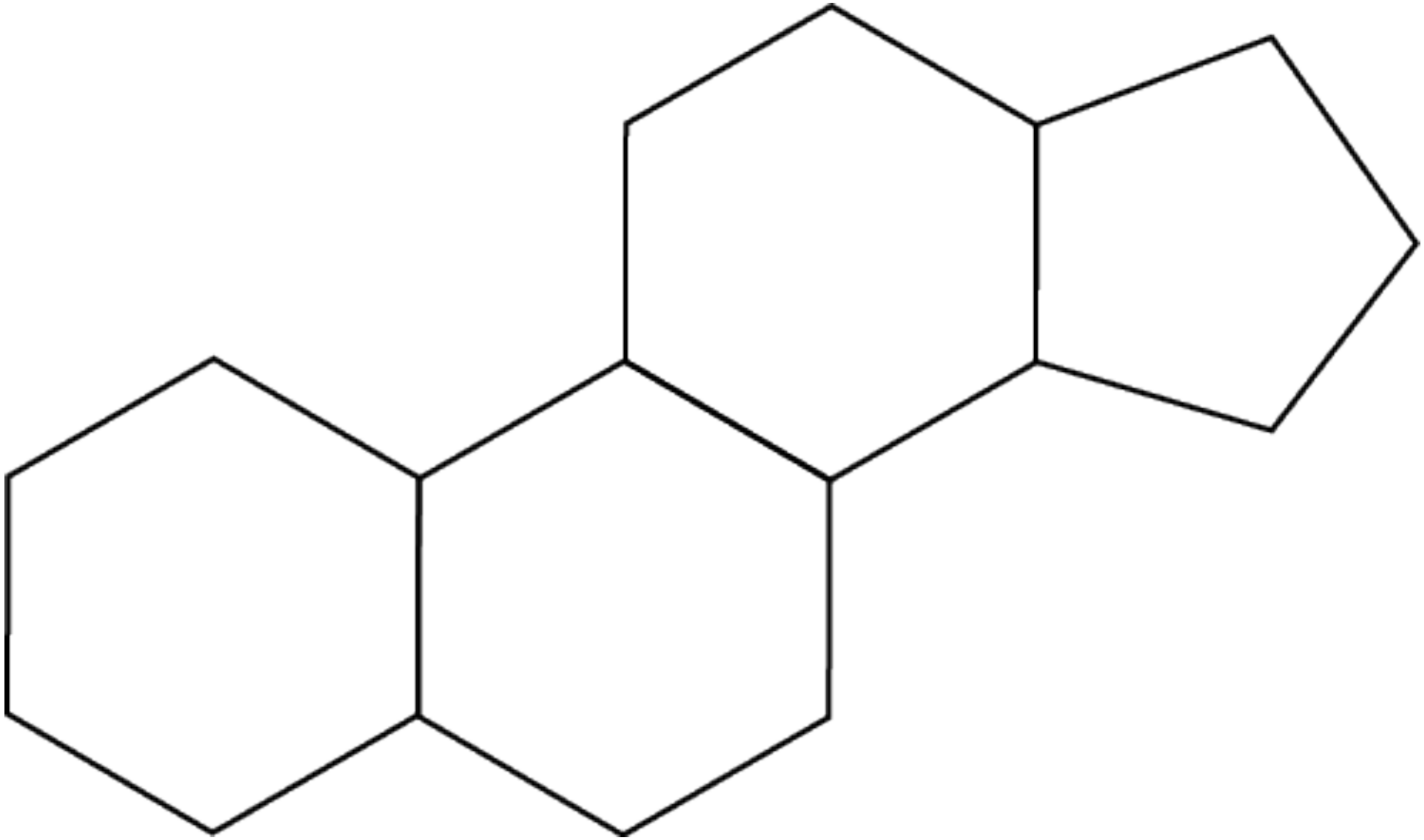
- Natural unsaturated triglycerides have the groups attached to the double-bonded carbon atoms in the cis arrangement.
- Hydrogenation is reversible.
- When the double bond is reformed, it is more likely to form the more stable trans form than the less stable cis form.
- Therefore, partially hydrogenated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



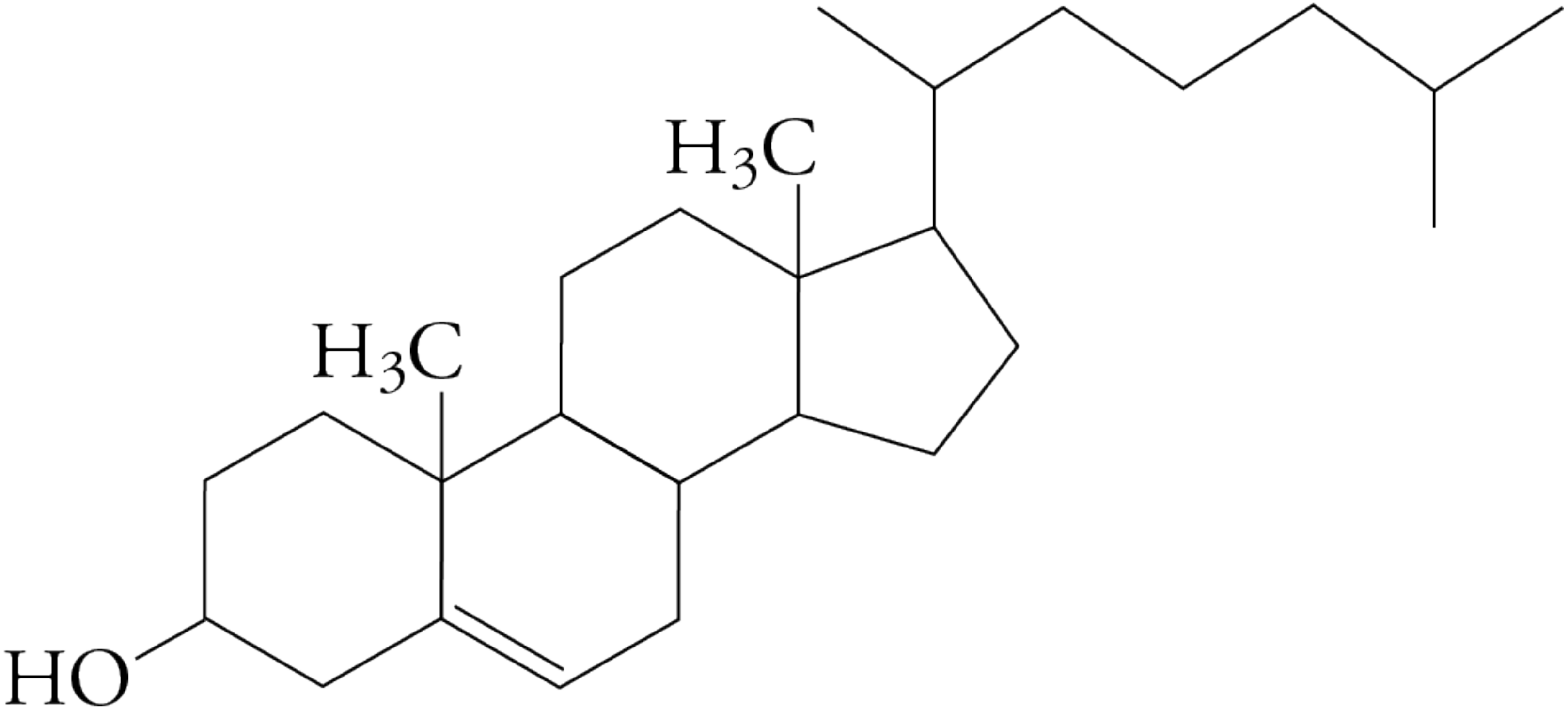
natural cis form

unnatural trans form

Steroid Skeleton

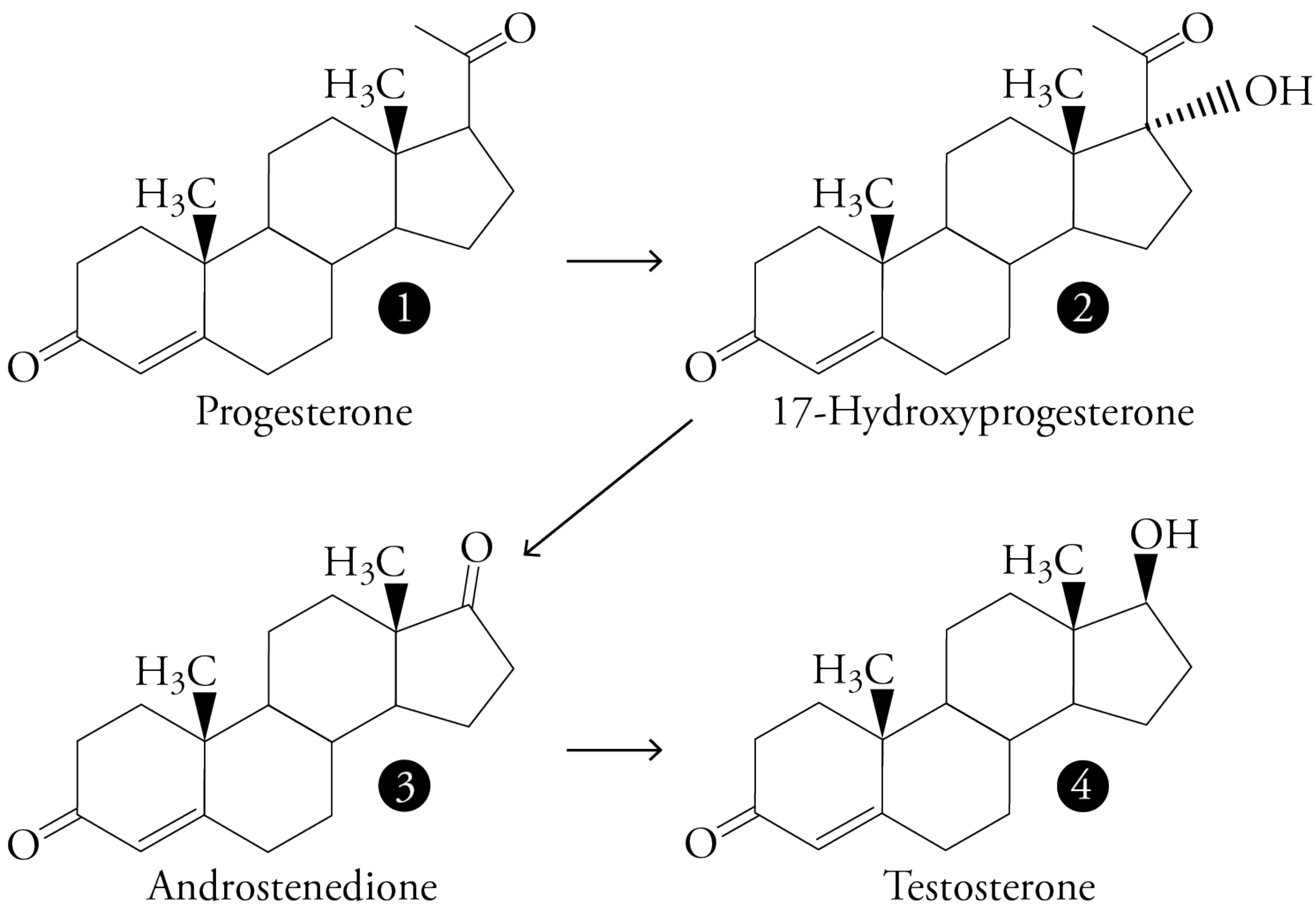


Cholesterol



cholesterol

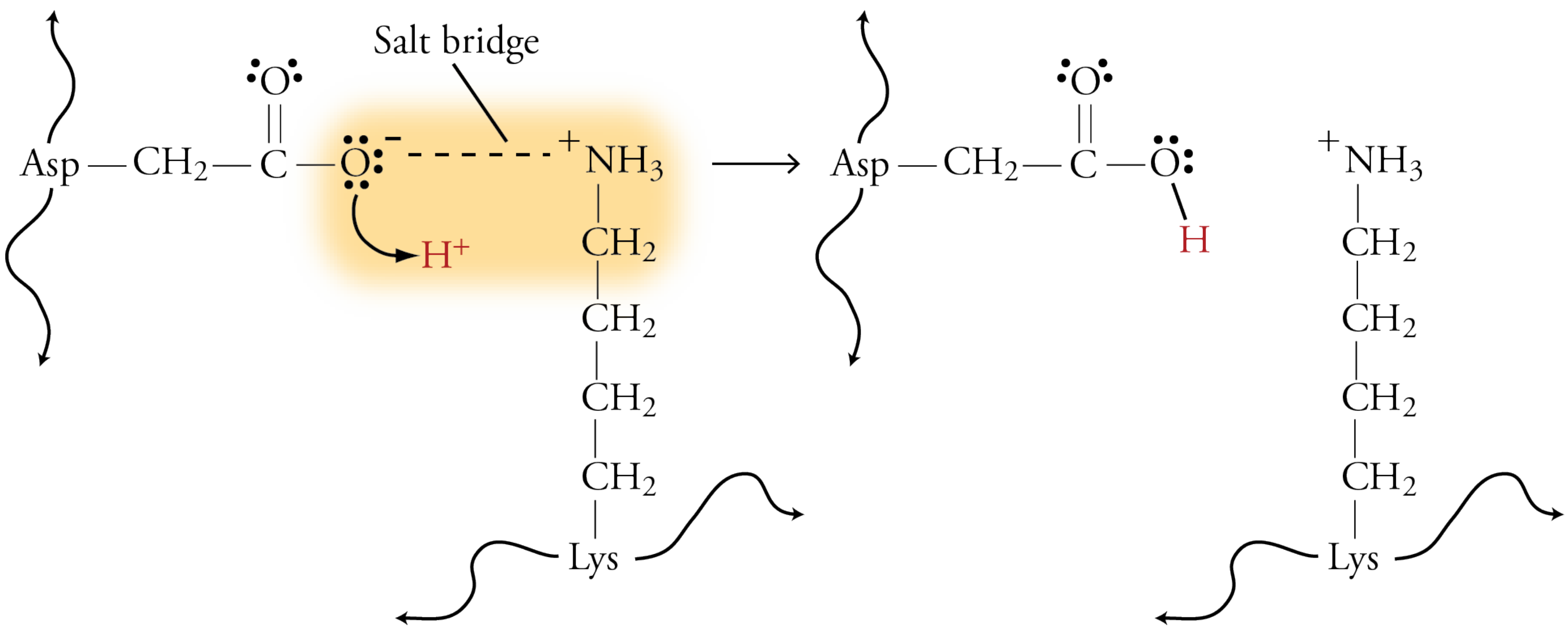
Testosterone Formation



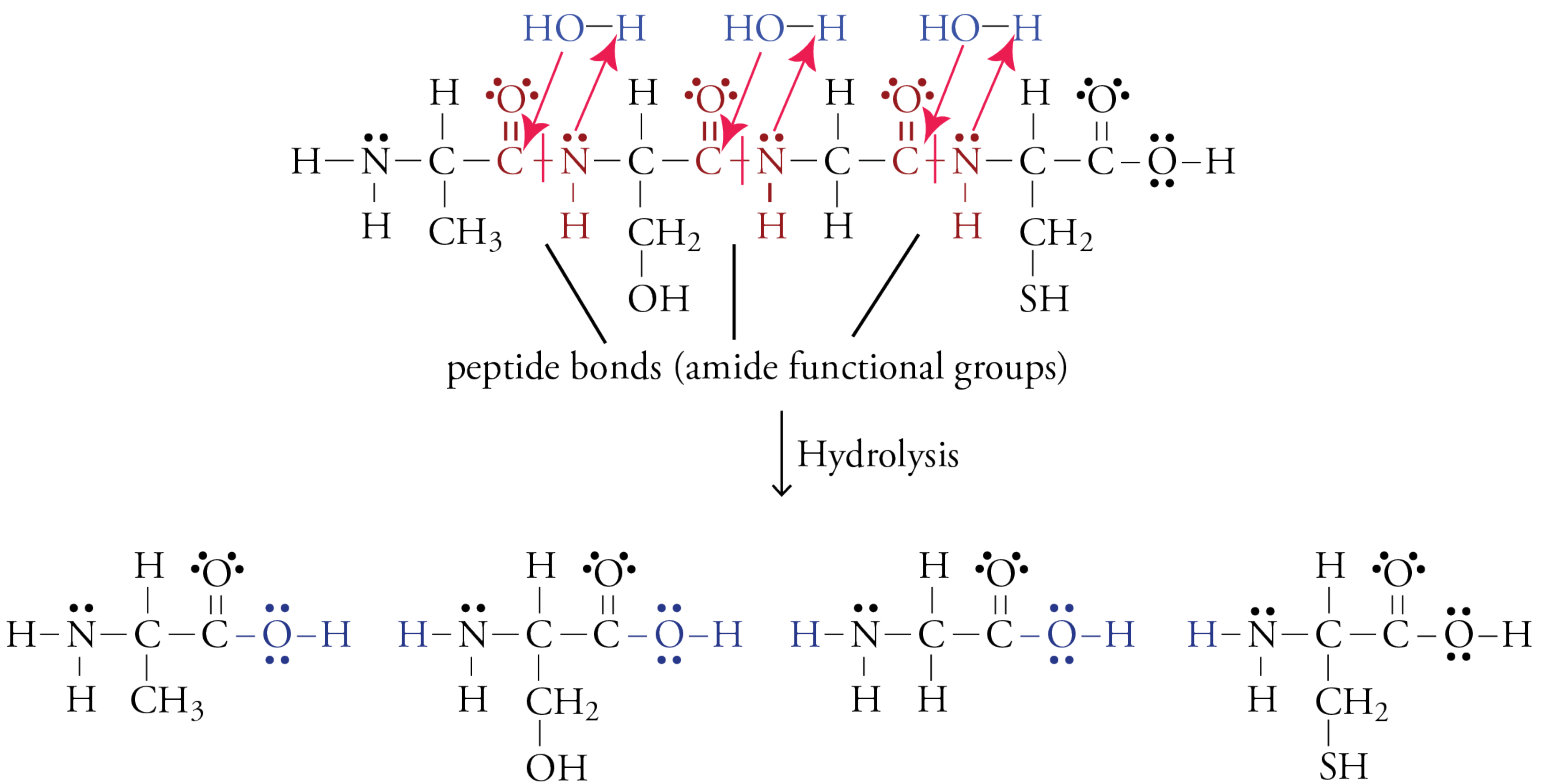
Digestion

- **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



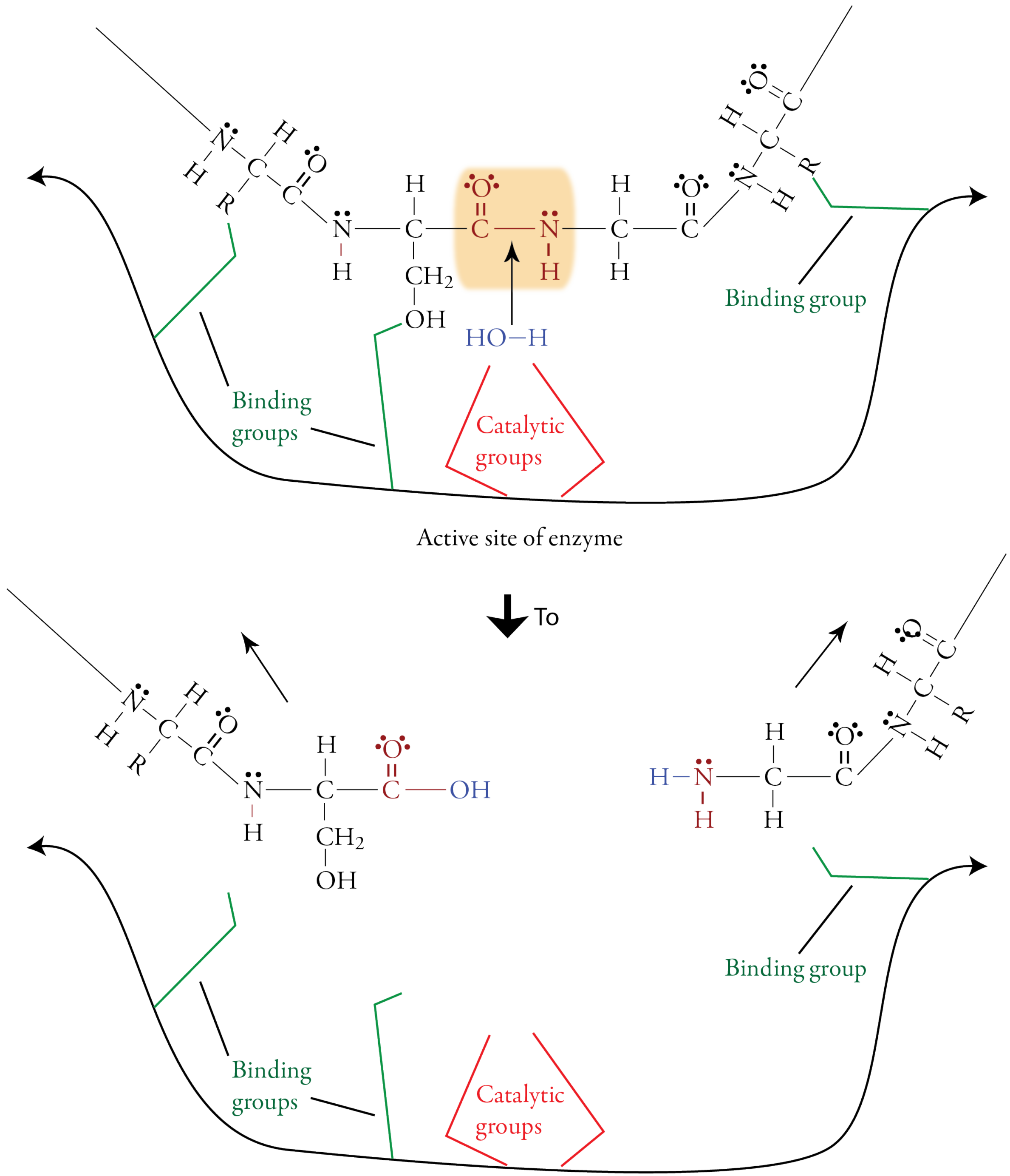
Protein Hydrolysis



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.

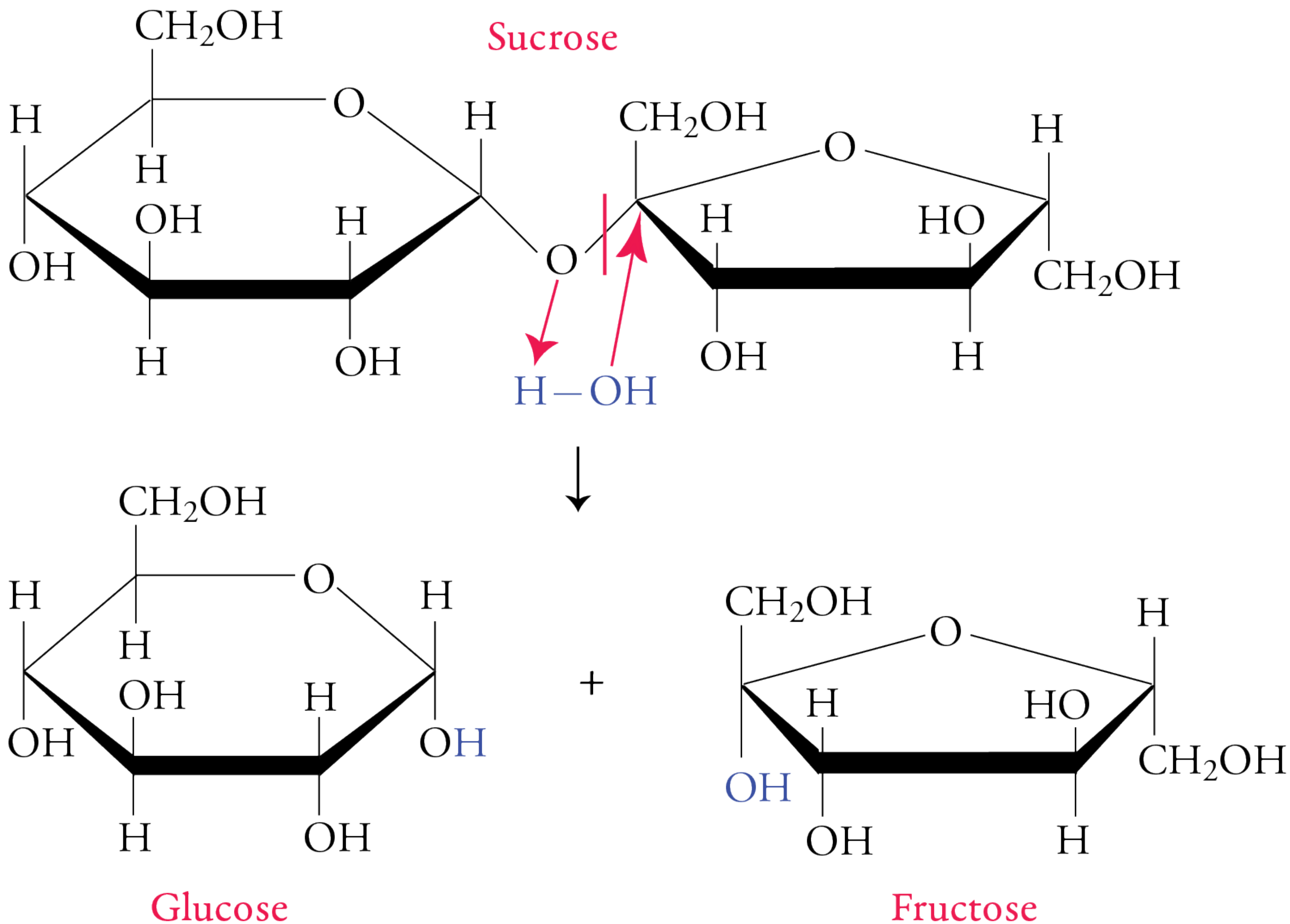
Enzymes Speed Chemical Reactions

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

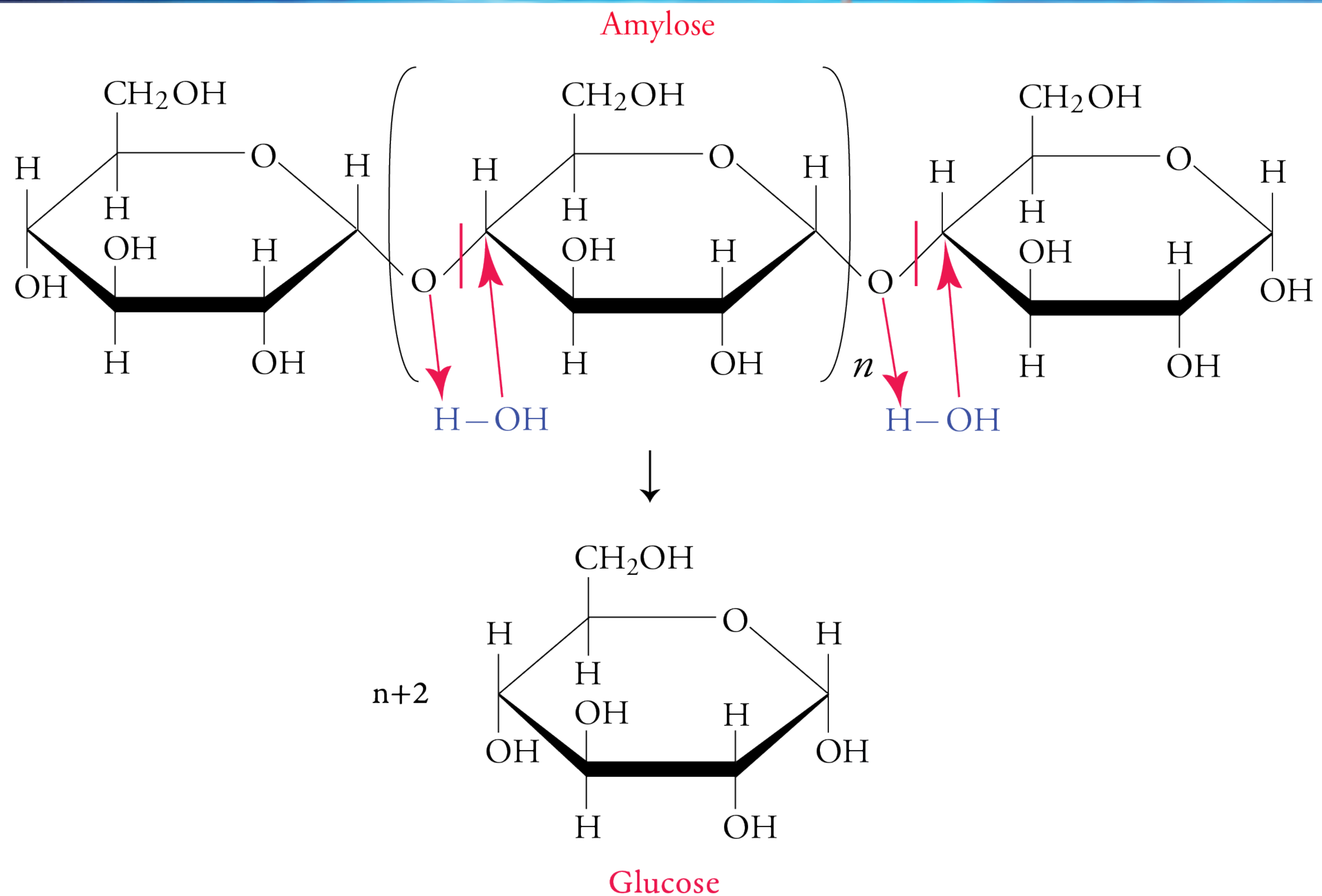
Digestion Products

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

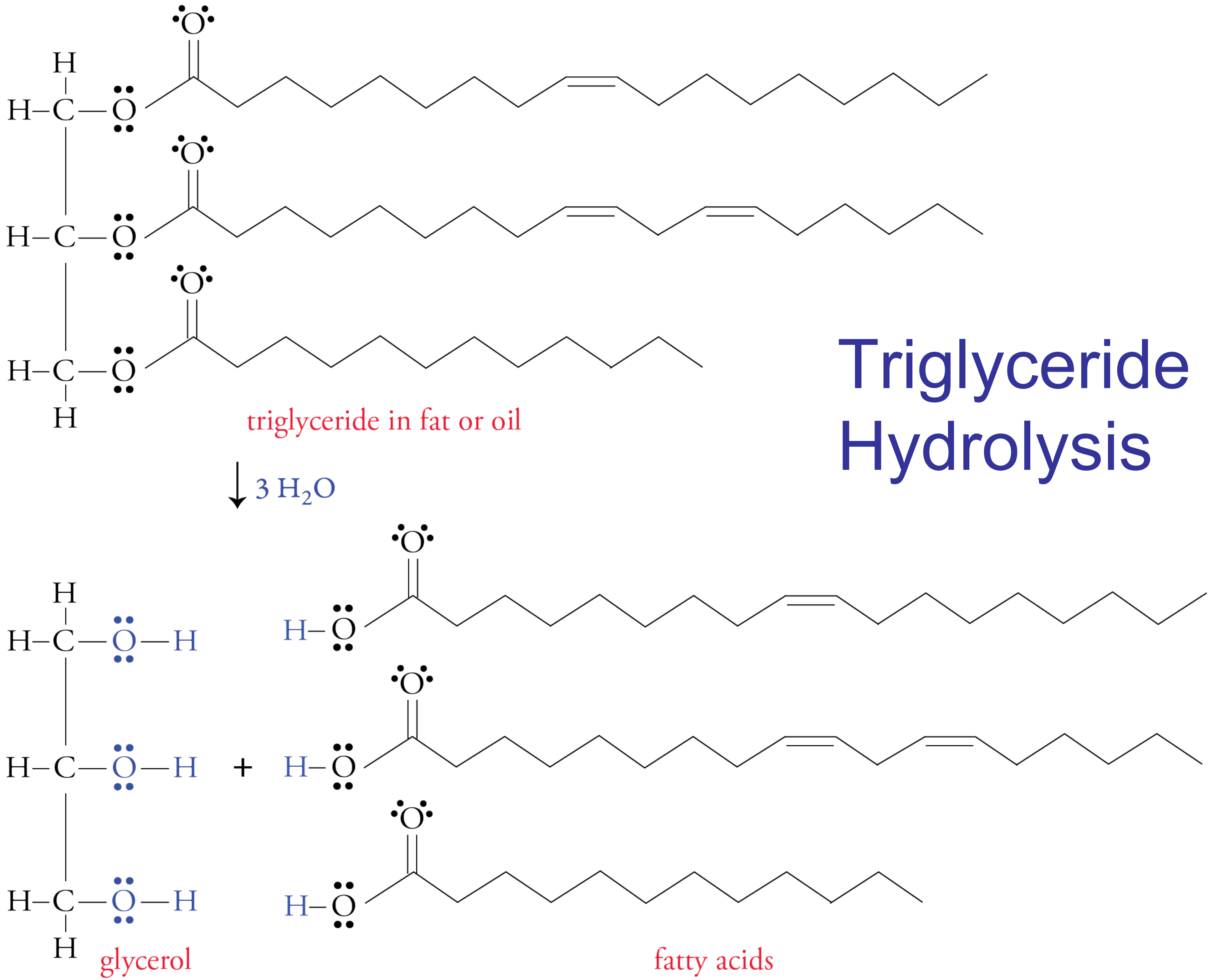
Sucrose Hydrolysis



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.

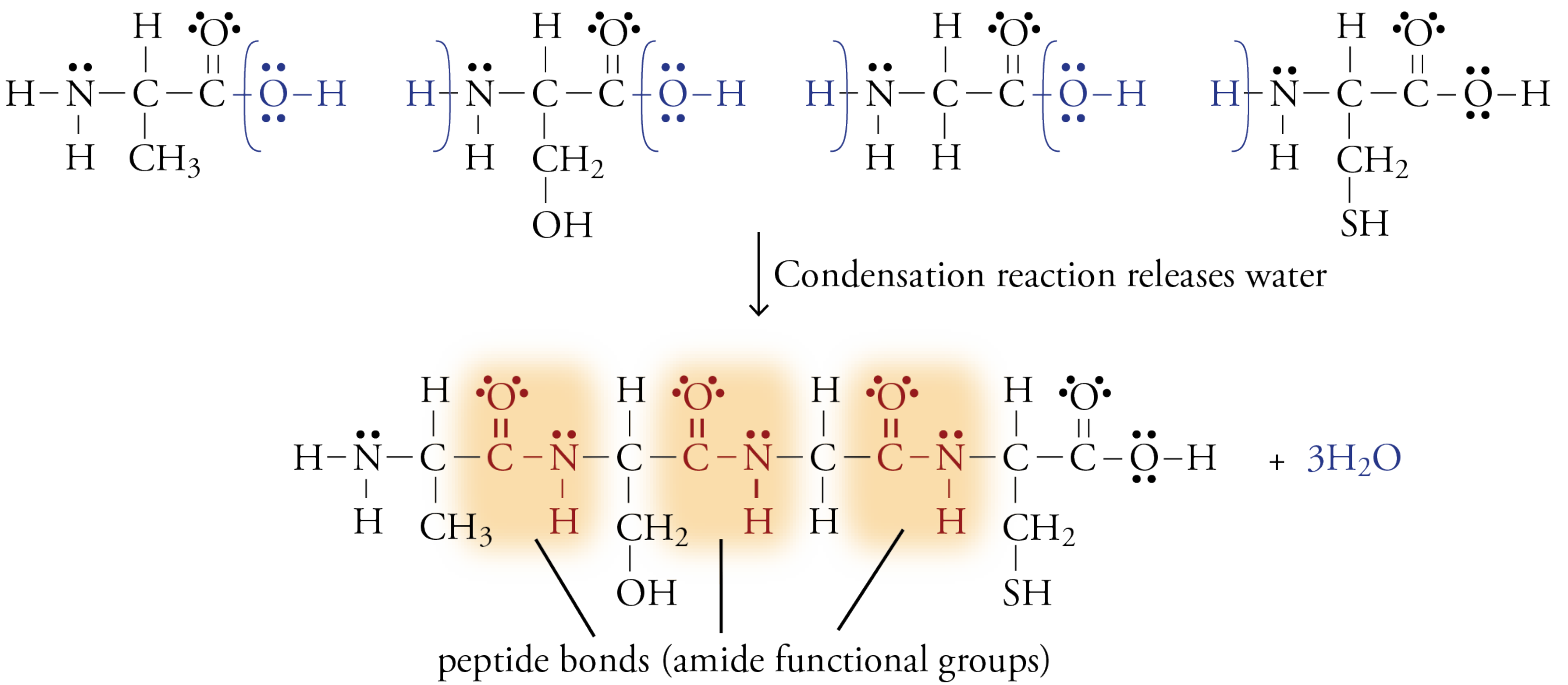
$$\left(-\text{repeated unit}- \right)_n$$

General polymer formula

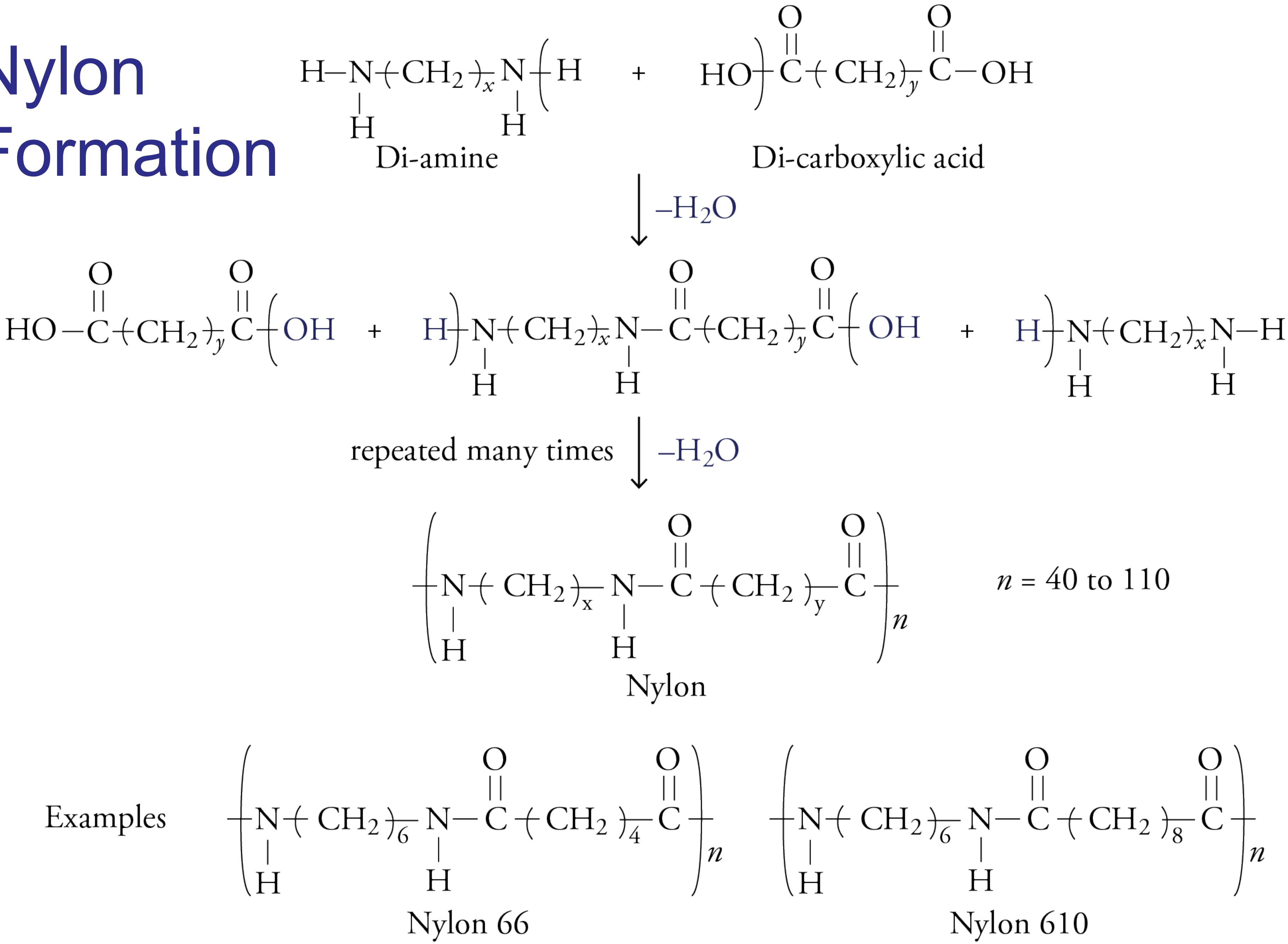
Natural and Synthetic Polymers

- 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



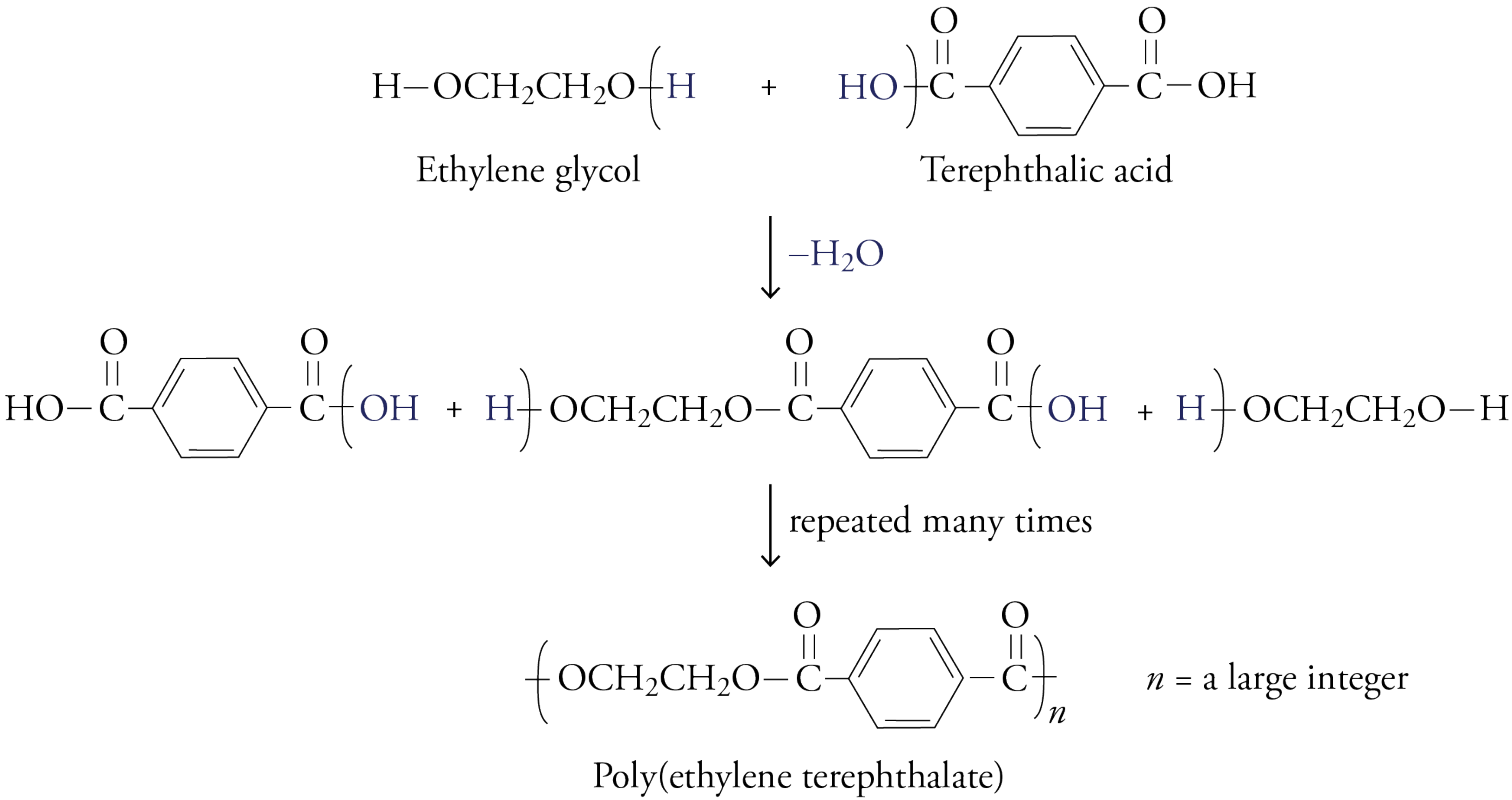
Nylon Formation



Condensation Polymers

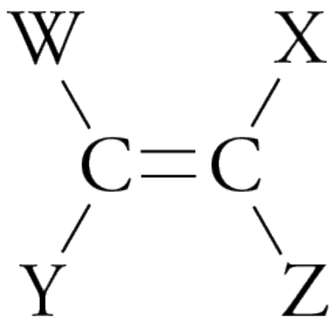
- **Condensation polymers** are polymers that are formed by condensation reactions in which two molecules are joined and a small molecule, such as water, is released.

Polyester Formation

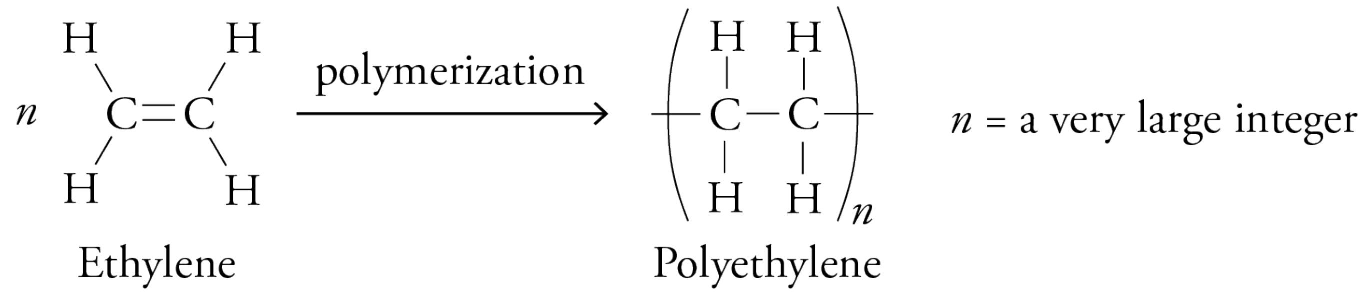


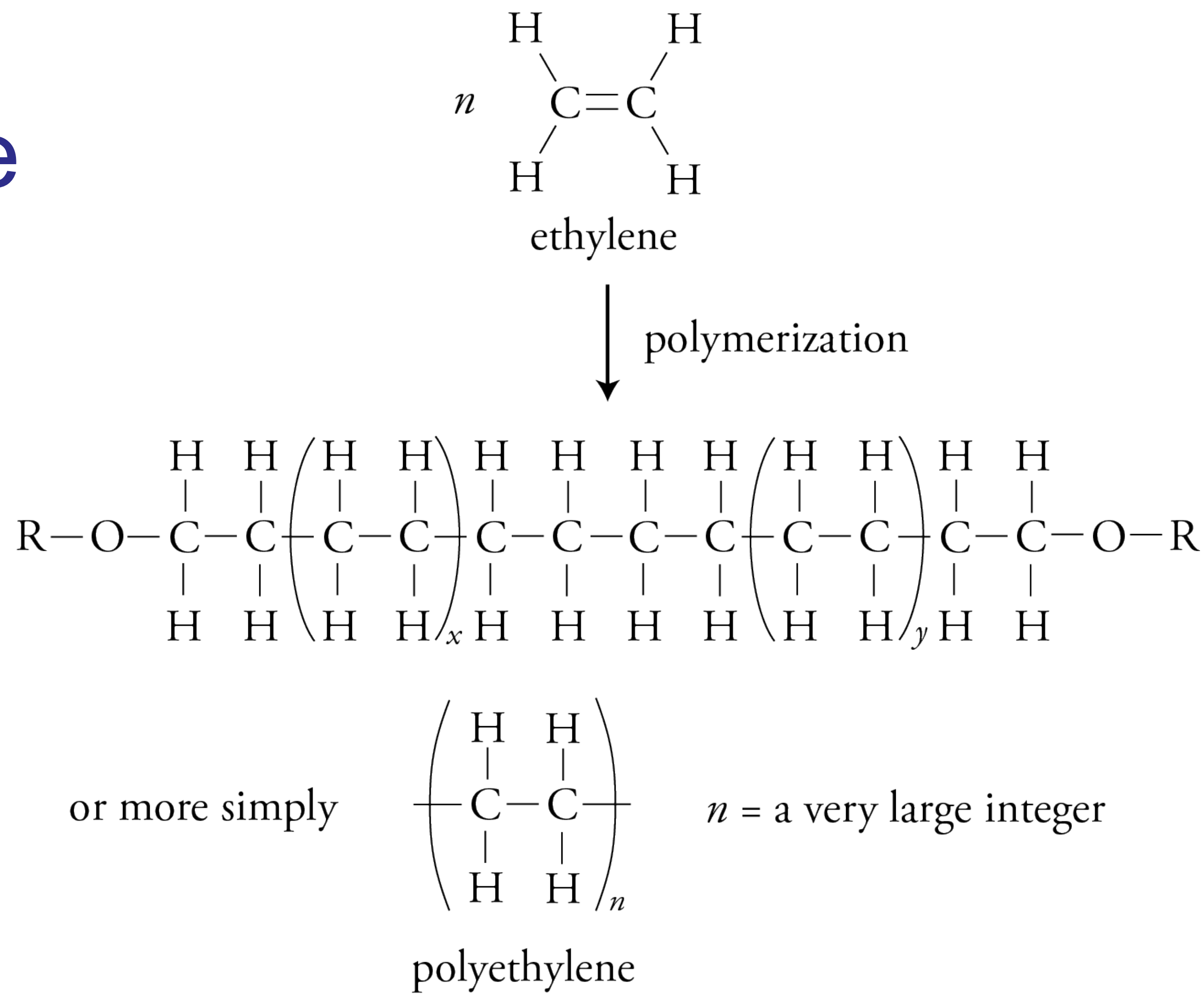
Addition Polymers

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



Polyethylene Formation

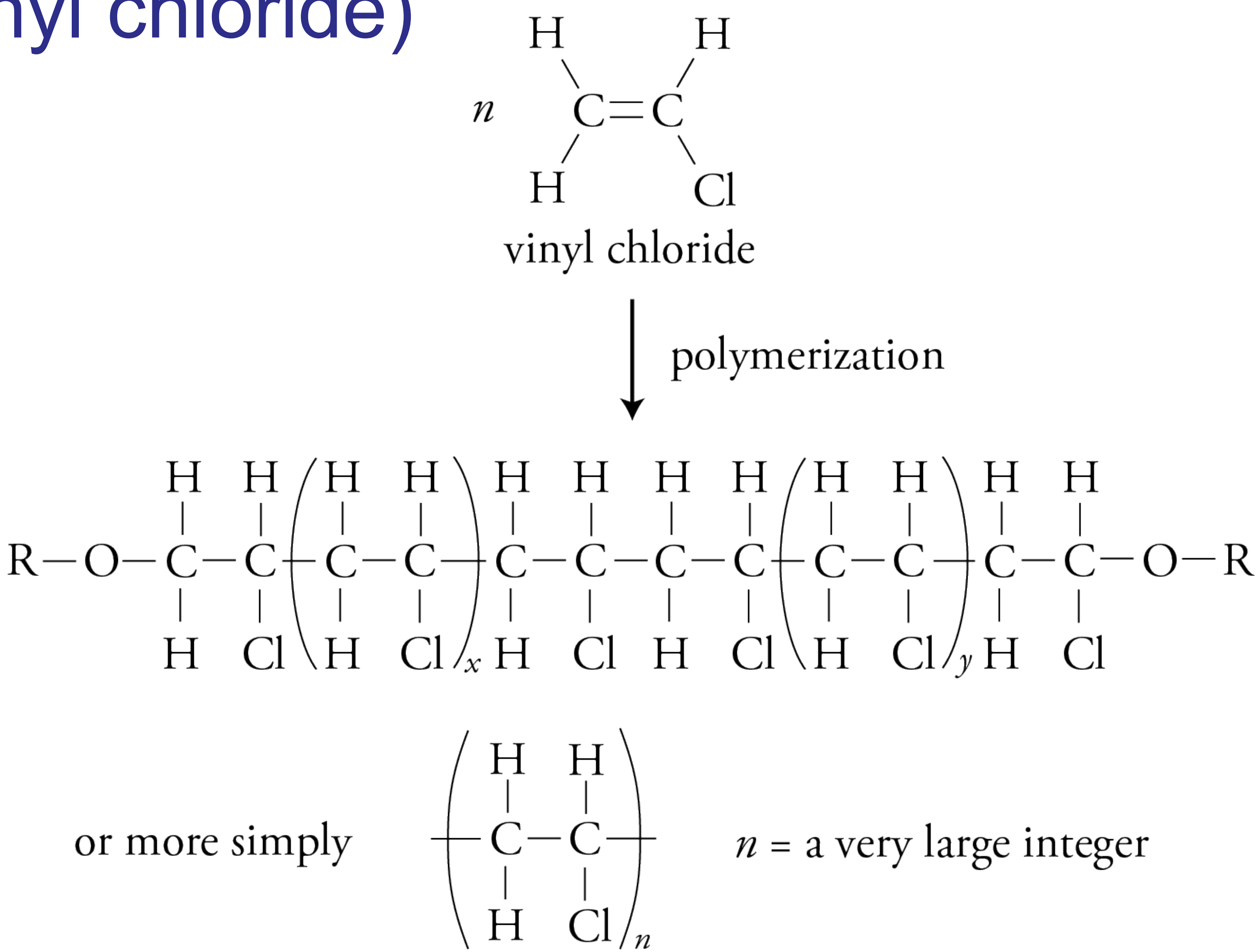




High- and Low-Density Polyethylene

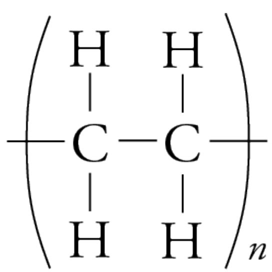
- If polyethylene is made under conditions that lead to mostly unbranched chains, the chains are able to pack together tightly forming high-density polyethylene, which is described by the acronym HDPE or sometimes PE-HD.
- If the polyethylene is made in a way that encourages branches, the molecules do 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

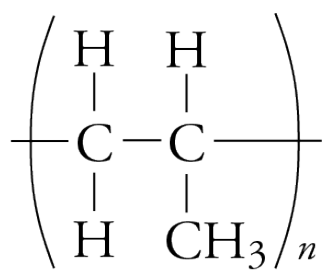


poly(vinyl chloride) or PVC

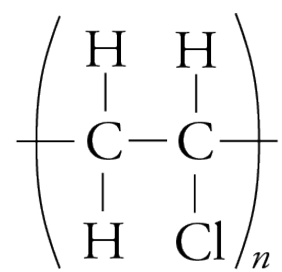
Addition Polymers



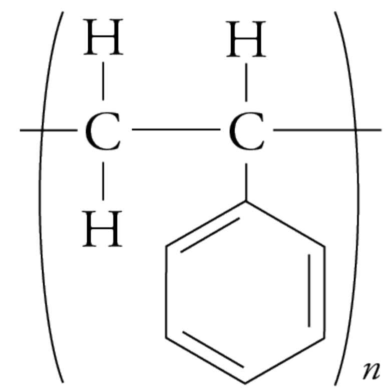
Polyethylene (HDPE or LDPE)



Polypropylene (PP)



Poly(vinyl chloride) (PVC)



Polystyrene (PS)

Recycling Codes

1
PET
(or PETE)

2
HDPE
(or PE-HD)

3
PVC
(or V)

4
LDPE
(or PE-LD)

5
PP

6
PS

7
OTHER