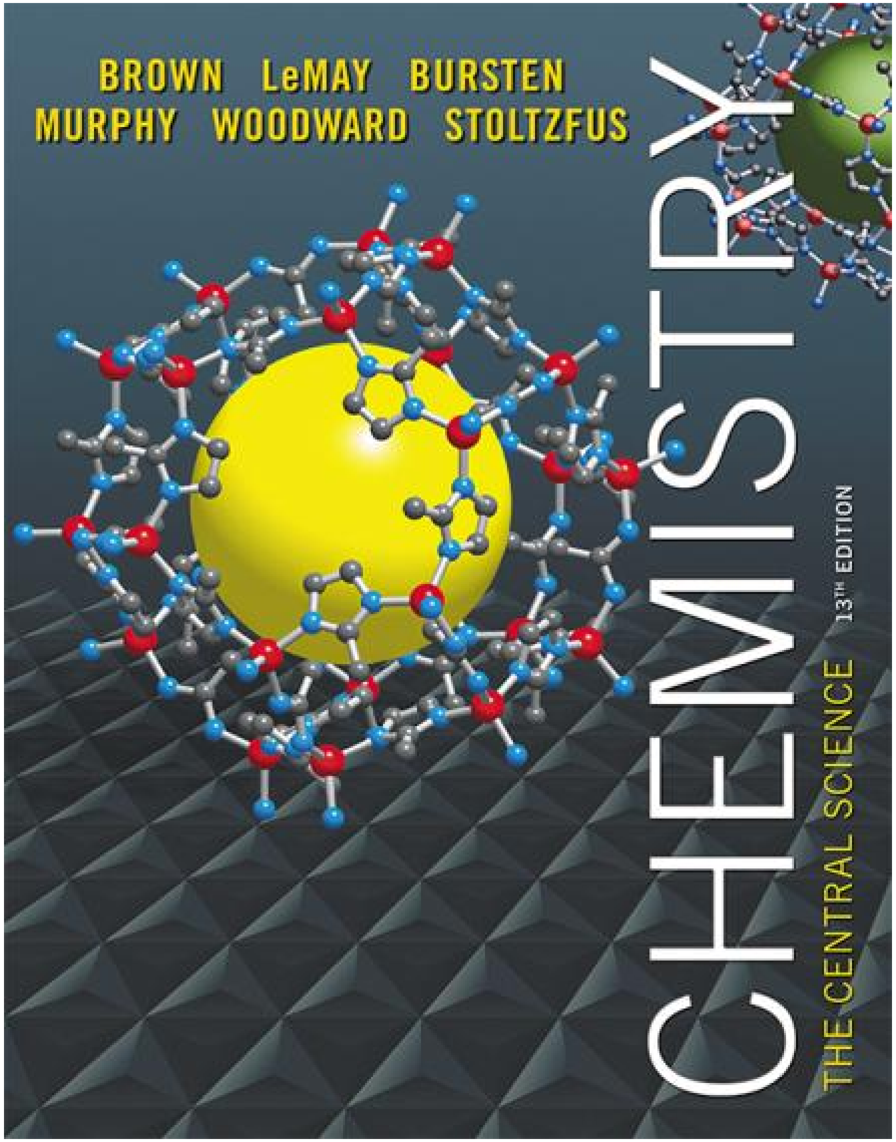
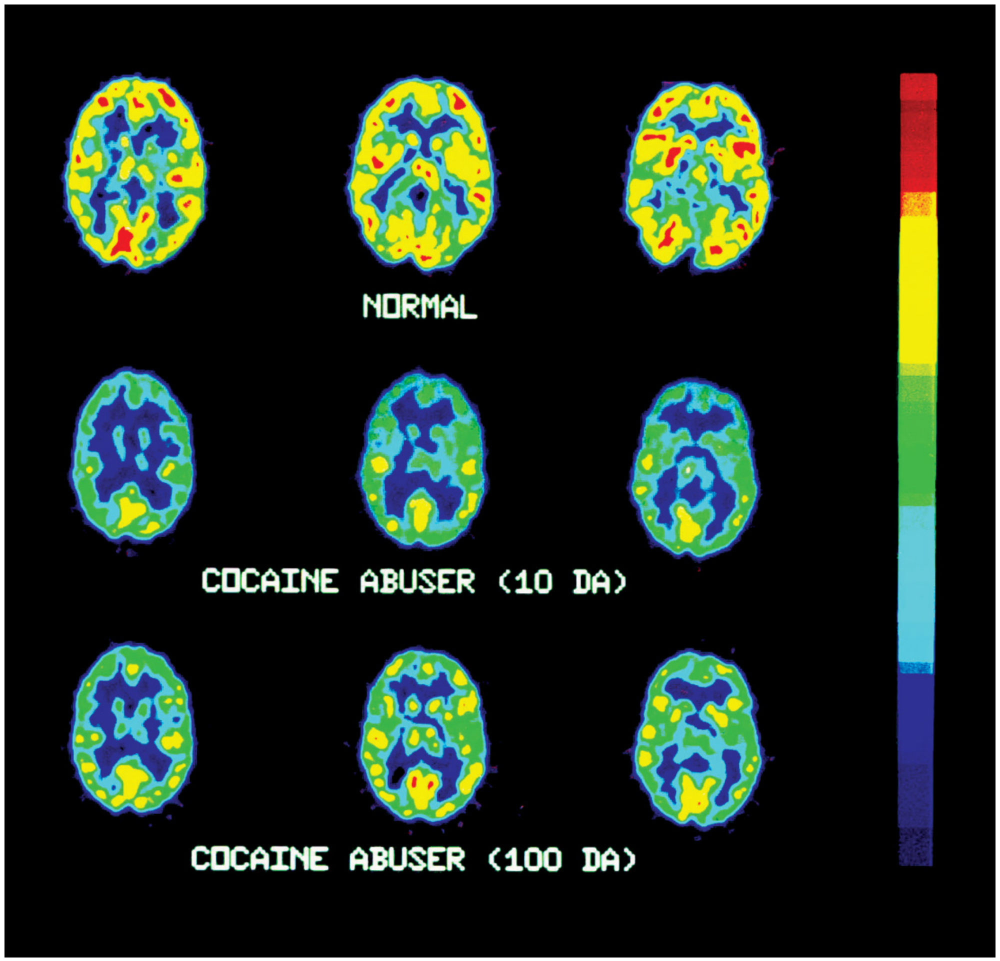


Lecture Presentation

Chapter 24

The Chemistry of Life: Organic and Biological Chemistry

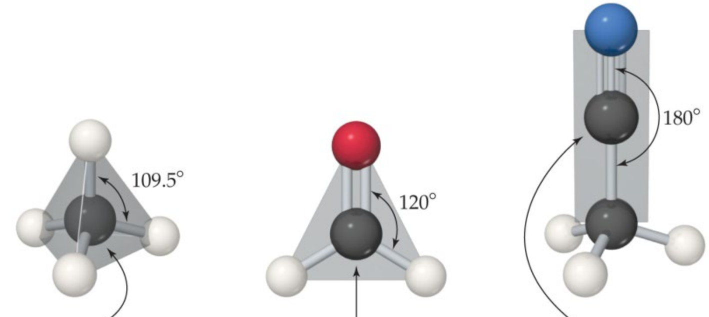
Organic Chemistry and Biochemistry



- Chapter focus: the molecules that bridge chemistry & biology
- Most common elements: C, H, O, N
- Organic chemistry: study of compounds containing carbon
- Biochemistry: the study of chemistry of living systems

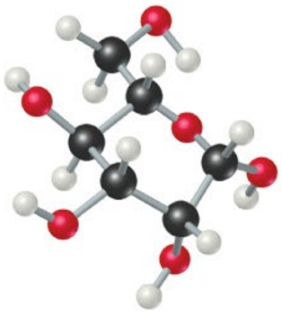
Organic and Biological Chemistry

General Characteristics of Organic Molecules

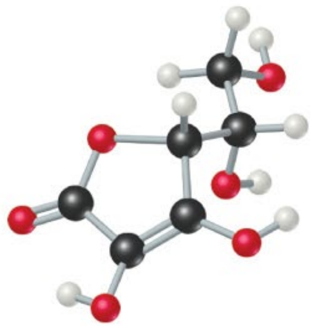


- Carbon makes four bonds.
- All single bonds: tetrahedral; *sp*^{3} hybridized
- One double bond: trigonal planar; *sp*^{2} hybridized
- One triple bond: linear; *sp* hybridized
- C—H are most common.
- C forms stable (strong) bonds with many elements, including C, H, O, N, and the halogens.
- Groups of atoms that determine how an organic molecule reacts are called **functional groups**.

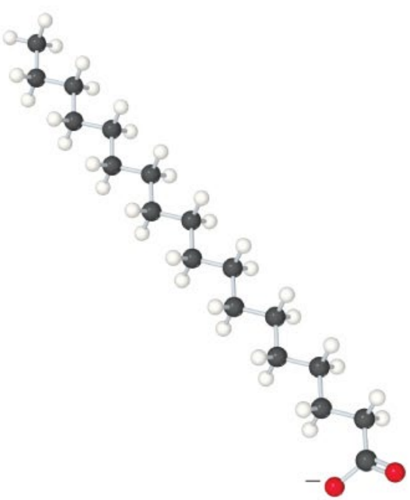
Solubility



Glucose ($C_6H_{12}O_6$)



Ascorbic acid ($HC_6H_7O_6$)



Stearate ($C_{17}H_{35}COO^-$)

- Most prevalent bonds are C—C and C—H, which are nonpolar; solubility in water is low for many organic compounds.
- Organic molecules, such as glucose, that have polar groups are soluble in polar solvents.
- Molecules with long nonpolar regions and polar regions act as surfactants, bringing polar material into aqueous solution (used in detergents and soaps).

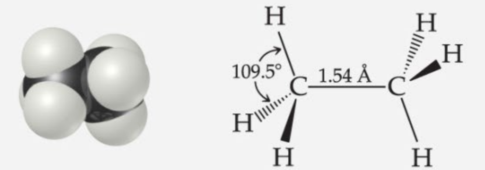
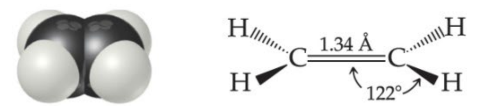
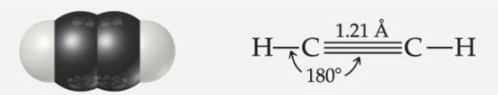
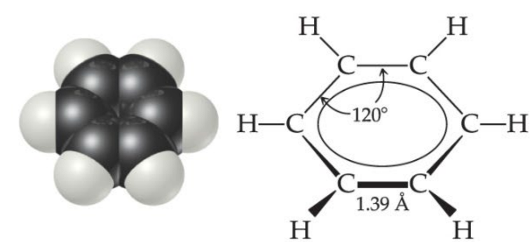
Acid–Base Properties

- Many organic molecules contain acidic or basic functional groups.
- Carboxylic acids (—COOH) are the most common acids.
- Amines (—NH_2, —NHR, or —NR_2, where R is an organic group made up of C and H atoms) are the most common bases.

Hydrocarbons

- Hydrocarbons consist of ONLY carbon and hydrogen.
- They are grouped based on the number of bonds between carbon atoms.
- There are four basic types of hydrocarbons:
  - Alkanes
  - Alkenes
  - Alkynes
  - Aromatic hydrocarbons

Table 24.1 The Four Hydrocarbon Types with Molecular Examples

Type	Example		
Alkane	Ethane	CH_3CH_3	
Alkene	Ethylene	$CH_2{=}CH_2$	
Alkyne	Acetylene	$CH{\equiv}CH$	
Aromatic	Benzene	C_6H_6	

Organic and Biological Chemistry

Properties Common to Hydrocarbons

- Since they are nonpolar, they are insoluble in water but soluble in nonpolar solvents.
- Melting points and boiling points are determined by dispersion forces (low molar mass hydrocarbons are gases; moderate molar mass hydrocarbons are liquids; high molar mass hydrocarbons are solids).

Table 24.2 First Ten Members of the Straight-Chain Alkane Series

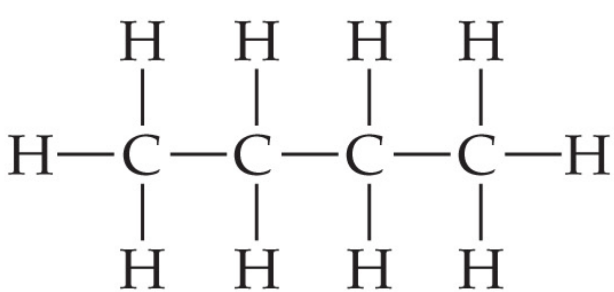
Molecular Formula	Condensed Structural Formula	Name	Boiling Point (°C)
CH_4	CH_4	Methane	−161
C_2H_6	CH_3CH_3	Ethane	−89
C_3H_8	$CH_3CH_2CH_3$	Propane	−44
C_4H_{10}	$CH_3CH_2CH_2CH_3$	Butane	−0.5
C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$	Pentane	36
C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$	Hexane	68
C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	Heptane	98
C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Octane	125
C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Nonane	151
$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	Decane	174

Uses of Some Simple Alkanes

- Methane (CH_4): in natural gas (heating fuel)
- Propane (C_3H_8): in bottled gas (heating and cooking fuel)
- Butane (C_4H_{10}): in disposable lighters and fuel canisters for camping
- Alkanes with 5 to 12 C atoms: gasoline

Methods for Writing Formulas

- There are a few common methods for writing the structures in organic chemistry.
- Structural formulas show how atoms are bonded to each other.
- Condensed structural formulas don't show all C—H; they condense them to groupings, like CH_3.

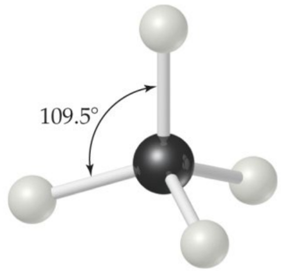


$$H_3C{-}CH_2{-}CH_2{-}CH_3$$

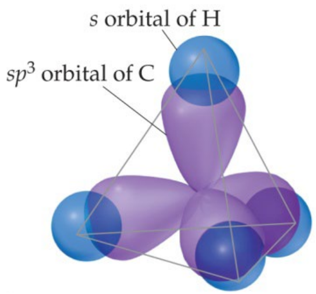
or

$$CH_3CH_2CH_2CH_3$$

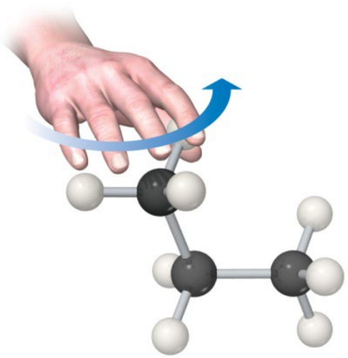
Organic and Biological Chemistry

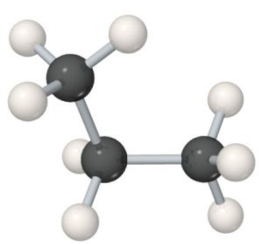


Structure of Alkanes



- Carbons in alkanes are *sp*^{3} hybridized, tetrahedral, and have 109.5° bond angles.
- In the straight chain form, all carbons connect in a continuous chain.
- C can make four bonds, so it is possible for a carbon atom to bond to three or four C atoms, making a branched alkane.
- Compounds with the same molecular formula but different connections of atoms are called structural isomers, as seen on the next slide.

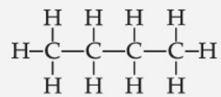
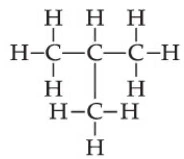
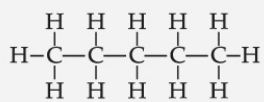
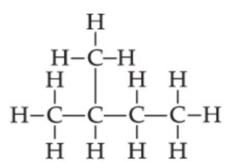
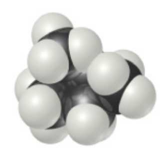
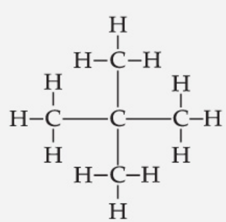




Organic and Biological Chemistry

Structural Isomers

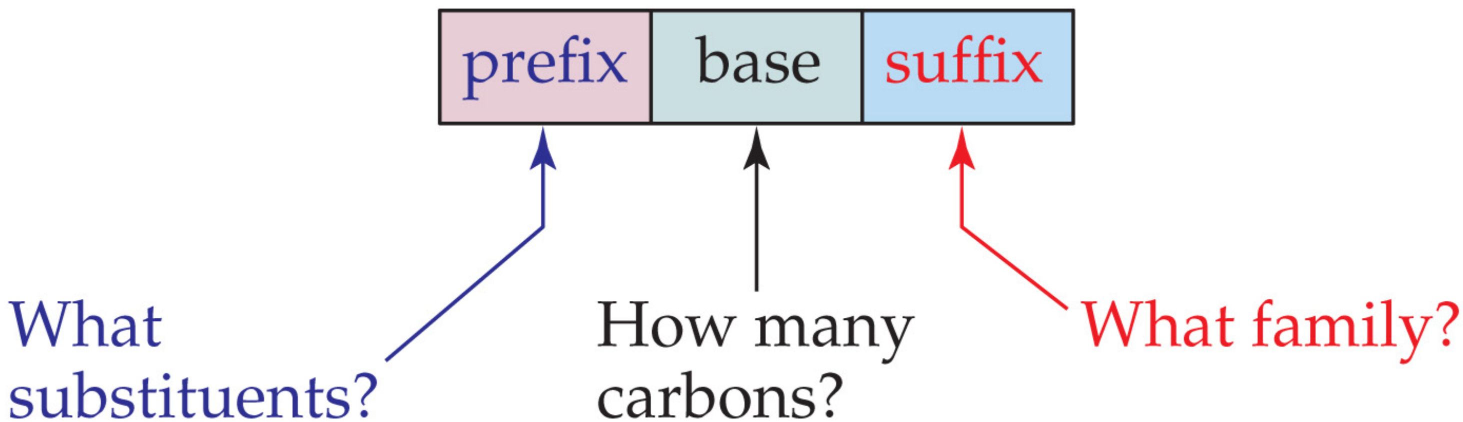
Table 24.3 Isomers of C_4H_{10} and C_5H_{12}

Systematic Name (Common Name)	Structural Formula	Condensed Structural Formula	Space-filling Model	Melting Point (°C)	Boiling Point (°C)
Butane (*n*-butane)		$CH_3CH_2CH_2CH_3$		−138	−0.5
2-Methylpropane (isobutane)		$CH_3-CH-CH_3$ CH_3		−159	−12
Pentane (*n*-pentane)		$CH_3CH_2CH_2CH_2CH_3$		−130	+36
2-Methylbutane (isopentane)		CH_3 $CH_3-CH-CH_2-CH_3$		−160	+28
2,2-Dimethylpropane (neopentane)		CH_3 CH_3-C-CH_3 CH_3		−16	+9

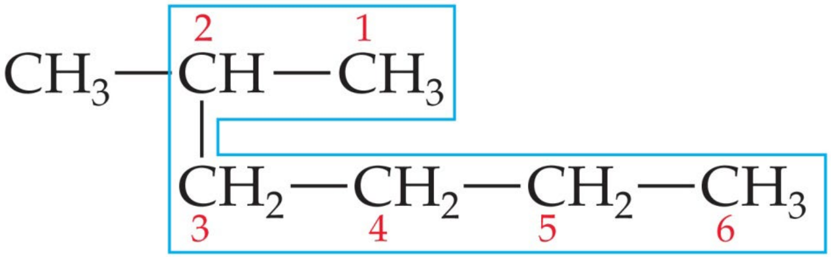
Organic and Biological Chemistry

Systematic Nomenclature of Organic Compounds

- There are three parts to a compound name:
  - Base: This tells how many carbons are in the longest continuous chain.
  - Suffix: This tells what type of compound it is.
  - Prefix: This tells what groups are attached to the chain.



How to Name a Compound



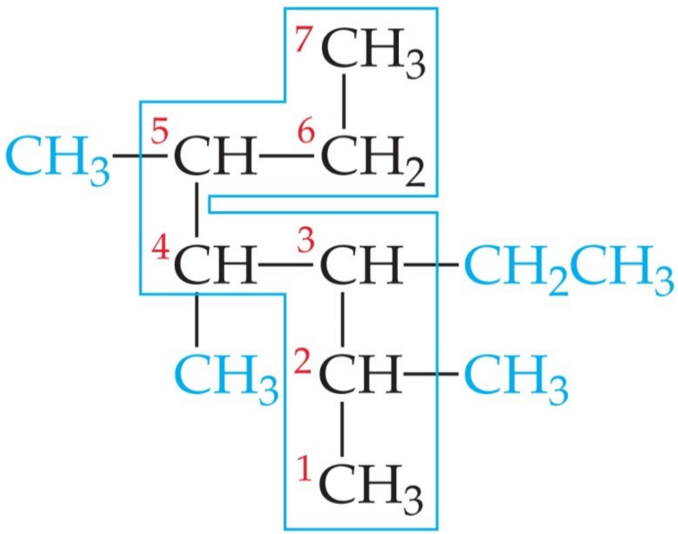
2-Methyl*hexane*

Table 24.4 Condensed Structural Formulas and Common Names for Several Alkyl Groups

Group	Name
CH_3—	Methyl
CH_3CH_2—	Ethyl
$CH_3CH_2CH_2$—	Propyl
$CH_3CH_2CH_2CH_2$—	Butyl
CH_3 | HC— | CH_3	Isopropyl
CH_3 | CH_3—C— | CH_3	*tert*-Butyl

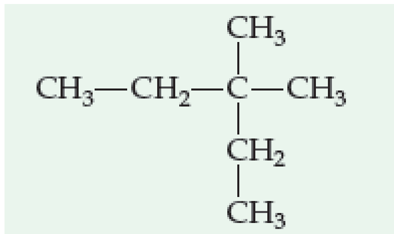
1. Find the longest continuous chain of C atoms, and use this as the base name.
2. Number the chain from the end nearest the first substituent encountered.
3. Name each substituent. (Side chains that are based on alkanes are called alkyl groups.)

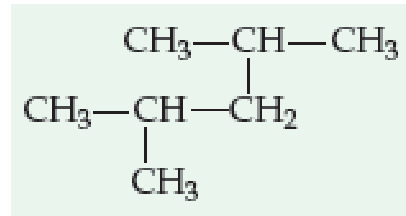
How to Name a Compound

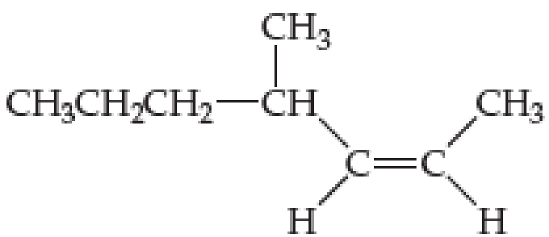


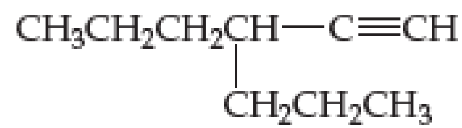
3-Ethyl-2,4,5-trimethylheptane

4. Begin the name with the number(s) on the C atom(s) to which each substituent is bonded.
5. When two or more substituents are present, list them alphabetically.





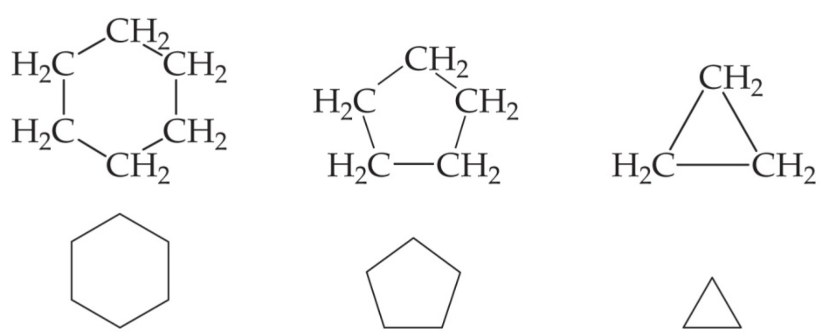


(b) 

3,3-dimethylpentane
2,4-dimethylpentane
4-methyl-*cis*-2-heptene.
3-propyl-1-hexyne

Cycloalkanes

- Alkanes that form rings or cycles
- Possible with at least three C atoms, but *sp*^{3} hybridization requires 109.5° angles—not a very stable molecule.
- Four-C ring is also not very stable.
- Five-C and more have room for proper bond angle.
- Naming: add *cyclo-* as a prefix to alkane name.



Cyclohexane
Each vertex represents one CH_2 group

Cyclopentane
Five vertices = five CH_2 groups

Cyclopropane
Three vertices = three CH_2 groups

Reactions of Alkanes

- Alkanes are relatively unreactive due to the lack of polarity and presence of only C—C and C—H σ bonds, which are very stable.
- They do not react with acids, bases, or oxidizing agents.
- However, the most important reaction observed is combustion:

$$2\ C_2H_6(g) + 7\ O_2(g) \rightarrow 4\ CO_2(g) + 6\ H_2O(l)$$

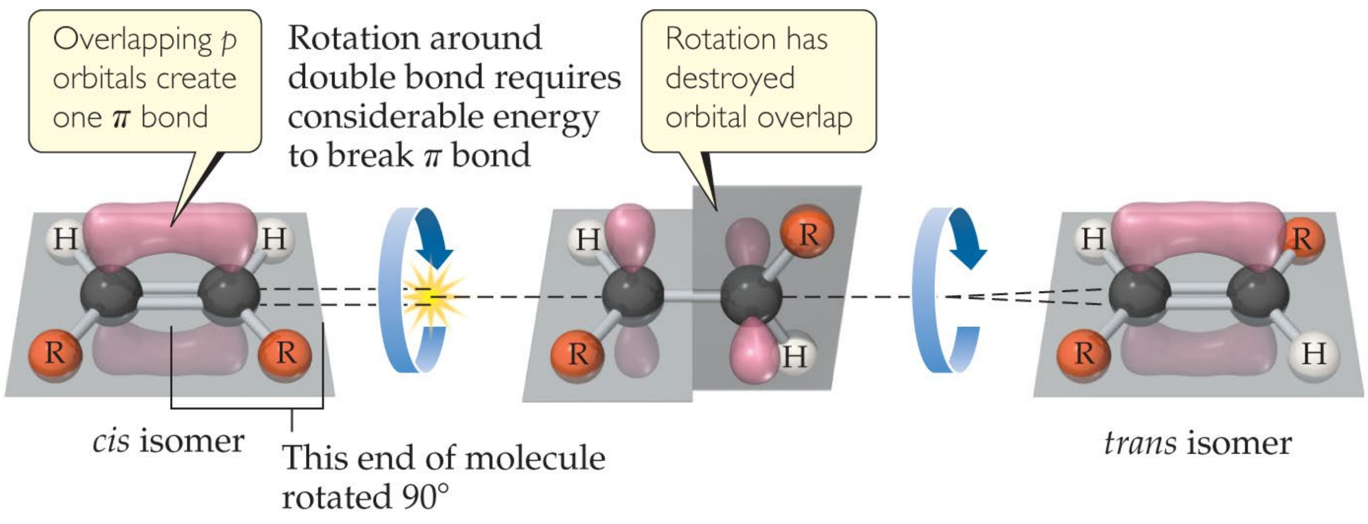
(exothermic! $\Delta H^\circ = -2885$ kJ)

Saturated vs. Unsaturated

- Hydrocarbons with single bonds only are called saturated hydrocarbons. These are the alkanes.
- Alkenes, alkynes, and aromatic hydrocarbons have fewer hydrogen atoms than alkanes with the same number of carbon atoms. They are called unsaturated hydrocarbons.
- Unsaturated hydrocarbons are more reactive than saturated hydrocarbons.

Alkenes

- Contain at least one C═C bond
- No free rotation about the double bond
- Naming: longest chain must include BOTH carbon atoms that share the double bond; end name in -*ene*; lowest number possible given to double-bond carbon atoms; isomers also indicated.



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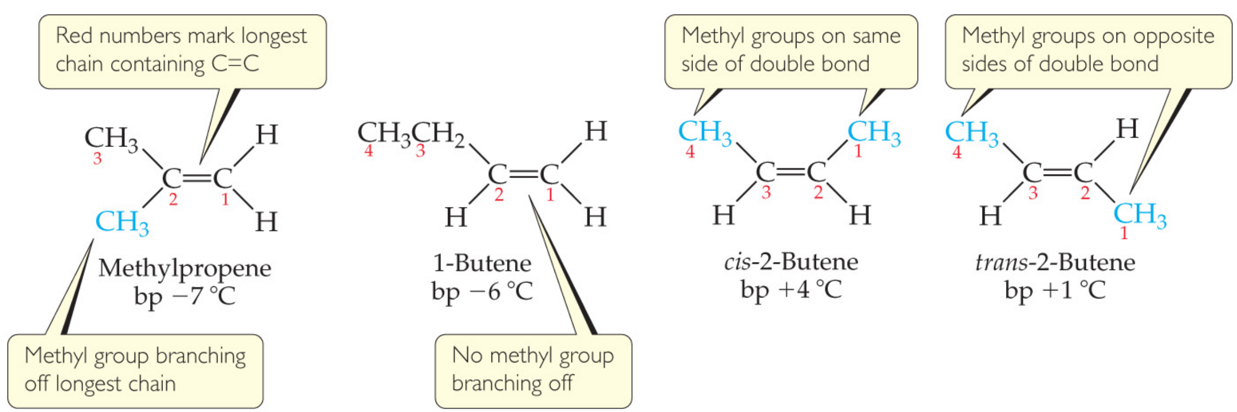
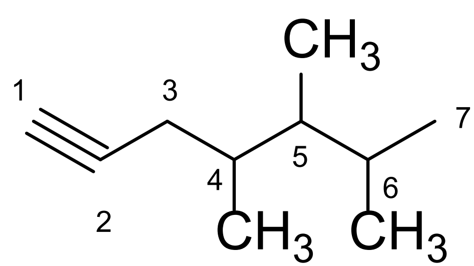
Geometric Isomers

- Since there is no free rotation around the double bond, the direction of the longest chain can differ for four or more C atoms.
- Compounds that have all atoms connected to the same atoms but differ in three-dimensional arrangement are geometric isomers.
- Alkenes have cis (same side of the double bond) or trans (opposite side of the double bond) isomers.



Alkynes

- Contain at least one C≡C
- Unsaturated
- Naming: longest continuous chain containing both carbon atoms in the triple bond; name ends in *-yne* (instead of *-ane* or *-ene*); give C atoms in triple bond lowest number.



4,5,6-trimethyl-1-heptyne

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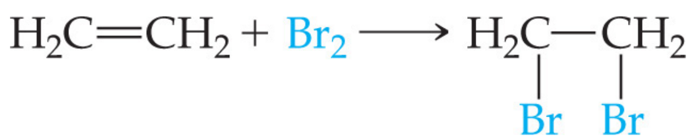
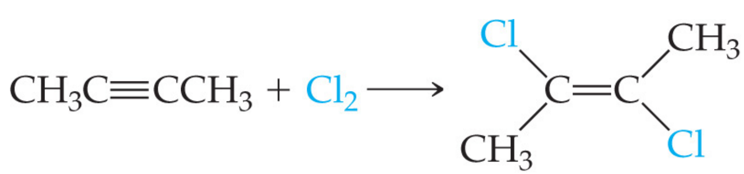
Addition Reactions of Alkenes and Alkynes

- Add atoms to the double or triple bond, making it saturated or more saturated
- *π* bonds are broken and electrons form *σ* bonds to added atoms.
- Work with H_2 (hydrogenation), HX (hydrogen halides or water), or X_2 (halogenation)



$$CH_3CH{=}CHCH_3 + H_2 \xrightarrow{\text{Ni, 500 °C}} CH_3CH_2CH_2CH_3$$

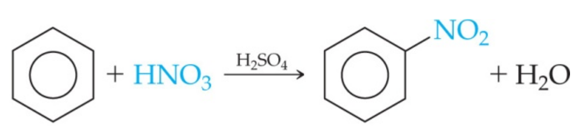
$$CH_2{=}CH_2 + H_2O \xrightarrow{H_2SO_4} CH_3CH_2OH$$



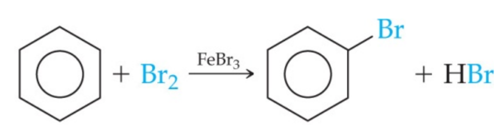
2-Butyne *trans*-2,3-Dichloro-2-butene

Aromatic Hydrocarbons

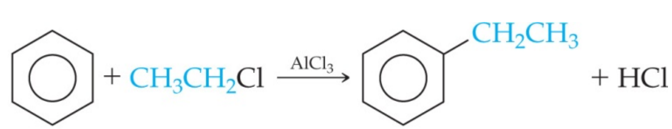
- Aromatic hydrocarbons have six-membered rings containing localized and delocalized electrons.
- The *π* ring is much more stable than a *π* bond. So, aromatic hydrocarbons are much less reactive than alkenes and alkynes.
- They undergo substitution reactions rather than addition reactions: groups replace H on a ring (e.g., nitration, halogenation, alkylation).



Benzene   Nitrobenzene



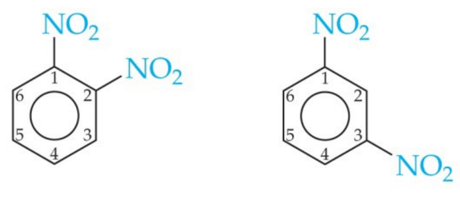
Benzene   Bromobenzene



Benzene   Ethylbenzene

Aromatic Nomenclature

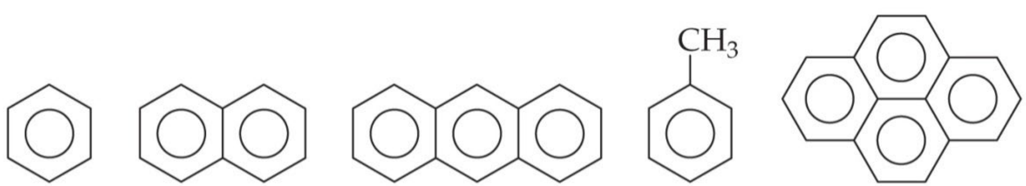
- Many aromatic hydrocarbons are known by their common names.
- Others are named as derivatives of benzene.
- Substitution positions for two substituents: 1,2 = *ortho-*; 1,3 = *meta-*; 1,4 = *para-*



ortho-Dinitrobenzene
1,2-Dinitrobenzene
mp 118 °C

meta-Dinitrobenzene
1,3-Dinitrobenzene
mp 90 °C

para-Dinitrobenzene
1,4-Dinitrobenzene
mp 174 °C

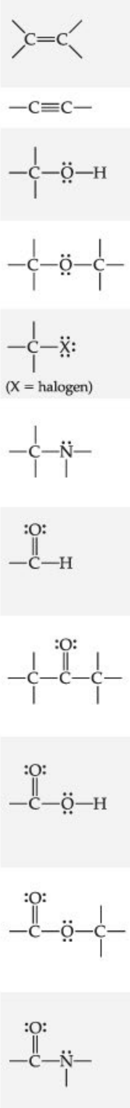


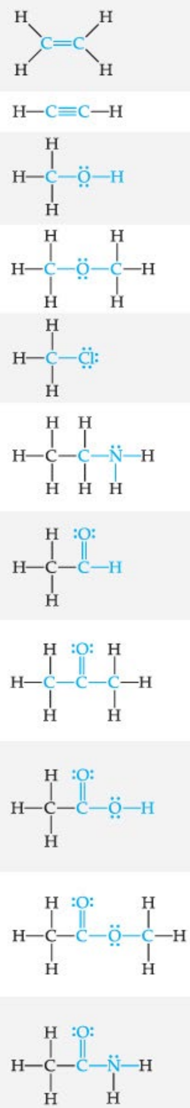
Benzene   Naphthalene   Anthracene   Toluene (Methylbenzene)   Pyrene

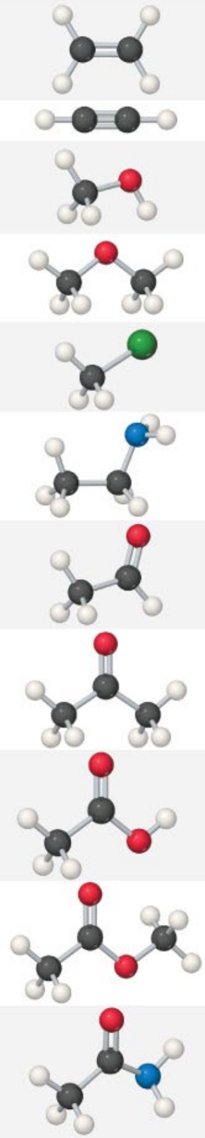
Organic and Biological Chemistry

Functional Groups

Table 24.6 Common Functional Groups





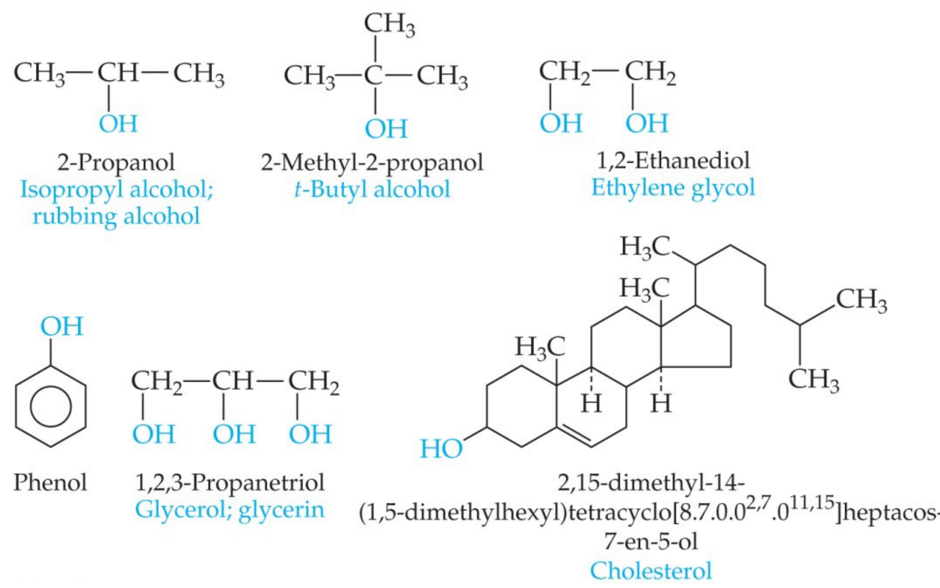


Functional Group	Compound Type	Suffix or Prefix	Example: Systematic Name (common name)
	Alkene	*-ene*	Ethene (Ethylene)
	Alkyne	*-yne*	Ethyne (Acetylene)
	Alcohol	*-ol*	Methanol (Methyl alcohol)
	Ether	*ether*	Dimethyl ether
(X = halogen)	Alkyl halide or haloalkane	*-ide*	Chloromethane (Methyl chloride)
	Amine	*-amine*	Ethylamine
	Aldehyde	*-al*	Ethanal (Acetaldehyde)
	Ketone	*-one*	Propanone (Acetone)
	Carboxylic acid	*-oic acid*	Ethanoic acid (Acetic acid)
	Ester	*-oate*	Methyl ethanoate (Methyl acetate)
	Amide	*-amide*	Ethanamide (Acetamide)

- The chemistry of an organic molecule is largely determined by the functional groups it contains.
- R represents the alkyl portion (C,H) of an organic molecule.

Alcohols

- Alcohols contain one or more —OH group (the alcohol group or the hydroxyl group).
- They are named from the parent hydrocarbon; the suffix is changed to ***-ol*** and a number designates the carbon to which the —OH group is attached.



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Properties and Uses of Alcohols

- Polar molecules: lead to water solubility and higher boiling points
- Methanol: used as a fuel additive
- Ethanol: in alcoholic beverages
- Ethylene glycol: in antifreeze
- Glycerol: cosmetic skin softener and food moisturizer
- Phenol: making plastics and dyes; topical anesthetic in throat sprays
- Cholesterol: important biomolecule in membranes, but can precipitate and form gallstones or block blood vessels

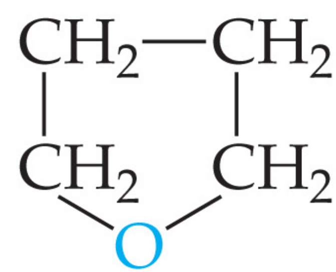
Organic and Biological Chemistry

Ethers

- R—O—R
- Formed by dehydration between alcohol molecules
- Not very reactive (except combustion)
- Used as solvents for organic reactions.

$CH_3CH_2—O—CH_2CH_3$

Diethyl ether



Tetrahydrofuran (THF)

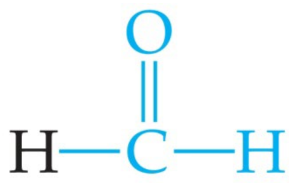
Organic and Biological Chemistry

Functional Groups Containing the Carbonyl Group

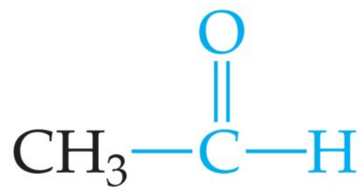
- The carbonyl group is C═O.
- Functional groups containing C═O:
  - Aldehydes
  - Ketones
  - Carboxylic acids
  - Esters
  - Amides

Aldehydes and Ketones

- Aldehydes have at least one hydrogen atom attached to the carbonyl carbon atom.

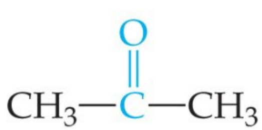


Methanal
Formaldehyde

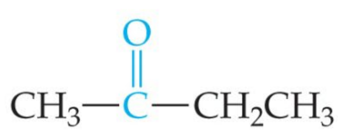


Ethanal
Acetaldehyde

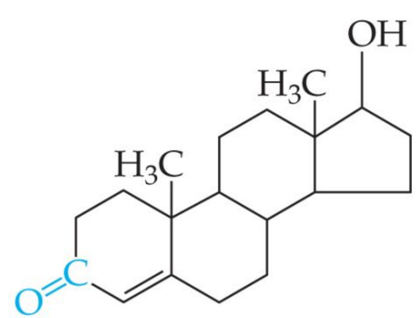
- Ketones have two R groups attached to the carbonyl carbon atom.



Propanone
Acetone



2-Butanone
Methyl ethyl ketone



Testosterone

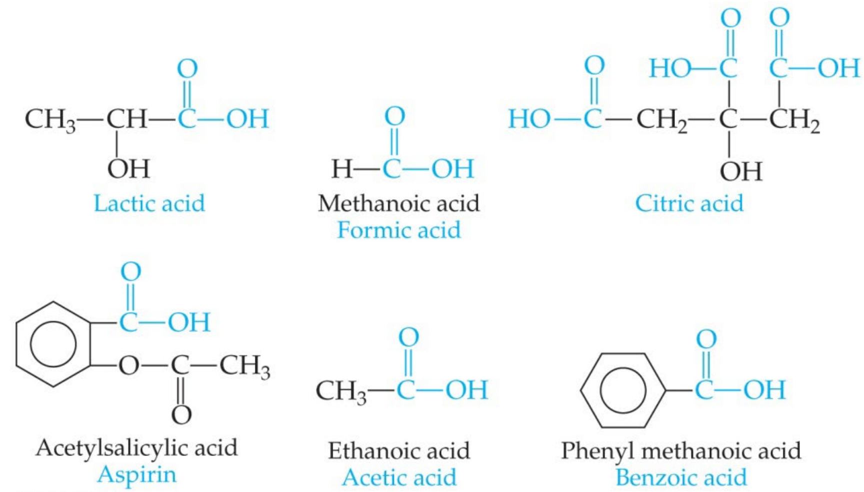
Organic and Biological Chemistry

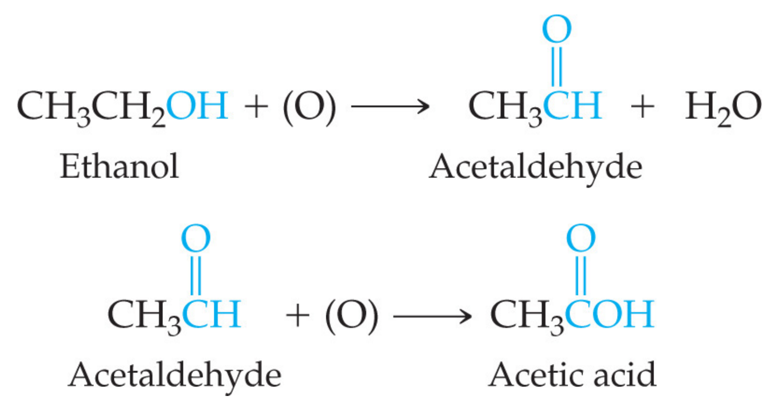
Important Aldehydes and Ketones

- Many aldehydes are natural flavorings: vanilla, cinnamon, spearmint, and caraway are from aldehydes.
- Ketones are used extensively as solvents; the most important solvent other than water is acetone, which dissolves in water and dissolves many organic compounds.

Carboxylic Acids

- Structure: hydroxyl group bonded to the carbonyl group
- H on the hydroxyl group is weakly acidic.
- Important in manufacturing polymers for films, fibers, and paints
- Oxidation product of alcohols (some make aldehydes)

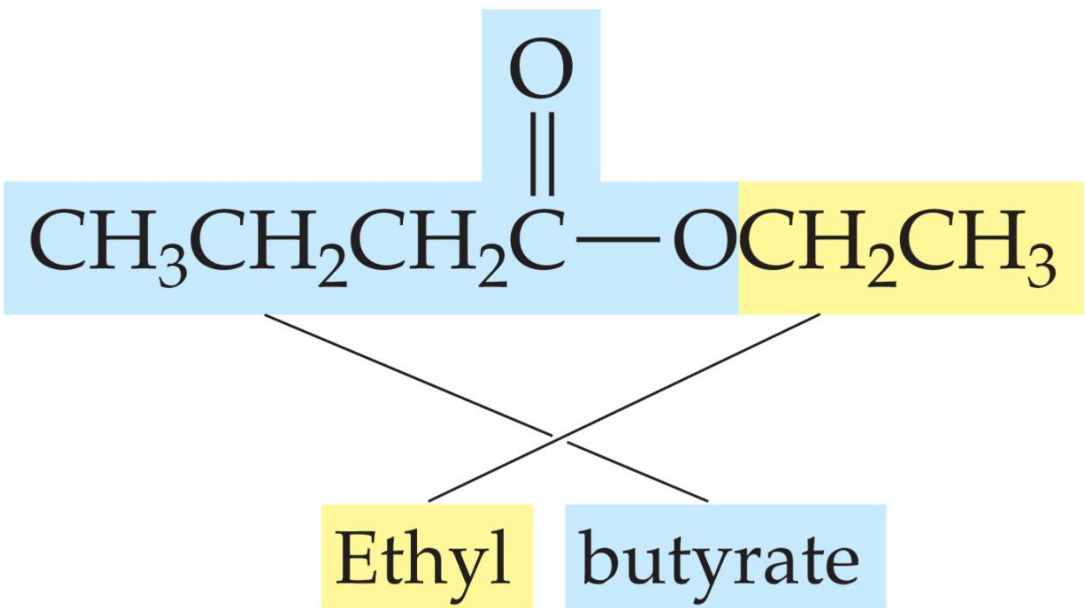




Organic and Biological Chemistry

Esters

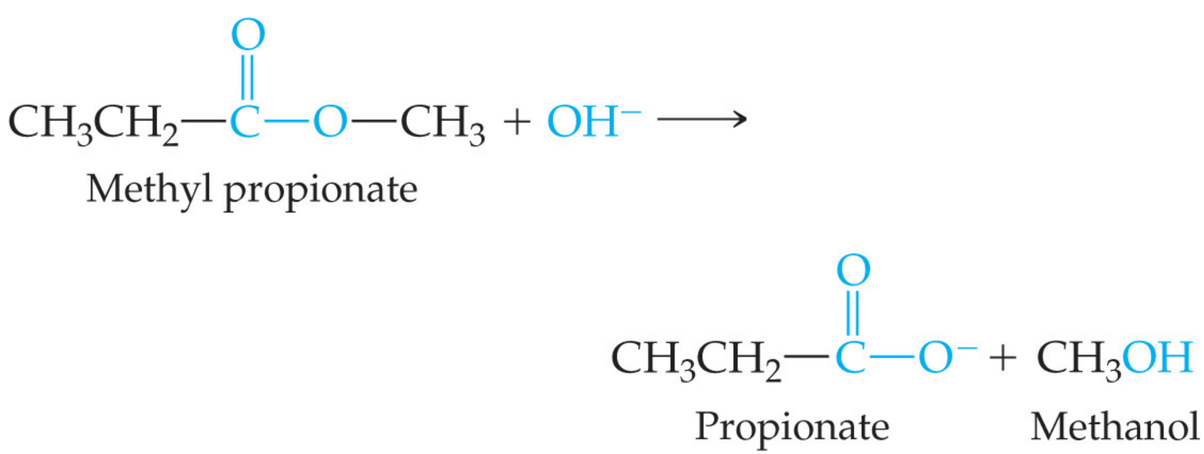
- Esters are the products of reactions between carboxylic acids and alcohols.
- They are found in many fruits and perfumes.
- Naming: name the alcohol part as an alkyl name; separate word is the acid part as an *-ate* anion.



Organic and Biological Chemistry

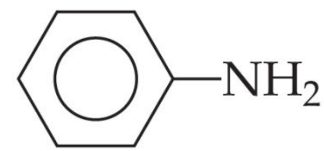
Decomposition of Esters

- Heating an ester in the presence of an acid catalyst and water can decompose the ester. (This is the reverse reaction of the preparation of an ester; it is an equilibrium.)
- Heating an ester in the presence of a base results in **saponification** (making soap).



Nitrogen Containing Organic Compounds

- Amines are organic derivatives of ammonia (NH_3). One, two, or all three H atoms can be replaced by R groups (the same or different R groups).

$CH_3CH_2NH_2$	$(CH_3)_3N$	
Ethylamine	Trimethylamine	Phenylamine Aniline

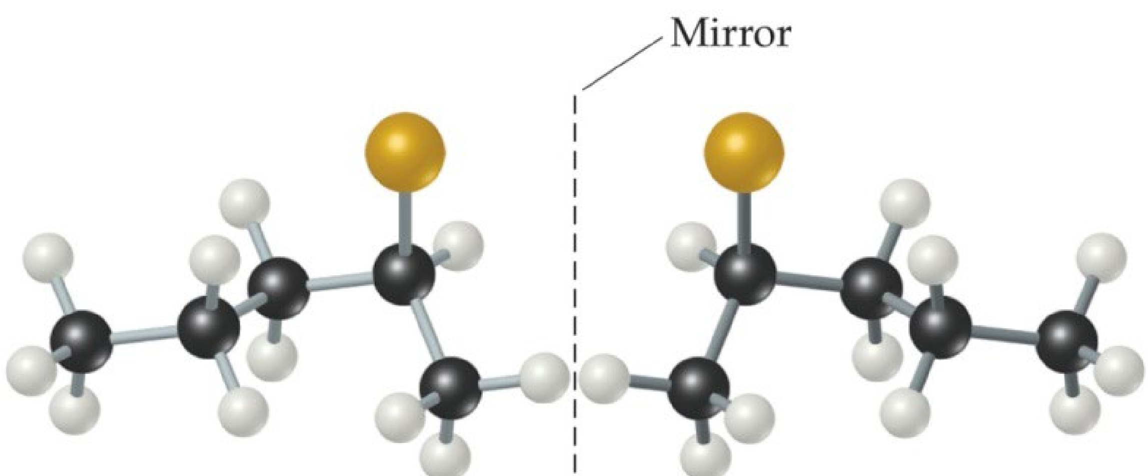
- If H in NH_3 or an amine is replaced by a carbonyl group (N directly attached to C═O), an amide is formed.

$$CH_3\overset{\overset{\displaystyle O}{\|}}{C}{-}OH + H{-}N(CH_3)_2 \longrightarrow CH_3\overset{\overset{\displaystyle O}{\|}}{C}{-}N(CH_3)_2 + H_2O$$

Organic and Biological Chemistry

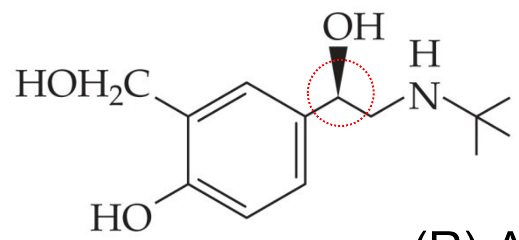
Chirality

- Carbons with four different groups attached to them are **chiral**.
- These are optical isomers, or **enantiomers**.
- Enantiomers have the same physical and chemical properties when they react with nonchiral reagents.
- Enantiomers rotate plane-polarized light in opposite directions

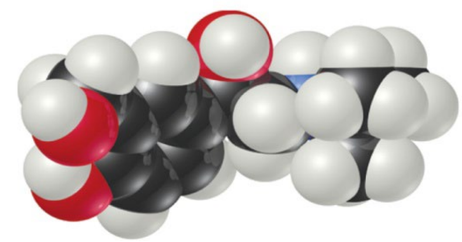


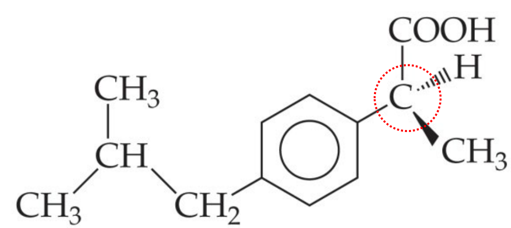
Chirality and Pharmaceuticals

- Many drugs are chiral compounds.
- Equal mixtures of enantiomers is called a racemic mixture. Often only one enantiomer is clinically active; the other can be inert OR harmful.

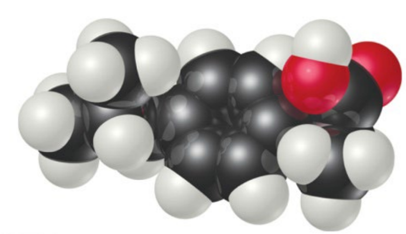


(R)-Albuterol





(S)-Ibuprofen



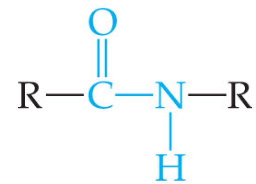
Organic and Biological Chemistry

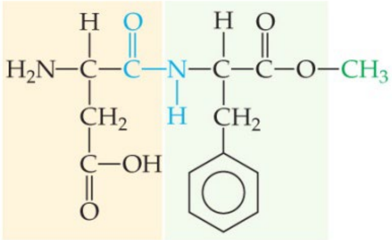
Biomolecules

- Biopolymers (large biological molecules built from small molecules)
  - ➢ Proteins
  - ➢ Polysaccharides (carbohydrates)
  - ➢ Nucleic acids
- Lipids are large biomolecules, but they are NOT polymers.

Amino Acids and Proteins

- Amino acids have amine and carboxylic acid functional groups.
- Proteins are polymers of *α*-amino acids.
- A condensation reaction between the amine end of one amino acid and the acid end of another produces a **peptide bond**, which is an amide linkage.

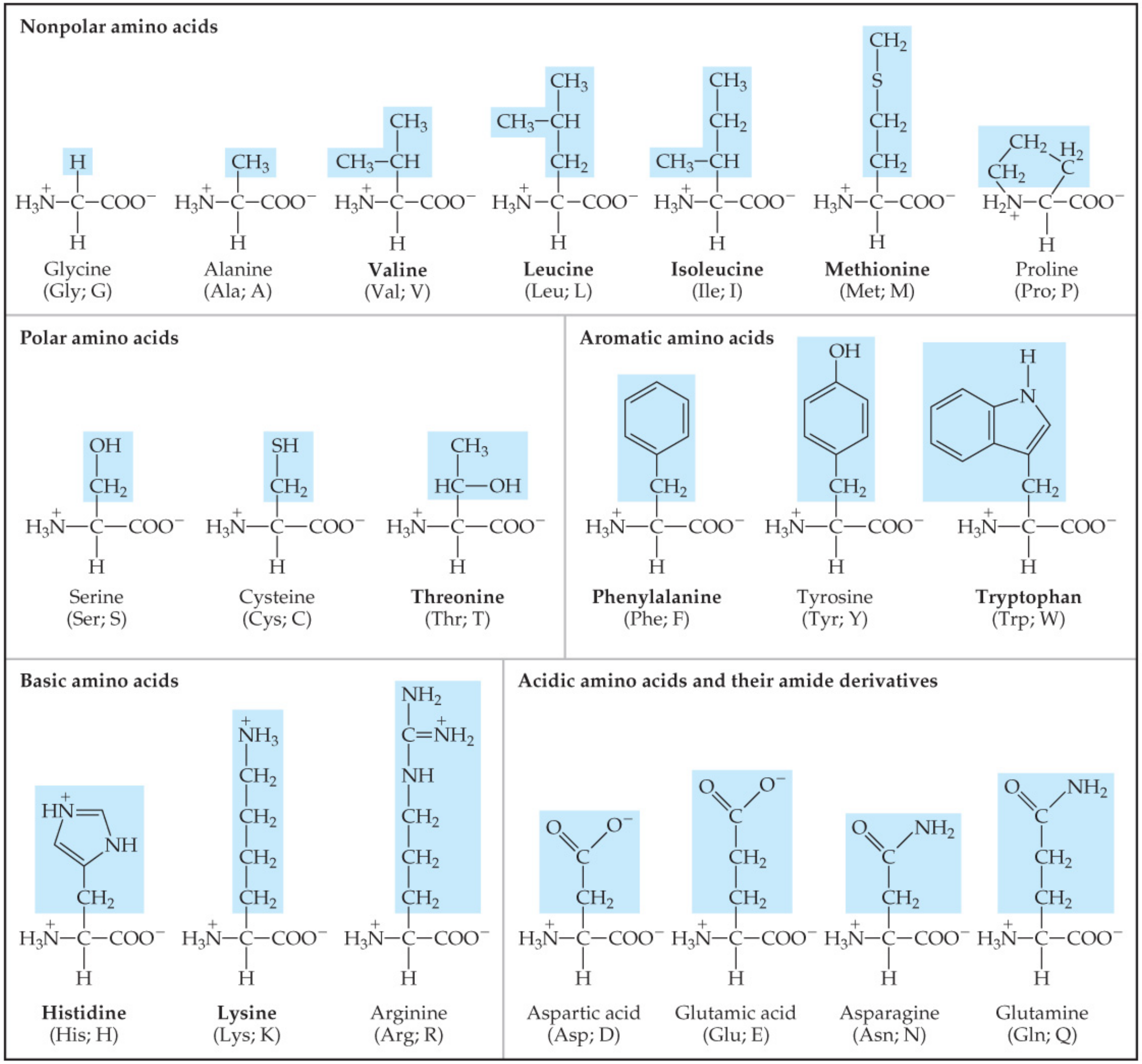




Aspartic acid (Asp)

Phenylalanine (Phe)

The Natural α-Amino Acids

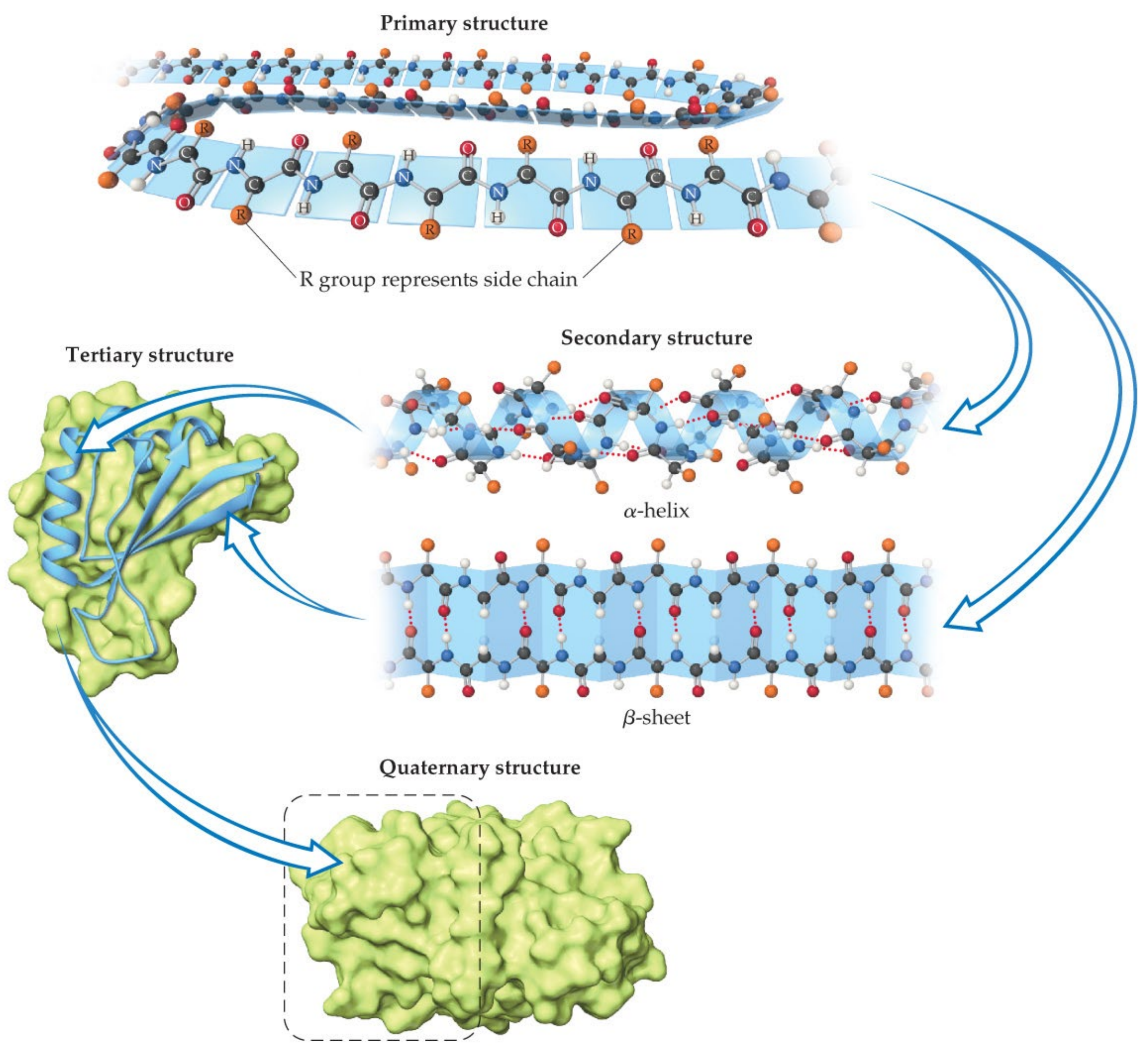


Organic and Biological Chemistry

Protein Structure

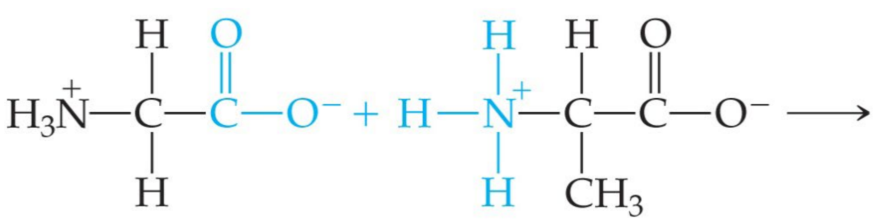
- Primary structure: the sequence of amino acids in the polypeptide/protein chain
- Secondary structure: interactions between the chain atoms (C═O and N—H atoms) that give structure to proteins
- Tertiary structure: “intermolecular” forces between side-chain atoms that give structure to proteins
- Quaternary structure: arrangement of multiple units and/or incorporation of non–amino acid portions of proteins

Protein Structure

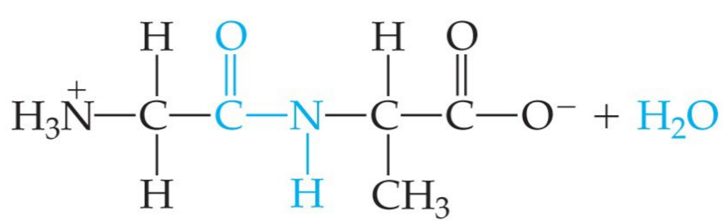


Primary Structure

- Formation of the amide bond between amino acids
- Repeats MANY times for a polypeptide/protein



Glycine (Gly; G)   Alanine (Ala; A)



Glycylalanine (Gly–Ala; GA)

Organic and Biological Chemistry

Secondary Structure

- Two common types:
  - *α*-Helix: looks like a corkscrew or spiral staircase; the C═O forms H bonds with the N—H from another amino acid in the chain.
  - *β*-Sheets: two or more "pleated" regions (looking like the shape of a pleated skirt or corrugated cardboard) are held together by the same H bonds as in an *α*-helix; one major difference is how far apart from each other the amino acids are in the amino acid sequence (*α*-helix atoms are much closer together).

Tertiary Structure

- Side chains interact with each other and the surrounding environment (usually aqueous environment).
- The forces we called "intermolecular" are mostly what drives tertiary structure.
- The side chains have polar, nonpolar, and charged groups; these give rise to ion–ion, ion–dipole, dipole–dipole, and dispersion force interactions.

Quaternary Structure

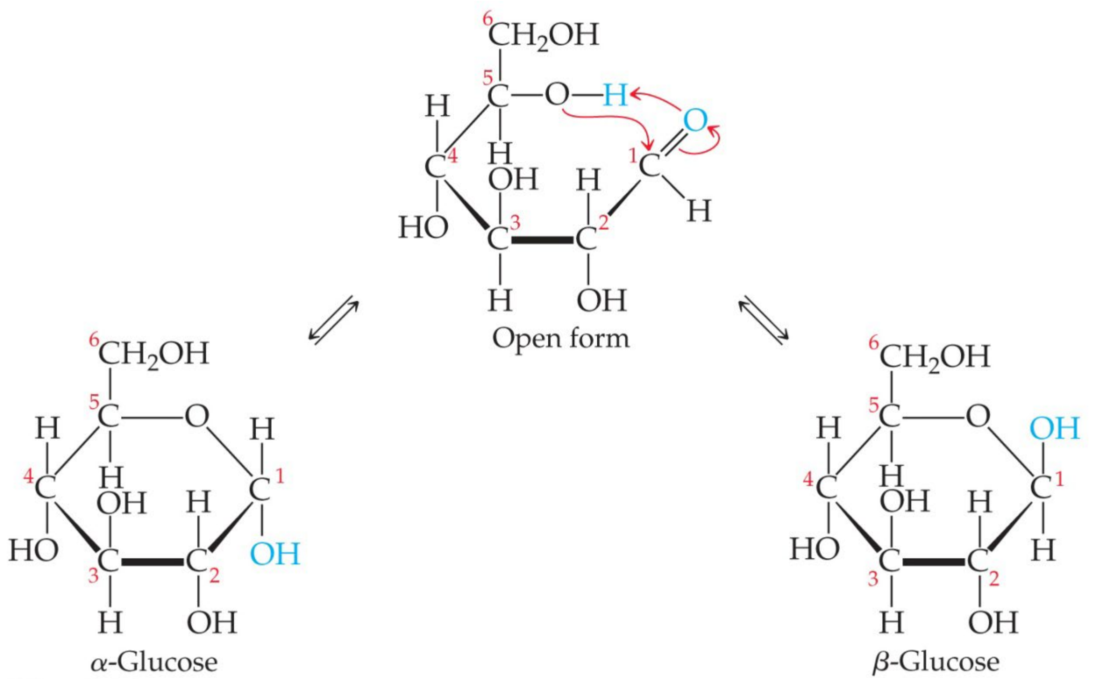
- Some proteins are made up of more than one polypeptide chain.
- Some proteins contain portions that are NOT amino acid in nature.
- The combination of subunits is quaternary structure.

Classifying Proteins

- One method to classify proteins is based on solubility:
  - Globular proteins are roughly spherical and dissolve in aqueous environments.
  - Fibrous proteins are usually long fibers that are insoluble in water and are used as structural materials.

Carbohydrates

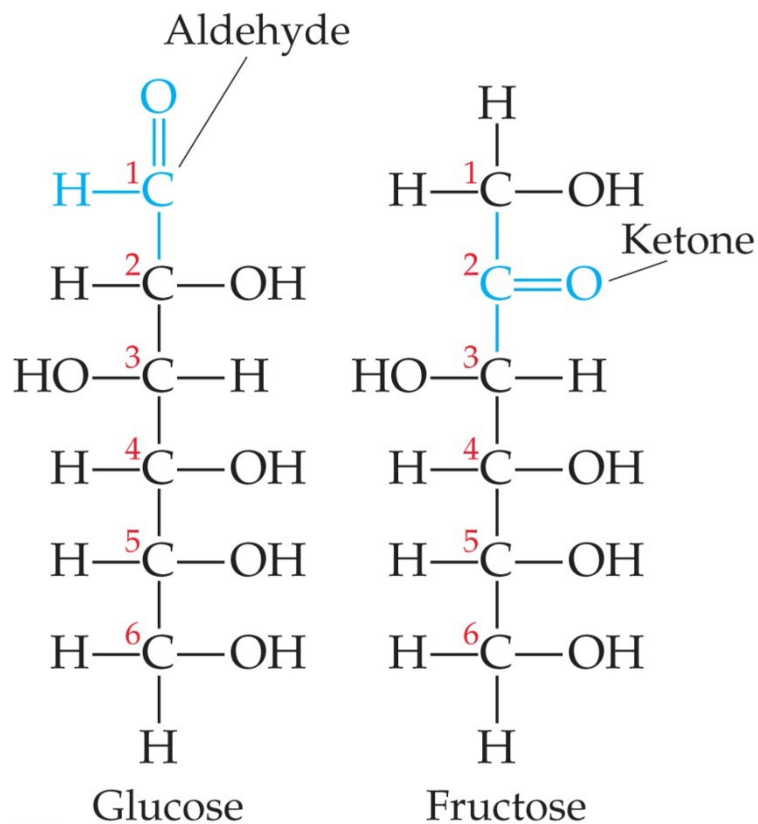
- The name comes from an empirical formula for sugars: $C_x(H_2O)_y$—for the simplest sugars, $x = y$.
- Simple sugars (monosacchharides) are polyhydroxy aldehydes or ketones. They are often drawn as chains but most frequently exist as rings in solution.



Organic and Biological Chemistry

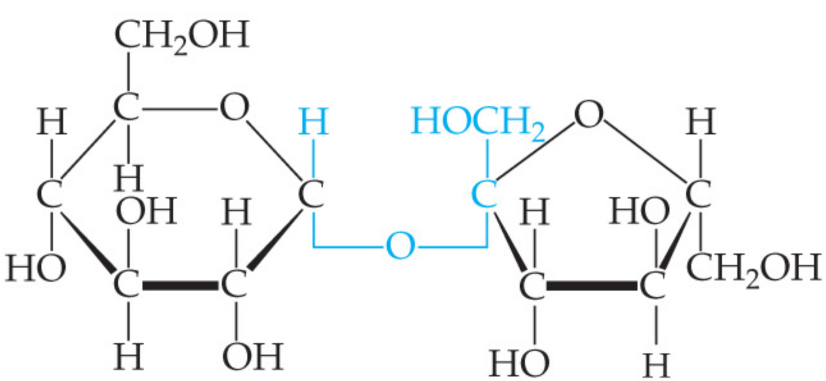
Monosaccharides

- The two most common monosaccharides are glucose and fructose.
- Glucose is an aldehyde; fructose is a ketone.

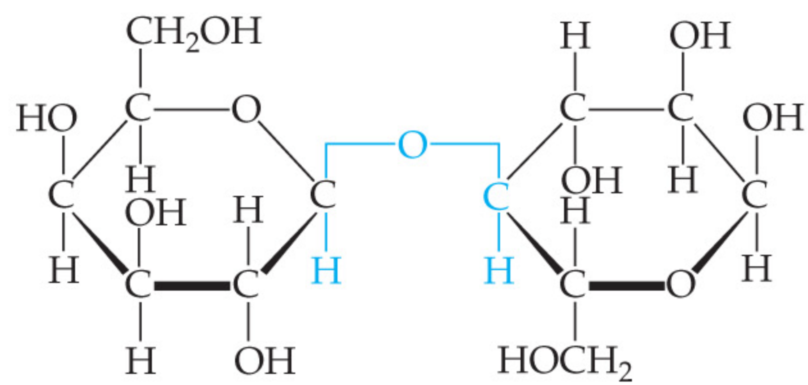


Disaccharides

- Dehydration between two monosaccharides forms a disaccharide.
- Sucrose and lactose are both disaccharides.
- Disaccharides are often referred to as sugars.



Glucose unit Sucrose Fructose unit



Galactose unit Lactose Glucose unit

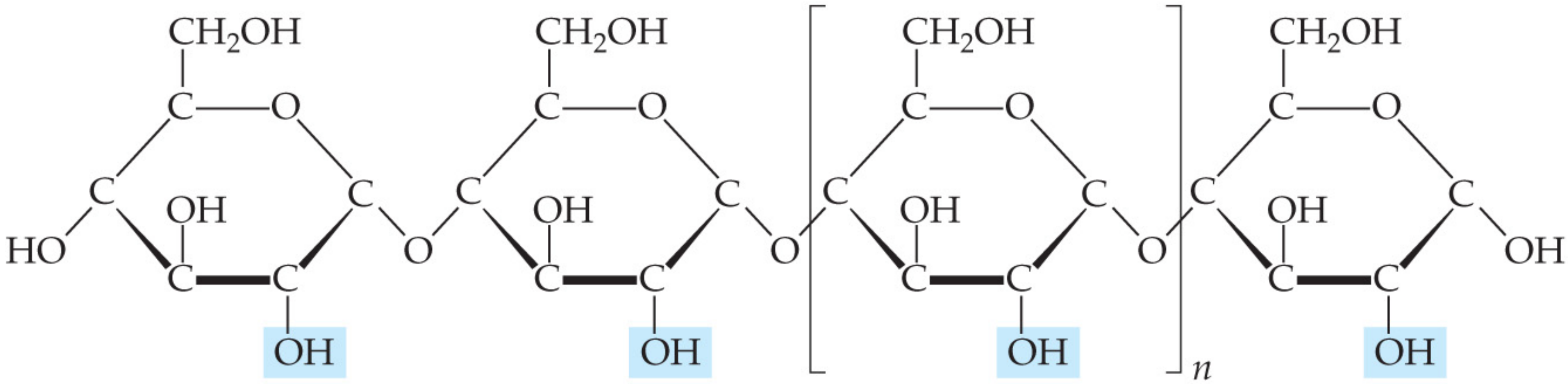
Organic and Biological Chemistry

Polysaccharides

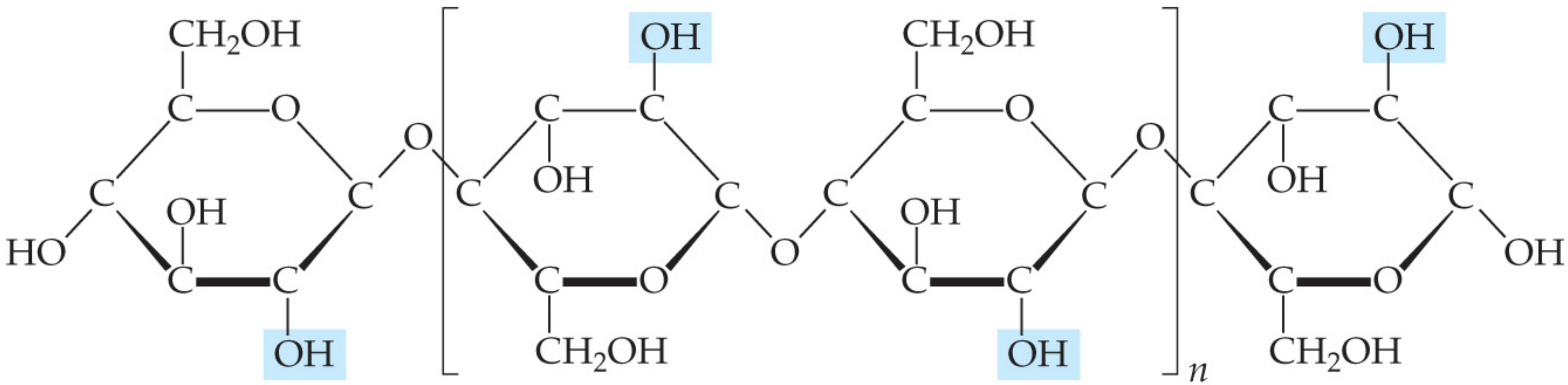
- Dehydration can create long-chain polysaccharides.
- The three most common are starch, glycogen, and cellulose.
  - Starch consists of many different-sized and various branching chains of glucose prepared by plants to store energy.
  - Glycogen is often called "animal starch"—it is for temporary energy storage in animals (which use fats for long-term energy storage).
  - Cellulose is a structural polysaccharide in plants, making up cell walls; it is unbranched.

Polysaccharides

(a)



(b)



Lipids

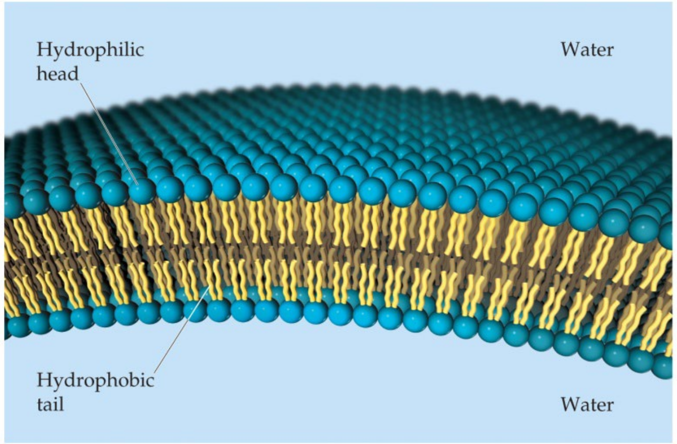
- Lipids are a broad class of nonpolar bioorganic molecules. They are grouped because they are insoluble in water.
- They are used biologically to store energy (fats, oils) and for biological structure (phospholipids in cell membranes).

Fats and Oils

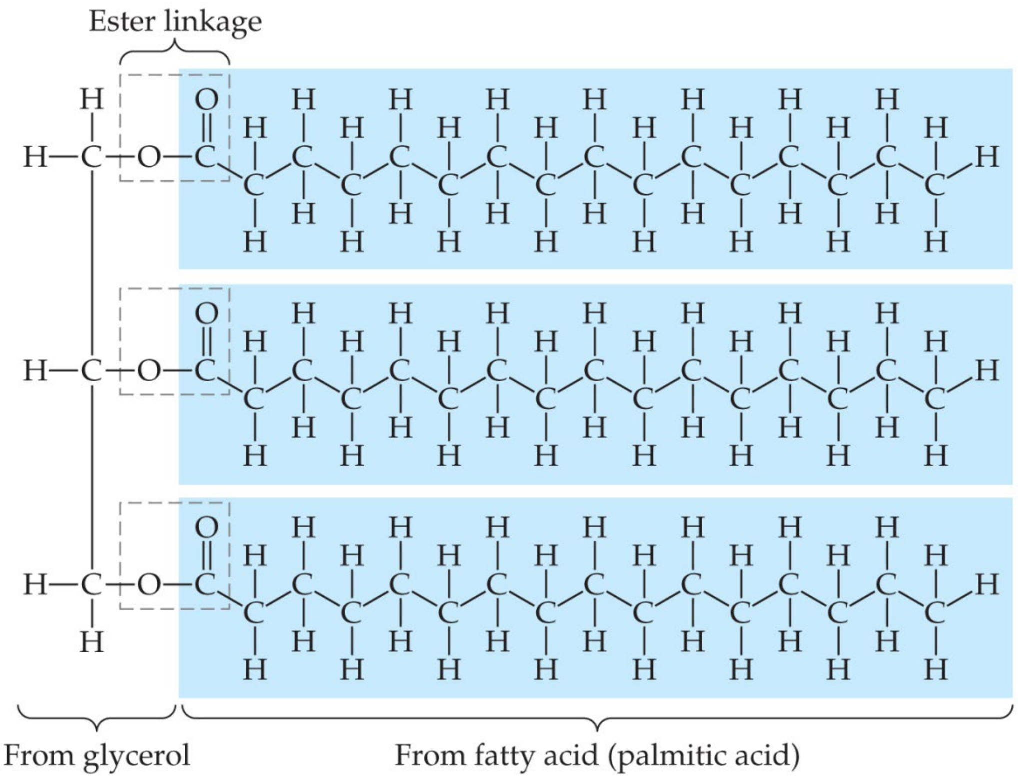
- Fats and oils are made from long-chain carboxylic acids and glycerol.
- Fats have only saturated carboxylic acids. They are solids. These are often called the "bad" fats in your diet.
- Oils have at least one unsaturated carboxylic acid. They are liquids. The more unsaturated, the better for you (polyunsaturated versus monounsaturated fats).
- Essential fatty acids (with double bonds) must be included in our diet. Our bodies can't produce them. They are often called omega-3 and omega-6 fatty acids.

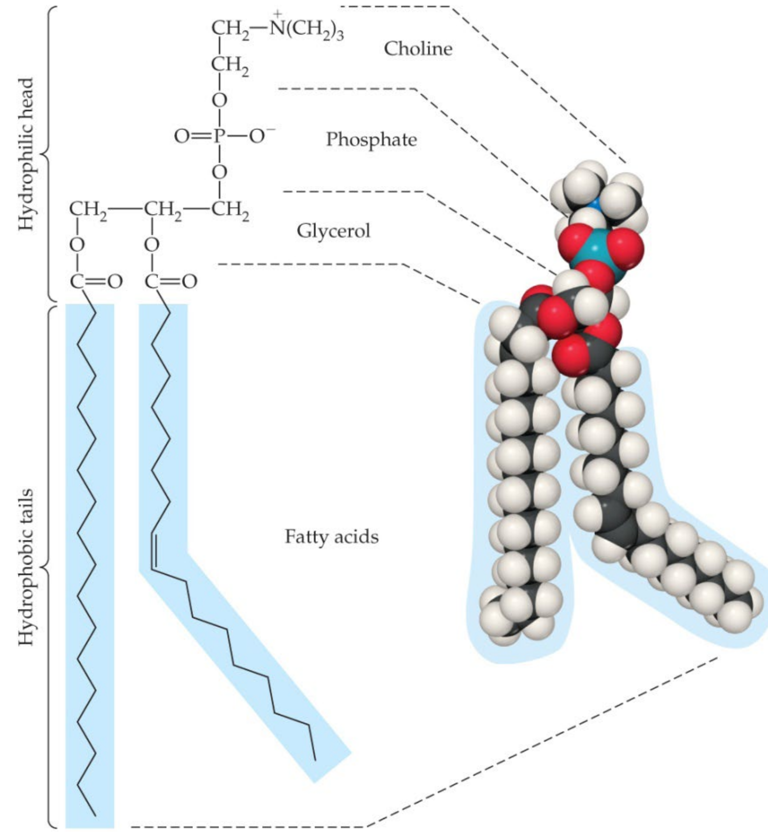
Phospholipids

- How their structure is similar to fats: glycerol with ester linkage to two fatty acids (instead of three)
- How it differs: the third site has a phosphate ester linkage connected to a charged or polar group, such as choline.
- They cluster together in water: polar regions pointing toward water; nonpolar fatty acid regions pointing toward each other—forming a “lipid bilayer”—the start of a cell membrane.



Comparing Phospholipids to Fats





Organic and Biological Chemistry

Nucleic Acids

- Class of biopolymers that are chemical carriers of genetic information
- Two types:
  - Deoxyribonucleic acid (DNA)
  - Ribonucleic acid (RNA)

Comparing Nucleic Acid Types

DNA

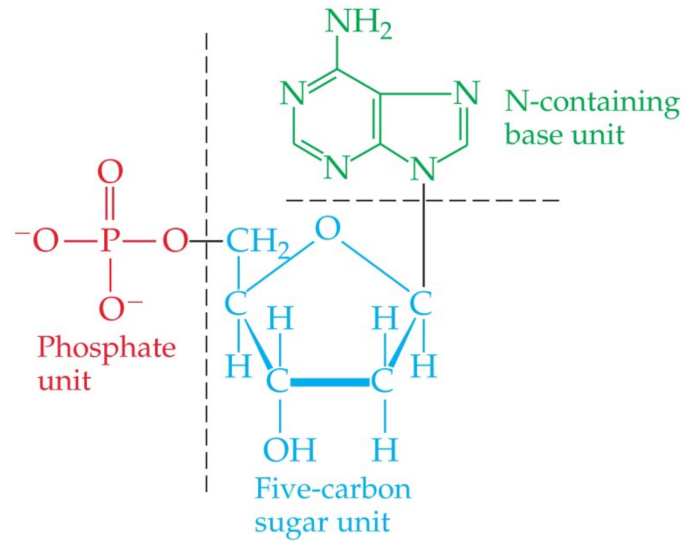
- Huge molecules (6 to 16 million amu)
- Primarily in nucleus of the cell
- Stores genetic information
- Specifies which proteins the cell can synthesize

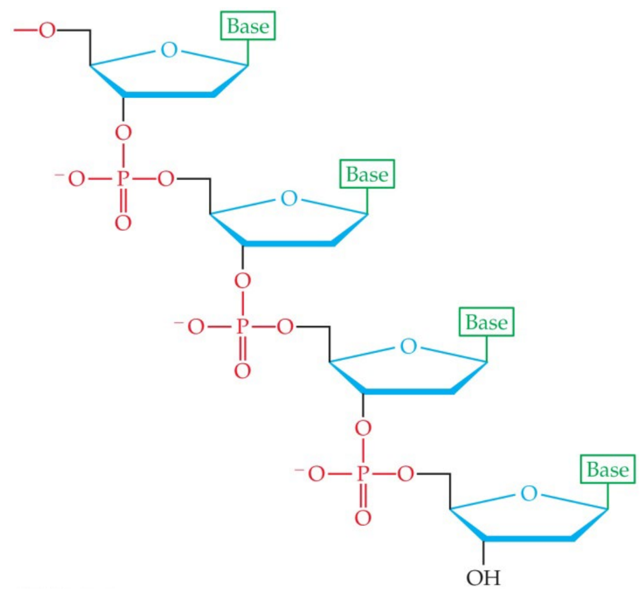
RNA

- Smaller molecules (20,000–40,000 amu)
- Mostly outside of nucleus (in cytoplasm)
- Carries stored info from DNA into cytoplasm
- Information is used in protein synthesis outside of nucleus

Structure of Nucleic Acids

- Nucleic acids consist of
  - a five-C sugar (ribose or deoxyribose);
  - a phosphate group;
  - a N-containing base (adenine, guanine, cytosine, and thymine or uracil).
- Polynucleotides form by condensation reactions between a phosphate and a sugar —OH.

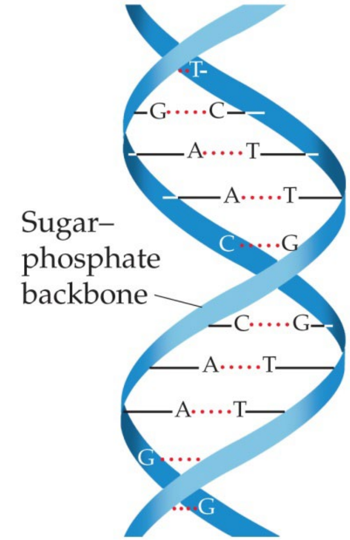


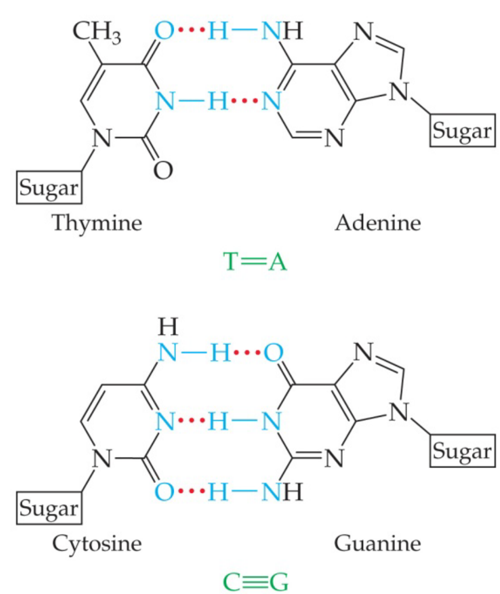


Organic and Biological Chemistry

The Double Helix

- Nucleotides combine to form the familiar double-helix form of the nucleic acids.
- H-bonding, dipole–dipole interactions, and dispersion forces hold the double helix together.
- Complementary base pairs form ideal H-bonding partners: A═T; C≡G. (Note: number of H-bonds, NOT a double/triple bond!)





Organic and Biological Chemistry