Chemistry, The Central Science, 10th edition
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and Bruce E. Bursten

Chapter 25
Organic and Biological Chemistry

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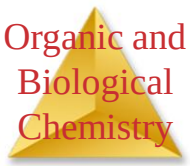
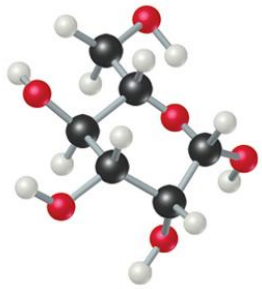
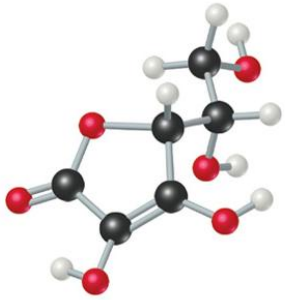
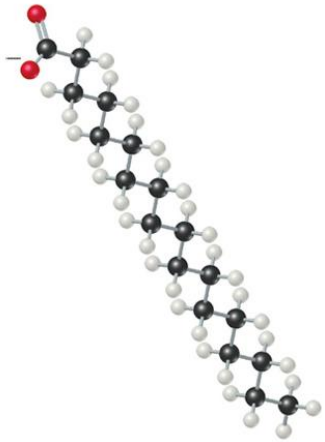




Glucose ($C_6H_{12}O_6$)



Ascorbic acid ($HC_6H_7O_6$)



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

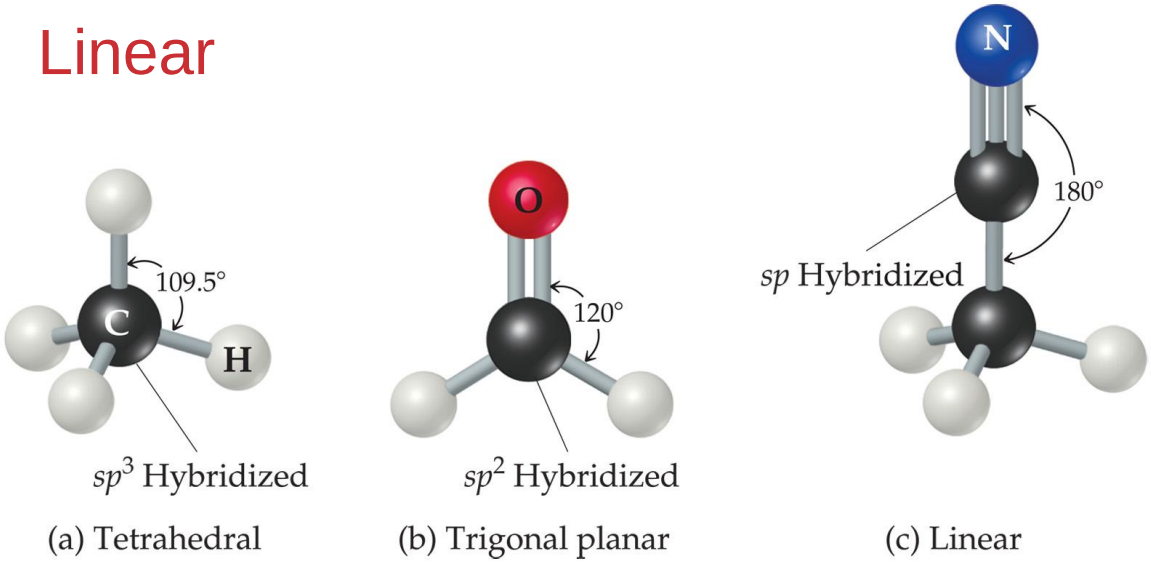
Organic Chemistry

- The chemistry of carbon compounds.
- Carbon has the ability to form long chains.
- Without this property, large biomolecules such as proteins, lipids, carbohydrates, and nucleic acids could not form.

Organic and Biological Chemistry

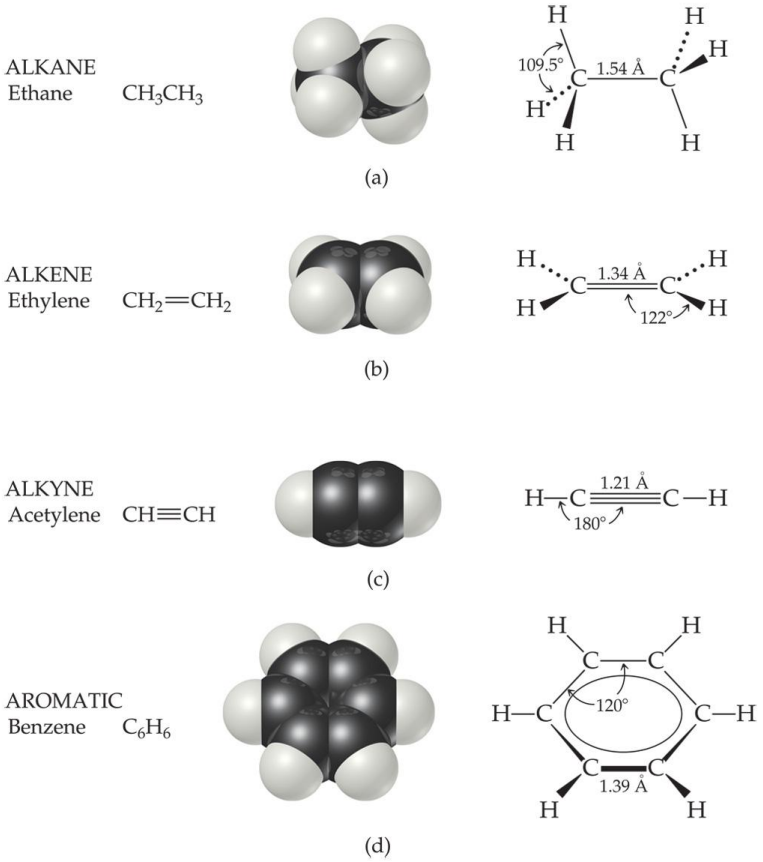
Structure of Carbon Compounds

- There are three hybridization states and geometries found in organic compounds:
  - sp^3 Tetrahedral
  - sp^2 Trigonal planar
  - sp Linear



Hydrocarbons

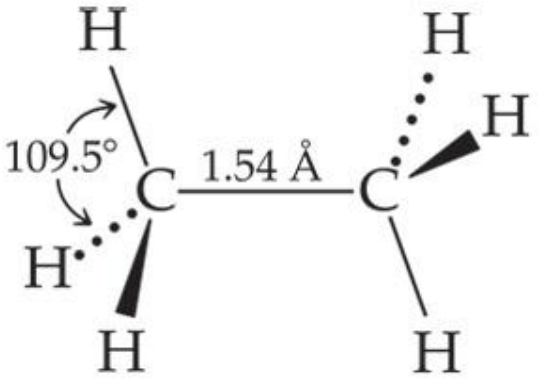
- Four basic types:
  - Alkanes
  - Alkenes
  - Alkynes
  - Aromatic hydrocarbons



Organic and Biological Chemistry

Alkanes

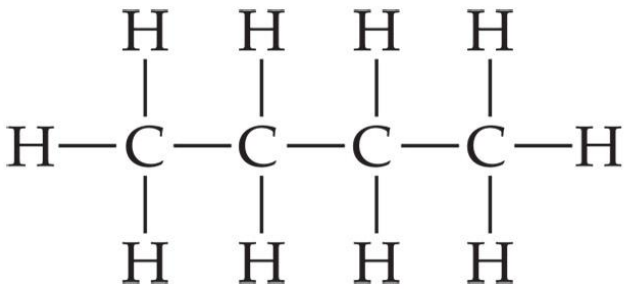
ALKANE
Ethane CH_3CH_3



- Only single bonds.
- Saturated hydrocarbons.
  - "Saturated" with hydrogens.

Formulas

- Lewis structures of alkanes look like this.
- Also called structural formulas.
- Often not convenient, though…



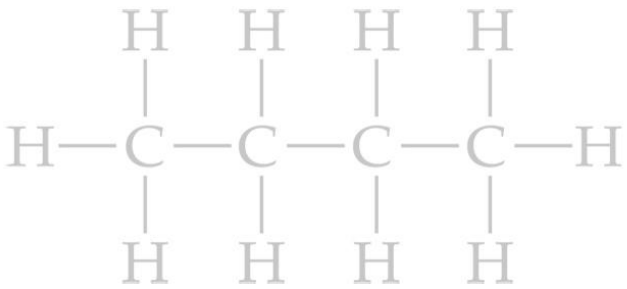
$H_3C—CH_2—CH_2—CH_3$

or

$CH_3CH_2CH_2CH_3$

Formulas

…so more often condensed formulas are used.



$H_3C—CH_2—CH_2—CH_3$

or

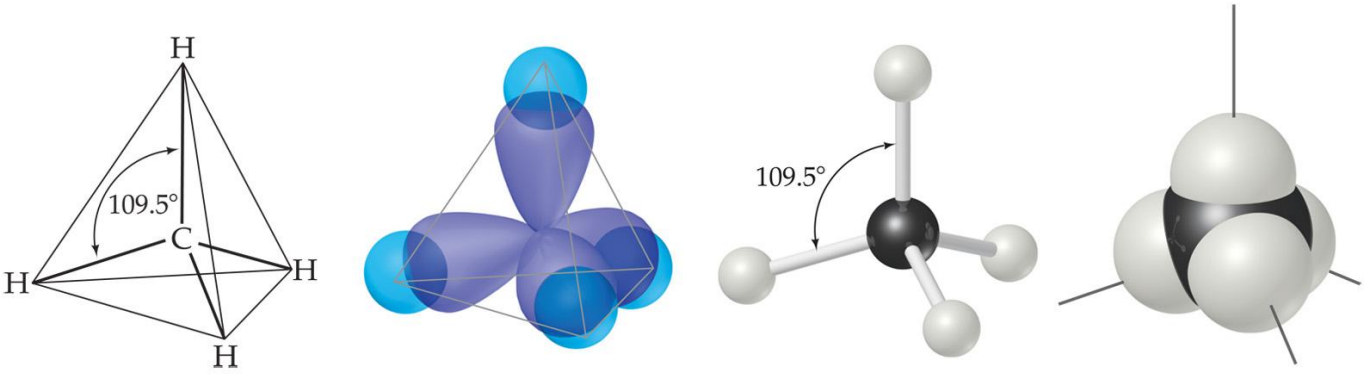
$CH_3CH_2CH_2CH_3$

Properties of Alkanes

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

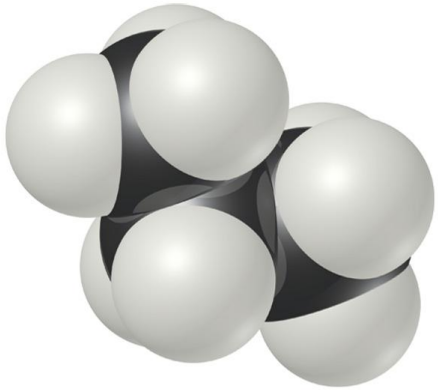
- Only van der Waals force: London force.
- Boiling point increases with length of chain.

Structure of Alkanes

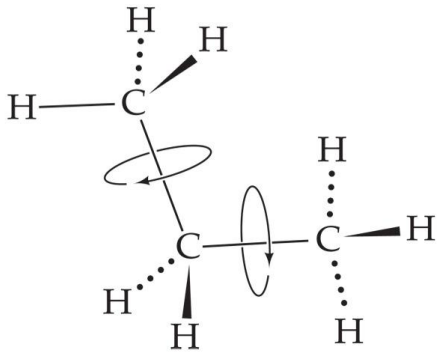


- Carbons in alkanes sp^3 hybrids.
- Tetrahedral geometry.
- 109.5˚ bond angles.

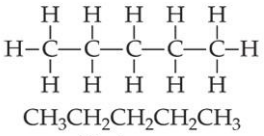
Structure of Alkanes

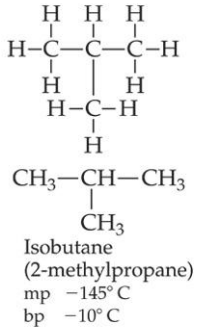


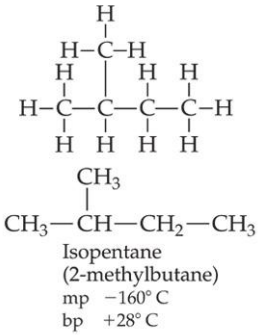
- Only σ-bonds in alkanes
- Free rotation about C—C bonds.

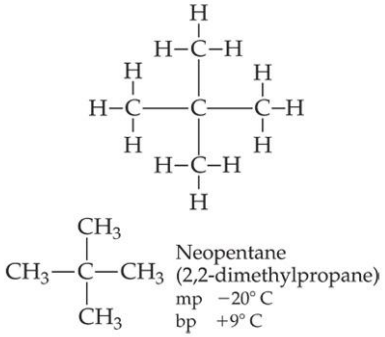


Isomers







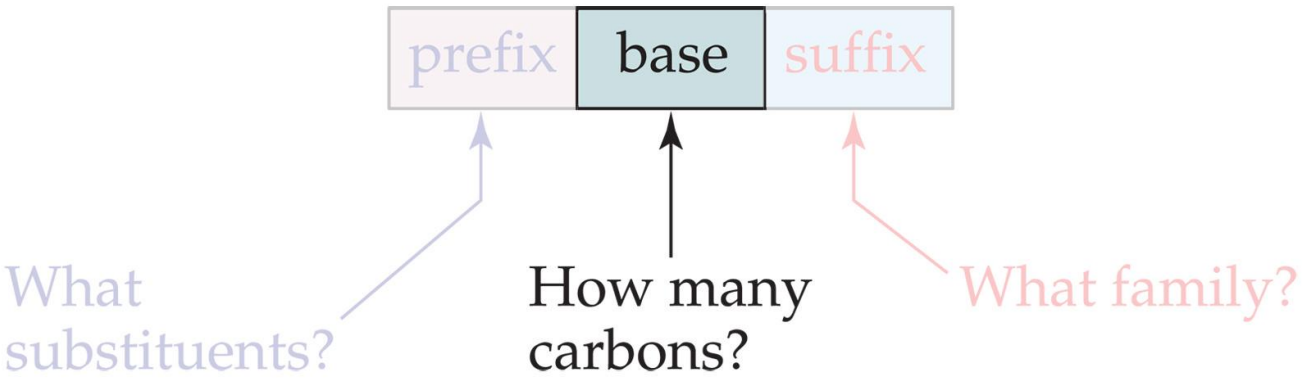


Have same molecular formulas, but atoms are bonded in different order.

Organic and Biological Chemistry

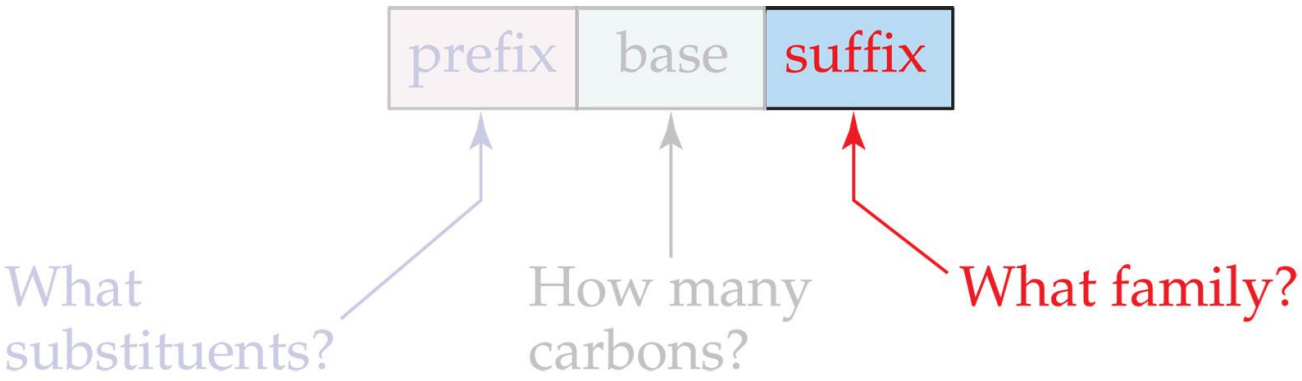
Organic Nomenclature

- Three parts to a compound name:
  - *Base*: Tells how many carbons are in the longest continuous chain.



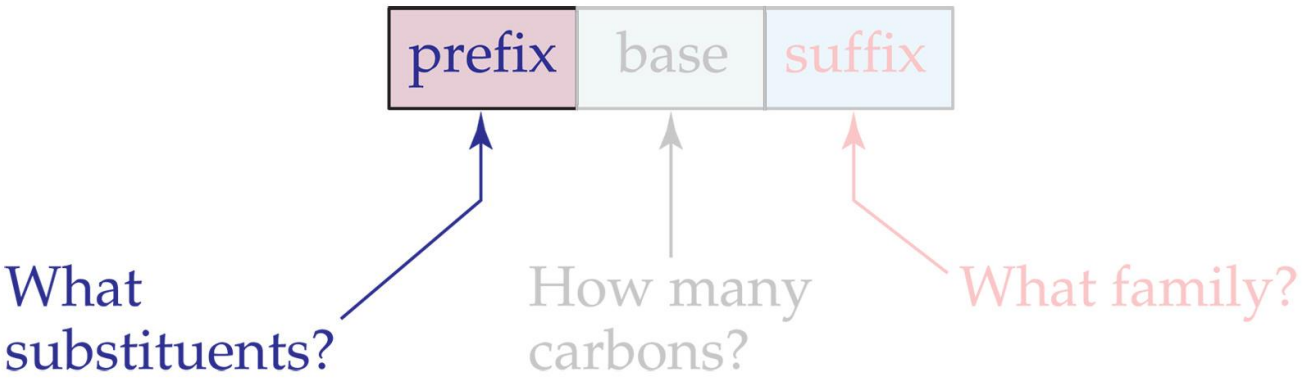
Organic Nomenclature

- Three parts to a compound name:
  - Base: Tells how many carbons are in the longest continuous chain.
  - Suffix: Tells what type of compound it is.

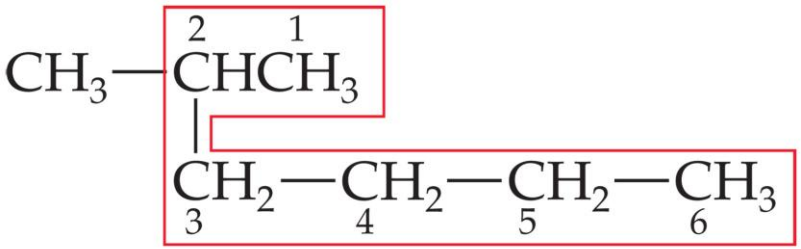


Organic Nomenclature

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



To Name a Compound…

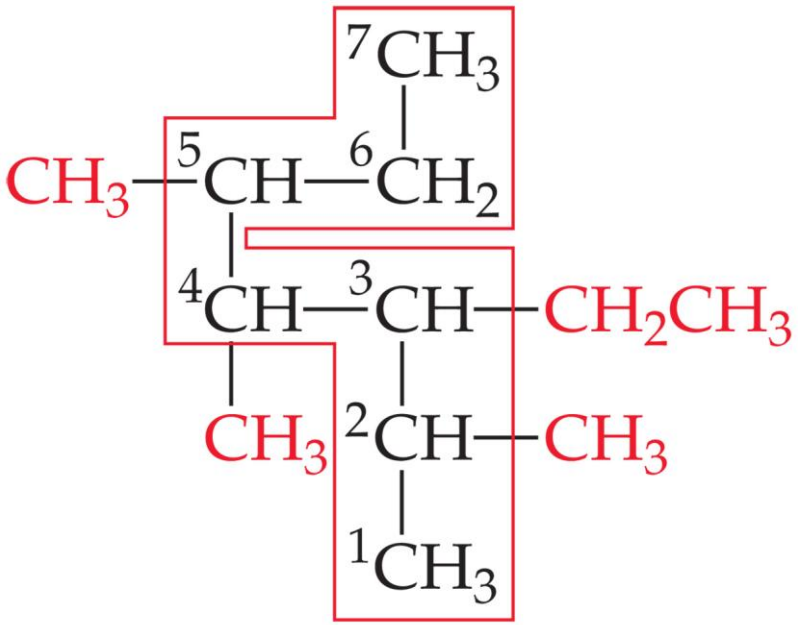


2-Methyl*hexane*

Group	Name
CH_3—	Methyl
CH_3CH_2—	Ethyl
$CH_3CH_2CH_2$—	Propyl
$CH_3CH_2CH_2CH_2$—	Butyl
$(CH_3)_2CH$—	Isopropyl
$(CH_3)_3C$—	*tert*-Butyl

1. Find the longest chain in the molecule.
2. Number the chain from the end nearest the first substituent encountered.
3. List the substituents as a prefix along with the number(s) of the carbon(s) to which they are attached.

To Name a Compound…

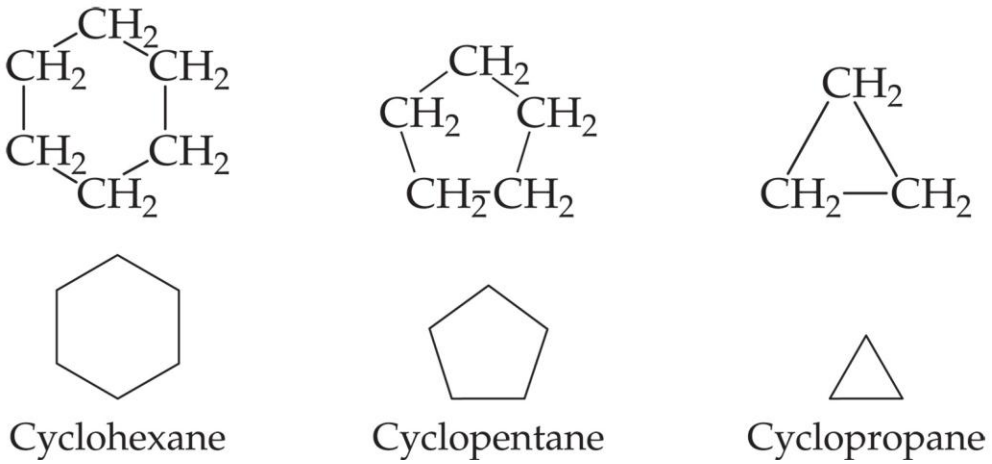


3-Ethyl-2,4,5-trimethylheptane

If there is more than one type of substituent in the molecule, list them alphabetically.

Cycloalkanes

- Carbon can also form ringed structures.
- Five- and six-membered rings are most stable.
  - Can take on conformation in which angles are very close to tetrahedral angle.
  - Smaller rings are quite strained.

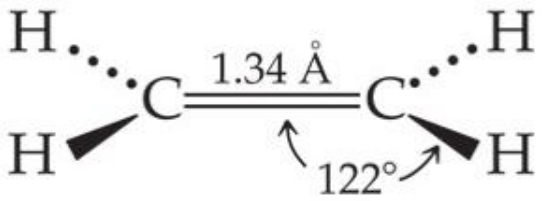


Reactions of Alkanes

- Rather unreactive due to presence of only C—C and C—H σ-bonds.
- Therefore, great nonpolar solvents.

Alkenes

ALKENE
Ethylene $CH_2{=}CH_2$

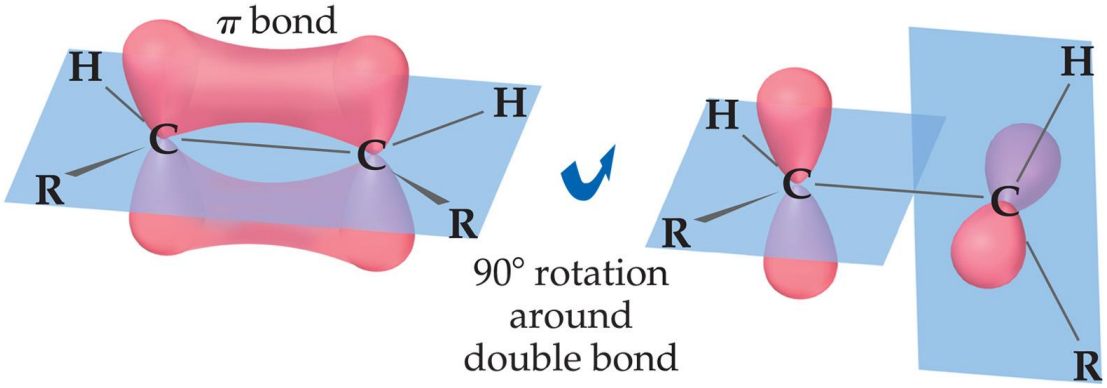


- Contain at least one carbon–carbon double bond.
- Unsaturated.
  - Have fewer than maximum number of hydrogens.

Organic and Biological Chemistry

Structure of Alkenes

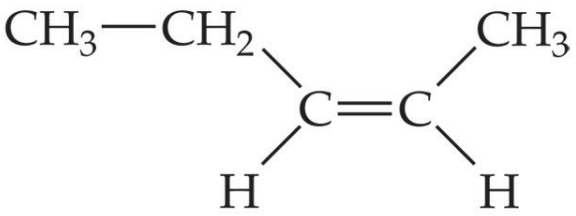
- Unlike alkanes, alkenes cannot rotate freely about the double bond.
  - Side-to-side overlap makes this impossible without breaking π-bond.



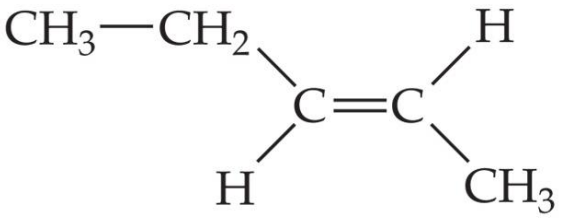
Organic and Biological Chemistry

Structure of Alkenes

This creates geometric isomers, which differ from each other in the spatial arrangement of groups about the double bond.

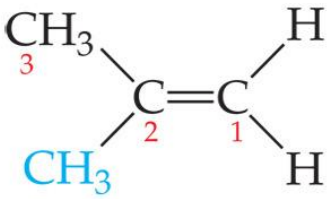


cis-2-Pentene

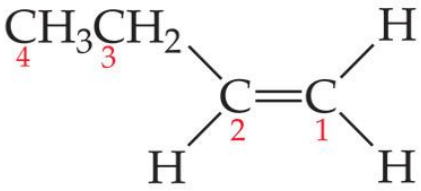


trans-2-Pentene

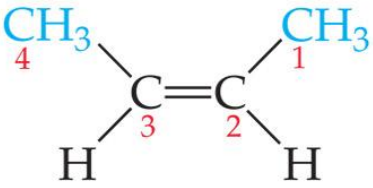
Properties of Alkenes



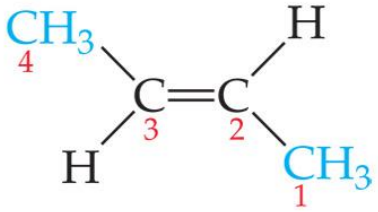
Methylpropene
bp −7°C



1-Butene
bp −6°C



cis-2-Butene
bp +4°C



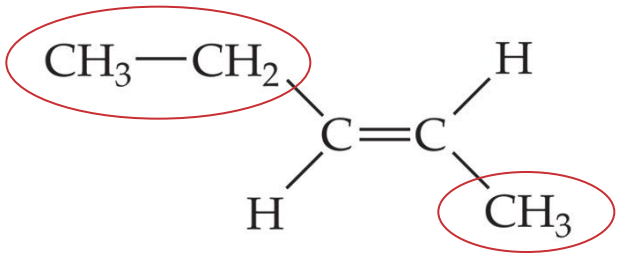
trans-2-Butene
bp +1°C

Structure also affects physical properties of alkenes.

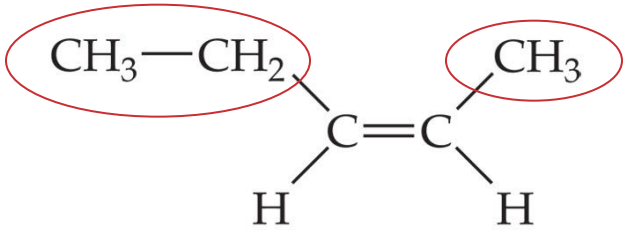
Nomenclature of Alkenes

- Chain numbered so double bond gets smallest possible number.
- *cis*- alkenes have carbons in chain on same side of molecule.
- *trans*- alkenes have carbons in chain on opposite side of molecule.

1-Pentene

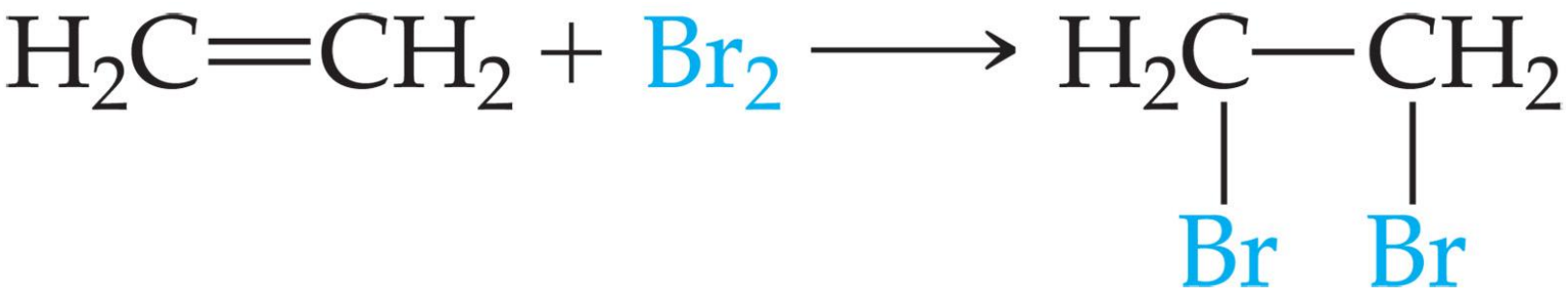


trans-2-Pentene



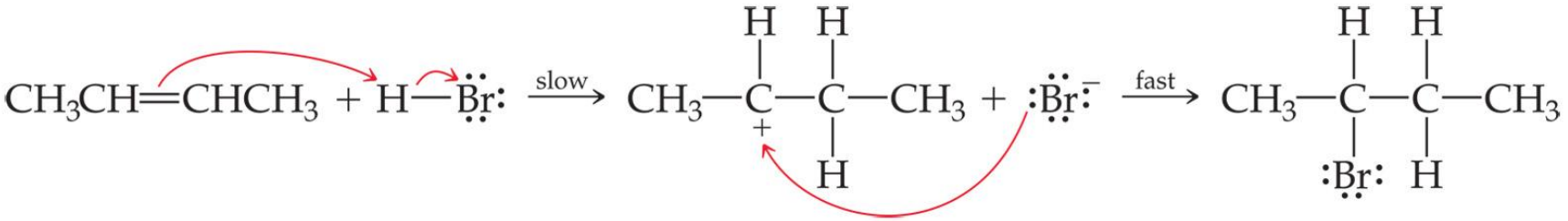
cis-2-Pentene

Reactions of Alkenes



- Addition Reactions
  - Two atoms (e.g., bromine) add across the double bond.
  - One π-bond and one σ-bond are replaced by two σ-bonds; therefore, ΔH is negative.

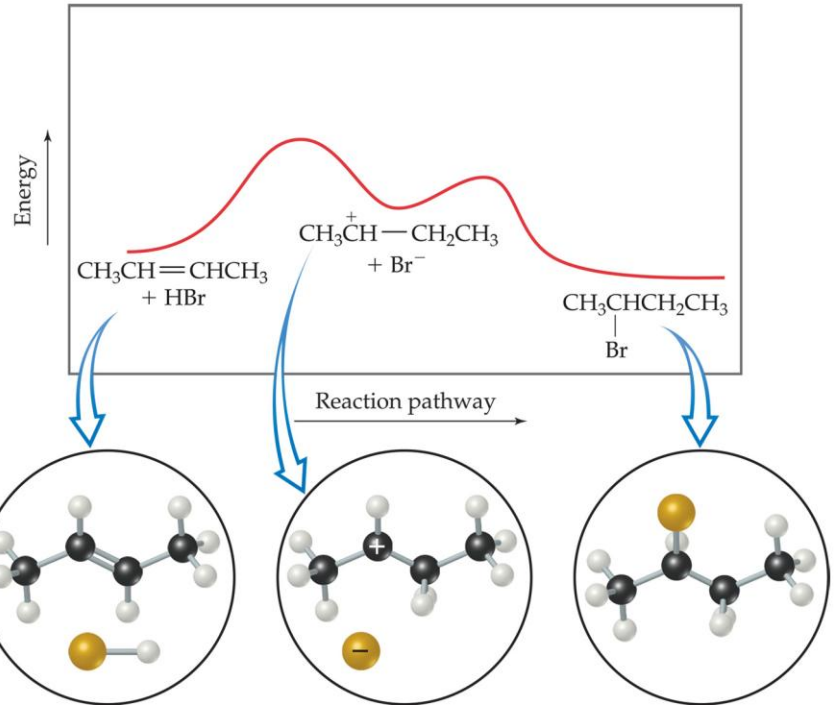
Mechanism of Addition Reactions



- Two-step mechanism:
  - First step is slow, rate-determining step.
  - Second step is fast.

Mechanism of Addition Reactions

In first step, π-bond breaks and new C—H bond and cation form.

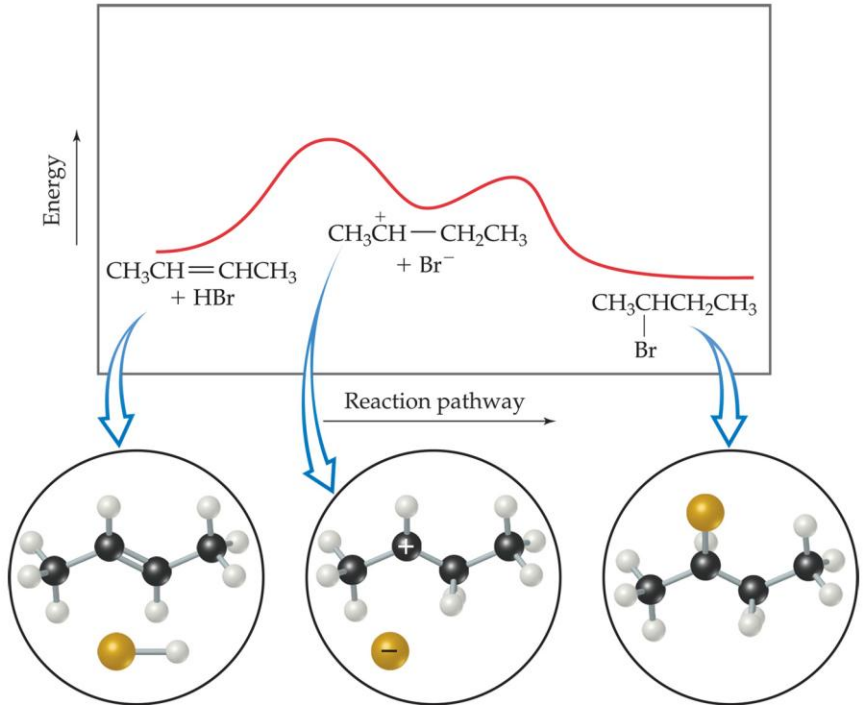


$$CH_3CH{=}CHCH_3 + HBr \longrightarrow \left[CH_3\overset{\delta+}{C}H{=}{=}CHCH_3 \quad H \quad Br^{\delta-}\right] \longrightarrow CH_3\overset{+}{C}H{-}CH_2CH_3 + Br^-$$

Organic and Biological Chemistry

Mechanism of Addition Reactions

In second step, new bond forms between negative bromide ion and positive carbon.



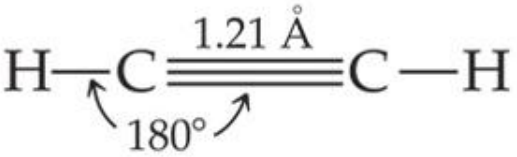
$$CH_3\overset{+}{C}H{-}CH_2CH_3 + Br^- \longrightarrow \left[CH_3\overset{\delta+}{C}H{-}CH_2CH_3 \quad Br^{\delta-}\right] \longrightarrow CH_3CHCH_2CH_3 \quad (Br)$$

Organic and Biological Chemistry

Alkynes

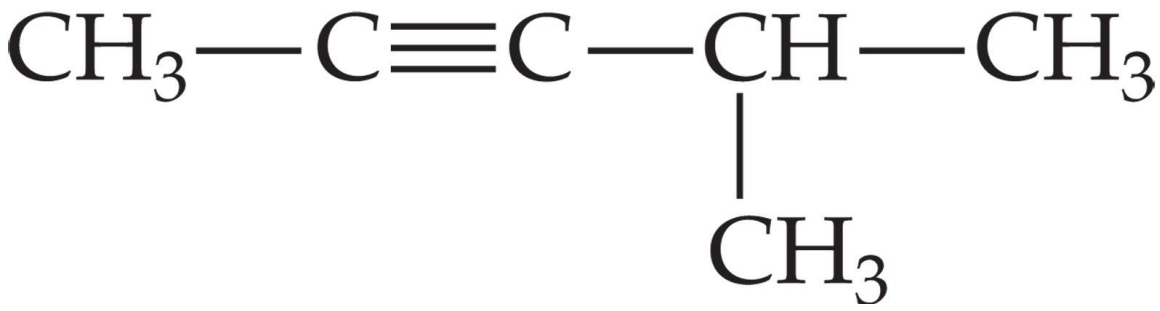
ALKYNE

Acetylene $CH{\equiv}CH$



- Contain at least one carbon–carbon triple bond.
- Carbons in triple bond *sp*-hybridized and have linear geometry.
- Also unsaturated.

Nomenclature of Alkynes

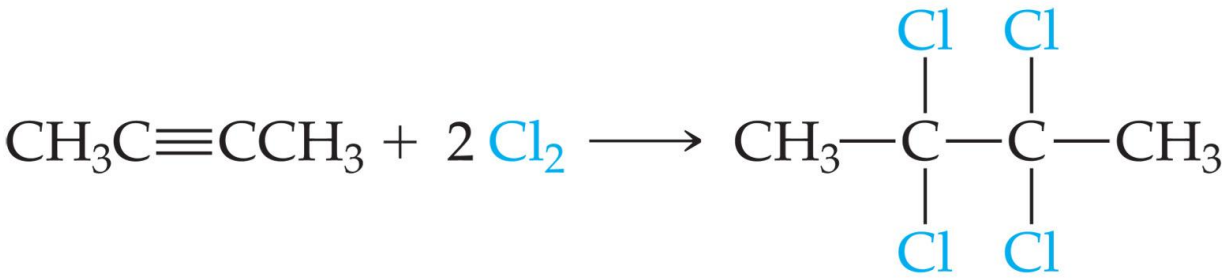


4-methyl-2-pentyne

- Analogous to naming of alkenes.
- Suffix is *-yne* rather than *–ene.*

Reactions of Alkynes

- Undergo many of the same reactions alkenes do.
- As with alkenes, impetus for reaction is replacement of π-bonds with σ-bonds.

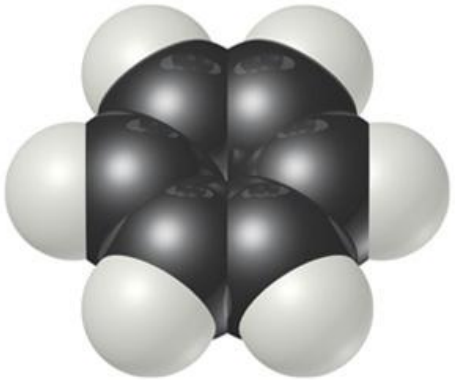


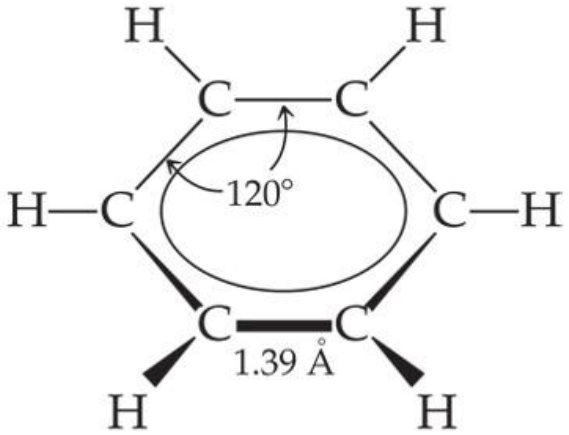
2-Butyne

2,2,3,3-Tetrachlorobutane

Aromatic Hydrocarbons

AROMATIC
Benzene C_6H_6





- Cyclic hydrocarbons.
- *p*-Orbital on each atom.
  - Molecule is planar.
- Odd number of electron pairs in π-system.

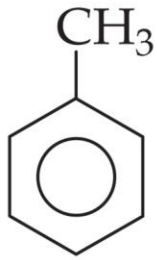
Aromatic Nomenclature

Many aromatic hydrocarbons are known by their common names.

Benzene

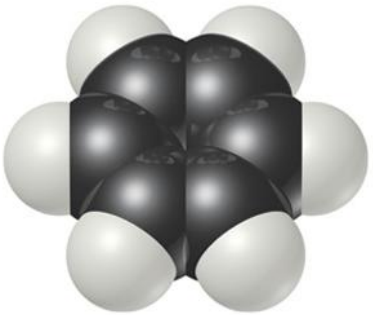
Naphthalene

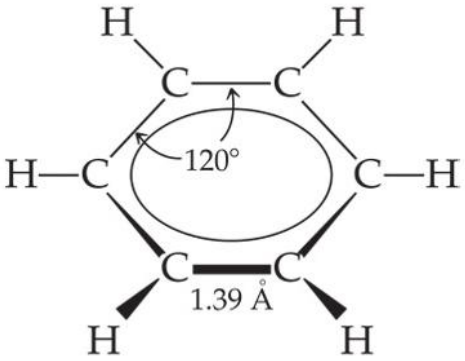
Anthracene



Toluene
Methylbenzene

Reactions of Aromatic Compounds

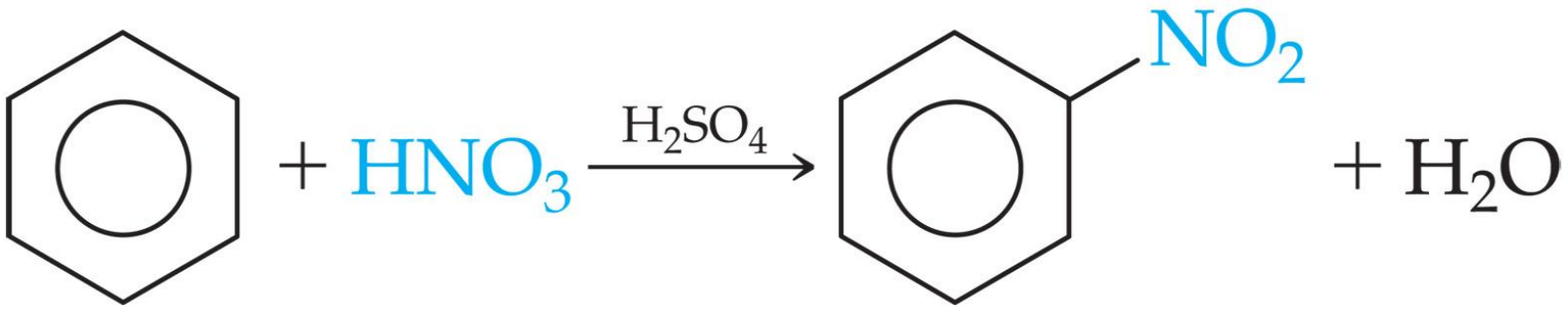




- Unlike in alkenes and alkynes, π-electrons do not sit between two atoms.
- Electrons are delocalized; this stabilizes aromatic compounds.

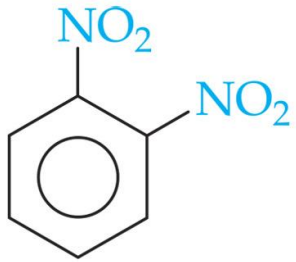
Organic and Biological Chemistry

Reactions of Aromatic Compounds

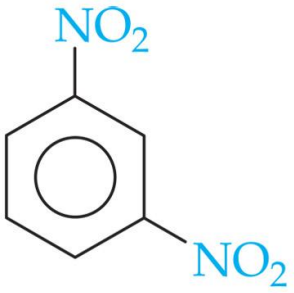


- Due to stabilization, aromatic compounds do not undergo addition reactions; they undergo substitution.
- Hydrogen is replaced by substituent.

Structure of Aromatic Compounds



ortho-Dinitrobenzene
mp 118°C

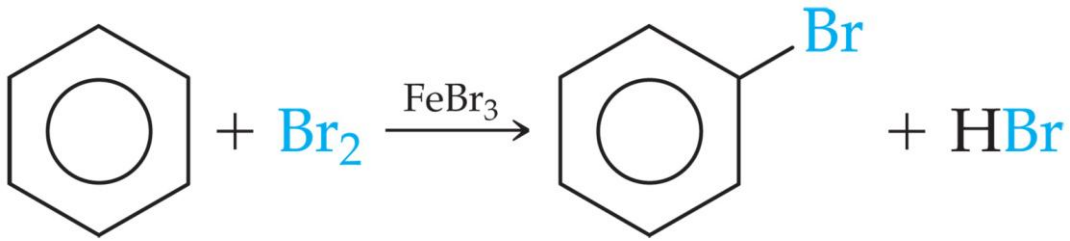


meta-Dinitrobenzene
mp 90°C

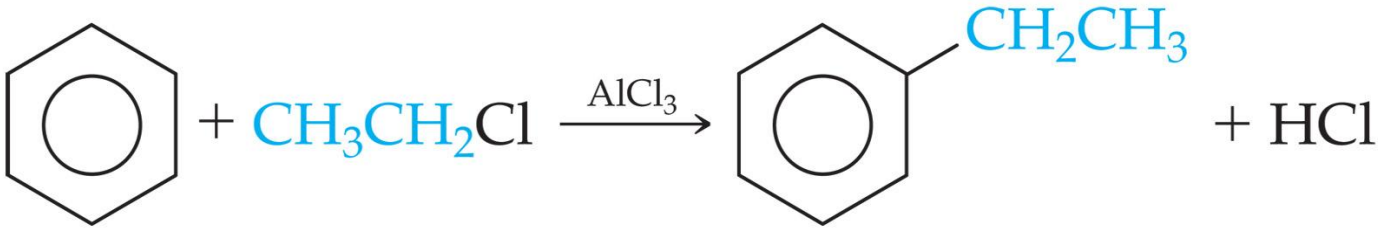
para-Dinitrobenzene
mp 174°C

- Two substituents on a benzene ring could have three possible relationships
  - *ortho-*: On adjacent carbons.
  - *meta-*: One carbon between them.
  - *para-*: On opposite sides of ring.

Reactions of Aromatic Compounds

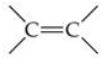
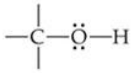
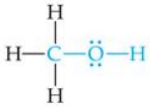
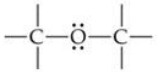
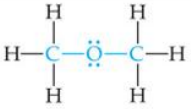
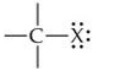
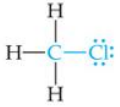
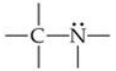
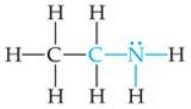
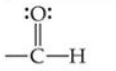
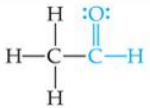
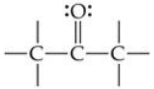
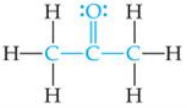
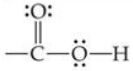
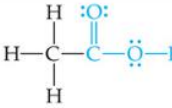
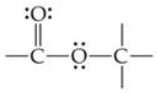
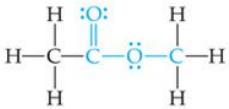
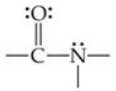
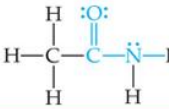


Halogenation



Friedel-Crafts Reaction

Reactions of aromatic compounds often require a catalyst.

Functional Group	Type of Compound	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)	Haloalkane	*halo-*		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)

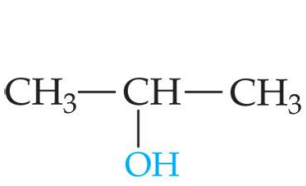
Functional Groups

Term used to refer to parts of organic molecules where reactions tend to occur.

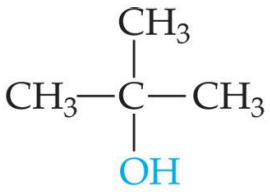
Organic and Biological Chemistry

Alcohols

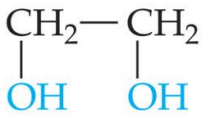
- Contain one or more hydroxyl groups, —OH
  - Named from parent hydrocarbon; suffix changed to *-ol* and number designates carbon to which hydroxyl is attached.



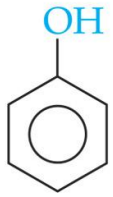
2-Propanol
Isopropyl alcohol;
rubbing alcohol



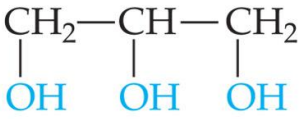
2-Methyl-2-propanol
t-Butyl alcohol



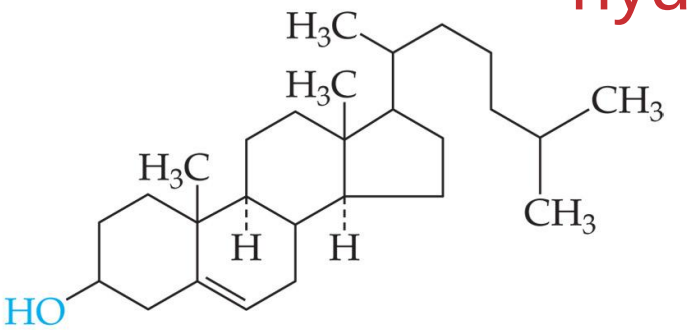
1,2-Ethanediol
Ethylene glycol



Phenol



1,2,3-Propanetriol
Glycerol; glycerin

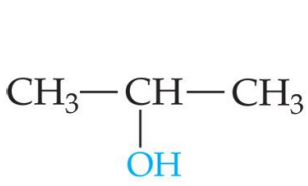


Cholesterol

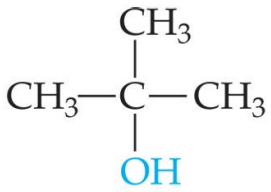
Organic and Biological Chemistry

Alcohols

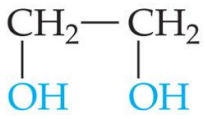
- Much more acidic than hydrocarbons.
  - pK_a ~15 for most alcohols.
  - Aromatic alcohols have pK_a ~10.



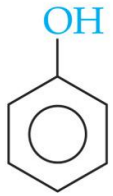
2-Propanol
Isopropyl alcohol; rubbing alcohol



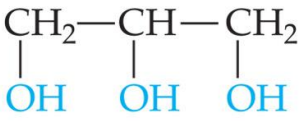
2-Methyl-2-propanol
t-Butyl alcohol



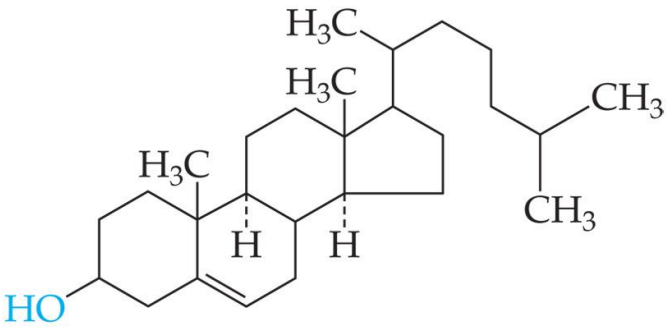
1,2-Ethanediol
Ethylene glycol



Phenol

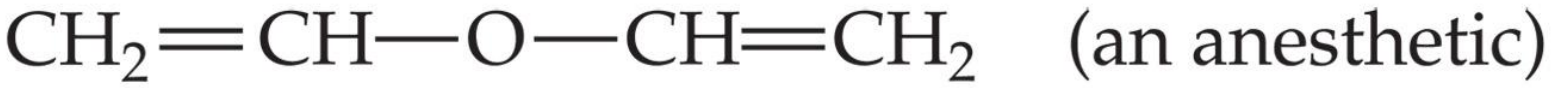


1,2,3-Propanetriol
Glycerol; glycerin



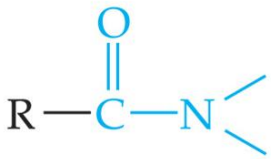
Cholesterol

Ethers

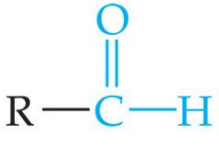


- Tend to be quite unreactive.
- Therefore, they are good polar solvents.

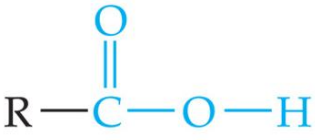
Carbonyl Compounds



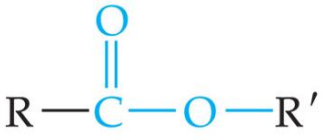
Amide



Aldehyde



Carboxylic acid



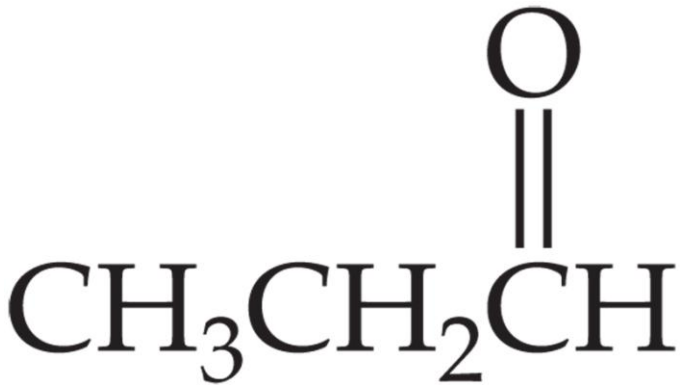
Ester

Ketone

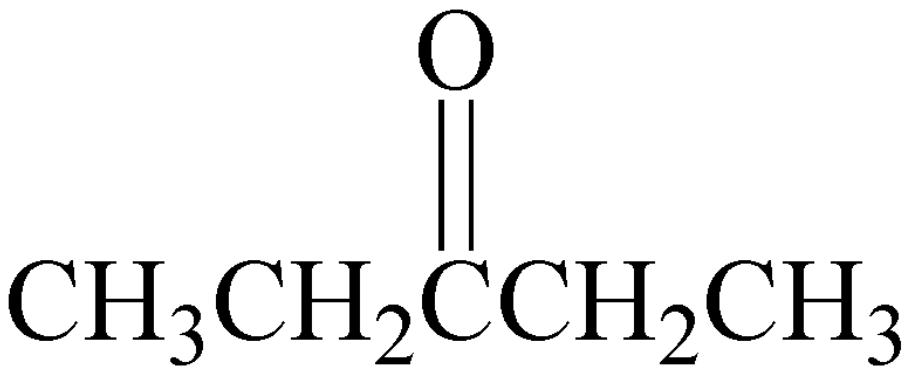
- Contain C—O double bond.
- Include many classes of compounds.

Aldehydes

At least one hydrogen attached to carbonyl carbon.



Ketones



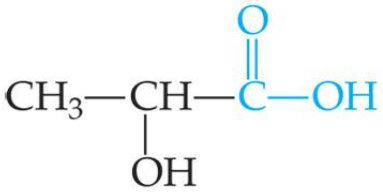
Two carbons bonded to carbonyl carbon.

Carboxylic Acids

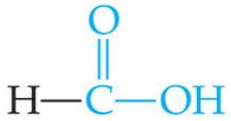
- Have hydroxyl group bonded to carbonyl group.
- Tart tasting.
- Carboxylic acids are weak acids□□.

CH_3COOH

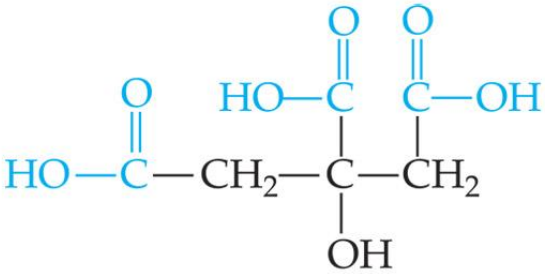
Carboxylic Acids



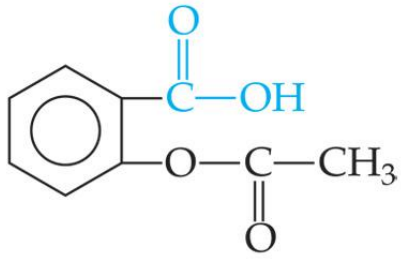
Lactic acid



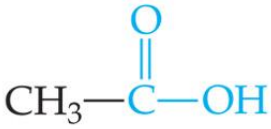
Methanoic acid
Formic acid



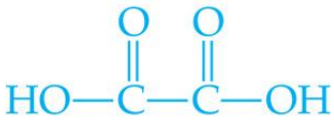
Citric acid



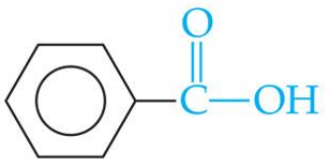
Acetylsalicylic acid
Aspirin



Ethanoic acid
Acetic acid



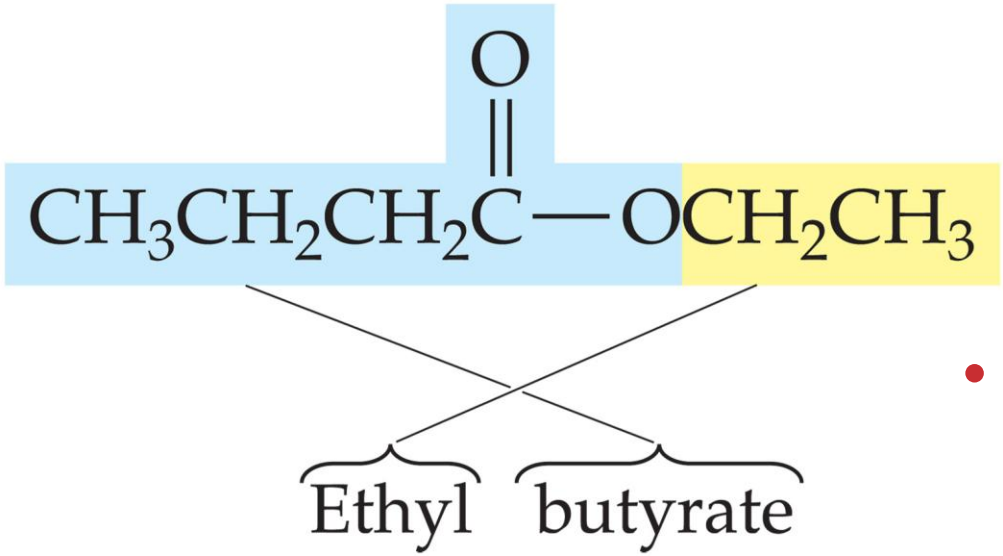
Oxalic acid



Phenyl methanoic acid
Benzoic acid

Organic and Biological Chemistry

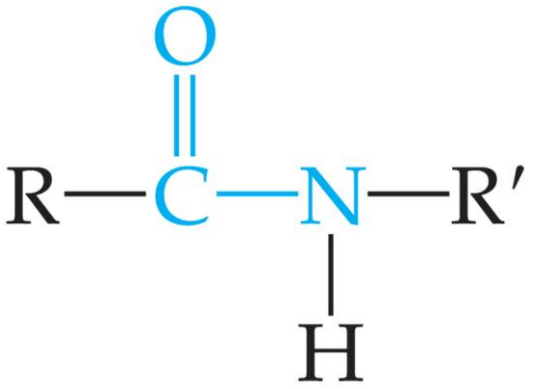
Esters



- Products of reaction between carboxylic acids and alcohols.
- Found in many fruits and perfumes.

Amides

Formed by reaction of carboxylic acids with amines.

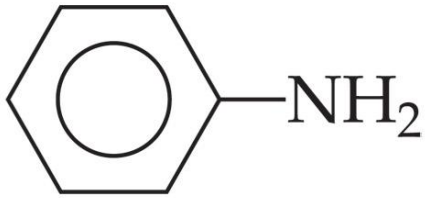


Amines

- Organic bases.
- Generally have strong, unpleasant odors.

$CH_3CH_2NH_2$ Ethylamine

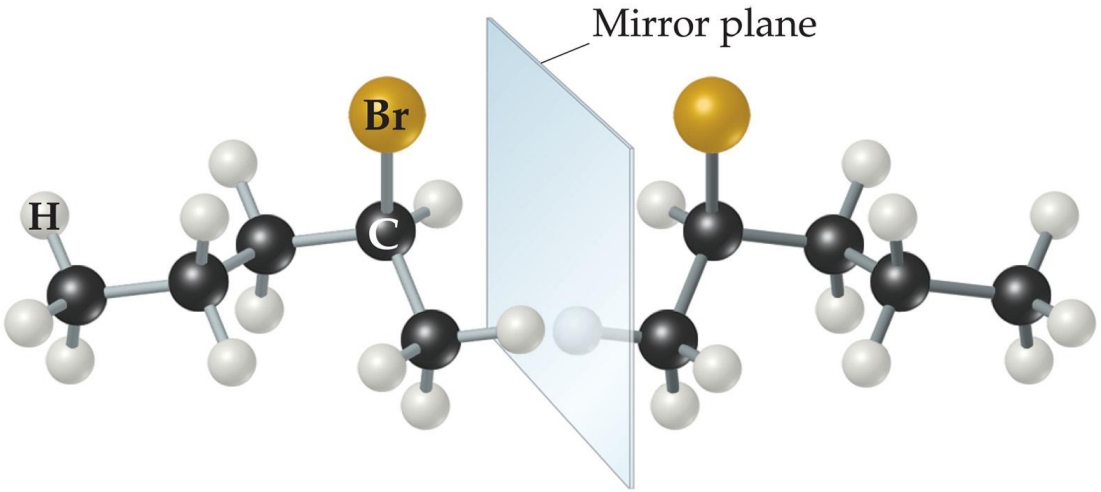
$(CH_3)_3N$ Trimethylamine



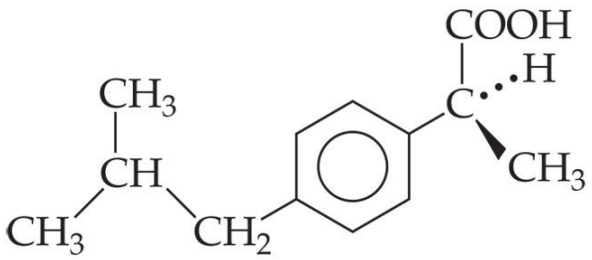
Phenylamine
Aniline

Chirality

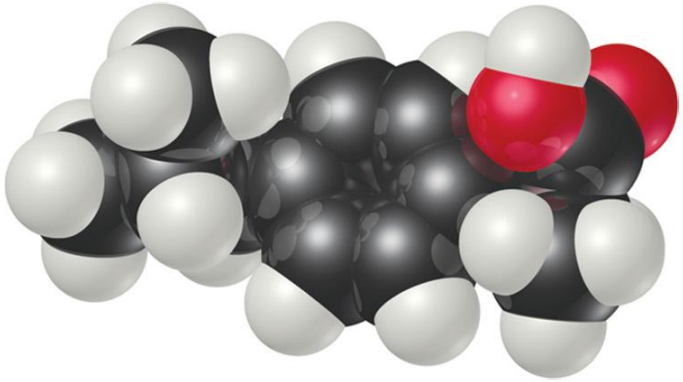
- Carbons with four different groups attached to them are handed, or chiral.
- Optical isomers or stereoisomers
- If one stereoisomer is “right-handed,” its enantiomer is “left-handed.”



Chirality



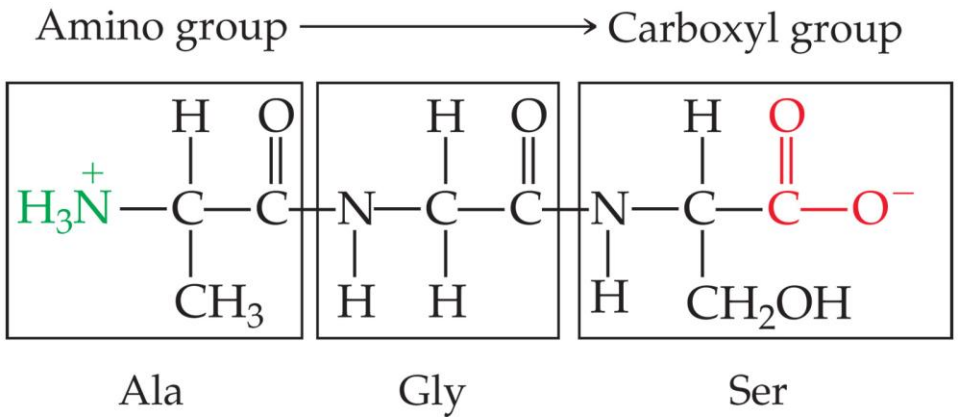
S-ibuprofen



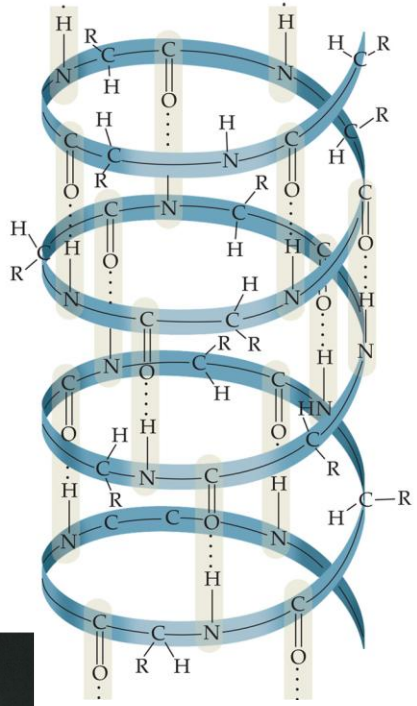
- Many pharmaceuticals are chiral.
- Often only one enantiomer is clinically active.

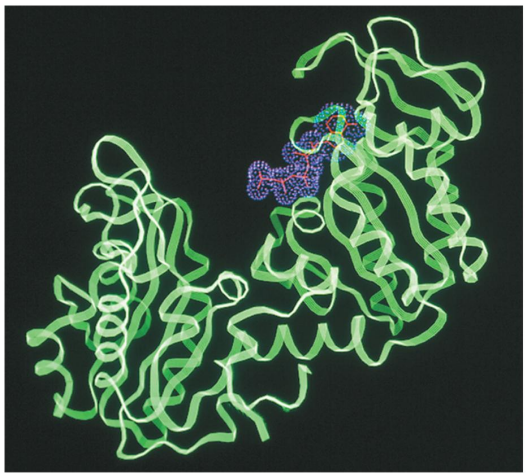
Amino Acids and Proteins

- 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.



Amino Acids and Proteins

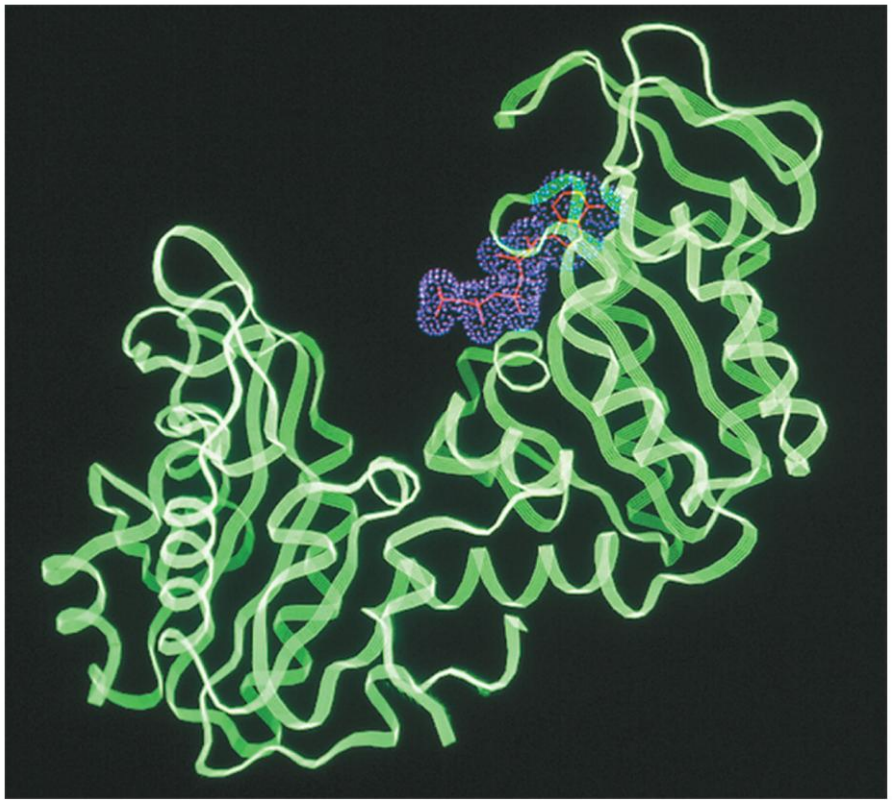




- Hydrogen bonding in peptide chains causes coils and helices in the chain.
- Kinking and folding of the coiled chain gives proteins a characteristic shape.

Organic and Biological Chemistry

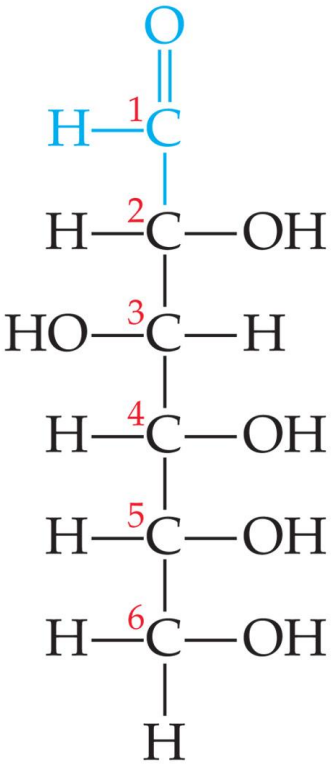
Amino Acids and Proteins



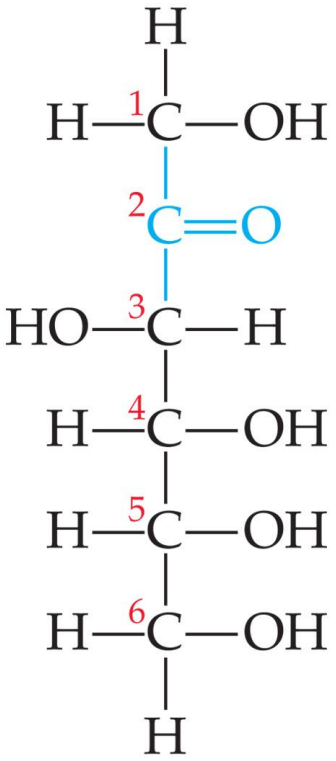
- Most enzymes are proteins.
- The shape of the active site complements the shape of the substrate on which the enzyme acts—hence, the “lock-and-key” model.

Carbohydrates

Simple sugars are polyhydroxy aldehydes or ketones.



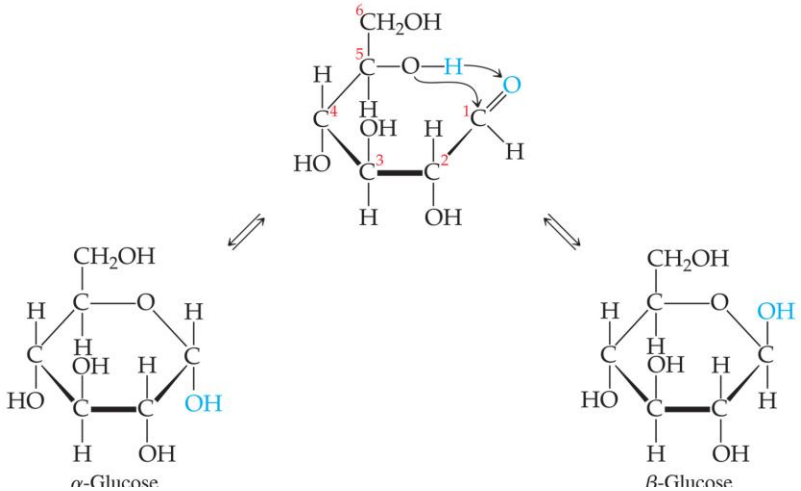
Glucose

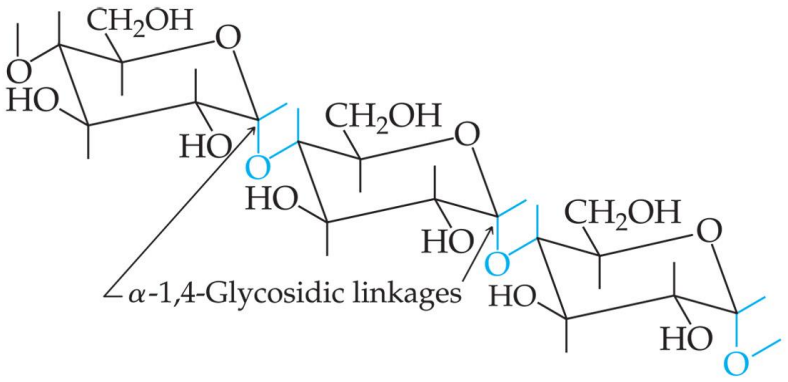


Fructose

Organic and Biological Chemistry

Carbohydrates



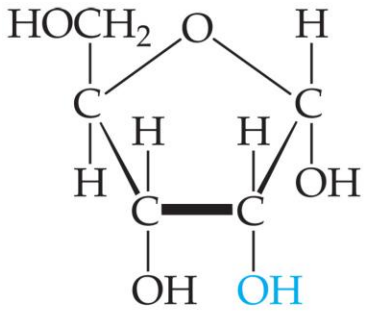


- In solution they form cyclic structures.
- These can form chains of sugars that form structural molecules such as starch and cellulose.

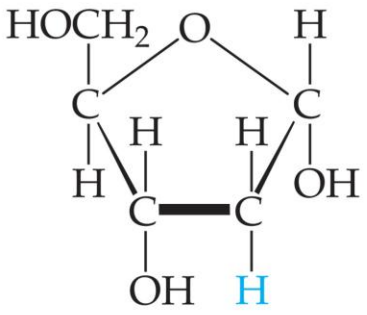
Organic and Biological Chemistry

Nucleic Acids

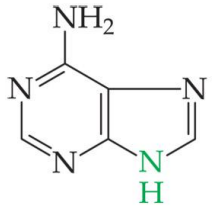
Two of the building blocks of RNA and DNA are sugars (ribose or deoxyribose) and cyclic bases (adenine, guanine, cytosine, and thymine or uracil).



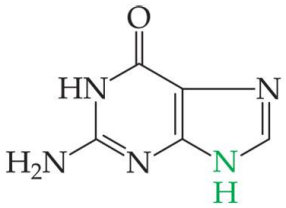
Ribose



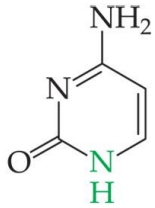
Deoxyribose



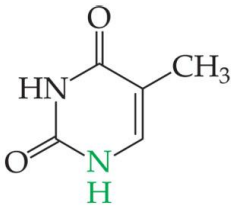
Adenine (A)
DNA
RNA



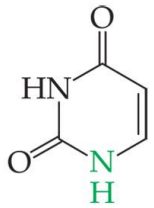
Guanine (G)
DNA
RNA



Cytosine (C)
DNA
RNA



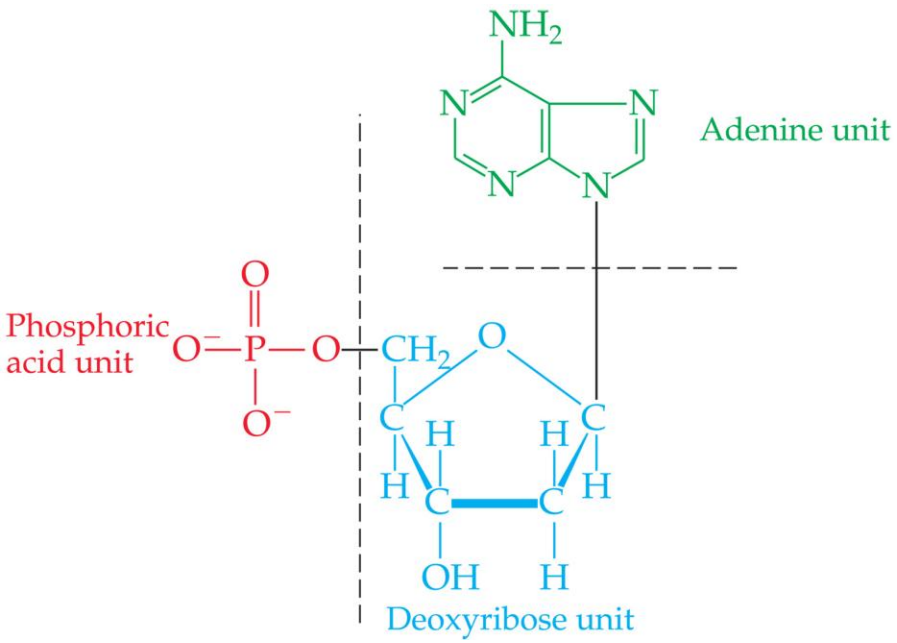
Thymine (T)
DNA



Uracil (U)
RNA

Organic and Biological Chemistry

Nucleic Acids



These combine with a phosphate to form a nucleotide.

Nucleic Acids

Nucleotides combine to form the familiar double-helix form of the nucleic acids.