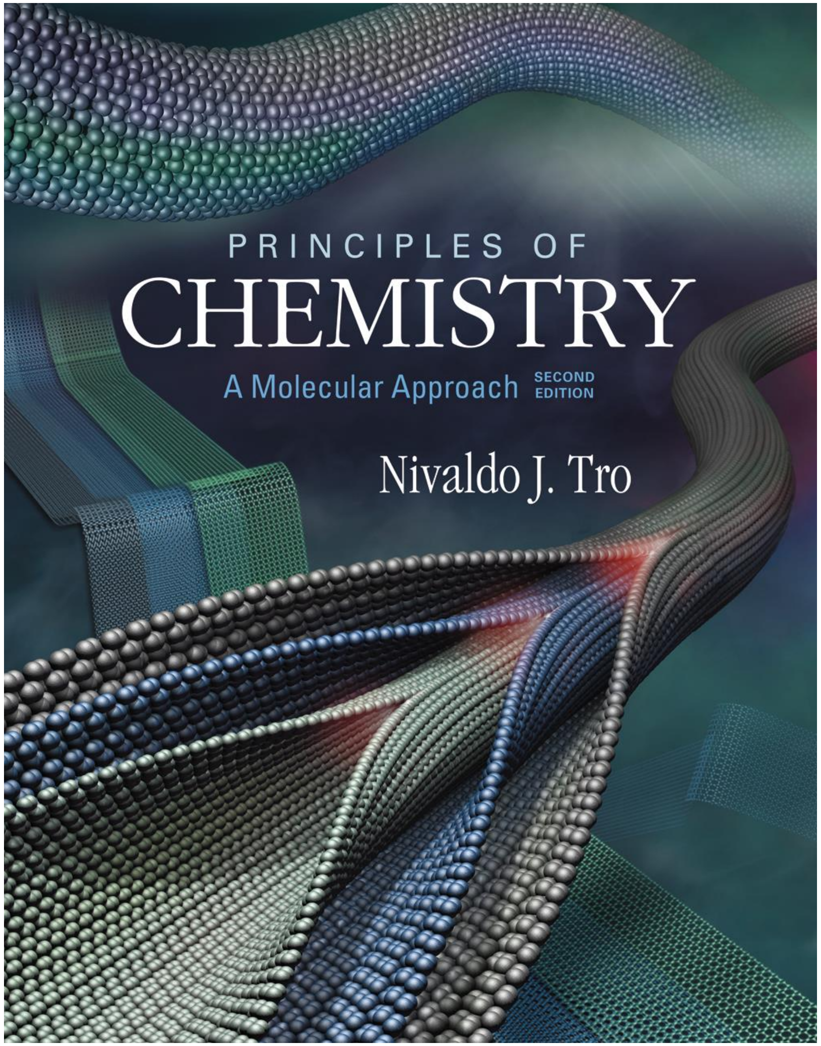

# Lecture Presentation

# Chapter 20

# Organic Chemistry

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# Organic vs. Inorganic

- Early 1800s
  - Organic
    - Came from living organisms
    - Chemically fragile
    - Unsuccessful synthesis…vital force?
  - Inorganic
    - Came from the earth
    - Chemically durable
    - Successfully synthesized by 19th century chemists

# Why Is Carbon "Special"?

- Of the millions of known compounds in our world, 95% have a single element in common – **CARBON**.

- Smallest member, and only nonmetal, of group 4
  - Has FOUR valence electrons to share with others to form covalent bonds
- Forms four covalent bonds
- It can form:
  - single, double, and triple bonds
  - bonds to itself and long straight chains, branched chains, and cyclic compounds
- It has the ability to form long chains, referred to as catenation.

# Saturated vs. Unsaturated

- Saturated carbon is a carbon atom with **FOUR** attachments.
  - Alkanes are saturated; they contain the maximum number of hydrogen atoms per carbon atom.
- Unsaturated carbon is a carbon atom that has **LESS THAN FOUR** attachments.
  - Alkenes and alkynes are unsaturated.
  - They contain at least one double or triple bond, respectively.
  - They have fewer hydrogen atoms per carbon atom than alkanes.

# What's Special about Organic Compounds?

- Organic compounds:
  - tend to be molecular and covalently bonded
  - are mainly composed of just six nonmetallic elements
    - C, H, O, N, S, and P
  - are found in all three states
    - Solids tend to have low melting points.
  - Solubility in water varies depending on which of the other elements are attached to C and how many there are.
    - Example: $CH_3OH$ is miscible with water; $C_{10}H_{21}OH$ is insoluble.

# Properties of Organic Compounds

- Chemical and physical properties of organic compounds are influenced by:
  - Bonding (single, double, triple)
  - Structure (straight, branched, cyclic, or aromatic)
  - Functional groups

# Polarity of Hydrocarbons

- Carbon-hydrogen bonds are mostly nonpolar; HOWEVER, any polarity would be symmetrically arranged about the central carbon atom(s).

- Methane's tetrahedral geometry makes it a nonpolar molecule.
  - All other hydrocarbons are nonpolar as well.

- Nonpolar substances are unable to mix with polar substances.

- Hydrocarbon compounds participate in dispersion intermolecular forces.

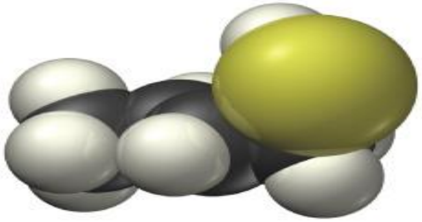
# Two Major Categories of Organic Compounds

**Group 1: Hydrocarbons**

- **Contain only carbon and hydrogen**
  - **Subcategories:**
    - **aliphatic or aromatic**
- **Are insoluble in water**
  - **They have no polar bonds to attract water molecules.**

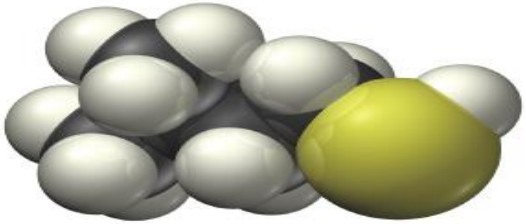
**Aliphatic hydrocarbons**

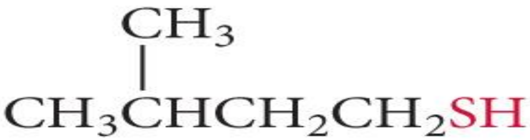
- **Saturated or unsaturated aliphatics**
  - **Saturated hydrocarbons are called alkanes.**
    - **All C to C bonds are single.**
  - **Unsaturated hydrocarbons contain multiple bonds between carbon atoms.**
    - **Alkenes are hydrocarbons that have double bonds.**
    - **Alkynes are hydrocarbons that contain triple bonds.**
- **May be chains or rings**
  - **Chains may be straight or branched.**



$CH_3CH{=}CHCH_2SH$

2-Butene-1-thiol





$$CH_3\overset{\overset{\displaystyle CH_3}{|}}{C}HCH_2CH_2SH$$

3-Methyl-1-butanethiol

# Two Major Categories of Organic Compounds

## Group 1: Hydrocarbons continued:

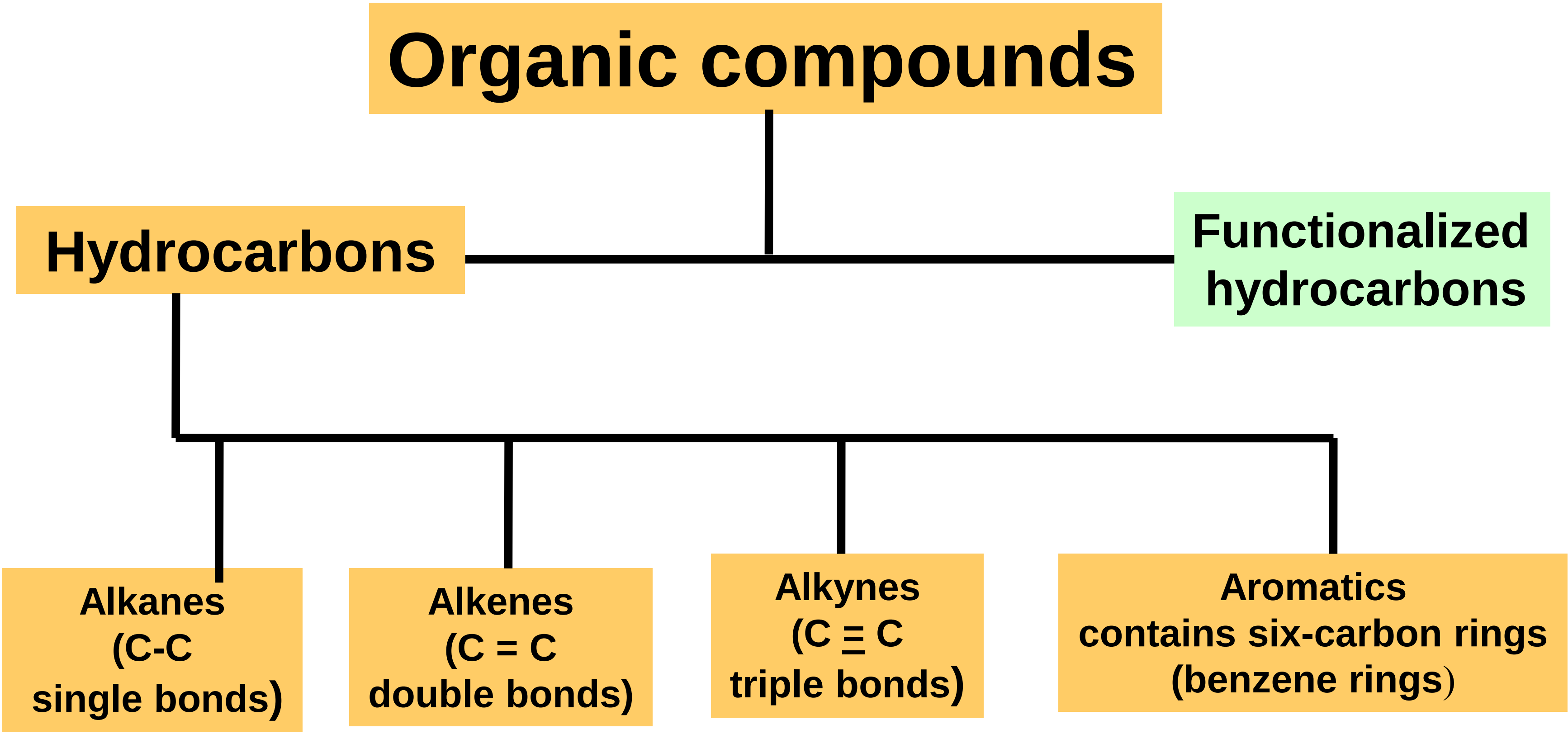
**Aromatic hydrocarbons**

- Contain a benzene ring
  - Six-membered carbon ring structure

## Group 2: Functionalized Hydrocarbons

- Hydrocarbons that contain additional atoms or groups of atoms
  - Hydrogen atoms are replaced by:
    - Single atoms such as halogens (halohydrocarbons)
    - Group of atoms such as -OH groups (alcohols)

**NOTE**: Both categories can be further divided into subfamilies.



Organic compounds

Hydrocarbons

Functionalized hydrocarbons

Alkanes
(C-C
single bonds)

Alkenes
(C = C
double bonds)

Alkynes
(C ≡ C
triple bonds)

Aromatics
contains six-carbon rings
(benzene rings)

# Writing Structural Formulas

**Molecular formulas:**

- **Indicate the number and type of atoms in the molecule, but don't show how the atoms are attached to one another**

**A structural formula is a two-dimensional representation of the molecule.**

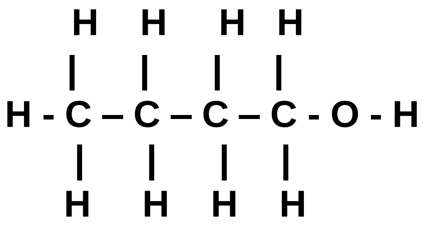
- **It shows how the atoms in the molecule are arranged and what atom is attached to what atom.**
  - **Gives an indication of the molecule's geometric shape**
  - **Shows the relative positions of atoms in a molecule**

- **Structural formulas for organic compounds are similar to Lewis structures, but dashes represent bonding electron pairs.**

- ***Condensed* structural formulas are compactly written structural formulas.**

# Ways to Represent a Compound

- Representation of an organic compound:
  - Structural formula
    - Example: 1-Butanol



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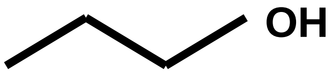
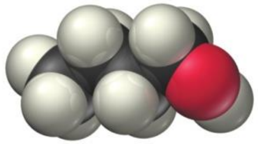
  - Condensed structural formula
    - Example: 1-Butanol

$C_4H_{10}O$ or $CH_3(CH_2)_3OH$

  - Carbon skeleton formula
    - Example: 1-Butanol



  - Ball and stick
  - Space-filling
    - Example: 1-Butanol



$CH_3-CH_2-CH_2-CH_2-OH$

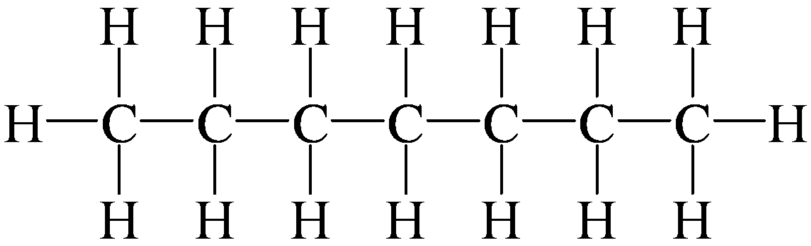
1-Butanol

**Problem:**

**Write the straight-chain structural formula for $C_7H_{16}$ and its carbon skeleton representation.**

**Problem:**
**Write the straight-chain structural formula for $C_7H_{16}$ and its carbon skeleton representation formula.**

**Structural formula:**



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**Carbon skeleton formula:**

# Isomers

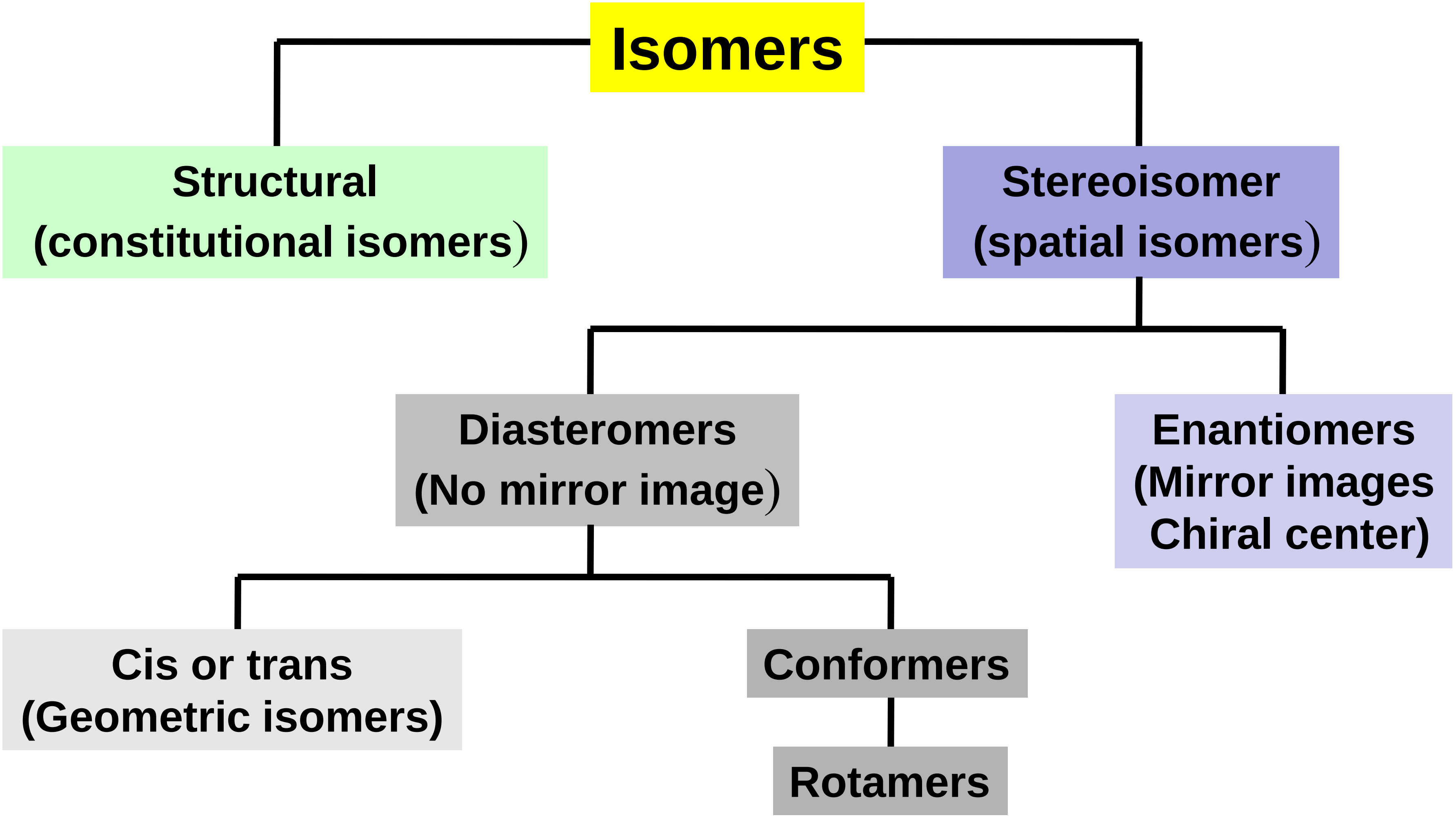
- It is possible for organic compounds to share a molecular formula but have different carbon chain structures.

- Isomers differ in their physical and chemical properties.

  Isomers are compounds that have the same molecular formula BUT the atoms have different arrangements.

- Structural/Constitutional isomers
  - Atoms are arranged differently.
  - Do NOT have mirror images

- Conformational isomers
  - Groups of atoms have different spatial arrangements.
    - Subcategories
      - Geometric or diastereoismoers
        - These isomers do NOT have mirror images.
        - Example: Cis and trans
      - Stereoisomers
        - These isomers DO HAVE mirror images (D or L).
        - Types: Enantiomer or epimer



Isomers

Structural
(constitutional isomers)

Stereoisomer
(spatial isomers)

Diasteromers
(No mirror image)

Enantiomers
(Mirror images
Chiral center)

Cis or trans
(Geometric isomers)

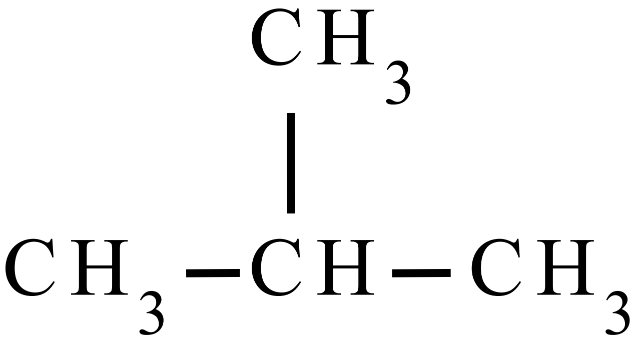
Conformers

Rotamers

# Structural/Constitutional Isomers

- <u>**Structural/Constitutional Isomers**</u>
  - **Atoms are arranged differently.**
  - **Do NOT have mirror images**

$CH_3-CH_2-CH_2-CH_3$ **Butane ($C_4H_{10}$)**

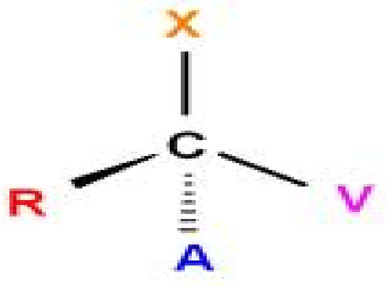


$$CH_3-\overset{\displaystyle CH_3\atop|}{CH}-CH_3$$

**2-methylpropane ($C_4H_{10}$)**

# Concept of Chirality and the Carbon Atom

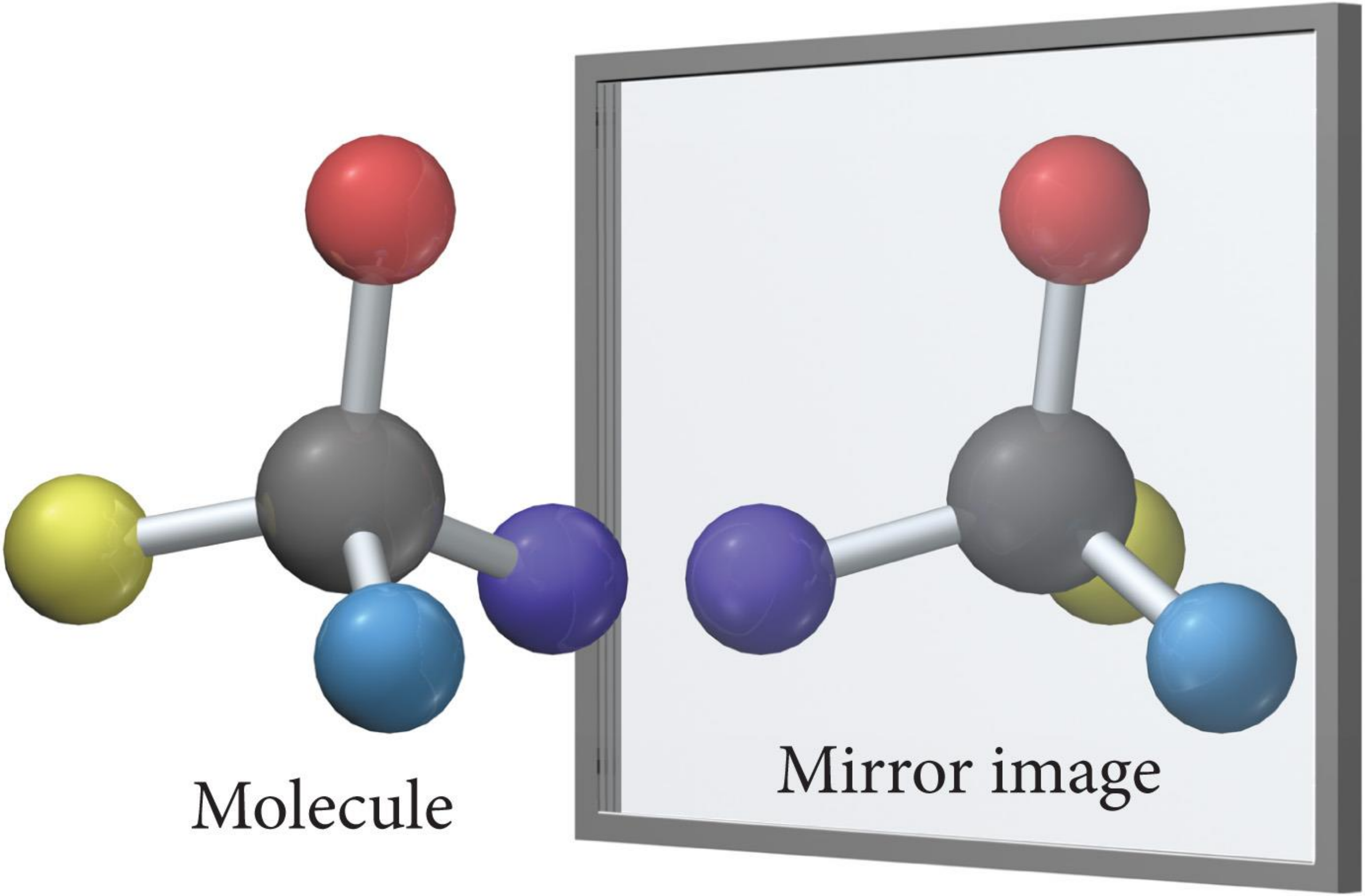
- **A chiral carbon:**
  - **Saturated carbon with FOUR DIFFERENT attachments**



- **A chiral compound has at least one chiral carbon in its structure.**
- **Chirality plays an important role in biomolecules and drug manufacturing.**
- **Chiral compound often can be classified as stereoisomers.**
  - **Have "handedness" and are not superimposable**

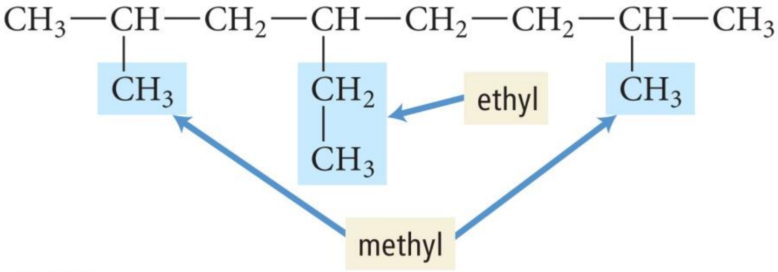
# Stereoisomers

- **Stereoisomers** are different molecules whose atoms are connected in the same order, but have a different spatial direction.
- **Optical isomers** are molecules that are nonsuperimposable mirror images of each other.
- **Geometric isomers (diastereo)** are stereoisomers that are not optical isomers.


Molecule
Mirror image

# Stereoisomers: Enantiomers

- Steroisomers: Enatiomers
  - Chemical and physical properties identical in many cases
    - Enantiomer pairs will have the same chemical reactivity in a nonchiral environment.
    - In a chiral environment may show different behavioral properties
  - Can differentiate **only** by rotation of polarized light
    - Light rotated to the right (D) or to the left (L)
  - Compounds having mirror images; not superimposable



$CH_3-CH(CH_3)-CH_2-CH(CH_2CH_3)-CH_2-CH_2-CH(CH_3)-CH_3$

# Optical Activity and Enantiomers

- **Enantiomers molecules have all the same physical properties except one, which is how they rotate the plane of plane-polarized light:**
  - **to the right (dextrorotatory (D) or**
  - **to the left (levorotatory (L)**

- **Light that has been filtered so that only those waves traveling in a single plane are allowed through will rotate the plane the same amount, but in opposite direction.**

# Mixtures of Enantiomers

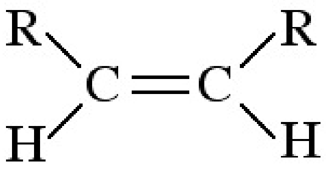
- **An equimolar mixture of a pair of enantiomers is called a racemic mixture.**

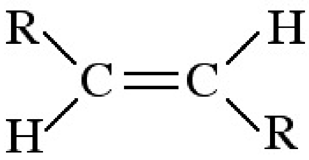
- **Racemic mixtures:**
  - **Do not cause the light to polarize when it is shined thorough the mixture**
    - **Why?**
      - **Since half the molecules are rotating the plane to the left and the other half are rotating it to the right, the rotations cancel, and the racemic mixture does not rotate the plane.**

- **A nonracemic mixture will rotate light.**
  - **If it rotates light to the right – dextrorotary (D)**
  - **If it rotates light to the left – levorotary (L)**
  - **The amount of rotation can be used to determine the percentages of each enantiomer in the mixture.**

# Diastereoisomers

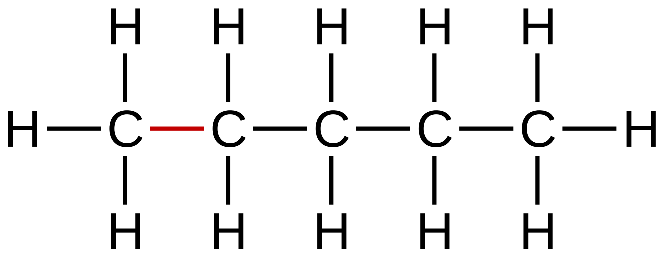
- **Geometric: *Cis and Trans***
  - **The arrangement of "like" (same) groups or atoms around a double bond**
  - **Diastereoisomers**
  - **Don't have mirror images**
  - **Examples**
    - ***Cis* – *neighbors*** **(side by side)** ***Trans* – *opposite*** **(across)**





# An Overview of the Hydrocarbon Family

- **Alkanes**
  - Only single bonds
  - "ane" suffix



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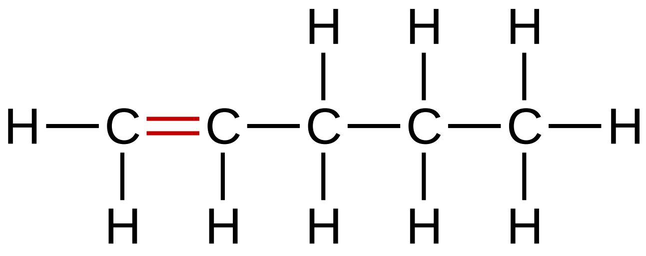
$C-C$

- **Alkenes**
  - One or more double bonds
  - "ene" suffix



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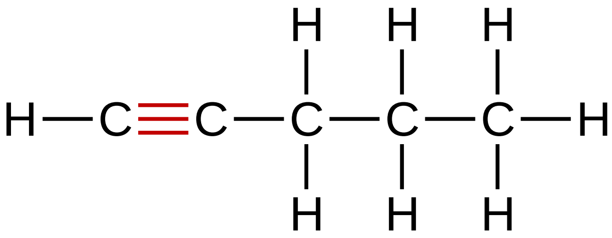
$C=C$

# An Overview of the Hydrocarbon Family

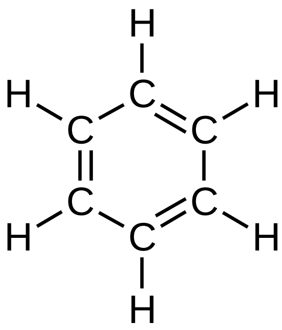
- **Alkynes**
  - One or more triple bonds
  - “yne” suffix

$C \equiv C$

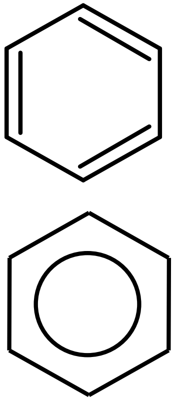


$$H-C\equiv C-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$$

- **Aromatic**
  - Six-carbon ring
    - Benzene ring

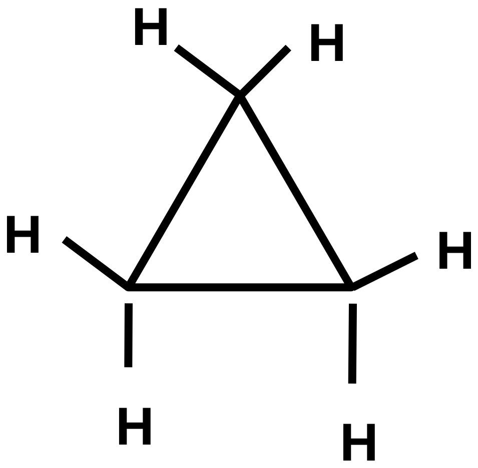


or



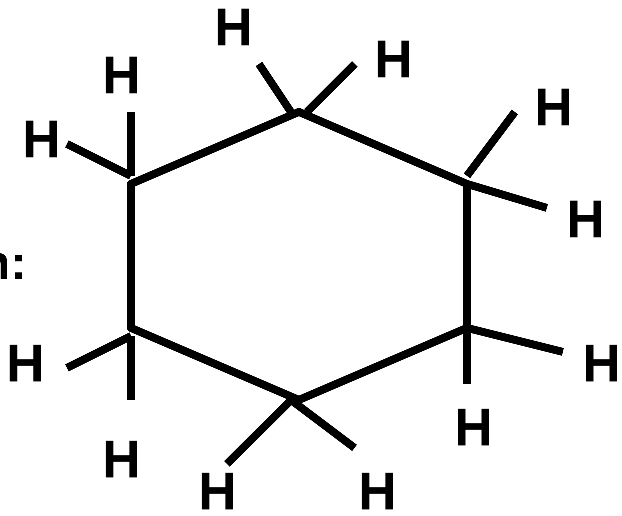
# The Hydrocarbon Family

- **Cyclic hydrocarbons**
  - **Smallest is cyclopropane**
  - **3-carbon ring**
    - $C_2H_6$

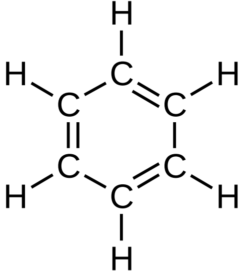


- **Cyclic hydrocarbons are not aromatics.**

**This is cyclohexane, $C_6H_{12}$.**
**Ring structure NOT an aromatic**

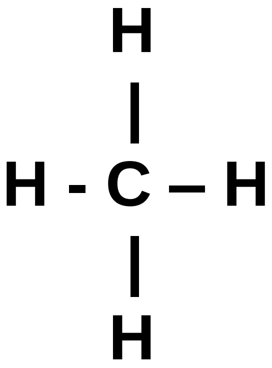


**NOTE:** **This is an aromatic hydrocarbon: it is a benzene ring, $C_6H_6$.**



# Alkanes

- All carbon atoms connected by single bonds
- General molecular formula: $C_nH_{2n+2}$
- Simplest is methane, $CH_4$



$$\begin{array}{c} H \\ | \\ H - C - H \\ | \\ H \end{array}$$

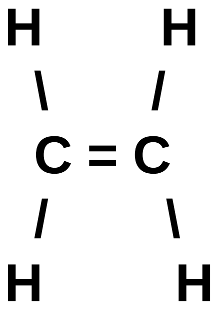
- Each atom attains an octet.
  - Molecular geometry of methane is tetrahedral.
  - *sp*$^3$ hybridization on carbon atom
- The most important property is their flammability.
  - Combustion reaction between oxygen and the alkane produces carbon dioxide and water.

# Alkenes (Olefins)

- **Double bond** makes them more chemically reactive than alkanes by addition across the double bond.

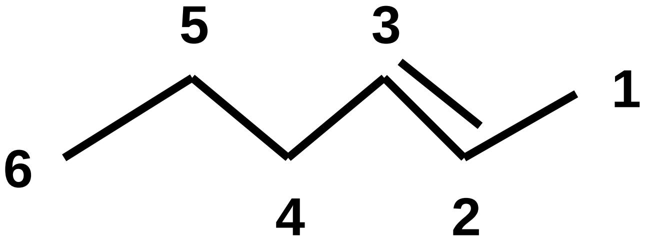
- Formula for one double bond = $C_nH_{2n}$
  - Subtract 2 H from alkane for each double bond

- Smallest alkene is ethene, $C_2H_4$



- *sp*$^2$ hybridization on carbon atoms
  - Trigonal planar
- Flammable and nonpolar, similar to alkane

- "ene" suffix on parent (longest continuous) chain
  - Number in name indicates position(s) of double bond(s) in molecules



2-hexene

# Alkynes

- **Triple bond** makes them more chemically reactive than alkanes by addition across the triple bond.
- *sp* hybridization on carbon atoms
- Simplest alkyne is ethyne, $C_2H_2$

$$H- C \equiv C - H$$

- Flammable and nonpolar, like alkanes
- “yne” suffix on parent chain
  - Number indicates position of triple bond

# Prefixes Name Bases

| Number of Carbon Atoms | Base Name (prefix) |
|---|---|
| 1 | Methyl (meth-) $CH_3$- |
| 2 | Ethyl (eth-) $C_2H_5$ - |
| 3 | Propyl (prop-) $C_3H_7$ - |
| 4 | Butyl (but-) $C_4H_9$ - |
| 5 | Pentyl (pent-) $C_5H_{11}$ - |
| 6 | Hexyl (hex-) $C_6H_{13}$ - |
| 7 | Heptyl (hept-) $C_7H_{15}$ - |
| 8 | Octyl (oct-) $C_8H_{17}$ - |
| 9 | Nonyl (non-) $C_9H_{19}$ - |
| 10 | Decyl (dec-) $C_{10}H_{21}$ – |

# Naming Organic Compounds (IUPAC)

- Each name consists of three parts.
  - ü **Prefix**
    - Indicates position, number, and type of branches
    - Indicates position, number, and type of each functional group
  - ü **Parent**
    - Indicates the length of the longest carbon chain or ring
  - ü **Suffix**
    - Indicates the type of hydrocarbon (bonds)
      - ane, ene, yne
    - Certain functional groups
      - Examples: "ol" for alcohols
        "al" for aldehydes

# Steps to Naming Organic Compounds

1. Find the longest continuous carbon chain having the dominating functional group/bond type within the chain.

    a. The number of carbon atoms in the longest chain will dictate the alkyl group name of the compound.

    b. Example: Longest chain contains 6 carbon atoms, so the alkyl group for the organic compound will be “hexyl”

2. The chain is numbered so that the carbon atom attached to the functional group/bond type will have lowest number.

    a. Example: A compound with the name 2-hexene tells you the following:

    The longest chain containing the functional group/bond type has 6 carbons with a double bond on carbon #2.

# Steps to Naming Organic Compounds

3. Organic compounds with more than one functional group will take on the suffix of the dominating functional group/bond type.

   a. Other functional groups are designated with number and suffix as prefixes.

   b. Example:

      1. A compound’s longest continuous carbon chain is 5 carbons.

      2. The dominating functional group is an alcohol attached to carbon #2.

      3. There is also a double bond on carbon #4. The name of this compound would be 4-ene-2-pentanol.

| | |
|---|---|
| “ene”: | The double bond is on carbon #4. |
| “ol”: | The dominating functional group is an alcohol group (-OH) located on carbon #2. |
| “penta”: | Five carbons is the longest chain having the dominant functional group. |

# Nomenclature Hierarchy

| Bond Type or Functional Group | Suffix (ending) |
|---|---|
| Carboxylic acid | oic |
| Ester | onate |
| Amides | ide |
| Nitriles | nitriles |
| Aldehydes | al |
| Ketones | one |
| Alcohols | ol |
| Thiols | thiols |
| Amines | amine |
| Ethers | oxy or ether |
| Sulfides | sulfides |
| Alkynes (most have at least one triple bond) | yne |
| Alkenes (most have at least one double bond) | ene |
|  | ane |

# Reactions of Hydrocarbons: Combustion

- All hydrocarbons undergo combustion.
  - Combustion:
    - is always exothermic
    - releases heat and light energy
      - The larger the hydrocarbon, the greater the amount of energy released.

- Chemical reaction:
  - hydrocarbon + oxygen → carbon dioxide + water

# Reactions of Hydrocarbons: Combustion

- **Alkane:**

  $2\ CH_3CH_2CH_2CH_3(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

- **Alkene:**

  $CH_3CH{=}CHCH_3(g) + 6\ O_2(g) \rightarrow 4\ CO_2(g) + 4\ H_2O(g)$

- **Alkyne:**

  $2\ CH_3C{\equiv}CCH_3(g) + 11\ O_2(g) \rightarrow 8\ CO_2(g) + 6\ H_2O(g)$

# Substitution Reactions: Alkanes

- **Substitution: halogenation**
  - **A H atom is exchanged for a halogen atom (F, Cl, Br, I)**
  - **Reaction is initiated by addition of energy that can be in the form of heat or ultraviolet light (hν)**
    - **to start breaking bonds**
  - **Reaction generally produces multiple products with multiple substitutions**

$$CH_3CH_3 + Br_2 \xrightarrow{h\nu} CH_3CH_2Br + HBr$$

# Addition Reactions: Alkenes and Alkynes

- **Alkenes and alkynes undergo “addition” reactions because when the multiple bond is broken, a H or another type of atom is “added to” the molecule to form a new compound.**

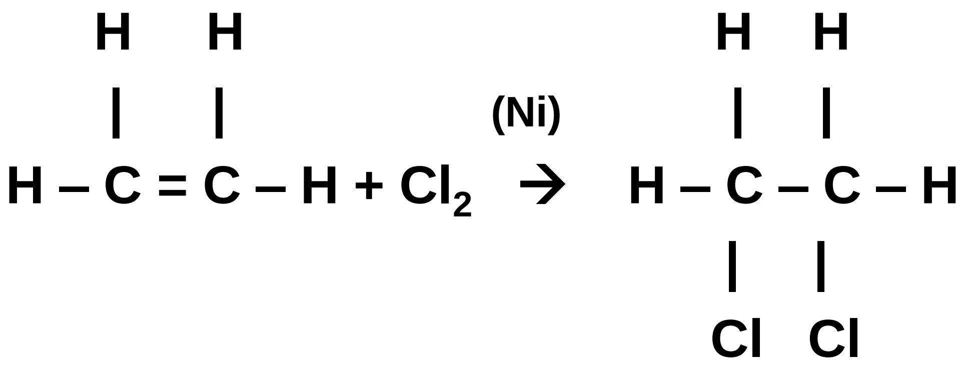
- **Addition reaction converts unsaturated carbons to saturated carbons.**

- **Types of addition reactions:**
  - **Hydrogenation = adding $H_2$ as a reactant**
    - **alkene or alkyne + $H_2$ → alkane**
      - **Generally requires a catalyst**
  - **Halogenation = adding $X_2$ (e.g., $F_2$, $Cl_2$, $Br_2$, $I_2$)**

  - **Hydrohalogenation = adding HX (X = F, Cl, Br, or I)**
    - **HX is polar.**
    - **When adding a polar reagent to a double or triple bond, the positive part attaches to the carbon with the most H’s.**

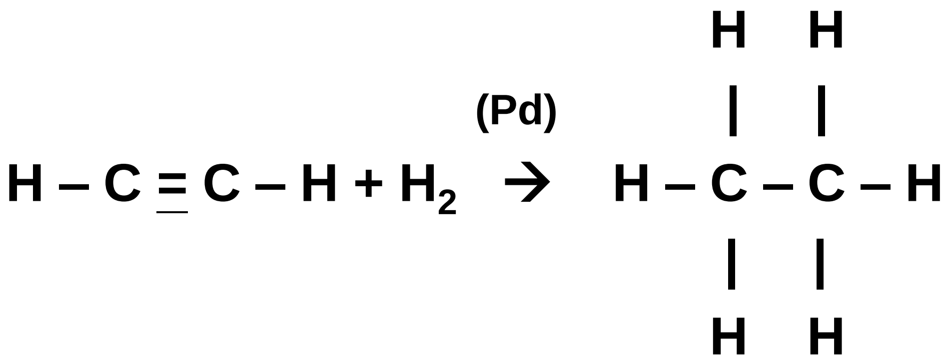
# Addition Reactions: Alkenes and Alkynes

## Halogenation of ethene to 2,2-dichloroethane



$$\mathrm{H-\overset{\overset{\displaystyle H}{|}}{C}=\overset{\overset{\displaystyle H}{|}}{C}-H + Cl_2 \xrightarrow{(Ni)} H-\underset{\underset{\displaystyle Cl}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-\underset{\underset{\displaystyle Cl}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-H}$$

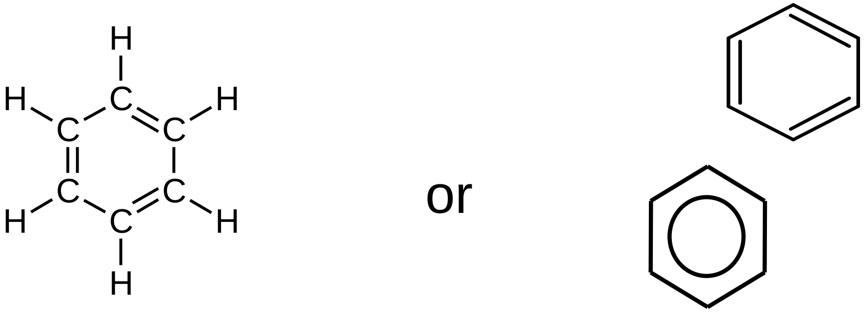
## Hydration of ethyne to ethane



$$\mathrm{H-C\equiv C-H + H_2 \xrightarrow{(Pd)} H-\underset{\underset{\displaystyle H}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-\underset{\underset{\displaystyle H}{|}}{\overset{\overset{\displaystyle H}{|}}{C}}-H}$$

# Aromatics

- Compounds classified as aromatic have a resonance cyclic ring.
  - The bonds between the carbon atoms are a single-double hybrid in length.
  - Stable; reactivity not within ring
- A six-member ring known as benzene, $C_6H_6$

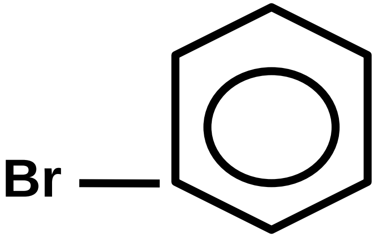


- Benzene rings are VERY stable and do not undergo reaction.
  - Don’t break the ring
- However, the hydrogens on the benzene ring can be substituted with other atoms or functional groups.

# Naming Benzene as a Substituent

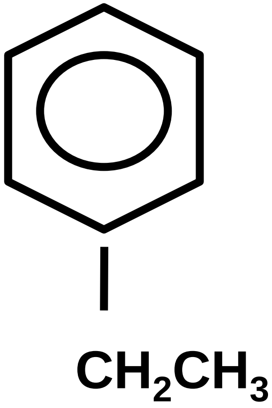
- When the benzene ring is not the base name, it is called a phenyl group.

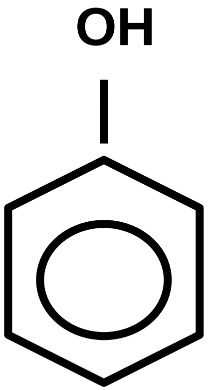
- Name of substituent atom or group that was substituted for H atom on the benzene ring
  - Halogen substituent = change ending to “o”
  - Alkyl group
  - OH substitution
    - Name is phenol



bromobenzene

ethylbenzene

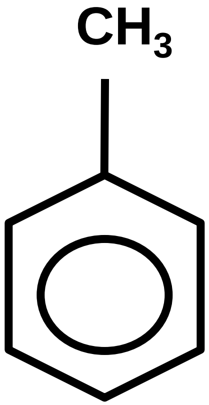




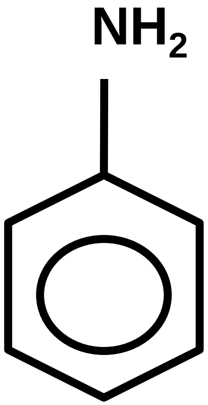
phenol

# Naming Benzene as a Substituent

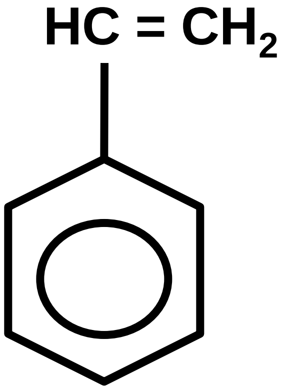
- **Some benzene derivatives go by common names.**



**Toluene**
**(methyl benzene)**



**Aniline**



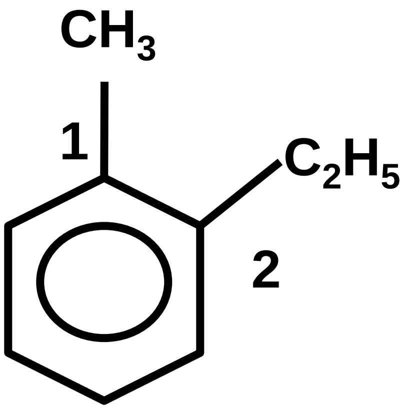
**Styrene**

# Naming Disubstituted Benzene Derivatives

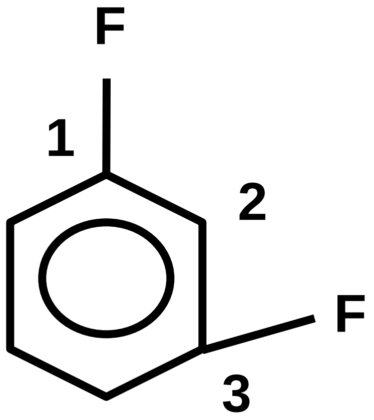
There are two ways to name a disubstituted benzene derivative:

- Method 1:
  - When more than one H atom on the benzene ring is replaced, then:
    - Begin by numbering the ring starting at attachment for first substituent, then move toward second.
    - Order substituents alphabetically.
    - Use “di” if both substituents are the same.

1-ethyl-2-methylbenzene



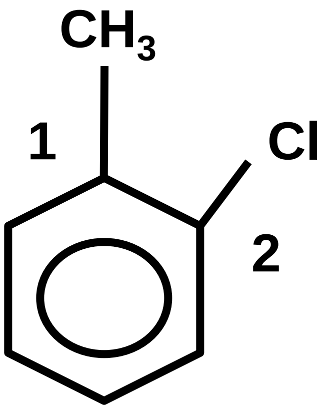
1,3, difluorobenzene

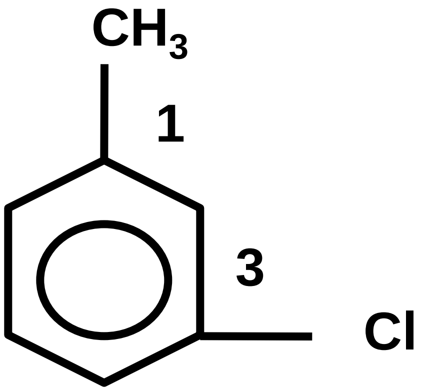


# Naming Disubstituted Benzene Derivatives

- **Method 2:**
  - **Use relative position prefix.**
    - ***ortho-* = 1,2**
    - ***meta-* = 1,3**
    - ***para-* = 1,4**

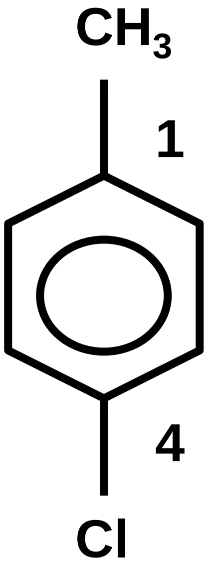
**Ortho-chlorotoluene**
**2-chlorotoluene**





**Meta-chlorotoluene**
**3-chlorobenzene**

**para-chlorotoluene**
**4-chlorobenzene**



# Functionalized Hydrocarbons

- **Basic hydrocarbon structures form a foundation for a major grouping of organic compounds.**
- **Insertion of functional groups to a hydrocarbon dramatically alters its properties.**
- Compounds containing the same functional group (**FG**) are called a family.
- Generic symbolism is **R**-**FG,** where **R** is the hydrocarbon part of the molecule and **FG** is the functional group.

R-OH symbolizes the alcohols.

- Functional groups help organize and classify organic compounds.

# Table of Common Functional Groups for Organic Compounds

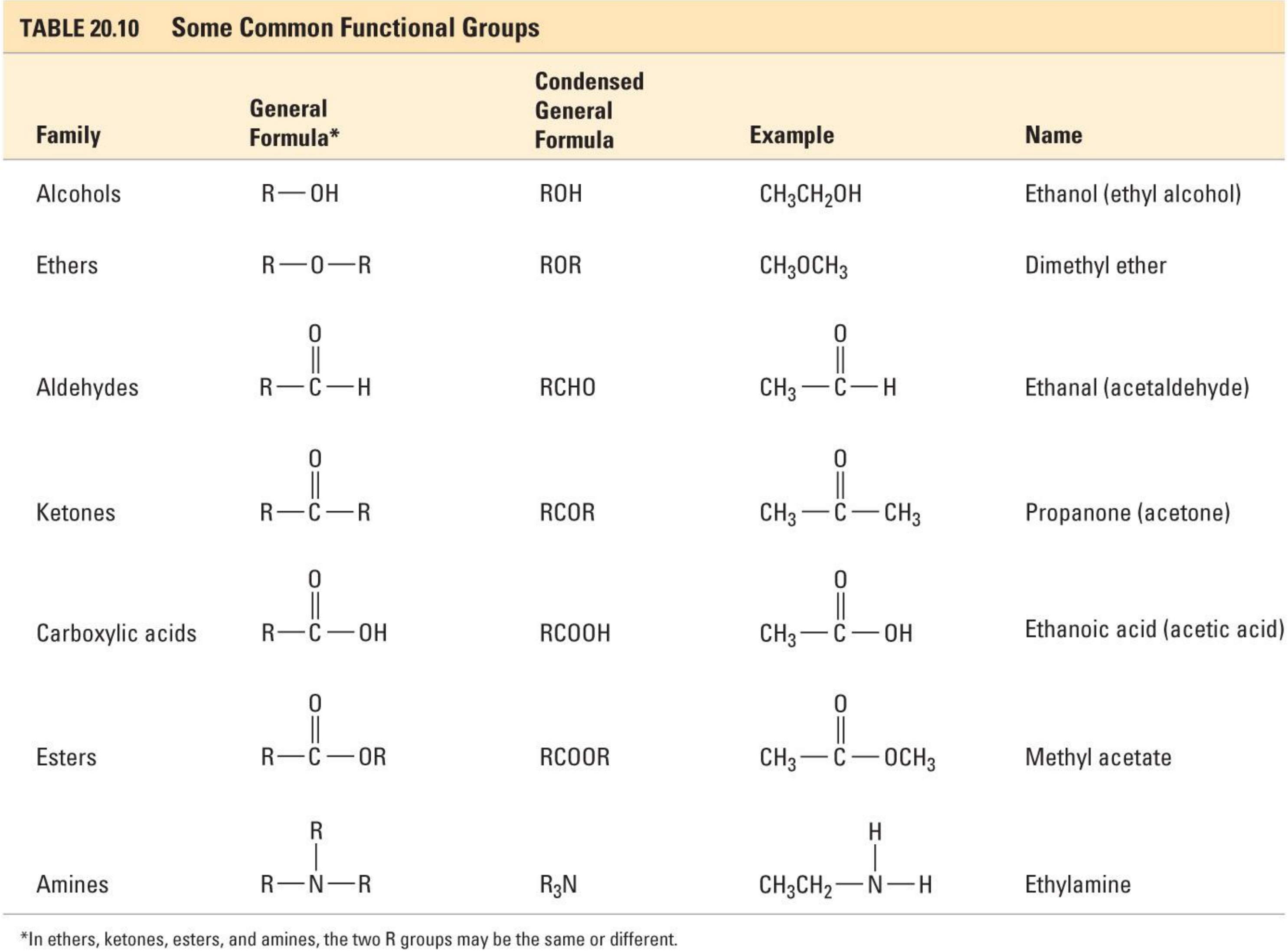


**TABLE 20.10 Some Common Functional Groups**

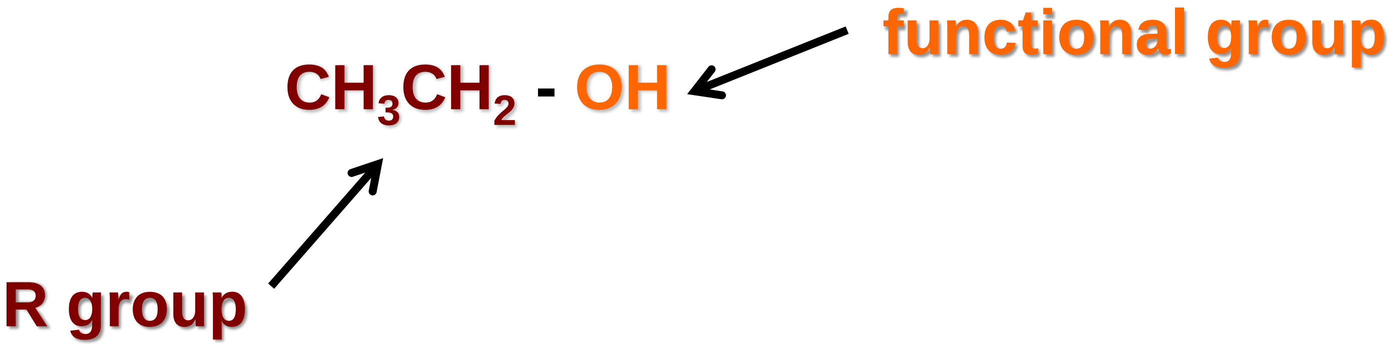
| Family | General Formula* | Condensed General Formula | Example | Name |
|---|---|---|---|---|
| Alcohols | $R-OH$ | ROH | $CH_3CH_2OH$ | Ethanol (ethyl alcohol) |
| Ethers | $R-O-R$ | ROR | $CH_3OCH_3$ | Dimethyl ether |
| Aldehydes | $R-\overset{\overset{O}{\|}}{C}-H$ | RCHO | $CH_3-\overset{\overset{O}{\|}}{C}-H$ | Ethanal (acetaldehyde) |
| Ketones | $R-\overset{\overset{O}{\|}}{C}-R$ | RCOR | $CH_3-\overset{\overset{O}{\|}}{C}-CH_3$ | Propanone (acetone) |
| Carboxylic acids | $R-\overset{\overset{O}{\|}}{C}-OH$ | RCOOH | $CH_3-\overset{\overset{O}{\|}}{C}-OH$ | Ethanoic acid (acetic acid) |
| Esters | $R-\overset{\overset{O}{\|}}{C}-OR$ | RCOOR | $CH_3-\overset{\overset{O}{\|}}{C}-OCH_3$ | Methyl acetate |
| Amines | $R-\overset{\overset{R}{\vert}}{N}-R$ | $R_3N$ | $CH_3CH_2-\overset{\overset{H}{\vert}}{N}-H$ | Ethylamine |

*In ethers, ketones, esters, and amines, the two R groups may be the same or different.

# Functional Groups

- Hydrocarbons that replace one or more of their H atoms with another atom (e.g., halogen) or group of atoms (e.g., –OH for alcohol) are referred to as functionalized hydrocarbons.

- A **functional group** is a group of atoms that show a characteristic influence on the chemical and physical properties of the molecule.
  - Reactions are determined by what functional groups are present in the molecule.
  - The **symbol R** is used to designate the alkyl (hydrocarbon group) chain.



$CH_3CH_2$ - OH

**functional group**

**R group**

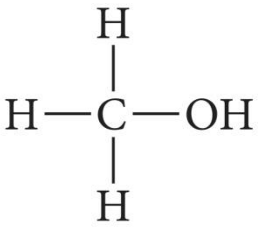
# Alcohols

- General formula: R-OH
  - The -OH group is on a saturated carbon atom.
- Parent chain ending changed to “ol”
  - Methane to methanol
- Additional of the -OH group makes alcohols polar compounds.
  - Degree of polarity affected by length of carbon chain and number of -OH groups
- Increased intermolecular attractive forces makes alcohols liquids.
- Classification of alcohols

| | |
|---|---|
| Primary: | -OH attached to a carbon atom with at least 2 H |
| Secondary: | -OH attached to a carbon atom with 1 H |
| Tertiary: | -OH attached to a carbon atom having no H |

# Classification of Alcohols

- Primary



$$\begin{array}{ccccc} & & \mathrm{H} & & \\ & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{OH} \\ & & | & & \\ & & \mathrm{H} & & \end{array}$$

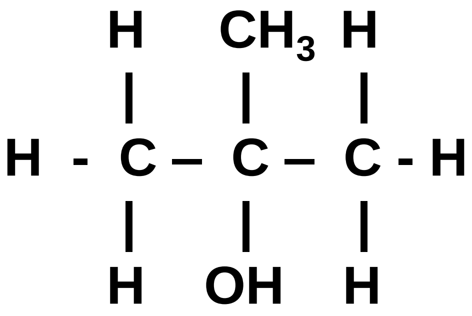
Methanol

- Secondary

$$\mathrm{CH_3CH_2CH_2}\underset{\underset{\mathrm{OH}}{|}}{\mathrm{C}}\mathrm{HCH_3}$$

2-Pentanol

- Tertiary

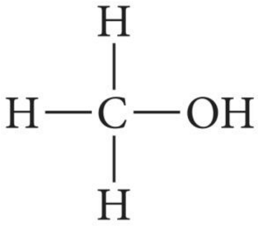


$$\begin{array}{ccccccccc} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \\ & & | & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & | & & | & & \\ & & \mathrm{H} & & \mathrm{OH} & & \mathrm{H} & & \end{array}$$

**2-methyl-2-propanol**

# Common Alcohols

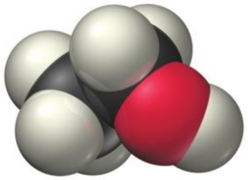
- Methanol
  - Toxic to liver
  - Wood alcohol



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & OH \\ & & | & & \\ & & H & & \end{array}$$

Methanol

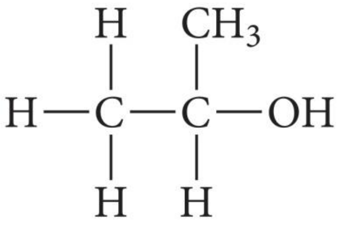
- Ethanol
  - Alcoholic beverages
  - Gasoline additive
  - Product of sugar fermentation



$CH_3-CH_2-OH$

Ethanol

- Isopropyl alcohol
  - Rubbing alcohol



$$\begin{array}{ccccccc} & & H & & CH_3 & & \\ & & | & & | & & \\ H & - & C & - & C & - & OH \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

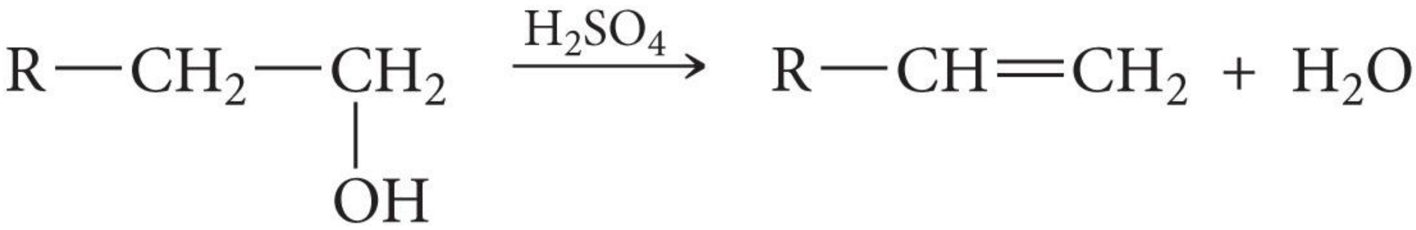
Isopropyl alcohol

# Reactions with Alcohols

- **Substitution (nucleophilic)**

$$CH_3 - OH + H - Br \rightarrow CH_3 - Br + H_2O$$

- **Elimination (dehydration)**

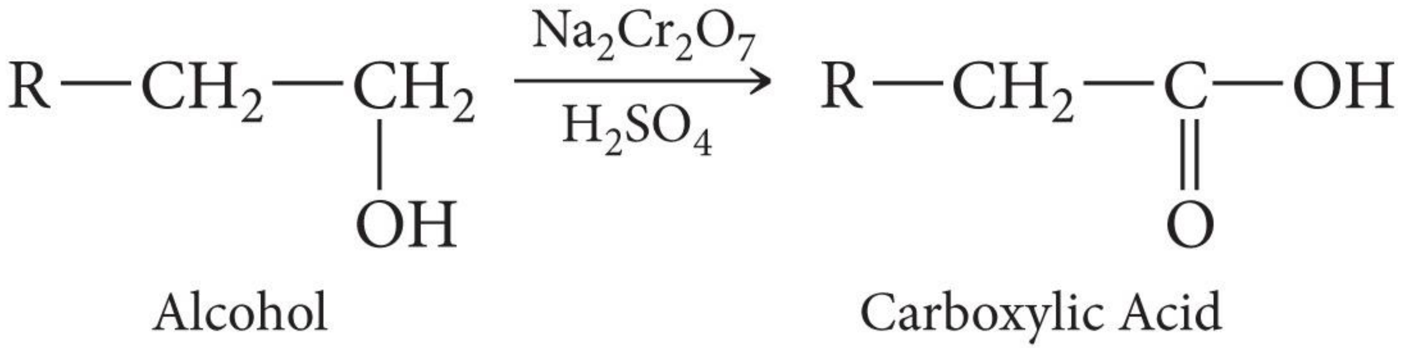


$$R-CH_2-\underset{\displaystyle OH}{\underset{|}{CH_2}} \xrightarrow{H_2SO_4} R-CH=CH_2 + H_2O$$

# Reactions with Alcohols

- Oxidation
  - Primary alcohols → aldehydes
  - Secondary alcohols → ketones
  - Tertiary alcohols → NO REACTION

- Oxidation to carboxylic acid



$$\mathrm{R{-}CH_2{-}\underset{\displaystyle OH}{\underset{|}{CH_2}}} \xrightarrow[\mathrm{H_2SO_4}]{\mathrm{Na_2Cr_2O_7}} \mathrm{R{-}CH_2{-}\underset{\displaystyle O}{\underset{\|}{C}}{-}OH}$$

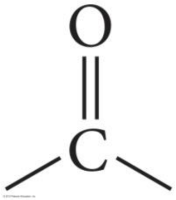
# Reactions with Alcohols

- **Substitution (nucleophilic)**
- **Elimination (dehydration)**
- **Oxidation**
  - **Primary alcohols → aldehydes**
  - **Secondary alcohols → ketones**
  - **Tertiary alcohols → NO REACTION**

# Aldehydes and Ketones

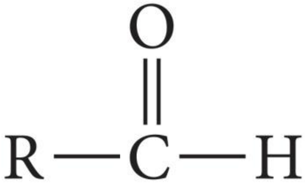
- They are commonly found in pleasant flavors and aromas.

- They each contain a carbonyl group:
  - Carbon double-bonded to an oxygen atom



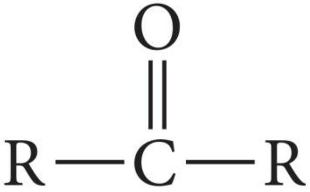
- The position of the carbonyl group

  in the molecule determines whether the compound is an
  aldehyde (at end) or ketone (within)



$R-\overset{O}{\overset{\|}{C}}-H$

Aldehyde



$R-\overset{O}{\overset{\|}{C}}-R$

Ketone

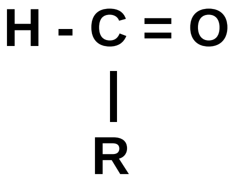
# Aldehydes

- Generic formula:

  - R – CHO

  - where R can be H atom or alkyl group

Structural formula



$$\begin{array}{c}H - \underset{\displaystyle R}{\underset{|}{C}} = O\end{array}$$

The carbonyl group is at the end of the Molecule.

- Name
  - Parent chain ending changed to “al’”

- Example of common aldehyde
  - Methanal
  - Simplest aldehyde

# Ketones

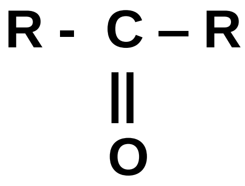
- **Generic formula:**

  **-R - CO - R**

**The carbonyl group is between two carbon atoms.**

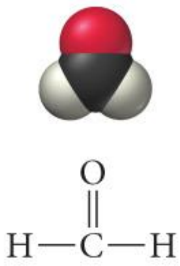
- **Name**
  - **Parent chain ending changed to “one”**
- **Example of common acetone**
  - **Propanone**
  - **Simplest ketone**

**Structural formula**



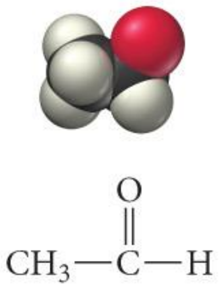
$$\mathrm{R - \underset{\underset{\displaystyle O}{\|}}{C} - R}$$

# Aldehydes and Ketones



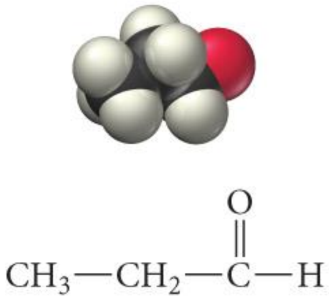
$$H-\overset{\overset{\displaystyle O}{\|}}{C}-H$$

Formaldehyde or methanal



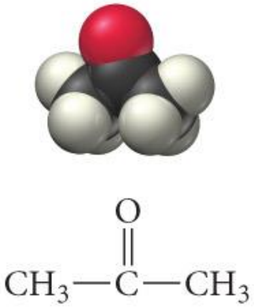
$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-H$$

Acetaldehyde or ethanal



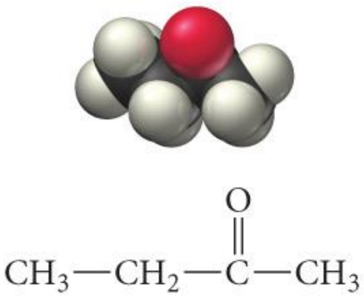
$$CH_3-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-H$$

Propanal



$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3$$

Acetone or propanone



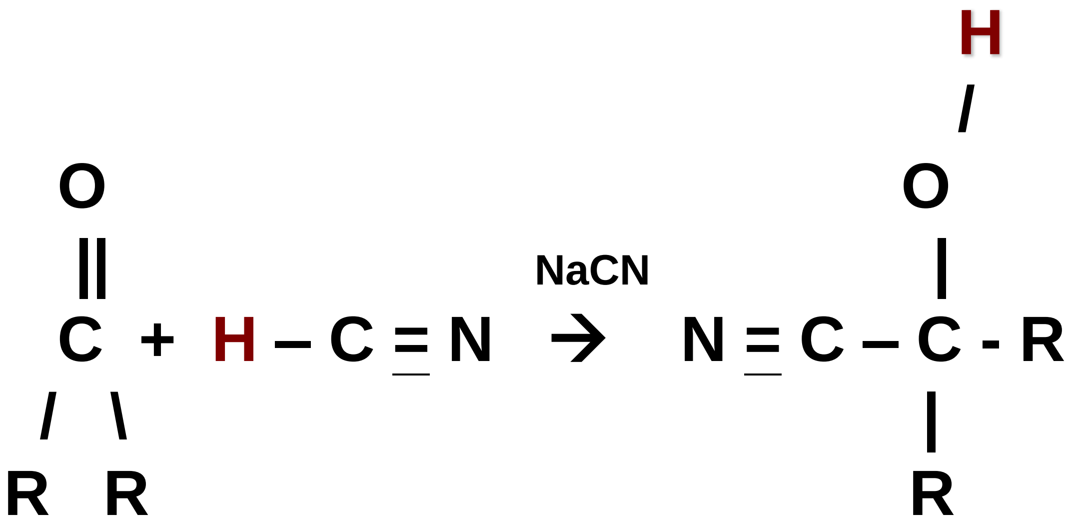
$$CH_3-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3$$

Butanone

# Reactions: Aldehydes and Ketones

- Aldehydes and ketones are synthesized by the oxidation of alcohols.
  - Aldehydes are formed via oxidation of primary alcohols.
  - Ketones are formed via oxidation of secondary alcohols.
- Reduction of an aldehyde or ketone results in the alcohol.

# Generic Example of Addition to C=O



$$\overset{\displaystyle O}{\underset{R\ \ R}{\overset{\|}{C}}} + \mathrm{H{-}C{\equiv}N} \xrightarrow{\mathrm{NaCN}} \mathrm{N{\equiv}C{-}}\overset{\displaystyle O{-}H}{\underset{\displaystyle R}{\overset{|}{C}}}\mathrm{{-}R}$$

**where R can be an H atom or alkyl group**

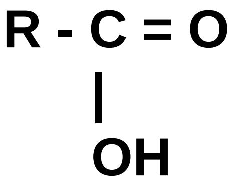
# Carboxylic Acids

- An organic acid
  - Composed of a carbonyl group with an -OH group
    - In an acid the -OH is attached to an unsaturated carbon atom.

- Generic formula

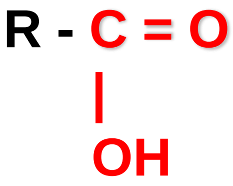
  R-COOH
  - where R can be a H atom or alkyl group

Structural formula



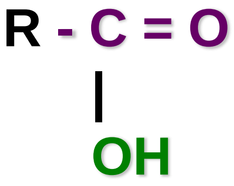
$$R-\underset{\underset{OH}{|}}{C}=O$$

- Functional group is the carboxylic acid.



$$R-\underset{\underset{OH}{|}}{C}=O$$

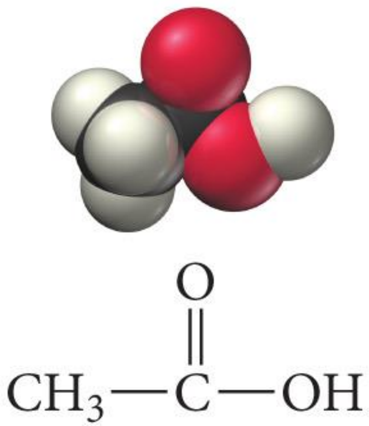
It is not a ketone function group + alcohol group



$$R-\underset{\underset{OH}{|}}{C}=O$$

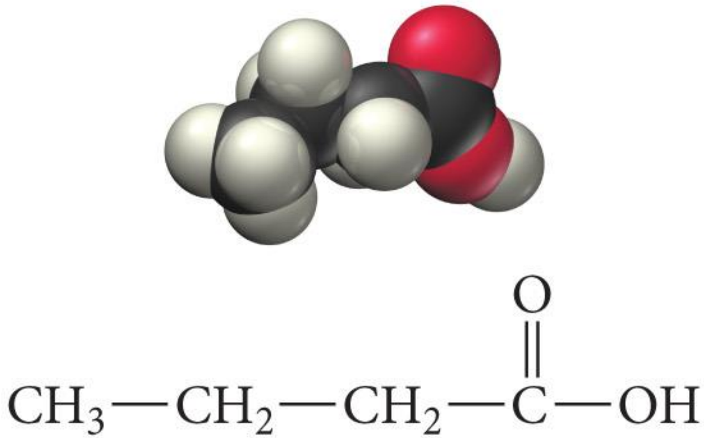
- Polar compound due to -COOH
  - Degree of polarity dictated by chain length and number of RCOOH groups

# Carboxylic Acids



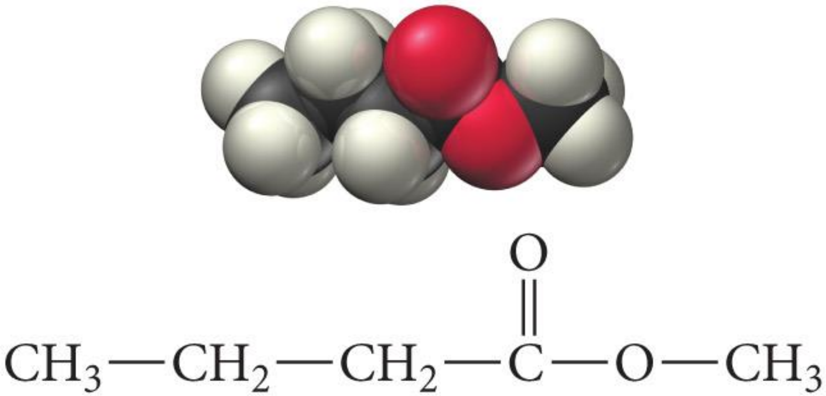
$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-OH$$

Ethanoic acid or acetic acid



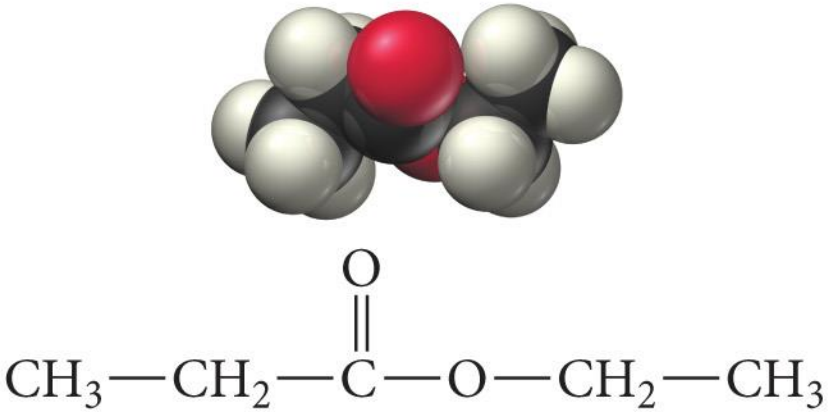
$$CH_3-CH_2-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-OH$$

Butanoic acid



$$CH_3-CH_2-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-O-CH_3$$

Methyl butanoate



$$CH_3-CH_2-\overset{\overset{\displaystyle O}{\|}}{C}-O-CH_2-CH_3$$

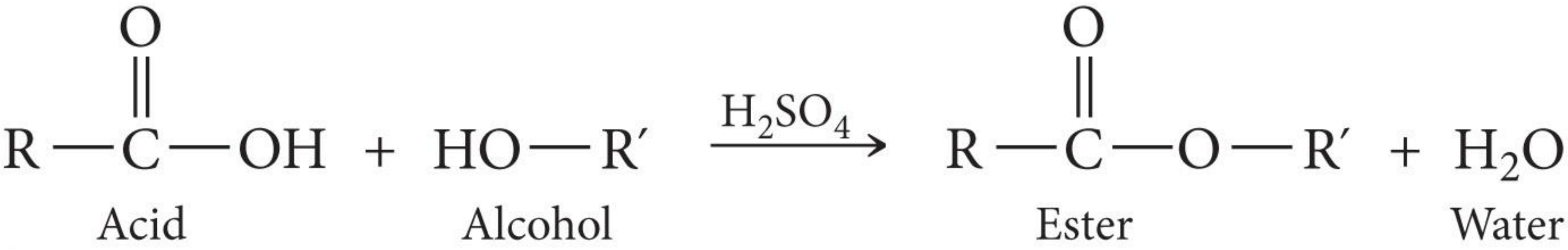
Ethyl propanoate

# Carboxylic Acid Reactions

- Carboxylic acids are products of an oxidation reaction via alcohols to aldehydes.
  - Alcohols $\xrightarrow{ox}$ Aldehydes → Carboxylic Acids
    - OH on the end of the chain

$$H_3C - OH \xrightarrow{ox} CH_3 - \underset{\underset{O}{\|}}{C} - OH$$

- Carboxylic acids react with alcohols to form esters (esterification).



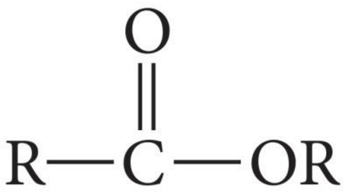
$$R-\overset{\overset{O}{\|}}{C}-OH + HO-R' \xrightarrow{H_2SO_4} R-\overset{\overset{O}{\|}}{C}-O-R' + H_2O$$

# Esters

- Generic formula

  R - COO - R

Structural formula



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-OR$$

Ester

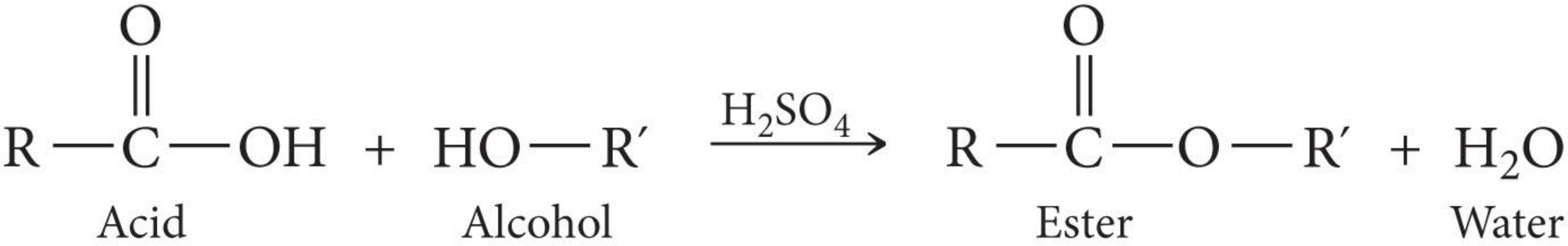
- Have a carbonyl group that is within the molecule BUT next to oxygen

- Named according to the relevant R groups and ending with “ate”
- Esters are “flavors.”

# Esterification Is a Type of Condensation Reaction

- A condensation reaction is any organic reaction driven by the removal of a small molecule, like water.

- Esters are made by the condensation reaction between a carboxylic acid and an alcohol.
  - The reaction is acid catalyzed.



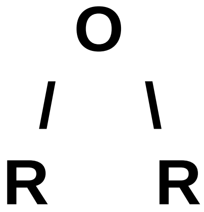
$$R-\overset{\displaystyle O}{\overset{\|}{C}}-OH + HO-R' \xrightarrow{H_2SO_4} R-\overset{\displaystyle O}{\overset{\|}{C}}-O-R' + H_2O$$

# Ethers

- **Generic formula**

  **R - O - R**

**Structural formula**



$$\begin{array}{ccc} & O & \\ / & & \backslash \\ R & & R \end{array}$$

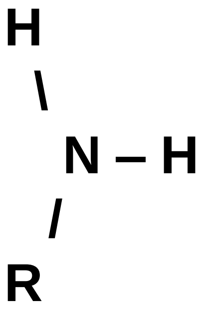
- **The functional group is -O-**
- **Named according to the two R groups and given the ending ether**
  - **Methyl ethyl ether**
    - **Formerly used as an anesthetic**

# Amines

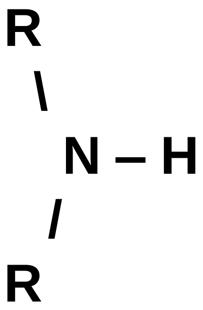
- Organic bases
- Associated with unpleasant odors
  - “Fishy” smell or skunk odor
- Amines are organic compounds that contain nitrogen.
- Generic formula

  $N - R_3$
  - where R can be a H atom or an alkyl group
- Structural formulas

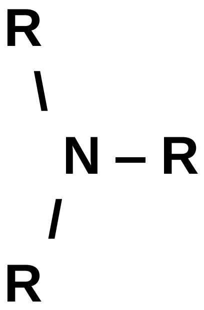
Primary amine



Secondary amine



Tertiary amine



# Amines

- Many amines are biologically active.
- Examples:
  - Dopamine, which is a neurotransmitter
  - Epinephrine is a type of an adrenal hormone.
  - Pyridoxine or vitamin $B_6$

- **Alkaloids** are plant products that are alkaline and biologically active.
  - They are often toxic and can become addictive.
    - Coniine from hemlock
    - Cocaine from coca leaves
    - Nicotine from tobacco leaves
    - Mescaline from peyote cactus
    - Morphine from opium poppies

# Amine Reactions

- Amines are weak organic bases.
  - Will react with strong acids to form ammonium salts (neutralization)

$$RNH_2 + HCl \rightarrow RNH_3^{+}Cl^{-}$$

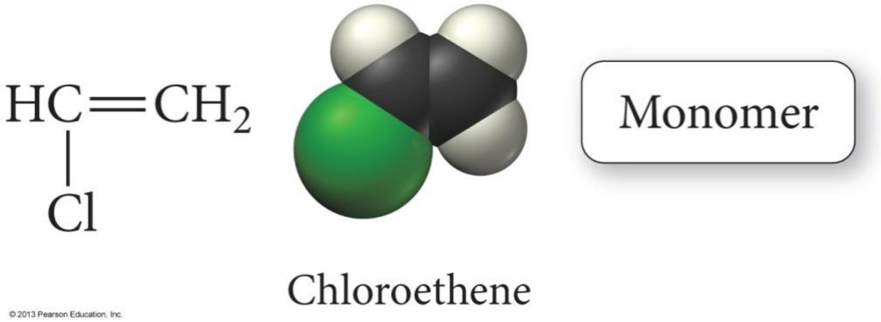
- When they react with carboxylic acids in a condensation reaction, an **amide** is produced.

$$RCOOH + HNHR' \Leftrightarrow RCONHR' + H_2O$$

# Polymers

# What Is a Polymer?

- Polymers are very large molecules made by repeated linking together of small molecules.
  - Units are called monomers.



$$HC{=}CH_2 \atop {|} \atop Cl$$

Chloroethene

- Polymers can be:
  - natural
  - modified natural polymers
  - synthetic
    - plastics, elastomers (rubber), fabrics, adhesives
  - composites
    - additives such as graphite, glass, metallic flakes

# Polymer Examples

## Naturally Occurring or Modified

- polysaccharides
  - cellulose (cotton)
  - starch
- proteins
- nucleic acids (DNA)
- natural latex rubber, etc.
- shellac
- amber, lignin, pine rosin
- asphalt, tar

## Human-Made or Synthetic

- cellulose acetate
  - Rayon
  - film
- vulcanized rubber
- gun cotton
- celluloid
  - ping-pong balls
- gutta percha
  - fill space for root canal
- casein
  - buttons, moldings, adhesives

# Table of Polymers of Commercial Importance

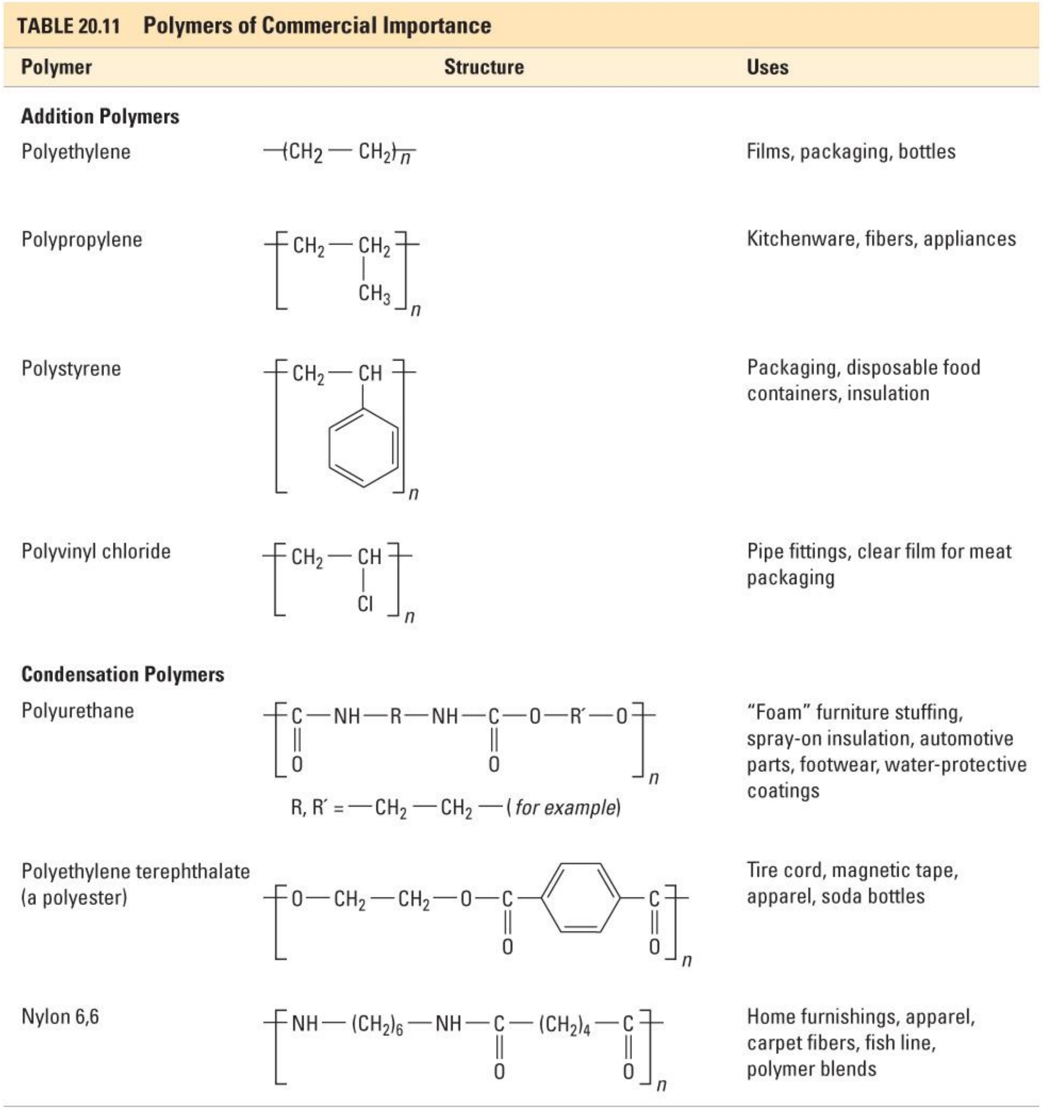


**TABLE 20.11** **Polymers of Commercial Importance**

| Polymer | Structure | Uses |
|---|---|---|
| **Addition Polymers** | | |
| Polyethylene | $-(CH_2-CH_2)_n-$ | Films, packaging, bottles |
| Polypropylene | $\left[CH_2-\underset{\underset{\displaystyle CH_3}{\vert}}{CH_2}\right]_n$ | Kitchenware, fibers, appliances |
| Polystyrene | $\left[CH_2-\underset{\vert}{CH}\right]_n$ | Packaging, disposable food containers, insulation |
| Polyvinyl chloride | $\left[CH_2-\underset{\underset{\displaystyle Cl}{\vert}}{CH}\right]_n$ | Pipe fittings, clear film for meat packaging |
| **Condensation Polymers** | | |
| Polyurethane | $\left[\underset{\underset{\displaystyle O}{\Vert}}{C}-NH-R-NH-\underset{\underset{\displaystyle O}{\Vert}}{C}-O-R'-O\right]_n$<br>R, R′ = $-CH_2-CH_2-$ (*for example*) | "Foam" furniture stuffing, spray-on insulation, automotive parts, footwear, water-protective coatings |
| Polyethylene terephthalate (a polyester) | $\left[O-CH_2-CH_2-O-\underset{\underset{\displaystyle O}{\Vert}}{C}-\quad-\underset{\underset{\displaystyle O}{\Vert}}{C}\right]_n$ | Tire cord, magnetic tape, apparel, soda bottles |
| Nylon 6,6 | $\left[NH-(CH_2)_6-NH-\underset{\underset{\displaystyle O}{\Vert}}{C}-(CH_2)_4-\underset{\underset{\displaystyle O}{\Vert}}{C}\right]_n$ | Home furnishings, apparel, carpet fibers, fish line, polymer blends |

# Additional Examples of Synthetic Polymers

- Polyethylene
  - HDPE: high-density polyethylene
  - LDPE: low-density polyethylene

- Polypropylene

- Polyvinyl chloride (PVC)

- Polyesters
  - Polyethylene terephthalate

- Polyamides
  - Nylon
  - Kevlar

# Polymerization Reactions

**Polymerization is the process of linking the monomer units together.**

- **There are two processes:**
  - **addition polymerization**
  - **condensation polymerization**

- **In the polymerization process monomers may be linked:**
  - **head to tail (most common)**
  - **head to head, or**
  - **tail to tail**

- **Regular pattern gives stronger attractions between chains than random arrangements.**

# Addition vs. Condensation Polymerization

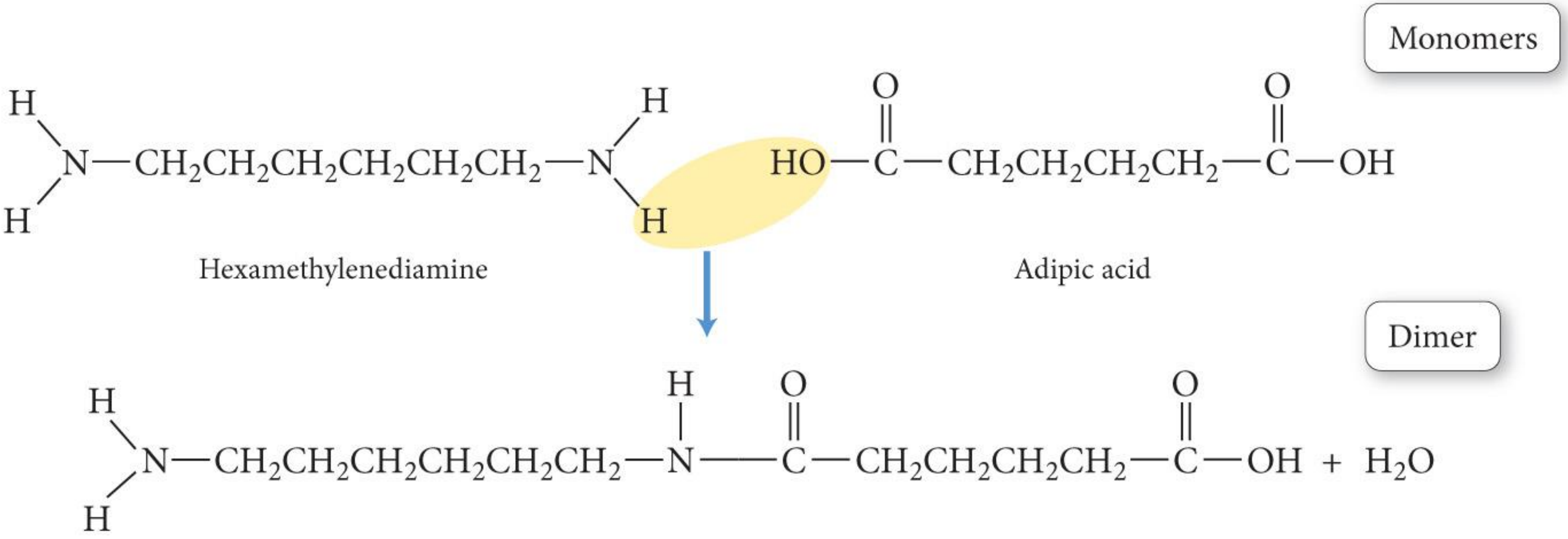
## Addition

- Monomers add to the growing chain in such a manner that all the atoms in the original monomer wind up in the chain.
  - No other side products formed, no atoms eliminated
- First monomer must "open" to start reaction
  - Done with heat or addition of an initiator
- Chain reaction
  - Each added unit ready to add another

## Condensation

- Monomer units are joined by removing small molecules from the combining units.
  - Polyesters, polyamides lose water
- No initiator needed
- Chain reaction
- Each monomer has two reactive ends, so chain can grow in two directions.

# Example of Head-Tail Polymerization



$$H_2N-CH_2CH_2CH_2CH_2CH_2CH_2-NH_2 \quad HO-\overset{O}{\overset{\|}{C}}-CH_2CH_2CH_2CH_2-\overset{O}{\overset{\|}{C}}-OH$$

$$H_2N-CH_2CH_2CH_2CH_2CH_2CH_2-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-CH_2CH_2CH_2CH_2-\overset{O}{\overset{\|}{C}}-OH + H_2O$$