HISTORY OF ORGANIC CHEMISTRY

- In the early days of chemistry, scientists classified chemical substances into 2 groups:

  1. **Inorganic**: those that were composed of **minerals**, such as rocks and nonliving matter.

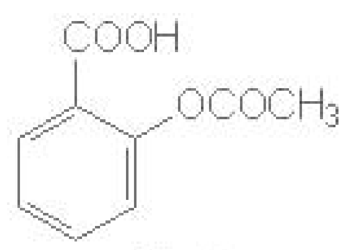
  2. **Organic**: those that were produced by **living organisms**, hence the name "organic".

- At the time, scientists believed that a "vital force", only present in living organisms, was necessary to produce organic compounds.

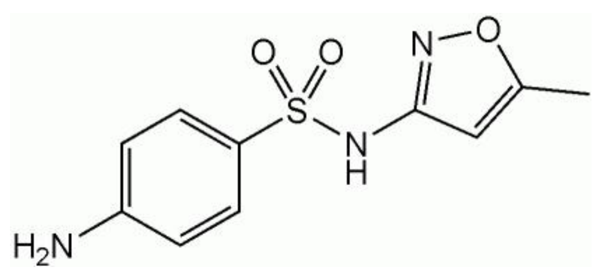
- In 1828, German chemist **Friedrick Wöhler** disproved this theory by producing urea, an organic compound found in urine, from inorganic compounds.

$$\underset{\substack{\textbf{Ammonium}\\\textbf{cyanate}\\\textbf{(inorganic)}}}{NH_4NCO} \longrightarrow \underset{\substack{\textbf{Urea}\\\textbf{(organic)}}}{H_2N-\overset{\overset{\displaystyle O}{\|}}{C}-NH_2}$$

- Now **organic** chemistry is defined as the study of compounds containing **carbon atom**. There are currently about 10 million organic compounds known to man.



Aspirin



Sulfa drug

Some examples of organic molecules

PROPERTIES OF ORGANIC COMPOUNDS

- **Organic** compounds differ from **inorganic** compounds in many ways. The table below summarizes these differences.

A Comparison of Properties of Organic and Inorganic Compounds		
Property	**Organic Compounds**	**Inorganic Compounds**
• Bonding within molecule	Usually covalent	Mostly ionic
• Forces between molecules	Generally weak	Very strong
• Physical states	Gas, liquids, or low melting solids	High melting solids
• Flammability	Often flammable	Nonflammable
• Solubility in water	Often low	Often high
• Conductivity of aqueous solutions	Nonconductor	Conductor
• Rate of chemical reactions	Usually slow	Usually fast

Examples:

1. Identify each compound below as organic or inorganic:

    A) $CaCl_2$ B) C_4H_{10} C) C_2H_5Cl D) Na_2CO_3

2. Match the following properties with the compounds ethane, C_2H_6 or sodium bromide, NaBr.

    a) boils at –89°C

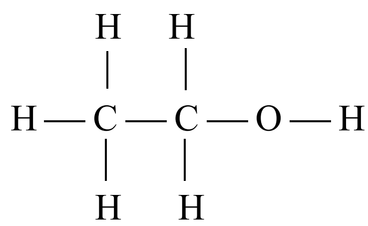
    b) burns vigorously

    c) dissolves in water

    d) solid at 250°C

STRUCTURE OF ORGANIC COMPOUNDS

- An **expanded structural formula** shows all the **atoms present** in a molecule and the **bonds** that connect them together. For example:

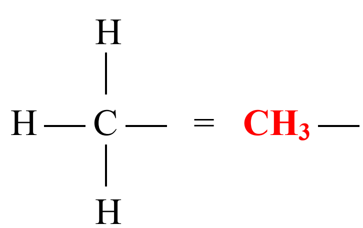


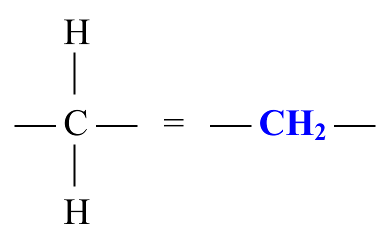
(Ethanol)

- A **condensed structural formula** shows the arrangement of the atoms, but shows each carbon atom and its attached hydrogen atoms as a group. For example:

$$CH_3 — CH_2 — OH$$

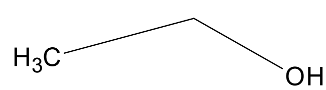
(Ethanol)





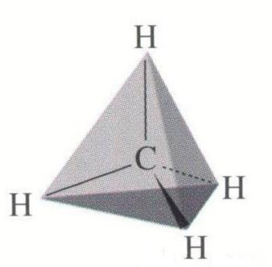
- A stick formula is a short-hand method of showing large and complex molecules easily. In these diagrams the non-terminal carbon atoms are displayed as joints and the non-terminal hydrogens are deleted.

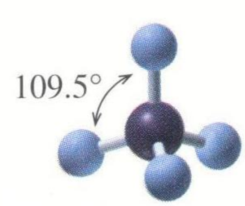
CH_3CH_2OH



- Many organic compounds contain carbon bonded to 4 other atoms through single bonds.

- The VSEPR theory predicts that these molecules should have a tetrahedral geometry with bond angles of 109.5°.

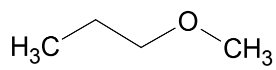




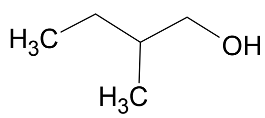
Examples:

1. Draw condensed structural formulas and determine molecular formula for each of the following stick structures:

   a)



   b)



2. Draw stick structures and determine molecular formulas for each of the following condensed structures:

   a)

$$\begin{array}{l} CH_3CH_2\overset{}{C}HCH_2CH_3 \\ \qquad\quad\;\; | \\ \qquad\quad CH_3 \end{array}$$

   b)

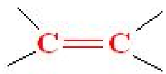
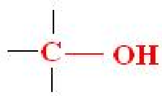
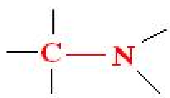
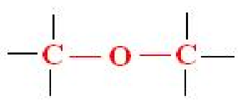
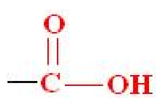
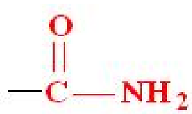
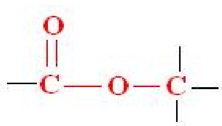
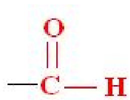
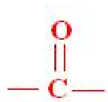
$$\begin{array}{l} \qquad\qquad\quad\; Cl \\ \qquad\qquad\quad\;\; | \\ CH_3CHCH_2CHCH_2CH_3 \\ \qquad\; | \\ \quad\;\; CH_3 \end{array}$$

FUNCTIONAL GROUPS

- Organic compounds are classified by common units called functional groups. Functional groups undergo similar chemical reactions. The simplest functional group is the alkyl group.

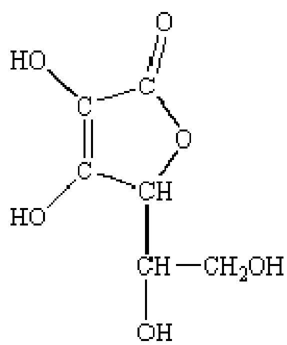
$$—CH_3 \quad = \quad R$$

- Some of the other important functional groups include:

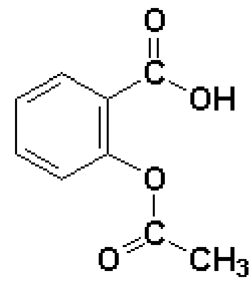
Name	Structure	Example
Alkene		$H_2C{=}CH_2$
Alkyne		$HC{\equiv}CH$
Alcohol		CH_3CH_2OH
Amine		$CH_3CH_2NH_2$
Ether		CH_3OCH_3
Acid		CH_3CO_2H
Amide		CH_3CONH_2
Ester		CH_3COOCH_3
Aldehyde		CH_3CHO
Ketone		CH_3COCH_3

Examples:
Identify the functional groups in each of the following famous molecules:

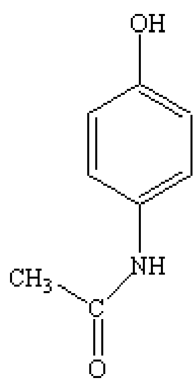
Vitamin C



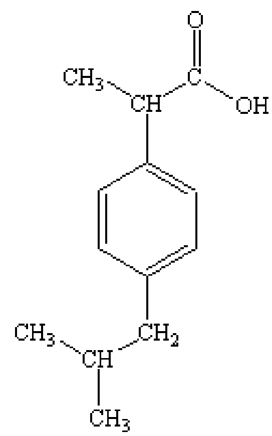
Aspirin



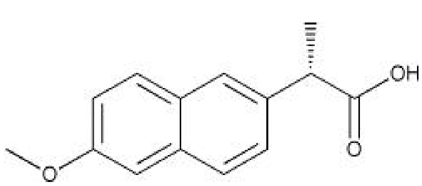
Tylenol



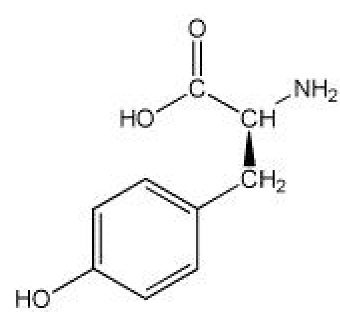
Advil



Aleve



Tyrosine

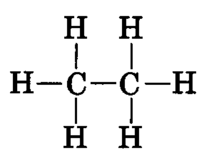


HYDROCARBONS

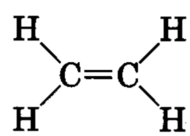
- **Hydrocarbons** are organic compounds composed of only **carbon** and **hydrogen**. Hydrocarbons are further broken down into several groups:

HYDROCARBONS

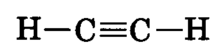
ALKANES	**ALKENES**	**ALKYNES**
Contain carbon-carbon single bonds	Contain carbon-carbon double bonds	Contain carbon-carbon triple bonds



Ethane



Ethene
(Ethylene)



Ethyne
(Acetylene)

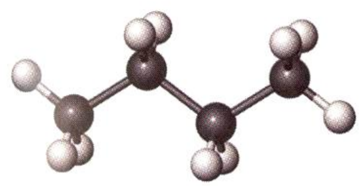
- **Saturated hydrocarbons** are those that contain only **carbon-carbon single bonds**. Ethane is an example of a saturated hydrocarbon.

- **Unsaturated hydrocarbons** are those that contain **carbon-carbon double and triple bonds**. Ethylene and acetylene are examples of unsaturated hydrocarbons.

ALKANES

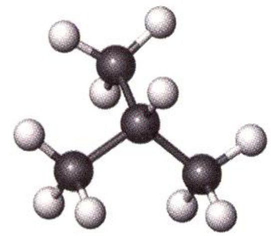
- **Alkanes** are hydrocarbons that contain only **carbon-carbon single bond** (saturated).

- Alkanes have the general molecular formula $\mathbf{C_nH_{2n+2}}$, and can be straight chain or branched.



$CH_3CH_2CH_2CH_3$

Butane
(bp −0.5°C)



$$\begin{array}{c} CH_3 \\ | \\ CH_3CHCH_3 \end{array}$$

2-Methylpropane
(bp −11.6°C)

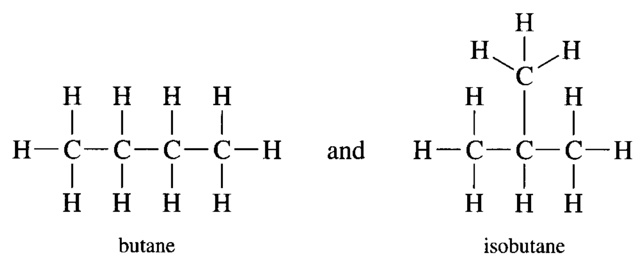
- Smaller alkanes were originally named in a random fashion, but larger alkanes are named by the IUPAC system. The first ten alkanes are named as shown below:

Number of Carbon Atoms	Prefix	Name	Molecular Formula	Condensed Structural Formula
1	Meth	Methane	CH_4	CH_4
2	Eth	Ethane	C_2H_6	$CH_3—CH_3$
3	Prop	Propane	C_3H_8	$CH_3—CH_2—CH_3$
4	But	Butane	C_4H_{10}	$CH_3—CH_2—CH_2—CH_3$
5	Pent	Pentane	C_5H_{12}	$CH_3—CH_2—CH_2—CH_2—CH_3$
6	Hex	Hexane	C_6H_{14}	$CH_3—CH_2—CH_2—CH_2—CH_2—CH_3$
7	Hept	Heptane	C_7H_{16}	$CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3$
8	Oct	Octane	C_8H_{18}	$CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3$
9	Non	Nonane	C_9H_{20}	$CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3$
10	Dec	Decane	$C_{10}H_{22}$	$CH_3—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_2—CH_3$

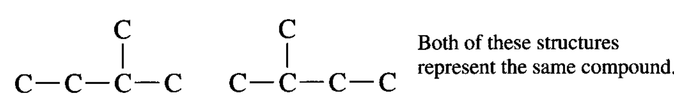
STRUCTURAL ISOMERS

- Compounds with the same molecular formula but ***different structural formulas*** are called ***isomers***.

- Most organic compounds have isomers. For example, butane has 2 isomers; pentane has 3 isomers, and hexane has 5 isomers. The two isomers of butane are shown below:



- In recognizing isomers of a compound, it is important to recognize molecules that might appear to have different structures, but are really the same.



Examples:

1. Identify all the isomers of C_3H_7Br from the choices given below:

$CH_3CH_2CH_2$—Br

$CH_3CH_2CH_2$
|
Br

CH_3CHCH_3
|
Br

Br
|
$CH_2CH_2CH_3$

Br—$CH_2CH_2CH_3$

2. Draw structural formulas for all the isomers of C_4H_9Cl.

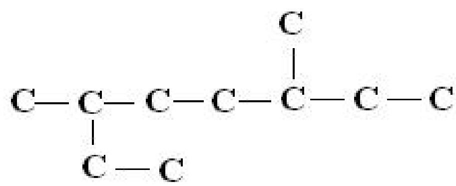
CLASSIFICATON OF CARBONS & HYDROGENS

Carbons in alkane molecules can be classified as one of 3 types:

- Primary (1°) carbons are those that are attached to only one other carbon atom.
- Secondary (2°) carbons are those that are attached to two other carbon atoms.
- Tertiary (3°) carbons are those that are attached to three other carbon atoms.

Examples:

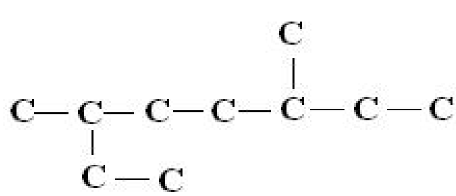
1. Identify the primary, secondary and tertiary carbon atoms in the skeleton structure shown below:



- Hydrogens in an alkane can be similarly classified as primary, secondary or tertiary.
- Primary (1°) hydrogens are those bonded to a primary carbon. Secondary (2°) hydrogens are those bonded to a secondary carbon. Tertiary (3°) hydrogens are bonded to a tertiary carbon.

Examples:

2. Draw all hydrogens missing in the skeleton structure above and classify as primary, secondary or tertiary.



NAMING ORGANIC COMPOUNDS

- Many organic compounds have common names that are used because of convenience and long usage. The majority of organic compounds however, are named systematically by the IUPAC system.

- In order to name compounds by the IUPAC system, a familiarity with common alkyl groups is necessary. Alkyl groups have the general formula C_nH_{2n+1} and are named based on the corresponding alkanes. Some common alkyl groups include:

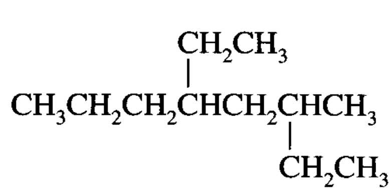
CH_3—	CH_3CH_2—	$CH_3CH_2CH_2$—
methyl	ethyl	n-propyl

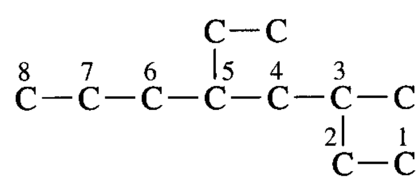
$$\begin{array}{c} | \\ CH_3CHCH_3 \end{array} \qquad\qquad \begin{array}{c} CH_3 \\ | \\ CH_3CHCH_2— \end{array}$$

isopropyl   isobutyl

<u>IUPAC Rules for Naming Alkanes:</u>

1. Select the longest continuous chain of carbons as the parent compound. All the other groups are considered side chains.
2. Number the carbon atoms in the parent chain so that the side chains fall on the smallest numbers.
3. Name each side chain alkyl group and designate its position on the parent chain by the carbon number. Side chains should be listed in alphabetical order.
4. Each side chain must possess a number designating its position on the parent chain. When the same side chains are present, use prefixes di-(2), tri-(3), etc.





Examples:

Name each compound shown below using the IUPAC system:

1. $$\begin{array}{ll} CH_3CH_2CH_2 & CHCH_3 \\ & | \\ & CH_3 \end{array}$$

2. $$\begin{array}{ll} CH_3CH_2CH_2 & CHCH_3 \\ & | \\ & CH_3CHCH_3 \end{array}$$

3. $$\begin{array}{ll} CH_3 & CHCH_3 \\ & | \\ & Cl \end{array}$$

4. $$\begin{array}{lll} & & CH_3 \\ & & | \\ CH_3 & CHCH_2 & CHCH_3 \\ & | & \\ & CH_2CH_3 & \end{array}$$

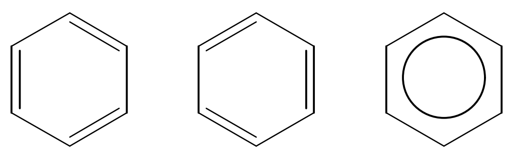
UNSATURATED HYDROCARBONS

- The ***unsaturated*** hydrocarbons consist of three families of ***homologous*** compounds that contain ***multiple bonds*** between carbon atoms.

- **Alkenes** contain carbon-carbon double bonds. Double bonded carbons possess an angle of 120° and hybridization of sp^2.

- **Alkynes** contain carbon-carbon triple bonds. Triple bonded carbons possess an angle of 180° and hybridization of sp.

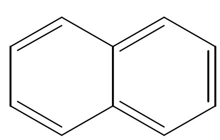
- **Aromatic compounds** contain benzene rings. Benzene rings are six membered rings that contain alternate double bonds and are represented by any of the structures shown below:



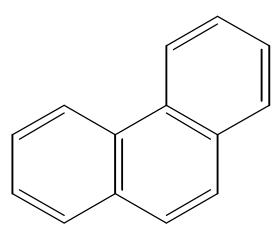
Representations of Benzene

- Benzene compounds are unlike other unsaturated compounds (alkenes and alkynes) and have their own characteristic properties and reactions.

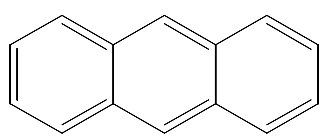
- Some organic molecules contain several benzene rings and are called polycyclic aromatic compounds. Some examples of are shown below:



naphthalene



phenanthrene



anthracene

NOMENCLATURE OF ALKENES

- Alkenes have the general formula C_nH_{2n} .
- To use the IUPAC rules for naming alkenes:

1. Select the longest continuous carbon-carbon chain that contains the double bond.
2. Name this parent compound as you would an alkane, but change the –***ane*** ending to –***ene***.
3. Number the carbon chain of the parent compound starting with the end nearer to the double bond. Use the smaller of the two numbers on the double-bonded carbon atoms to indicate the position of the double bond. Place this number in front of the alkene name.
4. Branch chains and other groups are treated as in naming alkanes, by numbering and assigning them to the carbon atom to which they are bonded.

$CH_3CH{=}CHCH_3$
2-butene

$CH_3CH_2CH_2CH{=}CH_2$
1-pentene

CH_3
|
$CH_3CHCH_2CH{=}CH_2$
4-methyl-1-pentene

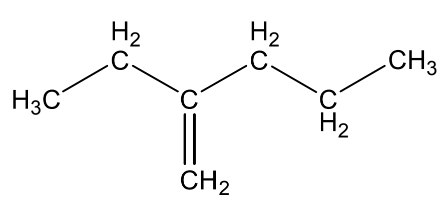
CH_2CH_3
|
$CH_3CH_2CH_2CHCH{=}CH_2$
3-ethyl-1-hexene

Examples:

1. Write a structural formula for 4-methyl-2-pentene.

2. Write a structural formula for 7-methyl-2-octene.

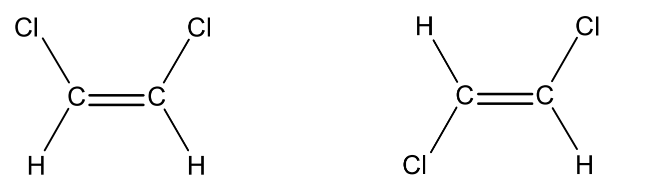
3. Name the compound shown :



GEOMETRIC ISOMERS

- Compounds containing a carbon-carbon double bond have restricted rotation about that double bond. This restricted rotation in a molecule gives rise to a type of isomer known as ***geometric isomer***.

- Isomers that differ from each other only in the geometry of their molecules and not in the order of their atoms are known as ***geometric isomers***. They are also called ***cis-trans isomers***.

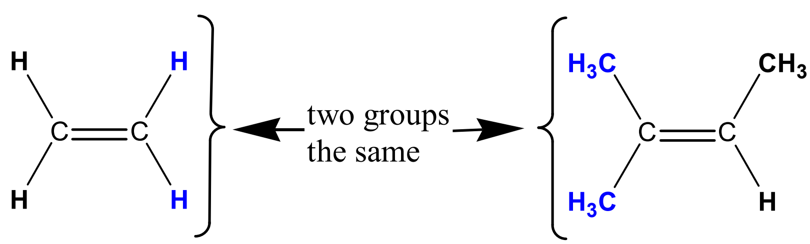


cis-1,2-dichloroethene (bp= 60.1°C) *trans*-1,2-dichloroethene (bp= 48.4°C)

- An alkene shows cis-trans isomerism when each carbon atom of the double bond has two different kinds of groups attached to it.

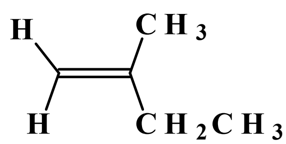
cis isomer trans isomer

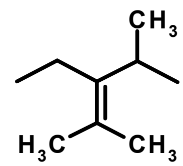
- An alkene ***does not show*** cis-trans isomerism if one carbon of the double bond has two identical groups attached to it.

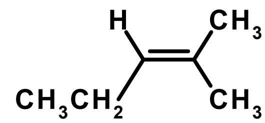


GEOMETRIC ISOMERS

- Shown below are some examples of alkenes that do not have cis/trans isomers.

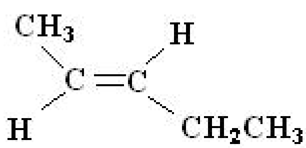


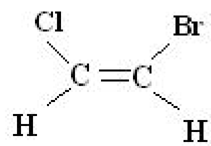




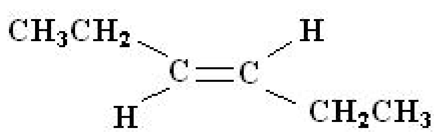
Examples:

1. Identify each of the molecules below as cis or trans isomers.

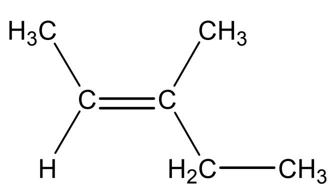
   a) 

   b) 

2. Name the following compound:



3. Is the compound shown below cis or trans isomer? Name this compound.



4. Draw structure for cis-5-chloro-2-hexene.