CHEMISTRY

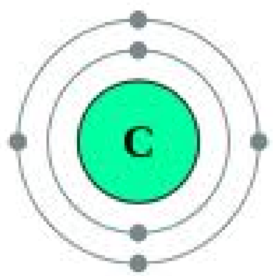
Carbon and its Compounds

Introduction

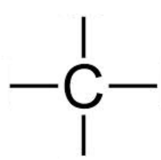
- Compounds of carbon are known as organic compounds.
- All organic compounds contain hydrogen along with carbon.
- Since, they are the fundamental organic compounds, they are also known as hydrocarbons.
- The study of carbon compounds such as hydrocarbons and its derivatives is called organic chemistry.

Bonding in Carbon

- Carbon atom has four electrons in its outermost shell.



- It requires four electrons to achieve the stable, 8 electron, inert gas configuration.
- Carbon atoms can achieve the inert gas electron arrangement only by sharing their electrons. Hence, carbon always forms covalent bonds.
- The valency of carbon is four since one carbon requires 4 electrons to achieve the nearest inert gas configuration. Thus, we can say that carbon is tetravalent.
- The four valencies of carbon are usually represented by drawing four short lines around the symbol of carbon (C).

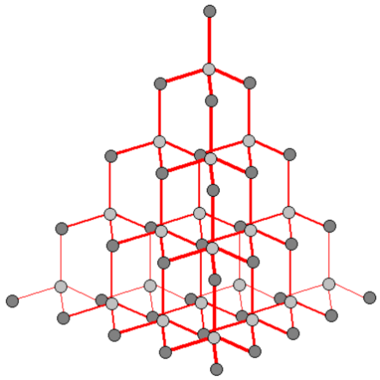


Allotropes of Carbon

- The various physical forms in which an element can exist are called the allotropes of that element.
- Carbon has three allotropes:
  - Diamond
  - Graphite
  - Buckminster fullerene

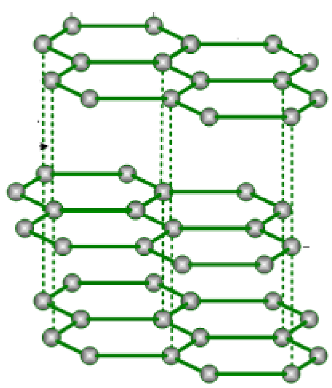
Diamond

- In diamond, each carbon atom is bonded to four other carbon atoms, forming a three dimensional structure.
- The rigid structure of diamond makes it a very hard substance.
- It is a non-conductor of electricity since there are no free electrons in a diamond crystal.
- It can be synthesised by subjecting pure carbon to a very high pressure and temperature.



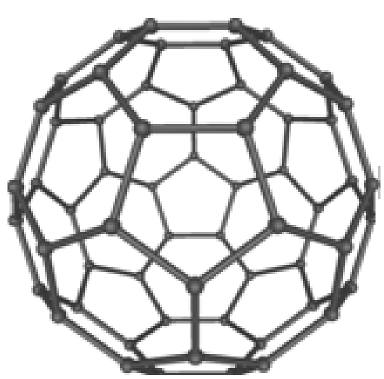
Graphite

- In graphite, each carbon atom is bonded to three other carbon atoms in the same plane, giving a hexagonal array.
- One of the bonds is a double bond and thus the valency of carbon is satisfied.
- Graphite structure is formed by the hexagonal arrays being placed in layers, one above another.
- Graphite is smooth and slippery.
- It is a very good conductor of electricity due to the presence of free electrons.



Fullerene

- It is an allotrope of carbon containing clusters of 60 carbon atoms joined together to form spherical molecules.
- There are 60 carbon atoms in a molecule of buckminsterfullerene, so its formula is C_{60}.
- The allotrope was named buckminsterfullerene after the American architect Buckminster Fuller.



Versatile Nature of Carbon

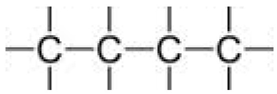
The two characteristic properties of the element carbon which leads to the formation of a very large number of organic compounds are:

i. **Catenation**: The property of the element carbon due to which its atoms can join one another to form long carbon chains is called catenation.

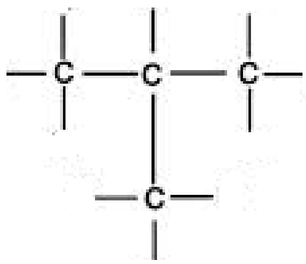
Types of Chains

- Straight chain
- Branched chains
- Closed or ring chains

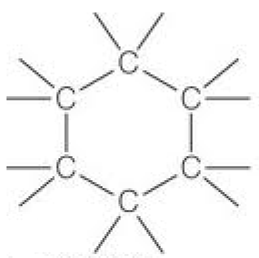
a. Straight chain of carbon atoms



b. Branched chain of carbon atoms



c. Closed or ring chain of carbon atoms



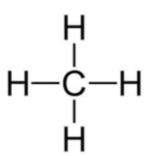
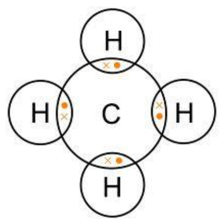
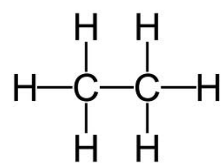
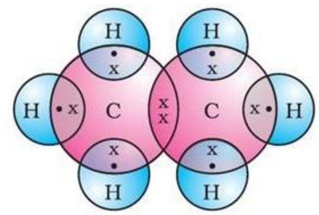
ii. **Tetravalency**: Carbon has a valency of four. So, it is capable of bonding with four other atoms of carbon or atoms of some other monovalent element.

Compounds of carbon are formed with oxygen, nitrogen, hydrogen, sulphur, chlorine and many other elements, giving rise to compounds with specific properties which depend on the elements other than the carbon present in the molecule.

Classification of Hydrocarbons

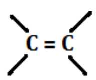
Saturated Hydrocarbons

- Hydrocarbons in which the carbon atoms are connected by only single bonds are called saturated hydrocarbons.
- Saturated hydrocarbons are called alkanes.
- General formula of alkanes: C_nH_{2n+2}, n = number of carbon atoms
- Methane and ethane are saturated hydrocarbons, which contain only carbon-carbon single bonds.

Methane	Ethane
  Electron dot structure	  Electron dot structure

Unsaturated Hydrocarbons (Alkenes and Alkynes)

- Hydrocarbons in which two carbon atoms are connected by a double or a triple bond are called unsaturated hydrocarbons.
- Unsaturated hydrocarbons are of two types
  - Alkenes
  - Alkynes

  - **Alkenes**
    An unsaturated hydrocarbon in which two carbon atoms are connected by a double bond is called an alkene.
    Alkenes contain the  group.
    General formula: C_nH_{2n}, where n = number of carbon atoms

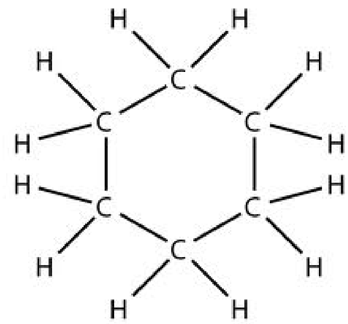
  - **Alkynes**
    An unsaturated hydrocarbon in which two carbon atoms are connected by a triple bond is called an alkyne.
    An alkyne contains the $-C \equiv C-$ group.
    General formula: C_nH_{2n-2}, where n = number of carbon atoms

Cyclic Hydrocarbons

- Hydrocarbons in which the carbon atoms are arranged in the form of a ring are called cyclic hydrocarbons.
- Cyclic hydrocarbons may be saturated or unsaturated.

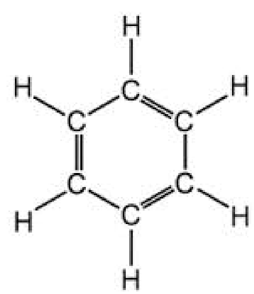
i. **Saturated cyclic hydrocarbon**

- Cyclohexane is an example of a saturated cyclic hydrocarbon.
- Formula: C_6H_{12}
- Cyclohexane contains 6 carbon atoms arranged in a hexagonal ring, with each carbon atom attached to 2 hydrogen atoms.



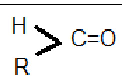
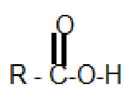
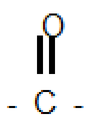
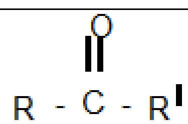
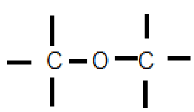
ii. Unsaturated cyclic hydrocarbon

- Benzene is an example of an unsaturated cyclic hydrocarbon.
- Formula: C_6H_6
- Benzene is made up of 6 carbon atoms and 6 hydrogen atoms.



Functional Groups

- All organic compounds are derivatives of hydrocarbons.
- Derivatives are obtained by replacing one or more hydrogen atoms by some other atom or group of atoms.
- The new set of compounds formed after replacement has functions different from the parent hydrocarbon.
- **Functional group**: An atom or a group of atoms present in the molecules, which determines the characteristics property of the organic compounds, is called the functional group.

Functional group	General formulae	Organic compound	Suffix	Examples with common & IUPAC name
Halide-X (F,Cl,Br,I)	R-X	Haloalkanes	-ane	CH_3Cl Common name: Methyl chloride IUPAC name: Chloromethane
Hydroxyl-OH	R-OH	Alcohols	-ol	C_2H_5OH Common name : Ethyl alcohol IUPAC name: Ethanol
Aldehyde-CHO		Aldehydes	-al	CH_3CHO Common name: Acetaldehyde IUPAC name: Ethanal
Carboxyl-COOH		Carboxylic acids	-oic acid	CH_3CH_2COOH Common name: Propionic acid IUPAC name: Propanoic acid
Keto 		Ketones	-one	$CH_3COC_2H_5$ Common name: Diethyl ketone IUPAC name: Pentanone
Ethers 	R-O-R’	Ethers	-oxy	$CH_3 – O – C_2H_5$ Common name: Ethyl methyl ether IUPAC name: Methoxy ethane

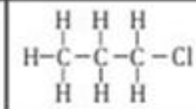
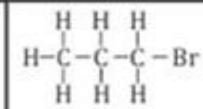
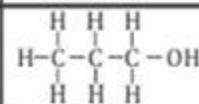
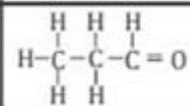
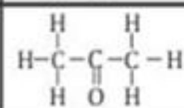
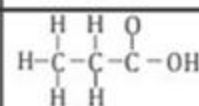
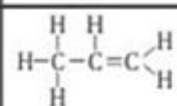
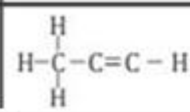
Homologous Series

It is a group of organic compounds having a similar structure and chemical properties in which the successive compounds differ by a -$\mathbf{CH_2}$ group.

Characteristics of a Homologous Series

- Each member of the series differs from the preceding one by the addition of a -CH_2 group and by 14 a.m.u.
- All members of a homologous series have the same general formula.
  For example: the general formula for alkane is C_nH_{2n+2} and alkene is C_nH_{2n}.
- The physical properties of the members show a gradation in properties as their molecular mass increases.
- The chemical properties also show a gradient similarity.
  For example: Methane and ethane react with chlorine to form methyl chloride and ethyl chloride respectively.
  $CH_4 + Cl_2 \rightarrow CH_3Cl$
  $C_2H_6 + Cl_2 \rightarrow C_2H_5Cl$
- All members of a homologous series can be prepared by the same general method of preparation.
  For example: Alcohols can be prepared from alkyl halides.
  $CH_3Br + KOH \xrightarrow{\text{Boil}} CH_3OH + KBr$
  $C_2H_5Br + KOH \xrightarrow{\text{Boil}} C_2H_5OH + KBr$

Nomenclature of Functional groups

Functional group	Prefix/Suffix	Example
1. Halogen	Prefix-chloro. bromo, etc.	 Chloropropane
		 Bromopropane
2. Alcohol	Suffix - ol	 Propanol
3. Aldehyde	Suffix - al	 Propanol
4. Ketone	Suffix - one	 Propanone
5. Carboxylic acid	Suffix - olc acid	 Propanoic acid
6. Double bond (alkenes)	Suffix - ene	 Propene
7. Triple bond (alkynes)	Suffix - yne	 Propyne

Chemical Properties of Carbon Compounds

Combustion

- The process of burning a carbon compound in air to give carbon dioxide, water, heat and light is known as combustion.
- These reactions are exothermic, with the evolution of a large amount of heat.
- Saturated hydrocarbons give a clean flame.
  For example:
  $CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O(g)$ + Heat and Light
  $2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(g)}$ + Heat and Light
- Unsaturated carbon compounds burn in air with a yellow, sooty flame with lots of black carbon.

Oxidation

- Carbon compounds can be oxidised.
- Alcohols on oxidation are converted to carboxylic acids.
- Alkaline $KMnO_4$ or acidified $K_2Cr_2O_7$ are used as oxidising agents.

$$CH_3-CH_2-OH \xrightarrow[\text{or Acidified } K_2Cr_2O_7]{\text{Alkaline } KMnO_4 + \text{Heat}} CH_3COOH$$

Addition Reaction

- This reaction occurs only in unsaturated compounds, where there are double or triple bonds.
- The addition of hydrogen to an unsaturated hydrocarbon to obtain a saturated hydrocarbon is called hydrogenation.

  For example:

  Ethene, on heating with hydrogen, in the presence of a nickel or palladium catalyst forms ethane.

$$CH_2=CH_2 + H_2 \xrightarrow[\text{Heat}]{\text{Ni catalyst}} CH_3-CH_3$$

- The process of hydrogenation is used in industries to prepare vegetable ghee (or vanaspati ghee) from vegetable oils.

Substitution Reaction

- The reaction in which one or more hydrogen atoms of a hydrocarbon are replaced by atoms of other elements is called a substitution reaction.
- Substitution reactions are a characteristic property of saturated hydrocarbons.

  For example: Methane reacts with chlorine in the presence of sunlight to form chloromethane and hydrogen chloride.

$$CH_4 + Cl_2 \xrightarrow{\text{Sunlight}} CH_3Cl + HCl$$

Some Important Carbon Compounds – Ethanol & Ethanoic Acid

Properties of Alcohols

- **Reaction with Sodium**: Sodium reacts steadily with ethanol to form sodium ethoxide along with the evolution of hydrogen gas.

$$\underset{\text{Ethanol}}{2C_2H_5OH} + \underset{\text{Sodium}}{2Na} \rightarrow \underset{\text{Sodium ethoxide}}{2C_2H_5ONa} + \underset{\text{Hydrogen}}{H_2\uparrow}$$

- **Dehydration:** Ethanol, on heating with excess of conc. H_2SO_4 at 170°C gets dehydrated to form ethene.

$$C_2H_5OH \xrightarrow{\text{Conc.} H_2SO_4,\ 170^oC} CH_2=CH_2 + H_2O$$

Properties of Ethanoic acid

- **Esterification:** Ethanoic acid reacts with alcohols in the presence of a little conc. sulphuric acid to form esters.

  $C_2H_5OH + CH_3COOH \xrightarrow{Conc.H_2SO_4} CH_3COOC_2H_5 + H_2O$

  The ester, on treating with a base such as NaOH is converted back to alcohol and sodium salt of carboxylic acid. This reaction is known as saponification because it is used in the manufacture of soap.

  $CH_3COOC_2H_5 + NaOH \rightarrow C_2H_5OH + CH_3COONa$

- **Reaction with a base:** Ethanoic acid reacts with a base such as sodium hydroxide to form a salt and water.

  $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

  Acetic acid → Sodium acetate + Water

- **Reaction with Carbonates & bicarbonates:** Acetic acid reacts with carbonates and bicarbonates to form salt, water and carbon dioxide.

  $2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$

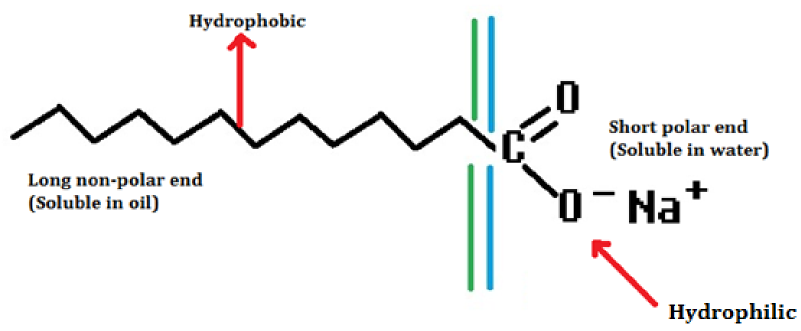
  Acetic acid → Sodium acetate

  $CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$

  Acetic acid → Sodium acetate

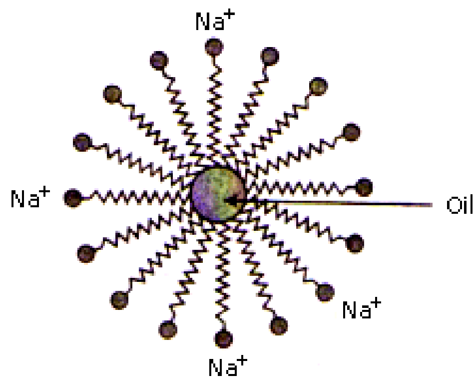
Soaps & Detergents

- Soaps are cleansing agents capable of reacting with water and dislodging the unwanted particles from clothes or skin.
- The molecules of soap are sodium or potassium salts of long chain carboxylic acids.
- A soap molecule has a tadpole shaped structure.
- At one end (long non-polar end) of the soap molecule is a hydrocarbon chain which is insoluble in water but soluble in oil.
- At the other end (short polar end) of the soap molecule, there is a carboxylate ion which is hydrophilic i.e. water soluble but insoluble in oil.



- Soap on mixing with water forms a concentrated solution and causes foaming.
- The long non-polar end of soap gravitates towards and surrounds the dirt and absorbs the dust in it.
- The short polar end with the carboxylate ion repels the water away from the dirt.

- A spherical aggregate of soap molecules is formed in the soap solution in water, and is called a micelle.
- Thus, the soap molecule dissolves the dirt and help in cleaning our clothes.



Formation of Micelles