



Carbon & It's Compounds

Key Points

- Fourth most abundant element in the universe.
- Forms the largest number of compounds and is studied as a separate branch of chemistry known as organic chemistry.
- Atomic No. = 6; Mass No. = 12
- Earth's crust has only 0.02% carbon in the form of minerals and atmosphere has 0.03% of carbon dioxide.



There is no living organism know which lacks carbon.

Bonding in carbon



The covalent bond :

- A chemical bond formed between two atoms of the same element or two atoms of different elements by sharing of electrons is called a covalent bond. The no. of electrons shared show the covalency of that atom.

1

It could gain four electrons forming C^{4-} anion. But it would be difficult for the nucleus with six protons to hold on to ten electrons, that is, four extra electrons.

2

It could lose four electrons forming C^{4+} cation. But it would require a large amount of energy to remove four electrons leaving behind a carbon cation with six protons in its nucleus holding on to just two electrons.

Examples of covalent bonds

- ① Formation of methane molecule [It is also called marsh gas, used as a fuel and is a major compound of CNG].



- ② Formation of carbon dioxide molecule (CO_2)



Properties of covalent compounds

- Covalently bonded molecules are seen to have strong bonds within the molecule, but intermolecular forces are small. This gives rise to the low melting and boiling points of these compounds. Exceptions: diamond and graphite.
- Since the electrons are shared between atoms and no charged particles are formed, such covalent compounds are generally poor conductors of electricity.
- These compounds are generally insoluble in water but some which are capable to form H-bond are soluble in water.
- H-bond : It is an electrostatic attractive force between covalently bonded hydrogen atom of one molecule and an electronegative atom (F, O, N).

Allotropes of carbon



Diamond

- Diamond is a crystalline allotrope of carbon. Its atomic symbol and empirical formula is 'C'.

Structure

- In diamond, each carbon atom is covalently bonded to four other carbon atoms in a tetrahedral arrangement.
- This tetrahedral arrangement of carbon atoms gives a rigid, three-dimensional structure to diamond.

Properties

1. Pure diamond is a transparent and colourless solid.
2. Polished diamond sparkles brightly because it reflects most of the light (refractive index of diamond is 2.45).

Preparation of synthetic diamond

- Diamond can be synthesized by subjecting pure carbon to very high pressure and temperature. These synthetic diamonds are smaller than natural diamonds.

Graphite

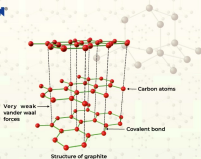
- Graphite is also known as black lead as it marks paper black. The name graphite has been taken from the Greek word "graphein" (which means to write) in reference to its uses as 'lead' in lead pencils.

Structure

- Graphite is an opaque and dark grey solid. In a crystal of graphite the carbon atoms are arranged in a hexagonal pattern in parallel planes.



Part of the covalent giant
Structure of diamond



- In a layer of graphite each carbon atom is strongly bonded to three other carbon atoms by covalent bonds.
- Thus, one valence electron of each carbon atom is free in every layer of graphite crystal.
- The free electron makes graphite a good conductor of electricity.
- Each layer is bonded to the adjacent layers by weak forces. As a result, each layer can easily slide over the other. This makes graphite slippery in nature.

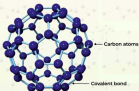
Uses of Graphite :

- As pencil lead
- As electrodes
- As a dry lubricant
- As heat resistant crucibles
- In making light weight composite material
- In making artificial diamonds



Fullerenes

- Fullerenes are recently discovered, spherical or tube-like allotropes of carbon. The molecule containing sixty atoms of carbon has been named as Buckminster fullerene.
- Fullerenes has been named after American architect and engineer R. Buckminster fuller whose geodesic domes follow similar building principles.



Structure of Fullerene

Types of fullerene

- C_{60} , C_{70} , C_{74} and C_{78} are the members of fullerene family. But C_{60} is the most stable and most studied form of fullerenes.
- C_{60} molecule has marvelously symmetrical structure. It is a fused ring of aromatic system containing 20 hexagons and 12 pentagons of C-atoms.



Buckminster fuller with geodesic dome

Versatile nature of carbon

About three million (or thirty lakh) compounds of carbon are known. The existence of such a large number of organic compounds is due to the following characteristic features of carbon.

- **Catenation** : Carbon has the unique ability to form bonds with other atoms of carbon, giving rise to large molecules. This property is called catenation. These compounds may have long chains of carbon, branched chains of carbon or even carbon atoms arranged in rings.

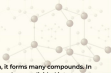


Catenation means self-linking,
like chains.

- **Tetra valency** : Compounds of carbon having double or triple bonds between their carbon atoms are called unsaturated compounds. Since, carbon has a valency of four, it is capable of bonding with four other atoms of carbon or atoms of some other mono-valent element.
- **Stability of C-C bonds** : No other element exhibits the property of catenation to the extent seen in carbon compounds. Silicon forms compounds with hydrogen which have chains of up to seven or eight atoms, but these compounds are very reactive. The carbon-carbon bond is very strong and hence stable. This gives us the large number of compounds with many carbon atoms linked to each other.
- **Small size of carbon** : The bonds that carbon forms with most other elements are very strong making these compounds exceptionally stable. One reason for the formation of strong bonds by carbon is its small size. This enables the nucleus to hold on to the shared pairs of electrons strongly. The bonds formed by elements having larger atoms are much weaker.

Note

Remember that the strength of bond decreases with increase in the size of atoms.



Vital force theory

Organic compounds :

- Because of versatile nature of carbon, it forms many compounds. In eighteenth century all known compounds were divided into two categories.



E.g. urea, sugar, oils, fats, dyes etc.

E.g. Like marble, common salt, alum, CuSO_4 , etc.

Vital force theory

- This theory was given by Berzelius in 1815.
- According to him, organic compounds were produced only under the influence of some mysterious force existing in the living organism. This mysterious force was called the vital force. So, it was believed that no organic compound can be prepared in the laboratory.

Wohler's synthesis

- Berzelius's theory was disapproved by Friedrich Wohler in 1828 by preparing urea from ammonium cyanate (NH_4CNO) in laboratory.



Modern definition of organic compounds

- Compounds of carbon, containing usually hydrogen and one and more other element such as oxygen, nitrogen, sulphur, halogens, phosphorus, etc. are called organic compounds.

Classification of organic compounds

Hydrocarbon

Aliphatic compound/ Acyclic (Open chain)

Straight chain compounds

E.g. $\text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CH}_3$

Saturated

Alkanes

Unsaturated

Alkenes

Branched chain compounds

E.g.



Carbocyclic compound

Aliphatic compounds

Homocyclic
(Only C atoms are present in the ring)

E.g.



Heterocyclic
(Contains an atom other than C in the ring)

E.g.



Aromatic compounds

- Unsaturated compound
- Always cyclic
- Planar and follow Hückel's rule
- Conjugation is present
- Delocalisation of electron is present

Homocyclic aromatic

E.g. Naphthalene

Heterocyclic aromatic

E.g. Pyridine

→ On the basis of bonding, carbon compounds can be classified in two categories.

Saturated Hydrocarbon :

→ The hydrocarbons which contain only single carbon-carbon covalent bonds are called saturated hydrocarbons.



Lewis dot structure of propane

Alkane



→ They are also called alkanes. General formula for alkanes is $\text{C}_n\text{H}_{2n+2}$, where 'n' is the number of carbon atoms.
E.g. Methane (CH_4), Ethane (C_2H_6).

Unsaturated hydrocarbons

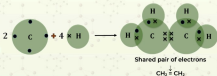
→ The hydrocarbons in which two carbon atoms are bonded to each other by a double (=) or a triple (≡) bond is called an unsaturated hydrocarbon.

Unsaturated hydrocarbons are of two types viz. alkenes and alkynes.



→ The hydrocarbons in which the two carbon atoms are bonded by a double bond are called alkenes.

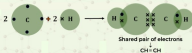
→ Their general formula is C_nH_{2n} , where 'n' is the number of carbon atoms. E.g. Ethene (C_2H_4), Propene (C_3H_6) or ($\text{CH}_2=\text{CH}-\text{CH}_3$)



→ The hydrocarbons in which two carbon atoms are bonded by a triple bond are called alkynes.

→ Their general formula is $\text{C}_n\text{H}_{2n-2}$, where 'n' is the number of carbon atoms.

→ E.g. Ethyne (C_2H_2 or $\text{HC}\equiv\text{CH}$), Propyne (C_3H_4 or $\text{H}_3\text{C}-\text{C}\equiv\text{C}-\text{H}$)



On the basis of structure, carbon compounds can be divided into 3 categories.

Straight chain compounds

- If a carbon compound has carbon-carbon link in chain fashion, we get a straight chain compound.
- In these, a carbon can form bond with a maximum of 2 carbon atoms.

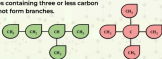
Example:



Branched chain compounds

- Thus, carbon compounds in which at least one carbon of the chain is linked to three or four other carbon atoms are called branched chain compounds.
- The alkanes containing three or less carbon atoms do not form branches.

Example:



Closed chains or cyclic hydrocarbons or ring hydrocarbons

These hydrocarbons contain closed chain or ring of atoms in their molecules. These can be of further two types.

(i) Alicyclic hydrocarbon

(Saturated cyclic carbon compounds or cycloalkanes)

- These hydrocarbons contain a ring chain of three or more carbon atoms.
- These cyclic compounds are named by prefixing 'cyclo' before the name of corresponding straight chain hydrocarbon.

Example :

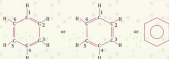


(ii) Aromatic hydrocarbon

(Unsaturated cyclic carbon compound)

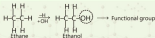
- (a) These have at least one benzene ring in their molecules.
- (b) It is a special type of ring of six carbon atoms with three double bonds in alternate positions.

Example: Benzene



Functional group

- Carbon forms most of the compounds with hydrogen. But carbon also forms bonds with other atoms such as halogen, oxygen, nitrogen and sulphur.
- These compounds are obtained by replacing one or more hydrogen atoms by other atoms such that the valency of carbon remains satisfied. The atom or a group of atoms replacing the hydrogen atom are called heteroatom or functional group respectively.
- Different organic compounds having same functional group have almost same properties. These are called families.
- To understand the meaning of a functional group, let us consider ethane (C_2H_6) and ethanol (C_2H_5OH).



→ Both ethane and ethanol have different physical and chemical properties.

Example,

- (i) Ethane is a gas while ethanol is a liquid at room temperature.
- (ii) Ethanol is an antiseptic and hypnotic (induces sleep) but ethane does not have these properties.

Some Functional Groups in Carbon compounds		
Hetero atom	Functional group	Formula of Functional Group
Halogen atom (F, Cl, Br, I)	Halo (Fluoro, Bromo, Iodo)	$-\text{F}, -\text{Cl}, -\text{Br}, -\text{I}$
Oxygen (O)	1. Alcohol	$-\text{OH}$
	2. Aldehydes	>C=O or $-\text{CHO}$
	3. Ketones	>C=O or $-\text{CO}-$
	4. Carboxylic acid	>C=O or $-\text{COOH}$

Homologous Series

→ Definition: "A series of organic compounds having similar structures and similar chemical properties in which the successive members differ in their molecular formula by $-\text{CH}_2$ group".

The different members of the series are called as homologues.

Characteristics of homologous series



Alkane



Homologous series

Alkene

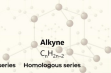


Homologous series

Alkyne



Homologous series



Name	Formula	Name	Formula	Name	Formula
Methane	CH ₄	—	—	—	—
Ethane	C ₂ H ₆	Ethene	C ₂ H ₄	Ethyne	C ₂ H ₂
Propane	C ₃ H ₈	Propene	C ₃ H ₆	Propyne	C ₃ H ₄
Butane	C ₄ H ₁₀	Butene	C ₄ H ₈	Butyne	C ₄ H ₆
Pentane	C ₅ H ₁₂	Pentene	C ₅ H ₁₀	Pentyne	C ₅ H ₈
Hexane	C ₆ H ₁₄	Hexene	C ₆ H ₁₂	Hexyne	C ₆ H ₁₀

Nomenclature of carbon compounds

There are two ways to name carbon compounds:

1. Trivial system
2. IUPAC system



IUPAC Logo

→ Trivial System :

In earlier days, organic compounds were named after the source from which they were obtained. For example, urea got its name because the substance was obtained from the urine of mammals. These names are without any systematic basis and are known as common names or trivial names.

IUPAC System :

It is the system for naming organic compound given by International Union of Pure and Applied Chemistry. This system is very useful in the study of organic compounds.

In IUPAC system of nomenclature, the name of organic compounds consists of three parts.

- (i) Word root
- (ii) Suffix
- (iii) Prefix

Word root :

The word root denotes the number of carbon atoms present in the chain. Example : Chains containing upto four carbon atoms, special word roots (meth-C1, eth-C2, prop-C3, but-C4) have been used



Chain length	Word root	Chain Length	Word Root
C-1	Meth	C-6	Hex
C-2	Eth	C-7	Hept
C-3	Prop	C-8	Oct
C-4	But	C-9	Non
C-5	Pent	C-10	Dec

Suffix :

The word root is linked to the suffix which may be primary or secondary or both.

(i) Primary suffix : It indicates the nature of linkage in the carbon atoms. For example, if the carbon atom is linked by single covalent bond ($C-C$), the primary suffix -ane is used. Similarly, for a double bond between two carbon atoms ($C=C$), -ene is used, the suffix -yne is used for a triple bond between two carbon atoms ($C\equiv C$).

(ii) Secondary suffix : It indicates the presence of functional group in the organic compound. A few important secondary suffixes are listed below.

Functional group	Suffix
Alcohols ($-OH$)	-ol
Aldehydes ($-CHO$)	-al
Ketones ($>C=O$)	-one
Carboxylic acids ($-COOH$)	-oic acid

Thus, a complete IUPAC name of an organic compound may be represented

as

Prefix + Word root + Primary suffix + Secondary suffix

Isomerism

- The existence of an organic compound with the same molecular formula and different structural formulae is called isomerism.
- The isomerism can be of various types depending on the type of variation in the structures of the molecules.

Example



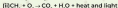
Chemical properties of carbon compounds

Carbon compounds generally show following four chemical reactions.



Combustion

- Carbon, in all its allotropic forms, burns in oxygen to give carbon dioxide along with the release of heat and light. Most carbon compounds also release a large amount of heat and light on burning.



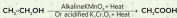


- Saturated hydrocarbons will generally give a clean flame while unsaturated carbon compounds will give a yellow flame with lots of black smoke. However, limiting the supply of air results in incomplete combustion of even saturated hydrocarbons giving a sooty flame.
- The gas/kerosene stove used at home has inlets for air so that a sufficiently oxygen-rich mixture is burnt to give a clean blue flame.
- Fuels such as coal and petroleum have some amount of nitrogen and sulphur in them. Their combustion results in the formation of oxides of sulphur and nitrogen which are major pollutants in the environment. This is because a flame is only produced when gaseous substances burn. When wood or charcoal is ignited, the volatile substances present vapourise and burn with a flame in the beginning.
- A luminous flame is seen when the atoms of the gaseous substance are heated and start to glow. The colour produced by each element is a characteristic property of that element.
- Carbon compounds can be easily oxidised on combustion. In addition to this complete oxidation, we have reactions in which alcohols are converted to carboxylic acids.
 - ▶ In general, Alcohols $\xrightarrow{[O]}$ Aldehyde $\xrightarrow{[O]}$ Acid
 - ▶ Remember that unsaturated compounds discharge the pink colour of alk. $KMnO_4$. This is known as test of unsaturation.
 - ▶ Remember, saturated acids are harmful for health.

Oxidation

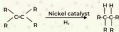
- Carbon compounds can be easily oxidised on combustion. In addition to this complete oxidation, we have reactions in which alcohols are converted to carboxylic acids, which are capable of adding oxygen to others. These substances are known as oxidising agents.

Alkaline potassium permanganate or acidified potassium dichromate are oxidising alcohols to acids, that is, adding oxygen to the starting material. Hence they are known as oxidising agents.



Addition Reaction

- Unsaturated hydrocarbons add hydrogen in the presence of catalysts such as palladium or nickel to give saturated hydrocarbons. Catalysts are substances that cause a reaction to occur or proceed at a different rate without the reaction itself being affected.
- This reaction is commonly used in the hydrogenation of vegetable oils using a nickel catalyst. Vegetable oils generally have long unsaturated carbon chains while animal fats have saturated carbon chains.



- You must have seen advertisements stating that some vegetable oils are 'healthy'. Animal fats generally contain saturated fatty acids which are said to be harmful for health. Oils containing unsaturated fatty acids should be chosen for cooking.

Substitution Reaction

- Saturated hydrocarbons are fairly unreactive and are inert in the presence of most reagents. However, in the presence of sunlight, chlorine is added to hydrocarbons in a very fast reaction.
- Chlorine can replace the hydrogen atoms one by one. It is called a substitution reaction because one type of atom or a group of atoms takes the place of another.
- A number of products are usually formed with the higher homologues of alkanes.





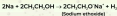
Some important carbon compounds

Ethanol

- Ethanol is a liquid at room temperature. It is commonly called alcohol and is the active ingredient of all alcoholic drinks.
- In addition, because it is a good solvent, it is also used in medicines such as tincture iodine, cough syrups, and many tonics.
- Ethanol is also soluble in water in all proportions. Consumption of small quantities of dilute ethanol causes drunkenness. Even though this practice is condemned,
- it is a socially widespread practice. However, intake of even a small quantity of pure ethanol (called absolute alcohol) can be lethal. Also, long-term consumption of alcohol leads to many health problems.

Reaction of Ethanol

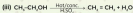
- (i) Reaction with sodium



Alcohols react with sodium leading to the evolution of hydrogen. With ethanol, the other product is sodium ethoxide.

- (ii) Reaction to give unsaturated hydrocarbon: Heating ethanol at 443 K with excess concentrated sulphuric acid results in the dehydration of ethanol to give ethene.

The concentrated sulphuric acid can be regarded as a dehydrating agent which removes water from ethanol.



Effect of alcohol on living beings

- When large quantities of ethanol are consumed, it tends to slow metabolic processes and to depress the central nervous system. This results in lack of coordination, mental confusion, drowsiness, lowering of the normal inhibitions and finally stupour.



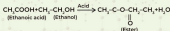
- The individual may feel relaxed but does not realise that his sense of judgement, sense of timing, and muscular coordination have been seriously impaired. Unlike ethanol, intake of methanol even in very small quantity can cause death.
- Methanol is oxidised to methanal in the liver. Methanal reacts rapidly with the components of cells.
- It causes the protoplasm to get coagulated, in much the same way an egg is coagulated by cooking. Methanol also affects the optic nerve, causing blindness.
- Ethanol is an important industrial solvent. To prevent the misuse of ethanol produced for industrial use, it is made unfit for drinking by adding poisonous substances like methanol to it.
- Dyes are also added to colour the alcohol blue so that it can be identified easily. This is called denatured alcohol.

Ethanoic acid

- Ethanoic acid is commonly called acetic acid and belongs to a group of acids called carboxylic acids. 5-8% solution of acetic acid in water is called vinegar and is used widely as a preservative in pickles.
- The melting point of pure ethanoic acid is 290 K and hence it often freezes during winter in cold climates. This gave rise to its name glacial acetic acid.
- Unlike mineral acids like HCl, which are completely ionised, carboxylic acids are weak acids.

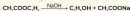
Reactions of ethanoic acid

- Esterification reaction: Esters are most commonly formed by reaction of an acid and an alcohol. Ethanoic acid reacts with absolute ethanol in the presence of an acid catalyst to give an ester





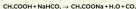
- Esters are sweet-smelling substances. These are used in making perfumes and as flavouring agents.
- Esters react in the presence of an acid or a base to give back the alcohol and carboxylic acid.
- This reaction is known as saponification because it is used in the preparation of soap.



- Reaction with a base: Like mineral acids, ethanoic acid reacts with a base such as sodium hydroxide to give a salt (sodium ethanoate or commonly called sodium acetate) and water.

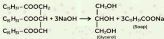


- Reaction with carbonates and hydrogencarbonates : Ethanoic acid reacts with carbonates and hydrogencarbonates to give rise to a salt, carbon dioxide and water. The salt produced is commonly called sodium acetate.



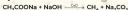
Soaps and detergents

- Commercially used soaps are sodium salts of fatty acid, such as oleic acid ($\text{C}_{18}\text{H}_{33}\text{COOH}$), stearic acid ($\text{C}_{18}\text{H}_{35}\text{COOH}$) and palmitic acid ($\text{C}_{16}\text{H}_{33}\text{COOH}$) which are plant or animal origin. Soap is made from oil or fat which are esters of fatty acids or glycerols as shown in the following equation.



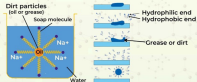
- The above reaction is known as **saponification**. The soap from the solution is separated by the addition of common salt.

- **Decarboxylation** : Sodium or potassium salt of acetic acid on reaction with soda lime gives methane due to the removal of CO_2 from the carboxylic acid :



The washing action of soap and detergents

- The soap is made up of two components; hydrocarbon part and $-\text{COONa}$ group. The former is hydrophobic (water repelling) whereas the latter is hydrophilic (water loving). The hydrocarbon part dissolves grease along with the dirt sticking to the cloth. The soap micelle thus helps in dissolving the dirt in water and we can wash out clothes clean.



- Synthetic detergents have a structure similar to that of soap. The water attracting part in detergents is sulphonate ($-\text{SO}_3\text{Na}$) group.
- Synthetic detergents can lather well even with hard water as unlike soaps, they do not form insoluble calcium or magnesium salts with hard water.



3D view of micelle