1. CARBON

Carbon is a non-metallic element.

Chemical symbol : C

Symbolic Representation : $^{12}_{6}C$

Where, atomic number is 6 and atomic mass is 12

Therefore, it has

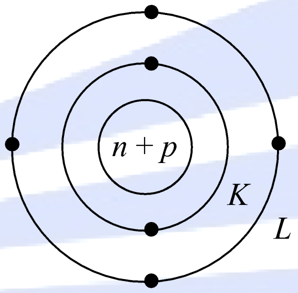
Number of protons = 6

Number of neutrons = 6

Number of electrons = 6

Electronic configuration : K L i.e. it has 4 electrons in its outermost shell.

2 4



1.1 PROPERTIES OF CARBON

(i) Position of Carbon in Periodic table: Since carbon atom has four electrons placed in the outermost shell, therefore it is placed in group IV of periodic table. Carbon is a non-metal present in the IIIrd period of the periodic table.

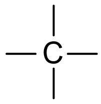
(ii) Covalent Bond Formation: Carbon has four electrons in its outermost shell. It can either gain or lose four electrons to achieve inert gas configuration to become stable.

(a) It could lose four electrons forming C^{4+} cation. But due to small size, four electrons already present are strongly held to the nucleus. 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.
Therefore, these four electrons are not lost.

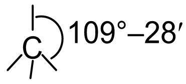
(b) It could gain four electrons forming C^{4-} anion. But it would be difficult for the nucleus with six protons to hold on to ten electrons i.e. four extra electrons. Therefore, it does not gain four electrons as well.

(c) Carbon overcomes this problem by sharing its valence electrons with other atoms of carbon or with atoms of other elements. By sharing of electrons, carbon atom can become stable. Thus, sharing of electrons (covalent bonding) which is responsible for various properties of carbon.

(iii) Carbon is Tetravalent: Since carbon has four electrons in its outmost shell and each C-atom requires four electrons to share, so, valency of C is 4 which can be represented as



(iv) Carbon is Tetrahedral: The four valencies of carbon do not lie in a plane but are directed towards the four corners of a regular tetrahedron i.e. carbon is tetrahedral. The angle between any two adjacent valencies is 109° - 28′



The angle of 109° - 28′ is also called tetrahedral angle.

2. TYPES OF CHEMICAL BONDS

There are two types of chemical bonds :

(i) Ionic bond, and

(ii) Covalent bond.

Ionic bonds are formed by the transfer of electrons from one atom to another whereas covalent bonds are formed by the sharing of electrons between two atoms. Ionic bond is also called electrovalent bond.

2.1 IONIC BOND

The chemical bond formed by the transfer of electrons from one atom to another is known as an ionic bond. The transfer of electrons takes place in such a way that the ions formed have the stable electron arrangement of an inert gas. The ionic bond is called so because it is a chemical bond between oppositely charged ions.

When a metal reacts with a non-metal, transfer of electrons takes place from metal atoms to the non-metal atoms, and an ionic bond is formed.

The compounds containing ionic bonds are called ionic compounds. Ionic compounds are made up of ions. Lets understand with the help of example.

Formation of Sodium Chloride.

Atomic number of sodium (Na) = 11

∴ Its electronic configuration is 2, 8, 1.

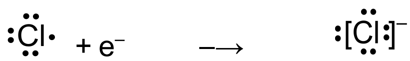
It has only one electron in the valence shell. It loses this electron to acquire the stable electronic configuration 2, 8 (similar to that of neon) and form sodium ion (Na^+).

$$\underset{\substack{\text{Sodium atom}\\(2,\,8,\,1)}}{Na^{\times}} \longrightarrow \underset{\substack{\text{Sodium ion}\\(2,\,8)}}{Na^{+}} + e^{-}$$

Atomic number of chlorine (Cl) = 17

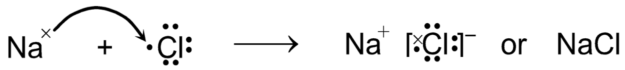
∴ Its electronic configuration is 2, 8, 7.

It has seven electrons in the valence shell. It gains one electron to acquire the stable electronic configuration 2, 8, 8 (similar to that of argon) and form chloride ion (Cl^-)



Chlorine atom (2, 8, 1) — Chloride ion (2, 8)

Thus, when a sodium atom and a chlorine atom approach each other, an electron is transferred from sodium atom to chlorine atom. In other words, sodium loses one electron to form Na^+ ion and chlorine gains that electron to form Cl^- ion. As a result, both acquire the stable nearest noble gas configuration. These oppositely charged ions are then held together by electrostatic forces of attraction forming the compound Na^+Cl^- or simply written as NaCl. The transfer of electron may be represented in one step as follows:



Sodium atom	Chlorine atom	Sodium chloride
(2, 8, 1)	(2, 8, 7)	

2.2 COVALENT BOND

The chemical bond formed by the sharing of electrons between two atoms is known as a covalent bond. The sharing of electrons takes place in such a way that each atom in the resulting molecule gets the stable electron arrangement of an inert gas.

Whenever a non-metal combines with another non-metal, sharing of electrons takes place between their atoms and a covalent bond is formed. A covalent bond can also be formed between two atoms of the same non-metal.

Covalent bonds are of three types :

(i) Single covalent bond

(ii) Double covalent bond

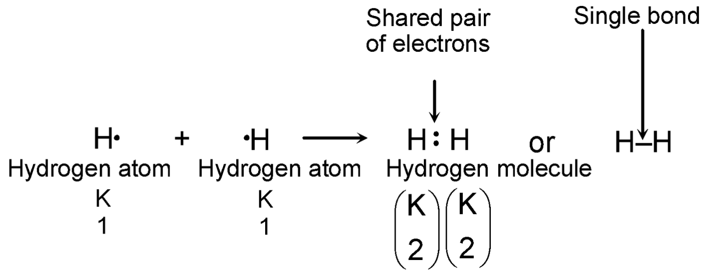
(iii) Triple covalent bond

(i) Single covalent Bond

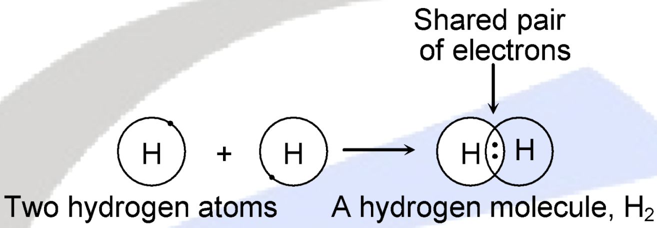
Single bond is formed by the sharing of one pair of electrons between two atoms. A single covalent bond is formed by the sharing of two electrons between the atoms, each atom contributing one electron for sharing.

For example, a hydrogen molecule H_2, contains a single covalent bond and it is written as H : H, the two dots drawn between the hydrogen atoms represent a pair of shared electrons which constitutes the single bond. A single covalent bond is denoted by written as H–H.

Formation of a Hydrogen Molecule, H_2 : A hydrogen atom is very reactive and cannot exist free because it does not have the stable, inert gas electron arrangement. So, hydrogen gas does not consist of single atoms, it consists of more stable H_2 molecules. The atomic number of hydrogen is 1, so its electronic configuration is K 1. Hydrogen atom has only one electron in the outermost shell (which is K shell), and this is not a stable arrangement of electrons. A stable arrangement is to have two electrons in the K shell because then the helium gas electron structure will be achieved. Thus, a hydrogen atom needs one more electron to become stable. It gets this electron by sharing with another hydrogen atom. So, two hydrogen atoms share one electron each to form a hydrogen molecule.



The formation of a hydrogen molecule from two hydrogen atoms can be shown by the following diagram:



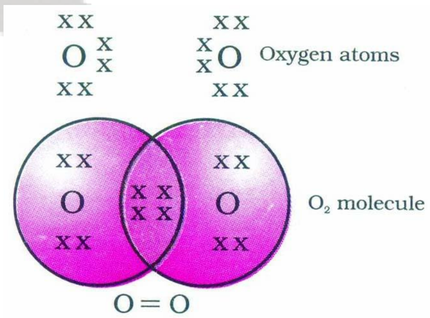
(ii) Double covalent Bond

Double bond is formed by the sharing of two pairs of electrons between two atoms. A double covalent bond is formed by the sharing of four electrons between two atoms, each atom contributing two electrons for sharing.

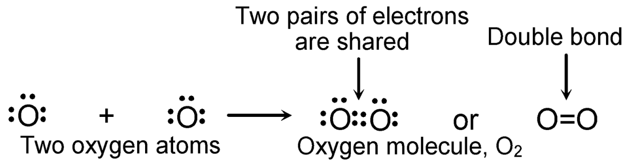
It is represented by putting two short line (=) between the two atoms. For example, oxygen molecule, O_2, contains a double bond between two atoms and it can be written as O=O.

Formation of Oxygen Molecule, O_2 : Oxygen atom is very reactive and cannot exist free because it does not have the stable, inert gas electron arrangement in its valence shell. The atomic number of oxygen is 8, so its electronic configuration is 2, 6. Thus, an oxygen atom has six electrons in its outermost shell. It requires two more electrons to achieve the stable, eight electron inert gas configuration. The oxygen atom gets these electrons by sharing its two electrons with the two electrons of another oxygen atom. So, two oxygen atoms share two electrons each and form a stable oxygen molecule.

The formation of a oxygen molecule from two oxygen atoms can be shown by the following diagram :



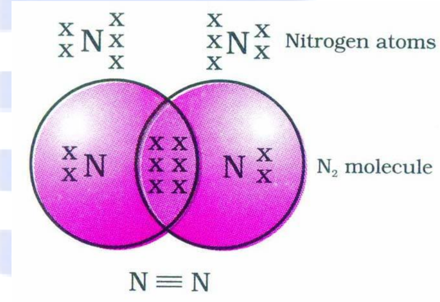
Thus, in the oxygen molecule, the two oxygen atoms are held together by a double bond.



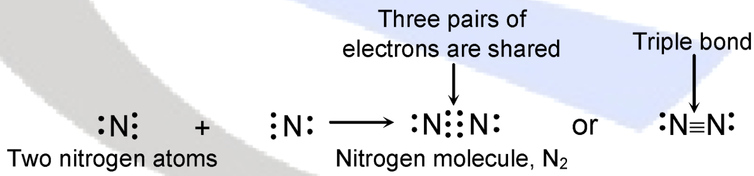
(iii) Triple covalent Bond

A triple bond is formed by the sharing of three pairs of electrons between two atoms. A triple bond is formed by the sharing of six electrons between two atoms, each atom contributing three electrons for sharing. A triple bond is actually a combination of three single bonds, so it is represented by putting three short line (≡) between the two atoms. Nitrogen molecule, N_2, contains a triple bond, so it can be written as N ≡ N.

Formation of a Nitrogen Molecule, N_2 : A nitrogen atom is very reactive and cannot exist free because it does not have the stable electron arrangement of an inert gas. The atomic number of nitrogen is 7, so its electronic configuration is 2, 5. This means that a nitrogen atom has five electrons in its outermost shell. Since a nitrogen atom has five electrons in its outermost shell, it needs three more electrons to achieve the eight electron structure of an inert gas and become stable. So, two nitrogen atoms combine together by sharing three electrons each to form a molecule of nitrogen gas.

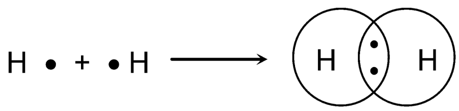


Thus, in the nitrogen molecule, the two nitrogen atoms are held together by a triple bond.



2.3 COMPARISON OF PROPERTIES OF IONIC AND COVALENT COMPOUNDS

Some main points of difference are given in the following table :

1. **Mode of formation.** They are formed by complete transfer of electrons from one atom to the other. $Na\times + \cdot\ddot{\underset{\cdot\cdot}{Cl}}: \longrightarrow Na^{+}\left[\times\ddot{\underset{\cdot\cdot}{Cl}}:\right]^{-}$	1. **Mode of formation.** They are formed by mutual sharing of electrons between the two atoms. For example.  Hydrogen molecule

	Thus, covalent compounds consist of molecules.
2. Physical state. Ionic compounds are generally solids. For example, NaCl (sodium chloride), MgO (magnesium oxide), Na_2O (sodium oxide), $MgCl_2$ (magnesium chloride), etc.	**2. Physical state.** These compounds may be solids, liquids and gases. For example, Cl_2 (chlorine) is a gas, Br_2 (bromine) is a liquid while I_2 (iodine) is a solid.
3. Melting points and boiling points. Due to strong forces of attraction between positive and negative ions, the melting points and boiling points of ionic compounds are quite high.	**3. Melting points and boiling points.** Due to weak intermolecular forces of attraction, covalent compounds generally have low melting and boiling points.
4. Solubility. '*Like dissolves like*' is the general rule of solubility. Thus, ionic compounds being polar are more soluble in polar solvents like water but are insoluble in non-polar or organic solvents such as alcohol, benzene, petrol, ether, chloroform, etc.	**4. Solubility.** Covalent compounds being non-polar are generally insoluble in polar solvents like water but are soluble in non-polar or organic solvents like alcohol, benzene, petrol, ether, chloroform, etc.
5. Electrical conductivity. Ionic compounds do not conduct electricity in the solid state but do so in the molten state or in their aqueous solutions. For example, solid sodium chloride does not conduct electricity because Na^+ and Cl^- ions are strongly attracted by each other. However in molten state NaCl splits to form Na^+ and Cl^- ions. Similarly, in water, sodium chloride ionizes to form Na^+ (aq) and Cl^- (aq). Since ions carry current, therefore, sodium chloride conducts electricity both in the molten state as well as in the aqueous solution.	**5. Electrical conductivity.** Covalent compounds do not contain ions and hence are generally bad conductors of electricity.
6. Nature of reactions. Ionic compounds undergo ionic reactions which are very fast, almost instantaneous and always proceed to completion. For example, $\underset{\text{Silver nitrate}}{AgNO_3\,(aq)} + \underset{\text{Sodium chloride}}{NaCl\,(aq)} \longrightarrow \underset{\substack{\text{Silver chloride}\\ \text{(white ppt.)}}}{AgCl\,(s)\downarrow} + \underset{\text{Sodium nitrate}}{NaNO_3\,(aq)}$	**6. Nature of reactions.** Covalent compounds undergo molecular reactions which are slow and never proceed to completion. For example, $\underset{\text{Methane}}{CH_4(g)} + \underset{\text{Chlorine}}{Cl_2(g)} \xrightarrow[\text{sunlight}]{\text{Diffused}} \underset{\text{Methyl chloride}}{CH_3Cl(g)} + \underset{\text{Hydrogen chloride}}{HCl(g)}$

3. OCCURENCE OF CARBON

- Free State
  - Diamond
  - Graphite
- Combined State
  - CO_2 (in air)
  - Fossil Fuels (like coal and petroleum)
  - Carbonates (in limestone, marble, chalk)
  - Organic compounds (like carbohydrates fats, proteins)

3.1 ALLOTROPES OF CARBON

The phenomenon of existence of an element in two or more forms which have different physical properties but identical chemical properties is called allotropy and the different forms are called allotropic forms or simply allotropes.

Carbon occurs in three crystalline allotropic forms. These are :

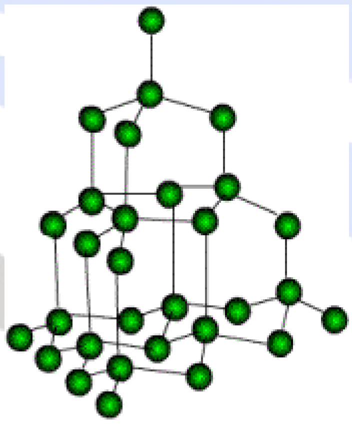
1. Diamond 2. Graphite 3. Fullerenes

All these three allotropes are the *purest form of carbon. They have the same chemical properties.*

For example, when diamond, graphite or fullerene is burnt in air, a colourless and odourless gas called carbon dioxide (CO_2) is formed which turns lime water milky.

3.1.1 Diamond

Occurrence : Although diamonds occur in nature, they have also been synthesized by subjecting pure carbon to very high pressure (50,000 – 60,000 atmospheres) and high temperature (1873 K). The synthetic diamonds are small in size but are otherwise indistinguishable from natural diamonds.



Structure of Diamond

Structure : In diamond, each carbon atom is attached to four other carbon atoms by strong single covalent bonds which are 1.54 Å (154 pm) long. The four surrounding carbon atoms lie at the four vertices (corners) of a regular tetrahedron. The angle between any two adjacent carbon atoms is 109°–28′ which is also called the **tetrahedral angle.** This tetrahedral arrangement of carbon atoms gives diamond a rigid three-dimensional network structure. Thus, *a crystal of diamond is a giant molecule consisting of only carbon atoms.*

Physical Properties

(i) **Hardness.** The three-dimensional network structure of diamond makes it the hardness natural substance known. It is because of this hardness, diamond is used for drilling, grinding and polishing equipments like rock borers, glass cutters, dies, etc.

(ii) **High density :** Due to network structure, the carbon atoms in diamond are closely packed and hence diamond has a high density.

(iii) **High melting point :** A large amount of energy is needed to break the network structure of diamond. Therefore, the melting point of diamond is quite high (3930°C or 4203 K).

(iv) **Electrical and Thermal conductivity :** Since all the four valence electrons are firmly held in carbon-carbon single bonds, there are *no free electrons* in a diamond crystal. Therefore, diamond is a bad conductor of electricity.

(v) **Transparency :** Because of high refractive index (2.5), diamonds can reflect and refract light. As a result, diamonds are transparent substances.

Uses :

(i) Because of hardness, diamonds are used for cutting glass, making borers for drilling rocks and for making abrasives.

(ii) Diamonds are used for making 'dies' for drawing thin wires from metals.

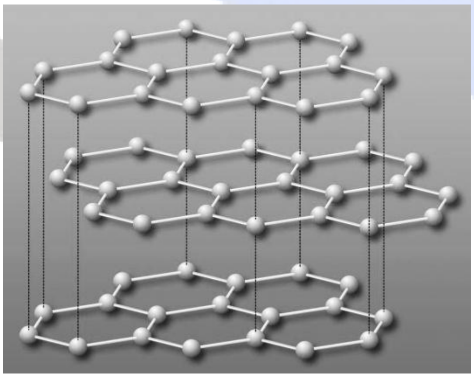
(iii) When diamond is cut and polished, brilliant light is refracted from their surfaces. That is why diamonds are used for making precious gems and jewellery.

(iv) Sharp edged diamonds are used as a tool by eye surgeons to remove cataract from eyes with great precision.

3.1.2 Graphite

Occurrence : Graphite is a grayish black substance. It occurs in nature mixed with mica, quartz and silica. It is also prepared artificially from carbon in an electric furnace at 2273–2773 K.

$$\underset{\text{Carbon}}{3C} + \underset{\text{Silica}}{SiO_2} \xrightarrow{2273\text{ K}} \underset{\text{Silicon carbide}}{SiC} + 2CO \xrightarrow{2273\text{ K}} \underset{\text{Graphite}}{3C} + \underset{\text{Silicon}}{Si(g)}$$



Structure of Graphite

Structure : The structure of graphite is altogether different from that of diamond. A graphite crystal actually consists of sheets or layers of carbon atoms.

Each carbon atom in a graphite layer is bonded to three other carbons in the same plane forming hexagonal rings. To satisfy the fourth valency of carbon, each hexagonal ring has three alternate single and double bonds. Thus, unlike diamond, *graphite has a two-dimensional sheet like (layered) structure, consisting of a number of benzene rings fused together.* The various sheets or layers are held together by weak *van der Waals* forces (or surface forces) or attraction. The distance between any two successive layers is 340 pm.

Physical properties

(i) **Low density :** Due to wide spacing (340 pm) between the two layers, the carbon atoms in graphite are less closely packed and hence the density of graphite (2.22 g cm^{-3}) is much lower than that of diamond.

(ii) **Softness :** The various layers of carbon atoms in graphite are held together by weak *van der Waals* forces of attraction. Therefore, one layer can easily slide over the other. This makes graphite soft and hence a useful dry (solid) lubricant for heavy machinery.

(iii) **Electrical and thermal conductivity :** Carbon has four valence electrons. But in a graphite crystal, each carbon atom is joined to three other carbon atoms by covalent bonds to form hexagonal rings. Thus, only three valence electrons are used for bond formation and hence the fourth valence electron is free to move. As a result, graphite is a good conductor of heat and electricity.

Uses :

(i) Due to its softness, powdered graphite is used either as a solid or dry lubricant or mixed with petroleum jelly as graphite grease. Since graphite is non-volatile, it can also be used as a lubricant for heavy machinery operating at very high temperatures.

(ii) Graphite is soft and black in colour and marks paper black. Mixed with desired quantity of wax or clay, graphite is used for making the cores of lead pencils.

(iii) Being a good conductor of electricity, graphite is used for making electrodes for dry cells and electric accessories. The carbon brushes of electric motors are also made up of graphite.

3.1.3 Difference between Diamond and Graphite

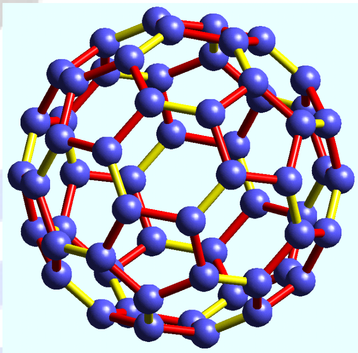
Some main points of difference between the properties of diamond and graphite are given below :

1. Diamond has a three-dimensional network structure.	**1.** Graphite has a two-dimensional sheet like structure consisting of a number of benzene rings fused together.
2. It is the hardest natural substance known.	**2.** Graphite is soft and greasy and is used as solid lubricant for heavy machinery operating at high temperatures.
3. It is a bad conductor of electricity but is a very good conductor of heat. Because of hardness and high thermal conductivity, diamond tipped tools do not overheat and hence are	**3.** It is a good conductor of both heat and electricity. Because of high electrical conductivity, graphite is used for making electrodes of battery and arcs.

extensively used for cutting and drilling purposes.	
4. It is a transparent substance with high refractive index. Therefore, it is used for making gemstones and jewellery.	**4.** It is an opaque grayish black substance.

3.1.4 Fullerenes

Fullerenes are a new class of carbon allotropes. They are spheroidal in shape and contain even number of carbon atoms ranging from 60 – 350 or above. The C_{60} fullerene is the most stable and was the first to be identified. It contains 60 carbon atoms which are arranged in the shape of a football or a soccer ball, therefore, it is also called **buckyball.** It contains 20 six-membered rings and 12 five-membered rings.



The structure of C-60 Buckminsterfullerene

These allotropes look like dome shaped halls designed by the US architect Buckminster Fuller for larger international exhibition. Therefore, they are called **Buckminster fullerenes** or simply **fullerenes.**

Physical properties : Buckminster fullerene is a dark solid at room temperature. Unlike diamond and graphite which are giant molecules containing thousands and thousands of carbon atoms, C_{60} fullerene is a very small molecule containing only 60 carbon atoms.

Another physical property in which the three allotropes differ from one another is their hardness. Whereas diamond is extremely hard, graphite is soft. Buckminster fullerene, on the other hand, is neither very hard nor very soft.

3.2 VERSATILE NATURE OF CARBON

(a) The number of carbon compounds whose formulae are known to chemists was recently estimated to be about three million. This out numbers by a large margin the compounds formed by all the other elements put together. Why is it that this property is seen in carbon and no other elements.

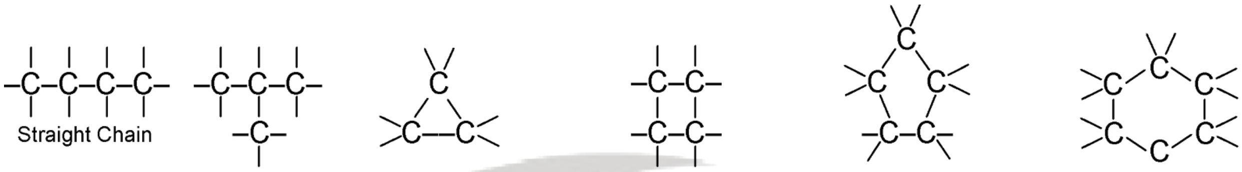
It is due to its following unique properties :

3.2.1 Catenation

Carbon atoms have a unique ability to combine with one another to form chains. This property is called **catenation.** The valency of each carbon atom can be satisfied by combining with other carbon atoms. In this way, an indefinite number of carbon atoms can unite with one another to form molecules.

This property of catenation is due to

(a) Small size
(b) Unique electronic configuration
(c) Great strength of carbon-carbon bonds.
The chains formed by carbon-carbon bonding may be straight, branched of varying lengths or cyclic (resigns) of different sizes.



For example, carbon forms compounds with hydrogen in which hundreds of carbon atoms can be joined together. These compounds of carbon and hydrogen called **hydrocarbons** are very stable. On the other hand, silicon also forms compounds with hydrogen which contain chains only upto seven or eight silicon atoms. These compounds of silicon and hydrogen called **silanes** are, however, very reactive. This is mainly due to the reason that carbon-carbon bonds are much stronger (355 kJ mol^{-1}) than silicon-silicon (200 kJ mol^{-1}) bonds.

3.2.2 Tetracovalency of carbon

Carbon has a valency of four. Therefore, it is capable of bonding four other atoms of carbon or atoms of some other monovalent elements. Further, due to small size, the nucleus of carbon atom can hold its shared pairs of electrons strongly. As a result, the bonds that carbon forms with most of the other elements such as hydrogen, oxygen, nitrogen, sulphur, chlorine, etc. are very strong thereby making these compounds exceptionally stable. This further increases the number of carbon compounds.

3.2.3 Tendency to form multiple bonds

Due to small size, carbon also forms multiple (double and triple) bonds with other carbon atoms, oxygen, and nitrogen. This multiplicity of carbon-carbon, carbon-oxygen and carbon-nitrogen bonds further increases the number of carbon compounds.

3.2.4 Isomerism

Another reason for huge number of carbon compounds is the phenomenon of isomerism.
If a given molecular formula represents two or more structures having different properties, the phenomenon is called isomerism and the different structures are called isomers.
For example, the formula C_4H_{10} represents two structures, the formula C_5H_{12} represents three structures and the formula C_4H_{14} represents five structures. The number of different structures with the same molecular formula further increases the number of carbon compounds.

4. ORGANIC COMPOUNDS

Since ancient times, minerals, plants and animals are the three major sources of naturally occurring substances. But it was only in the eighteenth century that these compounds were divided into two classes namely, Organic and Inorganic. Compounds like urea, sugar, oils, fats, dyes, proteins, vitamins, etc. which were isolated directly or indirectly from living organisms, such as animals and plants, were called Organic Compounds and the branch of chemistry which dealt with the study of these compounds was called **Organic Chemistry**.

Compounds like common salt, marble, alum, potassium nitrate, copper sulphate (blue vitriol), ferrous sulphate (green vitriol), zinc sulphate (white vitriol), etc., which were isolated from non-living sources, such as rocks and minerals, were called Inorganic Compounds and the branch of chemistry which dealt with the study of these compounds was called **Inorganic Chemistry**.

Vital Force Theory

Until early nineteenth century, it was believed that organic compounds cannot be prepared in the laboratory but can only be isolated from animals and plants. On the basis of this belief, **Berzelius,** a leading Swedish chemist in 1815, proposed **Vital Force Theory.** According to this theory, ***organic compounds are produced only under the influence of some mysterious force existing in the living organisms. This mysterious force was called the vital force.***

Wohler's Synthesis

In 1828, **Friedrich Wohler,** a German chemist, made an interesting discovery. He accidentally prepared **urea,** a well known organic compound isolated from the urine of man and other mammals. It was prepared by evaporating an aqueous solution of ammonium cyanate, an inorganic compound.

This synthesis gave a death blow to Vital Force Theory and clearly demonstrated that *no mysterious force was required in the formation of organic compounds in the laboratory.*

Modern Definition of Organic Compounds

With the downfall of **Vital Force Theory,** the term organic (pertaining to life) lost its original meaning. However, it was shown that all organic compounds whether **natural** or **synthetic** always contain carbon and hydrogen and sometimes as few other elements such as oxygen, nitrogen, sulphur, halogens and phosphorus. Thus, organic compounds are now defined as

Compounds of carbon containing usually hydrogen and one and more other elements such as oxygen, nitrogen, sulphur, halogens, phosphorus, etc. are called **Organic Compounds** *and the branch of chemistry which deals with the study of organic compounds is called* **Organic Chemistry.**

Types of Organic Compounds

Some common types of organic compounds are :

1. Hydrocarbons
2. Haloalkanes
3. Alcohols
4. Aldehydes
5. Ketones
6. Carboxylic acids

4.1 HYDROCARBONS

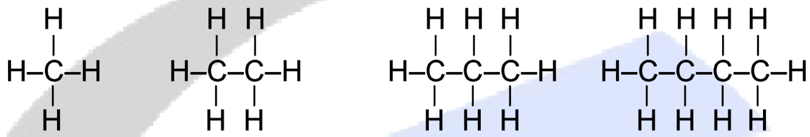
Carbon and Hydrogen combine in different proportions to form a large number of compounds called hydrocarbons.

4.1.1 Types of Hydrocarbons

There are two types of hydrocarbons : saturated and unsaturated.

(a) Saturated Hydrocarbons (Alkanes)

Hydrocarbons in which the four valencies of each carbon atom present in the molecule are fully satisfied are known as saturated hydrocarbons. In other words, the hydrocarbons, in which the carbon atoms are connected only by single bonds are called saturated hydrocarbons. For example, methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}) are saturated hydrocarbons.



methane ethane propane propane

Saturated hydrocarbons are also called *paraffins* or *alkanes.* They are represented by the general formula C_nH_{2n+2}, where n = number of carbon atoms in a molecule of the alkane.

When n = 1, the alkane is methane (CH_4).

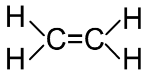
When n = 2, the alkane is ethane (C_2H_6) and so on.

The first ten members of the alkane series are listed below along with their molecular formulae and boiling points.

Name	**Condensed formula**	**Molecular formula**	**b.p. (°C)**
Methane	CH_4	CH_4	–64
Ethane	CH_3CH_3	C_2H_6	–89
Propane	$CH_3CH_2CH_3$	C_3H_8	–45
Butane	$CH_3CH_2CH_2CH_3$	C_4H_{10}	0.6
Pentane	$CH_3CH_2CH_2CH_2CH_3$	C_5H_{12}	36
Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	C_6H_{14}	69
Heptane	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	C_7H_{16}	98
Octane	$CH_3CH_2CH_2CH_2CH_2CH_2\ CH_2CH_3$	C_8H_{18}	126
Nonane	$CH_3CH_2CH_2CH_2CH_2CH_2\ CH_2\ CH_2CH_3$	C_9H_{20}	151
Decane	$CH_3CH_2CH_2CH_2CH_2CH_2\ CH_2\ CH_2\ CH_2CH_3$	$C_{10}H_{22}$	174

(b) Unsaturated hydrocarbons

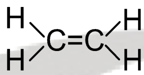
Hydrocarbons, in which the four valencies of a carbon atom present in the molecule are not fully satisfied are called unsaturated hydrocarbons. In other words, hydrocarbons in which two carbon atoms in the molecule are joined by a double (=) or triple (≡) bond, are called unsaturated hydrocarbons. For example,


ethylene

H–C≡C–H
acetylene

There are two types of unsaturated hydrocarbons :

(i) Alkenes Unsaturated hydrocarbons, the molecules of which contain a double bond between two carbon atoms, are called alkenes. In an alkene, the unsaturation is due to the presence of double bond. For example, ethylene (C_2H_4) and propylene (C_3H_6) are alkenes.


ethylene

H–C≡C–H
propylene

Alkenes are represented by the general formula, C_nH_{2n}, where n = number of carbon atoms in a molecule. When n = 2, the alkene is ethene or ethylene (C_2H_4), when n = 3, the alkene is propene or propylene (C_3H_6), and so on.

(ii) Alkynes : The molecules of hydrocarbons containing a triple bond between two carbon atoms are called alkynes. In an alkyne, the unsaturation is due to the presence of triple bond. They are represented by general formula C_nH2_{n-2},where n = number of carbon atoms in a molecule.

A few alkenes are listed below.

Name	Molecular formula	Condensed formula	Structural formula
Acetylene	C_2H_2	HC≡CH	H–C≡C–H
Methyl acetylene	C_3H_4	H_3C.C≡CH	H | H–C–C≡C–H | H
Dimethyl acetylene	C_4H_6	H H | | H–C–C≡C–C–H | | H H	H_3C.C≡C.CH_3

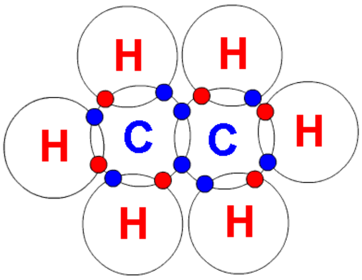
4.1.2 Structure of saturated and unsaturated hydrocarbons

(a) Structure of ethane (C_2H_6). To derive the structure of ethane, the following steps are followed.

Step 1. Link the two carbon atoms through a single bond, we have

C—C

Step 2. Satisfy the tetracovalency of each carbon by connecting the required number of hydrogen atoms to each carbon. Since in ethane, one valency of each carbon is satisfied by connecting the two carbon atoms together, therefore, attach three hydrogen atoms to each carbon, to satisfy the tetracovalency of carbon. Thus, the structure of ethane is



Electron dot structure of ethane

Such structures in which the bonds between different atoms are shown by dashes are called **complete structural formulae or graphic formulae or displayed formulae.** These structural formulae can be further abbreviated by omitting some or all the covalent bonds. For example, ethane may be written as CH_3—CH_3 or CH_3CH_3. These are called **condensed structural formulae.** The electron dot structure of ethane is shown in figure.

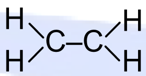
In a similar way, we can derive the structure of propane (figure) with the molecular formula, C_3H_8.

(b) Structure of ethene (C_2H_4). Another compound of carbon has the molecular formula, C_2H_4. It is called **ethene (ethylene).** Its structure can be derived by following the steps :

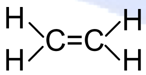
Step 1. Link the two carbon atoms together by a single bond, we have,

C—C

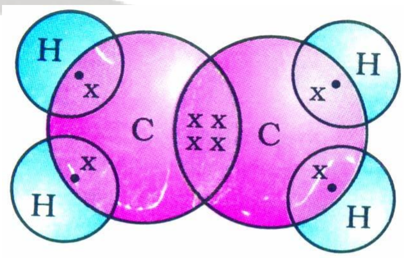
Step 2. Since there are a total of four hydrogen atoms, attach two hydrogen atoms to each carbon, we have,



Step 3. In the above formula, one valency of each carbon is free or unsatisfied. This can be satisfied if there is a double bond between the two carbon atoms. Thus, the graphic formula of ethene is



The electron dot structure of ethene is given in figure.



Electron dot structure of ethene

In ethene, the carbon atoms are held together by two pairs of electrons, therefore, a carbon-carbon double bond is shorter (134 pm) and stronger (599 kJ mol^{-1}) than a carbon-carbon single bond in ethane (bond length = 154 pm and bond strength = 348 kJ mol^{-1}).

(c) Structure of ethyne (C_2H_2). There is yet another compound of carbon and hydrogen having the molecular formula, C_2H_2. It is called **ethyne (acetylene).** Its structure can be derived following the steps :

Step 1. Link the two carbon atoms by a single bond, we have,

C—C

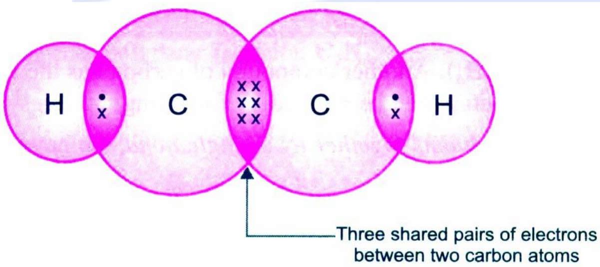
Step 2. Since there are only two hydrogens, attach one hydrogen to each carbon, we have,

H–C–C–H

Step 3. Now, two of the four valencies of each carbon are satisfied. In order to satisfy the remaining two valencies of each carbon, connect the two carbon atoms by a triple bond. Thus, the graphic formula of ethyne is

H–C≡C–H

The electron dot structure of ethyne is shown in figure below :

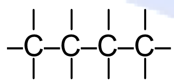


Electron dot structure of ethyne

In ethyne, the carbon atoms are held together by three pairs of electrons, therefore a carbon-carbon triple bond is even shorter (120 pm) and stronger (823 kJ mol^{-1}) than a carbon-carbon double bond.

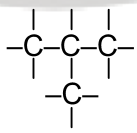
4.1.3 Types of carbon atom linkages

(i) Straight chain linkages : In these**,** linkages are straight with C-atoms.



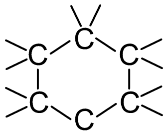
Straight Chain

(ii) Branched chain linkages : Chain of C-atoms are branched.



Branched Chain

(iii) Ring Type of closed chain linkages : C-atoms are closed to form rings.



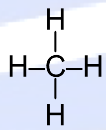
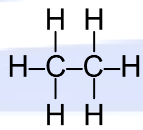
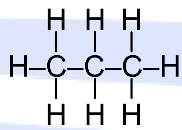
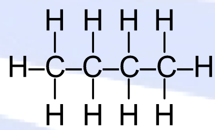
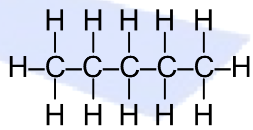
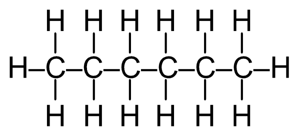
Six membered ring

4.1.4 Straight chain, Branched chain and cyclic compounds

(a) Straight chain compounds

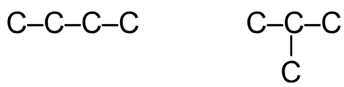
We have already read about the carbon compounds methane, ethane and propane containing respectively 1, 2 and 3 carbon atoms. Such chains of carbon atoms can contain tens of carbon atoms. The name and structures of six of them are mentioned as under :

Molecular Formulae and Structures of Saturated Compounds of Carbon and Hydrogen

No. of carbon atom	Name	Formula	Structure
1	Methane	CH_4	
2	Ethane	C_2H_6	
3	Propane	C_3H_8	
4	Butane	C_4H_{10}	
5	Pentane	C_5H_{12}	
6	Hexane	C_6H_{14}	

(b) Branched chain compounds

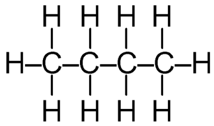
Butane has four carbon atoms. We can arrange these four carbon atoms in two different ways. The two possible carbon chains or skeletons are

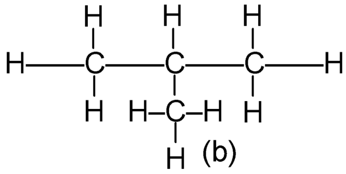


(a) (b)

Two possible carbon chains or skeletons.

Satisfying the remaining valencies of each carbon with hydrogen atoms, we get the following two structures having the molecular formula, C_4H_{10}


(a)


(b)

Complete structures of two molecules having the same molecular formula, C_4H_{10}.

Thus, we have two structures having the same molecular formula, C_4H_{10}. These are called structural isomers.

Thus, there are two structural isomers having the molecular formula, C_4H_{10}. The structure in which all the four carbon atoms are arranged in a straight line is called *n*-butane where the prefix '*n*' means **normal.**

Thus, carbon compounds in which no carbon atom of the chain is linked to more than two other carbon atoms are called straight chain compounds.

On the other hand structure in which one carbon atom is linked to three other carbon atoms is called isobutene. The prefix **'iso'** is used when there is one branch at the second carbon atom of the chain. Thus, carbon compounds in which atleast one carbon of the chain is linked to three or four other carbon atoms are called branched chain compounds.

Like saturated compounds, unsaturated compounds can also have either straight or branched chain structures. For example, structures (1–4) represent straight chain unsaturated compounds (hydrocarbons) while structures (5–6) represent branched chain unsaturated compounds (hydrocarbons).

$CH_3–CH_2–CH=CH_2$ (1)

$CH_3–CH=CH–CH_3$ (2)

$CH_3–CH_2–C\equiv CH$ (3)

$CH_3–C=C–CH_3$ (4)

$CH_3–\underset{\displaystyle |\atop CH_3}{C}=CH_2$ (5)

$CH_3–\underset{\displaystyle |\atop CH_3}{CH}–C\equiv CH$ (6)

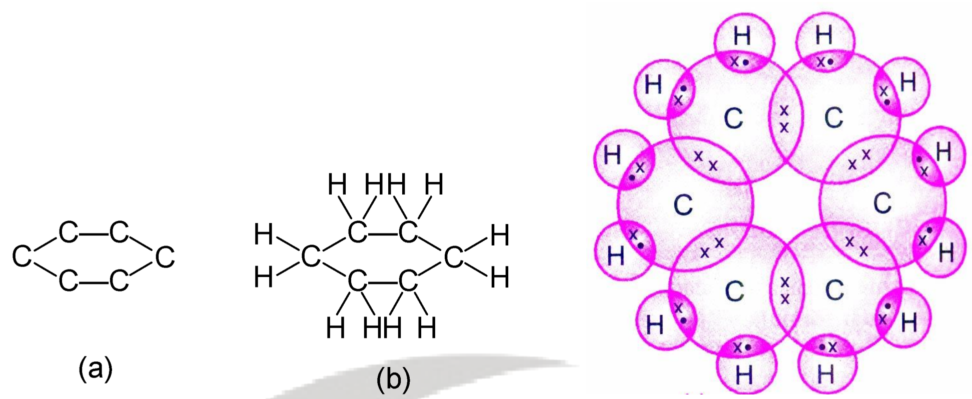
(c) Cyclic compounds

In addition to straight or branched chains, carbon atoms of some compounds can be arranged in a ring. Compounds of carbon in which carbon atoms are arranged in a ring are called cyclic compounds.

Like straight and branched chain compounds, cyclic compounds are also of the following two types :

(i) Saturated cyclic compounds

Cyclohexane with the molecular formula, C_6H_{12} is an example of a saturated cyclic compound (hydrocarbon).



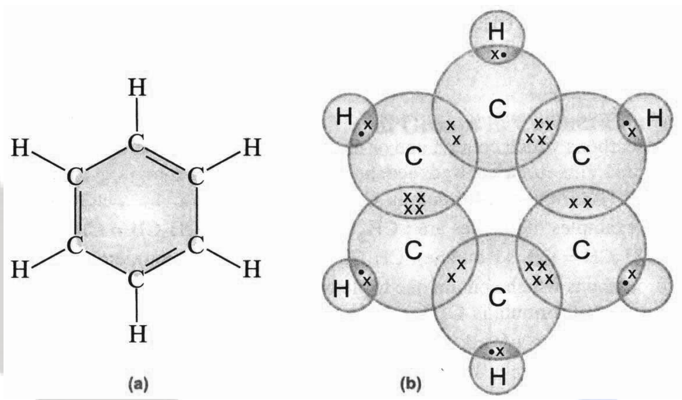
(a) (b) (c)

(a) Carbon skeleton (b) Complete structure (c) Electron dot structure of cyclohexane

A molecule of cyclohexane contains 6 carbon atoms arranged in a hexagonal ring with each carbon atom having 2 hydrogen atoms attached to it. Cyclohexane molecule has 6 carbon-carbon single bonds and 12 carbon-hydrogen single bonds. The saturated cyclic hydrocarbons are called 'cycloalkanes'.

Other examples of cyclic saturated compounds are cyclopropane, cyclobutane, cyclopentane, etc.

(ii) **Unsaturated cyclic compounds :** Benzene is an unsaturated cyclic compound. Its molecular formula is C_6H_6. It has three alternate single and double bonds between carbon atoms.



Complete structure

A molecule of benzene is made up of 6 carbon atoms and 6 hydrogen atoms. A benzene molecule has 3 carbon-carbon double bonds and 3 carbon-carbon single bonds. It also has 6 carbon-hydrogen single bonds.

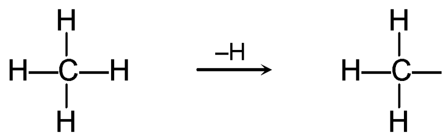
The unsaturated cyclic compounds like benzene are called *aromatic* compounds.

4.2 ALKYL GROUP

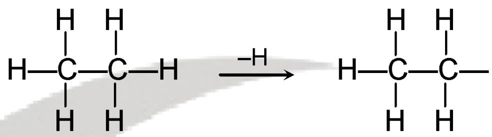
The group formed by the removal of one hydrogen atom from an alkane molecule is called an alkyl group.

Examples of alkyl group are methyl group (CH_3—) and ethyl group (C_2H_5—). Methyl group (CH_3—) is formed by the removal of one H atom from methane (CH_4); and ethyl group

(C_2H_5—) is formed by the removal of one H atom from ethane (C_2H_6). The structural formulae of the methyl group and ethyl group are :



methane methyl group



ethane Ethyl group

The free line (—) shown on the carbon atom of an alkyl group means that one valency of carbon atom is free in an alkyl group. The general formula of an alkyl group is C_nH_{2n+1} where n is the number of carbon atoms. The alkyl groups are usually denoted by the letter R.

4.3 NAMING OF HYDROCARBONS

Many organic compounds have two names :

(i) Trivial or common names : These names were given after the source from which the organic compounds were first isolated. For example, acetic acid got its name from **acetum** (Latin : **acetum** means vinegar) since it is present in vinegar.

(ii) IUPAC names : International Union of Pure and Applied Chemistry (IUPAC) have given certain rules to systematize the nomenclature of organic compounds. The names based upon these rules are called IUPAC names and are most widely used.

4.3.1 Naming straight-chain saturated hydrocarbons

1. A compound is named after the longest straight carbon chain in the molecule of the compound.
2. The prefix of a name indicates the number of carbon atoms present in the chain.

According to the number of carbon-atoms in a hydrocarbon the naming is done as :

Number of carbon atoms	Names as Prefix	Number of carbon atoms	Names as Prefix
1	meth-	6	hex-
2	eth-	7	hept-
3	prop-	8	oct-
4	but-	9	non-
5	pent-	10	dec-

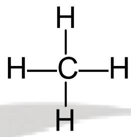
3. For saturated hydrocarbons, the suffix-ane is added to these prefixes as shown below :

Hydrocarbon	Number of carbon atoms	Prefix	Suffix	Name
CH_4	1	meth-	-ane	methane
C_2H_6	2	eth-	-ane	ethane

C_3H_8	3	prop-	-ane	propane
C_4H_{10}	4	but-	-ane	butane
C_5H_{12}	5	pent-	-ane	pentane
C_6H_{14}	6	hex-	-ane	hexane

For example,

1. **Naming of CH_4 :** The structure of CH_4 is

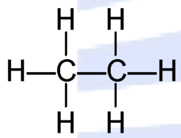


methane

This compound contains 1 carbon atom which is indicated by writing *'meth'.* This compound has all single bonds, so it is saturated. The saturated hydrocarbon is indicated by the ending *'ane'*. On joining *'meth'* and *'ane'*, the IUPAC name of this compound becomes *'methane'* (meth + ane = methane).

2. **Naming of C_2H_6 :** The structural formula of C_2H_6 is given below :

C_2H_6



Structural formula

or $CH_3—CH_3$

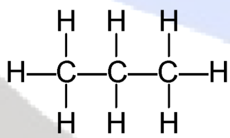
Condensed Structural formula

IUPAC name : Ethane
Common name : Ethane

This hydrocarbon contains 2 carbon atoms which are indicated by writing *'eth'*. This hydrocarbon has all single bonds, so it is saturated. The saturated hydrocarbon is indicated by using the suffix or ending *'ane'.* Now, by joining *'eth'* and *'ane',* the IUPAC name of the above hydrocarbon becomes *'ethane'* (eth + ane = ethane).

3. **Naming of C_3H_8 :** The structural formula of the C_3H_8 hydrocarbon is given below :

C_3H_8



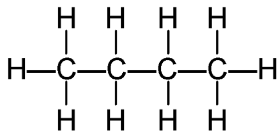
or $CH_3—CH_2—CH_3$

Condensed Structural formula

IUPAC name : Propane
Common name : Propane

This hydrocarbon contains 3 carbon atoms which are indicated by the word *'prop'.* This hydrocarbon has all single bonds, so it is saturated. The saturated hydrocarbon is indicated by using the ending *'ane'.* On joining *'prop'* and *'ane',* the IUPAC name of the above hydrocarbon becomes *'propane'* (prop + ane = propane).

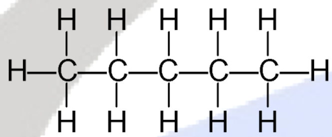
4. **Naming of C_4H_{10} :** One of the structural formula of C_4H_{10} hydrocarbon is given below :

C_4H_{10}  or $CH_3—CH_2—CH_2—CH_3$

IUPAC name : Butane
Common name : *n*-butane

This hydrocarbon has 4 carbon atoms in one continuous chain which are represented by the word *'but'.* This hydrocarbon has all single bonds, so it is saturated. A saturated hydrocarbon is represented by using the ending *'ane'.* So, joining *'but'* and *'ane',* IUPAC name of the above given hydrocarbon structure becomes *'butane'* (but + ane = butane).

5. **Naming of C_5H_{12} :** This hydrocarbon can have three possible structures. The simplest one is given below :

C_5H_{12}  or $CH_3—CH_2—CH_2—CH_2—CH_3$

IUPAC name : Pentane
Common name : *n*-pentane

This hydrocarbon has 5 carbon atoms in one continuous chain which are indicated by the word *'pent'.* This hydrocarbon has all single bonds, so it is saturated. A saturated hydrocarbon is indicated by using the ending *'ane'.* Now, by joining *pent* and *ane,* the IUPAC name of the above given hydrocarbon structure becomes *pentane* (pent + ane = pentane). The common name of this hydrocarbon is normal-pentane (which is written in short as *n*-pentane). Thus, **the IUPAC name of the above hydrocarbon is pentane but its common name is *n*-pentane.**

4.3.2 Naming branched-chain, saturated hydrocarbons

In order to name the saturated hydrocarbons having branched chains by the IUPAC method, we should remember the following rules :

1. The longest chain of carbon atoms in the structure of the compound (to be named) is found first. The compound is then named as a derivative of the alkane hydrocarbon which corresponds to the longest chain of carbon atoms (This is called parent hydrocarbon)..
2. The alkyl groups present as side chains (branches) are considered as substituents and named separately as methyl (CH_3—) or ethyl (C_2H_5—) groups.
3. The carbon atoms of the longest carbon chain are numbered in such a way that the alkyl groups (substituents) get the lowest possible number (smallest possible number).
4. The position of alkyl group is indicated by writing the number of carbon atom to which it is attached.
5. Thus, IUPAC name is given as
   Position and name of alkyl group + parent hydrocarbon
6. If two same alkyl derivatives are present on same carbon atom, then prefix 'di' or 'tri' can be used.

Lets understand with the help of few examples :

Example 1

$$\begin{array}{ccccc} 1 & & 2 & & 3 \\ CH_3 & — & CH & — & CH_3 \\ & & | & & \\ & & CH_3 & & \end{array}$$

The longest chain contains three C-atoms. The saturated hydrocarbon containing three carbon atoms is *propane.*

The methyl group (CH_3-) is attached to C-atom number 2 (numbering from either side gives number 2 to the C-atom to which the methyl group is attached).

Thus, the name of the compound is 2-methylpropane.

Example 2

$$\begin{array}{ccccccccc} 5 & & 4 & & 3 & & 2 & & 1 \\ CH_3 & — & CH_2 & — & CH_2 & — & CH & — & CH_3 \\ & & & & & & | & & \\ & & & & & & CH_3 & & \end{array}$$

The longest chain contains five C-atoms. The saturated hydrocarbon containing five C-atoms is pentane.

The numbering of C-atoms in the longest chain is done from the C-atom that is nearest to the methyl group which is present as the branched chain. Thus,

$$\begin{array}{ccccccccc} 5 & & 4 & & 3 & & 2 & & 1 \\ CH_3 & — & CH_2 & — & CH_2 & — & CH & — & CH_3 \\ & & & & & & | & & \\ & & & & & & CH_3 & & \\ & & & & & & \text{(correct)} & & \end{array}$$

This way of numbering is correct, but the way of numbering as shown below is wrong.

$$\begin{array}{ccccccccc} 1 & & 2 & & 3 & & 4 & & 5 \\ CH_3 & — & CH_2 & — & CH_2 & — & CH & — & CH_3 \\ & & & & & & | & & \\ & & & & & & CH_3 & & \\ & & & & & & \text{(wrong)} & & \end{array}$$

Hence, the correct name will be 2-methylpentane (and not 4-methylpentane).

Example 3

$$\begin{array}{ccccccccccc} 6 & & 5 & & 4 & & 3 & & 2 & & 1 \\ CH_3 & — & CH_2 & — & CH & — & CH_2 & — & CH & — & CH_3 \\ & & & & | & & & & | & & \\ & & & & CH_3 & & & & CH_3 & & \end{array}$$

The longest chain contains six C-atoms. The saturated hydrocarbon containing six C-atoms is hexane.

The methyl groups are attached to C-atom numbers 2 and 4. Hence, the name of this compound will be 2, 4-dimethylhexane.

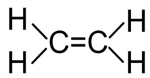
4.3.3 Naming unsaturated hydrocarbons containing a double bond

1. An unsaturated hydrocarbon containing a double bond between two adjacent carbon atoms is named by taking the prefix of the name of the corresponding saturated hydrocarbon and by replacing the suffix –ane by –ene.

2. The position of the double bond is indicated by a numerical prefix. This numerical prefix indicates the number of the carbon atom preceding the double bond.

Lets understand with the help of examples :

1. **Naming of C_2H_4 :** The common name is ethylene. The saturated hydrocarbon corresponding to two carbon atoms is ethane. C2H4 contains a double bond. Hence, the IUPAC name of this hydrocarbon will be ethene.



2. **Naming of C_4H_8 :** This unsaturated hydrocarbon is structurally represented as :

$$H_3\overset{4}{C}-\overset{3}{C}H_2-\overset{2}{C}H=\overset{1}{C}H_2$$

It has four carbon atoms in its molecule. The saturated hydrocarbon corresponding to four carbon atoms in butane. Since the molecule has a double bond, the IUPAC name of the compound is butene. As the double bond is preceded by carbon atom numbered 1, the IUPAC name of the compound will be 1-butene.

4.3.4 Naming unsaturated hydrocarbons containing a triple bond

An unsaturated hydrocarbon containing a triple bond between two adjacent carbon atoms is named by taking the prefix of the name of the corresponding saturated hydrocarbon and by replacing the suffix-ane by the suffix –yne.

For example,

1. **Naming of C_2H_2** The structure o this hydrocarbon is

$$H–C \equiv C–H$$

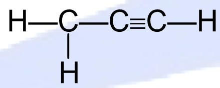
   The common name of this hydrocarbon is *acetylene*

   Acetylene contains two carbon atoms. The saturated hydrocarbon corresponding to two carbon atoms is ethane.

   As acetylene contains a triple bond, the suffix-*ane* of ethane is replaced by *–yne.*

   Thus, the IUPAC name of acetylene is *ethyne.*

2. **Naming of C_3H_4** The structure of this hydrocarbon is



   The common name of this hydrocarbon is *methyl acetylene* because it may be taken to be a derivative of acetylene in which one H atom has been replaced by a methyl group ($–CH_3$).

   This hydrocarbon contains three carbon atoms. The saturated hydrocarbon corresponding to three carbon atoms is propane. As it contains a triple bond, the suffix *–ane* of propane is replaced by *–yne.* Hence, the IUPAC name of methyl acetylene is *propyne.*

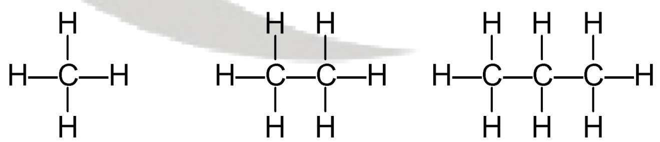
3. **Naming of C_4H_6** The structural representation of this unsaturated hydrocarbon is ,

$$\overset{4}{C}H_3—\overset{3}{C}H_2—\overset{2}{C}\equiv\overset{1}{C}H$$

   There are four carbon atoms in the molecule. The saturated hydrocarbon with the same number of carbon atoms is butane. There is a triple bond, so the IUPAC name of this hydrocarbon will be *1-butyne.*

4.4 ISOMERS

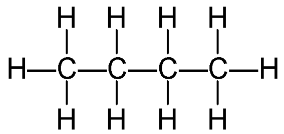
Let us consider the structural formulae of the first three members of the alkane series, i.e., the structural formulae of methane, ethane and propane.



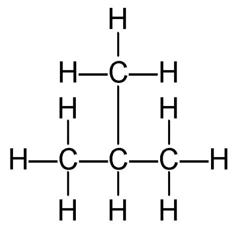
methane ethane propane

If the positions of carbon and hydrogen atoms in these molecules are rearranged, the same structural formulae are obtained. This means that the structural formulae of the first three members of the alkane series remain unchanged, even if the carbon and hydrogen atoms in them are rearranged.

Now consider the fourth member of the alkane series, i.e., butane. In butane, carbon and hydrogen atoms may be arranged differently to give different structures and, hence, different compounds.



n-butane



isobutane

Both *n*-butane and isobutene have the same molecular formula (C_4H_{10}) but their structures are different. In *n*-butane, the carbon atoms form a longer straight chain, while in isobutene, there is a shorter straight chain and a branch. In the straight chain (*n*-butane), no carbon atom is bonded to more than two carbon atoms, but in the branched chain (isobutene), one carbon atom is bonded to three other carbon atoms n-butane and isobutene are called *isomers.*

Organic compounds with the same molecular formula but different structural formulae are known as isomers.

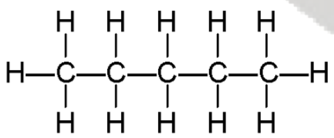
The existence of two or more compounds having the same molecular formula but different structural formulae is called isomerism.

4.4.1 Characteristics of isomers

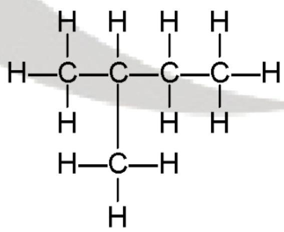
1. All the isomers of a compound have the same molecular formula.
2. The isomers of a compound have different structures.
3. The physical and chemical properties of all the isomers of a compound differ from one another.

4.4.2 For example,

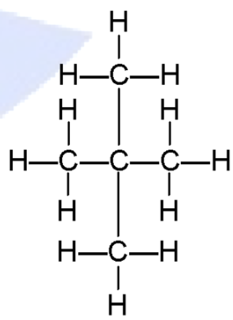
1. **Isomers of pentane :** The molecular formula of pentane is C_5H_{12}. Three isomers corresponding to this formula are possible.



Common Name : *n*-pentane
IUPAC Name : pentane

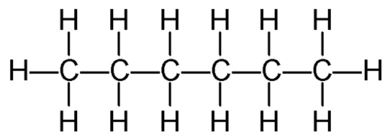


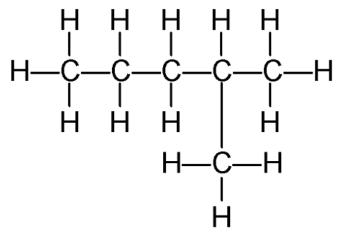
Common Name : iso pentane
IUPAC Name : 2-methyl butane

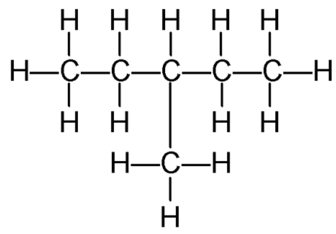


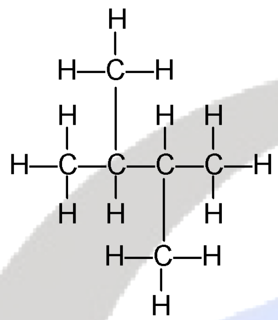
Common Name : neo pentane
IUPAC Name : 2,2-dimethyl propane

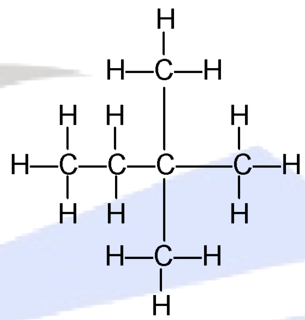
2. **Isomers of hexane :** The molecular formula of hexane is C_6H_{14}. Five isomers corresponding to this formula are possible.


I (*n*-hexane)


II (2-methyl pentane)


III (3-methyl pentane)


IV (2,3-dimethyl butane)


V (2,2-dimethyl butane)

4.5 Homologous Series

All the organic compounds having similar structures show similar properties and they are put together in the same group or series. In doing so, the organic compounds are arranged in the order of increasing molecular masses.

A homologous series is a group of organic compounds having similar structures and similar chemical properties in which the successive compounds differ by CH_2 group. The various organic compounds of a homologous series are called homologues.

For example :

The homologues of alkanes are represented by the general formula C_nH_{2n+2}. The homologues of alkanes are shown in table.

Homologues of alkanes

Compound	Molecular formula	Difference
Methane	CH_4	
Ethane	C_2H_6	
Propane	C_3H_8	—CH_2
Butane	C_4H_{10}	
Pentane	C_5H_{12}	
Hexane	C_6H_{14}	

The homologous series of alkenes and alkynes are shown in tables below :

Homologues of alkenes

Compound	Molecular formula	Difference
Ethene	C_2H_4	
Propene	C_3H_6	$—CH_2$
Butene	C_4H_8	
Pentene	C_5H_{10}	
Hexene	C_6H_{12}	

Homologues of alkynes

Compound	Molecular formula	Difference
Ethyne	C_2H_4	
Propyne	C_3H_6	$—CH_2$
Butyne	C_4H_6	
Pentyne	C_5H_8	
Hexyne	C_6H_{10}	

4.5.1 Characteristics of a Homologous Series

1. **All the members of a homologous series can be represented by the same general formula.** For example, all the members of the alkane series can be represented by the general formula C_nH_{2n+2}.
2. **Any two adjacent homologues differ by 1 carbon atom and 2 hydrogen atoms in their molecular formulae.** That is, any two adjacent homologues differ by a CH_2 group. For example, the first two adjacent homologues of the alkane series, methane (CH_4) and ethane (C_2H_6) differ by 1 carbon atom and 2 hydrogen atoms. The difference between CH_4 and C_2H_6 is CH_2.
3. **The difference in the molecular masses of any two adjacent homologues is 14 u.** For example, the molecular mass of methane (CH_4) is 16 u, and that of its next higher homologue ethane (C_2H_6) is 30 u. So, the difference in the molecular masses of ethane and methane is 30 – 16 = 14 *u*.
4. **All the compounds of a homologous series show similar chemical properties.** For example, all the compounds of alkane series like methane, ethane, propane, etc., undergo substitution reactions with chlorine.
5. **The members of a homologous series show a gradual change in their physical properties with increase in molecular mass.** For example, in the alkane series as the number of carbon atoms per molecule increases, the melting points, boiling points and densities of its members increase gradually as shown in the table below :

Alkanes	Formula	m.p. (°C)	b.p. (°C)	Density $g.cm^{-3}$(20°C)

Methane	CH_4	–183	–164	Gas
Ethane	C_2H_6	–172	–89	Gas
Propane	C_3H_8	–188	–45	Gas
Butane	C_4H_{10}	–135	–0.6	Gas
Pentane	C_5H_{12}	–130	36	0.625
Hexane	C_6H_{14}	–95	69	0.659

5. COMPOUNDS CONTAINING C, H AND O

We have studied earlier about the compounds containing C and H only is hydrocarbons. Now, well study about the compounds where carbon forms bonds with other elements such as halogens, oxygen, nitrogen, sulphur and phosphorus.

Organic molecules except hydrocarbons can be broadly divided into two parts :

A reactive part → Functional group

A skeleton of carbon and hydrogen atoms → Alkyl Radical

FUNCTIONAL GROUP

An atom or a group of atoms in an organic molecule that is responsible for the compound’s characteristic reactions and determines its properties is known as a functional group.

(i) The functional group in an organic molecule is the most reactive part of the molecule.

(ii) The chemical properties of an organic compound are determined by the functional group of its molecule while the physical properties of the compound are determined by the remaining part of the molecule.

Some of the important functional groups and their corresponding compounds are discussed below :

1. **Halo Group : –X (X can be Cl, Br or I)**

   The halo group can be chloro, —Cl; bromo, —Br ; or iodo, —I, depending upon whether a chlorine, bromine or iodine atom is linked to a carbon atom of the organic compound. The elements chlorine, bromine and iodine are collectively known as halogens, so the chloro group, bromo group and iodo group are called halo groups and represented by the general symbol —X. The halo group is present in chloromethane (CH_3—Cl), bromomethane (CH_3—Br) and iodomethane (CH_3—I). Halo group is also known as halogen group. The haloalkanes can be written as R—X (where R is an alkyl group and X is the halogen atom).

2. **Alcohol Group : —OH**

   The alcohol group is made up of one oxygen atom and one hydrogen atom joined together. The alcohol group is also known as alcoholic group or hydroxyl group. The compounds containing alcohol group are known as alcohols. The examples of compounds containing alcohol group are : methanol, CH_3OH, and ethanol, C_2H_5OH.

The general formula of an alcohol can be written as R—OH (where R is an alkyl group like CH_3, C_2H_5, etc., and OH is the alcohol group).

3. Aldehyde Group : **—CHO or $-\overset{\overset{\large O}{||}}{C}-H$ or $-\overset{\overset{\large H}{|}}{C}=O$**

The aldehyde group consists of one carbon atom, one hydrogen atom and one oxygen atom joined together. The oxygen atom of the aldehyde group is attached to the carbon atom. The carbon atom of the aldehyde group is attached to either a hydrogen atom or an alkyl group. The aldehyde group is sometimes called aldehydic group. The compounds containing aldehyde group are known as aldehydes. The examples of compounds containing an aldehyde group are : methanal, HCHO, and ethanal, CH_3CHO. The aldehydes can be represented by the general formula R—CHO (where R is an alkyl group).

4. Ketone Group : **C=O or $-\overset{\overset{\large O}{||}}{C}-$ or —CO—**

The ketone group consists of one carbon atom and one oxygen atom. The oxygen atom of the ketone group is joined to the carbon atom by a double bond. The carbon atom of the ketone group is attached to two alkyl groups (which may be same or different). The ketone group is sometimes called a ketonic group. The compounds containing ketone group are known as ketones. The examples of compounds containing ketone group are : propanone, CH_3COCH_3, and butanone, $CH_3COCH_2CH_3$.

5. Carboxylic Acid Group : **—COOH or $-\overset{\overset{\large O}{||}}{C}-OH$**

Carboxylic acid group is present in methanoic acid, H—COOH and ethanoic acid, CH_3—COOH. The carboxylic acid group is also called just carboxylic group or carboxyl group. The organic compounds containing carboxylic acid group (—COOH group) are called carboxylic acids or organic acids.

The functional groups are summarized in the table below :

S. No.	Hetero atom	Functional Group	Formula of a Functional Group	Class of Compounds
1.	O	Hydroxyl	—OH	Alcohols, R—OH
2.	O	Aldehydic	—CHO or $-\overset{\overset{\large O}{\|\|}}{C}-H$	Aldehydes, R—CHO
3.	O	Keto	—CO— or $-\overset{\overset{\large O}{\|\|}}{C}-$	Ketones, R—CO—R
4.	O	Carboxyl	—COOH or $-\overset{\overset{\large O}{\|\|}}{C}-OH$	Carboxylic acids, R—COOH

5.	Cl, Br	Halo (chloro, bromo)	—Cl, —Br	Haloalkanes, R—Cl, R—Br

5.1 HALOALKANES

When one hydrogen atom of an alkane is replaced by a halogen atom, we get haloalkane (also called halogenoalkane). For example, when one hydrogen atom of methane is replaced by a chlorine atom, we get chloromethane :

$$\underset{\text{Methane}}{CH_4} \xrightarrow{\text{Replace one H by Cl}} \underset{\substack{\text{Chloromethane}\\ \text{(A haloalkane)}}}{CH_3Cl}$$

Chloromethane is a haloalkane. The general formula of haloalkanes is C_nH_{2n+1} –X (where X represents Cl, Br or I).

5.1.1 Naming of Haloalkanes

There are two methods :

1. **The common method :** In this method the name of the parent alkyl group is combined with the word halide. For example, the common name of CH_3Cl is methyl chloride.
2. **The IUPAC System :** According to this system, haloalkanes are named after the parent alkane by using a prefix to show the presence of the halo group such as chloro (–Cl), bromo (–Br) or iodo (–I) group.

For example,

1. Naming of CH_3Cl

This compound contains 1 carbon atom so its parent alkane is methane, CH_4 (because methane also contains 1 carbon atom). This compound contains a chloro group (—Cl group) which is to be indicated by the prefix 'chloro'. So, by combining *chloro* and *methane* we get the name *chloromethane* (chloro + methane = chloromethane). Thus, the IUPAC name of CH_3Cl is chloromethane.

$$CH_3Cl \quad \text{or} \quad CH_3\text{—}Cl \quad \text{or} \quad \begin{array}{c} H \\ | \\ H\text{—}C\text{—}Cl \\ | \\ H \end{array}$$

IUPAC name : Chloromethane   Structure

The common name of chloromethane (CH_3Cl) is **methyl chloride.** Please note that CH_3Br will be bromomethane (or methyl bromide).

2. Naming of C_2H_5Cl

This compound contains 2 carbon atoms so its parent alkane is ethane. It also contains a chloro group. So, **the IUPAC name of C_2H_5Cl becomes chloroethane.**

$$C_2H_5Cl \quad \text{or} \quad CH_3\text{—}CH_2\text{—}Cl \quad \text{or} \quad \begin{array}{c} \;\;H\;\;\;H \\ \;\;|\;\;\;\;| \\ H\text{—}C\text{—}C\text{—}Cl \\ \;\;|\;\;\;\;| \\ \;\;H\;\;\;H \end{array}$$

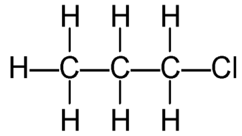
IUPAC name : Chloroethane   Structure

The common name of chloroethane is **ethyl chloride.**

3. Naming of C_3H_7Cl

This compound contains 3 carbon atoms so its parent alkane is propane. It also has a chloro group. So, **the IUPAC name of C_3H_7Cl becomes chloropropane.**

C_3H_7Cl or $CH_3—CH_2——CH_2—Cl$ or



IUPAC name : Chloropropane

Structure

The common name of chloropropane (C_3H_7Cl) is **propyl chloride.**

5.2 ALCOHOLS

Alcohols are a class of compounds which contain carbon, hydrogen and oxygen. Alcohol is obtained by the replacement of one hydrogen atom in an alkane by a hydroxyl group. For example, replacement of one hydrogen atom in methane by a hydroxyl group produces a new compound called methanol. Similarly, if one hydrogen atom in ethane is replaced by a hydroxyl group, we get ethanol.

$$\underset{\text{methane}}{CH_4} \xrightarrow[+OH]{-H} \underset{\text{methane}}{CH_3OH}$$

$$\underset{\text{ethane}}{C_2H_6} \xrightarrow[+OH]{-H} \underset{\text{ethanol}}{C_2H_5OH}$$

Functional group : —OH

General formula : R—OH

5.2.1 Naming of Alcohols

There are two methods of naming alcohols :

1. **Common method :** Name of the alkyl group + alcohol
2. **IUPAC system :** According to this system :

(a) Always start numbering from carbon atom of –OH group if it is the end carbon atom in the chain. If the hydroxyl group is not attached to the end carbon atom in the chain, the numbering starts from the end carbon atom in such a way that the carbon atom carrying the hydroxyl group has the smallest possible number.

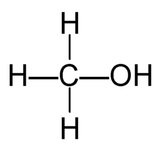
(b) 'e' of parent alkane is replaced by '*al'.*

i.e. Alkane –e + ol = Alkanol

For example

CH_3OH It contains 1 carbon atom, so its parent alkane is methane, CH_4. It also contains an alcohol group (OH group) which is indicated by using '*ol*' as a suffix or ending. Now, replacing the last *'e'* of methane by *'ol',* we get the name *methanol* (methan + ol = methanol). So, the IUPAC name of CH_3OH is methanol.

CH_3OH or

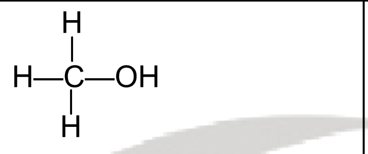
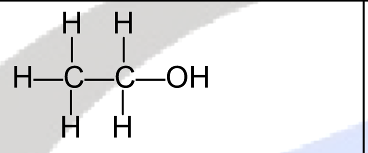
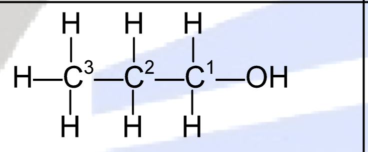
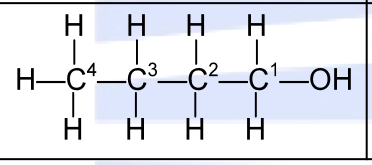


IUPAC name : Methanol

Structure

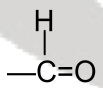
The common name of methanol is **methyl alcohol.**

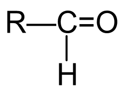
The name and structure of alcohols are summarized in the table below :

Molecular formula	Structural formula	IUPAC Name	Common Name
CH_3OH		Methanol	Methyl alcohol
C_2H_5OH		Ethanol	Ethyl alcohol
C_3H_7OH		1-Propanol	*n*-Propyl alcohol
C_4H_9OH		1-Butanol	*n*-Butyl alcohol

5.3 ALDEHYDES

Aldehydes are the organic compounds containing an aldehyde group (—CHO group) attached to a carbon atom. The two simple aldehydes are formaldehyde, HCHO (which is also called methanal) and acetaldehyde, CH_3CHO (which is also called ethanal). General molecular formula of aldehydes is $C_nH_{2n}O$ (where n is the number of carbon atoms in one molecule of the aldehyde). For example, if the number of carbon atoms in an aldehyde is 1, then n = 1, and its molecular formula will be $C_1H_{2\times1}O$ or CH_2O. This aldehyde must contain an aldehyde group, —CHO, so its chemical formula will be HCHO.

Functional group : 



General formula :

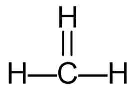
5.3.1 IUPAC Naming of aldehydes

1. Always start numbering from carbon atom of –CHO group.
2. ‘e’ of parent alkane is replaced by ‘*al*’.

i.e. Alkane –e + al = Alkanal

For Example,

1. **HCHO** : It contains 1 carbon atom, so its parent alkane HCHO also contains an aldehyde group (–CHO group) which is indicated by using *'al '* as suffix or ending. So, replacing the last *'e'* of methane by *'al'* we get the name *methanal* (methan + al = methanal). Thus, **the IUPAC name of HCHO is methanal.**

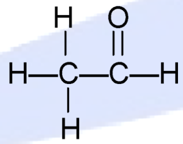
HCHO or H—CHO or 

IUPAC name : Methanal

Structure

The common name of methanal (HCHO) is **formaldehyde**.

2. **CH_3CHO** : It contains two carbon atoms, so its parent hydrocarbon is ethane. Thus, **the IUPAC name of CH_3CHO is ethanal.**

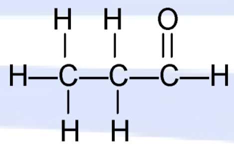
CH_3CHO or CH_3—CHO or 

IUPAC name : Ethanal

Structure

The common name of ethanal (CH_3CHO) is **acetaldehyde.**

3. **CH_3CH_2CHO** : It contains three carbon atoms, so its parent alkane is propane. Thus, **the IUPAC name of CH_3CH_2CHO is propanal.**

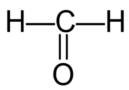
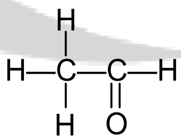
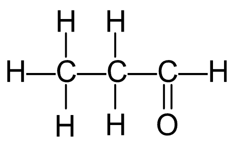
CH_3CH_2CHO or CH_3—CH_2—CHO or 

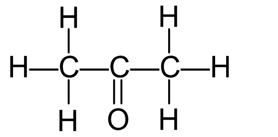
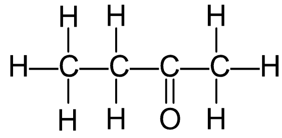
IUPAC name : Propanal

Structure

The common name of propanal (CH_3CH_2CHO) is **propionaldehyde.**

The name and structure of aldehydes are summarized in the table below :

	Molecular formula	**Structural formula**	**IUPAC Name**	**Common name**
Aldehydes	HCHO		Methanal	Formaldehyde
	CH_3CHO		Ethanal	Acetaldehyde
	CH_3CH_2CHO		Propanal	Propionaldehyde

Ketones	CH_3COCH_3		Propanone	Acetone
	$CH_3CH_2COCH_3$		Butanone	Ethyl methyl ketone

5.4 KETONES

Ketones are the carbon compounds (or organic compounds) containing the ketone group, —CO— group. Ketone group always occurs in the middle of a carbon chain, so a ketone must contain at least three carbon atoms in its molecule, one carbon atom of the ketone group and two carbon atoms on its two sides. There can be no ketone with less than three carbon atoms in it. The simplest ketone is acetone, CH_3COCH_3 (which is also known as propanone). This simplest ketone contains three carbon atoms in it (one carbon atom of the ketone group and two carbon atoms of the two methyl groups).

Functional group : $-\overset{\overset{\displaystyle O}{||}}{C}-$

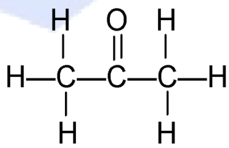
General Formula : $R-\overset{\overset{\displaystyle O}{||}}{C}-R$

5.4.1 IUPAC Naming

1. 'e ' of the parent alkane is replaced by 'one'.
   So, **IUPAC Name : Alkane –e + one = Alkanone**
2. Minimum numbering is given to the carbonyl group.

For Example,

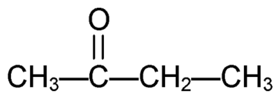
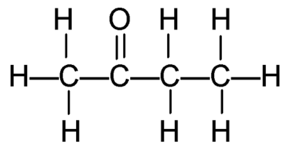
1. **CH_3COCH_3** : This contains three carbon atoms, so its parent alkane is propane. Thus, its IUPAC name is propanone. Its common name is acetone. Propanone is the simplest ketone.

CH_3COCH_3 or $CH_3-\overset{\overset{\displaystyle O}{||}}{C}-CH_3$ or 

IUPAC name : Propanone

Structure

2. **$CH_3COCH_2CH_3$. :** This compound contains 4 carbon atoms, so its parent alkane is butane. Thus, the IUPAC name of the compound $CH_3COCH_2CH_3$ is butanone.

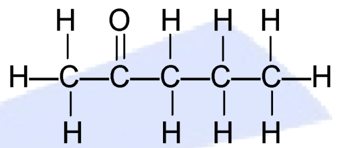
$CH_3COCH_2CH_3$ or  or 

IUPAC name : Butanone

Structure

The common name of butanone is ethyl methyl ketone.

3. **$CH_3COCH_2CH_2CH_3$:** This compound contains 5 carbon atoms, so its parent alkane is pentane. Thus, the IUPAC name of the compound $CH_3COCH_2CH_2CH_3$ is pentanone.

$CH_3COCH_2CH_2\ CH_3$ or 

IUPAC name : Pentanone

Structure

The common name of pentanone is **methyl propyl ketone.**

5.5 CARBOXYLIC ACIDS

Carboxylic acids are a class of organic compounds which contain carboxyl group (—COOH) as the functional group. This group is structurally represented as $-\overset{\overset{\large O}{||}}{C}-OH$.

Thus, carboxyl group is a combination of the carbonyl ($-\overset{\overset{\large O}{||}}{C}-OH$) and the hydroxyl (–OH) groups.

Formerly, higher members of the carboxylic acids were obtained from fats. Hence, these acids are also called fatty acids.

Functional group : —COOH

General formula : R—COOH

5.5.1 Nomenclature of carboxylic Acids

1. Common names

Common names of carboxylic acids have originated from the Latin or the Greek names of the sources from which the acids are obtained.

Formula	**Occurrence**	**Latin or Greek names of the source**	**Name of acid**
1. HCOOH	Ants	Ants are called *formica* in Latin	Formic acid
2. CH_3COOH	Vinegar	Vinegar is called *acetum* in Latin	Acetic acid
3. CH_3CH_2COOH	Butter	Butter is called *butyrum* in Latin	Butyric acid

2. **IUPAC names**

In IUPAC system, naming of carboxylic acids is done by replacing the end –e of the corresponding hydrocarbon by –oic acid. The first four acids with the corresponding hydro carbons are given below in the table :

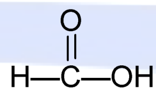
Formula of acid	**Number of carbon atoms**	**Corresponding hydrocarbon**	**IUPAC name**
1. HCOOH	1	Methane (CH_4)	Methanoic acid
2. CH_3COOH	2	Ethane (C_2H_6)	Ethanoic acid
3. CH_3CH_2COOH	3	Propane (C_3H_8)	Propanoic acid
4. $CH_3CH_2CH_2COOH$	4	Butane (C_4H_{10})	Butanoic acid

So, **IUPAC Name : Alkane –e + oic acid = Alkanoic acid**

The positions of the substituents are shown by allotting numbers to the carbon atoms to which the substituted groups are linked. The numbering of carbon atoms starts from the carbon atom of the carboxyl group.

For example,

1. **HCOOH** : This compound contains 1 carbon atom so its parent alkane is methane. It also contains a carboxylic acid group (—COOH group). The name of this compound can be obtained by replacing the last *'e'* of methane by 'oic acid' so it becomes methanoic acid (methan + oic acid = methanoic acid). Thus, the IUPAC name of HCOOH is methanoic acid.

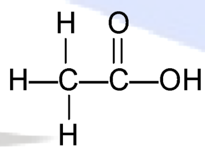
HCOOH or 

Structure

IUPAC name : Methanoic acid

The common name of methanoic acid (HCOOH) is **formic acid.**

2. **CH_3COOH :** This compound contains 2 carbon atoms so its parent alkane is ethane. Thus, the IUPAC name of CH_3COOH is ethanoic acid.

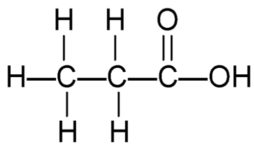
CH_3COOH or 

IUPAC name : Ethanoic acid

Structure

The common name of ethanoic acid (CH_3COOH) is **acetic acid.**

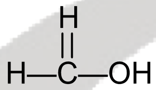
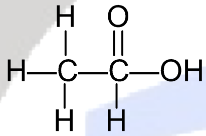
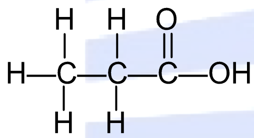
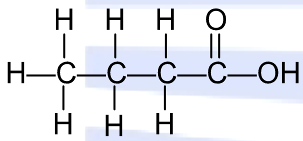
3. **CH_3CH_2COOH :** This compound contains 3 carbon atoms, so its parent alkane is propane. So, **the IUPAC name of CH_3CH_2COOH is propanoic acid.**

CH_3CH_2COOH or 

IUPAC name : Propanoic acid

Structure

The structure and IUPAC names of carboxylic acids are summarized below in the table :

Molecular formula	Structural formula	IUPAC Name	Common Name
$HCOOH$		Methanoic acid	Formic acid
CH_3COOH		Ethanoic acid	Acetic acid
C_2H_5COOH		Propanoic acid	Propionic acid
C_3H_7COOH		Butanoic acid	Butyric acid

6. COAL AND PETROLEUM

A fuel is a material that has energy stored inside it. **When a fuel is burned, the energy is released mainly as heat** (and some light). This heat energy can be used for various purposes like cooking food, heating water, and for running generators in thermal power stations, machines in factories and engines of motor cars. Most of the common fuels are either *free carbon* or *carbon compounds.* For example, the fuels such as coal, coke and charcoal contain free carbon whereas the fuels such as kerosene, petrol, LPG and natural gas, are all carbon compounds.

When carbon in any form (coal, coke, charcoal, etc.) is burned in the oxygen (of air), it forms carbon dioxide gas and releases a large amount of heat and some light :

$$\underset{\substack{\text{Carbon}\\\text{(Coal, coke or}\\\text{charcoal)}}}{C} + \underset{\substack{\text{Oxygen}\\\text{(From air)}}}{O_2} \longrightarrow \underset{\text{Carbon dioxide}}{CO_2} + \text{Heat} + \text{Light}$$

Most of the fuels which we use today are obtained from coal, petroleum and natural gas. Actually, coal, petroleum and natural gas are known as fossil fuels. Fossils are the remains of the pre-historic animals or plants buried under the earth, millions of years ago. Coal, petroleum and natural gas are known as fossil fuels because they were formed by the decomposition of the remains of the prehistoric plants and animals (fossils) buried under the earth, long, long, ago.

Coal is a complex mixture of compounds of carbon, hydrogen and oxygen, and some free carbon. Small amounts of nitrogen and sulphur compounds are also present in coal. It is found in deep coal mines under the surface of earth.

6.1 HOW COAL WAS FORMED ?

Coal was formed by the decomposition of large land plants and trees buried under the earth millions of years ago. It is believed that millions of years ago, due to earthquakes and volcanoes, etc., the forests were buried under the surface of the earth and got covered with sand, clay and water. Due to high temperature and high pressure inside the earth, and in the absence of air, wood was converted into coal.

Petroleum is dark coloured, viscous, and foul smelling crude oil. The name petroleum means rock oil (petra = rock; oleum = oil). It is called petroleum because it is found under the crust of earth trapped in rocks.

The fuels such as petrol, kerosene, diesel and LPG are obtained from petroleum.

6.2 HOW PETROLEUM WAS FORMED ?

Petroleum oil (and natural gas) were formed by the decomposition of the remains of extremely small plants and animals buried under the sea millions of years ago. It is believed that millions of years ago, the microscopic plants and animals which lived in seas, died. Their bodies sank to the bottom of the sea and were soon covered with mud and sand. The chemical effects of pressure, heat and bacteria, converted the remains of microscopic plants and animals into petroleum oil and natural gas just as they converted forest trees into coal. This conversion took place in the absence of oxygen or air. The petroleum thus formed got trapped between two layers of impervious rocks (non-porous rocks) forming an oil trap.

6.3 WHY DO SUBSTANCES BURN WITH A FLAME OR WITHOUT A FLAME ?

We are all familiar with a candle flame. A candle, cooking gas (LPG), and kerosene oil, all burn with a flame. A flame is the region where combustion (or burning) of gaseous substances takes place. So, a flame is produced only when gaseous substances burn.

Flames are of two types :

(a) Blue flame and

(b) Yellow flame.

(a) **When the oxygen supply (or air supply) is sufficient, then the fuels burn completely producing a blue flame.** This blue flame does not produce much light, so it said to be non luminous (or non light-giving) flame. In a gas stove, cooking gas (LPG) burns with a blue (non-luminous flame).

The gas stove has holes (or inlets) for air to mix properly with cooking gas. The cooking gas gets sufficient oxygen from this air and hence burns completely producing a blue flame. Thus, complete combustion of cooking gas takes place in a gas stove.

(b) **When the oxygen supply (or air supply) is insufficient, then the fuels burn incompletely producing mainly a yellow flame.**

The yellow colour of flame is caused by the glow of hot, unburnt carbon particles produced due to the incomplete combustion of fuel. This yellow flame produces light, so it is said to be a luminous (light-giving) flame.

When wax is burned in the form of a candle, it burns with a yellow, luminous flame. When a candle is lighted, the wax melts, rises up the wick and gets converted into vapours. In a candle, there is no provision for the proper mixing of oxygen (of air) for burning wax vapours. So, in a candle the wax vapours burn in an insufficient supply of oxygen (of air) which leads to incomplete combustion of wax. The incomplete combustion of wax in a candle produces small unburnt carbon particles. These solid carbon particles rise in the flame, get heated and glow to give out yellowish light. This makes the candle flame yellow and luminous. The unburnt carbon particles then leave the candle flame as soot and smoke. Thus, *incomplete combustion of wax takes place in a candle.*

7. CHEMICAL PROPERTIES OF CARBON COMPOUNDS

Most of the fuels we use (coal, wood, CNG, LPG, petrol, teroseve, diesel etc.) are either carbon or its compounds. So, we should know their chemical properties to understand their nature.

7.1 COMBUSTION (OR BURNING)

The process of burning of a carbon compound in air to give carbon dioxide, water, heat and light, is known as combustion. Combustion is also called *burning.* Most of the carbon compounds burn in air to produce a lot of heat. For example, **alkanes burn in air to produce a lot of heat due to which alkanes are excellent fuels.**

For example,

When methane (natural gas) burns in a sufficient supply of air, then carbon dioxide and water vapour are formed, and a lot of heat is also produced :

$$\underset{\text{(Natural gas)}}{\underset{\text{Methane}}{CH_4}} + \underset{\text{(From air)}}{\underset{\text{Oxygen}}{2O_2}} \xrightarrow{\text{Combustion}} \underset{\text{dioxide}}{\underset{\text{Carbon}}{CO_2}} + \underset{\text{Water}}{2H_2O} + \text{Heat} + \text{Light}$$

Since natural gas (methane) produces a lot of heat on burning, so it is used as a fuel in homes and in industry. The cooking gas (LPG) which we use in our homes is mainly an alkane called *butane* (C_4H_{10}). When butane (or LPG) burns in air in the burner of a gas stove, then it forms carbon dioxide and water vapour, with the evolution of a lot of heat (and some light). Due to this, butane (or LPG) is an excellent fuel.

Other examples of combustion are

$$\underset{\text{Carbon}}{C} + \underset{\text{Oxygen}}{O_2} \longrightarrow \underset{\text{Carbondioxide}}{CO_2} + \text{Heat and light}$$

$$\underset{\text{Ethanol}}{CH_3CH_2OH} + \underset{\text{Oxygen}}{3O_2} \longrightarrow \underset{\text{Carbondioxide}}{CO_2} + \underset{\text{Water}}{3H_2O} + \text{Heat and light}$$

7.1.1 Combustion of saturated hydrocarbons

The saturated hydrocarbons (alkanes) generally burn in air with a blue, non-sooty flame. This is because the percentage of carbon in the saturated hydrocarbons is *comparatively low* which gets oxidized completely by the oxygen present in air. **If, however, the supply of air (and hence oxygen) for burning is reduced (or limited), then incomplete combustion of even saturated hydrocarbons will take place and they will burn producing a sooty flame** (giving a lot of black smoke).

As we have already read, the gas stove (and kerosene stove) used in our homes have tiny holes (or inlets) for air so that sufficient oxygen of air is available for the complete burning of fuel to produce a smokeless blue flame. Thus, when the flame in a gas stove is blue, then the fuel is burning completely (or that complete combustion takes place). When the fuel in a gas stove (or kerosene stove) burns completely giving a blue flame, then the bottom of the cooking utensils (or vessels) remains clean from outside. It does not get blackened. If, however, the fuel in a gas stove (or kerosene stove) does not burn completely, then a sooty flame is produced which blackens the bottom of the cooking utensils from the outside. So, **if the bottom of the cooking utensils in our homes are getting blackened, it shows that the air holes of the gas stove (or kerosene stove) are getting blocked and the fuel is not burning completely.**

7.1.2 Combustion of unsaturated hydrocarbons

The **unsaturated hydrocarbons (alkenes and alkynes) burn in air with a yellow, sooty flame (producing black smoke).** For example, ethene and ethyne burn in air with a sooty flame. The unsaturated hydrocarbons (alkenes and alkynes) burn with a sooty flame because the percentage of carbon in unsaturated hydrocarbons is *comparatively higher* (than that of alkanes), which does not get oxidized completely in the oxygen of air. Now, air contains only about 21 per cent of oxygen in it which is insufficient for the complete combustion of unsaturated hydrocarbons (having higher carbon percentage). But **if unsaturated hydrocarbons are burned in pure oxygen, then they will burn completely producing a blue flame (without any smoke at all).**

7.1.3 Disadvantages of incomplete combustion

The most common fuels contain a high percentage of carbon, so it is obviously very important to burn them completely. The incomplete combustion of fuels has the following disadvantages :

(i) Incomplete combustion in insufficient supply of air, leads to unburnt carbon in the form of soot which pollutes the atmosphere, blackens cooking utensils, and blocks chimneys in factories.

(ii) The incomplete combustion also leads to the formation of an extremely poisonous gas called carbon monoxide.

(iii) A yet another disadvantage is that the incomplete combustion of a fuel produces less heat than that produced by complete combustion.

7.2 OXIDATION

Addition of oxygen to any substance is called oxidation and the substances which are capable of adding oxygen to other substances are called oxidizing agents.

We have discussed above the combustion of carbon compounds. Combustion, in fact, means complete oxidation. In addition to this complete oxidation, there are reactions in which partial oxidation occurs. Partial oxidation of substances is carried out by using certain oxidizing agents. Alkaline potassium permanganate and acidified potassium dichromate are good oxidizing agents. These can easily oxidize alcohols to carboxylic acids. For example.

$$\underset{\text{Potassium permanganate}}{2\,KMnO_4} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Potassium hydroxide}}{2\,KOH} + \underset{\text{Manganese dioxide}}{2\,MnO_2} + 3\,[O]$$

$$\underset{\text{Potassium dichromate}}{K_2Cr_2O_7} + \underset{\text{Sulphuric acid}}{4H_2SO_4} \longrightarrow \underset{\text{Potassium sulphate}}{K_2SO_4} + \underset{\text{Chromium sulphate}}{Cr_2(SO_4)_3} + 4H_2O + 3[O]$$

$$\underset{\text{Ethanol}}{CH_3CH_2OH} + \underset{\text{From oxidising agent}}{2\,[O]} \xrightarrow[\text{or } K_2Cr_2O_7 / H_2SO_4 \text{ Heat}]{KMnO_4 / KOH, \text{ Heat}} \underset{\text{Ethanoic acid}}{CH_3-\overset{\overset{\large O}{||}}{C}-OH} + H_2O$$

To demonstrate oxidation of alcohols to carboxylic acids, let us perform the following experiment.

Take about 3 mL of ethanol in a test tube and warm it gently in a water bath. Add a 5% solution of alkaline potassium permanganate drop by drop to this solution. The pink colour of potassium permanganate will disappear due to the oxidation of ethanol to ethanoic acid and a brown precipitate of manganese dioxide will be formed due to the reduction of potassium permanganate by ethanol.

7.3 SUBSTITUTION REACTION

Reactions which involve the direct replacement (displacement or substitution) of an atom or a group of atoms in an organic molecule by another atom or group of atoms without any change in the rest of the molecule are called **substitution reactions.**

Due to the presence of strong carbon-carbon and carbon-hydrogen bonds, saturated hydrocarbons (i.e., alkanes) are quite unreactive and are inert to the action of most of the reagents. It is because of this reason that alkanes are also called **paraffins** (Latin : *parum* means little and *afffinis* means affinity or reactivity). However, in presence of heat or light, chlorine reacts very rapidly with saturated hydrocarbons to form substitution products. For example,

$$\underset{\text{Methane}}{CH_4} + \underset{\text{Chlorine}}{Cl_2} \xrightarrow[\text{or 520-670 K}]{\text{Sunlight}} \underset{\substack{\text{Chloromethane} \\ \textit{(Substitution product)}}}{CH_3Cl} + \underset{\substack{\text{Hydrogen} \\ \text{chloride}}}{HCl}$$

However, with excess of chlorine all the hydrogen atoms of methane are replaced one by one to form a number of products as shown below :

$$\underset{\substack{\text{Chloromethane} \\ (\textit{Methyl chloride})}}{CH_3Cl} + Cl_2 \xrightarrow[\text{or 520-670 K}]{\text{Sunlight}} \underset{\substack{\text{Dichloromethane} \\ \textit{(Methylene chloride)}}}{CH_2Cl_2} + HCl$$

$$\underset{\substack{\text{Dichloromethane} \\ (\textit{Methylene chloride})}}{CH_2Cl_2} + Cl_2 \xrightarrow[\text{or 520-670 K}]{\text{Sunlight}} \underset{\substack{\text{Trichloromethane} \\ \textit{(Chloroform)}}}{CHCl_3} + HCl$$

$$\underset{\text{Trichloromethane}}{CHCl_3} + Cl_2 \xrightarrow[\text{or 520-670 K}]{\text{Sunlight}} \underset{\text{Carbon tetrachloride}}{CCl_4} + HCl$$

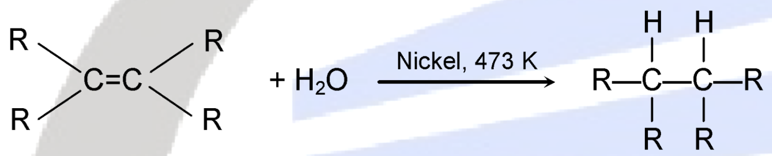
However, with higher homologues of alkanes, a number of products containing even one chlorine atom are formed. For example,

$$\underset{\text{Propane}}{CH_3-CH_2-CH_3} + Cl_2 \xrightarrow[\text{or 520-670 K}]{\text{Sunlight}} \underset{\text{1-Chloropropane}}{{}^3CH_3-{}^2CH_2-{}^1CH_2-Cl} + \underset{\text{2-Chloropropane}}{{}^3CH_3-{}^2\underset{|\atop Cl}{CH}-{}^1CH_3}$$

7.4 ADDITION REACTION

Reactions which involve addition of two reactants to form a single product are called addition reactions.

Due to the presence of double and triple bonds, unsaturated hydrocarbons are more reactive and hence add hydrogen in presence of a catalyst such as nickel, platinum or palladium to *form saturated hydrocarbons.* This process is called **catalytic hydrogenation.**



Unsaturated Hydrocarbon (*Alkene*) — Saturated Hydrocarbon (*Alkene*)

For example,

Addition reaction of Ethene with hydrogen

$$\underset{\substack{\text{Ethene}\\ \text{(unsaturated)}}}{CH_2=CH_2} + \underset{\text{Hydrogen}}{H_2} \xrightarrow[\text{Heat}]{\text{Ni catalyst}} \underset{\substack{\text{ethane}\\ \text{(saturated)}}}{CH_3-CH_3}$$

This addition reaction is commonly used in the hydrogenation (addition of hydrogen) of vegetable oils (such as soyabean oil, cotton seed oil, groundnut oil etc.) in presence of nickel as catalyst to form fats (vegetable ghee such as Gagan, Rath, Dalda, etc.).

The addition of hydrogen to an unsaturated hydrocarbon to obtain a saturated hydrocarbon is called hydrogenation. It is used to prepare vegetable ghee from vegetable oils.

Vegetable oils generally have long unsaturated carbon chains while animal fats have saturated carbon chains.

$$\underset{(\textit{Liquid})}{\text{Vegetable oil}} + H_2 \xrightarrow{\text{Nickel, 473 K}} \underset{(\textit{Solid})}{\text{Vegetable ghee}}$$

7.4.1 Need for hydrogenation

1. When vegetable oils are exposed to hot and humid weather for a long time, they turn *rancid*, i.e., they develop unpleasant smell and taste. *This process of developing unpleasant smell and taste is called* **rancidity** *and occurs due to the formation of carboxylic acids and aldehydes by the action of oxygen and moisture on the long unsaturated carbon chains present in vegetable oils.* Hydrogenation reduces (but does not eliminate) the number of such unsaturated carbon chains and hence slows down the development of rancidity.
2. **Vegetable oils are good for health.** Saturated carbon chains present in saturated fats increase the level of bad cholesterol (DLD, low density lipoprotein) in blood which sticks to the walls of the arteries and thus causes coronary heart disease. Vegetable oils (like Sundrop, Saffola, Fortune etc.) are good for health. On the other hand, animal fats like 'ghee' and butter (*desi ghee*) contain saturated fatty acids which are said to be bad for health. Therefore, oils containing unsaturated fatty acids should be used for cooking.

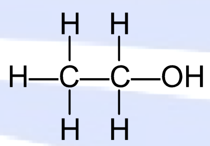
8. SOME IMPORTANT CARBON COMPOUNDS

Many carbon compounds are invaluable to us. But, here we shall study the properties of two commercially important compounds— ethanol and ethanoic acid.

8.1 ETHANOL (OR ETHYL ALCOHOL)

Ethanol is the second member of the homologous alcoholic series.

The structural formula of ethanol is



Formula : CH_3CH_2OH

IUPAC Name : Ethanol

Common Name : Ethyl alcohol

8.1.1 Physical Properties of Ethanol

Some important physical properties of ethanol are described below :

1. **Physical state, melting point and boiling point.** Ethanol is a colourless liquid at room temperature. Its freezing point is 156 K while its boiling point is 351 K.
2. **Smell and taste :** It has a distinct smell and a burning taste.
3. **Solubility.** Ethanol is soluble in water in all proportions.
4. **Physiological action.** Ethanol is commonly called alcohol. It is an active ingredient of all alcoholic drinks such as beer, rum, whisky, brandy, etc. Consumption of small quantities of dilute ethanol causes **drunkenness.** However, intake of even a small quantity of pure alcohol (absolute alcohol) can be lethal.

8.1.2 Chemical Properties of Ethanol

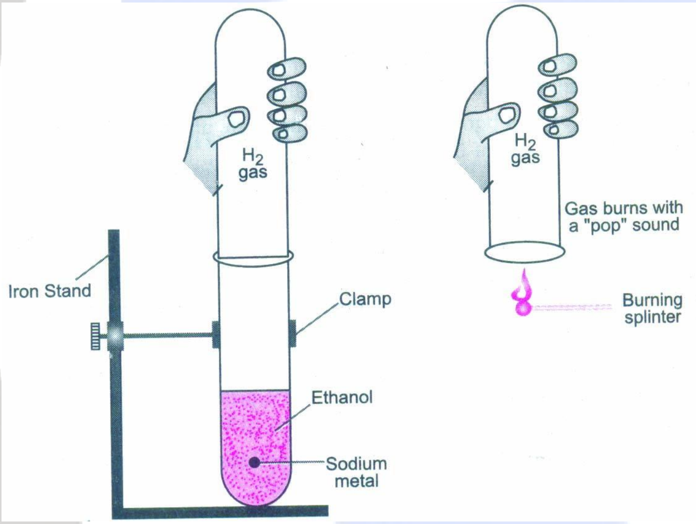
Some chemical properties of ethanol are described below :

1. **Reaction with sodium.** Ethanol reacts with sodium in the cold to form sodium ethoxide with the evolution of hydrogen gas

$$\underset{\text{Ethanol}}{2\,CH_3CH_2OH} + \underset{\text{Sodium}}{2Na} \xrightarrow{\text{Cold}} \underset{\text{Sodium ethoxide}}{2\,CH_3CH_2ONa} + H_2$$

When a small piece of sodium metal of the size of rice is added to ethanol taken in a dry test tube, a brisk effervescence due to the evolution of hydrogen gas takes place. Hydrogen is a combustible gas. Thus, when a burning splinter or match stick is brought near the mouth of the test tube, it burns with a **'pop'** sound which is a characteristic property of hydrogen gas.

Experiment : Take about 2 mL of absolute ethanol in a dry test tube (figure). Now take a small piece of freshly cut sodium metal. Dry it between the folds of a filter paper and add it to ethanol. A brisk effervescence due to the evolution of H_2 will be observed. Collect this gas in another test tube inverted over the test tube containing the reaction mixture. Bring a burning splinter near the mouth of the inverted test tube. The H_2 gas burns with a **'pop'** sound.



Hydrogen gas produced by the action of sodium metal on absolute ethanol burns with a "pop" sound

2. **Dehydration :** Dehydration of an alcohol means removal of water molecule from it. When ethanol is heated with excess of concentrated sulphuric acid at 170°C (443 K), it gets dehydrated to form ethene (which is an unsaturated hydrocarbon) :

$$\underset{\substack{\text{Ethanol}\\ \text{(Ethyl alcohol)}}}{CH_3 - CH_2OH} \xrightarrow[\text{(Dehydration)}]{\text{Conc. } H_2SO_4\text{ ; }170°C} \underset{\text{Ethene}}{CH_2 = CH_2} + \underset{\text{Water}}{H_2}$$

During dehydration of ethanol molecule (CH_3—CH_2OH), H from the CH_3 group and OH from CH_2OH group are removed in the form of a water molecule (H_2O) resulting in the formation of ethane molecule (CH_2=CH_2). In this reaction, **concentrated sulphuric acid acts as a dehydrating agent** (which removes water molecule from the ethanol molecule).

3. **Combustion :** Ethanol is a highly inflammable liquid. It catches fire easily and starts burning. Ethanol burns readily in air with a blue flame to form carbon dioxide and water vapour, and releasing a lot of heat and light :

$$\underset{\substack{\text{Ethanol}\\\text{(Ethyl alcohol)}}}{C_2H_5OH} + \underset{\substack{\text{Oxygen}\\\text{(From air)}}}{3O_2} \xrightarrow[\text{(Burning)}]{\text{Combustion}} \underset{\substack{\text{Carbon}\\\text{dioxide}}}{2CO_2} + \underset{\substack{\text{Water}\\\text{vapour}}}{3H_2O} + \text{Heat} + \text{Light}$$

4. **Oxidation :** 'Oxidation' means controlled combustion'. When ethanol is heated with alkaline potassium permanganate solution (or acidified potassium dichromate solution), it gets oxidized to ethanoic acid :

$$\underset{\substack{\text{Ethanol}\\\text{(Ethyl alcohol)}}}{CH_3CH_2OH} + \underset{\substack{\text{Nascent oxygen}\\\text{(From oxidising agent)}}}{2[O]} \xrightarrow[\text{(or Acidified } K_2Cr_2O_7\text{)}]{\text{Alkaline } KMnO_4\text{ ; Heat}} \underset{\substack{\text{Ethanoic acid}\\\text{(Acetic acid)}}}{CH_3COOH} + \underset{\text{Water}}{H_2O}$$

8.1.3 Uses of Ethanol

Some important uses of ethanol are listed below :

1. Ethanol in form of rectified spirit (95% alcohol + 5% water) is used as an ***antiseptic for wounds.*** It is also used for sterilizing skin before giving an injection.
2. Ethanol is used in ***alcoholic beverages,*** *i.e.,* beer, rum, whisky, brandy, etc.
3. Ethanol is widely used in industry as a ***solvent*** for paints, lacquers, tincture iodine, cough syrups, perfumes, etc.
4. It is also used in the preparation of dyes, cosmetics and transparent soaps.
5. It is used in the manufacture of number of other chemicals such as chloroform, iodoform, ether, acetic acid, acetaldehyde, etc.
6. It is used as an important ***laboratory reagent*** for carrying out organic reactions and for ***crystallization*** of organic compounds.
7. Ethanol is used as a ***fuel*** in internal combustion engines in form of ***power alcohol.***
8. In cold countries, ethanol is used as an ***antifreeze*** in the radiators of automobiles.
9. It is used in spirit levels and low temperature thermometers.

8.1.4 Harmful Effects of Drinking Alcohol

We should not use any alcoholic drinks because of the following harmful effects which they produce :

1. Alcohol slows down the activity of the nervous system and the brain due to which the judgement of a person is impaired and his 'reaction' becomes slow. So, a person driving a car under the influence of alcohol cannot judge a situation properly and act quickly in case of an emergency.
2. Alcohol drinking lowers inhibitions (mental restrain) due to which a drunken man becomes quarrelsome.
3. Drinking alcohol heavily on a particular occasion leads to staggered movement, slurred speech (unclear speech), blurred vision, dizziness, and vomiting.
4. Heavy drinking of alcohol over a long period of time can damage the stomach, liver, heart and even brain. The liver disease known as 'cirrhosis' caused by alcohol can lead to death.

5. The drinking of adulterated alcohol containing methyl alcohol (methanol), causes severe poisoning leading to blindness and even death.

8.1.5 Alcohol as a fuel

Sugarcane plants are the most efficient convertors of sunlight energy into chemical energy. The cheap source of alcohol is molasses. It is a dark coloured thick syrupy liquid left after the crystallization of sugar from sugarcane juice. It still contains about 40% of sugar which cannot be obtained by crystallization.

Fermentation of molasses in presence of yeast (which contains the enzymes invertase and zymase) gives alcohol (ethanol).

Fermentation may be defined as the slow decomposition of big organic molecules into simpler molecules in presence of enzymes.

Since alcohol in a cleaner fuel which gives only carbon dioxide and water as by products on burning in excess of air or oxygen, therefore, some countries now use alcohol as a fuel in internal combustion engines in form of **power alcohol.** Power alcohol is a mixture of absolute alcohol (100% alcohol) and petrol in the ratio 20 : 80. Since alcohol does not mix with petrol, therefore, a third solvent, *i.e.,* benzene is used to dissolve them. It is also used as a fuel in stoves and spirit lamps.

8.2 ETHANOIC ACID

Ethanoic acid is the second member of homologous series of carboxylic acids

Formula : CH_3COOH

IUPAC Name : Ethanoic Acid

Common Name : Acetic Acid

8.2.1 Physical properties of ethanoic acid

Some important physical properties of ethanoic acid are listed below :

1. **Physical state and smell.** Ethanoic acid is a colourless, pungent smelling liquid.
2. **Melting and boiling points.** When pure ethanoic acid is cooled, it freezes (m.p. 290 K) forming glacier like crystals. Therefore, 100% acetic acid, obtained by melting these crystals, is called **glacial acetic acid.** It boils at 391 K.
3. **Solubility.** Ethanoic acid is miscible with water in all proportions.

8.2.2 Chemical Properties of Ethanoic Acid

1. **Acidic Nature :** A dilute solution of ethanoic acid **turns blue litmus red,** therefore, *ethanoic acid is acidic in nature.* Mineral acids like hydrochloric acid sulphuric acid, etc. also turn blue litmus red. Thus, *both mineral acids and carboxylic acids are acidic in nature.* But, mineral acids are completely ionized

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$ ...completely ionized

$$CH_3COOH\ (aq) \rightleftharpoons H^+\ (aq) + CH^3COO-\ (aq)$$ ...partly ionized

Since, carboxylic acids are only partly ionized. Carboxylic acids are weaker acids than mineral acids.

2. **Reaction with Carbonates and Hydrogen carbonates.** Ethanoic acid reacts with carbonates and hydrogen carbonates to evolve carbon dioxide gas along with the formation of salt and water.

(i) **Reaction with Sodium Carbonate.** Ethanoic acid reacts with sodium carbonate to form sodium ethanoate and carbon dioxide gas :

$$\underset{\substack{\text{Ethanoic acid}\\\text{(Acetic acid)}}}{2CH_3COOH} + \underset{\text{Sodium carbonate}}{Na_2CO_3} \longrightarrow \underset{\substack{\text{Sodium ethanoate}\\\text{(Sodium acetate)}}}{2CH_3COONa} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2} + \underset{\text{Water}}{H_2O}$$

When sodium carbonate is added to a solution of ethanoic acid, brisk effervescence of carbon dioxide is given off.

(ii) **Reaction with Sodium Hydrogen carbonate.** Ethanoic acid reacts with sodium hydrogencarbonate to evolve brisk effervescence of carbon dioxide gas :

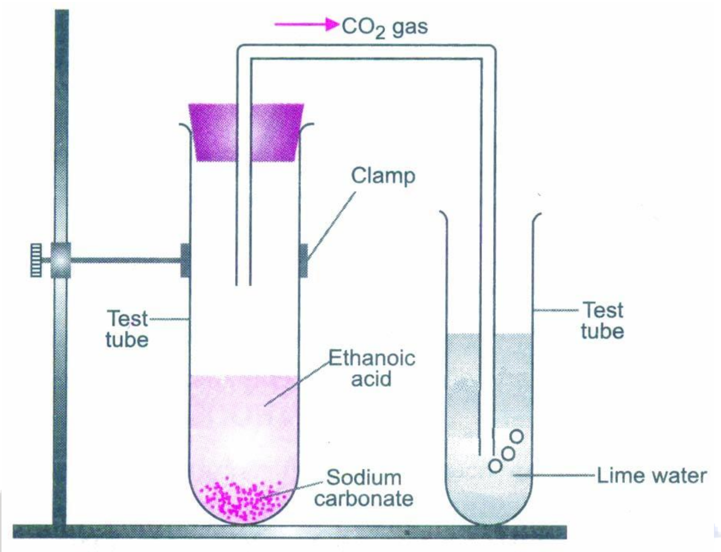
$$\underset{\text{Ethanoic acid}}{CH_3COOH} + \underset{\text{Sodium hydrogencarbonate}}{NaHCO_3} \longrightarrow \underset{\text{Sodium ethanoate}}{CH_3COONa} + \underset{\substack{\text{Carbon}\\\text{dioxide}}}{CO_2} + \underset{\text{Water}}{H_2O}$$

The CO_2 gas thus evolved can be easily identified by passing it through the freshly prepared lime water which turns milky due to formation of insoluble calcium carbonate. Thus,

$$\underset{\text{Ethanoic acid}}{Ca(OH)_2} + \underset{\text{Carbon dioxide}}{CO_2} \longrightarrow \underset{\substack{\text{Calcium carbonate}\\\text{(milkiness)}}}{CaCO_3} + \underset{\text{Water}}{H_2O}$$

Experiment to show that carboxylic acids react with sodium carbonate or sodium bicarbonate to form carbon dioxide gas.

Set up the apparatus as shown in figure. Take a spatula full of sodium carbonate in a test tube and add 2 mL of dilute ethanoic acid to it as shown in figure. You will soon observe brisk effervescence due to evolution of CO_2 gas. When this gas is passed through freshly prepared lime water, it turns lime water milky.



Carbon dioxide formed by the action of sodium carbonate on ethanoic acid turns lime water milky

3. **Reaction with Sodium Hydroxide**

   Ethanoic acid reacts with bases (or alkalis) to form salts and water. For example, ethanoic acid reacts with sodium hydroxide to form a salt called sodium ethanoate and water

   $$\underset{\text{Ethanoic acid}}{CH_3COOH} + \underset{\text{Sodium hydroxide}}{NaOH} \longrightarrow \underset{\text{Sodium ethanoate}}{CH_3COONa} + H_2O$$

Water

   In its reaction with bases, ethanoic acid behaves just like mineral acids (HCl, etc.). In fact, all the carboxylic acids react with bases (or alkalis) like sodium hydroxide to form the corresponding salts and water.

4. **Reaction with Alcohols**

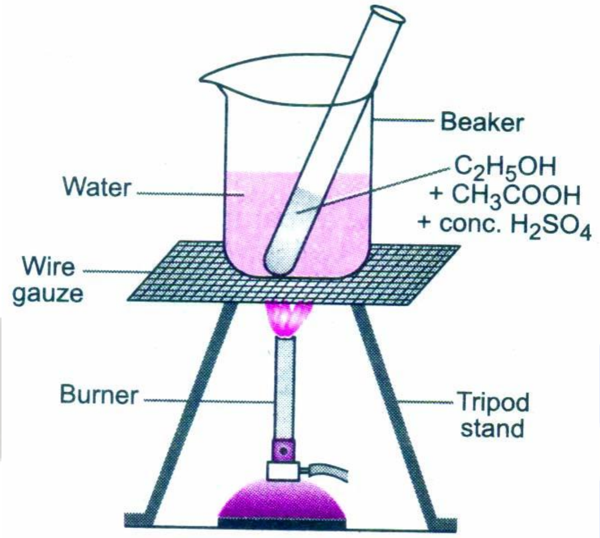
   Carboxylic acids react with alcohols to form **esters** For example, when ethanoic acid is warmed with ethnol in presence of a few drops of concentrated sulphuric acid as catalyst, an ester (ethyl ethanoate, commonly called ethyl acetate) and water are formed.

   $$\underset{\substack{\text{Ethanoic acid}\\(\textit{A carboxylic acid})}}{CH_3{-}\overset{\overset{\large O}{||}}{C}{-}}\boxed{OH + H}\underset{\substack{\text{Ethanol}\\(\textit{An alcohol})}}{{-}OCH_2CH_3} \xrightarrow[\text{Heat}]{\text{Conc. } H_2SO_4} \underset{\substack{\text{Ethyl ethanoate}\\(\textit{An ester})}}{CH_3{-}\overset{\overset{\large O}{||}}{C}{-}OCH_2CH_3} + H_2O$$

   This reaction between a carboxylic acid and an alcohol to form an ester is called the esterification reaction.

Experiment to show the formation of esters

Esters can be easily prepared in the laboratory as follows. Mix equal volumes of absolute ethanol (100% alcohol) and glacial acetic acid (100% acetic acid) in a dry test tube. Add to it a few drops of conc. H_2SO_4 and and keep the test tube in warm water as shown in figure for about five minutes. Thereafter, pour the contents of the test tube in about 20-30 mL of water and smell the reaction mixture. You will detect fruity smell due to the formation of an ester, *i.e.,* ethyl acetate.



Formation and detection of an ester

5. **Hydrolysis :** Esters, on heating with an aqueous acid or a base, give back the original alcohol and the original carboxylic acid. For example,

$$\underset{\text{Ethyl ethanoate}}{CH_3-\overset{\overset{\large O}{||}}{C}-OCH_2\,CH_3} + \underset{\text{Sodium hydroxide}}{NaOH} \xrightarrow{\text{Heat}} \underset{\text{Sodium ethanoate}}{CH_3-\overset{\overset{\large O}{||}}{C}-ONa} + \underset{\text{Ethanol}}{CH_3CH_2OH}$$

$$\underset{\text{Ethyl ethanoate}}{CH_3-\overset{\overset{\large O}{||}}{C}-OCH_2\,CH_3} + H_2O \xrightarrow[\text{Heat}]{\text{Dil. }H_2SO_4} \underset{\text{Ethanoic acid}}{CH_3-\overset{\overset{\large O}{||}}{C}-OH} + \underset{\text{Ethanol}}{CH_3CH_2OH}$$

This reaction is called hydrolysis.

When hydrolysis of an ester is carried out with a base such as sodium hydroxide, sodium salt of the original acid and alcohol are formed. Since sodium salts of higher fatty acids are called soaps, therefore, *alkaline hydrolysis of an ester to give the salt of the corresponding carboxylic acid and the alcohol is called saponification. It is reverse of esterification.*

9. SOAPS AND DETERGENTS

The substances which along with water are used for cleaning or for removing dirt are known as detergents. Soap has been as a detergent for about 2300 years. But substances, other than soap, are also used for cleaning. These are called synthetic detergents, soapless detergents or simply detergents. So, there are two types of detergents :

(i) Soapy detergents/soaps

(ii) Non-soapy detergents/Detergents

A soap is the sodium salt (or potassium salt) of a long chain carboxylic acid (fatty acid) which has cleaning properties in water.

Examples of the soaps are : Sodium stearate and Sodium palmitate.

(i) Sodium Stearate, $C_{17}H_{35}COO^{-}Na^{+}$: Sodium stearate 'soap' is the sodium salt of a long chain saturated fatty acid called stearic acid, $C_{17}H_{35}COOH$.

(ii) Sodium Palmitate, C15H31COO–Na+ : Sodium palmitate 'soap' is the sodium salt of a long chain saturated fatty acid called palmitic acid, $C_{15}H_{31}COOH$.

9.1 MANUFACTURE OF SOAP

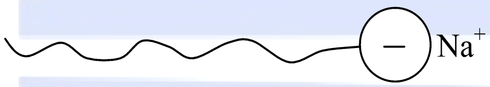
Soap is made by heating animal fat or vegetable oil with concentrated sodium hydroxide solution (caustic soda solution). The fats or oils react with sodium hydroxide to form soap and glycerol :

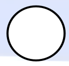
Fat or Oil	+	Sodium hydroxide	$\xrightarrow{\text{Heat}}$	Soap	+	Glycerol
(An ester)		(An alkali)		(Sodium salt of fatty acid)		(An alcohol)

The process of making soap by the hydrolysis of fats and oils with alkalis is called saponification.

9.2 STRUCTURE OF A SOAP MOLECULE

A soap has a large non-ionic hydrocarbon group and an ionic $COO^{-}Na^{+}$ group. The structure of soap can be represented as



where  represents the hydrocarbon group and  represents negatively charged carboxyl group.

The long hydrocarbon chain is hydrophobic i.e. water repelling, so the hydrocarbon part of soap molecule is insoluble in water but soluble in oil and grease, so it can attach to the oil and grease particles present on dirty clothes.

The ionic portion of soap molecule is hydrophilic i.e. water attracting due to the polar nature of water molecules. So it can attach to the water particles.

9.3 HARD AND SOFT WATER

Water that produces lather (foam) with soap readily is called soft water.

Examples of soft water are : rain water, distilled water, demineralized water (i.e., water which does not contain minerals).

Water that does not produce lather (foam) with soap readily is called hard water.

Examples of hard water are : sea water, river water, spring water, lake water, well water, tube-well water, hand-pump water, etc.

The hardness of water is due to the presence of bicarbonates, chlorides and sulphates of calcium and magnesium.

9.4 DETERGENTS

Detergents are also called 'soap-less soaps' because though they act like a soap in having the cleansing properties, they do not contain the usual 'soaps' like sodium stearate, etc.

A detergent is the sodium salt of a long chain benzene sulphonic acid (or the sodium salt of a long chain alkyl hydrogensulphate) which has cleansing properties in water. A detergent has a large non-ionic hydrocarbon group and an ionic group like sulphonate group, $SO_3^-Na^+$, or sulphate group $SO_4^-Na^+$. Examples of detergents are : Sodium *n*-dedecyl benzene sulphonate and Sodium *n*-dodecyl sulphate. These are shown below :

The structure of a detergent is similar to that of soaps. A detergent molecule also consists of two parts : a long hydrocarbon chain which is water repelling (hydrophobic), and a short ionic part which is water attracting (hydrophilic).

9.5 ADVANTAGES OF DETERGENTS OVER SOAPS

Synthetic detergents are widely used these days as cleansing agents. These have the following advantages over soaps.

(i) Synthetic detergents can be used even in hard water whereas some of the soap gets wasted if water is hard. Soaps cannot be used in hard water for washing. The reason being the the Ca^{2+} and Mg^{2+} ions present in hard water react with soap to form curdy white precipitates of calcium and magnesium salts of fatty acids. For examples,

$$\underset{\substack{\text{Sodium stearate}\\\text{(Soap)}}}{2\,C_{17}H_{35}COONa} + \underset{\substack{\text{Calcium ion}\\\text{(From hard water)}}}{Ca^{2+}} \longrightarrow \underset{\substack{\text{Calcium stearate}\\\text{(Precipitates or scum)}}}{(C_{17}H_{35}COO)_2Ca} + \underset{\text{Sodium ion}}{2\,Na^+}$$

$$\underset{\substack{\text{Sodium stearate}\\\text{(Soap)}}}{2\,C_{17}H_{35}COONa} + \underset{\substack{\text{Magnesium ion}\\\text{(From hard water)}}}{Mg^{2+}} \longrightarrow \underset{\substack{\text{Magnesium stearate}\\\text{(Precipitates or scum)}}}{(C_{17}H_{35}COO)_2Mg} + \underset{\text{Sodium ion}}{2\,Na^+}$$

These precipitates (also called scum) are either thrown out or stick to the surface of the clothes or bath room tubs, wash basins, etc. As a result, hard water does not produce lather (foam) with soap immediately. However, when all the Ca^{2+} and Mg^{2+} ions present in hard water have been precipitated by addition of sufficient quantity of soap, the resulting water becomes **soft** and thus readily produces lather with soap. Thus, soaps are not effective cleansing agents in hard water because lot of soap is wasted in precipitating out Ca^{2+} and Mg^{2+} ions present in hard water. On the other hand, calcium and magnesium salts of detergents are soluble even in water and hence can be used for washing even in hard water.

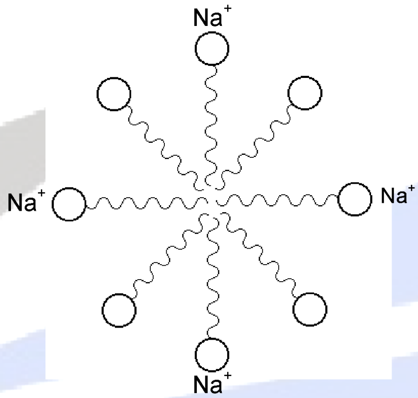
(ii) Synthetic detergents can be used even in acidic medium but soaps cannot be. The reason being that in acidic medium, synthetic detergents are converted into free sulphonic acids which are also soluble in water. As a result, cleansing ability of synthetic detergents is not blocked. On the other hand, in acidic medium, soaps are converted into free fatty acids which being insoluble stick to the surface of the fabric. As a result, cleanising ability of soaps is blocked.

(iii) The cleansing power of synthetic detergents is much higher than those of soaps.

(iv) Synthetic detergents are more soluble in water than soaps and hence produce lather much more easily than soaps.

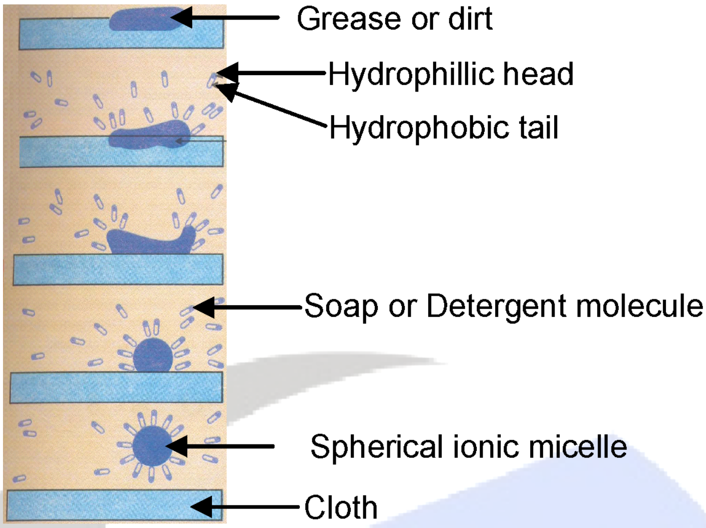
9.6 CLEANSING ACTION OF SOAPS AND DETERGENTS

Both soaps and detergents are made up of two parts, *i.e.,* a long hydrocarbon tail and a negatively charged head. The hydrocarbon tail being non-polar is insoluble in water and hence is ***hydrophobic*** (water repelling). On the other hand, the negatively charged head being polar is soluble in water and hence is ***hydrophilic*** (water-attracting).



When a soap or a detergent is added to water the polar heads of their molecules dissolve in water while non-polar tails dissolve in each other. As a result, the soap or the detergent forms **spherical ionic micelles,** *i.e.,* clusters of about 100-200 molecules with their polar heads (shown by solid circles) on the surface of the cluster and the non-polar chains (shown by wavy lines) directed towards the centre. In a similar way, detergents also form ionic micelles. These micelles remain suspended in water as a colloid and will not come together to precipitate out due to repulsion between the similar negative charges.

The dirt is generally held to the surface of a dirty cloth by a thin film of oil or grease. When a dirty cloth is treated with soap or detergent solution, the non-polar hydrocarbon tails of the soap or the detergent dissolve in oil or grease while the polar heads are held by the surrounding water. The stepwise formation of these micelles is shown in figure. In other words, soap or the detergent is attracted to both the greasy dirt and water. This lowers the surface tension of water and a stable emulsion of oil in water is formed.



When the surface of the cloth is mechanically scrubbed or beaten on a stone or with a wooden paddle or agitated in a washing machine, the loosened oily dirt particles are removed from the dirty surface and the cloth is cleaned. Since detergents lower the surface tension of water to a greater extent than soaps, therefore, **the cleansing power of detergents is much higher than those of soaps.**