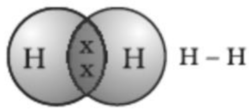
CHAPTER 4
CARBON AND ITS COMPOUNDS
1. BONDING IN CARBON – THE COVALENT BOND

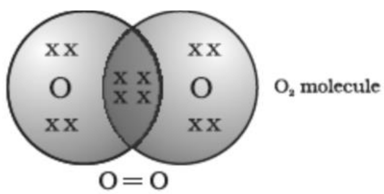
1. Covalent Bond: The chemical bond formed by the sharing of electrons between two atoms is called covalent bond.

(i) Single covalent bond: A covalent bond formed by sharing of one pair of electrons between two atoms is known as single covalent bond. For example, two hydrogen atoms share their electrons to form a molecule of hydrogen, H_2.



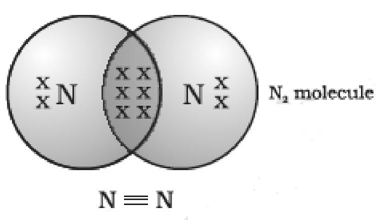
Single bond between two Hydrogen atoms

(ii) Double covalent bond: The covalent bond formed by sharing of two pairs of electrons between two atoms is known as double covalent bond. For example, the two electrons contributed by each oxygen atom give rise to two shared pairs of electrons. This is said to constitute a double bond between the two atoms.
The electron dot structure of O_2 and its double bond.



Double bond between two oxygen atoms

(iii) Triple covalent bond: The covalent bond formed by the sharing of three pairs of electrons between two atoms is known as triple covalent bond. In the case of a diatomic molecule of nitrogen, each nitrogen atom in a molecule of nitrogen contributes three electrons giving rise to three shared pairs of electrons. This is said to constitute a triple bond between the two atoms.
The electron dot structure of N_2 and its triple bond.



Triple bond between two nitrogen atoms

Covalent compounds exist as solids, liquids and gases. They are generally soluble in non-polar solvents like ether, benzene etc. and generally insoluble in polar solvents like water.
Molecules of covalent compounds are held together by relatively weaker forces as compared to ionic compounds. Therefore, covalent compounds have relatively lower melting and boiling points.

Covalent compounds are poor conductors of electricity because they contain neither the ions nor free electrons necessary for conduction.

2. VERSATILE NATURE OF CARBON

The nature of the covalent bond enables carbon to form a large number of compounds.
Two factors noticed in the case of carbon are –
(i) Catenation: Carbon has the unique ability to form bonds with other atoms of carbon, giving rise to large molecules. The self-linking property of carbon atoms through covalent bonds to form long chains of carbon, branched chains of carbon or even carbon atoms arranged in rings. In addition, carbon atoms may be linked by single, double or triple bonds.
Compounds of carbon, which are linked by only single bonds between the carbon atoms, are called saturated compounds.
Compounds of carbon having double or triple bonds between their carbon atoms are called unsaturated compounds.
(ii) Tetravalency: Carbon has a valency of four, it is capable of bonding with four other atoms of carbon or atoms of some other mono-valent element. Compounds of carbon are formed with oxygen, hydrogen, nitrogen, sulphur, chlorine and many other elements giving rise to compounds with specific properties which depend on the elements other than carbon present in the molecule.

Homologous Series: It is a family of organic compounds having the same functional group in which the formula of successive members differs by $–CH_2$ group. For example,
For alkanes CH_4, C_2H_6, C_3H_8, C_4H_{10} etc.
For alkenes C_2H_4, C_3H_6, C_4H_8 and C_5H_{10} etc.
For alkynes C_2H_2, C_3H_4, C_4H_6 and C_5H_8 etc.

For example, the chemical properties of CH_3OH, C_2H_5OH, C_3H_7OH and C_4H_9OH are all very similar. Hence, such a series of compounds in which the same functional group substitutes for hydrogen in a carbon chain is called a homologous series.
The melting and boiling points increase with increasing molecular mass.

5. Nomenclature of Carbon Compounds

S.No.	Class of Example compounds	Prefix/Suffix	Example	Structure
1.	Halo alkane	Prefix -Chloro, -Bromo	Chloropropane Bromopropane	$CH_3CH_2CH_2Cl$ $CH_3CH_2CH_2Br$
2.	Alcohol	Suffix - ol	Propanol	$CH_3CH_2CH_2OH$
3.	Aldehyde	Suffix - al	Propanal	CH_3CH_2CHO
4.	Ketone	Suffix - one	Propanone	CH_3COCH_3
5.	Carboxylic acid	Suffix - oic acid	Propanoic acid	CH_3CH_2COOH

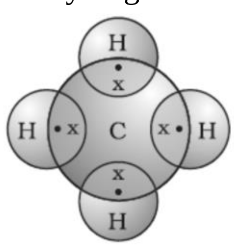
6.	Alkenes	Suffix - ene	Propene	$CH_3CH = CH_2$
7.	Alkynes	Suffix - yne	Propyne	$CH_3C \equiv CH$

Some functional groups in carbon compounds:

Hetero atom	Class of compounds	Formula of functional group	Examples
Cl/Br	Halo- (Chloro/Bromo) alkanes	-Cl, -Br (substitutes for hydrogen atom)	Chloroethane (C_2H_5Cl) Bromoethane(C_2H_5Br)
Oxygen	1. Alcohol	-OH	Ethanol (C_2H_5OH)
	2. Aldehyde	-CHO	Ethanal (CH_3CHO)
	3. Ketone	>C = O	Propanone (CH_3COCH_3)
	4. Carboxylic acid	-COOH	Ethanoic acid (CH_3COOH)

Saturated and Unsaturated Carbon Compounds

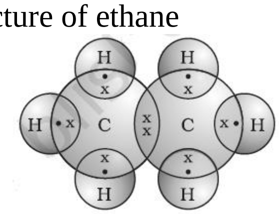
The carbon compounds which contain only carbon and hydrogen are called hydrocarbons. Among these, the saturated hydrocarbons are called alkanes. Methane, Ethane, Propane etc. Methane has a formula CH_4. Hydrogen has a valency of 1. Carbon is tetravalent because it has four valence electrons. In order to achieve noble gas configuration, carbon shares these electrons with four atoms of hydrogen as shown in Fig. is given below:



Electron dot structure for methane

Structure of ethane formed between carbon and hydrogen with a formula of C_2H_6.
The structure of ethane is arrived in the following steps –

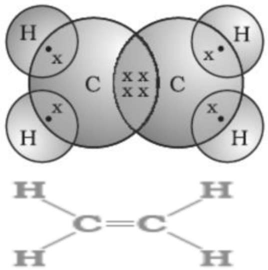
(a) Carbon atoms linked together with a single bond
(b) Each carbon atom bonded to three hydrogen atoms
(c) Electron dot structure of ethane



Electron dot structure for ethane

The unsaturated hydrocarbons which contain one or more double bonds are called alkenes. Ethene, Propene etc.
Those containing one or more triple bonds are called alkynes. Ethyne, Propyne etc.

The electron dot structure for Ethene.



Another compound of hydrogen and carbon has the formula C_2H_2 and is called Ethyne.

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

Chains, Branches and Rings
The carbon compounds methane, ethane and propane, containing respectively 1, 2 and 3 carbon atoms. Such 'chains' of carbon atoms can contain many more carbon atoms.

Formulae and structures of saturated compounds of carbon and hydrogen (Alkanes)

No. of C atoms	Name	Formula	Structure
1	Methane	CH_4	CH_4
2	Ethane	C_2H_6	$CH_3 – CH_3$
3	Propane	C_3H_8	$CH_3 – CH_2 – CH_3$
4	Butane	C_4H_{10}	$CH_3 – CH_2 – CH_2 – CH_3$
5	Pentane	C_5H_{12}	$CH_3 – CH_2 – CH_2 – CH_2 – CH_3$
6	Hexane	C_6H_{14}	$CH_3 – CH_2 – CH_2 – CH_2 – CH_2 – CH_3$
7	Heptane	C_7H_{16}	$CH_3 – CH_2 – CH_2 – CH_2 – CH_2 – CH_2 - CH_3$
8	Octane	C_8H_{18}	$CH_3 – CH_2 – CH_2 – CH_2 – CH_2 – CH_2 - CH_2 - CH_3$
9	Nonane	C_9H_{20}	$CH_3 – CH_2 – CH_2 – CH_2 – CH_2 – CH_2 - CH_2 - CH_2 - CH_3$
10	Decane	$C_{10}H_{22}$	$CH_3 – CH_2 – CH_2 – CH_2 – CH_2 – CH_2 - CH_2 - CH_2 - CH_2 - CH_3$

Formulae and structures of unsaturated compounds of carbon and hydrogen (Alkenes)

No. of C atoms	Name	Formula	Structure
1	Ethene	C_2H_4	$H_2C = CH_2$
2	Propene	C_3H_6	$CH_3 – CH = CH_2$
3	1-Butene	C_4H_8	$CH_3 – CH_2 – CH = CH_2$
4	1-Pentene	C_5H_{10}	$CH_3 – CH_2 – CH_2 – CH = CH_2$

Formulae and structures of unsaturated compounds of carbon and hydrogen (Alkynes)

No. of C atoms	Name	Formula	Structure
1	Ethyne	C_2H_2	$H - C \equiv C - H$
2	1-Propyne	C_3H_4	$CH_3 – C \equiv C - H$
3	1-Butyne	C_4H_6	$CH_3 – CH_2 – C \equiv C - H$
4	1-Pentyne	C_5H_8	$CH_3 – CH_2 – CH_2 – C \equiv C - H$

CHEMICAL PROPERTIES OF CARBON COMPOUNDS:

1. Combustion: Carbon, in all its allotropic forms, burns in oxygen to give carbon dioxide along with the release of heat and light.

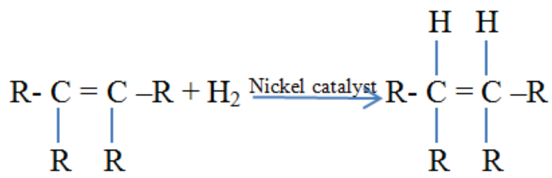
(i) $C + O_2 \longrightarrow CO_2$ + heat and light
(ii) $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$ + heat and light
(iii) $CH_3CH_2OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O$ + heat and light

Saturated hydrocarbons will generally give a clean flame while unsaturated hydrocarbons will give a yellow flame with lots of black smoke. Limiting the supply of air results in incomplete combustion of even saturated hydrocarbons giving a sooty flame.

2. Oxidation: Carbon compounds can be easily oxidised on combustion. In addition to this complete oxidation, in which ethyl alcohol is converted to ethanoic acid upon heating in the presence of alkaline potassium permanganate or acidified potassium dichromate (oxidising agents).

$$CH_3CH_2OH \xrightarrow{\text{alkaline KMnO4 + Heat}} CH_3COOH$$

3. Addition reaction: Unsaturated hydrocarbons add hydrogen in the presence of catalyst such as palladium or nickel to give saturated hydrocarbons.



4. Substitution reaction: Saturated hydrocarbons are fairly unreactive and are inert in the presence of most reagents. However, in the presence of sunlight, chlorine is added to methane in very fast reaction. Chlorine can replace the hydrogen atoms one by one. It is called a substitution reaction.

$CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl$ (in the presence of sunlight)

SOME IMPORTANT CARBON COMPOUNDS - ETHANOL AND ETHANOIC ACID

Properties of ethanol:

Ethanol is a liquid at room temperature. Ethanol is commonly called alcohol and is the active ingredient of all alcoholic drinks. Ethanol is also soluble in water in all proportions.

Reactions of Ethanol:

(i) Reaction with sodium: When ethyl alcohol reacts with sodium leading to the evolution of hydrogen and the other product is sodium ethoxide.
$2CH_3CH_2OH + 2Na \rightarrow 2CH_3CH_2O\text{–}Na + H_2$
(Sodium ethoxide)

(ii) Reaction to give unsaturated hydrocarbon: Heating ethanol at 443 K with excess concentrated Sulphuric acid results in the dehydration of ethanol to give Ethene
$CH_3CH_2OH \xrightarrow{\text{Hot Conc. H2SO4}} CH_2 = CH_2 + H_2O$
The concentrated Sulphuric acid can be regarded as a dehydrating agent who removes water from ethanol.

Uses: It is a good solvent; it is also used in medicines such as tincture iodine, cough syrups, and many tonics. Consumption of small quantities of dilute ethanol causes drunkenness. However, intake of even a small quantity of pure ethanol (called absolute alcohol) can be lethal. Also, long-term consumption of alcohol leads to many health problems.

Properties of ethanoic acid:

Ethanoic acid is commonly called acetic acid and belongs to a group of acids called carboxylic acids. Carboxylic acids are obviously characterized by their acidic nature. Carboxylic acids are weak acids. The melting point of pure ethanoic acid is 290 K and hence it often freezes during winter in cold climates. This gave rise to its name glacial acetic acid.

Reactions of ethanoic acid:

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

$CH_3COOH + CH_3CH_2OH \xrightarrow{\text{Acid}} CH_3COOCH_2CH_3 + H_2O$

(Ethanoic acid) (Ethanol) (Ester)

On treating with sodium hydroxide, which is an alkali, the ester is converted back to alcohol and sodium salt of carboxylic acid. This reaction is known as saponification because it is used in the preparation of soap. Soaps are sodium or potassium salts of long chain carboxylic acid.

$CH_3COOCH_2CH_3 + NaOH \longrightarrow CH_3COONa + CH_3CH_2OH$

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

$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$

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

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

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

Uses: Generally, esters are sweet-smelling substances. These are used in making perfumes and as flavouring agents. 5-8% solution of acetic acid in water is called vinegar and is used widely as a preservative in pickles.

SOAPS AND DETERGENTS:

Soaps: They form scum when reacted to hard water. Soaps are derived from natural substances such as vegetable oils and animal fats.

Detergents: They do not form scum. Detergents are generally a derivative of a synthetic compound.

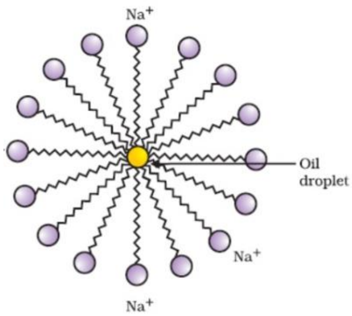
Preparation of soap: On heating with sodium hydroxide, vegetable oil or animal fat forms a sodium salt of fatty acid and glycerol. This process is known as saponification.

Vegetable oil/Animal fat + NaOH $\xrightarrow{\text{Saponification}}$ Glycerol + Sodium salt of fatty acid (Soap)

Cleansing action of soaps:

A soap molecule is made up of two chemically distinct parts that interact with water in different ways. It has one polar end with a short head carboxylate group (−COONa) and one non-polar end with a long tail made of the hydrocarbon chain.

Hydrophilic and hydrophobic end: The polar end is hydrophilic (water-loving) in nature, and it is drawn to water. The non-polar end is hydrophobic (hates water) in nature, and it is attracted to dirt or oil on the cloth but not to water. As a result, the hydrophobic part of the soap molecule traps the dirt while the hydrophilic part makes the entire molecule water-soluble.
When soap or detergent is dissolved in water, the molecules form clusters known as **'micelles'**.



Formation of micelles

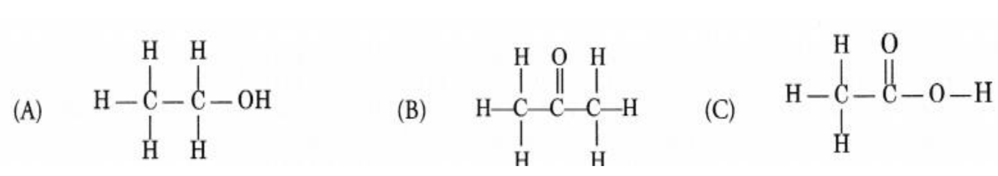
Their long hydrocarbon chains bind to the oil and dirt. As a result, the dirt is surrounded by the non-polar end of the soap molecules. The micelles are water-soluble because of the charged carboxylate end of the soap molecules. As a result, the soap washes away the dirt.

Detergents are generally sodium salts of sulphonic acids or ammonium salts with chlorides or bromides ions, etc. Both have long hydrocarbon chain. The charged ends of these compounds do not form insoluble precipitates with the calcium and magnesium ions in hard water. Thus, they remain effective in hard water. Detergents are usually used to make shampoos and products for cleaning clothes.

Assignments:

Q1. Give the names of the following functional groups:
(i) —OH (ii) –CHO (iii) —COOH
Answer. (i) Alcohol group (ii) Aldehydic group (iii) Carboxylic acid group

Q2. Write the IUPAC names of the following compounds.



Answer: (A) Ethanol (B) Propanone (C) Ethanoic acid.

Q3. Vapours of a hydrocarbon were passed through bromine dissolved in carbon tetrachloride. The yellow colour of bromine got discharged? Predict the nature of the hydrocarbon.
Answer: The hydrocarbon is unsaturated. It is either an alkene or alkyne.

Q4. What is the role of soap in cleansing of clothes?
Answer: Soap helps in forming a stable emulsion between oil drops carrying dirt particles and water. The emulsion is also known as micelle.

Q5. Which organic compound is added to make ethanol unfit for drinking purposes? What is the name of the mixture formed?
Answer: Methanol which is highly poisonous is added in small amount to ethanol in order to make it unfit for drinking purposes. The mixture is called methylated spirit or denatured alcohol.

Q6. Which element exhibits the property of catenation to maximum and why?
Answer: The element is carbon. This is because of very small size of carbon atom (77 pm) and high strength of C—C bond (355 kJ mol^{-1}).

Q7. How will you convert Ethene into Ethanol? Give the chemical reaction involved.
Answer: Ethene is converted into ethanol by passing its vapours through water in the presence of Sulphuric acid. This reaction is called hydration of Ethene.

$$H_2C = CH_2 + H_2O \xrightarrow{(H_2SO_4)} CH_3—CH_2—OH$$

Q08. Explain with the help of chemical equations, the following properties of carbon.
(i) Combustion
(ii) Oxidation.
Answer:

$$(i) \quad C_2H_5OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O \text{ (Combustion)}$$

$$(ii) \quad C_2H_5OH + O_2 \xrightarrow{K_2Cr_2O_7/H_2SO_4} CH_3COOH + H_2O \text{(Oxidation)}$$

Q9. Give a chemical test to distinguish between:
(i) Ethane and Ethene
(ii) Ethanol and ethanoic acid
(iii) Soaps and detergents.
Answer: (i) Ethene decolorizes the yellow colour of bromine water while ethane does not.
(ii) Ethanoic acid gives a brisk effervescence with sodium hydrogen carbonate while ethanol does not.
(iii) Soaps form curdy white precipitate or scum with hard water while detergents do not form any precipitate.

Q10. Give reasons for the following observations:
(a) The element carbon forms a very large number of compounds.
(b) Air holes of a gas burner have to be adjusted when the heated vessels get blackened by the flame.
(c) Use of synthetic detergents causes pollution of water.
Answer.
(a) Carbon forms large number of compounds since carbon is small in size and can form stable covalent bonds (Catenation) and it shows Tetravalency.

(b) Air holes of gas burner are made open (adjusted) so that air can pass through, which is needed for complete combustion, so that heated vessels do not get blackened.
(c) Some synthetic detergents are non-biodegradable, therefore, cause pollution of water.

Q11. What is a homologous series? Which two of the following organic compounds belong to the same homologous?
CH_3, C_2H_6, C_2H_6O, $C_2H_6O_2$, CH_4O
Answer. Homologous series is a series of organic compounds which has same functional group and similar chemical properties. Each member of this series differs by $–CH_2$ - in its molecular formula and 14u in its molecular mass.
CH_4O (CH_3OH) and C_2H_6O (C_2H_5OH) belong to same homologous series.

Q12. (i) An unknown compound has the smell of vinegar. Identify it.
(ii) What do we get when ethanoic acid reacts with ethanol in the presence of concentrated Sulphuric acid?

(iii)Give a test to identify the presence of ethanoic acid.
Answer: (i) The compound is ethanoic acid (CH_3COOH) also called acetic acid.

(ii)Ethyl ethanoate ($CH_3COOC_2H_5$) is formed by esterification reaction. It has fruity smell.

(iii)Dip a strip of blue litmus paper in the solution of ethanoic acid. Its colour will change to red.