8. CARBON AND ITS COMPOUNDS

Carbon is chemical element (C) with an atomic number of 6 and atomic weight of 12.01115 and electronic configuration 2,4. It is estimated that carbon makes up 0.032% of the earth's crust. Carbon is unique in chemistry because it forms a vast number of compounds, larger than the sum total of all other elements combined. By far the largest groups of these compounds are those composed of carbon and hydrogen. It has been estimated that there are at least 1,000,000 known organic compounds, and this number is increasing rapidly every year.

A carbon atom has 4 electrons in its outermost shell and since one carbon atom requires 4 electrons to achieve the eight electron inert gas configuration, therefore the valency of carbon is 4.

ALLOTROPY OF CARBON

Allotropy is the existence of an element in two or more different forms in the same physical state. The different forms of elements are called allotropes.

Elemental carbon exists in two well-defined crystalline allotropic forms, diamond (the hardest naturally occurring substance) and graphite. Other forms, which are poorly developed in cyrstallinity, are charcoal, coke, and carbon black which are amorphous forms of carbon. Chemically pure carbon is prepared by the thermal decomposition of sugar (sucrose) in the absence of air. The physical and chemical properties of carbon are dependent on the crystal structure of the element.

While diamond is very hard, transparent and a nonconductor of electricity, graphite is black, soft, opaque and a good conductor of electricity. Another form of graphite is carbon black. This is not present in nature. It is obtained by burning compounds of carbon and hydrogen in a limited supply of air. Diamond is employed where hardness is desired, like in drilling bits and abrasives. Graphite finds use as a lubricant, for making lead pencils, high temperature crucibles, arc light and in dry cells. Carbon black is used to harden rubber for tyre manufacture and printing inks. The less pure forms of the elemental carbon-charcoal and coke- are widely used as fuels. Coke is also used as a reducing agent in metallurgy. Charcoal is used as an absorbent for gases and as a decolourising agent.

COMPOUNDS OF CARBON

Elemental carbon is a fairly inert substance. It is insoluble in water, dilute acids and bases, and organic solvents. At elevated temperatures, it combines with oxygen to form carbon monoxide or carbon dioxide. Of halogens, only flourine reacts with elemental carbon. A number of metals combine with the element at elevated temperatures to form carbides.

Carbon atoms also have a great capacity to link with more and more carbon atoms. They can thus form large chains or large rings of compounds. This property of carbon is called catenation.

Carbon forms three gaseous compounds with oxygen: carbon monoxide, CO; carbon dioxide, CO2 and carbon sub oxide, C3O2. The first two oxides are more important from an industrial standpoint. Carbon forms compounds with the halogens which have the general formula CX4where X is fluorine, chlorine, bromine, or iodine. At room temperature, carbon tetrafluoride is a gas, carbon tetrachloride is a liquid, and the other two compounds are solids. Mixed carbon tetrahalides are also known. Perhaps the most important of them is dichlorodifluoromethane CCl_2F_2, commonly called Freon.

Extensive amounts of carbon are found in the form of its compounds. In the atmosphere, carbon is present as carbon dioxide. Various minerals such as limestone, dolomite, marble, and chalk all contain carbon in the form of carbonate. All plant and animal life is composed of complex organic compounds containing carbon combined with hydrogen, oxygen, nitrogen, and other elements. The remains of plant and animal life are found as deposits of petroleum, asphalt, and bitumen. Deposits of natural gas contain compounds that are composed of carbon and hydrogen.

Carbon dioxide is a colourless, odourless, tasteless gas, formula CO2, about 1.5 times as heavy as air. Under normal conditions, it is stable, inert, and nontoxic. The decay (slow oxidation) of all organic materials produces CO2. Fresh air contains approximately 0.03% CO2 by volume. In the respiratory action (breathing) of all animals and humans, CO2 is exhaled.

Carbon dioxide gas may be liquefied or solidified. Solid CO2 is known as dry ice. Carbon dioxide is obtained commercially from four sources: gas wells, fermentation, combustion of carbonaceous fuels, and as a by-product of chemical processing. Most CO2 is obtained as a by-product from steam-hydrocarbon reformers used in the production of ammonia, gasoline, and other chemicals. Applications include use as a refrigerant, in either solid (dry ice) or liquid form, inerting medium, chemical reactant, neutralising agent for alkalies, and pressurizing agent.

Carbon dioxide does not support the combustion of a splint or candle, but magnesium ribbon burns with a

crackle in carbon dioxide forming white magnesium oxide and black specks of carbon. Carbon dioxide turns calcium hydroxide solution (lime water) milky. This is due to the formation of calcium carbonate which is a white insoluble solid. When excess carbon dioxide is bubbled through the solution, calcium hydrogen carbonate is formed. This is soluble in water and the milkiness therefore disappears and the solution becomes clear.

Carbon monoxide is formed when carbon compounds burn in limited supply of air. Carbon monoxide is very poisonous and particularly dangerous because it has no smell. More people have been killed by carbon monoxide than by any other gas. Carbon monoxide is poisonous because it reacts with the haemoglobin in blood and prevents the blood from acting as an oxygen carrier. The gas can be produced accidentally by leaving a car engine running in a closed garage or by burning a fire or boiler with restricted ventilation. Carbon monoxide can act as a reducing agent. At higher temperatures it reduces the oxides of copper, lead, and iron to the metals. Carbon monoxide is the principal reducing agent in a blast furnace.

ORGANIC COMPOUNDS

Organic chemistry is the chemistry of carbon compounds. Most of these compounds are known as organic compounds because of their origin in the tissue of living organisms. As there are a very large number of carbon compounds, their study forms an entire branch of chemistry. Carbon and hydrogen are the essential components of all organic compounds while oxygen, nitrogen, sulphur, phosphorus and halogens may also be present. Organic compounds constitute major components of energy sources like petroleum and coal; components of food like proteins, fats, carbohydrates and vitamins, drugs like anaesthetics, antiseptic and antibiotics, materials like cotton, wool, silk and synthetic fibres (e.g. nylon and terylene).

It is possible to divide organic compounds into two main divisions depending on their structure: acyclic and cyclic. The acyclic compounds are those in which the carbon atoms are linked to each other in such a manner that the molecule is having an open chain structure. They are also known as open-chain compounds or aliphatic compounds. Examples: methane, ethane, ethylene, ethyl alcohol, acetone, acetic acid, etc. These open-chain compounds may have a straight or branched chain of carbon atoms and are accordingly referred to as straight chain or branched chain aliphatic compounds.

When the carbon atoms are linked to each other or to the atoms of some other elements in a manner so as to form a closed chain or ring type structure, the compounds are known as cyclic compounds. The compounds with only one ring of atoms in the molecule are known as monocyclic but those with more than one ring of atoms are termed as polycyclic. . Again the ring may be made up of only carbon atoms or it may contain different atoms like N, O, S, etc., besides the carbon in the ring. The former types of compounds are known as homocyclic or carbocyclic whereas the latter are referred to as heterocyclic. A large number of cyclic compounds having alternate single and double bonds show unusual stability towards addition reaction and undergo substitution reactions despite the unsaturation in the molecule. Such compounds are designated as arene or aromatic.

HYDROCARBONS

Hydrocarbons are organic compounds containing carbon and hydrogen only. Examples: methane, ethane, propane, butane, benzene. Hydrocarbons occur abundantly in nature, largely in petroleum, natural gas and coal. They can be considered as the parent organic compounds from which other organic compounds are derived. The major use of hydrocarbons is as fuels and as petrochemicals.

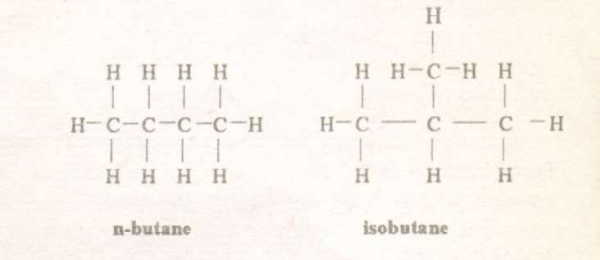
The simplest hydrocarbon is methane (CH_4). A molecule of methane has four hydrogen atoms linked to one central atom of carbon. We know that the valency of carbon is 4 (tetravalent). The carbon atom, therefore, forms a chemical bond with 4 atoms of hydrogen by sharing an electron with each of them. The valency of hydrogen is 1 (monovalent) and each of the hydrogen atoms also shares an electron with the carbon atom. A methane molecule thus formed by 4 hydrogen atoms surrounding a carbon atom (four single covalent bonds) in a chemical bond makes for a very stable arrangement. Like carbon dioxide, methane molecules also contribute to greenhouse effect. In fact, methane molecules trap 20 times as much heat as a molecule of carbon dioxide.

Hydrocarbons are of two types: saturated hydrocarbons and unsaturated hydrocarbons.

Saturated Hydrocarbons. A hydrocarbon, in which the carbon atoms are attached by single covalent bonds only, is called a saturated hydrocarbon. Alkanes (types of hydrocarbon) are saturated hydrocarbons. The general formula of alkanes is C_nH_{2n+2} where n is the number of carbon atoms in one molecule of alkane. The hydrocarbons methane (CH_4) ethane (C_2H_6) propane (C_3H_8) and butane (C_4H_{10}) form a series of carbon compounds belonging to a family, in which one member to another is called a homologous series. Alkanes are excellent fuels.

Isomerism. Compounds having the same molecular formula but different structural arrangement of atoms in them are known as isomers, and the phenomenon is known as isomerism. All members of alkanes, except first three methane, ethane and propane can have more than one

structural formula. For example butane can have 2 different arrangements of atoms in its molecule as shown below.



Unsaturated Hydrocarbons. A hydrocarbon in which the two carbon atoms are attached by a double bond or a triple bond is called an unsaturated hydrocarbon. Unsaturated hydrocarbons are of two types: (1) those containing double bonds—alkenes, and (ii) those containing triple bonds— alkynes.

Alkenes. The general formula of alkenes is C_nH_{2n} where n is the number of carbon atoms in its one molecule. Ethylene, C2H4 or H2C=CH2 and propylene C_3H_6 or CH_2=CH- CH_3 are the two examples of alkenes. Alkenes are also known as olefins.

Alkynes. The general formula of alkynes is C_nH_{2n-2}, where n is the number of carbon atoms in its one molecule. Examples are acetylene, C_2H_2 or HCºCH; propylene C_3H_4 or HCºC-CH3, etc. It is to be noticed that there can be no alkenes or alkynes having only one carbon atom.

Unsaturated hydrocarbons are obtained mostly from petroleum by a process called cracking (means breaking down).

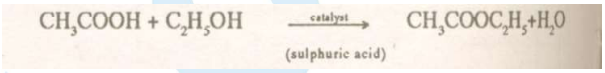
SOME COMPOUNDS OF CARBON, HYDROGEN AND OXYGEN

Alcohols. An alcohol is a compound containing hydroxyl group, —OH. It is produced by replacing one hydrogen atom of an alkane by a—OH group. Common examples are methanol (CH_3OH), ethanol ($C2H_5OH$), propanol (C_3H_7OH), etc. Alcohols also form homologous series with the general formula $C_nH_{2n+1}OH$. They are named after parent alkane by replacing the last letter E by OL. Most common alcohols are liquids.

Methanol is poisonous, mixed with ethanol it used in spirit lamps and as a solvent for wood polish. Methanol is also used for making perfumes and synthetic fibres. Ethanol is the most widely used alcohol. It is prepared by fermentation process whereby sugar and starch molecules are broken down into smaller molecules along with the formation of carbon dioxide. Ethanol is a constituent of beer, wine, whisky and other liquors. A mixture of alcohol and water known as antifreeze is used in radiators of vehicles in cold countries. Alcohols are used as fuels and solvents.

Organic Acids. Organic acids contain-COOH group (carboxyl group). Organic acids can be prepared by oxidation of alcohols. Acids are named after the respective alkane containing the same number of carbon atoms, by substituting the last letter E of the corresponding alkane by OIC ACID. For example HCOOH is methanoic acid (formic Acid), CH_3COOH is ethanoic acid (Acetic acid) etc. Lower acids are liquids. However those acids whose molecules contain large number of carbon atoms (>16) occur as solid, and are known as fatty acids. They are used as mild acids, in foods, cold drinks, drugs, perfumes and soaps.

Esters. Compounds which contain the functional group COO are called esters. Esters are formed when organic acids react with alcohols in the presence of sulphuric acid.



Esters have a fruity smell. They are used in cold drinks, icecreams, sweets and perfumes. They are also found to occur in fruits.

PETROLEUM AND NATURAL GAS

Petroleum or rock oil (Petra—rock and oleum–oil) usually floats on a layer of salt water, deep below the rocks and has a layer of natural gas upon it. Natural gas contains about 80% methane and 10% ethane, the remaining 10% being a mixture of higher gaseous hydrocarbons. Compressed Natural Gas (CNG) is natural gas filled in cylinders under high pressure. Most of it is used as an industrial fuel, without purification. The propane-butane fraction is separated from the more volatile components by liquefaction: it is compressed into cylinders and sold as bottled gas or LPG (liquified petroleum gas) which is used as domestic fuel for cooking.

Mining of oil is done by drilling holes in the earth's crust and sinking pipes up to the oil bearing porous rock. As the pipe reaches the oil, it rushes up through the pipe due to the pressure of the gases inside. As the gas pressure gets low, the oil is pumped out by applying air pressure. The crude oil is obtained as a viscous, dark coloured liquid, often with a distinct odour. It consists of a mixture of gaseous, liquid and solid hydrocarbons. Besides hydrocarbons, small amounts of organic compounds containing oxygen, nitrogen and sulphur are also present. The hydrocarbons present in crude oil are paraffins (C1 to C40 alkanes), naphthenes (cycloalkanes), olefins and aromatic compounds in varying percentages. It is separated into various fractions by the process known as refining of petroleum. According to the nature of the main constituents present, the crudes are classified into three groups:

(a) **Paraffin-base** petroleum mainly consists of hydrocarbons of the paraffin series. On distillation, solid

paraffin wax is left behind.

(b) **Asphalt-base** petroleum is rich in nonparaffinic hydrocarbons, like aromatic and naphthenic compounds, and on distillation asphalt or bitumen is left behind.

(c) **Mixed base** has a composition between the above two types.

The history of petroleum in India began with its accidental discovery in Digboi, Assam in 1889-90. After independence (1947), extensive oil exploration began which changed the picture of the petroleum industry in India. In 1956, Oil and Natural Gas Commission (ONGC) was set up. It has been very successful in locating new oil fields and mining the crude. The chief oil producing areas are Assam, Gujarat and Bombay High (offshore).

Refining of Petroleum The refining of crude oil involves separation into fractions with different boiling points. The distillation of petroleum is carried in tubular furnace with a tall steel fractionating column. The fractionating column consists of a vertical steel cylinder divided by horizontal plates into a number of sections. These plates are called trays. The trays have a large number of perforations, through which vapour pass in the upward direction. Each perforation in mounted by a short pipe and a cap, called the bubble cap. The system is such that the vapours have to pass through the liquid collected on one tray so that reasonably good contact between the two is accomplished.

Uses of Various Fractions

(a) **Gaseous Hydrocarbons** This fraction is mainly used as industrial or domestic fuel.

(b) **Petroleum Ether** It is used as solvent in perfumery and also for drycleaning clothes.

(c) **Gasoline** This fraction, when obtained directly from refining process is called straight run gasoline, commonly known as petrol. Crude petroleum contains only a small percentage of this low-boiling fraction. Its yield is therefore, increased by cracking of high boiling fractions, e.g. kerosene or diesel oil.

(d) **Kerosene** Kerosene was the most important petroleum product for almost fifty years since crude oil was first processed. Although it has now lost its leading place to gasoline, it is still in considerable demand. It is used in lamps, burners (stoves), and turbojet aircraft. It is also subjected to the process of cracking to meet the increasing demand for gasoline.

(e) **Diesel oil or Gas Oil** This fraction is used as fuel for diesel engines, for industrial heating (hence also called furnace oil) and as a feed stock for cracking processes where it is converted to high grade gasoline.

(f) **Lubricating oils and Greases** As the name indicates, they are chiefly used for lubrication. Lubricating greases are semi-solid substances made by thickening lubricating oils with soaps, clays, silica gel or other thickening agents.

(g) **Paraffin Wax** It is used in making candles, shoe polish, floor polish, waxed paper, etc. White petroleum jelly (Vaseline) is a paraffin wax with little oil content and is a major constituent of many ointments and cosmetics.

(h) **Asphalt and Coke** These are dark semisolid or solid residues of the distillation process. They are used for roofing, road building, making underground cables, battery boxes and electrodes, etc.

Other Fractions

Other fractions are less useful and are converted by various processes into useful chemicals, e.g. plastics, detergents, solvents, rubber, etc. All chemicals derived from petroleum fractions are called petrochemicals. Another way of converting the high-boiling fractions into useful gasoline is by cracking when smaller hydrocarbons (C_2–C_5) are formed. The quality of petrol for use in car engines is denoted by their anti-knock properties. The anti-knock property of petrol samples are measured by the values of their octane numbers. The higher the octane number of a petrol sample, the more anti-knocking property it has and more useful it is. The highest octane number is 100. To increase octane number, tetra ethyl lead (TEL) is added to petrol.