Chapter

3

Organic Chemistry

INTRODUCTION

Organic chemistry is the study of properties and structure of carbon containing compounds. Thus

"**Organic chemistry deals with hydrocarbons and their derivatives**".

- ✓ However, a few numbers of carbon containing compounds are excluded from organic chemistry either by their properties or nature of bonding.
- ✓ These are carbonates, bicarbonates, cyanides, carbides, carbon dioxide, carbon monoxide and carbon disulphide etc.
- ✓ Organic chemistry is probably the biggest sub-field in chemical sciences and is recognized as the fundamental field for all chemists to study. It serves as a bridge between chemistry and biology.

Old Concept of Organic Chemistry(Vital Force Theory)

Before the 18h century, the term organic chemistry was used only for those substances that were obtained from animals and plants and could not be prepared in laboratory.

It was extensively believed by chemists that there existed a vital force in all living things that was required for the production of organic compounds.

End of Vital Force Theory (Preparation of Urea)

In 1828, a German chemist Friedrich Wohler prepared urea in the laboratory by boiling ammonium cyanate with water.

$$\underset{\text{(ammonium cyanate)}}{NH_4CNO} \xrightarrow{Heat} \underset{\text{(urea)}}{CO(NH_2)_2}$$

Urea is a typical organic compound that is excreted from urine.

Laboratory synthesis of urea by Wohler disapproved the vital force theory and turned the minds of chemists towards synthetic organic chemistry and since then millions of organic compounds have been synthesized.

SOURCES

- ✓ Organic compounds are abundant in nature and can be found in various natural sources such as fossil fuels, plants, animals and microorganisms.
- ✓ They play an important role in our society in various aspects.
- ✓ Fossil Remains (Coal, Petroleum, Natural Gas)
- ✓ Fossil remains refer to the remnants of ancient animals and plants that have been preserved in rocks and sediments.
- ✓ These remains can include bones, teeth, shells imprints of leaves or other plant parts and provide important clues about the history of life on earth.
- ✓ Fossils are formed when an organism dies and its remains are quickly buried by sediment without decomposition.

- ✓ The buried remains become compressed and the organic material in the remains is slowly transformed into fossil fuel leaving behind the minerals of the rock.
- ✓ Fossil fuels are nonrenewable energy source.

The three main types of fossil fuels are coal, petroleum and natural gas.

Coal

Coal is a plant-derived black mineral found beneath the earth's crust and is a solid fossil fuel that has significance all over the world. Plants that were buried underneath the earth crust millennia ago were slowly turned to coal under high temperature and pressure owing to bacterial and chemical processes.
The coal types and their some uses are:

Peat 45– 60%
It is the earliest stage of coal formation resulting from the decomposition of fossilized remains. It has very low heat contents and use for domestic heating as an alternate of fire wood.

Lignite 60-70%
It is a brownish black coloured soft coal. It is typically used to generate electricity in power plants.

Bituminous 70– 85%
It is a black coloured soft coal. It has a higher carbon content than lignite. It is often used for electric generation and steel production.

Anthracite 90–95%
It is a dark black coloured hard coal. It is the highest ranking coal with the highest carbon content. It is used in furnaces, power stations and as a domestic fuel.

Petroleum

The term petroleum refers to rock oil or crude oil since it is a thick black liquid that oozes out of the earth.
It is a complex combination of alkanes, cycloalkanes and aromatic hydrocarbons etc.
Petroleum is formed from the ancient marine animals that were buried millions of years ago in the earth's crust.
It is used for transportation, power generation and many other purposes.
Some important products that are extracted from petroleum include gasoline, kerosene, diesel, naphtha, parafin wax etc.

Natural Gas

Natural gas produced by the decomposition of marine microorganisms over the millions of years.

Natural gas is a mixture of methane, ethane, propane and butane. The highest composition in natural gas is methane (85 - 90% approximately). Natural gas is a more beneficial source of energy than coal and petroleum because its combustion causes less pollution.

Natural Products (Plants and Animals)

Many organic compounds are isolated from plants, animals and microbes. These are referred to as natural products.
These products are typically produced by living organisms through natural metabolic processes and extracted out through various methods such as distillation, fermentation, purification etc.
Natural products have been utilized for millennia for medicinal, cosmetic, and nutritional reasons.

Some examples of natural products are glucose, cellulose, insulin, cholesterol, caffeine, nicotine, menthol and peppermint oil etc.

Partial and Total Synthesis

Partial Synthesis:

Partial synthesis involves starting with a simpler molecule and modifying it through a series of chemical reactions to create a more complex target molecule.
This method is particularly useful when the target molecule challenging to synthesize directly or requires multiple steps.

One example of partial synthesis is the production of the anti-inflammatory drug ibuprofen from a compound called cumene. Cumene undergoes several chemical transformations, including oxidation and rearrangement, to yield ibuprofen.

Total Synthesis:

Total synthesis involves building a complex target molecule entirely from simple starting materials.
It requires designing a route that carefully selects and assembles the necessary building blocks through a series of chemical reactions.
Total synthesis is often used to produce natural products or pharmaceutical compounds that are not readily available from natural sources.
For example, the total synthesis of the anti-cancer drug paclitaxel (Taxol) involves numerous steps to construct the molecule from simple building blocks.

Products of Biotechnology

"Products that are made by using living organisms or their constituents such as cells enzymes, DNA, etc called as products of biotechnology."

Destructive Distillation of Coal

The process in which coal is heated in the absence of air to produce a range of useful products is known as destructive distillation".

The process requires an elevated temperature typically 400°C to 900°C in a closed container. The four principal products of destructive distillation of coal are coke, coal tar, coal gases and ammonia liquor.

Coke

It is a greyish black hard solid contain 98-99% carbon. It is used as fuel and reducing agent.

Coaltar

It is thick black liquid. Its fractional distillation gives many useful organic compounds such as benzene, toluene, xylene, naphthalene and phenol etc.

Coal Gases

It is a mixture of methane and water gas. It is highly flammable and is employed for heating and municipal lighting.

Ammonia Liquor

It is a mixture of ammonium compounds and liquid ammonia and is usually obtained from bituminous coal.

Reforming of Petroleum

"The process of conversion of hydrocarbons (gasoline) with low octane rating into those with higher octane rating that can be utilized as a fuel in internal combustion engine is known as reforming".

The process of reforming is carried out under high pressure and temperature using platinum catalyst.

CHARACTERISTICS OF ORGANIC COMPOUNDS

Catenation

Organic compounds are made up of carbon atoms. Carbon is distinctive in its ability to bond covalently with other carbon atoms in many different ways to form long chain, branch chain and cyclic compounds. This unique property of organic compounds is known as catenation.

Non Ionic Nature

Organic compounds are made up of carbons and a carbon atom contains four valence electrons.
It does not have the ability to lose or gain four electrons since it requires very high energy. Therefore, in contrast with inorganic compounds, it forms covalent bonds by the sharing of electrons.

Solubility

The solubility of organic compounds can vary widely depending on their chemical structure and the solvent in which they are dissolved. For examples:

Water-soluble organic compounds:

Organic compounds that contain polar functional groups, such as hydroxyl (-OH) or carboxyl (-COOH) groups, tend to be soluble in water due to the ability to form hydrogen bonds with water molecules.
For example, ethanol (C_2H_5OH) and acetic acid (CH_3CO0H) are both water-soluble organic compounds.

Nonpolar organic compounds:

Nonpolar organic compounds, such as hydrocarbons, generally have low solubility in water but are soluble in nonpolar solvents like hexane or diethyl ether.
For instance, hexane (C_6H_{14}) and toluene ($C_6H_5CH_3$) are nonpolar organic compounds that exhibit poor solubility in water but dissolve readily in nonpolar solvents.

Low Melting and Boiling Point

Organic compounds in comparison to inorganic compounds have lower melting and boiling points. This is due to the comparatively weak intermolecular forces found in these molecules. They exist as gases, liquids and soft solids.

Flammability

The majority of organic compounds are combustible and readily react with oxygen to form carbon dioxide and water, thereby releasing heat. As a result, most fuels are organic, such as wood, coal, oil, gasoline, and natural

gas. Burning of organic compounds provide heat energy. The combustion reaction for methane (CH_4) is as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{Heat energy}$$

Reactivity

Organic compounds react at a substantially slower rate than the ionic reactions that are often found in inorganic compounds. To accelerate the reaction, they generally require heating, mixing, and a catalyst.

Isomerism

Isomerism is a characteristic of organic compounds where compounds with the same number of atoms of each element can arrange those atoms in different ways, resulting in distinct structures and properties. These compounds with different structures but the same molecular formula are called isomers.

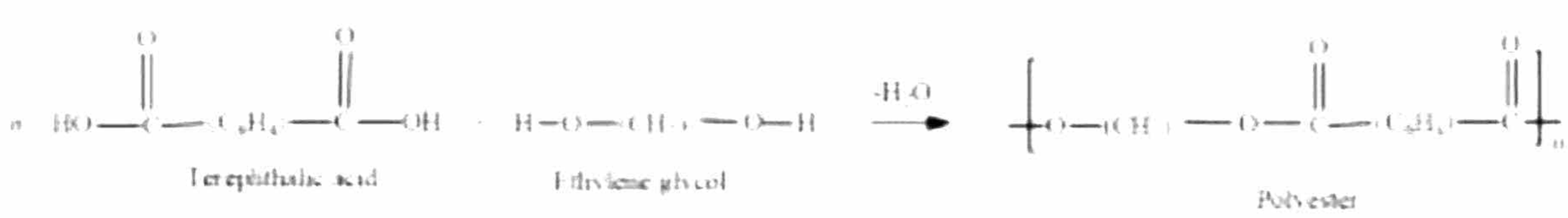
For example:

There are two isomers of butane: n-butane and isobutane.
In n-butane, the carbon atoms form a straight chain, while in isobutane, the carbon atoms form a branched structure.
n-Butane: CH_3-CH_2-CH_2-CH_3
Isobutane: CH_3-$CH(CH_3)$-CH_3

Polymerization

Many small organic molecules (monomers) can unite through addition or condensation process to form a single large molecule. This process is known as polymerization and the macromolecule thus formed is called as a polymer.

For example, the polymerization of terephthalic acid (a dicarboxylic acid) with ethylene glycol (a diol) forms polyethylene terephthalate (PET), which is a common type of polyester used in various applications, including textiles, packaging, and beverage containers.



USES OF ORGANIC COMPOUNDS

Organic compounds are widely used in various applications, including pharmaceuticals, agriculture, plastics, fuel, material production, and energy generation.

Use of common organic compounds

Organic Compounds	Common Use
Gasoline	Fuel for automobiles
Natural gas	Domestic fuel
Ethene	Ripening of fruits
Ethyne	Gas Welding
Formalin	Preservative of biological specimen
Ethylene glycol	Antifreeze and coolant in automobiles
Phenol	Antiseptics and ink preservatives
Diethyl ether	Anesthesia
Acetic acid	Vinegar
Ethyl acetate	Artificial flavors and essences
Acetone	Nail polish remover
Nylon	Ropes and fish nets
Poly ester	Fabrics
Carbohydrate, protein, fats, vitamins	Food components

NEW ALLOTROPIC FORM OF CARBON (BUCKY BALLS)

It has been known for centuries that pure carbon exists in two allotropic forms with diamond and graphite.

In 1985, Richard Smalley and Harry Kroto introduced a new allotropic form of carbon that consists of 60 carbons.

The shape of this newly discovered form of carbon was similar to the geodesic dome developed by American architect and scholar Richard Buckminster Fuller. The name of this new form of C_{60} was suggested as Fullerene or Bucky Ball.

It consists of twelve (12) five membered ring and twenty (20) six membered ring. Structurally each pentagon is surrounded by hexagon. Forming a hollow cage-like structure.

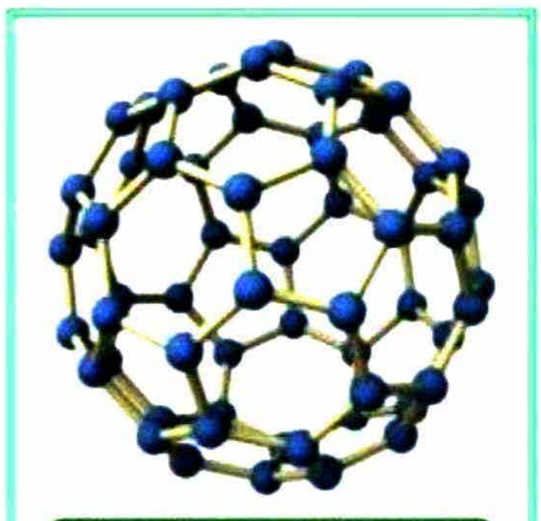
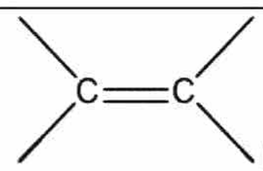
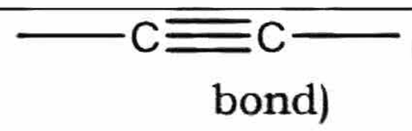
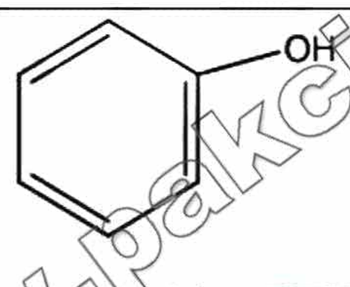
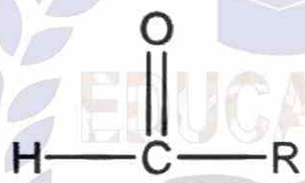
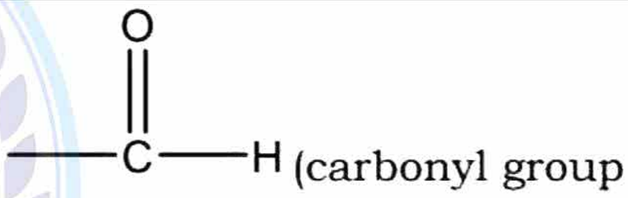
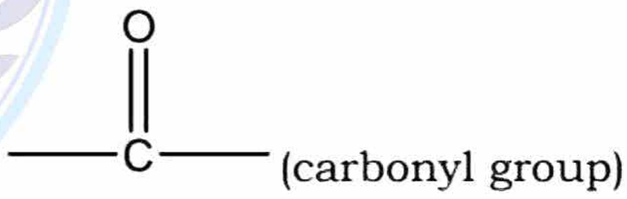


Fig 3.2: Structure of Bucky Ball

Functional Group

"A functional group is a specific group of atoms within the molecule that is responsible for unique chemical properties and determines its characteristic reactions".

HOMOLOGUES SERIES	GENERAL FORMULA	FUNCTIONAL GROUP
Alkane	R — H or C_nH_{2n+2}	—
Alkene	R = H or C_nH_{2n}	 (double bond)
Alkyne	R ≡ H or C_nH_{2n-2}	 (triple bond)
Haloalkane	R — X (where X = F, Cl, Br, I Or $C_nH_{2n+1}X$	—X (halide group)
Alcohol	R — OH or $C_nH_{2n+1}OH$	— OH (hydroxyl group)
Phenol	 Or R — O —R' or C_6H_5OH	— OH (hydroxyl group)
Ether	R — O —R' or $C_nH_{2n+2}O$	— OR' (alkoxyl group)
Aldehydes		 (carbonyl group or —CHO) aldehyde group
ketone		 (carbonyl group) (Ketonic group)

Homologous Series

"A series refers to group of organic compounds with similar structural characteristics but differing from each other by the addition of a methylene group (-CH_2-) in their structure is called homologous series".

The general characteristics of homologous series are given below:

(i) The composition of all the members of a homologous series can be expressed by a general formula.

Alkane C_nH_{2n+2}
Alkene C_nH_{2n}
Alkynes C_nH_{2n-2}
Alcohol $C_nH_{2n+1}OH$
Alkyl halide $C_nH_{2n+1}X$
Amine $C_nH_{2n+1}NH_2$

(ii) The molecular mass of each member of homologous series differs from the next higher or lower member by 14 a.m.u.
(ii) All the members of homologous series show similar chemical properties due to the presence of similar functional group.
(iv) There is a gradual variation in the physical properties such as physical state, solubility, melting and boiling points etc as the number of carbon atoms per molecule increases.

Short Questions

1. Define organic chemistry and give the significance of some organic compounds in everyday life

Organic chemistry is the study of the structure, properties, composition, reactions, and preparation of organic compounds. Organic compounds are chemical compounds that contain carbon atoms. They are the basis of all life on Earth, and they are also found in many non-living things, such as petroleum, coal, and natural gas.

Some of the most important organic compounds in everyday life include:

- **Food:** Organic compounds make up all of the food that we eat. Carbohydrates, proteins, fats, and vitamins are all organic compounds.
- **Clothing:** Many of the fibers that are used to make clothing, such as cotton, wool, and polyester, are organic compounds.
- **Plastics:** Plastics are synthetic organic compounds that are used to make a wide variety of products, from food packaging to medical devices.
- **Fuels:** Petroleum and coal are both organic compounds. They are used to generate electricity and power vehicles.
- **Medicines:** Many medicines are organic compounds. For example, aspirin, ibuprofen, and penicillin are all organic compounds.

2. What is Vital force theory? Why was it disapproved?

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3. Define functional group and write the structure of three oxygen containing functional group.

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4. Define the following terms: (a) Catenation (b) Isomerism

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5. How can you differentiate between total and partial synthesis of organic compounds?

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6. What is meant by Reforming? Why is it considered a useful technique?

Reforming is a chemical process that converts low-octane hydrocarbons into high-octane hydrocarbons. It is a widely used process in the petroleum industry to produce gasoline and other high-value products.

Reforming is a useful technique because it allows refiners to produce high-octane gasoline from low-octane hydrocarbons. This is important because high-octane gasoline produces less emissions and less engine knocking.

Here are some of the specific benefits of reforming:

- Improved octane rating: Reforming produces high-octane gasoline, which is better for engines and produces less emissions.
- Increased yield of high-value products: Reforming also produces other high-value products, such as benzene, toluene, and xylene, which can be used to make a variety of other products, such as plastics and petrochemicals.
- Reduced environmental impact: Reforming can help to reduce the environmental impact of gasoline production by reducing the amount of waste products that are produced.

7. Write down some examples of products that can be produced using biotechnology?

- **Food:**

Biotechnology can be used to produce food that is more nutritious, pest-resistant, or drought-tolerant. For example, genetically modified (GM) crops such as soybeans, corn, and rice are widely grown around the world. Biotechnology can also be used to produce food additives and enzymes, such as rennet for cheesemaking and aspartame for sweeteners.

- **Medicine:**

Biotechnology is used to produce a wide range of medicines, including vaccines, antibiotics, and hormones. For example, recombinant insulin is produced using biotechnology, and it is used to treat diabetes. Biotechnology is also being used to develop new treatments for cancer and other diseases.

- **Biofuels:**

Biotechnology can be used to produce biofuels such as ethanol and biodiesel from renewable resources such as corn and soybeans. Biofuels can help to reduce our reliance on fossil fuels and reduce greenhouse gas emissions.

- **Industrial chemicals:**

Biotechnology can be used to produce a variety of industrial chemicals, such as bioplastics, detergents, and solvents. Biobased chemicals can help to reduce our reliance on petroleum and other fossil fuels.

- **Environmental products:**

Biotechnology can be used to produce a variety of environmental products, such as bioremediation agents and wastewater treatment products. Bioremediation agents can be used to clean up contaminated soil and water, and wastewater treatment products can be used to remove pollutants from wastewater.

8. Write down some common uses of organic compounds?

Organic compounds are used in a wide variety of products and applications.

- **Food:** Organic compounds make up all of the food that we eat. Carbohydrates, proteins, fats, and vitamins are all organic compounds.
- **Clothing:** Many of the fibers that are used to make clothing, such as cotton, wool, and polyester, are organic compounds.
- **Plastics:** Plastics are synthetic organic compounds that are used to make a wide variety of products, from food packaging to medical devices.
- **Fuels:** Petroleum and coal are both organic compounds. They are used to generate electricity and power vehicles.
- **Medicines:** Many medicines are organic compounds. For example, aspirin, ibuprofen, and penicillin are all organic compounds.
- **Personal care products:** Organic compounds are used in a wide variety of personal care products, such as soaps, shampoos, conditioners, and cosmetics.
- **Cleaning products:** Organic compounds are used in a variety of cleaning products, such as detergents, dishwashing liquids, and all-purpose cleaners.
- **Construction materials:** Organic compounds are used in a variety of construction materials, such as asphalt, roofing materials, and insulation.
- **Industrial products:** Organic compounds are used in a variety of industrial products, such as paints, solvents, and adhesives.

Descriptive Questions

1. Describe the natural sources of organic compounds.

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2. Define Bucky Ball? Explain its structure and mention its some properties.

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3. Explain destructive distillation of coal? What are the various products obtained from it?

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4. Describe homologous series of organic compounds? Write three main properties of homologous series.

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5. Explain various unique characteristics associated with organic compounds.

- **Carbon-based:**

All organic compounds contain carbon. Carbon is a unique element because it can form four bonds with other atoms, which allows it to form a wide variety of complex structures.
Covalent bonding: Organic compounds are held together by covalent bonds. Covalent bonds are strong bonds that are formed when two atoms share electrons.

- **High molecular weights:**

Organic compounds can have very high molecular weights, which means that they can be made up of millions of atoms. This allows organic compounds to form complex structures with a variety of properties.

- **Isomerism:**

Organic compounds can exhibit isomerism. Isomers are compounds that have the same molecular formula but different structures and properties.

- **Functional groups:**

Organic compounds contain functional groups, which are groups of atoms that have specific chemical properties. The presence or absence of functional groups can have a significant impact on the properties of an organic compound.

6. Describe natural product chemistry and explain the use of plants and animals as sources of organic compounds.

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7. Write down the different types of coal and how do they differ from each other?

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