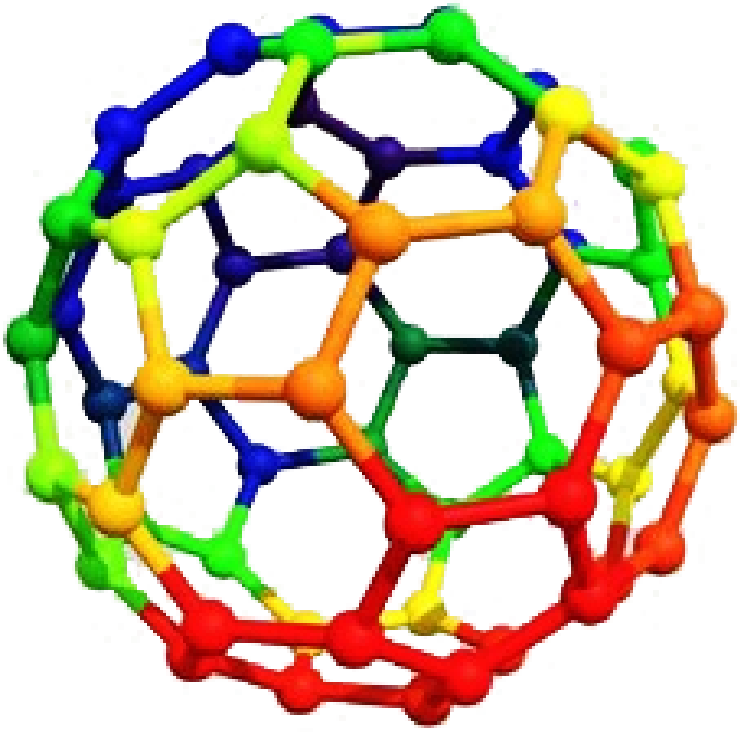
CHAPTER 3

ORGANIC COMPOUNDS

Teaching Periods	04	Assessment	01	Weightage %	03



Students will be able to:

- ✓ Define organic chemistry and organic compounds. (Remembering)
- ✓ Explain why there is such a diversity and magnitude of organic compounds. (Analyzing)
- ✓ Explain the use of coal as a source of both aliphatic and aromatic hydrocarbons. (Understanding)
- ✓ Explain the use of plants as a source of organic compounds. (Understanding)
- ✓ Explain that organic compounds are also synthesized in the lab. (Understanding)
- ✓ Define functional groups and homologous series. (Remembering)
- ✓ Explain reforming of petroleum. (Understanding)
- ✓ Explain different uses of organic compounds in our daily life. (Understanding)
- ✓ Explain Bucky ball. (Understanding)

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.

Before the 18^{th} 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. In 1828, a German chemist Friedrich Wohler prepared urea in the laboratory by boiling ammonium cyanate with water.

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

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.

The methane (CH_4) can also be synthesized in the laboratory from hydrogen (H_2) and carbon monoxide (CO) in presence of catalyst at high temperature and moderate pressure.

$$CO + 3H_2 \xrightarrow{\text{Ni / Heat}} \underset{\text{(methane)}}{CH_4} + H_2O$$

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.

3.1 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.

3.1.1 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.

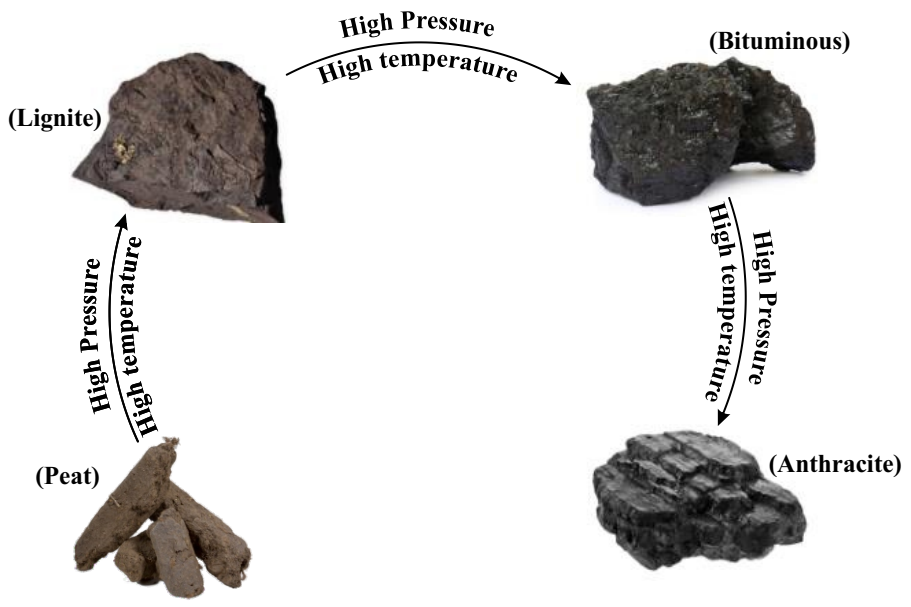


Fig. 3.1: Chemical and bacterial changes of fossil remains

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 (Fig.3.1). The coal types and their some uses are given in Table 3.1.

Table 3.1 Coal types and uses

Coal type	% age of carbon contents	Properties and uses
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 (Latin words: 'petra' which means rock and 'oleum' means oil). 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, paraffin 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.

The initial discovery of natural gas in Pakistan dates back to 1952 when it was found in the Sui area of Baluchistan. Subsequently, natural gas deposits were also identified in Khairpur and Ghotki districts in the province of Sindh.

Self Assessment

- Write the names of ten organic compounds used in daily life.

3.1.2 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.

3.1.3 Partial and Total Synthesis

Partial synthesis and total synthesis are two approaches used in organic chemistry to create complex molecules.

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 is 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.

These examples illustrate how partial synthesis modifies an existing compound to create a target molecule, while total synthesis involves constructing the target molecule from scratch using simpler starting materials.

3.1.4 Products of Biotechnology

Biotechnology is the field of biological sciences that deals with the involvement of living organisms or their ingredients in preparation or development of valuable products. **"Products that are made by using living organisms or their constituents such as cells enzymes, DNA, etc are called as products of biotechnology."**

These products have been used across various industries including food production, healthcare, agriculture genetic engineering etc.

Biotechnology has enabled the development of vaccines for a variety of fatal diseases such as COVID-19. Vaccines consist of inactive pathogens which produce proteins that act as stimulants for our immune system to develop antibodies so that if the virus enters our body, our immune system can easily fight it.

These products have been used across various industries including food production, healthcare, agriculture genetic engineering etc. For example, ethyl alcohol is commercially manufactured by fermentation process in which certain enzymes secreted by microorganisms (yeast) are involved.

3.2 COAL AS A SOURCE OF ORGANIC COMPOUNDS

Coal mines can be considered a valuable asset for countries. In addition to its widespread use in power generation, coal is also a source of many important organic compounds. These organic compounds can be extracted from coal or obtained as a by product of coal processing. Further, coal can be gasified or liquefied to produce a range of organic compounds such as methane, ethene, ethyne, hexane etc. These compounds can be used as raw materials for the production of many useful chemicals.

DO YOU KNOW?

The largest coal reserves in Pakistan are found in the Thar Desert, Tharparkar district of Sindh province. Tharcoal reserves are considered to be the sixteenth largest in the world containing approximately 175 billion tons of lignite coal.

3.2.1 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

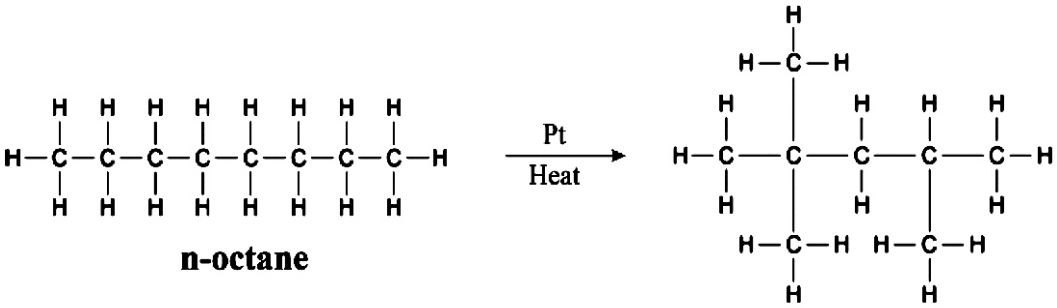
It is a mixture of methane and water gas. It is highly flammable and is employed for heating and municipal lighting.

Ammonia Liquor

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

3.2.2 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.



n-octane **Isooctane**

Low-quality gasoline can cause knocking when ignited in an internal combustion engine due to improper combustion. Knocking produces a sharp sound. Higher-quality gasoline tends to produce less knocking. To measure a fuel's resistance to knocking, chemists use the octane number or octane rating. This standard measure assesses the fuel's ability to resist knocking and helps determine its quality. **"The octane number quantifies a fuel's ability to resist knocking during combustion."**

DO YOU KNOW?

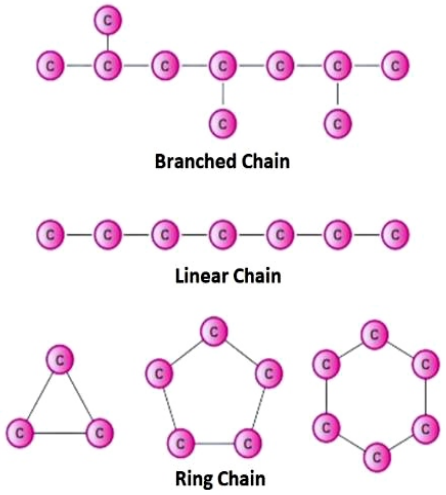
The octane number is measured using the Research Octane Number (RON) scale. RON compares a fuel's performance against a mixture of iso-octane (rated 100) and n-heptane (rated 0) in a standardized engine test. The higher the percentage of iso-octane needed to match the fuel's performance, the higher its octane number.

Previously, Tetra Ethyl Lead $(C_2H_5)_4Pb$ (TEL) was used as an additive in gasoline to prevent knocking. However, the production of harmful pollutants led to the search for alternatives to reduce atmospheric pollution. Chemists developed a process called reforming as an alternative to TEL. Reforming converts low-octane gasoline into a higher-octane fuel, effectively reducing knocking without the need for TEL. This advancement in the production of higher-octane gasoline helped replace the use of TEL and mitigate its negative environmental impact.

3.3 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_3COOH) 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:

$$CH_{4(g)} + 2O_{2(g)} \longrightarrow CO_{2(g)} + 2H_2O_{(g)} + \text{Heat energy}$$

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.

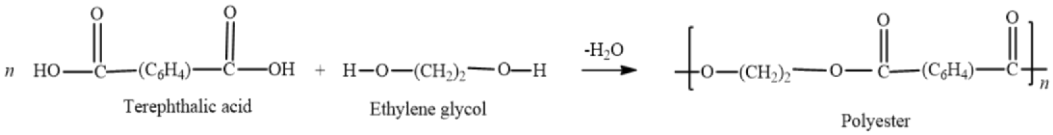
For example: there are two isomers of butane: n-butane and isobutane. In n-butane, the carbon atoms form a straight chain, while in isobutane, the carbon atoms form a branched structure.

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.



3.4 USES OF ORGANIC COMPOUNDS

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

Table 3.2 displays several organic compounds and their applications that are relevant to our everyday existence.

Table 3.2 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	Anaesthesia
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

3.5 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.

Bucky balls are hollow spheres made up of carbon atoms that have a diameter of approximately one nanometer (Fig.3.1). They have high tensile strength and exhibit high degree of stability with a melting point of 2800°C. They are light weight with a high surface area and are good conductors of electricity and heat.

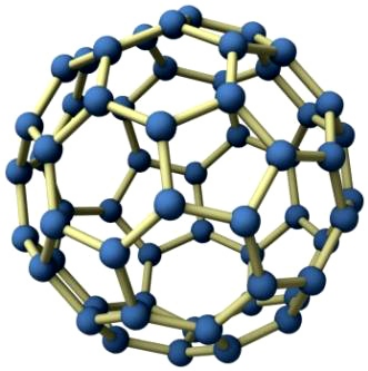


Fig 3.2: Structure of Bucky Ball

Bucky balls are used in nanotechnology such as nanoscale sensors, drug delivery system and high storage batteries and electronic devices.

3.6 FUNCTIONAL GROUPS AND HOMOLOGOUS SERIES

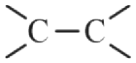
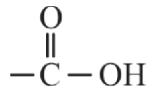
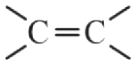
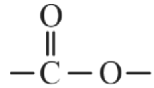
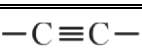
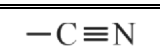
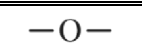
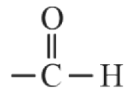
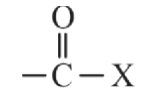
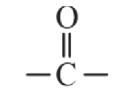
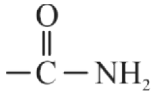
Functional Group

A large number of organic compounds are considered to be derivatives of hydrocarbons in which one or more hydrogen atoms are replaced by another atom or group of atoms known as a 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".** Each functional group has its own chemical characteristic; therefore, all the

compounds having the same functional group behave alike and belong to the same family. For example, alcohol is a class of organic compounds and all the members of this class possess hydroxyl (–OH) functional group.

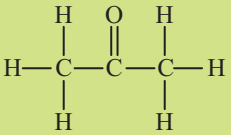
Some common functional groups and their corresponding classes of organic compounds are listed below Table 3.3.

Table 3.3 Name and structure of some common functional groups

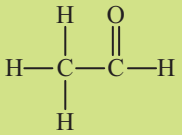
Class of Compound	Structure of Functional Group	Class of Compound	Structure of Functional Group
Alkane		Carboxylic acid	
Alkene		Ester	
Alkyne		Nitrile	
Alcohol		Thiol	
Ether		Alkyl Halide	
Amine			
Aldehyde		Acyl halide	
Ketone		Amide	

Self Assessment

Predict the functional group present in the structures given below:



(a)



(b)

Homologous Series

The chemical and physical properties of organic compounds depend to a great extent on their functional group. The physical properties of all the compounds of the same functional group are not precisely same but change with the length of hydrocarbon chain thus **"A series refers to a 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}	Alcohol	$C_nH_{2n+1}OH$
Alkene	C_nH_{2n}	Alkyl halide	$C_nH_{2n+1}X$
Alkynes	C_nH_{2n-2}	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**.

(iii) 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.

Self Assessment

Write down the general molecular formula of the homologous series of ethers and alcohols.

SOCIETY, TECHNOLOGY AND SCIENCE

Isolation of organic compounds from plants and animals

There are many organic compounds that are obtained from plants and animals. For example, animal **manure** and **seaweed** are gathered from animals and plants respectively which are used as fertilizers in the farms and agricultural lands.

Moreover, countless medicines are directly extracted from plants. For instance, **Caffeine** is obtained from tea, cocoa and coffee beans. It is used as Central Nervous System Stimulant. **Bromelain** is obtained from lemon, orange, grapefruit, etc. and it aids in the treatment of fragility.

SUMMARY

- Urea is a typical organic compound prepared by Friedrich Wohler by boiling ammonium cyanate with water.
- Fossil fuels are nonrenewable energy sources. They include coal, petroleum and natural gases.
- There are four types of coal named as peat, lignite, bituminous and anthracite.
- Petroleum is formed from the ancient marine animals by the chemical and bacterial degradation.
- Organic compounds that are isolated from plants, animals and microbes are known as natural products.
- The process of synthesizing a target molecule directly from an intermediate compound, rather than through stepwise reaction from starting material is called as partial synthesis.
- The process of synthesizing a target molecule from simple starting material using stepwise series of reaction is known as total synthesis.

- Products that are made by using living organisms or their constituents such as enzymes, DNA etc are called products of biotechnology.
- The process in which coal is heated in the absence of air to produce coke, coltar, coal gases and ammonia liquour is known as destructive distillation of coal.
- Octance number measures the quality of fuel in terms of its capacity to with stand knocking during combustion.
- The C_{60} molecule of Bucky ball consists of twelve (12) five membered rings and twenty (20) six membered rings.
- Functional group is a specific group of atoms within the molecule which is responsible for unique chemical properties.
- A series of organic compounds in which the various members have similar structural features but differ from each other by methylene group ($-CH_2-$) is called homologous series.

Multiple Choice Questions

(i) The functional group that contains a nitrogen atom is:
(a) Alcohol (b) Ketone
(c) Ester (d) Amide

(ii) The compound belongs to the alkene family is:
(a) CH_4 (b) C_2H_6
(c) C_3H_8 (d) C_2H_4

(iii) Destructive distillation of coal gives coke, coaltar, coal gas and:
(a) Natural gas (b) Petroleum
(c) Naphtha (d) Ammonia liquor

(iv) The knocking of internal combustion engine can be reduced by the following petroleum process:
(a) Reforming (b) Refining
(c) Distillation (d) Condensation

(v) The general formula of the homologous series of alcohol is:
(a) C_nH_{2n} (b) C_nH_{2n+2}
(c) $C_nH_{2n+1}OH$ (d) $C_nH_{2n-1}OH$

(vi) The number of five membered and six membered rings in C_{60} Bucky ball are respectively:
(a) 12 and 12 (b) 5 and 15
(c) 12 and 20 (d) 40 and 20

(vii) The pair of compounds that exhibit isomerism is:
(a) C_2H_5-OH and C_3H_7-OH
(b) CH_3-CH_2-CH_2-CH_3 and CH_3-$CH(CH_3)$-CH_3
(c) C_2H_5-CH_2-Cl and C_3H_7-CH_2-Cl
(d) CH_3-NH_2 and CH_3-CH_2-NH_2

(viii) The type of coal that is hard and high ranked is:
(a) Peat (b) Lignite
(c) Bituminous (d) Anthracite

(ix) Which of the following hydrocarbon is the chief constituent of natural gas?
(a) CH_4 (b) C_2H_6
(c) C_3H_8 (d) C_4H_{10}

(x) Urea was first synthesized by Wohler from an inorganic material named as:
(a) Ammonium nitrate (b) Ammonium chloride
(c) Ammonium cyanate (d) Ammonium bicarbonate

Short Questions

1. Define organic chemistry and give the significance of some organic compounds in everyday life
2. What is Vital force theory? Why was it disapproved?
3. Define functional group and write the structure of three oxygen containing functional group.

4. Define the following terms:
   (a) Catenation (b) Isomerism
5. How can you differentiate between total and partial synthesis of organic compounds?
6. What is meant by Reforming? Why is it considered a useful technique?
7. Write down some examples of products that can be produced using biotechnology?
8. Write down some common uses of organic compounds?

Descriptive Questions

1. Describe the natural sources of organic compounds.
2. Define Bucky Ball? Explain its structure and mention its some properties.
3. Explain destructive distillation of coal? What are the various products obtained from it?
4. Describe homologous series of organic compounds? Write three main properties of homologous series.
5. Explain various unique characteristics associated with organic compounds.
6. Describe natural product chemistry and explain the use of plants and animals as sources of organic compounds.
7. Write down the different types of coal and how do they differ from each other?