CHAPTER 3

ORGANIC COMPOUNDS

The branch of chemistry which deals with study of the structure, properties, preparation, composition and reactions of organic compounds is called organic chemistry.

Organic Compounds

Organic compounds can be defined as follows.

Definition.1: Carbon containing compounds are called organic compounds. All carbon containing compounds are not organic like oxides of C (CO, CO_2), carbonates, bicarbonates, carbides, cyanides, cyanates, thiocyanides, thiocyanates, carbon sulphides, metal carbonyls, diamond, graphite etc. are not organic as these do not possess all the properties of organic compounds.

Definition.2: Those compounds which possess C essentially, H generally, O and N commonly and halogens, metals and sulphurseldomely are called organic compounds.

Definition.3: Hydrocarbons are known as organic compounds. Hydrocarbons are organic compounds which contain H and C only. But there are many compounds which contain O, N, S etc. alongwith H and C and these are also organic. So another definition of organic compounds is required.

Definition.4: Hydrocarbons and their derivatives, either obtained from organisms or synthesized in the laboratory are called organic compounds.

Old concept about organic compounds

In the past all the known compounds were classified according to their source from which these were obtained. Compounds obtained from living organisms, plants and animals (like sugar from plants and urea from animals) were named as organic compounds. In 1770, Torbern Bergman, Swedish chemist derived the word organic from "organisms" (life) as these compounds came from living things. On the other hand compounds obtained from the mineral sources were named as inorganic compounds. The word inorganic mean "lifeless" as these compounds came from non-living things.

Vital force theory (VFT)

In the past it was believed that organic compounds can only be obtained from the organisms and these can't be synthesized in the laboratory. There is the involvement of a supernatural force (vital force) in the preparation of organic compounds that's why these can't be prepared in the laboratory. Berzellius was one the supporter of VFT.

Rejection of the vital force theory

In 1828, a German Chemist, Friedrick Wohler prepared the first organic compound "urea" in the laboratory by heating an inorganic compound "ammonium cyanate" and hence the VFT get rejected.

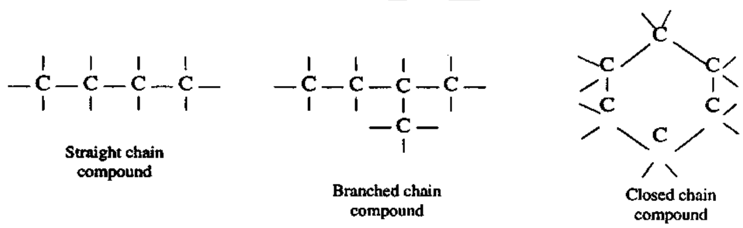
$$\underset{\text{Ammonium cyanate}}{NH_4CNO} \xrightarrow{\Delta} \underset{\text{Urea}}{NH_2CONH_2}$$

Characteristics of organic compounds

Some of the important features of organic compounds are given below.

1. Combustion: All organic compounds are combustable. In excess amount of oxygen organic compounds combusts and form carbon dioxide, water and heat is evolved.

2. Catenation: Catenation or chain formation or self linkage is the characteristic property of carbon. The self linkage of carbon atoms to form chains and ringed compounds is called catenation. Carbon can link with 100s and 1000s of other carbon atoms and form long chains or rings.



3. Multiple bonding: Double and triple bond formation is called multiple bonding. Carbon can form stable single and multiple bonds with one another and with other atoms like O, S, and N.

4. Isomerism: Organic compounds exhibit the phenomenon of isomerism. When two or more compounds with the same molecular formula possess widely different physical and chemical properties. This is due to the difference in the arrangement of their atoms. The phenomenon is called isomerism and the compounds are called isomers.

5. Composition: Organic compounds are made up of a few elements viz., C, H, O, N, S, P and halogens. This differentiates them from inorganic compounds which are made up out of 109 elements approximately.

6. Large number: The number of organic compounds exceeds the number of inorganic compounds despite the fact that organic compounds are constituted of a few elements.

7. Type of linkage: Most of the organic compounds contain covalent bonds in contrast to inorganic compounds which are generally electrovalent.

8. Complex nature: Organic compounds are highly complex and possess higher molecular weights. For example, molecular formula for starch is $(C_6H_{10}O_5)_{200}$.

9. Melting points and boiling points: Organic compounds are usually volatile having low melting and low boiling points. This is because the molecules are usually non-polar and held together by vander waal's forces (London forces).

10. Solubility: As organic compounds are covalent, non-ionic and almost non-polar so most of these compounds have generally low solubility in water and high solubility in organic solvents. Some of the organic compounds such as lower alcohols, sugar, etc., dissolve freely in water.

11. Conductance: Aqueous solutions of organic compounds have lower conductances, which is due to their covalent bonding and non-ionizing nature.

12. Rates of reactions: Reactions involving organic compounds are generally slower than those involving inorganic compounds. This is because the bonds are covalent and non polar.

13. Similar structural features and behavior: Mostly organic compounds have similar structural features and similar physical and chemical properties. The similarities in properties have reduced the study of millions of organic compounds to a few homologous series.

14. Burning with Smokey and sooty flames: Organic compounds burns with flames which are associated with smoke and soot.

How to decide whether a compound of carbon is organic or not?

If a compound possess all the above mentioned properties then it will be organic otherwise inorganic. Diamond, graphite,oxides of C, carbonates, bicarbonates, carbides, cyanides, cyanates, thiocyanides, thiocyanates and carbon sulphides are not organic while buckyballs are organic in nature.

Importance of Organic Chemistry

Life is a practical version of organic chemistry. We live in the age of organic chemistry. No field of science is so closely related with our daily activities as is organic chemistry. Most of the things that we come across in our daily life are organic in nature. The food we eat (carbohydrates, proteins, vitamins, fats etc) is mainly organic in nature. The changes which this food undergoes in our bodies, are organic chemical reactions. Metabolism, growth and maintenance of our bodily functions involves organic chemistry, as do the analogous changes taking place throughout the entire living world, plant and animal. We are totally dependent on organic compounds for food, clothing and medicines.

The clothes we wear, the dyes that colour them, the soap and starch used to launder them, the leather in our shoes, as well as the dye and shoe polish, are products of organic chemical industry. Many of structural materials in our houses and furniture, as well as paints and varnishes used for finishing them, are all organic. Many of the appointments in our motor cars, their fuels and lubricants, and the fuels (petrol, diesel, CNG, coal gas and suigas) which power our industrial plants are all organic in nature. The tremendous importance of organic compounds in everyday life is illustrated by the following list:

Food (Proteins, fats, carbohydrates), Clothing (Cotton silk, wool, nylon, rayon, dacron), Shelter (Wood, paints, varnishes), Power and Transportation (Natural gas, petroleum products, coal), Medicines and Drugs (Penicillin G, streptomycin, LSD), Insecticides (DDT, DDE, Aldrin), Herbicides (Treflan, 2,4-D), Fertilizers and preservatives, Inks, polishes and cosmetics, Hormones and Steroids, Vitamins and Enzymes, Antiseptics and Anaesthetics, Pigments and Dyes, Paper and inks, Photographic films and Developers, Perfumes and Flavours, Plastics, Rubber and Resins, Propellants and Explosives, Leather and fibres, Soaps, Detergents and Refrigerants etc etc.

Our body is made of thousands of complex organic compounds like, proteins, fats, enzymes, lipids, nucleic acids etc. these are called life molecules. Frequently investigations based upon organic chemistry have profoundly influenced the lives of many people, sometimes even the course of civilization. The course of civilization has been greatly affected by the advances in medicine. Much of the advance has been due to the introduction of such organic compounds as antiseptics, anesthetics, and antibiotics. Disease has been checked, the death rate reduced, and the life expectancy of mankind doubled within the last half century. Such profound alteration in human economy, of course, poses new problems of mankind. Possible over population, inadequate supplies of food, increased average age of population, and the like, now challenge the ingenuity of our leaders in the various fields of human endeavour.

Besides the practical applications, most biological problems are concerned with organic chemistry. The composition of tissues and of foods; their changes in metabolism, growth processes, physiology, diseases, all involve the reactions of organic chemistry. An understanding of biological processes, the functioning of plants and animals, and many fundamental phases of agriculture and medicine can be based only upon a knowledge of organic chemistry.

Sources of organic compounds

Principal natural sources of organic compounds are coal, petroleum and natural gas. Coal, petroleum and natural gas are called fossil fuels.

Fossil fuels: Fuels obtained from the anaerobic decomposition of plants and animals are called fossil fuels. Examples are coal petroleum and natural gas.

Fuel: The source of energy is called fuel. Fuel may be fossilized or non-fossilized. Fuel may be natural or artificial. Fuel may be renewable or non-renewable. Fuel may be exhaustible or non-exhaustible. Fuel may be conventional or non-conventional.

Fuel may be primary or secondary. Fuel may be solid, liquid or gaseous.

1. Coal

Coal is black or brownish black solid fossil fuel. Coal is stratified organic rock. It is an important fuel normally occurring in rock strata in layers called coal beds. Due to its importance it is also called black gold or black diamond. Coal is formed in nature from the decay of plants buried under the soil millions of years ago. Coal is mainly composed of carbon along with other elements like H, O, N and S. The approximate ratio of C, H, S, O and N in coal is 135:97:9:1:1.

Theories about the coal: There are two theories about the coal formation.

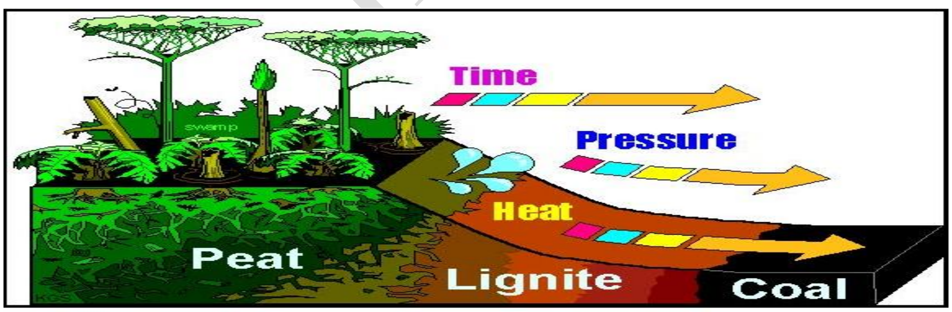
Insitu theory: According to this theory, the coal is formed at the same place where the plants falls, buries and decays.

Drift theory: According to this theory, plants falls at one place, get shifts to other place, buries, decomposes there and changes into coal.

Coalification: The process of formation of coal is called coalification. It is a long process which takes thousands and millions of years. The process takes place under high pressure and high temperature. First the wood changes into peat then into lignite, then bitumen is formed and then anthracite and finally super anthracite is formed. Chemical changes, physical changes and biological changes takes place in the plant matter during coalification process.

$$Plants \xrightarrow[Chemical+Physical+Biological\ Changes]{High\ T,\ High\ P} Peat \longrightarrow Lignite \longrightarrow$$

$$\longrightarrow Bitumen \longrightarrow Anthracite \longrightarrow Super\ \ Anthracite$$



Peat is low quality coal having less %age of carbon while anthracite and super anthracite are best quality coal having high %age of carbon (more than 90%). Peat, lignite and bitumen has small amount of fix carbon and low calorific value while anthracite and super anthracite has large amount of fix carbon and high calorific value.

Composition of coal: Coal is a rich source of organic compounds. It contains more than 200 different organic compounds. Coal consists of the compounds of carbon, compounds of oxygen, compounds of nitrogen, compounds of sulphur, organometallic compounds and some inorganic salts. Organic part of the coal is called maceral while inorganic part is called mineral. Coal contains open chain, close chain, straight chain, branched chain, saturated, unsaturated, alicyclic and aromatic compounds. In coal C is 70-90%, H is 5%, N is 1-2%, O is10% and S is 0.5-5%.

Biological markers: There are some compounds in coal which confirm that coal has been formed from plants, such compounds are called biological markers.

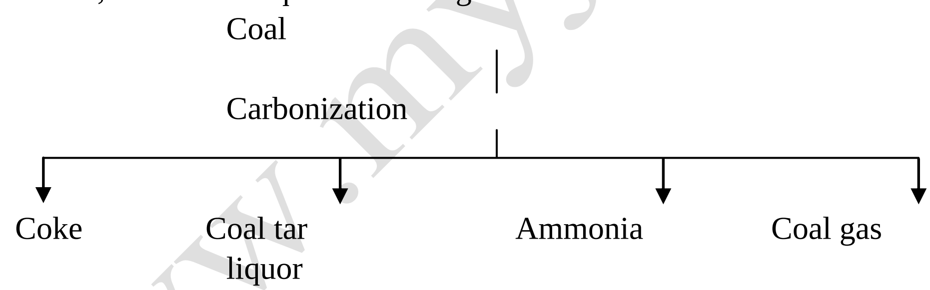
Isolation of organic compounds from coal

Organic compounds can be isolated from coal by a variety of process and techniques which are listed below.

1. Destructive distillation
2. Thermal diffusion
3. Liquefaction
4. Soxhlet extraction
5. Stirring
6. Refluxing

Destructive distillation of coal

It is also called carbonization process. In destructive distillation coal is heated in a metallic chamber in the absence of oxygen and four main products are obtained. Coke, coal tar,ammonical liquor and coal gas.



I. Coke: Coke is a solid powdery product. It is 100% pure carbon. It is also called carbon black or lamp black. It is used as a fuel in homes. It can also be used as a reducing agent in industrial processes (metallurgy).

II. Coal tar: Coal tar is a liquid product of destructive distillation and is a mixture of many organic compounds. When its fractional distillation is carried out we get four fractions.

Light oil: Contain benzene, toluene, aniline and pyridine.

Middle oil: Contain phenol, naphthalene and creosol.

Heavy oil: Contain creosol.

Anthracine oil: Contain anthracine and phenanthrene.

Fractional distillation of these fractions is carried out to get pure compounds. These compounds can be used for making soaps, dyes, plastics, perfumes, drugs, explosives, pesticides etc etc.

III. Ammonical liquor: Ammonical liquor is ammonia solution which consists of ammonium chloride, ammonium sulphide, ammonium bisulphide, ammonium carbonate, ammonium nitrate, ammonium sulphate, ammonium carbide etc. This fraction is used for the preparation of fertilizers.

IV. Coal gas: Coal gas also called town gas. It is a mixture of hydrogen and carbon monoxide. It can be used as a fuel and can also be converted into petroleum.

2. Petroleum

Petroleum is a thick, viscous, dark brown coloured, oily liquid with unpleasant smell extracted from the underground porous rocks. Petroleum is from "petra" mean "rock" and "oleum" means "oil". It is also called rock oil, crude oil, mineral oil and liquid gold. Its colour, odour and composition vary with depth and location. Petroleum is present at a depth of 500 to 2600 feet.

Formation of petroleum: Petroleum is formed from the decay of marine animals. Petroleum formation is also a long process and takes 1000s of years. During the process, physical, chemical and biological processes takes place in the animal matter and petroleum is formed under high temperature and high pressure. Petroleum accumulates in the porous rocks which occur in the form of fault, salt plug and anticline.

Theories about petroleum formation: There are many theories which explain the formation of petroleum. Some old theories consider that petroleum has been formed from inorganics while the modern theories consider the organic origin of petroleum. Berzellious theory, Mendeleev's theory, carbide theory, Engler theory, Berthelot theory, volcanic theory and modern theory explain the petroleum formation.

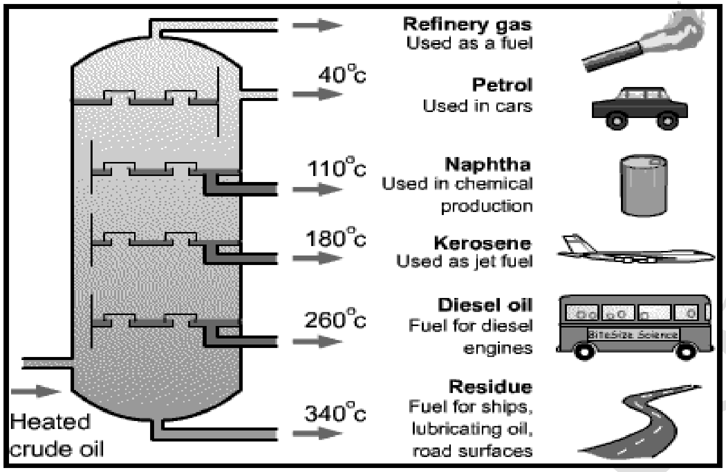
Composition of petroleum: Petroleum is a mixture of various hydrocarbons. The hydrocarbons are mostly alkanes, cycloalkanes, nepthenes and aromatics. Compounds containing N, O, S, halogens and metals (Ni, Cu, V) are also present. The undesirable smell of petroleum is due to the presence of S compounds. Just like in coal there are biological markers in petroleum also which confirm the petroleum origin from animals. Examples of biological markers in petroleum are Limonin, Pristine, Phytol, Phytane, Decaline, Cholestane and Admontane.

Sour oil: Crude oil containing more amount of S is called sour oil.

Sweet oil: Crude oil containing less amount or no S is called sweet oil.

Sweetening of crude oil: The removal of S from crude oil is called desulphurization or sweetening.

Purification or refining of petroleum: Crude oil can be refined by fractional distillation process into various fractions, such as gases, petroleum ether, gasoline, kerosene oil, lubricating oil, etc. at different temperatures. These fractions are used for various purposes.



3. Natural gas

Natural gas is a gaseous fossil fuel associated with crude oil. It is also formed by the decay of marine animal matter and is usually found above the underground deposits of petroleum. It is produced in large volume from oil wells where it is collected in pockets above the crude oil and also in gas wells. Usually the petroleum and natural gas deposits are found in association with each others. It is a mixture of low boiling hydrocarbons like methane, ethane, propane and butane. It mainly contains methane, CH_4 which is used as household fuel.

Composition of natural gas: The composition of natural gas on volume basis is given below.

Methane = 70-90%	Ethane = 1.33-20%	Propane = 0-20%
Butane = 0.05%	Pentane = 0.02%	Hydrogen = 10%
Carbon dioxide = 0-8%	Nitrogen = 0-5%	Oxygen = 0.02%
Hydrogen sulphide = 0-5%	Rare gases = Trace amount.	

The composition of natural gas varies widely depending on the locality. Natural gas of Pannsylvania has high %age of ethane than methane. Natural gas of France has 17% H_2S while the natural gas of Germany has 15% nitrogen.

Specific smell of the natural gas: Sulphurous compounds usually thiols or mercaptanes are added to give characteristic smell to natural gas inorder to make its detection easy.

Types of natural gas: Natural gas is of two types, dry natural gas and wet natural gas. ***Dry natural gas*** contains no oils and no higher hydrocarbons while ***wet natural gas*** contains pentane, hexane and natural gasoline.

Uses of natural gas: Natural gas is usually used as domestic and industrial fuel. It is used for the production of synthesis gas and fuel gas. It is also used as starting material for the production of ammonium fertilizers, hydrogen and carbon black. In addition to this, natural gas i.e., methane is employed for the preparation of other organic compounds like methyl alcohol CH_3OH, methyl chloride CH_3Cl, chloroform $CHCl_3$, etc.

Water gas: Mixture of hydrogen and carbon monoxide.

Producer gas: Mixture of nitrogen and carbon monoxide.

CNG: Compressed natural gas.

LPG: Liquefied petroleum gas.

LNG: Liquefied natural gas.

Octane number and cetane number: The quality and standard of a fuel can be measured interms of cetane and octane numbers. If octane or cetane number of a fuel is high its quality is good and vice versa.

Natural products or natural compounds: Those compounds which are produced by plants and animals are called natural compounds or natural products.

Natural products chemistry: Study of the chemistry of natural products is called natural products chemistry.

Plants have always been a rich source of organic compounds. Natural compounds may be extracted from the tissues of plants. These compounds may be of medicinal importance and can be used in pharmaceutical drugs discovery and drugs designing. Clinically useful drugs which have been isolated from plants are; (Taxol), the anticancer agent palliate isolated from yew tree and artemisinin an anti malarial agent from artimisia annual. There are over hundreds chemical substances, that have been derived from plants for use as medicines e.g. Quinine is used as antimalarial agent, Asprine is used against cardiac diseases and as pain killer, Borneol an antiflamametery agent, Benzylbenzoate as scabicide and Galantaminehydrobromide which is used against Alzheimer’s disease.

Synthetic organic compounds: Those organic compounds which are synthesized in the laboratory from living or non living sources are called synthetic organic compounds.

Synthetic organic chemistry: Study of the processes and chemical reactions of synthesizing organic compounds in the laboratory is called synthetic organic chemistry.

Partial synthesis: When an intermediate product of a reaction is used to synthesize a required compound, the process is known as partial synthesis or semi synthesis. In the preparation of certain organic compounds, bio-molecules are used which may be obtained from organisms. These bio-molecules are complex in structure and cannot easily be prepared in the laboratory from the raw materials. These bio-molecules are treated with other reactants to get the targeted drugs and medicines. Like for example, in the saponification process oils and fats used are obtained from organisms and treated with caustic soda to get soap. Soap formation in which bio-molecules (Fats and oils) are used is a partial synthesis or semi synthesis process.

Total synthesis: when the starting material converts through many steps into the targeted product, the process is known as total synthesis. In the total synthesis, a complex organic molecule is obtained from simple commercially available raw materials.

The first demonstration of total synthesis was the synthesis of urea by F. Wohler in 1828 and the process was commercialized by GustafKompa in 1903 from the synthesis of camphor.

Biotechnology

The field of applied biology that deals with the study of the use of living organisms and bioprocesses in medicine, technology and engineering is called biotechnology. Biotechnology is the use of living organisms to develop useful products. For thousands of years humankind has used biotechnology in agriculture, food production and medicines. In the last 20^{th} and early 21^{st} century, biotechnology has expanded to include new and diverse sciences such as genomics, recombinant gene technologies, applied immunology and development of pharmaceutical therapies and diagnostic tests.

Biotechnology encompasses a wide range of procedures for modifying living organisms according to human purposes, domestication of animals, cultivation of plants and improvement of these through breeding programs that employ artificial selection and hybridization. Modern usage also includes genetic engineering as well as cell and tissue culture technologies. Biotechnology has applications in four major areas including health care, crop production, agriculture and industry. One application of biotechnology is the directed use of organisms for the manufacturing of organic products like beer and milk products. Another example is using naturally present bacteria in bioleaching. Biotechnology is also used to recycle, treat waste, cleanup sites contaminated by industrial activities.

Braches of biotechnology

1. Bioinformatics: It is an interdisciplinary field which addresses biological problems using computational techniques and makes the rapid organization as well as analysis of biological data possible.

2. Blue biotechnology: It deals with the marine and aquatic applications of biotechnology but its use is very rare.

3. Green biotechnology: It is the biotechnology applied to agricultural processes. It deals with the selection and domestication of plants via micro propagation and the designing of transgenic plants.

4. Red biotechnology: It deals with medical processes, the designing of organisms to produce antibiotics and the engineering of genetic cures through genetic manipulation.

5. White biotechnology: It is also known as industrial biotechnology. It is the biotechnology applied to industrial processes. An example is the designing of an organism to produce a useful chemical.

6. Bioeconomy: The investment and economic output of all these types of applied biotechnologies is termed as bioeconomy.

In medicines, modern biotechnology finds applications in areas such as pharmaceutical drug discovery and production, pharmacogenomics and genetic screening.

In agriculture, genetically modified crops and plants are used in agriculture the DNA of which has been modified using genetic engineering.

In industrial biotechnology, biotechnology is applied for industrial purposes including industrial fermentation which finds applications in food, feed, detergents, paper, pulp and textiles.

Most of the products of biotechnology are organic compounds. One application of biotechnology is the direct use of organisms for the manufacturing of organic compounds like beer and milk products. Chemicals which have been made using biotechnology are:

Benzylpeniciline: An antibiotic (discovered by Alexander Fleming)
Insulin: A hormone.
Polyhydroxybutyrate: A biodegradable thermoplastic.
Renin: An enzyme.
Chemosensory protein, ethanol and ethylene glycol etc etc.

Conversion of coal to petroleum

When coal is destructively distilled it gives coal gas alongwith other fractions. The coal gas contains hydrogen and carbon monoxide, which can be converted into petroleum by Fischer-Tropsch process. The process was first of all introduced by Franz Fischer and Hans Tropsch in 1925 in Germany. F-T process is a set of chemical reactions that convert a mixture of carbon monoxide and hydrogen into liquid hydrocarbons mainly alkanes. The conversion of CO to alkanes in the presence of hydrogen involves the hydrogenolysis of C-O bond and the formation of C-C and C-

H bonds. This process takes place in the presence of transition metal catalysts like cobalt, iron, nickel, ruthenium etc. at 150-300^oC.

$$nCO + (2n+1)H_2 \xrightarrow[Temp]{Catalyst} C_nH_{2n+2} + nH_2O$$

Coal is first gasified i.e it is converted into CO and H_2 and then the gaseous reactants are converted into petroleum substitute that is then used as synthetic fuel and synthetic lubricating oil.

Coal liquefaction

The conversion of coal into liquid synthetic fuel is called coal liquefaction. Coal liquefaction was practiced during World War II. Clayton, Becker, Serle, Demarsilly, Berthelot, Bergius, Billwiller, Pott, Bruch, Fischer and tropsch were the important contributors in the coal liquefaction process. Petroleum reservoirs are limited compared to coal whose availability is 100 times more than petroleum. Storage and transportation of liquid fuel is easy compared to solid fuel. Less environmental pollution is associated with liquid fuel combustion. Energy content and calorific value of liquid fuel is high compared to coal, that's why coal liquefaction process was carried out.

Buckyballs

According to the Wikipedia pure carbon is encountered in eleven different forms or allotropes. All forms of carbon are solid at room temperature, are relatively resistant to chemical corrosion and they all burn to form CO and CO_2 when heated to high temperatures in the presence of oxygen. Carbon is found mainly in the form of diamond, graphite, soot, fullerenes and carbon nanotubes.

For centuries it was believed that the element carbon only existed in two very different forms, soft, black, conductive graphite and hard, transparent, insulating diamond. Fullerenes are a family of carbon allotropes,molecules composed entirely of carbon, in the form of a hollow sphere, ellipsoid, tube, or plane. Carbon atoms are arranged in a series of interlocking hexagons and pentagons, forming a structure that looks similar to a soccer ball. The most famous, roundest, most symmetrical and stable molecule, known also by "buckyball" or fullerene C_{60}.An Australian theoretician at the University of California at Berkeley, Tony Haymet, called it 'footballene'. Other relatively common fullerenes are C_{70}, C_{72}, C_{74}, C_{76}, C_{80}, C_{82}, C_{84} and plenty of others, higher or lower than C_{60} exist too but less abundant.

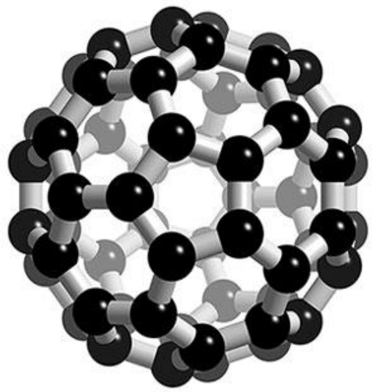
C_{60} fullerene is also called Buckminsterfullerene after Richard Buckminster a known architect who popularized geodesic domes and the shape of C_{60} is similar to these domes.The existence of Buckminsterfullerene was speculated by David Jones in 1966 and it was theoretically studied by Osawa and Yoshida in 1970 and Bochvar and Galpern in 1973. Orville L. Chapman independently thought of C_{60} structure and devoted much time to the planned, systematic synthesis of C_{60}. The first evidence of Buckminsterfullerene's existence was serendipitously obtained by Kroto*et al.* In 1985, Harold Kroto (of the University of Sussex, now the Florida State University), James R. Heath, Sean O. Brien, Robert Curl and Richard Smalley, from Rice University, discovered C_{60}, and then discovered the fullerenes. Kroto, Curl, and Smalley were awarded the 1996Nobel Prize in Chemistry for their roles in the discovery of this class of compounds.

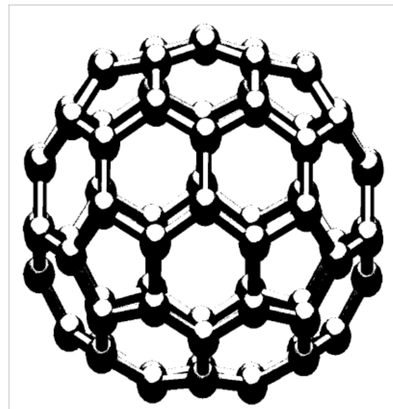
Fullerene C_{60} is called by various names such as Buckminsterfullerene, Buckminsterfullerene C_{60}, Buckyball, C_{60}-Fullerene, (5,6) fullerene-C_{60}-$I_{h,}$ fullerene, Footballene, Fullerene 60, Fullerene C_{60}andSoccerballene, etc. Its Formula is C_{60} with molecular weight of 720.66amu. It is black fine crystalline powder with granular appearance while in sublimed form appears as deep blue-black needle-like crystals reaching 5 nm in size.

Another fairly common fullerene is C_{70}, but fullerenes with 72, 76, 84, 86, 90, 100, 180, 240, 260, 320, 500, 720 and even up to 1000 carbon atoms are existed. The smallest fullerene is the dodecahedron the unique C_{20} which consist of 20 carbon atoms.

Shape and Structure of Buckminsterfullerene

Buckminsterfullerene is the exact structure of a soccer ball, closed cage structure molecule with carbon network, having both pentagonal and hexagonal rings arranged in an alternating fashion, in which no two pentagons share an edge. C_{60} is actually a truncated icosahedron; typically consist of 90 edges, 32 faces, including 20 hexagons and 12 pentagonswhich connect to form a shape with 60 vertices. Each five-member ring of carbon atoms is surrounded by five six-member rings. Carbon atoms are arranged in a series of interlocking hexagons and pentagons, forming a structure that looks similar to a soccer ball. Overall, the resultant structure has patterns of alternating single and double bonds as one trace the C-C bonding framework. Each of the carbons lies at the vertex of fused 5- and 6-membered rings. The alternation of single and double bonds in a molecule has been found to correlate with unexpected stability in molecules closely related to C_{60}. The unusual stability of C_{60} is due to its resonance structures. Thus, by arranging the carbon atoms in hexagonal and pentagonal rings, we find that a nearly spherical molecule with substantial resonance stabilization can be formed from 60 carbon atoms. The structure proposed by Kroto and Smalley is highly symmetric. Each carbon atom is located at the intersection point of two hexagons and one pentagon. The 60 vertices of the buckyball C_{60} are similar. Therefore, all the carbon atoms in buckyball are in the same environment and are chemically equivalent, the structure contains two distinct bond types, the inter pentagonal double bonds (6:6 bond) being short, typically 1.39 A^{o}, whereas the intra pentagonal single bonds (5:6 bond) are long, typically 1.44 A^{o}. In pure C_{60} the near spherical molecules pack in a face-centered cubic (fcc) arrangement.





Fullerene C_{60} Fullerene C_{70}

Variations in Fullerenes

Buckybabies, Fuzzyballs, Giant fullerenes, Rugby balls, Buckyball clusters, Buckypapers, Nano Onions, Linked ball-and-chain dimmers, Fullerites, Bucky Eggs, Exohedral fullerenes, Endohedral fullerenes, Metallofullerenes, Nanopeapods, Nanobuds,Megatubes, Nanotubes are the varities of fullerenes.

Applications and Uses of Fullerenes

Fullerenes are studied in various disciplines such as Astronomy, Chemistry, Electronics, Material Science and Physics.C_{60} fullerene possesses a variety of interesting biological properties such as, HIVP inhibition, DNA photo cleavage, Neuroprotection and Apoptosis. The buckminsterfullerene seems to have an incredible range of electrical properties. It exists in insulating, conducting, semi conducting, and superconducting forms.It can be used as catalysts, used in cosmetics, as abrasive agent for cutting and grinding, dyes and pigments, electrodes, lubricant additive, artificial diamonds, battery chemicals, battery components, diamond film nucleation, dyes, electronics coatings, fuel cells, solar cells, industrial diamond abrasives, optical limiters, photorefractive polymers, photovoltaic polymers, pigments, plastic and polymer additives, plastic transistors, rubber additives,sensors, SiC films, propellants, optical equipment.

During my M.Phil.research we have worked three years on the preparation, characterization, functionalization and applications of fullerenes (bucky balls). Thermocatalytic conversion of buckyballs to carbon nanorods was carried out and the research was highly appreciated when carbon nanorods were prepared thermocatalytically from buckyballs at high pressure for the first time in the history of nanoscience and nanochemistry.

Hydrocarbons

The compounds which consist of hydrogen and carbon only are called hydrocarbons. Hydrocarbons may be saturated or unsaturated.

1. Saturated hydrocarbons

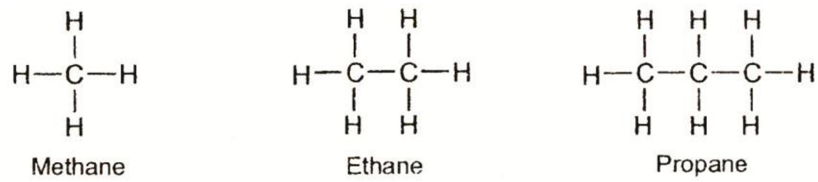
Those hydrocarbons in which the valency of carbon is satisfied by single bonds are called saturated hydrocarbons. All the bonds are single between carbon atoms in saturated hydrocarbons. These are also called paraffins due to their chemical stability (less reactivity)(Latin, *parumaffinis*= little affinity). These are also called alkanes. In these hydrocarbons all the carbon atoms are sp^3 hybridized. All the C-C bond lengths are 1.54Å and C-H bond lengths are 1.09Å. The general formula of saturated hydrocarbons is C_nH_{2n+2}. It means that the number of H atoms will be two more than the double of the number of C atoms in these hydrocarbons. For example if C atoms are five in a saturated hydrocarbon then H atoms must be 2×5+2=12. The formula of such compound will be C_5H_{12}.

Names of First few Alkanes

No. of Carbon atoms	*Name*	*Molecular formula*	*Structural formula*
1	Methane	CH_4	CH_4
2	Ethane	C_2H_6	CH_3CH_3
3	Propane	C_3H_8	$CH_3CH_2CH_3$
4	Butane	C_4H_{10}	$CH_3CH_2CH_2CH_3$
5	Pentane	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$
6	Hexane	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$
7	Heptane	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
8	Octane	C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
9	Nonane	C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
10	Decane	$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
20	Icosane	$C_{20}H_{42}$	
30	Tricontane	$C_{30}H_{62}$	
40	Tetracontane	$C_{40}H_{82}$	
50	Pentacontane	$C_{50}H_{102}$	
100	Hectane	$C_{100}H_{202}$	

Structure of the first three members of this group can be represented as follows.

2. Unsaturated hydrocarbons



In these hydrocarbons there are double and triple bonds between carbons atoms. The valency of carbon atoms is satisfied by the formation of double and triple bonds. The carbon atoms are not fully saturated with hydrogens, that's why these are called as unsaturated hydrocarbons. These may further be divided into alkenes and alkynes.

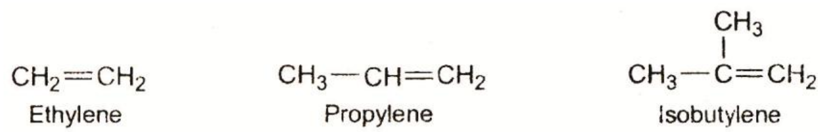
a. Alkenes

Alkenes are unsaturated hydrocarbons in which there must be at least a double bond between carbon atoms. These are also called ollifins (Latin, *Oleum* = oil; *fiacre* = to make) because these form oily substances when react halogens. The two carbon atoms which are connected by double bond are sp^2 hybridized. The bond length between carbon atoms connected by double bond is 1.34Å. General formula of the alkenes is C_nH_{2n}. The number of hydrogen atoms are double than the number of carbon atoms in an alkene. In an alkene there are two hydrogen atoms less than the corresponding alkane. If the number of carbon atoms is 5 then the number of hydrogen atoms will be 2×5=10 and it will be written as $C_5H_{10.}$ Their common names are obtained by changing the ending *–ane* of the corresponding alkane to *ene* (Alkane – ane + ene = Alkene).

Names of First few Alkenes

No. of Carbon atoms	*Name*	*Molecular formula*	*Structural formula*
1	Ethene	C_2H_4	CH_2=CH_2
2	Propene	C_3H_6	CH_2=$CHCH_3$
3	Butene	C_4H_8	$CH_2CHCH_2CH_3$
4	Pentene	C_5H_{10}	$CH_2CHCH_2CH_2CH_3$
5	Hexene	C_6H_{12}	$CH_2CHCH_2CH_2CH_2CH_3$
6	Heptene	C_7H_{14}	$CH_2CHCH_2CH_2CH_2CH_2CH_3$
7	Octene	C_8H_{16}	$CH_2CHCH_2CH_2CH_2CH_2CH_2CH_3$
8	Nonene	C_9H_{18}	$CH_2CHCH_2CH_2CH_2CH_2CH_2CH_2CH_3$
9	Decene	$C_{10}H_{20}$	$CH_2CHCH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
10			

Structure of the first three members of this group can be represented as follows.



b. Alkynes

Alkynes are unsaturated hydrocarbons in which there must be at least a triple bond between carbon atoms. The two carbon atoms which are connected by triple bond are sp hybridized. The bond length between carbon atoms connected by triple bond is 1.24Å. General formula of the alkenes is C_nH_{2n-2}. The number of hydrogen atoms is two less than the double of the number of carbon atoms in an alkyne. Alkynes contain four H−atoms less than the corresponding alkanes and are characterised by the presence of a triple bond in the molecule. The first and the most important member of this series of hydrocarbons is acetylene, HC≡CH, and hence these are also called the Acetylenes, and the triple bond is often referred to as the Acetylenic Linkage. If the number of carbon atoms in an alkyne is 5 then the number of hydrogen atoms will be 2×5-2=8 and it will be written as C_5H_8. Name of the alkyne is obtained by replacing "ane" of the corresponding alkane by "yne". Names, general formulae and structures of some alkynes are given below.

Name	General Formula	Structure
Ethyne	C_2H_2	$CH \equiv CH$
Propyne	C_3H_4	$CH \equiv CCH_3$
1-Butyne	C_4H_6	$CH \equiv CCH_2CH_3$
1-Pentyne	C_5H_8	$CH \equiv CCH_2CH_2CH_3$

Structures of ethyne andbutynes are.

$H—C \equiv C—H$ (Ethyne) $CH_3—CH_2—C \equiv CH$ (1-Butyne) $CH_3—C \equiv C—CH_3$ (2-Butyne)

Types of Carbon Atoms

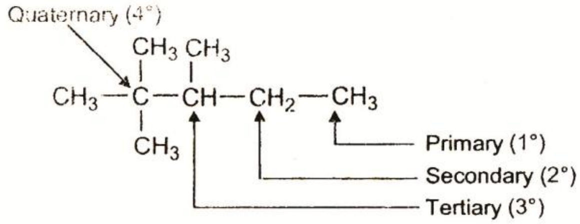
The structural formulas of alkanes contain four types of carbons:

(1) Primary Carbon: A carbon atom attached to one other (or no other) carbon atom is called primary carbon (1^o carbon; 1^o = primary).

(2) Secondary Carbon: A carbon atom attached to two other carbon atoms is called secondary carbon (2^o carbon; 2^o = secondary).

(3) Tertiary Carbon: A carbon atom attached to three other carbon atoms is called tertiary carbon (3^o carbon; 3^o = tertiary).

(4) Quaternary Carbon: A carbon atom attached to four other carbon atoms is called quaternary carbon (4^o carbon; 4^o = quaternary).



Types of hydrogen atoms

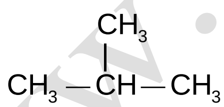
Hydrogen atoms attached to 1^o, 2^o, 3^o carbon atoms are often referred to as primary, secondary and tertiary hydrogen atoms.

Types of alkanes

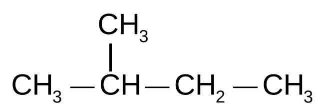
1. Normal alkanes: Alkanes in which all carbons are in one continuous chain are called normal alkanes. These are linear and straight chain alkanes. All the carbon atoms are primary and secondary; there are no tertiary or quaternary carbon atoms in these alkanes. The prefix *n*- is placed before the name of the alkane like;

$CH_3CH_2CH_2CH_3$ (*n*–Butane) $CH_3CH_2CH_2CH_2CH_3$ (*n*–Pentane)

2. Iso-alkanes: These are singly branched alkanes. These are alkanes which have a methyl group (CH_3–) attached to the second last carbon atom of the continuous chain. There is a tertiary carbon atom in these alkanes. The prefix "iso-" is written before the name of the alkane like;

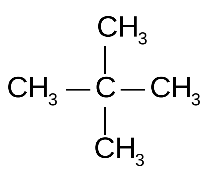


Isobutane

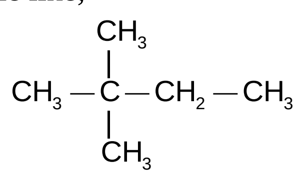


Isopentane

3. Neo-alkanes: These are doubly branched alkanes. Those alkanes which have two methyl groups attached to the second last carbon atom of the continuous chain are called neo-alkanes. There is a quaternary carbon atom in these alkanes. The prefix neo- is written before the name of the alkane like;



Neopentane



Neohexane

Alkyl Groups:

All alkyl groups is formed by removing one hydrogen atom from an alkane.

$$\underset{\text{Alkane}}{RH} \xrightarrow{-H} \underset{\text{Alkyl group}}{R-}$$

$$\underset{\text{Methane}}{CH_4} \xrightarrow{-H} \underset{\text{Methyl group}}{CH_3-}$$

$$\underset{\text{Ethane}}{CH_3CH_3} \xrightarrow{-H} \underset{\text{Ethyl group}}{CH_3CH_2-}$$

The symbol R− is often used to represent an alkyl group. The grouping R− (e.g. CH_3CH_2-) is not a compound and must be bonded to another atom or group of atoms. Alkyl groups are named by dropping *–ane* from the name of the corresponding alkane, and adding the ending *–yl.* Alkane – ane + yl = Alkyl.

CH_4	Methane	CH_3-	Methyl
C_2H_6	Ethane	C_2H_5-	Ethyl
C_3H_8	Propane	C_3H_7-	Propyl
C_4H_{10}	Butane	C_4H_9-	Butyl
C_5H_{12}	Pentane	C_5H_{11}-	Pentyl
C_6H_{14}	Hexane	C_6H_{13}-	Hexyl
C_7H_{16}	Heptane	C_7H_{15}-	Heptyl
C_8H_{18}	Octane	C_8H_{17}-	Octyl
C_9H_{20}	Nonane	C_9H_{19}-	Nonyl
$C_{10}H_{22}$	Decane	$C_{10}H_{21}$-	Decyl

Homologous series

The series of organic compounds in which any two adjacent members differ by a CH_2 (methylene group) unit is called homologous series. The individual members are called Homologs. The members of homologous series possess similar structural features and similar chemical properties as these have the same functional groups. Alkanes, alkenes, alkynes, alkyl halides, alcohols etc form homologous series. The homologous series of alkanes, alkenes, alkynes and alcohols are shown below:

Alkanes		Alkenes		Alkynes		Alcohols	
Methane	CH_4					Methanol	CH_3OH
Ethane	C_2H_6	Ethene	C_2H_4	Ethyne	C_2H_2	Ethanol	C_2H_5OH
Propane	C_3H_8	Propene	C_3H_6	Propyne	C_3H_4	Propanol	C_3H_7OH
Butane	C_4H_{10}	Butene	C_4H_8	Butyne	C_4H_6	Butanol	C_4H_9OH
Pentane	C_5H_{12}	Pentene	C_5H_{10}	Pentyne	C_5H_8	Pentanol	$C_5H_{11}OH$

Hexane	C_6H_{14}		Hexene	C_6H_{12}		Hexyne	C_6H_{10}	Hexanol	$C_6H_{13}OH$
Heptane	C_7H_{16}		Heptene	C_7H_{14}		Heptyne	C_7H_{12}	Heptanol	$C_7H_{15}OH$
Octane	C_8H_{18}		Octene	C_8H_{16}		Octyne	C_8H_{14}	Octanol	$C_8H_{17}OH$
Nonane	C_9H_{20}		Nonene	C_9H_{18}		Nonyne	C_9H_{16}	Nonanol	$C_9H_{19}OH$
Decane	$C_{10}H_{22}$		Decene	$C_{10}H_{20}$		Decyne	$C_{10}H_{18}$	Decanol	$C_{10}H_{21}OH$

Characteristics of a homologous series

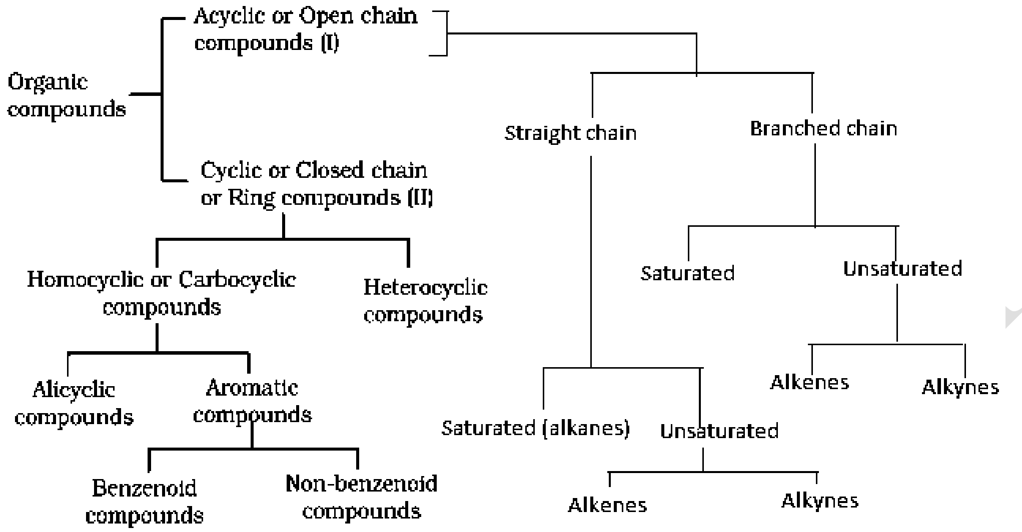
1. All members of the homologous series have the same elements and the same functional group.
2. All members of the homologous series can be represented by the same general formula.
3. The molecular formula of each homolog differs from one *above* and one *below* it by a CH_2 unit.
4. All members of the series can be prepared by similar methods.
5. All members of the series have similar chemical properties.
6. There is a gradual variation in physical properties with increasing molecular weight.

Classification of Organic Compounds

There are 6 million organic compounds known so far and thousands are discovered and synthesized every year. It is difficult to study the chemistry of each individual compound. In order to study these compounds easily and systematically their classification is necessary. Organic compounds can be classified on the basis of structure and on the basis of functional group.

Classification of organic compounds on the basis of structure

This classification is on the basis of the arrangement of carbon atoms in the molecule. It is an old type of classification.



1. Acyclic/ open chain compounds
2. Cyclic/ closed chain/ringed compounds

(1) Open Chain Compounds

Those compounds in which the carbon atoms are linked to each others in open chains are called open chain compounds. There is no cycle, no ring in these compounds. Open chain compounds are further classified in to two types.

(a) Straight chain compounds
(b) Branched chain compounds

(a) Straight Chain compounds

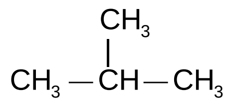
Those compounds, in which no branches are present, are called straight chain compounds. These are linear compounds. There are only primary and secondary carbon atoms and no tertiary or quaternary carbon atoms in such compounds. These may further be saturated or unsaturated in nature. The saturated compounds are called alkanes while the unsaturated are called alkenes and alkynes. Examples are:

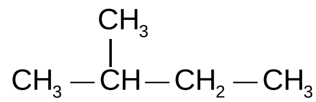
$CH_3CH_2CH_2CH_3$ (*n*–Butane) $CH_3CH_2CH_2CH_2CH_3$ (*n*–Pentane)

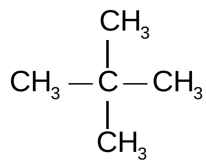
Ethane	$CH_3—CH_3$	
Propane	$CH_3—CH_2—CH_3$	
Ethyl alcohol	$CH_3—CH_2—OH$	
Acetic acid	$CH_3—COOH$	
n-Butylamine	$CH_3—CH_2—CH_2—CH_2—NH_2$	
Ethylene	$CH_2{=}CH_2$	*It is unsaturated*
Acetylene	$HC{\equiv}CH$	*It is unsaturated*

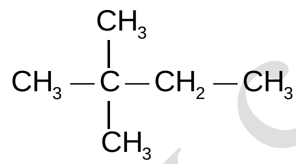
(b) Branch chain compounds

Those compounds, in which a carbon atom may be linked to three or four carbon atoms directly, are called branched chain compounds. These may be singly branched or doubly branched compounds. In such compounds tertiary or quaternary or both type of carbon atoms are present. These are neo and iso compounds.These may further be saturated or unsaturated in nature. The saturated compounds are called alkanes while the unsaturated are called alkenes and alkynes.

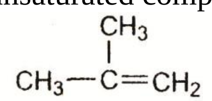

Isobutane

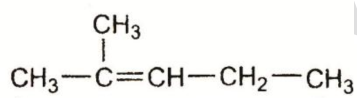

Isopentane

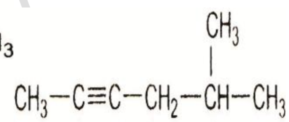

Neopentane


Neohexane

Examples of the branches unsaturated compounds are given below.


2-Methylpropene


2-Methyl-2-pentene



(2) Closed Chain or Ringed or Cyclic Compounds

The hydrocarbons that contain a ring in their structure are called closed chain hydrocarbons. In such compounds carbon atoms are arranged in close chain form. Cyclic or closed chain compounds are further classified in to two types.

i. Homocyclic or cabocyclic compounds
ii. Heterocyclic compounds

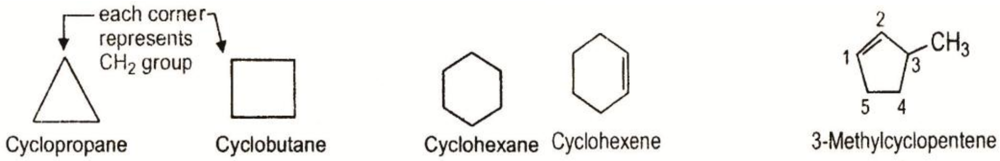
(i) Homocyclic compounds

Hydrocarbons that contain only carbon in their ring structure are called homocyclic or carbocyclic compounds. In these hydrocarbons the ring is only made up of carbon atoms.

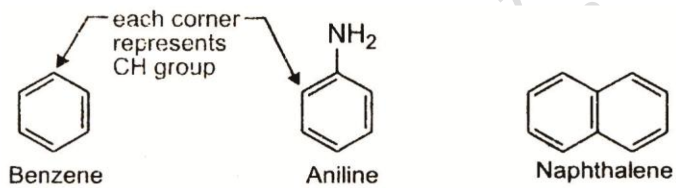
Homocyclic compounds are further classified in to two types.

a. Alicyclic Compounds
b. Aromatic Compounds

(a) Alicyclic Compounds: The homocyclic compounds containing three or more than three carbon atoms in the ring and resemble with aliphatic compounds are called alicyclic compounds. These may be saturated or unsaturated. These do not obey Huckle rule that's why these are not aromatic. Examples are given below.



(b) Aromatic Compounds: The compounds, which contain at least one benzene ring in their structure, are called aromatic compounds. These are cyclic and have conjugation (alternate single double bonds) and obey Huckle rule. Benzene and all compounds that have structures and chemical properties resembling benzene are called aromatic compounds. Examples are:

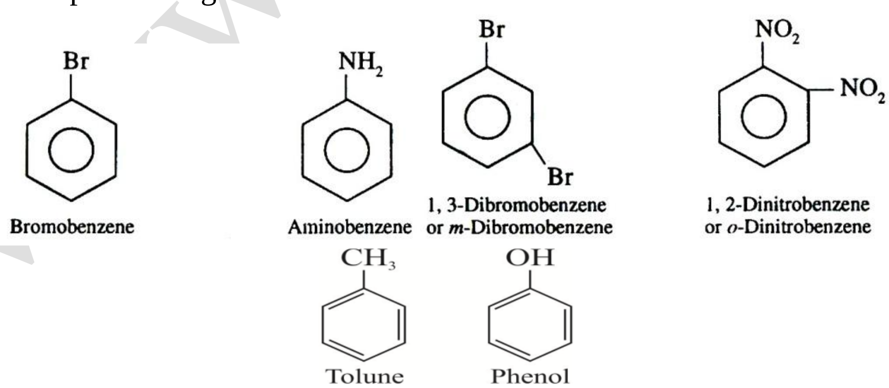


There are two types of aromatic compounds.

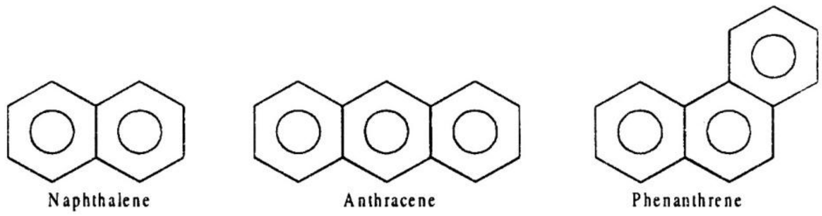
(i) Mono aromatic compounds

(ii) Poly aromatic compounds

(i) Mono Aromatic: The compounds having one benzene ring are called mono aromatic compounds. e.g.

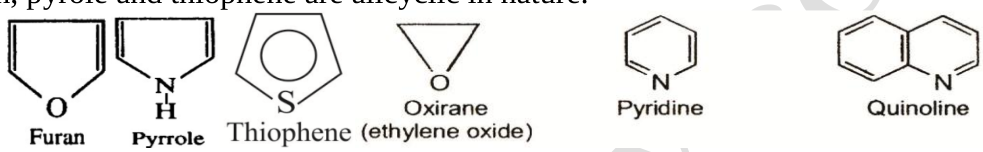


(ii) Polyaromatic: The compounds in which more than one benzene rings are present are called poly aromatic compounds. e.g.



(2) Heterocyclic Compounds

The cyclic compounds in which at least one carbon atom of the ring is replaced by a heteroatom (S,O,N) are called Heterocyclic compounds. The common heteroatom present in the ring other than carbon is oxygen, Sulphur and nitrogen. These may be alicyclic and aromatic both. Pyridine is heterocyclic but aromatic while furan, pyrole and thiophene are alicyclic in nature.



Acyclic and alicyclic both are combinely called as aliphatic hydrocarbons.

Classification of organic compounds on the basis of functional group

On the basis of functional group organic compounds may be divided into two main groups. Hydrocarbons and derivatives of hydrocarbons.

1. Hydrocarbons: The compounds which consists of hydrogen and carbon only are called hydrocarbons. These may be saturated and unsaturated hydrocarbons. The saturated hydrocarbons are called alkanes while the unsaturated hydrocarbons are alkens and alkynes. In alkanes there are single bonds between carbons atoms while in alkenes atleast a double bond is present between the adjacent carbon atoms. In case of alkynes atleast a triple bond is present between the adjacent carbon atoms. The alkanes, alkenes and alkynes may further be open chain or closed chain. The closed chain may further be alicyclic or aromatic in nayure.

2. Derivatives of hydrocarbons: The derivatives of hydrocarbons are obtained when atleasta hydrogen of saturated hydrocarbons or aromatic hydrocarbons is replaced by another atom or group of atoms. The derivatives of hydrocarbons are alcohols, phenols, amines, amides, alkyl halides, aldehydes, ketones, ethers, carboxylic acids etc.

Functional Group

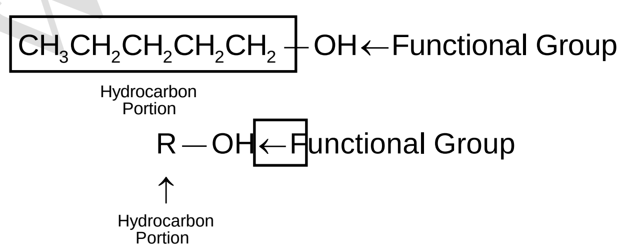
A functional group is an atom or group of atoms in a molecule that gives the molecule its characteristic chemical properties. Double and triple bonds are also functional groups. Other examples include –Cl, −Br, −OH, $-NH_2$ groups. Remember that the functional group is the reactive group in the organic compound. It is the functional and chemically active group. It specifies the chemical nature of a compound. The identity and the selectivity of a compound can be done on the basis of functional group present in it. Millions of organic compounds have been classified into certain groups on the basis of functional group. Organic compounds having the same functional groups will be chemically of the same nature and will show same reactivity

Each functional group undergoes characteristic reactions. By recognising the functional group in a molecule, it is possible to predict the reactions which that molecule will undergo. The concept of functional group is important to organic chemistry for three reasons:

1. Functional groups serve as basis for nomenclature of organic compounds.
2. Functional groups serve to classify organic compounds into classes (families). All compounds with the same functional group belong to the same class.
3. A functional group is a site of chemical reactivity in a molecule. Compounds in the same class have similar chemical properties.

A molecule can contain more than one functional group. It is then said to be **Polyfunctional,** and the properties of each functional group may be modified by the presence of the others.

An organic compound consists of two part, hydrocarbon and functional group part. The hydrocarbon portion remains inert while the functional group part remains active and functional.



We often use the symbol R− to represent the hydrocarbon portion to which the functional group is attached. Thus R− can be CH_3-, CH_3CH_2-, $(CH_3)_2CH-$, or any other group of *C* and *H* atoms with one free valency by which the functional group is attached. Table below shows some common functional groups and the corresponding classes of compounds.

Classes, and functional groups of organic compounds

Class of Compounds	Functional group	Name of functional group	General Formula	Example
Alkane	$-\overset{\vert}{\underset{\vert}{C}}-\overset{\vert}{\underset{\vert}{C}}$	Single bond	C_nH_{2n+2} $n = 1, 2, 3......$ shows member of carbon atoms	$\underset{\text{Methane}}{CH_4}, \underset{\text{Ethane}}{CH_3-CH_3}$ or C_2H_6
Alkene	$>C=C<$	Double bond	C_nH_{2n}	C_2H_4 or $\underset{\text{Ethene}}{CH_2=CH_2}$
Alkyne	$-C\equiv C-$	Triple bond	C_nH_{2n-2}	$HC\equiv CH$ or C_2H_2 (ethyne)
Alkyl halide	$-X(F, Cl, Br, I)$	Halo (Flouro, Chloro, Bromo)	$R-X$ or $C_nH_{2n+1}X$	CH_3-Cl Methyl chloride C_2H_5-I Ethyl Iodide
Alcohol or Alkanol	$-OH$	Hydroxyl	$R-OH$ or $C_nH_{2n+1}OH$	CH_3-OH Methylalcohol (Methanol)
Amine	$-NH_2$	Amino	$R-NH_2$ or $C_nH_{2n+1}NH_2$	CH_3-NH_2 Methylamine
Ether	$-O-$	Oxygen	$R-O-R$ or $(C_nH_{2n+2})O$	CH_3-O-CH_3 Dimethylether
Ketone	$-\overset{O}{\overset{\Vert}{C}}-$	Carbonyl (Keto group)	$(C_nH_{2n+2})CO$	$CH_3-\overset{O}{\overset{\Vert}{C}}-CH_3$ Dimethyl ketone (acetone)
Class of Compounds	**Functional group**	**Name of functional group**	**General Formula**	**Example**

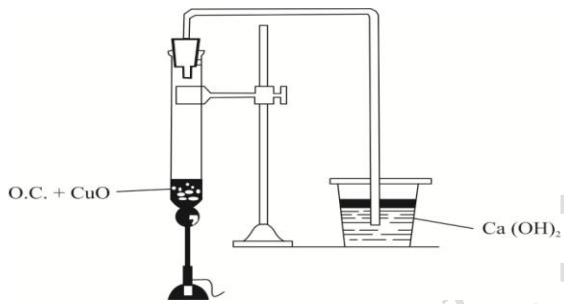
Aldehyde	$-\overset{\overset{O}{\|}}{C}-H$ or $-CHO$	Formyl	$R-\overset{\overset{O}{\|}}{C}-H$ or $C_nH_{2n+1}CHO$	$CH_3-\overset{\overset{O}{\|}}{C}-H$ (acetaldehyde)
Carboxylic acid	$-\overset{\overset{O}{\|}}{C}-OH$ or $-COOH$	Carboxyl	$R-\overset{\overset{O}{\|}}{C}-OH$ or $C_nH_{2n+1}COOH$	$CH_3-\overset{\overset{O}{\|}}{C}-OH$ (acetic acid)
Acid halide	$-\overset{\overset{O}{\|}}{C}-X$ or $-COX$	Acyl	$R-\overset{\overset{O}{\|}}{C}-X$ or $C_nH_{2n+1}Cox$	$CH_3-\overset{\overset{O}{\|}}{C}-Cl$ (acetyl chloride)
Acid amide	$-\overset{\overset{O}{\|}}{C}-NH_2$ or $-CONH_2$	Amide	$R-\overset{\overset{O}{\|}}{C}-NH_2$ or $(C_nH_{2n+1}CONH_2)$	$CH_3-\overset{\overset{O}{\|}}{C}-NH_2$ (Acetamide)
Ester	$-\overset{\overset{O}{\|}}{C}-OR'$ or $-COOR$	Ester	$R-\overset{\overset{O}{\|}}{C}-O-R$ or $(C_nH_{2n+1}COOC_nH_{2n+1})$	$CH_3-\overset{\overset{O}{\|}}{C}-OCH_3$ (Methyl acetate)
Alkyl cyanide or Nitrile	$-C\equiv N$	Cyano	$R-CN$ or $C_nH_{2n+1}CN$	CH_3CN Methyl cyanide

Detection of elements in the organic compounds

Most of the organic compounds contain carbon and hydrogen. Some organic compounds also contain nitrogen, oxygen, sulphur and halogens. Various tests can be performed to confirm the presence of various elements in the organic compounds. Organic compounds are covalent and do not ionize in solution so these should be converted first into inorganic (ionic form) and then tests are performed to detect different elements.

1. Detection of carbon: Carbon is always present in all organic compounds. There is no need to test it. The test is performed only to check whether a given compound is organic or not.

Procedure: Mix the given organic compound (one part) with dry cupric oxide (three parts) and heat in a test tube fitted with a delivery tube. Other end of the delivery tube is dipped in a beaker containing lime water $Ca(OH)_2$. On heating the carbon of organic compound changes into carbon dioxide. When the CO_2 gas is passed through the lime water, it turns milky due to the formation of calcium carbonate. The turning of lime water to milky confirms the presence of carbon in the given organic compound.



Reactions:

$$2CuO + \underset{Urea}{H_2N - CO - NH_2} \rightarrow CO_2 + 2Cu + NO_2 + H_2O$$

$$CO_2 + Ca(OH)_2 \rightarrow \underset{Milky}{CaCO_3} + H_2O$$

2. Detection of hydrogen: If hydrogen is present in the organic compound it will oxidize to water vapours, which will condense in small droplets on the cooler end of the test tube. The water formation is further confirmed by passing the issuing gases (water vapours) through anhydrous copper sulphate. The change in colour from white to blue confirms the presence of hydrogen in the given organic compound. Anhydrous copper sulphate is white in colour , the water vapours convert it into hydrated form (copper sulphate pentahydrate) which is blue in colour.

Reactions:

$$2CuO + \underset{Urea}{H_2N - CO - NH_2} \rightarrow CO_2 + 2Cu + NO_2 + H_2O$$

$$\underset{White}{CuSO_4} + 5H_2O \rightarrow \underset{Blue}{CuSO_4.5H_2O}$$

Detection of nitrogen, sulphur and halogens

Lassaign's solution or sodium fusion extract must be prepared to detect nitrogen, sulphur and halogens in the given organic compound.

Preparation of lassaign's solution:A small piece of sodium metal is taken in a fusion tube. It is heated gently to melting. A small quantity of the organic compound is putted over molten sodium. It is heated gently first then strongly till the tube becomes red hot. Dip it into distilled water taken in beaker. The fusion tube will break. Dissolve the contents by stirring with a glass rod. The solution is boiled and filtered. The filtrate is called Lassaign's solution or sodium fusion extract.

Due to the fusion of organic compound with sodium, the covalent bonds are converted into ionic bonds. Thus the elements like S, N and halogens are converted into their respective ions. The following reactions take place.

$$Na + (C + N) \rightarrow NaCN$$
$$Na + (C + N + S) \rightarrow NaSCN$$
$$Na + S \rightarrow Na_2S$$
$$Na + Cl \rightarrow NaCl$$
$$Na + Br \rightarrow NaBr$$
$$Na + I \rightarrow NaI$$

3. Detection of nitrogen: Take 2mL of the Lassaign's solution in a test tube and add few drops of NaOH solution to it. Now add few mL of freshly prepared $FeSO_4$ (ferrous sulphate) solution to it. Boil it and after cooling add few drops of $FeCl_3$ (ferric chloride) solution to it. Acidify it with conc. H_2SO_4 or HCl. Appearance of Prussian blue or green precipitate or solution confirms the presence of nitrogen. Sulpuric acid is used to dissolve ferrous hydroxide or ferric hydroxide formed in the solution.

Reactions:

$$FeSO_4 + 2NaOH \rightarrow Fe(OH)_2 + Na_2SO_4$$
$$Fe(OH)_2 + 2NaCN \rightarrow Na_4[Fe(CN)_6]$$
$$3Na_4[Fe(CN)_6] + 4FeCl_3 \rightarrow Fe_4[Fe(CN)_6]_3 + 12NaCl$$

4. Detection of sulphur: Take 2mL of the Lassaign's solution in a test tube and acidify it with few drops of acetic acid. Add to it lead acetate solution. Black precipitate of lead sulphide confirms the presence of sulphur.

Reaction:

$$Pb(CH_3COO)_2 + Na_2S \rightarrow PbS + 2CH_3COONa$$

Also when NaOH is added to L.S and then sodium nitroprusside is added, a deep violet colouration confirms the presence of sulphur.

$$Na_2[Fe(CN)_5NO] + Na_2S \rightarrow Na_2[Fe(CN)_5NOS] \quad (Violet\ Color)$$
$$Sod.Nitroprusside \qquad\qquad Sod.Thio\ Nitroprusside$$

When both N and S are present

In this case sodium thiocyanate is formed instead of sodium cyanide. Sodium thiocyanate react with ferric ion and give a blood red coloration of $Fe(CNS)_2$.

$$Fe(OH)_2 + 2NaSCN \rightarrow Na_4[Fe(SCN)_6]$$
$$Sod.ferrothiocyanate$$
$$3Na_4[Fe(SCN)_6] + 4FeCl_3 \rightarrow Fe_4[Fe(SCN)_6]_3 + 12NaCl$$
$$(Blood\ Red\ Ferricferrothiocyanate)$$

5. Detection of halogens: Take lassaign's solution in a china dish and add few drops of conc. HNO_3 and boil it to remove any cyanide and sulphide ions in the form of HCN and H_2S. Add silver nitrate solution to it.

The formation of curdy white precipitate soluble in ammonium hydroxide indicates the presence of chlorine.

$$NaCl + AgNO_3 \rightarrow AgCl \ (White\ PPT) + NaNO_3$$
$$AgCl + 2NH_4OH \rightarrow [Ag(NH_3)_2]Cl \quad (Soluble\ Complex) + 2H_2O$$

Pale yellow precipitate partially soluble in NH_4OH indicates the presence of bromine.

$$NaBr + AgNO_3 \rightarrow AgBr \ (Pale\ Yellow\ PPT) + NaNO_3$$

Deep yellow precipitate, insoluble in ammonium hydroxide indicates the presence of iodine.

$$NaI + AgNO_3 \rightarrow AgI \ (Deep\ Yellow\ PPT) + NaNO_3$$

6. Detection of oxygen: Oxygen cannot be detected directly, for its detection the following indirect methods are used.

A. The organic compound is heated in the presence of nitrogen atmosphere. Formation of water droplets on the cooler part of the test tube indicates the presence of oxygen.

B. In the combustion analysis method the percentages of C and H are determined, their sum is subtracted from 100 and the percentage of oxygen is determined.

C. The presence of oxygen is confirmed by the detection of alcoholic, aldehydic, ketonic and carboxylic functional groups.

EXERCISE

Q.1. Choose the correct answer from the given choices in each case.

(i) The first organic compound prepared in the laboratory was.
(a) Peat (b)✓ Urea
(c) Sugar (d) Alcohol

(ii) All the substances are organic except.
(a)✓ Graphite (b) Urea
(c) Methane (d) Acetic acid

(iii) The final stage of conversion of decaying plants into coal is
(a)✓ Anthracite (b) Lignite
(c) Peat (d) Bituminous

(iv) Petroleum is mainly a mixture of
(a) Heterocyclic compounds (b) Aromatic Hydrocarbons
(c)✓ Saturated hydrocarbons (d) Unsaturated hydrocarbons

(v) The major component of natural gas is
(a) Butane (b) Ethane
(c) Propane (d)✓ Methane

(vi) All of the following fractions are obtained by destructive distillation of coal except.
(a) Coal tar (b)✓ Refinery Gas
(c) Coal gas (d) Coke

(vii) Coal can be converted to petroleum by
(a) Haber process (b) Destructive distillation
(c)✓ Fischer – Tropsch process (d) Fractional distillation

(viii) Pyridine belongs to which class of organic compounds.
(a)✓ Heterocyclic (b) Hydrocarbons
(c) Alicyclic (d) Homocyclic

(ix) Which of the following represents the functional group of amides.
(a) –COOR (b) $-NH_2$
(c) $-C \equiv N$ (d)✓ $-CONH_2$

(x) Which of the following elements cannot be detected in a given organic compound directly.
(a) Chlorine (b) Phosphorous
(c) Nitrogen (d)✓ Oxygen

LONG QUESTIONS

Q.2. Briefly answer the following questions.

(i) What is meant by organic compounds and organic chemistry?

Ans: Given in the theory.

(ii) Why dil.HNO_3 is added to the sodium extract before detection of halogens in organic compound.

Ans: Dil HNO_3 is used before the detection of halogen when sulphur and nitrogen both are present in the organic compound. Dil. HNO_3 will remove the interfering radicals (cyanide, carbonate and sulphide ions).

$$NaCN + HNO_3 \longrightarrow NaNO_3 + HCN\uparrow$$

$$Na_2S + HNO_3 \longrightarrow 2NaNO_3 + H_2S\uparrow$$

Halogens are then detected with Ag ion which forms precipitate.

(iii) Explain the significance of Wohler's work in the development of organic chemistry.

Ans: Given in the theory.

(iv) Although Bucky ball is an allotropic form of carbon, but it is included in organic chemistry.

Ans: On the basis of properties we can decide that either a compound is organic or inorganic. If the properties are similar to the organic compounds then it will be considered as organic and if it posses the properties of inorganic compounds then it will be considered as inorganic.Bucky ball is an allotropic form of carbon yet it has been included in organic chemistry due to its properties that show close resemblance with organic compounds. Like for example, buckyballs can be hydrogenated, halogenated and alkylated just like other organic compounds.

(v) What are those compounds which although contain carbon but are not considered organic?

Ans: All carbon containing compounds are not organic like oxides of C (CO, CO_2), carbonates, bicarbonates, carbides, cyanides, cyanates, thiocyanides, thiocyanates, carbon sulphides, metal carbonyls, diamond, graphite etc. are not organic as these do not possess all the properties of organic compounds.

(vi) Differentiate between partial and total synthesis.

Ans: Partial synthesis: When an intermediate product of a reaction is used to synthesize a required compound, the process is known as partial synthesis or semi synthesis. In the preparation of certain organic compounds, bio-molecules are used which may be obtained from organisms. These bio-molecules are complex in structure and cannot easily be prepared in the laboratory from the raw materials. These bio-molecules are treated with other reactants to get the targeted drugs and medicines. Like for example, in the saponification process oils and fats used are obtained from organisms and treated with caustic soda to get soap. Soap formation in which bio-molecules (Fats and oils) are used is a partial synthesis or semi synthesis process.

Total synthesis: when the starting material converts through many steps into the targeted product, the process is known as total synthesis. In the total synthesis, a complex organic molecule is obtained from simple commercially available raw materials.

(vii) How coal can be converted into petroleum.

Ans: Given in the theory.

(viii) Discuss the reasons for the presence of large number of organic compounds?

Ans: First reason: The sources of organic compounds on the earth are available in larger quantities so their number is large. Major sources of organic compounds are plants and animals, as plants and animals are abundantly available so organic compounds present in them are also large in number. Coal, petroleum and natural gas are available in large amounts and these also consist of organic compounds.

Secound reason: The second reason is the tetravalency of carbon which is the basic element of organic compounds. Carbon can form four bonds with other elements and the chain get extends and hence large numbers of compounds are formed due to the catenation phenomenon.

Third reason: Organic compounds having the phenomenon of isomerism in which compounds having the same molecular formula but different structures, different connectivity and spatial arrangement. So many organic compounds are present in the universe.

Fourth reason: Carbon has the capability of forming double, triple and single bonds so it can form alkenes, alkynes and alkanes and the number of organic compounds becomes more and more.

(ix) Differentiate between acyclic and cyclic organic compounds.

Ans: 1. Cyclic compounds are those in which the carbon atoms are arranged in such a way to form cycle or ring while there is no cycle no ring in the open chain hydrocarbons.

2. The numbers of hydrogen atoms in a cyclic compound are less than the corresponding open chain compound.
3. The general formula of open chain saturated hydrocarbon is C_nH_{2n+2}, while that of a cyclic compound is C_nH_{2n}.
4. The stability of open chain compounds is more than the ringed hydrocarbons in which angle strain is present.
5. Reactivity of the cyclic compounds is more due to angle strain.
6. Melting points, boiling points and densities of the open chain compounds are lower than the corresponding cyclic compounds.

Q.3. What are fossil fuels? Discuss different types of fossil fuels.

Ans: Given in the theory.

Q.4. Elaborate the detection of various elements in organic compound.

Ans: Given in the theory.

Q.5. What are the different fractions obtained by the destructive distillation of coal. Give their importance.

Ans: Given in the theory.

Q.6. Explain some of the important characteristics of organic compounds.

Ans: Given in the theory.

Q.7. Define functional group. How organic compounds are classified on the basis of functional group.

Ans: Given in the theory.

Q.8. Give old classification of organic compounds based on arrangement of carbon atoms in the molecule.

Ans: Given in the theory.