

Carbon and Its Compounds

Carbon, a non-metal with atomic number 6 and mass number 12, occurs in free as well as in combined form. All living creatures are based on it. Its amount in the earth's crust and in the atmosphere is quite meagre. In earth's crust, there is only 0.02% carbon which is present as minerals and in the atmosphere 0.03% carbon is present in the form of carbon dioxide. Carbon thus forms a large number of compounds with itself and with the atoms of other elements; some of which are studied in this chapter.

Bonding in Carbon Compounds : The Covalent Bond

Atomic number of carbon is 6, so there are 4 electrons in its outermost shell and it needs to gain or loss 4 electrons in order to attain a stable configuration, *i.e.*, **noble gas configuration**.

The octet can be completed by following two ways

- It could lose 4 electrons and form C^{4+} cation. But a massive amount of energy is required to remove 4 electrons leaving behind a carbon cation with 6 protons in its nucleus holding on to just two electrons.
- It could gain 4 electrons and can form C^{4-} anion. But for a nucleus having 6 protons, it would be difficult to hold on to 10 electrons, *i.e.*, 4 extra electrons.

In order to overcome this problem, carbon shares its valence electrons with its other atoms or atoms of other elements.

These shared electrons belong to the outer shells of both the atoms and in this way, both atoms attain the noble gas configuration. This type of bonding is called **covalent bonding**. Thus, the bonds which are formed by the sharing of an electron pair between two same or different atoms are known as covalent bonds.

Topics Checklist

- ✓ Bonding in Carbon Compounds: The Covalent Bond
- ✓ Allotropes of Carbon
- ✓ Versatile Nature of Carbon
- ✓ Organic Compounds
- ✓ Hydrocarbons
- ✓ Functional Groups
- ✓ Nomenclature of Carbon Compounds
- ✓ Chemical Properties of Carbon Compounds
- ✓ Fuels and Flames
- ✓ Some Important Carbon Compounds
- ✓ Soaps and Detergents

The number of electrons shared show the **covalency** of that atom. Other atoms also exhibit similar type of bonding.

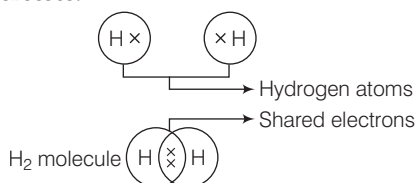
Examples

(i) Formation of Hydrogen Molecule

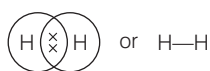
Atomic number of H = 1

It has 1 electron in its *K* shell and needs 1 more electron to fill the *K* shell completely.

Thus, 2 H atoms share each of their electron to form a molecule of H_2 and thus, each H atom attains the nearest noble gas configuration of helium (having two electrons in its *K* shell). Valence electrons are depicted by using dots or crosses.



The shared pair of electrons constitute a single bond between the two H-atoms, which is represented by a single line between the two atoms.

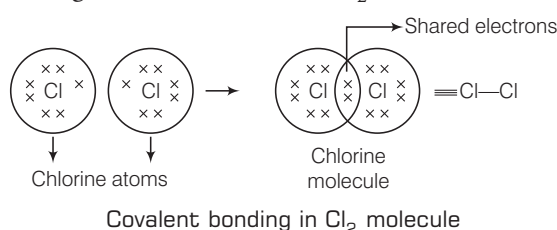


(ii) Formation of Chlorine Molecule

Atomic number of Cl = 17

Electronic configuration = 2, 8, 7

It has 7 electrons in its outermost shell and thus requires 1 more electron to fulfill its outermost shell. This is achieved by sharing of 1 electron with another Cl atom, forming a chlorine molecule (Cl_2).

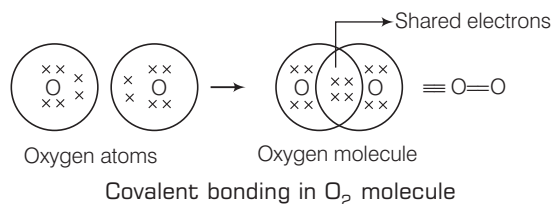


(iii) Formation of Oxygen Molecule

Atomic number of O = 8

Electronic configuration = 2, 6

It requires 2 electrons to fulfill its octet and attain noble gas configuration. This is achieved by sharing of 2 electrons of an another oxygen atom.



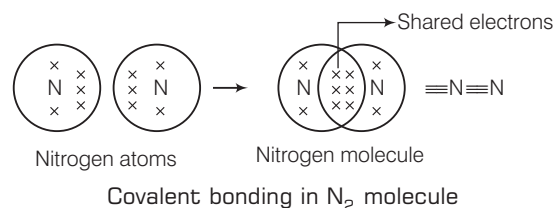
Here, a double bond between two oxygen atoms forming an oxygen molecule represents the sharing of 4 electrons.

(iv) Formation of Nitrogen Molecule

Atomic number of N = 7

Electronic configuration = 2, 5

It needs 3 more electrons to attain noble gas configuration. Thus, 2 nitrogen atoms share 3 each of their electrons, forming a triple bond of nitrogen molecule.

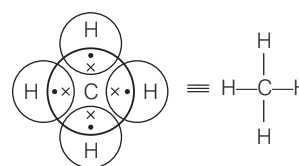


(v) Formation of Methane

Molecular formula CH_4

In methane molecule formation, one carbon shares 4 electrons with four different hydrogen atoms (one each of different hydrogen atoms).

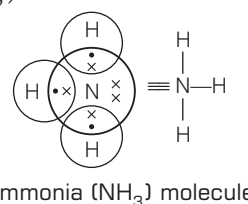
It shows carbon is tetravalent because it possesses four valence electrons and hydrogen is **monovalent** because it has only one valence electron.



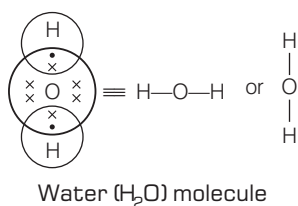
♦ Methane is a carbon compound and also called **marsh gas**. It is used as a fuel and a major component of **CNG** (Compressed Natural Gas) and **biogas**.

(vi) Formation of Ammonia and Water Molecule

Ammonia (NH_3)



Water (H₂O)



are the bad conductors of electricity due to the absence of free electrons or ions. However, graphite is an exception of it, which is a good conductor of electricity.

- These compounds are generally insoluble in water but some which are capable to form H-bond are soluble in water.

(vii) Formation of Carbon Dioxide (CO₂)

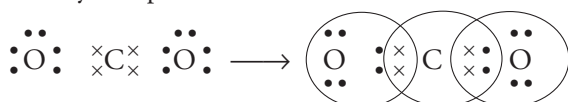
Atomic number of C = 6

Electronic configuration = 2 4 ^{K L}

Atomic number of O = 8

Electronic configuration = 2 6 ^{K L}

Thus, they complete their octet as



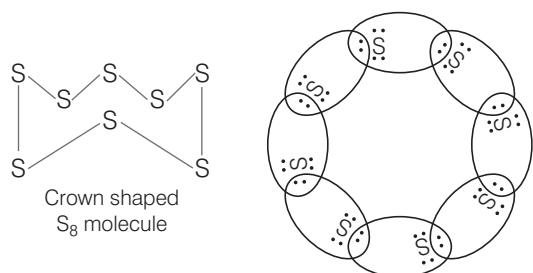
or $O = C = O$

(viii) Formation of Sulphur Molecule (S₈)

Atomic number of sulphur = 16

Electronic configuration = 2 8 6 ^{K L M}

So, the valency of each S atom is 2.



Properties of Covalent Compounds

Covalently bonded molecules are called *covalent compounds*.

Their important properties are

- Their constituents are molecules, not ions.
- They have strong bonds within the molecule but intermolecular forces are weak, which is responsible for the low melting and boiling points of these compounds (graphite and diamond are exceptions of this).
- In these compounds, electrons are only shared and no charged particle is formed, therefore, these compounds

Allotropes of Carbon

Some chemical elements can exist in two or more different forms, which differ in arrangement of atoms and in number of atoms but are chemically same. These are known as *allotropes* and this phenomenon is known as *allotropism*.

For example, Carbon exists in several allotropic forms like diamond, graphite, buckminster fullerene, coal, charcoal, etc. The former three are crystalline while others are amorphous form.

Diamond

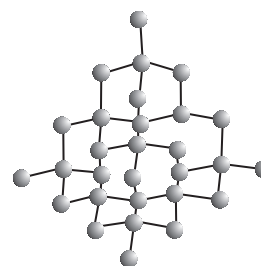
General Properties

General properties of diamond are

- It is a colourless transparent substance with extraordinary brilliance due to its high refractive index.
- It is quite heavy.
- It is extremely hard (hardest natural substance known).
- It does not conduct electricity (because of the absence of free electrons).
- It has high thermal conductivity and high melting point.
- It burns on strong heating to form carbon dioxide.

Structure

It is a giant molecule of carbon atoms in which each carbon atom is linked to four other carbon atoms by strong covalent bonds forming a rigid three-dimensional network structure, which is responsible for its hardness. Moreover, a lot of energy is required to break the network of strong covalent bonds in the diamond crystal, thus its melting point is very high.



Diamond structure

Uses

Uses of diamond are

- Due to its hardness it is used in knives for cutting marble, granite and glass.
- It is used for the purpose of ornaments studded as precious stones.
- It is used as an abrasive and for polishing hard surface.
- Dies made from diamond are used for drawing wires from the metals.

♦ *Diamond can be prepared artificially by subjecting pure carbon to very high pressure and temperature. These synthetic diamonds are small but are otherwise indistinguishable from natural diamonds.*

Graphite

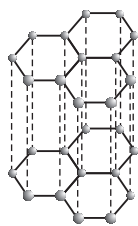
General Properties

General properties of graphite are

- It is a greyish black opaque substance.
- It is lighter than diamond, feels soft and slippery to touch.
- It is a good conductor of electricity (due to the presence of free electrons) but bad conductor of heat.
- It burns on strong heating to form carbon dioxide.

Structure

A graphite crystal consists of layers of carbon atoms or sheets of carbon atoms. Each carbon atom in a graphite layer is joined to three other carbon atoms by strong covalent bonds to form flat hexagonal rings. However, the fourth electron of each carbon atom is free which makes it good conductor of electricity. The various layers of carbon atoms in graphite are held together by weak van der Waals' forces so these can slide over one another.



Graphite Structure

Uses

Uses of graphite are

- It is used as a powdered lubricant for the parts of machinery.
- It is used for making electrodes of cells.
- It is used for making lead for pencils as it can mark paper black. It is therefore called **black lead** or **plumbago**.
- It can withstand high temperature so used for making crucibles to melt substances with high melting points and tiles on the nose cone of space shuttle.

Fullerenes

These are recently prepared allotropic forms of carbon and were prepared first time by **HW Kroto**, **Smalley** and **Robert Curt** by the action of laser beam on the vapours of graphite. Most commonly known fullerene contains 60 C atoms (C_{60}) with smaller proportion of C_{70} and traces of compounds containing even upto 370 carbon atoms.

C_{60} fullerene was named **buckminsterfullerene** after the American architect **Buckminster Fuller** because its structure resembled with the framework of domeshaped halls designed by **Fuller** for the large international exhibitions.

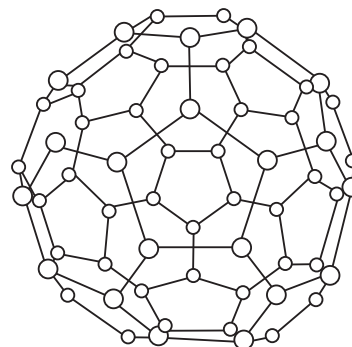
Properties

Properties of fullerenes are

- These are dark solids at room temperature.
- These are neither too hard nor too soft.
- These are the purest allotropic forms of carbon because of the absence of free valencies or surface bonds.
- On burning, these produce only carbon dioxide gas. Other properties of fullerene are still being investigated.

Structure

C_{60} is a football shaped spherical molecule in which 60 C atoms are arranged in interlocking hexagonal and pentagonal rings of carbon atoms. One C_{60} molecule contains 20 hexagons and 12 pentagons of carbon atoms.



Buckminster fullerene (C_{60}) Structure

Uses

Uses of fullerene are

- In pure form, these behave as insulators. However, these can be converted into semiconductors under suitable conditions.
- $C_{60}O$, a molecule formed when C_{60} traps O atoms, is used in cancer as well as AIDS therapy.
- In small amounts, these are used to catalyse the photochemical refining in industry.

Check Point 1

1. What is the covalency of nitrogen atom in nitrogen gas?
2. Name the two properties of carbon which makes it different from other elements.
3. Why are covalent compounds bad conductor of electricity?
4. Graphite is a covalent molecule but a good conductor of electricity. Explain why?
5. Why are fullerene so called?

Versatile Nature of Carbon

The estimate number of carbon compounds known today is about three million. But now the question is, which property or properties of carbon is/are responsible for the formation of such a large number of carbon compounds. Two characteristic properties of carbon are responsible for this.

These properties are

- (i) Catenation (ii) Tetravalency

(i) Catenation

Carbon atoms have a unique ability to form bonds (single, double as well as triple) with other carbon atoms to form large molecules. These can arrange themselves in straight chain, in branched chains or in the form of rings. This property of self linking of carbons atom through covalent bonds to form straight chains or cyclic rings of carbon atoms is called *catenation*.

Carbon exhibits the property of catenation to maximum extent due to large C-C bond energy and hence, forms large number of compounds.

(ii) Tetravalency

Due to the valency of four, carbon is capable of bonding or pairing with four other carbon atoms or with the atoms of

some other monovalent elements. It also forms compounds with oxygen, nitrogen, sulphur, hydrogen and many other elements. This gives rise to compounds with specific properties which depend on the element other than carbon present in the molecule.

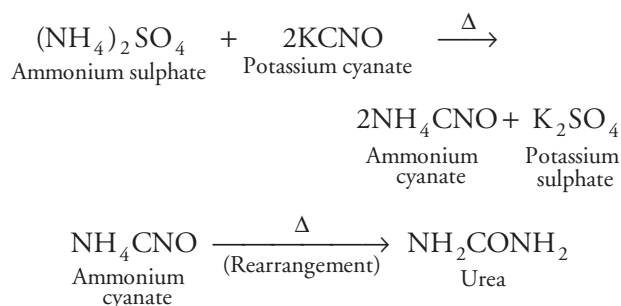
Bonds which carbon forms with other elements are very strong thus, making these compounds very stable. The main reason for such strong bond formation is the small size of carbon. As a result, the shared pair of electrons are tightly held by the nucleus.

♦ *The strength of bond decreases with increase in the size of atoms.*

Organic Compounds

The compounds of carbon except its oxides, carbonates and hydrogen carbonate salts, are known as *organic compounds*. These compounds were initially extracted from natural substances and was believed that some vital force was necessary for the synthesis of these compounds (vital force theory).

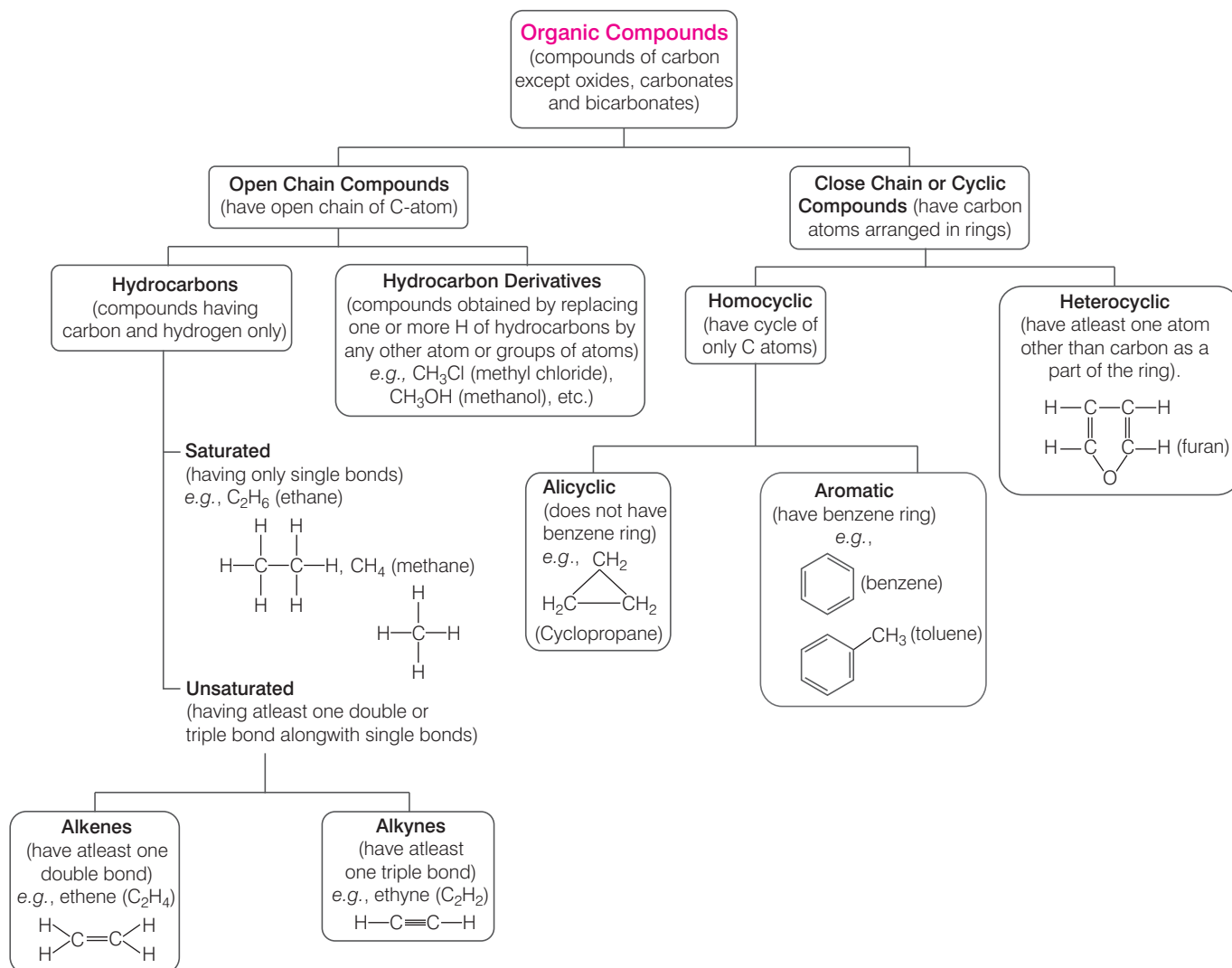
In 1828, synthesis of urea, by German chemist **Friedrich Wohler** accidentally when he was trying to prepare ammonium cyanate by heating ammonium sulphate and potassium cyanate, gave death blow to this theory.



Synthesis of acetic acid from its elements by Kolbe in 1845 also disproved the vital force theory.

Classification of Organic Compounds

Organic compounds are classified into following manner



Hydrocarbons

All the carbon compounds which contain only carbon and hydrogen are called **hydrocarbons**. Their main sources are petroleum (or crude oil) and natural gas.

On the basis of types of bond present (only single or double or triple bond along with single bonds), hydrocarbons are divided into two classes.

Saturated Hydrocarbons

The hydrocarbons in which all the carbon atoms are connected by only single bonds are called **saturated hydrocarbons** or **alkanes** or **paraffins**.

The general formula of these compounds is C_nH_{2n+2} , where, n = number of carbon atoms in one molecule of a hydrocarbon.

For example, if there is only one carbon atom then its formula should be $C_1H_{2 \times 1 + 2} = CH_4$ (methane).

Similarly, if there are two carbon atoms in the saturated hydrocarbon (alkane), its formula must be $C_2H_{2 \times 2 + 2} = C_2H_6$ (ethane)

These compounds are chemically inert (*i.e.*, less reactive) and burn with blue flame due to their complete combustion. These compounds generally show substitution reaction (which are discussed later in this chapter).

Unsaturated Hydrocarbons

Those carbon compounds in which at least one double or triple bond (or multiple bond) is present along with single bonds, are called *unsaturated compounds*.

These compounds generally burn with sooty flame due to their incomplete combustion. These are highly reactive and generally undergo addition reaction (which are discussed later in the chapter).

Unsaturated compounds further divided into following two classes

(i) Alkanes or Olefins

Those carbon compounds which have at least one double bond along with single bonds are called *alkanes*. (A **double bond** is formed by the sharing of two pairs of electrons between the two carbon atoms).

General formula of these compounds is C_nH_{2n} .

For example, if an alkene have two carbon atoms, its formula is $C_2H_{2 \times 2} = C_2H_4$ (ethane).

(ii) Alkynes

Those unsaturated hydrocarbons which have one or more triple bonds along with the single bonds are called *alkynes*. (A **triple bond** is formed by the sharing of three pairs of electrons between two carbon atoms).

General formula of these compounds is C_nH_{2n-2} .

For example, if an alkyne have two carbon atoms then its formula is $C_2H_{2 \times 2 - 2} = C_2H_2$ (ethyne). If there are 3 carbon atoms in the alkyne then its formula must be $C_3H_{2 \times 3 - 2} = C_3H_4$.

♦ The minimum number of carbon atoms present in an unsaturated compound is 2 because formation of double or triple bonds is possible only then.

How to Draw the Structure of Saturated and Unsaturated Compounds?

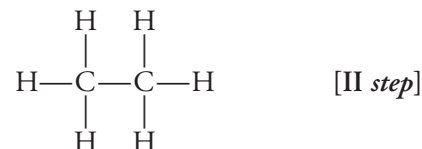
- Step 1** To draw the structure of carbon compound, first connect all the carbon atoms by a single bond.
- Step 2** After that satisfy the tetravalency of carbon with available hydrogen atom.
- Step 3** If number of available H-atoms are less than that required, satisfy the remaining valency by using double or triple bond.

(i) Structure of Ethane (C_2H_6)



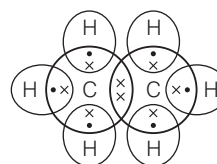
Here only one valency of carbon is satisfied and the three remains unsatisfied.

Each of these unsatisfied valencies are satisfied by hydrogen atoms.



Now, the tetravalency of carbon in ethane is satisfied.

Electron dot structure of ethane (C_2H_6)

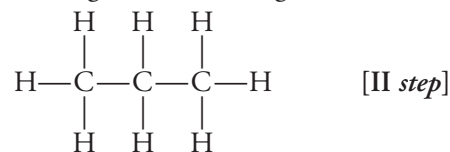


(ii) Structure of Propane (C_3H_8)

Same rules are followed as in case of ethane.

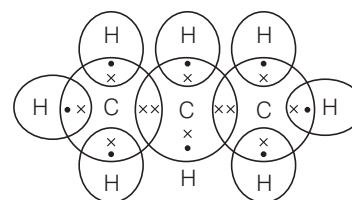


Carbon atoms linked together with a single bond.

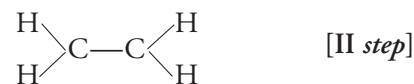


Two C-atoms are bonded to 3 hydrogen atoms and one carbon atom is bonded to 2 hydrogen atoms.

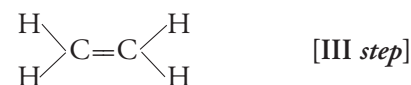
Electron dot structure of propane



(iii) Structure of Ethene (C_2H_4)

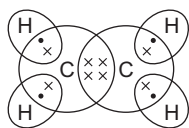


But in this case, even after linking the hydrogen atoms with carbon atoms, still one valency of each carbon remain unsatisfied. To satisfy it, a double bond is used between the two carbon atoms.



Now, all the four valencies of carbon are satisfied.

Electron dot structure of ethene

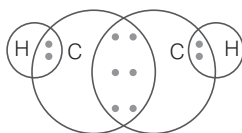


(iii) Structure of Ethyne (C_2H_2)



In ethyne, the two carbon atoms share three pairs of electrons among themselves to form a carbon-carbon triple bond. Each carbon atom shares one electron with each hydrogen atom to form two carbon-hydrogen single bonds.

Electron dot structure of ethyne



How to Draw Structure of Cyclic Compounds ?

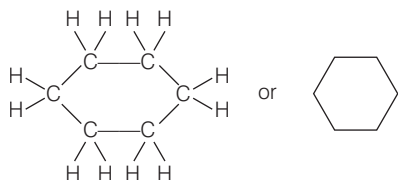
Some carbon compounds also exist in cyclic or ring structure.

To draw the structure of cyclic or ring compounds

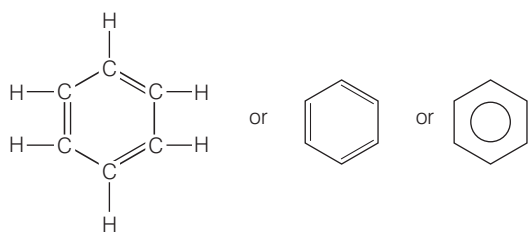
- Step 1** First connect the available carbon atoms by a single bond in the cyclic form.
- Step 2** Try to satisfy the tetravalency of each carbon with the available hydrogen atoms.
- Step 3** Now check the valency of each carbon. If it is found unsatisfied, use double or triple bond to satisfy it.

Examples

Cyclohexane (C_6H_{12})



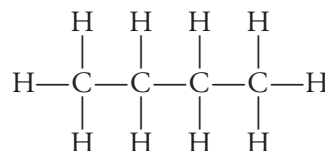
Benzene (C_6H_6)



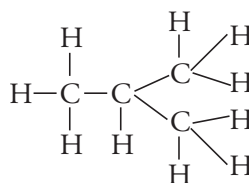
Isomerism

Carbon compounds or organic compounds with same molecular formula can show different structures and hence, different properties. This phenomenon is called **isomerism** and compounds are called **isomers**.

For example, following two arrangements are possible for butane, an alkane with four C atoms (C_4H_{10})



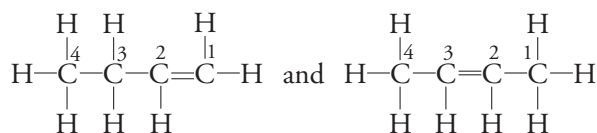
Straight chain structure



Branched chain structure

Such pair of isomers is called **chain isomers** and the isomerism is called **chain isomerism**. Thus, **chain isomers** are the compounds that have same molecular formula but differ in the arrangement of carbon chains.

Further, if we draw the structure of an alkane with 4 carbon atoms, *the following two arrangements are possible*



The above two structures differ in the position of double bond (functional group), so these are called **position isomers** and the phenomenon is called **position isomerism**.

♦ Chain and position isomerism is possible only when, atleast 4 carbon atoms are present in the hydrocarbons.

Functional Groups

Carbon can also form bonds with other elements such as halogens, oxygen, nitrogen, sulphur, etc. These are called **hetero atoms**. These atoms or the groups containing these, replace one or more hydrogen atoms of the hydrocarbon and are responsible for the chemical reactivity of the compound, regardless of the length and nature of carbon chain. Hence, these are called **functional groups**.

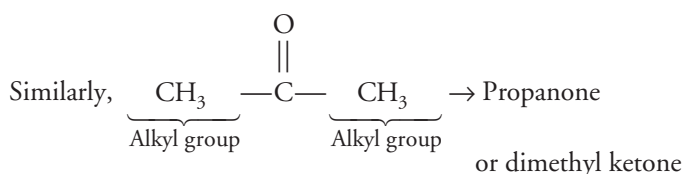
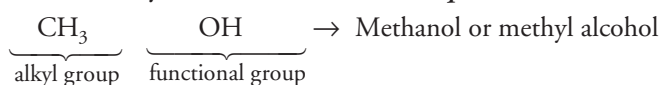
Some important functional groups are tabulated below

Representation of Different Functional Groups

Functional group	Family	Representation with alkyl group
—OH	Alcohols	R—O—H
$\begin{array}{c} \text{H} \\ \\ \text{—C=O} \end{array}$	Aldehydes	$\begin{array}{c} \text{O} \\ \\ \text{R—C—H} \end{array}$
$\begin{array}{c} \text{O} \\ \\ \text{—C—} \end{array}$	Ketone	$\begin{array}{c} \text{O} \\ \\ \text{R—C—R} \end{array}$
$\begin{array}{c} \text{O} \\ \\ \text{—C=OH} \end{array}$	Carboxylic acids	$\begin{array}{c} \text{O} \\ \\ \text{R—C—O—H} \end{array}$
—NH ₂	Amines	R—NH ₂
—O—	Ethers	R—O—R
—X	Halogen	R—X
—NO ₂	Nitro group	R—NO ₂

♦ Free valency or valencies of the functional group are shown by the single line.

The formula of a particular family is made up of two parts. These are alkyl group and functional group linked to each other by covalent bond. *For example,*



Homologous Series

A series of compounds in which hydrogen in a carbon chain is replaced by the same functional group, is called **homologous series**.

Characteristics of a Homologous Series

- All the members of a homologous series can be represented by the same general formulae.
- Any two adjacent homologues differ by 1 carbon atom and 2 hydrogen atoms in their molecular formulae.
- All the compounds of a homologous series show similar chemical properties.
- With increase in the molecular mass the gradual change in the physical properties occurs.
- The 14 u is the difference in the molecular masses of any two adjacent homologues.

For example,

CH₄, C₂H₆, C₃H₈, C₄H₁₀—these all compounds differ by a —CH₂— unit.

Nomenclature of Carbon Compounds

In general, the names of organic compounds are based on the name of basic carbon chain modified by a prefix (phrase before) or suffix (phrase after) showing the name of the functional group.

Following steps are used to write the name of an organic compound

- Step 1** Count the number of carbon atoms in the given compound and write the root word for it (Root word upto 10 carbon atoms are tabulated below.)

Root Words for Carbon Atoms

No. of C atoms	Root word	No. of C atoms	Root word
1 (C ₁)	Meth	6 (C ₆)	Hex
2 (C ₂)	Eth	7 (C ₇)	Hept
3 (C ₃)	Prop	8 (C ₈)	Oct
4 (C ₄)	But	9 (C ₉)	Non
5 (C ₅)	Pent	10 (C ₁₀)	Dec

- Step 2** If the compound is saturated, add suffix 'ane' to the root word, but if is unsaturated, add suffix 'ene' and 'yne' for double and triple bonds respectively.

For example, CH₃CH₂CH₃ contains three C atoms so root word is 'prop' and it contains only single bonds, so suffix used is 'ane'. Hence, the name of this compound is propane.

Similarly, the compound CH₃CH=CH₂ is named as propene as here suffix 'ene' is used for double bond.

- Step 3** If functional group is present in the compound, it is indicated by adding its suffix (which are given in the table below).

Prefix and Suffix of Different Functional Groups

Functional Group	Prefix/Suffix	Example
Alcohol	Suffix -ol	C ₃ H ₇ OH - Propane-e+ol Propanol
Aldehyde	Suffix -al	CH ₃ CHO - Ethane-e+al= Ethanal
Ketone	Suffix -one	CH ₃ COCH ₃ - Propane-e+one Propanone
Carboxylic acid	Suffix -oic acid	CH ₃ COOH - Acetic acid/ Ethanoic acid
Halogen	Prefix -chloro, bromo, etc.	CH ₃ Cl - Chloromethane C ₂ H ₅ Br - Bromoethane

Functional Group	Prefix/Suffix	Example
Double bond (alkenes)	Suffix -ene	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}=\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \quad \quad \text{H} \end{array}$ - Propene
Triple bond (alkynes)	Suffix -yne	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{C}\equiv\text{C}-\text{H} \\ \\ \text{H} \end{array}$ - Propyne

- ◆ Prefix 'iso' and 'neo' represent the presence of one or two carbon atoms respectively as side chain.
- ◆ If the functional group is named as a suffix, the final 'e' of alkane (or alkene or alkyne) is substituted by appropriate suffix.
- ◆ If the functional group and substituents are not present at first carbon, then their location is indicated by digits 1,2,3...

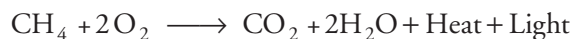
Check Point 2

- Draw the electron dot structure of propene (C₃H₆).
- What is the formula of an alkyne having five carbon atoms?
- Draw all the isomers of pentane (C₅H₁₂).
- Name the following compounds according to IUPAC.
 - CH₃CH₂CH₂COOH
 - $$\begin{array}{c} \text{H} \\ | \\ \text{H}-\text{C}-\text{C}=\text{O} \\ | \quad | \\ \text{H} \quad \text{H} \end{array}$$
 - CH₃ — OH
- Write the name of the functional group present in the following compounds.
 - CH₃OH
 - $$\begin{array}{c} \text{Cl} \\ | \\ \text{CH}_3 - \text{C} - \text{HCH}_3 \end{array}$$
 - Ethanal
 - Acetic acid
 - Hexyne

Chemical Properties of Carbon Compounds

Combustion

All the carbon compounds burn in oxygen and yield carbon dioxide and water vapour. Heat and light are also released during this process. This reaction is called **combustion**.



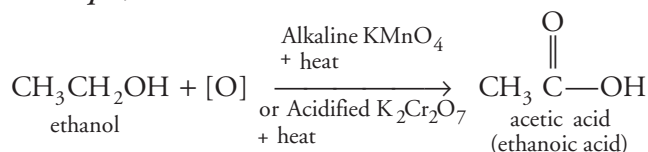
Further, once carbon and its compounds ignite, they keep on burning without the requirement of additional energy. That's why these compounds are used as fuels.

Saturated hydrocarbons give a clean flame due to their complete combustion whereas, unsaturated hydrocarbons give a yellow flame with lots of black smoke as they do not undergo complete combustion.

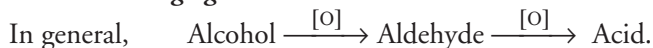
Oxidation

Oxidation is a process of intake of oxygen and removal of hydrogen. Reagents used for this purpose are alkaline KMnO₄ + heat or acidified K₂Cr₂O₇ + heat.

For example,



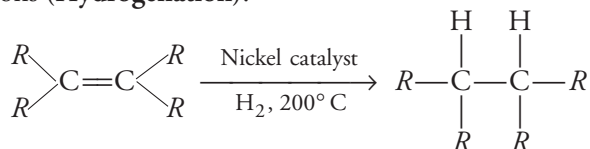
Substances that are capable of providing oxygen to other substances are called **oxidising agents**.



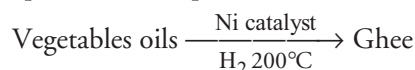
Addition Reactions

The reaction in which a reagent adds completely on a substance without the removal of small molecules are called **addition reactions**.

For example, addition of hydrogen (in the presence of catalysts like **Palladium or Nickel**) to unsaturated hydrocarbons, yields saturated hydrocarbons (**Hydrogenation**).



Hydrogenation (addition of hydrogen) of vegetable oil (which are unsaturated compounds) in the presence of nickel catalyst gives ghee (saturated compounds). This process is called **hardening of oils**.



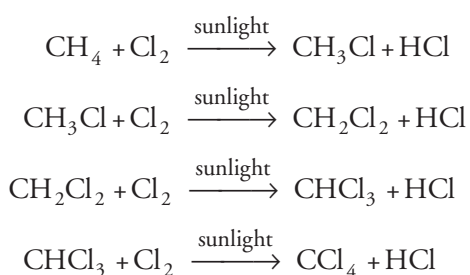
- ◆ A **catalyst** is that substance which alters the rate of a reaction without being consumed.
- ◆ Saturated fatty acids are harmful for health.
- ◆ Unsaturated compound discharge the pink colour of alkaline KMnO₄. This is known as **test of unsaturation**.

Substitution Reactions

The reactions in which a reagent substitutes (replaces) an atom or a group of atoms from the reactant (substrate) are called *substitution reactions*. These are generally shown by saturated compounds and benzene.

Most of the saturated hydrocarbons are fairly inert and unreactive in the presence of most reagents. So, presence of sunlight is necessary for their substitution reactions.

When chlorine is added to hydrocarbons at a rapid rate, in the presence of sunlight, Cl replaces H atom one by one.



Fuels and Flames

Fuels

Those carbon compounds which have stored energy in them and burn with heat and light are called *fuels*. The released energy (heat or light) is utilised for various purposes like for cooking food, running machines in factories, etc.

In fuels, the carbon can be in free state as present in coal, coke and charcoal or in combined state as present in petrol, LPG, kerosene, petroleum, natural gas, etc.

Those fuels which were formed by the decomposition of the remains of the pre-historic plants and animals (fossils) buried under the earth long ago, are called *fossils fuels*.

For example, coal, petroleum and natural gas.

Coal

It is a complex mixture of compounds of carbon, hydrogen and oxygen and some free carbon along with traces of nitrogen and sulphur.

It was formed by the decomposition of plants and trees buried under the earth millions of years ago.

Petroleum

It is a dark viscous foul smelling oil and is also known as **rock oil** or **black gold**. It was formed by the decomposition of the remains of extremely small plants and animals buried under the sea millions of years ago.

◆ Since coal and petroleum have nitrogen and sulphur in small amounts that's why they play an important role in causing pollution (air pollution).

Flame

A flame is the region where combustion (or burning) of gaseous substances takes place.

Depending upon the amount of oxygen available and burning of fuels, flames are of following two types

(i) Blue or Non-luminous Flame

When the oxygen supply is sufficient, the fuels burn completely producing a blue flame. Since, light is not produced during this type of combustion, so the flame is called *non-luminous* (non-light giving flame), e.g., burning of LPG in gas stove.

(ii) Yellow or Luminous Flame

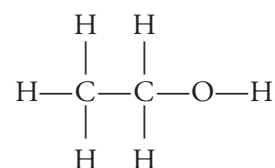
In the insufficient supply of air, the fuels burn incompletely and produce yellow flame. The colour of the flame is yellow because of the presence of unburnt carbon particles. This flame produces light so also known as *luminous flame*. e.g., burning of wax vapours.

◆ Some solid and liquid fuels like coal and charcoal do not vaporise on heating. Such fuels burn without producing a flame. They just glow red and give out heat.

Some Important Carbon Compounds

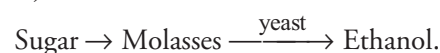
Ethanol

Its common name is ethyl alcohol and formula is $\text{C}_2\text{H}_5\text{OH}$.



Preparation

Alcohol (ethanol) is obtained by the fermentation of molasses which are obtained from sugarcane juice.



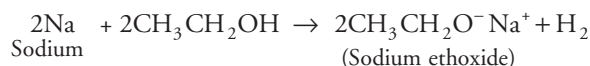
Physical Properties

Physical properties of ethanol are

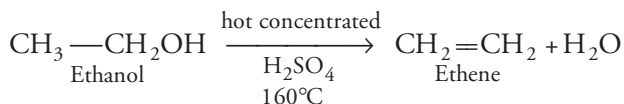
- It is a liquid at room temperature. Its melting point is 156 K and boiling point is 351 K.
- It is soluble in water due to its ability to form H-bonds with water molecules.

Chemical Reactions

(i) **With sodium** Hydrogen is evolved



(ii) **Dehydration** (Removal of water) it is done by conc. H_2SO_4 .



Uses

Uses of ethanol are

- It is used as active ingredients in all alcoholic drinks.
- It is useful in medicines like tincture of iodine, cough syrups and many other tonics.
- Alcohol is used as an additive in petrol, since it is a cleaner fuel and gives rise to only CO_2 and H_2O .
- It is used as hypnotic (induces sleep).
- It is used for the preparation of chloroform, iodoform, ethanoic acid, ethanal, etc.

Harmful Effects of Drinking

When consumed in large quantities, it tends to slow metabolic processes and depress the central nervous system which in turn results in lack of coordination, drowsiness, mental confusion, lowering of the normal inhibitors and finally stupour.

The individual may feel relaxed but does not realise that his sense of judgement and muscular coordination have been seriously impaired.

In order to stop the misuse of ethanol, it is made unfit for drinking by adding poisonous substances like methanol, copper sulphate pyridine, etc and coloured substances like dyes. Such alcohol is called **denatured alcohol**.

In liver, methanol is oxidised to methanal which reacts readily with the components of cells and causes coagulation of protoplasm. It also affects optic nerves, causing blindness.

Ethanoic Acid or Acetic Acid

It is commonly known as acetic acid. Its formula is CH_3COOH . 5–8% solution of ethanoic acid in water is known as **vinegar**.

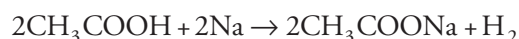
Physical Properties

Physical properties of ethanoic acid are

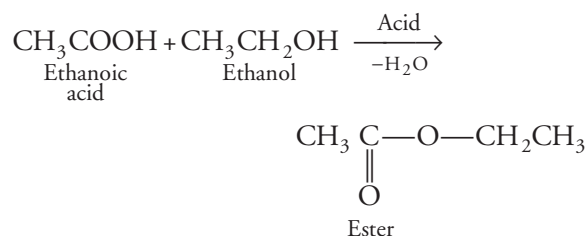
- Its melting point is 290 K.
- During winters in cold climates it often freezes and forms ice like flakes so it is also called **glacial acetic acid**.

Chemical Reactions

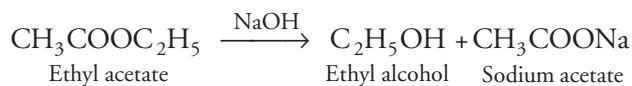
(i) **Acidity** It is a weaker acid than HCl but stronger than alcohol. It evolves hydrogen with sodium metal, which shows its acidic nature.



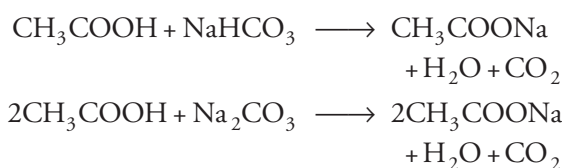
(ii) **Esterification** When ethanol (an alcohol) reacts with acetic acid (a carboxylic acid), a fruity (sweet) smelling liquid called **ester**, is obtained. This reaction is called **esterification**.



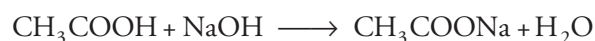
The ester gets converted back into alcohol and sodium salt of acid when treated with alkali like sodium hydroxide. This reaction is called **saponification**, as it is used for the preparation of soap.



(iii) **Reaction with carbonates and hydrogen carbonates** Carbon dioxide gas is obtained. It is an example of acid base reaction.



(iv) **Reaction with a base**



♦ Esters are used in making perfumes and as flavouring agents.

Uses of Acetic Acid

- (i) It is used for making vinegar.
- (ii) It is used in making pickles.
- (iii) It is used for the synthesis of other compounds like esters.

Soaps and Detergents

Soaps are sodium or potassium salts of long chain carboxylic acids and have general formula RCOONa .

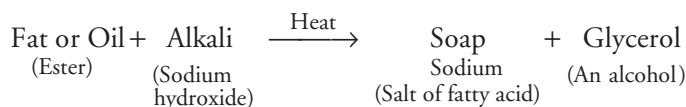
where, $R = \text{C}_{15}\text{H}_{31}, \text{C}_{17}\text{H}_{35}$, etc.

$\text{C}_{15}\text{H}_{31}\text{COOH}$ is called **palmitic acid**.

Detergents are usually ammonium or sulphonate salts of long chain carboxylic acids.

Manufacture of Soap and Detergents

Soaps are made from animal fat or vegetable oils by heating it with sodium hydroxide.



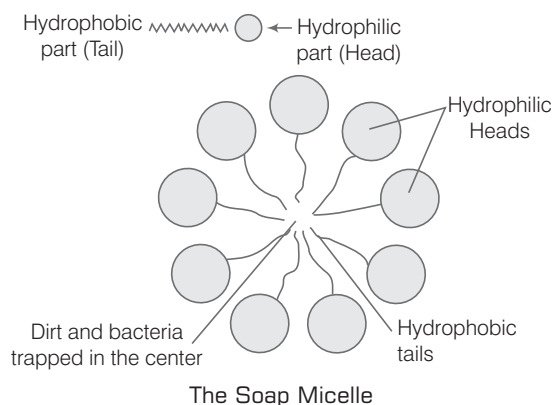
This process of preparation of soap by the fats and oil hydrolysis with alkalis is called *saponification*.

In case of detergents, the long chain hydrocarbons obtained from petroleum is taken instead of fat or oil.

♦ In the soap manufacturing, common salt is added to precipitate soap.

Structure of a Soap Molecule

A soap molecule is made up of two parts—a long hydrocarbon part and a short ionic part containing –COONa group. The long hydrocarbon part is hydrophobic and therefore insoluble in water but soluble in oil. The ionic portion of the soap molecule is hydrophilic so soluble in water and insoluble in oil.



Cleaning Action of Soaps (Micelle Formation)

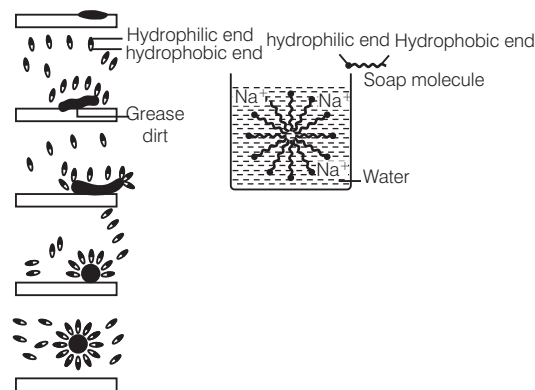
Soap molecules have different properties at their two ends, one is **hydrophilic** (soluble in water) and other is **hydrophobic** (soluble in fats or oils).

At the surface of water, the hydrophobic end or 'tail' of soap will be insoluble in water and the soap will lie along the surface of water with the ionic end in water and the hydrocarbon 'tail' protruding out of water.

Inside water, these molecules show a unique orientation that keeps the hydrocarbon portion out of the water. This is done by forming clusters of molecules in which the hydrophobic tails are in the interior of the cluster and on the surface of cluster, ionic ends are present. This formation is called *micelle formation*. To wash away the loosened dirt particles in the form of micelles from the surface of the cloth, it is either scrubbed mechanically or beaten or agitated in washing machine.

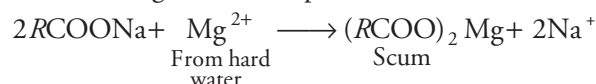
In the form of a micelle, soap is able to clean, since the oily dirt is being collected in the centre of micelle. Micelles stays as colloids in the solution and does not come closer to precipitate due to

ion-ion repulsion. Hence, the dirt suspended in the micelles is also easily rinsed away.



Cleaning Action of Soap (Micelle formation)

Soap forms scum with hard water as it reacts with calcium and magnesium ions present in the hard water.



Here, $R = \text{C}_{17}\text{H}_{35}$ or $\text{C}_{15}\text{H}_{31}$

Charged ends of detergents do not form insoluble precipitates with the magnesium and calcium ions in water. Hence, they are effective in hard water. Thus, detergents are used as cleansing agents in case of hard water.

Detergents are useful in making shampoos and products for cleaning clothes but their main disadvantage is that these are generally non-biodegradable.

Advantages of Detergents Over Soaps

- Synthetic detergents do not require vegetable oil or fats for their preparation, hence they help in saving oils and fats for human consumption.
- Synthetic detergents can be used with hard water while soaps cannot be used with hard water.

♦ Soap solution appears cloudy because the soap micelles are large enough to scatter light.

Check Point 3

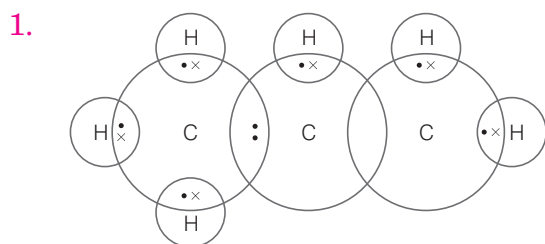
1. Which metal is used as a catalyst in the conversion of vegetable oil into fat (ghee)?
2. Why is sunlight necessary for the substitution reactions of alkanes?
3. Why are esters used in perfume industry?
4. What is the product formed when acetic acid reacts with alcohol?
5. Write the chemical reactions of soap formation or saponification.

ANSWERS for Check Points

Check Point 1

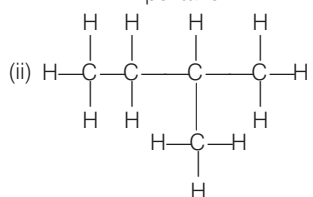
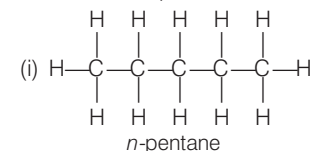
- 3
- (i) Catenation (ii) Tetravalency
- Because of the absence of free ions or electrons.
- Although graphite is a covalent molecule but its each carbon atom utilise only three electrons for bonding and the fourth electron of each carbon atom is free which makes it good conductor of electricity.
- Because of the resemblance with framework of domeshaped halls designed by the American architect Buckminster Fuller.

Check Point 2



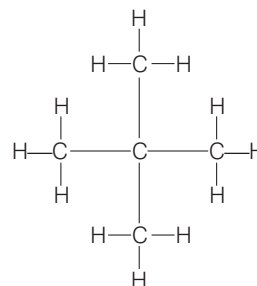
- General formula of alkynes is C_nH_{2n-2} .
If $n = 5$
The formula of alkyne is $C_5H_{2 \times 5 - 2} = C_5H_{10-2} = C_5H_8$.

- The isomers of pentane are as



iso-pentane or 2-methylbutane

(iii)



2,2-dimethyl propane or neo-pentane

- (i) Butanoic acid
(ii) Ethanal
(iii) Methanol
- (i) Alcohol
(ii) Chloro
(iii) Aldehyde
(iv) Carboxylic acid
(v) Triple bond (alkyne).

Check Point 3

- Nickel
- Because these are inert and sunlight generates free radicals which readily attacks on alkanes.
- Because of their sweet smell.

- Ester

