Chapter 4 - Carbon and its Compounds

Introduction

The list given below illustrates the importance of carbon compounds in our daily life:

- Foods [starch, sugar, fats, vitamins, proteins]
- Fuels [wood, coal, alcohol, petrol]
- Household and commercial articles [paper, soap, cosmetics, oils, paints]
- Textile fabrics [cotton, wool, silk, linen, rayon, nylon]
- Drugs and disinfectants [penicillin, quinine, aspirin, sulpha drugs]
- Poisons [opium, strychnine]
- Perfumes [vanillin, camphor]
- Explosives [nitro glycerine, dynamite, picric acid, TNT]
- Dyes [indigo, congo red, malachite green]
- War gases [mustard gas, chloropicrin, lewisite]

Hydrocarbons – Compounds containing carbon and hydrogen.

Organic Compounds – Hydrocarbons and compounds derived from hydrocarbons.

Bonding in Carbon - The Covalent Bond

Covalent Bond

A covalent bond is defined 'as the force of attraction arising due to mutual sharing of electrons between the two atoms.' The combining atoms may share one, two or three pairs of electrons. The covalent bond is formed between two similar or dissimilar atoms by a mutual sharing of electrons, which are counted towards the stability of both the participating atoms. When the two atoms combine by mutual sharing of electrons, each of the atoms does so, in order to acquire stable configuration of the nearest noble gas. A small line (-) between the two atoms is represents a covalent bond. The compounds formed due to covalent bonding are called covalent compounds.

Properties of Covalent Compounds

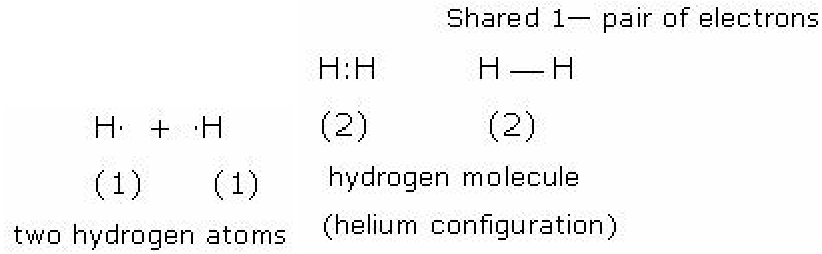
- The covalent compounds do not exist as ions but they exist as molecules
- They exist at room temperature, as liquids or gases. However, a few compounds also exist in the solid state e.g. urea, sugar, etc.
- The melting and boiling points of covalent compounds are generally low
- Covalent compounds are generally insoluble or less soluble in water and in other polar solvents
- These are poor conductors of electricity in the fused or dissolved state
- Since the covalent bond is localized in between the nuclei of atoms, it is directional in nature
- A covalent bond can be formed in different ways. When a bond is formed by mutual sharing of one pair of electrons it is known as a 'single covalent bond', or simply 'a single bond'. When a bond is developed due to mutual sharing of more than one pairs of electrons it is termed as 'multiple covalent bond'. Such bonds can be a double covalent bond or a triple covalent bond.

Types of Covalent Bonds

Single Bond

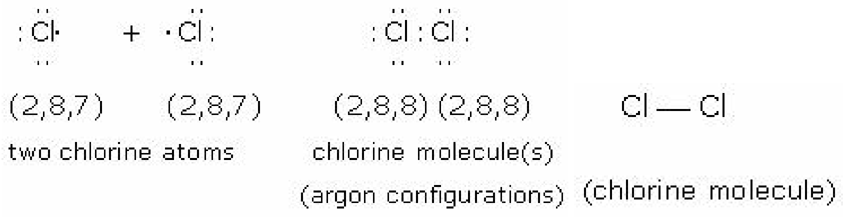
Hydrogen Molecule

Hydrogen atom has only one electron in its outermost shell, and requires one more electron to acquire the nearest noble gas configuration of helium (He:$1s^2$). To do so, two hydrogen atoms contribute one electron each to share one pair of electrons between them. This leads to the formation of a single covalent bond between the two hydrogen atoms.



Chlorine Molecule

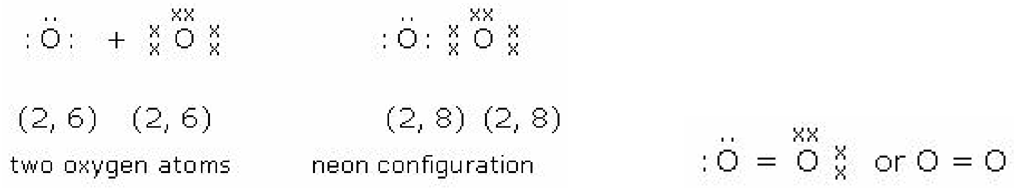
Chlorine atom has seven valence electrons. Thus, each Cl atom requires one more electron to acquire the nearest noble gas configuration (Ar:2, 8, 8). This they do by mutual sharing of one pair of electrons as shown below.



Double Bond

Oxygen Molecule

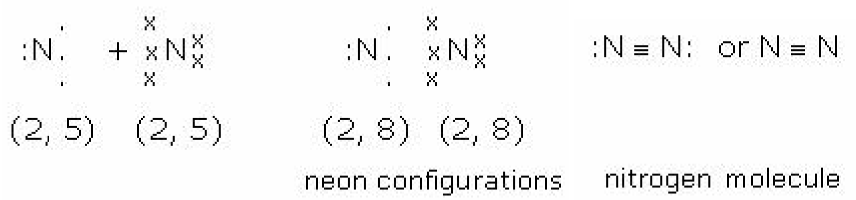
An oxygen atom has six electrons in its valence shell. As a result, it requires 2 more electrons to achieve the nearest noble gas configuration. When two oxygen atoms share two pairs of electrons this is achieved:



Triple Bond

Nitrogen Molecule

Nitrogen atom has five electrons in its valence shell. It requires three more electrons to acquire a stable configuration of the nearest noble gas (neon). This is done by mutually sharing three pairs of electrons as shown below.

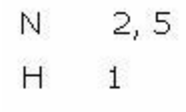


Activity

Show how nitrogen shares a covalent bond with hydrogen in the formation of ammonia (NH_3). Are all electrons involved in the bonding? Give the Lewis structure of the covalent bond also.

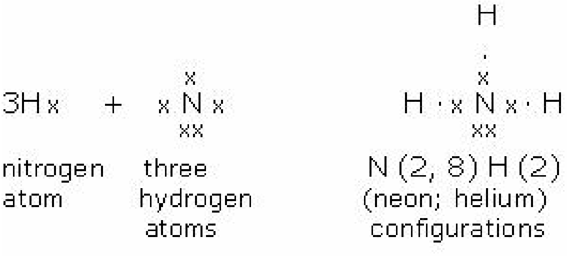
Suggested Answer

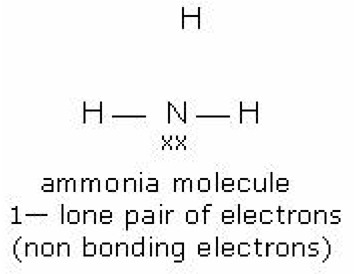
The electronic configurations of nitrogen and hydrogen are



N	2, 5
H	1

Thus, each nitrogen atom requires three more electrons to acquire a stable noble gas configuration. On the other hand, each H-atom requires only one electron to achieve the stable helium configuration. This is done by mutually sharing three pairs of electrons between one nitrogen and three hydrogen atoms, as shown below.





The unshared pair of electrons on the nitrogen atom (in ammonia molecule) is not involved in bond formation and is called a lone pair of electrons.

Multiple Bonds – Double and triple bonds are collectively known as multiple bonds.

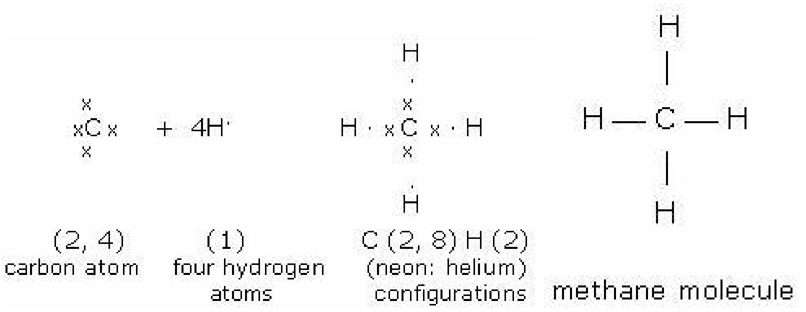
Covalency: The number of electrons contributed by an atom of the element for sharing while forming covalent bonds is known as covalency of the element.

Tetravalency in Carbon

A carbon atom has a total of six electrons occupying the first two shells, i.e., the K-shell has two electrons and the L-shell has four electrons. This distribution indicates that in the outermost shell there are one completely filled 's' orbital and two half-filled 'p' orbitals, showing carbon to be a divalent atom. But in actuality, carbon displays tetravalency in the combined state. Therefore, a carbon atom has four valence electrons. It could gain four electrons to form C^{4-} anion or lose four electrons to form C^{4+} cation. Both these conditions would take carbon far away from achieving stability by the octect rule. To overcome this problem carbon undergoes bonding by sharing its valence electrons. This allows it to be covalently bonded to one, two, three or four carbon atoms or atoms of other elements or groups of atoms.

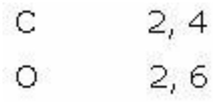
Methane Molecule

Carbon atom has four electrons in its outermost shell. Thus, it requires four more electrons to acquire a stable noble gas configuration. Each of the hydrogen atoms has only one electron in its outermost shell and requires one more electron to complete its outermost shell (to acquire He configuration).



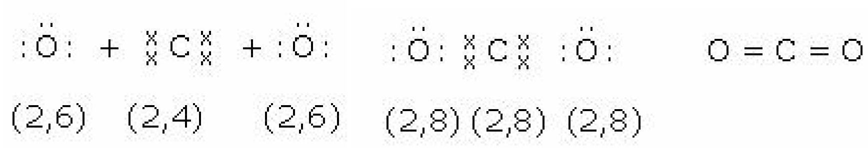
Carbon Dioxide Molecule

The electronic configurations of carbon and oxygen are:



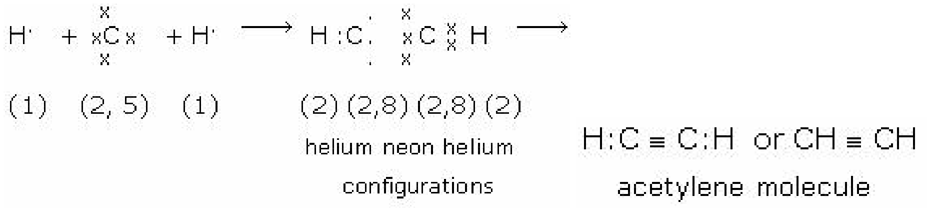
C	2, 4
O	2, 6

Thus, each carbon atom requires four, and each oxygen atom requires two more electrons to acquire noble gas configurations. To achieve this, two oxygen atoms form a double covalent bond with carbon as follows.



Acetylene Molecule

Carbon atom has four electrons in its outermost shell and hydrogen atoms have only one electron in its outermost shell. Carbon share one of its electrons with hydrogen to form a single bond each. Each carbon then requires three more electrons to acquire a stable configuration of the nearest noble gas (neon). This is done by mutually sharing three pairs of electrons between the two carbon atoms to form a triple bond as shown below.



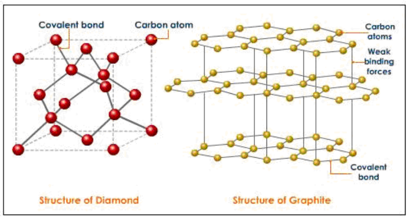
Allotropes of Carbon

Allotropy: The phenomenon of existence of an element in different forms having different physical properties but identical chemical properties is called allotropy and the various forms are called allotropic forms or allotropes.

Crystalline form: Diamond, Graphite

Amorphous form: Coal, Coke, Charcoal (or wood charcoal), Animal Charcoal (or bone black), Lamp black, Carbon black, Gas carbon and Petroleum coke.

Diamonds and graphite are two crystalline allotropes of carbon. Diamond and graphite both are covalent crystals. But, they differ considerably in their properties.



Comparison of the Properties of Diamond and Graphite

Diamond	Graphite
It occurs naturally in free state.	It occurs naturally and is manufactured artificially.
It is the hardest natural substance known.	It is soft and greasy to touch.
It has high relative density (about 3.5).	Its relative density is 2.3.
It is transparent and has high refractive index (2.45).	It is black in colour and opaque
It is non-conductor of heat and electricity.	Graphite is a good conductor of heat and electricity.
It burns in air at 900°C to give CO_2.	It bums in air at 700-800°C to give CO_2.
It occurs as octahedral crystals.	It occurs as hexagonal crystals
It is insoluble in all solvents.	It is insoluble in all ordinary solvents

These differences in the properties of diamond and graphite are due to the difference in their structures. In diamond, each C atom is linked to its neighbors by four single covalent bonds. This leads to a three-dimensional network of covalent bonds. In graphite, the carbon atoms are arranged in flat parallel layers as regular hexagons. Each carbon in these layers is bonded to three others by covalent bonds. Graphite thus acquires some double bond character. Each layer is bonded to adjacent layers by weak van der Waals forces. This allows each layer to slide over the other easily. Due to this type of structure graphite is soft and slippery, and can act as a lubricant. Graphite is also a good conductor of electricity due to mobile electrons in it.

Amorphous Forms of Carbon

Coal

Coal is formed in nature by the 'carbonisation' of wood. Conversion of wood to coal under the influence of high temperature, high pressure, and in the absence of air is termed carbonisation.

$$\text{Wood} \rightarrow \text{Peat} \rightarrow \underset{\text{(brown coal)}}{\text{Lignite}} \rightarrow \text{Wood} \rightarrow \text{Peat} \rightarrow \underset{\text{(brown coal)}}{\text{Lignite}} \rightarrow$$

Amongst coal varieties, anthracite is the purest form. It contains about 94 - 95% of carbon. The common variety of coal is bituminous coal; it is black, hard and burns with smoky flame.

Wood Charcoal

When wood is heated strongly in a very limited supply of air, wood charcoal is obtained. This process is called destructive distillation of wood. The volatile products are allowed to escape. Charcoal is a black, porous and brittle solid. It is a good adsorbent. Charcoal powder adsorbs colouring matter from solutions, and poisonous gases from the air. Charcoal is also a good reducing agent.

Animal Charcoal

Animal charcoal (or Bone charcoal) is obtained by destructive distillation of bones. It contains about 10-12% of amorphous carbon.

Sugar Charcoal

It is obtained by heating sugar in the absence of air. Sugar charcoal is the purest form of amorphous carbon.

$$C_{12}H_{22}O_{11} \xrightarrow[\text{(absence of air)}]{\text{heat}} \underset{\text{sugar charcoal}}{12C} + 11H_2O$$

Sugar charcoal becomes activated charcoal when it is powdered to particle size of about 5 Âµ and heated at about 1000 K in vacuum. Activated charcoal has an increased adsorption capacity.

Lamp Black

Lamp black is manufactured when tar and vegetable oils (rich in carbon) are burnt in an insufficient supply of air and the resulting soot is deposited on wet blankets hung in a room. Lamp black is a velvety black powder. It is used in the manufacture of India ink, printer's ink, black paint and varnishes and carbon papers.

Carbon Black

When natural gas is burned in limited supply of air, the resulting soot is deposited on the underside of a revolving disc. This is carbon black and it is then scraped off and filled in bags. It differs from lamp black in being not so greasy. Carbon black is added to the rubber mix used for making automobile tyres, and has replaced the use of lampblack for a number of purposes.

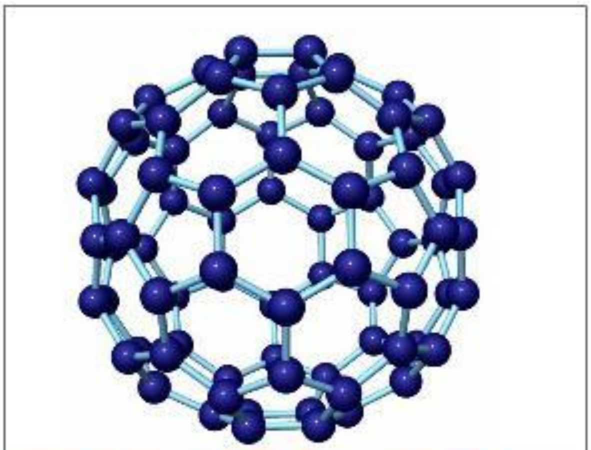
Gas Carbon and Petroleum Coke

Carbon scraped that is from the walls of the retort used for the destructive distillation of coal in called gas carbon. During refining of crude petroleum, petroleum coke is deposited on the walls of the distillation tower.

Both, gas carbon and petroleum coke are used for making electrodes in dry cells and are good conductors of electricity.

Fullerenes

Fullerenes are allotropes of carbon that were discovered as recently as 1985. They have been found to exist in the interstellar dust as well as in geological formations on earth. They are large cage like spherical molecules with formulae C_{32}, C_{50} C_{60}, C_{70}, C_{76}, C_{84} etc. The most commonly known fullerene is C_{60} which is named as 'buckminster fullerene after the designer of the geodesic dome, American architect Buckminister.



The Structure of C-60 Buckminster Fullerene

C_{60} molecule has marvellously symmetrical structure. It is a fused-ring of aromatic system containing 20 hexagons and 12 pentagons of C atoms. The structure bends around and closes to form a soccer ball shaped molecule. It is therefore, called buckyball also. Fullerene looks different from diamond and graphite. It is a yellow powdery substance, which turns pink on dissolution in solvents like toluene. It polymerizes on exposure to U.V. radiations.

Fullerenes are fascinating because they show unusual characteristics and applications like:

- They are wonderful lubricants because the balls can roll between the surfaces.
- Alkali compounds of C_{60} (A_3C_{60}) are super conducting materials even at high temperatures of the order of 10-40 K.

Organic Compounds – Compounds of carbon and hydrogen.

Organic Chemistry – The branch of Chemistry that deals with the study of compounds of carbon and hydrogen.

Distinguishing features of Organic Compounds

1. Types of Linkages – Organic compounds generally contain covalent linkages while Inorganic Compounds are ionic in nature.

2. Melting and Boiling Point – Organic Compounds have low melting and boiling points because of their covalent nature. Inorganic Compounds usually have high melting and boiling points.

3. Solubility – Organic Compounds are insoluble in water but soluble in organic solvents.

4. Electrical Conductivity – Organic Compounds are bad conductors of electricity while inorganic compounds are good conductors of electricity.

5. Nature of reactions – Organic reactions are complicated and slow whereas Inorganic reactions are instantaneous.

6. Stability – Organic Compounds are less stable to heat than Inorganic Compounds.

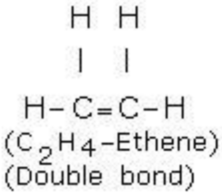
7. Combustibility – Organic Compounds are combustible and generally leave no residue, when burnt. Inorganic Compounds are incombustible.

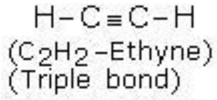
Reasons for the formation of large number of Organic Compounds

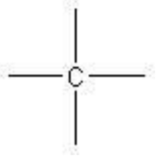
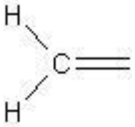
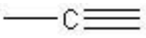
1. Catenation – The property of atoms of an element to link with one another forming chains of identical atoms is called catenation.
Carbon exhibits catenation to maximum extent because of strong carbon carbon bond and tetravalency.

2. Formation of C-C Multiple Bonds
Due to its small size the carbon atom can also form multiple bonds i.e., double and triple bonds with not only carbon but with atoms of other elements like oxygen,

nitrogen, etc. The formation of these multiple bonds gives rise to a variety in the carbon compounds.

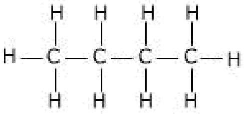

(C_2H_4-Ethene)
(Double bond)

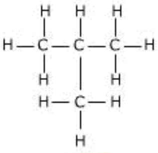

(C_2H_2-Ethyne)
(Triple bond)

Types and number of bonds	**Structure**
Linked to four atoms with four single bonds. Tetrahedral geometry (sp^3 hybridisation)	
Linked to three atoms with two single and one double bond. Trigonal geometry (sp^2 hybridisation)	
Linked to two atoms with one single and one triple bond. Linear geometry (sp hybridisation)	

Whatever be the nature of bonding, all the compounds of carbon always have a total of four bonds around the carbon atom.

3. Isomerism - The unique feature of the carbon-carbon bonding has also led to the formation of compounds that can have the same molecular formula, but different structures. This phenomenon of different structural formula of the same molecule, giving rise to different properties of compounds, is called Isomerism. In the above illustrations pentane and iso-pentane display isomerism. Such compounds with the same molecular formula are called isomers of one another. Another common instance of isomerism is butane, where there are following two possible structures for the same molecular formula C_4H_{10}.


Butane
C_4H_{10}


Iso-Butane
C_4H_{10}

Saturated and Unsaturated Carbon Compounds

Organic Compounds are classified as saturated and unsaturated depending upon whether they contain single or multiple bonds.

Saturated Carbon Compounds

Compounds of carbon and hydrogen whose adjacent carbon atoms contain only one (carbon-carbon) bond are known as saturated hydrocarbons. Their carbon-hydrogen bonds are also single covalent bonds. They are called saturated compounds because all the four bonds of carbon are fully utilised and no more hydrogen or other atoms can attach to it. Thus, they can undergo only substitution reactions. They are also representative of open-chain aliphatic hydrocarbons. These saturated hydrocarbons are called as alkanes.

Unsaturated Hydrocarbons

Compounds of carbon and hydrogen that contain one double covalent bond between carbon atoms (carbon=carbon) or a triple covalent bond between carbon atoms ($\text{carbon} \equiv \text{carbon}$) are called unsaturated hydrocarbons. In these molecules, since all the bonds of carbon are not fully utilised by hydrogen atoms, more of these can be attached to them. Thus, they undergo addition reactions (add on hydrogen) as they have two or more hydrogen atoms less than the saturated hydrocarbons (alkanes).
Unsaturated hydrocarbons can be divided into 'alkenes' and 'alkynes' depending on the presence of double or triple bonds respectively.

Properties of Saturated and Unsaturated Compounds

Saturated Organic Compounds	**Unsaturated Organic Compounds**
These organic compounds contain single Carbon carbon covalent bond.	These organic compounds contain at least one double or triple covalent bond. $>C=C<$ or $-C \equiv C-$
Due to the presence of all single covalent bonds, these compounds are less reactive.	Due to the presence of double and triple Covalent bonds, these compounds bonds, these compounds are more reactive.
Saturated compounds undergo substitution reactions. Example: $CH_4 + Cl_2 \longrightarrow \underset{\text{Chloromethane}}{CH_3Cl + HCl}$	Unsaturated compounds undergo addition reactions. Example: $\underset{\text{Ethene}}{C_2H_4} + Cl_2 \longrightarrow \underset{\text{1,2 dichloroethane}}{C_2H_4Cl_2}$
The number of hydrogen atoms is more when compared to its corresponding unsaturated hydrocarbon.	The number of hydrogen atoms is less when compared to its corresponding unsaturated hydrocarbon.

Classification of Hydrocarbons

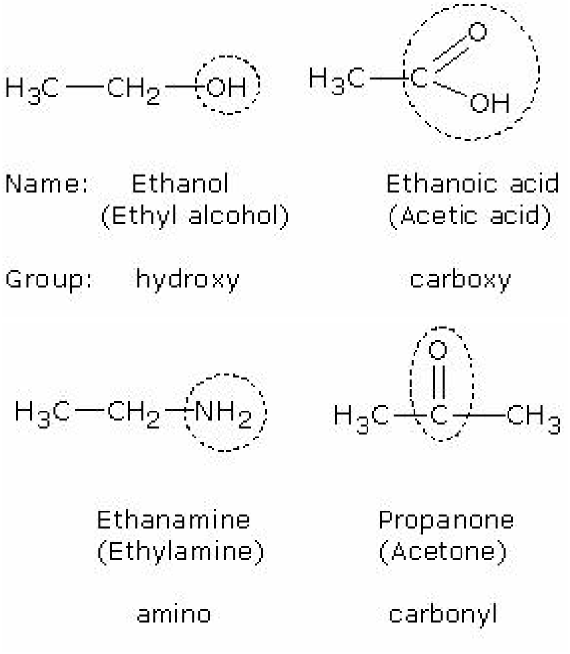
Hydrocarbons are broadly classified into two categories – Open chain/Aliphatic/Acyclic Compounds and Carbocyclic Compounds. Aliphatic hydrocarbons are further classified into alkanes, alkenes and alkynes. Carbocyclic Compounds are further classified into two types – Alicyclic Compounds and Aromatic Compounds.

Homologous Series & Nomenclature

Affinity of Carbon with Other Elements

It is quite evident that carbon displays a great propensity in forming a large variety of carbon and hydrogen compounds. But carbon can also form bonds with other elements in a hydrocarbon chain, when one or more hydrogen is replaced by an element like oxygen, nitrogen, sulphur etc. such that the valency of carbon remains satisfied. When an atom or a group of atoms forms a bond with the carbon atom in the chain or ring of an organic compound, while showing some characteristic properties of their own, they are termed as a functional group. The property of the whole organic molecule is then due to this functional group. In such compounds, the element replacing hydrogen is referred to as a heteroatom. These heteroatoms confer specific properties to the compound, regardless of the length and nature of the carbon chain and form the functional group. Thus a functional group is the site of chemical reaction in an organic compound and all compounds containing a particular functional group undergo similar reactions.

For example, in alcohols like methanol and ethanol, -OH is the functional group and in acids like ethanoic acid, -COOH is the functional group. The -NH_2 functional group possesses basic character. The functional group present in the following molecules is encircled. Free valency or valencies of the group are shown by the single line. The functional group is attached to the carbon chain through this valency by replacing one hydrogen atom or atoms.



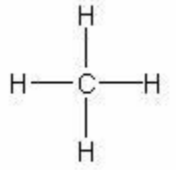
Homologous Series

All organic compounds are made up of a progressively building chain of carbon atoms with a number of compounds having the same functional groups. Such a series of similarly constituted compounds are called a homologous series. Members of a homologous group are similar in structure and display similar chemical characteristics. The two consecutive members of the series differ in their molecular formula by a 'CH_2' group.

Some important characteristics of the homologous series are:

- All the members conform to a general molecular formula and have a similar functional group.
- Each consecutive member differs in the molecular formula by a unit of 'CH_2'.
- All the members of the series exhibit similar properties, but the extent of the reactions varies with increasing relative molecular mass.
- The physical properties, such as solubility, melting point, boiling point, specific gravity etc. show a gradual change with the increase in their relative molecular masses.

Hydrocarbons and their major sub groups form a homologous series of organic compounds. As an illustrative example, the simplest of all hydrocarbons is methane whose molecular formula is CH_4. This molecule consists of a single carbon atom linked to four hydrogen atoms by single covalent bonds. A straight line is used to represent each shared pair of electrons (bond) and the structure of methane (structural formula) can be thus written as follows:



Methane

There are about 60 hydrocarbons of the methane type i.e., whose carbon atoms are linked to each other in single covalent bonds while the hydrogen atoms satisfy the remaining valencies. If their molecular formulae are arranged in order of increasing number of carbon atoms in their molecules, the following series is obtained.

CH_4,	C_2H_6,	C_3H_8,	C_4H_{10},	C_5H_{12},	C_6H_{14},	etc.
Methane	Ethane	Propane	Butane	Pentane	hexane	

Each member of this series differs from the previous one by an increment of -CH_2- group. Thus, the methane family is a homologous series that can be characterised by the formula C_nH_{2n+2}. All members of this group can be prepared by the reduction of their appropriate alkyl halides ($C_nH_{2n+1}X$). This group is called the alkane group. Similarly the alkene and alkyne groups are characterised by the formula C_nH_{2n-2} and C_nH_{2n} respectively.

Nomenclature of Carbon Compounds

"Nomenclature is the system of assigning a proper name to a particular carbon compound on the basis of certain rules."

Most of the carbon compounds have two types of names:

- Trivial Names
- IUPAC Names

Trivial Names

The trivial names are the commonly used names of carbon compounds. They are derived mostly from the source of the compound e.g., the name of formic acid is derived from 'formicus' the Greek word meaning red ants. Names arrived in this way were ambiguous and repeating.

IUPAC Names

With the large growth of carbon compounds, it was necessary to name these compounds in a more systematic way. A committee called the 'International Union for Pure and Applied Chemistry' (IUPAC) put forward a system of giving proper scientific names to carbon based compounds. The names derived by their rules are the names followed all over the world and in short are called IUPAC names.

In this system the name of a carbon compound has three main parts as mentioned below:

Wood Root

This denotes the number of carbon atoms present in a given molecule. For e.g., C_1-Meth, C_2-Eth, C_3 - Prop, C_4- But.

Suffix

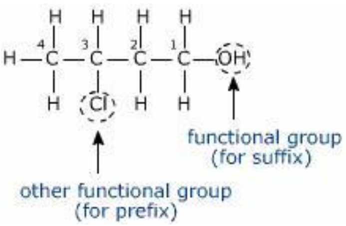
The suffix denotes the type of bonds or the functional group present in the carbon chain, e.g.

'ane' - (single bond)
'ol' for alcohols -(-OH)
'ene' (double bond)
'al' for aldehydes - (-CHO)
'yne' - (triple bond)
'oic acid' for carboxylic acid - (-COOH)

Prefix

This denotes the presence of other functional groups and their position.

For e.g., the following compound can be named as:



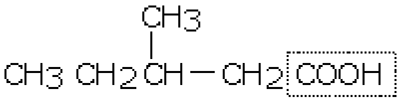
Word root: But (C_4)
Prefix: 3, chloro
Suffix: -ol
Name: 3-chloro butanol
Note carbon atoms are numbered from the side of the functional group (-OH in this case).
The IUPAC names along with trivial names and formula of some organic compounds are given in the following table:

Trivial Names, IUPAC Names and Molecular Formula of some Organic

Trivial Name	IUPAC Name	Formula
Methane	Methane	CH_4
Ethane	Ethane	C_2H_6
Ethylene	Ethene	C_2H_4
Acetylene	Ethyne	C_2H_2
Formaldehyde	Methanal	$HCHO$
Acetaldehyde	Ethanal	CH_3CHO
Formic acid	Methanoic acid	$HCOOH$
Acetic acid	Ethanoic acid	CH_3COOH

The Following Four Steps are Involved in Naming the Compound Containing Functional Group.

- The functional group present is identified. This enables us to choose the appropriate suffix or prefix. For example, the functional group present in the following compound is carboxylic acid and the suffix is oic acid.



$$CH_3\,CH_2\,\overset{\displaystyle CH_3}{\underset{}{CH}} - CH_2\,\boxed{COOH}$$

- The longest continuous chain containing the functional group is determined. The longest continuous chain in the above compound contains five carbon atoms. Therefore, the base name is pentane.

- Following the principle of assigning the lowest possible number to the functional group, the chain is numbered. In the above compound, carboxylic acid carbon is number 1 and the carbon at which the branching is present is carbon 3.
- Then the name is arrived at. The alkyl group (CH_3-) at carbon 3 comes as a prefix. In this way, the name of the compound is completed(3-methylpentanoic acid).

Isomers and Isomerism

Compounds which have same molecular but different structural formulae are called isomers and the phenomenon is known as isomerism.

1. Chain Isomerism – The isomerism in which the isomers differ from each other due to the presence of different carbon chain skeletons .Example: n-butane and iso-butane.

2. Position Isomerism – the type of isomerism in which the isomers differ in the position of the functional group. Example: But-1-ene and But-2-ene.

3. Functional Isomerism – The type of isomerism in which the isomers differ in structure due to the presence of different functional groups.

Chemical Properties of Carbon Compounds

Most of the carbon-containing compounds associated with hydrogen i.e., hydrocarbons are fuels that produce heat on burning. Petroleum products like natural gas, petrol, diesel, kerosene, heavy oils etc., and in a larger sense, wood, biogas, charcoal and coke are all rich source of carbon compounds used as fuels.

Combustion

Combustion means the burning of a substance. It is a process that is highly exothermic i.e., produces a lot of heat. The products of combustion of carbon and its compounds are heat energy, carbon dioxide and water (vapour).

In order that a fuel undergoes combustion, three basic requirements are to be present.

- A combustible substance: All carbon compounds are combustible, but carbon as diamond is not. Petrol is a combustible substance.
- A supporter of combustion: Atmospheric air or oxygen gas is a supporter of combustion. In their absence, combustion will not be supported. Carbon dioxide or nitrogen gases do not support combustion.
- Heating to ignition temperature: A minimum amount of temperature or heat is required to enable a fuel to catch fire. Coal has a high ignition temperature; a matchstick cannot produce enough heat to ignite it. However, a matchstick can ignite paper or LPG gas as it has low ignition temperature.

When the above conditions are present in any combustion process, proper combustion (energy production) takes place with minimum wastage and pollution. For example, if an ideal fuel like LPG (high calorific value and relatively high amounts of branched hydrocarbons) is available, a sufficient and continuous supply of oxygen should be maintained to burn it. If the ignition spark or flame is sufficient then the combustion is smooth and complete as follows.

$$\underset{\substack{\text{Butane}\\ \text{(petroluem gas)}}}{2C_4H_{10}(g)} + \underset{\substack{\text{Oxygen}\\ \text{(of air)}}}{13O_2(g)} \xrightarrow[\text{combustion}]{\text{Exothermic}} \underset{\substack{\text{Carbon}\\ \text{dioxide}}}{8CO_2(g)} + \underset{\text{Water}}{10H_2O(vap)} + \underset{\text{Heat}}{2658\,kJ}$$

It produces high heat energy with no wastage of raw material (un-reacted) and no production of undesirable by products (pollutants).

Most of the carbon compounds like the hydrocarbons when burnt in air or oxygen produce large amounts of heat, together with carbon dioxide and water vapour formation. Hence they are used as fuels. For example, methane burns with a blue flame in air. Alkanes burn with a non sooty flame in plenty of oxygen, but when the supply of oxygen is limited, they burn with a sooty flame.

$$\underset{\text{Methane}}{CH_4(g)} + \underset{\substack{\text{Oxygen}\\ \text{(from air)}}}{O_2(g)} \xrightarrow{\Delta} \underset{\substack{\text{Carbon}\\ \text{dioxide}}}{CO_2(g)} + \underset{\text{Water}}{2H_2O(vap)} + \text{Heat}$$

In a very limited supply of air methane gives carbon black.

$$CH_4 + \underset{\substack{\text{Air}\\ \text{(very limited)}}}{O_2} \longrightarrow \underset{\text{Carbon black}}{C} + 2H_2O$$

Some carbon compounds are very combustible and have an explosive reaction with air e.g., alkenes. They burn with a luminous flame to produce carbon dioxide and water vapour.

Some hydrocarbon compounds undergo cracking or thermal decomposition. In this process, substances are heated to high temperatures of (500 - 800^{0}C) in the absence of air, and they decompose into a mixture of saturated and unsaturated hydrocarbons and hydrogen.

Oxidation

Carbon

Carbon undergoes oxidation by combining with oxygen at higher temperature to form to oxides, viz., carbon monoxide (CO) and carbon dioxide (CO_2). Carbon monoxide is formed, when incomplete combustion of carbon or carbon containing fuels takes place

$$C + \frac{1}{2}O_2 \longrightarrow CO_{(g)}$$

CO is present in automobile exhausts (when there is incomplete combustion), volcanic gases, chimney gases etc.

Carbon dioxide may be prepared by the complete combustion of carbon, hydrocarbons, carbon monoxide etc.

$$C + O_{2(g)} \longrightarrow CO_{2(g)} + \text{Heat}$$

$$2CO + O_{2(g)} \longrightarrow 2CO_{2(g)} + \text{Heat}$$

$$CH_4 + 2O_{2(g)} \longrightarrow CO_{2(g)} + 2H_2O$$

Carbon Containing Compounds

These undergo oxidation reactions when burnt in air or oxygen. For example, when methane is mixed with oxygen and heated in presence of molybdenum oxide, it gets oxidized to methanal or formaldehyde.

$$\underset{\text{Methane}}{2CH_4\,(g)} + \underset{\substack{\text{Oxygen}\\ \text{(from air)}}}{O_2\,(g)} \xrightarrow[\text{Molybdenum}]{350-500°C} \underset{\text{formaldyhyde}}{HCHO} + H_2O$$

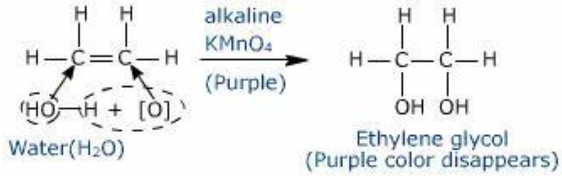
Oxidation of carbon compounds is used as for producing other carbon compounds with different functional groups like alcohol, carboxylic acid, ethers etc. Oxidation is achieved by using an oxygen atmosphere or oxidizing agents like alkaline $KMnO_4$ or acidified $K_2Cr_2O_7$. Methanol, an industrial alcohol, for instance, is prepared by the oxidation of methane.

$$\underset{\text{Methane}}{2CH_4\,(g)} + \underset{\substack{\text{Oxygen}\\ \text{(from air)}}}{O_2\,(g)} \xrightarrow[\text{copper tube}]{200°C} \underset{\substack{\text{Methyl}\\ \text{alcohol}}}{2CH_3OH\,(g)}$$

Acetic acid is manufactured by the oxidation of fermented liquors (10-15% alcohol) in air along with the presence of mycoderma aceti. A 3-7% solution of acetic acid is obtained and it is called vinegar.

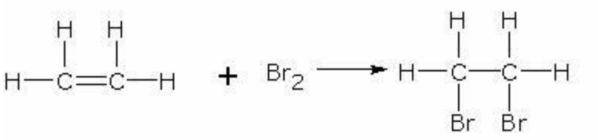
$$\underset{\text{Ethanol}}{C_2H_5OH} + O_2 \longrightarrow \underset{\text{acetic acid}}{CH_3COOH} + H_2O$$

When ethene is passed through an alkaline solution of potassium permanganate, the purple colour of the permanganate solution fades away.

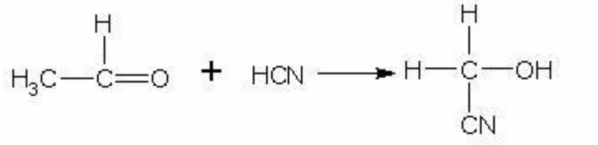


Addition Reaction

The reactions in which an unsaturated hydrocarbon combines with another substance to form a single product are called addition reactions. For example,



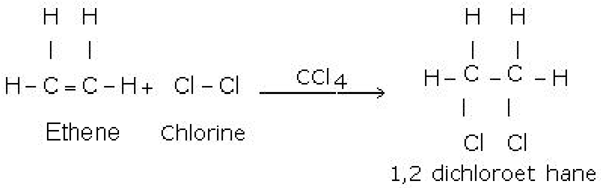
Addition product

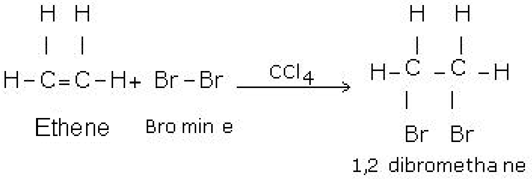


Addition product

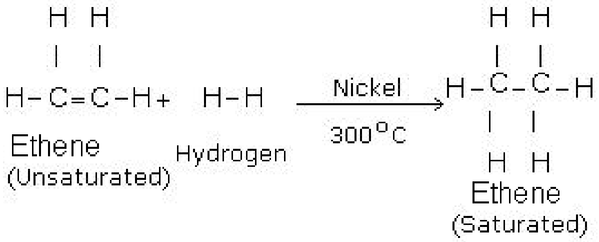
Carbon containing double bonds like the alkenes readily react with certain molecules to form saturated addition products.

The addition of Cl_2, Br_2 or I_2 molecule across the double bond of the alkene is called halogenation.





The addition of a hydrogen molecule across the double bond of the alkene to form saturated products is called hydrogenation. This takes place in the presence of the catalyst, nickel.



Vegetable oils like ground nut oil, cotton seed oil & mustard oil are unsaturated compounds containing double bonds.

They exist as liquids at room temperature.

Hydrogenation occurs at the double bonds to form saturated products called vanaspati ghee or vegetable ghee.

These are solids at room temperature.

$R_2C{=}CR_2 + H_2 \rightarrow R_2CH.CHR_2$ (in the presence of Ni at high temperature & pressure.

Substitution Reaction

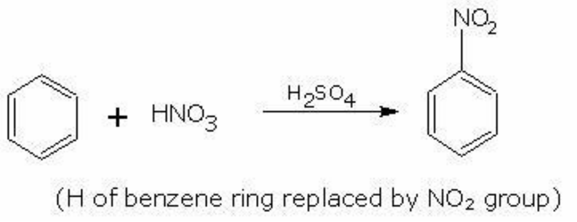
The reactions in which an atom or group of atoms in a molecule is replaced or substituted by different atoms or group of atoms are called substitution reaction. For example,

$$CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl$$

(H replaced by Cl)

$$CH_3CH_2I + KOH_{(aq)} \longrightarrow CH_3CH_2OH$$

(I replaced by OH)



(H of benzene ring replaced by NO_2 group)

In substitution reactions the hydrogen of the alkane molecule is replaced by another atom or a group of atoms (like alkyl) resulting in the formation of the derivatives of that hydrocarbon. Substitution by halogen atom is generally called halogenation. This type of substitution results in chlorination, bromination or iodination.

Chlorination of Methane

Chlorination of methane is carried out by taking a mixture of methane and chlorine in the sunlight or by heating to a temperature of 250^o- 300^{o}C. If chlorine is in excess, a number of substitution products are obtained.

$$\underset{\text{Methane}}{CH_4} + Cl_2 \xrightarrow[\text{or } \Delta]{\text{UV light}} \underset{\substack{\text{Methyl chloride}\\ \text{or chloro methane}}}{CH_3Cl} + HCl$$

$$\underset{\text{Chloromethane}}{CH_3Cl} + Cl_2 \longrightarrow \underset{\substack{\text{Methyl chloride}\\ \text{or dichloro methane}}}{CH_2Cl_2} + HCl$$

$$\underset{\text{Dichloro methane}}{CH_2Cl_2} + Cl_2 \longrightarrow \underset{\substack{\text{Chloroform}\\ \text{or trichloro methane}}}{CHCl_3} + HCl$$

$$\underset{\text{trichloro methane}}{CHCl_3} + Cl_2 \longrightarrow \underset{\substack{\text{Carbon terachloride or}\\ \text{tetrachloro methane}}}{CCl_4} + HCl$$

Like methane, ethane also forms a series of substitution products in the presence of excess chlorine and sunlight.

$$\underset{\text{Ethane}}{C_2H_6} + Cl_2 \xrightarrow{\text{UV light}} \underset{\text{Chloroethane}}{C_2H_5Cl} + HCl$$

$$\underset{\text{Chloroethane}}{C_2H_5Cl} + \underset{\text{(excess)}}{Cl_2} \longrightarrow \underset{\text{Dichloroethane}}{C_2H_4Cl_2} + HCl$$

$$\underset{\text{Dichloroethane}}{C_2H_4Cl_2} + Cl_2 \longrightarrow \underset{\text{Trichloroethane}}{C_2H_3Cl_3} + HCl$$

$$\underset{\text{Trichloroethane}}{C_2H_3Cl_3} + Cl_2 \longrightarrow \underset{\text{Tetrachloroethane}}{C_2H_2Cl_4} + HCl$$

$$\underset{\text{Tetrachloroethane}}{C_2H_2Cl_4} + Cl_2 \longrightarrow \underset{\text{Pentachloroethane}}{C_2HCl_5} + HCl$$

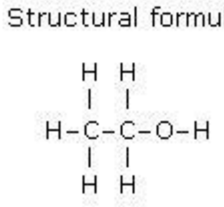
$$\underset{\text{Pentachloroethane}}{C_2HCl_5} + Cl_2 \longrightarrow \underset{\text{Hexachloro ethane}}{CCl_6} + HCl$$

Some Important Carbon Compounds

Ethanol or Ethyl Alcohol

Usually the term 'alcohol' refers to ethanol. Man has been using ethanol for thousands of years especially in the form of wine.

The structural formula of ethanol is given as follows:



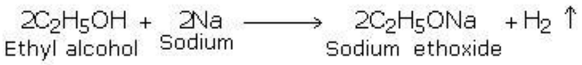
Its molecular formula is CH_3CH_2OH or C_2H_5OH

- Ethanol is colourless liquid and has a pleasant odour.
- Its boiling point is 78° C and its freezing point is -114°C.
- It is soluble in water and almost all the organic solvents.
- It is highly intoxicating in nature.
- It is combustible and burns with a blue flame.

Properties of Ethanol

Action with Sodium Metal

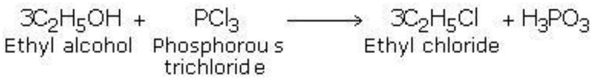
When a piece of sodium is dropped in ethyl alcohol, bubbles of hydrogen gas are observed.



$$\underset{\text{Ethyl alcohol}}{2C_2H_5OH} + \underset{\text{Sodium}}{2Na} \longrightarrow \underset{\text{Sodium ethoxide}}{2C_2H_5ONa} + H_2 \uparrow$$

Action with Phosphorus Trichloride

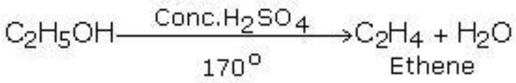
Ethanol reacts with phosphorus trichloride to form ethyl chloride.



$$\underset{\text{Ethyl alcohol}}{3C_2H_5OH} + \underset{\text{Phosphorous trichloride}}{PCl_3} \longrightarrow \underset{\text{Ethyl chloride}}{3C_2H_5Cl} + H_3PO_3$$

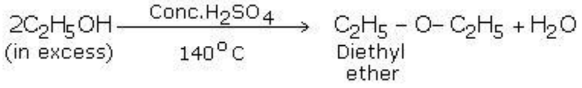
Action with Concentrated Sulphuric Acid

At 170°C ethyl alcohol undergoes dehydration when treated with concentrated H_2SO_4 to form ethane.



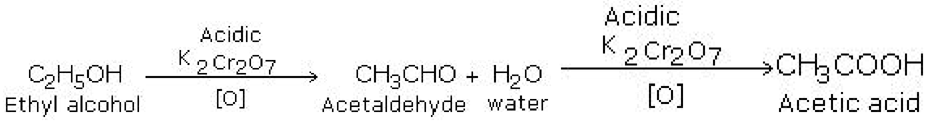
$$C_2H_5OH \xrightarrow[170^{\circ}]{Conc.H_2SO_4} \underset{\text{Ethene}}{C_2H_4} + H_2O$$

At lower temperature of 140°C and when present in excess ethyl alcohol forms a pleasant smelling substance called diethyl ether.



Oxidation of Ethyl Alcohol by Acidified Potassium Dichromate

Alcohols on oxidation give aldehydes. The aldehydes on further oxidation give carboxylic acids.



Uses

All these are important chemical compounds used further by chemical industries.

- Ethyl Alcohol is used as a solvent for many organic solutes, especially which are insoluble in water.
- It is used in the preparation of perfumes.
- It is used in the manufacturing of gasohol, which is 90% mixture of petrol (gasoline) and 10% ethanol. It helps to save gasoline.
- Ethyl Alcohol is used in making tinctures and medical syrups.
- It is used in alcoholic beverages.
- It is used as a solvent for paints, varnishes, dyes etc.
- It is used in the production of many organic compounds.

Effect of Alcohol on Human Beings

Chemically the term alcohol refers to a group of organic compounds, having
-OH group in their composition. But the word alcohol used by the common man refers to ethyl alcohol or ethanol. It has a variety of uses, especially as a solvent. But by far the greatest use of alcohol is in the form of alcoholic beverages, such as wine, beer, rum, brandy, whisky etc. In small quantities it may serve as a source of energy, but in large amounts, it affects the nervous system. The person experiences loss of control over muscles and loses his or her sense of balance and mental ability. It can be a habit forming activity. If consumed over a period of time, alcohol can ruin one's health especially the liver, which gets affected by cirrhosis. This type of consumption can be fatal and ruins one's family life.

Methylated Spirit or Denatured Alcohol

Alcoholic drinks are heavily taxed by the government, so as to discourage people from over consuming it. Alcohol used for industrial and surgical purposes is not taxed heavily. But in order to prevent people from buying and consuming this alcohol, it is mandatory that ethyl alcohol be mixed with a certain percentage of highly poisonous methyl alcohol or methanol. This renders the ethyl alcohol unfit for human consumption. This mixture is called "Methylated Spirit". If chemicals like copper sulphate or pyridine are added to ethyl alcohol it is called 'denatured alcohol'.

Remember

Denatured spirit or methylated spirit mixture is prepared so as to prevent people from drinking ethanol heavily.

Spurious Alcohol

This is illicit liquor made by improper distillation or by using methylated spirit. It is cheap and is mostly used by the lower strata of our society. It contains higher percentage of methyl alcohol, which is poisonous. Consumption of such liquor may cause blindness, other serious health problems and even death. Sometimes even other chemicals are mixed with the ethyl alcohol so that the consumer gets a feeling of "intoxication". Even these are highly poisonous and can cause severe damages to the body and even death can occur.

Ethanoic Acid

Acetic acid is one of the commonest organic acids and has been known for quite a long time in the form of vinegar. It is also present free in a number of fruit juices. In the combined state it occurs in many oils and essential oils.

Formula: CH_3COOH, IUPAC Name: Ethanoic acid

Acetic acid is a colourless, corrosive liquid with a pungent smell at ordinary temperatures. But below 290K, it solidifies to an icy mass called glacial acetic acid. It boils at 391K and its specific gravity is 1.08 at 273K. It is miscible with water, alcohol and ether in all ratios. It is a good solvent for phosphorus, sulphur, iodine and inorganic compounds.

Since acetic acid contains an alkyl group and an acid moiety (each of the two parts into which a thing is divided), it exhibits the properties of both these groups.

Reactions of Alkyl Group - Halogenation

In acetic acid, halogen atoms successively replace the three hydrogen atoms of the alkyl group.

$$\underset{\text{Acetic acid}}{CH_3COOH} + Cl_2 \longrightarrow \underset{\text{monochloro acetic acid}}{CH_2ClCOOH} + HCl$$

$$CH_2ClCOOH + Cl_2 \longrightarrow \underset{\text{Dichloro acetic acid}}{CHCl_2COOH} + HCl$$

$$CHCl_2COOH + Cl_2 \longrightarrow \underset{\text{Trichloro acetic acid}}{CCl_3COOH} + HCl$$

Reactions Involving Replaceable Hydrogen Atom

Acetic acid ionizes in polar media to give hydrogen ion that is responsible for its acidic behaviour.

$$CH_3COOH \rightleftharpoons CH_3COO^{(-)} + H^{(+)}$$

Accordingly, acetic acid can react with alkalis and alkali metal carbonates and also with metals.

With Alkalis, Carbonates and Bicarbonates

Acetic acid turns blue litmus to red, neutralizes alkalis to form salt and water. It also decomposes carbonates and bicarbonates to liberate carbon dioxide indicated by effervescence.

$$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$$

$$2CH_3COONa + H_2O + CO_2 \uparrow$$

Sodium acetate

$$CH_3COO^-Na^+ + H_2O + CO_2 \uparrow$$

$$2CH_3COOH + Na_2CO_3 \longrightarrow$$

$$CH_3COOH + NaHCO_3 \longrightarrow$$

Bicarbonate test is used as an identification test for the presence of carboxylic group in a compound.

With Metals

Acetic acid reacts with strongly electropositive metals like sodium and zinc to give the respective acetate and liberate hydrogen.

$$2CH_3COOH + 2Na \longrightarrow \underset{\text{Sodium acetate}}{2CH_3COONa} + H_2$$

With Alcohols

Acetic acid reacts with alcohols in the presence of dehydrating agents like anhydrous zinc chloride or concentrated sulphuric acid to form esters.

$$CH_3COOH + \underset{\text{Ethanol}}{HOC_2H_5} \longrightarrow \underset{\substack{\text{ethyl acetate} \\ \text{(ester)}}}{CH_3COOC_2H_5} + H_2O$$

Reactions Involving Carboxyl Group as a Whole

Dry distillation of the anhydrous alkali salts of acetic acid with soda-lime yields methane.

$$\underset{\text{Sodium acetate}}{CH_3COONa} + NaOH \xrightarrow{CaO} Na_2CO_3 + \underset{\text{methane}}{CH_4}$$

Reduction

Though acetic acid is resistant to reduction, prolonged heating under pressure with concentrated hydriodic acid and red phosphorus gives ethane. This is also possible by heating the acid with hydrogen at high temperature and under pressure in the presence of a nickel catalyst.

$$CH_3COOH + 3H_2 \xrightarrow{Ni} C_2H_6 + 2H_2O$$

In the presence of lithium aluminium hydride, acetic acid can be reduced to ethanol. Hydrogenation in the presence of ruthenium or copper-chromium oxide catalyst gives the same result.

$$CH_3COOH + 3H_2 \xrightarrow{LiAlH_4} CH_3CH_2OH$$

Oxidation

On prolonged heating with a strong oxidizing agent, acetic acid is oxidized to carbon dioxide and water.

$$CH_3COOH \xrightarrow{[O]} 2CO_2 + 2H_2O$$

Uses

- Ethanoic aid is used in the manufacture of dyes, perfumes and rayons
- Manufacture of rubber from latex and casein from milk. It is used for coagulation.
- In the form of salts in medicine and paints.
- In the form of acetates of aluminium and chromium is used as mordants.
- In dilute form is used as vinegar and in the concentrated form as a solvent.
- In form of organic esters as perfumes.

Soaps & Detergents

Introduction

Soaps or detergents are cleansing agents that are capable of reacting with water to dislodge these foreign particles from a solid surface (e.g. cloth or skin). Soaps have their origin in oils and fats present in the animal and plant kingdom and synthetic detergents find their source in mineral oils (hydrocarbon compounds of petroleum or coal). Chemically speaking, Soaps are sodium or potassium salts of higher fatty acids like stearic, palmitic and oleic acids can be either saturated or unsaturated. They contain a long hydrocarbon chain of about 10-20 carbon with one carboxylic acid group as the functional group.

Saturated fatty acids such as stearic and palmitic etc. contain only single bonds in their molecule, while unsaturated fatty acids such as oleic, linoleic etc., contain one or more double bonds. Thus, soaps are usually a mixture of the sodium salts of the following acids:

- Stearic acid as sodium stearate ($C_{17}H_{35}COONa$) - saturated fatty acid; from vegetable oils like linseed oil, soyabean oil.
- Palmitic acid as sodium palmitate ($C_{15}H_{31}COONa$) - saturated fatty acid; Palm oil, animal fat
- Oleic acid as sodium oleate ($C_{17}H_{33}COONa$) - unsaturated fatty acid; Vegetable oils like linseed oil, soyabean oil.

When soap is made from the sodium salts of the acids of cheap oils or fats, the resulting soap is hard. These soaps contain free alkalis and are mainly used as washing bars for laundry. When soap is prepared from the potassium salts of the acids of good grade oils and fat, it results in soft soap. These soaps do not contain free alkalis. They produce more lather and are used mainly as toilet soaps, shaving cream and shampoos.

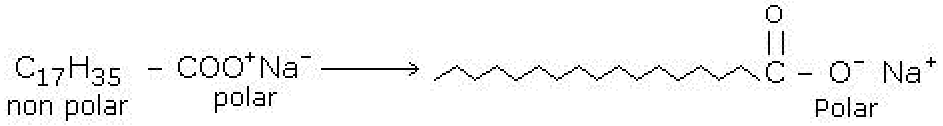
Difference between Toilet Soap and Laundry Soap

Toilet soap	Laundry soap
High quality fats and oils are used as raw materials	Cheaper quality fats and oils are used as raw materials

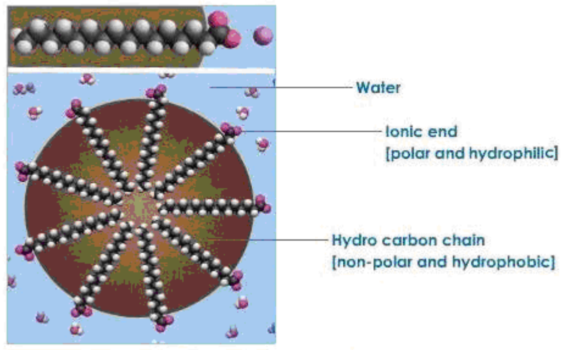
Expensive perfumes added	Cheap perfumes added
Care is taken to ensure that there is no free alkali content to prevent injuries to the skin	No such care is taken
No fillers	Fillers present

Cleansing Action of Soap

A soap molecule a tadpole shaped structure, whose ends have different polarities. At one end is the long hydrocarbon chain that is non-polar and hydrophobic, i.e., insoluble in water but oil soluble. At the other end is the short polar carboxylate ion which is hydrophilic i.e., water soluble but insoluble in oil and grease.



When soap is shaken with water it becomes a soap solution that is colloidal in nature. Agitating it tends to concentrate the solution on the surface and causes foaming. This helps the soap molecules make a unimolecular film on the surface of water and to penetrate the fabric. The long non-polar end of a soap molecule that are hydrophobic, gravitate towards and surround the dirt (fat or oil with dust absorbed in it). The short polar end containing the carboxylate ion, face the water away from the dirt. A number of soap molecules surround or encircle dirt and grease in a clustered structure called 'micelles', which encircles such particles and emulsify them.



Cleaning Action of a Soap

The subsequent mechanical action of rubbing or tumbling dislodges the dirt and grease from the fabric. These get detached and are washed away with excess of water leaving the fabric clean.

Limitations of Soaps

- Soaps do not wash well in hard water and does not form much lather or foam. The calcium, magnesium or iron ions of hard water form an insoluble sticky grey coloured precipitate called scum, which restricts the cleansing action of soap and makes washing more difficult. The scum formed also hardens and discolours the fabric. Thus, a large amount of soap is wasted and cleaning is not efficient.

- Ordinary soaps are not suited for fabrics such as silks, wool etc. The alkalis in them injure the fibre.
- If the water is slightly acidic in nature soaps cannot be used for cleaning purpose. The acid media change soaps into carboxylic acid and the action of soap becomes ineffective.

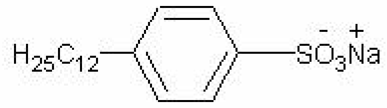
  To overcome these drawbacks new types of chemical based cleansing agents were developed. These are called synthetic detergents or simply detergents.

Synthetic Detergents

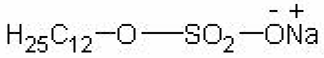
A detergent is a non-soapy cleaning agent that uses a surface-active agent for cleaning a substance in solution. Synthetic detergents are described as soapless soaps. Unlike soaps they are effective even in hard or salt water, as they form no scum.

Modern synthetic detergents are alkyl or aryl sulphonates produced from petroleum (or coal) and sulphuric acid. They can be defined as 'the sodium or potassium salt of a long chain alkyl benzene sulphonic acid or the sodium or potassium salt of a long chain alkyl hydrogen sulphate that have cleansing properties in water'.

Like soaps, detergents contain one large non-polar hydrocarbon group and one short ionic or highly polar group at each end, which allow for the cleansing action of dirt in water. Two basic examples of well-known detergents of the sulphonate group $S\overset{-}{O_3}\overset{+}{Na}$ or the sulphate group $OS\overset{-}{O_3}\overset{+}{Na}$ are:



Sodium p-dodecyl benzene sulphonate



$H_{25}C_{12}-O-SO_2-\overset{-}{O}\overset{+}{Na}$

Sodium lauryl sulphate or
Sodium n-dodecyl sulphate

Cleansing Action of Detergents

Synthetic detergents have the same type of molecular structure as soaps i.e. a tadpole like molecule having two parts at each end i.e., one large non-polar hydrocarbon group that is water repelling (hydrophobic) and one short ionic group usually containing the $S\overset{-}{O_3}\overset{+}{Na}$ or $OS\overset{-}{O_3}\overset{+}{Na}$ group that is water attracting (hydrophilic). Thus the cleansing action is exactly similar to that of soaps whereby the formation of micelles followed by emulsification occurs. However, synthetic detergents can lather well even in hard water. This is because they are soluble sodium or potassium salts of sulphonic acid or alkyl hydrogen sulphate and similarly form soluble calcium or magnesium salts on reacting with the calcium ions or magnesium ions present in water. This is a major advantage of the cleansing property of detergents over soap.

Advantages of Detergents

- Synthetic detergents clean effectively and lather well even in hard water and salt water (sea water). There is no scum formation.
- Since detergents are the salts of strong acids they do not decompose in acidic medium. Thus detergents can effectively clean fabric even if the water is acidic.
- Synthetic detergents are more soluble in water than soaps.
- They have a stronger cleansing action than soaps.
- As detergents are derived from petroleum they save on natural vegetable oils, which are important as essential cooking medium.

Disadvantages of Detergents

Detergents are surface-active agents and cause a variety of water pollution problems.

- Many detergents are resistant to the action of biological agents and thus are not biodegradable. Their elimination from municipal wastewaters by the usual treatments is a problem.
- They have a tendency to produce stable foams in rivers that extend over several hundred meters of the river water. This is due to the effects of surfactants used in their preparation. Thus they pose a danger to aquatic life.
- They tend to inhibit oxidation of organic substances present in wastewaters because they form a sort of envelope around them.

Differences between Soaps and Detergents

Soaps	Detergents
They are metal salts of long Chain higher fatty acids.	These are sodium salts of long chain hydrocarbons like alkyl sulphates or alkyl benzene sulphonates.
These are prepared from vegetable, Oils and animal fats	They are prepared from hydrocarbons of petroleum or coal.
They cannot be used effectively in hard water As they produce scum. i.e .insoluble Precipitates of $Ca^{2+,}$ $Mg^{2+,}$ Fe^{2+}	These do not produce insoluble precipitates in hard water. They are They are effective in soft, hard or salt water.
These cannot be used in acid solutions.	They can be used even in acid solutions.
Their cleansing action is not very strong	Their cleansing action is by surfactants, which is a strong cleansing action.
These are biodegradable.	Some of these are not biodegradable.

If a straight chain hydrocarbon is used in the detergent instead of a branched chain hydrocarbon, then the detergent becomes biodegradable. Thus the major disadvantage of detergents can be overcome.