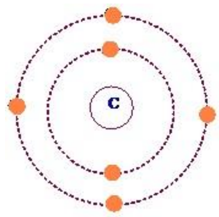
SCIENCE (CHEMISTRY)
CHAPTER 04: CARBON AND ITS COMPOUNDS
(Notes)

Introduction

All living and non-living components in the environment are carbon based. Human body contains 18% of carbon and act as the basic building block of the cells present in human body. It is necessary for the cellular respiration of the various parts of human body. Carbon is basically an element and is of extensive importance and significance, both in its elemental form and in its combined form for the survival on earth. 0.02% of carbon is present in the earth's crust in the form of carbonates, hydrogen carbonates, coal, petroleum and other minerals whereas 0.03% of carbon is present in the atmosphere.

Bonding in Carbon



a) Atomic number of carbon is 6
b) Electronic configuration has 2 electrons in K-shell and 4 electrons in L-shell.
c) In order to attain the noble gas configuration, carbon should either gain 4 electrons or lose 4 electrons or can share it's 4 electrons with some other element.
d) Gain of 4 electrons (to form octet, i.e. 8 electrons in C^{4-} anion) is difficult because then a nucleus with 6 protons will have to hold extra four electrons.
e) Loss of 4 electrons (to attain duplet, i.e., 2 electrons like He atom in C^{4+} cation) is difficult as it requires large amount of energy to remove four electrons.
f) Carbon, hence, overcomes this difficulty by sharing it's four valence electrons with other atoms of carbon or with atoms of other elements.
g) The simplest molecule formed by sharing of electrons (i.e., covalent bonds), can be represented by electron dot structure.
h) Carbon attains the noble gas configuration by sharing its valence electrons with other atoms. Such mutual sharing of electrons between atoms to attain a stable noble gas configuration is called **Covalent bonding**.
i) Atoms of other elements like hydrogen, oxygen, nitrogen, chlorine also show sharing of valence electrons.
j) Depending on the number of electron pairs shared, covalent bond is of three types :
   - **Single Covalent Bond**: Single covalent bond is formed because of sharing of two electrons, i.e. one pair .Example : Hydrogen, Chlorine, Methane (CH_4).
   - **Double covalent bond**: Double bond is formed by sharing of four electrons, i.e. two pairs of electrons. Example : Oxygen molecule, Carbon Dioxide molecule.
   - **Triple Covalent Bond**: Triple covalent bond is formed because of the sharing of six electrons, three pairs of electrons. Example: Nitrogen, C_2H_2

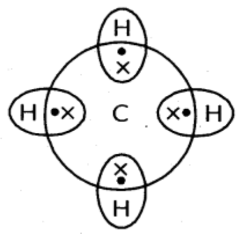


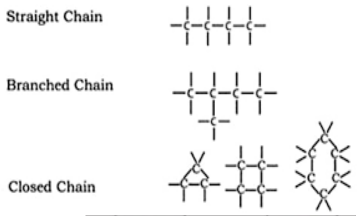
Fig. Electron dot structure for methane (CH_4).

Properties of Covalent Bonds

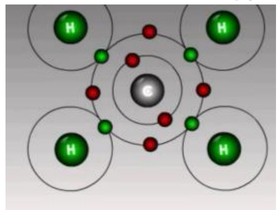
- Covalently bonded molecules have low melting and boiling points;
- Comparatively weaker intermolecular forces, unlike ionic compounds;
- These molecules are generally poor conductor of electricity since no charged particles are formed.

Two important properties which enable carbon to form enormously large number of compounds:

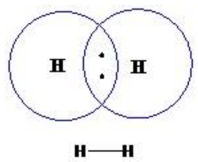
(i) **CATENATION** is property of carbon atom to form bond with other atoms of carbon.



(ii) **TETRAVALENCY**: Having a valency of 4, carbon atom is capable of bonding with atoms of oxygen, hydrogen, nitrogen, Sulphur, chlorine and other elements. Since it requires four electrons, carbon is said to be tetravalent. The smaller size of carbon atom enables nucleus to hold the shared pair of electrons strongly, thus carbon compounds are very stable in general.



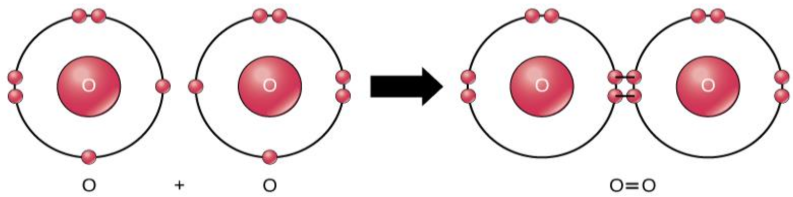
Bonding in Hydrogen



- The atomic number of Hydrogen is 1 and has only one electron in its K shell;
- This shell needs to either acquire or lose an electron to attain noble gas configuration of helium;
- Due to this reason two Hydrogen atoms share their outermost electrons leading to the formation of a molecule of a hydrogen, H_2;
- The shared pair of electrons between the hydrogen atoms constitutes a single bond between them and is also represented by a line between the two atoms.

Bonding in Oxygen

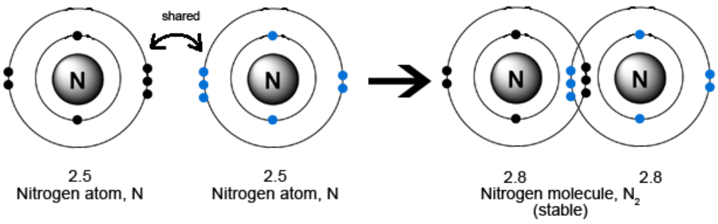
- The atomic number of Oxygen is 8 and has 6 electrons in its L-shell;
- This shell needs to either acquire or lose electrons 2 electrons to attain noble gas configuration of Neon;
- So, each atom of oxygen shares two electrons with other atom of oxygen to attain the nearest noble gas configuration;



- The shared pair of electrons between the oxygen atoms constitutes a double bond between them and is also represented by two parallel lines between the two atoms as shown in configure and exists as O molecule.

Bonding in Nitrogen

- Nitrogen has the atomic number 7 and has 5 electrons in its outermost shell.
- This shell needs to either acquire 3 electrons to attain noble gas configuration of Neon;
- So, each atom of nitrogen shares 3 electrons with other atom of nitrogen to attain the nearest noble gas configuration;



- The shared pair of electrons between the nitrogen atoms constitutes a triple bond between them and is also represented by three parallel lines between the two atoms as shown in the figure above and exists as N_2 molecule.

Versatile nature of Carbon

- The versatile nature of carbon due to the presence of covalent bond enables it to form a large number of compounds.
  (i) Carbon due to its property of catenation possesses a unique ability to form bonds with other atoms of carbon rise to large number of molecules and compounds having long chains of carbon, branched chains of carbon or carbon atoms arranged in rings and linked by single, double or triple bonds.

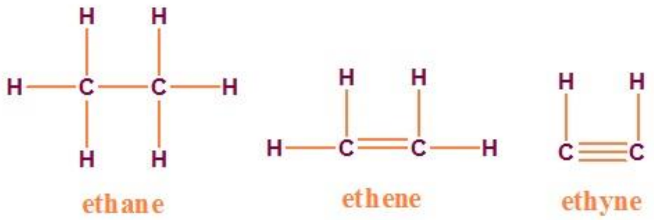
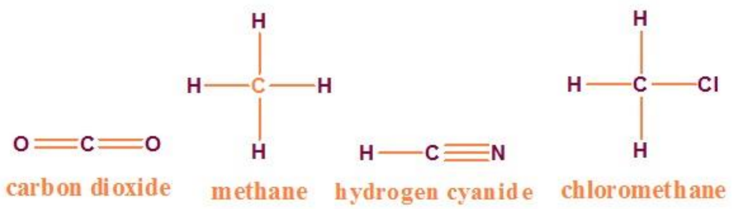


Figure - Carbon forming single, double and triple bonds with each other

  (ii) Carbon being tetravalent is capable of bonding with four other atoms of carbon or any other combining mono-valent element.
  (iii) Carbon forms compounds with oxygen (Carbon-dioxide), hydrogen (Methane), nitrogen (Hydrogen cyanide), chlorine (Chloromethane) and many other elements giving rise to compounds with specific properties depending the elements present in the compound.



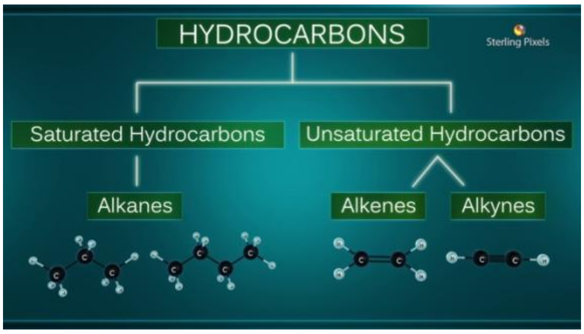
  (iv) The compounds formed are stable due to their strong bonds as a result of its small size which enables the nucleus to hold the shared pair of electrons firmly.

Hydrocarbons

The compounds which are majorly made of hydrogen and carbon atoms. Hydrocarbons are further classified as:

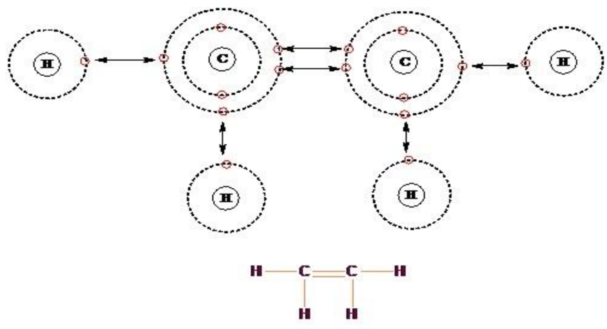
(i) **<u>Saturated Compounds</u>**: Saturated compounds are hydrocarbons in which hydrogen and carbon have <u>single bonds</u>. They are also known as Alkanes. (Formula: C_nH_{2n+2})

- Methane with a formula CH is one of the simplest compounds formed by carbon;
- This saturated compound is extensively used as a fuel and is one of the significant constituent of bio-gas a Compressed Natural Gas (CNG).



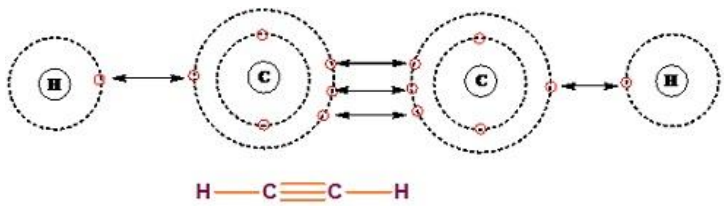
(ii) **<u>Unsaturated Compounds</u>**: Hydrocarbons in which hydrogen and carbon have double or triple bonds. hydrocarbons with <u>double covalent bonds are alkenes</u> and those with <u>triple covalent bonds are alkynes</u>. These compounds are more reactive than saturated carbon compounds.
(Formula: C_nH_{2n})
<u>Note</u>: Alkene does not exist with one carbon atom, thus, methene does not exist.

<u>For example</u>, Ethene (C_2H_4) is an alkene in which one carbon atom gets bonded to another carbon atom by a double bond. The remaining valencies of each carbon are satisfied by two hydrogen atoms.



ALKYNE Formula: C_nH_{2n-2}
<u>Note</u>: Minimum two carbon atoms are required to form alkyne.

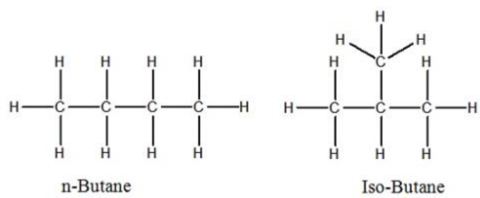
Ethyne (C_2H_2) is an alkyne in which one carbon atom gets bonded to another carbon atom by a double or triple bond. The remaining valency of each carbon is satisfied by one hydrogen atom.



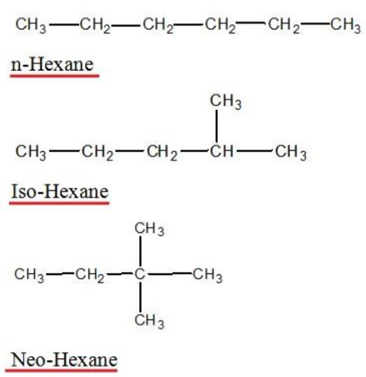
Structural Isomers

Compounds having same molecular formula but different molecular structures are known as structural isomers. Examples:

a) Structural isomers of butane →



b) Structural isomers of hexane →



Functional Group

- An atom or a group of atoms which when present in a compound gives specific properties to it, is called a functional group.
- A single line shown along with a functional group is called as its free valency by which it gets attached to a compound by replacing one hydrogen atom or atoms, e.g., -Cl.
- Functional group, replacing the hydrogen is also called as heteroatom because it is different from carbon, and can be nitrogen, sulphur, or halogen, etc.

Table . Some functional groups in carbon compounds.

Heteroatom	Functional group	Formula of functional group	Suffix
Cl/Br	Halo-(chloro/bromo)	—Cl, —Br	(Named as prefix)
Oxygen	1. Alcohols	—OH	—ol
	2. Aldehyde	—C(=O)H	— al
	3. Ketone	—C(=O)—	— one
	4. Carboxylic acid	—C(=O)—OH	— oic acid
	5. Esters	—C(=O)—OR	— oate
Nitrogen	1. Amino	$-NH_2$	(Named as prefix)
	2. Nitro	$-NO_2$	(Named as prefix)

Important: Replacement of hydrogen atom by a functional group is always in such a manner that valency of carbon remains satisfied.

Note:

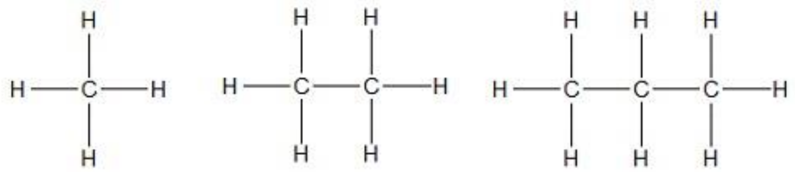
- Cl is named as prefix Chloro; Br as Bromo; NH_2 as Amino and NO_2 as Nitro.
- Symbol 'R' in a formula represents an Alkyl Group which is formed by the removal of one hydrogen atom from an alkane.

e.g., Alkane $\xrightarrow{-H}$ Alkyl Group

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

Homologous Series

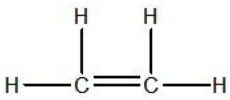
- A series of carbon compounds in which **same functional group substitutes the hydrogen atom** is called a homogeneous series.
- These compounds have similar chemical properties due to the addition of same kind of functional group throughout the chain. For example, the series of alkanes i.e. Methane, ethane, propane, butane and so on is a homologous series.



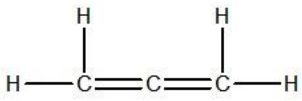
methane   ethane   propane

- Similarly, the series of alkene and alkynes also forms homologous series.

- Homologous series of alkenes are as follows:

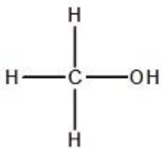


ethene

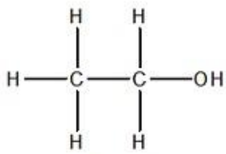


propene

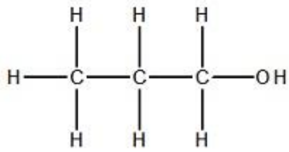
- Homologous series of alkynes are as follows:
- The series like methanol, ethanol, propanol, butanol and so on is also a homologous series. The functional group attached to these compounds is alcohol.



methanol



ethanol



propan-1-ol

- With the increase in molecular mass in a homologous series, the physical properties like melting points, boiling points and solubility in a particular solvent increase.
- But the chemical properties of a homologous series determined by the functional group remain same.

Steps to determine the Nomenclature of Carbon Compounds

(i) Identify the number of carbon atoms in the compound.

No. of carbon atoms	Term to be used
1	Meth
2	Eth
3	Prop
4	But
5	Pent
6	Hex
7	Hept
8	Oct
9	Non
10	Dec

(ii) If the compound contains a functional group, it is indicated in the name of the compound with either a prefix or a suffix:

Functional Group	Prefix (R-)/ Suffix(-R)	Example
Halogen	-chloro or – bromo	**Chloro**ethane/ **Bromo**ethane
	Depending upon the functional group added	
Alcohol	-ol	Ethanol
Aldehyde	-al	Ethanal
Ketone	-one	Ethanone
Carboxylic acid	-oic acid	Ethanoic acid

(iii) The functional group present in the compound is indicated as suffix by removing the "e" at the end and adding appropriate suffix as discussed in the table. For example, a two-carbon chain with an Aldehyde group would be named as:

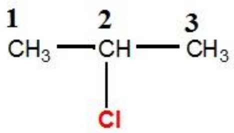
- Ethane – 'e' = Ethan + 'one' = Ethanone

FUNCTIONAL GROUPS	FORMULA
ALCOHOL	C – OH
ALDEHYDE	C = O H
KETONE	C = O
CARBOXYLIC ACID	C = O OH

(iv) In case of unsaturated carbon chain the final 'ane' in the name of the carbon chain is substituted by 'ene' for double bond or 'yne' for triple bond.

Functional Group	Prefix (R-)/ Suffix(-R)	Example
Alkane (Single bond)	-ane	Eth**ane**
Alkene (Double bond)	-ene	Eth**ene**
Alkyne (Triple bond)	-yne	Eth**yne**

For example –



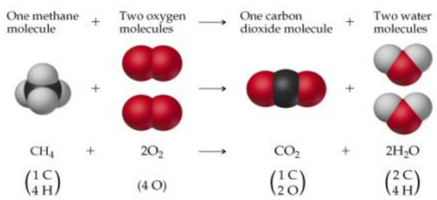
2-chloropropane

- Here number of carbon atoms = 3 with single bond, so the term to be used is "**propane**";
- The functional group added is Chlorine so the suffix to be used is "**chloro**";
- Position of chloro is second carbon so the IUPAC name of the given compound is **2-chloropropane**.

Chemical properties of Carbon Compounds

(i) **Combustion** - All the allotropic forms of carbon burn in the presence of oxygen releasing carbon dioxide along with heat and light. The chemical equation for the carbon compounds undergoing combustion are as follows:

- $C + O_2 \longrightarrow CO_2$ + heat and light
- C_2H_5 (Ethane) + $O_2 \longrightarrow CO_2 + H_2O$ + heat and light
- $C_5H_{12}OH$ (Pentanol) + $O_2 \longrightarrow CO_2 + H_2O$ + heat and light



a) Saturated hydrocarbons undergo combustion giving a clean flame. But in the presence of limited supply of air hydrocarbons produces a sooty flame as a result of incomplete combustion.

Examples:

- ♦ Gas stove at home has inlets for sufficient supply of oxygen and hence the mixture burns giving a clean blue flame the inlets get blocked the fuel remains unburnt and hence the bottom part of the cooking vessels gets blackened. Combustion of fossil fuels such as coal and petroleum containing nitrogen and sulphur leads to the formation of oxides of nitrogen and sulphur that acts as major pollutants in the environment.

- Take a gas stove having clean inlets for sufficient supply of oxygen. Burn the stove and heat a spoon. The spoon get a deposition of a black layer.

  Take another gas stove having blocked inlets and heat the spoon. Soon deposition of a black layer over the spoon can be easily observed due to insufficient supply of oxygen resulting in the production of unburnt carbon particles.

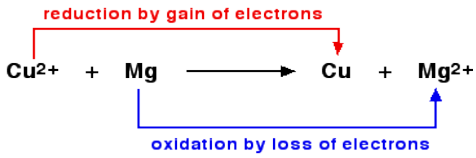
  Figure depicts that limited supply of air hydrocarbons produces a sooty flame and deposits black layer on the utensils.

b) Unsaturated hydrocarbons gives a yellow flame releasing an enormous amount of black smoke.

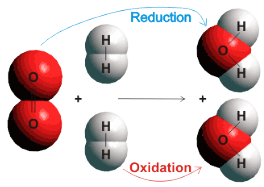
(ii) Oxidation

Carbon compounds gets readily oxidised on combustion. The following equation shows the conversion of alcohol carboxylic acid.

$$\underset{\text{Ethanol}}{CH_3CH_2OH} \xrightarrow[\text{or Acidified } K_2Cr_2O_7 + \text{Heat}]{\text{Alkaline } KMnO_4 + \text{Heat}} \underset{\text{Acetic Acid}}{CH_3COOH}$$

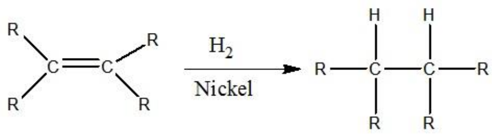


Alcohols can be converted to carboxylic acids by oxidizing them using alkaline potassium permanganate or acidified potassium di-chromate (they add oxygen to the reactant, thus are called oxidizing agents).



(iii) Addition Reaction

- During addition reaction an unsaturated hydrocarbon adds hydrogen to the reaction in the presence of catalysts.
- Catalysts such as palladium or nickel proceed a reaction to a different rate without affecting the reaction to give saturated hydrocarbons.

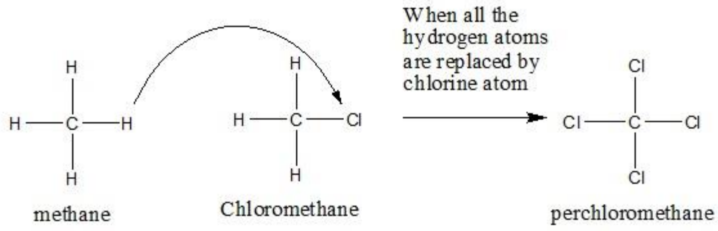


- This reaction is extensively used in the hydrogenation of vegetable oils containing long unsaturated carbon chains using a nickel catalyst.
- Animal fats on the other hand have saturated carbon chains.

(iv) Substitution Reaction

A reaction in which one functional group or atom is replaced by another functional group or atom is called substitution reaction.

In the presence of sunlight addition of chlorine to hydrocarbons is a fast reaction that results in replacement of the hydrogen atoms one by one. This is an example of substitution reaction because chlorine replaces the hydrogen to the carbon atom in the hydrocarbon.



Properties of Ethanol

- Ethanol exists in liquid state at room temperature;
- Mixture of alcohol to ethane results in the formation of ethanol and it is the active ingredient of all alcoholic drinks. Even a small quantity of ethanol if consumed can causes drunkenness.
- Being a good solvent, it is also used in medicines like tincture of iodine, cough syrups, and many other tonics.
- Reactions of Ethanol:
  - <u>Reaction with sodium</u> - Reaction of alcohols with sodium leads to the evolution of hydrogen. Reaction of sodium with ethanol the product along with hydrogen is sodium ethoxide.

$$\underset{\text{Ethanol}}{2Na + 2\,CH_3CH_2OH} \longrightarrow \underset{\text{Sodium Ethoxide}}{2CH_3CH_2ONa} + H_2$$

  - <u>Reaction to give unsaturated hydrocarbon</u> - Reaction of ethanol with excess concentrated sulphuric acid acting as dehydrating agent at 443 K results in the dehydration of Ethanol leading to the formation of Ethene.

$$\underset{\text{Ethanol}}{2CH_3CH_2OH} \xrightarrow[H_2SO_4]{\text{Hot Conc.}} \underset{\text{Ethene}}{2CH_2{=}CH_2} + H_2O$$

Properties of Ethanoic Acid

- Ethanoic acid commonly known as acetic acid belongs to a group of carboxylic acids;
- Vinegar used in our day to day life is a 5-8% solution of acetic acid in water. It is extensively used as a preservative in pickles;
- Pure ethanoic acid has a melting point of 290 K due to which it often freezes in cold climates giving rise to its name as glacial acetic acid;
- **<u>Esterification Reaction</u>**: Esters are produced as a result of the reaction of an acid such as ethanoic acid and an alcohol such as ethanol in the presence of an acid catalyst;

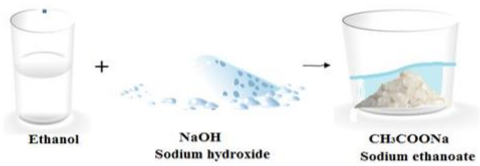
$$\underset{\text{Ethanoic Acid}}{CH_3COOH} + \underset{\text{Ethanol}}{CH_3CH_2OH} \xrightarrow{\textbf{Acid}} \underset{\text{Ester}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}OCH_2CH_3}$$

- Esters are sweet-smelling substances and used for various purposes like in perfumes and also used as flavouring agents;
- Reaction of ester with sodium hydroxide, results in the conversion of ester to alcohol and sodium salt of carboxylic acid;

$$CH_3COOC_2H_5 \xrightarrow{NaOH} C_2H_5OH + CH_3COONa$$

- The reaction above is known as saponification and is extensively used in the preparation of soap

- **Reaction with a base**: Ethanoic acid reacts with base leading to the production of salt and water. For example, it reacts with sodium hydroxide to give salt of sodium ethanoate or commercially known as sodium acetate and water. The reaction is as follows:



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

- **Reaction with carbonates and hydrogen carbonates**: Carbonates are salt of carbonic acid possessing carbonate ion, CO_2^{-3}. On the other hand Hydrogen carbonates are formed when CO_2 reacts with water.

$$CO_2\,(aq) + H_2O \longrightarrow H^+ + HCO_3^-$$

- Ethanoic acid reacts with carbonates and hydrogen carbonates leading to the production of salt, carbon dioxide and water. The salt produced is commonly known as sodium acetate.

$$2CH_3COOH + NA_2CO_3 \longrightarrow 2CH_3COONa + H_2O + CO_2$$
$$CH_3COOH + NaHCO_3 \longrightarrow CH_3COONa + H_2O + CO_2$$

Soaps and Detergents

Soaps and Synthetic Detergents : Soaps and detergents are substances used for cleaning.

Soaps are sodium or potassium salts of higher fatty acids, such as Oleic acid ($C_{17}H_{33}COOH$), Stearic acid ($C_{17}H_{35}COOH$), Palmitic acid ($C_{15}H_{31}COOH$), etc. These acids are present in the form of their esters along with glycerol (an alcohol containing three hydroxyl groups). These esters, called 'glycerides' are present in fats and oils of animal and vegetable origin.

Preparation of Soap: When an oil or a fat (glyceride) is treated with sodium hydroxide solution, it gets converted to sodium salt of the acid (soap) and glycerol. The reaction is known as saponification.

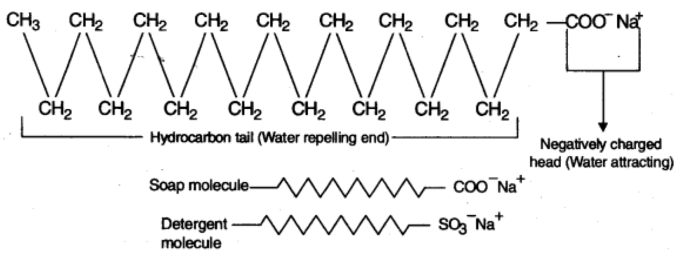
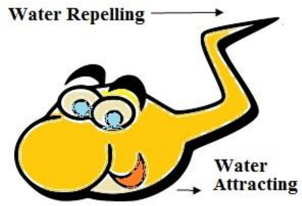
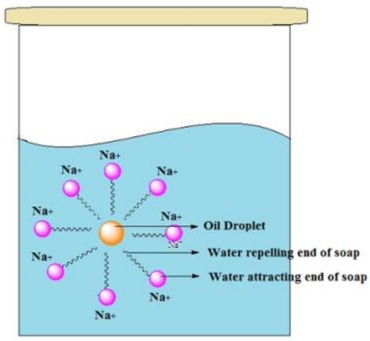


Fig. Long hydrocarbon chain.





- Dirt is oily in nature and hence does not dissolve in water;
- To removes these dirt we often use soaps that contains sodium or potassium salts of long-chain carboxylic acid;
- In soap the ionic-end is hydrophilic and hence dissolves in water;
- The end containing carbon chain is hydrophobic and hence dissolves in oil leading to the formation of structure called **micelles** that dissolves the dirt in water thereby making it easier to clean the clothes;
- This leads to the creation of emulsion in water;

- But in case of hard water it becomes difficult to form foam and the forms scum[1] with the salts of hard water. In case another kind of cleansing agent used is known as detergents.

Detergents : Chemically, detergents are sodium salts of sulphonic acids, i.e., detergents contain a sulphonic acid group (—SO_3H), instead of a carboxylic acid group (—COOH), on one end of the hydrocarbon. They are used to clean clothes in hard water and considered to be more effective than a soap.

- Hard water is the water containing calcium and magnesium carbonates. Soap forms lather with these carbonate salts thereby making it difficult to clean the clothes;
- The charged ends of detergent do not form scum or precipitates with the calcium and magnesium ions present in the hard water.
- Therefore they remain effective in cleaning dirt in hard water as compared to soap.

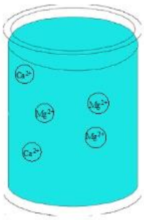
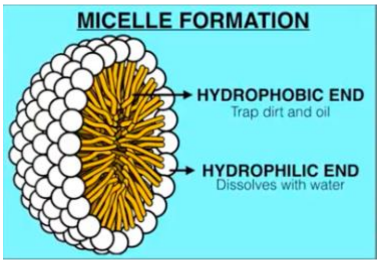


Figure - Ions present in hard water

Cleansing Action of Soaps and Detergents: The cleansing action of soaps and detergents follows the same principle. When a soap or detergent is dissolved in water, the molecules gather together as clusters, called micelles. The tails stick inwards and the heads outwards. In cleansing, the hydrocarbon tail attaches itself to oily dirt. When water is agitated, the oily dirt tends to lift off from the dirty surface and dissociates into fragments. This gives an opportunity to other tails to stick to oil. The solution now contains small globules of oil surrounded by detergent molecules. The negatively charged heads present in water prevent the small globules from coming together and form aggregates. Thus, the oily dirt is removed from the object.



[1] Scum: The insoluble precipitates formed by soap molecule when they react with calcium and magnesium ions present in hard water. Due to this, lot of soap gets wasted and cleansing action gets reduced to a larger extent.

SUMMARY
(Fig)

PROPERTIES AND VERSATILE NATURE OF CARBON

- Always forms covalent bonds
- Tetravalent
- Tetrahedral
- 3 allotropes – diamond, graphite and fullerenes
- Catenation – Unique property of self-linking of carbon atoms

Name of compounds	IUPAC Name
Alkene	Alkane – ane + ene = Alkene
Alkyne	Alkane – ane + yne = Alkyne
Haloalkanes	Halo + alkane = Haloalkane
Alcohols	Alkane – e + ol = Alkanol
Aldehydes	Alkane – e + al = Alkanal
Ketone	Alkane – e + one = Alkanone
Carboxylic acid	Alkane – e + oic acid = Alkanoic acid

CARBON AND ITS COMPOUNDS

Chemical properties of Carbon compounds

Combustion
Burning of carbon compound in air

Substitution
Replacement of an atom or a group of atoms in a organic molecule by another atoms or group of atoms

Addition
Addition of two reactants to form a single product

Oxidation
Addition of oxygen

Ethanol

- Colourless, distinct smell and burning taste, soluble in water in all proportions, neutral to litmus
- Reaction with sodium
  $2CH_3CH_2OH + Na \rightarrow CH_3CH_2ONa + H_2$
- Reaction with concentrated H_2SO_4
  $CH_3{-}CH_2{-}OH \xrightarrow[H_2SO_4]{Conc.} H_2C{=}CH_2 + H_2O$
- Combustion
  $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 2H_2O + Heat$

Soaps

- Sodium salts (or potassium salts) of the long chain carboxylic acids. The ionic group in soaps is $-COO^-Na^+$.
- Not suitable for washing purposes when water is hard.

Detergents

- Sodium salts of long chain benzene sulphonic acids. The ionic group in a detergent is $-SO_3^-Na^+$ or $-SO_4^-\ Na^+$.
- Can be used for washing even when the water is hard.

Ethanoic Acid

- Colourless, pungent smelling liquid, soluble in water in all proportions
- Reaction with sodium carbonate
  $2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + CO_2 + H_2O$
- Reaction with sodium hydrogen carbonate
  $CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + CO_2 + H_2O$
- Esterification $CH_3{-}\overset{O}{\overset{\|}{C}}{-}OH + H{-}OCH_2{-}CH_3 \xrightarrow[\Delta]{Conc.\ H_2SO_4} CH_3{-}\overset{O}{\overset{\|}{C}}{-}OCH_2CH_3 + H_2O$
- Hydrolysis $CH_3COOC_2H_5 \xrightarrow{NaOH} C_2H_8OH + CH_3COOH$