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Introduction

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Chapter 4: Carbon and its Compounds

Chapter 4: Carbon and its Compounds

Bonding in Carbon

Most carbon compounds are poor conductors of electricity. From the data melting points of the carbon compounds, we find that these compounds have low melting and boiling points as compared to ionic compounds. We can conclude that the forces of attraction between the molecules are not very strong. Since these compounds are largely non-conductors of electricity, we can conclude that the bonding in these compounds does not give rise to any ions.

Chapter 4: Carbon and its Compounds

Bonding in Carbon

Covalent Bond

A covalent bond is formed when pairs of electrons are shared between two atoms. It is primarily formed between two same nonmetallic atoms or between nonmetallic atoms with similar electronegativity.

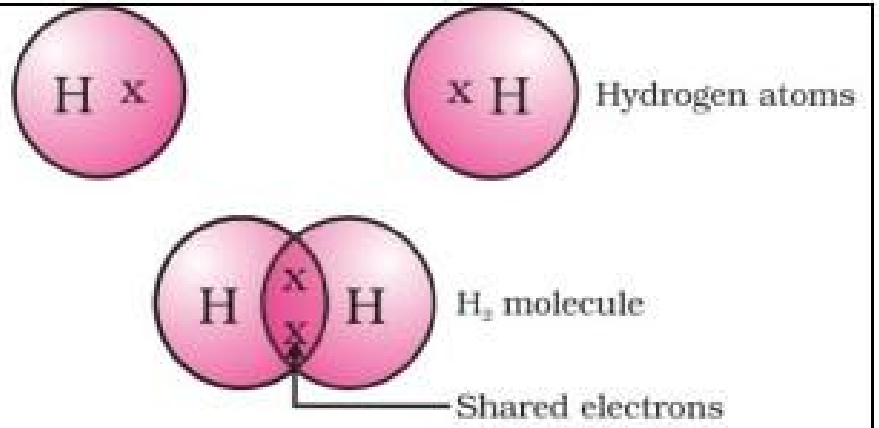
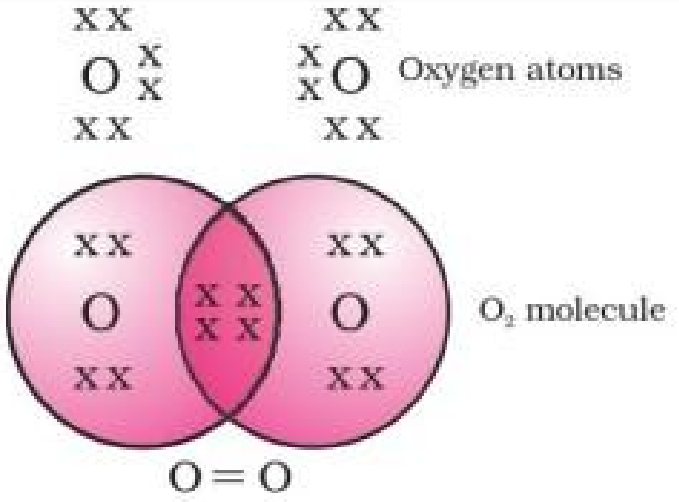
Chapter 4: Carbon and its Compounds

Noble gas configuration of Carbon

- Carbon is tetravalent, it does not form ionic bond by either losing four electrons (C4+) or by gaining four electrons (C4-). It is difficult to hold four extra electron and would require large amount of energy to remove four electrons. So, carbon can form bond by sharing of its electrons with the electrons of other carbon atom or with other element and attain noble gas configuration.
- The atoms of other elements like hydrogen, oxygen and nitrogen, chlorine also form bonds by sharing of electrons.

Chapter 4: Carbon and its Compounds

Noble gas configuration of Carbon

H – H single bond between hydrogen atoms (H2)	
O = O double bond between oxygen atoms (O2)	

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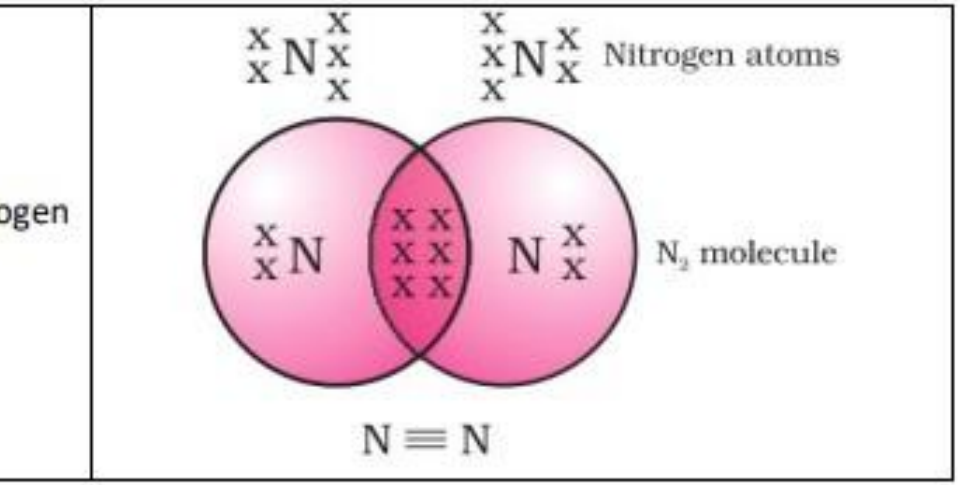
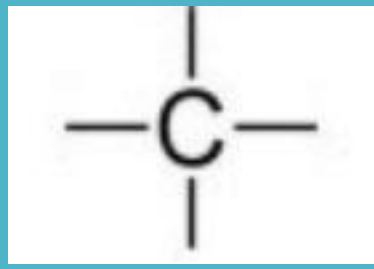
Noble gas configuration of Carbon

N ≡ N triple bond between nitrogen atoms	

Chapter 4: Carbon and its Compounds

Carbon atom has four electrons in its outermost shell.

- It requires four electrons to achieve the stable, 8 electron, inert gas configuration.
- Carbon atoms can achieve the inert gas electron arrangement only by sharing their electrons. Hence, carbon always forms covalent bonds.
- The valency of carbon is four since one carbon requires 4 electrons to achieve the nearest inert gas configuration. Thus, we can say that carbon is tetravalent.
- The four valencies of carbon are usually represented by drawing four short lines around the symbol of carbon (C).



Chapter 4: Carbon and its Compounds

Allotropes of Carbon

The various physical forms in which an element can exist are called the allotropes of that element. Carbon has three allotropes:

- Diamond
- Graphite
- Buckminster fullerene

Chapter 4: Carbon and its Compounds

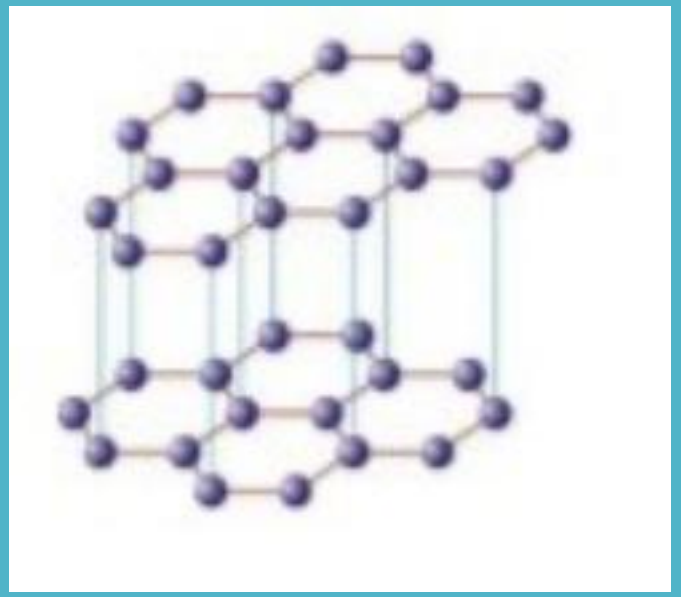
Diamond

- In diamond, each carbon atom is bonded to four other carbon atoms, forming a three dimensional structure.
- The rigid structure of diamond makes it a very hard substance.
- It is a non-conductor of electricity since there are no free electrons in a diamond crystal.
- It can be synthesised by subjecting pure carbon to a very high pressure and temperature.

Chapter 4: Carbon and its Compounds

Graphite

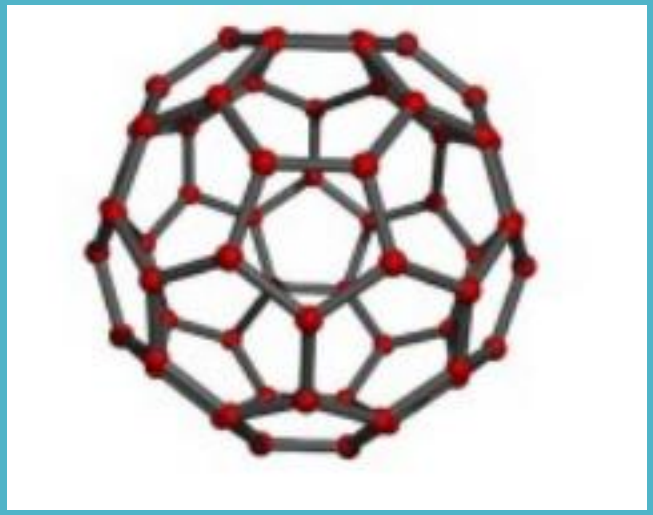
- In graphite, each carbon atom is bonded to three other carbon atoms in the same plane, giving a hexagonal array.
- One of the bonds is a double bond and thus the valency of carbon is satisfied.
- Graphite structure is formed by the hexagonal arrays being placed in layers, one above another.
- Graphite is smooth and slippery.
- It is a very good conductor of electricity due to the presence of free electrons.



Chapter 4: Carbon and its Compounds

Fullerene

- It is an allotrope of carbon containing clusters of 60 carbon atoms joined together to form spherical molecules.
- There are 60 carbon atoms in a molecule of buckminsterfullerene, so its formula is C60.
- The allotrope was named buckminsterfullerene after the American architect Buckminster Fuller.



Chapter 4: Carbon and its Compounds

Versatile Nature of Carbon

The two characteristic properties of the element carbon which leads to the formation of a very large number of organic compounds are:

i. Catenation: The property of the element carbon due to which its atoms can join one another to form long carbon chains is called catenation.

Types of Chains

a) Straight chain of carbon atoms

b) Branched chain of carbon atoms

c) Closed or ring chain of carbon atoms

Chapter 4: Carbon and its Compounds

Versatile Nature of Carbon

ii. Tetravalency: Carbon has a valency of four. So, it is capable of bonding with four other atoms of carbon or atoms of some other monovalent element.

Compounds of carbon are formed with oxygen, nitrogen, hydrogen, sulphur, chlorine and many other elements, giving rise to compounds with specific properties which depend on the elements other than the carbon present in the molecule.

Chapter 4: Carbon and its Compounds

Classification of Hydrocarbons

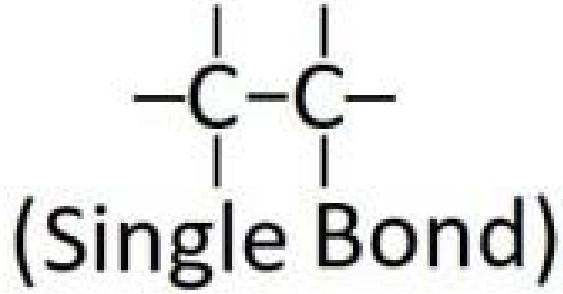
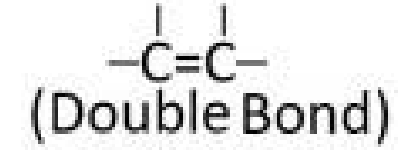
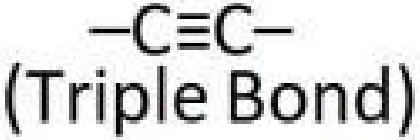
Comparison of Saturated and Unsaturated Hydrocarbons

Saturated hydrocarbons	Unsaturated hydrocarbons
1. All the four valencies of each carbon atom are satisfied by forming single covalent bonds with carbon and with hydrogen atoms.	1. The valencies of at least two carbon atoms are not fully satisfied by hydrogen atoms.

Chapter 4: Carbon and its Compounds

Classification of Hydrocarbons

Comparison of Saturated and Unsaturated Hydrocarbons

2. Carbon atoms are joined by a single covalent bond. 	2. Carbon atoms are joined by double covalent bonds.  or by triple covalent bonds. 
3. They are less reactive due to the non-availability or electrons in the single covalent bond, and therefore, they undergo substitution reaction.	3. They are more reactive due to the presence of electrons in the double or triple bond and therefore undergo addition reaction.

Chapter 4: Carbon and its Compounds

Classification of Hydrocarbons

Cyclic Hydrocarbons

- Hydrocarbons in which the carbon atoms are arranged in the form of a ring are called cyclic hydrocarbons.
- Cyclic hydrocarbons may be saturated or unsaturated.

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Classification of Hydrocarbons

Cyclic Hydrocarbons

Saturated cyclic hydrocarbon	Unsaturated cyclic hydrocarbon
• Cyclohexane is an example of a saturated cyclic hydrocarbon. • Formula: C_6H_{12} • Cyclohexane contains 6 carbon atoms arranged in a hexagonal ring, with each carbon atom attached to 2 hydrogen atoms.	• Benzene is an example of an unsaturated cyclic hydrocarbon. • Formula: C_6H_6 • Benzene is made up of 6 carbon atoms and 6 hydrogen atoms.

Chapter 4: Carbon and its Compounds

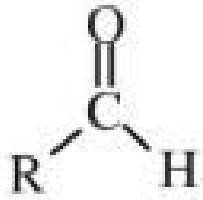
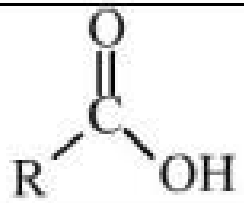
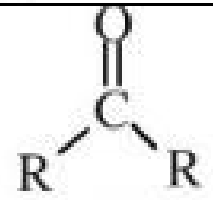
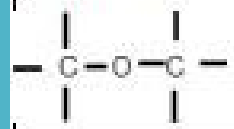
Functional Groups

- **Functional group: An atom or a group of atoms present in the molecules, which determines the characteristics property of the organic compounds, is called the functional group.**

Functional group	General formulae	Organic compound	Suffix	Examples with common & IUPAC name
Halide-X (F,Cl,Br,I)	R-X	Haloalkanes	-ane	CH_3Cl Common name: Methyl chloride IUPAC name: Chloromethane
Hydroxyl-OH	R-OH	Alcohols	-ol	C_2H_5OH Common name : Ethyl alcohol IUPAC name: Ethanol

Chapter 4: Carbon and its Compounds

Functional Groups

Aldehyde- CHO		Aldehydes	-al	CH_3CHO Common name: Acetaldehyde IUPAC name: Ethanal
Carboxyl- COOH		Carboxylic acids	-oic acid	$CH_3CH2COOH$ Common name: Propionic acid IUPAC name: Propanoic acid
Keto 		Ketones	-one	$CH_3COC_2H_5$ Common name: Diethyl ketone IUPAC name: Pentanone
Ethers 	R-O-R'	Ethers	-oxy	$CH_3 - O - C_2H_5$ Common name: Ethyl methyl ether IUPAC name: Methoxy ethane

Chapter 4: Carbon and its Compounds

Homologous Series

It is a group of organic compounds having a similar structure and chemical properties in which the successive compounds differ by a -CH2 group.

Characteristics of a Homologous Series

Each member of the series differs from the preceding one by the addition of a -CH2 group and by 14 a.m.u.

All members of a homologous series have the same general formula.

The physical properties of the members show a gradation in properties as their molecular mass increases.

All members of a homologous series can be prepared by the same general method of preparation.

Chapter 4: Carbon and its Compounds

Nomenclature of Carbon Compounds:

The system of designating a suitable name to a particular carbon compound based on certain rules is known as nomenclature. of the basic carbon chain modified by a “prefix” “phrase before” or “suffix” “phrase after” indicating the nature of the functional group.

Suffix: The suffix refers to the sort of bond or functional group that exists in the carbon chain.

Prefix: This indicates the presence and position of other functional groups

Chapter 4: Carbon and its Compounds

Nomenclature of Carbon Compounds:

Most carbon compounds have one of two names:

Trivial Names: The common names for carbon compounds are known as trivial names. They are typically derived from the compound's source, such as the name formic acid, which comes from the Greek term "formicus," which means "red ants." The names that came this way were unclear and repetitive.

Chapter 4: Carbon and its Compounds

Nomenclature of Carbon Compounds:

Most carbon compounds have one of two names:

IUPAC Names: As the number of carbon compounds increased, it became necessary to name them in a more methodical manner. The International Union for Pure and Applied Chemistry (IUPAC) proposed a system for naming carbon-based compounds with valid scientific names. The names derived from their rules are known all throughout the world and are referred to as IUPAC names.

Chapter 4: Carbon and its Compounds

Chemical Properties of Carbon Compounds

The majority of carbon-containing molecules connected with hydrogen, i.e. hydrocarbons, are fuels that emit heat when burned. Natural gas, petrol, gasoline, kerosene, heavy oils, and, more broadly, wood, biogas, charcoal, and coke are all rich sources of carbon molecules that are utilised as fuels.

Chapter 4: Carbon and its Compounds

Combustion

The process of burning a carbon compound in air to give carbon dioxide, water, heat and light is known as combustion.

Flame Characteristics: Saturated hydrocarbons give clean flame while unsaturated hydrocarbons give smoky flame. In the presence of limited oxygen, even saturated hydrocarbons give smoky flame.

For example:

$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) + \text{Heat and Light}$

Chapter 4: Carbon and its Compounds

Oxidation

Carbon undergoes oxidation when it meets oxygen at a higher temperature, resulting in the formation of oxides such as carbon monoxide (CO) and carbon dioxide (CO2). When carbon or carbon-containing fuels are burned incompletely, carbon monoxide is produced.

Chapter 4: Carbon and its Compounds

Oxidation

We see that some substances are capable of adding oxygen to others. These substances are known as oxidising agents.

Alkaline potassium permanganate or acidified potassium dichromate are oxidising alcohols to acids, that is, adding oxygen to the starting material. Hence they are known as oxidising agents.

Carbon compounds can be oxidised.

Alcohols on oxidation are converted to carboxylic acids.

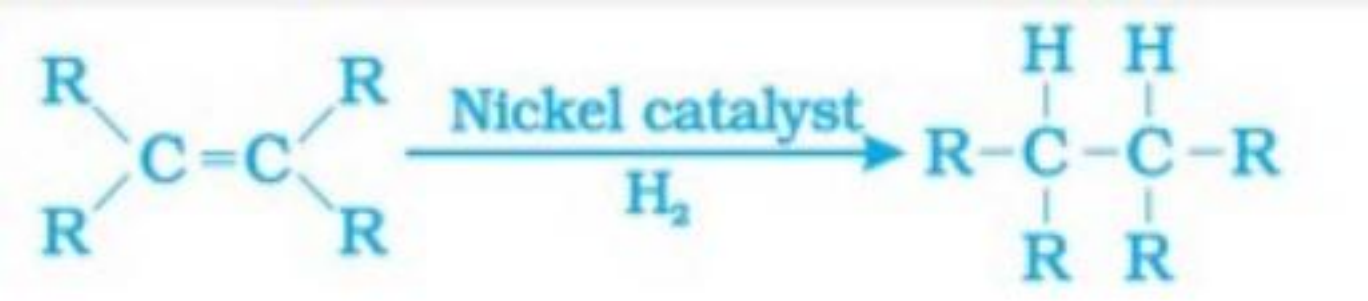
Alkaline $KMnO_4$ or acidified $K_2Cr_2O_7$ are used as oxidising agent

Chapter 4: Carbon and its Compounds

Addition Reaction

Addition reactions are those in which an unsaturated hydrocarbon reacts with another chemical to generate a single product.

Unsaturated hydrocarbon add hydrogen in the presence of catalyst palladium or nickel. Vegetable oils are converted into vegetable ghee using this process.



Chapter 4: Carbon and its Compounds

Addition Reaction

This reaction occurs only in unsaturated compounds, where there are double or triple bonds.

The addition of hydrogen to an unsaturated hydrocarbon to obtain a saturated hydrocarbon is called hydrogenation.

The process of hydrogenation is used in industries to prepare vegetable ghee (or vanaspati ghee) from vegetable oils.

Chapter 4: Carbon and its Compounds

Substitution Reaction

The reaction in which an atom or group of atoms in a molecule is replaced or substituted by different atoms or group of atoms is called substitution reaction. In alkanes, hydrogen atoms are replaced by other elements.

$CH_4 + Cl_2 + \text{Sunlight} \rightarrow CH_3Cl + HCl$

The reaction in which one or more hydrogen atoms of a hydrocarbon are replaced by atoms of other elements is called a substitution reaction.

Substitution reactions are a characteristic property of saturated hydrocarbons.

Chapter 4: Carbon and its Compounds

Some Important Carbon Compounds – Ethanol & Ethanoic Acid

Properties of Alcohols

Reaction with Sodium: Sodium reacts steadily with ethanol to form sodium ethoxide along with the evolution of hydrogen gas.

$2C_2H_5OH + 2Na \rightarrow 2C_2H_5ONa + H_2 \uparrow$

Ethanol Sodium Sodium ethoxide Hydrogen

Dehydration: Ethanol, on heating with excess of conc. H_2SO_4 at 170°C gets dehydrated to form ethene.

Chapter 4: Carbon and its Compounds

Some Important Carbon Compounds – Ethanol & Ethanoic Acid

Reactions of Ethanoic acid

Esterification: Ethanoic acid reacts with alcohols in the presence of a little conc. sulphuric acid to form esters.

The ester, on treating with a base such as NaOH is converted back to alcohol and sodium salt of carboxylic acid. This reaction is known as saponification because it is used in the manufacture of soap.

$CH3COOC2H5 + NaOH \rightarrow C2H5OH + CH3COONa$

Chapter 4: Carbon and its Compounds

Some Important Carbon Compounds – Ethanol & Ethanoic Acid

Reaction with a base: Ethanoic acid reacts with a base such as sodium hydroxide to form a salt and water.

$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

Acetic acid Sodium acetate Water

Reaction with Carbonates & bicarbonates: Acetic acid reacts with carbonates and bicarbonates to form salt, water and carbon dioxide.

$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$

Acetic acid Sodium acetate

$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$

Acetic acid Sodium acetat

Chapter 4: Carbon and its Compounds

Soaps & Detergents

The molecules of soap are sodium or potassium salts of long-chain carboxylic acids. The ionic-end of soap interacts with water while the carbon chain interacts with oil. The soap molecules, thus form structures called micelles where one end of the molecules is towards the oil droplet while the ionic-end faces outside. This forms an emulsion in water. The soap micelle thus helps in pulling out the dirt in water and we can wash our clothes clean.

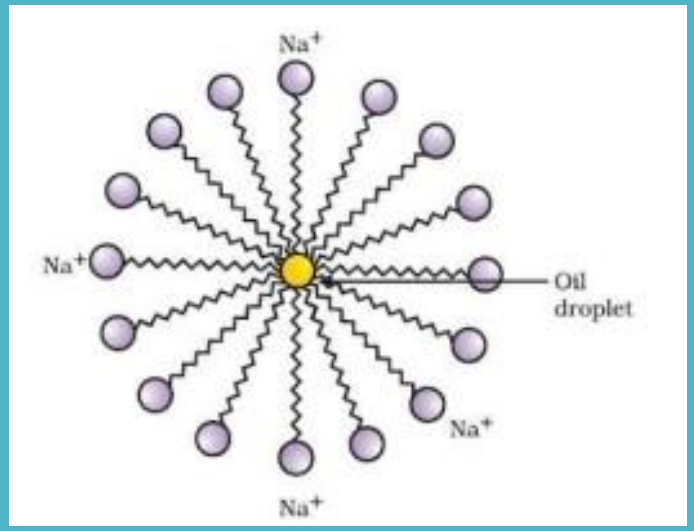
Chapter 4: Carbon and its Compounds

Micelles

Soaps are molecules in which the two ends have differing properties, one is hydrophilic, that is, it interacts with water, while the other end is hydrophobic, that is, it interacts with hydrocarbons. When soap is at the surface of water, the hydrophobic ‘tail’ of soap will not be soluble in water and the soap will align along the surface of water with the ionic end in water and the hydrocarbon ‘tail’ protruding out of water. Inside water, these molecules have a unique orientation that keeps the hydrocarbon portion out of the water. Thus, clusters of molecules in which the hydrophobic tails are in the interior of the cluster and the ionic ends are on the surface of the cluster. This formation is called a micelle.

Chapter 4: Carbon and its Compounds

Micelles



Soap in the form of a micelle is able to clean, since the oily dirt will be collected in the centre of the micelle. The micelles stay in solution as a colloid and will not come together to precipitate because of ion-ion repulsion. Thus, the dirt suspended in the micelles is also easily rinsed away. The soap micelles are large enough to scatter light. Hence a soap solution appears cloudy.

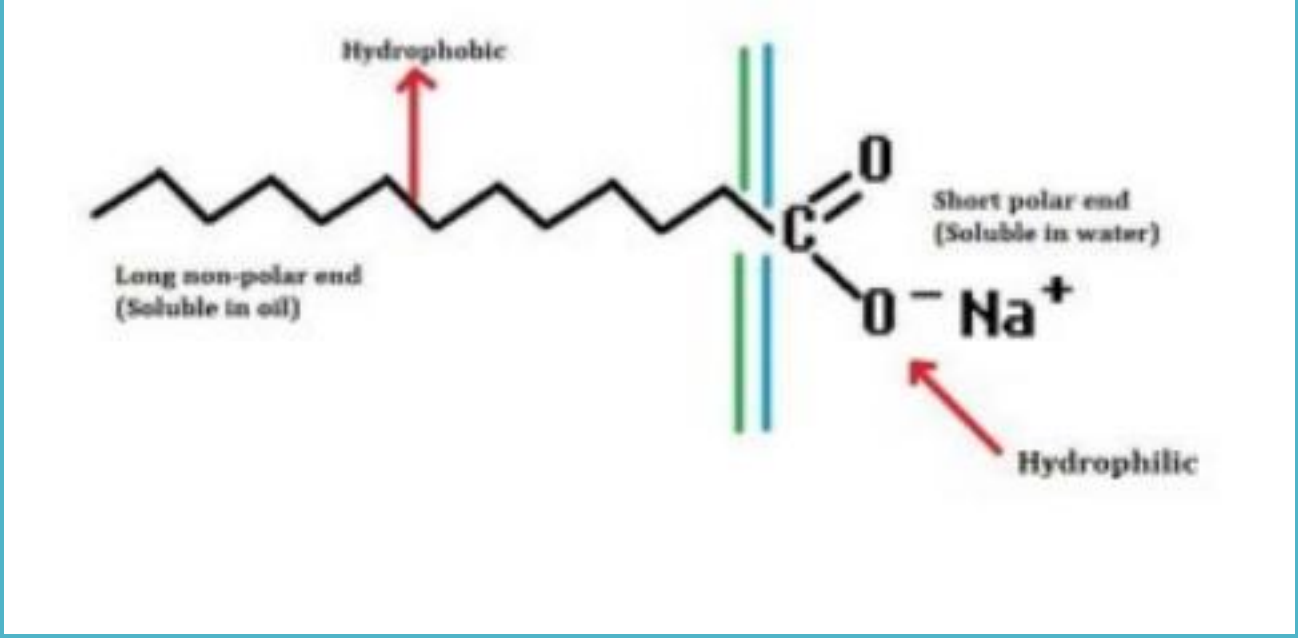
Chapter 4: Carbon and its Compounds

Micelles

- Soaps are cleansing agents capable of reacting with water and dislodging the unwanted particles from clothes or skin.
- The molecules of soap are sodium or potassium salts of long chain carboxylic acids.
- A soap molecule has a tadpole shaped structure.
- At one end (long non-polar end) of the soap molecule is a hydrocarbon chain which is insoluble in water but soluble in oil.
- At the other end (short polar end) of the soap molecule, there is a carboxylate ion which is hydrophilic i.e. water soluble but insoluble in oil.

Chapter 4: Carbon and its Compounds

Micelles



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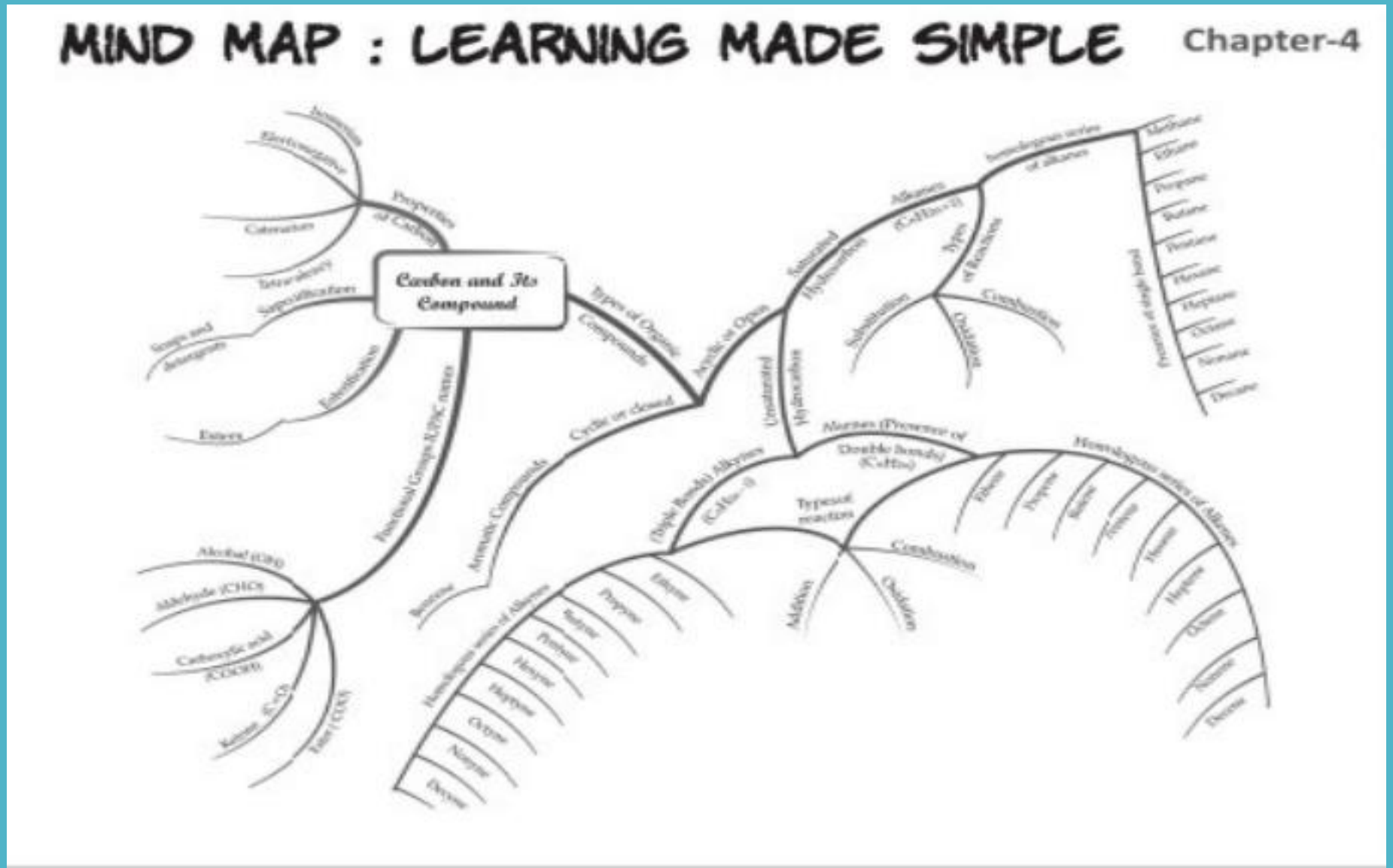

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