ORGANIC CHEMISTRY

This is a branch of chemistry concerned with study of carbon compounds except oxides of carbon, carbonates and hydrogen carbonates.

Carbon forms a wide range of compounds and it is for this reason that its compounds form a full branch of chemistry called organic chemistry.

Carbon's ability to form a large number of compounds is due to the fact that:

I. Carbon forms four covalent bonds hence can bond to different atoms/groups of atoms.
II. Carbon can form single or double or tripple bonds to itself.

Organic compounds are divided into different groups called **homologous series**

Dfn:**A homologous series** is a group of organic compounds with the same functional group and are related to each other by the same general formula.

The members of each homologous series:

I. differ from the next by methylene($-CH_2$) group.
II. Have similar chemical properties
III. Show a particular pattern of change in physical properties

Dfn: A functional group is an atom or group of atoms or bonds which determines the chemical properties of compounds in homologous series.

The table below shows examples of homologous series, their functional groups and their general formula

Homologous series	Functional group	General formula
Alk**an**es	C – C (single bond)	$C_n H_{2n+2}$
Alk**en**es	C=C (double bond)	$C_n H_{2n}$
Alk**yn**es	C≡C (triple bond)	C_nH_{2n-2}
Alcohols	-OH (hydroxyl group)	$C_nH_{2n+1}OH$
Carboxylic acids	-COOH (carboxyl group)	$C_nH_{2n+1}COOH$

- A large number of organic compounds is made up of carbon and hydrogen <u>only</u>. These are called **hydrocarbons**.

Hydrocarbons

A hydrocarbon is an organic compound that contains carbon and hydrogen **<u>only</u>**.

Hydrocarbons have a molecular formula, C_xH_y, where x and y are whole numbers.

There are three main types of hydrocarbons. These include:

1. Alkanes
2. Alkene
3. Alkynes

In hydrocarbons, carbon atoms may be bonded to each other by single or double or triple bonds.

Saturated and unsaturated organic compounds

- **A saturated compound** is one in which **all** carbon atoms are bonded to each other by single bonds. Each carbon is bonded to four other atoms and

therefore carbon exerts its normal valency (combining power). **Alkanes** are the only hydrocarbons which are saturated.

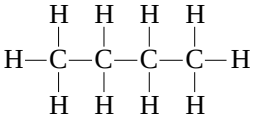
- **An unsaturated compound** is one with **at least a double bond or triple** bond between **any two carbon** atoms. Hydrocarbons which are unsaturated are alkenes (with at least a double bond) and alkynes (with at least a triple bond)

Molecular and structural formula of an organic compound

- A molecular formula is one that shows the elements present in a compound in their correct ratio/proportion.
- **A structural formula** is a formula that shows how atoms are arranged in an organic. For example: the organic compound butane has;

(i) Molecular formula - C_4H_{10} (four carbon atoms and 10 hydrogen atoms) and

(ii) Structural formula; **$CH_3CH_2CH_2CH_3$ or (using stick diagram)**



Check point: Have you understood?

Write the structural formula of the following organic compounds:

I. C_2H_6
II. C_3H_8

1. ALKANES

These are hydro carbons which have only single bonds between all carbon atoms. They have a general formula $C_2\ H_{2n+2}$, Where n=1,2,3,4,

The table below shows the first four alkanes:

Number of Atoms (n)	Molecular formula	Structural formula	Name
1	CH_4	CH_4	Methane
2	$C_2\ H_6$	CH_3CH_3	Ethane
3	$C_3\ H_8$	$CH_3CH_2CH_3$	Propane
4	$C_4\ H_{10}$	$CH_3CH_2CH_2CH_3$	Butane

Think!!!

What do you think is the name, molecular formula and structural formula of the fifth alkane?

NB:

- Removal of one hydrogen atom from an alkane molecule leaves a group called an alky radical/group. For example:

Alkane	**One hydrogen removed**	**Name of alkyl group formed**
CH_4 (methane)	CH_3-	methyl group
CH_3CH_3 (ethane)	CH_3CH_2-	ethyl group

Isomerism in alkanes.

- Isomerism is the existence of two or more compounds with the same molecular formula but different structural formulae.

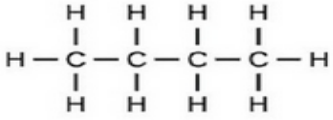
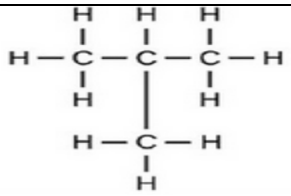
Compounds which exhibit isomerism are called isomers.

Isomers are compounds with the same molecular formula but different structural formulae. The first three alkanes have no isomers but rest have isomers.

Example: Butane has four carbon atoms. These can be joined in two ways:

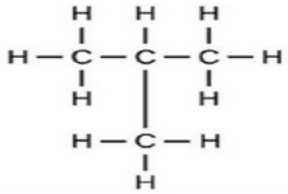
(i) An unbranched chain of four carbon atoms or

(ii) A branched chain having the fourth carbon atom joined to the middle of hthree other atoms.

Isomer	Molecular formula	Structural formula	Name
1. Unbranched isomer	C_4H_{10}		Butane
2. Branched isomer	C_4H_{10}		2-methylpropane

Rules followed in naming alkanes.

1. Given the structural formula of the alkane, select the longest straight chain and name it. This is called the parent chain. E.g isomer 2 in the table above has structure:

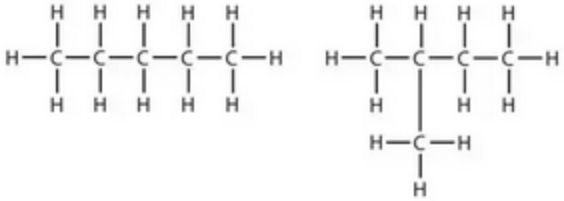


The number of carbon atoms in the longest straight chain is 3, hence the parent name of the alkane is **propane.**

2. Identify any branch attached to the parent structure and name it. In the above example it is a methyl group(-CH_3).

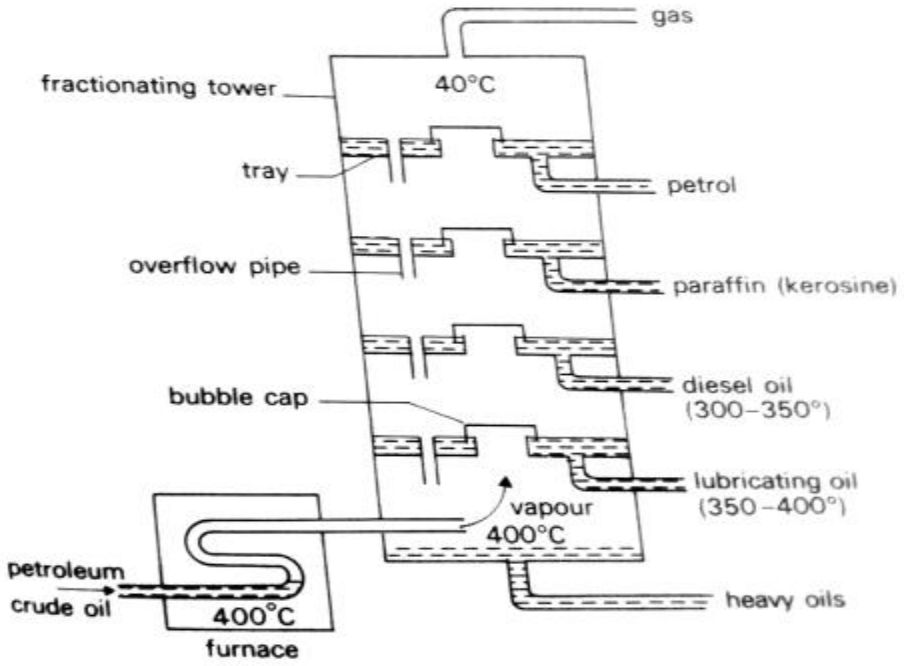
3. Next you have to state the position of the side group. To do this, number the carbon atoms in the straight chain from both sides, starting from 1. For the above example, the methyl group is on carbon atom number 2 (whether you count from left or from the right). For an alkane with a straight chain longer than 3 carbon atoms, the side chain is given the smaller position when the carbon atoms are numbered from either sides. Therefore, the name of the alkane with the structure in the example above is 2-methylpropane (the figure is separated a letter by a hyphen)

Using the above rules, name the following isomers of pentane:



Isolation of alkanes from petroleum (crude oil)

- Petroleum is a mixture of many alkanes which are separated by fractional distillation because they have different boiling points.
- It is first heated at the bottom of the fractionating tower until it vapourizes.
- Up the fractionating tower, the temperatures keep on decreasing. Therefore the most volatile component is collected at top of the tower.



Uses of the components (fractions) from petroleum.

Fraction/component	Distilling temperature in	Uses
Natural gas	Below 40	Heating and lighting
Petrol oil	40-175	Motor and aviation fuel
Paraffin/kerosine	175-250	Heating and Lighting
Diesel oil	300-350	Motor fuel (diesel engine)
Lubricating oil	350-400	Lubrication of machine parts
Waxes	Above 400	Making Vaseline, greases, candles etc
Bitumen	Above 400	Road construction

CRACKING OF OILS

- This is a process by which large molecules of alkanes are broken into smaller molecules of petrol and gases.
- **In thermal cracking**, the larger alkanes are heated under pressure and the resulting liquid mixture is separated by fractional distillation
- **In catalytic cracking**, the larger alkanes are heated at a lower temperature and pressure but in presence of a catalyst to form the smaller alkanes and other gaseous products.

Properties of alkanes.

- The lower members (methane, ethane, propane and butane) are gases at room temperature.
- Their boiling points increase with increasing size of their molecules (number of carbon atoms).
- They are insoluble in water.

- Their melting and boiling points increase with the increase in the relative molecular mass.
- Alkanes are unreactive. Their most important reaction id combustion (burning in air/oxygen).

- On complete combustion (when oxygen supply is enough), they burn with a blue flame forming carbondioxide and water (steam) e.g $CH_4(g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2\ O\ (g)$
- In limited oxygen, they burn with a luminous yellow flame and form carbonmoxide, carbon and water (steam)
  $2CH_4\ (g) + 3O_2\ (g) \longrightarrow 2CO\ (g) + 4H_2\ O\ (g)$
  $CH_4\ (g) + O_2\ (g) \longrightarrow C\ (s) + 2H_2\ O\ (g)$
- The yellow zone of the flame is due to formation of carbon particles which glow with a yellow colour when heated.

Uses of alkanes.

- They are used as fuels since they burn. Methane occurs in natural gas and coal gas which are used as fuels.

ALKENES

Alkynes are hydrocarbons with at least a double bond between any two carbon atoms. They have a general formula, C_nH_{2n}, where $n \geq 2$. They contain carbon-carbon double bond ($-\ C \equiv C\ -$) as the functional group. They **are unsaturated compounds**

The alkynes are named by dropping the ending 'ane' of the corresponding alkane and replacing it with the suffix 'ene'. Examples

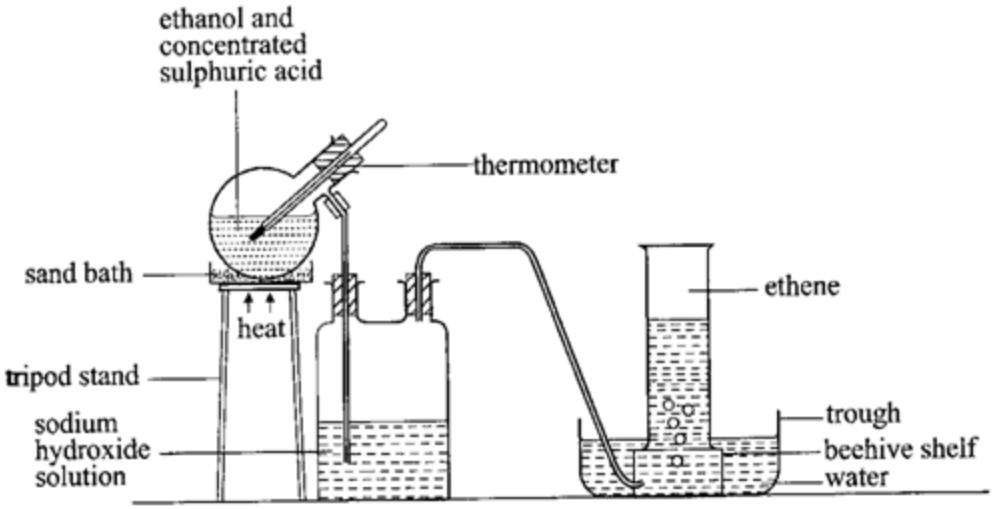
Number of carbon atoms	**Alkene**	**Molecular formula**	**Structure (discuss with stds)**
2	Ethene	C_2H_4	
3	Propene	C_3H_6	
4	Butene	C_4H_8	

- Ethene is the most important alkene and it is a gas at room temperature.

Laboratory preparation of ethene

- ✓ Ethene is obtained by dehydration of ethanol by excess hot concentrated sulphuric acid.
- ✓ The mixture is heated with care to about 180°C.
- ✓ Ethene is evolved and is passed through a bottle containing sodium hydroxide solution to remove sulphur dioxide which is a by-product of the reaction.
- ✓ Ethene is collected over water since it is insoluble in water.

$CH_3CH_2OH(1) \rightarrow CH_2=CH_2(g) + H_2O(g)$
Set up:



(please insert a connector on the delivery tube)

Properties of ethene
Physical properties
(i) Ethene is a colourless, sweet smelling and non-poisonous gas.
(ii) It is slightly less dense than air.
(iii) It is insoluble in water but soluble in organic solvents.

Chemical properties

1. **Combustion: like any other hydrocarbon, e**thene burns in air and the products of complete combustion are carbon dioxide and steam.
   $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$

2. **Addition reactions; I**n these reactions, the double bonds converted to single bonds by addition of other atoms such as hydrogen, chlorine or bromine. Examples

(i) Reaction with /addition of bromine atoms

When ethene gas is passed through liquid bromine or bromine water (reddish brown), the liquid becomes colourless. Eqn:

$$\mathbf{CH_2{=}CH_2(g) + Br_2(l) \rightarrow BrCH_2CH_2Br(l)}$$

Ethene **1,2-dibromoethane**

Or if bromine water is used;

$$\mathbf{CH_2{=}CH_2(g) + HOBr(aq) \rightarrow Br^{-}CH_2CH_2OH(aq)}$$

NOTE: **All** unsaturated compounds behave in the same way. For this reason, bromine water/liquid bromine is used to distinguish between saturated compounds such as alkanes (e.g ethane) and unsaturated ones such as alkenes (e.g ethene) and alkynes (e.g ethyne)

The reaction is more efficient when bromine is dissolved in an organic solvent such as tetrachloro methane (CCl_4).

ii) Reaction with/addition of hydrogen

Ethene combines with hydrogen if the two are passed over nickel catalyst at about 150^{o}C or. platinum catalyst at room temperature. The reaction is called **catalytic hydrogenation.**

$$CH_2{=}CH_2(g) + H_2(g) \rightarrow CH_3CH_3\ (g)$$

Ethene ethane

Note: liquid vegetable oils contain unsaturated organic compounds and can be converted to solid fats by bubbling hydrogen though them. This is applied in margarine production. The hardening of liquid vegetable oils into solid fats is called **addition hydrogenation.**

(3) Ethene decolourises acidified potassium permanganate solution (from purple to colourless). This reaction is also used to distinguish between alkenes (unsaturated compound) and alkanes (saturated compounds).

Uses of ethene

1. In the manufacture of plastics such as polyethene.
2. In the manufacture of ethanol.
3. In the process of ripening of fruits.

Exercise

1. The compound with the molecular formula $C_{10}H_{22}$ can undergo the following reaction:
   $C_{10}H_{22} \rightarrow C_8H_{18} + W$
   (a) Name the process involved in this reaction.
   (b) To which hydrocarbon series does W belong?

(c) Name gas W.
(d) Write the equation for complete combustion of gas W.
(e) Gas W was bubbled through
    (i) Bromine.
    (ii) Bromine water.
(f) Write the equation for the reaction that took place in e(i) and (ii).
(g) Name the product formed in e(i)

2. Two hydrocarbon compounds are represented by the molecular formulae, C_3H_6 and C_3H_8
   (a) To which hydrocarbon series does each of them belong?
   (b) Give the name of each compound.
   (c) Describe any chemical test that can be used to distinguish between the two compounds.
   (d) Which one of the compounds is unsaturated?
   (e) The unsaturated compounds named in (d) was reacted with hydrogen under certain conditions.
       (i) State the conditions necessary for the reaction to take place.
       (ii) Name the type of reaction.
       (iii) State one industrial application of the type of reaction named in (ii

Alkynes

Alkynes are hydrocarbons with at least a triple bond between any two carbon atoms. They have a general formula, C_nH_{2n-2}, where $n \geq 2$. They contain carbon-carbon triple bond (– C ≡ C –) as the functional group. They are unsaturated compounds

The alkynes are named by dropping the ending 'ane' of the corresponding alkane and replacing it with the suffix 'yne'. Examples

Number of carbon atoms	**Alkyne**	**Molecular formula**	**Structure**
2	Ethyne	C_2H_2	
3	Propyne	C_3H_4	
4	Butyne	C_4H_6	

Ethyne is the most important alkyne is a colourless, odourless and sweet smelling gas.

Exercise

Two hydrocarbon compounds, Q ans Z, are represented by the molecular formula

C_5H_{12} ans C_3H_4 respectively.

(a) Give the name of each hydrocarbon.
(b) To which homologous series does each of them belong?
(c) Which hydrocarbon contains multiple bonds?
(d) Write the equation for complete combustion of Z.
(e) Name the products of incomplete combustion of Z.

ALCOHOL

Alcohols have a general formula, $C_nH_{2n+1}OH$. The functional group of the alcohols is the **hydroxyl group** (-OH).

Nomenclature: The name of a particular member is obtained by dropping the ending ' e' of the corresponding alkane and replacing it with the suffix ' o1' .
E.g

Number of carbon atoms	**Molecular formula**	**Name**	**Structural formula**
1	CH_3OH	Methanol	
2	C_2H_5OH	Ethanol	
3	C_3H_7OH	Propanol	

- The most important alcohol is **ethanol**

Manufacture of ethanol on a large scale inindustries.

Ethanol is prepared by <u>fermentation of sugars in the presence of yeast.</u>

Fermentation is a process in which sugars are decomposed by enzymes into alcohol.

Manufacture of ethanol in industries

- ✓ Cassava or sweet potatoes are crushed and heated in steam under pressure to extract starch.
- ✓ The starch obtained is mixed with malt (partially spouted barley) for an hour at 60°C.
- ✓ Malt supplies an enzyme called diastase, which hydrolyses/breaks down starch to maltose. Eqn:

$$\underset{\text{starch}}{2C_6H_{10}O_5(aq)} + H_2O(1) \rightarrow \underset{\text{maltose}}{C_{12}H_{22}O_{11}(aq)}$$

- ✓ Yeast is then added. One of its enzymes called **maltase**, catalyses the hydrolysis/breakdown of maltose to glucose.

$$C_{12}H_{22}O11(aq) + H_2O(1) \rightarrow \underset{\text{glucose}}{2C_6H_{12}O_6(aq)}$$

- ✓ Another enzyme present in yeast called **zymase**, catalyses the decomposition of glucose to ethanol and carbon dioxide.

$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH\ (aq) + 2CO_2(g)$

NOTE: The resulting solution is crude ethanol which is converted to pure ethanol by fractional distillation.

Making local brew in Uganda

PARTICIPATE ALSO!!!! Outline the names used in your locality for local brew.

Local brew can be made from ripe bananas, sorghum and millet.

Local brew from bananas and sorghum:

The ripe bananas are peeled and squeezed with dry banana leaves or spear grass to obtain the juice.
The juice is then filtered to remove solid particles
The juice is mixed with ground roasted sorghum, covered in a container and left in a cool place.
The lleft for sometime (3-4) days for fermentation to occur and obtain crude ethanol.

From millet

Millet is ground and the resulting flour mixed with water to form a paste.
Yeast is then added to the paste and the mixture covered.
The mixture is left to ferment for 2-4 days to obtain crude ethanol.

Note: in both procedures above, the ethanol obtained is crude but it can be made more pure by distillation.

Think!!!

1. Suggest one way of determining whether the ethanol is pure or not (ans: determining its boiling point, pure ethanol boils at 78°C)
2. Give the name you use for local brew in your locality (names vary from tribe to tribe)

3. Name the uses of ethanol (brain storm with students)

- Making ethane gas
- Manufacture of perfumes
- Manufacture of drugs
- Making alcoholic drinks such as beer, wines and spirits.
- Ethanol is used as a fuel.
- As a solvent for vanishes, paints etc

Properties of ethanol

(i) Ethanol is a colourless liquid with a burning taste. It is soluble in water. It is a **hygroscopic** substance.

(ii) Combustion; Ethanol burns in air with a blue flame to give carbon dioxide and water. The reaction is exothermic. (lab demonstration)

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

(iii) Dehydration of ethanol ; When excess concentrated sulphuric acid is added to ethanol and the mixture heated to 180°C , ethanol is dehydrated (water is removed) to form ethene gas

$$C_2H_5OH(l) \rightarrow C_2H_4(g) + H_2O(l)$$

PREP Exercise

1. When ethanol reacts with concentrated sulphuric acid, a hydrocarbon T is formed.

   (a) Give the name of the hydrocarbon T.

   (b) To which homologous series does the hydrocarbon T belong?

   (c) State the conditions necessary for the reaction to take place.

   (d) Name the type of reaction that occurs.

Carboxylic acids

This is a group of organic compounds which contain the functional group, COOH. They are represented as RCOOH where R is either hydrogen or alkyl group. For example:

R group	Formula	Name
H-	HCOOH	Methanoic acid
CH_3-	CH_3COOH	Ethanoic acid.

Uses of carboxylic acids:

- Long chain carboxylic acids are used in making soap. They are obtained from vegetable oils and animal fats in form of organic compounds called esters.

SOAPS AND DETERGENTS.

Soap

Soap is a sodium or potassium salt of long chain carboxylic acids (e.g stearic acid). There are two types of soap:

- Sodium soap also called sodium stearate (RCOONa / Nast)
- Potassium soap also called potassium stearate. (RCOOK/Kst))

In each case, R is along chain alkyl group.

Manufacture of soap

Saponification: This is a process by which soap is made by heating vegetable oils or animal fats with concentrated sodium hydroxide or potassium hydroxide.

The sources of vegetable oils include:

- Sunflower seeds, cotton seeds, sim-sim, G-nuts.

Sources of animal fats include,

- lard, skimmed milk, ghee etc

Procedure of soap making:

- ✓ Vegetable oils e.g .. or animal fat are boiled with concentrated sodium hydroxide until a froth is formed.
- ✓ Concentrated solution of sodium chloride (brine) is added to the mixture to precipitate out soap from solution.
- ✓ The precipitate (soap) floats on top of the liquid which is skimmed off/ removed and processed into bars.
- ✓ Other ingredients like colour, fragrance etc may be added during the process to increase the value of soap.

CLEANSING ACTION OF SOAP (How does soap work?)

- ✓ Soap dissolves in water and its molecules spread in water. The soap molecules have a polar end that is attracted to water (hydrophilic) and a non-polar end that is repelled by water but is attracted and dissolves in the dirt /grease particle on the cloth.
- ✓ On agitation or rubbing, the dirt particle is broken up and lifted off the fabric/cloth into water.

NOTE: if water is hard, soap will first react with the calcium ions or magnesium ions and form scum (insoluble calcium stearate/magnesium stearate) i.e

$CaSO_4(aq) + 2Nast(aq) \longrightarrow CaSt_2(s) + Na_2SO_4(aq)$

$Ca^{2+}(aq) + 2Nast(aq) \longrightarrow CaSt_2(s) + 2Na^{+}(aq)$

SYNTHETIC/ SOAPLESS DETERGENTS OR DETERGENTS

These are substances used as alternatives to soap to improve the cleansing properties of water. Examples of detergents include:

- Omo, Nomi, .. expand the list

The cleansing action of detergents is similar to that of soaps.

Advantages of using synthetic detergents (soapless detergents)

- ✓ They are more soluble in water than soap.
- ✓ Can easily be used in hard water since they do not form scum with it.
- ✓ Use of synthetic detergents make it possible to save vegetable oils for other important uses.

Disadvantages

- They are more expensive than sap
- Some are non-biodegradable i.e cannot be broken down by microorganisms hence causing pollution.

Advantages of soap over synthetic detergents (soap is sometimes called a soapy detergent)

- ✓ It is cheaper than synthetic detergents
- ✓ They are biodegradable

Disadvantages of soap over soapless detergents

- Forms scum with hard water

THE CHEMISTRY OF **POLYMERS**

A polymer is a large/complex molecule made up of many small repeating units called monomers.

A monomer is a small molecule that can join with other small molecules to form a larger molecule/polymer.

Polymerization is the process by which mny small molecules combine to form one large/complex molecule called a polymer.

There are two types of polymers:

- Natural polymers
- Synthetic polymers

1. **Natural polymers; those which naturally exist in plant and animal bodies.**

E.g

Polymer	**monomer**
Cellulose	glucose
Starch	glucose
Protein	amino acids
Natural rubber	

Uses of natural polymers

- These polymers make up bodies of plants and animals
- Cotton is used in making clothes
- Wood is made of cellulose and is used in making and paper respectively.
- Natural rubber is used in making vehicle tyres, shoe soles, etc

- **Natural rubber** is obtained from rubber trees in a sticky liquid form. Therefore, it cannot easily be converted into useful products. To improve its properties, it undergoes a process called vulcanization.

Dfn: **Vulcanization of rubber:** this is a process of adding Sulphur t natural rubber to improve on its undesirable properties. i.e vulcanized rubber is

- Stronger
- Harder
- More durable etc

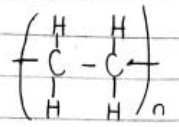
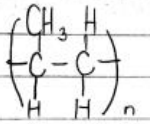
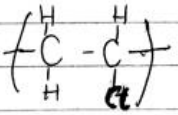
2. Synthetic polymers: These are polymers made through chemical reactions in industries or laboratories. All synthetic polymers are called **plastics.**
Examples include; polyethene, nylon, polystyrene, Perspex, polypropene, poly vinyl chloride (PVC).

Types of polymerization

(a) Addition polymerization: is a type of polymerization where many small identical molecules combine to form a single large molecule/polymer i.e without loss of any small molecules.

It occurs in only monomers containing double or triple bond i.e unsaturated compounds

Examples of addition polymers include:

Polymer	Structure	Monomers
Polyethene		ethene ($CH_2=CH_2$)
Polypropyne		Propene ($CH_3CH=CH_2$)
Polyvinyl chloride (PVC)		Chloroethene ($CH_2=CHCl$)

- Synthetic rubber etc

(b) **Condensation polymerization**; Is the type of polymerization where many small molecules combine to form a larger molecule with loss of smaller molecules such as water, ammonia etc.

Examples of condensation polymers include:

- Nylon; Used in making ropes, curtains, fish nets, tooth brush etc
- Bakelite; used in making electric plugs, sockets etc
- Melamine; used in making plates, cups etc.

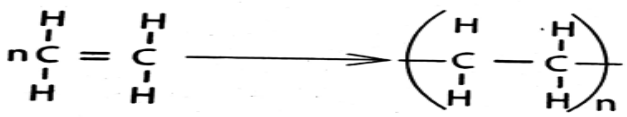
Classification of synthetic polymers/plastics basing of effect of heat
There are two types:
(i) thermosoftening plastics
(ii) thermosetting plastics

(a) Thermosoftening plastics

These are plastics which when heated soften and can be re-shaped or remoulded. Heat does not cause any chemical change to them. On cooling, they harden. Examples include:

- Polyethene;

The monomer is ethene. Ethene polymerises in the presence of a catalyst at high pressure to form polyethene according to the following equation:



Polyethene is used in making plastic bags and toys, making kitchen ware, buckets etc

- Polystyrene; used in making ice cream containers, making toothbrush and handles.
- Polypropene
- Polyvinyl chloride (PVC); used in making water pipes.

(b) Thermosetting plastics; these are plastics which do not soften on heating but decompose and therefore cannot be reshaped or remoulded.

Advantages of synthetic polymers (plastics) over natural polymers;

- They are relatively cheaper
- Easy to manufacture
- They are stronger than corresponding natural polymers.

Disadvantages

- They cause environmental pollution because they are non-biodegradable
- Exposes people making them to health problems.