12.0.0 GAS LAWS (15 LESSONS)

(a)Gas laws

1. Matter is made up of small particle in accordance to Kinetic Theory of matter: Naturally, there are basically **three** states of matter: **Solid, Liquid** and **gas:** (i)A solid is made up of particles which are very closely packed with a definite/fixed shape and fixed/definite volume /occupies definite space. It has a very high density.

(ii) A liquid is made up of particles which have some degree of freedom. It thus has no definite/fixed shape. It takes the shape of the container it is put. A liquid has fixed/definite volume/occupies definite space.

(iii)A gas is made up of particles free from each other. It thus has no definite /fixed shape. It takes the shape of the container it is put. It has no fixed/definite volume/occupies every space in a container.

2.Gases are affected by **physical conditions**. There are **two** physical conditions:

(i)**Temperature**

(ii)**Pressure**

3. The SI unit of temperature is **Kelvin**(**K**).

Degrees Celsius/Centigrade(^oC) are also used.

The two units can be interconverted from the relationship:

$$^oC + 273 = K$$

Practice examples

1. Convert the following into Kelvin.

(i) O ^oC

^oC + 273 = K substituting : O ^oC + 273 = **273 K**

(ii) -273 ^oC

^oC + 273 = K substituting : -273^oC + 273 = **0 K**

(iii) 25 ^oC

^oC + 273 = K substituting : 25 ^oC + 273 = **298 K**

(iv) 100 ^oC

^{o}C + 273 = K substituting : 100 ^{O}C + 273 = **373 K**

2. Convert the following into degrees Celsius/Centigrade(^{O}C).
(i) 10 K

K -273 = ^{o}C substituting: 10 – 273 = **-263 ^{o}C** (ii)

(i) 1 K

K -273 = ^{o}C substituting:1 – 273 = **-272 ^{o}C**

(iii) 110 K

K -273 = ^{o}C substituting: 110 – 273 = -163 ^{o}C

(iv) -24 K

K -273 = ^{o}C substituting: -24 – 273 = -297 ^{o}C

The **standard** temperature is **273K** = **0 ^{o}C**.
The **room** temperature is assumed to be **298K** = **25^{o}C**

4. The SI unit of pressure is Pascal(**Pa**) / Newton per metre squared (**Nm^{-2}**)
. Millimeters' of mercury(**mmHg**) ,centimeters of mercury(**cmHg**) and **atmospheres** are also commonly used.

The units are **not** interconvertible but Pascals(Pa) are equal to Newton per metre squared(Nm^{-2}).
The **standard** pressure is the **atmospheric** pressure.
Atmospheric pressure is **equal** to about:

(i)101325 Pa
(ii)101325 Nm^{-2}
(iii)760 mmHg
(iv)76 cmHg

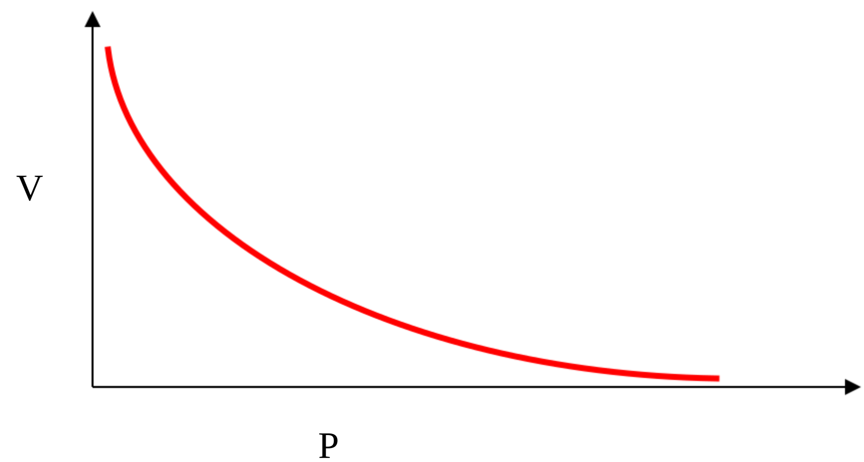
5. Molecules of gases are always in continuous random motion at high speed. This motion is affected by the physical conditions of temperature and pressure. Physical conditions change the volume occupied by gases in a **closed** system.
The effect of physical conditions of temperature and pressure was investigated and expressed in both Boyles and Charles laws.

6. Boyles law states that
"the volume of a fixed mass of a gas is inversely proportional to the pressure at constant/fixed temperature "
Mathematically:

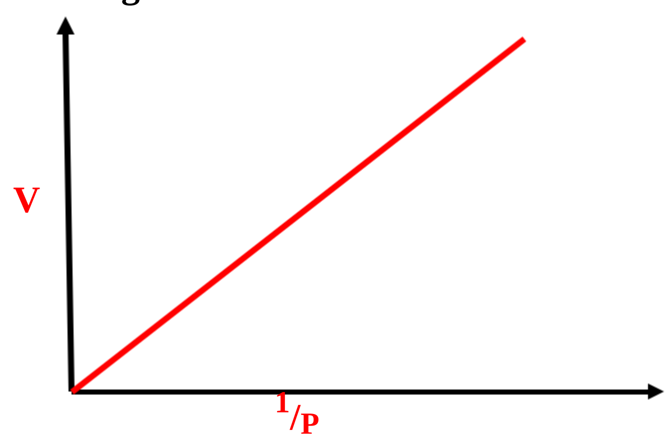
$$\text{Volume} \;\alpha\; \frac{1}{\text{Pressure}}$$ **(Fixed /constant Temperature)**

$$V \;\alpha\; \frac{1}{P}$$ **(Fixed /constant T)** ie **PV = Constant**(k)

From Boyles law , an **increase** in pressure of a gas cause a **decrease** in volume. i.e **doubling** the pressure cause the volume to be **halved**.
Graphically therefore a plot of volume(**V**) **against** pressure (**P**) produces a **curve**.



Graphically a plot of volume(**V**) **against** inverse/reciprocal of pressure (**1/p**) produces a **straight line**



For **two** gases then **$P_1 V_1 = P_2 V_2$**

P_1 = Pressure of gas 1
V_1 = Volume of gas 1
P_2 = Pressure of gas 2
V_2 = Volume of gas 2

Practice examples:

1. A fixed mass of gas at 102300Pa pressure has a volume of 25cm3.Calculate its volume if the pressure is doubled.

Working

$P_1 V_1 =$ $P_2 V_2$ Substituting :102300 x 25 = (102300 x **2**) x V_2 V_2

$= \frac{102300 \times 25}{(102300 \times 2)} =$ **12.5cm3**

2. Calculate the pressure which must be applied to a fixed mass of $100cm^3$ of Oxygen for its volume to triple at $100000Nm^{-2}$.

$P_1 V_1 = P_2 V_2$ Substituting :100000 x 100 = P_2 x (100 x **3**)

$V_2 = \frac{100000 \times 100}{(100 \times 3)} =$ **$33333.3333\ Nm^{-2}$**

3.A $60cm^3$ weather ballon full of Hydrogen at atmospheric pressure of 101325Pa was released into the atmosphere. Will the ballon reach stratosphere where the pressure is 90000Pa?

$P_1 V_1 = P_2 V_2$ Substituting :101325 x 60 = 90000 x V_2

$V_2 = \frac{101325 \times 60}{90000} =$ **67.55 cm3**

The new volume at 67.55 cm^3 **exceed** ballon capacity of 60.00 cm^3.It will **burst** before reaching destination.

7.Charles law states that**"the volume of a fixed mass of a gas is directly proportional to the absolute temperature at constant/fixed pressure "**

Mathematically:

Volume α Pressure **(Fixed /constant pressure)**

V α T **(Fixed /constant P)** ie $V = \frac{\text{Constant}}{T}$ (k)

From Charles law , an **increase** in temperature of a gas cause an **increase** in volume. i.e **doubling** the temperature cause the volume to be **doubled**.

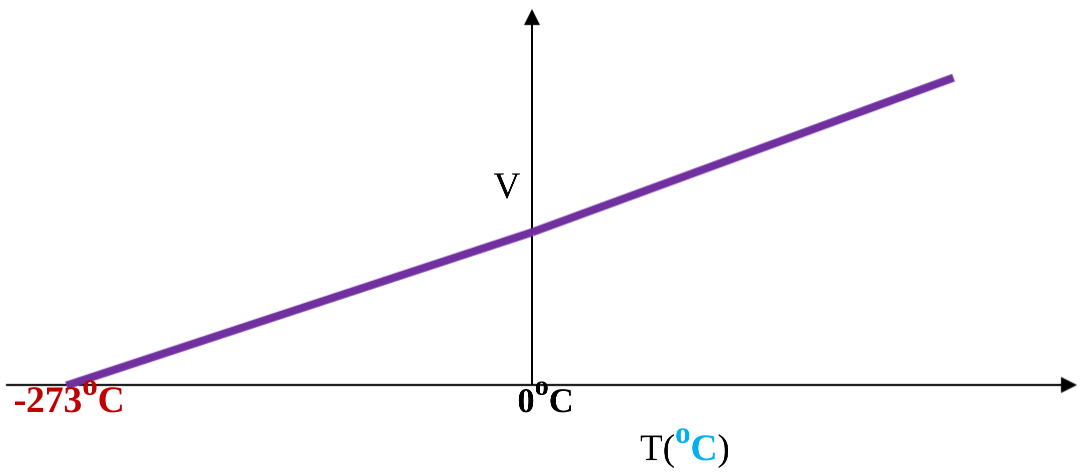
Gases expand/increase by $^{1}/_{273}$ by volume on heating.Gases contact/decrease by $^{1}/_{273}$ by volume on cooling at constant/fixed pressure.

The volume of a gas continue decreasing with decrease in temperature until at **-273^{o}C /0 K** the volume is **zero**. i.e. there is no gas.

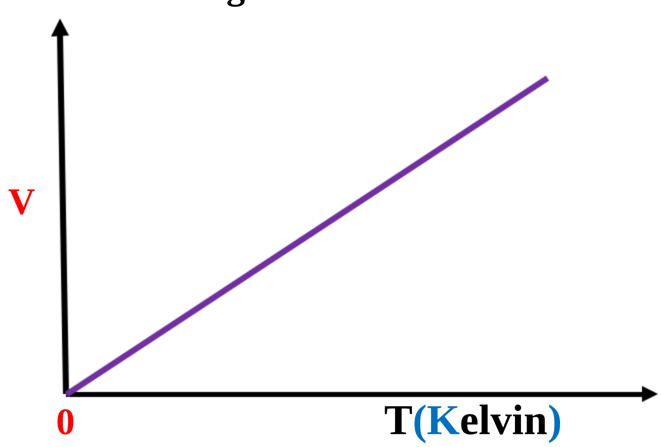
This temperature is called **absolute zero.** It is the **lowest** temperature at which a gas **can** exist.

Graphically therefore a plot of volume(**V**) **against** Temperature(**T**) in:

(**i**)^{O}C produces a **straight line** that is **extrapolated** to the absolute zero of -273**^{o}C** .



(**ii**)Kelvin/K produces a **straight line** from absolute zero of **O Kelvin**



For **two** gases then $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

T_1 = Temperature <u>**in Kelvin**</u> of gas 1

V_1 = Volume of gas 1

T_2 = Temperature <u>**in Kelvin**</u> of gas 2

V_2 = Volume of gas 2

<u>Practice examples:</u>

1. 500cm^3 of carbon(IV)oxide at 0^{o}C was transfered into a cylinder at -4^{o}C. If the capacity of the cylinder is 450 cm^3,explain what happened.

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ substituting $\frac{500}{(0 + 273)} = \frac{V_2}{(-4 + 273)}$

$= \frac{500 \times (-4 \times 273)}{(0 + 273)}$ = **492.674cm^3**

The capacity of cylinder (500cm^3) is **less** than new volume(492.674cm^3).
7.326cm^3(500-492.674cm^3)of carbon(IV)oxide gas did not fit into the cylinder.

2. A mechanic was filling a deflated tyre with air in his closed garage using a hand pump. The capacity of the tyre was 40,000cm^3 at room temperature. He rolled the tyre into the car outside. The temperature outside was 30^{o}C.Explain what happens.

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ substituting $\frac{40000}{(\mathbf{25} + 273)} = \frac{V_2}{(\mathbf{30} + 273)}$

$= \frac{40000 \times (30 \times 273)}{(25 + 273)}$ = **40671.1409cm3**

The capacity of a tyre (40000cm3) is **less** than new volume(40671.1409cm3).
The tyre thus bursts.

3. A hydrogen gas balloon with 80cm3 was released from a research station at room temperature. If the temperature of the highest point it rose is -30^{o}C , explain what happened.

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$ substituting $\frac{80}{(\mathbf{25} + 273)} = \frac{V_2}{(-\mathbf{30} + 273)}$

$= \frac{80 \times (-30 \times 273)}{}$ = **65.2349cm3**

(25 + 273)

The capacity of balloon (80cm3) is **more** than new volume (65.2349cm3). The balloon thus remained intact.

8. The continuous random motion of gases differ from gas to the other.The movement of molecules (of a gas) from region of high concentration to a region of low concentration is called **diffusion.**

The rate of diffusion of a gas depends on its density. i.e. **The higher the rate of diffusion, the less dense the gas**.

The density of a gas depends on its molar mass/relative molecular mass. i.e. **The** higher **the density the** higher **the molar mass/relative atomic mass and thus the** lower **the rate of diffusion.**

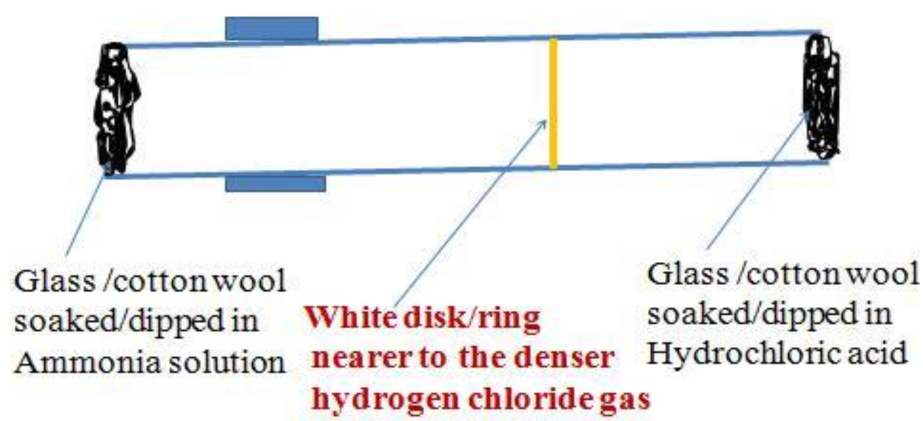
Examples

1.Carbon (IV)oxide(CO_2) has a molar mass of 44g.Nitrogen(N_2)has a molar mass of 28g. (N_2)is thus lighter/less dense than Carbon (IV)oxide(CO_2). N_2 diffuses faster than CO_2.

2.Ammonia(NH_3) has a molar mass of 17g.Nitrogen(N_2)has a molar mass of 28g. (N_2)is thus about **twice** lighter/less dense than Ammonia(NH_3). Ammonia(NH_3) diffuses twice faster than N_2.

3. Ammonia(NH_3) has a molar mass of 17g.Hydrogen chloride gas has a molar mass of 36.5g.Both gases on contact react to form **white fumes** of ammonium chloride .When a glass/cotton wool dipped in ammonia and another glass/cotton wool dipped in hydrochloric acid are placed at opposite ends of a glass tube, both gases diffuse towards each other. A white disk appears near to glass/cotton wool dipped in hydrochloric acid. This is because hydrogen chloride is heavier/denser than Ammonia and thus its rate of diffusion is lower .

Diffusion of ammonia and hydrogen chloride



Chemical equation: $HCl(g) + NH_3(s) \rightarrow NH_3Cl(s)$

The rate of diffusion of a gas is in accordance to **Grahams law of diffusion**. Grahams law states that:

"the rate of diffusion of a gas is inversely proportional to the square root of its density, at the same/constant/fixed temperature and pressure"

Mathematically

$R \; \alpha \; \frac{1}{\sqrt{p}}$ and since density is proportional to mass then $R \; \alpha \; \frac{1}{\sqrt{m}}$

For two gases then:

$\frac{R_1}{\sqrt{M_2}} = \frac{R_2}{\sqrt{M_1}}$ where: R_1 and R_2 is the **rate** of diffusion of **1**st and **2**nd gas.

M_1 and M_2 is the **molar mass** of **1**st and **2**nd gas.

Since rate is inverse of time. i.e. the higher the rate the less the time:

For two gases then:

$\frac{T_1}{\sqrt{M_1}} = \frac{T_2}{\sqrt{M_2}}$ where: T_1 and T_2 is the **time taken** for **1**st and **2**nd gas to diffuse.

M_1 and M_2 is the **molar mass** of **1**st and **2**nd gas.

Practice examples:

1. It takes 30 seconds for 100cm3 of carbon(IV)oxide to diffuse across a porous plate. How long will it take 150cm3 of nitrogen(IV)oxide to diffuse across the same plate under the same conditions of temperature and pressure. (C=12.0,N=14.0=16.0)

Molar mass CO_2=44.0 Molar mass NO_2=46.0

Method 1

100cm3 CO_2 takes 30seconds

150cm3 takes $\frac{150 \times 30}{100}$ = 45seconds

$$\frac{T\,CO_2}{T\,NO_2} = \frac{\sqrt{\text{molar mass } CO_2}}{\sqrt{\text{molar mass } NO_2}} \Rightarrow \frac{45\text{seconds}}{T\,NO_2} = \frac{\sqrt{44.0}}{\sqrt{46.0}}$$

$$T\,NO_2 = \frac{45\text{seconds} \times \sqrt{46.0}}{\sqrt{44.0}} = \mathbf{46.0114} \text{ seconds}$$

Method 2

100cm3 CO_2 takes 30seconds

1cm3 takes $\frac{100 \times 1}{30}$ = **3.3333cm3sec^{-1}**

$\frac{R\ CO_2}{R\ NO_2} = \frac{\sqrt{\text{molar mass } NO_2}}{\sqrt{\textbf{molar mass } CO_2}} \Rightarrow \frac{3.3333\text{cm3sec}^{-1}}{R\ NO_2} = \frac{\sqrt{46.0}}{\sqrt{44.0}}$

$RNO_2 = \frac{3.3333\text{cm3sec}^{-1} \times \sqrt{44.0}}{\sqrt{46.0}}$ = **3.2601**cm3sec^{-1}

3.2601cm3 takes 1seconds

150cm3 take $\frac{150\text{cm3}}{3.2601\text{cm3}}$ = **46.0109seconds**

2. How long would 200cm3 of Hydrogen chloride take to diffuse through a porous plug if carbon(IV)oxide takes 200seconds to diffuse through.

Molar mass CO_2 = 44g Molar mass HCl = 36.5g

$\frac{T\ CO_2}{T\ HCl} = \frac{\sqrt{\text{molar mass } CO_2}}{\sqrt{\textbf{molar mass } HCl}} \Rightarrow \frac{200 \text{ seconds}}{T\ HCl} = \frac{\sqrt{44.0}}{\sqrt{\mathbf{36.5}}}$

$T\ HCl = \frac{\mathbf{200seconds \times \sqrt{36.5}}}{\sqrt{\mathbf{44.0}}}$ = **182.1588** seconds

3. Oxygen gas takes 250 seconds to diffuse through a porous diaphragm. Calculate the molar mass of gas Z which takes 227 second to diffuse.

Molar mass O_2 = 32g Molar mass Z = x g

$\frac{T\ O_2}{T\ Z} = \frac{\sqrt{\text{molar mass } O_2}}{\sqrt{\textbf{molar mass } Z}} \Rightarrow \frac{250 \text{ seconds}}{227\text{seconds}} = \frac{\sqrt{32.0}}{\sqrt{\mathbf{x}}}$

$\sqrt{\mathbf{x}} = \frac{\mathbf{227seconds \times \sqrt{32}}}{250}$ = **26.3828** grams

4. 25cm3 of carbon(II)oxide diffuses across a porous plate in 25seconds. How long will it take 75cm3 of Carbon(IV)oxide to diffuse across the same plate under the same conditions of temperature and pressure. (C=12.0,0=16.0)

Molar mass CO_2 = 44.0 Molar mass CO = 28.0

Method 1

25cm3 CO takes 25seconds

75cm3 takes $\frac{75 \times 25}{25}$ = 75seconds

$$\frac{T\,CO_2}{T\,CO} = \frac{\sqrt{\text{molar mass } CO_2}}{\sqrt{\textbf{molar mass } CO}} \Rightarrow \frac{T\,CO_2\text{seconds}}{75} = \frac{\sqrt{44.0}}{\sqrt{\mathbf{28}.0}}$$

$$TCO_2 = \frac{\mathbf{75seconds\ x}\sqrt{\mathbf{44}.0}}{\sqrt{\mathbf{28}.0}} = \mathbf{94.0175}\text{ seconds}$$

Method 2

25cm3 CO_2 takes 25seconds

1cm3 takes $\frac{25\text{ x1}}{25} = \mathbf{1.0cm3sec^{-1}}$

$$\frac{R\,CO_2}{R\,CO} = \frac{\sqrt{\text{molar mass } CO}}{\sqrt{\textbf{molar mass } CO_2}} \Rightarrow \frac{x\text{ cm3sec}^{-1}}{1.0\text{cm3sec}^{-1}} = \frac{\sqrt{28.0}}{\sqrt{44.0}}$$

$$RCO_2 = \frac{1.0\text{cm3sec}^{-1}\ \mathbf{x}\sqrt{28.0}}{\sqrt{44.0}} = \mathbf{0.7977}\text{cm3sec}^{-1}$$

0.7977cm3 takes 1 seconds

75cm3 takes $\frac{75\text{cm3}}{0.7977\text{cm3}}$ = **94.0203seconds**

13.0.0 THE MOLE-FORMULAE AND CHEMICAL EQUATIONS (40 LESSONS)

Introduction to the mole, molar masses and Relative atomic masses

1. The mole is the **SI** unit of the **amount** of substance.
2. The number of particles e.g. atoms, ions, molecules, electrons, cows, cars are all measured in terms of moles.
3. The number of particles in one mole is called the **Avogadros Constant**. It is denoted **"L"**.

The Avogadros Constant contain **6.023 x10 ^{23}** particles. i.e.

1mole = 6.023 x10 ^{23} particles = 6.023 x10 ^{23}
2 moles = 2 x 6.023 x10 ^{23} particles = 1.205 x10 ^{24}
0.2 moles = 0.2 x 6.023 x10 23 particles = 1.205 x10 ^{22}
0.0065 moles = 0.0065 x 6.023 x10 ^{23} particles = 3.914 x10 ^{21}

3. The mass of one mole of a substance is called **molar mass**. The molar mass of: (i)an **element** has mass equal to relative **atomic** mass /RAM(in grams)of the element e.g.

Molar mass of carbon(C)= relative atomic mass = 12.0g
6.023 x10 ^{23} particles of carbon = 1 mole =12.0 g

Molar mass of sodium(Na) = relative atomic mass = 23.0g
6.023 x10 ^{23} particles of sodium = 1 mole =23.0 g

Molar mass of Iron (Fe) = relative atomic mass = 56.0g
6.023 x10 ^{23} particles of iron = 1 mole =56.0 g

(ii)a **molecule** has mass equal to relative molecular mass /RMM (in grams)of the molecule. Relative molecular mass is the **sum** of the relative atomic masses of the elements making the molecule.

The number of atoms making a molecule is called **atomicity**. Most **gaseous** molecules are **diatomic (e.g. O_2, H_2, N_2, F_2, Cl_2, Br_2, I_2)**noble gases are **monoatomic(e.g. He, Ar, Ne, Xe)**,Ozone gas(**O_3**) is **triatomic** e.g.

Molar mass **Oxygen molecule(O_2)** =relative molecular mass =(16.0x 2)g =32.0g 6.023 x10 ^{23} particles of Oxygen molecule = 1 mole = 32.0 g

Molar mass **chlorine molecule(Cl_2)** =relative molecular mass =(35.5x 2)g =71.0g 6.023 x10 ^{23} particles of chlorine molecule = 1 mole = 71.0 g

Molar mass **Nitrogen molecule(N_2)** =relative molecular mass =(14.0x 2)g =28.0g 6.023 x10 ^{23} particles of Nitrogen molecule = 1 mole = 28.0 g

(ii)a <u>**compound**</u> has mass equal to <u>relative formular mass</u> /RFM (in grams)of the molecule. Relative formular mass is the **sum** of the relative atomic masses of the elements making the compound. e.g.

(i)Molar mass **Water(H_2O)** = relative formular mass =[(1.0 x 2) + 16.0]g =18.0g

6.023 x10 ^{23} particles of Water molecule = 1 mole = 18.0 g
6.023 x10 ^{23} particles of Water molecule has:

- **2** x 6.023 x10 ^{23} particles of Hydrogen atoms
- **1** x 6.023 x10 ^{23} particles of Oxygen atoms

(ii)Molar mass **sulphuric(VI)acid(H_2SO_4)** = relative formular mass =[(1.0 x 2) + 32.0 + (16.0 x 4)]g =98.0g

6.023 x10 ^{23} particles of sulphuric(VI)acid(H_2SO_4) = 1 mole = 98.0g
6.023 x10 ^{23} particles of sulphuric(VI)acid(H_2SO_4) has:

- **2** x 6.023 x10 ^{23} particles of **H**ydrogen atoms
- **1** x 6.023 x10 ^{23} particles of **S**ulphur atoms
- **4** x 6.023 x10 ^{23} particles of **O**xygen atoms

(iii)Molar mass **sodium carbonate(IV)(Na_2CO_3)** = relative formular mass =[(23.0 x 2) + 12.0 + (16.0 x 3)]g =106.0g

6.023 x10 ^{23} particles of sodium carbonate(IV)(Na_2CO_3) = 1 mole = 106.0g
6.023 x10 ^{23} particles of sodium carbonate(IV)(Na_2CO_3) has:

- **2** x 6.023 x10 ^{23} particles of **S**odium atoms
- **1** x 6.023 x10 ^{23} particles of **C**arbon atoms
- **3** x 6.023 x10 ^{23} particles of **O**xygen atoms

(iv)Molar mass **Calcium carbonate(IV)($CaCO_3$)** = relative formular mass =[(40.0+ 12.0 + (16.0 x 3)]g =100.0g.

6.023 x10 ^{23} particles of Calcium carbonate(IV)($CaCO_3$) = 1 mole = 100.0g

6.023×10^{23} particles of Calcium carbonate(IV)($CaCO_3$) has:

- **1** x 6.023×10^{23} particles of **C**alcium atoms
- **1** x 6.023×10^{23} particles of **C**arbon atoms
- **3** x 6.023×10^{23} particles of **O**xygen atoms

(v)Molar mass **Water(H_2O)** = relative formular mass =[(2 x 1.0)+ 16.0]g =18.0g

6.023×10^{23} particles of Water(H_2O) = 1 mole = 18.0g
6.023×10^{23} particles of Water(H_2O) has:

- **2** x 6.023×10^{23} particles of Hydrogen atoms
- **2** x 6.023×10^{23} particles of **O**xygen atoms

<u>Practice</u>

1. Calculate the number of moles present in: (i)0.23 g of Sodium atoms

Molar mass of Sodium atoms = 23g

$$\text{Moles} = \frac{\text{mass in grams}}{\text{Molar mass}} \Rightarrow \frac{0.23g}{23} = \mathbf{0.01moles}$$

(ii) 0.23 g of Chlorine atoms

Molar mass of Chlorine atoms = 35.5 g

$$\text{Moles} = \frac{\text{mass in grams}}{\text{Molar mass}} \Rightarrow \frac{0.23g}{35.5} = \mathbf{0.0065moles\ /6.5 \times 10^{-3}\ moles}$$

(iii) 0.23 g of Chlorine molecules

Molar mass of Chlorine molecules =(35.5 x 2) = **71.0** g

$$\text{Moles} = \frac{\text{mass in grams}}{\text{Molar mass}} \Rightarrow \frac{0.23g}{71} = \mathbf{0.0032moles\ /3.2 \times 10^{-3}\ moles}$$

(iv) 0.23 g of dilute sulphuric(VI)acid

Molar mass of H_2SO_4 = [(2 x 1) + 32 + (4 x14)] = **98.0**g

$$\text{Moles} = \frac{\text{mass in grams}}{\text{Molar mass}} \Rightarrow \frac{0.23g}{98} = \mathbf{0.0023moles\ /2.3 \times 10^{-3}\ moles}$$

2. Calculate the number of atoms present in:(Avogadros constant L = 6.0×10^{23})

(i) 0.23 g of dilute sulphuric (VI)acid

<u>Method I</u>

Molar mass of H_2SO_4 = [(2 x 1) + 32 + (4 x14)] = **98.0**g

Moles = $\frac{\text{mass in grams}}{\text{Molar mass}}$ => $\frac{0.23g}{98}$ = **0.0023moles /2.3 x 10^{-3} moles**

1 mole has 6.0 x 10^{23} atoms
2.3 x 10^{-3} moles has $\frac{(2.3 \times 10^{-3} \times 6.0 \times 10^{23})}{1}$ = **1.38 x 10^{21}** atoms

Method II

Molar mass of H_2SO_4 = [(2 x 1) + 32 + (4 x14)] = **98.0**g
98.0g = 1 mole has 6.0 x 10^{23} atoms
0.23 g therefore has $\frac{(0.23 g \times 6.0 \times 10^{23})}{98}$ = **1.38 x 10^{21}** atoms

(ii)0.23 g of sodium carbonate(IV)decahydrate

Molar mass of $Na_2CO_3.10H_2O$=
[(2 x 23) + 12 + (3 x16) + (10 x 1.0) + (10 x 16)] = **276.0**g

Method I

Moles = $\frac{\text{mass in grams}}{\text{Molar mass}}$ => $\frac{0.23g}{276}$ = **0.00083moles / 8.3 x 10^{-4} moles**

1 mole has 6.0 x 10^{23} atoms
8.3 x 10^{-4} moles has $\frac{(8.3 \times 10^{-4} \text{ moles} \times 6.0 \times 10^{23})}{1}$ = **4.98 x 10^{20}** atoms

Method II

276.0g = 1 mole has 6.0 x 10^{23} atoms
0.23 g therefore has $\frac{(0.23 g \times 6.0 \times 10^{23})}{276.0}$ = **4.98 x 10^{20}** atoms

(iii)0.23 g of Oxygen gas

Molar mass of O_2 = (2 x16) = **32.0** g

Method I

Moles = $\frac{\text{mass in grams}}{\text{Molar mass}}$ => $\frac{0.23g}{32}$ = **0.00718moles / 7.18 x 10^{-3} moles**

1 mole has **2** x 6.0 x 10^{23} **atoms** in O_2
7.18 x 10^{-3}moles has (7.18 x 10^{-3}moles x **2** x 6.0 x 10^{23}) =**8.616 x 10^{21}**atoms

Method II

32.0g = 1 mole has **2** x 6.0 x 10^{23} **atoms** in O_2

0.23 g therefore has $\left(\frac{0.23\text{ g} \times \mathbf{2} \times 6.0 \times 10^{23}}{32.0}\right)$ = **8.616 x 10 ^{21}**atoms

(iv)0.23 g of Carbon(IV)oxide gas

Molar mass of CO_2 = [12 + (2 x16)] = **44.0** g

Method I

Moles = $\frac{\text{mass in grams}}{\text{Molar mass}}$ = > $\frac{0.23\text{g}}{44}$ = **0.00522moles / 5.22 x 10^{-3} moles**

1 mole has **3** x 6.0 x 10 ^{23} **atoms** in CO_2

7.18 x 10^{-3}moles has (5.22 x 10^{-3}moles x **3** x 6.0 x 10 ^{23}) =**9.396 x 10 ^{21}**atoms

Method II

44.0g = 1 mole has **3** x 6.0 x 10 ^{23} **atoms** in CO_2

0.23 g therefore has (0.23 g x 3 x 6.0 x 10 ^{23}) = **9.409 x 10 ^{21}**atoms

(c)Empirical and molecular formula

1.The empirical formula of a compound is its simplest formula. It is the simplest whole number ratios in which atoms of elements combine to form the compound. 2.It is mathematically the lowest common multiple (LCM) of the atoms of the elements in the compound

3.Practically the empirical formula of a compound can be determined as in the following examples.

To determine the empirical formula of copper oxide

(a) Method 1:From copper to copper(II)oxide

Procedure.

Weigh a clean dry covered crucible(**M_1**).Put two spatula full of copper **powder** into the crucible. Weigh again (**M_2**).Heat the crucible on a strong Bunsen flame for five minutes. Lift the lid, and swirl the crucible carefully using a pair of tong. Cover the crucible and continue heating for another five minutes. Remove the lid and stop heating. Allow the crucible to cool. When cool replace the lid and weigh the contents again (**M_3**).

Sample results

Mass of crucible(**M_1**)	15.6g
Mass of crucible + copper before heating(**M_2**)	18.4
Mass of crucible + copper after heating(**M_3**)	19.1

Sample questions

1. Calculate the mass of copper powder used.

Mass of crucible + copper before heating(**M_2**) = 18.4
Less Mass of crucible(**M_1**) = - 15.6g
Mass of copper **2.8 g**

2. Calculate the mass of Oxygen used to react with copper.

Method I

Mass of crucible + copper after heating(**M_3**) = 19.1g

Mass of crucible + copper before heating(**M_2**) = -18.4g
Mass of Oxygen = **0.7 g**

Method II

Mass of crucible + copper after heating(**M_3**) = 19.1g
Mass of crucible = - 15.6g
Mass of copper(II)Oxide = 3.5 g

Mass of copper(II)Oxide = 3.5 g
Mass of copper = - 2.8 g
Mass of Oxygen = **0.7 g**

3. Calculate the number of moles of:

(i) copper used (Cu = 63.5)

number of moles of copper = $\frac{\text{mass used}}{\text{Molar mass}}$ => $\frac{2.8}{63.5}$ = **0.0441moles**

(ii) Oxygen used (O = 16.0)

number of moles of oxygen = $\frac{\text{mass used}}{\text{Molar mass}}$ => $\frac{0.7}{16.0}$ = **0.0441moles**

4. Determine the mole ratio of the reactants

$\frac{\text{Moles of copper}}{\text{Moles of oxygen}}$ = $\frac{0.0441\text{moles}}{0.0441\text{moles}}$ = $\frac{1}{1}$ => Mole ratio Cu: O = **1:1**

5.What is the empirical, formula of copper oxide formed.

CuO (copper(II)oxide

6. State and explain the observations made during the experiment. Observation

Colour change from **brown** to **black**

Explanation

Copper powder is brown. On heating it reacts with oxygen from the air to form black copper(II)oxide

7. Explain why magnesium ribbon/shavings would be unsuitable in a similar experiment as the one above.

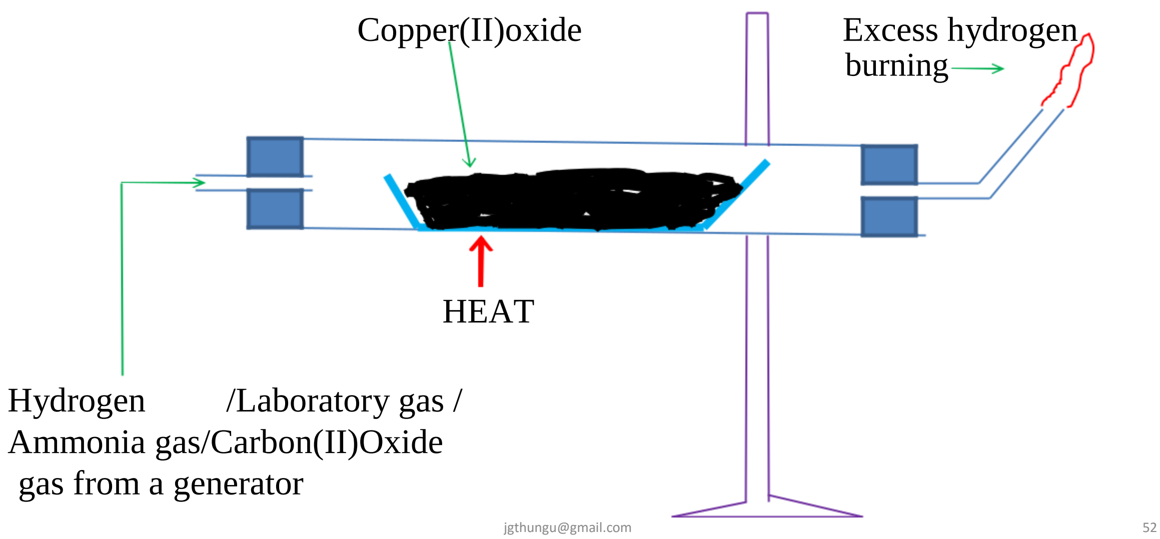
Hot magnesium generates enough heat energy to react with **both** Oxygen and Nitrogen in the air forming a white solid mixture of Magnesuin oxide and magnesium nitride. This causes experimental mass errors.

(b) Method 2:From copper(II)oxide to copper

Procedure.

Weigh a clean dry porcelain boat (**M1**). Put two spatula full of copper(II)oxide **powder** into the crucible. Reweigh the porcelain boat (**M2**).Put the porcelain boat in a glass tube and set up the apparatus as below;

Determining empirical formula from copper(II)oxide **to copper**



Pass slowly(to prevent copper(II)oxide from being blown away)a stream of either dry Hydrogen /ammonia/laboratory gas/ carbon(II)oxide gas for about two minutes from a suitable generator.

When all the in the apparatus set up is driven out ,heat the copper(II)oxide strongly for about five minutes until there is no further change. Stop heating. Continue passing the gases until the glass tube is cool.

Turn off the gas generator.

Carefully remove the porcelain boat form the combustion tube.

Reweigh (**M3**).

Sample results

Mass of boat(**M1**)	15.6g
Mass of boat before heating(**M2**)	19.1
Mass of boat after heating(**M3**)	18.4

Sample questions

1. Calculate the mass of copper(II)oxide used.

Mass of boat before heating(**M_2**)	=	19.1
Mass of empty boat(**M_1**)	=	- 15.6g
Mass of copper(II)Oxide		**3.5 g**

2. Calculate the mass of

(i) Oxygen.

Mass of boat before heating(**M_2**)	=	19.1
Mass of boat after heating (**M_3**)	=	- 18.4g
Mass of oxygen	=	**0.7 g**

(ii)Copper

Mass of copper(II)Oxide	=	3.5 g
Mass of oxygen	=	0.7 g
Mass of oxygen	=	**2.8 g**

3. Calculate the number of moles of:

(i) Copper used (Cu = 63.5)

number of moles of copper $= \frac{\text{mass used}}{\text{Molar mass}} \Rightarrow \frac{2.8}{63.5} =$ **0.0441moles**

(ii) Oxygen used (O = 16.0)

number of moles of oxygen $= \frac{\text{mass used}}{\text{Molar mass}} \Rightarrow \frac{0.7}{16.0} =$ **0.0441moles**

4. Determine the mole ratio of the reactants

$\frac{\text{Moles of copper}}{\text{Moles of oxygen}} = \frac{0.0441\text{moles}}{0.0441\text{moles}} = \frac{1}{1}$ => Mole ratio Cu: O = **1:1**

5.What is the empirical, formula of copper oxide formed.

CuO (copper(II)oxide)

6. State and explain the observations made during the experiment. Observation

Colour change from **black** to **brown**

Explanation

Copper(II)oxide powder is black. On heating it is reduced by a suitable reducing agent to brown copper metal.

7. Explain why magnesium oxide would be unsuitable in a similar experiment as the one above.

Magnesium is high in the reactivity series. None of the above reducing agents is strong enough to reduce the oxide to the metal.

8. Write the equation for the reaction that would take place when the reducing agent is:

(i) Hydrogen

$CuO(s)$ (Black) + $H_2(g)$ -> $Cu(s)$ (brown) + $H_2O(l)$ (colourless liquid form on cooler parts)

(ii)Carbon(II)oxide

$CuO(s)$ (Black) + $CO(g)$ -> $Cu(s)$ (brown) + $CO_2(g)$ (colourless gas, form white ppt with lime water)

(iii)Ammonia

$3CuO(s)$ (Black) + $2NH_3(g)$ -> $3Cu(s)$ (brown) + $N_2(g)$ + $3H_2O(l)$ (colourless liquid form on cooler parts)

9. Explain why the following is necessary during the above experiment;

(i)A stream of dry hydrogen gas should be passed before heating copper (II) Oxide.

Air combine with hydrogen in presence of heat causing an explosion

(ii)A stream of dry hydrogen gas should be passed after heating copper (II) Oxide has been stopped.

Hot metallic copper can be re-oxidized back to copper(II)oxide

(iii) A stream of excess carbon (II)oxide gas should be ignited to burn

Carbon (II)oxide is highly poisonous/toxic. On ignition it burns to form less toxic carbon (IV)oxide gas.

10. State two sources of error in this experiment.

(i)All copper(II)oxide may not be reduced to copper.

(ii)Some copper(II)oxide may be blown out the boat by the reducing agent.

4.Theoreticaly the empirical formula of a compound can be determined as in the following examples.

(a)A oxide of copper contain 80% by mass of copper. Determine its empirical formula. (Cu = 63.5, 16.0)

% of Oxygen = 100% - % of Copper => 100- 80 = **20%** of Oxygen

Element	Copper	Oxygen
Symbol	Cu	O
Moles present = $\frac{\text{\% composition}}{\text{Molar mass}}$	$\frac{80}{63.5}$	$\frac{20}{16}$
Divide by the smallest value	$\frac{1.25}{1.25}$	$\frac{1.25}{1.25}$
Mole ratios	1	1

Empirical formula is **CuO**

(b)1.60g of an oxide of Magnesium contain 0.84g by mass of Magnesium. Determine its empirical formula(Mg = 24.0, 16.0)

Mass of Oxygen = 1.60 – 0.84 => **0.56 g** of Oxygen

Element	Magnesium	Oxygen
Symbol	Mg	O
Moles present = $\frac{\text{\% composition}}{\text{Molar mass}}$	$\frac{0.84}{24}$	$\frac{0.56}{16}$
Divide by the smallest value	$\frac{0.35}{0.35}$	$\frac{0.35}{0.35}$
Mole ratios	1	1

Empirical formula is **MgO**

(c)An oxide of Silicon contain 47% by mass of Silicon. What is its empirical formula(Si = 28.0, 16.0)

Mass of Oxygen = 100 – 47 => **53%** of Oxygen

Element	Silicon	Oxygen
Symbol	Si	O
Moles present = $\frac{\text{\% composition}}{\text{Molar mass}}$	$\frac{47}{28}$	$\frac{53}{16}$
Divide by the smallest value	$\frac{1.68}{1.68}$	$\frac{3.31}{1.68}$
Mole ratios	1	1.94 = 2

Empirical formula is **SiO_2**

(d)A compound contain 70% by mass of Iron and 30% Oxygen. What is its empirical formula(Fe = 56.0, 16.0)

Mass of Oxygen = 100 – 47 => **53%** of Oxygen

Element	Silicon	Oxygen
Symbol	Si	O
Moles present = % composition / Molar mass	47 / 28	53 / 16
Divide by the smallest value	1.68 / 1.68	3.31 / 1.68
Mole ratios	1	1.94 = 2

Empirical formula is **SiO_2**

2.During heating of a hydrated copper (II)sulphate(VI) crystals, the following readings were obtained:

Mass of evaporating dish =300.0g

Mass of evaporating dish + hydrated salt = 305.0g

Mass of evaporating dish + anhydrous salt = 303.2g

Calculate the number of water of crystallization molecules in hydrated copper (II)sulphate(VI)

(Cu =64.5, S = 32.0,O=16.0, H = 1.0)

Working

Mass of Hydrated salt = 305.0g -300.0g = **5.0g**

Mass of anhydrous salt = 303.2 g -300.0g = **3.2 g**

Mass of water in hydrated salt = 5.0g -3.2 g = **1.8g**

Molar mass of water(H_2O) = **18.0g**

Molar mass of anhydrous copper (II)sulphate(VI) ($CuSO_4$) = **160.5g**

Element/compound	anhydrous copper (II) sulphate(VI)	Oxygen
Symbol	Si	O
Moles present = composition by mass / Molar mass	3,2 / 160.5	1.8 / 18
Divide by the smallest value	0.0199 / 0.0199	0.1 / 18
Mole ratios	1	5

The **empirical formula** of hydrated salt = $CuSO_4.\underline{5}H_2O$

Hydrated salt has **five/5 molecules** of water of crystallizations

4. The molecular formula is the actual number of each kind of atoms present in a **molecule** of a compound.

The empirical formula of an ionic compound is the same as the chemical formula but for simple molecular structured compounds, the empirical formula may not be the same as the chemical formula.

The molecular formula is a multiple of empirical formula .It is determined from the relationship:

(i) $\mathbf{n} = \frac{\text{Relative formular mass}}{\text{Relative empirical formula}}$

where **n** is a whole number.

(ii) Relative empirical formula x **n** = Relative formular mass
where **n** is a whole number.

Practice sample examples

1. A hydrocarbon was found to contain 92.3% carbon and the remaining Hydrogen.
If the molecular mass of the compound is 78, determine the molecular formula(C=12.0, H =1.0)

Mass of Hydrogen = 100 – 92.3 => **7.7%** of Oxygen

Element	Carbon	Hydrogen
Symbol	C	H
Moles present = $\frac{\text{\% composition}}{\text{Molar mass}}$	$\frac{92.3}{12}$	$\frac{7.7}{1}$
Divide by the smallest value	$\frac{7.7}{7.7}$	$\frac{7.7}{7.7}$
Mole ratios	1	1

Empirical formula is **CH**
The molecular formular is thus determined :
n = Relative formular mass = 78 = 6

Relative empirical formula 13

The molecular formula is (C H) x 6 = $\underline{C_6H_6}$

2. A compound of carbon, hydrogen and oxygen contain 54.55% carbon, 9.09% and remaining 36.36% oxygen.

If its relative molecular mass is 88, determine its molecular formula(C=12.0, H =1.0, O= 16.0)

Element	Carbon	Hydrogen	Oxygen
Symbol	C	H	O
Moles present = $\frac{\%\ composition}{Molar\ mass}$	$\frac{54.55}{12}$	$\frac{9.09}{1}$	$\frac{36.36}{16}$
Divide by the smallest value	$\frac{4.5458}{2.2725}$	$\frac{9.09}{2.2725}$	$\frac{2.2725}{2.2725}$
Mole ratios	2	4	1

Empirical formula is $\mathbf{C_2H_4O}$

The molecular formula is thus determined :

$$n = \frac{\text{Relative formular mass}}{\text{Relative empirical formula}} = \frac{88}{44} = 2$$

The molecular formula is (C_2H_4O) x 2 = $\mathbf{C_4H_8O_2}$.

4.A hydrocarbon burns completely in excess air to form 5.28 g of carbon (IV) oxide and 2,16g of water.

If the molecular mass of the hydrocarbon is 84, draw and name its molecular structure.

Since a hydrocarbon is a compound containing Carbon and Hydrogen only. Then:

Mass of carbon in CO_2 = $\frac{\text{Mass of C in CO}_2}{\text{Molar mass of CO}_2}$ x mass of CO_2 =>

$\frac{12 \times 5.28}{44}$ = **1.44g**√

Mass of Hydrogen in H_2O = $\frac{\text{Mass of C in H}_2\text{O}}{\text{Molar mass of H}_2\text{O}}$ x mass of H_2O =>

$\frac{2 \times 2.16}{18}$ = **0.24g**√

Element	Carbon	Hydrogen

Symbol	C	H
Moles present = mass / Molar mass	1.44g / 12	0.24g√ / 1
Divide by the smallest value	0.12 / 0.12	0.24 / 0.12
Mole ratios	1	2√

Empirical formula is **CH_2**√

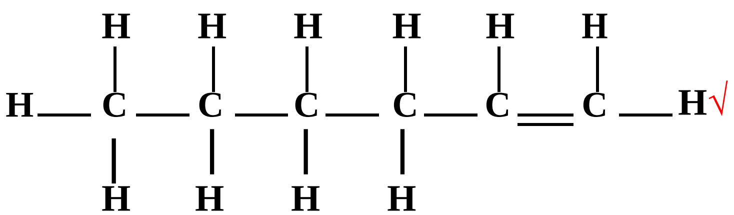
The molecular formular is thus determined :

$$\mathbf{n} = \frac{\text{Relative formular mass}}{\text{Relative empirical formula}} = \frac{84}{14} = \mathbf{6}\surd$$

The molecular formula is $(CH_2) \times 6 = \mathbf{C_6H_{12}}$. √

molecular name **Hexene**√/**Hex-1-ene** **(or any position isomer of Hexene)**

Molecular structure



5. Compound A contain 5.2% by mass of Nitrogen .The other elements present are Carbon, hydrogen and Oxygen. On combustion of 0.085g of A in excess Oxygen,0.224g of carbon(IV)oxide and 0.0372g of water was formed. Determine the empirical formula of A (N=14.0, O=16.0 , C=12.0 , H=1.0)

Mass of **N** in A = 5.2% x 0.085 = **0.00442 g**

Mass of C in A = $\frac{12}{44}$ x 0.224 = **0.0611g**

Mass of H in A = $\frac{2}{18}$ x 0.0372 = **0.0041g**

Mass of O in A = 0.085g – 0.004442g = **0.0806g** (Mass of C,H,O)

=> 0.0611g + 0.0041g = **0.0652g (Mass of C,H)**

0.0806g (Mass of C,H,O)- 0.0652g (Mass of C,H) = **0.0154 g**

Element	Nitrogen	Carbon	Hydrogen	Oxygen
Symbol	N	C	H	O
Moles present = mass / Molar mass	0.00442 g / 14	0.0611g / 12	0.0041g / 1	0.0154 g / 16
Divide by the smallest value	0.00032	0.00509	0.0041g	0.00096

	0.00032	0.00032	0.00032	0.00032
Mole ratios	1	16	13	3

Empirical formula = $C_{16}H_{13}NO_3$

(d)Molar gas volume

The volume occupied by one mole of all gases at the same temperature and pressure is a constant.It is:

(i) 24dm3/24litres/24000cm3 at **r**oom **t**emperature(25^{o}C/298K)and **p**ressure(**r.t.p**).

i.e. 1mole of all gases =24dm3/24litres/24000cm3 at r.t.p

Examples

1mole of O_2 = 32g =6.0 x10^{23} particles**= 24dm3/24litres/24000cm3 at r.t.p**
1mole of H_2 = 2g =6.0 x10^{23} particles **=24dm3/24litres/24000cm3 at r.t.p**
1mole of CO_2 = 44g = 6.0 x10^{23} particles **=24dm3/24litres/24000cm3 at r.t.p**
1mole of NH_3 = 17g =6.0 x10^{23} particles **= 24dm3/24litres/24000cm3 at r.t.p**
1mole of CH_4 = 16g =6.0 x10^{23} particles **=24dm3/24litres/24000cm3 at r.t.p**

(**ii**)22.4dm3/22.4litres/22400cm3 at **s**tandard **t**emperature(0^{o}C/273K) and **p**ressure(**s.t.p**)

i.e. 1mole of all gases =22.4dm3/22.4litres/22400cm3 at s.t.p Examples

1mole of O_2 = 32g =6.0 x10^{23} particles**= 22.4dm3/22.4litres/22400cm3 at s.t.p**
1mole of H_2 = 2g =6.0 x10^{23} particles **= 22.4dm3/22.4litres/22400cm3 at s.t.p**
1mole of CO_2 = 44g = 6.0 x10^{23} particles **= 22.4dm3/22.4litres/22400cm3 at s.t.p** **1mole of NH_3** = 17g =6.0 x10^{23} particles**= 22.4dm3/22.4litres/22400cm3 at s.t.p** **1mole of CH_4** = 16g =6.0 x10^{23} particles **= 22.4dm3/22.4litres/22400cm3 at s.t.p** The volume occupied by one mole of a gas at r.t.p or s.t.p is commonly called the **molar gas volume.** Whether the molar gas volume is at r.t.p or s.t.p must always be **specified**.

From the above therefore a less or more volume can be determined as in the examples below.

<u>Practice examples</u>

1. Calculate the number of particles present in:

(Avogadros constant =6.0 x10^{23}mole^{-1} **)**

(i) 2.24dm3 of Oxygen.

22.4dm3 -> 6.0×10^{23}
2.24dm3 -> $\frac{2.24 \times 6.0 \times 10^{23}}{22.4}$

$= \underline{6.0 \times 10^{22}}$ **molecules** $= 2 \times 6.0 \times 10^{22}$. $= \underline{1.2 \times 10^{23}}$ **atoms**

(ii) 2.24dm3 of Carbon(IV)oxide.

22.4dm3 -> 6.0×10^{23}
2.24dm3 -> $\frac{2.24 \times 6.0 \times 10^{23}}{22.4}$

$= \underline{6.0 \times 10^{22}}$ **molecules** $= (CO_2) = 3 \times 6.0 \times 10^{22}$. $= \underline{1.8 \times 10^{23}}$ **atoms**

2. 0.135 g of a gaseous hydrocarbon X on complete combustion produces 0.41g of carbon(IV)oxide and 0.209g of water.0.29g of X occupy 120cm3 at room temperature and 1 atmosphere pressure .Name X and draw its molecular structure.(C=12.0,O= 16.O,H=1.0,1 mole of gas occupies 24dm3 at r.t.p)

Molar mass CO_2= 44 $gmole^{-1}$√ Molar mass H_2O = 18 $gmole^{-1}$√

Molar mass X = $\frac{0.29 \times (24 \times 1000)cm3}{120cm3}$ = 58 $gmole^{-1}$√

Since a hydrocarbon is a compound containing Carbon and Hydrogen only. Then:

Mass of carbon in CO_2 = $\frac{\text{Mass of C in } CO_2}{\text{Molar mass of } CO_2}$ x mass of CO_2 =>

$\frac{12 \times 0.41}{44}$ = **0.1118g**√

Mass of Hydrogen in H_2O = $\frac{\text{Mass of C in } H_2O}{\text{Molar mass of } H_2O}$ x mass of H_2O =>

$\frac{2 \times 0.209}{18}$ = **0.0232g**√

Element	Carbon	Hydrogen
Symbol	C	H
Moles present = $\frac{\text{\% composition}}{\text{Molar mass}}$	$\frac{0.g118}{12}$	$\frac{0.0232g}{1}$√
Divide by the smallest value	$\frac{0.0093}{0.0093}$	$\frac{0.0232}{0.0093}$ √
Mole ratios	1 x2	2.5x2

	2	5√

Empirical formula is $\mathbf{C_2H_5}$√

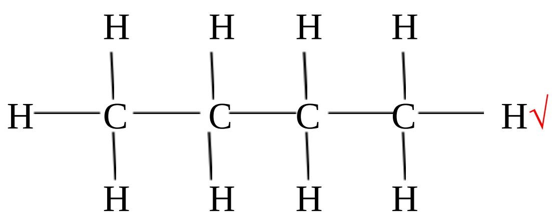
The molecular formular is thus determined :

n = Relative formular mass / Relative empirical formula = 58/29 = **2**√

The molecular formula is $(\mathbf{C_2H_5})$ x 2 = $\mathbf{C_4H_{10}}$.√

Molecule name **Butane**

Molecula structure



(e)**Gravimetric analysis**

Gravimetric analysis is the relationship between reacting masses and the volumes and /or masses of products. All reactants are in mole **ratios** to their products in accordance to their stoichiometric equation. Using the mole ration of reactants and products any volume and/or mass can be determined as in the examples:

1. Calculate the volume of carbon(IV)oxide at r.t.p produced when 5.0 g of calcium carbonate is strongly heated.(Ca=40.0, C= 12.0,O = 16.0,1 mole of gas =22.4 at r.t.p)

Chemical equation

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

Mole ratios 1: 1: 1

Molar Mass $CaCO_3$ =100g

Method 1

100g $CaCO_3(s)$ -> 24dm3 $CO_2(g)$ at r.t.p

5.0 g $CaCO_3(s)$ -> $\frac{5.0 \text{ g} \times 24\text{dm}^3}{100\text{g}}$ = **1.2dm3/1200cm3**

Method 2

Moles of 5.0 g $CaCO_3(s)$ = $\frac{5.0\ g}{100\ g}$ = **0.05** moles

Mole ratio 1:1
Moles of $CO_2(g)$ = **0.05**moles
Volume of $CO_2(g)$ = 0.05 x 24000cm3 =**1200cm3 /1.2dm3**

2. 1.0g of an alloy of aluminium and copper were reacted with excess hydrochloric acid. If 840cm3 of hydrogen at s.t.p was produced, calculate the % of copper in the alloy.(Al =27.0,one mole of a gas at s.t.p =22.4dm3)

Chemical equation
Copper does not react with hydrochloric acid
$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$
Method 1

$3H_2(g)$ = 3 moles x (22.4 x 1000)cm3 => 2 x 27 g Al
840cm3 => $\frac{840cm3 \times 2 \times 27}{3 \times 22.4 \times 1000}$ = **0.675**g of Aluminium
Total mass of alloy – mass of aluminium = mass of copper
=> 1.0g - 0.675g =**0.325**g of copper

% copper = $\frac{\text{mass of copper x100\%}}{\text{Mass of alloy}}$ = **32.5%**

Method 2
Mole ratio 2Al : $3H_2$ = 2:3
Moles of Hydrogen gas = $\frac{\text{volume of gas}}{\text{Molar gas volume}}$ => $\frac{840cm3}{22400cm3}$ =**0.0375moles**

Moles of Al = $^2/_3$ moles of H_2 => $^2/_3$x 0.0375moles = **0.025moles**

Mass of Al = moles x molar mass =>0.025moles x 27 = **0.675g**

Total mass of alloy – mass of aluminium = mass of copper
=> 1.0g - 0.675g = **0.325** g of copper

% copper= $\frac{\text{mass of copper x100\%}}{\text{Mass of alloy}}$ = **32.5%**

(f)Gay Lussac's law

Gay Lussacs law states that **"when gases combine/react they do so in simple volume ratios to each other and to their gaseous products at constant/same temperature and pressure"**

Gay Lussacs law thus only apply to gases

Given the volume of one gas reactant, the other gaseous reactants can be deduced thus:

Examples

1. Calculate the volume of Oxygen required to completely react with 50cm3 of Hydrogen.

Chemical equation:	$2H_2$ (g)	+	O_2 (g)	->	$2H_2O$(l)
Volume ratios	2	:	1	:	0
Reacting volumes	50cm3	:	**25cm3**		

50cm3 of Oxygen is used

2. Calculate the volume of air required to completely reacts with 50cm3 of Hydrogen.(assume Oxygen is 21% by volume of air)

Chemical equation: $2H_2$ (g) + O_2 (g) -> $2H_2O$(l)

Volume ratios	2	:	1	: 0
Reacting volumes	50cm3	:	**25cm3**	

50cm3 of Oxygen is used

21% = 25cm3

100% = $\frac{100 \times 25}{21}$ =

3.If 5cm3 of a hydrocarbon C_xH_y burn in 15cm3 of Oxygen to form 10cm3 of Carbon(IV)oxide and 10cm3 of water vapour/steam, obtain the equation for the reaction and hence find the value of x and y in C_xH_y.

Chemical equation:	C_xH_y (g)	+	O_2 (g)	->	H_2O(g)	+	CO_2(g)
Volumes	5cm3	:	15cm3	:	10cm3	:	10cm3
Volume ratios (divide by lowest volume)	$\frac{5cm3}{\mathbf{5}}$	:	$\frac{15cm3}{\mathbf{5}}$	:	$\frac{10cm3}{\mathbf{5}}$	:	$\frac{10cm3}{\mathbf{5}}$
Reacting volume ratios	1volume		3 volume		2 volume		2 volume

Balanced chemical equation:**C_xH_y (g) + 3O_2 (g) -> 2H_2O(g) + 2CO_2(g)**

If **"4H"** are in 2H_2O(g) the y=4

If **"2C"** are in 2CO_2 (g) the x=2

Thus(i) chemical formula of hydrocarbon = **C_2H_4**

(ii) chemical name of hydrocarbon = **Ethene**

4.100cm3 of nitrogen (II)oxide NO combine with 50cm3 of Oxygen to form 100cm3 of a single gaseous compound of nitrogen. All volumes measured at the same temperature and pressure. Obtain the equation for the reaction and name the gaseous product.

Chemical equation:	NO (g)	+	O_2 (g)	->	NO_x
Volumes	100cm3	:	50cm3	:	100
Volume ratios (divide by lowest volume)	$\frac{100cm3}{\mathbf{50}}$	:	$\frac{50cm3}{\mathbf{50}}$	:	$\frac{100cm3}{\mathbf{50}}$
Reacting volume ratios	2volume		1 volume		2 volume

Balanced chemical equation: 2 **NO (g) + O_2 (g) -> 2NO_x(g)**

Thus(i) chemical formula of the nitrogen compound = **2 NO_2**

(ii) chemical name of compound = **Nitrogen(IV)oxide**

5.When 15cm3 of a gaseous hydrocarbon was burnt in 100cm3 of Oxygen ,the resulting gaseous mixture occupied70cm3 at room temperature and pressure.

When the gaseous mixture was passed through, potassium hydroxide its volume decreased to 25cm3.

(a)What volume of Oxygen was used during the reaction.(1mk)

Volume of Oxygen used =100-25

=75cm3√ (P was completely burnt)

(b)Determine the molecular formula of the hydrocarbon(2mk)

C_xH_y + O_2 -> xCO_2 + yH_2O

15cm3 : 75cm3

15 15

1 : 3√

=> 1 atom of C react with 6 (3x2)atoms of Oxygen

Thus x = 1 and y = 2 => P has molecula formula CH_4√

(g) Ionic equations

An ionic equation is a chemical statement showing the movement of ions (cations and anions) from reactants to products.

Solids, **gases** and **liquids** do not ionize/dissociate into free ions. **Only** ionic compounds in **aqueous/solution** or **molten** state ionize/dissociate into free cations and anions (**ions**)

An ionic equation is usually derived from a stoichiometric equation by using the following guidelines

Guidelines for writing ionic equations

1.Write the balanced stoichiometric equation

2.Indicate the state symbols of the reactants and products

3.**Split** into cations and anions all the reactants and products that exist in **aqueous** state.

4.**Cancel out** any cation and anion that appear on **both** the product and reactant side.

5. Rewrite the chemical equation. It is an ionic equation.

Practice

(**a**)Precipitation of an insoluble salt

All insoluble salts are prepared in the laboratory from double decomposition /precipitation. This involves mixing **two soluble** salts to form **one soluble** and **one insoluble** salt

1. When silver nitrate(V) solution is added to sodium chloride solution,sodium nitrate(V) solution and a white precipitate of silver chloride are formed.

Balanced stoichiometric equation

$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

Split reactants product existing in aqueous state as cation/anion

$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$

Cancel out ions appearing on reactant and product side

$Ag^+(aq) + \cancel{NO_3^-}(aq) + \cancel{Na^+}(aq) + Cl^-(aq) \rightarrow AgCl(s) + \cancel{Na^+}(aq) + \cancel{NO_3^-}(aq)$

Rewrite the equation

$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$ (ionic equation)

2. When barium nitrate(V) solution is added to copper(II)sulphate(VI) solution, copper(II) nitrate(V) solution and a white precipitate of barium sulphate(VI) are formed.

Balanced stoichiometric equation

$Ba(NO_3)_2(aq) + CuSO_4(aq) \rightarrow BaSO_4(s) + Cu(NO_3)_2(aq)$

Split reactants product existing in aqueous state as cation/anion

$Ba^{2+}(aq) + 2NO_3^-(aq) + Cu^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + 2NO_3^-(aq) + Cu^{2+}(aq)$

Cancel out ions appearing on reactant and product side

$Ba^{2+}(aq) + \cancel{2NO_3^-}(aq) + \cancel{Cu^{2+}}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + \cancel{2NO_3^-}(aq) + \cancel{Cu^{2+}}(aq)$

Rewrite the equation

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ (ionic equation)

3.A yellow precipitate of Potassium Iodide is formed from the reaction of Lead(II)nitrate(v) and potassium iodide.

Balanced stoichiometric equation

$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$

Split reactants product existing in aqueous state as cation/anion

Pb^{2+}(aq) + **2**NO_3^- (aq) + 2K^+(aq) + 2I^- (aq) -> PbI_2 (**s**) + **2**NO_3^- (aq)+ 2K^+(aq)

Cancel out ions appearing on reactant and product side

Pb^{2+}(aq) + **2**NO_3^- (aq) + 2K^+(aq) + 2I^- (aq) -> PbI_2 (**s**) + **2**NO_3^- (aq)+ 2K^+(aq)

Rewrite the equation

Pb^{2+}(aq) + 2I^- (aq) -> PbI_2 (s) (ionic equation**)**

(**b**)Neutralization

Neutralization is the reaction of an acid with a **soluble** base/alkali or **insoluble** base.

(i)Reaction of alkalis with acids

1.Reaction of nitric(V)acid with potassium hydroxide

Balanced stoichiometric equation

HNO_3(aq) + KOH (aq) -> H_2O (**l**) + KNO_3 (aq)

Split reactants product existing in aqueous state as cation/anion

H^+(aq) + NO_3^- (aq) + K^+(aq) + OH^- (aq) -> H_2O (**l**) + NO_3^- (aq)+ K^+(aq)

Cancel out ions appearing on reactant and product side

H^+(aq) + NO_3^- (aq) + K^+(aq) + OH^- (aq) -> H_2O (**l**) + NO_3^- (aq)+ K^+(aq)

Rewrite the equation

H^+ (aq) + OH^- (aq) -> H_2O (l) (ionic equation)

2.Reaction of sulphuric(VI)acid with ammonia solution

Balanced stoichiometric equation

H_2SO_4(aq) + $2NH_4OH$ (aq) -> H_2O (**l**) + $(NH_4)_2SO_4$ (aq)

Split reactants product existing in aqueous state as cation/anion

$2H^+$(aq) + SO_4^{2-} (aq) + 2NH_4^+(aq)+ 2OH^- (aq) ->2H_2O (**l**) +SO_4^{2-} (aq)+ 2NH_4^+ (aq)

Cancel out ions appearing on reactant and product side

$2H^+$(aq) + SO_4^{2-} (aq) + 2NH_4^+(aq)+ 2OH^- (aq) ->2H_2O (**l**) +SO_4^{2-} (aq)+ 2NH_4^+ (aq)

Rewrite the equation

$2H^+$ **(aq) + 2OH** $^-$ **(aq) ->** **$2H_2O$ (l)**

H^+ (aq) + OH^- (aq) -> H_2O (l) (ionic equation)

3.Reaction of hydrochloric acid with Zinc hydroxide

Balanced stoichiometric equation

2HCl(aq) + $Zn(OH)_2$ (**s**) -> $2H_2O$ (**l**) + $ZnCl_2$ (aq)

Split reactants product existing in aqueous state as cation/anion

$2H^+$(aq) + $2Cl^-$ (aq) + $Zn(OH)_2$ (**s**) ->$2H_2O$ (**l**) + $2Cl^-$ (aq)+ Zn^{2+} (aq)

Cancel out ions appearing on reactant and product side

$2H^+$(aq) + ~~2~~Cl^- (aq) + $Zn(OH)_2$ (**s**) ->$2H_2O$ (**l**) + ~~2~~Cl^- (aq)+ Zn^{2+} (aq)

Rewrite the equation

$2H^+$(aq) + $Zn(OH)_2$ (**s**) ->$2H_2O$ (**l**) + Zn^{2+} (aq) **(ionic equation)**

(h)Molar solutions

A molar solution is one whose concentration is known. The SI unit of concentration is **Molarity** denoted **M**.

Molarity may be defined as the number of moles of solute present in **one** cubic **decimeter** of solution.

One cubic decimeter is equal to **one litre** and also equal to **1000cm3**.

The higher the molarity the higher the concentration and the higher/more solute has been dissolved in the solvent to make one cubic decimeter/ litre/1000cm3 **solution.**

Examples

2M sodium hydroxide means 2 moles of sodium hydroxide solute is dissolved in enough water to make one cubic decimeter/ litre/1000cm3 uniform **solution** mixture of sodium hydroxide and water.

0.02M sodium hydroxide means 0.02 moles of sodium hydroxide solute is dissolved in enough water to make one cubic decimeter/ litre/1000cm3 uniform **solution** mixture of sodium hydroxide and water.

"2M" is **more concentrated** than**"0.02M"**.

Preparation of molar solution

Procedure

Weigh accurately 4.0 g of sodium hydroxide pellets into a 250cm3 volumetric flask.

Using a wash bottle add about 200cm3 of distilled water.

Stopper the flask.

Shake vigorously for three minutes.

Remove the stopper for a second then continue to shake for about another two minutes until **all** the solid has dissolved.

Add more water slowly upto **exactly** the 250 cm3 **mark**.

Sample questions

1.Calculate the number of moles of sodium hydroxide pellets present in:

(i) 4.0 g.

Molar mass of NaOH = (23 + 16 + 1) = 40g

Moles = $\frac{\text{Mass}}{\text{Molar mass}}$ => $\frac{4.0}{40}$ = **0.1 / 1.0×10^{-1}** moles

(ii) 250 cm3 solution in the volumetric flask.

Moles in 250 cm3 = **0.1 / 1.0×10^{-1}** moles

(iii) one decimeter of solution

Method 1

Moles in decimeters = **Molarity** = $\frac{\text{Moles x 1000cm3/1dm3}}{\text{Volume of solution}}$

=> 1.0×10^{-1} moles x 1000cm3 =

= **0.4 M / 0.4 molesdm^{-3}**

Method 2

250cm3 solution contain 1.0×10^{-1} moles

1000cm3 solution = Molarity contain $\frac{1000 \times 1.0 \times 10^{-1} \text{ moles}}{250 \text{ cm3}}$

= **0.4 M / 0.4 molesdm^{-3}**

Theoretical sample practice

1. Calculate the molarity of a solution containing:

(i) 4.0 g sodium hydroxide dissolved in 500cm3 solution

Molar mass of NaOH = (23 + 16 + 1) = 40g

Moles = $\frac{\text{Mass}}{\text{Molar mass}}$ => $\frac{4.0}{40}$ = **0.1 / 1.0 x 10 $^{-1}$** moles

Method 1

Moles in decimeters = **Molarity** = $\frac{\text{Moles x 1000cm3/1dm3}}{\text{Volume of solution}}$

=> 1.0 x 10 $^{-1}$ moles x 1000cm3

= **0.2 M / 0.2 molesdm^{-3}**

Method 2

500 cm3 solution contain 1.0 x 10 $^{-1}$ moles

1000cm3 solution = Molarity contain $\frac{1000 \text{ x } 1.0 \text{ x } 10^{-1} \text{ moles}}{500 \text{ cm3}}$

= **0.2 M / 0.2 molesdm^{-3}**

(ii) 5.3 g anhydrous sodium carbonate dissolved in 50cm3 solution

Molar mass of Na_2CO_3 = (23 x 2 + 12 + 16 x 3) = 106 g

Moles = $\frac{\text{Mass}}{\text{Molar mass}}$ => $\frac{5.3}{106}$ = **0.05 / 5. 0 x 10^{-2}** moles

Method 1

Moles in decimeters = **Molarity** = $\frac{\text{Moles x 1000cm3/1dm3}}{\text{Volume of solution}}$

=> $\frac{\text{1.0 moles x 1000cm3}}{\text{50cm3}}$ =

=**1.0 M**

Method 2

50 cm3 solution contain 5.0 x 10 $^{-2}$ moles

1000cm3 solution = Molarity contain $\frac{1000 \text{ x } 5.0 \text{ x } 10^{-2} \text{ moles}}{50 \text{ cm3}}$

= **1.0M / 1.0 molesdm^{-3}**

(iii) 5.3 g hydrated sodium carbonate decahydrate dissolved in 50cm3 solution

Molar mass of $Na_2CO_3.10H_2O$ = (23 x 2 + 12 + 16 x 3 + 20 x 1 + 10 x 16) =286g

$$\text{Moles} = \frac{\text{Mass}}{\text{Molar mass}} \Rightarrow \frac{5.3}{286} = \mathbf{0.0185 / 1.85 \times 10^{-2}} \text{ moles}$$

Method 1

$$\text{Moles in decimeters} = \textbf{Molarity} = \frac{\text{Moles x 1000cm3/1dm3}}{\text{Volume of solution}}$$

$$\Rightarrow \underline{1.85 \times 10^{-2}} \ \underline{\text{moles x 1000cm3}} =$$

= **$\underline{0.37 \text{ M}/0.37 \text{ molesdm}^{-3}}$**

Method 2

50 cm3 solution contain 1.85×10^{-2} moles

$$\text{1000cm3 solution = Molarity contain } \frac{1000 \times 1.85 \times 10^{-2} \text{ moles}}{50 \text{ cm3}}$$

= **$\underline{3.7 \times 10^{-1} \text{ M} / 3.7 \times 10^{-1} \text{ molesdm}^{-3}}$**

(iv) 7.1 g of anhydrous sodium sulphate(VI)was dissolved in 20.0 cm3 solution. Calculate the molarity of the solution.

Method 1

20.0cm3 solution ->7.1 g

$$\text{1000cm3 solution} \rightarrow \frac{1000 \times 71}{20} = \underline{3550 \text{ g } \mathbf{dm^{-3}}}$$

Molar mass Na_2SO_4 = 142 g

$$\text{Moles } \mathbf{dm^{-3}} = \text{Molarity} = \frac{\text{Mass}}{\text{Molar mass}} \quad \frac{3550}{142} = \underline{2.5 \text{ M/ moles}\mathbf{dm^{-3}}}$$

Method 2

Molar mass Na_2SO_4 = 142 g

$$\text{Moles} = \frac{\text{Mass}}{\text{Molar mass}} \Rightarrow \frac{7.1}{142} = \mathbf{0.05 / 5.0 \times 10^{-2}} \text{ moles}$$

Method 2(a)

$$\text{Moles in decimeters} = \textbf{Molarity} = \frac{\text{Moles x 1000cm3/1dm3}}{\text{Volume of solution}}$$

$$\Rightarrow \frac{5.0 \times 10^{-2} \text{ moles x 1000cm3}}{20\text{cm3}}$$

= **$\underline{2.5 \text{ M}/2.5 \text{ molesdm}^{-3}}$**

Method 2(b)

20 cm3 solution contain 5.0×10^{-2} moles

1000cm3 solution = Molarity contain $\frac{1000 \times 5.0 \times 10^{-2} \text{ moles}}{20 \text{ cm3}}$

= **2.5 M/2.5 molesdm^{-3}**

(iv) The density of sulphuric(VI) is 1.84gcm^{-3} Calculate the molarity of the acid.

Method 1

1.0cm3 solution ->1.84 g

1000cm3 solution -> $\frac{1000 \times 1.84}{1}$ = 1840 g **dm^{-3}**

Molar mass H_2SO_4 = 98 g

Moles **dm^{-3}** = Molarity = $\frac{\text{Mass}}{\text{Molar mass}}$ = $\frac{1840}{98}$

= **18.7755 M**/ moles**dm^{-3}**

Method 2

Molar mass H_2SO_4 = 98 g

Moles = $\frac{\text{Mass}}{\text{Molar mass}}$ => $\frac{1.84}{98}$ = **0.0188 / 1.88 x 10^{-2}** moles

Method 2(**a**)

Moles in decimeters = **Molarity** = $\frac{\text{Moles} \times 1000\text{cm3/1dm3}}{\text{Volume of solution}}$

=> 1.88×10^{-2} $\frac{\text{moles} \times 1000\text{cm3}}{1.0\text{cm3}}$

= **18.8M/18.8 molesdm^{-3}**

Method 2(**b**)

20 cm3 solution contain 1.88×10^{-2} moles

1000cm3 solution = Molarity contain $\frac{1000 \times 1.88 \times 10^{-2} \text{ moles}}{1.0 \text{ cm3}}$

= **18.8M/18.8 molesdm^{-3}**

2. Calculate the mass of :

(i) 25 cm3 of 0.2M sodium hydroxide solution(Na =23.0.O =16.0, H=1.0)

Molar mass NaOH = **40g**

Moles in 25 cm3 = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{0.2 \text{ x } 25}{1000}$ = **0.005/5.0 x 10^{-3}**moles

Mass of NaOH =Moles x molar mass = 5.0 x 10^{-3} x 40 = **0.2 g**

(ii) 20 cm3 of 0.625 M sulphuric(VI)acid (S =32.0.O =16.0, H=1.0)

Molar mass H_2SO_4 = **98g**

Moles in 20 cm3 = $\frac{\text{Molarity x volume}}{1000}$=> $\frac{0.625 \text{ x } 20}{1000}$ = **0.0125/1.25.0 x 10^{-3}**moles

Mass of H_2SO_4 =Moles x molar mass => 5.0 x 10^{-3} x 40 = **0.2 g**

(iii) 1.0 cm3 of 2.5 M Nitric(V)acid (N =14.0.O =16.0, H=1.0)

Molar mass HNO_3 = **63 g**

Moles in 1 cm3 = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{2.5 \text{ x } 1}{1000}$ = **0.0025 / 2.5. x 10^{-3}**moles

Mass of HNO_3 =Moles x molar mass => 2.5 x 10^{-3} x 40 = **0.1 g**

3. Calculate the volume required to dissolve :
(a)(i) 0.25moles of sodium hydroxide solution to form a 0.8M solution

Volume (in cm3) = $\frac{\text{moles x 1000}}{\text{Molarity}}$ => $\frac{0.25 \text{ x } 1000}{0.8}$ = **312.5cm3**

(ii) 100cm3 was added to the sodium hydroxide solution above. Calculate the concentration of the solution.

C_1 x V_1 = C_2 x V_2 where:

C_1 = molarity/concentration before diluting/adding water
C_2 = molarity/concentration after diluting/adding water
V_1 = volume before diluting/adding water
V_2 = volume after diluting/adding water

=> 0.8M x 312.5cm3 = C_2 x (312.5 + 100)

C_2 = 0.8M x 312.5cm3 = **0.6061M**

412.5

(b)(ii) 0.01M solution containing 0.01moles of sodium hydroxide solution .

$$\text{Volume (in cm3)} = \frac{\text{moles x 1000}}{\text{Molarity}} \Rightarrow \frac{0.01 \times 1000}{0.01} = \mathbf{1000\ cm3}$$

(ii) Determine the quantity of water which must be added to the sodium hydroxide solution above to form a 0.008M solution.

$C_1 \times V_1 = C_2 \times V_2$ where:

C_1 = molarity/concentration before diluting/adding water

C_2 = molarity/concentration after diluting/adding water

V_1 = volume before diluting/adding water

V_2 = volume after diluting/adding water

=> 0.01M x 1000 cm3 = 0.008 x V_2

$$V_2 = \frac{0.01\text{M} \times 1000\text{cm3}}{0.008} = \mathbf{1250cm3}$$

Volume added = 1250 - 1000 = **250cm3**

(c)Volumetric analysis/Titration

Volumetric analysis/Titration is the process of determining unknown concentration of one reactant from a known concentration and volume of another. Reactions take place in simple mole ratio of reactants and products.

Knowing the concentration/ volume of one reactant, the other can be determined from the relationship:

$$\frac{M_1V_1}{n_1} = \frac{M_2V_2}{n_2}$$ where**:**

M_1 = Molarity of 1st reactant

M_2 = Molarity of 2nd reactant

V_1 = Volume of 1st reactant

V_1 = Volume of 2nd reactant

n_1 = number of moles of 1st reactant from stoichiometric equation

n_2 = number of moles of 2nd reactant from stoichiometric equation

Examples

1.Calculate the molarity of MCO_3 if 5.0cm3 of MCO_3 react with 25.0cm3 of 0.5M hydrochloric acid.(C=12.0 ,O =16.0)

Stoichiometric equation: $MCO_3(s) + 2HCl(aq) \rightarrow MCl_2(aq) + CO_2(g) + H_2O(l)$ Method 1

$\frac{M_1V_1}{n_1} = \frac{M_2V_2}{n_2}$ -> $\frac{M_1 \times 5.0cm3}{1} = \frac{0.5M \times 25.0cm3}{2}$

=> $M_1 = \frac{0.5 \times 25.0 \times 1}{5.0 \times 2}$ = **1.25M** / **1.25 moledm^{-3}**

Method 2

Moles of HCl used = $\frac{\text{molarity x volume}}{1000}$

=> $\frac{0.5 \times 25.0}{1000}$ = **0.0125 /1.25 x 10^{-2}moles**

Mole ratio MCO_3 : HCl = 1:2

Moles MCO_3 = $\frac{0.0125 / 1.25 \times 10^{-2} \text{moles}}{2}$ = **0.00625 / 6.25 x 10^{-3} moles**

Molarity MCO_3 = $\frac{\text{moles x 1000}}{\text{Volume}}$ => $\frac{0.00625 / 6.25 \times 10^{-3} \times 1000}{5}$

= **1.25M / 1.25 moledm^{-3}**

2. 2.0cm3 of 0.5M hydrochloric acid react with 0.1M of M_2CO_3. Calculate the volume of 0.1M M_2CO_3 used.

Stoichiometric equation: M_2CO_3 (aq) + 2HCl(aq) -> 2MCl (aq) + CO_2(g) + H_2O(l) Method 1

$\frac{M_1V_1}{n_1} = \frac{M_2V_2}{n_2}$ -> $\frac{0.5 \times 2.0cm3}{2} = \frac{0.1M \times V_2 cm3}{1}$

=> V_2= $\frac{0.5 \times 2.0 \times 1}{0.1 \times 2}$ = **1.25M** / **1.25 moledm^{-3}**

Method 2

Moles of HCl used = $\frac{\text{molarity x volume}}{1000}$

=> $\frac{0.5 \times 2.0}{1000}$ = **0.0125 /1.25 x 10^{-2}moles**

Mole ratio M_2CO_3 : HCl = 1:2

Moles M_2CO_3 = $\frac{0.0125 / 1.25 \times 10^{-2} \text{moles}}{2}$ = **0.00625 / 6.25 x 10^{-3} moles**

Molarity M_2CO_3 = $\frac{\text{moles x 1000}}{\text{Volume}}$ => $\frac{0.00625 / 6.25 \times 10^{-3} \times 1000}{5}$

$= \underline{\mathbf{1.25M}}$ **/** $\underline{\mathbf{1.25\ moledm^{-3}}}$

3. 5.0cm3 of 0.1M sodium iodide react with 0.1M of Lead(II)nitrate(V). Calculate(i) the volume of Lead(II)nitrate(V) used.

(ii)the mass of Lead(II)Iodide formed

(Pb=207.0, I =127.0)

Stoichiometric equation: $2NaI(aq) + Pb(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + PbI_2(s)$

(i)Volume of Lead(II)nitrate(V) used

Method 1

$$\frac{M_1V_1}{n_1} = \frac{M_2V_2}{n_2} \rightarrow \frac{5 \times 0.1cm3}{2} = \frac{0.1M \times V_2 cm3}{1}$$

$$\Rightarrow V_2 = \frac{0.1 \times 5.0 \times 1}{0.1 \times 2} = \mathbf{1.25M} \ / \mathbf{1.25\ moledm^{-3}}$$

Method 2

Moles of HCl used = $\frac{\text{molarity x volume}}{1000}$

$$\Rightarrow \frac{0.1 \times 5.0}{1000} = \mathbf{0.0125 / 1.25 \times 10^{-2} moles}$$

Mole ratio M_2CO_3 : HCl = 1:2

Moles M_2CO_3 = $\frac{0.0125 / 1.25 \times 10^{-2} moles}{2}$ = $\mathbf{0.00625 / 6.25 \times 10^{-3}\ moles}$

Molarity M_2CO_3 = $\frac{\text{moles x 1000}}{\text{Volume}}$ => $\frac{0.00625 / 6.25 \times 10^{-3} \times 1000}{5}$

$= \underline{\mathbf{1.25M}}$ **/** $\underline{\mathbf{1.25\ moledm^{-3}}}$

4. 0.388g of a monobasic organic acid B required 46.5 cm3 of 0.095M sodium hydroxide for complete neutralization. Name and draw the structural formula of B

Moles of NaOH used = $\frac{\text{molarity x volume}}{1000}$

$$\Rightarrow \frac{0.095 \times 46.5}{1000} = \mathbf{0.0044175 / 4.4175 \times 10^{-3} moles}$$

Mole ratio B : NaOH = 1:1

Moles B = **0.0044175 /4.4175 x 10^{-3}moles**

Molar mass B = $\frac{\text{mass}}{\text{moles}}$ => $\frac{0.388}{0.0044175 /4.4175 \times 10^{-3}\text{moles}}$

= **87.8324 gmole^{-1}**

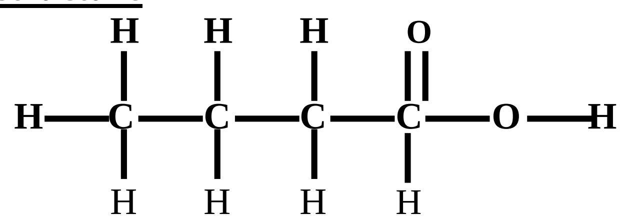
X-COOH = 87.8324 where X is an alkyl
group X =87.8324- 42 = 42.8324=43

By elimination: CH_3 = 15 CH_3CH_2 = 29 **CH_3CH_2 CH_2 = 43**

Molecula formula : CH_3CH_2 CH_2COOH

Molecule name : Butan-1-oic acid

Molecular structure



5. 10.5 g of an impure sample containing ammonium sulphate (VI) fertilizer was warmed with 250cm3 of o.8M sodium hydroxide solution.The excess of the alkali was neutralized by 85cm3 of 0.5M hydrochloric acid. Calculate the % of impurities in the ammonium sulphate (VI)fertilizer. (N=14.0,S=32.0,O=16.0, H=1.0)

Equation for neutralization

NaOH(aq) + HCl(aq) -> NaOH(aq) + H_2O(l)

Mole ratio NaOH(aq):HCl(aq)= 1:1

Moles of HCl = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{0.5 \times 85}{1000}$ = **0.0425 moles**

Excess moles of NaOH(aq)= **0.0425 moles**

Equation for reaction with ammonium salt

2NaOH(aq) + $(NH_4)_2SO_4$(aq) -> Na_2SO_4(aq) + $2NH_3$ (g)+$2H_2O$(l)

Mole ratio NaOH(aq): $(NH_4)_2SO_4$(aq)= 2:1

Total moles of NaOH = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{0.8 \times 250}{1000}$ = **0.2 moles**

Moles of NaOH that reacted with$(NH_4)_2SO_4$ = 0.2 - 0.0425 = **0.1575moles**

Moles $(NH_4)_2SO_4$ = ½ x 0.1575moles = **0. 07875moles**

Molar mass $(NH_4)_2SO_4$= **132 gmole^{-1}**

Mass of in impure sample = moles x molar mass =>0. 07875 x 132 = **10.395 g**

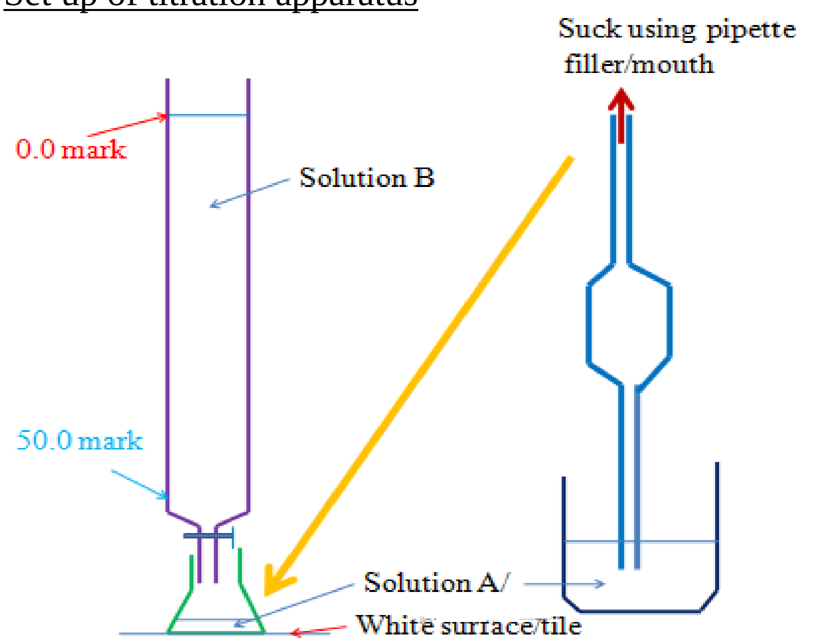
Mass of impurities = 10.5 -10.395 = **0.105 g**

% impurities = $\frac{0.105 \times 100}{10.5}$ = **1.0 %**

Practically volumetric analysis involves **titration**.

Titration generally involves filling a burette with known/unknown concentration of a solution then adding the solution to unknown/known concentration of another solution in a conical flask until there is complete reaction. If the solutions used are both colourless, an **indicator** is added to the conical flask. When the reaction is over, a **slight**/**little** excess of burette contents **change** the colour of the indicator. This is called the **end point**.

Set up of titration apparatus



Set up of Titration apparatus

The titration process involve involves determination of **titre.** The titre is the volume of burette contents/reading **before** and **after** the end point. Burette contents/reading **before** titration is usually called the **Initial** burette reading. Burette contents/reading **after** titration is usually called the **Final** burette reading. The titre value is thus a sum of the **Final** less **Initial** burette readings.

To reduce errors, titration process should be repeated at least once more. The results of titration are recorded in a **titration table** as below

Sample titration table

Titration number	1	2	3
Final burette reading (cm3)	20.0	20.0	20.0
Initial burette reading (cm3)	0.0	0.0	0.0
Volume of solution used(cm3)	20.0	20.0	20.0

As **evidence** of a titration **actually** done examining body requires the candidate to record their burette readings before and after the titration.

For KCSE candidates burette readings **must** be recorded **in** a titration table in the **format provided** by the Kenya National Examination Council.

As **evidence** of all titration **actually** done Kenya National Examination Council require the candidate to record their burette readings before and after the titration to complete the titration table **in the format provided**.

Calculate the average volume of solution used

$$\frac{24.0 + 24.0 + 24.0}{3} = \mathbf{24.0\ cm3}$$

As evidence of understanding the degree of accuracy of burettes , all readings must be recorded to **a** decimal point.

As evidence of accuracy in carrying the out the titration , candidates value should be **within 0.2** of the **school value** .

The school value is the **teachers** readings presented to the examining body/council based on the concentrations of the solutions s/he presented to her/his candidates. Bonus mark is awarded for averaged reading **within 0.1** school value as Final answer.

Calculations involved after the titration require candidates **thorough** practical and theoretical **practice mastery** on the:

(**i**)relationship among the mole, molar mass, mole ratios, concentration, molarity.
(**ii**) mathematical application of 1^{st} principles.

Very useful information which candidates forget appears usually in the beginning of the question paper as:
"You are provided with…"

All calculation must be to the **4^{th} decimal point** unless they divide fully to a lesser decimal point.
Candidates are expected to use a non programmable scientific calculator.

(**a**)Sample Titration Practice 1 **(Simple Titration)**

You are provided with:

0.1M sodium hydroxide solution A
Hydrochloric acid solution B

You are required to determine the concentration of solution B in moles per litre.

Procedure

Fill the burette with solution B. Pipette 25.0cm3 of solution A into a conical flask. Titrate solution A with solution B using phenolphthalein indicator to complete the titration table 1

Sample results Titration table 1

Titration number	1	2	3
Final burette reading (cm3)	**20.0**	**20.0**	**20.0**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of solution B used(cm3)	**20.0**	**20.0**	**20.0**

Sample worked questions

1. Calculate the average volume of solution B used

Average titre = $\frac{\text{Titre 1 + Titre 2 +Titre 3}}{3}$ => $\frac{(20.0 +20.0 +20.0)}{3}$ = **20.0cm3**

2. How many moles of:

(i)solution A were present in 25cm3 solution.

Moles of solution A = $\frac{\text{Molarity x volume}}{1000}$ = $\frac{0.1 \times 25}{1000}$ = **2.5×10^{-3}** moles

(ii)solution B were present in the average volume.

Chemical equation: $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

Mole ratio 1:1 => Moles of A = Moles of B = **2.5×10^{-3}** moles

(iii) solution B in moles per litre.

Moles of B per litre = $\frac{\text{moles x 1000}}{\text{Volume}}$ = $\frac{2.5 \times 10^{-3} \times 1000}{20}$ = **0.1M** (**b**)Sample Titration Practice 2 **(Redox Titration)**

You are provided with:

Acidified Potassium manganate(VII) solution
A 0.1M of an iron (II)salt solution B
8.5g of ammonium iron(II)sulphate(VI) crystals$(NH_4)_2SO_4FeSO_4.xH_2O$ solid C

You are required to

(i)standardize acidified potassium manganate(VII)
(ii)determine the value of x in the formula $(NH_4)_2\ SO_4FeSO_4.xH_2O$.

Procedure 1

Fill the burette with solution A. Pipette 25.0cm3 of solution B into a conical flask. Titrate solution A with solution B until a pink colour just appears.
Record your results to complete table 1.

Table 1:**Sample results**

Titration number	1	2	3
Final burette reading (cm3)	**20.0**	**20.0**	**20.0**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of solution A used(cm3)	**20.0**	**20.0**	**20.0**

Sample worked questions

1. Calculate the average volume of solution A used

Average titre = $\frac{\text{Titre 1 + Titre 2 + Titre 3}}{3}$ => $\left(\frac{20.0 + 20.0 + 20.0}{3}\right)$ = **20.0cm3**

2. How many moles of:

(i)solution B were present in 25cm3 solution.

Moles of solution A = $\frac{\text{Molarity x volume}}{1000}$ = $\frac{0.1 \times 25}{1000}$ = **2.5×10^{-3}** moles

(ii)solution A were present in the average volume. Assume one mole of B react with five moles of B

Mole ratio A : B = 1:5

=> Moles of A = $\frac{\text{Moles of B}}{5}$ = $\frac{2.5 \times 10^{-3}\ \text{moles}}{5}$ = **5.0×10^{-4} moles**

(iii) solution B in moles per litre.

Moles of B per litre = $\frac{\text{moles x 1000}}{\text{Volume}}$ = $\frac{2.5 \times 10^{-3} \times 1000}{20}$

= **0.025** M /moles per litre /moles l^{-1}

Procedure 2

Place all the solid C into the 250cm3 volumetric flask carefully. Add about 200cm3 of distilled water. Shake to dissolve. Make up to the 250cm3 of solution by adding more distilled water. Label this solution C. Pipette 25cm3 of solution C into a conical flask, Titrate solution C with solution A until a permanent pink colour just appears. Complete table 2.

Table 2:**Sample results**

Titration number	1	2	3
Final burette reading (cm3)	**20.0**	**20.0**	**20.0**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of solution A used(cm3)	**20.0**	**20.0**	**20.0**

Sample worked questions

1. Calculate the average volume of solution A used

Average titre = $\frac{\text{Titre 1 + Titre 2 +Titre 3}}{3}$ => ($\frac{20.0 + 20.0 + 20.0}{3}$) = **20.0cm3**

2. How many moles of:

(i)solution A were present inin the average titre.

Moles of solution A = $\frac{\text{Molarity x volume}}{1000}$ = $\frac{0.025 \times 20}{1000}$ = **5.0×10^{-4}** moles

(ii)solution C in 25cm3 solution given the equation for the reaction:

MnO_4^- (aq) + $8H^+$(aq) + $5Fe^{2+}$ (aq) -> Mn^{2+}(aq) + $5Fe^{3+}$(aq) + $4H_2O$(l)

Mole ratio MnO_4^- (aq): $5Fe^{2+}$ (aq) = 1:5 =>

Moles of $5Fe^{2+}$ (aq) = $\frac{\text{Moles of} MnO_4^- \text{(aq)}}{5}$ = $\frac{5.0 \times 10^{-4}}{5}$ moles = **1.0×10^{-4} moles**

(iii) solution B in 250cm3.

Moles of B per litre = $\frac{\text{moles x 250}}{\text{Volume}}$ = $\frac{1.0 \times 10^{-4} \times 250}{25}$ = **1.0×10^{-3} moles**

3. Calculate the molar mass of solid C and hence the value of x in the chemical formula $(NH_4)_2SO_4FeSO_4.xH_2O$.

(N=14.0, S=32.0, Fe=56.0, H=1.0 O=16.0)

Molar mass = $\frac{\text{mass perlitre}}{\text{Moles per litre}}$ = $\frac{8.5}{1.0 \times 10^{-3} \text{ moles}}$ = **8500 g**

$NH_4)_2SO_4FeSO_4.xH_2O$ = 8500

284 + 18x =8500

8500 - 284 = $\frac{8216}{18}$= $\frac{18x}{18}$ = **454.4444**

x = **454** (whole number)

(c) Sample Titration Practice 3 **(Back titration)**

You are provided with:

(i)an impure calcium carbonate labeled M

(ii)Hydrochloric acid labeled solution N

(iii)solution L containing 20g per litre sodium hydroxide.

You are required to determine the concentration of N in moles per litre and the % of calcium carbonate in mixture M.

Procedure 1

Pipette 25.0cm3 of solution L into a conical flask. Add 2-3 drops of phenolphthalein indicator. Titrate with dilute hydrochloric acid solution N and record your results in table 1(4mark)

Sample Table 1

	1	2	3
Final burette reading (cm3)	**6.5**	**6.5**	**6.5**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of N used (cm3)	**6.5**	**6.5**	**6.5**

Sample questions

(a) Calculate the average volume of solution N used $\frac{6.5 + 6.5 + 6.5}{3}$ = **6.5** cm3

(b) How many moles of sodium hydroxide are contained in 25cm3of solution L Molar mass NaOH =**40**g

Molarity of L = mass per litre => 20 = **0.5**M

Molar mass NaOH 40

Moles NaOH in 25cm3 = $\frac{\text{molarity x volume}}{1000}$ => $\frac{\text{0.5M x 25cm3}}{1000}$ = **0.0125** moles

(c)Calculate:

(i)the number of moles of hydrochloric acidthat react with sodium hydroxide in (b)above.

Mole ratio NaOH : HCl from stoichiometric equation= **1:1**

Moles HCl =Moles NaOH => **0.0125** moles

(ii)the molarity of hydrochloric acid solution N.

Molarity = $\frac{\text{moles x 1000}}{6.5}$ => $\frac{\text{0.0125 moles x 1000}}{6.5}$ =**1.9231**M/moledm^{-3}

Procedure 2

Place the 4.0 g of M provided into a conical flask and add 25.0cm3 of the dilute hydrochloric acid to it using a clean pipette. Swirl the contents of the flask vigorously until effervescence stop.Using a 100ml measuring cylinder add 175cm3 distilled waterto make up the solution up to 200cm3.Label this solution K.Using a clean pipettetransfer 25.0cm3 of the solution into a clean conical flask and titrate with solution L from the burette using 2-3 drops of methyl orange indicator.Record your observations in table 2.

Sample Table 2

	1	2	3
Final burette reading (cm3)	**24.5**	**24.5**	**24.5**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of N used (cm3)	**24.5**	**24.5**	**24.5**

Sample calculations

(a)Calculate the average volume of solution L used(1mk)

$\frac{24.5 + 24.5 + 24.5}{3}$ = **24.5**cm3

(b)How many moles of sodium hydroxide are present in the average volume of solution L used?

Moles = $\frac{\text{molarity x average burette volume}}{1000}$ => $\frac{0.5 \text{ x } 24.5}{1000}$

= **0.01225 /1.225 x 10^{-2}** moles

(c) How many moles of hydrochloric acid are present in the original 200cm3 of solution K?

Mole ratio NaOH: HCl = 1:1 => moles of HCl = **0.01225 /1.225 x 10^{-2}** moles

Moles in 200cm3 = $\frac{200cm3 \times 0.01225 / 1.225 \times 10^{-2} moles}{25cm3 (volume\ pipetted)}$

=**0.49 /4.9 x 10^{-1}**moles

(d)How many moles of hydrochloric acid were contained in original 25 cm3 solution N used

Original moles = $\frac{Original\ molarity \times pipetted\ volume}{1000cm3}$ =>

$\frac{1.9231 M/moledm^{-3} \times 25}{}$ = **0.04807/4.807 x 10^{-2}** moles

(e)How many moles of hydrochloric acid were used to react with calcium carbonate present?

Moles that reacted = original moles –moles in average titre =>

0.04807/4.807 x 10^{-2}moles - 0.01225 /1.225 x 10^{-2}moles

= **0.03582/3.582 x 10^{-2}** moles

(f)Write the equation for the reaction between calcium carbonate and hydrochloric acid.

$CaCO_3(s)$ + 2HCl(aq) -> $CaCl_2(aq)$ + $CO_2(g)$ + $H_2O(l)$

(g)Calculate the number of moles of calcium carbonate that reacted with hydrochloric acid.

From the equation $CaCO_3(s)$:2HCl(aq) = 1:2

=> Moles $CaCO_3(s)$ = $^1/_2$moles HCl

= $^1/_2$ x 0.03582/3.582 x 10^{-2} moles

= **0.01791 /1.791 x 10^{-2}**moles

(h)Calculate the mass of calcium carbonate in 4.0g of mixture M (Ca=40.0,O = 16.0,C=12.0)

Molar mass $CaCO_3$ = 100g
Mass $CaCO_3$ = moles x molar mass => 0.01791 /1.791 x 10^{-2}moles x 100g
= **1.791**g

(i)Determine the % of calcium carbonate present in the mixture

$$\% CaCO_3 = \frac{\text{mass of pure x 100\%}}{\text{Mass of impure}} \Rightarrow \frac{1.791\text{g x 100\%}}{4.0} = \mathbf{44.775}\%$$

(d)Sample titration practice 4 (**Multiple titration**)

You are provided with:

(i)sodium L containing 5.0g per litre of a dibasic organic acid $H_2X.2H_2O$. (ii)solution M which is acidified potassium manganate(VII)
(iii)solution N a mixture of sodium ethanedioate and ethanedioic acid (iv)0.1M sodium hydroxide solution P (v)1.0M sulphuric(VI)

You are required to:

(i)standardize solution M using solution L
(ii)use standardized solution M and solution P to determine the % of sodium ethanedioate in the mixture.

Procedure 1

Fill the burette with solution M. Pipette 25.0cm3 of solution L into a conical flask. Heat this solution to about 70^{o}C(**but not to boil**).Titrate the hot solution L with solution M until a permanent pink colour just appears .Shake thoroughly during the titration. Repeat this procedure to complete table 1.

Sample Table 1

	1	2	3
Final burette reading (cm3)	**24.0**	**24.0**	**24.0**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of N used (cm3)	**24.0**	**24.0**	**24.0**

Sample calculations

(a)Calculate the average volume of solution L used (1mk)

$$\frac{24.0 + 24.0 + 24.0}{3} = \mathbf{24.0}\text{cm3}$$

(b)Given that the concentration of the dibasic acid is 0.05molesdm^{-3}.determine the value of x in the formula $H_2X.2H_2O$ (H=1.0,O=16.0)

Molar mass $H_2X.2H_2O = \frac{\text{mass per litre}}{\text{Moles/litre}} \Rightarrow \frac{5.0\text{g/litre}}{0.05\text{molesdm}^{-3}} = \mathbf{100}$g

$H_2X.2H_2O$ =100

X = 100 – ((2 x1) + 2 x (2 x1) + (2 x 16) => 100 – 34=**66**

(c) Calculate the number of moles of the dibasic acid $H_2X.2H_2O$.

Moles = $\frac{\text{molarity x pipette volume}}{1000} \Rightarrow \frac{0.5 \times 25}{1000} =$ **0.0125/1.25 x10 $^{-2}$** moles

(d)Given the mole ratio manganate(VII)(MnO_4^-): acid H_2X is 2:5, calculate the number of moles of manganate(VII) (MnO_4^-) in the average titre.

Moles H_2X = $^2/_5$ moles of MnO_4^-

=> $^2/_5$ x 0.0125/1.25 x10 $^{-2}$ moles

= **0.005/5.0 x 10 $^{-3}$**moles

(e)Calculate the concentration of the manganate(VII)(MnO_4^-) in moles per litre.

Moles per litre/molarity = $\frac{\text{moles x 1000}}{\text{average burette volume}}$

=> $\frac{0.005/5.0 \times 10^{-3}\text{moles} \times 1000}{24.0}$ = **0.2083** molesl^{-1}/M

Procedure 2

With solution M still in the burette ,pipette 25.0cm3 of solution N into a conical flask. Heat the conical flask containing solution N to about 70^{o}C.Titrate while hot with solution M.Repeat the experiment to complete table 2.

Sample Table 2

	1	2	3
Final burette reading (cm3)	**12.5**	**12.5**	**12.5**

Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of N used (cm3)	**12.5**	**12.5**	**12.5**

Sample calculations

(a)Calculate the average volume of solution L used (1mk)

$$\frac{12.5 + 12.5 + 12.5}{3} = \mathbf{12.5}\text{cm3}$$

(b)Calculations:

(i)How many moles of manganate(VII)ions are contained in the average volume of solution M used?

$$\text{Moles} = \frac{\text{molarity of solution M x average burette volume}}{1000}$$

=> $\frac{0.2083 \text{ molesl}^{-1}/ \text{M x } 12.5}{1000}$ = **0.0026 / 2.5 x 10^{-3}** moles

(ii)The reaction between manganate(VII)ions and ethanedioate ions that reacted with is as in the equation:

$2MnO_4^-$ (aq) + $5C_2O_4^{2-}$ (aq) + $16H^+$ (aq) -> $2Mn^{2+}$(aq) + $10CO_2$(g) + $8H_2O$(l)

Calculate the number of moles of ethanedioate ions that reacted with manganate (VII) ions in the average volume of solution M.

From the stoichiometric equation,mole ratio MnO_4^- (aq): $C_2O_4^{2-}$ (aq) = 2:5

=> moles $C_2O_4^{2-}$ = $^5/_2$ moles MnO_4^- => $^5/_2$ x 0.0026 / 2.5 x 10^{-3} moles

= **0.0065 /6.5 x10^{-3}** moles

(iii)Calculate the number of moles of ethanedioate ions contained in 250cm3 solution N.

25cm3 pipette -> 0.0065 /6.5 x10^{-3} moles
volume 250cm3 ->

$$\frac{0.0065 / 6.5 \times 10^{-3} \text{ moles} \times 250}{25} = \mathbf{0.065 / 6.5 \times 10^{-2}} \text{ moles}$$

Procedure 3

Remove solution M from the burette and rinse it with distilled water. Fill the burette with sodium hydroxide solution P. Pipette 25cm3 of solution N into a conical flask and add 2-3 drops of phenolphthalein indicator. Titrate this solution N with solution P from the burette. Repeat the procedure to complete table 3.

Sample Table 2

	1	2	3
Final burette reading (cm3)	**24.9**	**24.9**	**24.9**
Initial burette reading (cm3)	**0.0**	**0.0**	**0.0**
Volume of N used (cm3)	**24.9**	**24.9**	**24.9**

Sample calculations

(a)Calculate the average volume of solution L used (1mk)

$$\frac{24.9 + 24.9 + 24.9}{3} = \mathbf{24.9\ cm3}$$

(b)Calculations:

(i)How many moles of sodium hydroxide solution P were contained in the average volume?

$$\text{Moles} = \frac{\text{molarity of solution P x average burette volume}}{1000}$$

$$=> \quad \frac{0.1\ \text{molesl}^{-1} \times 24.9}{1000} = \mathbf{0.00249 / 2.49 \times 10^{-3}}\ \text{moles}$$

(ii)Given that NaOH solution P reacted with the ethanedioate ions from the acid only and the equation for the reaction is:

$2NaOH (aq) + H_2C_2O_4 (aq) \rightarrow Na_2C_2O_4(g) + 2H_2O(l)$

Calculate the number of moles of ethanedioic acid that were used in the reaction

From the stoichiometric equation,mole ratio NaOH(aq): $H_2C_2O_4$ (aq) = 2:1

=> moles $H_2C_2O_4$ = $^1/_2$ moles NaOH => $^1/_2$ x 0.00249 / 2.49 x 10^{-3} moles

= **$0.001245/1.245 \times 10^{-3}$** moles.

(iii)How many moles of ethanedioic acid were contained in 250cm3 of solution N?

25cm3 pipette volume -> 0.001245/1.245 x10-3 moles

250cm3 ->

$$\frac{0.001245/1.245 \times 10^{-3} \text{ moles} \times 250}{25} = \mathbf{0.01245/1.245 \times 10^{-2}} \text{ moles}$$

(iii)Determine the % by mass of sodium ethanedioate in the micture
(H= 1.0,O=16.0,C=12.0 and total mass of mixture =2.0 g in 250cm3 solution)

Molar mass $H_2C_2O_4$ = **90.0**g

Mass of $H_2C_2O_4$ in 250cm3 = moles in 250cm3 x molar mass $H_2C_2O_4$

=>0.01245/1.245 x10^{-2} moles x 90.0

= **1.1205**g

% by mass of sodium ethanedioate

$$= \frac{(\text{Mass of mixture} - \text{mass of } H_2C_2O_4)}{\text{Mass of mixture}} \times 100\%$$

$$\Rightarrow \frac{2.0 - 1.1205 \text{ g}}{2.0} = \mathbf{43.975}\%$$

Note

(i) L is 0.05M Oxalic acid

(ii) M is 0.01M KMnO4

(iii) N is 0.03M oxalic acid(without sodium oxalate)

Practice example 5.(Determining equation for a reaction)

You are provided with

-0.1M hydrochloric acid solution A

-0.5M sodium hydroxide solution B

You are to determine the equation for thereaction between solution A and B

Procedure

Fill the burette with solution A.Using a pipette and pipette filler transfer 25.0cm3 of solution B into a conical flask.Add 2-3 drops of phenolphthalein indicator.Run solution A into solution B until a permanent pink colour just appears.Record your results in Table 1.Repeat the experiment to obtain three concordant results to complete Table 1

Table 1(Sample results)

Titration	1	2	3
Final volume(cm3)	**12.5**	**25.0**	**37.5**
Initial volume(cm3)	**0.0**	**12.5**	**25.0**
Volume of solution A used(cm3)	**12.5**	**12.5**	**12.5**

Sample questions

Calculate the average volume of solution A used.

$$\frac{12.5+12.5+12.5}{3} = \textbf{12.5cm3}$$

Theoretical Practice examples

1. 1.0g of dibasic acid $HOOC(CH_2)_xCOOH$ was dissolved in 250cm3 solution. 25.0 cm3 of this solution reacted with 30.0cm3 of 0.06M sodium hydroxide solution. Calculate the value of x in $HOOC(CH_2)_xCOOH$. (C=12.0,H=1.0,O=16.)

Chemical equation

$2NaOH(aq) + H_2X(aq) \rightarrow Na_2X(aq) + 2H_2O(aq)$

Mole ratio $NaOH(aq) : H_2X(aq) = 2:1$

Method 1

$$\frac{M_a V_a = n_a}{M_b V_b = n_b} \Rightarrow \frac{M_a \times 25.0}{0.06 \times 30.0} = \frac{1}{2} \Rightarrow M_a = \frac{0.06 \times 30.0 \times 1}{25.0 \times 2}$$

Molarity of acid = **0.036M/Mole l^{-1}**

Mass of acid per lite = $\frac{1.0 \times 1000}{250}$ = **4.0 g/l**

0.036M/ Mole l^{-1} -> 4.0 g /l

1 mole= molar mass of $HOOC(CH_2)_xCOOH$ = $\frac{4.0 \times 1}{0.036}$ = **111.1111**g

Molar mass $(CH_2)_x$ = 111.1111 – (HOOCCOOH = 90.0) **= 21.1111**

$(CH_2)_x = 14x = \frac{21.1111}{14}$ = **1.5 = 1 (whole number)**

Method 2

Moles of sodium hydroxide = $\frac{\text{Molarity x volume}}{1000}$ = 0.06 x 30 = **1.8 x 10 $^{-3}$moles**

Moles of Hydrochloric acid = $^{1}/_{2}$ x 1.8 x 10 $^{-3}$moles = 9.0 x10 $^{-4}$moles

Molarity of Hydrochloric acid = $\frac{\text{moles x 1000}}{\text{Volume}}$ = $\frac{9.0 \text{ x}10^{-4}\text{moles x}1000}{25}$

Molarity of acid = **0.036M/Mole l^{-1}**

Mass of acid per lite = $\frac{1.0 \text{ x}1000}{250}$ = **4.0 g/l**

0.036M/ Mole l^{-1} -> 4.0 g /l

1 mole= molar mass of $HOOC(CH_2)_xCOOH$ = $\frac{4.0 \text{ x } 1}{0.036}$ = **111.1111**g

Molar mass $(CH_2)_x$ = 111.1111 – (HOOCCOOH = 90.0) **= 21.1111**

$(CH_2)_x$ = 14x = $\frac{21.1111}{14}$ = **1.5 = 1 (whole number)**

2. 20.0cm3 of 0.05 M acidified potassium manganate(VII)solution oxidized 25.0cm3 of Fe^{2+}(aq) ions in 40.0g/l of impure Iron (II)sulphate(VI) to Fe^{3+}(aq) ions. Calculate the percentage impurities in the Iron (II)sulphate(VI).

MnO_4^- (aq) + $8H^+$(aq)+ $5Fe^{2+}$(aq)-> $5Fe^{3+}$(aq) + Mn^{2+}(aq) + $4H_2O$(aq) Fe=56.0,S= 32.0, O=16.0).

Moles of MnO_4^- (aq) = $\frac{\text{Molarity x volume}}{1000}$ = $\frac{0.05 \text{ x } 20.0}{1000}$ =**0.001 Moles**

Mole ratio MnO_4^- (aq): $5Fe^{2+}$(aq)= 1:5

Moles $5Fe^{2+}$(aq) **=** 5 x0.001 **= 0.005 Moles**

Moles of $5Fe^{2+}$(aq) per litre/molarity = $\frac{\text{Moles x 1000}}{\text{Volume}}$ = $\frac{0005 \text{ x } 1000}{25.0}$

= 0.2 M/ Moles/litre

Molar mass =$FeSO_4$=**152 g**

Mass of in the mixture = Moles x molar mass => 0.2 x 152 = **30.4** g

Mass of impurity = 40.0 – 30.4 =**9.6 g**

% impurity = $\frac{9.6 \text{ g} \times 100}{40.0}$ = **24.0 % impurity**

3.9.7 g of a mixture of Potassium hydroxide and Potassium chloride was dissolved to make one litre solution.20.0cm3 of this solution required 25.0cm3 of 0.12M hydrochloric acid for completed neutralization. Calculate the percentage by mass of Potassium chloride.(K=39.0,Cl= 35.5)

Chemical equation

$KOH(aq) + HCl(aq) \rightarrow KCl(aq) + H_2O(l)$

Moles of HCl = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{0.12 \times 25.0}{1000}$ = **0.003/3.0 x 10^{-3}** moles

Mole ratio KOH(aq) : HCl(aq) -= 1:1

Moles KOH =**0.003/3.0 x 10^{-3}** moles

Method 1

Molar mass KOH =**56.0**g

Mass KOH in 25cm3 =0.003/3.0 x 10^{-3} moles x56.0 = 0.168g

Mass KOH in 1000cm3/1 litre = $\frac{0.168 \times 1000}{20}$= **8.4 g/l**

Mass of KCl = 9.7g - 8.4g = **1.3** g

% of KCl =1.3 $\frac{\times 100}{9.7}$ = **13.4021%**

Method 2

Moles KOH in 1000cm3 /1 litre = $\frac{\text{Moles in 20cm3 x 1000}}{20}$ =>$\frac{0.003 \times 1000}{20}$

=**0.15M/Moles /litre**

Molar mass KOH =**56.0**g

Mass KOH in 1000/1 litre = 0.15M/Moles /litre x 56.0 = **8.4g/l**

Mass of KCl = 9.7g - 8.4g = **1.3** g

% of KCl =1.3 $\frac{\times 100}{9.7}$ = **13.4021%**

4.**A certain carbonate, GCO3, reacts with dilute hydrochloric acid according to the equation given below:**

$$GCO_{3(s)} + 2HCl_{(aq)} \rightarrow GCl_{2\,(aq)} + CO_{2\,(g)} + H_2O_{(l)}$$

If 1 g of the carbonate reacts completely with 20 cm3 of 1 M hydrochloric acid ,calculate the relative atomic mass of G (C = 12.0 = 16.0)

Moles of HCl = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{1 \times 20}{1000}$ = **0.02 moles**

Mole ratio HCl; GCO_3 = 2:1

Moles of GCO_3= $\frac{0.02 \text{ moles}}{2}$ = **0.01moles**

Molar mass of GCO_3 = $\frac{\text{mass}}{\text{moles}}$ => $\frac{1}{0.01\text{moles}}$ = **100** g

G= GCO_3 - CO_3 =>100g – (12+ 16 x3 = 60) = **40**(**no units**)

5. 46.0g of a metal carbonate MCO_3 was dissolved 160cm3 of 0.1M excess hydrochloric acid and the resultant solution diluted to one litre.25.0cm3 of this solution required 20.0cm3 of 0.1M sodium hydroxide solution for complete neutralization. Calculate the atomic mass of 'M'

Equation

Chemical equation

NaOH(aq) + HCl(aq) -> KCl(aq) + H_2O(l)

Moles of NaOH = $\frac{\text{Molarity x volume}}{1000}$ => $\frac{0.1 \times 20}{1000}$ = **0.002 moles**

Mole ratio HCl; NaOH = 1:1

Excess moles of HCl = **0.002 moles**

25cm3 -> 0.002 moles

1000cm3 -> $\frac{1000 \times 0.002}{25\text{cm3}}$ = **0.08moles**

Original moles of HCl = Molarity x volume => 1M x 1litre = **1.0 moles**

Moles of HCl reacted with MCO_3 = **1.0 - 0.08 moles** = **0.92moles**

Chemical equation

$MCO_{3(s)}$ + $2HCl_{(aq)}$ -> $MCl_{2\,(aq)}$ + CO_2 (g) + $H_2O_{(l)}$

Mole ratio $MCO_{3(s)}$: $HCl_{(aq)}$ =1:2

Moles of MCO_3 = $\frac{0.92\text{moles}}{2}$ => **0.46moles**

Molar mass of MCO_3= $\frac{\text{mass}}{\text{moles}}$ => $\frac{46\text{g}}{0.46\text{moles}}$ = **100 g**

M= MCO_3 - CO_3 =>100g – (12+ 16 x3 = 60) = **40**

6. 25.0cm3 of a mixture of Fe^{2+} and Fe^{3+} ions in an aqueous salt was acidified with sulphuric(VI)acid then titrated against potassium manganate(VI).The salt required 15cm3 ofe0.02M potassium manganate(VI) for complete reaction.
A second 25cm3 portion of the Fe^{2+} and Fe^{3+} ion salt was reduced by Zinc then titrated against the same concentration of potassium manganate(VI).19.0cm3 of potassium manganate(VI)solution was used for complete reaction.
Calculate the concentration of Fe^{2+} and Fe^{3+} ion in the solution on moles per litre.

Mole ratio Fe^{2+} :$Mn0_4^-$=5:1

Moles $Mn0_4^-$ used = $\frac{0.02 \times 15}{1000}$ = **3.0×10^{-4}** moles

Moles **Fe^{2+}** = $\frac{3.0 \times 10^{-4} \text{ moles}}{5}$ = **6.0×10^{-5}** moles

Molarity of **Fe^{2+}** = $\frac{\mathbf{6.0 \times 10^{-4}} \text{ moles} \times 1000}{25}$ = **2.4×10^{-3} moles l^{-1}**

Since Zinc reduces **Fe^{3+}** to **Fe^{2+}** in the mixture:

Moles $Mn0_4^-$ that reacted with all **Fe^{2+}**= $\frac{0.02 \times 19}{1000}$ = **3.8×10^{-4}** moles

Moles of all **Fe^{2+}** = $\frac{3.8 \times 10^{-4} \text{ moles}}{5}$ = 7.6×10^{-5} moles

Moles of Fe^{3+} = 3.8×10^{-4} - 6.0×10^{-5} = **1.6×10^{-5}** moles

Molarity of **Fe^{3+}** = $\frac{1.6 \times 10^{-5} \text{ moles} \times 1000}{25}$ = **4.0×10^{-4} moles l^{-1}**

14.0.0 ORGANIC CHEMISTRY I (HYDROCARBONS) (25 LESSONS)

Introduction to Organic chemistry

Organic chemistry is the branch of chemistry that studies carbon compounds present in living things, once living things or synthetic/man-made.

Compounds that makes up living things whether alive or dead mainly contain carbon. Carbon is tetravalent.

It is able to form stable covalent bonds with itself and many non-metals like hydrogen, nitrogen ,oxygen and halogens to form a variety of compounds. This is because:

(i) carbon uses all the four valence electrons to form four strong covalent bond.

(ii)carbon can covalently bond to form a single, double or triple covalent bond with itself.

(iii)carbon atoms can covalently bond to form a very long chain or ring.
When carbon covalently bond with Hydrogen, it forms a group of organic compounds called **Hydrocarbons**

A.HYDROCARBONS (HCs)

Hydrocarbons are a group of organic compounds containing /made up of hydrogen and carbon atoms only.

Depending on the type of bond that exist between the individual carbon atoms, hydrocarbon are classified as:

(i) Alk**a**nes
(ii) Alk**e**nes
(iii) Alk**y**nes

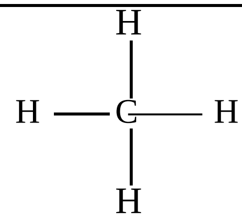
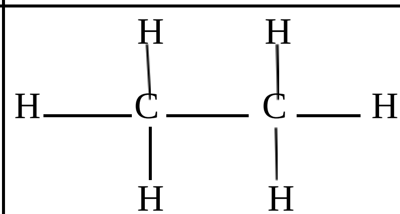
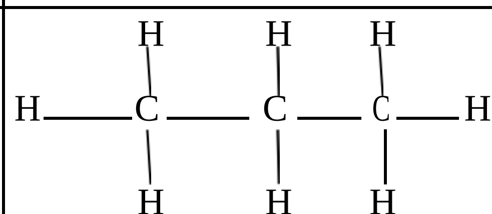
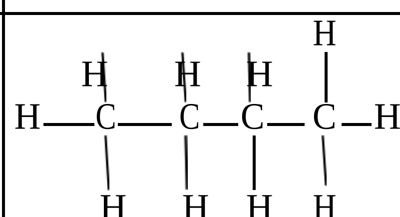
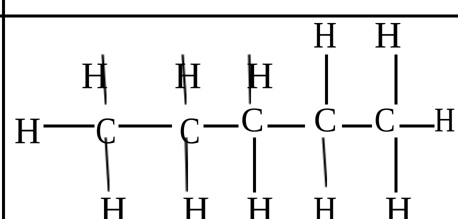
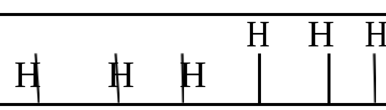
(i) Alkanes

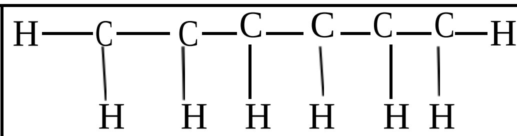
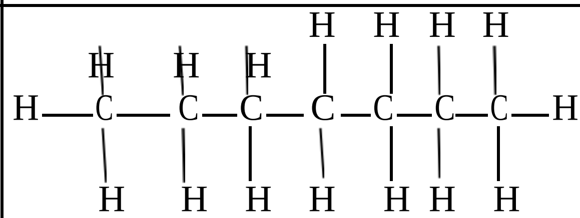
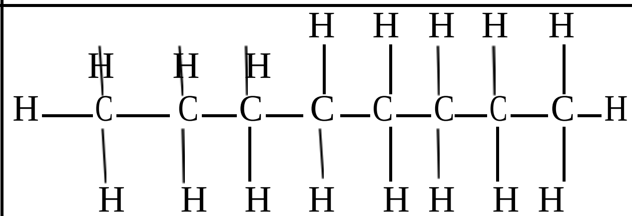
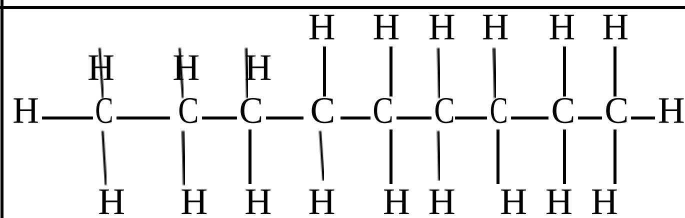
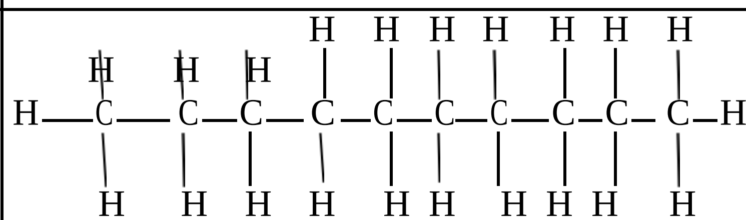
(a)Nomenclature/Naming

These are hydrocarbons with a general formula C_nH_{2n+2} where **n** is the number of Carbon atoms in a molecule.

The carbon atoms are linked by single bond to each other and to hydrogen atoms.

They include:

n	General/ Molecular formula	Structural formula	Name
1	CH_4		Meth**ane**
2	C_2H_6		Eth**ane**
3	C_3H_8		Prop**ane**
4	C_4H_{10}		But**ane**
5	C_5H_{12}	 $CH_3\ (CH_2)\ _6CH_3$	Pent**ane**
6	C_6H_{14}		Hex**ane**

		 $CH_3(CH_2)_6CH_3$	
7	C_7H_{16}		Hept**ane**
8	C_8H_{18}		Oct**ane**
9	C_9H_{20}		Non**ane**
10	$C_{10}H_{22}$		dec**ane**

Note

1.The **general formula/molecular formular** of a compound shows the number of each atoms of elements making the compound e.g.

Decane has a general/molecular formula **$C_{10}H_{22}$** ;this means there are 10 carbon atoms and 22 hydrogen atoms in a molecule of decane.

2.The **structural formula** shows the arrangement/bonding of atoms of each element making the compound e.g

Decane has the structural formula as in the table above ;this means the 1st carbon from left to right is bonded to three hydrogen atoms and one carbon atom.

The 2nd carbon atom is joined/bonded to two other carbon atoms and two Hydrogen atoms.

3.Since carbon is **tetravalent** ,each atom of carbon in the alkane **MUST** always be bonded using **four** covalent bond /four shared pairs of electrons.

4.Since Hydrogen is **monovalent** ,each atom of hydrogen in the alkane **MUST** always be bonded using **one** covalent bond/one shared pair of electrons.

5.One member of the alkane differ from the next/previous by a CH_2 group.
e.g
Propane differ from ethane by one carbon and two Hydrogen atoms form ethane. Ethane differ from methane also by one carbon and two Hydrogen atoms

6.A group of compounds that differ by a CH_2 group from the next /previous **consecutively** is called a **homologous series**.

7.A homologous series:

(i) differ by a CH_2 group from the next /previous consecutively
(ii)have similar chemical properties
(iii)have similar chemical formula that can be represented by a general formula e.g alkanes have the general formula C_nH_{2n+2}.
(iv)the physical properties (e.g.melting/boiling points)show steady gradual change)

8.The 1st four alkanes have the prefix **meth_,eth_,prop_** and **but_** to represent 1,2,3 and 4 carbons in the compound. All other use the numeral prefix **pent_,Hex_,hept_** , etc to show also the number of carbon atoms.

9.If one hydrogen atom in an alkane is removed, an alkyl group is formed.e.g

Alkane name	molecular structure C_nH_{2n+2}	**Alkyl name**	**Molecula structure C_nH_{2n+1}**
methane	CH_4	**methyl**	**CH_3**
ethane	CH_3CH_3	**ethyl**	**CH_3 CH_2**
propane	CH_3 CH_2 CH_3	**propyl**	**CH_3 CH_2 CH_2**
butane	CH_3 CH_2 CH_2 CH_3	**butyl**	**CH_3 CH_2 CH_2 CH_2**

(b)Isomers of alkanes

Isomers are compounds with the same molecular **general formula** but different molecular **structural formula**.

Isomerism is the existence of a compounds having the same general/molecular formula but different structural formula.

The 1st three alkanes do not form isomers.Isomers are named by using the IUPAC(**I**nternational **U**nion of **P**ure and **A**pplied **C**hemistry) system of **nomenclature/naming.**

The IUPAC system of nomenclature uses the following basic rules/guidelines:

1.Identify the longest continuous carbon chain to get/determine the parent alkane.

2.Number the longest chain form the end of the chain that is near the branches so as the branch get the lowest number possible

3. Determine the position, number and type of branches. Name them as methyl, ethyl, propyl e.tc. according to the number of carbon chains attached to the parent alkane. Name them fluoro-,chloro-,bromo-,iodo- if they are halogens

4.Use prefix di-,tri-,tetra-,penta-,hexa- to show the number of branches attached to the parent alkane.

Practice on IUPAC nomenclature of alkanes

(a)Draw the structure of:

(i)2-methylpentane

Procedure

1. Identify the longest continuous carbon chain to get/determine the parent alkane.

Butane is the parent name **CH_3 CH_2 CH_2 CH_3**

2. Number the longest chain form the end of the chain that is near the branches so as the branch get the lowest number possible

The methyl group is attached to Carbon **"2"**

3. Determine the position, number and type of branches. Name them as methyl, ethyl, propyl e.tc. according to the number of carbon chains attached to the parent alkane i.e

Position of the branch at carbon **"**2**"**

Number of branches at carbon **"**1**"**

Type of the branch **"**methyl**"** hence

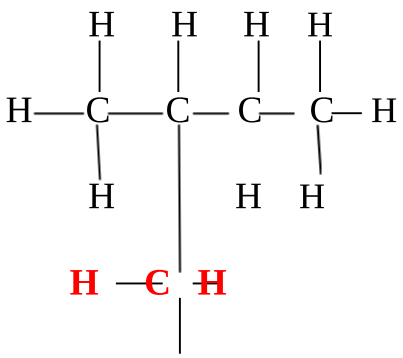
Molecular formula

CH_3

|

CH_3 CH CH_2 CH_3 // CH_3 CH (CH_3) CH_2CH_3

Structural formula



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(ii)2,2-dimethylpentane

Procedure

1. Identify the longest continuous carbon chain to get/determine the parent alkane.

Butane is the parent name **CH_3 CH_2 CH_2 CH_3**

2. Number the longest chain form the end of the chain that is near the branches so as the branch get the lowest number possible

The methyl group is attached to Carbon **"2"**

3. Determine the position, number and type of branches. Name them as methyl, ethyl, propyl e.tc. according to the number of carbon chains attached to the parent alkane i.e

Position of the branch at carbon **"**2**"**

Number of branches at carbon **"**2**"** Type of the branch <u>two</u>**"**methyl**"** hence

<u>Molecular formular</u>

CH_3

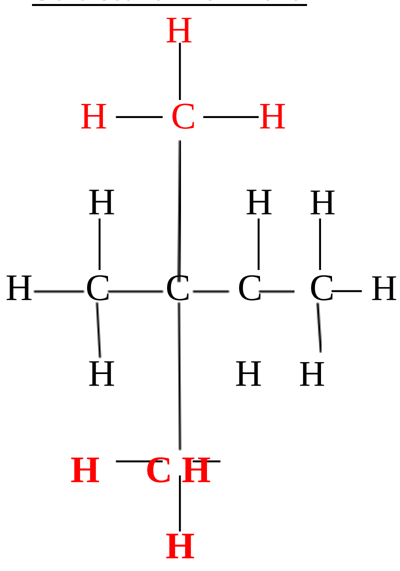
|

CH_3 C CH_2 CH_3 // CH_3 C (CH_3)$_2$ CH_2CH_3

|

CH_3

<u>Structural formula</u>



(iii) 2,2,3-trimethylbutane

Procedure

1. Identify the longest continuous carbon chain to get/determine the parent alkane.

Butane is the parent name **$CH_3\ CH_2\ CH_2\ CH_3$**

2. Number the longest chain form the end of the chain that is near the branches so as the branch get the lowest number possible

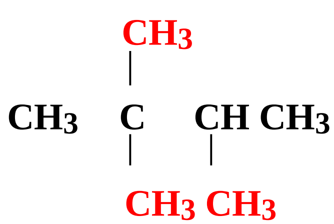
The methyl group is attached to Carbon **"2 and 3"**

3. Determine the position, number and type of branches. Name them as methyl, ethyl, propyl e.tc. according to the number of carbon chains attached to the parent alkane i.e

Position of the branch at carbon "2 and 3" Number of branches at carbon "3"

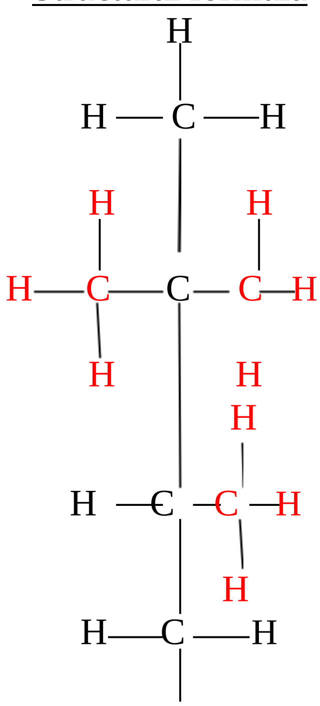
Type of the branch <u>three</u> "methyl" hence

<u>Molecular formular</u>



// CH_3 C (CH_3)$_3$ CH_2CH_3

<u>Structural formula</u>



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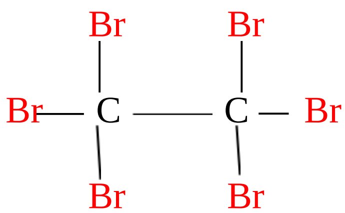
(iv) 1,1,1,2,2,2-hexabromoethane

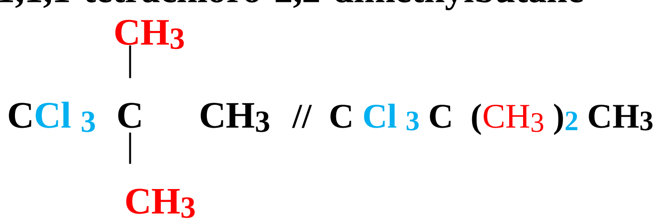
Molecular formula

CBr_3 CBr_3

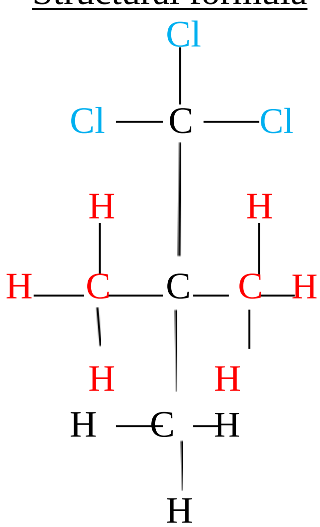
Structural formula



(v) 1,1,1-tetrachloro-2,2-dimethylbutane



Structural formula



(c)Occurrence and extraction

Crude oil ,**natural gas** and **biogas** are the main sources of alkanes:

(i)Natural gas is found on top of crude oil deposits and consists mainly of methane.

(ii)Biogas is formed from the decay of waste organic products like animal dung and cellulose. When the decay takes place in absence of oxygen , 60-75% by volume of the gaseous mixture of methane gas is produced.

(iii)Crude oil is a mixture of many flammable hydrocarbons/substances. Using fractional distillation, each hydrocarbon fraction can be separated from the other. The hydrocarbon with lower /smaller number of carbon atoms in the chain have lower boiling point and thus collected first.

As the carbon **chain increase**, the **boiling** point, **viscosity** (ease of flow) and colour **intensity** increase as **flammability** decrease. Hydrocarbons in crude oil are not pure. They thus have no sharp fixed boiling point.

Uses of different crude oil fractions

Carbon atoms in a molecule	Common name of fraction	Uses of fraction
1-4	Gas	L.P.G gas for domestic use
5-12	Petrol	Fuel for petrol engines
9-16	Kerosene/Paraffin	Jet fuel and domestic lighting/cooking
15-18	Light diesel	Heavy diesel engine fuel
18-25	Diesel oil	Light diesel engine fuel
20-70	Lubricating oil	Lubricating oil to reduce friction.
Over 70	Bitumen/Asphalt	Tarmacking roads

(d)School laboratory preparation of alkanes

In a school laboratory, alkanes may be prepared from the reaction of a sodium alkanoate with solid sodium hydroxide/soda lime.

Chemical equation:

Sodium alkanoate + soda lime -> alkane + Sodium carbonate

$C_nH_{2n+1}COONa(s)$ + $NaO\mathbf{H}(s)$ -> C_nH_{2n+2} + $Na_2CO_3(s)$

The **"H"** in NaO**H** is transferred/moves to the C_nH_{2n+1} in $C_nH_{2n+1}COONa(s)$ to form C_nH_{2n+2}.

Examples

1. **Meth**ane is prepared from the heating of a mixture of sodium **ethan**oate and soda lime and collecting over water

Sodium **ethan**oate + soda lime -> **meth**ane + Sodium carbonate

$CH_3COONa(s)$ + NaO**H**(s) -> CH_4 + $Na_2CO_3(s)$

The **"**H**"** in NaO**H** is transferred/moves to the CH_3 in $CH_3COONa(s)$ to form CH_4.

2. **Eth**ane is prepared from the heating of a mixture of sodium **prop**anoate and soda lime and collecting over water

Sodium **prop**anoate + soda lime -> **eth**ane + Sodium carbonate

$CH_3\ CH_2COONa(s)$ + NaO**H**(s) -> $CH_3\ CH_3$ + $Na_2CO_3(s)$

The **"**H**"** in NaO**H** is transferred/moves to the $CH_3\ CH_2$ in $CH_3\ CH_2COONa\ (s)$ to form $CH_3\ CH_3$

3. **Prop**ane is prepared from the heating of a mixture of sodium **but**anoate and soda lime and collecting over water

Sodium **but**anoate + soda lime -> **prop**ane + Sodium carbonate

$CH_3\ CH_2CH_2COONa(s)$ + NaO**H**(s) -> $CH_3\ CH_2CH_3$ + $Na_2CO_3(s)$

The **"**H**"** in NaO**H** is transferred/moves to the $CH_3\ CH_2\ CH_2$ in $CH_3\ CH_2CH_2COONa\ (s)$ to form $CH_3\ CH_2CH_3$

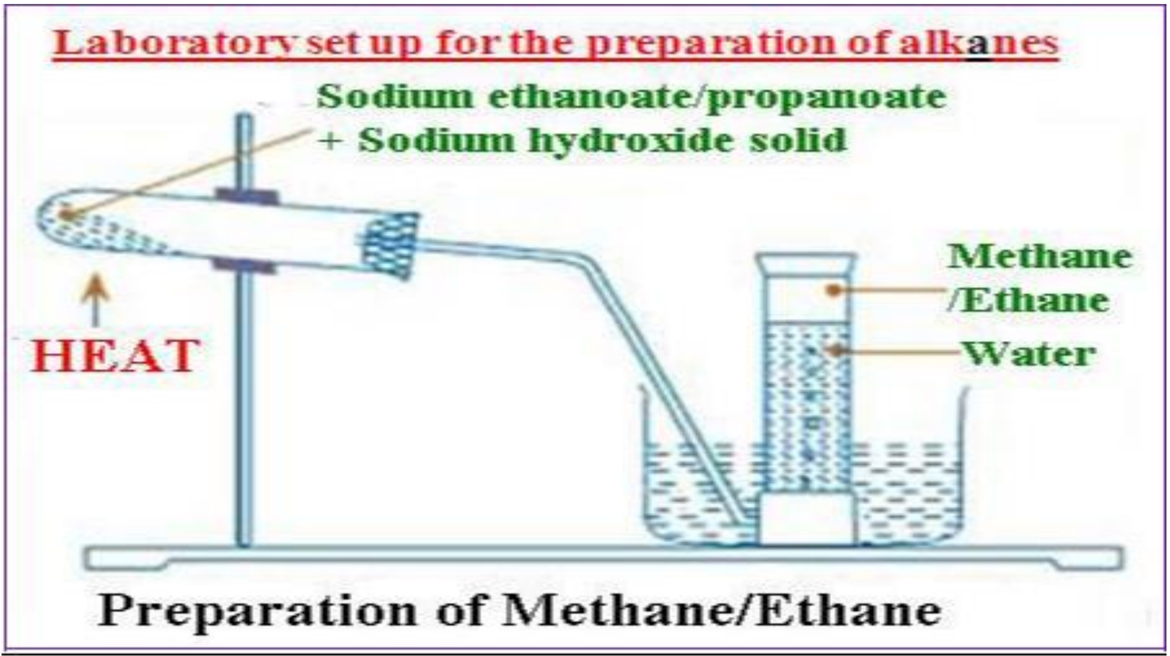
4. **But**ane is prepared from the heating of a mixture of sodium **pent**anoate and soda lime and collecting over water

Sodium **pent**anoate + soda lime -> **but**ane + Sodium carbonate

$CH_3\ CH_2\ CH_2CH_2COONa(s)$+NaO**H**(s) -> $CH_3\ CH_2CH_2CH_3$ + $Na_2CO_3(s)$

The **"**H**"** in NaO**H** is transferred/moves to the $CH_3CH_2\ CH_2\ CH_2$ in $CH_3\ CH_2CH_2\ CH_2COONa\ (s)$ to form $CH_3\ CH_2\ CH_2CH_3$

Laboratory set up for the preparation of alkanes



(d)Properties of alkanes
I. Physical properties

Alkanes are colourless gases, solids and liquids that are not poisonous.
They are slightly soluble in water.
The solubility decrease as the carbon chain and thus the molar mass increase
The melting and boiling point increase as the carbon chain increase.
This is because of the increase in van-der-waals /intermolecular forces as the carbon chain increase.
The 1st four straight chain alkanes (methane,ethane,propane and butane)are therefore gases ,the nect six(pentane ,hexane, heptane,octane,nonane, and decane) are liquids while the rest from unidecane(11 carbon atoms) are solids .

The density of straight chain alkanes increase with increasing carbon chain as the intermolecular forces increases.
This reduces the volume occupied by a given mass of the compound.

Summary of physical properties of alkanes

Alkane	General formula	Melting point(K)	Boiling point(K)	Density gcm^{-3}	State at room(298K) temperature and pressure atmosphere (101300Pa)
Methane	CH4	90	112	0.424	gas

Ethane	CH_3CH_3	91	184	0.546	gas
Propane	$CH_3CH_2CH_3$	105	231	0.501	gas
Butane	$CH_3(CH_2)_2CH_3$	138	275	0.579	gas
Pentane	$CH_3(CH_2)_3CH_3$	143	309	0.626	liquid
Hexane	$CH_3(CH_2)_4CH_3$	178	342	0.657	liquid
Heptane	$CH_3(CH_2)_5CH_3$	182	372	0.684	liquid
Octane	$CH_3(CH_2)_6CH_3$	216	399	0.703	liquid
Nonane	$CH_3(CH_2)_7CH_3$	219	424	0.708	liquid
Octane	$CH_3(CH_2)_8CH_3$	243	447	0.730	liquid

II.Chemical properties
(i)Burning.

Alkanes burn with a **blue**/non-luminous **non-sooty**/non-smoky flame in **excess** air to form carbon(IV) oxide and water.

Alkane + Air -> carbon(**IV**) oxide + water (excess air/oxygen)

Alkanes burn with a **blue**/non-luminous **no-sooty**/non-smoky flame in **limited** air to form carbon(II) oxide and water.

Alkane + Air -> carbon(**II**) oxide + water (limited air)

Examples

1.(a) Methane when ignited burns with a **blue non sooty** flame in **excess** air to form carbon(IV) oxide and water.

Methane + Air -> carbon(**IV**) oxide + water (excess air/oxygen)

$CH_4(g)$ + $2O_2(g)$ ->$CO_2(g)$ + $2H_2O(l/g)$

(b) Methane when ignited burns with a **blue non sooty** flame in **limited** air to form carbon(II) oxide and water.

Methane + Air -> carbon(**II**) oxide + water (excess air/oxygen)

$2CH_4(g)$ + $3O_2(g)$ -> $2CO(g)$ + $4H_2O(l/g)$

2.(a) Ethane when ignited burns with a **blue non sooty** flame in **excess** air to form carbon(IV) oxide and water.

Ethane + Air -> carbon(**IV**) oxide + water (excess air/oxygen)

$2C_2H_6(g)$ + $7O_2(g)$ ->$4CO_2(g)$ + $6H_2O(l/g)$

(b) Ethane when ignited burns with a **blue non sooty** flame in **limited** air to form carbon(II) oxide and water.

Ethane + Air -> carbon(**II**) oxide + water (excess air/oxygen)
$2C_2H_6(g)$ + $5O_2(g)$ -> $4CO(g)$ + $6H_2O(l/g)$

3.(a) Propane when ignited burns with a **blue non sooty** flame in **excess** air to form carbon(IV) oxide and water.

Propane + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$C_3H_8(g)$ + $5O_2(g)$ ->$3CO_2(g)$ + $4H_2O(l/g)$

(b) Ethane when ignited burns with a **blue non sooty** flame in **limited** air to form carbon(II) oxide and water.

Ethane + Air -> carbon(**II**) oxide + water (excess air/oxygen)
$2C_3H_8(g)$ + $7O_2(g)$ -> $6CO(g)$ + $8H_2O(l/g)$

ii)Substitution

Substitution reaction is one in which a hydrogen atom is replaced by a halogen in presence of ultraviolet light.

Alkanes react with halogens in presence of ultraviolet light to form halogenoalkanes.

During substitution:

(i)the halogen molecule is split into free atom/radicals.

(ii)one free halogen radical/atoms knock /remove one hydrogen from the alkane leaving an alkyl radical.

(iii) the alkyl radical combine with the other free halogen atom/radical to form halogenoalkane.

(iv)the chlorine atoms substitute repeatedly in the alkane. Each substitution removes a hydrogen atom from the alkane and form hydrogen halide.

(v)substitution stops when all the hydrogen in alkanes are replaced with halogens.

Substitution reaction is a highly **explosive** reaction in presence of **sunlight / ultraviolet** light that act as **catalyst**.

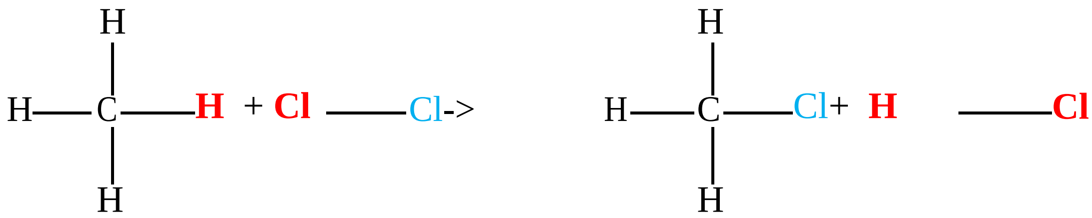
Examples of substitution reactions

Methane has no effect on bromine or chlorine in diffused light/dark. In sunlight , a mixture of chlorine and methane explode to form colourless mixture of chloromethane and hydrogen chloride gas. The pale green colour of chlorine gas fades.

Chemical equation

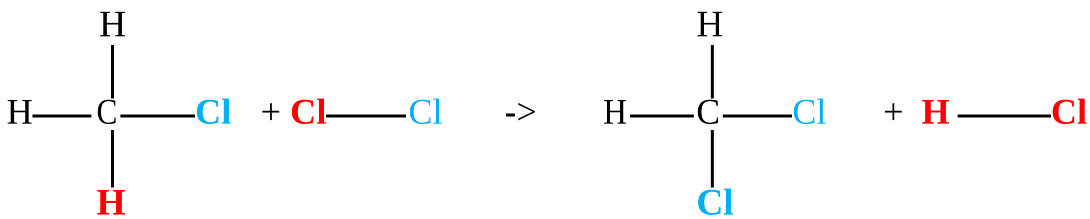
1.(a)Methane + chlorine -> Chloromethane + Hydrogen chloride

$CH_4(g)$ + $Cl_2(g)$ -> $CH_3Cl\ (g)$ + $HCl\ (g)$



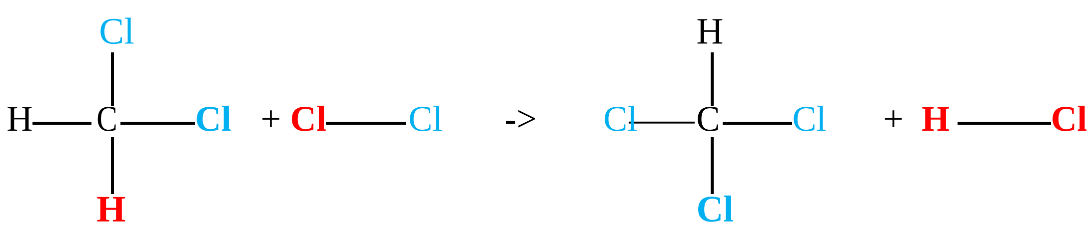
(b) Chloromethane + chlorine -> dichloromethane + Hydrogen chloride

$CH_3Cl\ (g)$ + $Cl_2(g)$ -> $CH_2Cl_2\ (g)$ + $HCl\ (g)$



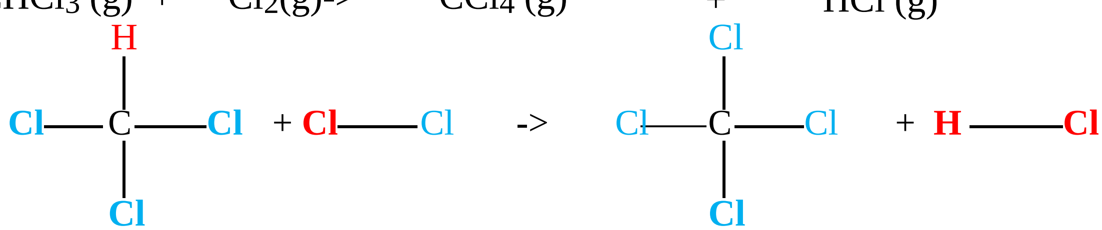
(c) dichloromethane + chlorine -> trichloromethane + Hydrogen chloride

$CH_2Cl_2\ (g)$ + $Cl_2(g)$ -> $CHCl_3\ (g)$ + $HCl\ (g)$



(c) trichloromethane + chlorine -> tetrachloromethane + Hydrogen chloride

$CHCl_3\ (g)$ + $Cl_2(g)$-> $CCl_4\ (g)$ + $HCl\ (g)$

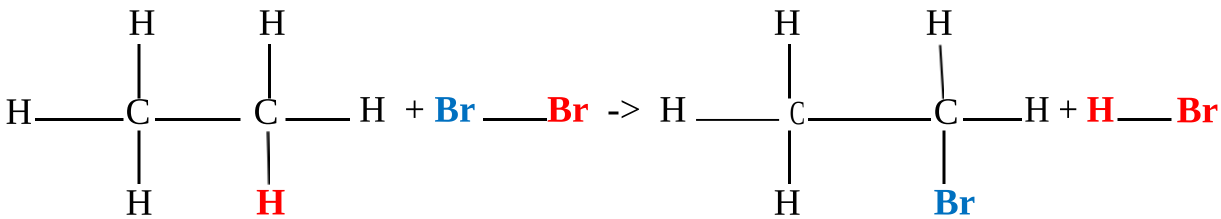


Ethane has no effect on bromine or chlorine in diffused light/dark. In sunlight , a mixture of bromine and ethane explode to form colourless mixture of bromoethane and hydrogen chloride gas. The red/brown colour of bromine gas fades.

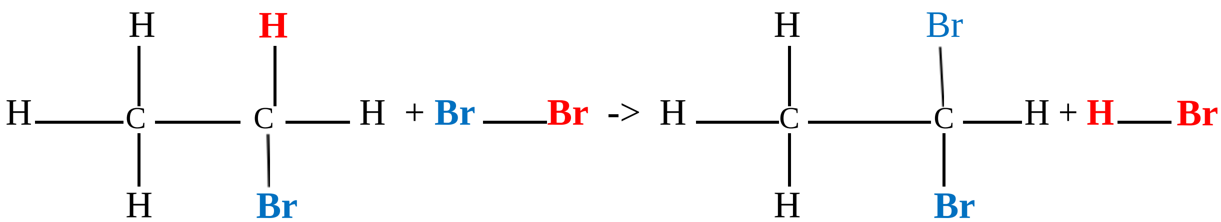
<u>Chemical equation</u>

(a)Ethane + chlorine -> Chloroethane + Hydrogen chloride

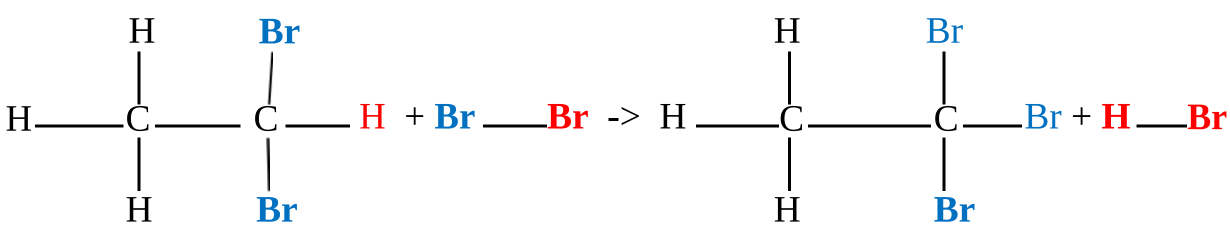
$CH_3CH_3(g)$ + $Br_2(g)$ -> CH_3CH_2Br (g) + HBr (g)



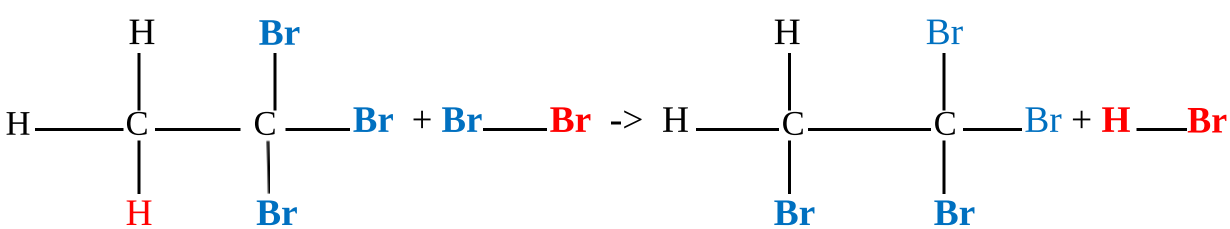
Bromoethane



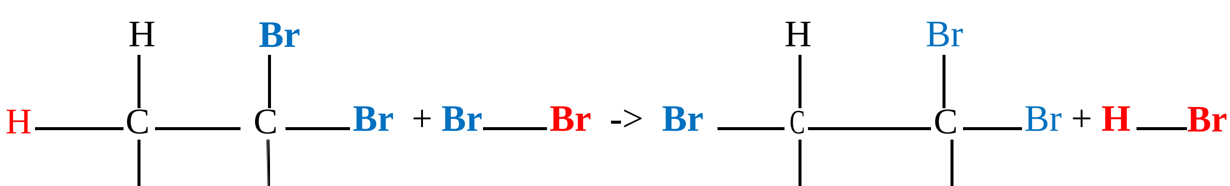
1,1-dibromoethane



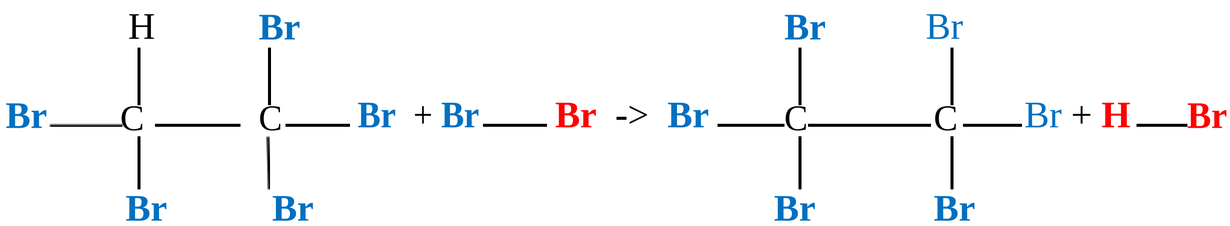
1,1,1-tribromoethane



1,1,1,2-tetrabromoethane



1,1,1,2,2-pentabromoethane



1,1,1,2,2,2-hexabromoethane

Uses of alkanes

1.Most alkanes are used as fuel e.g. Methane is used as biogas in homes.Butane is used as the Laboratory gas.

2.On cracking ,alkanes are a major source of Hydrogen for the manufacture of ammonia/Haber process.

3.In manufacture of Carbon black which is a component in printers ink.

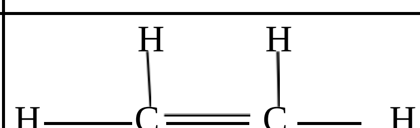
4.In manufacture of useful industrial chemicals like methanol, methanol, and chloromethane.

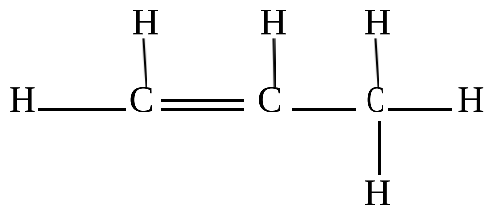
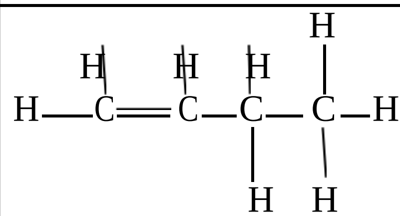
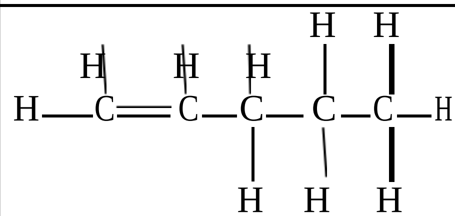
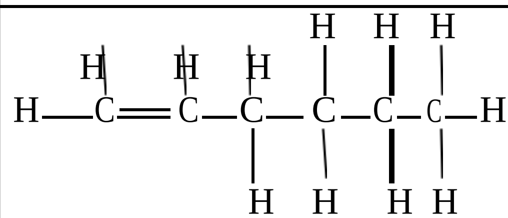
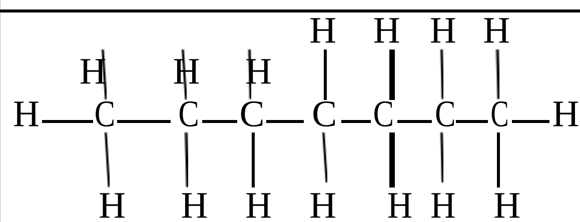
(ii) Alkenes

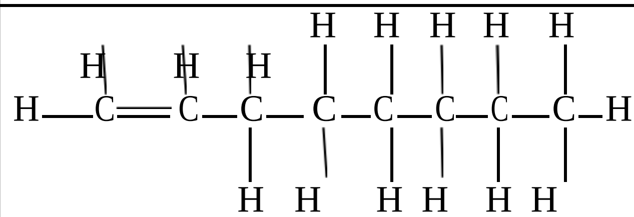
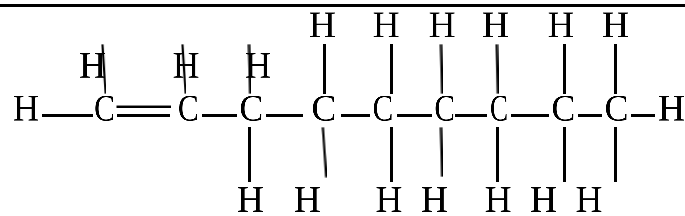
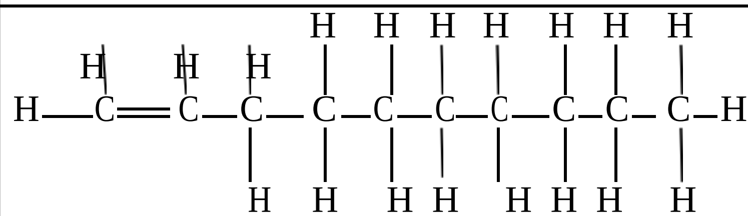
(a)Nomenclature/Naming

These are hydrocarbons with a general formula C_nH_{2n} and C═C double bond as the functional group . **n** is the number of Carbon atoms in the molecule. The carbon atoms are linked by at least one **double** bond to each other and single bonds to hydrogen atoms.

They include:

n	General/ Molecular formula	Structural formula	Name
1		Does not exist	
2	C_2H_6		Eth**ene**

		CH_2 CH_2	
3	C_3H_8	 CH_2 CH CH_3	Prop**ene**
4	C_4H_{10}	 CH_2 CH CH_2CH_3	But**ene**
5	C_5H_{12}	 CH_2 CH $(CH_2)_2CH_3$	Pent**ene**
6	C_6H_{14}	 CH_2 CH $(CH_2)_3CH_3$	Hex**ene**
7	C_7H_{16}		Hept**ene**

		$CH_2\ CH\ (CH_2)_4CH_3$	
8	C_8H_{18}	 $CH_2\ CH\ (CH_2)_5CH_3$	Oct**ene**
9	C_9H_{20}	 $CH_2\ CH\ (CH_2)_6CH_3$	Non**ene**
10	$C_{10}H_{22}$	 $CH_2\ CH\ (CH_2)_7CH_3$	dec**ene**

Note

1.Since carbon is **<u>tetravalent</u>** ,each atom of carbon in the alkene **MUST** always be bonded using **four** covalent bond /four shared pairs of electrons including at the double bond.

2.Since Hydrogen is **<u>monovalent</u>** ,each atom of hydrogen in the alkene **MUST** always be bonded using **one** covalent bond/one shared pair of electrons.

3.One member of the alkene ,like alkanes,differ from the next/previous by a CH_2 group.They also form a homologous series.

e.g

Propene differ from ethene by one carbon and two Hydrogen atoms from ethene.

4.A homologous series of alkenes like that of alkanes:

(i) differ by a CH_2 group from the next /previous consecutively

(ii)have similar chemical properties

(iii)have similar chemical formula represented by the general formula C_nH_{2n}

(iv)the physical properties also show steady gradual change

5.The = C= C = double bond in alkene is the functional group. A functional group is the **reacting site** of a molecule/compound.

6. The = C= C = double bond in alkene can easily be broken to accommodate more two more monovalent atoms. The = C= C = double bond in alkenes make it thus **unsaturated.**

7. An unsaturated hydrocarbon is one with a double =C=C= or triple **–** C ≡ C **–** carbon bonds in their molecular structure. Unsaturated hydrocarbon easily reacts to be **saturated**.

8.A saturated hydrocarbon is one without a double =C=C= or triple **–** C≡ C **–** carbon bonds in their molecular structure.

Most of the reactions of alkenes take place at the = C **=** C =bond.

(b)Isomers of alkenes

Isomers are alkenes lie alkanes have the same molecular **general formula** but different molecular **structural formula**.

Ethene and propene do not form isomers. Isomers of alkenes are also named by using the IUPAC(**I**nternational **U**nion of **P**ure and **A**pplied **C**hemistry) system of **nomenclature/naming.**

The IUPAC system of nomenclature of naming alkenes uses the following basic rules/guidelines:

1.Identify the longest continuous/straight carbon chain which contains the **=C = C= double** bond get/determine the **parent** alkene.

2.Number the longest chain form the end of the chain which contains the **=C = C= double** bond so he **=C = C= double** bond lowest number possible.

3 Indicate the positions by splitting **"alk**-positions-**ene"** e.g. but-2-ene, pent-1,3-diene.

4.The position **indicated** must be for the carbon atom at the **lower** position in the **=C = C= double bond.**i.e

But-2-ene means the double =C = C= is between Carbon **"**2**"**and **"**3**"** Pent-1,3-diene means there are two double bond one between carbon **"**1**"** and **"**2**"**and another between carbon **"**3**"** and **"**4**"**

5. Determine the position, number and type of branches. Name them as methyl, ethyl, propyl e.tc. according to the number of alkyl carbon chains attached to the alkene. Name them fluoro-,chloro-,bromo-,iodo- if they are halogens

6.Use prefix di-,tri-,tetra-,penta-,hexa- to show the number of **double** C = C bonds and **branches** attached to the alkene.

7.Position isomers can be formed when the=C = C= double bond is shifted between carbon atoms e.g.

But-2-ene means the double =C = C= is between Carbon “2”and “3”

But-1-ene means the double =C = C= is between Carbon “1”and “2”

Both But-1-ene and But-2-ene are position isomers of Butene

8.Position isomers are molecules/compounds having the same general formular but different position of the functional group.i.e.

Butene has the molecular/general formular C_4H_8 position but can form both But-1-ene and But-2-ene as position isomers.

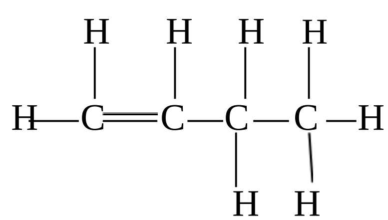
9. Like alkanes ,an alkyl group can be attached to the alkene. Chain/branch isomers are thus formed.

10.Chain/branch isomers are molecules/compounds having the same general formula but different structural formula e.g

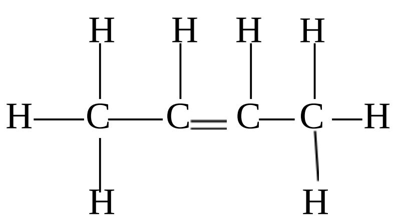
Butene and 2-methyl propene both have the same general formualr but different branching chain.

<u>Practice on IUPAC nomenclature of alkenes</u>

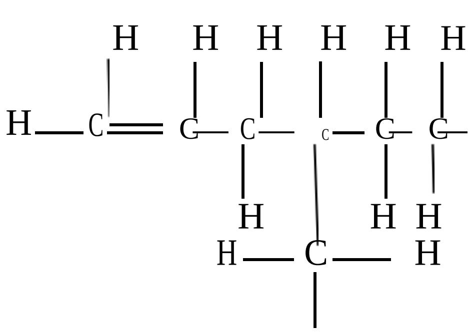
<u>Name the following isomers of alkene</u>



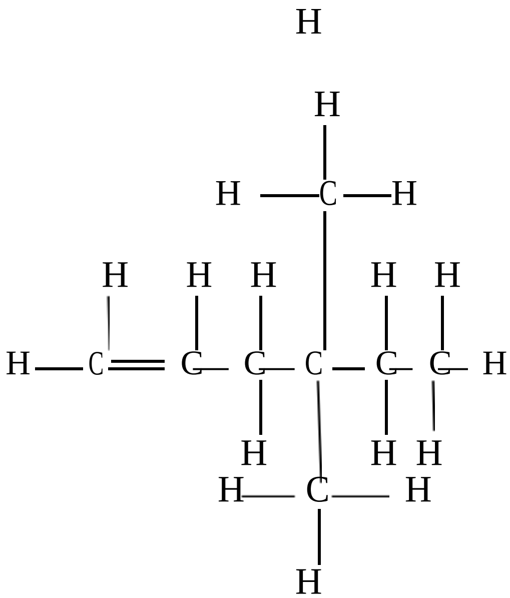
But-1-ene



But-2-ene

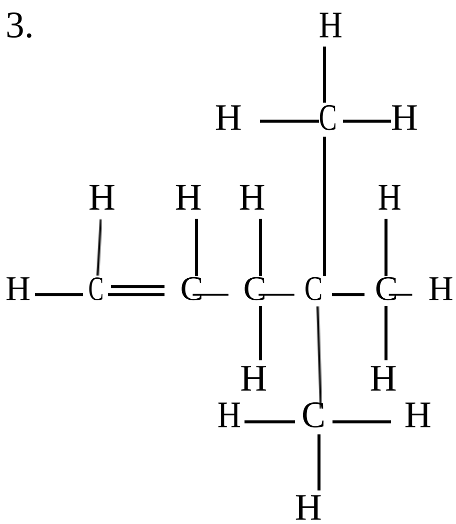


H4-methylhex-1-ene



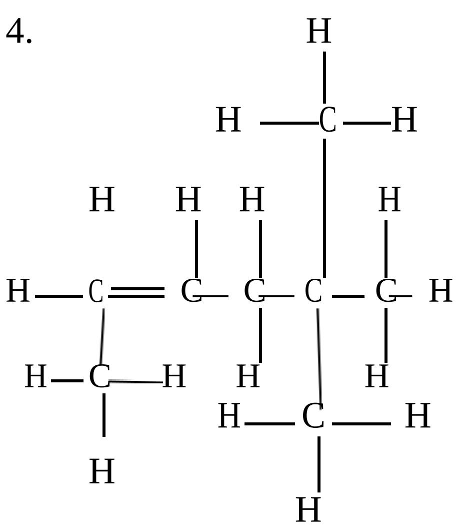
4,4-dimethylhex-1-ene

3.



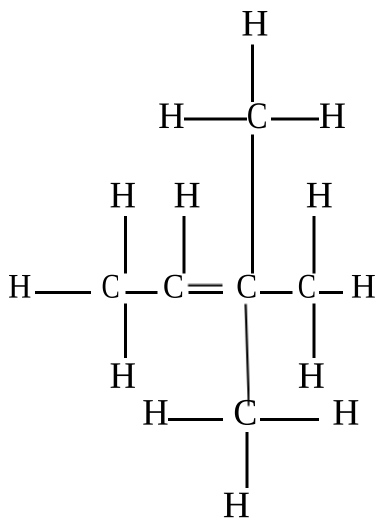
4,4-dimethylpent -1- ene

4.



5,5-dimethylhex-2- ene

5.



2,2-dimethylbut -2- ene

8. H_2C $CHCH_2$ CH_2 CH_3 — pent -1- ene

9. H_2C $C(CH_3)CH_2$ CH_2 CH_3 — 2-methylpent -1- ene

10. H_2C $C(CH_3)C(CH_3)_2$ CH_2 CH_3 — 2,3,3-trimethylpent -1- ene

11. H_2C $C(CH_3)C(CH_3)_2$ $C(CH_3)_2$ CH_3 — 2,3,3,4,4-pentamethylpent -1- ene

12. H_3C $C(CH_3)C(CH_3)$ $C(CH_3)_2$ CH_3 — 2,3,4,4-tetramethylpent -2- ene

13. H_2C $C(CH_3)C(CH_3)$ $C(CH_3)$ CH_3 — 2,3,4-trimethylpent -1,3- diene

14. H_2C CBrCBr CBr CH_3 — 2,3,4-tribromopent -1,3- diene

15. H_2C CHCH CH_2 — But -1,3- diene

16. Br_2C CBrCBr CBr_2 — 1,1,2,3,4,4-hexabromobut -1,3- diene

17. I_2C CICI CI_2 — 1,1,2,3,4,4-hexaiodobut -1,3- diene

18. H_2C $C(CH_3)C(CH_3)$ CH_2 — 2,3-dimethylbut -1,3- diene

<u>(c)Occurrence and extraction</u>

At indusrial level,alkenes are obtained from the cracking of alk**a**nes.Cracking is the process of breaking long chain alkanes to smaller/shorter alk**a**nes, an alk**e**ne and hydrogen gas at high temperatures.

Cracking is a major source of useful hydrogen gas for manufacture of ammonia/nitric(V)acid/HCl i.e.

Long chain alkane -> smaller/shorter alk**a**ne + Alk**e**ne + Hydrogen gas

Examples

1.When irradiated with high energy radiation,Propane undergo cracking to form methane gas, ethene and hydrogen gas.

Chemical equation

$CH_3CH_2CH_3$ (g) -> CH_4(g) + CH_2=CH_2(g) + H_2(g)

2.Octane undergo cracking to form hydrogen gas, butene and butane gases

Chemical equation

$CH_3(CH_2)_6CH_3$ (g) -> $CH_3CH_2CH_2CH_3$(g) + CH_3CH_2CH=CH_2(g) + H_2(g)

(d)School laboratory preparation of alkenes

In a school laboratory, alk**e**nes may be prepared from dehydration of alkanols using:

(i) concentrated sulphuric(VI)acid(H_2SO_4).

(a) aluminium(III)oxide(Al_2O_3) i.e

Alkanol --Conc. H_2SO_4 --> Alkene + Water

Alkanol --Al_2O_3 --> Alkene + Water e.g.

1.(a)At about 180^{o}C,concentrated sulphuric(VI)acid dehydrates/removes water from ethanol to form eth**e**ne.

The gas produced contain traces of carbon(IV)oxide and sulphur(IV)oxide gas as impurities.

It is thus passed through concentrated sodium/potassium hydroxide solution to remove the impurities.

Chemical equation

CH_3CH_2**OH** (l) --conc H_2SO_4/180^{o}C--> CH_2=CH_2(g) + **H_2O**(l)

(b)On heating strongly aluminium(III)oxide(Al_2O_3),it dehydrates/removes water from ethanol to form eth**e**ne.

Ethanol vapour passes through the hot aluminium (III) oxide which catalyses the dehydration.

Activated aluminium(III)oxide has a very high affinity for water molecules/elements of water and thus dehydrates/ removes water from ethanol to form eth**e**ne.

Chemical equation

CH_3CH_2**OH** (l) --(Al_2O_3/strong heat--> CH_2=CH_2(g) + **H_2O**(l)

2(a) Propan-1-ol and Propan-2-ol(position isomers of propanol) are dehydrated by conc H_2SO_4 at about 180^oC to prop**e**ne(propene has no position isomers).

Chemical equation

CH_3CH_2 CH_2**OH** (l) -- conc H_2SO_4/180^oC --> CH_3CH_2=CH_2(g) + **H_2O**(l)

Propan-**1**-ol Prop-**1**-ene

CH_3CH**OH** CH_3 (l) -- conc H_2SO_4/180^oC --> CH_3CH_2=CH_2(g) + **H_2O**(l)

Propan-**2**-ol Prop-**1**-ene

(b) Propan-1-ol and Propan-2-ol(position isomers of propanol) are dehydrated by heating strongly aluminium(III)oxide(Al_2O_3) form prop**e**ne

Chemical equation

CH_3CH_2 CH_2**OH** (l) -- Heat/Al_2O_3 --> CH_3CH_2=CH_2(g) + **H_2O**(l)

Propan-**1**-ol Prop-**1**-ene

CH_3CH**OH** CH_3 (l) -- Heat/Al_2O_3 --> CH_3CH_2=CH_2(g) + **H_2O**(l)

Propan-**2**-ol Prop-**1**-ene

3(a) Butan-1-ol and Butan-2-ol(position isomers of butanol) are dehydrated by conc H_2SO_4 at about 180^oC to But-1-**e**ne and But-2-**e**ne respectively

Chemical equation

CH_3CH_2 CH_2 CH_2**OH** (l) -- conc H_2SO_4/180^oC -->CH_3 CH_2CH_2=CH_2(g) + **H_2O**(l)

Butan-**1**-ol But-**1**-ene

CH_3CH**OH** CH_2CH_3 (l)-- conc H_2SO_4/180_oC -->CH_3CH=CH CH_2(g) + **H_2O**(l)

Butan-**2**-ol But-**2**-ene

(b) Butan-1-ol and Butan-2-ol are dehydrated by heating strongly aluminium (III) oxide (Al_2O_3) form But-1-**e**ne and But-2-**e**ne respectively.

Chemical equation

CH_3CH_2 CH_2 CH_2**OH** (l) -- Heat/Al_2O_3 --> CH_3 CH_2CH_2=CH_2(g) + **H_2O**(l)

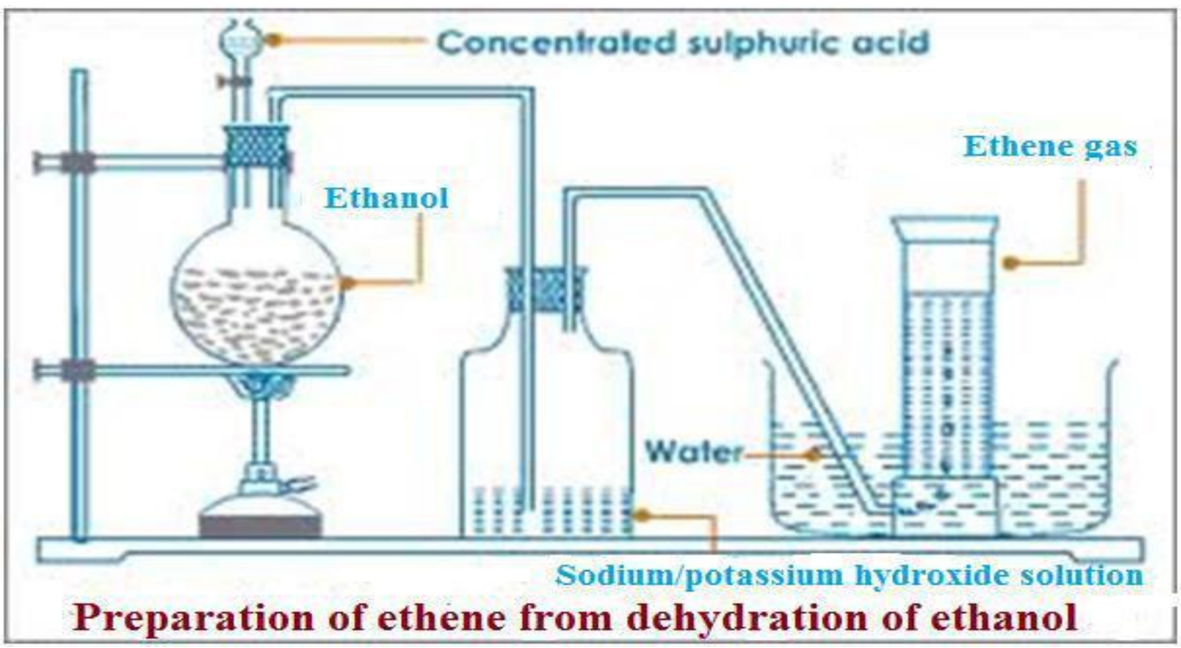
Butan-**1**-ol But-**1**-ene

$CH_3CH\textbf{OH}\ CH_2CH_3$ (l) -- Heat/Al_2O_3 --> $CH_3CH{=}CH\ CH_2$(g) + $\mathbf{H_2O}$(l)
Butan-**2**-ol But-**2**-ene

<u>Laboratory set up for the preparation of alk**e**nes/**ethene**</u>

<u>Caution</u>
(i) Ethanol is highly inflammable
(ii) Conc H_2SO_4 is highly corrosive on skin contact.
(iii) Common school thermometer has maximum calibration of 110^{o}C and thus cannot be used. It breaks/cracks.

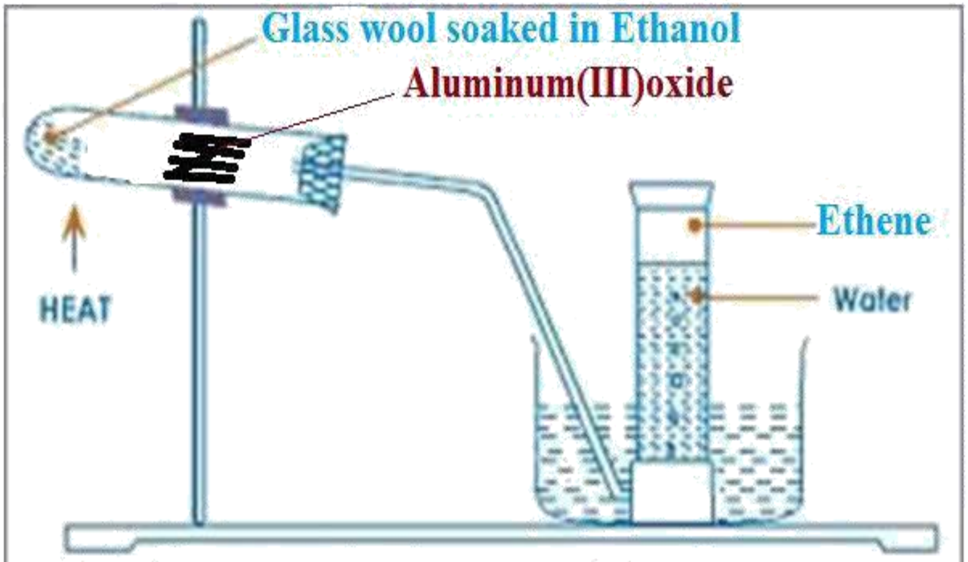
(i)Using conentrated sulphuric(VI)acid



Some <u>broken porcelain</u> or <u>sand</u> should be put in the flask when heating to:
(i)prevent bumping which may break the flask.
(ii)ensure uniform and smooth boiling of the mixture

The temperatures should be maintained at above160^{o}C.
At lower temperatures another compound **-ether** is predominantly formed instead of ethene gas**.**

(ii)Using aluminium(III)oxide



Preparation of ethene from dehydration of ethanol

<u>(e)Properties of alkenes</u>

I. Physical properties

Like alk**a**nes, alk**e**nes are colourles gases, solids and liquids that are not poisonous. They are slightly soluble in water.

The solubility in water decrease as the carbon chain and as the molar mass increase but very soluble in organic solvents like tetrachloromethane and methylbenzene. The melting and boiling point increase as the carbon chain increase.

This is because of the increase in van-der-waals /intermolecular forces as the carbon chain increase.

The 1st four straight chain alk**e**nes (eth**e**ne,propane,but-1-**e**ne and pent-1-**e**ne)are gases at room temperature and pressure.

The density of straight chain alk**e**nes,like alkanes, increase with increasing carbon chain as the intermolecular forces increases reducing the volume occupied by a given mass of the alk**e**ne.

Summary of physical properties of the 1st five alk**e**nes

Alk**e**ne	General formula	Melting point(^{o}C)	Boiling point(K)	State at room(298K) temperature and pressure atmosphere (101300Pa)

Eth**e**ne	CH_2CH_2	-169	-104	gas
Prop**e**ne	CH_3 $CHCH_2$	-145	-47	gas
But**e**ne	CH_3CH_2 $CHCH_2$	-141	-26	gas
Pent-1-**e**ne	$CH_3(CH_2$ $CHCH_2$	-138	30	liquid
Hex-1-**e**ne	$CH_3(CH_2)$ $CHCH_2$	-98	64	liquid

II. Chemical properties
(a)Burning/combustion

Alk**e**nes burn with a **yellow**/ luminous **sooty**/ smoky flame in **excess** air to form carbon(IV) oxide and water.
Alk**e**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)

Alk**e**nes burn with a **yellow**/ luminous **sooty**/ smoky flame in **limited** air to form carbon(II) oxide and water.
Alk**e**ne + Air -> carbon(**II**) oxide + water (limited air)

Burning of alkenes with a **yellow**/ luminous **sooty**/ smoky flame is a confirmatory test for the **presence** of the **=C=C=** double bond because they have **higher C:H ratio.**
A homologous series with —C = C— double or —C≡C— triple bond is said to be **unsaturated.**
A homologous series with —C—C— single bond is said to be **saturated**.Most of the reactions of the unsaturated compound involve trying to be saturated to form a —C—C single bond .

<u>Examples of burning alkenes</u>

1.(a) Eth**e**ne when ignited burns with a **yellow sooty** flame in **excess** air to form carbon(IV) oxide and water.
Eth**e**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$C_2H_4(g)$ + $3O_2(g)$ -> $2CO_2(g)$ + $2H_2O(l/g)$

(b) Eth**e**ne when ignited burns with a **yellow sooty** flame in **limited** air to form carbon(II) oxide and water.

Eth**e**ne + Air -> carbon(**II**) oxide + water (limited air)
$C_2H_4(g)$ + $3O_2(g)$ -> $2CO_2(g)$ + $2H_2O(l/g)$

2.(a) Prop**e**ne when ignited burns with a **yellow sooty** flame in **excess** air to form carbon(IV) oxide and water.

Prop**e**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$2C_3H_6(g)$ + $9O_2(g)$ ->$6CO_2(g)$ + $6H_2O(l/g)$

(a) Prop**e**ne when ignited burns with a **yellow sooty** flame in **limited** air to form carbon(II) oxide and water.

Prop**e**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$C_3H_6(g)$ + $3O_2(g)$ -> $3CO(g)$ + $3H_2O(l/g)$

(b)Addition reactions

An addition reaction is one which an unsaturated compound reacts to form a saturated compound.Addition reactions of alkenes are named from the reagent used to cause the addtion/convert the double =C=C= to single C-C bond.

(i)Hydrogenation

Hydrogenation is an addition reaction in which **hydrogen** in presence of **Palladium/Nickel** catalyst at high temperatures react with alk**e**nes to form alk**a**nes.

Examples

1.When Hydrogen gas is passed through liquid vegetable and animal **oil** at about $180^{o}C$ in presence of Nickel catalyst,solid **fat** is formed.

Hydrogenation is thus used to **harden** oils to solid fat especially margarine. During hydrogenation, one hydrogen atom in the hydrogen molecule attach itself to one carbon and the other hydrogen to the second carbon breaking the double bond to single bond.

Chemical equation

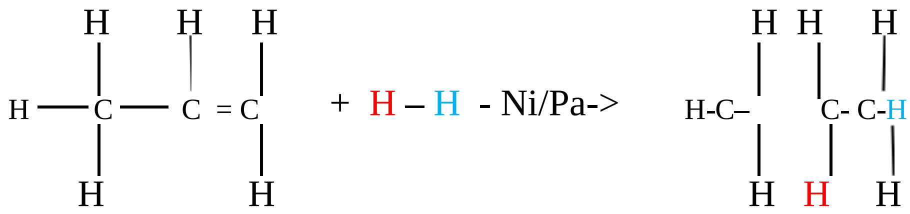
$H_2C=CH_2$ + H_2 -Ni/Pa-> H_3C - CH_3

```
H     H                                   H   H
|     |                                   |   |
C  =  C    +   H – H  - Ni/Pa -> H - C    –C-H
|     |                                   |   |
H     H                                   H   H
```

2.Prop**e**ne undergo hydrogenation to form Propane

<u>Chemical equation</u>

$H_3C\ CH{=}CH_2$ + H_2 -Ni/Pa-> $H_3C\ CH - CH_3$

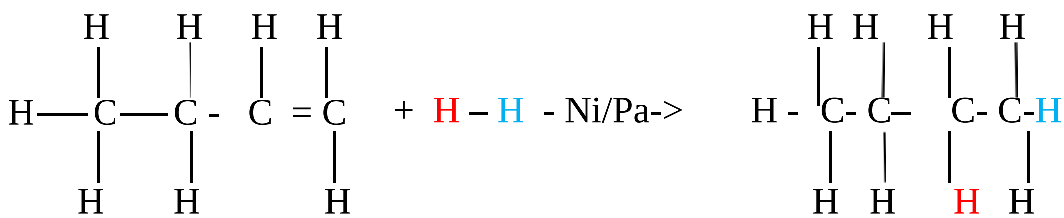


3.Both But-1-**e**ne and But-2-**e**ne undergo hydrogenation to form Butane

<u>Chemical equation</u>

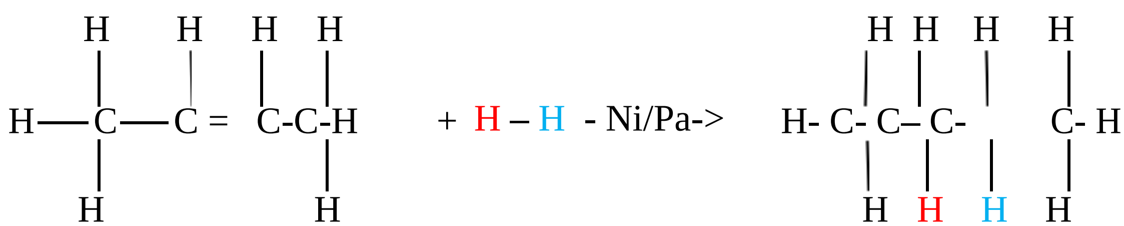
But-1-**e**ne + Hydrogen –Ni/Pa-> Butane

$H_3C\ CH_2\ CH{=}CH_2$ + H_2 -Ni/Pa-> $H_3C\ CH_2CH - CH_3$



But-2-**e**ne + Hydrogen –Ni/Pa-> Butane

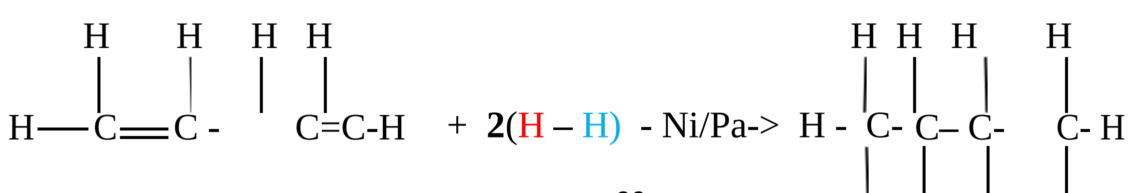
$H_3C\ CH_2 {=}CH\ CH_2$ + H_2 -Ni/Pa-> $H_3C\ CH_2CH - CH_3$



4. But-1,3-di**e**ne should undergo hydrogenation to form Butane. The reaction uses **two** <u>moles</u> of hydrogen molecules/**four** hydrogen atoms to break the two double bonds.

But-1,3-di**e**ne + Hydrogen–Ni/Pa-> Butane

$H_2C\ CH\ CH{=}CH_2$ + **2**H_2 -Ni/Pa->$H_3C\ CH_2CH - CH_3$



H H H H

(ii) Halogenation.

Halogenation is an addition reaction in which a halogen (Fluorine, chlorine, bromine, iodine) reacts with an alk**e**ne to form an alkane.

The double bond in the alk**e**ne break and form a single bond.

The colour of the halogen **fades** as the number of moles of the halogens remaining unreacted decreases/reduces.

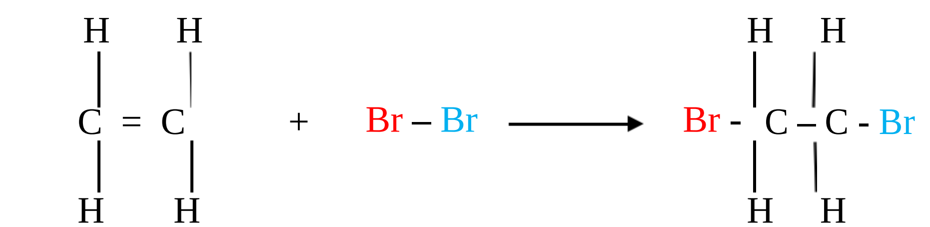
One bromine atom bond at the 1st carbon in the double bond while the other goes to the 2nd carbon.

<u>Examples</u>

1Ethene reacts with bromine to form 1,2-dibromoethane.

<u>Chemical equation</u>

$H_2C{=}CH_2 + Br_2 \longrightarrow H_2BrC - CH_2Br$



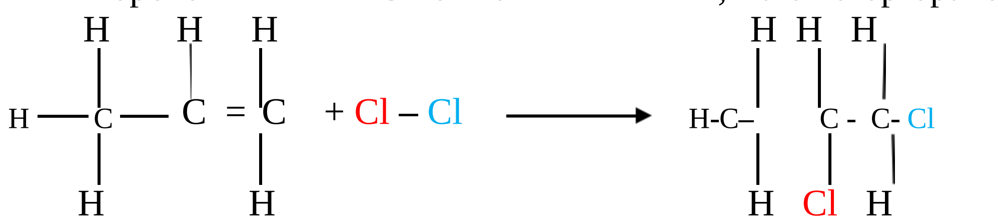
Ethene + Bromine ⟶ 1,2-dibromoethane

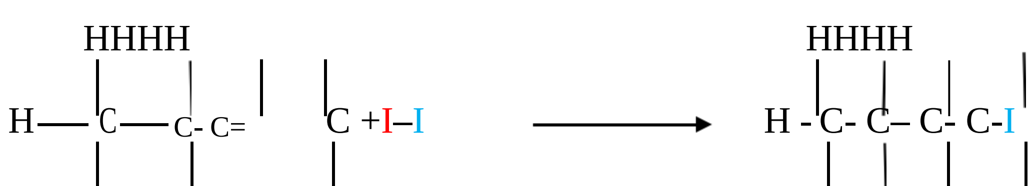
2.Propene reacts with chlorine to form 1,2-dichloropropane.

<u>Chemical equation</u>

$H_3C\,CH{=}CH_2 + Cl_2 \longrightarrow H_3C\,CHCl - CH_2Cl$

Propene + Chlorine ⟶ 1,2-dichloropropane





3.Both But-1-**e**ne and But-2-**e**ne undergo halogenation with iodine to form 1,2-diiodobutane and 2,3-diiodobutane

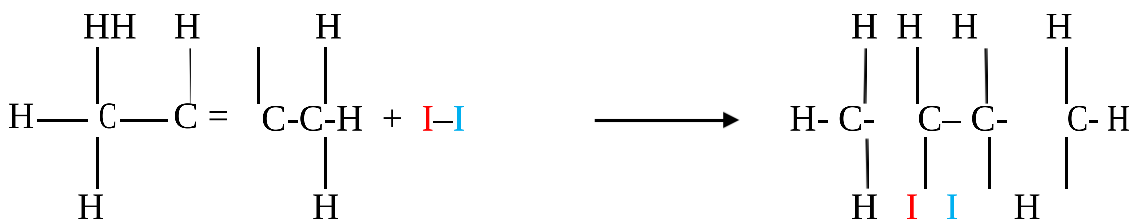
<u>Chemical equation</u>

But-1-**e**ne + iodine ⟶ 1,2 diiodobutane

$H_3C\ CH_2\ CH{=}CH_2 + I_2 \longrightarrow H_3C\ CH_2CH\ I - CH_2I$

But-2-**e**ne + Iodine ⟶ 2,3-diiodobutane

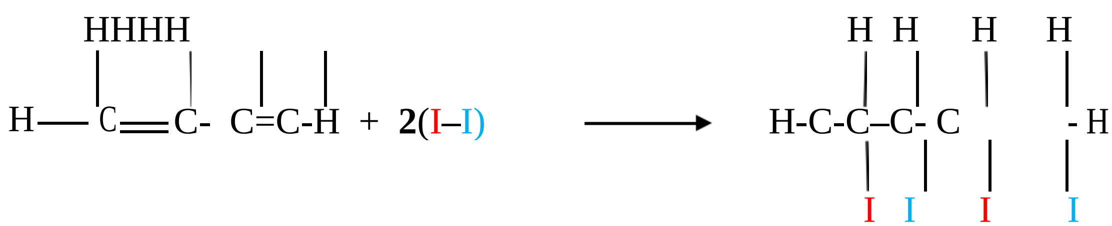
$H_3C\ CH{=}\ CH{-}CH_2 + F_2 \longrightarrow H_3C\ CHICHI - CH_3$



4. But-1,3-di**e**ne should undergo halogenation to form Butane. The reaction uses **two** <u>moles</u> of iodine molecules/**four** iodine atoms to break the two double bonds.

But-1,3-di**e**ne + iodine ⟶ 1,2,3,4-tetraiodobutane

$H_2C{=}\ CH\ CH{=}CH_2 + \mathbf{2}I_2 \longrightarrow H_2CI\ CHICHI - CHI$



(iii) Reaction with hydrogen halides.

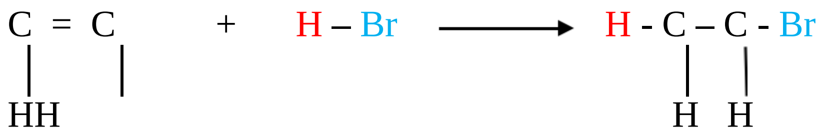
Hydrogen halides reacts with alk**e**ne to form a halogenoalkane. The double bond in the alk**e**ne break and form a single bond.

The main compound is one which the **hydrogen** atom bond at the carbon with **more hydrogen** .

<u>Examples</u>

1. Ethene reacts with hydrogen bromide to form bromoethane. <u>Chemical equation</u>

$H_2C{=}CH_2 + HBr \longrightarrow H_3C - CH_2Br$



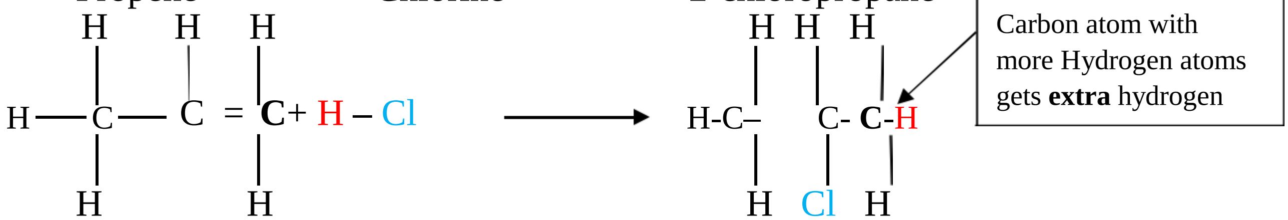
Ethene + Bromine → bromoethane

2. Propene reacts with hydrogen iodide to form 2-iodopropane.

<u>Chemical equation</u>

$H_3C\ CH{=}CH_2$ + HI → $H_3C\ CHI - CH_3$

Propene + Chlorine → 2-chloropropane

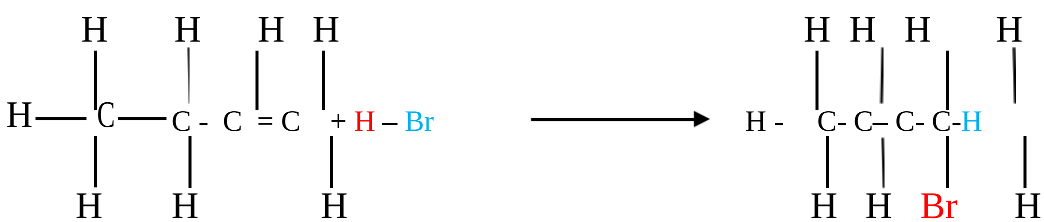


3. Both But-1-**e**ne and But-2-**e**ne reacts with hydrogen bromide to form 2-bromobutane

<u>Chemical equation</u>

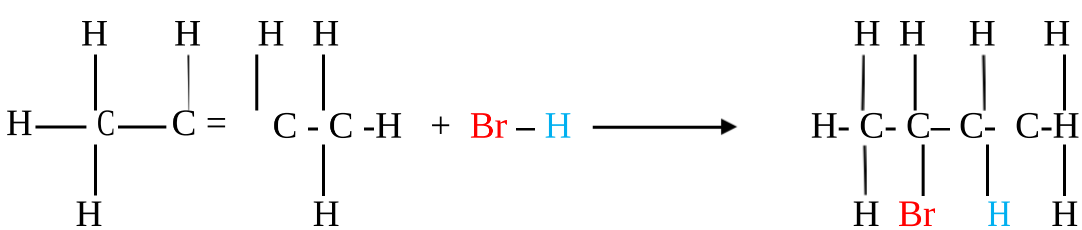
But-1-**e**ne + hydrogen bromide → 2-bromobutane

$H_3C\ CH_2\ CH{=}CH_2$ + HBr → $H_3C\ CH_2CHBr - CH_3$



But-2-**e**ne + Hydrogen bromide → 2-bromobutane

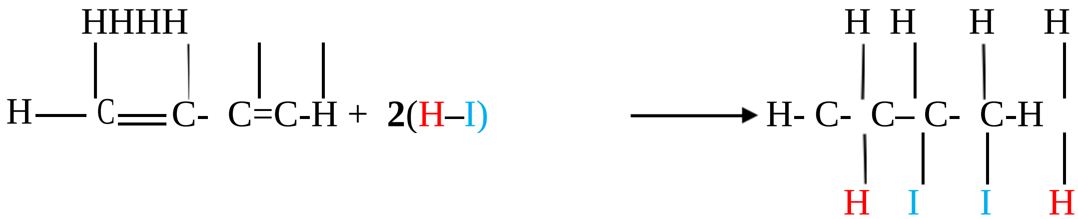
$H_3C\ CH{=}\ CH{-}CH_2$ + HBr → $H_3C\ CHBrCH_2 - CH_3$



4. But-1,3-di**e**ne react with hydrogen iodide to form 2,3- diiodobutane. The reaction uses **two** <u>moles</u> of hydrogen iodide molecules/**two** iodine atoms and two hydrogen atoms to break the two double bonds.

But-1,3-di**e**ne + iodine → 2,3-diiodobutane

$H_2C= CH\ CH=CH_2$ + **2HI$_2$** ⟶ $H_3CCHICHI - CH_3$



(iv) Reaction with bromine/chlorine water.

Chlorine and bromine water is formed when the halogen is dissolved in distilled water.Chlorine water has the formular HOCl(hypochlorous/chloric(I)acid) .Bromine water has the formular HOBr(hydrobromic(I)acid).

During the addition reaction .the halogen move to one carbon and the OH to the other carbon in the alkene at the =C=C= double bond to form a **halogenoalkanol.**

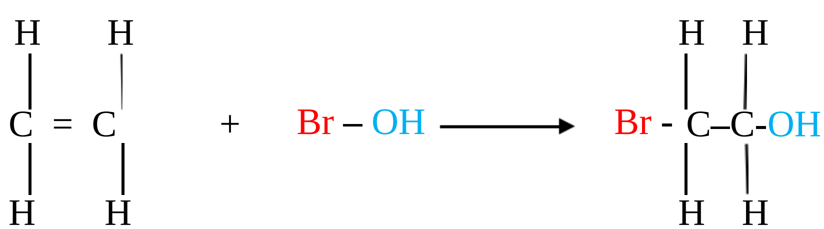
Bromine water + Alkene -> bromoalkan**o**l
Chlorine water + Alkene -> bromoalkan**o**l

Examples

1Ethene reacts with bromine water to form bromoethan**ol**.

Chemical equation

$H_2C=CH_2$ + HOBr ⟶ $H_2\ Br\ C - CH_2\ OH$



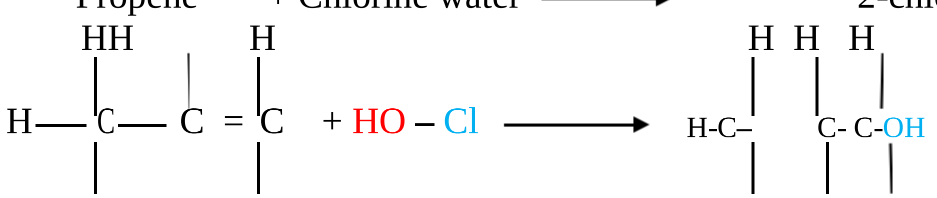
Ethene + Bromine water ⟶ bromoethan**ol**

2.Propene reacts with chlorine water to form chloropropan-2-ol / 2-chloropropan-1-ol.

Chemical equation

I.$H_3C\ CH=CH_2$ +HOCl ⟶ $H_3C\ CHCl - CH_2OH$

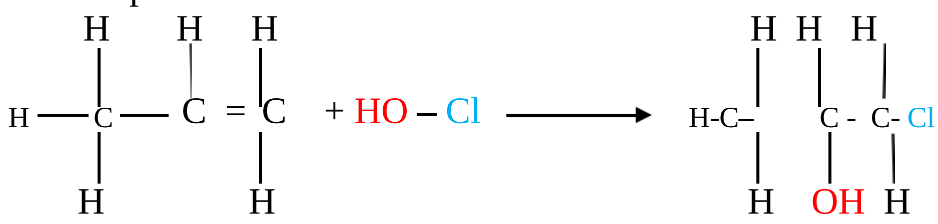
Propene + Chlorine water ⟶ 2-chloropropane



H H H Cl H

II.$H_3C\ CH{=}CH_2$ + HOCl ⟶ $H_3C\ CHOH - CH_2Cl$

Propene + Chlorine ⟶ chloropropan-2-ol

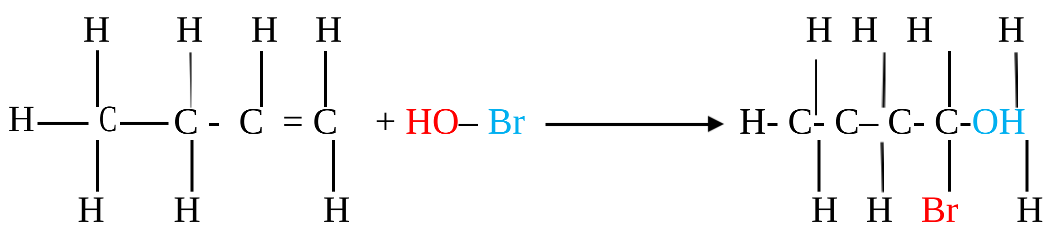


3.Both But-1-**e**ne and But-2-**e**ne react with bromine water to form 2-bromobutan-1-**ol** /3-bromobutan-2-**ol** respectively

<u>Chemical equation</u>

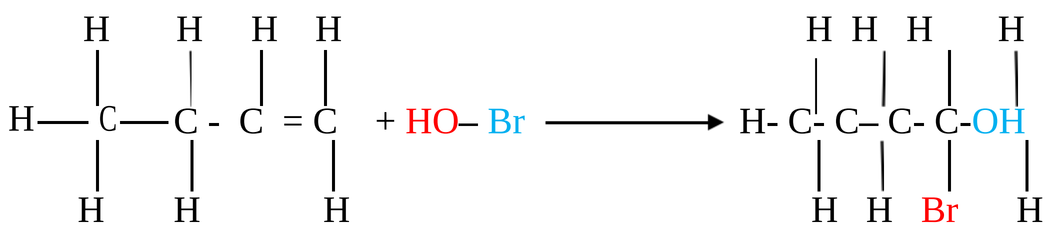
I.But-1-**e**ne + bromine water ⟶ 2-bromobutan-1-ol

$H_3C\ CH_2\ CH{=}CH_2$ + HOBr ⟶ $H_3C\ CH_2CH\ Br - CH_2OH$



II. But-2-**e**ne + bromine water ⟶ 3-bromobutan-2-ol

$H_3C\ CH{=}\ CHCH_3$ + HOBr ⟶ $H_3C\ CH_2OHCH\ Br\ CH_3$

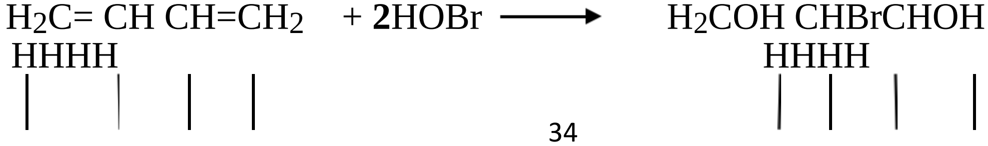


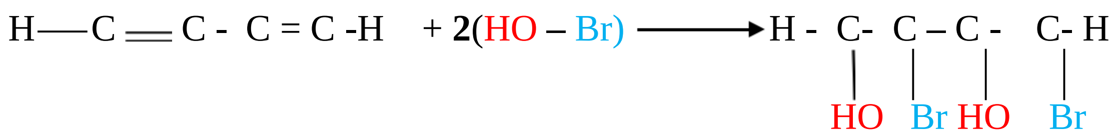
4. But-1,3-di**e**ne reacts with bromine water to form Butan-1,3-diol.

The reaction uses **two** <u>moles</u> of bromine water molecules to break the two double bonds.

But-1,3-di**e**ne + bromine water ⟶ 2,4-dibromobutan-1,3-diol

$H_2C{=}\ CH\ CH{=}CH_2$ + **2**HOBr ⟶ $H_2COH\ CHBrCHOH\ CHBr$





(v) Oxidation.

Alkenes are oxidized to alkanols with **duo/double** functional groups by oxidizing agents.

When an alk**e**ne is bubbled into orange acidified potassium/sodium dichromate (VI) solution,the colour of the oxidizing agent changes to green.

When an alk**e**ne is bubbled into purple acidified potassium/sodium manganate(VII) solution, the oxidizing agent is decolorized.

<u>Examples</u>

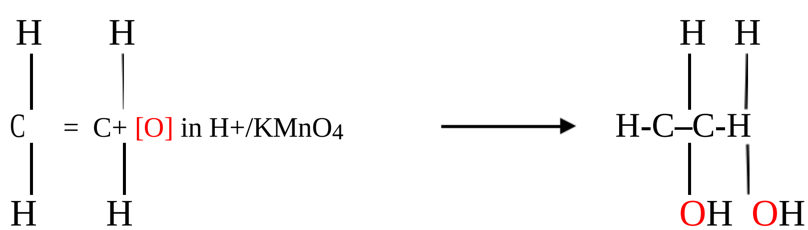
1Ethene is oxidized to ethan-1,2-di**ol** by acidified potassium/sodium manganate(VII) solution/ acidified potassium/sodium dichromate(VI) solution.

The purple acidified potassium/sodium manganate(VII) solution is decolorized.

The orange acidified potassium/sodium dichromate(VI) solution turns to green.

<u>Chemical equation</u>

$H_2C=CH_2$ —**[O]** in $H^+/K_2Cr_2O_7$ → HO CH_2 - CH_2 OH

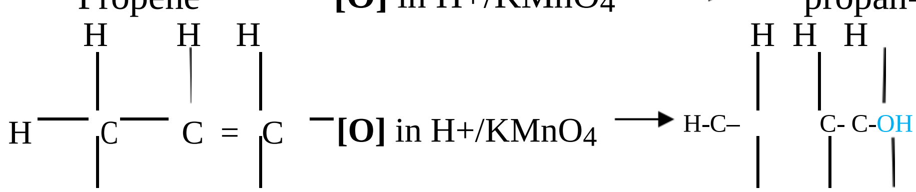


Ethene + [O] in $H^+/KMnO_4$ → ethan-1,2-di**ol**

2. Propene is oxidized to propan-1,2-di**ol** by acidified potassium/sodium manganate(VII) solution/ acidified potassium/sodium dichromate(VI) solution. The purple acidified potassium/sodium manganate(VII) solution is decolorized. The orange acidified potassium/sodium dichromate(VI) solution turns to green. <u>Chemical equation</u>

$H_3C\ CH=CH_2$ — **[O]** in $H^+/KMnO_4$ → $H_3C\ CHOH$ - CH_2OH

Propene —**[O]** in $H^+/KMnO_4$ → propan-1,2-diol



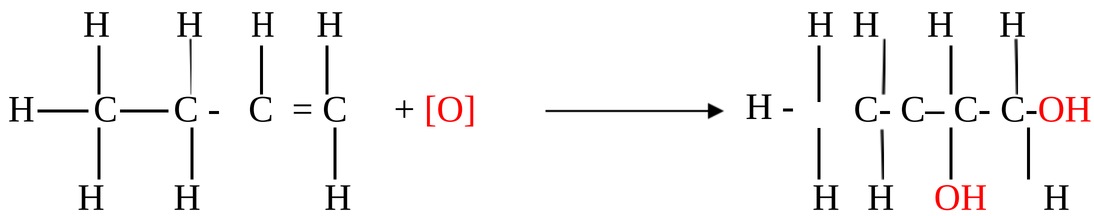
H H H OHH

3.Both But-1-**e**ne and But-2-**e**ne react with bromine water to form butan-1,2-diol and butan-2,3-diol

Chemical equation

I.But-1-**e**ne + **[O]** in H+/$KMnO_4$ ⟶ butan-1,2-diol

$H_3C\ CH_2\ CH=CH_2$ + [O] ⟶ $H_3C\ CH_2CHOH$ - CH_2OH



(v) Hydrolysis.

Hydrolysis is the reaction of a compound with water/addition of H-OH to a compound.

Alkenes undergo hydrolysis to form alkanols .

This takes place in two steps:

(i)Alkenes react with **concentrated sulphuric(VI)acid** at room temperature and pressure to form **alkylhydrogen sulphate(VI)**.

Alkenes + concentrated sulphuric(VI)acid -> alkylhydrogen sulphate(VI)

(ii)On adding **water** to alkylhydrogen sulphate(VI) then warming, an alkanol is formed.

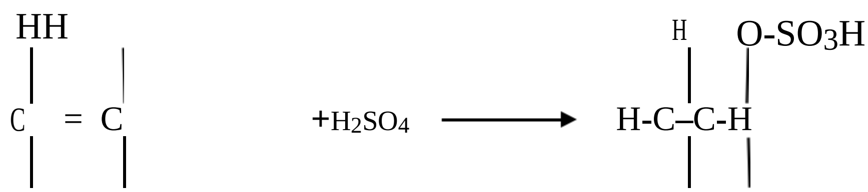
alkylhydrogen sulphate(VI) + water -warm-> Alkanol.

Examples

(i)Ethene reacts with cold concentrated sulphuric(VI)acid to form ethyl hydrogen sulphate(VII)

Chemical equation

$H_2C=CH_2$ + H_2SO_4 ⟶ CH_3 - CH_2OSO_3H

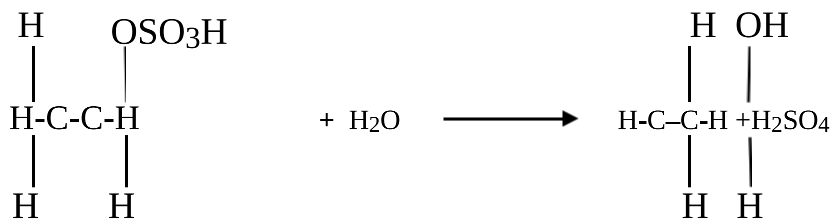


H H H H

Ethene + H_2SO_4 ethylhydrogen sulphate(VI)

(ii) Ethylhydrogen sulphate(VI) is hydrolysed by water to ethanol <u>Chemical equation</u>

$$CH_3 - CH_2OSO_3H + H_2O \longrightarrow CH_3 - CH_2OH + H_2SO_4$$

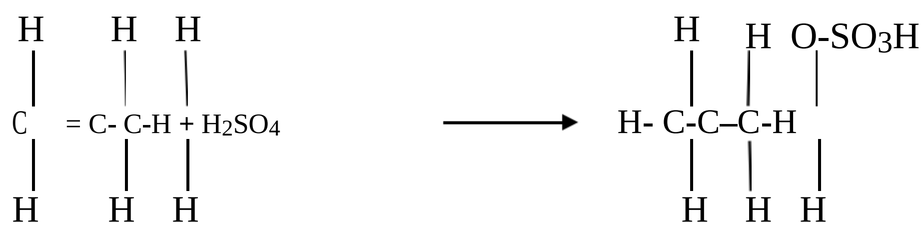


ethylhydrogen sulphate(VI) + H_2O ⟶ Ethanol

2. Propene reacts with cold concentrated sulphuric(VI)acid to form propyl hydrogen sulphate(VII)

<u>Chemical equation</u>

$$CH_3H_2C{=}CH_2 + H_2SO_4 \longrightarrow CH_3CH_2 - CH_2OSO_3H$$

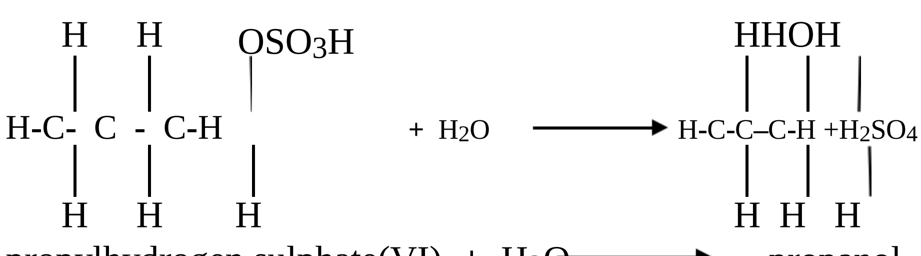


Propene + H_2SO_4 ⟶ propylhydrogen sulphate(VI)

(ii) Propylhydrogen sulphate(VI) is hydrolysed by water to propanol

<u>Chemical equation</u>

$$CH_3 - CH_2OSO_3H + H_2O \longrightarrow CH_3 - CH_2OH + H_2SO_4$$



propylhydrogen sulphate(VI) + H_2O ⟶ propanol

(vi) Polymerization/self addition

Addition polymerization is the process where a small unsaturated monomer (alkene) molecule join together to form a large saturated molecule.

Only alkenes undergo addition polymerization.

Addition polymers are named from the alkene/monomer making the polymer and adding the prefix **“poly”** before the name of monomer to form a **polyalkene**

During addition polymerization

(i)the double bond in alkenes break

(ii)free radicals are formed

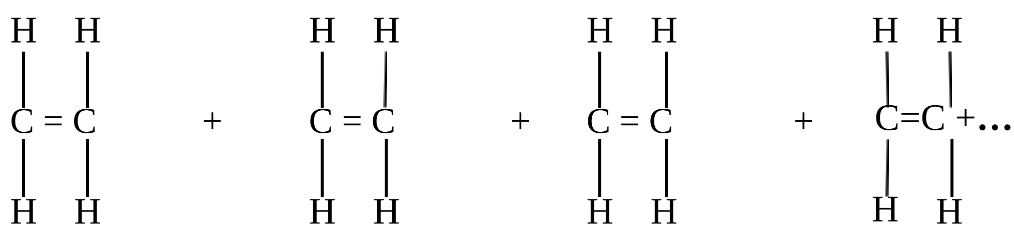
(iii)the free radicals collide with each other and join to form a larger molecule. The more collisions the larger the molecule.

Examples of addition polymerization

<u>1.Formation of Polyethene</u>

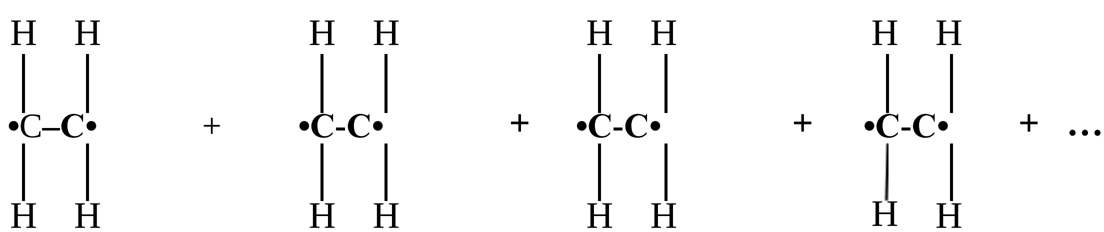
Polyethene is an addition polymer formed when ethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting paticles)



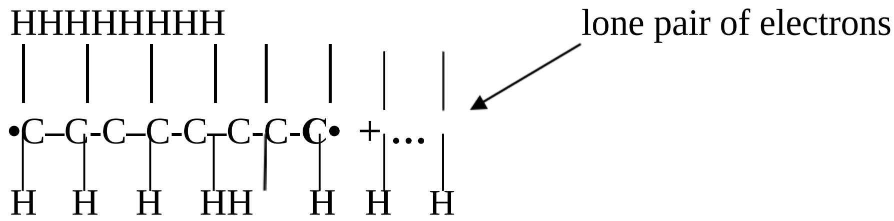
Ethene + Ethene + Ethene + Ethene + …

(ii)the double bond joining the ethane molecule break to free readicals



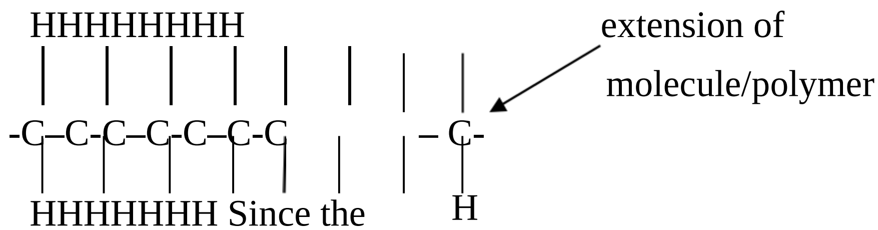
Ethene radical + Ethene radical + Ethene radical + Ethene radical + …

(iii)the free radicals collide with each other and join to form a larger molecule

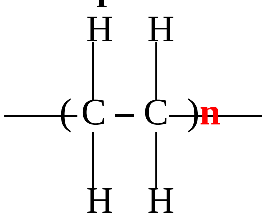


Lone pair of electrons can be used to join more monomers to form longer polyethene.

Polyethene molecule can be represented as:



Since the molecule is a **repetition** of one monomer, then the polymer is:



Where **n** is the number of monomers in the polymer. The number of monomers in the polymer can be determined from the molar mass of the polymer and monomer from the relationship:

$$\text{Number of monomers/repeating units in monomer} = \frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$$

<u>Examples</u>

Polythene has a molar mass of 4760.Calculate the number of ethene molecules in the polymer(C=12.0, H=1.0)

$$\text{Number of monomers/repeating units in polyomer} = \frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$$

=> Molar mass ethene (C_2H_4)= 28 Molar mass polyethene = 4760

Substituting $\frac{4760}{28}$ = <u>170 ethene molecules</u>

The **commercial** name of polyethene is **polythene**.

It is an elastic, tough, transparent and durable plastic.
Polythene is used:

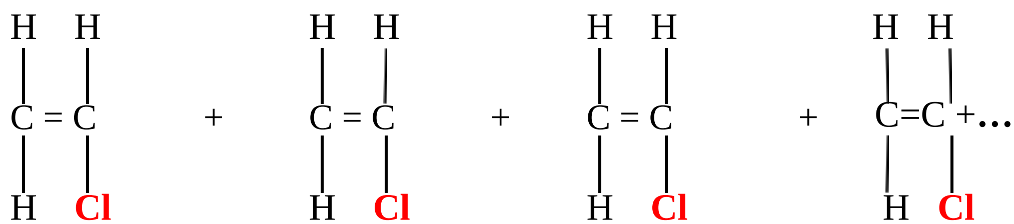
(i)in making plastic bag
(ii)bowls and plastic bags
(iii)packaging materials

<u>2.Formation of Polychlorethene</u>

Polychloroethene is an addition polymer formed when chloroethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

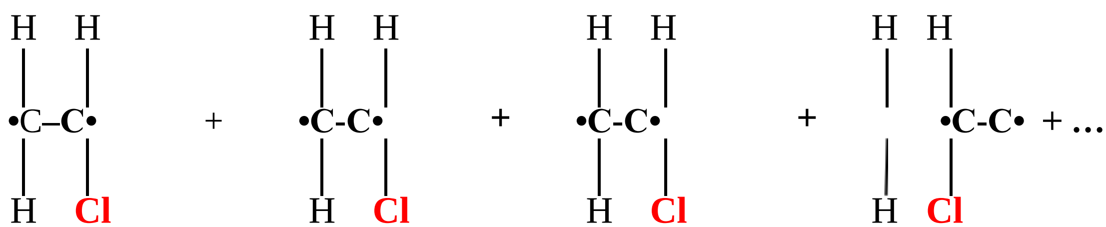
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

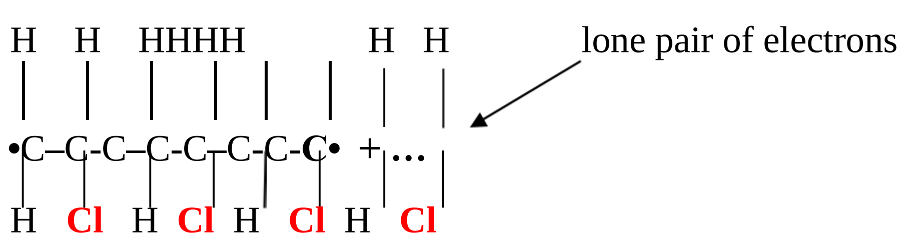


chloroethene + chloroethene + chloroethene + chloroethene + …

(ii)the double bond joining the chloroethene molecule break to free radicals

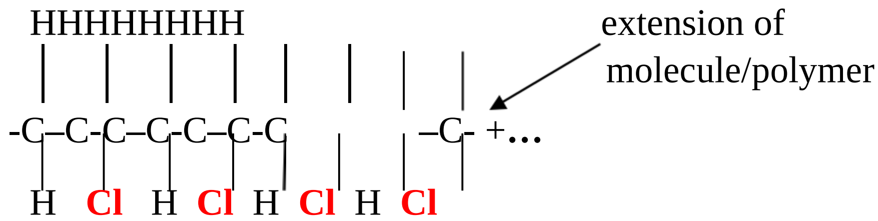


(iii)the free radicals collide with each other and join to form a larger molecule

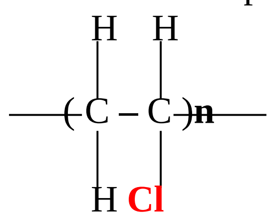


Lone pair of electrons can be used to join more monomers to form longer polychloroethene.

Polychloroethene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



Examples

Polychlorothene has a molar mass of 4760.Calculate the number of chlorethene molecules in the polymer(C=12.0, H=1.0,Cl=35.5)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass ethene (C_2H_3Cl)= 62.5 Molar mass polyethene = 4760

Substituting $\frac{4760}{62.5}$ = 77.16 => 77 polychloroethene molecules**(whole number)**

The **commercial** name of polychloroethene is **polyvinylchloride(PVC)**. It is a tough, non-transparent and durable plastic. PVC is used:

(i)in making plastic rope

(ii)water pipes

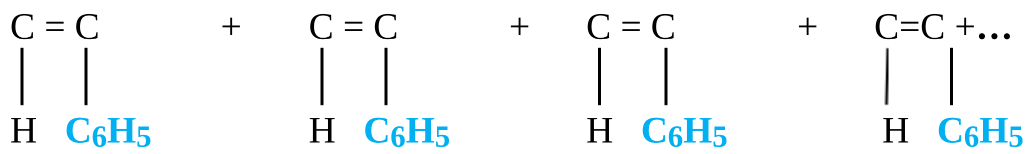
(iii)crates and boxes

3.Formation of Polyphenylethene

Polyphenylethene is an addition polymer formed when phenylethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

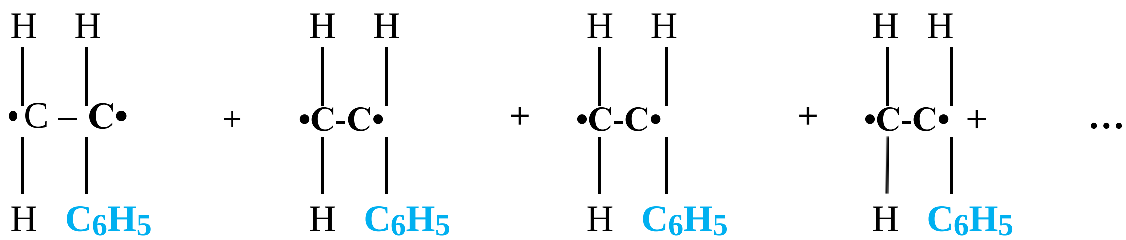
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

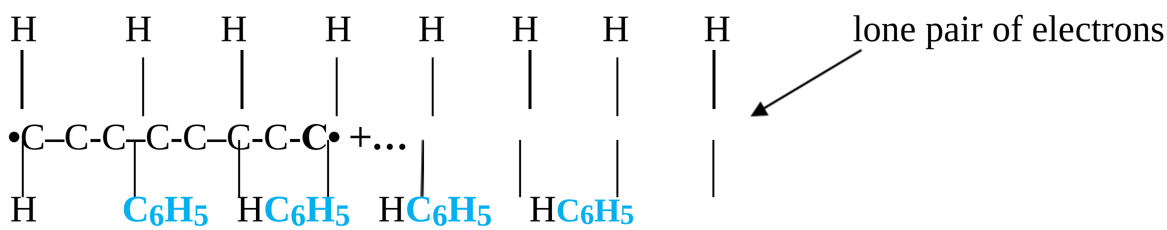


phenylethene + phenylethene + phenylethene + phenylethene + ...

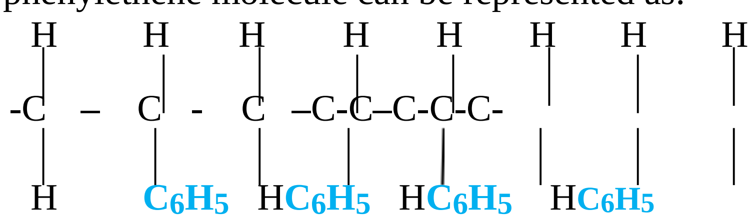
(ii)the double bond joining the phenylethene molecule break to free radicals



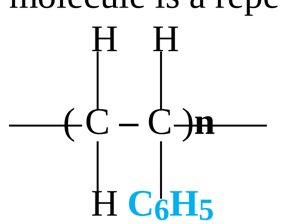
(iii)the free radicals collide with each other and join to form a larger molecule



Lone pair of electrons can be used to join more monomers to form longer polyphenylethene.
Polyphenylethene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



<u>Examples</u>

Polyphenylthene has a molar mass of 4760.Calculate the number of phenylethene molecules in the polymer(C=12.0, H=1.0,)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass ethene (C_8H_8)= 104 Molar mass polyethene = 4760

Substituting $\frac{4760}{104}$ = 45.7692 =>45 polyphenylethene molecules**(whole number)**

The **commercial** name of polyphenylethene is **polystyrene**. It is a very light durable plastic. Polystyrene is used:

(i)in making packaging material for carrying delicate items like computers, radion,calculators.

(ii)ceiling tiles

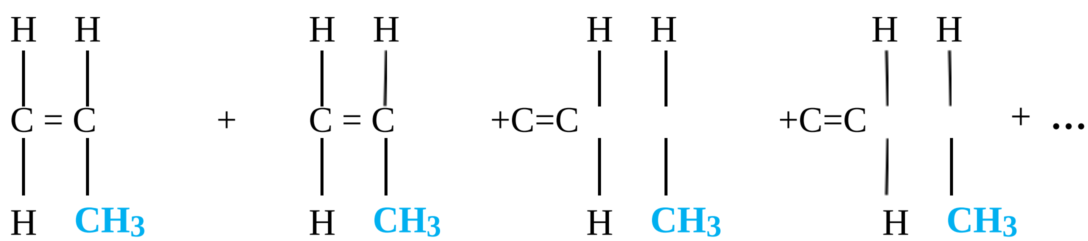
(iii)clothe linings

4.Formation of Polypropene

Polypropene is an addition polymer formed when propene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

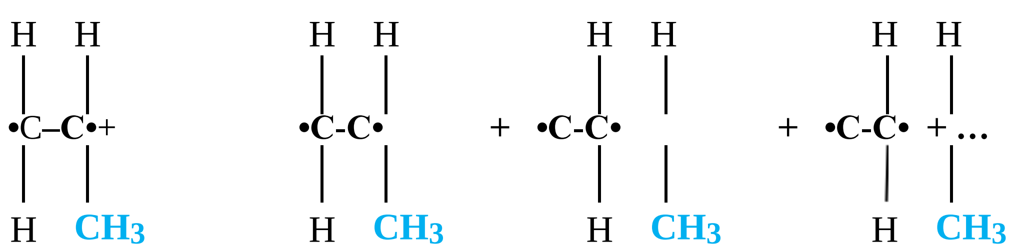
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

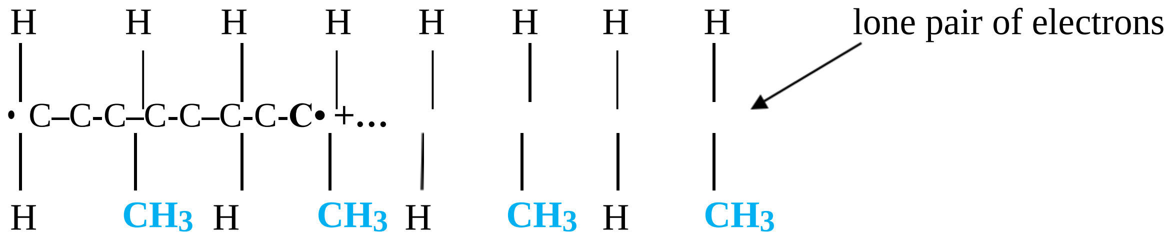


propene + propene + propene + propene + …

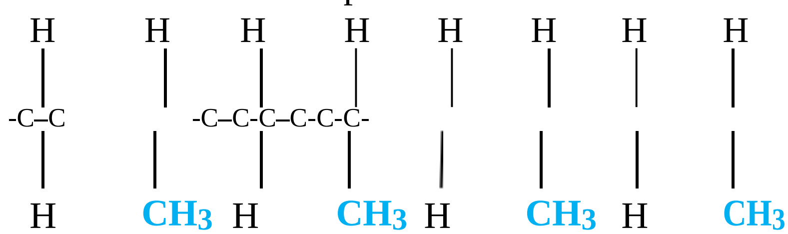
(ii)the double bond joining the phenylethene molecule break to free radicals



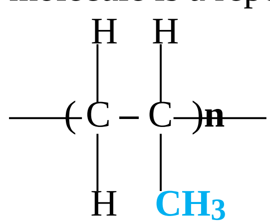
(iii)the free radicals collide with each other and join to form a larger molecule



Lone pair of electrons can be used to join more monomers to form longer propene. propene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



Examples

Polypropene has a molar mass of 4760.Calculate the number of propene molecules in the polymer(C=12.0, H=1.0,)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass propene (C_3H_8)= 44 Molar mass polyethene = 4760

Substituting $\frac{4760}{44}$ = <u>108.1818</u> =><u>108 propene molecules</u>**(whole number)**

The **commercial** name of polyphenylethene is **polystyrene**. It is a very light durable plastic. Polystyrene is used:

(i)in making packaging material for carrying delicate items like computers, radion,calculators.

(ii)ceiling tiles

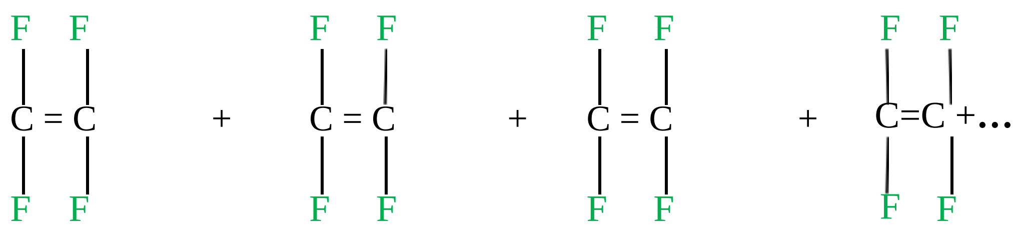
(iii)clothe linings

5.Formation of Polytetrafluorothene

Polytetrafluorothene is an addition polymer formed when tetrafluoroethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

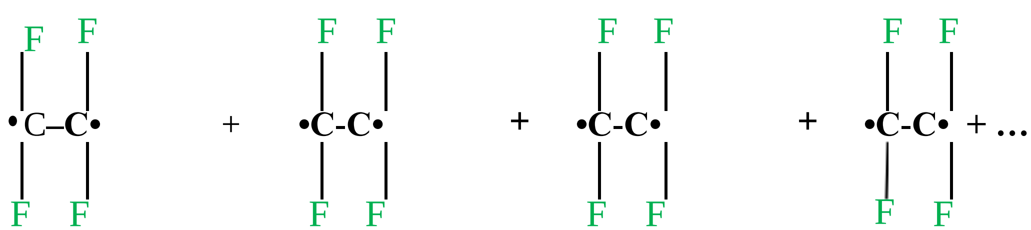
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

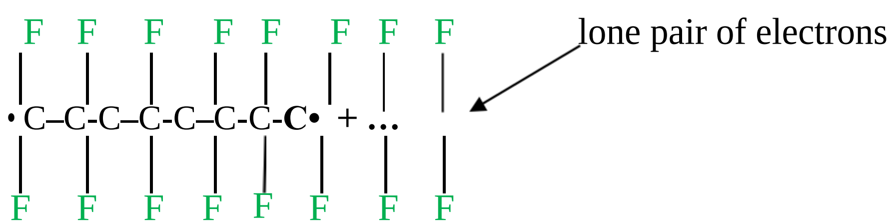


tetrafluoroethene + tetrafluoroethene+ tetrafluoroethene+ tetrafluoroethene + …

(ii)the double bond joining the tetrafluoroethene molecule break to free radicals

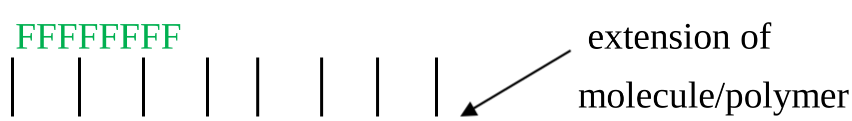


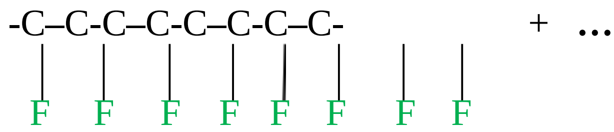
(iii)the free radicals collide with each other and join to form a larger molecule



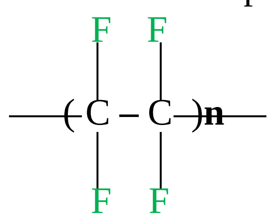
Lone pair of electrons can be used to join more monomers to form longer polytetrafluoroethene.

polytetrafluoroethene molecule can be represented as:





Since the molecule is a repetition of one monomer, then the polymer is:



<u>Examples</u>

Polytetrafluorothene has a molar mass of 4760.Calculate the number of tetrafluoroethene molecules in the polymer(C=12.0, ,F=19)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass ethene (C_2F_4)= 62.5 Molar mass polyethene = 4760

Substituting $\frac{4760}{62.5}$ = <u>77.16</u> => <u>77 polychloroethene molecules</u>**(whole number)**

The **commercial** name of polytetrafluorethene(**P.T.F.E**) is **Teflon(P.T.F.E)**. It is a tough, non-transparent and durable plastic. PVC is used:

(i)in making plastic rope
(ii)water pipes
(iii)crates and boxes

<u>6.Formation of rubber from Latex</u>

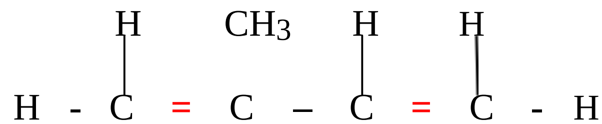
Natural rubber is obtained from rubber trees.

During harvesting an incision is made on the rubber tree to produce a milky white substance called **latex.**

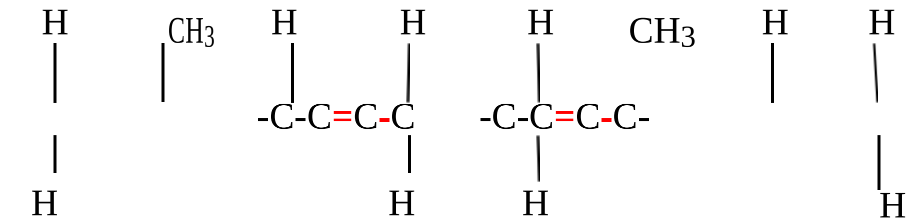
Latex is a mixture of rubber and lots of water.

The latex is then added an acid to coagulate the rubber.

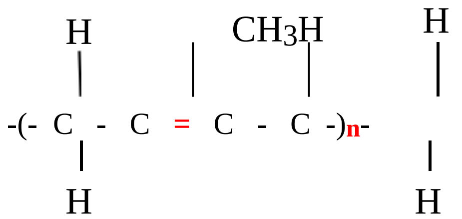
Natural rubber is a polymer of 2-methylbut-1,3-diene ;

$CH_2=C(CH_3)CH=CH_2$ 

During natural polymerization to rubber, one double C=C bond break to self add to another molecule.The double bond remaining move to carbon **"**2**"** thus;

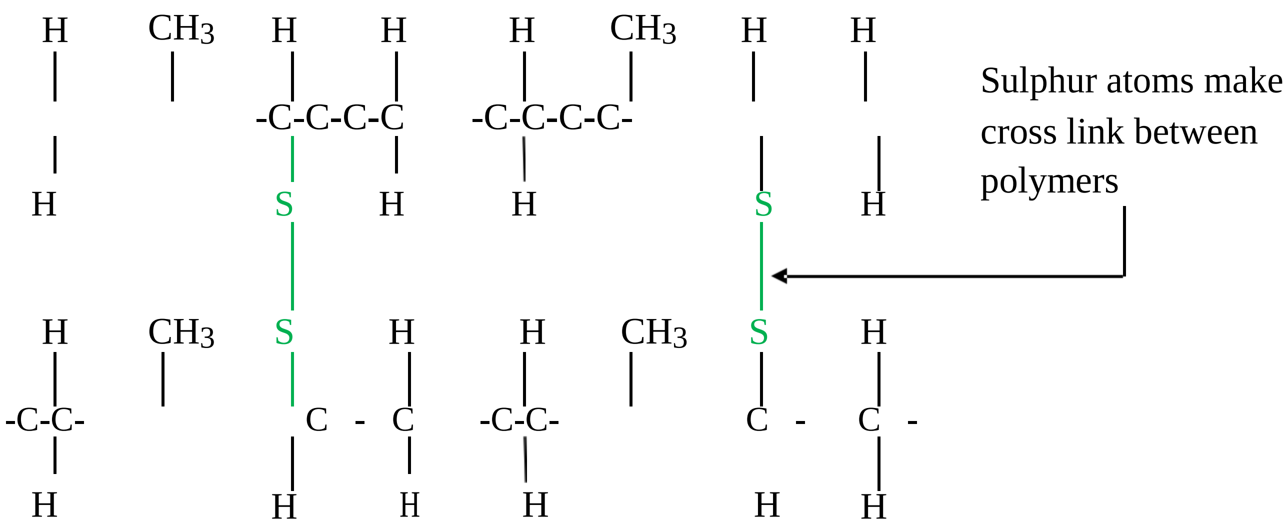


Generally the structure of rubber is thus;



Pure rubber is soft and sticky.It is used to make erasers, car tyres. Most of it is vulcanized.Vulcanization is the process of heating rubber with sulphur to make it harder/tougher.

During vulcanization the sulphur atoms form a cross link between chains of rubber molecules/polymers. This decreases the number of C=C double bonds in the polymer.

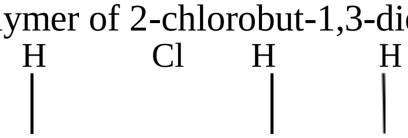


Vulcanized rubber is used to make **tyres**, **shoes** and **valves**.

7.Formation of synthetic rubber

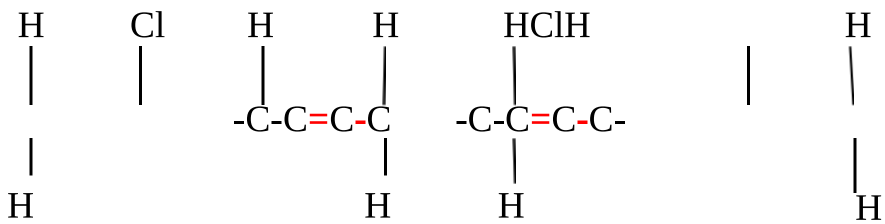
Synthetic rubber is able to resist action of oil,abrasion and organic solvents which rubber cannot.

Common synthetic rubber is a polymer of 2-chlorobut-1,3-diene ;

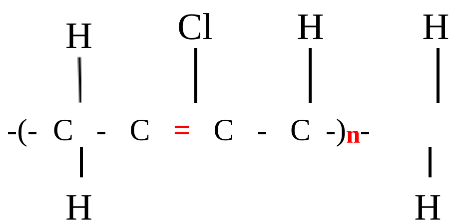


$CH_2=C$ (Cl $CH = CH_2$ H - C = C – C = C - H

During polymerization to synthetic rubber, one double C=C bond is broken to self add to another molecule. The double bond remaining move to carbon **"**2**"** thus;



Generally the structure of rubber is thus;



Rubber is thus strengthened through <u>vulcanization</u> and manufacture of <u>synthetic</u> rubber.

(c)Test for the presence of – C = C – double bond.

(i)Burning/combustion

All unsaturated hydrocarbons with a **– C = C –** or **– C = C–** bond burn with a yellow sooty flame.

<u>Experiment</u>

Scoop a sample of the substance provided in a clean metallic spatula. Introduce it on a Bunsen burner.

Observation	Inference
Solid melt then burns with a yellow sooty flame	**–C=C–,** – **C** ≡ **C** – bond

(ii)Oxidation by acidified $KMnO_4$/$K_2Cr_2O_7$

Bromine water ,Chlorine water and Oxidizing agents acidified $KMnO_4$/$K_2Cr_2O_7$ change to **unique** colour in presence of **– C = C –**

or $– C = C –$ bond.

Experiment

Scoop a sample of the substance provided into a clean test tube. Add 10cm3 of distilled water. Shake. Take a portion of the solution mixture. Add three drops of acidified $KMnO_4/K_2Cr_2O_7$.

Observation	Inference
Acidified $KMnO_4$ decolorized Orange colour of acidified $K_2Cr_2O_7$ turns green Bromine water is decolorized Chlorine water is decolorized	$–C=C–$ $– C \equiv C –$ bond

(d)Some uses of Alkenes

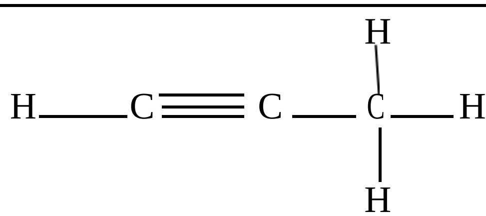
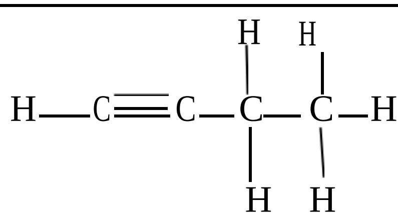
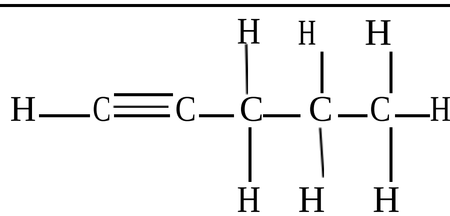
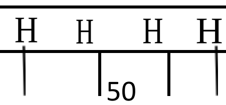
1. In the manufacture of plastic
2. Hydrolysis of eth**e**ne is used in industrial manufacture of ethanol.
3. In ripening of fruits.
4. In the manufacture of detergents.

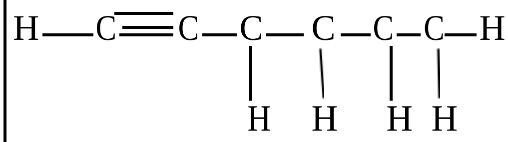
(iii) <u>Alkynes</u>

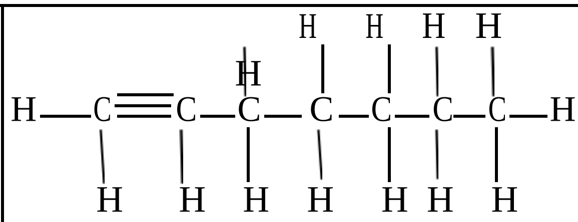
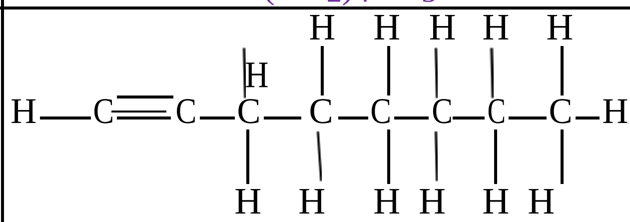
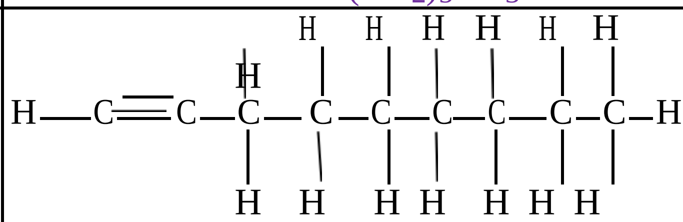
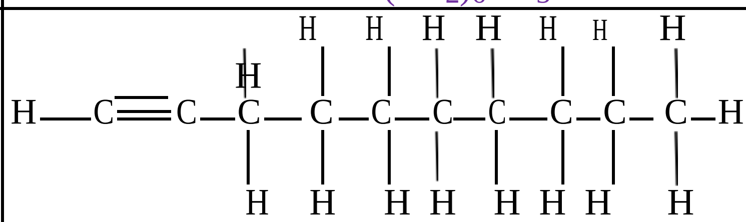
<u>(a)Nomenclature/Naming</u>

These are hydrocarbons with a general formula **C_nH_{2n-2}** and $C \equiv C$ double bond as the functional group . **n** is the number of Carbon atoms in the molecule. The carbon atoms are linked by at least one **triple** bond to each other and single bonds to hydrogen atoms.

They include:

n	General/ Structural formula Name Molecular formula		
1		Does not exist	-
2	C_2H_2	 CH CH	Eth**y**ne
3	C_3H_4	 CH C CH_3	Prop**y**ne
4	C_4H_6	 CH C CH_2CH_3	But**y**ne
5	C_5H_8	 CH C $(CH_2)_2CH_3$	Pent**y**ne
6	C_6H_{10}		Hex**y**ne

		 $CH \equiv C(CH_2)_3CH_3$	

7	C_7H_{12}	 $CH \equiv C(CH_2)_4CH_3$	Heptyne
8	C_8H_{14}	 $CH \equiv C(CH_2)_5CH_3$	Octyne
9	C_9H_{16}	 $CH \equiv C(CH_2)_6CH_3$	Nonyne
10	$C_{10}H_{18}$	 $CH \equiv C(CH_2)_7CH_3$	Decyne

Note

1. Since carbon is **tetravalent** ,each atom of carbon in the alk**y**ne **MUST** always be bonded using **four** covalent bond /four shared pairs of electrons including at the triple bond.

2. Since Hydrogen is **monovalent** ,each atom of hydrogen in the alk**y**ne **MUST** always be bonded using **one** covalent bond/one shared pair of electrons.

3. One member of the alk**y**ne ,like alk**e**nes and alk**a**nes, differ from the next/previous by a CH_2 group(molar mass of 14 **a**tomic **m**ass **u**nits).They thus form a homologous series.

e.g

Prop**y**ne differ from eth**y**ne by (14 a.m.u) one carbon and two Hydrogen atoms from eth**y**ne.

4.A homologous series of alkenes like that of alkanes:

(i) differ by a CH_2 group from the next /previous consecutively

(ii) have similar chemical properties

(iii)have similar chemical formula with general formula C_nH_{2n-2} (iv)the physical properties also show steady gradual change

5.The - C ≡ C - triple bond in alk**y**ne is the functional group. The functional group is the **reacting site** of the alk**y**nes.

6. The - C = C - triple bond in alk**y**ne can easily be broken to accommodate more /four more monovalent atoms. The - C ≡ C - triple bond in alk**y**nes make it thus **unsaturated** like alkenes**.**

7. Most of the reactions of alk**y**nes like alkenes take place at the - C ≡ C- triple bond.

<u>(b)Isomers of alkynes</u>

Isomers of alk**y**nes have the same molecular **general formula** but <u>different</u> molecular **structural formula**.

Isomers of alk**y**nes are also named by using the IUPAC(**I**nternational **U**nion of **P**ure and **A**pplied **C**hemistry) system of **nomenclature/naming.**

The IUPAC system of nomenclature of naming alk**y**nes uses the following basic rules/guidelines:

1.Identify the longest continuous/straight carbon chain which contains the **- C ≡ C- triple** bond to get/determine the **parent** alkene.

2. Number the longest chain form the end of the chain which contains the **-C ≡ C- triple** bond so as **- C ≡ C- triple** bond get lowest number possible.

3 Indicate the positions by splitting **"alk**-positions-**yne"** e.g. but-2-**y**ne, pent-1,3-di**y**ne.

4.The position **indicated** must be for the carbon atom at the **lower** position in the **-C ≡ C- triple bond.** i.e

But-2-**y**ne means the triple -C ≡ C- is between Carbon **"**2**"**and **"**3**"** Pent-1,3-di**y**ne means there are two triple bonds; one <u>between</u> carbon **"**1**"** and **"**2**"**and another <u>between</u> carbon **"**3**"** and **"**4**"**

5. Determine the position, number and type of branches. Name them as methyl, ethyl, propyl e.t.c. according to the number of alkyl carbon chains attached to the alk**y**ne. Name them fluoro-,chloro-,bromo-,iodo- if they are halogens

6.Use prefix di-,tri-,tetra-,penta-,hexa- to show the number of **triple -** C ≡ C- bonds and **branches** attached to the alk**y**ne.

7.Position isomers can be formed when the - C ≡ C- triple bond is shifted between carbon atoms e.g.

But-2-**y**ne means the double - C = C- is between Carbon "2"and "3"

But-1-**y**ne means the double - C = C- is between Carbon "1"and "2"

Both But-1-**y**ne and But-2-yne are position isomers of But**y**ne.

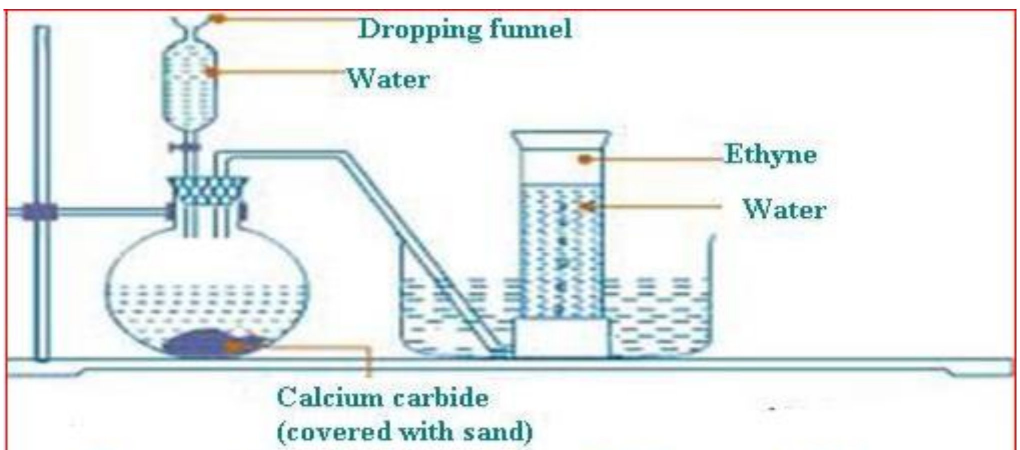
9. Like alkanes and alkynes , an alkyl group can be attached to the alk**y**ne. Chain/branch isomers are thus formed.

But**y**ne and 2-methyl prop**y**ne both have the same general formular but different branching chain.

(**More on powerpoint**)

(c)Preparation of Alkynes.

Ethyne is prepared from the reaction of water on calcium carbide. The reaction is highly exothermic and thus a layer of sand should be put above the calcium carbide to absorb excess heat to prevent the reaction flask from breaking. Copper(II)sulphate(VI) is used to catalyze the reaction



Preparation of Ethyne from Calcium carbide

Chemical equation

$CaC_2(s) + 2 H_2O(l) \rightarrow Ca(OH)_2 (aq) + C_2H_2 (g)$

(d)Properties of alkynes
I. Physical properties

Like alk**a**nes and alk**e**nes,alkynes are colourles gases, solids and liquids that are not poisonous.

They are slightly soluble in water. The solubility in water decrease as the carbon chain and as the molar mass increase but very soluble in organic solvents like tetrachloromethane and methylbenzene. Ethyne has a pleasant taste when pure. The melting and boiling point increase as the carbon chain increase.

This is because of the increase in van-der-waals /intermolecular forces as the carbon chain increase. The 1st three straight chain alk**y**nes (eth**y**ne,prop**y**ne and but-1-**y**ne)are gases at room temperature and pressure.

The density of straight chain alk**y**nes increase with increasing carbon chain as the intermolecular forces increases reducing the volume occupied by a given mass of the alk**y**ne.

Summary of physical properties of the 1st five alk**e**nes

Alk**y**ne	General formula	Melting point(^oC)	Boiling point(^oC)	State at room(298K) temperature and pressure atmosphere (101300Pa)
Eth**y**ne	CH CH	-82	-84	gas
Prop**y**ne	CH_3 C CH	-103	-23	gas
But**y**ne	CH_3CH_2 CCH	-122	8	gas
Pent-1-**y**ne	$CH_3(CH_2)_2$ CCH	-119	39	liquid
Hex-1-**y**ne	$CH_3(CH_2)_3$C CH	-132	71	liquid

II. Chemical properties
(a)Burning/combustion

Alk**y**nes burn with a **yellow**/ luminous very **sooty**/ smoky flame in **excess** air to form carbon(IV) oxide and water.

Alk**y**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)

Alk**e**nes burn with a **yellow**/ luminous very**sooty**/ smoky flame in **limited** air to form carbon(II) oxide/carbon and water.

Alk**y**ne + Air -> carbon(**II**) oxide /carbon + water (limited air) Burning of alk**y**nes with a **yellow**/ luminous **sooty**/ smoky flame is a confirmatory test for the **presence** of the **- C = C –** triple bond because they have very **high**
C:H ratio.

Examples of burning alk**y**nes

1.(a) Eth**y**ne when ignited burns with a **yellow** very **sooty** flame in **excess** air to form carbon(IV) oxide and water.

Eth**y**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$2C_2H_2(g)$ + $5O_2(g)$ -> $4CO_2(g)$ + $2H_2O(l/g)$

(b) Eth**y**ne when ignited burns with a **yellow sooty** flame in **limited** air to form a mixture of unburnt carbon and carbon(II) oxide and water.

Eth**y**ne + Air -> carbon(**II**) oxide + water (limited air)
$C_2H_2(g)$ + $O_2(g)$ -> $2CO_2(g)$ + C + $2H_2O(l/g)$

2.(a) Prop**y**ne when ignited burns with a **yellow sooty** flame in **excess** air to form carbon(IV) oxide and water.

Prop**y**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$C_3H_4(g)$ + $4O_2(g)$ ->$3CO_2(g)$ + $2H_2O(l/g)$

(a) Prop**y**ne when ignited burns with a **yellow sooty** flame in **limited** air to form carbon(II) oxide and water.

Prop**e**ne + Air -> carbon(**IV**) oxide + water (excess air/oxygen)
$2C_3H_4(g)$ + $5O_2(g)$ -> $6CO(g)$ + $4H_2O(l/g)$

(b)Addition reactions

An addition reaction is one which an unsaturated compound reacts to form a saturated compound. Addition reactions of alk**y**nes are also named from the reagent used to cause the addition/convert the triple - C = C- to single C- C bond.

(i)Hydrogenation

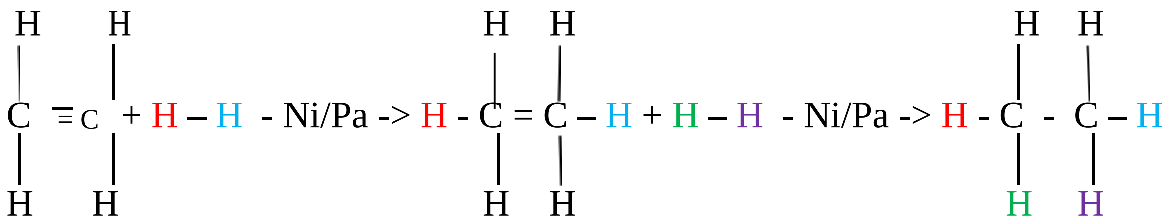
Hydrogenation is an addition reaction in which **hydrogen** in presence of **Palladium/Nickel** catalyst at <u>150^{O}C temperatures</u> react with alk**y**nes to form alk**e**nes then alk**a**nes.

Examples

1.During hydrogenation, **two** hydrogen atom in the hydrogen molecule attach itself to one carbon and the other **two** hydrogen to the second carbon breaking the **triple** bond to **double** the **single**.

Chemical equation

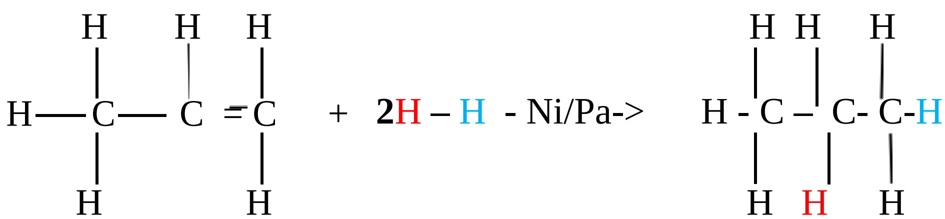
$HC \equiv CH + H_2$ -Ni/Pa -> $H_2C = CH_2$ + H_2 -Ni/Pa -> H_2C - CH_2



2.Propyne undergo hydrogenation to form Propane

Chemical equation

$H_3C\ CH$ [redacted] CH_2 + **2**H_2 -Ni/Pa->$H_3C\ CH$ - CH_3

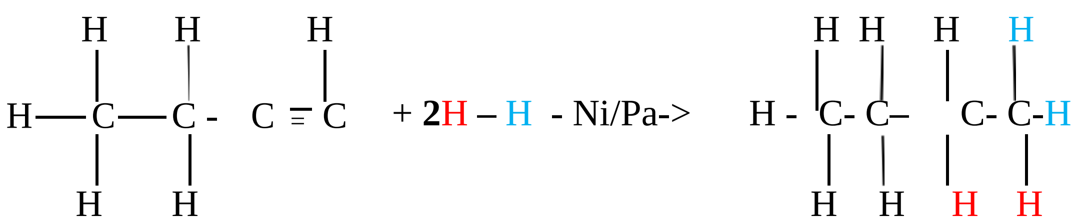


3(a) But-1-**y**ne undergo hydrogenation to form Butane

Chemical equation

But-1-**y**ne + Hydrogen –Ni/Pa-> Butane

$H_3C\ CH_2\ C \equiv CH$ + **2**H_2 -Ni/Pa-> $H_3C\ CH_2CH$ - CH_3

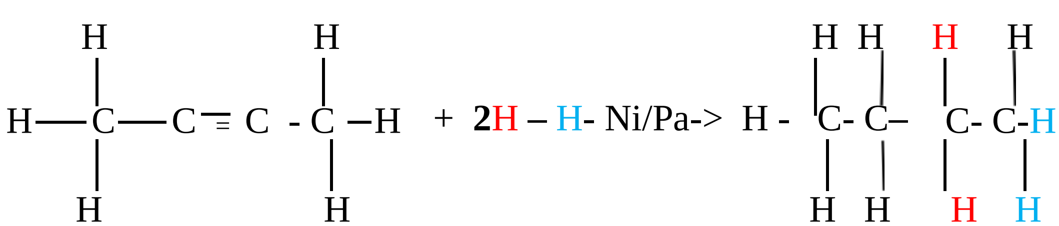


(b) But-2-**y**ne undergo hydrogenation to form Butane

Chemical equation

But-2-yne + Hydrogen –Ni/Pa-> Butane

$H_3CC{=}CCH_2$ + **2**H_2 -Ni/Pa-> $H_3C\ CH_2CH$ - CH_3



(ii) Halogenation.

Halogenation is an addition reaction in which a halogen (Fluorine, chlorine, bromine, iodine) reacts with an alk**y**ne to form an alkene then alkane.

The reaction of alkynes with halogens with alkynes is **faster** than with alkenes. The triple bond in the alk**y**ne break and form a double then single bond.

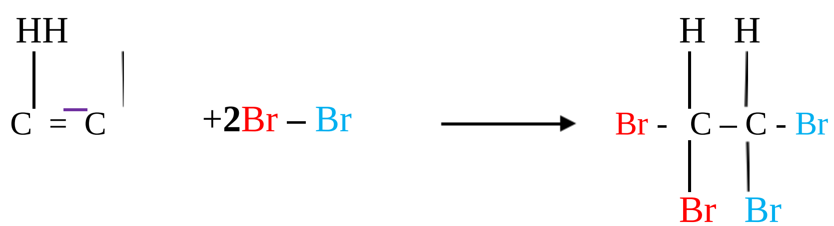
The colour of the halogen **fades** as the number of moles of the halogens remaining unreacted decreases.

Two bromine atoms bond at the 1st carbon in the triple bond while the other two goes to the 2nd carbon.

<u>Examples</u>

1Ethyne reacts with brown bromine vapour to form 1,1,2,2-tetrabromoethane. <u>Chemical equation</u>

$$HC \equiv CH \quad + \quad 2Br_2 \longrightarrow H\,Br_2\,C - CH\,Br_2$$



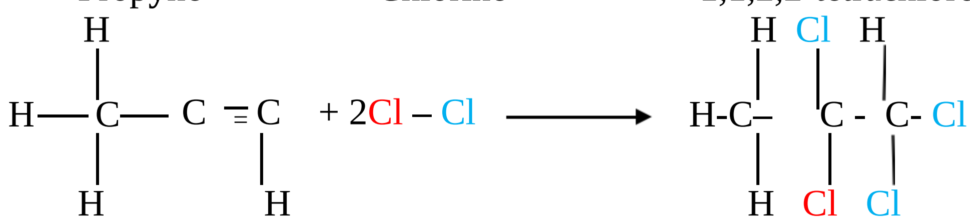
Ethyne + Bromine ⟶ 1,1,2,1-tetrabromoethane

2.Prop**y**ne reacts with chlorine to form 1,1,2,2-tetrachloropropane.

<u>Chemical equation</u>

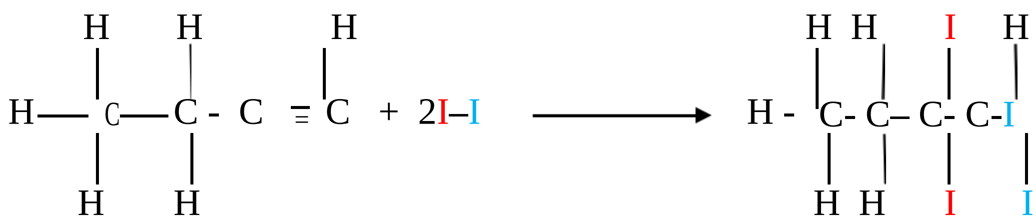
$$H_3CC \equiv CH \quad + \quad \mathbf{2}Cl_2 \longrightarrow H_3C\,CHCl_2 - CHCl_2$$

Prop**y**ne + Chlorine ⟶ 1,1,2,2-tetrachloropropane



Prop**y**ne + Iodine ⟶ 1,1,2,2-tetraiodopropane

$$H_3CC=CH \quad + \quad \mathbf{2}I_2 \qquad H_3C\,CHI_2 - CHI_2$$

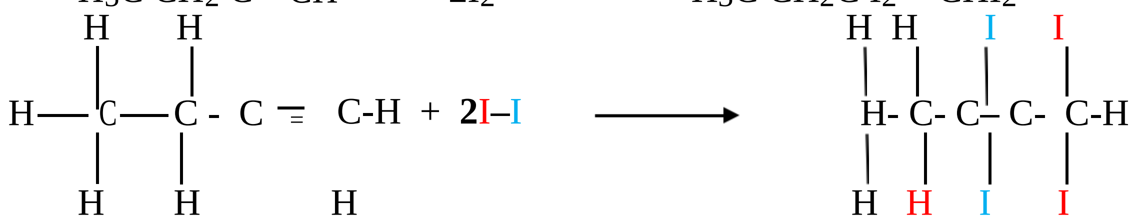


3(a)But-1-**y**ne undergo halogenation to form 1,1,2,2-tetraiodobutane with iodine

<u>Chemical equation</u>

But-1-**y**ne + iodine ⟶ 1,1,2,2-tetrabromobutane

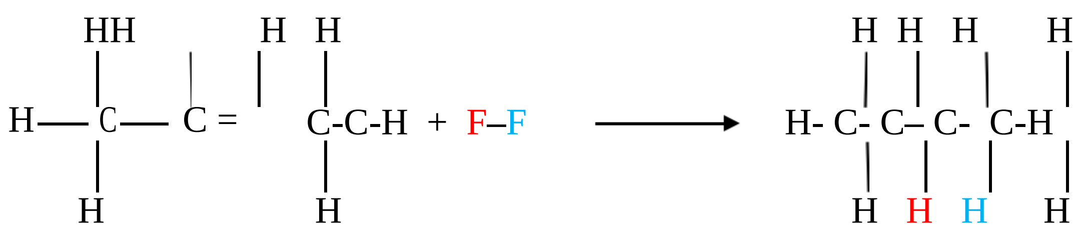
$H_3C\ CH_2\ C \equiv CH\ +\ \mathbf{2}I_2 \longrightarrow H_3C\ CH_2C\ I_2 - CHI_2$



(b) But-2-**y**ne undergo halogenation to form 2,2,3,3-tetrafluorobutane with fluorine

But-2-**y**ne + Fluorine ⟶ 2,2,3,3-tetrafluorobutane

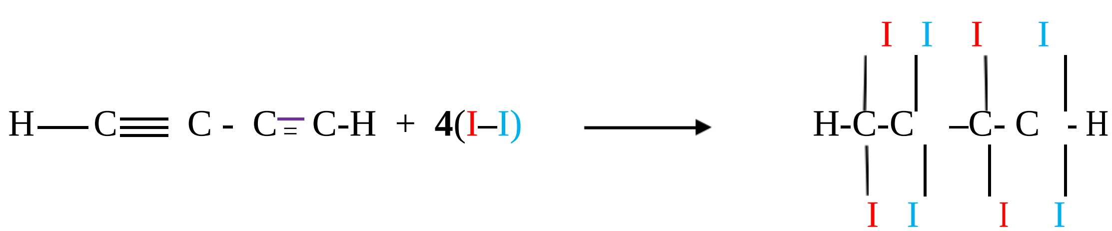
$H_3C\ C \equiv C\ -CH_2\ +\ \mathbf{2}F_2 \longrightarrow H_3C\ CF_2CF_2 - CH_3$



4. But-1,3-di**y**ne should undergo halogenation to form 1,1,2,3,3,4,4 octaiodobutane. The reaction uses **four** <u>moles</u> of iodine molecules/**eight** iodine atoms to break the two(2) triple double bonds at carbon **"**1**"** and **"**2**"**.

But-1,3-di**e**ne + iodine ⟶ 1,2,3,4-tetraiodobutane

HC[redacted]C C $\equiv CH\ +\ \mathbf{4}I_2 \longrightarrow H\ C\ I_2C\ I_2C\ I_2C\ H\ I_2$



(iii) Reaction with hydrogen halides.

Hydrogen halides reacts with alk**y**ne to form a halogenoalk**e**ne then halogenoalk**a**ne. The triple bond in the alk**y**ne break and form a double then single bond.

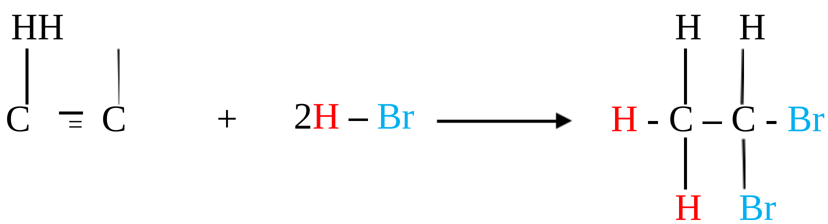
The main compound is one which the **hydrogen** atom bond at the carbon with **more hydrogen** .

Examples

1. Ethyne reacts with hydrogen bromide to form bromoethane.

Chemical equation

HC=CH + 2HBr ⟶ H_3C - $CH Br_2$



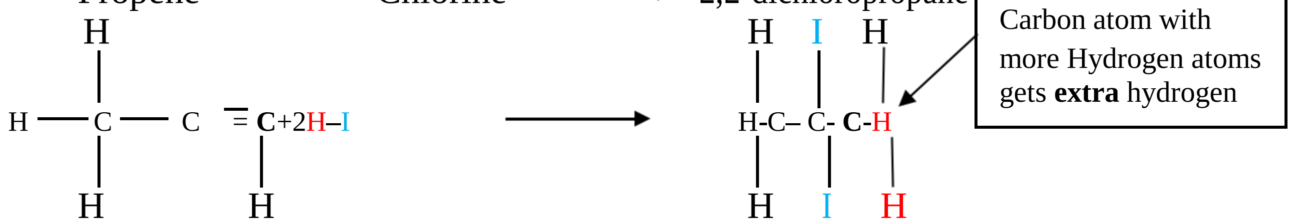
Ethyne + Bromine ⟶ 1,1-dibromoethane

2. Propyne reacts with hydrogen iodide to form 2,2-diiodopropane (as the main product)

Chemical equation

$H_3CC\equiv CH$ + 2HI ⟶ H_3C CHI_2 - CH_3

Propene + Chlorine ⟶ 2,2-dichloropropane

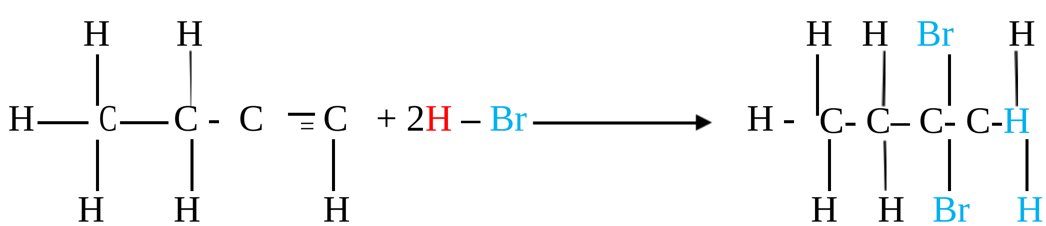


3. Both But-1-**y**ne and But-2-**y**ne reacts with hydrogen bromide to form 2,2-dibromobutane

Chemical equation

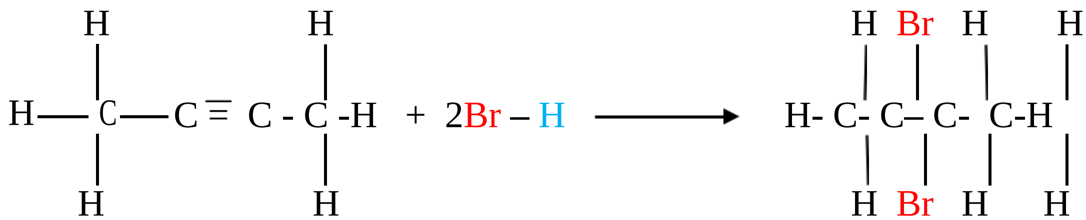
But-1-**e**ne + hydrogen bromide ⟶ 2,2-dibromobutane

H_3C CH_2 C = CH + 2HBr ⟶ H_3C CH_2CHBr -CH_3



But-2-**y**ne + Hydrogen bromide ⟶ 2,2-dibromobutane

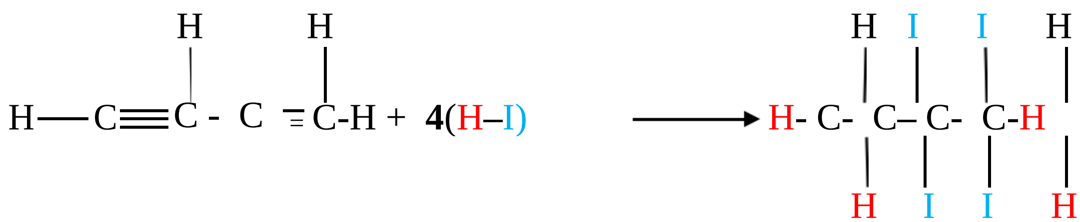
$H_3C\ C \equiv C\ -CH_3\ +\ 2HBr \longrightarrow H_3C\ CBr_2CH_2 -\ CH_3$



4. But-1,3-di**e**ne react with hydrogen iodide to form 2,3- diiodobutane. The reaction uses **four** moles of hydrogen iodide molecules/**four** iodine atoms and two hydrogen atoms to break the two double bonds.

But-1,3-di**y**ne + iodine ⟶ 2,2,3,3-tetraiodobutane

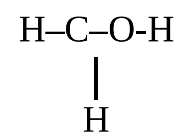
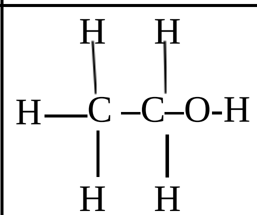
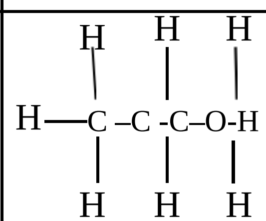
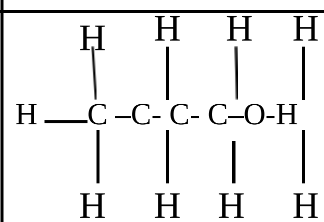
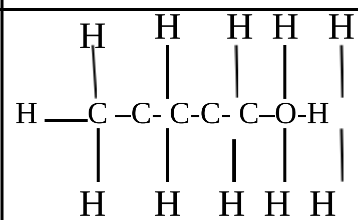
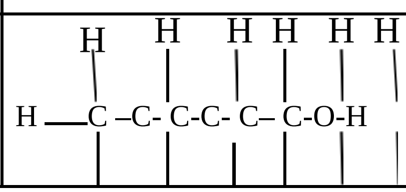
$H\ C \equiv C\ C \equiv CH\ +\ \mathbf{4H}I \longrightarrow H_3C\ C\ I_2\ C\ I_2\ CH_3$

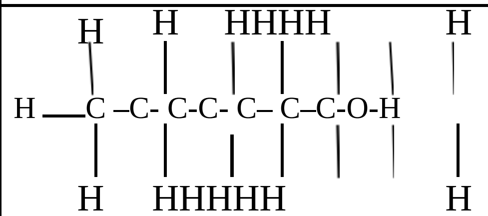
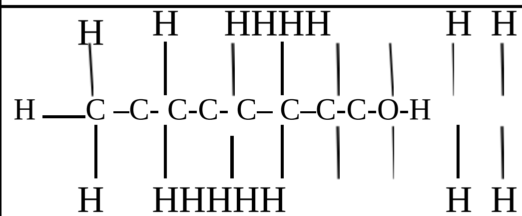
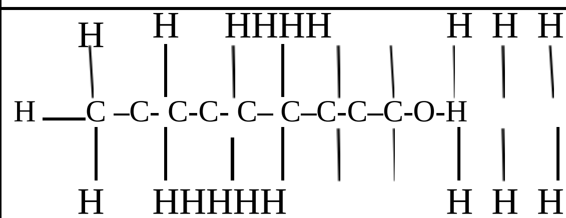
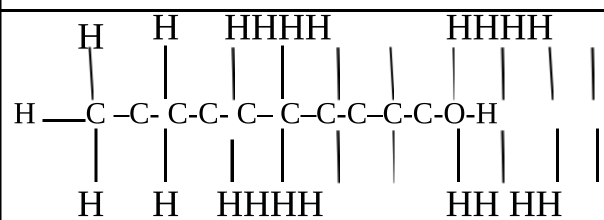


B.ALKANOLS(Alcohols)

(A) INTRODUCTION.

Alkanols belong to a homologous series of organic compounds with a general formula **C_nH_{2n+1} OH** and thus **-OH** as the functional group .The 1st ten alkanols include

n	General / molecular formular	Structural formula	IUPAC name
1	CH_3OH		Methan**ol**
2	CH_3 CH_2OH C_2H_5 OH		Ethan**ol**
3	CH_3 $(CH_2)_2OH$ C_3H_7 OH		Propan**ol**
4	CH_3 $(CH_2)_3OH$ C_4H_9 OH		Butan**ol**
5	$CH_3(CH_2)_4OH$ C_5H_{11} OH		Pentan**ol**
6	$CH_3(CH_2)_5OH$ C_6H_{13} OH		Hexan**ol**

		H HHHHH	
7	$CH_3(CH_2)_6OH$ C_7H_{15} OH		Heptan**ol**
8	$CH_3(CH_2)_7OH$ C_8H_{17} OH		Octan**ol**
9	$CH_3(CH_2)_8OH$ C_9H_{19} OH		Nonan**ol**
10	$CH_3(CH_2)_9OH$ $C_{10}H_{21}$ OH		Decan**ol**

Alkanols like Hydrocarbons(alkanes/alkenes/alkynes) form a homologous series where:

(i)general name is derived from the alkane name then ending with **"-ol"** (ii)the members have –OH as the fuctional group

(iii)they have the same general formula represented by R-OH where R is an alkyl group.

(iv) each member differ by –CH_2 group from the next/previous.

(v)they show a similar and gradual change in their physical properties e.g. boiling and melting points.

(vi)they show similar and gradual change in their chemical properties.

B. ISOMERS OF ALKANOLS.

Alkanols exhibit both structural and position isomerism. The isomers are named by using the following basic guidelines:

(i)Like alkanes , identify the **longest** carbon chain to be the parent name.
(ii)Identify the position of the **-OH** functional group to give it the **smallest /lowest** position.
(iii) Identify the type and position of the **side** branches.

Practice examples of isomers of alkanols

(i)Isomers of propanol C_3H_7OH

$CH_3CH_2CH_2OH$ - Propan-1-ol

```
    OH
    |
CH3CHCH3  - Propan-2-ol
```

Propan-2-ol and Propan-1-ol are position isomers because only the position of the –OH functional group changes.

(ii)Isomers of Butanol C_4H_9OH

CH_3 CH_2 CH_3 CH_2 OH Butan-1-ol

```
CH3 CH2 CH CH3
        |
        OH          Butan-2-ol
```

```
    CH3
    |
CH3 CH3 CH3
    |
    OH              2-methylpropan-2-ol
```

Butan-2-ol and Butan-1-ol are position isomers because only the position of the -OH functional group changes.

2-methylpropan-2-ol is both a structural and position isomers because both the position of the functional group and the arrangement of the atoms in the molecule changes.

(iii)Isomers of Pentanol $C_5H_{11}OH$

CH_3 CH_2 $CH_2CH_2CH_2$ OH Pentan-1-ol (Position isomer)

$CH_3\ CH_2\ CH\ CH_3$

|

OH Pentan-2-ol (Position isomer)

$CH_3\ CH_2\ CH\ CH_2\ CH_3$

|

OH Pentan-3-ol (Position isomer)

CH_3

|

$CH_3\ CH_2\ CH_2\ C\ CH_3$

|

OH 2-methylbutan-2-ol (Position /structural isomer)

CH_3

|

$CH_3\ CH_2\ CH_2\ C\ CHOH$

|

CH_3 2,2-dimethylbutan-1-ol (Position /structural isomer)

CH_3

|

$CH_3\ CH_2\ CH\ \ C\ CH_3$

| |

CH_3 OH 2,3-dimethylbutan-1-ol (Position /structural isomer)

(iv)1,2-dichloropropan-2-ol

$CClH_2\ CCl\ CH_3$

|

OH

(v)1,2-dichloropropan-1-ol

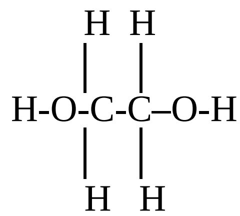
$CClH_2\ CHCl\ CH_2$

|

OH

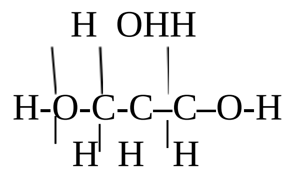
(vi) Ethan1,2-diol

$HOCH_2CH_2OH$



(vii) Propan1,2,3-triol

$HOCH_2CHOHCH_2OH$



C. LABORATORY PREPARATION OF ALKANOLS.

For decades the world over, people have been fermenting grapes juice, sugar, carbohydrates and starch to produce ethanol as a social drug for relaxation.

In large amount, drinking of ethanol by mammals /human beings causes mental and physical lack of coordination.

Prolonged intake of ethanol causes permanent mental and physical lack of coordination because it damages vital organs like the liver.

Fermentation is the reaction where sugar is converted to alcohol/alkanol using biological catalyst/enzymes in **yeast.**

It involves **three** processes:

(i)Conversion of starch to maltose using the enzyme **diastase.**

$(C_6H_{10}O_5)n\ (s) + H_2O(l)$ --diastase enzyme --> $C_{12}H_{22}O_{11}(aq)$
(Starch) (Maltose)

(ii)Hydrolysis of Maltose to glucose using the enzyme **maltase.**

$C_{12}H_{22}O_{11}(aq) + H_2O(l)$ -- maltase enzyme -->2 $C_6H_{12}O_6(aq)$
(Maltose) (glucose)

(iii)Conversion of glucose to ethanol and carbon(IV)oxide gas using the enzyme **zymase.**

$C_6H_{12}O_6(aq)$ -- zymase enzyme --> 2 $C_2H_5OH(aq)$ + $2CO_2(g)$
(glucose) (Ethanol)

At concentration greater than 15% by volume, the ethanol produced kills the yeast enzyme stopping the reaction.

To increases the concentration, fractional distillation is done to produce spirits (e.g. Brandy=40% ethanol).

Methanol is much more poisonous /toxic than ethanol.

Taken large quantity in small quantity it causes instant blindness and liver, killing the consumer victim within hours.

School laboratory preparation of ethanol from fermentation of glucose

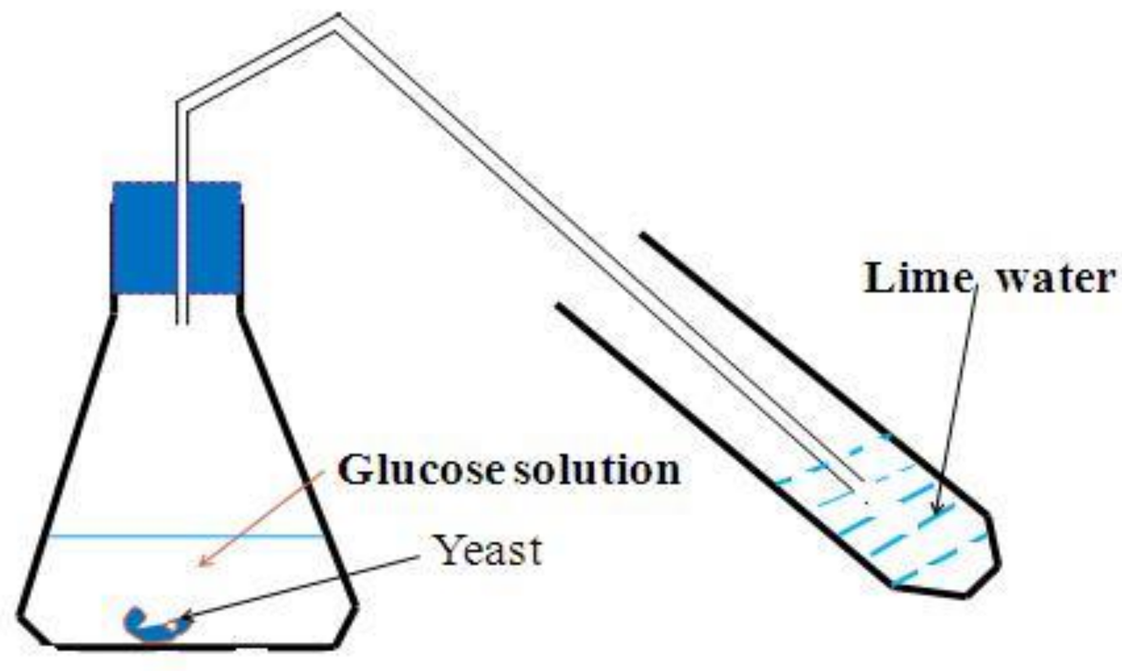
Measure 100cm3 of pure water into a conical flask.

Add about five spatula end full of glucose.

Stir the mixture to dissolve.

Add about one spatula end full of yeast.

Set up the apparatus as below.



Preserve the mixture for about **three** days.

D.PHYSICAL AND CHEMICAL PROPERTIES OF ALKANOLS

Use the prepared sample above for the following experiments that shows the characteristic properties of alkanols

(a) <u>Role of yeast</u>

Yeast is a single cell fungus which contains the enzyme maltase and zymase that catalyse the fermentation process.

(b) **Observations in lime water.**

A white precipitate is formed that dissolve to a colourless solution later. Lime water/Calcium hydroxide reacts with carbon(IV)0xide produced during the fermentation to form insoluble calcium carbonate and water.

More carbon (IV)0xide produced during fermentation react with the insoluble calcium carbonate and water to form soluble calcium hydrogen carbonate.

$$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s)$$
$$H_2O(l) + CO_2(g) + CaCO_3(s) \rightarrow Ca(HCO_3)_2(aq)$$

(c)Effects on litmus paper

Experiment

Take the prepared sample and test with both blue and red litmus papers.
Repeat the same with pure ethanol and methylated spirit.

Sample Observation table

Substance/alkanol	**Effect on litmus paper**
Prepared sample	Blue litmus paper remain blue Red litmus paper remain red
Absolute ethanol	Blue litmus paper remain blue Red litmus paper remain red
Methylated spirit	Blue litmus paper remain blue Red litmus paper remain red

Explanation

Alkanols are neutral compounds/solution that have characteristic sweet smell and taste.
They have no effect on both blue and red litmus papers.

(d)Solubility in water.

Experiment

Place about 5cm3 of prepared sample into a clean test tube Add equal amount of distilled water.
Repeat the same with pure ethanol and methylated spirit.

Observation

No layers formed between the two liquids.

Explanation

Ethanol is **miscible** in water.Both ethanol and water are polar compounds .

The solubility of alkanols decrease with increase in the alkyl chain/molecular mass. The alkyl group is insoluble in water while –OH functional group is soluble in water.

As the molecular chain becomes **longer** ,the effect of the **alkyl** group **increases** as the effect of the functional group **decreases**.

e)Melting/boiling point.

Experiment

Place pure ethanol in a long boiling tube .Determine its boiling point.

Observation

Pure ethanol has a boiling point of $78^{o}C$ at sea level/one atmosphere pressure. Explanation

The melting and boiling point of alkanols increase with increase in molecular chain/mass .

This is because the intermolecular/van-der-waals forces of attraction between the molecules increase.

More heat energy is thus required to weaken the longer chain during melting and break during boiling.

f)Density

Density of alkanols increase with increase in the intermolecular/van-der-waals forces of attraction between the molecule, making it very close to each other.

This reduces the volume occupied by the molecule and thus increase the their mass per unit volume (density).

Summary table showing the trend in physical properties of alkanols

Alkanol	Melting point (^{o}C)	Boiling point (^{o}C)	Density gcm^{-3}	Solubility in water
Methanol	-98	65	0.791	soluble
Ethanol	-117	78	0.789	soluble
Propanol	-103	97	0.803	soluble
Butanol	-89	117	0.810	Slightly soluble
Pentanol	-78	138	0.814	Slightly soluble
Hexanol	-52	157	0.815	Slightly soluble
Heptanol	-34	176	0.822	Slightly soluble
Octanol	-15	195	0.824	Slightly soluble
Nonanol	-7	212	0.827	Slightly soluble
Decanol	6	228	0.827	Slightly soluble

g)Burning

Experiment

Place the prepared sample in a watch glass. Ignite. Repeat with pure ethanol and methylated spirit.

Observation/Explanation

Fermentation produce ethanol with a lot of water(about a ratio of 1:3)which prevent the alcohol from igniting.

Pure ethanol and methylated spirit easily catch fire / highly flammable.

They burn with an almost colourless non-sooty/non-smoky **blue** flame to form **carbon(IV) oxide** (in excess air/oxygen)or **carbon(II) oxide** (limited air) and **water**.

Ethanol is thus a **saturated** compound like alkanes.

Chemica equation

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

$C_2H_5OH(l) + 2O_2(g) \rightarrow 3H_2O(l) + 2CO(g)$ (limited air)

$2CH_3OH(l) + 3O_2(g) \rightarrow 4H_2O(l) + 2CO_2(g)$ (excess air)

$2CH_3OH(l) + 2O_2(g) \rightarrow 4H_2O(l) + 2CO(g)$ (limited air)

$2C_3H_7OH(l) + 9O_2(g) \rightarrow 8H_2O(l) + 6CO_2(g)$ (excess air)

$C_3H_7OH(l) + 3O_2(g) \rightarrow 4H_2O(l) + 3CO(g)$ (limited air)

$2C_4H_9OH(l) + 13O_2(g) \rightarrow 20H_2O(l) + 8CO_2(g)$ (excess air)

$C_4H_9OH(l) + 3O_2(g) \rightarrow 4H_2O(l) + 3CO(g)$ (limited air)

Due to its flammability, ethanol is used;

(i) as a fuel in spirit lamps

(ii) as gasohol when blended with gasoline

(h)Formation of alkoxides

Experiment

Cut a very small piece of sodium. Put it in a beaker containing about 20cm3 of the prepared sample in a beaker.

Test the products with litmus papers. Repeat with absolute ethanol and methylated spirit.

Sample observations

Substance/alkanol	Effect of adding sodium
Fermentation prepared sample	(i)effervescence/fizzing/bubbles

	(ii)colourless gas produced that extinguish burning splint with explosion/ **"Pop"** sound (iii)colourless solution formed (iv)blue litmus papers remain blue (v)red litmus papers turn blue
Pure/absolute ethanol/methylated spirit	(i)**slow** effervescence/fizzing/bubbles (ii)colourless gas **slowly** produced that extinguish burning splint with explosion/ **"Pop"** sound (iii)colourless solution formed (iv)blue litmus papers remain blue (v)red litmus papers turn blue

Explanations

Sodium/potassium reacts slowly with alkanols to form basic solution called **alkoxides** and producing **hydrogen** gas.

If the alkanol has some water the metals react faster with the water to form **soluble hydroxides/alkalis** i.e.

Sodium + Alkanol -> Sodium **alk**oxides + Hydrogen gas
Potassium + Alkanol -> Potassium **alk**oxides + Hydrogen gas

Sodium + Water -> Sodium **hydr**oxides + Hydrogen gas
Potassium + Water -> Potassium **hydr**oxides + Hydrogen gas

Examples

1.Sodium metal reacts with ethanol to form sodium **eth**oxide
Sodium metal reacts with water to form sodium **Hydr**oxide

$2CH_3CH_2OH(l) + 2Na(s) \rightarrow 2CH_3CH_2ONa(aq) + H_2(s)$

$2H_2O(l) + 2Na(s) \rightarrow 2NaOH(aq) + H_2(s)$

2.Potassium metal reacts with ethanol to form Potassium **eth**oxide
Potassium metal reacts with water to form Potassium **Hydr**oxide

$2CH_3CH_2OH(l) + 2K(s) \rightarrow 2CH_3CH_2OK(aq) + H_2(s)$

$2H_2O(l) + 2K(s) \rightarrow 2KOH(aq) + H_2(s)$

3.Sodium metal reacts with propanol to form sodium **prop**oxide
Sodium metal reacts with water to form sodium **Hydr**oxide

$2CH_3CH_2CH_2OH(l) + 2Na(s) \rightarrow 2CH_3CH_2CH_2ONa(aq) + H_2(s)$

$2H_2O(l) + 2Na(s) \rightarrow 2NaOH(aq) + H_2(s)$

4.Potassium metal reacts with propanol to form Potassium **prop**oxide
Potassium metal reacts with water to form Potassium **Hydr**oxide

$2CH_3CH_2\ CH_2OH(l)$ + $2K(s)$ -> $2CH_3CH_2\ CH_2OK\ (aq)$ + $H_2\ (s)$

$2H_2O(l)$ + $2K(s)$ -> $2KOH\ (aq)$ + $H_2\ (s)$

5.Sodium metal reacts with butanol to form sodium **but**oxide
Sodium metal reacts with water to form sodium **Hydr**oxide

$2CH_3CH_2\ CH_2\ CH_2OH(l)$ + $2Na(s)$ -> $2CH_3CH_2\ CH_2\ CH_2ONa\ (aq)$ + $H_2\ (s)$

$2H_2O(l)$ + $2Na(s)$ -> $2NaOH\ (aq)$ + $H_2\ (s)$

6.Sodium metal reacts with pentanol to form sodium **pent**oxide
Sodium metal reacts with water to form sodium **Hydr**oxide

$2CH_3CH_2\ CH_2\ CH_2\ CH_2OH(l)$+$2Na(s)$ -> $2CH_3CH_2\ CH_2\ CH_2\ CH_2ONa\ (aq)$ + $H_2\ (s)$

$2H_2O(l)$ + $2Na(s)$ -> $2NaOH\ (aq)$ + $H_2\ (s)$

(i)Formation of Esters/Esterification

Experiment

Place 2cm3 of ethanol in a boiling tube.
Add equal amount of ethanoic acid.To the mixture add carefully 2drops of concentrated sulphuric(VI)acid.
Warm/Heat gently.
Pour the mixture into a beaker containing about 50cm3 of cold water.
Smell the products.
Repeat with methanol

Sample observations

Substance/alkanol	**Effect on adding equal amount of ethanol/concentrated sulphuric(VI)acid**
Absolute ethanol	Sweet fruity smell
Methanol	Sweet fruity smell

Explanation

Alkanols react with alkanoic acids to form a group of homologous series of sweet smelling compounds called esters and water. This reaction is catalyzed by concentrated sulphuric(VI)acid in the laboratory.

Alkanol + Alkanoic acid –Conc. H_2SO_4-> Ester + water

Naturally esterification is catalyzed by sunlight. Each ester has a characteristic smell derived from the many possible combinations of alkanols and alkanoic acids that create a variety of known natural(mostly in fruits) and synthetic(mostly in juices) esters .

Esters derive their names from the alkanol first then alkanoic acids. The alkanol **"**becomes**"** an **alkyl** group and the alkanoic acid **"**becomes**" alkanoate** hence **alkylalkanoate**. e.g.

Ethanol	+	Ethanoic acid	->	Ethylethanoate	+	Water
Ethanol	+	Propanoic acid	->	Ethylpropanoate	+	Water
Ethanol	+	Methanoic acid	->	Ethylmethanoate	+	Water
Ethanol	+	butanoic acid	->	Ethylbutanoate	+	Water
Propanol	+	Ethanoic acid	->	Propylethanoate	+	Water
Methanol	+	Ethanoic acid	->	Methyethanoate	+	Water
Methanol	+	Decanoic acid	->	Methyldecanoate	+	Water
Decanol	+	Methanoic acid	->	Decylmethanoate	+	Water

During the formation of the ester, the **"**O**"** joining the alkanol and alkanoic acid comes from the alkanol.

R_1 -CO**OH** + R_2 –O**H** -> **R_1 -COO –R_2** + **H_2O**

e.g.

1. Ethanol reacts with ethanoic acid to form the ester ethyl ethanoate and water.

Ethanol + Ethanoic acid --Conc. H_2SO_4 -->Ethylethanoate + Water

C_2H_5OH (l) + CH_3COOH(l) --Conc. H_2SO_4 --> $CH_3COO C_2H_5$(**aq**) +H_2O(l)

CH_3CH_2OH (l)+ CH_3COOH(l) --Conc. H_2SO_4 --> $CH_3COOCH_2CH_3$(**aq**) +H_2O(l)

2. Ethanol reacts with propanoic acid to form the ester ethylpropanoate and water.

Ethanol + Propanoic acid --Conc. H_2SO_4 -->Ethylethanoate + Water

C_2H_5OH (l)+ CH_3 CH_2COOH(l) --Conc. H_2SO_4 -->$CH_3CH_2COO C_2H_5$(**aq**) +H_2O(l)

CH_3CH_2OH (l)+ CH_3 CH_2COOH(l) --Conc. H_2SO_4 -->

CH_3 $CH_2COOCH_2CH_3$(**aq**) +H_2O(l)

3. Methanol reacts with ethanoic acid to form the ester methyl ethanoate and water.

Methanol + Ethanoic acid --Conc. H_2SO_4 -->Methylethanoate + Water

CH_3OH (l) + CH_3COOH(l) --Conc. H_2SO_4 --> CH_3COO CH_3(**aq**) +H_2O(l)

4. Methanol reacts with propanoic acid to form the ester methyl propanoate and water.

Methanol + propanoic acid --Conc. H_2SO_4 -->Methylpropanoate + Water

CH_3OH (l)+ CH_3 CH_2COOH(l) --Conc. H_2SO_4 --> CH_3 CH_2COO CH_3(**aq**) +H_2O(l)

5. Propanol reacts with propanoic acid to form the ester propylpropanoate and water.

Propanol + Propanoic acid --Conc. H_2SO_4 -->Ethylethanoate + Water

C_3H_7OH (l)+ CH_3 CH_2COOH(l) --Conc. H_2SO_4 -->CH_3CH_2COO C_3H_7(**aq**) +H_2O(l)

CH_3CH_2 CH_2OH (l)+ CH_3 CH_2COOH(l) --Conc. H_2SO_4 -->

CH_3 CH_2COOCH_2 CH_2CH_3(**aq**) +H_2O(l)

(j)Oxidation

Experiment

Place 5cm3 of absolute ethanol in a test tube.Add three drops of acidified potassium manganate(VII).Shake thoroughly for one minute/warm.Test the solution mixture using pH paper. Repeat by adding acidified potassium dichromate(VII).

Sample observation table

Substance/alkanol	Adding acidified $KMnO_4$/$K_2Cr_2O_7$	pH of resulting solution/mixture	Nature of resulting solution/mixture
Pure ethanol	(i)Purple colour of $KMnO_4$decolorized (ii) Orange colour of $K_2Cr_2O_7$turns green.	pH= 4/5/6 pH = 4/5/6	Weakly acidic Weakly acidic

Explanation

Both acidified $KMnO_4$ and $K_2Cr_2O_7$ are oxidizing agents(add oxygen to other compounds. They oxidize alkan**o**ls to a group of homologous series called alkan**a**ls then further oxidize them to alkan**oic** acids.The oxidizing agents are themselves reduced hence changing their colour:

(i) Purple $KMnO_4$ is reduced to colourless Mn^{2+}

(ii)Orange $K_2Cr_2O_7$is reduced to green Cr^{3+}

The pH of alkanoic acids show they have few H^+ because they are weak acids i.e

Alkanol + [O] -> Alkanal + [O] -> alkanoic acid

NB The [O] comes from the oxidizing agents acidified $KMnO_4$ or $K_2Cr_2O_7$ Examples

1.When ethanol is warmed with three drops of acidified $KMnO_4$ there is decolorization of $KMnO_4$

Ethanol + [O] -> Ethanal + [O] -> Ethanoic acid

CH_3CH_2OH + [O] -> CH_3CH_2O + [O] -> CH_3COOH

2.When methanol is warmed with three drops of acidified $K_2Cr_2O_7$,the orange colour of acidified $K_2Cr_2O_7$ changes to green.

methanol + [O] -> methanal + [O] -> methanoic acid

CH_3OH + [O] -> CH_3O + [O] -> HCOOH

3.When propanol is warmed with three drops of acidified $K_2Cr_2O_7$,the orange colour of acidified $K_2Cr_2O_7$ changes to green.

Propanol + [O] -> Propanal+ [O] -> Propanoic acid

CH_3CH_2 CH_2OH + [O] -> CH_3CH_2 CH_2O + [O] -> CH_3 CH_2COOH

4.When butanol is warmed with three drops of acidified $K_2Cr_2O_7$,the orange colour of acidified $K_2Cr_2O_7$ changes to green.

Butanol + [O] -> Butanal + [O] -> Butanoic acid

CH_3CH_2 CH_2 CH_2OH + [O] ->CH_3CH_2 CH_2CH_2O +[O] -> CH_3 CH_2COOH

Air slowly oxidizes ethanol to dilute ethanoic acid commonly called **vinegar.** If beer is not tightly corked, a lot of carbon(IV)oxide escapes and there is slow oxidation of the beer making it **"**flat**"**.

(k)Hydrolysis /Hydration and Dehydration

I. Hydrolysis/Hydration is the reaction of a compound/substance with water. Alkenes react with water vapour/steam at high temperatures and high pressures in presence of phosphoric acid catalyst to form alkanols.i.e.

Alkenes + Water - H_3PO_4 catalyst-> Alkanol

Examples

(i)Ethene is mixed with steam over a phosphoric acid catalyst at 300^oC temperature and 60 atmosphere pressure to form ethanol

Ethene + water ---60 atm/300^oC/ H_3PO_4 --> Ethanol

H_2C =CH_2 (g) + **H_2O**(l) --60 atm/300^oC/ H_3PO_4 --> CH_3 C**H_2O**H(l)

This is the main method of producing large quantities of ethanol instead of fermentation

(ii) Propene + water ---60 atm/300^oC/ H_3PO_4 --> Propanol

CH_3C =CH_2 (g) + **H_2O**(l) --60 atm/300^oC/ H_3PO_4 --> CH_3 CH_2 C**H_2O**H(l)

(iii) Butene + water ---60 atm/300^oC/ H_3PO_4 --> Butanol

CH_3 CH_2 C=CH_2 (g) + **H_2O**(l) --60 atm/300^oC/ H_3PO_4 --> CH_3 CH_2 CH_2 C**H_2O**H(l)

II. Dehydration is the process which concentrated sulphuric(VI)acid (**dehydrating agent**) removes water from a compound/substances.

Concentrated sulphuric(VI)acid dehydrates alkanols to the corresponding alkenes at about 180^oC. i.e

Alkanol --Conc. H_2 SO_4/180^oC--> Alkene + Water

Examples

1. At 180^{o}C and in presence of Concentrated sulphuric(VI)acid, ethanol undergoes dehydration to form ethene.

Ethanol ---180$_o$C/ H_2SO_4 --> Ethene + Water

CH_3 C**H_2O**H(l) --180$_o$C/ H_2SO_4 --> H_2C =CH_2 (g) + **H_2O**(l)

2. Propanol undergoes dehydration to form propene.

Propanol ---180$_o$C/ H_2SO_4 --> Propene + Water

CH_3 CH_2 C**H_2O**H(l) --180$_o$C/ H_2SO_4 --> CH_3CH =CH_2 (g) + **H_2O**(l)

3. Butanol undergoes dehydration to form Butene.

Butanol ---180$_o$C/ H_2SO_4 --> Butene + Water

CH_3 CH_2 CH_2C**H_2O**H(l) --180$_o$C/ H_2SO_4 --> CH_3 CH_2C =CH_2 (g) + **H_2O**(l)

3. Pentanol undergoes dehydration to form Pentene.

Pentanol ---180$_o$C/ H_2SO_4 --> Pentene + Water

CH_3 CH_2 CH_2 CH_2 C**H_2O**H(l)--180^{o}C/ H_2SO_4-->CH_3 CH_2 CH_2C =CH_2 (g)+**H_2O**(l)

(l)Similarities of alkanols with Hydrocarbons **I.** Similarity with alkanes

Both alkanols and alkanes burn with a **blue non-sooty flame** to form carbon(IV)oxide(in excess air/oxygen)/carbon(II)oxide(in limited air) and water. This shows they are saturated with high C:H ratio. e.g.

Both ethanol and ethane ignite and burns in air with a **blue non-sooty flame** to form carbon(IV)oxide(in excess air/oxygen)/carbon(II)oxide(in limited air) and water.

CH_2 CH_2OH(l) + 3O_2(g) -Excess air-> 2CO_2 (g) + 3H_2 O(l)

CH_2 CH_2OH(l) + 2O_2(g) -Limited air-> 2CO (g) + 3H_2 O(l)

CH_3 CH_3(g) + 3O_2(g) -Excess air-> 2CO_2 (g) + 3H_2 O(l)

2CH_3 CH_3(g) + 5O_2(g) -Limited air-> 4CO (g) + 6H_2 O(l)

II. Similarity with alkenes/alkynes

Both alkanols(R-OH) and alkenes/alkynes(with = C = C = double and **–** C = C- triple) bond:

(i)decolorize acidified $KMnO_4$

(ii)turns Orange acidified $K_2Cr_2O_7$ to green.

Alkan**o**ls(R-**OH**) are oxidized to alkan**a**ls(R-**O**) ant then alkan**oic** acids(R-**OOH**). Alkenes are oxidized to alkanols with duo/double functional groups.

Examples

1.When ethanol is warmed with three drops of acidified $K_2Cr_2O_7$ the orange of acidified $K_2Cr_2O_7$ turns to green. Ethanol is oxidized to ethanol and then to ethanoic acid.

Ethan**o**l + [O] -> Ethan**a**l + [O] -> Ethan**oic** acid
CH_3CH_2OH + [O] -> CH_3CH_2O + [O] -> CH_3COOH

2.When ethene is bubbled in a test tube containing <u>acidified</u> $K_2Cr_2O_7$,the orange of <u>acidified</u> $K_2Cr_2O_7$ turns to green. Ethene is oxidized to ethan-1,2-diol.

Ethene + [O] -> Ethan-1,2-diol.
$H_2C=CH_2$ + [O] -> $HOCH_2$ -CH_2OH

III. <u>Differences with alkenes/alkynes</u>
Alkanols do not decolorize bromine and chlorine water.

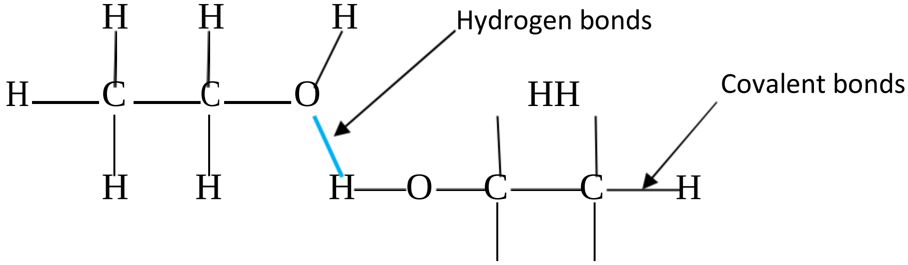
Alkenes decolorizes bromine and chlorine water to form halogenoalkanols <u>Example</u>

When ethene is bubbled in a test tube containing bromine water,the bromine water is decolorized. Ethene is oxidized to bromoethanol.

Ethene + Bromine water -> Bromoethanol.
$H_2C=CH_2$ + HOBr -> $BrCH_2$ -CH_2OH

IV. <u>Differences in melting and boiling point with Hydrocarbons</u>
Alkanos have higher melting point than the corresponding hydrocarbon (alkane/alkene/alkyne)

This is because most alkanols exist as **dimer.**A dimer is a molecule made up of two other molecules joined usually by van-der-waals forces/hydrogen bond or dative bonding.
Two alkanol molecules form a dimer joined by hydrogen bonding.
<u>Example</u>
In Ethanol the oxygen atom attracts/pulls the shared electrons in the covalent bond more to itself than Hydrogen.
This creates a partial negative charge ($^{\delta-}$) on oxygen and partial positive charge($^{\delta+}$) on hydrogen.
Two ethanol molecules attract each other at the partial charges through Hydrogen bonding forming a **dimme**r.



H H

Dimerization of alkanols means more energy is needed to break/weaken the Hydrogen bonds before breaking/weakening the intermolecular forces joining the molecules of all organic compounds during boiling/melting.

E.**USES OF SOME ALKANOLS**

(a)Methanol is used as industrial alcohol and making methylated spirit
(b)Ethanol is used:

1. as alcohol in alcoholic drinks e.g Beer, wines and spirits.
2. as antiseptic to wash woulds
3. in manufacture of vanishes, ink ,glue and paint because it is volatile and thus easily evaporate
4. as a fuel when blended with petrol to make gasohol.

B.ALKANOIC ACIDS (Carboxylic acids)

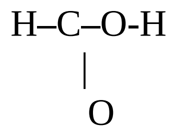
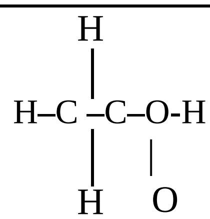
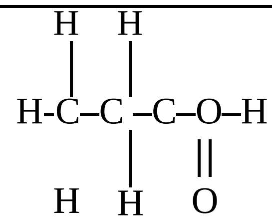
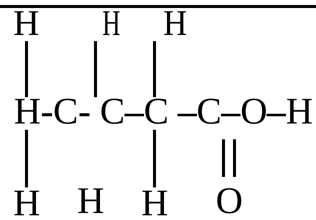
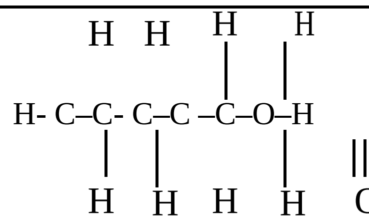
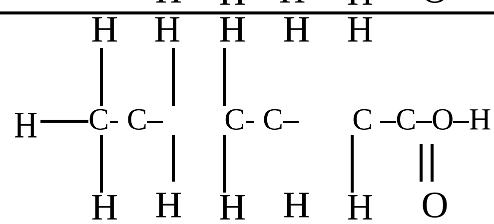
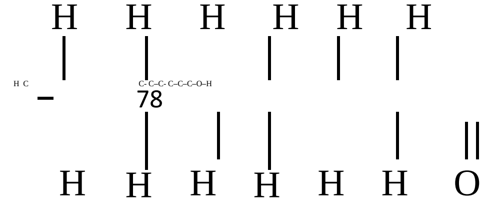
(A) INTRODUCTION.

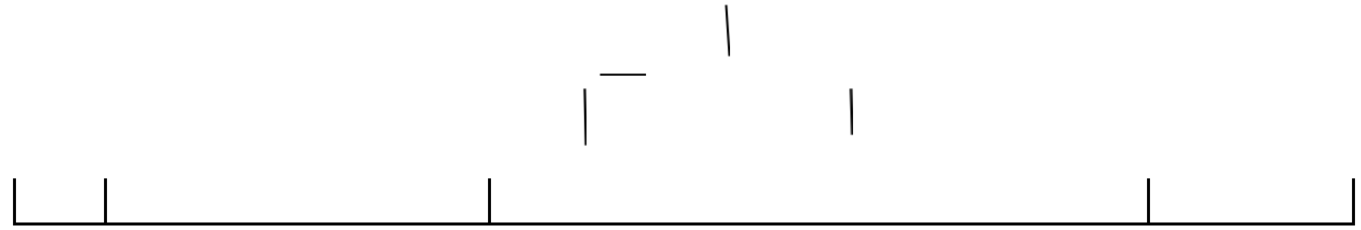
Alkanoic acids belong to a homologous series of organic compounds with a general formula $\mathbf{C_nH_{2n+1}COOH}$ and thus **-COOH** as the functional group .The 1st ten alkanoic acids include:

Alkanoic acids like alkanols /alkanes/alkenes/alkynes form a homologous series where:

(i)the general name of an alkanoic acids is derived from the alkane name then ending with **"–oic"** acid as the table above shows.

(ii) the members have R-**COOH**/R **—** C-O-H as the functional group.

n	General /molecular formular	Structural formula	IUPAC name
0	HCOOH		Methanoic acid
1	CH_3 COOH		Ethanoic acid
2	CH_3 CH_2 COOH C_2 H_5 COOH		Propanoic acid
3	CH_3 CH_2 CH_2 COOH C_3 H_7 COOH		Butanoic acid
4	$CH_3CH_2CH_2CH_2$ COOH C_4 H_9 COOH		Pentanoic acid
5	CH_3CH_2 $CH_2CH_2CH_2$ COOH C_5 H_{11} COOH		Hexanoic acid
6	CH_3CH_2 CH_2 $CH_2CH_2CH_2$ COOH C_6 H_{13} COOH		Pentanoic acid



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(iii)they have the same general formula represented by R-COOH where R is an alkyl group.

(iv)each member differ by $-CH_2-$ group from the next/previous.

(v)they show a similar and gradual change in their physical properties e.g. boiling and melting point.

(vi)they show similar and gradual change in their chemical properties.

(vii) since they are acids they show similar properties with mineral acids.

(B) ISOMERS OF ALKANOIC ACIDS.

Alkanoic acids exhibit both structural and position isomerism. The isomers are named by using the following basic guidelines

(i)Like alkanes. identify the longest carbon chain to be the parent name.

(ii)Identify the position of the -C-O-H functional group to give it the smallest
                                                    ||
                                                    O

/lowest position.

(iii)Identify the type and position of the side group branches.

Practice examples on isomers of alkanoic acids 1.Isomers of butanoic acid C_3H_7COOH

$CH_3\ CH_2\ CH_2\ COOH$

Butan-1-oic acid

$$\begin{array}{l} \quad\ \ CH_3 \\ \quad\ \ \ | \\ H_2C-C-COOH \end{array}$$

2-methylpropan-1-oic acid

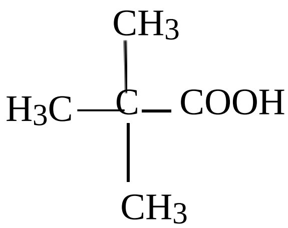
2-methylpropan-1-oic acid and Butan-1-oic acid are structural isomers because the position of the functional group does not change but the arrangement of the atoms in the molecule does.

2.Isomers of pentanoic acid C_4H_9COOH

$CH_3CH_2CH_2CH_2\ COOH$ pentan-1-oic acid

$$\begin{array}{l} \qquad\qquad\ \ CH_3 \\ \qquad\qquad\quad | \\ CH_3CH_2CH\ COOH \end{array}$$

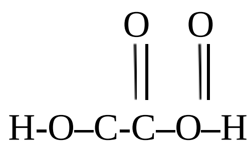
2-methylbutan-1-oic acid



2,2-dimethylpropan-1-oic acid

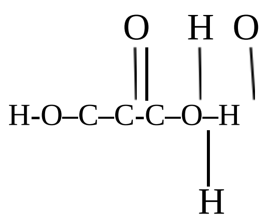
3.Ethan-1,2-dioic acid

HOOC- COOH//



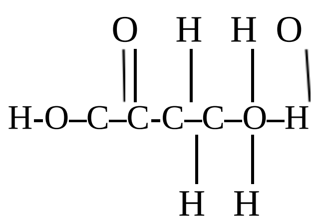
4.Propan-1,3-dioic acid

HOOC- CH_2COOH//

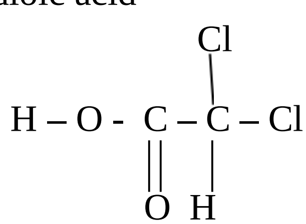


5.Butan-1,4-dioic acid

HOOC CH_2 CH_2 COOH



6.2,2-dichloroethan-1,2-dioic acid
$HOOCCHCl_2$



(C) LABORATORY AND INDUSTRIAL PREPARATIONOF ALKANOIC ACIDS.

<u>In a school laboratory</u>, alkanoic acids can be prepared by adding an oxidizing agent ($H^+/KMnO_4$ or $H^+/K_2Cr_2O_7$)to the corresponding alkanol then warming.

The oxidation converts the alkanol first to an alkanal the alkanoic acid.
NB Acidified $KMnO_4$ is a stronger oxidizing agent than acidified $K_2Cr_2O_7$
General equation:

R- CH_2 **– OH** + [O] --H^+/$KMnO_4$--> R- CH **–O** + H_2O(l)
(alkanol) (alkanal)

R-CH**–O** + [O] --H^+/$KMnO_4$--> R- C **–OOH**
(alkanal) (alkanoic acid)

Examples

1.Ethan**o**l on warming in acidified $KMnO_4$ is oxidized to ethan**a**l then ethan**oic** acid .

CH_3- CH_2 **– OH** + [O] --H^+/$KMnO_4$--> CH_3- CH **–O** + H_2O(l)
(ethanol) (ethanal)

CH_3- CH **– O** + [O] --H^+/$KMnO_4$--> CH_3- C **–OOH**
(ethanal) (ethanoic acid)

2Propan**o**l on warming in acidified $KMnO_4$ is oxidized to propan**a**l then propan**oic** acid

CH_3- CH_2 CH_2 **– OH** + [O] --H^+/$KMnO_4$--> CH_3- CH_2 CH **–O** + H_2O(l)
(propanol) (propanal)

CH_3- CH **– O** + [O] --H^+/$KMnO_4$--> CH_3- C **–OOH**
(propanal) (propanoic acid)

Industrially,large scale manufacture of alkanoic acid like ethanoic acid is obtained from:

(a)Alk**e**nes reacting with steam at high temperatures and pressure in presence of phosphoric(V)acid catalyst and undergo hydrolysis to form alkanols. i.e.

Alkenes + Steam/water -- H_2PO_4 Catalyst--> Alkanol

The alkanol is then oxidized by air at 5 atmosphere pressure with Manganese (II)sulphate(VI) catalyst to form the alkanoic acid.

Alkanol + Air -- $MnSO_4$ Catalyst/5 atm pressure--> Alkanoic acid

Example

Ethene is mixed with steam over a phosphoric(V)acid catalyst,300oC temperature and 60 atmosphere pressure to form ethanol.

$CH_2=CH_2$ + H_2O -> CH_3 CH_2OH
(Ethene) (Ethanol)

This is the industrial large scale method of manufacturing ethanol
Ethanol is then oxidized by air at 5 atmosphere pressure with Manganese (II)sulphate(VI) catalyst to form the ethanoic acid.

CH_3 CH_2OH + [O] -- $MnSO_4$ Catalyst/5 atm pressure--> CH_3 COOH
(Ethanol) (Ethanoic acid)

(b)Alk**y**nes react with liquid water at high temperatures and pressure in presence of Mercury(II)sulphate(VI)catalyst and 30% concentrated sulphuric(VI)acid to form alkan**a**ls.
Alk**y**ne + Water -- Mercury(II)sulphate(VI)catalyst--> Alkan**a**l

The alkan**a**l is then oxidized by air at 5 atmosphere pressure with Manganese (II) sulphate(VI) catalyst to form the alkan**oic** acid.
Alkan**a**l + air/oxygen -- Manganese(II)sulphate(VI)catalyst--> Alkan**oic acid**

<u>Example</u>
Eth**y**ne react with liquid water at high temperature and pressure with Mercury (II) sulphate (VI)catalyst and 30% concentrated sulphuric(VI)acid to form ethan**a**l.

$CH \equiv CH$ + H_2O --$HgSO_4$--> CH_3 CH_2O
(Ethyne) (Ethan**a**l)

This is another industrial large scale method of manufacturing ethanol from large quantities of ethyne found in natural gas.
Ethan**a**l is then oxidized by air at 5 atmosphere pressure with Manganese (II)sulphate(VI) catalyst to form the ethanoic acid.

CH_3 CH_2O + [O] -- $MnSO_4$ Catalyst/5 atm pressure--> CH_3 COOH
(Ethan**a**l) (Oxygen from air) (Ethanoic acid)

(D) PHYSICAL AND CHEMICAL PROPERTIES OF ALKANOIC

ACIDS. I.Physical properties of alkanoic acids

The table below shows some physical properties of alkanoic acids

Alkanol	Melting point(^{o}C)	Boiling point(^{o}C)	Density(gcm^{-3})	Solubility in water
Methanoic acid	18.4	101	1.22	soluble
Ethanoic acid	16.6	118	1.05	soluble
Propanoic acid	-2.8	141	0.992	soluble
Butanoic acid	-8.0	164	0.964	soluble
Pentanoic acid	-9.0	187	0.939	Slightly soluble
Hexanoic acid	-11	205	0.927	Slightly soluble
Heptanoic acid	-3	223	0.920	Slightly soluble
Octanoic acid	11	239	0.910	Slightly soluble
Nonanoic acid	16	253	0.907	Slightly soluble
Decanoic acid	31	269	0.905	Slightly soluble

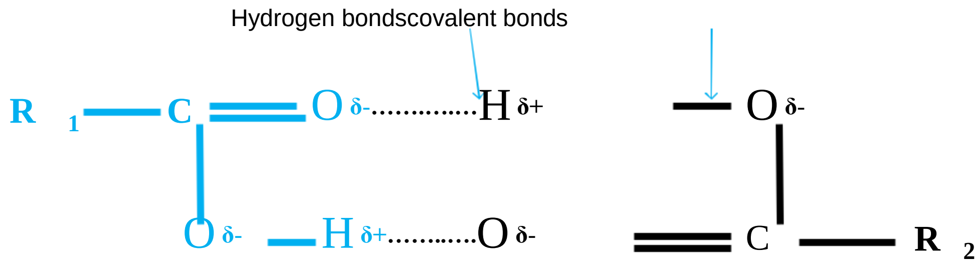
From the table note the following:

(i) Melting and boiling point decrease as the carbon chain increases due to increase in intermolecular forces of attraction between the molecules requiring more energy to separate the molecules.

(ii) The density decreases as the carbon chain increases as the intermolecular forces of attraction increases between the molecules making the molecule very close reducing their volume in unit mass.

(iii) Solubility decreases as the carbon chain increases as the soluble –COOH end is shielded by increasing insoluble alkyl/hydrocarbon chain.

(iv) Like alkanols ,alkanoic acids exist as dimmers due to the hydrogen bonds within the molecule. i.e..



R_1 and $_2$ are **extensions** of the molecule.
For ethanoic acid the extension is made up of **CH_3 –** to make the structure;

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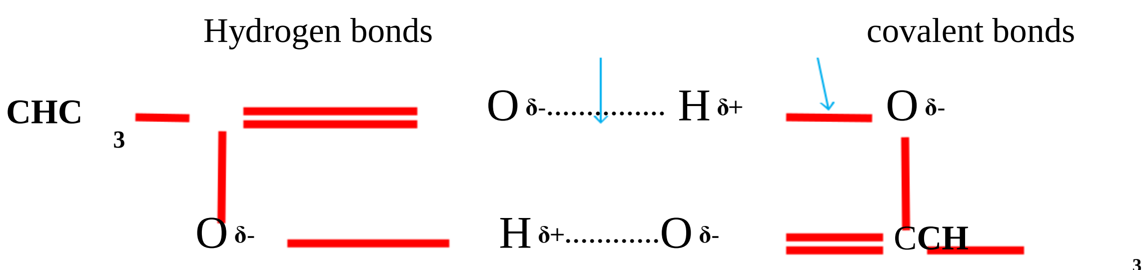
For ethanoic acid the extension is made up of CH_3 – to make the structure;



Ethanoic acid has a **higher** melting/boiling point than ethanol .This is because ethanoic acid has **two/more** hydrogen bond than ethanol.

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II Chemical properties of alkanoic acids

The following experiments shows the main chemical properties of ethanoic (alkanoic) acid.

(a)Effect on litmus papers

Experiment

Dip both blue and red litmus papers in ethanoic acid. Repeat with a solution of succinic acid, citric acid, oxalic acid, tartaric acid and dilute nitric(V)acid.

Sample observations

Solution/acid	Observations/effect on litmus papers	Inference
Ethanoic acid	Blue litmus paper turn red Red litmus paper remain red	H_3O^+/H^+(aq)ion

Succinic acid	Blue litmus paper turn red Red litmus paper remain red	H_3O^+/H^+(aq)ion
Citric acid	Blue litmus paper turn red Red litmus paper remain red	H_3O^+/H^+(aq)ion
Oxalic acid	Blue litmus paper turn red Red litmus paper remain red	H_3O^+/H^+(aq)ion
Tartaric acid	Blue litmus paper turn red Red litmus paper remain red	H_3O^+/H^+(aq)ion
Nitric(V)acid	Blue litmus paper turn red Red litmus paper remain red	H_3O^+/H^+(aq)ion

Explanation

All acidic solutions contains H^+/H_3O^+(aq) ions. The H^+ /H_3O^+ (aq) ions is responsible for turning blue litmus paper/solution to red

(b)pH

Experiment

Place 2cm3 of ethaoic acid in a test tube. Add 2 drops of universal indicator solution and determine its pH. Repeat with a solution of succinic acid, citric acid, oxalic acid, tartaric acid and dilute sulphuric (VI)acid.

Sample observations

Solution/acid	pH	Inference
Ethanoic acid	4/5/6	Weakly acidic
Succinic acid	4/5/6	Weakly acidic
Citric acid	4/5/6	Weakly acidic
Oxalic acid	4/5/6	Weakly acidic
Tartaric acid	4/5/6	Weakly acidic
Sulphuric(VI)acid	**1/2/3**	**Strongly acidic**

Explanations

Alkanoic acids are weak acids that partially/partly dissociate to release few H^+ ions in solution. The pH of their solution is thus 4/5/6 showing they form weakly acidic solutions when dissolved in water.

All alkanoic acid dissociate to releases the **"H"** at the functional group in -COO**H** to form the **alkanoate ion;** $–COO^-$

Mineral acids(Sulphuric(VI)acid, Nitric(V)acid and Hydrochloric acid) are strong acids that wholly/fully dissociate to release many H^+ ions in solution. The pH of their solution is thus 1/2/3 showing they form strongly acidic solutions when dissolved in water.i.e

Examples

1. $CH_3COO\mathbf{H}(aq) \longleftarrow CH_3COO^-(aq) + H^+(aq)$

(ethanoic acid) $\dashrightarrow$ (ethanoate ion) (few H^+ ion)

2. $CH_3CH_2COO\mathbf{H}(aq) \rightleftharpoons CH_3CH_2COO^-(aq) + H^+(aq)$
(propanoic acid) (propanoate ion) (few H^+ ion)

3. $CH_3CH_2CH_2COO\mathbf{H}(aq) \rightleftharpoons CH_3CH_2CH_2COO^-(aq) + H^+(aq)$
(Butanoic acid) (butanoate ion) (few H^+ ion)

4. $HOO\mathbf{H}(aq) \rightleftharpoons HOO^-(aq) + H^+(aq)$
(methanoic acid) (methanoate ion) (few H^+ ion)

5. $H_2SO_4(aq) \rightleftharpoons SO_4^{2-}(aq) + 2H^+(aq)$
(sulphuric(VI) acid) (sulphate(VI) ion) (**many** H^+ ion)

6. $HNO_3(aq) \rightleftharpoons NO_3^-(aq) + H^+(aq)$
(nitric(V) acid) (nitrate(V) ion) (**many** H^+ ion)

(c)Reaction with metals

Experiment

Place about 4cm3 of ethanoic acid in a test tube. Put about 1cm length of polished magnesium ribbon. Test any gas produced using a burning splint. Repeat with a solution of succinic acid, citric acid, oxalic acid, tartaric acid and dilute sulphuric (VI) acid.

Sample observations

Solution/acid	Observations	Inference
Ethanoic acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that burn with "pop" sound/explosion	H_3O^+/H^+(aq)ion
Succinic acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that burn with "pop" sound/explosion	H_3O^+/H^+(aq)ion
Citric acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that burn with "pop" sound/explosion	H_3O^+/H^+(aq)ion
Oxalic acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that burn with "pop" sound/explosion	H_3O^+/H^+(aq)ion
Tartaric acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that burn with "pop" sound/explosion	H_3O^+/H^+(aq)ion

Nitric(V)acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that burn with "pop" sound/explosion	H_3O^+/H^+(aq)ion

Explanation

Metals higher in the reactivity series displace the hydrogen in all acids to evolve/produce hydrogen gas and form a salt. Alkanoic acids react with metals with metals to form alkanoates salt and produce/evolve hydrogen gas .Hydrogen extinguishes a burning splint with a pop sound/explosion. Only the "H"in the functional group -COO**H** is /are displaced and not in the alkyl hydrocarbon chain.

Alkanoic acid + Metal -> Alkanoate + Hydrogen gas. i.e.

Examples

1. For a monovalent metal with monobasic acid

2R – COO**H** + 2M -> 2R- COO**M** + $2H_2$(g)

2.For a divalent metal with monobasic acid

2R – COO**H** + M -> (R- COO) $_2$**M** + H_2(g)

3.For a divalent metal with dibasic acid

HOOC-R-COO**H**+ M -> **M**OOC-R-COO**M** + H_2(g)

4.For a monovalent metal with dibasic acid

HOOC-R-COO**H**+ 2M -> **M**OOC-R-COO**M** + H_2(g)

5 For mineral acids

(i)Sulphuric(VI)acid is a dibasic acid

H_2SO_4 (aq) + 2M -> M_2SO_4 (aq) + H_2(g)

H_2SO_4 (aq) + M -> MSO_4 (aq) + H_2(g)

(ii)Nitric(V) and hydrochloric acid are monobasic acid

HNO_3 (aq) + 2M -> $2MNO_3$ (aq) + H_2(g) HNO_3 (aq) + M -> $M(NO_3)_2$ (aq) + H_2(g)

Examples

1.Sodium reacts with ethanoic acid to form sodium ethanoate and produce. hydrogen gas.

Caution: This reaction is explosive.

CH_3COO**H** (aq) + Na(s) -> CH_3COO**Na** (aq) + H_2(g)

(Ethanoic acid) (Sodium ethanoate)

2.Calcium reacts with ethanoic acid to form calcium ethanoate and produce. hydrogen gas.

$2CH_3$COO**H** (aq) + Ca(s) -> $(CH_3COO)_2$**Ca** (aq) + H_2(g)

(Ethanoic acid) (Calcium ethanoate)

3.Sodium reacts with ethan-1,2-dioic acid to form sodium ethan-1,2-dioate and produce. hydrogen gas.

HOOC-COO**H**+ 2Na -> **Na**OOC - COO**Na** + $H_2(g)$
(ethan-1,2-dioic acid) (sodium ethan-1,2-dioate)

Commercial name of ethan-1,2-dioic acid is oxalic acid. The salt is sodium oxalate.

4.Magnesium reacts with ethan-1,2-dioic acid to form magnesium ethan-1,2-dioate and produce. hydrogen gas.

HOOC-R-COO**H**+ Mg -> (OOC - COO) **Mg** + $H_2(g)$
(ethan-1,2-dioic acid) (magnesium ethan-1,2-dioate)

5.Magnesium reacts with
(i)Sulphuric(VI)acid to form Magnesium sulphate(VI)

$\mathbf{H_2}SO_4$ (aq) + Mg -> $MgSO_4$ (aq) + $H_2(g)$

(ii)Nitric(V) and hydrochloric acid are monobasic acid

2**H**NO_3 (aq) + Mg -> $M(NO_3)_2$ (aq) + $H_2(g)$

(d)Reaction with hydrogen carbonates and carbonates

Experiment

Place about 3cm3 of ethanoic acid in a test tube. Add about 0.5g/ ½ spatula end full of sodium hydrogen carbonate/sodium carbonate. Test the gas produced using lime water. Repeat with a solution of succinic acid, citric acid, oxalic acid, tartaric acid and dilute sulphuric (VI) acid.

Sample observations

Solution/acid	Observations	Inference
Ethanoic acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that forms a white precipitate with lime water	H_3O^+/H^+(aq)ion
Succinic acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that forms a white precipitate with lime water	H_3O^+/H^+(aq)ion
Citric acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that forms a white precipitate with lime water	H_3O^+/H^+(aq)ion
Oxalic acid	(i)effervescence, fizzing, bubbles	H_3O^+/H^+(aq)ion

	(ii)colourless gas produced that forms a white precipitate with lime water	
Tartaric acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that forms a white precipitate with lime water	H_3O^+/H^+(aq)ion
Nitric(V)acid	(i)effervescence, fizzing, bubbles (ii)colourless gas produced that forms a white precipitate with lime water	H_3O^+/H^+(aq)ion

All acids react with hydrogen carbonate/carbonate to form salt ,water and evolve/produce bubbles of carbon(IV)oxide and water.

Carbon(IV)oxide forms a white precipitate when bubbled in lime water/extinguishes a burning splint.

Alkanoic acids react with hydrogen carbonate/carbonate to form alkanoates ,water and evolve/produce bubbles of carbon(IV)oxide and water.

Alkanoic acid + hydrogen carbonate -> alkanoate + water + carbon(IV)oxide

Alkanoic acid + carbonate -> alkanoate + water + carbon(IV)oxide

Examples

1. Sodium hydrogen carbonate reacts with ethanoic acid to form sodium ethanoate ,water and carbon(IV)oxide gas.

$CH_3COO\mathbf{H}$ (aq) + $NaHCO_3$ (s) -> $CH_3COO\mathbf{Na}$ (aq) + H_2O(l) + CO_2 (g)
(Ethanoic acid) (Sodium ethanoate)

2.Sodium carbonate reacts with ethanoic acid to form sodium ethanoate ,water and carbon(IV)oxide gas.

$2CH_3COO\mathbf{H}$ (aq) + Na_2CO_3 (s) -> $2CH_3COO\mathbf{Na}$ (aq) + H_2O(l) + CO_2 (g)
(Ethanoic acid) (Sodium ethanoate)

3.Sodium carbonate reacts with ethan-1,2-dioic acid to form sodium ethanoate ,water and carbon(IV)oxide gas.

HOOC-COO**H**+ Na_2CO_3 (s) -> **Na**OOC - COO**Na** + H_2O(l) + CO_2 (g)
(ethan-1,2-dioic acid) (sodium ethan-1,2-dioate)

4.Sodium hydrogen carbonate reacts with ethan-1,2-dioic acid to form sodium ethanoate ,water and carbon(IV)oxide gas.

HOOC-COO**H**+ $2NaHCO_3$ (s) -> **Na**OOC - COO**Na** + H_2O(l) + $2CO_2$ (g)
(ethan-1,2-dioic acid) (sodium ethan-1,2-dioate)

(e)Esterification

Experiment

Place 4cm3 of ethanol acid in a boiling tube.

Add equal volume of ethanoic acid. To the mixture, add 2 drops of concentrated sulphuric(VI)acid **carefully**. Warm/heat gently on Bunsen flame.

Pour the mixture into a beaker containing 50cm3 of water. Smell the products. Repeat with a solution of succinic acid, citric acid, oxalic acid, tartaric acid and dilute sulphuric (VI) acid.

Sample observations

Solution/acid	Observations
Ethanoic acid	Sweet fruity smell
Succinic acid	Sweet fruity smell
Citric acid	Sweet fruity smell
Oxalic acid	Sweet fruity smell
Tartaric acid	Sweet fruity smell
Dilute sulphuric(VI)acid	**No sweet fruity smell**

Explanation

Alkanols react with alkanoic acid to form the sweet smelling homologous series of esters and water.The reaction is catalysed by concentrated sulphuric(VI)acid in the laboratory but naturally by sunlight /heat.Each ester has a characteristic smell derived from the many possible combinations of alkanols and alkanoic acids.

Alkanol + Alkanoic acids -> Ester + water

Esters derive their names from the alkanol first then alkanoic acids. The alkanol **"**becomes**"** an **alkyl** group and the alkanoic acid **"**becomes**" alkanoate** hence **alkylalkanoate**. e.g.

Ethanol + Ethanoic acid -> Ethylethanoate + Water
Ethanol + Propanoic acid -> Ethylpropanoate + Water
Ethanol + Methanoic acid -> Ethylmethanoate + Water
Ethanol + butanoic acid -> Ethylbutanoate + Water
Propanol + Ethanoic acid -> Propylethanoate + Water
Methanol + Ethanoic acid -> Methyethanoate + Water
Methanol + Decanoic acid -> Methyldecanoate + Water
Decanol + Methanoic acid -> Decylmethanoate + Water

During the formation of the ester, the **"O"** joining the alkanol and alkanoic acid comes from the alkanol.

R_1 -CO**OH** + R_2 –O**H** -> **R_1 -COO –R_2** + **H_2O**

<u>Examples</u>

1. Ethanol reacts with ethanoic acid to form the ester ethyl ethanoate and water.

Ethanol + Ethanoic acid --Conc. H_2SO_4 -->Ethylethanoate + Water

C_2H_5OH (l) + CH_3COOH(l) --Conc. H_2SO_4 --> $CH_3COO C_2H_5$(**aq**) +H_2O(l)

CH_3CH_2OH (l)+ CH_3COOH(l) --Conc. H_2SO_4 --> $CH_3COOCH_2CH_3$(**aq**) +H_2O(l)

2. Ethanol reacts with propanoic acid to form the ester ethylpropanoate and water.

Ethanol + Propanoic acid --Conc. H_2SO_4 -->Ethylethanoate + Water

C_2H_5OH (l)+ $CH_3 CH_2COOH$(l) --Conc. H_2SO_4 -->$CH_3CH_2COO C_2H_5$(**aq**) +H_2O(l)

CH_3CH_2OH (l)+ $CH_3 CH_2COOH$(l) --Conc. H_2SO_4 -->

$CH_3 CH_2COOCH_2CH_3$(**aq**) +H_2O(l)

3. Methanol reacts with ethanoic acid to form the ester methyl ethanoate and water.

Methanol + Ethanoic acid --Conc. H_2SO_4 -->Methylethanoate + Water

CH_3OH (l) + CH_3COOH(l) --Conc. H_2SO_4 --> $CH_3COO CH_3$(**aq**) +H_2O(l)

4. Methanol reacts with propanoic acid to form the ester methyl propanoate and water.

Methanol + propanoic acid --Conc. H_2SO_4 -->Methylpropanoate + Water

CH_3OH (l)+ $CH_3 CH_2COOH$(l) --Conc. H_2SO_4 --> $CH_3 CH_2COO CH_3$(**aq**) +H_2O(l)

5. Propanol reacts with propanoic acid to form the ester propylpropanoate and water.

Propanol + Propanoic acid --Conc. H_2SO_4 -->Ethylethanoate + Water

C_3H_7OH (l)+ $CH_3 CH_2COOH$(l) --Conc. H_2SO_4 -->$CH_3CH_2COO C_3H_7$(**aq**) +H_2O(l)

$CH_3CH_2 CH_2OH$ (l)+ $CH_3 CH_2COOH$(l) --Conc. H_2SO_4 -->

$CH_3 CH_2COOCH_2 CH_2CH_3$(**aq**) +$H_2O$(l)

C. DETERGENTS

Detergents are cleaning agents that improve the cleaning power /properties of water.A detergent therefore should be able to:

(i)dissolve substances which water can not e.g grease ,oil, fat (ii)be washed away after cleaning.

There are two types of detergents:

(a)Soapy detergents

(b)Soapless detergents

(a) SOAPY DETERGENTS

Soapy detergents usually called soap is long chain salt of organic alkanoic acids.Common soap is sodium octadecanoate .It is derived from reacting concentrated sodium hydroxide solution with octadecanoic acid(18 carbon alkanoic acid) i.e.

Sodium hydroxide + octadecanoic acid -> Sodium octadecanoate + water

NaOH(aq) + CH_3 $(CH_2)_{16}$ COOH(aq) -> CH_3 $(CH_2)_{16}$ COO^- $\mathbf{Na}^+$ (aq) +H_2O(l) Commonly ,soap can thus be represented ;

R- COO^- $\mathbf{Na}^+$ where;

R is a long chain alkyl group and -COO^- $\mathbf{Na}^+$ is the alkanoate ion.

In a school laboratory and at industrial and domestic level,soap is made by reacting concentrated sodium hydroxide solution with esters from (animal) **fat** and **oil**. The process of making soap is called **saponification.** During saponification ,the ester is **hydrolyzed** by the alkali to form sodium salt /soap and **glycerol/propan-1,2,3-triol** is produced.

Fat/oil(ester)+sodium/potassium hydroxide->sodium/potassium salt(soap)+ glycerol

Fats/Oils are esters with fatty acids and glycerol parts in their structure; $C_{17}H_{35}COO\mathbf{CH_2}$

$C_{17}H_{35}COO\mathbf{CH}$

$C_{17}H_{35}COO\mathbf{CH_2}$

When boiled with concentrated sodium hydroxide solution NaOH;

(i)NaOH ionizes/dissociates into **Na^+** and **OH^-** ions (ii)fat/oil split into **three** $C_{17}H_{35}COO^-$ and **one** CH_2 CH CH_2

(iii) the three **Na^+** combine with the three $C_{17}H_{35}COO^-$ to form the salt $C_{17}H_{35}COO^-$ **Na^+**

(iv)the three **OH^-**ions combine with the CH_2 CH CH_2 to form an alkanol with three functional groups CH_2 **OH** CH **OH** CH_2 **OH(propan-1,2,3-triol)**

$C_{17}H_{35}COO$ **CH_2** | **CH_2OH**

$C_{17}H_{35}COO$ **CH** +**NaOH** -> **3** $C_{17}H_{35}COO^-$ **Na^+** + **CHOH**

$C_{17}H_{35}COO$ **CH_2** | **CH_2OH**

Ester **Alkali** **Soap** **glycerol**

Generally:

$C_nH_{2n+1}COO$ **CH_2** | **CH_2OH**

$C_nH_{2n+1}COO$ **CH** +**NaOH** -> **3** $C_nH_{2n+1}COO^-$ **Na^+** + **CHOH**

$C_nH_{2n+1}COO$**CH_2** | **CH_2OH**

Ester **Alkali** **Soap** **glycerol**

R-COO **CH_2** | **CH_2OH**

R-COO **CH** +**NaOH** -> **3**R-COO$^-$ **Na^+**+ **CHOH**

R- COO**CH_2** | **CH_2OH**

Ester **Alkali** **Soap** **glycerol**

During this process a little sodium chloride is added to **precipitate** the soap by reducing its solubility. This is called **salting out**.

The soap is then added colouring agents ,perfumes and herbs of choice.

School laboratory preparation of soap

Place about 40 g of fatty (animal fat)beef/meat in 100cm3 beaker .Add about 15cm3 of 4.0M sodium hydroxide solution. Boil the mixture for about 15minutes.Stir the mixture .Add about 5.0cm3 of distilled water as you boil to make up for evaporation. Boil for about another 15minutes.Add about four spatula end full of pure sodium chloride crystals. Continue stirring for another five minutes. Allow to cool. Filter of

/decant and wash off the residue with distilled water .Transfer the clean residue into a dry beaker. Preserve.

The action of soap

Soapy detergents:

(i)act by reducing the surface tension of water by forming a thin layer on top of the water.

(ii)is made of a **non-polar** alkyl /hydrocarbon tail and a **polar** $-COO^{-}Na^{+}$ head. The non-polar alkyl /hydrocarbon tail is **hydrophobic** (water hating) and thus does not dissolve in water .It dissolves in non-polar solvent like grease, oil and fat. The polar $-COO^{-}Na^{+}$ head is **hydrophilic** (water loving)and thus dissolve in water. When washing with soapy detergent, the non-polar tail of the soapy detergent surround/dissolve in the dirt on the garment /grease/oil while the polar head dissolve in water.

Through **mechanical agitation**/stirring/sqeezing/rubbing/beating/kneading, some grease is dislodged/lifted of the surface of the garment. It is immediately surrounded by more soap molecules It float and spread in the water as tiny droplets that scatter light in form of emulsion making the water cloudy and shinny. It is removed from the garment by rinsing with fresh water.The repulsion of the soap head prevent /ensure the droplets do not mix.Once removed, the dirt molecules cannot be redeposited back because it is surrounded by soap molecules.

Advantages and disadvantages of using soapy detergents

Soapy detergents are biodegradable. They are acted upon by bacteria and rot.They thus do not cause environmental pollution. Soapy detergents have the diadvatage in that:

(i)they are made from fat and oils which are better eaten as food than make soap.

(ii)forms an insoluble precipitate with hard water called **scum.** Scum is insoluble calcium octadecanoate and Magnesium octadecanoate formed when soap reacts with Ca^{2+} and Mg^{2+} present in hard water.

Chemical equation

$2C_{17}H_{35}COO^{-}\,\mathbf{Na}^{+}(aq) + Ca^{2+}(aq) \rightarrow (C_{17}H_{35}COO^{-})Ca^{2+}(s) + \mathbf{2Na}^{+}(aq)$

(insoluble Calcium octadecanote/scum)

$2C_{17}H_{35}COO^{-}\,\mathbf{Na}^{+}(aq) + Mg^{2+}(aq) \rightarrow (C_{17}H_{35}COO^{-})Mg^{2+}(s) + \mathbf{2Na}^{+}(aq)$

(insoluble Magnesium octadecanote/scum)

This causes wastage of soap.

Potassium soaps are better than Sodium soap. Potassium is more expensive than sodium and thus its soap is also more expensive.

(b)SOAPLESS DETERGENTS

Soapless detergent usually called detergent is a long chain salt fromed from by-products of fractional distillation of crude oil.Commonly used soaps include:

(i)washing agents

(ii)toothpaste

(iii)emulsifiers/wetting agents/shampoo

Soapless detergents are derived from reacting:

(i)concentrated sulphuric(VI)acid with a long chain alkanol e.g. Octadecanol(18 carbon alkanol) to form alkyl hydrogen sulphate(VI)

Alkanol + Conc sulphuric(VI)acid -> alkyl hydrogen sulphate(VI) + Water R –O**H** + **H**$_2$SO$_4$ -> R –O-SO$_3$H + **H**$_2$O

(ii)the alkyl hydrogen sulphate(VI) is then neutralized with sodium/potassium hydroxide to form sodium/potassium alkyl hydrogen sulphate(VI) Sodium/potassium alkyl hydrogen sulphate(VI) is the soapless detergent.

alkyl hydrogen sulphate(VI) + Potassium/sodium hydroxide -> Sodium/potassium alkyl hydrogen sulphate(VI) + Water

$R-O-SO_3H + \mathbf{Na}OH \rightarrow R-O-SO_3^- Na^+ + \mathbf{H_2}O$

Example

Step I : Reaction of Octadecanol with Conc.**H**$_2$SO$_4$

$C_{17}H_{35}CH_2OH\ (aq) + H_2SO_4 \rightarrow C_{17}H_{35}CH_2\text{-}\mathbf{O\text{-}SO_3^-}\ \mathbf{H^+}\ (aq) + H_2O\ (l)$

octadecanol + sulphuric(VI)acid -> Octadecyl hydrogen sulphate(VI) + water

Step II: Neutralization by an alkali

$C_{17}H_{35}CH_2\text{-}\mathbf{O\text{-}SO_3^-}\ \mathbf{H^+}\ (aq) + NaOH \rightarrow C_{17}H_{35}CH_2\text{-}\mathbf{O\text{-}SO_3^-}\ \mathbf{Na^+}\ (aq) + H_2O\ (l)$

Octadecyl hydrogen sulphate(VI) + sodium/potassium hydroxide -> sodium/potassium octadecyl hydrogen sulphate(VI) +Water

School laboratory preparation of soapless detergent

Place about 20g of olive oil in a 100cm3 beaker. Put it in a trough containing ice cold water.

Add dropwise carefully 18M concentrated sulphuric(VI)acid stirring continuously into the olive oil until the oil turns brown.Add 30cm3 of 6M sodium hydroxide solution.Stir.This is a soapless detergent.

The action of soapless detergents

The action of soapless detergents is similar to that of soapy detergents.The soapless detergents contain the hydrophilic head and a long hydrophobic tail. i.e.

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv$-COO^{-}Na^{+}$

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv $-O-SO_3^{-}Na^{+}$

(long hydrophobic /non-polar alkyl tail) (hydrophilic/polar/ionic head)

The tail dissolves in fat/grease/oil while the ionic/polar/ionic head dissolves in water.

The tail stick to the dirt which is removed by the attraction of water molecules and the polar/ionic/hydrophilic head by mechanical agitation /squeezing/kneading/ beating/rubbing/scrubbing/scatching.

The suspended dirt is then surrounded by detergent molecules and repulsion of the anion head preventing the dirt from sticking on the material garment.

The tiny droplets of dirt emulsion makes the water cloudy. On rinsing the cloudy emulsion is washed away.

Advantages and disadvantages of using soapless detergents

Soapless detergents are non-biodegradable unlike soapy detergents.

They persist in water during sewage treatment by causing foaming in rivers ,lakes and streams leading to marine /aquatic death. Soapless detergents have the advantage in that they:

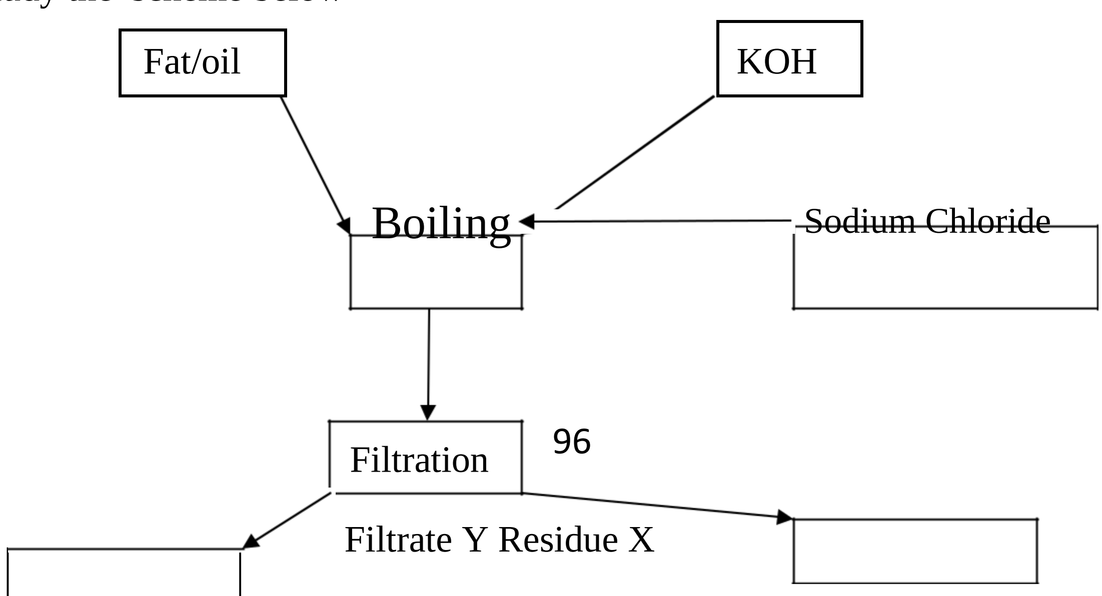
(i)do not form scum with hard water.

(ii)are cheap to manufacture/buying

(iii)are made from petroleum products but soapis made from fats/oil for human consumption.

Sample revision questions

1. Study the scheme below



(a)Identify the process

Saponification

(b)Fats and oils are esters. Write the formula of the a common structure of ester

$C_{17}H_{35}COO\mathbf{CH_2}$
$|$
$C_{17}H_{35}COO\mathbf{CH}$
$|$
$C_{17}H_{35}COO\mathbf{CH_2}$

(c)Write a balanced equation for the reaction taking place during boiling

$$\begin{array}{llll} C_{17}H_{35}COOCH_2 & & & CH_2OH \\ | & & & | \\ C_{17}H_{35}COOCH & +3NaOH & \rightarrow 3\ C_{17}H_{35}COO^- Na^+ \ + & CHOH \\ | & & & | \\ C_{17}H_{35}COOCH_2 & & & CH_2OH \\ \text{Ester} & \text{Alkali} & \text{Soap} & \text{glycerol} \end{array}$$

(d)Give the IUPAC name of:

(i)Residue X

Potassium octadecanoate

(ii)Filtrate Y

Propan-1,2,3-triol

(e)Give one use of fitrate Y

Making paint

(f)What is the function of sodium chloride

To reduce the solubility of the soap hence helping in precipitating it out

(g)Explain how residue X helps in washing.

Has a non-polar hydrophobic tail that dissolves in dirt/grease /oil/fat Has a polar /ionic hydrophilic head that dissolves in water.

From mechanical agitation,the dirt is plucked out of the garment and surrounded by the tail end preventing it from being deposited back on the garment.

(h)State one:

(i)advantage of continued use of residue X on the environment

Is biodegradable and thus do not pollute the environment

(ii)disadvantage of using residue X

Uses fat/oil during preparation/manufacture which are better used for human consumption.

(i)Residue X was added dropwise to some water.The number of drops used before lather forms is as in the table below.

	Water sample		
	A	**B**	**C**
Drops of residue X	**15**	**2**	**15**
Drops of residue X in boiled water	**2**	**2**	**15**

(i)State and explain which sample of water is:

I. Soft

Sample B .Very little soap is used and no effect on amount of soap even on boiling/heating.

II. Permanent hard

Sample C . A lot of soap is used and no effect on amount of soap even on boiling/heating. Boiling does not remove permanent hardness of water.

III. Temporary hard

Sample A . A lot of soap is used before boiling. Very little soap is used on boiling/heating. Boiling remove temporary hardness of water.

(ii)Write the equation for the reaction at water sample C.

Chemical equation

$2C_{17}H_{35}COO^{-}\,\mathbf{K}^{+}(aq) + CaSO_4(aq) \rightarrow (C_{17}H_{35}COO^{-})Ca^{2+}(s) + \mathbf{K}_2SO_4(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^{-}\,\mathbf{K}^{+}(aq) + Ca^{2+}(aq) \rightarrow (C_{17}H_{35}COO^{-})Ca^{2+}(s) + \mathbf{2K}^{+}(aq)$

(insoluble Calcium octadecanote/scum)

Chemical equation

$2C_{17}H_{35}COO^{-}\mathbf{K}^{+}(aq) + MgSO_4(aq) \rightarrow \mathbf{(}C_{17}H_{35}COO^{-}\mathbf{)}Mg^{2+}(s) + \mathbf{K}_2SO_4(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^{-}\mathbf{K}^{+}(aq) + Mg^{2+}(aq) \rightarrow \mathbf{(}C_{17}H_{35}COO^{-}\mathbf{)}Mg^{2+}(s) + \mathbf{2K}^{+}(aq)$

(insoluble Magnesium octadecanote/scum)

(iii)Write the equation for the reaction at water sample A before boiling.

Chemical equation

$2C_{17}H_{35}COO^{-}\mathbf{K}^{+}(aq) + Ca(HCO_3)(aq) \rightarrow \mathbf{(}C_{17}H_{35}COO^{-}\mathbf{)}Ca^{2+}(s) + 2KHCO_3(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^{-}\mathbf{K}^{+}(aq) + Ca^{2+}(aq) \rightarrow \mathbf{(}C_{17}H_{35}COO^{-}\mathbf{)}Ca^{2+}(s) + 2K^{+}(aq)$

(insoluble Calcium octadecanote/scum)

Chemical equation

$2C_{17}H_{35}COO^{-}\mathbf{K}^{+}(aq) + Mg(HCO_3)(aq) \rightarrow \mathbf{(}C_{17}H_{35}COO^{-}\mathbf{)}Mg^{2+}(s) + 2KHCO_3(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^{-}\mathbf{K}^{+}(aq) + Mg^{2+}(aq) \rightarrow \mathbf{(}C_{17}H_{35}COO^{-}\mathbf{)}Mg^{2+}(s) + 2K^{+}(aq)$

(insoluble Magnesium octadecanote/scum)

(iv)Explain how water becomes hard

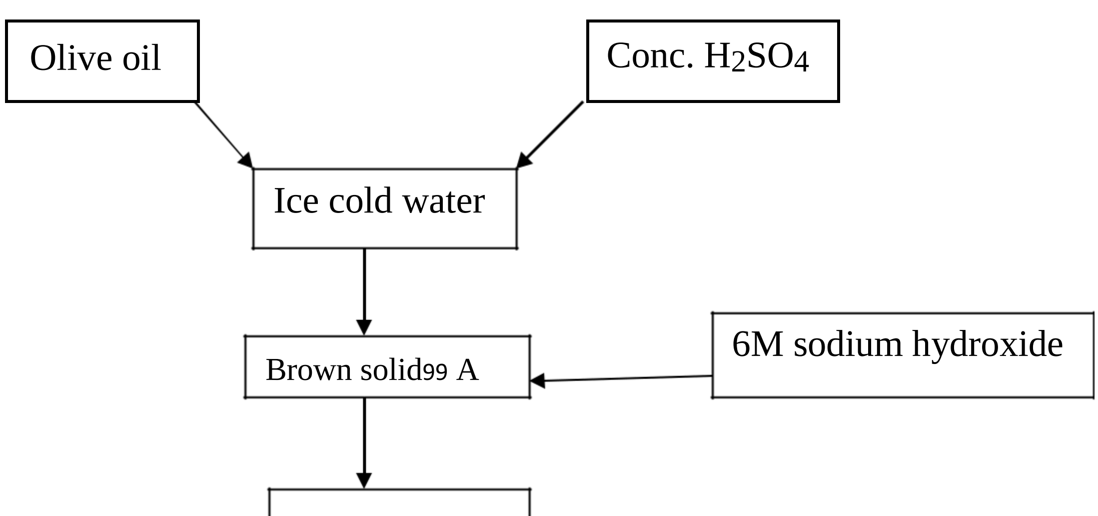
Natural or rain water flowing /passing through rocks containing calcium (chalk, gypsum, limestone)and magnesium compounds (dolomite)dissolve them to form soluble Ca^{2+} and Mg^{2+} ions that causes water hardness.

(v)State two useful benefits of hard water -

Used in bone and teeth formation

-Coral polyps use hard water to form coral reefs -Snails use hard water to make their shells

2.Study the scheme below and use it to answer the questions that follow.



(a)Identify :

(i)brown solid A

Alkyl hydrogen sulphate(VI)

(ii)substance B

Sodium alkyl hydrogen sulphate(VI)

(b)Write a general formula of:

(i)Substance A.

```
                  O
                  ||
R-O-S O3 H //R-O-S- O  - H
                  ||
                  O
```

(ii)Substance B

```
                      O
                      ||
R-O-S O3 - Na+   R-O-S- O  - Na+
                      ||
                      O
```

(c)State one

(i) advantage of continued use of substance B

-Does not form scum with hard water -Is cheap to make

-Does not use food for human as a raw material.

(ii)disadvantage of continued use of substance B.

Is non-biodegradable therefore do not pollute the environment

(d)Explain the action of B during washing.

Has a non-polar hydrocarbon long tail that dissolves in dirt/grease/oil/fat.
Has a polar/ionic hydrophilic head that dissolves in water

Through mechanical agitation the dirt is plucked /removed from the garment and surrounded by the tail end preventing it from being deposited back on the garment.

(e) Ethene was substituted for olive oil in the above process. Write the equation and name of the new products A and B.

Product A

Ethene	+	Sulphuric(VI)acid	->	Ethyl hydrogen sulphate(VI)
$H_2C=CH_2$	+	H_2SO_4	–>	$H_3C – CH_2 –O\text{-}SO_3H$

Product B

Ethyl hydrogen sulphate(VI) + sodium hydroxide -> sodium Ethyl hydrogen sulphate(VI) +Water

$H_3C – CH_2 –O\text{-}SO_3H$ + **Na**OH -> $H_3C – CH_2 –O\text{-}SO_3^-$**$Na^+$** + H_2O

(f)Ethanol can also undergo similar reactions forming new products A and B.Show this using a chemical equation.

Product A

Ethanol+		Sulphuric(VI)acid	->	Ethyl hydrogen sulphate(VI) + water
$H_3C\text{-}CH_2OH$	+	H_2SO_4	–>	$H_3C – CH_2 –O\text{-}SO_3H$ + H_2O

Product B

Ethyl hydrogen sulphate(VI) + sodium hydroxide -> sodium Ethyl hydrogen sulphate(VI) + Water

$H_3C – CH_2 –O\text{-}SO_3H$ + **Na**OH -> $H_3C – CH_2 –O\text{-}SO_3^-$**$Na^+$** + H_2O

3.Below is part of a detergent

$H_3C –(CH_2)_{16} – O - SO_3^-K^+$ (a)Write the formular of the polar and non-polar end

Polar end

$H_3C – (CH_2)_{16} –$

Non-polar end

$– O - SO_3^-K^+$

(b)Is the molecule a soapy or saopless detergent?

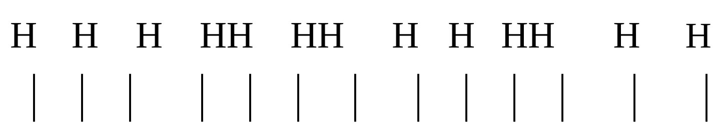
Soapless detergent

(c)State one advantage of using the above detergent

-does not form scum with hard water

-is cheap to manufacture

4.The structure of a detergent is



H- C- C- C-C- C- C- C- C- C- C -C- C- -C- COO^-Na^+
| | | | | | | | | | | | |
HHHHHHHHHHHHHH

a)Write the molecular formula of the detergent. (1mk)

$CH_3(CH_2)_{12}COO^-Na^+$

b)What type of detergent is represented by the formula? (1mk)

Soapy detergent

c) When this type of detergent is used to wash linen in hard water, spots (marks) are left on the linen. Write the formula of the substance responsible for the spots

$(CH_3(CH_2)_{12}COO^-)_2Ca^{2+}$ / $CH_3(CH_2)_{12}COO^-)_2Mg^{2+}$

D. POLYMERS AND FIBRES

Polymers and fibres are giant molecules of organic compounds. Polymers and fibres are formed when **small** molecules called monomers join together to form **large** molecules called polymers at high temperatures and pressures. This process is called polymerization.

Polymers and fibres are either:

(a)**Natural** polymers and fibres

(b)**Synthetic** polymers and fibres

Natural polymers and fibres are found in living things(plants and animals) Natural polymers/fibres include:

-proteins/polypeptides making amino acids in animals

-cellulose that make cotton,wool,paper and silk -

Starch that come from glucose -Fats and oils

-Rubber from latex in rubber trees.

Synthetic polymers and fibres are man-made. They include:

-polyethene

-polychloroethene
-polyphenylethene(polystyrene)
-Terylene(Dacron)
-Nylon-6,6
-Perspex(artificial glass)

Synthetic polymers and fibres have the following characteristic advantages over natural polymers

1. They are light and portable
2. They are easy to manufacture.
3. They can easily be molded into shape of choice.
4. They are resistant to corrosion, water, air , acids, bases and salts.
5. They are comparatively cheap, affordable, colourful and aesthetic

Synthetic polymers and fibres however have the following disadvantages over natural polymers

1. They are non-biodegradable and hence cause environmental pollution during disposal
2. They give out highly poisonous gases when burnt like chlorine/carbon(II)oxide
3. Some on burning produce Carbon(IV)oxide. Carbon(IV)oxide is a green house gas that cause global warming.
4. Compared to some metals, they are poor conductors of heat,electricity and have lower tensile strength.
5.

To reduce environmental pollution from synthetic polymers and fibres, the followitn methods of disposal should be used:

1.Recycling: Once produced all synthetic polymers and fibres should be recycled to a new product. This prevents accumulation of the synthetic polymers and fibres in the environment.

2.Production of biodegradable synthetic polymers and fibres that **rot** away.

There are two types of polymerization:

(a)addition polymerization
(b)condensation polymerization

(a)addition polymerization

Addition polymerization is the process where a small unsaturated monomer (alkene) molecule join together to form a large saturated molecule. Only alkenes undergo addition polymerization.

Addition polymers are named from the alkene/monomer making the polymer and adding the prefix **“poly”** before the name of monomer to form a **polyalkene**

During addition polymerization

(i)the double bond in alkenes break

(ii)free radicals are formed

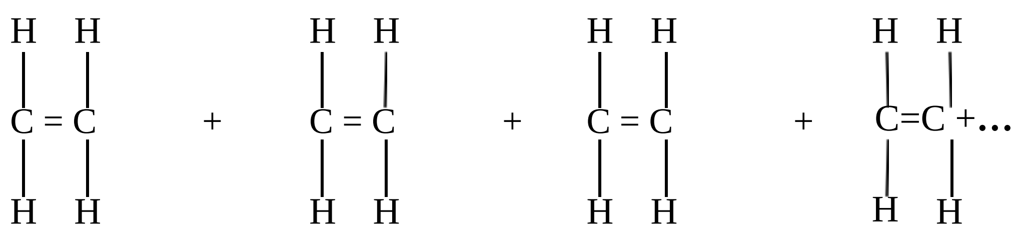
(iii)the free radicals collide with each other and join to form a larger molecule. The more collisions the larger the molecule.

Examples of addition polymerization

<u>1.Formation of Polyethene</u>

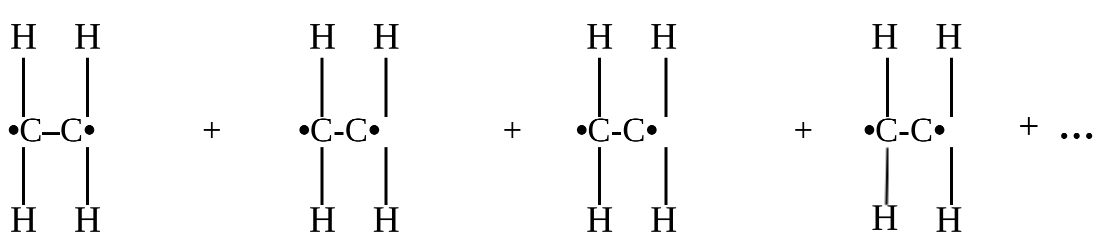
Polyethene is an addition polymer formed when ethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting paticles)



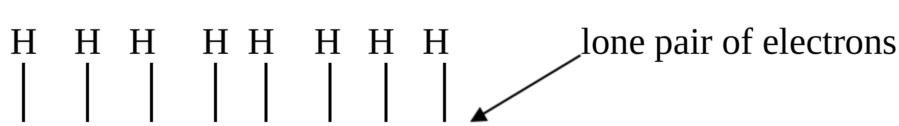
Ethene + Ethene + Ethene + Ethene + …

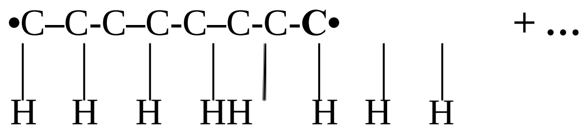
(ii)the double bond joining the ethane molecule break to free readicals



Ethene radical + Ethene radical + Ethene radical + Ethene radical + …

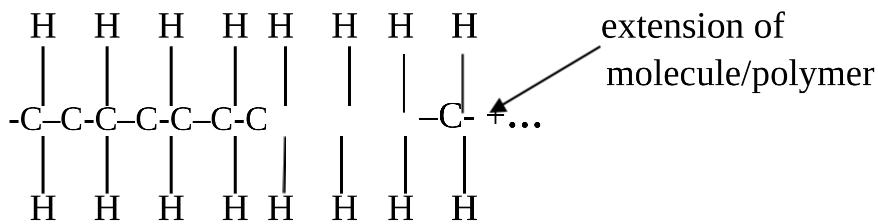
(iii)the free radicals collide with each other and join to form a larger molecule



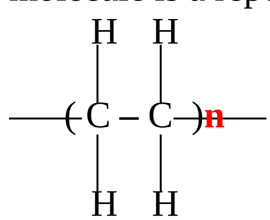


Lone pair of electrons can be used to join more monomers to form longer polyethene.

Polyethene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



Where n is the number of monomers in the polymer. The number of monomers in the polymer can be determined from the molar mass of the polymer and monomer from the relationship:

$$\text{Number of monomers/repeating units in monomer} = \frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$$

Examples

Polythene has a molar mass of 4760.Calculate the number of ethene molecules in the polymer(C=12.0, H=1.0)

$$\text{Number of monomers/repeating units in polyomer} = \frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$$

=> Molar mass ethene (C_2H_4)= 28 Molar mass polyethene = 4760

Substituting $\frac{4760}{28}$ = 170 ethene molecules

The **commercial** name of polyethene is **polythene**. It is an elastic, tough, transparent and durable plastic. Polythene is used:

(i)in making plastic bag

(ii)bowls and plastic bags

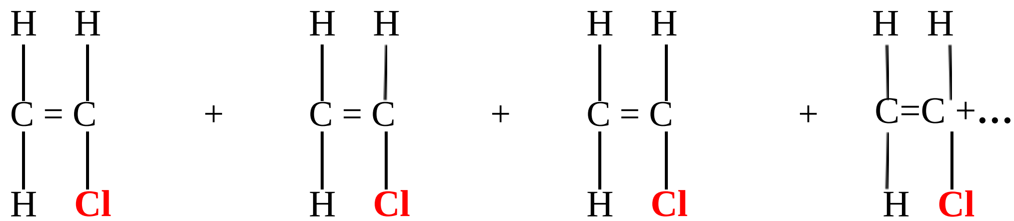
(iii)packaging materials

2.Formation of Polychlorethene

Polychloroethene is an addition polymer formed when chloroethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

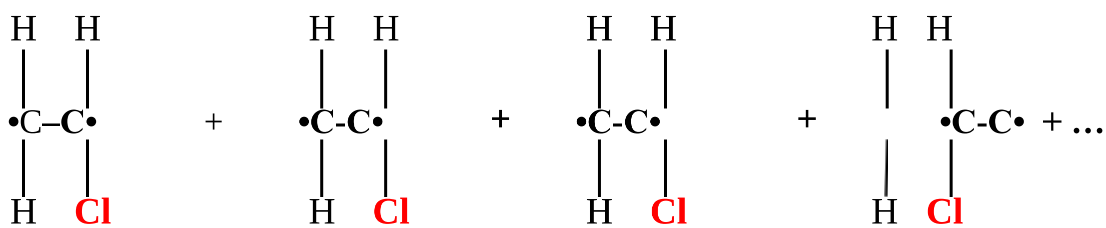
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

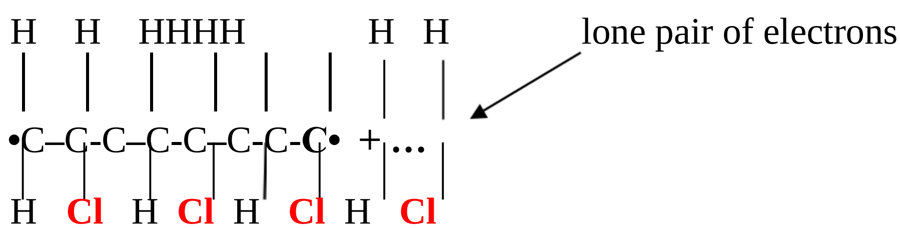


chloroethene + chloroethene + chloroethene + chloroethene + …

(ii)the double bond joining the chloroethene molecule break to free radicals

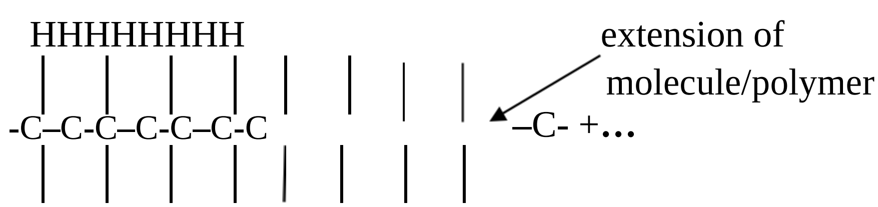


(iii)the free radicals collide with each other and join to form a larger molecule



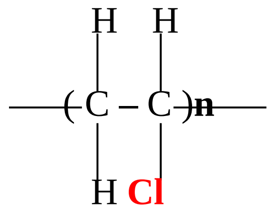
Lone pair of electrons can be used to join more monomers to form longer polychloroethene.

Polychloroethene molecule can be represented as:



H Cl H Cl H Cl H Cl

Since the molecule is a repetition of one monomer, then the polymer is:



Examples

Polychlorothene has a molar mass of 4760.Calculate the number of chlorethene molecules in the polymer(C=12.0, H=1.0,Cl=35.5)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass ethene (C_2H_3Cl)= 62.5 Molar mass polyethene = 4760

Substituting $\frac{4760}{62.5}$ = 77.16 => 77 polychloroethene molecules**(whole number)**

The **commercial** name of polychloroethene is **polyvinylchloride(PVC)**. It is a tough, non-transparent and durable plastic. PVC is used:

(i)in making plastic rope

(ii)water pipes

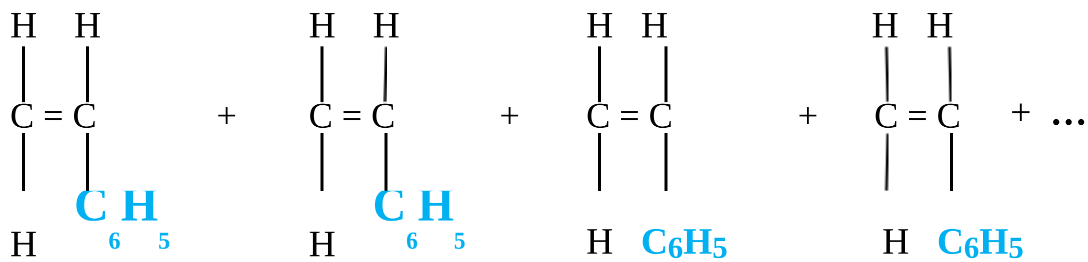
(iii)crates and boxes

3.Formation of Polyphenylethene

Polyphenylethene is an addition polymer formed when phenylethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

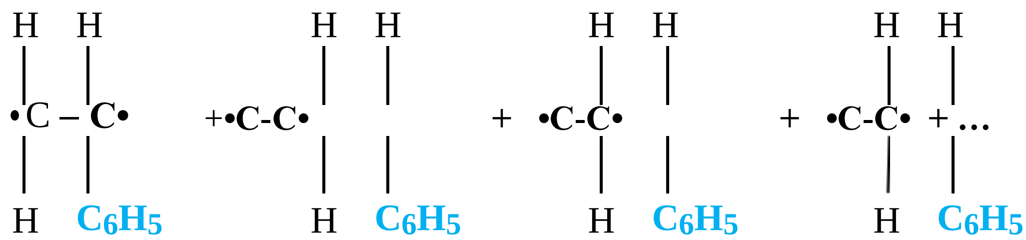
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

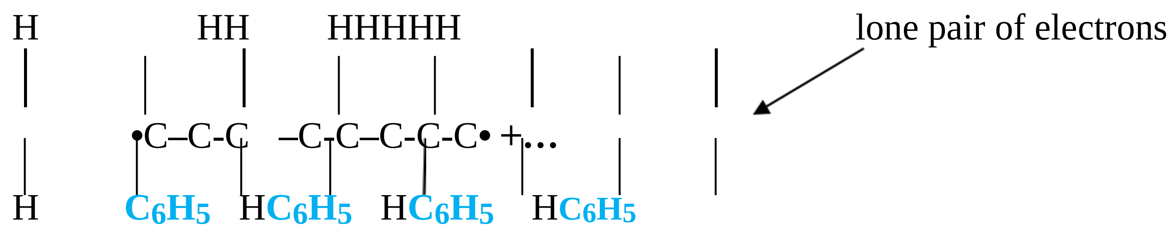


phenylethene + phenylethene + phenylethene + phenylethene + …

(ii)the double bond joining the phenylethene molecule break to free radicals

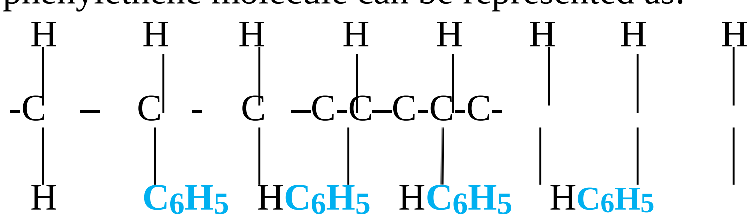


(iii)the free radicals collide with each other and join to form a larger molecule

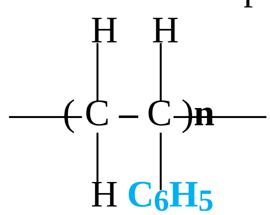


Lone pair of electrons can be used to join more monomers to form longer polyphenylethene.

Polyphenylethene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



Examples

Polyphenylthene has a molar mass of 4760.Calculate the number of phenylethene molecules in the polymer(C=12.0, H=1.0,)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass ethene (C_8H_8)= 104 Molar mass polyethene = 4760

Substituting $\frac{4760}{104}$ = $\frac{45.7692}{}$ =>45 polyphenylethene molecules**(whole number)**

The **commercial** name of polyphenylethene is **polystyrene**. It is a very light durable plastic. Polystyrene is used:

(i)in making packaging material for carrying delicate items like computers, radion,calculators.

(ii)ceiling tiles

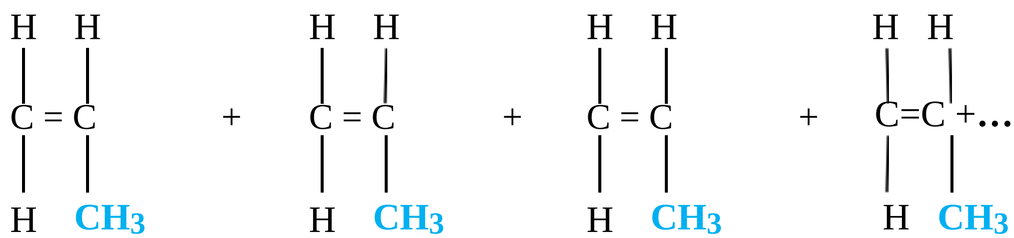
(iii)clothe linings

4.Formation of Polypropene

Polypropene is an addition polymer formed when propene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

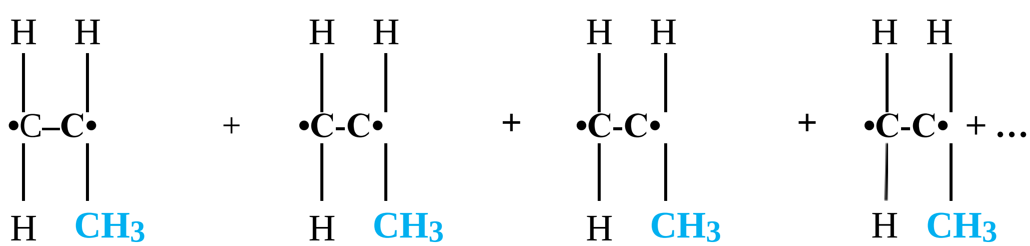
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

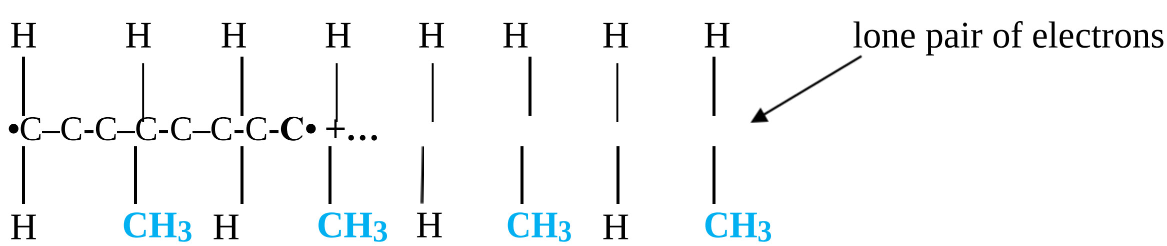


propene + propene + propene + propene + …

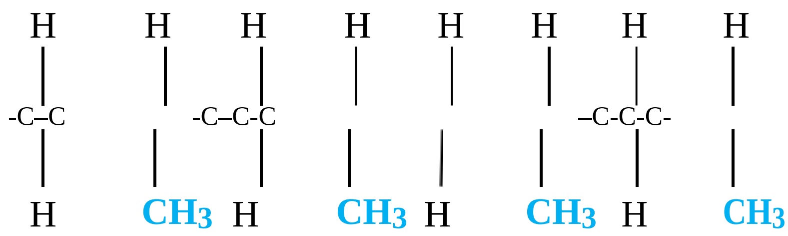
(ii)the double bond joining the phenylethene molecule break to free radicals



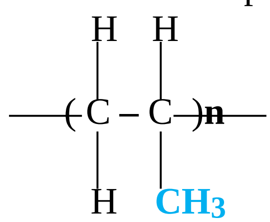
(iii)the free radicals collide with each other and join to form a larger molecule



Lone pair of electrons can be used to join more monomers to form longer propene. propene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



<u>Examples</u>

Polypropene has a molar mass of 4760.Calculate the number of propene molecules in the polymer(C=12.0, H=1.0,)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass propene (C_3H_8)= 44 Molar mass polyethene = 4760

Substituting $\frac{4760}{44}$ = <u>108.1818</u> =><u>108 propene molecules</u>**(whole number)**

The **commercial** name of polyphenylethene is **polystyrene**. It is a very light durable plastic. Polystyrene is used:

(i)in making packaging material for carrying delicate items like computers, radion,calculators.

(ii)ceiling tiles

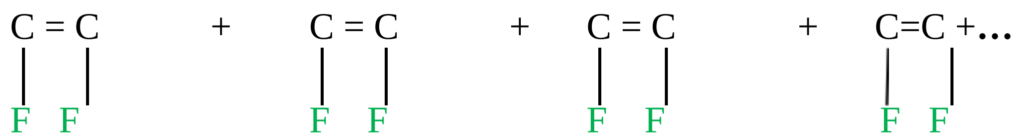
(iii)clothe linings

<u>5.Formation of Polytetrafluorothene</u>

Polytetrafluorothene is an addition polymer formed when tetrafluoroethene molecule/monomer join together to form a large molecule/polymer at high temperatures and pressure.

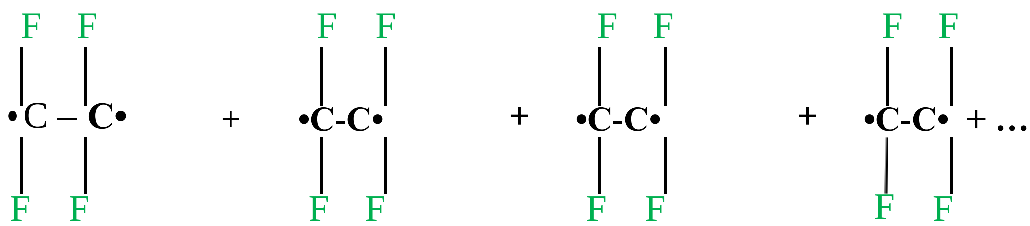
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

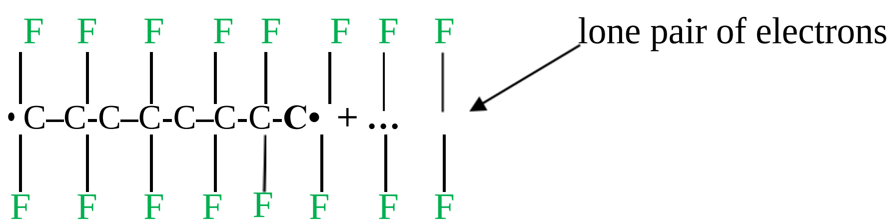


tetrafluoroethene + tetrafluoroethene+ tetrafluoroethene+ tetrafluoroethene + ...

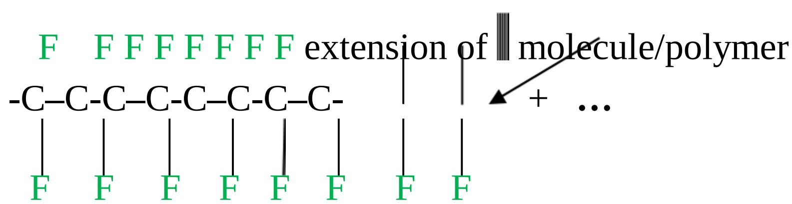
(ii)the double bond joining the tetrafluoroethene molecule break to free radicals



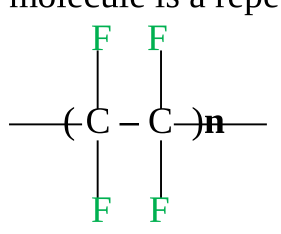
(iii)the free radicals collide with each other and join to form a larger molecule



Lone pair of electrons can be used to join more monomers to form longer polytetrafluoroethene.
polytetrafluoroethene molecule can be represented as:



Since the molecule is a repetition of one monomer, then the polymer is:



Examples

Polytetrafluorothene has a molar mass of 4760.Calculate the number of tetrafluoroethene molecules in the polymer(C=12.0, ,F=19)

Number of monomers/repeating units in monomer = $\frac{\text{Molar mass polymer}}{\text{Molar mass monomer}}$

=> Molar mass ethene (C_2F_4)= 62.5 Molar mass polyethene = 4760

Substituting $\frac{4760}{62.5}$ = 77.16 => 77 polychloroethene molecules**(whole number)**

The **commercial** name of polytetrafluorethene(**P.T.F.E**) is **Teflon(P.T.F.E)**. It is a tough, non-transparent and durable plastic. PVC is used:

(i)in making plastic rope

(ii)water pipes

(iii)crates and boxes

5.Formation of rubber from Latex

Natural rubber is obtained from rubber trees.

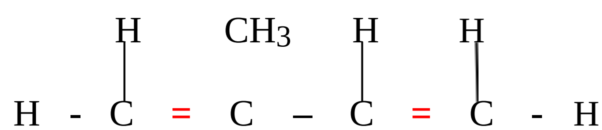
During harvesting an incision is made on the rubber tree to produce a milky white substance called **latex.**

Latex is a mixture of rubber and lots of water.

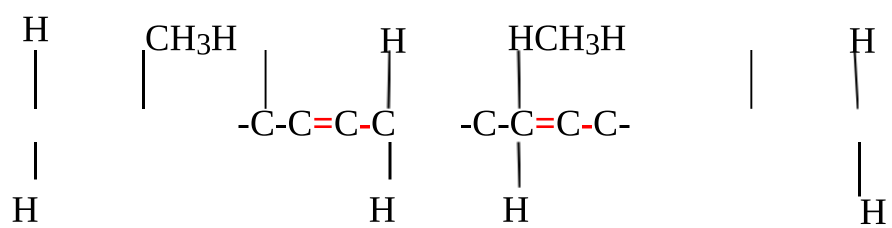
The latex is then added an acid to coagulate the rubber.

Natural rubber is a polymer of 2-methylbut-1,3-diene ;

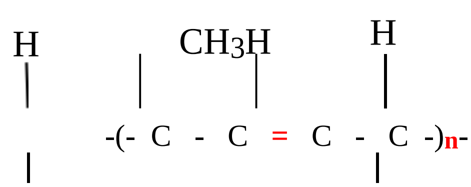
$CH_2=C(CH_3)CH=CH_2$



During natural polymerization to rubber, one double C=C bond break to self add to another molecule.The double bond remaining move to carbon "2" thus;



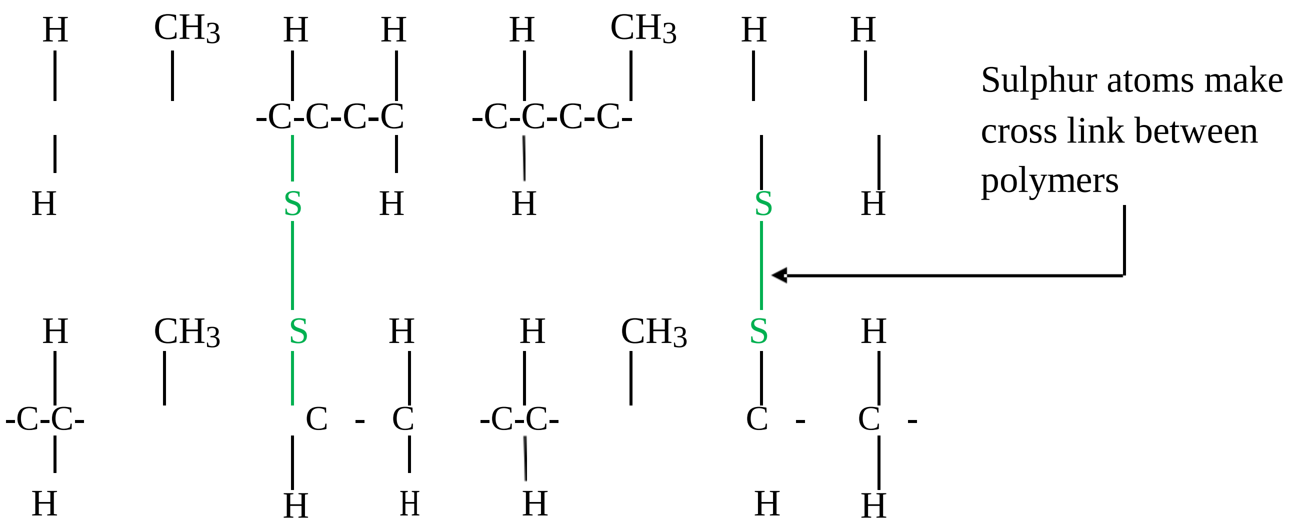
Generally the structure of rubber is thus;



H H

Pure rubber is soft and sticky.It is used to make erasers, car tyres. Most of it is vulcanized.Vulcanization is the process of heating rubber with sulphur to make it harder/tougher.

During vulcanization the sulphur atoms form a cross link between chains of rubber molecules/polymers. This decreases the number of C=C double bonds in the polymer.



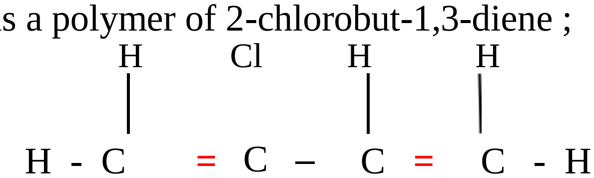
Vulcanized rubber is used to make **tyres**, **shoes** and **valves**.

<u>6.Formation of synthetic rubber</u>

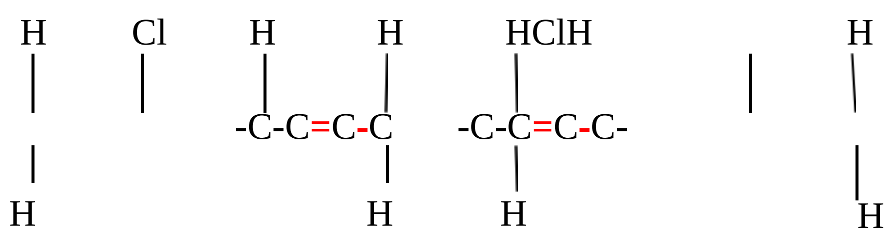
Synthetic rubber is able to resist action of oil,abrasion and organic solvents which rubber cannot.

Common synthetic rubber is a polymer of 2-chlorobut-1,3-diene ;

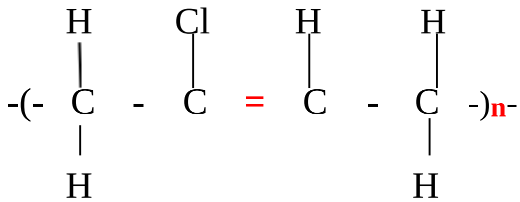
CH_2=C (Cl CH = CH_2



During polymerization to synthetic rubber, one double C=C bond is broken to self add to another molecule. The double bond remaining move to carbon **“**2**”** thus;



Generally the structure of rubber is thus;



Rubber is thus strengthened through vulcanization and manufacture of synthetic rubber.

(b)Condensation polymerization

Condensation polymerization is the process where two or more small monomers join together to form a larger molecule by elimination/removal of a simple molecule. (usually water).

Condensation polymers acquire a different name from the monomers because the two monomers are two different compounds

During condensation polymerization:

(i)the two monomers are brought together by high pressure to reduce distance between them.

(ii)monomers realign themselves at the functional group.

(iii)from each functional group an element is removed so as to form simple molecule (of usually H_2O/HCl)

(iv)the two monomers join without the simple molecule of H_2O/HCl

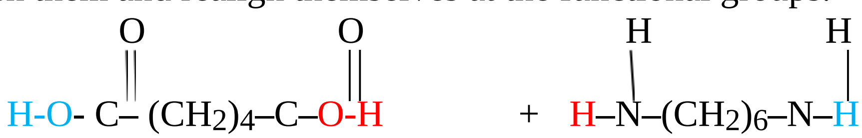
Examples of condensation polymerization

1.Formation of Nylon-6,6

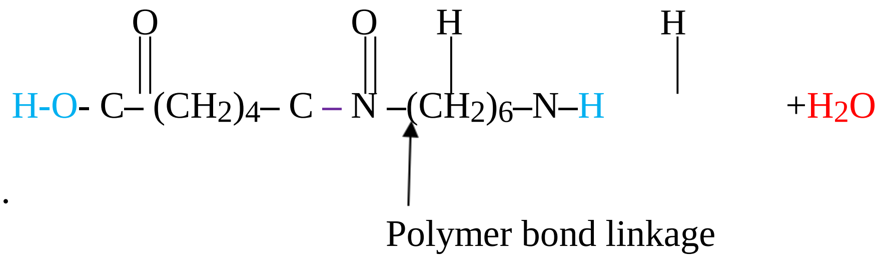
Method 1: Nylon-6,6 can be made from the condensation polymerization of hexan-1,6-dioic acid with hexan-1,6-diamine.Amines are a group of homologous series with a general formula R-NH_2 and thus -NH_2 as the functional group.

During the formation of Nylon-6,6:

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



(iii)from each functional group an element is removed so as to form a molecule of H_2O and the two monomers join at the linkage .



Nylon-6,6 derive its name from the two monomers each with **six** carbon chain

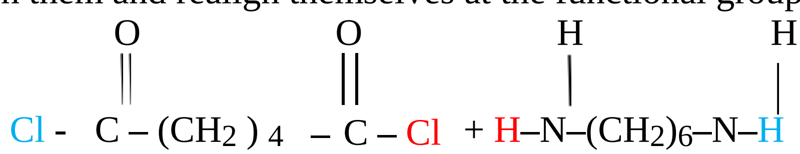
Method 2: Nylon-6,6 can be made from the condensation polymerization of hexan-1,6-dioyl dichloride with hexan-1,6-diamine.

Hexan-1,6-dioyl dichloride belong to a group of homologous series with a general formula R-OCl and thus -OCl as the functional group.

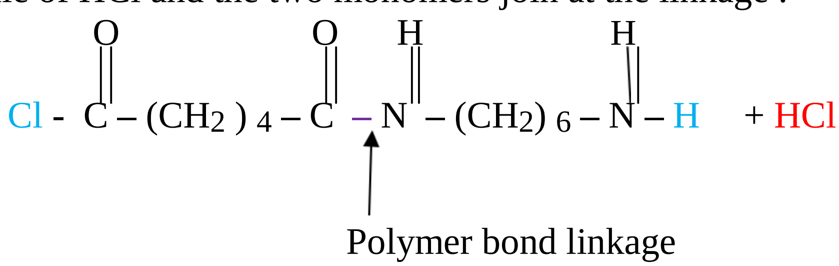
The R-OCl is formed when the **"**OH**"** in R-O**OH**/alkanoic acid is replaced by Cl/chlorine/Halogen

During the formation of Nylon-6,6:

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



(iii)from each functional group an element is removed so as to form a molecule of HCl and the two monomers join at the linkage .



The two monomers each has **six** carbon chain hence the name **"**nylon-6,6**"**

The commercial name of Nylon-6,6 is **Nylon** It is a a tough, elastic and durable plastic. It is used to make **clothes**, **plastic ropes** and **carpets.**

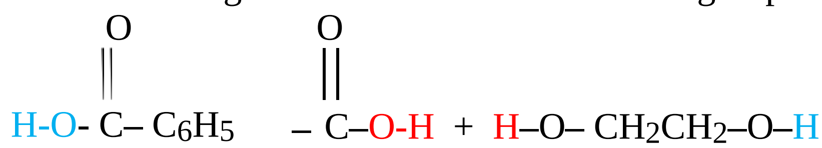
<u>2.Formation of Terylene</u>

Method 1: Terylene can be made from the condensation polymerization of ethan-1,2-diol with benzene-1,4-dicarboxylic acid.

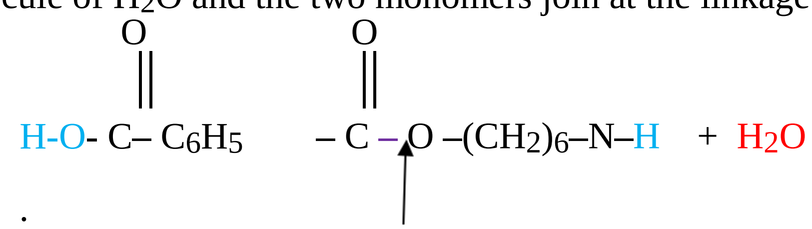
Benzene-1,4-dicarboxylic acid a group of homologous series with a general formula R-COOH where R is a ring of six carbon atom called Benzene ring .The functional group is -COOH.

During the formation of Terylene:

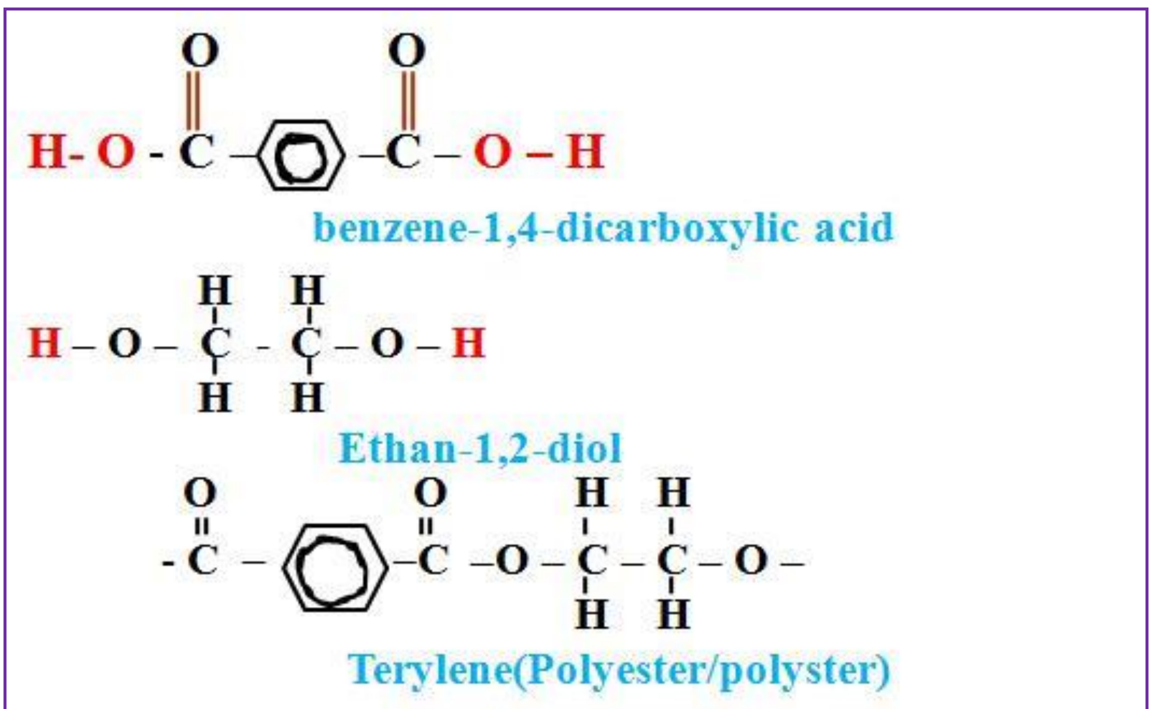
(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



(iii)from each functional group an element is removed so as to form a molecule of H_2O and the two monomers join at the linkage .



Polymer bond linkage of terylene



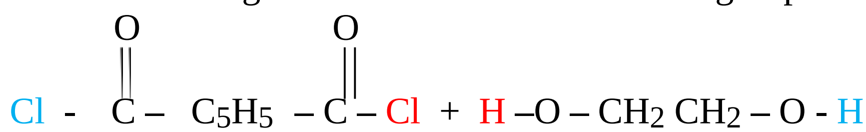
Condensation polymerization of Benzene-1,4-dicarboxylic acid and Ethan-1,2-diol to form Terylene

Method 2: Terylene can be made from the condensation polymerization of benzene-1,4-dioyl dichloride with ethan-1,2-diol.

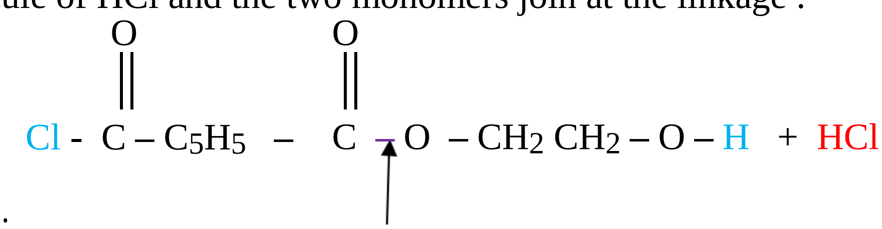
Benzene-1,4-dioyl dichloride belong to a group of homologous series with a general formula R-OCl and thus -OCl as the functional group and R as a benzene ring.
The R-OCl is formed when the **"**OH**"** in R-O**OH** is replaced by Cl/chlorine/Halogen

During the formation of Terylene

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



(iii)from each functional group an element is removed so as to form a molecule of HCl and the two monomers join at the linkage .



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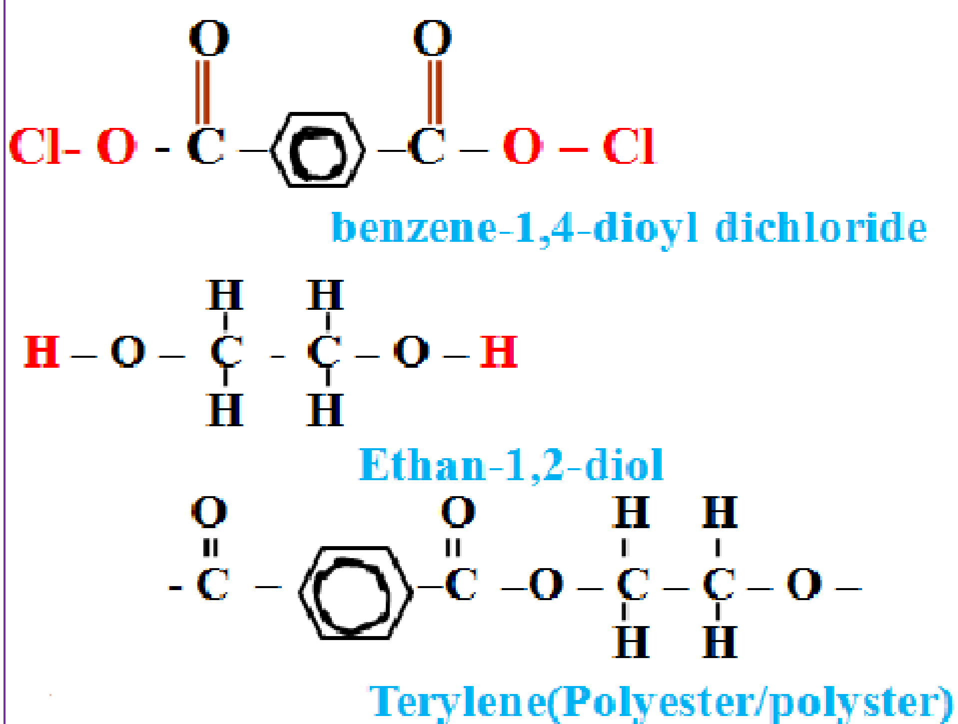
Polymer bond linkage of terylene



Condensation polymerization of benzene-1,4-dioyl dichloride with Ethan-1,2-diol to form Terylene

The commercial name of terylene is **Polyester /polyster** It is a a tough, elastic and durable plastic. It is used to make **clothes**, **plastic ropes and sails** and **plastic model kits.**

Practice questions Organic chemistry

1. A student mixed equal volumes of Ethanol and butanoic acid. He added a few drops of concentrated Sulphuric (VI) acid and warmed the mixture

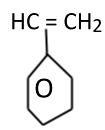
(i) Name and write the formula of the main products

Name………………………………….

Formula……………………………………..

(ii) Which homologous series does the product named in (i) above belong?

2. The structure of the monomer phenyl ethene is given below:-



a) Give the structure of the polymer formed when four of the monomers are added together

b) Give the name of the polymer formed in **(a)** above

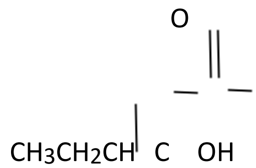
3. Explain the environmental effects of burning plastics in air as a disposal method

4. Write chemical equation to represent the effect of heat on ammonium carbonate

5. Sodium octadecanoate has a chemical formula $CH_3(CH_2)_6\ COO^-Na^+$, which is used as soap.

Explain why a lot of soap is needed when washing with hard water

6. A natural polymer is made up of the monomer:



(a) Write the structural formula of the repeat unit of the polymer

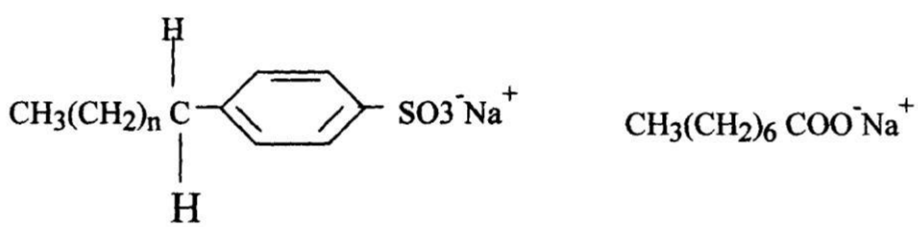
(b) When 5.0 x 10^{-5} moles of the polymer were hydrolysed, 0.515g of the monomer

were obtained.

Determine the number of the monomer molecules in this polymer.

(C=12;H=1;N=14;O=16)

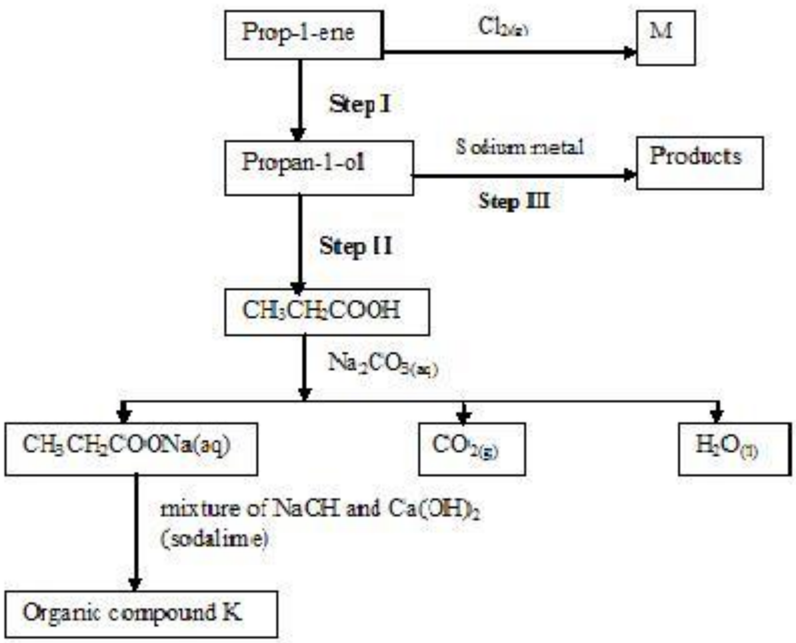
7. The formula below represents active ingredients of two cleansing agents **A** and **B**



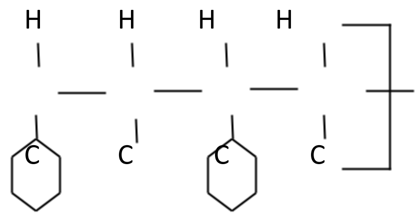
Agent A Agent B

Which one of the cleansing agents would be suitable to be used in water containing magnesium hydrogen carbonate? Explain

(b)Study the flow chart below and use it to answer the questions that follow.



8. Study the polymer below and use it to answer the questions that follow:



(a) Give the name of the monomer and draw its structures

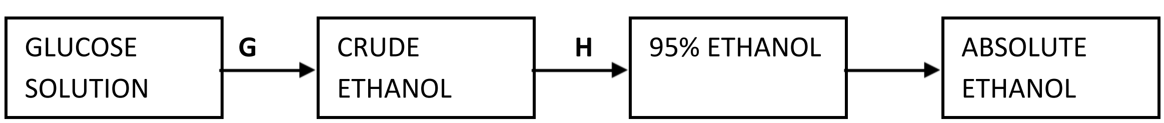
(b) Identify the type of polymerization that takes place

(c) State **one** advantage of synthetic polymers

9. Ethanol and Pentane are miscible liquids. Explain how water can be used to separate a mixture

of ethanol and pentane

10.



(a) What is absolute ethanol?

(b) State **two** conditions required for process **G** to take place efficiently

11. (a) (i) The table below shows the volume of oxygen obtained per unit time when hydrogen

peroxide was decomposed in the presence of manganese (IV) Oxide. Use it to answer

the questions that follow:-

Time in seconds	**Volume of Oxygen evolved (cm^3)**
0	0
30	10
60	19
90	27
120	34
150	38
180	43
210	45
240	45
270	45
300	45

(i) Plot a graph of volume of oxygen gas against time

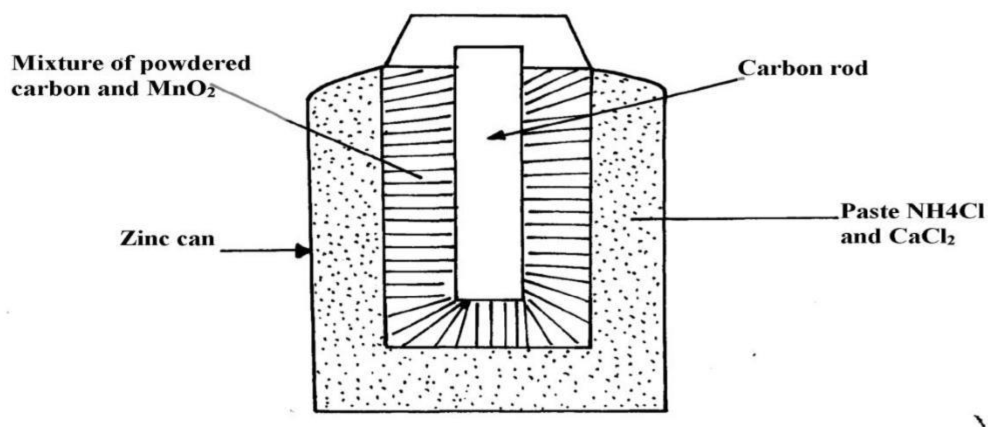
(ii) Determine the rate of reaction at time 156 seconds

(iii) From the graph, find the time taken for $18cm^3$ of oxygen to be produced

(iv) Write a chemical equation to show how hydrogen peroxide decomposes in the presence

of manganese (IV) Oxide

(b) The diagram below shows how a Le'clanche (Dry cell) appears:-



(i) What is the function of MnO_2 in the cell above?

(ii) Write the equation of a reaction that occurs at the cathode

(iii) Calculate the mass of Zinc that is consumed when a current of 0.1amperes flows

through the above cell for 30minutes (1F =96500c Zn =65)

12. (a) Give the IUPAC names of the following compounds:

(i) $CH_3COOCH_2CH_3$

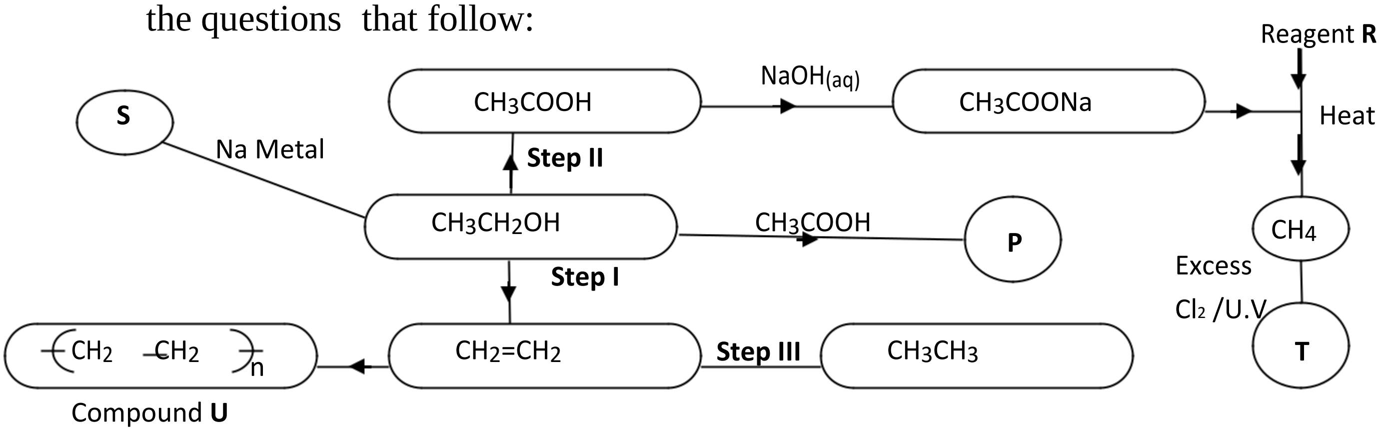
*

$CH_2 = C - CHCH_3$

(ii) |

(b) The structure below shows some reactions starting with ethanol. Study it and answer

the questions that follow:



(i) Write the formula of the organic compounds **P** and **S**
*

(ii) Name the type of reaction, the reagent(s) and condition for the reactions in the following steps :-

(I) Step I *

(II) Step II *

(III) Step III *

(iii) Name reagent **R**
…………………………………………………………… *

(iv) Draw the structural formula of **T** and give its name
*

(v) (I) Name compound **U**……………………………………………………..

(II) If the relative molecular mass of **U** is 42000, determine the value of n (**C**=12, **H**=1)

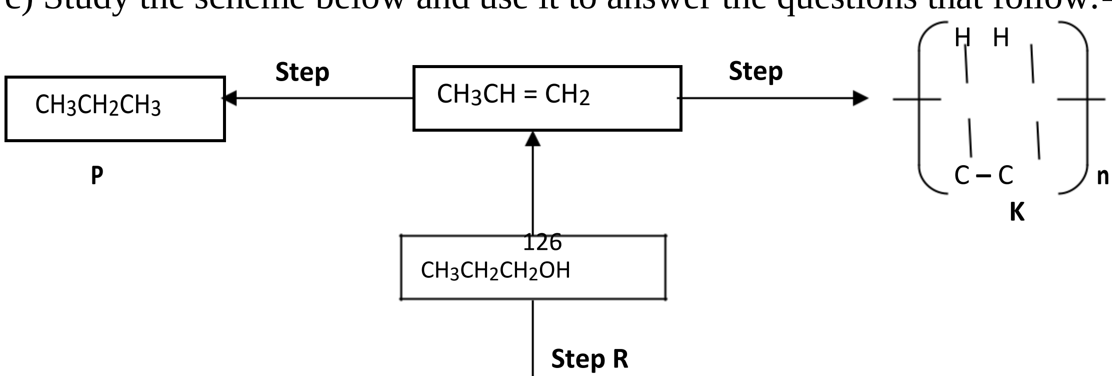
(c) State why C_2H_4 burns with a more smoky flame than C_2H_6
*

13. a) State **two** factors that affect the properties of a polymer

b) Name the compound with the formula below :

$CH_3CH_2CH_2ONa$

c) Study the scheme below and use it to answer the questions that follow:-



i) Name the following compounds:-

I. Product **T** **…………………………** **II. K** **………**

ii) State **one** common physical property of substance **G**

iii) State the type of reaction that occurred in step **J**

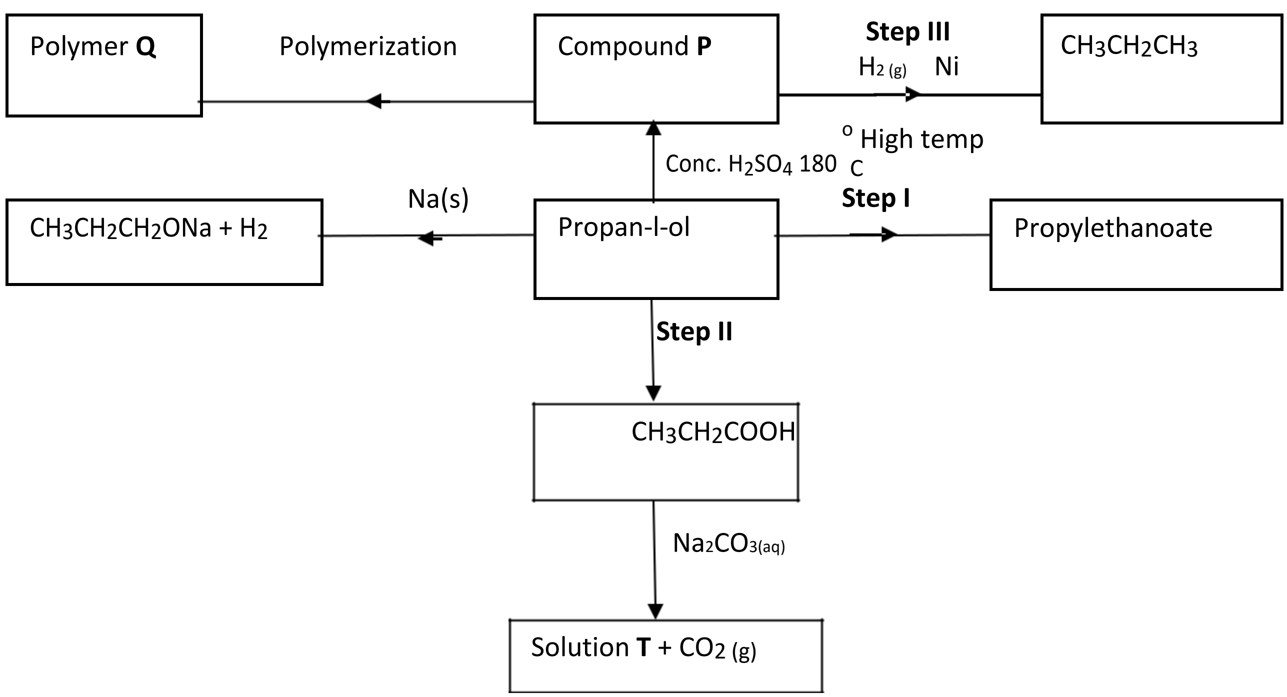
iv) Give **one** use of substance **K**

v) Write an equation for the combustion of compound **P**

vi) Explain how compounds CH_3CH_2COOH and $CH_3CH_2CH_2OH$ can be distinguished chemically

vii) If a polymer **K** has relative molecular mass of 12,600, calculate the value of **n** (H=1 C =12)

14. Study the scheme given below and answer the questions that follow:-



(a) (i) Name compound **P**
………………………………………………………………………

(ii) Write an equation for the reaction between CH_3CH_2COOH and Na_2CO_3

(b) State **one** use of polymer **Q**

(c) Name **one** oxidising agent that can be used in **step II**
……………………………………..

(d) A sample of polymer **Q** is found to have a molecular mass of 4200.
Determine the number of

monomers in the polymer (H = 1, C = 12)

(e) Name the type of reaction in **step I**
…………………………………………………………………..

(f) State **one** industrial application of **step III**

(g)State how burning can be used to distinguish between propane and propyne.
Explain your

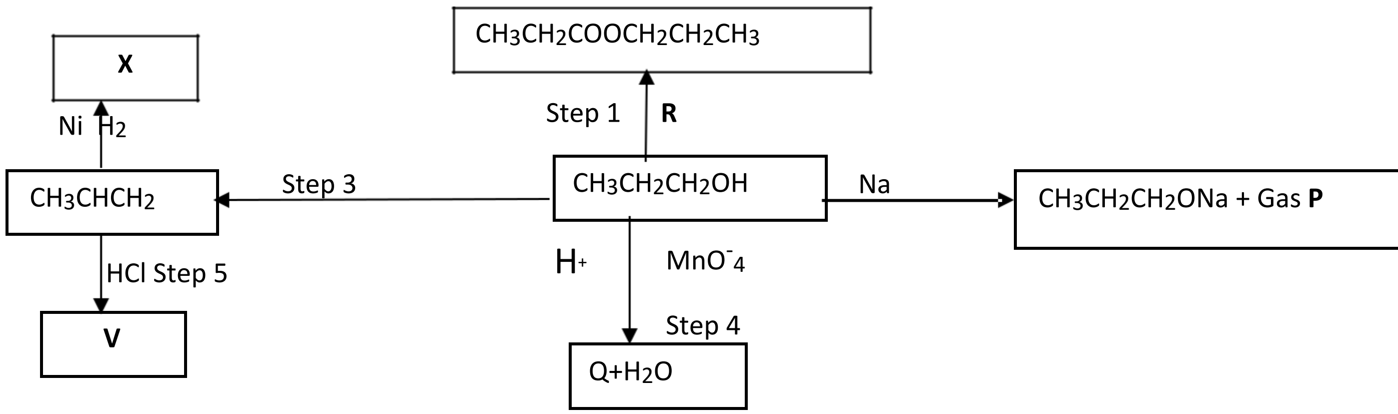
answer

(h) 1000cm^3 of ethene (C_2H_4) burnt in oxygen to produce Carbon (II) Oxide
and water vapour.

Calculate the minimum volume of air needed for the complete combustion of ethene

(Air contains 20% by volume of oxygen)

15. (a) Study the schematic diagram below and answer the questions that follow:-



(i) Identify the following:

Substance **Q** ....

Substance **R**..

Gas **P**..

(ii) Name:

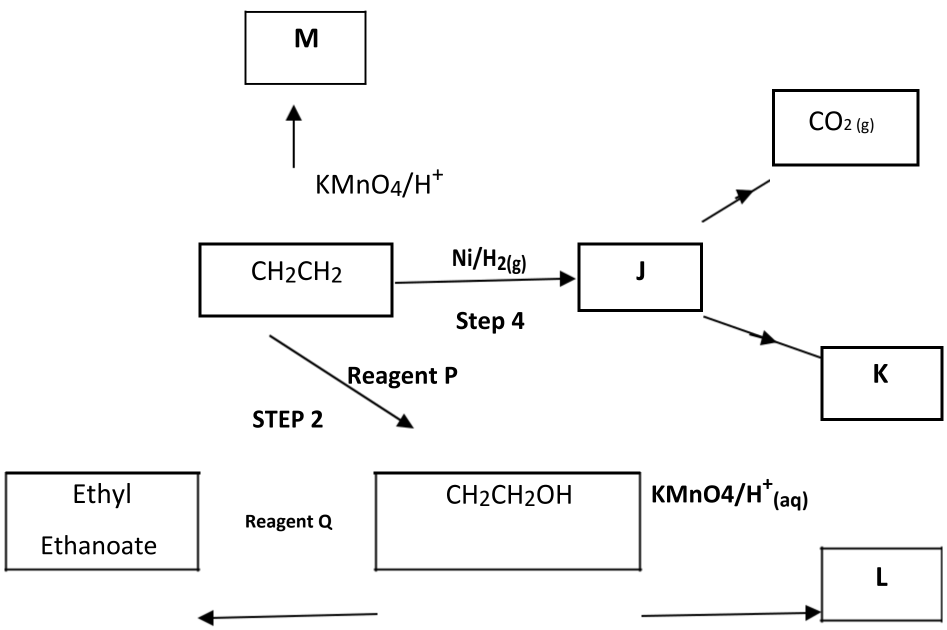
Step 1...

Step 4...

(iii) Draw the structural formula of the major product of step **5**

(iv) State the condition and reagent in step **3**

16. Study the flow chart below and answer the questions that follow



(a) (i) Name the following organic compounds:

M…………………………………………………………………..……..

L………………………………………………………………………..

(ii) Name the process in step:

Step 2

……………………………………………………………………

Step 4 ……………………………………………………………………

(iii) Identify the reagent **P** and **Q**

(iv) Write an equation for the reaction between $CH_3CH_2CH_2OH$ and sodium

17. a) Give the names of the following compounds:

i) $CH_3CH_2CH_2CH_2OH$

……………………………………………………………………

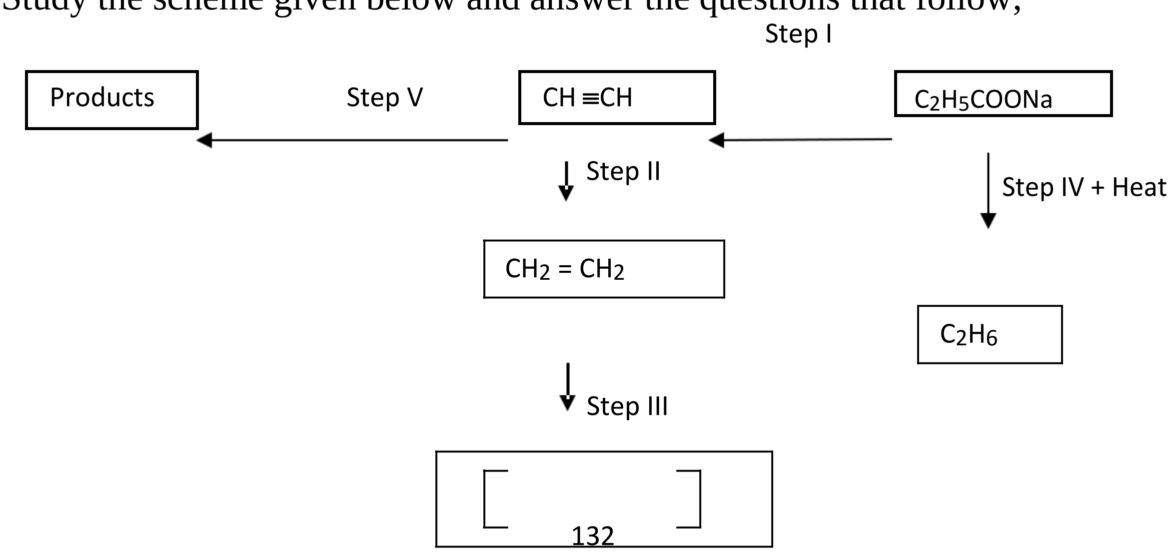
ii) CH_3CH_2COOH

……………………………………………………………………

iii) $CH_3C – O- CH_2CH_3$

……………………………………………………………………

18. Study the scheme given below and answer the questions that follow;



— —
n

i) Name the reagents used in:

Step I:
……………………………………………………………………………

Step II
…………………………………………………………………………

Step III
……………………………………………………………………………

ii) Write an equation to show products formed for the complete combustion of CH=CH

iii) Explain **one** disadvantage of continued use of items made form the compound formed

in step III

19. A hydrated salt has the following composition by mass. Iron 20.2 %, oxygen 23.0%,

sulphur 11.5%, water 45.3%

i) Determine the formula of the hydrated salt (Fe=56, S=32, O=16, H=11)

ii) 6.95g of the hydrated salt in **c(i)** above were dissolved in distilled water and the total

volume made to 250cm^3 of solution. Calculate the concentration of the resulting salt solution

in moles per litre. (Given that the molecula mass of the salt is 278)

20. Write an equation to show products formed for the complete combustion of CH = CH

iii) Explain **one** disadvantage of continued use of items made form the compound formed

in step III

21. Give the IUPAC name for each of the following organic compounds;

i) CH_3 - |CH - CH_2 - CH_3

OH

ii)CH_3 – CH – CH_2 – CH_2 - CH_3

|

C_2H_5

iii)$CH_3COOCH_2CH_2CH_3$

22. The structure below represents a cleansing agent.

O

||

R – S – O^-Na^+

||

O

a) State the type of cleansing agent represented above

b) State **one** advantage and one disadvantage of using the above cleansing agent.

23. The structure below shows part of polymer .Use it to answer the questions that follow.

CH_3 CH_3 CH_3

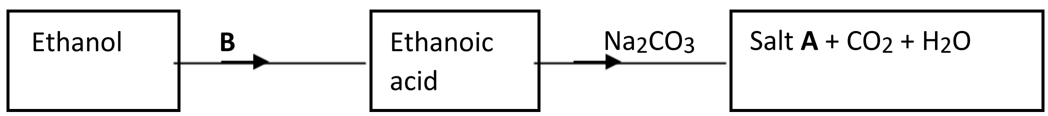
| | |

— **CH** - CH_2 – CH- CH_2- CH – CH_2—

a) Derive the structure of the monomer

b) Name the type of polymerization represented above

24. The flow chart below represents a series of reactions starting with ethanoic acid:-



(a) Identify substances **A** and **B**

(b) Name the process **I**

25. a) Write an equation showing how ammonium nitrate may be prepared starting with

ammonia gas

(b) Calculate the maximum mass of ammonium nitrate that can be prepared using 5.3kg of

ammonia (H=1, N=14, O=16)

26. (a) What is meant by the term, esterification?

(b) Draw the structural formulae of **two** compounds that may be reacted to form ethylpropanoate

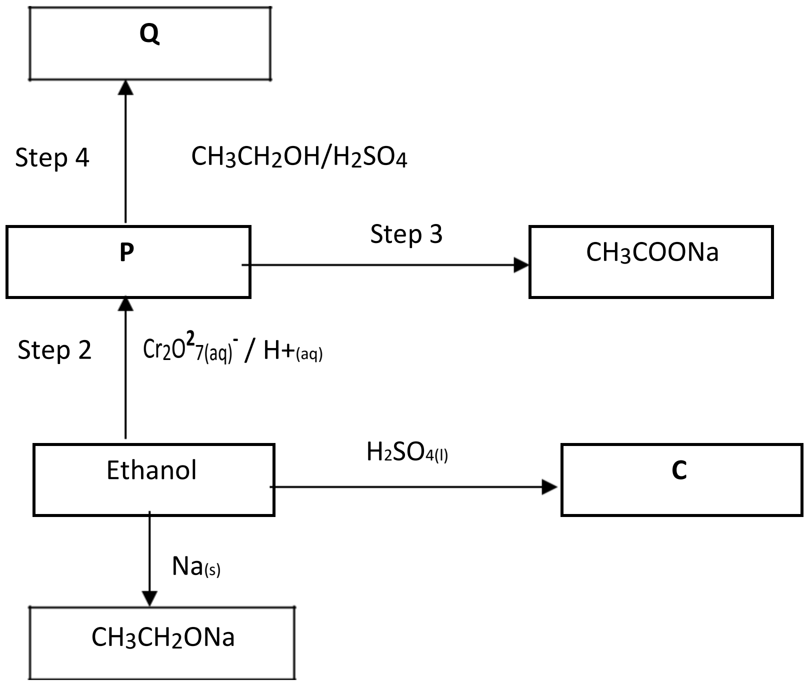
27. (a) Draw the structure of pentanoic acid

(b) Draw the structure and give the name of the organic compound formed when ethanol

reacts with pentanoic acid in presence of concentrated sulphuric acid

28. The scheme below shows some reactions starting with ethanol. Study it and answer the questions

that follow:-



(i) Name and draw the structure of substance **Q**

(ii) Give the names of the reactions that take place in **steps 2** and **4**

(iii) What reagent is necessary for reaction that takes place in step 3

29. Substances **A** and **B** are represented by the formulae **ROH** and **RCOOH** respectively.

They belong to two different homologous series of organic compounds. If both A and B

react with potassium metal:

(a) Name the common product produced by both

(b) State the observation made when each of the samples **A** and **B** are reacted with sodium

hydrogen carbonate

(i) **A**

(ii) **B**

30. Below are structures of particles. Use it to answer questions that follow. In each case only

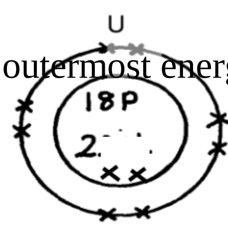
electrons in the outermost energy level are shown

key

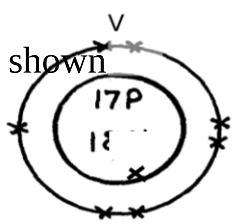
P = Proton

N = Neutron

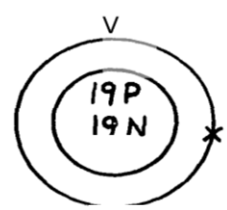
X = Electron



U

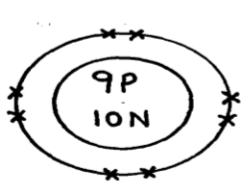


V

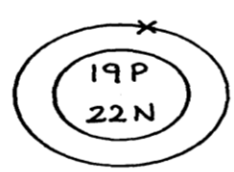


19P

W



Y



Z

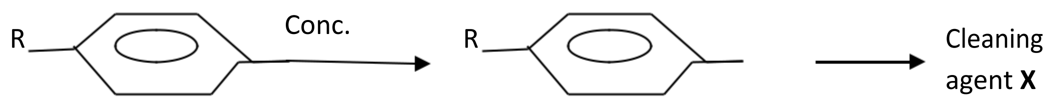
(a) Identify the particle which is an anion

31. Plastics and rubber are extensively used to cover electrical wires.

(a) What term is used to describe plastic and rubbers used in this way?

(b) Explain why plastics and rubbers are used this way

32. The scheme below represents the manufacture of a cleaning agent **X**



(a) Draw the structure of **X** and state the type of cleaning agent to which **X** belong

(b) State **one** disadvantage of using **X** as a cleaning agent

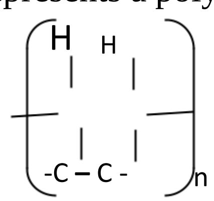
33. **Y** grams of a radioactive isotope take 120days to decay to 3.5grams. The half-life period

of the isotope is 20days

(a) Find the initial mass of the isotope

(b) Give **one** application of radioactivity in agriculture

34. The structure below represents a polymer. Study and answer the questions that follow:-



(i) Name the polymer above..

(ii) Determine the value of **n** if giant molecule had relative molecular mass of 4956

35. $RCOO^-Na^+$ and $RCH_2OSO_3^-Na^+$ are two types of cleansing agents;

i) Name the class of cleansing agents to which each belongs

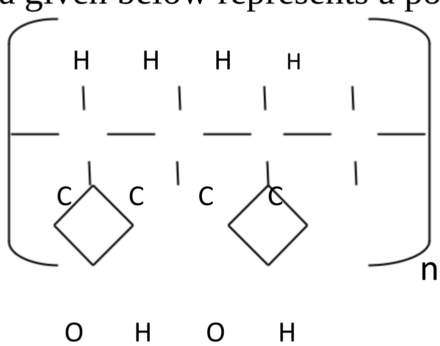
ii) Which one of these agents in **(i)** above would be more suitable when washing with water

from the Indian ocean. Explain

iii) Both sulphur (IV) oxide and chlorine are used bleaching agents. Explain the difference

in their bleaching properties

36. The formula given below represents a portion of a polymer



(a) Give the name of the polymer

(b) Draw the structure of the monomer used to manufacture the polymer

<u>15.0.0 NITROGEN AND IT'S COMPOUNDS (30 LESSONS)</u>

Introduction to oxides of nitrogen

Nirogen has a position in second period of group V in the modern periodic table. It has molecular formula N_2. It has atomic number 7 and atomic weight 14.08 and its electronic configuration of 2,5.

Besides combining with hydrogen and forming NH_3 , nitrogen combines with oxygen in different ratios and forms five different oxides.

The **oxides of nitrogen** and the details of the oxygen states of nitrogen and the N:O ratio can be presented in a tabular form as:

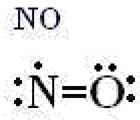
Name	Formula	Oxidation state of N	Ratio of N:O
1) Nitrogen Oxide or nitrous oxide	NO	+2	1:1
2) Nitrogen dioxide	NO_2	+4	1:2
3) Nitrous oxide (also called laughing gas)	N_2O	+1	2:1

All of these oxides of nitrogen are gases, excepting NO and N_2O the other oxides are brownish gases. Except the oxides of NO and N_2O all the other oxides are acidic. NO and N_2O are neutral.

The other oxides are prepared in the laboratory using different methods characteristic to each oxide.

Example of Oxides of Nitrogen (nitric Oxide - NO)

Structure:



Laboratory Preparation: The oxide is prepared in the laboratory by treating the metallic copper with a moderately concentarted nitric acid (1:1) at room temperature.

The reaction is given as :

$2Cu + 8\ HNO_3$ ------> $Cu(NO_3)_2 + 2NO + 4H_2O$

The gas is collected by downward displacement of water.The apparatus used is Wolfe's apparatus. The purification is done by absorbing the NO gas in frashly prepared ferrous sulphate solution. Ferrous sulphate absorbs all the NO gas and forms

$Fe(H_2O)_5$ NO and the solution becomes brown. On heating this solution pure Nitric Oxide is obatined.

Physical Properties: NO is not a combustible gas. At high temperature around 1000°C it decomposes into N_2 and O_2 .

$$2NO = N_2 + O_2 \quad \text{at high temperature}$$

From the equation above we can see that once the decomposition starts 50% O_2 gets evolved and this O_2 supports combustion thus making the reaction more violent.

Chemical properties:

1) NO acts as an **oxidising agent**, oxidising SO_2 in presence of water to give H_2SO_4:

$SO_2 + 2NO + H_2O \rightarrow H_2SO_4 + N_2O$

2) NO acts as a **reducing agent,**

i) reducing an acidified solution of potassium permanganate (pink) to colorless manganous salt.

$3KMnO_4 + 6H_2SO_4 + 5NO_2 \rightarrow 3KHSO_4 + 3MnSO_4 + 2H_2O + 5NO_3$

ii) It can also reduce aqueous solution of I_2 to HI

$3I_2 + 2NO + 4H_2O \rightarrow 2HNO_3 + 6HI$

3) **With halogens** NO can form addition compounds as

$2NO + Cl_2 \rightarrow 2NOCl$ (NOCl is nitrosyl chloride)

It reacts in the same way with flourine and bromine.

4) With ferrous sulphate NO forms an addition compound as

$FeSO_4 + 5H_2O + NO = [Fe(H_2O)_5NO]SO_4$

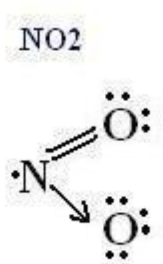
penta aqua nitrosyl iron (II) sulphate

This is the famous **brown ring test** used to identify the nitrate radical or the NO radical.

Uses: NO is used to prepare nitric acid.

Nitrogen Dioxide - NO2

Structure:



Laboratory Preparation: In the laboratory NO_2 is prepared by thermal decomposition of $Pb(NO_3)_2$. Thus

$2Pb(NO_3)_2 \rightarrow 2PbO + 4NO_2 + O_2$

Care is taken to ensure the use of dried $Pb(NO_3)_2$ as hydrated nitrate salts on heating react violently and explode.

Physical Properties: NO_2 is a poisonous gas, main source being the exhaust of automobiles.

1) At room temperature it is a deep brown gas.

2) It does not support combustion.

3) It is not combustible.

Chemical Properties:

1) With cold water NO_2 reacts to give a mixture of HNO_2 and HNO_3 acid.

$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$

2) With hot water the reaction is

$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

3) Being acidic it reacts with bases as

$2NO_2 + KOH \rightarrow KNO_3 + H_2O + KNO_2$

4) It is also a strong oxidising agent.

$H_2S + NO_2 \rightarrow NO + H_2S + S$

5) With excess oxygen and water NO_2 gives

HNO_3. $4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$

6) It reacts with concentrated H_2SO_4 to give nitrosyl hydrogen

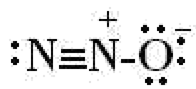
sulphate $2NO_2 + H_2SO_4 \rightarrow SO_2(OH)ONO + HNO_3$

Uses: NO_2 is used as a fuel in rockets besides being used to prepare HNO_3 .

Nitrous Oxide - N2O (laughing Gas)

Structure:

N2O



Laboratory Preparation: N_2O can be prepared in the laboratory by heating NH_4NO_3 below 200°C to avoid explosion. Sometimes as a safety measure instead of directly using NH_4NO_3, a mixture of $(NH_4)_2SO_4$ and $NaNO_3$ are heated to give NH_4NO_3 which decomposes further to give N_2O.

$NH_4NO_3 \rightarrow N_2O + H_2O$ (endothermic reaction)

Physical Properties:

1) N_2O has a faint sweet smell and produces a tickling sensation on the neck when inhaled and makes people laugh hysterically. Excess of inhalation leads to unconsiousness.

2) Unlike other oxides of nitrogen, N_2O supports combustion though it does not burn itself.

Chemical Properties:

1) At very high temperature N_2O decomposes to N_2 and O_2

$2N_2O \rightarrow 2N_2 + O_2$

If a glowing piece of Mg, Cu, or P is introduced in such an environment, these pieces burn brightly due to the O_2 produced from decomposition of N_2O.

2) With Sodium and potassium N_2O reacts to give the corresponding peroxides liberating N_2 in the process.

$2N_2O + 2Na \rightarrow Na_2O + 2N_2$.

Na_2O is sodium peroxide

Uses:

1) It is used as propellent gas.

2)Used in combination with oxygen in the ratio $N_2O : O_2$ = 1:10 as a mild anaesthetic.

16.0.0 SULPHUR AND ITS COMPOUNDS (25 LESSONS)

A.SULPHUR (S)

Sulphur is an element in Group VI Group 16)of the Periodic table . It has atomic number 16 and electronic configuration 16 and valency 2 /divalent and thus forms the ion S^{2-}

A. Occurrence.

Sulphur mainly occurs :

(i) as **free** element in Texas and Louisiana in USA and Sicily in Italy. (ii)**Hydrogen sulphide** gas in active volcanic areas e.g. Olkaria near Naivasha in Kenya
(iii)as **copper pyrites(**$CuFeS_2$**)** ,**Galena** (PbS,**Zinc blende**(ZnS))and **iron pyrites**(FeS_2) in other parts of the world.

B. Extraction of Sulphur from **Fraschs** process

Suphur occurs about 200 metres underground. The soil structure in these areas is usually **weak** and can easily **cave** in.

Digging of tunnels is thus discouraged in trying to extract the mineral. Sulphur is extracted by drilling three concentric /round pipes of diameter of ratios 2:8: 18 centimeters.

Superheated water at 170^oC and 10atmosphere pressure is forced through the outermost pipe.

The high pressures ensure the water remains as liquid at high temperatures instead of vapour of vapour /gas.

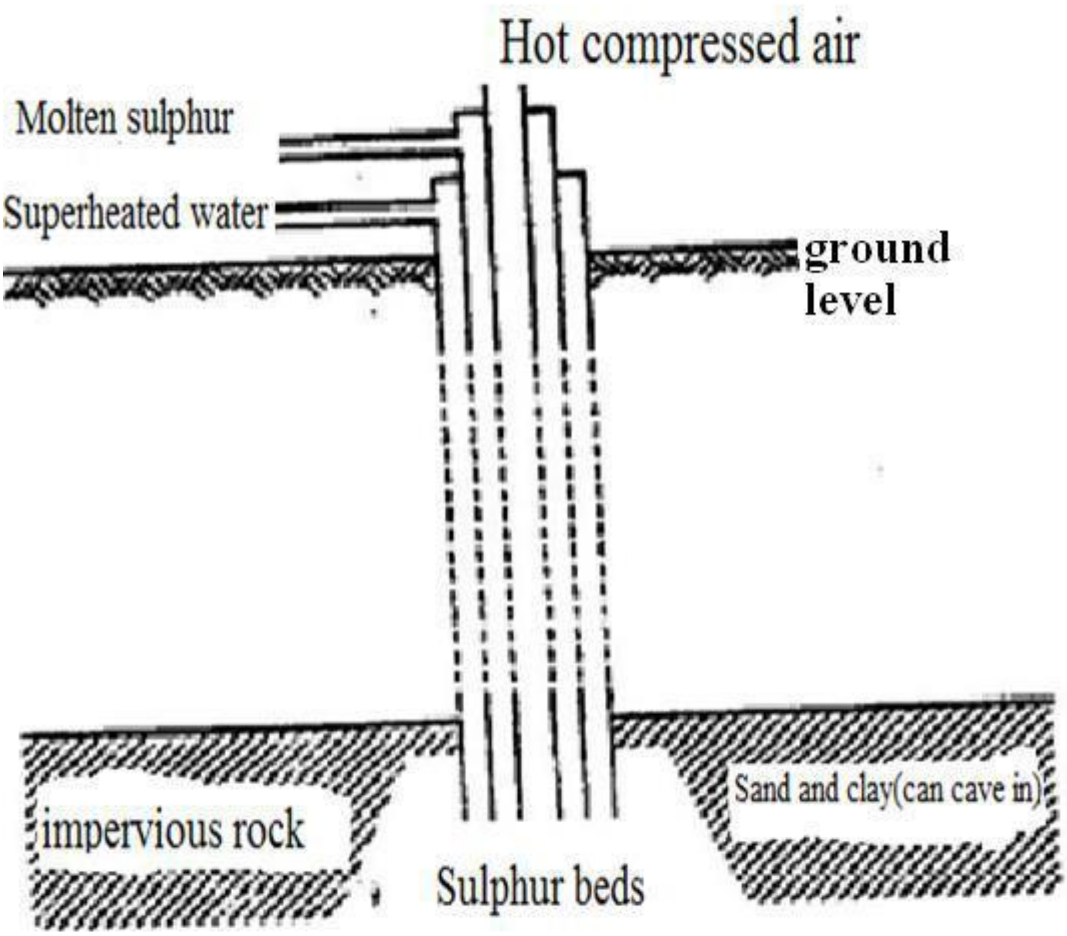
The superheated water melts the sulphur because the melting point of sulphur is lower at about at about 115^oC.

A compressed air at 15 atmospheres is forced /pumped through the innermost pipe.

The hot air forces the molten sulphur up the middle pipe where it is collected and solidifies in a large tank.

It is about 99% pure.

Diagram showing extraction of Sulphur from Fraschs Process



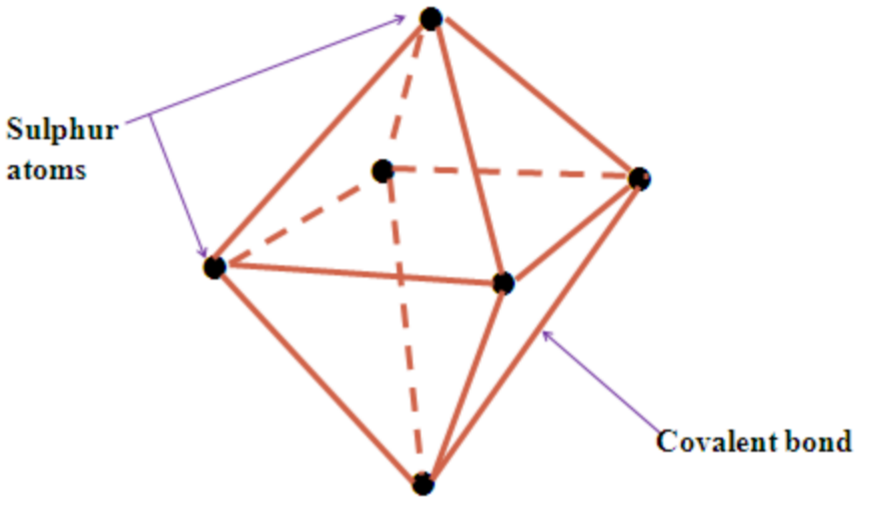
C. Allotropes of Sulphur.

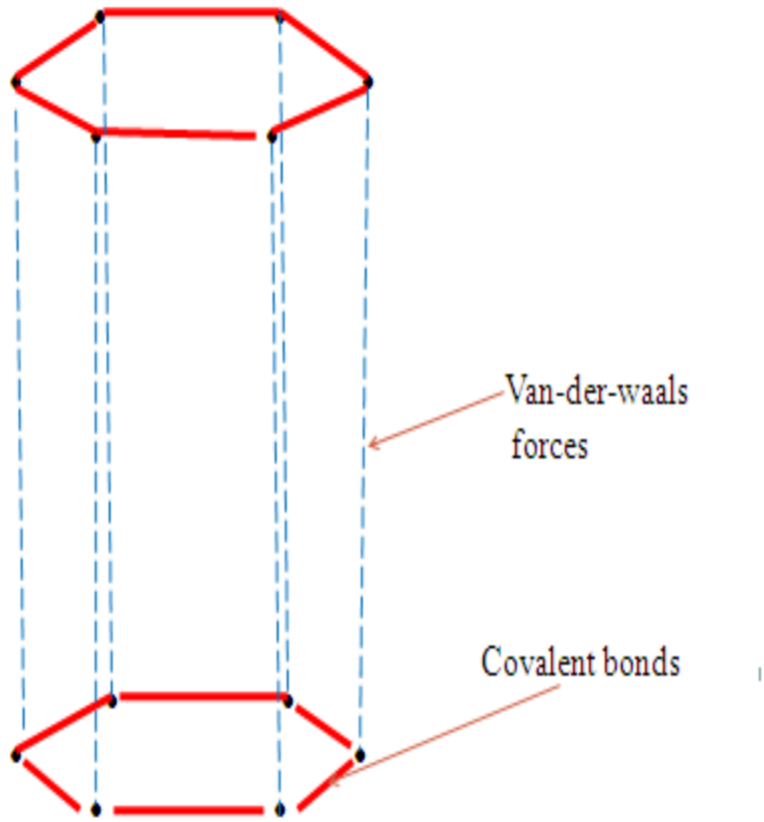
1. Sulphur exist as two crystalline allotropic forms: (i)Rhombic sulphur
(ii)Monoclinic sulphur

Rhombic sulphur	Monoclinic sulphur
Bright yellow crystalline solid Has a melting point of 113^{o}C Has a density of 2.06gcm^{-3} Stable below 96^{o}C Has octahedral structure	Pale yellow crystalline solid Has a melting point of 119^{o}C Has a density of 1.96gcm^{-3} Stable above 96^{o}C Has a needle-like structure

Rhombic sulphur and Monoclinic sulphur have a **transition** temperature of 96^{o}C.This is the temperature at which one allotrope changes to the other.

Sketch of Octahedral structure of Rhombic sulphur





Sketch of the needle-like structure of monoclinic sulphur

2. Sulphur exists in non-crystalline forms as:

(i)Plastic sulphur-

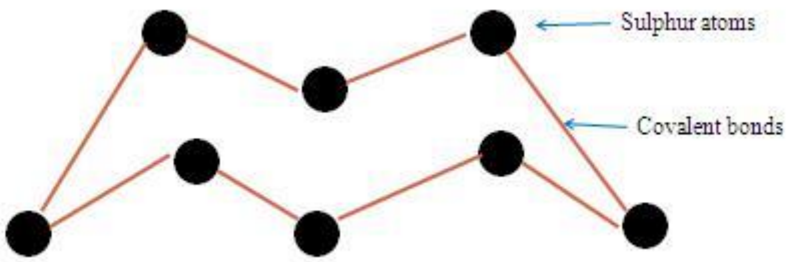
Plastic sulphur is prepared from heating powdered sulphur to boil then pouring a thin continuous stream in a beaker with cold water. A long thin elastic yellow thread of plastic sulphur is formed .If left for long it turn to bright yellow crystalline rhombic sulphur.

(ii)Colloidal sulphur-

Colloidal sulphur is formed when sodium thiosulphate ($Na_2S_2O_3$) is added hydrochloric acid to form a yellow precipitate.

D. Heating Sulphur.

A molecule of sulphur exists as puckered ring of eight atoms joined by covalent bonds as S_8.



On heating the yellow sulphur powder melts at 113^{o}C to clear amber liquid with low viscosity and thus flows easily.

On further heating to 160^{o}C the molten liquid darkens to a brown very viscous liquid that does not flow easily.

This is because the S_8 rings break into S_8 chain that join together to form very long chains made of over 100000 atoms of Sulphur.

The long chains **entangle** each other reducing their mobility /flow and hence increases their viscosity.

On continued further heating to above 160^{o}C, the viscous liquid darkens but becomes more mobile/flows easily and thus less viscous.

This is because the long chains break to smaller/shorter chains.

At 444^{o}C, the liquid boils and forms brown vapour of a mixture of S_8 ,S_6 ,S_2 molecules that solidifies to S_8 ring of “flowers of sulphur” on the cooler parts.

Summary of changes on heating sulphur

Observation on heating	Explanation/structure of Sulphur
Solid sulphur	Puckered S_8 ring
Heat to 113^{o}C Amber yellow liquid	Puckered S_8 ring in liquid form (low viscosity/flow easily)
Heat to 160^{o}C Liquid darkens	Puckered S_8 ring break/opens then join to form long chains that entangle (very high viscosity/very low rate of flow)
Heat to 444^{o}C Liquid boils to brown vapour	Mixture of S_8 ,S_6 ,S_2 vapour
Cool to room temperature Yellow sublimate (Flowers of Sulphur)	Puckered S_8 ring

E. Physical and Chemical properties of Sulphur.(**Questions**)

1. State three physical properties unique to Sulphur Sulphur is a yellow solid, insoluble in water, soluble in carbon disulphide/tetrachloromethane/benzene, poor conductor of heat and electricity. It has a melting point of 115^{o}C and a boiling point of 444^{o}C.

2. Moist/damp/wet blue and red litmus papers were put in a gas jar containing air/oxygen. Burning sulphur was then lowered into the gas jar. State and explain the observation made.

Observations

-Sulphur melts then burns with a blue flame
Colourless gas produced that has a pungent smell
Red litmus paper remains red. Blue litmus paper turns red.

Explanation

Sulphur burns in air and faster in Oxygen to form Sulphur(IV)Oxide gas and traces/small amount of Sulphur(VI)Oxide gas. Both oxides react with water to form the corresponding acidic solution i.e

(i) Sulphur(IV)Oxide gas reacts with water to form sulphuric(IV)acid
(ii) Sulphur(VI)Oxide gas reacts with water to form sulphuric(VI)acid Chemical equation

$S(s) + O_2(g) \rightarrow SO_2(g)$ (Sulphur(IV)Oxide gas)

$2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$ (Sulphur(VI)Oxide gas traces)

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ (sulphuric(IV)acid)

$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ (sulphuric(VI)acid).

3. Iron filings were put in a test tube containing powdered sulphur then heated on a Bunsen flame. Stop heating when reaction starts. State and explain the observations made. Test the effects of a magnet on the mixture before and after heating. Explain.

Observations

Before heating, the magnet attracts iron filings leaving sulphur After heating, the magnet does not attract the mixture.

After heating, a red glow is observed that continues even when heating is stopped..

Black solid is formed.

Explanation

Iron is attracted to a magnet because it is ferromagnetic.

When a mixture of iron and sulphur is heated, the reaction is exothermic giving out heat energy that makes the mixture to continue glowing even after stopping heating.

Black Iron(II)sulphide is formed which is a compound and thus not ferromagnetic.

Chemical equation

$Fe(s) + S(s) \rightarrow FeS(s)$ (Exothermic reaction/ $-\Delta H$)

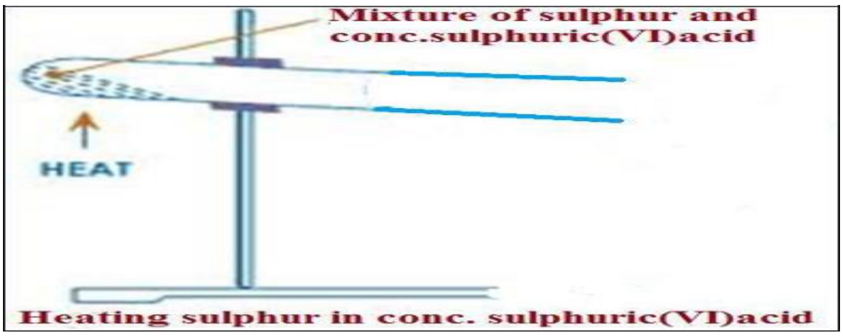
Heated powdered heavy metals combine with sulphur to form **black** sulphides.

$Cu(s) + S(s) \rightarrow CuS(s)$

$Zn(s) + S(s) \rightarrow ZnS(s)$

$Pb(s) + S(s) \rightarrow PbS(s)$

4.The set up below show the reaction of sulphur on heated concentrated sulphuric(VI)acid.



(i)State and explain the observation made.

Observation

Yellow colour of sulphur fades

Orange colour of potassium dichromate(VI)paper turns to green.

Explanation

Hot concentrated sulphuric(VI)acid oxidizes sulphur to sulphur (IV)oxide gas. The oxide is also reduced to water. Traces of sulphur (VI)oxide is formed.

Chemical equation

$S(s) + 3H_2SO_4(l) \rightarrow 3SO_2(g) + 3H_2O(l) + SO_3(g)$

Sulphur (IV)oxide gas turns Orange potassium dichromate(VI)paper to green.

(ii)State and explain the observation made if concentrated sulphuric (VI) acid is replaced with concentrated Nitric (V) acid in the above set up.

Observation

Yellow colour of sulphur fades

Colurless solution formed

Brown fumes/gas produced.

Explanation

Hot concentrated Nitric(V)acid oxidizes sulphur to sulphuric (VI)acid. The Nitric (V) acid is reduced to brown nitrogen(IV)oxide gas.

Chemical equation

$S(s) + 6HNO_3(l) \rightarrow 6NO_2(g) + 2H_2O(l) + H_2SO_4(l)$

NB:

Hydrochloric acid is a weaker oxidizing agent and thus cannot oxidize sulphur like the other mineral acids.

5.State three main uses of sulphur .

Sulphur is mainly used in:

(i)Contact process for the manufacture/industrial/large scale production of concentrated sulphuric(VI)acid.

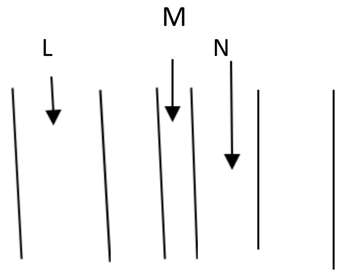
(ii)Vulcanization of rubber to make it harder, tougher, stronger, and more durable.

(iii)Making gun powder and match stick heads

(iv) As ointments to treat fungal infections

6. Revision Practice

The diagram below represents the extraction of sulphur by Fraschs process. Use it to answer the questions that follow.



(a)Name the substances that passes through:

M Superheated water at 170oC and 10 atmosphere pressure

L Hot compressed air

N Molten sulphur

(b)What is the purpose of the substance that passes through L and M?

M- Superheated water at $170^{O}C$ and 10 atmosphere pressure is used to melt the sulphur

L- Hot compressed air is used to force up the molten sulphur.

(c) The properties of the two main allotropes of sulphur represented by letters A and B are given in the table below. Use it to answer the questions that follow.

	A	**B**
Appearance	**Bright yellow**	**Pale yellow**
Density(gcm^{-3})	**1.93**	**2.08**
Melting point(^{o}C)	**119**	**113**
Stability	**Above $96^{o}C$**	**Below $96^{o}C$**

I.What are allotropes?

Different forms of the same element existing at the same temperature and pressure without change of state.

II. Identify allotrope:

A. Monoclinic sulphur

B . Rhombic sulphur

III. State two main uses of sulphur.

-Manufacture of sulphuric(VI)acid

-as fungicide

-in vulcanization of rubber to make it harder/tougher/ stronger -manufacture of dyes /fibres

(d)Calculate the volume of sulphur (IV)oxide produced when 0.4 g of sulphur is completely burnt in excess air.(S = 32.0 ,I mole of a gas occupies 24 dm3 at room temperature)

Chemical equation

$S(s) + O_2(g) \rightarrow SO_2(g)$

Mole ratio S: SO_2 = 1:1

Method 1

32.0 g of sulphur -> 24 dm3 of $SO_2(g)$

0.4 g of sulphur -> $\frac{0.4 \text{ g x } 24 \text{ dm3}}{32.0 \text{ g}}$ = **0.3 dm3**

Method 2

Moles of sulphur used = $\frac{\text{Mass of sulphur}}{\text{Molar mass of sulphur}}$ => $\frac{0.4}{32}$ = 0.0125 moles

Moles of sulphur used = Moles of sulphur(IV)oxide used=>0.0125 moles

Volume of sulphur(IV)oxide used = Moles of sulphur(IV)oxide x volume of one mole of gas =>0.0125 moles x 24 dm3 = **0.3 dm3**

B.COMPOUNDS OF SULPHUR

The following are the main compounds of sulphur:

(i) Sulphur(IV)oxide
(ii) Sulphur(VI)oxide
(iii) Sulphuric(VI)acid
(iv) Hydrogen Sulphide
(v) Sulphate(IV)/SO_3^{2-} and Sulphate(VI)/ SO_4^{2-} salts

(i) Sulphur(IV)oxide(SO_2)

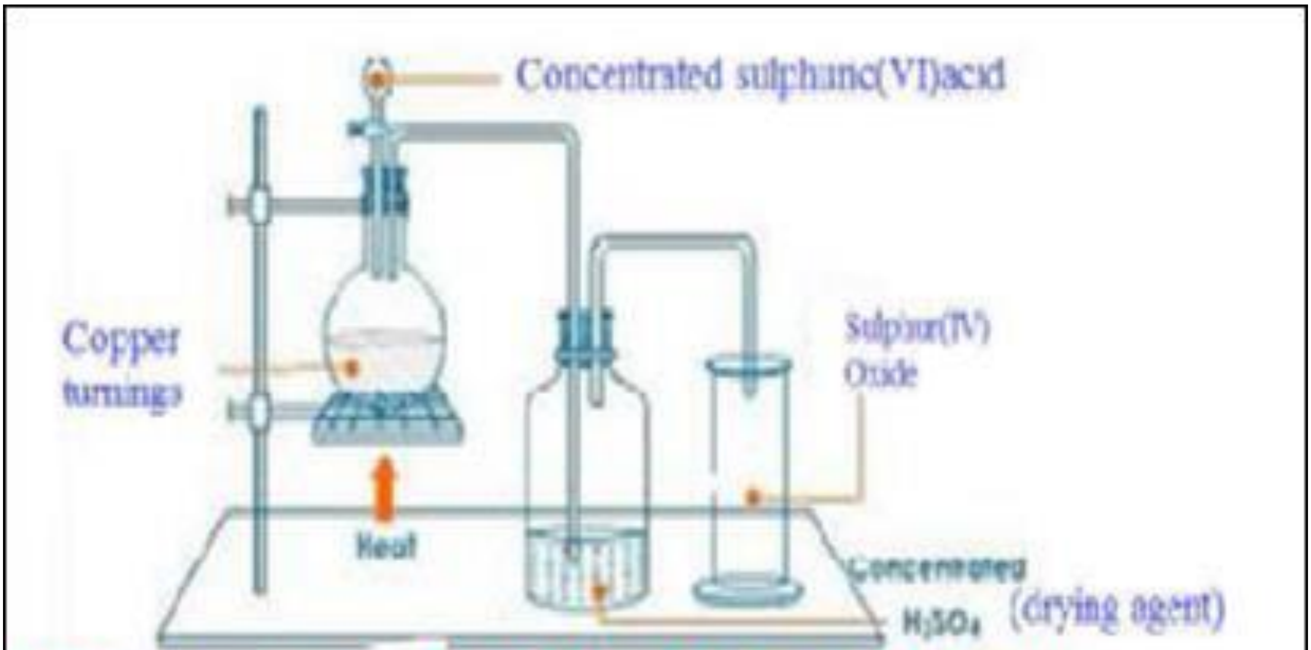
(a) Occurrence

Sulphur (IV)oxide is found in volcanic areas as a gas or dissolved in water from geysersand hot springs in active volcanic areas of the world e.g. Olkaria and Hells gate near Naivasha in Kenya.

(b) School laboratory preparation

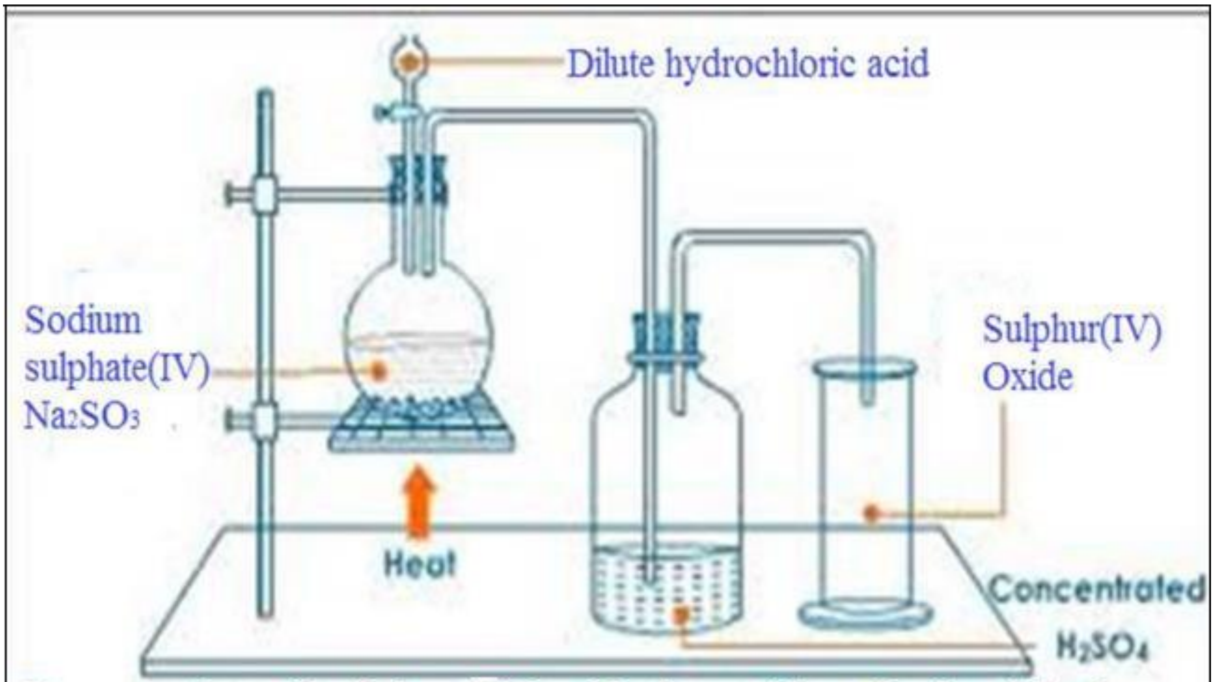
In a Chemistry school laboratory Sulphur (IV)oxide is prepared from the reaction of

<u>Method 1:Using Copper and Sulphuric(VI)acid.</u>



Preparation of sulphur(IV)oxide from Copper turnings and conc. Sulphuric(VI)acid

<u>Method 2:Using Sodium Sulphate(IV) and hydrochloric acid.</u>



Preparation of sulphur(IV)oxide from dilute hydrochloric acid and sodium sulphate(IV)

(c)Properties of Sulphur(IV)oxide(Questions)

1. Write the equations for the reaction for the formation of sulphur (IV)oxide using:
(i)Method 1

$Cu(s) + 2H_2SO_4(l) \rightarrow CuSO_4(aq) + SO_2(g) + 2H_2O(l)$
$Zn(s) + 2H_2SO_4(l) \rightarrow ZnSO_4(aq) + SO_2(g) + 2H_2O(l)$

$Mg(s) + 2H_2SO_4(l) \rightarrow MgSO_4(aq) + SO_2(g) + 2H_2O(l)$
$Fe(s) + 2H_2SO_4(l) \rightarrow FeSO_4(aq) + SO_2(g) + 2H_2O(l)$

Calcium ,Lead and Barium will form insoluble sulphate(VI)salts that will cover unreacted metals stopping further reaction thus producing very small amount/quantity of sulphur (IV)oxide gas.

(ii)Method 2

$Na_2SO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + SO_2(g) + 2H_2O(l)$
$K_2SO_3(aq) + HCl(aq) \rightarrow KCl(aq) + SO_2(g) + 2H_2O(l)$

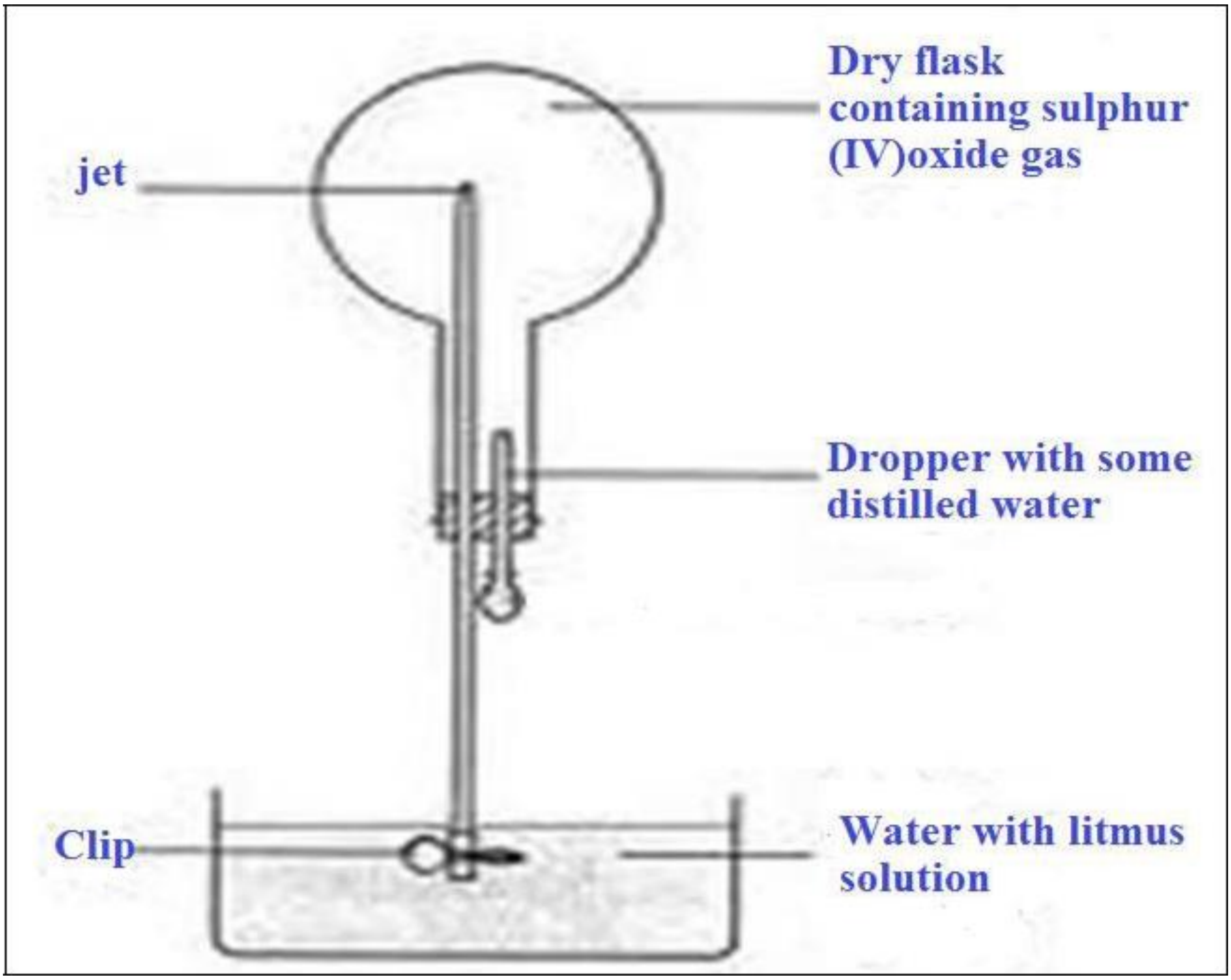
$BaSO_3(s) + 2HCl(aq) \rightarrow BaCl_2(aq) + SO_2(g) + H_2O(l)$
$CaSO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + SO_2(g) + H_2O(l)$
$PbSO_3(s) + 2HCl(aq) \rightarrow PbCl_2(\mathbf{s}) + SO_2(g) + H_2O(l)$

Lead(II)chloride is soluble on heating thus reactants should be heated to prevent it coating/covering unreacted $PbSO_3(s)$

2.State the physical properties unique to sulphur (IV)oxide gas.

Sulphur (IV)oxide gas is a colourless gas with a pungent irritating and choking smell which **liquidifies** easily. It is about two times denser than air.

3. The diagram below show the solubility of sulphur (IV)oxide gas. Explain.



Sulphur(IV) oxide is very soluble in water.

One drop of water dissolves all the Sulphur (IV) oxide in the flask leaving a vacuum.

If the clip is removed, atmospheric pressure forces the water up through the narrow tube to form a fountain to occupy the vacuum.

An acidic solution of sulphuric (IV)acid is formed which turns litmus solution red.

Chemical equation

$SO_2(g)$ + $H_2O(l)$ ->H_2SO_3 (aq) (sulphuric(IV)acid turn litmus red)

4.Dry litmus papers and wet/damp/moist litmus papers were put in a gas jar containing sulphur(IV) oxide gas. State and explain the observations made.

Observations

(i)Dry Blue litmus paper remains blue.

Dry red litmus paper remains red.

(ii) Wet/damp/moist blue litmus paper turns red.
Moist/damp/wet red litmus paper remains red. Both litmus papers are then bleached /decolorized.

Explanation

Dry sulphur(IV) oxide gas is a molecular compound that does not dissociate/ionize to release H+(aq)ions and thus has no effect on dry blue/red litmus papers.

Wet/damp/moist litmus papers contain water that dissolves /react with dry sulphur(IV) oxide gas to form a solution of weak sulphuric(IV)acid ($H_2 SO_3$ (aq)).

Weak sulphuric(IV)acid($H_2 SO_3$ (aq)) dissociates /ionizes into free H+(aq)ions:

$$H_2 SO_3 (aq) \rightarrow 2H^+(aq) + SO_3^{2-} (aq)$$

The free H^+(aq)ions are responsible for turning blue litmus paper turns red showing the gas is acidic.

The SO_3^{2-} (aq) ions in wet/damp/moist sulphur(IV) oxide gas is responsible for many reactions of the gas.

It is easily/readily oxidized to sulphate(VI) SO_4^{2-} (aq) ions making sulphur(IV)

(a)Bleaching agent

Wet/damp/moist coloured flowers/litmus papers are bleached/decolorized when put in sulphur(IV) oxide gas.

This is because sulphur(IV) oxide removes atomic oxygen from the coloured dye/ material to form sulphuric(VI)acid.

Chemical equations

(i)Formation of sulphuric(IV)acid

$$SO_2(g) + H_2O(l) \rightarrow H_2 SO_3 (aq)$$

(ii)Decolorization/bleaching of the dye/removal of atomic oxygen.

Method I. $H_2 SO_3$ (aq) + (dye + O) -> $H_2 SO_4$ (aq) + dye
(coloured) (colourless)

Method II. $H_2 SO_3$ (aq) + (dye) -> $H_2 SO_4$ (aq) + (dye - O)
(coloured) (colourless)

Sulphur(IV) oxide gas therefore bleaches by reduction /removing oxygen from a dye unlike chlorine that bleaches by oxidation /adding oxygen.
The bleaching by removing oxygen from Sulphur(IV) oxide gas is temporary.

This is because the bleached dye regains the atomic oxygen from the atmosphere/air in presence of sunlight as catalyst thus regaining/restoring its original colour. e.g.

Old newspapers turn brown on exposure to air on regaining the atomic oxygen.
The bleaching through adding oxygen by chlorine gas is permanent.

(b)Turns Orange acidified potassium dichromate(VI) to green

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing acidified potassium dichromate(VI) solution. or;

(ii)Dip a filter paper soaked in acidified potassium dichromate(VI) into a gas jar containing Sulphur(IV) oxide gas.

Observation:
Orange acidified potassium dichromate(VI) turns to green.

Explanation:
Sulphur(IV) oxide gas reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:
(i)Reaction of Sulphur(IV) oxide gas with water

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$$H_2SO_3(aq) \rightarrow 2H^+(aq) + SO_3^{2-}(aq)$$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of $Cr_2O_7^{2-}$(aq)

$$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$$

This is a **confirmatory** test for the presence of Sulphur(IV) oxide gas.

Hydrogen sulphide also reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions leaving a yellow residue.

(c)Decolorizes acidified potassium manganate(VII)

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing acidified potassium manganate(VII) solution. or;

(ii)Dip a filter paper soaked in acidified potassium manganate(VII) into a gas jar containing Sulphur(IV) oxide gas.

Observation:
Purple acidified potassium manganate(VII) turns to colourless/ acidified potassium manganate(VII) is decolorized.

Explanation:
Sulphur(IV) oxide gas reduces acidified potassium manganate(VII) from purple MnO_4^- ions to green Mn^{2+} ions without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:
(i)Reaction of Sulphur(IV) oxide gas with water

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$H_2SO_3(aq) \rightarrow 2H^+(aq) + SO_3^{2-}(aq)$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of MnO_4^- (aq)

$5SO_3^{2-}(aq) + 2MnO_4^-(aq) + 6H^+(aq) \rightarrow 5SO_4^{2-}(aq) + 2Mn^{2+}(aq) + 3H_2O(l)$
(purple) (colourless)

This is another test for the presence of Sulphur(IV) oxide gas.

Hydrogen sulphide also decolorizes acidified potassium manganate(VII) from purple MnO_4^- ions to colourless Mn^{2+} ions leaving a **yellow** residue.

(d)Decolorizes bromine water

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing bromine water . or;

(ii)Put three drops of bromine water into a gas jar containing Sulphur(IV) oxide gas. Swirl.

Observation:
Yellow bromine water turns to colourless/ bromine water is decolorized.

Explanation:

Sulphur(IV) oxide gas reduces yellow bromine water to colourless hydrobromic acid (HBr) without leaving a residue itself oxidized from SO_3^{2-} ions in sulphuric (IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:

(i)Reaction of Sulphur(IV) oxide gas with water

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$H_2SO_3(aq) \rightarrow 2H^+(aq) + SO_3^{2-}(aq)$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of MnO_4^- (aq)

$SO_3^{2-}(aq) + Br_2(aq) + H_2O(l) \rightarrow SO_4^{2-}(aq) + 2HBr(aq)$

(yellow) (colourless)

This can also be used as another test for the presence of Sulphur(IV) oxide gas.

Hydrogen sulphide also decolorizes yellow bromine water to colourless leaving a yellow residue.

(e)Reduces Iron(III) Fe^{3+} salts to Iron(II) salts Fe^{2+}

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing about 3 cm3 of Iron (III)chloride solution. or;

(ii)Place about 3cm3 of Iron (III)chloride solution into a gas jar containing Sulphur(IV) oxide gas.Swirl.

Observation:

Yellow/brown Iron (III)chloride solution turns to green

Explanation:

Sulphur(IV) oxide gas reduces Iron (III)chloride solution from yellow/brown Fe^{3+} ions to green Fe^{2+} ions without leaving a residue itself oxidized from SO_3^{2-}ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:

(i)Reaction of Sulphur(IV) oxide gas with water

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$

(ii)Dissociation /ionization of Sulphuric(IV)acid.

$H_2SO_3(aq) \rightarrow 2H^+(aq) + SO_3^{2-}(aq)$

(iii)Oxidation of SO_3^{2-} (aq)and reduction of Fe^{3+} (aq)

$SO_3^{2-}(aq) + 2Fe^{3+}(aq) + 3H_2O(l) \rightarrow SO_4^{2-}(aq) + 2Fe^{2+}(aq) + 2H^+(aq)$

(yellow) (green)

(f)Reduces Nitric(V)acid to Nitrogen(IV)oxide gas

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing about 3 cm3 of concentrated nitric(V)acid. or;

(ii)Place about 3cm3 of concentrated nitric(V)acid into a gas jar containing Sulphur(IV) oxide gas. Swirl.

Observation:

Brown fumes of a gas evolved/produced.

Explanation:

Sulphur(IV) oxide gas reduces concentrated nitric(V)acid to brown nitrogen(IV)oxide gas itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

Chemical/ionic equation:

$$SO_2(g) + 2HNO_3(l) \rightarrow H_2SO_4(l) + NO_2(g)$$

(brown fumes/gas)

(g)Reduces Hydrogen peroxide to water

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing about 3 cm3 of 20 volume hydrogen peroxide. Add four drops of Barium nitrate(V)or Barium chloride followed by five drops of 2M hydrochloric acid/ 2M nitric(V) acid.

Observation:

A white precipitate is formed that persist /remains on adding 2M hydrochloric acid/ 2M nitric(V) acid.

Explanation:

Sulphur(IV) oxide gas reduces 20 volume hydrogen peroxide and itself oxidized from SO_3^{2-} ions in sulphuric(IV) acid to SO_4^{2-} ions in sulphuric(VI) acid.

When Ba^{2+} ions in Barium Nitrate(V) or Barium chloride solution is added, a white precipitate of insoluble Barium salts is formed showing the presence of of either SO_3^{2-} ,SO_4^{2-} ,CO_3^{2-} ions. i.e.

Chemical/ionic equation:

$$SO_3^{2-}(aq) + Ba^{2+}(aq) \rightarrow BaSO_3(s)$$

white precipitate

$$SO_4^{2-}(aq) + Ba^{2+}(aq) \rightarrow BaSO_4(s)$$

white precipitate

$$CO_3^{2-}(aq) + Ba^{2+}(aq) \rightarrow BaCO_3(s)$$

white precipitate

If nitric(V)/hydrochloric acid is added to the three suspected insoluble white precipitates above, the white precipitate:

(i) persist/remains if SO_4^{2-}(aq)ions ($BaSO_4$(s)) is present.

(ii)dissolves if SO_3^{2-}(aq)ions ($BaSO_3$(s)) and CO_3^{2-}(aq)ions ($BaCO_3$(s))is present. This is because:

I. $BaSO_3$(s) reacts with Nitric(V)/hydrochloric acid to produce acidic SO_2 gas that turns Orange moist filter paper dipped in acidified Potassium dichromate to green.

Chemical equation

$BaSO_3(s) + 2H^+(aq) \rightarrow Ba^{2+}(aq) + SO_2(g) + H_2O(l)$

I. $BaCO_3$(s) reacts with Nitric(V)/hydrochloric acid to produce acidic CO_2 gas that forms a white precipitate when bubbled in lime water.

Chemical equation

$$BaCO_3(s) + 2H^+(aq) \rightarrow Ba^{2+}(aq) + CO_2(g) + H_2O(l)$$

5.Sulphur(IV)oxide also act as an oxidizing agent as in the following examples.

(a)Reduction by burning Magnesium

Experiment

Lower a burning Magnesium ribbon into agas jar containing Sulphur(IV)oxide gas

Observation

Magnesium ribbon continues to burn with difficulty.

White ash and yellow powder/speck

Explanation

Sulphur(IV)oxide does not support burning/combustion. Magnesium burns to produce enough heat energy to decompose Sulphur(IV)oxide to sulphur and oxygen.

The metal continues to burn on Oxygen forming white Magnesium oxide solid/ash.

Yellow specks of sulphur residue form on the sides of reaction flask/gas jar. During the reaction, Sulphur(IV)oxide is reduced(oxidizing agent)while the metal is oxidized (reducing agent)

Chemical equation

$SO_2(g) + 2Mg(s) \rightarrow 2MgO(s) + S(s)$

(white ash/solid) (yellow speck/powder)

(b)Reduction by Hydrogen sulphide gas

Experiment

Put two drops of water into a gas jar containing dry Sulphur(IV)oxide gas
Bubble hydrogen sulphide gas into the gas jar containing Sulphur(IV)oxide gas.
Or

Put two drops of water into a gas jar containing dry Sulphur(IV)oxide gas
Invert a gas jar full of hydrogen sulphide gas over the gas jar containing Sulphur(IV)oxide gas. Swirl

Observation

Yellow powder/speck

Explanation

Sulphur(IV)oxide oxidizes hydrogen sulphide to yellow specks of sulphur residue and itself reduced to also sulphur that form on the sides of reaction flask/gas jar.

A little moisture/water act as catalyst /speeds up the reaction.

Chemical equation

$SO_2(g) + 2H_2S(g) \rightarrow 2H_2O(l) + 3S(s)$

(yellow speck/powder)

6.Sulphur(IV)oxide has many industrial uses. State three.

(i)In the contact process for the manufacture of Sulphuric(VI)acid (ii)As a bleaching agent of pulp and paper.
(iii)As a fungicide to kill microbes'
(iv)As a preservative of jam, juices to prevent fermentation

(ii) Sulphur(VI)oxide(SO_3)

(a) Occurrence

Sulphur (VI)oxide is does not occur free in nature/atmosphere

(b) Preparation

In a Chemistry school laboratory Sulphur (VI)oxide may prepared from:

Method 1;**Catalytic oxidation of sulphur(IV)oxide gas**.

Sulphur(IV)oxide gas and oxygen mixture are first dried by being passed through Concentrated Sulphuric(VI)acid .

The dry mixture is then passed through platinised asbestos to catalyse/speed up the combination to form Sulphur (VI)oxide gas.

Sulphur (VI)oxide gas readily solidify as silky white needles if passed through a freezing mixture /ice cold water.

The solid fumes out on heating to a highly acidic poisonous gas.

Chemical equation

$2SO_2(g) + O_2(g)$ --platinised asbestos--> $2SO_3(g)$

Method 2; Heating Iron(II)sulphate(VI) heptahydrate

When green hydrated Iron(II)sulphate(VI) heptahydrate crystals are heated in a boiling tube ,it loses the water of crystallization and colour changes from green to white.

Chemical equation

$FeSO_4.7H_2O(s)$ -> $FeSO_4(s)$ + $7H_2O(l)$
(green solid) (white solid)

On further heating ,the white anhydrous Iron(II)sulphate(VI) solid decomposes to a mixture of Sulphur (VI)oxide and Sulphur (IV)oxide gas.

Sulphur (VI) oxide readily / easily solidify as white silky needles when the mixture is passed through a freezing mixture/ice cold water. Iron(III)oxide is left as a brown residue/solid.

Chemical equation

$2FeSO_4(s)$ -> $Fe_2O_3(s)$ + $SO_2(g)$ + $SO_3(g)$
(green solid) (brown solid)

Caution

On exposure to air Sulphur (VI)oxide gas produces highly corrosive poisonous fumes of concentrated sulphuric(VI)acid and thus its preparation in a school laboratory is very risky.

(c) Uses of sulphur(VI)oxide

One of the main uses of sulphur(VI)oxide gas is as an intermediate product in the contact process for industrial/manufacture/large scale/production of sulphuric(VI)acid.

(iii) Sulphuric(VI)acid(H_2SO_4)

(a) Occurrence

Sulphuric (VI)acid(H_2SO_4) is one of the three mineral acids. There are three mineral acids;

Nitric(V)acid
Sulphuric(VI)acid
Hydrochloric acid.

Mineral acids do not occur naturally but are prepared in a school laboratory and manufactured at industrial level.

(b)The Contact process for industrial manufacture of H_2SO_4 .

I. Raw materials

The main raw materials for industrial preparation of Sulphuric(VI)acid include:

(i)**Sulphur** from Fraschs process or from heating metal sulphide ore like Galena(PbS),Zinc blende(ZnS)

(ii)**Oxygen** from fractional distillation of air
(iii)**Water** from rivers/lakes

II. Chemical processes

The contact process involves four main chemical processes:

(i)Production of Sulphur (IV)oxide

As one of the raw materials, Sulphur (IV)oxide gas is got from the following sources;

I. Burning/roasting sulphur in air.

Sulphur from Fraschs process is roasted/burnt in air to form Sulphur (IV)oxide gas in the **burners**
Chemical equation

$$S(s) + O_2(g) \dashrightarrow SO_2(g)$$

II. Burning/roasting sulphide ores in air.

Sulphur (IV)oxide gas is produced as a by product in extraction of some metals like:

- Lead from Lead(II)sulphide/Galena,(PbS)
- Zinc from zinc(II)sulphide/Zinc blende, (ZnS)
- Copper from Copper iron sulphide/Copper pyrites, ($CuFeS_2$)

On roasting/burning, large amount /quantity of sulphur(IV)oxide is generated/produced.
Chemical equation

(i) $2PbS(s) + 3O_2(g) \rightarrow 2PbO(s) + 2SO_2(g)$
(ii) $2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$
(ii) $2CuFeS_2(s) + 4O_2(g) \rightarrow 2FeO(s) + 3SO_2(g) + Cu_2O(s)$

Sulphur(IV)oxide easily/readily liquefies and thus can be transported to a far distance safely.

(ii)Purification of Sulphur(IV)oxide

Sulphur(IV)oxide gas contain dust particles and Arsenic(IV)oxide as impurities. These impurities **"**poison**"**/impair the catalyst by adhering on/covering its surface.

The impurities are removed by electrostatic precipitation method .

In the contact process Platinum or Vanadium(V)oxide may be used.

Vanadium(V)oxide is preferred because it is :

(i) cheaper/less expensive

(ii) less easily poisoned by impurities

(iii)Catalytic conversion of Sulphur(IV)oxide to Sulphur(VI)oxide

Pure and dry mixture of Sulphur (IV)oxide gas and Oxygen is heated to 450^oC in a heat exchanger.

The heated mixture is passed through long pipes coated with pellets of Vanadium (V)oxide catalyst.

The close **"**contact**"** between the reacting gases and catalyst give the process its name.

Vanadium (V)oxide catalyse the conversion/oxidation of Sulphur(IV)oxide to Sulphur(VI)oxide gas.

<u>Chemical equation</u>

$$2SO_2\,(g) + O_2(g) \quad \text{-- } V_2O_5 \text{ -->} \quad 2SO_2\,(g)$$

This reaction is exothermic (**-ΔH) and the temperatures need to** be maintained at around 450^oC to ensure that:

(**i**)reaction rate/time taken for the formation of Sulphur(VI)oxide is not too **slow/long** at **lower** temperatures below 450^oC

(**ii**) Sulphur(VI)oxide gas does not **decompose** back to Sulphur(IV)oxide gas and Oxygen gas at **higher** temperatures than 450^oC.

(iv)Conversion of Sulphur(VI)oxide of Sulphuric(VI)acid

Sulphur(VI)oxide is the acid anhydride of concentrated Sulphuric(VI)acid. Sulphur(VI)oxide reacts with water to form thick mist of fine droplets of very/highly corrosive concentrated Sulphuric(VI)acid because the reaction is highly exothermic.

To prevent this, Sulphur (VI)oxide is a passed up to meet downward flow of 98% Sulphuric(VI)acid in the absorption chamber/tower.

The reaction forms a very **viscous oily** liquid called **Oleum/fuming Sulphuric (VI) acid/ pyrosulphuric (VI) acid.**

<u>Chemical equation</u>

$$H_2SO_4\,(aq) + SO_3\,(g) \quad \text{->} \quad H_2S_2O_7\,(l)$$

Oleum/fuming Sulphuric (VI) acid/ pyrosulphuric (VI) acid is diluted carefully with distilled water to give concentrated sulphuric (VI) acid .

Chemical equation

$H_2S_2O_7$ (l) + H_2O (l) -> $2H_2SO_4$ (l)

The acid is stored ready for market/sale.

III. Environmental effects of contact process

Sulphur(VI)oxide and Sulphur(IV)oxide gases are atmospheric pollutants that form acid rain if they escape to the atmosphere.

In the Contact process, about 2% of these gases do not form sulphuric (VI) acid.

The following precautions prevent/minimize pollution from Contact process:

(i)recycling back any unreacted Sulphur(IV)oxide gas back to the heat exchangers.

(ii)dissolving Sulphur(VI)oxide gas in concentrated sulphuric (VI) acid instead of water.

This prevents the formation of fine droplets of the corrosive/ toxic/poisonous fumes of concentrated sulphuric (VI) acid.

(iii)**scrubbing-**This involves passing the exhaust gases through very tall chimneys lined with quicklime/calcium hydroxide solid.

This reacts with Sulphur (VI)oxide gas forming harmless calcium(II)sulphate (IV) /$CaSO_3$

Chemical equation

$Ca(OH)_2$ (aq) + SO_2(g) --> $CaSO_3$ (aq) + H_2O (g)

IV. Uses of Sulphuric(VI)acid

Sulphuric (VI) acid is used:

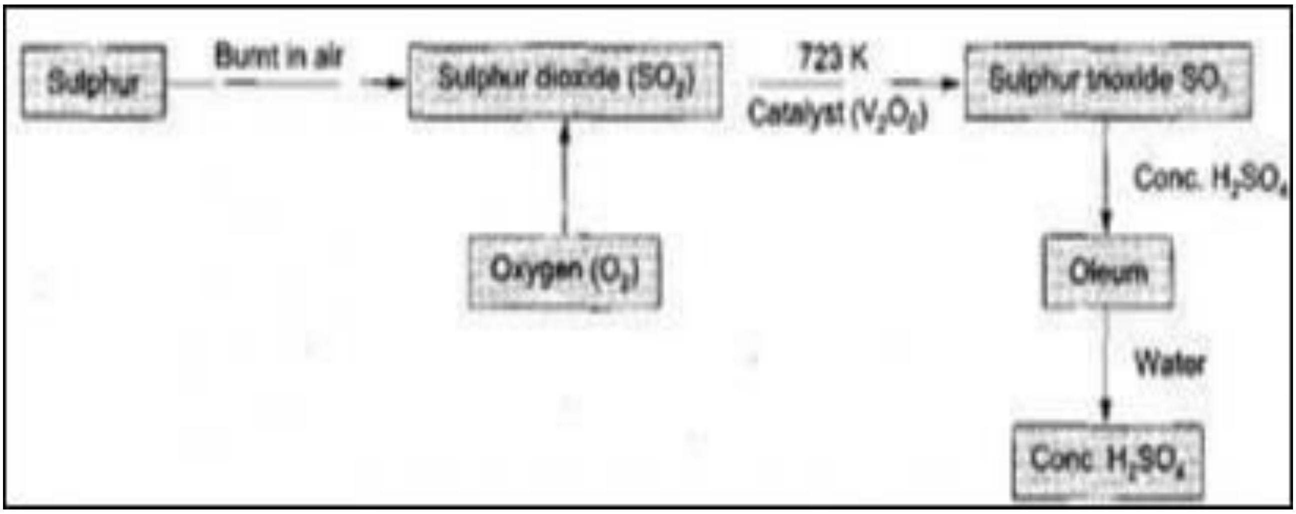
(i) in making dyes and paint

(ii)as acid in Lead-acid accumulator/battery

(iii) for making soapless detergents

(iv) for making sulphate agricultural fertilizers

VI. Sketch chart diagram showing the Contact process



(c) Properties of Concentrated sulphuric(VI)acid

(i)Concentrated sulphuric(VI)acid is a colourless oily liquid with a density of 1.84gcm^{-3}.It has a boiling point of 338^{o}C.

(ii) Concentrated sulphuric(VI)acid is very soluble in water.
The solubility /dissolution of the acid very highly exothermic.
The concentrated acid should thus be diluted slowly in excess water.
Water should never be added to the acid because the hot acid scatters highly corrosive fumes out of the container.

(iii) Concentrated sulphuric (VI)acid is a covalent compound. It has no free H^+ ions.
Free H^+ ions are responsible for turning the blue litmus paper red.
Concentrated sulphuric (VI) acid thus do not change the blue litmus paper red.

(iv) Concentrated sulphuric (VI)acid is hygroscopic. It absorbs water from the atmosphere and do not form a solution.
This makes concentrated sulphuric (VI) acid very suitable as drying agent during preparation of gases.
(v)The following are some **chemical properties** of concentrated sulphuric (VI) acid:

I. As a dehydrating agent

Experiment I;

Put about four spatula end fulls of brown sugar and glucose in separate 10cm3 beaker.
Carefully add about 10cm3 of concentrated sulphuric (VI) acid .Allow to stand for about 10 minutes.
Observation;
Colour(in brown sugar)change from brown to **black**.
Colour (in glucose) change from white to **black**.
10cm3 beaker becomes very hot.
Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.

It removes chemically and physically combined elements of water(Hydrogen and Oxygen in ratio 2:1)from compounds.

When added to sugar /glucose a vigorous reaction that is highly exothermic take place.

The sugar/glucose is **charred** to **black mass** of carbon because the acid dehydrates the sugar/glucose leaving carbon.

Caution

This reaction is highly exothermic that start slowly but produce fine particles of carbon that if inhaled cause quick suffocation by blocking the lung villi.

Chemical equation

Glucose: $C_6H_{12}O_6(s)$ --conc.H_2SO_4--> 6C (**s**) +6$H_2O(l)$
(white) (**black**)

Sugar: $C_{12}H_{22}O_{11}(s)$ --conc.H_2SO_4--> 12C (**s**) +11$H_2O(l)$
(brown) (**black**)

Experiment II;

Put about two spatula end full of hydrated copper(II)sulphate(VI)crystals in a boiling tube .Carefully add about 10cm3 of concentrated sulphuric (VI) acid .Warm .

Observation;

Colour change from blue to white.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.It removes physically combined elements of water(Hydrogen and Oxygen in ratio 2:1)from hydrated compounds.

The acid dehydrates blue copper(II)sulphate to white anhydrous copper(II)sulphate .

Chemical equation

$CuSO_4.5H_2O(s)$ --conc.H_2SO_4--> $CuSO_4$ (s) +5$H_2O(l)$
(blue) (white)

Experiment III;

Put about 4cm3 of absolute ethanol in a boiling tube .Carefully add about 10cm3 of concentrated sulphuric (VI) acid.

Place moist/damp/wet filter paper dipped in acidified potassium dichromate(VI)solution on the mouth of the boiling tube. Heat strongly. Caution:

Absolute ethanol is highly flammable.

Observation;

Colourless gas produced.

Orange acidified potassium dichromate (VI) paper turns to green.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.

It removes chemically combined elements of water(Hydrogen and Oxygen in ratio 2:1)from compounds.

The acid dehydrates ethanol to ethene gas at about $170^{o}C$.

Ethene with =C=C= double bond turns orange acidified potassium dichromate (VI) paper turns to green.

Chemical equation

$$C_2H_5OH(l) \text{ --conc.}H_2SO_4/170^{o}C \text{ --> } C_2H_4(g) + H_2O(l)$$

NB: This reaction is used for the school laboratory preparation of ethene gas

Experiment IV;

Put about 4cm3 of methanoic acid in a boiling tube .Carefully add about 6 cm3 of concentrated sulphuric (VI) acid. Heat gently

Caution:

This should be done in a fume chamber/open Observation;

Colourless gas produced.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent. It removes chemically combined elements of water (Hydrogen and Oxygen in ratio 2:1)from compounds.

The acid dehydrates methanoic acid to poisonous/toxic carbon(II)oxide gas.

Chemical equation

$$HCOOH(l) \text{ --conc.}H_2SO_4 \text{ --> } CO(g) + H_2O(l)$$

NB: This reaction is used for the school laboratory preparation of small amount carbon (II)oxide gas

Experiment V;

Put about 4cm3 of ethan-1,2-dioic/oxalic acid in a boiling tube .Carefully add about 6 cm3 of concentrated sulphuric (VI) acid. Pass any gaseous product through lime water.Heat gently

Caution:

This should be done in a fume chamber/open

Observation;

Colourless gas produced.

Gas produced forms a white precipitate with lime water.

Explanation

Concentrated sulphuric (VI) acid is strong dehydrating agent.

It removes chemically combined elements of water (Hydrogen and Oxygen in ratio 2:1)from compounds.

The acid dehydrates ethan-1,2-dioic/oxalic acid to a mixture of poisonous/toxic carbon(II)oxide and carbon(IV)oxide gases.

Chemical equation

$$HOOCCOOH(l) \xrightarrow{conc. H_2SO_4} CO(g) + CO_2(g) + H_2O(l)$$

NB: This reaction is also used for the school laboratory preparation of small amount carbon (II) oxide gas.

Carbon (IV) oxide gas is removed by passing the mixture through concentrated sodium/potassium hydroxide solution.

II. As an Oxidizing agent

Experiment I

Put about 2cm3 of Concentrated sulphuric (VI) acid into three separate boiling tubes. Place a thin moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution on the mouth of the boiling tube. Put about 0.5g of Copper turnings, Zinc granule and Iron filings to each boiling tube separately.

Observation;

Effervescence/fizzing/bubbles
Blue solution formed with copper,
Green solution formed with Iron
Colourless solution formed with Zinc
Colourless gas produced that has a pungent irritating choking smell.

Gas produced turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.

Explanation

Concentrated sulphuric (VI) acid is strong oxidizing agent.

It oxidizes metals to metallic sulphate(VI) salts and itself reduced to sulphur(IV)oxide gas.

Sulphur (IV) oxide gas turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.

$CuSO_4(aq)$ is a blue solution. $ZnSO_4(aq)$ is a colourless solution. $FeSO_4(aq)$ is a green solution.

Chemical equation

$$Cu(s) + 2H_2SO_4(aq) \rightarrow CuSO_4(aq) + SO_2(g) + 2H_2O(l)$$
$$Zn(s) + 2H_2SO_4(aq) \rightarrow ZnSO_4(aq) + SO_2(g) + 2H_2O(l)$$
$$Fe(s) + 2H_2SO_4(aq) \rightarrow FeSO_4(aq) + SO_2(g) + 2H_2O(l)$$

Experiment II

Put about 2cm3 of Concentrated sulphuric (VI) acid into two separate boiling tubes. Place a thin moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution on the mouth of the boiling tube.
Put about 0.5g of powdered charcoal and sulphur powder to each boiling tube separately.
Warm.

Observation;

Black solid charcoal dissolves/decrease
Yellow solid sulphur dissolves/decrease
Colourless gas produced that has a pungent irritating choking smell.
Gas produced turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.

Explanation

Concentrated sulphuric (VI) acid is strong oxidizing agent. It oxidizes non-metals to non metallic oxides and itself reduced to sulphur(IV)oxide gas. Sulphur (IV) oxide gas turn orange moist/damp/wet filter paper dipped in acidified potassium dichromate (VI)solution to green.
Charcoal is oxidized to carbon(IV)oxide. Sulphur is oxidized to Sulphur(IV)oxide .

Chemical equation

$C(s) + 2H_2SO_4(aq) \rightarrow CO_2(aq) + 2SO_2(g) + 2H_2O(l)$
$S(s) + 2H_2SO_4(aq) \rightarrow 3SO_2(g) + 2H_2O(l)$

III. As the least volatile acid

Study the table below showing a comparison in boiling points of the three mineral acids

Mineral acid	Relative molecula mass	Boiling point(^oC)
Hydrochloric acid(HCl)	36.5	35.0
Nitric(V)acid(HNO_3)	63.0	83.0
Sulphuric(VI)acid(H_2SO_4)	98.0	333

1.Which is the least volatile acid? Explain

Sulphuric(VI)acid(H_2SO_4) because it has the largest molecule and joined by Hydrogen bonds making it to have the highest boiling point/least volatile.

2. Using chemical equations, explain how sulphuric(VI)acid displaces the less volatile mineral acids.

(i)Chemical equation

$KNO_3(s) + H_2SO_4(aq) \rightarrow KHSO_4(l) + HNO_3(g)$
$NaNO_3(s) + H_2SO_4(aq) \rightarrow NaHSO_4(l) + HNO_3(g)$

This reaction is used in the school laboratory preparation of Nitric(V) acid (HNO_3).

(ii)Chemical equation

$$KCl(s) + H_2SO_4(aq) \rightarrow KHSO_4(s) + HCl(g)$$
$$NaCl(s) + H_2SO_4(aq) \rightarrow NaHSO_4(s) + HCl(g)$$

This reaction is used in the school laboratory **preparation** of Hydrochloric acid (HCl).

(d) Properties of dilute sulphuric(VI)acid.

Dilute sulphuric(VI)acid is made when about 10cm3 of concentrated sulphuric (VI) acid is carefully added to about 90cm3 of distilled water.

Diluting concentrated sulphuric (VI) acid should be done carefully because the reaction is highly exothermic.

Diluting concentrated sulphuric (VI) acid decreases the number of moles present in a given volume of solution which makes the acid less corrosive.

On diluting concentrated sulphuric(VI) acid, water ionizes /dissociates the acid fully/wholly into two(**dibasic**)free $H^+(aq)$ and $SO_4^{2-}(aq)$ions:

$$H_2SO_4(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$$

The presence of free $H^+(aq)$ions is responsible for ;

(**i**)turn litmus red because of the presence of free $H^+(aq)$ions

(ii)have pH 1/2/3 because of the presence of many free $H^+(aq)$ions hence a strongly acidic solution.

(iii)Reaction with metals

Experiment:

Place 5cm3 of 0.2M dilute sulphuric(VI)acid into four separate clean test tubes. Add about 0.1g of Magnesium ribbon to one test tube. Cover the mixture with a finger as stopper. Introduce a burning splint on top of the finger and release the finger "stopper". Repeat by adding Zinc, Copper and Iron instead of the Magnesium ribbon.

Observation:

No effervescence/ bubbles/ fizzing with copper

Effervescence/ bubbles/ fizzing with Iron ,Zinc and Magnesium

Colourless gas produced that extinguishes burning splint with a "pop" sound.

Colourless solution formed with Zinc and Magnesium.

Green solution formed with Iron

Explanation:

When a metal higher than hydrogen in the reactivity/electrochemical series is put in a test tube containing dilute sulphuric(VI)acid, effervescence/ bubbling/ fizzing takes place with evolution of Hydrogen gas.

Impure hydrogen gas extinguishes burning splint with a “pop” sound.

A sulphate (VI) salts is formed. Iron, Zinc and Magnesium are higher than hydrogen in the reactivity/electrochemical series.

They form Iron (II)sulphate(VI), Magnesium sulphate(VI) and Zinc sulphate(VI).

. When a metal lower than hydrogen in the reactivity/electrochemical series is put in a test tube containing dilute sulphuric(VI)acid, there is no effervescence/ bubbling/ fizzing that take place.

Copper thus do not react with dilute sulphuric(VI)acid.

Chemical/ionic equation

$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$

$Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$

$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$

$Fe(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$

$Fe(s) + H^+(aq) \rightarrow Fe^{2+}(aq) + H_2(g)$

NB:(i) Calcium,Lead and Barium forms insoluble sulphate(VI)salts that cover/coat the unreacted metals.

(ii)Sodium and Potassium react explosively with dilute sulphuric(VI)acid

(**iv**)Reaction with metal carbonates and hydrogen carbonates

Experiment:

Place 5cm3 of 0.2M dilute sulphuric(VI)acid into four separate clean boiling tubes. Add about 0.1g of sodium carbonate to one boiling tube. Introduce a burning splint on top of the boiling tube. Repeat by adding Zinc carbonate, Copper (II)carbonate and Iron(II)Carbonate in place of the sodium hydrogen carbonate.

Observation:

Effervescence/ bubbles/ fizzing.

Colourless gas produced that extinguishes burning splint.

Colourless solution formed with Zinc carbonate, sodium hydrogen carbonate and sodium carbonate.

Green solution formed with Iron(II)Carbonate

Blue solution formed with Copper(II)Carbonate

Explanation:

When a metal carbonate or a hydrogen carbonates is put in a test tube containing dilute sulphuric(VI)acid, effervescence/ bubbling/ fizzing takes place with evolution of carbon(IV)oxide gas. carbon(IV)oxide gas extinguishes a burning splint and forms a white precipitate when bubbled in lime water.

A sulphate (VI) salts is formed.

Chemical/ionic equation

$ZnCO_3(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2O(l) + CO_2(g)$

$ZnCO_3(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O(l) + CO_2(g)$

$CuCO_3(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l) + CO_2(g)$

$CuCO_3(s) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l) + CO_2(g)$

$FeCO_3(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2O(l) + CO_2(g)$

$FeCO_3(s) + 2H^+(aq) \rightarrow Fe^{2+}(aq) + H_2O(l) + CO_2(g)$

$2NaHCO_3(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$

$NaHCO_3(s) + H^+(aq) \rightarrow Na^+(aq) + H_2O(l) + CO_2(g)$

$Na_2CO_3(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l) + CO_2(g)$

$NaHCO_3(s) + H^+(aq) \rightarrow Na^+(aq) + H_2O(l) + CO_2(g)$

$(NH_4)_2CO_3(s) + H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq) + H_2O(l) + CO_2(g)$

$(NH_4)_2CO_3(s) + H^+(aq) \rightarrow NH_4^+(aq) + H_2O(l) + CO_2(g)$

$2NH_4HCO_3(aq) + H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq) + H_2O(l) + CO_2(g)$

$NH_4HCO_3(aq) + H^+(aq) \rightarrow NH_4^+(aq) + H_2O(l) + CO_2(g)$

NB:

Calcium, Lead and Barium carbonates forms insoluble sulphate(VI)salts that cover/coat the unreacted metals.

(v)Neutralization-reaction of metal oxides and alkalis/bases

Experiment I:

Place 5cm3 of 0.2M dilute sulphuric(VI)acid into four separate clean boiling tubes. Add about 0.1g of copper(II)oxide to one boiling tube. Stir. Repeat by adding Zinc oxide, calcium carbonate and Sodium (II)Oxide in place of the Copper(II)Oxide.

Observation:

Blue solution formed with Copper(II)Oxide

Colourless solution formed with other oxides

Explanation:

When a metal oxide is put in a test tube containing dilute sulphuric(VI)acid, the oxide dissolves forming a sulphate (VI) salt.

Chemical/ionic equation

$ZnO(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2O(l)$

$ZnO(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O(l)$

$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$
$CuO(s) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l)$

$MgO(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l)$
$MgO(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2O(l)$

$Na_2O(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$
$Na_2O(s) + 2H^+(aq) \rightarrow 2Na^+(aq) + H_2O(l)$

$K_2CO_3(s) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + H_2O(l)$
$K_2O(s) + H^+(aq) \rightarrow 2K^+(aq) + H_2O(l)$

NB:
Calcium, Lead and Barium oxides forms insoluble sulphate(VI)salts that cover/coat the unreacted metals oxides.

Experiment II:
Fill a burette wuth 0.1M dilute sulphuric(VI)acid. Pipette 20.0cm3 of 0.1Msodium hydroxide solution into a 250cm3 conical flask. Add three drops of phenolphthalein indicator.Titrate the acid to get a permanent colour change.Repeat with0.1M potassium hydroxide solution inplace of 0.1Msodium hydroxide solution

Observation:

Colour of phenolphthalein changes from pink to colourless at the end point.

Explanation

Like other (mineral) acids dilute sulphuric(VI)acid neutralizes bases/alkalis to a sulphate salt and water only.
Colour of the indicator used changes when a slight excess of acid is added to the base at the end point
Chemical equation:

$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$
$OH^-(s) + H^+(aq) \rightarrow H_2O(l)$

$2KOH(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + H_2O(l)$
$OH^-(s) + H^+(aq) \rightarrow H_2O(l)$

$2NH_4OH(aq) + H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq) + H_2O(l)$
$OH^-(s) + H^+(aq) \rightarrow H_2O(l)$

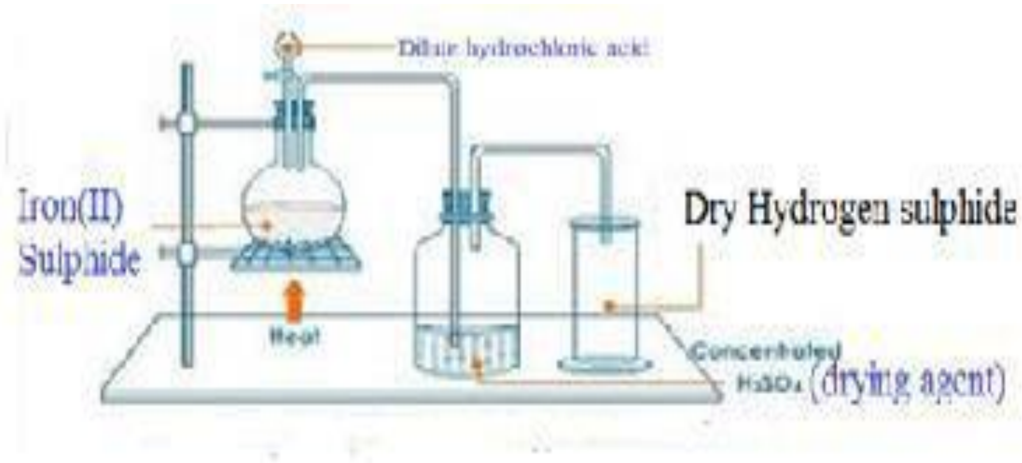
(iv) Hydrogen sulphide(H_2S)

(a) Occurrence

Hydrogen sulphide is found in volcanic areas as a gas or dissolved in water from geysers and hot springs in active volcanic areas of the world e.g. Olkaria and Hells gate near Naivasha in Kenya.
It is present in rotten eggs and human excreta.

(b) Preparation

Hydrogen sulphide is prepared in a school laboratory by heating Iron (II) sulphide with dilute hydrochloric acid.



(c) Properties of Hydrogen sulphide(Questions)

1. Write the equation for the reaction for the school laboratory preparation of Hydrogen sulphide.

Chemical equation: $FeS (s) + 2HCl (aq) \rightarrow H_2S (g)\ FeCl_2 (aq)$

2. State three physical properties unique to Hydrogen sulphide. Hydrogen sulphide is a colourless gas with characteristic pungent poisonous smell of rotten eggs. It is soluble in cold water but insoluble in warm water. It is denser than water and turns blue litmus paper red.

3. Hydrogen sulphide exist as a dibasic acid when dissolved in water. Using a chemical equation show how it ionizes in aqueous state.

$$H_2S(aq) \rightarrow H^+(aq) + HS^-(aq)$$

$$H_2S(aq) \rightarrow \mathbf{2}H^+(aq) + S^{2-}(aq)$$

Hydrogen sulphide therefore can form both normal and acid salts e.g
Sodium hydrogen sulphide and sodium sulphide both exist

4. State and explain one gaseous impurity likely to be present in the gas jar containing hydrogen sulphide above.

Hydrogen/ H_2

Iron(II)sulphide contains Iron as impurity .The iron will react with dilute hydrochloric acid to form iron(II)chloride and produce hydrogen gas that mixes with hydrogen sulphide gas.

5. State and explain the observations made when a filter paper dipped in Lead(II) ethanoate /Lead (II) nitrate(V) solution is put in a gas jar containing hydrogen sulphide gas.

Observations

Moist Lead(II) ethanoate /Lead (II) nitrate(V) paper turns black.

Explanation

When hydrogen sulphide is bubbled in a metallic salt solution, a metallic sulphide is formed.

All sulphides are insoluble black salts except sodium sulphide, potassium sulphide and ammonium sulphides.

Hydrogen sulphide gas blackens moist Lead (II) ethanoate /Lead (II) nitrate(V) paper .

The gas reacts with Pb^{2+} in the paper to form black Lead(II)sulphide.

This is the chemical test for the presence of H_2S other than the physical smell of rotten eggs.

Chemical equations

$$Pb^{2+}(aq) + H_2S \rightarrow PbS \text{ (black)} + 2H^+(aq)$$

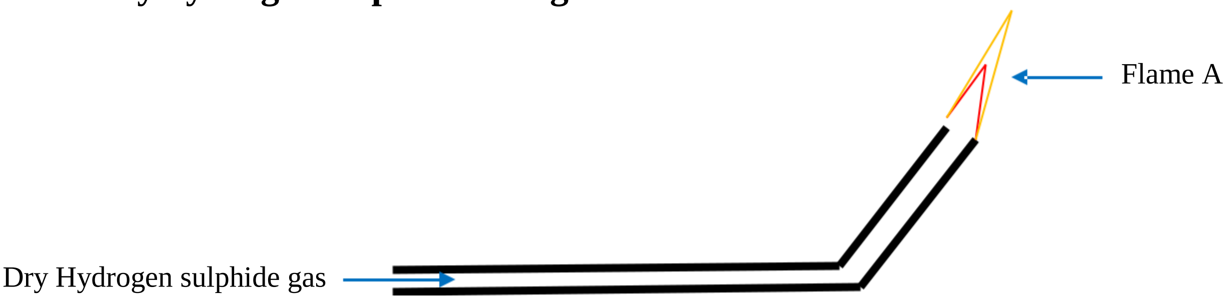
$$Fe^{2+}(aq) + H_2S \rightarrow FeS \text{ (black)} + 2H^+(aq)$$

$$Zn^{2+}(aq) + H_2S \rightarrow ZnS \text{ (black)} + 2H^+(aq)$$

$$Cu^{2+}(aq) + H_2S \rightarrow CuS \text{ (black)} + 2H^+(aq)$$

$2Cu^{+}(aq) + H_2S \rightarrow Cu_2S + 2H^{+}(aq)$

6. Dry hydrogen sulphide was ignited as below.



(i) State the observations made in flame A

Hydrogen sulphide burns in excess air with a blue flame to form sulphur(IV)oxide gas and water.

Chemical equation: $2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$

Hydrogen sulphide burns in limited air with a blue flame to form sulphur solid and water.

Chemical equation: $2H_2S(g) + O_2(g) \rightarrow 2H_2O(l) + 2S(s)$

7. Hydrogen sulphide is a strong reducing agent that is oxidized to yellow solid sulphur as precipitate. The following experiments illustrate the reducing properties of Hydrogen sulphide.

(a)Turns Orange acidified potassium dichromate(VI) to green

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing acidified potassium dichromate (VI) solution. or;

(ii)Dip a filter paper soaked in acidified potassium dichromate (VI) into a gas jar containing Hydrogen sulphide gas.

Observation:

Orange acidified potassium dichromate (VI) turns to green.

Yellow solid residue.

Explanation:

Hydrogen sulphide gas reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions leaving a yellow solid residue as itself is oxidized to sulphur.

Chemical/ionic equation:

$4H_2S(aq) + Cr_2O_7^{2-}(aq) + 6H^{+}(aq) \rightarrow 4S(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$

This test is used for differentiating Hydrogen sulphide and sulphur (IV)oxide gas.

Sulphur(IV)oxide also reduces acidified potassium dichromate(VI) from orange $Cr_2O_7^{2-}$ ions to green Cr^{3+} ions without leaving a yellow residue.

(b)Decolorizes acidified potassium manganate(VII)

Experiment:

(i)Pass a stream of Sulphur(IV) oxide gas in a test tube containing acidified potassium manganate(VII) solution. or;

(ii)Dip a filter paper soaked in acidified potassium manganate(VII) into a gas jar containing Hydrogen Sulphide gas.

Observation:

Purple acidified potassium manganate(VII) turns to colourless/ acidified potassium manganate(VII) is decolorized. Yellow solid residue.

Explanation:

Hydrogen sulphide gas reduces acidified potassium manganate(VII) from purple MnO_4^- ions to green Mn^{2+} ions leaving a residue as the gas itself is oxidized to sulphur.

Chemical/ionic equation:

$5H_2S(g) + 2MnO_4^-(aq) + 6H^+(aq) \rightarrow 5S(s) + 2Mn^{2+}(aq) + 8H_2O(l)$

(purple) (colourless)

This is another test for differentiating Hydrogen sulphide and Sulphur(IV) oxide gas.

Sulphur(IV) oxide also decolorizes acidified potassium manganate(VII) from purple MnO_4^- ions to colourless Mn^{2+} ions leaving no yellow residue.

(c)Decolorizes bromine water

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing bromine water . or;

(ii)Put three drops of bromine water into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:

Yellow bromine water turns to colourless/ bromine water is decolorized. Yellow solid residue

Explanation:

Hydrogen sulphide gas reduces yellow bromine water to colourless hydrobromic acid (HBr) leaving a yellow residue as the gas itself is oxidized to sulphur.

Chemical/ionic equation:

$H_2S(g) + Br_2(aq) \rightarrow S(s) + 2HBr(aq)$

(yellow solution) (yellow solid) (colourless)

This is another test for differentiating Hydrogen sulphide and Sulphur(IV) oxide gas.

Sulphur(IV) oxide also decolorizes acidified potassium manganate(VII) from purple MnO_4^- ions to colourless Mn^{2+} ions leaving no yellow residue.

3+ 2+ (d)Reduces Iron(III) Fe salts to Iron(II) salts Fe

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of Iron (III)chloride solution. or;

(ii)Place about 3cm3 of Iron (III)chloride solution into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:

Yellow/brown Iron (III)chloride solution turns to green.

Yellow solid solid

Explanation:

Hydrogen sulphide gas reduces Iron (III)chloride solution from yellow/brown Fe^{3+} ions to green Fe^{2+} ions leaving a yellow residue.The gas is itself oxidized to sulphur.

Chemical/ionic equation:

$H_2S(aq) + 2Fe^{3+}(aq) \rightarrow S(s) + Fe^{2+}(aq) + 2H^+(aq)$

(yellow solution) (yellow residue) (green)

(e)Reduces Nitric(V)acid to Nitrogen(IV)oxide gas

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of concentrated nitric(V)acid. or;

(ii)Place about 3cm3 of concentrated nitric(V)acid into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:

Brown fumes of a gas evolved/produced.

Yellow solid residue

Explanation:

Hydrogen sulphide gas reduces concentrated nitric(V)acid to brown nitrogen(IV)oxide gas itself oxidized to yellow sulphur.

Chemical/ionic equation:

$H_2S(g) + 2HNO_3(l) \rightarrow 2H_2O(l) + S(s) + 2NO_2(g)$

(yellow residue) (brown fumes)

(f)Reduces sulphuric(VI)acid to Sulphur

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of concentrated sulphuric(VI)acid. or;

(ii)Place about 3cm3 of concentrated sulphuric (VI) acid into a gas jar containing Hydrogen sulphide gas. Swirl.

Observation:

Yellow solid residue

Explanation:

Hydrogen sulphide gas reduces concentrated sulphuric(VI)acid to yellow sulphur.

Chemical/ionic equation:

$3H_2S(g) + H_2SO_4(l) \rightarrow 4H_2O(l) + 4S(s)$

(yellow residue)

(g)Reduces Hydrogen peroxide to water

Experiment:

(i)Pass a stream of Hydrogen sulphide gas in a test tube containing about 3 cm3 of 20 volume hydrogen peroxide.

Observation:

Yellow solid residue

Explanation:

Hydrogen sulphide gas reduces 20 volume hydrogen peroxide to water and itself oxidized to yellow sulphur

Chemical/ionic equation:

$H_2S(g) + H_2O_2(l) \rightarrow 2H_2O(l) + S(s)$

(yellow residue)

8.Name the salt formed when:

(i)equal volumes of equimolar hydrogen sulphide neutralizes sodium hydroxide solution:

Sodium hydrogen sulphide

Chemical/ionic equation:

$H_2S(g) + NaOH(l) \rightarrow H_2O(l) + NaHS(aq)$

(ii) hydrogen sulphide neutralizes excess concentrated sodium hydroxide solution:

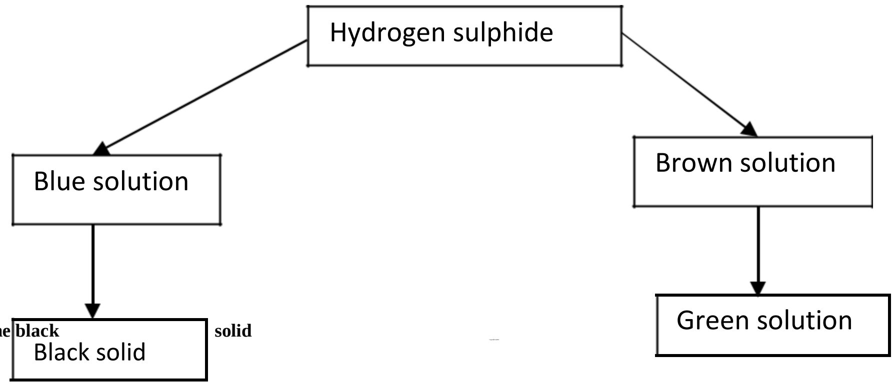
Sodium sulphide

Chemical/ionic equation:

$H_2S(g) + 2NaOH(l) \rightarrow 2H_2O(l) + Na_2S(aq)$

Practice

Hydrogen sulphide gas was bubbled into a solution of metallic nitrate(V)salts as in the flow chart below



(a)Name the black solid

(b)Identify the cation responsible for the formation of:

I. Blue solution $Cu^{2+}(aq)$

II. Green solution $Fe^{2+}(aq)$

III. Brown solution $Fe^{3+}(aq)$

(c)Using acidified potassium dichromate(VI) describe how you would differentiate between sulphur(IV)Oxide and hydrogen sulphide

-Bubble the gases in separate test tubes containing acidified Potassium dichromate(VI) solution.

-Both changes the Orange colour of acidified Potassium dichromate(VI) solution to green.

-Yellow solid residue/deposit is formed with Hydrogen sulphide

Chemical/ionic equation:

$4H_2S(aq) + Cr_2O_7^{2-}(aq) + 6H^+(aq) \rightarrow 4S(aq) + 2Cr^{3+}(aq) + 7H_2O(l)$

$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$

(d)State and explain the observations made if a burning splint is introduced at the mouth of a hydrogen sulphide generator.

Observation Gas continues burning with a blue flame

Explanation: Hydrogen sulphide burns in excess air with a blue flame to form sulphur(IV)oxide gas and water.

Chemical equation: $2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$

(v)Sulphate (VI) (SO_4^{2-})and Sulphate(IV) (SO_3^{2-}) salts

1. Sulphate (VI) (SO_4^{2-}) salts are normal and acid salts derived from Sulphuric (VI)acid H_2SO_4.
2. Sulphate(IV) (SO_3^{2-}) salts are normal and acid salts derived from Sulphuric (IV)acid H_2SO_3.
3. Sulphuric (VI)acid H_2SO_4 is formed when sulphur(VI)oxide gas is bubbled in water.

The acid exist as a dibasic acid with two ionisable hydrogen. It forms therefore the Sulphate (VI) (SO_4^{2-}) and hydrogen sulphate (VI) (HSO_4^-) salts.
i.e.

H_2SO_4 (aq) -> $2H^+$(aq) + SO_4^{2-}(aq)
H_2SO_4 (aq) -> H^+(aq) + HSO_4^-(aq)

All Sulphate (VI) (SO_4^{2-}) salts **dissolve** in water/are soluble except Calcium (II) sulphate (VI) ($CaSO_4$), Barium (II) sulphate (VI) ($BaSO_4$) and Lead (II)

All Hydrogen sulphate (VI) (HSO_3^-) salts **exist** in solution/dissolved in water. Sodium (I) hydrogen sulphate (VI) ($NaHSO_4$), Potassium (I) hydrogen sulphate (VI) ($KHSO_4$) and Ammonium hydrogen sulphate (VI) (NH_4HSO_4) exist also as solids.
Other Hydrogen sulphate (VI) (HSO_4^-) salts do not **exist** except those of Calcium (II) hydrogen sulphate (VI) ($Ca(HSO_4)_2$) and Magnesium (II) hydrogen sulphate (VI) ($Mg(HSO_4)_2$).

4. Sulphuric (IV)acid H_2SO_3 is formed when sulphur(IV)oxide gas is bubbled in water.

The acid exist as a dibasic acid with two ionisable hydrogen. It forms therefore the Sulphate (IV) (SO_3^{2-}) and hydrogen sulphate (VI) (HSO_4^-) salts.
i.e.

H_2SO_3 (aq) -> $2H^+$(aq) + SO_3^{2-}(aq)

H_2SO_3 (aq) -> H^+(aq) + HSO_3^-(aq)

All Sulphate (IV) (SO_3^{2-}) salts **dissolve** in water/are soluble except Calcium (II) sulphate (IV) ($CaSO_3$), Barium (II) sulphate (IV) ($BaSO_3$) and Lead (II)

All Hydrogen sulphate (IV) (HSO_3^-) salts **exist** in solution/dissolved in water. Sodium (I) hydrogen sulphate (IV) ($NaHSO_3$), Potassium (I) hydrogen sulphate (IV) ($KHSO_3$) and Ammonium hydrogen sulphate (IV) (NH_4HSO_3) exist also as solids.
Other Hydrogen sulphate (IV) (HSO_3^-) salts do not **exist** except those of Calcium (II) hydrogen sulphate (IV) ($Ca(HSO_3)_2$) and Magnesium (II) hydrogen sulphate (IV) ($Mg(HSO_3)_2$).

5.The following experiments show the effect of heat on sulphate(VI) (SO_4^{2-})and sulphate(IV) (SO_3^{2-}) salts:

Experiment:
In a clean dry test tube place separately about 1.0g of :

Zinc(II)sulphate (VI), Iron(II)sulphate(VI), Copper(II)sulphate(VI),Sodium (I) sulphate (VI), Sodium (I) sulphate (IV).Heat gently then strongly. Test any gases produced using litmus papers.

Observations:

-Colourless droplets of liquid forms on the cooler parts of the test tube in all cases.

-White solid residue is left in case of Zinc (II)sulphate(VI),Sodium (I) sulphate (VI) and Sodium (I) sulphate (IV).

-Colour changes from green to brown /yellow in case of Iron (II)sulphate(VI)
-Colour changes from blue to white then black in case of Copper (II) sulphate (VI)

-Blue litmus paper remain and blue and red litmus paper remain red in case of Zinc(II)sulphate(VI), Sodium (I) sulphate (VI) and Sodium (I) sulphate (IV) -Blue litmus paper turns red and red litmus paper remain red in case of Iron (II)sulphate(VI) and Copper (II) sulphate (VI).

Explanation
(i)All Sulphate (VI) (SO_4^{2-}) salts exist as **hydrated** salts with water of crystallization that condenses and collects on cooler parts of test tube as a colourless liquid on gentle heating. e.g.

$K_2SO_4.10H_2O(s)$ -> $K_2SO_4(s)$ + $10H_2O(l)$
$Na_2SO_4.10H_2O(s)$ -> $Na_2SO_4(s)$ + $10H_2O(l)$
$MgSO_4.7H_2O(s)$ -> $MgSO_4(s)$ + $7H_2O(l)$
$CaSO_4.7H_2O(s)$-> $CaSO_4(s)$ + $7H_2O(l)$
$ZnSO_4.7H_2O(s)$ -> $ZnSO_4(s)$ + $7H_2O(l)$
$FeSO_4.7H_2O(s)$ -> $FeSO_4(s)$ + $7H_2O(l)$
$Al_2(SO_4)_3.6H_2O(s)$ -> $Al_2(SO_4)_3$ (s) + $6H_2O(l)$

$CuSO_4.5H_2O(s)$ -> $CuSO_4(s)$ + $5H_2O(l)$

All Sulphate (VI) (SO_4^{2-}) salts do not decompose on heating **except** Iron (II) sulphate (VI) and Copper (II) sulphate (VI).

(i)Iron (II) sulphate (VI) decomposes on strong heating to produce acidic sulphur (IV)oxide and sulphur(VI)oxide gases. Iron(III)oxide is formed as a brown /yellow residue.

Chemical equation

$2FeSO_4$ (s) -> Fe_2O_3(s) + SO_2(g) + SO_3(g)

This reaction is used for the school laboratory preparation of small amount of sulphur(VI)oxide gas.

Sulphur (VI) oxide readily /easily solidifies as white silky needles when the mixture is passed through freezing mixture/ice cold water. Sulphur (IV) oxide does not.

(ii) Copper(II)sulphate(VI) decomposes on strong heating to black copper (II) oxide and Sulphur (VI) oxide gas.

Chemical equation

$2CuSO_4$ (s) ->CuO(s) + SO_3(g)

This reaction is used for the school laboratory preparation of small amount of sulphur(VI)oxide gas.

6. The following experiments show the test for the presence of sulphate (VI) (SO_4^{2-})and sulphate(IV) (SO_3^{2-}) ions in a sample of a salt/compound:

Experiments/Observations:

(a)Using Lead(II)nitrate(V)

I. To about 5cm3 of a salt solution in a test tube add four drops of Lead(II)nitrate(V)solution. Preserve.

Observation	Inference
White precipitate/ppt	SO_4^{2-}, SO_3^{2-}, CO_3^{2-}, Cl^- ions

II. To the preserved sample in (I) above, add six drops of 2M nitric(V) acid . Preserve.

Observation 1

Observation	Inference
White precipitate/ppt persists	SO_4^{2-}, Cl^- ions

Observation 2

Observation	Inference
White precipitate/ppt dissolves	SO_3^{2-}, CO_3^{2-}, ions

III.(a)To the preserved sample observation 1 in (II) above, Heat to boil.

Observation 1

Observation	Inference
White precipitate/ppt persists on boiling	SO_4^{2-} ions

Observation 2

Observation	Inference
White precipitate/ppt dissolves on boiling	Cl^- ions

.(b)To the preserved sample observation 2 in (II) above, add 4 drops of acidified potassium manganate(VII) /dichromate(VI).

Observation 1

Observation	Inference
(i)acidified potassium manganate(VII)decolorized (ii)Orange colour of acidified potassium dichromate(VI) turns to green	SO_3^{2-} ions

Observation 2

Observation	Inference
(i)acidified potassium manganate(VII) not decolorized (ii)Orange colour of acidified potassium dichromate(VI) does not turns to green	CO_3^{2-} ions

Experiments/Observations:

(b)Using Barium(II)nitrate(V)/ Barium(II)chloride

I. To about 5cm3 of a salt solution in a test tube add four drops of Barium(II) nitrate (V) / Barium(II)chloride. Preserve.

Observation	Inference
White precipitate/ppt	SO_4^{2-} , SO_3^{2-} , CO_3^{2-} ions

II. To the preserved sample in (I) above, add six drops of 2M nitric(V) acid . Preserve.

Observation 1

Observation	Inference
White precipitate/ppt persists	SO_4^{2-} , ions

Observation 2

Observation	Inference
White precipitate/ppt dissolves	SO_3^{2-} , CO_3^{2-} , ions

III.To the preserved sample observation 2 in (II) above, add 4 drops of acidified potassium manganate(VII) /dichromate(VI).

Observation 1

Observation	Inference
(i)acidified potassium manganate(VII)decolorized (ii)Orange colour of acidified potassium dichromate(VI) turns to green	SO_3^{2-} ions

Observation 2

Observation	Inference
(i)acidified potassium manganate(VII) not decolorized (ii)Orange colour of acidified potassium dichromate(VI) does not turns to green	CO_3^{2-} ions

Explanations

Using Lead(II)nitrate(V)

(i)Lead(II)nitrate(V) solution reacts with chlorides(Cl^-), Sulphate (VI) salts (SO_4^{2-}), Sulphate (IV)salts (SO_3^{2-}) and carbonates(CO_3^{2-}) to form the insoluble white precipitate of Lead(II)chloride, Lead(II)sulphate(VI), Lead(II) sulphate (IV) and Lead(II)carbonate(IV).

Chemical/ionic equation:

$$Pb^{2+}(aq) \quad + \quad Cl^-(aq) \quad -> \quad PbCl_2(s)$$
$$Pb^{2+}(aq) \quad + \quad SO_4^{2+}(aq) \quad -> \quad PbSO_4(s)$$
$$Pb^{2+}(aq) \quad + \quad SO_3^{2+}(aq) \quad -> \quad PbSO_3(s)$$
$$Pb^{2+}(aq) \quad + \quad CO_3^{2+}(aq) \quad -> \quad PbCO_3(s)$$

(ii)When the insoluble precipitates are acidified with nitric(V) acid,

- Lead(II)chloride and Lead(II)sulphate(VI) do not react with the acid and thus their white precipitates remain/ persists.

- Lead(II) sulphate (IV) and Lead(II)carbonate(IV) reacts with the acid to form **soluble** Lead(II) nitrate (V) and produce/effervesces/fizzes/bubbles out **sulphur(IV)oxide** and **carbon(IV)oxide** gases respectively.

. Chemical/ionic equation:

$PbSO_3 (s) + 2H^+(aq) \rightarrow H_2O (l) + Pb^{2+}(aq) + SO_2 (g)$

$PbCO_3 (s) + 2H^+(aq) \rightarrow H_2O (l) + Pb^{2+}(aq) + CO_2 (g)$

(iii)When Lead(II)chloride and Lead(II)sulphate(VI) are heated/warmed;

- Lead(II)chloride dissolves in hot water/on boiling(recrystallizes on cooling)

- Lead(II)sulphate(VI) do not dissolve in hot water thus its white precipitate persists/remains on heating/boiling.

(iv)When sulphur(IV)oxide and carbon(IV)oxide gases are produced;

- **sulphur(IV)oxide** will decolorize acidified potassium manganate(VII) and / or Orange colour of acidified potassium dichromate(VI) will turns to green. **Carbon(IV)oxide will not.**

Chemical equation:

$5SO_3^{2-}(aq) + 2MnO_4^- (aq) + 6H^+(aq) \rightarrow 5SO_4^{2-}(aq) + 2Mn^{2+}(aq) + 3H_2O(l)$
(purple) (colourless)

$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$
(Orange) (green)

- **Carbon(IV)oxide** forms an insoluble white precipitate of calcium carbonate if three drops of lime water are added into the reaction test tube when effervescence is taking place. **Sulphur(IV)oxide will not.**

Chemical equation:

$Ca(OH)_2(aq) + CO_2 (g) \rightarrow CaCO_3(s) + H_2O(l)$

These tests should be done immediately after acidifying to ensure the gases produced react with the oxidizing agents/lime water.

Using Barium(II)nitrate(V)/ Barium(II)Chloride

(i)Barium(II)nitrate(V) and/ or Barium(II)chlo**ride** solution reacts with Sulphate (VI) salts (SO_4^{2-}), Sulphate (IV)salts (SO_3^{2-}) and carbonates(CO_3^{2-}) to form the insoluble white precipitate of Barium(II)sulphate(VI), Barium(II) sulphate (IV) and Barium(II)carbonate(IV).

Chemical/ionic equation:

$Ba^{2+}(aq)$ + $SO_4^{2+}(aq)$ -> $BaSO_4(s)$

$Ba^{2+}(aq)$ + $SO_3^{2+}(aq)$ -> $BaSO_3(s)$

$Ba^{2+}(aq)$ + $CO_3^{2+}(aq)$ -> $BaCO_3(s)$

(ii)When the insoluble precipitates are acidified with nitric(V) acid,

- Barium (II)sulphate(VI) do not react with the acid and thus its white precipitates remain/ persists.

- Barium(II) sulphate (IV) and Barium(II)carbonate(IV) reacts with the acid to form **soluble** Barium(II) nitrate (V) and produce /effervesces /fizzes/ bubbles out **sulphur(IV)oxide** and **carbon(IV)oxide** gases respectively.

. Chemical/ionic equation:

$BaSO_3(s)$ + $2H^+(aq)$ -> $H_2O(l)$ + $Ba^{2+}(aq)$ + $SO_2(g)$

$BaCO_3(s)$ + $2H^+(aq)$ -> $H_2O(l)$ + $Ba^{2+}(aq)$ + $CO_2(g)$

(iii) When sulphur(IV)oxide and carbon(IV)oxide gases are produced;

- **sulphur(IV)oxide** will decolorize acidified potassium manganate(VII) and / or Orange colour of acidified potassium dichromate(VI) will turns to green. **Carbon(IV)oxide will not.**

Chemical equation:

$5SO_3^{2-}(aq)$ + $2MnO_4^-(aq)$ +6H+(aq) -> $5SO_4^{2-}(aq)$ + $2Mn^{2+}(aq)$ + $3H_2O(l)$
(purple) (colourless)

$3SO_3^{2-}(aq)$ + $Cr_2O_7^{2-}(aq)$ +8H+(aq) -> $3SO_4^{2-}(aq)$ + $2Cr^{3+}(aq)$ + $4H_2O(l)$
(Orange) (green)

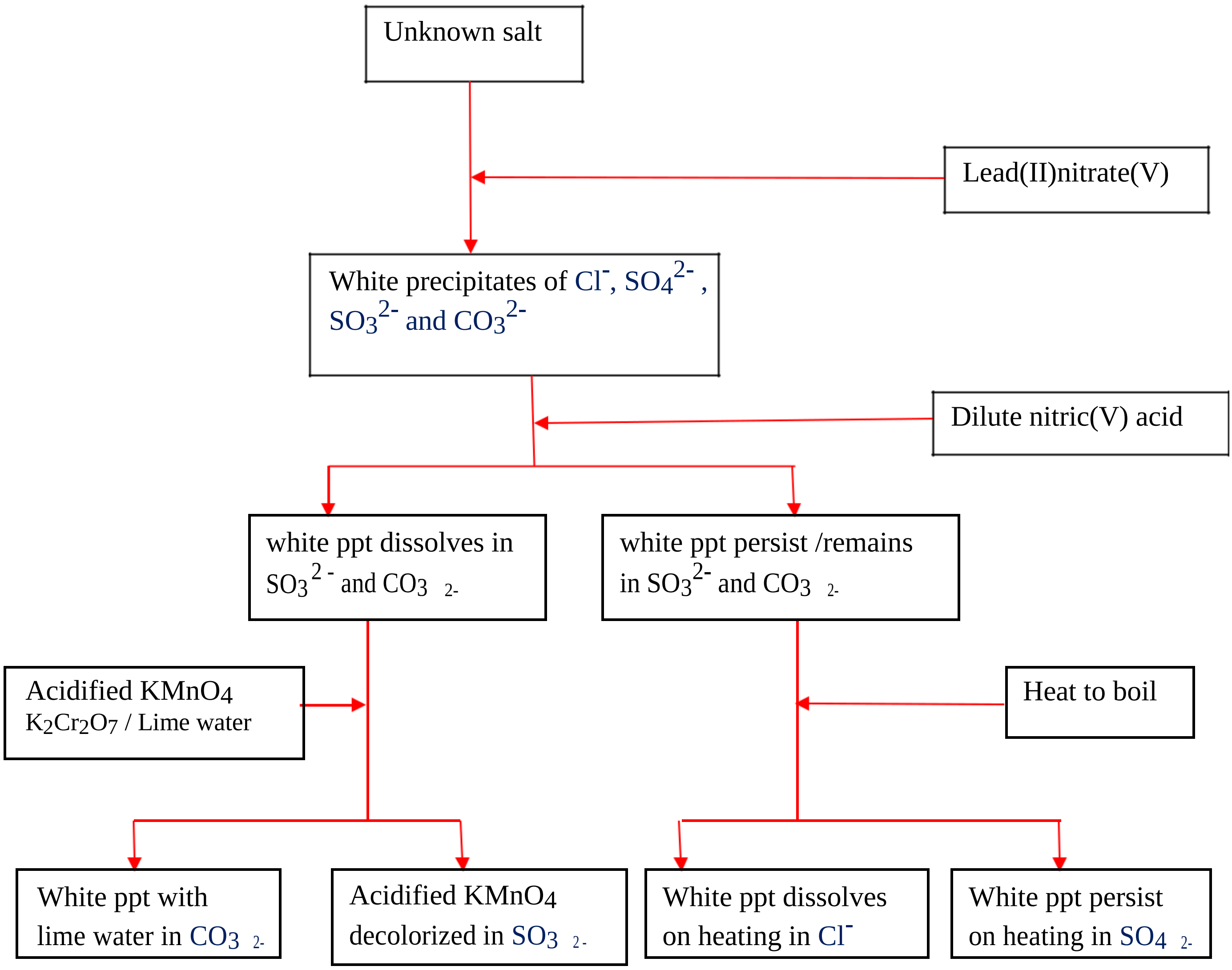
- **Carbon(IV)oxide** forms an insoluble white precipitate of calcium carbonate if three drops of lime water are added into the reaction test tube when effervescence is taking place. **Sulphur(IV)oxide will not.**

Chemical equation:

$Ca(OH)_2(aq)$ + $CO_2(g)$ -> $CaCO_3(s)$ + $H_2O(l)$

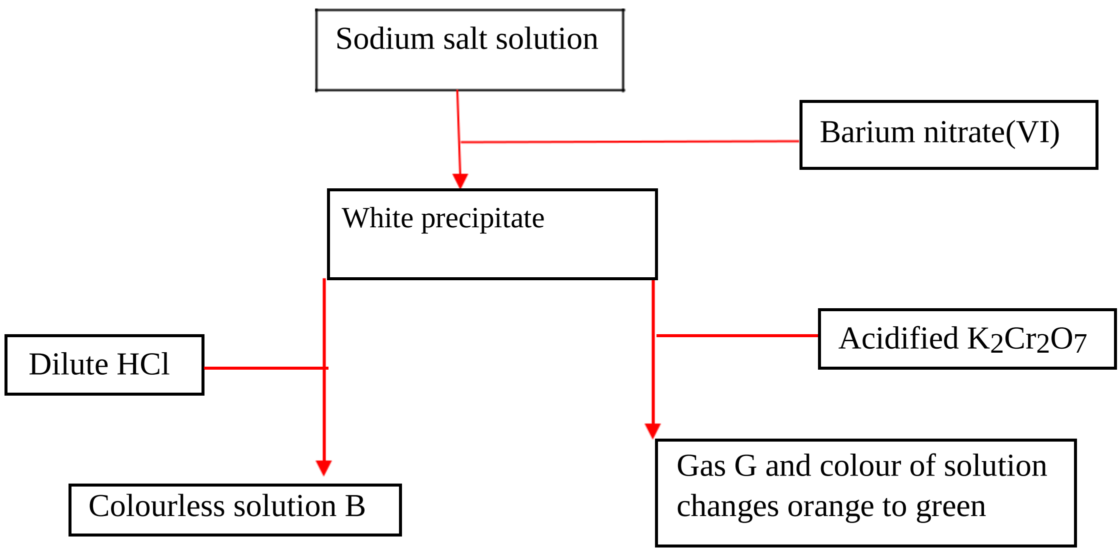
These tests should be done immediately after acidifying to ensure the gases produced react with the oxidizing agents/lime water.

Summary test for Sulphate (VI) (SO_4^{2-})and Sulphate(IV) (SO_3^{2-}) salts



Practice revision question

1. Study the flow chart below and use it to answer the questions that follow



(a)**Identify the:**

I: Sodium salt solution

Sodium sulphate(IV)/Na_2SO_3

II: White precipitate

Barium sulphate(IV)/$BaSO_3$

III: Gas G

Sulphur (IV)Oxide /SO_2

IV: Colourless solution H

Barium chloride /$BaCl_2$

(b)**Write an ionic equation for the formation of:**

I.White precipitate

Ionic equation $Ba^{2+}(aq) + SO_3^{2-}(aq) \rightarrow BaSO_3(s)$

II.Gas G

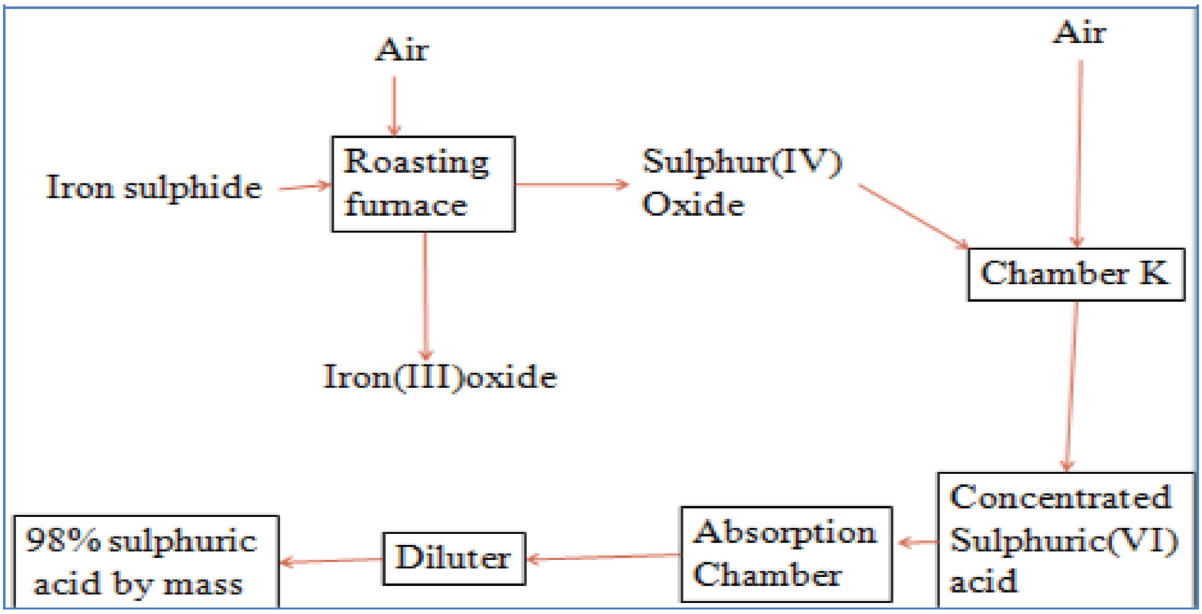
Ionic equation $BaSO_3(s) + 2H^+(aq) \rightarrow SO_2(g) + H_2O(l) + Ba^{2+}(aq)$

III. Green solution from the orange solution

$3SO_3^{2-}(aq) + Cr_2O_7^{2-}(aq) + 8H^+(aq) \rightarrow 3SO_4^{2-}(aq) + 2Cr^{3+}(aq) + 4H_2O(l)$

(Orange) (green)

2. Study the flow chart below and answer the questions that follow.



(i)Write equation for the reaction taking place at:

I.The roasting furnace (1mk)

$2FeS_2$ (s) + $5O_2$ (g) -> 2FeO(s) + $4SO_2$ (g)

II.The absorption tower (1mk)

H_2SO_4 (l) + SO_3 (g) -> $H_2S_2O_7$(l)

III.The diluter (1mk)

$H_2S_2O_7$(l) + H_2 O(l) -> $2H_2SO_4$ (l)

(ii)The reaction taking place in chamber K is

$SO_{2\,(g)} + {}^{1}/{}_{2}O_{2\,(g)} \rightleftharpoons SO_{3\,(g)}$

I. Explain why it is necessary to use excess air in chamber K

To ensure all the SO_2 reacts

II.Name another substance used in chamber K

Vanadium(V)oxide

3.(a)Describe a chemical test that can be used to differentiate between sodium sulphate (IV) and sodium sulphate (VI).

Add acidified Barium nitrate(V)/chloride.
White precipitate formed with sodium sulphate (VI)
No white precipitate formed with sodium sulphate (IV)

(b)Calculate the volume of sulphur (IV) oxide formed when 120 kg of copper is reacted with excess concentrated sulphuric(VI)acid.(Cu = 63.5 ,1 mole of a gas at s.t.p =22.4dm3)

Chemical equation
Cu(s) + $2H_2SO_4$(l) -> $CuSO_4$(aq)+ H_2O(l) + SO_2 (g)
Mole ratio Cu(s: SO_2 (g) = 1:1

Method 1
1 Mole Cu =63.5 g -> 1 mole SO_2 = 22.4dm3
(120 x 1000) g -> $\frac{(120 \times 1000)\text{ g} \times 22.4\text{.dm3})}{63.5\text{ g}}$

= **42330.7087**

Method 2

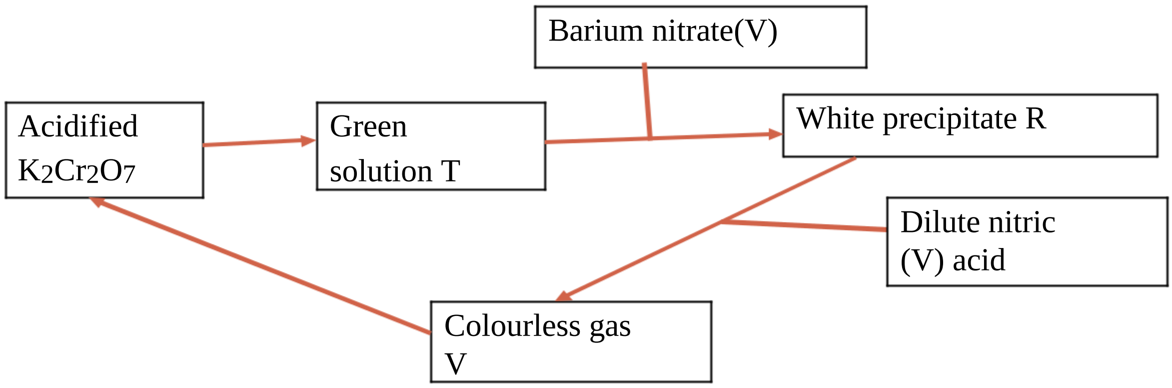
Moles of Cu = $\frac{(120 \times 1000)\ g}{63.5}$ = **1889.7639** moles

Moles SO_2 = Moles of Cu = **1889.7639** moles

Volume of SO_2 = Mole x molar gas volume = (1889.7639 moles x 22.4)

= **42330.7114**

4.Use the reaction scheme below to answer the questions that follow.



(a)Identify the:

(i)cation responsible for the green solution T

$\mathbf{Cr^{3+}}$

(ii)possible anions present in white precipitate R

$\mathbf{CO_3^{2-}}$, $\mathbf{SO_3^{2-}}$, $\mathbf{SO_4^{2-}}$

(b)Name gas V

Sulphur (IV)oxide

(c)Write a possible ionic equation for the formation of white precipitate R.

$\mathbf{Ba^{2+}(aq) + CO_3^{2-}(aq) \rightarrow BaCO_3(s)}$

$\mathbf{Ba^{2+}(aq) + SO_3^{2-}(aq) \rightarrow BaSO_3(s)}$

$\mathbf{Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)}$