18.0.0 ACIDS, BASES AND SALTS

(25 LESSONS)

A.ACIDS AND BASES

At a school laboratory:
(i)An acid may be defined as a substance that turn litmus red.
(ii)A base may be defined as a substance that turn litmus blue.
Litmus is a lichen found mainly in West Africa. It changes its colour depending on whether the solution it is in, is basic/alkaline or acidic.It is thus able to identify/show whether

1. An acid is a substance that dissolves in water to form H^+/H_3O^+ as the only positive ion/cation. This is called the **Arrhenius definition** of an acid. From this definition, an acid dissociate/ionize in water releasing H^+ thus:

$\mathbf{H}Cl(aq) \rightarrow \mathbf{H}^+(aq) + Cl^-(aq)$
$\mathbf{H}NO_3(aq) \rightarrow \mathbf{H}^+(aq) + NO_3^-(aq)$
$CH_3COO\mathbf{H}(aq) \rightarrow \mathbf{H}^+(aq) + CH_3COO^-(aq)$
$\mathbf{H_2}SO_4(aq) \rightarrow 2\mathbf{H}^+(aq) + SO_4^{2-}(aq)$
$\mathbf{H_2}CO_3(aq) \rightarrow 2\mathbf{H}^+(aq) + CO_3^{2-}(aq)$
$\mathbf{H_3}PO_4(aq) \rightarrow 3\mathbf{H}^+(aq) + PO_4^{3-}(aq)$

2.A base is a substance which dissolves in water to form OH^- as the only negatively charged ion/anion.
This is called Arrhenius definition of a base.
From this definition, a base dissociate/ionize in water releasing OH^- thus:

$KOH(aq) \rightarrow K^+(aq) + OH^-(aq)$
$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$
$NH_4OH(aq) \rightarrow NH_4^+(aq) + OH^-(aq)$
$Ca(OH)_2(aq) \rightarrow Ca^{2+}(aq) + 2OH^-(aq)$
$Mg(OH)_2(aq) \rightarrow Mg^{2+}(aq) + 2OH^-(aq)$

3. An acid is a proton donor.
A base is a proton acceptor.
This is called Bronsted-Lowry definition of acids and bases.

From this definition, an acid donates H^+ .
H^+ has no electrons and neutrons .It contains only a proton.

Examples

I. From the equation:

$$\mathbf{H}Cl(aq) \quad + \quad H_2O(l) \quad \rightleftharpoons \quad H_3O^+(aq) \quad + \quad Cl^-(aq)$$

(a)(i)For the forward reaction from left to right, H_2O gains a proton to form H_3O^+ and thus H_2O is a proton **acceptor** .It is a **Bronsted-Lowry base**

(ii) For the backward reaction from right to left, H_3O^+ donates a proton to form H_2O and thus H_3O^+ is an 'opposite' proton **donor**. It is a **Bronsted-Lowry conjugate acid**

(b)(i)For the forward reaction from left to right, HCl donates a proton to form Cl^- and thus HCl is a proton **donor** .
It is a **Bronsted-Lowry acid**

(ii) For the backward reaction from right to left, Cl^- gains a proton to form HCl and thus Cl^- is an 'opposite' proton **acceptor**.
It is a **Bronsted-Lowry conjugate base.**

Every base /acid from Bronsted-Lowry definition thus must have a conjugate product/reactant.

II. From the equation:

$$\mathbf{H}Cl(aq) \quad + \quad NH_3(aq) \quad \rightleftharpoons \quad NH_4^+(aq) \quad + \quad Cl^-(aq)$$

(a)(i)For the forward reaction from left to right, NH_3 gains a proton to form NH_4^+ and thus NH_3 is a proton **acceptor** .
It is a **Bronsted-Lowry base**

(ii) For the backward reaction from right to left, NH_4^+ donates a proton to form NH_3 and thus NH_4^+ is an 'opposite' proton **donor**.
It is a **Bronsted-Lowry conjugate acid**

(b)(i)For the forward reaction from left to right, HCl donates a proton to form Cl^- and thus HCl is a proton **donor** .
It is a **Bronsted-Lowry acid**

(ii) For the backward reaction from right to left, Cl^- gains a proton to form HCl and thus Cl^- is an 'opposite' proton **acceptor**.
It is a **Bronsted-Lowry conjugate base**.

4. Acids and bases show acidic and alkaline properties/characteristics only in **water** but not in other solvents e.g.

(a)Hydrogen chloride gas dissolves in water to form hydrochloric acid Hydrochloric acid dissociates/ionizes in water to free $H^+(aq)/H_3O^+(aq)$ ions. The free $H_3O^+(aq)$ / $H^+(aq)$ ions are responsible for:

(i)turning blue litmus paper/solution red.
(ii)show pH value 1/2/3/4/5/6
(iii)are good electrolytes/conductors of electricity/undergo electrolysis.

(iv)react with metals to produce /evolve hydrogen gas and a salt. i.e.
Ionically:
-For a monovalent metal: $2M(s) + 2H^+(aq) \rightarrow 2M^+(aq) + H_2(g)$
-For a divalent metal: $M(s) + 2H^+(aq) \rightarrow M^{2+}(aq) + H_2(g)$
-For a trivalent metal: $2M(s) + 6H^+(aq) \rightarrow 2M^{3+}(aq) + 3H_2(g)$

Examples:
-For a monovalent metal: $2Na(s) + 2H^+(aq) \rightarrow 2Na^+(aq) + H_2(g)$
-For a divalent metal: $Ca(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2(g)$
-For a trivalent metal: $2Al(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2(g)$

(v)react with metal carbonates and hhydrogen carbonates to produce /evolve carbon(IV)oxide gas ,water and a salt. i.e.
Ionically:
-For a monovalent metal: $M_2CO_3(s) + 2H^+(aq) \rightarrow 2M^+(aq) + H_2O(l) + CO_2(g)$
$MHCO_3(s) + H^+(aq) \rightarrow M^+(aq) + H_2O(l) + CO_2(g)$

-For a divalent metal: $MCO_3(s) + 2H^+(aq) \rightarrow M^{2+}(aq) + H_2O(l) + CO_2(g)$
$M(HCO_3)_2(\mathbf{aq}) + 2H^+(aq) \rightarrow M^{2+}(aq) + 2H_2O(l) + 2CO_2(g)$

Examples:
-For a monovalent metal: $K_2CO_3(s) + 2H^+(aq) \rightarrow 2K^+(aq) + H_2O(l) + CO_2(g)$
$NH_4HCO_3(s) + H^+(aq) \rightarrow NH_4^+(aq) + H_2O(l) + CO_2(g)$

-For a divalent metal: $ZnCO_3(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O(l) + CO_2(g)$
$Mg(HCO_3)_2(\mathbf{aq}) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + 2H_2O(l) + 2CO_2(g)$

(vi)neutralize metal oxides/hydroxides to salt and water only. i.e.
Ionically:
-For a monovalent metal: $M_2O(s) + 2H^+(aq) \rightarrow 2M^+(aq) + H_2O(l)$
$MOH(\mathbf{aq}) + H^+(aq) \rightarrow M^+(aq) + H_2O(l)$

-For a divalent metal: $MO(s) + 2H^+(aq) \rightarrow M^{2+}(aq) + H_2O\ (l)$
$M(OH)_2(s) + 2H^+(aq) \rightarrow M^{2+}(aq) + 2H_2O(l)$

-For a trivalent metal: $M_2O_3(s) + 6H^+(aq) \rightarrow 2M^{3+}(aq) + 3H_2O\ (l)$
$M(OH)_3(s) + 3H^+(aq) \rightarrow M^{3+}(aq) + 3H_2O(l)$

Examples:
-For a monovalent metal: $K_2O(s) + 2H^+(aq) \rightarrow 2K^+(aq) + H_2O\ (l)$
$NH_4OH(aq) + H^+(aq) \rightarrow NH_4^+(aq) + H_2O\ (l)$

-For a divalent metal: $ZnO\ (s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O\ (l)$
$Pb(OH)_2(s) + 2H^+(aq) \rightarrow Pb^{2+}(aq) + 2H_2O(l)$

(b)Hydrogen chloride gas dissolves in methylbenzene /benzene but does not dissociate /ionize into free ions.
It exists in molecular state showing none of the above properties.

(c)Ammonia gas dissolves in water to form aqueous ammonia which dissociate/ionize to free NH_4^+ (aq) and OH^-(aq) ions.
This dissociation/ionization makes aqueous ammonia to:

(i)turn litmus paper/solution blue.

(ii)have pH 8/9/10/11

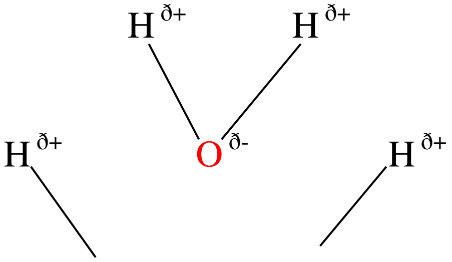
(iii)be a good electrical conductor

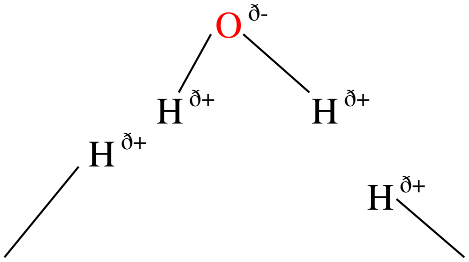
(iv)react with acids to form ammonium salt and water only.

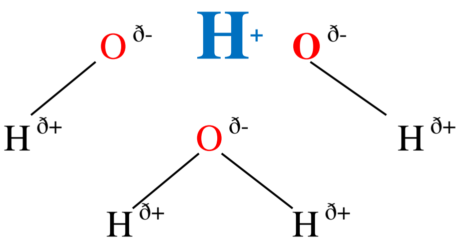
$$NH_4OH(aq) + HCl(aq) \rightarrow NH_4Cl(aq) + H_2O(l)$$

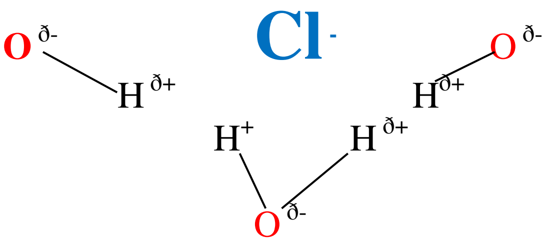
(d)Ammonia gas dissolves in methylbenzene/benzene /kerosene but does not dissociate into free ions therefore existing as molecules

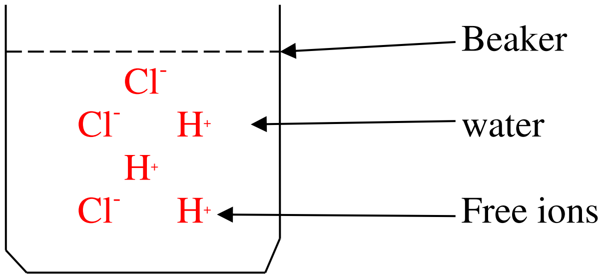
6. Solvents are either **polar** or **non-polar**.
A polar solvent is one which dissolves ionic compounds and other polar solvents.
Water is polar solvent that dissolves ionic and polar substance by surrounding the free ions as below:











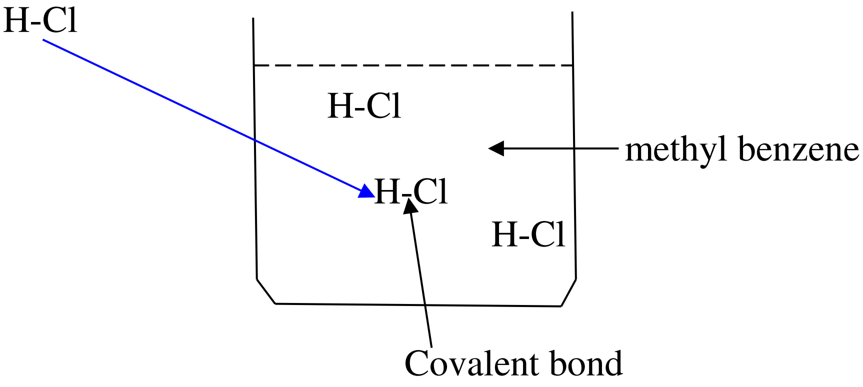
Note:Water is polar .It is made up of :

Oxygen atom is partially negative and two hydrogen atoms which are partially positive.

They surround the free H$^+$ and Cl$^-$ ions.

A non polar solvent is one which dissolved non-polar substances and covalent compounds.

If a polar ionic compound is dissolved in non-polar solvent ,it does not ionize/dissociate into free ions as below:



7. Some acids and bases are **strong** while others are **weak**.

(a)A strong acid/base is one which is fully/wholly/completely dissociated / ionized into many free H$^+$ /OH$^-$ ions i.e.

I. Strong acids exists more as free **H$^+$** ions than molecules. e.g.

$$\underset{\text{(molecules)}}{HCl(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{H^+(aq)} + \underset{\text{(anion)}}{Cl^-(aq)}$$

$$\underset{\text{(molecules)}}{HNO_3(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{H^+(aq)} + \underset{\text{(anion)}}{NO_3^-(aq)}$$

$$\underset{\text{(molecules)}}{H_2SO_4(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{2H^+(aq)} + \underset{\text{(anion)}}{SO_4^{2-}(aq)}$$

II. Strong bases/alkalis exists more as free **OH^-** ions than molecules. e.g.

$$\underset{\text{(molecules)}}{KOH(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{K^+(aq)} + \underset{\text{(anion)}}{OH^-(aq)}$$

$$\underset{\text{(molecules)}}{NaOH(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{Na^+(aq)} + \underset{\text{(anion)}}{OH^-(aq)}$$

(b) A weak base/acid is one which is partially /partly dissociated /ionized in water into free OH^- (aq) and H^+(aq) ions.

I. Weak acids exists more as molecules than as free **H^+** ions. e.g.

$$\underset{\text{(molecules)}}{CH_3COOH(aq)} \mathrel{\substack{\dashrightarrow \\ \longleftarrow}} \underset{\text{(cation)}}{H^+(aq)} + \underset{\text{(anion)}}{CH_3COO^-(aq)}$$

$$\underset{\text{(molecules)}}{H_3PO_4(aq)} \mathrel{\substack{\dashrightarrow \\ \longleftarrow}} \underset{\text{(cation)}}{3H^+(aq)} + \underset{\text{(anion)}}{PO_4^{3-}(aq)}$$

$$\underset{\text{(molecules)}}{H_2CO_3(aq)} \mathrel{\substack{\dashrightarrow \\ \longleftarrow}} \underset{\text{(cation)}}{2H^+(aq)} + \underset{\text{(anion)}}{CO_3^{2-}(aq)}$$

II. Weak bases/alkalis exists more as molecules than free **OH^-** ions. e.g.

$$\underset{\text{(molecules)}}{NH_4OH(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{NH_4^+(aq)} + \underset{\text{(anion)}}{OH^-(aq)}$$

$$\underset{\text{(molecules)}}{Ca(OH)_2(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{Ca^{2+}(aq)} + \underset{\text{(anion)}}{2OH^-(aq)}$$

$$\underset{\text{(molecules)}}{Mg(OH)_2(aq)} \mathrel{\substack{\longrightarrow \\ \dashleftarrow}} \underset{\text{(cation)}}{Mg^{2+}(aq)} + \underset{\text{(anion)}}{2OH^-(aq)}$$

8. The concentration of an acid/base/alkali is based on the number of moles of acid/bases dissolved in a decimeter(litre)of the solution.
An acid/base/alkali with more acid/base/alkali in a decimeter(litre) of solution is said to be **concentrated** while that with less is said to be **dilute**.

9. (a) (i)strong acids have pH 1/2/3 while weak acids have high pH 4/5/6.

(ii)a neutral solution have pH 7
(iii)strong alkalis/bases have pH 12/13/14 while weak bases/alkalis have pH 11/10 /9 / 8.
(b) pH is a measure of H^+(aq) concentration in a solution.
The higher the H^+(aq)ions concentration ;
-the higher the acidity
-the lower the pH
-the lower the concentration of OH^-(aq)
-the lower the alkalinity
At pH 7 , a solution has **equal** concentration of H^+(aq) and OH^-(aq).
Beyond pH 7,the concentration of the OH^-(aq) increases as the H^+(aq) ions decreases.

10.(a) When acids /bases dissolve in water, the ions present in the solution conduct electricity.
The more the dissociation the higher the yield of ions and the greater the electrical conductivity of the solution.
A compound that conducts electricity in an electrolyte and thus a compound showing high electrical conductivity is a strong electrolyte while a compound showing low electrical conductivity is a weak electrolyte.

(b) Practically, a bright light on a bulb ,a high voltage reading from a voltmeter high ammeter reading from an ammeter, a big deflection on a galvanometer is an indicator of strong electrolyte(acid/base) and the opposite for weak electrolytes(acids/base)

11. Some compounds exhibit/show both properties of acids and bases/alkalis.
A substance that reacts with both acids and bases is said to be **amphotellic.**
The examples below show the amphotellic properties of:

(a) **Zinc (II)oxide(ZnO) and Zinc hydroxide($Zn(OH)_2$)**
(i) When ½ spatula full of Zinc(II)oxide is placed in a boiling tube containing 10cm3 of either 2M nitric(V)acid or 2M sodium hydroxide hydroxide solution, it dissolves on both the acid and the alkali/base to form a colourless solution. i.e.

(i) when reacting with nitric(V)acid, the oxide shows **basic** properties by reacting with an acid to form a **simple salt** and **water** only.

Basic oxide + Acid -> salt + water

Examples:

Chemical equation

$ZnO(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + H_2O(l)$

$ZnO(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l)$

$ZnO(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2O(l)$

Ionic equation

$ZnO(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O(l)$

(ii) when reacting with sodium hydroxide, the oxide shows **acidic** properties by reacting with a base to form a **complex** salt.

Basic oxide + Base/alkali + Water -> Complex salt

Examples:

Chemical equation

1.When Zinc oxide is reacted with sodium hydroxide the complex salt is sodium tetrahydroxozincate(II) complex salt.

$ZnO(s) + 2NaOH(aq) + H_2O(l) \rightarrow Na_2Zn(OH)_4(aq)$

2.When Zinc oxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxozincate(II) complex salt.

$ZnO(s) + 2KOH(aq) + H_2O(l) \rightarrow K_2Zn(OH)_4(aq)$

Ionic equation

$ZnO(s) + 2OH^-(aq) + H_2O(l) \rightarrow 2[Zn(OH)_4]^{2-}(aq)$

(ii) When Zinc(II)hydroxide is placed in a boiling tube containing 10cm3 of either 2M nitric(V)acid or 2M sodium hydroxide hydroxide solution, it dissolves on both the acid and the alkali/base to form a colourless solution. i.e.

(i) when reacting with nitric(V)acid, the hydroxide shows **basic** properties. It reacts with an acid to form a **simple salt** and **water** only.

Basic hydroxide + Acid -> salt + water

Examples:

Chemical equation

$Zn(OH)_2(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + 2H_2O(l)$

$Zn(OH)_2(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + 2H_2O(l)$

$Zn(OH)_2(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + 2H_2O(l)$

Ionic equation

$Zn(OH)_2(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + 2H_2O(l)$

(ii) when reacting with sodium hydroxide, the hydroxide shows **acidic** properties by reacting with a base to form a **complex** salt.

Basic hydroxide + Base/alkali -> Complex salt

Examples:

Chemical equation

1.When Zinc hydroxide is reacted with sodium hydroxide the complex salt is sodium tetrahydroxozincate(II) complex salt.

$Zn(OH)_2(s) + 2NaOH(aq) \rightarrow Na_2Zn(OH)_4(aq)$

2.When Zinc hydroxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxozincate(II) complex salt.

$Zn(OH)_2(s) + 2KOH(aq) \rightarrow K_2Zn(OH)_4(aq)$

Ionic equation

$Zn(OH)_2(s) + 2OH^-(aq) \rightarrow 2[Zn(OH)_4]^{2-}(aq)$

(b) Lead (II)oxide(PbO) and Lead(II) hydroxide ($Pb(OH)_2$)

(i) When ½ spatula full of Lead(II)oxide is placed in a boiling tube containing 10cm3 of either 2M nitric(V)acid or 2M sodium hydroxide hydroxide solution, it dissolves on both the acid and the alkali/base to form a colourless solution. i.e.

(i) when reacting with nitric(V)acid, the oxide shows **basic** properties by reacting with an acid to form a **simple salt** and **water** only. All other Lead salts are insoluble.

Chemical equation

$PbO(s) + 2HNO_3(aq) \rightarrow Pb(NO_3)_2(aq) + H_2O(l)$

Ionic equation

$PbO(s) + 2H^+(aq) \rightarrow Pb^{2+}(aq) + H_2O(l)$

(ii) when reacting with sodium hydroxide, the oxide shows **acidic** properties by reacting with a base to form a **complex** salt.

Chemical equation

1.When Lead(II) oxide is reacted with sodium hydroxide the complex salt is sodium tetrahydroxoplumbate(II) complex salt.

$$PbO(s) \quad + \quad 2NaOH(aq) + \quad H_2O(l) \quad -> \quad Na_2Pb(OH)_4(aq)$$

2.When Lead(II) oxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxoplumbate(II) complex salt.

$$PbO(s) \quad + \quad 2KOH(aq) + \quad H_2O(l) \quad -> \quad K_2Pb(OH)_4(aq)$$

Ionic equation

$$PbO(s) \quad + \quad 2OH^-(aq) \quad + \quad H_2O(l) \quad -> \quad 2[Pb(OH)_4]^{2-}(aq)$$

(ii) When Lead(II)hydroxide is placed in a boiling tube containing 10cm3 of either 2M nitric(V)acid or 2M sodium hydroxide hydroxide solution, it dissolves on both the acid and the alkali/base to form a colourless solution. i.e.

(i) when reacting with nitric(V)acid, the hydroxide shows **basic** properties. It reacts with the acid to form a **simple salt** and **water** only.

Chemical equation

$$Pb(OH)_2(s) \quad + \quad 2HNO_3(aq) \quad -> \quad Pb(NO_3)_2(aq) \quad + \quad 2H_2O(l)$$

Ionic equation

$$Pb(OH)_2(s) \quad + \quad 2H^+(aq) \quad -> \quad Pb^{2+}(aq) \quad + \quad 2H_2O(l)$$

(ii) when reacting with sodium hydroxide, the hydroxide shows **acidic** properties. It reacts with a base to form a **complex** salt.

Chemical equation

1.When Lead(II) hydroxide is reacted with sodium hydroxide the complex salt is sodium tetrahydroxoplumbate(II) complex salt.

$$Pb(OH)_2(s) \quad + \quad 2NaOH(aq) \quad -> \quad Na_2Pb(OH)_4(aq)$$

2.When Lead(II) hydroxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxoplumbate(II) complex salt.

$$Pb(OH)_2(s) \quad + \quad 2KOH(aq) \quad -> \quad K_2Pb(OH)_4(aq)$$

Ionic equation

$$Pb(OH)_2(s) \quad + \quad 2OH^-(aq) \quad -> \quad 2[Pb(OH)_4]^{2-}(aq)$$

(c)Aluminium(III)oxide(Al_2O_3) and Aluminium(III)hydroxide($Al(OH)_3$)

(i) When ½ spatula full of Aluminium(III)oxide is placed in a boiling tube containing 10cm3 of either 2M nitric(V)acid or 2M sodium hydroxide hydroxide solution, it dissolves on both the acid and the alkali/base to form a colourless solution. i.e.

(i) when reacting with nitric(V)acid, the oxide shows **basic** properties by reacting with an acid to form a **simple salt** and **water** only.

Chemical equation

$Al_2O_3(s) + 6HNO_3(aq) \rightarrow Al(NO_3)_3(aq) + 3H_2O(l)$

$Al_2O_3(s) + 6HCl(aq) \rightarrow AlCl_3(aq) + 3H_2O(l)$

$Al_2O_3(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$

Ionic equation

$Al_2O_3(s) + 3H^+(aq) \rightarrow Al^{3+}(aq) + 3H_2O(l)$

(ii) when reacting with sodium hydroxide, the oxide shows **acidic** properties by reacting with a base to form a **complex** salt.

Chemical equation

1.When Aluminium(III) oxide is reacted with sodium hydroxide the complex salt is sodium tetrahydroxoaluminate(III) complex salt.

$Al_2O_3(s) + 2NaOH(aq) + \mathbf{3}H_2O(l) \rightarrow 2NaAl(OH)_4(aq)$

2.When Aluminium(III) oxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxoaluminate(II) complex salt.

$Al_2O_3(s) + 2KOH(aq) + \mathbf{3}H_2O(l) \rightarrow 2NaAl(OH)_4(aq)$

Ionic equation

$Al_2O_3(s) + 2OH^-(aq) + \mathbf{3}H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq)$

(ii) When Aluminium(III)hydroxide is placed in a boiling tube containing 10cm3 of either 2M nitric(V)acid or 2M sodium hydroxide hydroxide solution, it dissolves on both the acid and the alkali/base to form a colourless solution. i.e.

(i) when reacting with nitric(V)acid, the hydroxide shows **basic** properties. It reacts with the acid to form a **simple salt** and **water** only.

Chemical equation

$Al(OH)_3(s) + 3HNO_3(aq) \rightarrow Al(NO_3)_3(aq) + 3H_2O(l)$

$Al(OH)_3 (s) + 3HCl(aq) \rightarrow AlCl_3 (aq) + 3H_2O(l)$
$2Al(OH)_3 (s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3 (aq) + 3H_2O(l)$

Ionic equation
$Al(OH)_3 (s) + 3H^+ (aq) \rightarrow Al^{3+} (aq) + 3H_2O(l)$

(ii) when reacting with sodium hydroxide, the hydroxide shows **acidic** properties. It reacts with a base to form a **complex** salt.

Chemical equation
1.When aluminium(III) hydroxide is reacted with sodium hydroxide the complex salt is sodium tetrahydroxoaluminate(III) complex salt.
$Al(OH)_3 (s) + NaOH(aq) \rightarrow NaAl(OH)_4(aq)$

2.When aluminium(III) hydroxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxoaluminate(III) complex salt.
$Al(OH)_3 (s) + KOH(aq) \rightarrow KAl(OH)_4(aq)$

Ionic equation
$Al(OH)_3 (s) + OH^-(aq) \rightarrow [Al(OH)_4]^- (aq)$

Summary of amphotellic oxides/hydroxides

Oxide	**Hydroxide**	**Formula of simple salt from nitric (V)acid**	**Formula of complex salt from sodium hydroxide**
ZnO	$Zn(OH)_2$	$Zn(NO_3)_2$	$Na_2Zn(OH)_4$ $[Zn(OH)_4]^{2-}(aq)$ Sodium tetrahydroxozincate(II)
PbO	$Pb(OH)_2$	$Pb(NO_3)_2$	$Na_2Pb(OH)_4$ $[Pb(OH)_4]^{2-}(aq)$ Sodium tetrahydroxoplumbate(II)
Al_2O_3	$Al(OH)_3$	$Al(NO_3)_3$	$NaAl(OH)_4$ $[Al(OH)_4]^-(aq)$ Sodium tetrahydroxoaluminate(II)

12.(a) A salt is an ionic compound formed when the cation from a base combine with the anion derived from an acid.

A salt is therefore formed when the hydrogen ions in an acid are replaced wholly/fully or partially/partly ,directly or indirectly by a metal or ammonium radical.

(b) The number of ionizable/replaceable hydrogen in an acid is called basicity of an acid.

Some acids are therefore:

(i)**mono**basic acids generally denoted HX e.g.

HCl, HNO_3,$HCOOH$,$CH3COOH$.

(ii)**di**basic acids ; generally denoted H_2X e.g.

H_2SO_4, H_2SO_3, H_2CO_3,$HOOCOOH$.

(iii)**tri**basic acids ; generally denoted H_3X e.g.

H_3PO_4.

(c) Some salts are **normal** salts while other are **acid** salts.

(i)A normal salt is formed when all the ionizable /replaceable hydrogen in an acid is replaced by a metal or metallic /ammonium radical.

(ii)An acid salt is formed when part/portion the ionizable /replaceable hydrogen in an acid is replaced by a metal or metallic /ammonium radical.

Table showing normal and acid salts derived from common acids

Acid name	**Chemical formula**	**Basicity**	**Normal salt**	**Acid salt**
Hydrochloric acid	HCl	Monobasic	Chloride(Cl^-)	None
Nitric(V)acid	HNO_3	Monobasic	Nitrate(V)(NO_3^-)	None
Nitric(III)acid	HNO_2	Monobasic	Nitrate(III)(NO_2^-)	None
Sulphuric(VI)acid	H_2SO_4	Dibasic	Sulphate(VI) (SO_4^{2-})	Hydrogen sulphate(VI) (HSO_4^-)
Sulphuric(IV)acid	H_2SO_3	Dibasic	Sulphate(IV) (SO_3^{2-})	Hydrogen sulphate(IV) (HSO_3^-)
Carbonic(IV)acid	H_2CO_3	Dibasic	Carbonate(IV)(CO_3^{2-})	Hydrogen carbonate(IV) (HCO_3^-)
Phosphoric(V)	H_3PO_4	Tribasic	Phosphate(V)(PO_4^{3-})	Dihydrogen

acid				phosphate(V) ($H_2PO_4^{2-}$) Hydrogen diphosphate(V) ($HP_2O_4^{2-}$)

The table below show shows some examples of salts.

Base/alkali	Cation	Acid	Anion	Salt	Chemical name of salts
$NaOH$	Na^+	HCl	Cl^-	$NaCl$	Sodium(I)chloride
$Mg(OH)_2$	Mg^{2+}	H_2SO_4	SO_4^{2-}	$MgSO_4$ $Mg(HSO_4)_2$	Magnesium sulphate(VI) Magnesium hydrogen sulphate(VI)
$Pb(OH)_2$	Pb^{2+}	HNO_3	NO_3^-	$Pb(NO_3)_2$	Lead(II)nitrate(V)
$Ba(OH)_2$	Ba^{2+}	HNO_3	NO_3^-	$Ba(NO_3)_2$	Barium(II)nitrate(V)
$Ca(OH)_2$	Ba^{2+}	H_2SO_4	SO_4^{2-}	$MgSO_4$	Calcium sulphate(VI)
NH_4OH	NH_4^+	H_3PO_4	PO_4^{3-}	$(NH_4)_3PO_4$ $(NH_4)_2HPO_4$ $NH_4H_2PO_4$	Ammonium phosphate(V) Diammonium phosphate(V) Ammonium diphosphate(V)
KOH	K^+	H_3PO_4	PO_4^{3-}	K_3PO_4	Potassium phosphate(V)
$Al(OH)_3$	Al^{3+}	H_2SO_4	SO_4^{2-}	$Al_2(SO_4)_2$	Aluminium(III)sulphate(VI)
$Fe(OH)_2$	Fe^{2+}	H_2SO_4	SO_4^{2-}	$FeSO_4$	Iron(II)sulphate(VI)
$Fe(OH)_3$	Fe^{3+}	H_2SO_4	SO_4^{2-}	$Fe_2(SO_4)_2$	Iron(III)sulphate(VI)

(d) Some salts undergo **hygroscopy**, **deliquescence** and **efflorescence**.

(i) Hygroscopic salts /compounds are those that absorb water from the atmosphere but do not form a solution.
Some salts which are hygroscopic include anhydrous copper(II)sulphate(VI), anhydrous cobalt(II)chloride, potassium nitrate(V) common table salt.

(ii)Deliquescent salts /compounds are those that absorb water from the atmosphere and form a solution.
Some salts which are deliquescent include: Sodium nitrate(V),Calcium chloride, Sodium hydroxide, Iron(II)chloride, Magnesium chloride.

(iii)Efflorescent salts/compounds are those that lose their water of crystallization to the atmosphere.
Some salts which effloresces include: sodium carbonate decahydrate, Iron(II)sulphate(VI)heptahydrate, sodium sulphate (VI)decahydrate.

(e)Some salts contain water of crystallization.They are hydrated.Others do not contain water of crystallization. They are anhydrous.

Table showing some hydrated salts.

Name of hydrated salt	Chemical formula
Copper(II)sulphate(VI)pentahydrate	$CuSO_4.5H_2O$
Aluminium(III)sulphate(VI)hexahydrate	$Al_2 (SO_4)_3.6H_2O$
Zinc(II)sulphate(VI)heptahydrate	$ZnSO_4.7H_2O$
Iron(II)sulphate(VI)heptahydrate	$FeSO_4.7H_2O$
Calcium(II)sulphate(VI)heptahydrate	$CaSO_4.7H_2O$
Magnesium(II)sulphate(VI)heptahydrate	$MgSO_4.7H_2O$
Sodium sulphate(VI)decahydrate	$Na_2SO_4.10H_2O$
Sodium carbonate(IV)decahydrate	$Na_2CO_3.10H_2O$
Potassium carbonate(IV)decahydrate	$K_2CO_3.10H_2O$
Potassium sulphate(VI)decahydrate	$K_2SO_4.10H_2O$

(f)Some salts exist as a simple salt while some as complex salts. Below are some complex salts.

Table of some complex salts

Name of complex salt	Chemical formula	Colour of the complex salt
Tetraamminecopper(II)sulphate(VI)	$Cu(NH_3)_4 SO_4 H_2O$	Royal/deep blue solution
Tetraamminezinc(II)nitrate(V)	$Zn(NH_3)_4 (NO_3)_2$	Colourless solution
Tetraamminecopper(II) nitrate(V)	$Cu(NH_3)_4 (NO_3)_2$	Royal/deep blue solution
Tetraamminezinc(II)sulphate(VI)	$Zn(NH_3)_4 SO_4$	Colourless solution

(g)Some salts exist as two salts in one. They are called **double salts**.

Table of some double salts

Name of double salts	Chemical formula
Trona(sodium sesquicarbonate)	Na_2CO_3 $NaHCO_3.2H_2O$
Ammonium iron(II)sulphate(VI)	$FeSO_4(NH_4)_2SO_4.2H_2O$
Ammonium aluminium(III)sulphate(VI)	$Al_2(SO_4)_3(NH_4)_2SO_4.H_2O$

(h)Some salts dissolve in water to form a **solution**. They are said to be soluble. Others do not dissolve in water. They form a **suspension/precipitate** in water.

Table of solubility of salts

Soluble salts	Insoluble salts
All nitrate(V)salts	
All sulphate(VI)/SO_4^{2-} salts **except** →	Barium(II) sulphate(VI)/$BaSO_4$ Calcium(II) sulphate(VI)/$CaSO_4$ Lead(II) sulphate(VI)/$PbSO_4$
All sulphate(IV)/SO_3^{2-} salts **except** →	Barium(II) sulphate(IV)/$BaSO_3$ Calcium(II) sulphate(IV)/$CaSO_3$ Lead(II) sulphate(IV)/$PbSO_3$
All chlorides/Cl^- **except** →	Silver chloride/$AgCl$ Lead(II)chloride/$PbCl_2$(dissolves in hot water)
All phosphate(V)/PO_4^{3-}	
All sodium,potassium and ammonium salts	
All hydrogen carbonates/HCO_3^-	
All hydrogen sulphate(VI)/ HSO_4^-	
Sodium carbonate/Na_2CO_3, potassium carbonate/ K_2CO_3, ammonium carbonate $(NH_4)_2CO_3$ ←	**except** All carbonates
All alkalis(KOH,NaOH, NH_4OH) ←	**except** All bases

13 Salts can be prepared in a school laboratory by a method that uses its solubility in water.

(a) Soluble salts may be prepared by using any of the following methods:

(i)Direct displacement/reaction of a metal with an acid.

By reacting a metal higher in the reactivity series than hydrogen with a dilute acid,a salt is formed and hydrogen gas is evolved.
Excess of the metal must be used to ensure all the acid has reacted.
When effervescence/bubbling /fizzing has stopped ,excess metal is filtered.
The filtrate is heated to concentrate then allowed to crystallize.
Washing with distilled water then drying between filter papers produces a sample crystal of the salt. i.e.

$$M(s) + H_2X \rightarrow MX(aq) + H_2(g)$$

<u>Examples</u>

$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$
$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$
$Pb(s) + 2HNO_3(aq) \rightarrow Pb(NO_3)_2(aq) + H_2(g)$
$Ca(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2(g)$
$Mg(s) + 2HNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + H_2(g)$
$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

(ii)Reaction of an insoluble base with an acid

By adding an insoluble base (oxide/hydroxide)to a dilute acid until **no more dissolves**, in the acid,a salt and water are formed. Excess of the base is filtered off. The filtrate is heated to concentrate ,allowed to crystallize then washed with distilled water before drying between filter papers e.g.

$PbO(s) + 2HNO_3(aq) \rightarrow Pb(NO_3)_2(aq) + H_2O(l)$
$Pb(OH)_2(s) + 2HNO_3(aq) \rightarrow Pb(NO_3)_2(aq) + 2H_2O(l)$
$CaO(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O(l)$
$MgO(s) + 2HNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + H_2O(l)$
$MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$
$ZnO(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2O(l)$
$Zn(OH)_2(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + 2H_2O(l)$
$CuO(s) + 2HCl(aq) \rightarrow CuCl_2(aq) + H_2O(l)$
$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$
$Ag_2O(s) + 2HNO_3(aq) \rightarrow 2AgNO_3(aq) + H_2O(l)$
$Na_2O(s) + 2HNO_3(aq) \rightarrow 2NaNO_3(aq) + H_2O(l)$

(iii)reaction of insoluble /soluble carbonate /hydrogen carbonate with an acid.

By adding an excess of a soluble /insoluble carbonate or hydrogen carbonate to adilute acid, effervescence /fizzing/bubbling out of carbon(IV)oxide gas shows the reaction is taking place. When effervescence /fizzing/bubbling out of the gas is over, excess of the insoluble carbonate is filtered off. The filtrate is heated to concentrate ,allowed to crystallize then washed with distilled water before drying between filter paper papers e.g.

$PbCO_3 (s) + 2HNO_3(aq) \rightarrow Pb(NO_3)_2(aq) + H_2O (l)+ CO_2(g)$
$ZnCO_3 (s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + H_2O (l)+ CO_2(g)$
$CaCO_3 (s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O (l)+ CO_2(g)$
$MgCO_3 (s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O (l)+ CO_2(g)$
$Cu CO_3 (s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O (l) + CO_2(g)$
$Ag_2CO_3 (s) + 2HNO_3(aq) \rightarrow 2AgNO_3(aq) + H_2O (l) + CO_2(g)$
$Na_2CO_3 (s) + 2HNO_3(aq) \rightarrow 2NaNO_3(aq) + H_2O (l) + CO_2(g)$
$K_2CO_3 (s) + 2HCl(aq) \rightarrow 2KCl(aq) + H_2O (l) + CO_2(g)$
$NaHCO_3 (s) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O (l) + CO_2(g)$
$KHCO_3 (s) + HCl(aq) \rightarrow KCl(aq) + H_2O (l) + CO_2(g)$

(iv)neutralization/reaction of soluble base/alkali with dilute acid

By adding an acid to a burette into a known volume of an alkali with 2-3 drops of an indicator, the colour of the indicator changes when the acid has completely reacted with an alkali at the **end point.** The procedure is then repeated without the indicator .The solution mixture is then heated to concentrate , allowed to crystallize ,washed with distilled water before drying with filter papers. e.g.

$NaOH (aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O (l)$
$KOH (aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O (l)$
$KOH (aq) + HCl(aq) \rightarrow KCl(aq) + H_2O (l)$
$2KOH (aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2H_2O (l)$
$2 NH_4OH (aq) + H_2SO_4(aq) \rightarrow (NH_4)_2SO_4(aq) + 2H_2O (l)$
$NH_4OH (aq) + HNO_3(aq) \rightarrow NH_4NO_3(aq) + H_2O (l)$

(iv)direct synthesis/combination.

When a metal **burn** in a gas jar containing a non metal , the two directly combine to form a salt. e.g.

$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$
$2K(s) + Cl_2(g) \rightarrow 2KCl(s)$
$Mg(s) + Cl_2(g) \rightarrow Mg Cl_2 (s)$
$Ca(s) + Cl_2(g) \rightarrow Ca Cl_2 (s)$

Some salts once formed undergo **sublimation** and **hydrolysis**. Care should be taken to avoid water/moisture into the reaction flask during their preparation.Such salts include aluminium(III)chloride($AlCl_3$) and iron (III)chloride($FeCl_3$)

1. Heated aluminium foil reacts with chlorine to form aluminium(III)chloride that sublimes away from the source of heating then deposited as solid again

$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(\mathbf{s/g})$

Once formed aluminium(III)chloride hydrolyses/reacts with water vapour / moisture present to form aluminium hydroxide solution and highly acidic fumes of hydrogen chloride gas.

$AlCl_3(s) + 3H_2O(g) \rightarrow Al(OH)_3(\mathbf{aq}) + 3HCl(g)$

2. Heated iron filings reacts with chlorine to form iron(**III**)chloride that sublimes away from the source of heating then deposited as solid again

$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(\mathbf{s/g})$

Once formed , aluminium(III)chloride hydrolyses/reacts with water vapour / moisture present to form aluminium hydroxide solution and highly acidic fumes of hydrogen chloride gas.

$FeCl_3(s) + 3H_2O(g) \rightarrow Fe(OH)_3(\mathbf{aq}) + 3HCl(g)$

(b)**Insoluble** salts can be prepared by reacting **two** suitable **soluble** salts to form **one soluble** and **one insoluble**. This is called **double decomposition** or **precipitation**. The mixture is filtered and the **residue** is washed with distilled water then dried.

$\mathbf{Cu}SO_4(aq) + Na_2\mathbf{CO_3}(aq) \rightarrow \mathbf{CuCO_3}(s) + Na_2SO_4(aq)$

$\mathbf{Ba}Cl_2(aq) + K_2\mathbf{SO_4}(aq) \rightarrow \mathbf{BaSO_4}(s) + 2KCl(aq)$

$\mathbf{Pb}(NO_3)_2(aq) + K_2\mathbf{SO_4}(aq) \rightarrow \mathbf{PbSO_4}(s) + 2KNO_3(aq)$

$2\mathbf{Ag}NO_3(aq) + Mg\mathbf{Cl_2}(aq) \rightarrow 2\mathbf{AgCl}(s) + Mg(NO_3)_2(aq)$

$\mathbf{Pb}(NO_3)_2(aq) + (NH_4)_2\mathbf{SO_4}(aq) \rightarrow \mathbf{PbSO_4}(s) + 2NH_4NO_3(aq)$

$\mathbf{Ba}Cl_2(aq) + K_2\mathbf{SO_3}(aq) \rightarrow \mathbf{BaSO_3}(s) + 2KCl(aq)$

14. Salts may lose their water of crystallization , decompose ,melt or sublime on heating on a Bunsen burner flame.

The following shows the behavior of some salts on heating gently /or strongly in a laboratory school burner:

(a)effect of heat on chlorides

All chlorides have very high melting and boiling points and therefore are not affected by laboratory heating except ammonium chloride. Ammonium chloride **sublimes** on **gentle** heating. It **dissociate** into the constituent **ammonia** and **hydrogen chloride** gases on strong heating.

$NH_4Cl(s) \underset{\text{(sublimation)}}{\rightleftharpoons} NH_4Cl(g) \underset{\text{(dissociation)}}{\rightleftharpoons} NH_3(g) + HCl(g)$

(b)effect of heat on nitrate(V)

(i) Potassium nitrate(V)/KNO_3 and sodium nitrate(V)/$NaNO_3$ decompose on heating to form Potassium nitrate(III)/KNO_2 and sodium nitrate(III)/$NaNO_2$ and producing Oxygen gas in each case.

$2KNO_3 (s) \rightarrow 2KNO_2(s) + O_2(g)$
$2NaNO_3 (s) \rightarrow 2NaNO_2(s) + O_2(g)$

(ii)Heavy metal nitrates(V) salts decompose on heating to form the oxide and a mixture of brown acidic nitrogen(IV)oxide and oxygen gases. e.g.

$2Ca(NO_3)_2 (s) \rightarrow 2CaO(s) + 4NO_2(g) + O_2(g)$
$2Mg(NO_3)_2(s) \rightarrow 2MgO(s) + 4NO_2(g) + O_2(g)$
$2Zn(NO_3)_2(s) \rightarrow 2ZnO(s) + 4NO_2(g) + O_2(g)$
$2Pb(NO_3)_2(s) \rightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$
$2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$
$2Fe(NO_3)_2(s) \rightarrow 2FeO(s) + 4NO_2(g) + O_2(g)$

(iii)Silver(I)nitrate(V) and mercury(II) nitrate(V) are lowest in the reactivity series. They decompose on heating to form the **metal**(silver and mercury)and the Nitrogen(IV)oxide and oxygen gas. i.e.

$2AgNO_3(s) \rightarrow 2Ag (s) + 2NO_2(g) + O_2(g)$
$2Hg(NO_3)_2 (s) \rightarrow 2Hg (s) + 4NO_2(g) + O_2(g)$

(iv)Ammonium nitrate(V) and Ammonium nitrate(III) decompose on heating to Nitrogen(I)oxide(relights/rekindles glowing splint) and nitrogen gas respectively.Water is also formed.i.e.

$NH_4NO_3(s) \rightarrow N_2O (g) + H_2O(l)$
$NH_4NO_2(s) \rightarrow N_2 (g) + H_2O(l)$

(c) effect of heat on nitrate(V)

Only Iron(II)sulphate(VI), Iron(III)sulphate(VI) and copper(II)sulphate(VI) decompose on heating. They form the **oxide**, and produce highly acidic fumes of acidic **sulphur(IV)oxide** gas.

$2FeSO_4 (s) \rightarrow Fe_2O_3(s) + SO_3(g) + SO_2(g)$
$Fe_2(SO_4)_3(s) \rightarrow Fe_2O_3(s) + SO_3(g)$
$CuSO_4 (s) \rightarrow CuO(s) + SO_3(g)$

(d) effect of heat on carbonates(IV) and hydrogen carbonate(IV).

(i)Sodium carbonate(IV)and potassium carbonate(IV)**do not decompose** on heating.

(ii)Heavy metal nitrate(IV)salts decompose on heating to form the **oxide** and produce **carbon(IV)oxide** gas. Carbon (IV)oxide gas forms a white precipitate when bubbled in lime water. The white precipitate dissolves if the gas is in excess.

e.g. $CuCO_3$ (s) -> CuO(s) + CO_2(g)

$CaCO_3$ (s) -> CaO(s) + CO_2(g)

$PbCO_3$ (s) -> PbO(s) + CO_2(g)

$FeCO_3$ (s) -> FeO(s) + CO_2(g)

$ZnCO_3$ (s) -> ZnO(s) + CO_2(g)

(iii)Sodium hydrogen carbonate(IV) and Potassium hydrogen carbonate(IV)decompose on heating to give the corresponding carbonate (IV) and form water and carbon(IV)oxide gas. i.e.

$2NaHCO_3$(s) -> Na_2CO_3(s) + CO_2(g) + H_2O(l)

$2KHCO_3$(s) -> K_2CO_3(s) + CO_2(g) + H_2O(l)

(iii) Calcium hydrogen carbonate (IV) and Magnesium hydrogen carbonate(IV) decompose on heating to give the corresponding carbonate (IV) and form water and carbon(IV)oxide gas. i. e.

$Ca(HCO_3)_2$(**aq**) -> $CaCO_3$(s) + CO_2(g) + H_2O(l)

$Mg(HCO_3)_2$(**aq**) -> $MgCO_3$(s) + CO_2(g) + H_2O(l)

15. Salts contain cation(positively charged ion) and anions(negatively charged ion).When dissolved in polar solvents/water.

The cation and anion in a salt is determined/known usually by precipitation of the salt using a **precipitating reagent**.

The colour of the precipitate is a basis of qualitative analysis of a compound.

16.Qualitative analysis is the process of identifying an unknown compound /salt by identifying the unique qualities of the salt/compound.

It involves some of the following processes.

(a)Reaction of cation with sodium/potassium hydroxide solution.

Both sodium/potassium hydroxide solutions are precipitating reagents.

The alkalis produce **unique** colour of a precipitate/suspension when a few/three drops is added and then excess alkali is added to **unknown** salt/compound solution.

NB: Potassium hydroxide is not commonly used because it is more expensive than sodium hydroxide.

The table below shows the observations, inferences / deductions and explanations from the following test tube experiments:

Procedure

Put about 2cm3 of $MgCl_2$, $CaCl_2$, $AlCl_3$, NaCl, KCl, $FeSO_4$, $Fe_2(SO_4)_3$, $CuSO_4$, $ZnSO_4NH_4NO_3$, $Pb(NO_3)_2$, $Ba(NO_3)_2$ each into separate test tubes. Add three drops of 2M sodium hydroxide solution then excess ($^{2}/_{3}$ the length of a standard test tube).

Observation	**Inference**	**Explanation**
No white precipitate	Na^+ and K^+	Both Na^+ and K^+ ions react with OH^- from 2M sodium hydroxide solution to form soluble colourless solutions $Na^+(aq) + OH^-(aq) \rightarrow NaOH(aq)$ $K^+(aq) + OH^-(aq) \rightarrow KOH(aq)$
No white precipitate then pungent smell of ammonia /urine	NH_4^+ ions	NH_4^+ ions react with 2M sodium hydroxide solution to produce pungent smelling ammonia gas $NH_4^+ (aq) + OH^-(aq) \rightarrow NH_3 (g) + H_2O(l)$
White precipitate insoluble in excess	Ba^{2+} ,Ca^{2+}, Mg^{2+} ions	Ba^{2+} ,Ca^{2+} and Mg^{2+} ions react with OH^- from 2M sodium hydroxide solution to form insoluble white precipitate of their hydroxides. $Ba^{2+}(aq) + 2OH^-(aq) \rightarrow Ba(OH)_2(s)$ $Ca^{2+}(aq) + 2OH^-(aq) \rightarrow Ca(OH)_2(s)$ $Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(s)$
White precipitate soluble in excess	Zn^{2+} ,Pb^{2+}, Al^{3+} ions	Pb^{2+} ,Zn^{2+} and Al^{3+} ions react with OH^- from 2M sodium hydroxide solution to form insoluble white precipitate of their hydroxides. $Zn^{2+}(aq) + 2OH^-(aq) \rightarrow Zn(OH)_2(s)$ $Pb^{2+}(aq) + 2OH^-(aq) \rightarrow Pb(OH)_2(s)$ $Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$

		The hydroxides formed react with more OH^- ions to form complex salts/ions. $Zn(OH)_2(s) + 2OH(aq) \rightarrow [Zn(OH)_4]^{2-}(aq)$ $Pb(OH)_2(s) + 2OH(aq) \rightarrow [Pb(OH)_4]^{2-}(aq)$ $Al(OH)_3(s) + OH(aq) \rightarrow [Al(OH)_4]^-(aq)$
Blue precipitate insoluble in excess	Cu^{2+}	Cu^{2+} ions react with OH^- from 2M sodium hydroxide solution to form insoluble blue precipitate of copper(II) hydroxide. $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$
Green precipitate insoluble in excess On adding 3cm3 of hydrogen peroxide, **brown**/yellow solution formed	Fe^{2+} Fe^{2+} oxidized to Fe^{3+}	Fe^{2+} ions react with OH^- from 2M sodium hydroxide solution to form insoluble green precipitate of Iron(II) hydroxide. $Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$ Hydrogen peroxide is an oxidizing agent that oxidizes green Fe^{2+} oxidized to brown Fe^{3+} $Fe(OH)_2(s) + 2H^+ \rightarrow Fe(OH)_3(aq)$
Brown precipitate insoluble in excess	Fe^{3+}	Fe^{3+} ions react with OH^- from 2M sodium hydroxide solution to form insoluble **brown** precipitate of **Iron(II) hydroxide**. $Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$

(b)Reaction of cation with aqueous ammonia

Aqueous ammonia precipitating reagent that can be used to identify the cations present in a salt.
Like NaOH/KOH the OH^- ion in NH_4OH react with the cation to form a characteristic hydroxide .

Below are the observations ,inferences and explanations of the reactions of aqueous ammonia with salts from the following test tube reactions.

Procedure

Put about 2cm3 of $MgCl_2$, $CaCl_2$, $AlCl_3$, $NaCl$, KCl, $FeSO_4$, $Fe_2(SO_4)_3$, $CuSO_4$, $ZnSO_4NH_4NO_3$, $Pb(NO_3)_2$, $Ba(NO_3)_2$ each into separate test tubes.
Add three drops of 2M aqueous ammonia then excess ($^2/_3$ the length of a standard test tube).

Observation	**Inference**	**Explanation**
No white precipitate	Na^+ and K^+	NH_4^+,Na^+ and K^+ ions react with OH^- from 2M aqueous ammonia to form soluble colourless solutions $NH_4^+(aq) + OH^-(aq) \rightarrow NH_4^+OH(aq)$ $Na^+(aq) + OH^-(aq) \rightarrow NaOH(aq)$ $K^+(aq) + OH^-(aq) \rightarrow KOH(aq)$
White precipitate insoluble in excess	Ba^{2+} ,Ca^{2+}, Mg^{2+} ,Pb^{2+}, Al^{3+}, ions	Ba^{2+} ,Ca^{2+},Mg^{2+} ,Pb^{2+} and Al^{3+}, ions react with OH^- from 2M aqueous ammonia to form insoluble white precipitate of their hydroxides. $Pb^{2+}(aq) + 2OH^-(aq) \rightarrow Pb(OH)_2(s)$ $Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$ $Ba^{2+}(aq) + 2OH^-(aq) \rightarrow Ba(OH)_2(s)$ $Ca^{2+}(aq) + 2OH^-(aq) \rightarrow Ca(OH)_2(s)$ $Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(s)$
White precipitate soluble in excess	Zn^{2+} ions	Zn^{2+} ions react with OH^- from 2M aqueous ammonia to form insoluble white precipitate of Zinc hydroxide. $Zn^{2+}(aq) + 2OH^-(aq) \rightarrow Zn(OH)_2(s)$ The Zinc hydroxides formed react $NH_3(aq)$ to form a complex salts/ions. $Zn(OH)_2(s) + 4NH_3(aq) \rightarrow [Zn(NH_3)_4]^{2+}(aq) + 2OH^-(aq)$
Blue precipitate	Cu^{2+}	Cu^{2+} ions react with OH^- from 2M aqueous

that dissolves in excess ammonia solution to form a **deep/royal blue solution**		ammonia to form blue precipitate of copper(II) hydroxide. $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow \mathbf{Cu(OH)_2(s)}$ The copper(II) hydroxide formed react $NH_3(aq)$ to form a complex salts/ions. $\mathbf{Cu(OH)_2}\ (\mathbf{s}) + 4NH_3(aq) \rightarrow \mathbf{[\ Cu(NH_3)_4]}^{2+}(\mathbf{aq}) + 2OH^-(aq)$
Green precipitate insoluble in excess.	Fe^{2+}	Fe^{2+} ions react with OH^- from 2M aqueous ammonia to form insoluble green precipitate of Iron(II) hydroxide. $Fe^{2+}(aq) + 2OH^-(aq) \rightarrow \mathbf{Fe(OH)_2(s)}$
On adding 3cm3 of hydrogen peroxide, **brown**/yellow solution formed	Fe^{2+} oxidized to Fe^{3+}	Hydrogen peroxide is an oxidizing agent that oxidizes green Fe^{2+} oxidized to brown Fe^{3+} $\mathbf{Fe(OH)_2(s)} + 2H^+ \rightarrow \mathbf{Fe(OH)_3(aq)}$
Brown precipitate insoluble in excess	Fe^{3+}	Fe^{3+} ions react with OH^- from 2M aqueous ammonia to form insoluble **brown** precipitate of **Iron(II) hydroxide**. $Fe^{3+}(aq) + 3OH^-(aq) \rightarrow \mathbf{Fe(OH)_3(s)}$

Note
(i) Only **Zn^{2+}** ions/salts form a **white precipitate** that **dissolve** in excess of both 2M sodium hydroxide and 2M aqueous ammonia.

(ii) **Pb^{2+}** and **Al^{3+}** ions/salts form a **white precipitate** that **dissolve** in excess of 2M sodium hydroxide but not in 2M aqueous ammonia.

(iii) **Cu^{2+}** ions/salts form a **blue precipitate** that **dissolve** to form a **deep/royal blue** solution in excess of 2M aqueous ammonia but only **blue** insoluble **precipitate** in 2M sodium hydroxide

(c)Reaction of cation with Chloride (Cl$^-$)ions

All chlorides are soluble in water except **Silver chloride** and **Lead (II)chloride** (That dissolve in hot water).When a soluble chloride like NaCl, KCl, NH_4Cl is added to about 2cm3 of a salt containing Ag^+ or Pb^{2+}ions a white precipitate of AgCl or $PbCl_2$ is formed. The following test tube reactions illustrate the above.

Experiment

Put about 2cm3 of silver nitrate(V) andLead(II)nitrate(V)solution into separate test tubes. Add five drops of NaCl /KCl / NH_4Cl/HCl. Heat to boil.

Observation	**Inference**	**Explanation**
(i)White precipitate does not dissolve on heating	Ag^+ ions	Ag^+ ions reacts with Cl^- ions from a soluble chloride salt to form a white precipitate of AgCl
(ii)White precipitate dissolve on heating	Pb^{2+} ions	Pb^{2+} ions reacts with Cl^- ions from a soluble chloride salt to form a white precipitate of $PbCl_2$. $PbCl_2$ dissolves on heating.

Note

Both Pb^{2+} and Al^{3+} ions forms an insoluble white precipitate in excess aqueous ammonia. A white precipitate on adding Cl^- ions/salts shows **Pb^{2+}**.

No white precipitate on adding Cl^- ions/salts shows **Al^{3+}**.

Adding a chloride/ Cl^- ions/salts can thus be used to separate the identity of **Al^{3+} and Pb^{2+}**.

(d)Reaction of cation with sulphate(VI)/SO_4^{2-} and sulphate(IV)/SO_3^{2-} ions

All sulphate(VI) and sulphate(IV)/SO_3^{2-} ions/salts are soluble/dissolve in water **except** Calcium sulphate(VI)/$CaSO_4$**,** Calcium sulphate(IV)/$CaSO_3$**,** Barium sulphate(VI)/$BaSO_4$**,** Barium sulphate(IV)/$BaSO_3$**,** Lead(II) sulphate(VI)/$PbSO_4$ and Lead(II) sulphate(IV)/$PbSO_3$.When a soluble sulphate(VI)/SO_4^{2-} salt like Na_2SO_4, H_2SO_4, $(NH_4)_2SO_4$ or Na_2SO_3 is added to a salt containing Ca^{2+}, Pb^{2+}, Ba^{2+} ions, a white precipitate is formed.

The following test tube experiments illustrate the above.

Procedure

Place about 2cm3 of $Ca(NO_3)_2$, $Ba(NO_3)_2$, $BaCl_2$ and $Pb(NO_3)_2$, in separate boiling tubes. Add six drops of sulphuric(VI)acid /sodium sulphate(VI)/ammonium sulphate(VI)solution. Repeat with six drops of sodium sulphate(IV).

Observation	Inference	Explanation
White	Ca^{2+}, Ba^{2+},	$CaSO_3$ and $CaSO_4$ do not form a thick precipitate as

precipitate	Pb^{2+} ions	they are sparingly soluble. $Ca^{2+}(aq)+ SO_3^{2-}(aq) \rightarrow CaSO_3(s)$ $Ca^{2+}(aq)+ SO_4^{2-}(aq) \rightarrow CaSO_4(s)$ $Ba^{2+}(aq)+ SO_3^{2-}(aq) \rightarrow BaSO_3(s)$ $Ba^{2+}(aq)+ SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ $Pb^{2+}(aq)+ SO_3^{2-}(aq) \rightarrow PbSO_3(s)$ $Pb^{2+}(aq)+ SO_4^{2-}(aq) \rightarrow PbSO_4(s)$

(e)Reaction of cation with carbonate(IV)/CO_3^{2-} ions

All carbonate salts are insoluble except sodium/potassium carbonate(IV) and ammonium carbonate(IV).
They dissociate /ionize to release CO_3^{2-} ions. CO_3^{2-} ions produce a white precipitate when the soluble carbonate salts is added to any metallic cation.

Procedure
Place about 2cm3 of $Ca(NO_3)_2$, $Ba(NO_3)_2$, $MgCl_2$,$Pb(NO_3)_2$ and$ZnSO_4$ in separate boiling tubes.
Add six drops of Potassium /sodium carbonate(IV)/ ammonium carbonate (IV)solution.

Observation	Inference	Explanation
Green precipitate	Cu^{2+} ,Fe^{2+},ions $CO_3^{2-}(aq)$	Copper(II)carbonate(IV) and Iron(II) carbonate (IV) are precipitated as insoluble **green** precipitates. $Cu^{2+}(aq)+ CO_3^{2-}(aq) \rightarrow CuCO_3(s)$ $Fe^{2+}(aq)+ CO_3^{2-}(aq) \rightarrow FeCO_3(s)$ When sodium carbonate(IV)is added to $CuCO_3(s)$ the $CO_3^{2-}(aq)$ ions are first **hydrolysed** to produce $CO_2(g)$ and $OH^-(aq)$ions. $CO_3^{2-}(aq) + H_2O (l) \rightarrow CO_2 (g) + 2OH^- (aq)$ The $OH^-(aq)$ ions further react to form basic copper(II) carbonate(IV). Basic copper(II) carbonate(IV) is the **only green** salt of copper. $Cu^{2+}(aq)+ CO_3^{2-}(aq)+2OH^- (aq)$

		->$\mathbf{CuCO_3.Cu(OH)_2}$ (s)
White precipitate	CO_3^{2-}	White ppt of the carbonate(IV)salt is precipitated $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$ $Mg^{2+}(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s)$ $Pb^{2+}(aq) + CO_3^{2-}(aq) \rightarrow PbCO_3(s)$ $Zn^{2+}(aq) + CO_3^{2-}(aq) \rightarrow ZnCO_3(s)$

Note

(i)Iron(III)carbonate(IV) does not exist.

(ii)Copper(II)Carbonate(IV) exist only as the basic $CuCO_3.Cu(OH)_2$

(iii)Both $BaCO_3$ and $BaSO_3$ are insoluble white precipitate. If hydrochloric acid is added to the white precipitate;

I. $BaCO_3$ produces CO_2 gas. When bubbled/directed into lime water solution,a white precipitate is formed.

II. I. $BaSO_3$ produces SO_2 gas. When bubbled/directed into orange acidified potassium dichromate(VI) solution, it turns to green/decolorizes acidified potassium manganate(VII).

(f) Reaction of cation with sulphide / S^{2-} ions

All sulphides are insoluble **black** solids/precipitates **except** sodium sulphide/ Na_2S/ potassium sulphide/K_2S.When a few/3drops of the soluble sulphide is added to a metal cation/salt, a black precipitate is formed.

Procedure

Place about 2cm3 of $Cu(NO_3)_2$, $FeSO_4$, $MgCl_2$,$Pb(NO_3)_2$ and $ZnSO_4$ in separate boiling tubes.

Add six drops of Potassium /sodium sulphide solution.

Observation	Inference	Explanation
Black ppt	S^{2-} ions	CuS, FeS,MgS,PbS, ZnS are black insoluble precipitates $Cu^{2+}(aq) + S^{2-}(aq) \rightarrow \mathbf{CuS}(s)$ $Pb^{2+}(aq) + S^{2-}(aq) \rightarrow \mathbf{PbS}(s)$ $Fe^{2+}(aq) + S^{2-}(aq) \rightarrow \mathbf{FeS}(s)$ $Zn^{2+}(aq) + S^{2-}(aq) \rightarrow \mathbf{ZnS}(s)$

Sample qualitative analysis guide

You are provided with solid Y(aluminium (III)sulphate(VI)hexahydrate).Carry out the following tests and record your observations and inferences in the space provided.

1(a) Appearance

Observations	inference (1mark)
White crystalline solid	Coloured ions Cu^{2+} , Fe^{2+} ,Fe^{3+} absent

(b)Place about a half spatula full of the solid into a clean dry boiling tube. Heat gently then strongly.

Observations	inference (1mark)
Colourless droplets formed on the cooler part of the test tube Solid remains a white residue	Hydrated compound/compound containing water of crystallization

(c)Place all the remaining portion of the solid in a test tube .Add about 10cm3 of distilled water. Shake thoroughly. Divide the mixture into five portions.

Observation	Inference (1mark)
Solid dissolves to form a colourless solution	Polar soluble compound Cu^{2+} , Fe^{2+} ,Fe^{3+} absent

(i)To the first portion, add three drops of sodium hydroxide then add excess of the alkali.

Observation	Inference (1mark)
White ppt, soluble in excess	Zn^{2+} , Pb^{2+} , Al^{3+}

(ii)To the second portion, add three drops of aqueous ammonia then add excess of the alkali.

Observation	Inference (1mark)
White ppt, insoluble in excess	Pb^{2+} , Al^{3+}

(iii)To the third portion, add three drops of sodium sulphate(VI)solution.

Observation	Inference (1mark)
No white ppt	Al^{3+}

(iv)I.To the fourth portion, add three drops of Lead(II)nitrate(IV)solution. **Preserve**

Observation	Inference (1mark)
White ppt	CO_3^{2-}, SO_4^{2-}, SO_3^{2-}, Cl^-,

II.To the portion in (iv) I above , add five drops of dilute hydrochloric acid.

Observation	Inference (1mark)
White ppt persist/remains	SO_4^{2-}, Cl^-,

III.To the portion in (iv) II above, heat to boil.

Observation	Inference (1mark)
White ppt persist/remains	SO_4^{2-},

Note that:

(i)From test above, it can be deduced that solid Y is hydrated aluminium(III)sulphate(VI) solid

(ii)Any ion inferred from an observation **below** must be derived from previous correct observation and inferences **above**. e.g.

Al^{3+} in c(iii) must be correctly inferred in either/or in c(ii) or c(i)**above**

SO_4^{2-} in c(iv)III must be correctly inferred in either/or in c(iv)II or c(iv)I **above**

(iii)Contradiction in observations and inferences should be avoided.e.g.
"White ppt soluble in excess" to infer presence of Al^{3+} ,**Ba^{2+}** ,Pb^{3+}

(iv)Symbols of elements/ions should be correctly capitalized. e.g.
"SO_4^{-2}" is wrong, "sO_4^{2-}" is wrong, "cu^{2+}" is wrong.

Sample solutions of salt were labeled as I,II, III and IV. The actual solutions, not in that order are lead nitrate, zinc sulphate potassium chloride and calcium chloride.

a)When aqueous sodium carbonate was added to each sample separately, a white precipitate was formed in I, III and IV only. Identify solution II.

b)When excess sodium hydroxide was added to each sample separately, a white precipitate was formed in solutions III and I only.

Identify solution I

17.When solids/salts /solutes are added to a solvent ,some dissolve to form a solution.

Solute + Solvent -> Solvent

If a solution has **a lot** of solute dissolved in a solvent ,it is said to be **concentrated**.

If a solution has **little** solute dissolved in a solvent ,it is said to be **dilute**.

There is a limit to how much solute can dissolve in a given /specified amount of solvent/water at a given /specified temperature.

The maximum mass of salt/solid/solute that dissolve in 100g of solvent/water at a specified temperature is called **solubility of a salt.**

When **no more solute can dissolve in a given amount of solvent at a specified temperature**, a saturated solution is formed.

For some salts, on heating, more of the salt/solid/solute dissolve in the saturated solution to form a super saturated solution.

The solubility of a salt is thus calculated from the formula

$$\textbf{Solubility} = \frac{\textbf{Mass of solute/salt/solid} \times 100}{\textbf{Mass/volume of water/solvent}}$$

Practice examples

(a)Calculate the solubility of potassium nitrate(V) if 5.0 g of the salt is dissolved in 50.0cm3 of water.

$$\text{Solubility} = \frac{\text{Mass of solute/salt/solid} \times 100}{\text{Mass/volume of water/solvent}} \Rightarrow \left(\frac{5.0 \times 100}{50.0}\right) = \underline{\mathbf{10.0\ g\ /100g\ H_2O}}$$

(b)Calculate the solubility of potassium chlorate(V) if 50.0 g of the salt is dissolved in 250.0cm3 of water.

$$\text{Solubility} = \underline{\text{Mass of solute/salt/solid} \times 100} \Rightarrow \left(\underline{50.0 \times 100}\right) = \underline{\mathbf{20.0\ g\ /100g\ H_2O}}$$

Mass/volume of water/solvent 250.0

(c)If the solubility of potassium chlorate(V) is 5g/100g H_2O at 80°C,how much can dissolve in 5cm3 of water at 80°C .

Mass of solute/salt/solid = $\frac{\text{Solubility x Mass/volume of water/solvent}}{100}$

=> $\frac{5 \times 5}{100}$ = **0.25g** of $KClO_3$ dissolve

(d)If the solubility of potassium chlorate(V) is 72g/100g H_2O at 20°C,how much can saturate 25g of water at 20°C .

Mass of solute/salt/solid = $\frac{\text{Solubility x Mass/volume of water/solvent}}{100}$

=> $\frac{72 \times 25}{100}$ = **18.0g** of $KClO_3$ dissolve/saturate

(e) 22g of potassium nitrate(V) was dissolved in 40.0g of water at 10°C. Calculate the solubility of potassium nitrate(V) at 10°C.

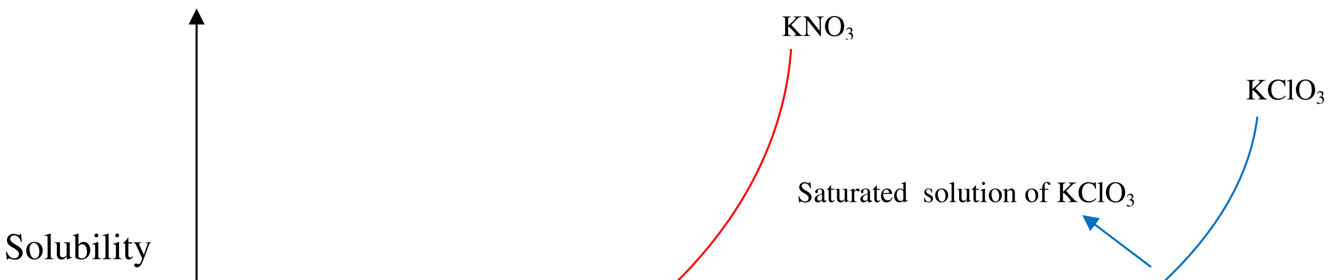
Solubility = $\frac{\text{Mass of solute/salt/solid x 100}}{\text{Mass/volume of water/solvent}}$ =>($\frac{22 \times 100}{40.0}$) = **55.0 g /100g H_2O**

(f)What volume of water should be added to 22.0g of water at 10°C if the solubility of KNO_3 at 10°C is 5.0g/100g H_2O?

Solubility is mass/100g H_2O => 22.0g + x = 100cm3/100g H_2O

X= 100 – 22 = **78** cm3 of H_2O

18. A graph of solubility against temperature is called solubility curve.
It shows the influence of temperature on solubility of different substances/solids/salts.
Some substances dissolve more with increase in temperature while for others dissolve less with increase in temperature



Note:
(i)solubility of KNO_3 and $KClO_3$ increase with increase in temperature.

(ii)solubility of KNO_3 is always higher than that of $KClO_3$ at any specified temperature.

(iii)solubility of NaCl decrease with increase in temperature.
(iv)NaCl has the highest solubility at low temperature while $KClO_3$ has the lowest solubility at low temperature.

(v)At point A both NaCl and KNO_3 are equally soluble.

(vi)At point B both NaCl and $KClO_3$ are equally soluble.

(vii) An area above the solubility curve of the salt shows a **saturated** /supersaturated solution.

(viii) An area below the solubility curve of the salt shows an **unsaturated** solution.

19.(a) For salts whose solubility **increases** with increase in temperature, crystals form when the salt solution at **higher** temperatures is **cooled** to a lower temperature.

(b) For salts whose solubility **decreases** with increase in temperature, crystals form when the salt solution at **lower** temperatures is **heated** to a higher temperature.

The examples below shows determination of the mass of crystals deposited with changes in temperature.

1.The solubility of $KClO_3$ at 100°C is 60g/100g water .What mass of $KClO_3$ will be deposited at:

(i)75 °C if the solubility is now 39g/100g water.

At 100°C = 60.0g

Less at 75°C = - 39.0g

Mass of crystallized out **21.0g**

(i)35 °C if the solubility is now 28 g/100g water.

At 100°C = 60.0g

Less at 35°C = - 28.0.0g

Mass of crystallized out **32.0g**

2. KNO_3 has a solubility of 42 g/100g water at 20°C.The salt was heated and added 38g more of the solute which dissolved at100°C. Calculate the solubility of KNO_3 at 100°C.

Solubility of KNO_3 at 100°C = solubility at 20°C + mass of KNO_3 added

=> 42g + 38g = **80g KNO_3 /100g H_2O**

3. A salt solution has a mass of 65g containing 5g of solute. The solubility of this salt is 25g per 100g water at 20°C. 60g of the salt are added to the solution at 20°C.Calculate the mass of the solute that remain undissolved.

Mass of solvent at 20°C = mass of solution – mass of solute

=> 65 - 5 = **60g**

$$\text{Solubility before adding salt} = \frac{\text{mass of solute x 100}}{\text{Volume of solvent}}$$

$$=> \frac{5 \times 100}{60} = \mathbf{8.3333g/100g}\text{ water}$$

Mass of solute to equalize with solubility = 25 – 8.3333g = **16.6667g**

Mass of solute undissolved = 60.0 - 16.6667g = **43.3333** g

4. Study the table below

Salt	Solubility in gram at

	50^oC	20^oC
KNO_3	90	30
$KClO_3$	20	6

(i)What happens when the two salts are dissolved in water then cooled from 50^oC to 20^oC.

(90 – 30) = 60.0 g of KNO_3 crystals precipitate
(20 – 6) = 14.0 g of $KClO_3$ crystals precipitate

(ii)State the assumption made in (i) above.
Solubility of one salt has no effect on the solubility of the other.

5. **10.0 g of hydrated potassium carbonate (IV) $K_2CO_3.xH_2O$ on heating leave 7.93 of the hydrate.**

(a)Calculate the mass of anhydrous salt obtained.
Hydrated on heating leave anhydrous = **<u>7.93</u>** g

(b)Calculate the mass of water of crystallization in the hydrated salt

Mass of water of crystallization = hydrated – anhydrous
=> 10.0 - 7.93 = **<u>2.07 g</u>**

(c)How many moles of anhydrous salt are there in 10of hydrate? (K= 39.0,C=12.0.O= 16.0)

Molar mass K_2CO_3= 138

$$\text{Moles } K_2CO_3 = \frac{\text{mass of } K_2CO_3}{\text{Molar mass } K_2CO_3} \Rightarrow \frac{7.93}{138} = \mathbf{\underline{0.0515}\ moles}$$

(d)How many moles of water are present in the hydrate for every one mole of K_2CO_3 ? (H=1.0.O= 16.0)

Molar mass H_2O = 18

$$\text{Moles } H_2O = \frac{\text{mass of } H_2O}{\text{Molar mass } H_2O} \Rightarrow \frac{2.07}{18} = \mathbf{\underline{0.115}\ moles}$$

$$\text{Mole ratio } H_2O : K_2CO_3 = \frac{0.115 \text{ moles}}{0.0515 \text{ moles}} \quad \frac{2}{1} = \mathbf{2}$$

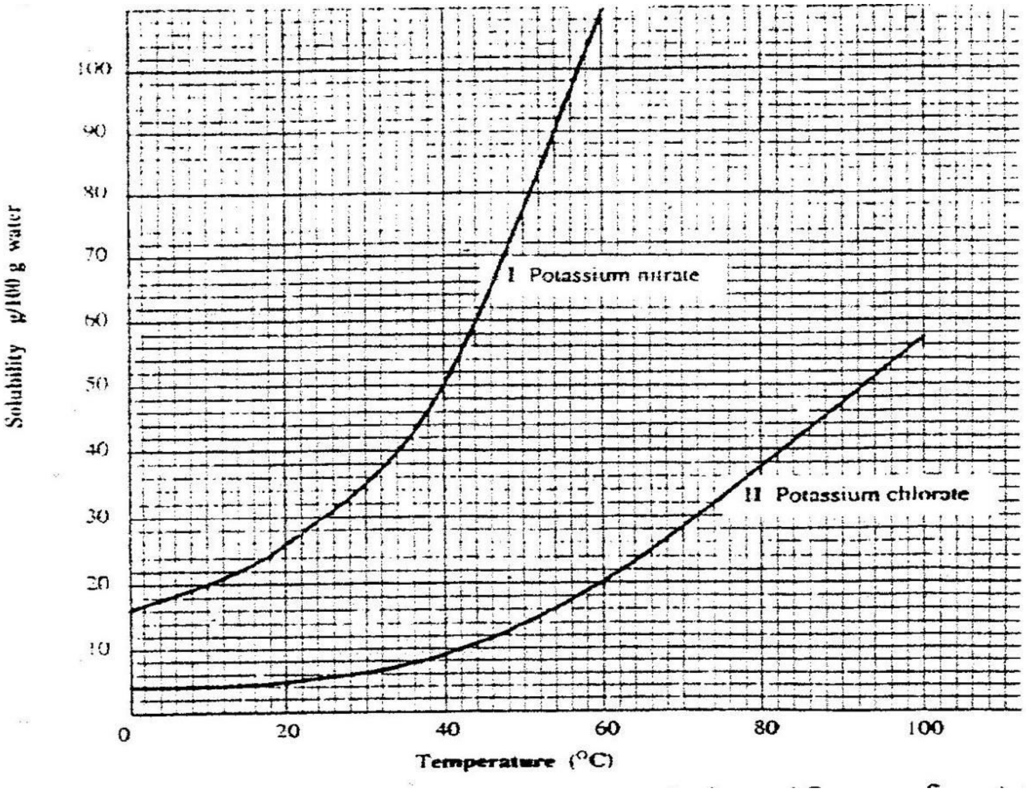
(e)What is the formula of the hydrated salt?

$K_2CO_3\ .\underline{2}\ H_2O$

6. The table below shows the solubility of Potassium nitrate(V) at different temperatures.

Temperature(°C)	5.0	10.0	15.0	30.0	40.0	50.0	60.0
mass KNO_3/ 100g water	15.0	20.0	25.0	50.0	65.0	90.0	120.0

(a)Plot a graph of mass of in 100g water(y-axis) against temperature in °C



(b)From the graph show and determine

(i)the mass of KNO_3 dissolved at:

I. 20°C

From a correctly plotted graph = **32g**

II. 35°C

From a correctly plotted graph = **57g**

III. 55°C

From a correctly plotted graph = **104g**

(ii)the temperature at which the following mass of KNO_3 dissolved:

I. 22g

From a correctly plotted graph =**13.0°C**

II. 30g

From a correctly plotted graph =**17.5°C**

III.100g

From a correctly plotted graph =**54.5°C**

(c)Explain the shape of your graph.

Solubility of KNO_3 increase with increase in temperature/More KNO_3 dissolve as temperature rises.

(d)Show on the graph the supersaturated and unsaturated solutions.

Above the solubility curve write; “supersaturated”
Below the solubility curve write; “unsaturated”

(e)From your graph, calculate the amount of crystals obtained when a saturated solution of KNO_3 containing 180g of the salt is cooled from 80°C to:

I. 20°C

Solubility before heating = 180 g
Less Solubility after heating(from the graph) = 32 g
Mass of KNO_3crystals = **148 g**

II. 35°C

Solubility before heating = 180 g
Less Solubility after heating(from the graph) = 58 g
Mass of KNO_3crystals = **122 g**

III. 55°C

Solubility before heating = 180 g
Less Solubility after heating(from the graph) = 102 g
Mass of KNO_3crystals = **78 g**

7. The table below shows the solubility of salts A and B at various temperatures.

Temperature(°C)	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0
Solubility of A	28.0	31.0	34.0	37.0	40.0	43.0	45.0	48.0	51.0
Solubility of B	13.0	21.0	32.0	46.0	64.0	85.0	110.0	138.0	169.0

(a)On the same axis plot a graph of solubility (y-axis) against temperature for each salt.

(b)At what temperature are the two salts equally soluble.

The point of intersection of the two curves = 24°C

(c)What happens when a mixture of 100g of salt B with 100g if water is heated to 80°C

From the graph, the solubility of B at 80°C is 169g /100g water. All the 100g crystals of B dissolve.

(d)What happens when the mixture in (c) above is then cooled from 50°C to 20°C.

Method I.

Total mass before cooling at 50°C = 100.0 g
(From graph) Solubility/mass after cooling at 20°C = 32.0 g
Mass of crystals deposited **68.0 g**

Method II.

Mass of soluble salt crystals at 50°C added = 100 g
(From graph)Solubility/mass before cooling at 50°C = 85.0 g
Mass of crystals that cannot dissolve at 50°C **15.0** g

(From graph) Solubility/mass before cooling at 50°C = 85.0 g
(From graph) Solubility/mass after cooling at 20°C = 32.0 g
Mass of crystals deposited after cooling **53.0 g**

Total mass of crystals deposited = 15.0 + 53.0 = **68.0 g**

(e)A mixture of 40g of A and 60g of B is added to 10g of water and heated to 70^{o}C.The solution is then allowed to cool to 10^{o}C.Describe clearly what happens.

<u>I.For salt A</u>

Solubility of A before heating = $\frac{\text{mass of A} \times 100}{\text{Volume of water added}}$

=> $\frac{40 \times 100}{10}$ = **400g/100g Water**

(Theoretical)Solubility of A before heating = 400 g
Less (From graph) Solubility of A after heating at 70^{o}C = <u>48g</u>
Mass of crystals that can not dissolve at70^{o}C = **352 g**

(From graph) Solubility of A after heating at 70^{o}C = 48g
Less (From graph) Solubility of A after cooling to 10^{o}C = <u>31g</u>
Mass of crystals that crystallize out on cooling to10^{o}C = **17 g**

Mass of crystals that can not dissolve at70^{o}C = **352 g**
Add Mass of crystals that crystallize out on cooling to10^{o}C = **17 g**
Total mass of A that does not dissolve/crystallize/precipitate = <u>369 g</u>

<u>I.For salt B</u>

Solubility of B before heating = $\frac{\text{mass of B} \times 100}{\text{Volume of water added}}$

=> $\frac{60 \times 100}{10}$ = **600g/100g Water**

(Theoretical)Solubility of B before heating = 600 g
Less (From graph) Solubility of B after heating at 70^{o}C = <u>138g</u>
Mass of crystals that cannot dissolve at70^{o}C = **462 g**

(From graph) Solubility of B after heating at 70^{o}C = 138g
Less (From graph) Solubility of B after cooling to 10^{o}C = <u>21g</u>
Mass of crystals that crystallize out on cooling to10^{o}C = **117 g**

Mass of crystals that cannot dissolve at70^{o}C = **462 g**
Add Mass of crystals that crystallize out on cooling to10^{o}C = **117 g**
Total mass of A that does not dissolve/crystallize/precipitate = <u>579 g</u>

(f)State the assumption made in (e)above

Solubility of one salt has no effect on the solubility of the other

8. When 5.0 g of potassium chlorate (V) was put in 10cm3 of water and heated, the solid dissolves. When the solution was cooled , the temperature at which crystals reappear was noted. Another 10cm3 of water was added and the mixture heated to dissolve then cooled for the crystals to reappear .The table below shows the the results obtained

Total volume of water added(cm3)	10.0	20.0	30.0	40.0	50.0
Mass of $KClO_3$	5.0	5.0	5.0	5.0	5.0
Temperature at which crystals appear	80.0	65.0	55.0	45.0	30.0
Solubility of $KclO_3$	**50.0**	**25.0**	**16.6667**	**12.5**	**10.0**

(a)Complete the table to show the solubility of $KclO_3$ at different temperatures.

(b)Plot a graph of mass of $KClO_3$ per 100g water against temperature at which crystals form.

(c)From the graph, show and determine ;

(i)the solubility of $KClO_3$ at

I. 50°C

From a well plotted graph = 14.5 g $KClO_3$/100g water

II. 35°C

From a well plotted graph = 9.0 g $KclO_3$/100g water

(ii)the temperature at which the solubility is:

I.10g/100g water

From a well plotted graph = 38.0 °C

II.45g/100g water

From a well plotted graph = 77.5 °C

(d)Explain the shape of the graph.

Solubility of $KClO_3$ increase with increase in temperature/more $KclO_3$dissolve as temperature rises.

(e)What happens when 100g per 100g water is cooled to 35.0 °C

Solubility before heating = 100.0

(From the graph) Solubility after cooling = 9.0

Mass of salt precipitated/crystallization = 91.0 g

9. 25.0cm3 of water dissolved various masses of ammonium chloride crystals at different temperatures as shown in the table below.

Mass of ammonium chloride(grams)	4.0	4.5	5.5	6.5	9.0
Temperature at which solid dissolved(°C)	30.0	50.0	70.0	90.0	120.0
Solubility of NH_4Cl	**16.0**	**18.0**	**22.0**	**26.0**	**36.0**

(a)Complete the table
(b)Plot a solubility curve

(c)What happens when a saturated solution of ammonium chloride is cooled from 80°C to 40°C.

(From the graph)Solubility at 80°C = 24.0 g
Less (From the graph)Solubility at 40°C = 16.8 g
Mass of crystallized/precipitated = 7.2 g

20. Solubility and solubility curves are therefore **used**
(i) to know the effect of temperature on the solubility of a salt
(ii)to fractional crystallize two soluble salts by applying their differences in solubility at different temperatures.
(iii)determine the mass of crystal that is obtained from crystallization.

21.Natural fractional crystallization takes place in Kenya/East Africa at:
(i) Lake Magadi during extraction of soda ash(Sodium carbonate) from Trona(sodium sesquicarbonate)
(ii) Ngomeni near Malindi at the Indian Ocean Coastline during the extraction of common salt(sodium chloride).

22.Extraction of soda ash from Lake Magadi in Kenya

Rain water drains underground in the great rift valley and percolate underground where it is heated geothermically.

The hot water dissolves underground soluble sodium compounds and comes out on the surface as alkaline springs which are found around the edges of Lake Magadi in Kenya.

Temperatures around the lake are very high ($30-40^{\circ}C$) during the day.

The solubility of trona decrease with increase in temperature therefore solid crystals of trona grows on top of the lake (upto or more than 30metres thick)

A bucket dredger mines the trona which is then crushed ,mixed with lake liquor and pumped to washery plant where it is further refined to a green granular product called CRS.

The CRS is then heated to chemically decompose trona to soda ash(Sodium carbonate)

Chemical equation

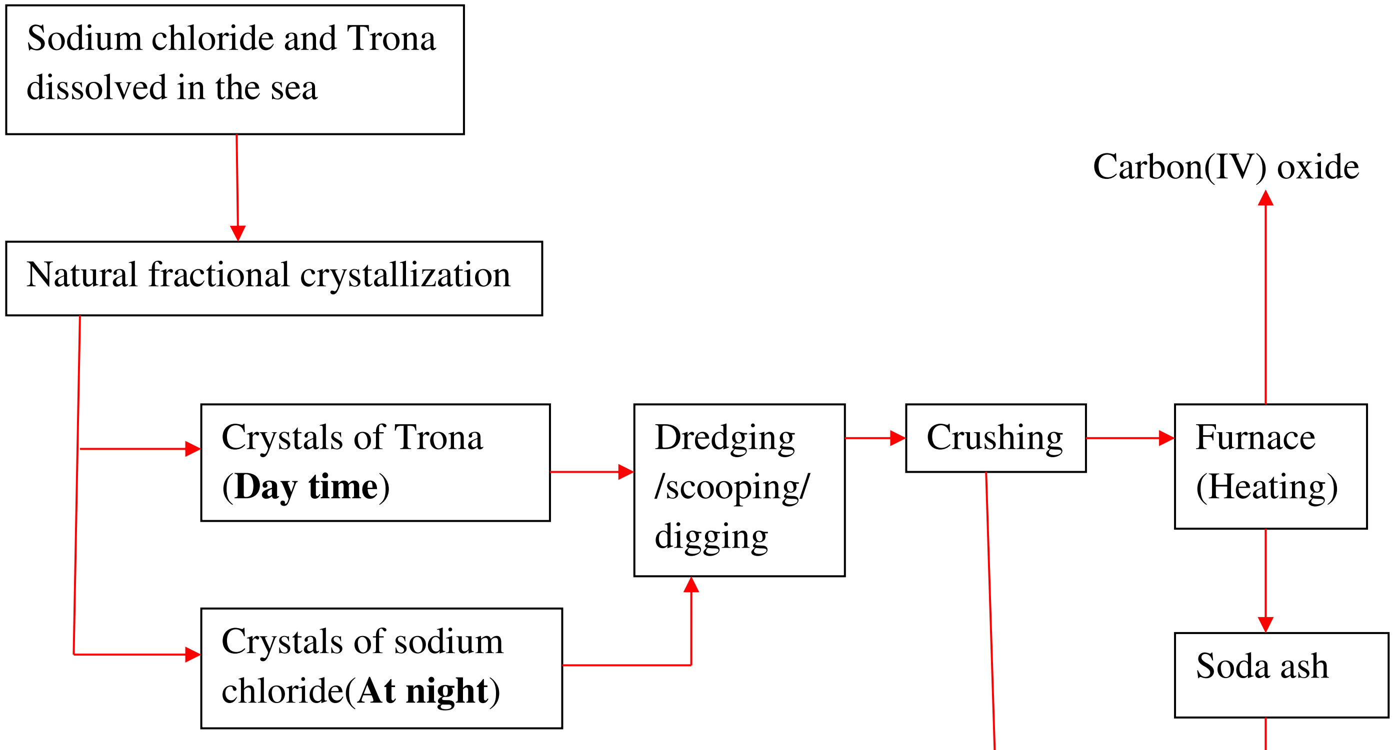
$2Na_2CO_3.NaHCO_3.2H_2O(s) \rightarrow 3Na_2CO_3(s) + CO_2(g) + 5H_2O(l)$

Soda ash(Sodium carbonate) is then stored .It is called Magadi Soda. Magadi Soda is used :

(i) make glass
(ii) for making soapless detergents
(iii) softening hard water.
(iv)

Common salt is colledcted at night because its solubility decreases with decrease in temperature. It is used as salt lick/feed for animals.

Summary flow diagram showing the extraction of Soda ash from Trona



23.Extraction of common salt from Indian Ocean at Ngomeni in Kenya

Oceans are salty.They contain a variety of dissolved salts (about 77% being sodium chloride).
During high tide ,water is collected into shallow pods and allowed to crystallize as evaporation takes place.The pods are constructed in series to increase the rate of evaporation.
At the final pod ,the crystals are scapped together,piled in a heap and washed with brine (concentrated sodium chloride).
It contains **$MgCl_2$** and **$CaCl_2$** . $MgCl_2$ and $CaCl_2$are **hygroscopic**. They absorb water from the atmosphere and form a solution.
This makes table salt damp/wet on exposure to the atmosphere.

24.Some water form lather easily with soap while others do not.
Water which form lather easily with soap is said to be "**soft**"
Water which do not form lather easily with soap is said to be "**hard**"
Hardness of water is caused by the presence of Ca^{2+} and Mg^{2+} ions.
Ca^{2+} and Mg^{2+} ions react with soap to form an **insoluble** grey /white suspension/precipitate called **Scum/ curd.** Ca^{2+} and Mg^{2+} ions in water come from the water sources passing through rocks containing soluble salts of Ca^{2+} and Mg^{2+} e.g. Limestone or gypsum
There are two types of water hardness:
(a)temporary hardness of water
(b)permanent hardness of water

(a)temporary hardness of water

Temporary hardness of water is caused by the presence of dissolved calcium hydrogen carbonate/**$Ca(HCO_3)_2$** and magnesium hydrogen carbonate/**$Mg(HCO_3)_2$**
When rain water dissolve carbon(IV) oxide from the air it forms waek carbonic(IV) acid i.e.

$$CO_2(g) \quad + \quad H_2O(l) \quad -> \quad H_2CO_3(aq)$$

When carbonic(IV) acid passes through limestone/dolomite rocks it reacts to form soluble salts i.e.

In limestone areas; $H_2CO_3(aq) \quad + \quad CaCO_3(s) \quad -> \quad Ca(HCO_3)_2\ (aq)$

In dolomite areas; $H_2CO_3(aq) \quad + \quad MgCO_3(s) \quad -> \quad Mg(HCO_3)_2\ (aq)$

(b)permanent hardness of water

Permanent hardness of water is caused by the presence of dissolved calcium sulphate(VI)/**$CaSO_4$** and magnesium sulphate(VI)/**$Mg\ SO_4$** Permanent hardness of water is caused by water dissolving **$CaSO_4$** and **$MgSO_4$** from ground rocks.

Hardness of water can be removed by the following methods:

(a) Removing temporary hardness of water

(i)Boiling/heating.

Boiling decomposes insoluble calcium hydrogen carbonate/**$Ca(HCO_3)_2$** and magnesium hydrogen carbonate/**$Mg(HCO_3)_2$** to insoluble **$CaCO_3$** and **$MgCO_3$** that precipitate away. i.e

Chemical equation

$$Ca(HCO_3)_2(aq) \quad -> \quad CaCO_3\ (s) \quad + \quad CO_2(g) \quad + \quad H_2O(l)$$

$$Mg(HCO_3)_2(aq) \quad -> \quad MgCO_3\ (s) \quad + \quad CO_2(g) \quad + \quad H_2O(l)$$

(ii)Adding sodium carbonate (IV) /Washing soda.

Since boiling is expensive on a large scale ,a calculated amount of sodium carbonate decahydrate /**$Na_2CO_3.10H_2O$** precipitates insoluble $Ca^{2+}(aq)$ and $Mg^{2+}(aq)$ ions as carbonates to remove **both** temporary and permanent hardness of water .This a double decomposition reaction where **two soluble** salts form an **insoluble** and **soluble** salt. i.e.

(i)with temporary hard water

Chemical equation

$$Na_2CO_3\ (aq) \quad + \quad Ca(HCO_3)_2\,(aq) \quad -> \quad NaHCO_3(aq) \quad + \quad CaCO_3\ (s)$$

$$Na_2CO_3\ (aq) \quad + \quad Mg(HCO_3)_2\,(aq) \quad -> \quad NaHCO_3(aq) + MgCO_3\ (s)$$

Ionic equation

$$CO_3^{2-}\ (aq) \quad + \quad Ca^{2+}\ (aq) \quad -> \quad CaCO_3\ (s)$$

$$CO_3^{2-}\ (aq) + Mg^{2+}\ (aq) \rightarrow MgCO_3\ (s)$$

<u>(ii)with permanent hard water</u>

<u>Chemical equation</u>

$$Na_2CO_3\ (aq) + MgSO_4\ (aq) \rightarrow Na_2SO_4\ (aq) + MgCO_3\ (s)$$
$$Na_2CO_3\ (aq) + CaSO_4\ (aq) \rightarrow Na_2SO_4\ (aq) + MgCO_3\ (s)$$

<u>Ionic equation</u>

$$CO_3^{2-}\ (aq) + Ca^{2+}\ (aq) \rightarrow CaCO_3\ (s)$$
$$CO_3^{2-}\ (aq) + Mg^{2+}\ (aq) \rightarrow MgCO_3\ (s)$$

(iii)Adding calcium (II)hydroxide/Lime water

Lime water/calcium hydroxide removes <u>only temporary</u> hardness of water from by precipitating insoluble calcium carbonate(IV).

<u>Chemical equation</u>

$$Ca(OH)_2\ (aq) + Ca(HCO_3)_2\ (aq) \rightarrow 2H_2O(l) + 2CaCO_3\ (s)$$

Excess of Lime water/calcium hydroxide should not be used because it dissolves again to form soluble calcium hydrogen carbonate(IV) causing the hardness again.

(iv)Adding aqueous ammonia

Aqueous ammonia removes temporary hardness of water by precipitating insoluble calcium carbonate(IV) and magnesium carbonate(IV)

<u>Chemical equation</u>

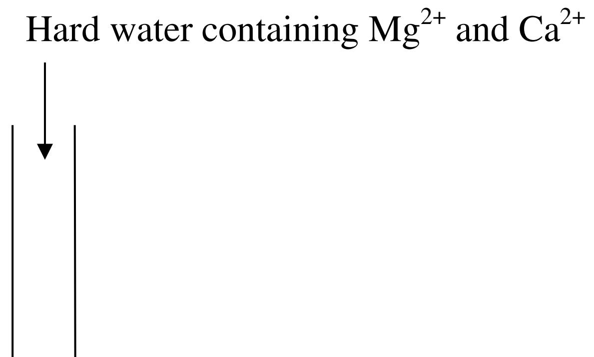
$$2NH_3\ (aq) + Ca(HCO_3)_2\ (aq) \rightarrow (NH_4)_2CO_3(aq) + CaCO_3\ (s)$$
$$2NH_3\ (aq) + Mg(HCO_3)_2\ (aq) \rightarrow (NH_4)_2CO_3(aq) + MgCO_3\ (s)$$

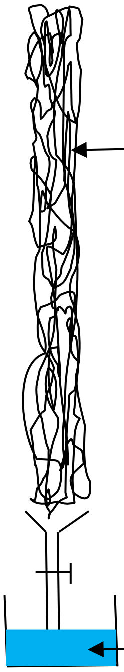
(v)Use of ion-exchange permutit

This method involves packing a chamber with a resin made of insoluble complex of sodium salt called **sodium permutit**.

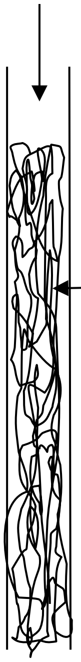
The sodium permutit releases sodium ions that are <u>exchanged</u> with Mg^{2+} and Ca^{2+} ions in hard water making the water to be soft. i.e.

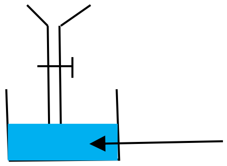
$$Na_2X(aq) + Ca^{2+}\ (aq) \rightarrow Na^{+}\ (aq) + CaX(s)$$
$$Na_2X(aq) + Mg^{2+}\ (aq) \rightarrow Na^{+}\ (aq) + MgX(s)$$





When all the Na+ ions in the resin is fully exchanged with Ca2+ and Ng2+ ions in the permutit column ,it is said to be **exhausted**.
Brine /concentrated sodium chloride solution is passed through the permutit column to regenerated /recharge the column again.





Na^+ ions replace Mg^{2+} and Ca^{2+} to make the water soft.

(vi)Deionization /demineralization

This is an advanced ion exchange method of producing deionized water .Deionized water is extremely pure water made only of hydrogen and oxygen only without any dissolved substances.

Deionization involve using the resins that remove all the cations by using:

(i)A <u>cation exchanger</u> which remove /absorb all the **cations** present in water and leave **only H^+** ions.

(ii)An <u>anion exchanger</u> which remove /absorb all the **anions** present in water and leave **only OH^-** ions.

The H^+(aq) and OH^- (aq) neutralize each other to form <u>pure</u> water.

Chemical equation

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

When exhausted the cation exchanger is regenerated by adding H^+(aq) from sulphuric(VI)acid/hydrochloric acid.

When exhausted the anion exchanger is regenerated by adding OH^-(aq) from sodium hydroxide.

Advantages of hard water

Hard water has the following advantages:

(i)Ca^{2+}(aq) in hard water are useful in bone and teeth formation

(ii) is good for brewing beer

(iii)contains minerals that cause it to have better /sweet taste

(iv)animals like snails and coral polyps use calcium to make their shells and coral reefs respectively.

(v)processing mineral water

Disadvantages of hard water

Hardness of water:

(i)waste a lot of soap during washing before lather is formed.

(ii)causes stains/blemishes/marks on clothes/garments

(iii)causes fur on electric appliances like kettle ,boilers and pipes form decomposition of carbonates on heating .This reduces their efficiency hence more/higher cost of power/electricity.

Sample revision questions

In an experiment, soap solution was added to three separate samples of water. The table below shows the volumes of soap solution required to form lather with 1000cm3 of each sample of water before and after boiling.

	Sample I	Sample II	Sample III
Volume of soap before water is boiled (cm3)	27.0	3.0	10.0
Volume of soap after water is boiled(cm3)	27.0	3.0	3.0

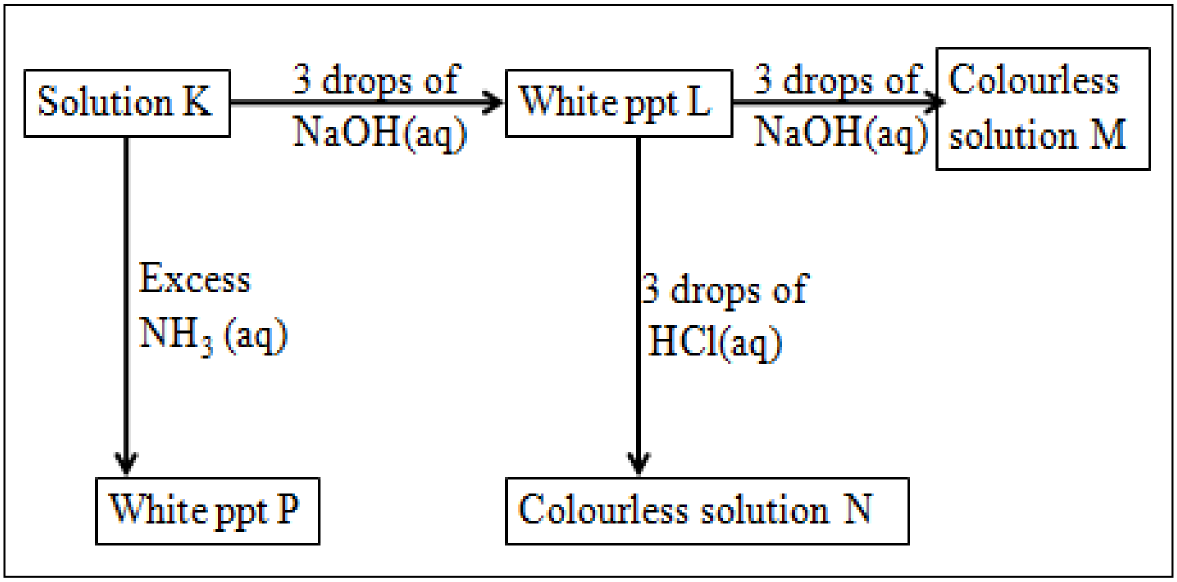
a) Which water sample is likely to be soft? Explain. (2mks)

Sample II: Uses little sample of soap .

c) Name the change in the volume of soap solution used in sample III (1mk)

On heating the sample water become soft bcause it is temporary hard.

2.Study the scheme below and use it to aanswer the questions that follow:



(a)Write the formula of:

(i)Cation in solution K

Al^{3+}

(ii)white ppt L

$Al(OH)_3$

(iii) colourless solution M

$[Al(OH)_4]^-$

(iv) colourless solution N

$AlCl_3$

(v)white ppt P

$Al(OH)_3$

(b)Write the ionic equation for the reaction for the formation of:

(i)white ppt L

$Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$

(v)white ppt P

$Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$

(c)What property is illustrated in the formation of colourless solution M and N.

Amphotellic

19.0.0 ENERGY CHANGES IN CHEMICAL AND PHYSICAL PROCESSES

(25 LESSONS)

1.Introduction to Energy changes

Energy is the capacity to do **work**. There are many/various **forms** of energy like heat, electric, mechanical, and/ or chemical energy.There are two types of energy:

(i)Kinetic Energy(KE) ;the energy in motion.

(ii)Potential Energy(PE); the stored/internal energy.

Energy like matter , is **neither created nor destroyed** but can be transformed /changed from one form to the other/ is interconvertible. This is the **principle of conservation** of energy. e.g. Electrical energy into heat through a filament in bulb.
Chemical and physical processes take place with **absorption** or **evolution/**production of energy mainly in form of **heat**

The study of energy changes that accompany physical/chemical reaction/changes is called **Thermochemistry.** Physical/chemical reaction/changes that involve energy changes are called **thermochemical reactions.** The SI unit of energy is the **Joule**(**J**).Kilo Joules(**kJ**)and megaJoules(**MJ**) are also used. The Joule(J) is defined as the:

(i) quantity of energy transferred when a force of one **newton** acts through a distance of one **metre**.

(ii) quantity of energy transferred when one **coulomb** of electric charge is passed through a potential difference of one **volt**.

All thermochemical reactions should be carried out at standard conditions of:

(i) **298K /25^oC** temperature

(ii)**101300Pa/101300N/m^2 /760mmHg/1** atmosphere pressure.

2.Exothermic and endothermic processes/reactions

Some reactions / processes take place with evolution/production of energy. They are said to be **exothermic** while others take place with **absorption** of energy. They are said to be **endothermic.**

Practically exothermic reactions / processes cause a rise in temperature (by a rise in thermometer reading/mercury or alcohol level rise)

Practically endothermic reactions / processes cause a fall in temperature (by a fall in thermometer reading/mercury or alcohol level decrease)

To demonstrate/illustrate exothermic and endothermic processes/reactions

a) Dissolving Potassium nitrate(V)/ammonium chloride crystals

Procedure:

Measure 20cm3 of water in a beaker. Determine and record its temperature T_1.Put about 1.0g of Potassium nitrate(V) crystals into the beaker. Stir the mixture carefully and note the highest temperature rise /fall T_2.Repeat the whole procedure by using ammonium chloride in place of Potassium nitrate (V) crystals.

Sample results

Temperture (^oC)	**Using Potassium nitrate(V) crystals**	**Using Ammonium chloride crystals**
T_2(Final temperature)	21.0	23.0
T_1 (Initial temperature)	25.0	26.0
Change in temperature(T_2 –T_1)	**4.0**	**3.0**

Note:

(i)Initial(**T_1**) temperature of dissolution of both potassium nitrate(V) crystals and ammonium chloride crystals is **higher** than the final temperature(**T_2**)

(ii) Change in temperature(T_2 –T_1) is **not** a mathematical "**-4.0**" or "**-3.0**".

(iii)Dissolution of both potassium nitrate(V) and ammonium chloride crystals is an **endothermic** process because initial(**T_1**) temperature is **higher** than the final temperature(**T_2**) thus causes a **fall/drop** in temperature.

b) Dissolving concentrated sulphuric(VI) acid/sodium hydroxide crystals

Procedure:

Measure 20cm3 of water in a beaker. Determine and record its temperature T_1.**Carefully** put about 1.0g/four pellets of sodium hydroxide crystals into the beaker. Stir the mixture carefully and note the highest temperature rise /fall T_2.Repeat the whole procedure by using 2cm3 of concentrated sulphuric(VI) acid in place of sodium hydroxide crystals.

CAUTION:

(i)Sodium hydroxide crystals are **caustic** and cause painful blisters on contact with skin.

(ii) Concentrated sulphuric (VI) acid is **corrosive** and cause painful wounds on contact with skin.

Sample results

Temperture (^oC)	**Using Sodium hydroxide pellets**	**Using Concentrated sulphuric(VI) acid**
T_2(Final temperature)	30.0	32.0
T_1 (Initial temperature)	24.0	25.0
Change in temperature($T_2 - T_1$)	**6.0**	**7.0**

Note:

(i)Initial (**T_1**) temperature of dissolution of both concentrated sulphuric (VI) acid and sodium hydroxide pellets is **lower** than the final temperature (**T_2**).

(ii)Dissolution of both Sodium hydroxide pellets and concentrated sulphuric (VI) acid is an **exothermic** process because final (**T_2**) temperature is **higher** than the initial temperature (**T_1**) thus causes a **rise** in temperature.

The above reactions show heat loss **to** and heat gain **from** the surrounding as illustrated by a **rise** and **fall** in temperature/thermometer readings.

Dissolving both potassium nitrate(V) and ammonium chloride crystals causes heat **gain from** the **surrounding** that causes **fall** in thermometer reading.

Dissolving both Sodium hydroxide pellets and concentrated sulphuric (VI) acid causes heat **loss to** the **surrounding** that causes **rise** in thermometer reading.

At the same temperature and pressure ,heat absorbed and released is called enthalpy/ heat content denoted **H.**

Energy change is measured from the heat content/enthalpy of the **final** and **initial** products. It is denoted **ΔH(**delta H).i.e.

Enthalpy/energy/ change in heat content $\Delta H = H_{\textbf{final}} - H_{\textbf{initial}}$

For chemical reactions:

$\Delta H = H_{\textbf{products}} - H_{\textbf{reactants}}$

For exothermic reactions, the heat contents of the **reactants** is **more** than/**higher** than the heat contents of **products**, therefore the ΔH is negative (**-ΔH**)

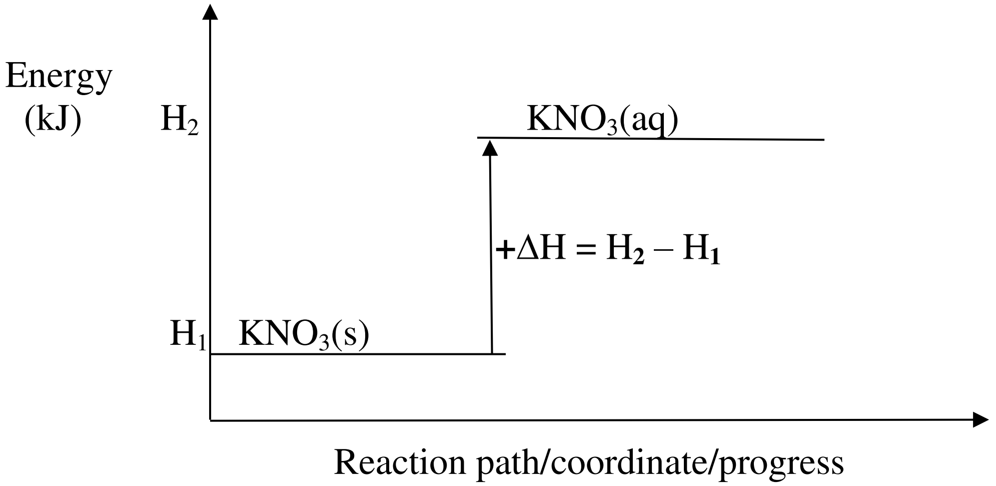
For endothermic reactions, the heat contents of the **reactants** is **less** than/**lower** than the heat contents of **products**, therefore the ΔH is negative (**+ΔH**)

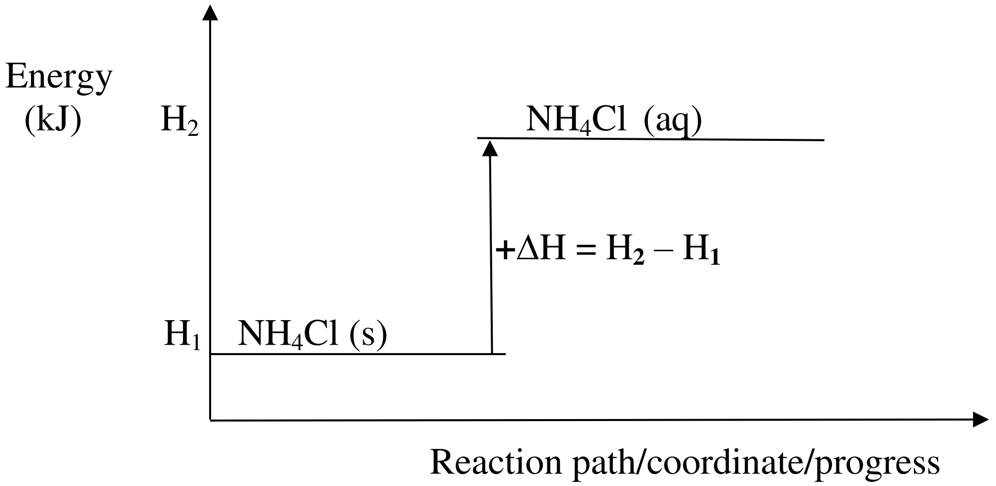
Graphically, in a **sketch** energy level diagram:

(i)For endothermic reactions the heat content of the reactants should be relatively/slightly **lower** than the heat content of the products

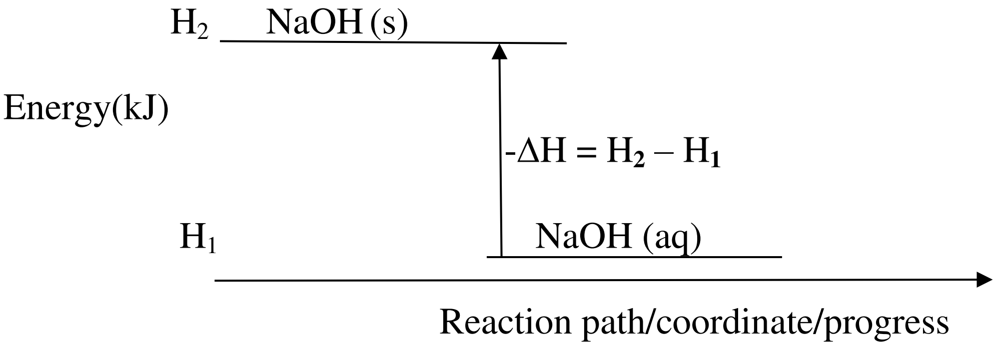
(ii)For exothermic reactions the heat content of the reactants should be relatively/slightly **higher** than the heat content of the products

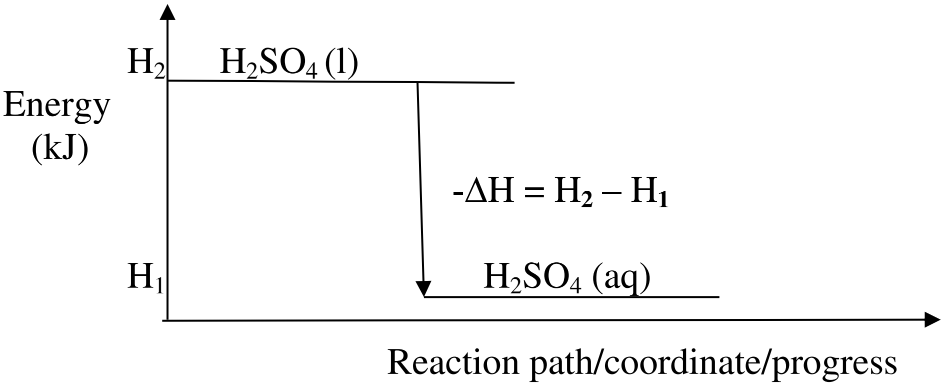
Sketch energy level diagrams for endothermic dissolution





Sketch energy level diagrams for exothermic dissolution





3.Energy changes in physical processes

Melting/freezing/fusion/solidification and **boiling/vaporization/evaporation** are the two physical processes. Melting /freezing point of pure substances is fixed /constant. The boiling point of pure substance depend on **external** atmospheric **pressure**.

Melting/fusion is the physical change of a **solid** to **liquid**. Freezing is the physical change of a **liquid** to **solid**.

Melting/freezing/fusion/solidification are therefore two **opposite** but **same** reversible physical processes. i.e

A (**s**) ========A(**l**)

Boiling/vaporization/evaporation is the physical change of a **liquid** to **gas/vapour**. Condensation/liquidification is the physical change of **gas/vapour** to **liquid**. Boiling/vaporization/evaporation and condensation/liquidification are therefore two **opposite** but **same** reversible physical processes. i.e

B (**l**) ========B(**g**)

Practically

(i) Melting/liquidification/fusion involves **heating** a solid to **weaken** the strong bonds holding the solid particles together. Solids are made up of very strong bonds holding the particles **very close** to each other (**Kinetic Theory of matter**).On heating these particles gain energy/heat from the surrounding heat source to form a liquid with **weaker** bonds holding the particles close together but with some degree of **freedom**. Melting/freezing/fusion is an **endothermic** (+ΔH)process that require/absorb energy from the surrounding.

(ii)Freezing/fusion/solidification involves cooling a a liquid to reform /rejoin the very strong bonds to hold the particles **very close** to each other as solid and thus lose their degree of **freedom** (**Kinetic Theory of matter**). Freezing /fusion / solidification is an **exothermic** (**-**ΔH)process that require particles holding the liquid together to lose energy to the surrounding.

(iii)Boiling/vaporization/evaporation involves **heating** a liquid to completely **break/free** the bonds holding the liquid particles together. Gaseous particles have high degree of **freedom** (**Kinetic Theory of matter**). Boiling /vaporization / evaporation is an **endothermic** (+ΔH) process that require/absorb energy from the surrounding.

(iv)Condensation/liquidification is **reverse** process of boiling /vaporization / evaporation.It involves gaseous particles losing energy to the surrounding to form a liquid.It is an **exothermic**(+ΔH) process.

The quantity of energy required to **change** one mole of a solid **<u>to</u>** liquid or to **form** one mole of a solid **<u>from</u>** liquid at constant temperature is called **molar enthalpy/latent heat of fusion**. e.g.

$H_2O(\mathbf{s})$ -> $H_2O(\mathbf{l})$ ΔH = **+6.0kJ** $\mathbf{mole^{-1}}$ (endothermic process)
$H_2O(\mathbf{l})$ -> $H_2O(\mathbf{s})$ ΔH = **-6.0kJ** $\mathbf{mole^{-1}}$ (exothermic process)

The quantity of energy required to **change** one mole of a liquid **<u>to</u>** gas/vapour or to **form** one mole of a liquid **<u>from</u>** gas/vapour at constant temperature is called **molar enthalpy/latent heat of vapourization**. e.g.

$H_2O(\mathbf{l})$ -> $H_2O(\mathbf{g})$ ΔH = **+44.0kJ** $\mathbf{mole^{-1}}$ (endothermic process)
$H_2O(\mathbf{g})$ -> $H_2O(\mathbf{l})$ ΔH = **-44.0kJ** $\mathbf{mole^{-1}}$ (exothermic process)

The following experiments illustrate/demonstrate practical determination of melting and boiling

a) To determine the boiling point of water

Procedure:

Measure 20cm3 of tap water into a 50cm3 glass beaker. Determine and record its temperature.Heat the water on a strong Bunsen burner flame and record its temperature after every thirty seconds for four minutes.

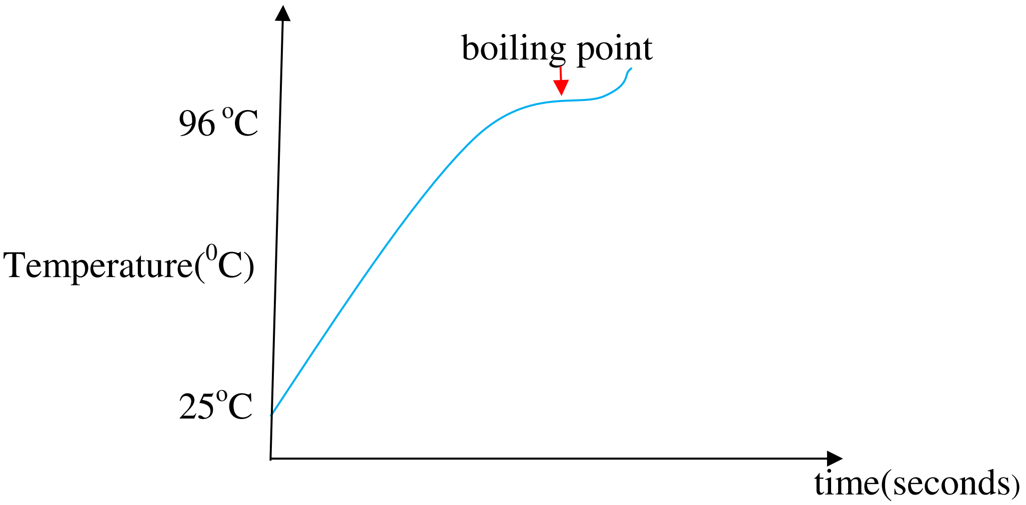
Sample results

Time(seconds)	0	30	60	90	120	150	180	210	240
Temperature(°C)	25.0	45.0	85.0	95.0	96.0	96.0	96.0	97.0	98.0

Questions

1.Plot a graph of temperature against time(y-axis)

Sketch graph of temperature against time



2.From the graph show and determine the boiling point of water

Note:

Water boils at 100°C at sea level/one atmosphere pressure/101300Pa **but** boils at **below** 100°C at **higher** altitudes. The sample results above are from Kiriari Girls High School-Embu County on the slopes of Mt Kenya in Kenya. Water here boils at 96°C.

3.Calculate the molar heat of vaporization of water.(H= 1.0,O= 16.O)

Working:

Mass of water = density x volume => (20 x 1) /1000 = **0.02kg**

Quantity of heat produced

= mass of water x specific heat capacity of water x temperature change

=>0.02kg x 4.2 x (96 – 25) = **5.964kJ**

Heat of vaporization of one mole H_2O = $\frac{\text{Quantity of heat}}{\text{Molar mass of } H_2O}$

=> $\frac{5.964\text{kJ}}{18}$ = **0.3313 kJ mole $^{-1}$**

To determine the melting point of candle wax

Procedure

Weigh exactly 5.0 g of candle wax into a boiling tube. Heat it on a strongly Bunsen burner flame until it completely melts. Insert a thermometer and remove the boiling tube from the flame. Stir continuously. Determine and record the temperature after every 30seconds for four minutes.

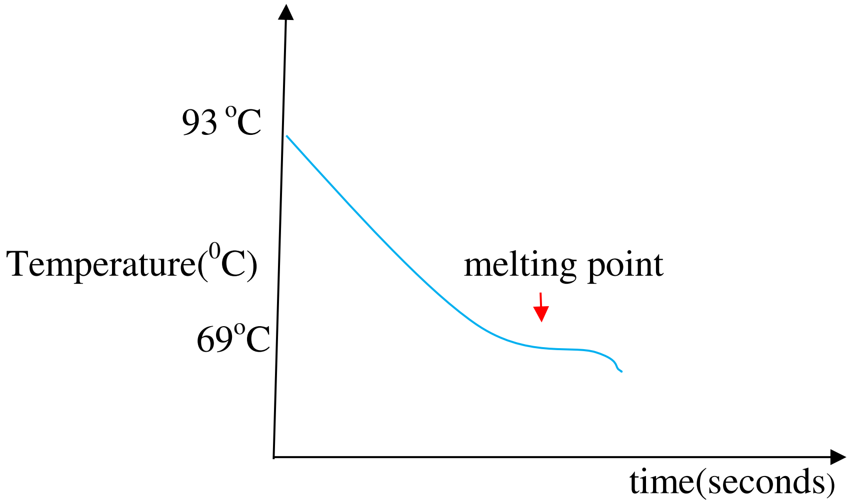
Sample results

Time(seconds)	0	30	60	90	120	150	180	210	240
Temperature(^oC)	93.0	85.0	78.0	70.0	69.0	69.0	69.0	67.0	65.0

Questions

1.Plot a graph of temperature against time(y-axis)

Sketch graph of temperature against time



2.From the graph show and determine the melting point of the candle wax

4.Energy changes in chemical processes

Thermochemical reactions measured at **standard** conditions of 298K(25°C) and 101300Pa/101300Nm^2/ 1 atmospheres/760mmHg/76cmHg produce standard **enthalpies** denoted ΔH^{θ}.

Thermochemical reactions are named from the type of reaction producing the energy change. Below are some thermochemical reactions:

(a) Standard enthalpy/heat of reaction ΔH^{θ}_{r}
(b) Standard enthalpy/heat of combustion ΔH^{θ}_{c}
(c) Standard enthalpy/heat of displacement ΔH^{θ}_{d}
(d) Standard enthalpy/heat of neutralization ΔH^{θ}_{n}
(e) Standard enthalpy/heat of solution/dissolution ΔH^{θ}_{s}
(f) Standard enthalpy/heat of formation ΔH^{θ}_{f}

(a)Standard enthalpy/heat of reaction ΔH^{θ}_{r}

The molar standard enthalpy/heat of reaction may be defined as the energy/heat change when one mole of products is formed at standard conditions

A chemical reaction involves the reactants forming products. For the reaction to take place the bonds holding the reactants must be broken so that new bonds of the products are formed. i.e.

A-**B** + C-D -> **A**-C + **B**-D

Old Bonds **broken** A-B and C-D on reactants

New Bonds **formed** A-C and B-D on products

The energy required to break one mole of a (covalent) bond is called **bond dissociation energy**. The SI unit of bond dissociation energy is **kJmole^{-1}**

The higher the bond dissociation energy the stronger the (covalent)bond

<u>Bond dissociation energies of some (covalent)bonds</u>

Bond	Bond dissociation energy (kJmole^{-1})		Bond dissociation energy (kJmole^{-1})
H-H	431	I-I	151
C-C	436	C-H	413
C=C	612	O-H	463
C ≡ C	836	C-O	358
N = N	945	H-Cl	428
N-H	391	H-Br	366
F-F	158	C-Cl	346
Cl-Cl	239	C-Br	276
Br-Br	193	C-I	338
H-I	299	O=O	497
Si-Si	226	C-F	494

The molar enthalpy of reaction can be calculated from the bond dissociation energy by:

(i)**adding** the total bond dissociation energy of the **reactants**(endothermic process/+**ΔH**) and total bond dissociation energy of the **products**(exothermic process/**-ΔH**).

(ii)**subtracting** total bond dissociation energy of the **reactants from** the total bond dissociation energy of the **products**(exothermic process/**-ΔH less/minus** endothermic process/+**ΔH**).

Practice examples/Calculating ΔH_r

1.Calculate ΔH_r from the following reaction:

a) $H_2(g)$ + $Cl_2(g)$ -> $2HCl(g)$

Working

Old bonds broken (endothermic process/+**ΔH**)

= (H-H + Cl-Cl) => (+431 + (+ 239)) = **+ 670kJ**

New bonds broken (exothermic process/**-ΔH**)

= (2(H-Cl) => (- 428 x 2)) = **-856kJ**

ΔH_r =(+ 670kJ + -856kJ) = $\frac{186}{2}$ kJ = **-93kJ mole^{-1}**

The above reaction has negative **-ΔH** enthalpy change and is therefore practically exothermic.

The thermochemical reaction is thus:

½ $H_2(g)$ + ½ $Cl_2(g)$ -> $HCl(g)$ ΔH_r = -93kJ

b) $CH_4(g)$ + $Cl_2(g)$ -> CH_3Cl + $HCl(g)$

Working

Old bonds broken (endothermic process/+**ΔH**)

= (4(C-H) + Cl-Cl)

=> ((4 x +413) + (+ 239)) = **+ 1891kJ**

New bonds broken (exothermic process/**-ΔH**)

= (3(C-H + H-Cl + C-Cl)

=> ((3 x - 413) + 428 + 346) = -**2013 kJ**

ΔH_r =(+ 1891kJ + -2013 kJ) = **-122 kJ mole^{-1}**

The above reaction has negative **-ΔH** enthalpy change and is therefore practically exothermic.

The thermochemical reaction is thus:

$CH_4(g)$ + $Cl_2(g)$ -> $CH_3Cl(g)$ + $HCl(g)$ ΔH = -122 kJ

c) $CH_2CH_2(g)$ + $Cl_2(g)$ -> CH_3Cl CH_3Cl (g)

Working

Old bonds broken (endothermic process/+**ΔH**)

= (4(C-H) + Cl-Cl + C=C)

=> ((4 x +413) + (+ 239) +(612)) = **+ 2503kJ**

New bonds broken (exothermic process/**-ΔH**)

= (4(C-H + C-C + 2(C-Cl))

=> ((3 x - 413) + -436 +2 x 346 = **-2367 kJ**

ΔH_r =(+ 2503kJ + -2367 kJ) = **+136 kJ mole^{-1}**

The above reaction has negative **+ΔH** enthalpy change and is therefore practically endothermic.

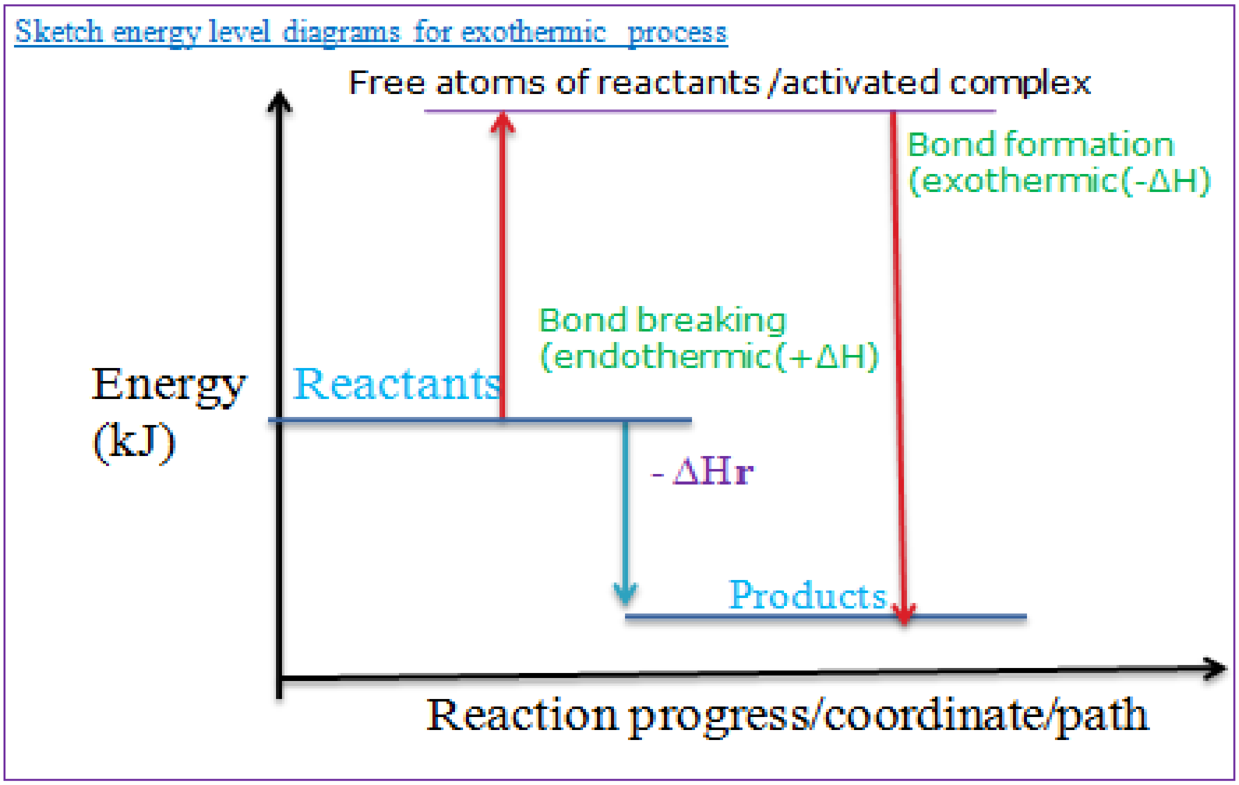
The thermochemical reaction is thus:

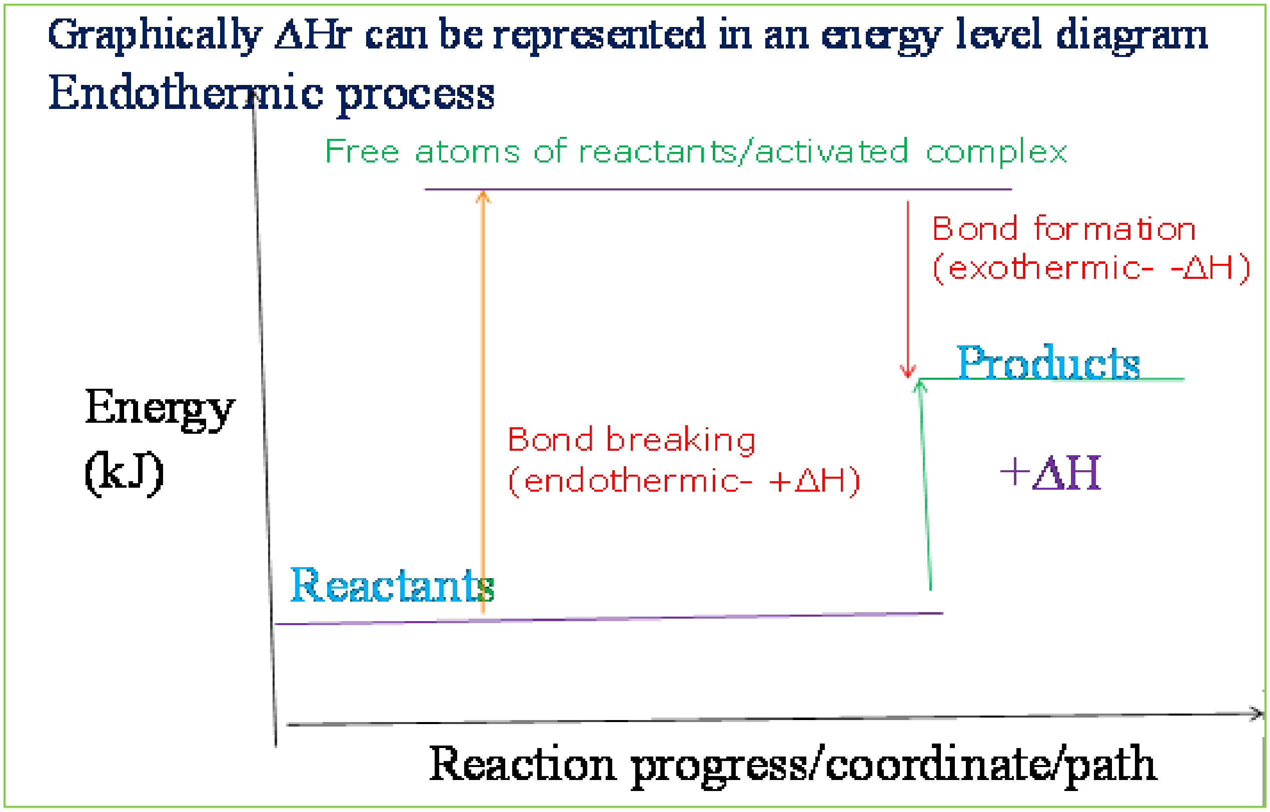
$CH_2CH_2(g)$ + $Cl_2(g)$ -> CH_3Cl CH_3Cl (g) ΔH = +136 kJ

Note that:

(i)a reaction is **exothermic** if the bond dissociation energy of **reactants** is **more** than bond dissociation energy of products.

(ii)a reaction is **endothermic** if the bond dissociation energy of **reactants** is **less** than bond dissociation energy of products.





(b)Standard enthalpy/heat of combustion ΔH^0_c

The molar standard enthalpy/heat of **combustion(ΔH^0_c)** is defined as the energy/heat change when one mole of a substance is burnt in oxygen/excess air at standard conditions.

Burning is the reaction of a substance with oxygen/air. It is an exothermic process producing a lot of energy in form of heat.

A substance that undergoes burning is called a **fuel.** A fuel is defined as the combustible substance which burns in air to give heat energy for domestic or industrial use. A fuel may be **solid** (e.g coal, wood, charcoal) **liquid** (e.g petrol, paraffin, ethanol, kerosene) or **gas** (e.g liquefied petroleum gas/LPG, Water gas-CO_2/H_2, biogas-methane, Natural gas-mixture of hydrocarbons)

To determine the molar standard enthalpy/heat of **combustion(ΔH^0_c)** of ethanol

Procedure

Put 20cm3 of distilled water into a 50cm3 beaker. Clamp the beaker. Determine the temperature of the water T_1.Weigh an empty burner(empty tin with wick).

Record its mass M_1.Put some ethanol into the burner. Weigh again the burner with the ethanol and record its mass M_2. Ignite the burner and place it below the clamped 50cm3 beaker. Heat the water in the beaker for about one minute. Put off the burner. Record the highest temperature rise of the water, T_2. Weigh the burner again and record its mass M_3

Sample results:

Volume of water used	20cm3
Temperature of the water before heating T_1	25.0°C
Temperature of the water after heating T_2	35.0°C
Mass of empty burner M_1	28.3g
Mass of empty burner + ethanol before igniting M_2	29.1g
Mass of empty burner + ethanol after igniting M_3	28.7g

Sample calculations:

1.Calculate:

(a) ΔT the change in temperature

$\Delta \mathbf{T} = T_2 - T_1$ => (35.0°C – 25.0°C) = **10.0°C**

(b) the mass of ethanol used in burning

mass of ethanol used = $M_2 - M_1$ => 29.1g – 28.7g = **0.4g**

(c) the number of moles of ethanol used in burning

$$\text{moles of ethanol} = \frac{\text{mass used}}{\text{molar mass of ethanol}} \Rightarrow \frac{0.4}{46} = \mathbf{0.0087\ /8.7 \times 10^{-3}}\ \text{moles}$$

2. Given that the specific heat capacity of water is 4.2 $kJ^{-1}kg^{-1}K^{-1}$,determine the heat produced during the burning.

Heat produced Δ**H** = mass of water(**m**) x specific heat capacity (**c**)x Δ**T**

$$\Rightarrow 20 \times 4.2 \times 10 = \frac{\mathbf{840\ J}}{1000}\text{oules} = \mathbf{0.84\ kJ}$$

3.Calculate the molar heat of combustion of ethanol

$$\text{Molar heat of combustion } \Delta H_c = \frac{\text{Heat produced } \Delta H}{\text{Number of moles of fuel}}$$

$$\Rightarrow \frac{0.84\ \text{kJ}}{0.0087\ /8.7 \times 10^{-3}\ \text{moles}} = \mathbf{96.5517\ kJmole^{-1}}$$

4.List two sources of error in the above experiment.

(i)Heat loss to the surrounding **lowers** the practical value of the molar heat of combustion of ethanol.

A draught shield tries to minimize the loss by protecting wind from wobbling the flame.

(ii) Heat gain by reaction vessels/beaker **lowers** ΔT and hence ΔH_c

5.Calculate the heating value of the fuel.

$$\text{Heating value} = \frac{\text{molar heat of combustion}}{\text{Molar mass of fuel}} \Rightarrow \frac{96.5517\ \text{kJmole}^{-1}}{46\ \text{g}} = \mathbf{2.0989\ kJg^{-1}}$$

6.Explain other factors used to determine the choice of fuel for domestic and industrial use.

(i) **availability and affordability**-some fuels are more available cheaply in rural than in urban areas at a lower cost.

(ii)**cost of storage and transmission**-a fuel should be easy to transport and store safely. e.g LPG is very convenient to store and use. Charcoal and wood are bulky.

(iii)**environmental effects** –Most fuels after burning produce carbon(IV) oxide gas as a byproduct. Carbon(IV) oxide gas is green house gas that causes global warming. Some other fuel produce acidic gases like sulphur(IV) oxide ,and nitrogen(IV) oxide. These gases cause acid rain. Internal combustion engines exhaust produce lead vapour from leaded petrol and diesel. Lead is carcinogenic.

(iv)**ignition point-**The temperature at which a fuel must be heated before it burns in air is the ignition point. Fuels like petrol have very low ignition point, making it highly flammable. Charcoal and wood have very high ignition point.

7.Explain the methods used to reduce pollution from common fuels.

(i)Planting trees-Plants absorb excess carbon(IV)oxide for photosynthesis and release oxygen gas to the atmosphere.

(ii)using catalytic converters in internal combustion engines that convert harmful/toxic/poisonous gases like carbon(II)oxide and nitrogen(IV)oxide to harmless non-poisonous carbon(IV)oxide, water and nitrogen gas by using platinum-rhodium catalyst along the engine exhaust pipes.

<u>Further practice calculations</u>

1.Calculate the heating value of methanol CH_3OH given that 0.87g of the fuel burn in air to raise the temperature of 500g of water from 20°C to 27°C.(C-12.0,H=1.0 O=16.0).

$$\text{Moles of methanol used} = \frac{\text{Mass of methanol used}}{\text{Molar mass of methanol}} \Rightarrow \frac{0.87\ \text{g}}{32} = \mathbf{0.02718\ moles}$$

Heat produced Δ**H** = mass of water(**m**) x specific heat capacity (**c**)x Δ**T**

$$\Rightarrow 500 \times 4.2 \times 7 = \frac{14700\ \text{Joules}}{1000} = \mathbf{14.7\ kJ}$$

$$\text{Molar heat of combustion } \Delta H_c = \frac{\text{Heat produced } \Delta H}{\text{Number of moles of fuel}}$$

$$\Rightarrow \frac{14.7 \text{ kJ}}{0.02718 \text{ moles}} = \mathbf{540.8389\ kJmole^{-1}}$$

$$\text{Heating value} = \frac{\text{molar heat of combustion}}{\text{Molar mass of fuel}} \Rightarrow \frac{540.8389 \text{ kJmole}^{-1}}{32 \text{ g}} = \mathbf{16.9012\ kJg^{-1}}$$

2. 1.0 g of carbon burn in excess air to raise the temperature of 400g of water by 18°C.Determine the molar heat of combustion and hence the heating value of carbon(C-12.0,).

$$\text{Moles of carbon used} = \frac{\text{Mass of carbon used}}{\text{Molar mass of carbon}} \Rightarrow \frac{1.0}{12}\text{ g} = \mathbf{0.0833\ moles}$$

Heat produced $\Delta\mathbf{H}$ = mass of water(**m**) x specific heat capacity (**c**)x $\Delta\mathbf{T}$

$$\Rightarrow 400 \times 4.2 \times 18 = \frac{30240 \text{ Joules}}{1000} = \mathbf{30.24\ kJ}$$

$$\text{Molar heat of combustion } \Delta H_c = \frac{\text{Heat produced } \Delta H}{\text{Number of moles of fuel}}$$

$$\Rightarrow \frac{30.24 \text{ kJ}}{0.0833 \text{ moles}} = \mathbf{363.0252\ kJmole^{-1}}$$

$$\text{Heating value} = \frac{\text{molar heat of combustion}}{\text{Molar mass of fuel}} \Rightarrow \frac{363.0252 \text{ kJmole}^{-1}}{12 \text{ g}} = \mathbf{30.2521\ kJg^{-1}}$$

(c)Standard enthalpy/heat of displacement ΔH^{θ}_{d}

The molar standard enthalpy/heat of **displacement** ΔH^{θ}_{d} is defined as the energy/heat change when one mole of a substance is displaced from its solution.
A displacement reaction takes place when a more reactive element/with less electrode potential $\mathbf{E^{\theta}}$ / negative E^{θ} /higher in the reactivity/electrochemical series remove/displace another with less reactive element/with higher electrode potential $\mathbf{E^{\theta}}$ / positive E^{θ} /lower in the reactivity/electrochemical series **from** its solution.e.g.

(i)$Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq)$
Ionically: $Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$
(ii)$Fe(s) + CuSO_4(aq) \rightarrow Cu(s) + FeSO_4(aq)$
Ionically: $Fe(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Fe^{2+}(aq)$
(iii)$Pb(s) + CuSO_4(aq) \rightarrow Cu(s) + PbSO_4(\mathbf{s})$

This reaction stops after some time as insoluble $PbSO_4(\mathbf{s})$ coat/cover unreacted lead.

(iv)$Cl_2(g) + 2NaBr(aq) \rightarrow Br_2(aq) + 2NaCl(aq)$
Ionically: $Cl_2(g) + 2Br^-(aq) \rightarrow Br_2(aq) + 2Cl^-(aq)$

Practically, a displacement reaction takes place when a known amount /volume of a solution is added excess of a more reactive metal.

To determine the molar standard enthalpy/heat of **displacement(ΔH^0_d)** of copper

Procedure

Place 20cm3 of 0.2M copper(II)sulphate(VI)solution into a 50cm3 plastic beaker/calorimeter. Determine and record the temperature of the solution T_1.Put all the Zinc powder provided into the plastic beaker. Stir the mixture using the thermometer. Determine and record the highest temperature change to the nearest 0.5°C- T_2 . Repeat the experiment to complete table 1 below

Table 1

Experiment	I	II
Final temperature of solution(T_2)	30.0°C	31.0°C
Final temperature of solution(T_1)	25.0°C	24.0°C
Change in temperature(ΔT)	5.0	6.0

Questions

1.(a) Calculate:

(i)average ΔT

AverageΔT = change in temperature in experiment I and II

$$=> \frac{5.0 + 6.0}{2} = \mathbf{5.5^oC}$$

(ii)the number of moles of solution used

$$\text{Moles used} = \frac{\text{molarity x volume of solution}}{1000} = \frac{0.2 \times 20}{1000} = \mathbf{0.004\ moles}$$

(iii)the enthalpy change ΔH for the reaction

Heat produced Δ**H** = mass of solution(**m**) x specific heat capacity (**c**)x Δ**T**

$$=> 20 \times 4.2 \times 5.5 = \frac{462 \text{ Joules}}{1000} = \mathbf{0.462\ kJ}$$

(iv)State two assumptions made in the above calculations.

Density of solution = density of water = 1gcm^{-3}

Specific heat capacity of solution=Specific heat capacity of solution=4.2 kJ^{-1}kg^{-1}K

This is because the solution is assumed to be **infinite dilute.**

2. Calculate the enthalpy change for one mole of displacement of Cu^{2+} (aq) ions.

Molar heat of displacement ΔH_d = Heat produced ΔH

Number of moles of fuel

$$\Rightarrow \frac{0.462\ \text{kJ}}{0.004} = \mathbf{115.5\ kJmole^{-1}}$$

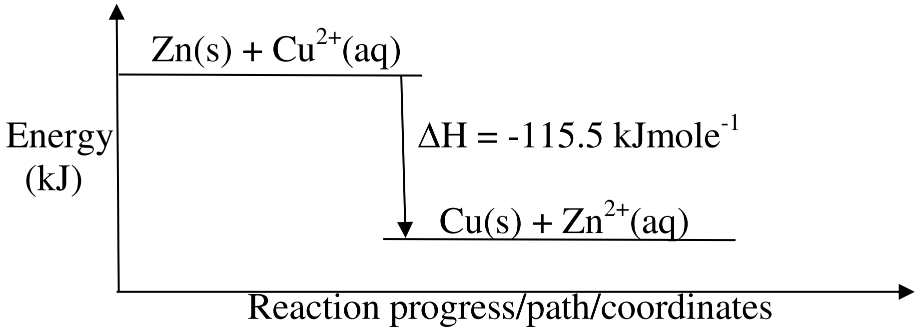
3.Write an ionic equation for the reaction taking place.

$Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$

4.State the observation made during the reaction.

Blue colour of copper(II)sulphate(VI) fades/becomes less blue/colourless.
Brown solid deposits are formed at the bottom of reaction vessel/ beaker.

5.Illustrate the above reaction using an energy level diagram.



6. Iron is less reactive than Zinc. Explain the effect of using iron instead of Zinc on the standard molar heat of displacement ΔH_d of copper(II)sulphate (VI) solution.

No effect. Cu^{2+} (aq) are displaced from their solution.The element used to displace it does not matter.The reaction however faster if a more reactive metal is used.

7.(a)If the standard molar heat of displacement ΔH_d of copper(II)sulphate (VI) solution is 209kJmole^{-1} calculate the temperature change if 50cm3 of 0.2M solution was displaced by excess magnesium.

$$\text{Moles used} = \frac{\text{molarity x volume of solution}}{1000} = \frac{0.2 \times 50}{1000} = \mathbf{0.01\ moles}$$

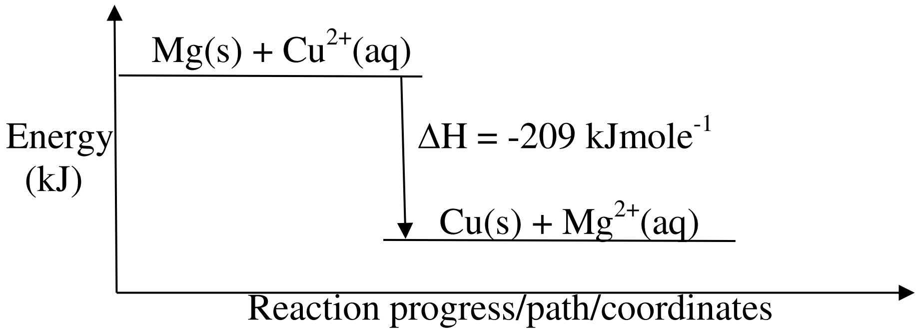
Heat produced ΔH = Molar heat of displacement ΔH_d x Number of moles

$$\Rightarrow 209\text{kJmole}^{-1} \times 0.01 \text{ moles} = \mathbf{2.09\ kJ}$$

$$\Delta T \text{ (change in temperature)} = \frac{\text{Heat produced } \Delta H}{\text{Molar heat of displacement } \Delta H_d \text{ x Number of moles}}$$

$$\Rightarrow \frac{2.09\ \text{kJ}}{0.01 \text{ moles}} = \mathbf{9.9524K}\text{elvin}$$

(b)Draw an energy level diagram to show the above energy changes



8. The enthalpy of displacement ΔH_d of copper(II)sulphate (VI) solution is 12k6kJmole^{-1}.Calculate the molarity of the solution given that 40cm3 of this solution produces 2.204kJ of energy during a displacement reaction with excess iron filings.

$$\text{Number of moles} = \frac{\text{Heat produced } \Delta H}{\text{Molar heat of displacement } \Delta H_d}$$

$$\Rightarrow \frac{2.204\text{ kJ}}{126\text{ moles}} = \mathbf{0.0206moles}$$

$$\text{Molarity of the solution} = \frac{\text{moles x 1000}}{\text{Volume of solution used}}$$

$$= \frac{0.0206\text{moles x 1000}}{40} = \mathbf{0.5167\ M}$$

9. If the molar heat of displacement of Zinc(II)nitrate(V)by magnesium powder is 25.05kJmole^{-1} ,calculate the volume of solution which must be added 0.5 moles solution if there was a 3.0K rise in temperature.

Heat produced ΔH = Molar heat of displacement ΔH_d x Number of moles

=>25.08kJmole^{-1}x 0.5 moles = **1.254 kJ** x 1000 **=1254J**

$$\text{Mass of solution } (\mathbf{m}) = \frac{\text{Heat produced } \mathbf{\Delta H}}{\text{specific heat capacity } (\mathbf{c}) \text{x } \mathbf{\Delta T}}$$

$$\Rightarrow \frac{1254J}{4.2 \text{ x } 3} = \mathbf{99.5238\ g}$$

Volume = mass x density = 99.5238 g x 1 = **99.5238cm3**

Note: The solution assumes to be too dilute /infinite dilute such that the density and specific heat capacity is assumed to be that of water.

Graphical determination of the molar enthalpy of displacement of copper

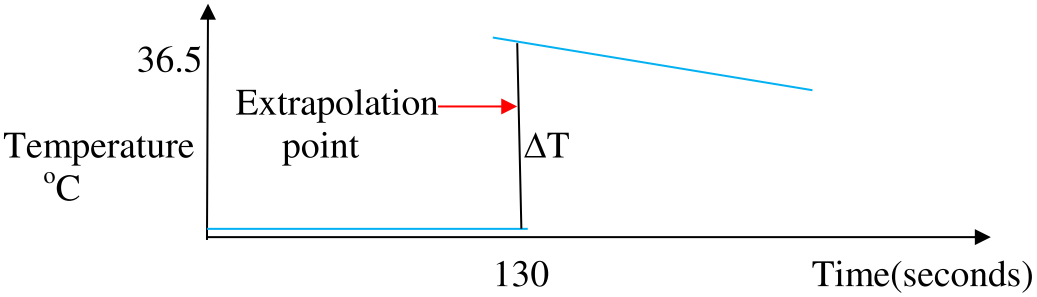
Procedure:

Place 20cm3 of 0.2M copper(II)sulphate (VI) solution into a calorimeter/50cm3 of plastic beaker wrapped in cotton wool/tissue paper.
Record its temperature at time T= 0.
Stir the solution with the thermometer carefully and continue recording the temperature after every 30 seconds .
Place all the (1.5g) Zinc powder provided.
Stir the solution with the thermometer carefully and continue recording the temperature after every 30 seconds for five minutes.
Determine the highest temperature change to the nearest 0.5°C.

Sample results

Time °C	0.0	30.0	60.0	90.0	120.0	150.0	180.0	210.0	240.0	270.0
Temperature	25.0	25.0	25.0	25.0	25.0	xxx	36.0	35.5	35.0	34.5

Sketch graph of temperature against time



Questions

1. **Show and determine the change in temperature ΔT**

From a well constructed graph ΔT= T2 –T1 at **150** second by **extrapolation**

$$\Delta T = 36.5 - 25.0 = 11.5°C$$

2.Calculate the number of moles of copper(II) sulphate(VI)used given the molar heat of displacement of Cu^{2+} (aq)ions is $125kJmole^{-1}$

Heat produced Δ**H** = mass of solution(**m**) x specific heat capacity (**c**)x Δ**T**

$$=> 20 \times 4.2 \times 11.5 = \frac{966 \text{ Joules}}{1000} = \mathbf{0.966\ kJ}$$

$$\text{Number of moles} = \frac{\text{Heat produced } \Delta H}{\text{Molar heat of displacement } \Delta H_d}$$

$$=> \frac{.966 \text{ kJ}}{125 \text{ moles}} = \mathbf{0.007728moles} \quad \mathbf{7.728 \times 10^{-3}moles}$$

2. **What was the concentration of copper(II)sulphate(VI) in moles per litre.**

$$\text{Molarity} = \frac{\text{moles x 1000}}{\text{Volume used}} \Rightarrow \frac{7.728 \times 10^{-3}\text{moles x 1000}}{20} = \mathbf{0.3864M}$$

4.The actual concentration of copper(II)sulphate(VI) solution was 0.4M.Explain the differences between the two.

Practical value is **lower** than theoretical. Heat/energy **loss** to the surrounding and that absorbed by the reaction vessel **decreases** ΔT hence **lowering** the practical number of moles and molarity against the theoretical value

5.a) In an experiment to determine the molar heat of reaction when magnesium displaces copper ,0.15g of magnesium powder were added to 25.0cm^3 of 2.0M copper (II) chloride solution. The temperature of copper (II) chloride solution was 25^{o}C.While that of the mixture was 43^{o}C.
i)Other than increase in temperature, state and explain the observations which were made during the reaction.(3mks)

ii)Calculate the heat change during the reaction (specific heat capacity of the solution = 4.2jg^{-1}k^{-1}and the density of the solution = 1g/cm^3(2mks)

iii)Determine the molar heat of displacement of copper by magnesium.(Mg=24.0).
iv)Write the ionic equation for the reaction.(1mk)

v)Sketch an energy level diagram for the reaction.(2mks)

b)Use the reduction potentials given below to explain why a solution containing copper ions should not be stored in a container made of zinc.

$Zn^{2+}_{(aq)} + 2e \rightarrow Zn_{(s)}$; $E^{\phi} = -0.76v$
$Cu^{2+}_{(aq)} + 2e \rightarrow Cu_{(s)}$; $E^{\phi} = +0.34v$ (2mks)

(c)Standard enthalpy/heat of neutralization ΔH^0_n

The molar standard enthalpy/heat of **neutralization** ΔH^0_n is defined as the energy/heat change when one mole of a H^+ (H_3O^+)ions react completely with one mole of OH^- ions to form one mole of H_2O/water.
Neutralization is thus a reaction of an acid /H^+ (H_3O^+)ions with a base/alkali/ OH^- ions to form salt and water only.

Strong acids/bases/alkalis are completely dissociated to **many** free ions(H^+ /H_3O^+ and OH^- ions).
Weak acids/bases/alkalis are partially dissociated to **few** free ions(H^+ (H_3O^+ and OH^- ions) and exist **more** as molecules.
Neutralization is an exothermic(-ΔH) process.The enrgy produced during neutralization depend on the amount of free ions (H^+ H_3O^+ and OH^-)ions existing in the acid/base/alkali reactant:

(i)for weak acid-base/alkali neutralization,some of the **energy** is used to dissociate /ionize the **molecule** into free H^+ H_3O^+ and OH^- ions therefore the overall energy evolved is comparatively **lower/lesser/smaller** than strong acid / base/ alkali neutralizations.

(ii) (i)for strong acid/base/alkali neutralization, no **energy** is used to dissociate /ionize since **molecule** is wholly/fully dissociated/ionized into free H^+ H_3O^+ and OH^- ions.The overall energy evolved is comparatively **higher/more** than weak acid-base/ alkali neutralizations. For strong acid-base/alkali neutralization, the enthalpy of neutralization is **constant** at about **57.3**kJmole^{-1} irrespective of the acid-base used. This is because ionically:

$OH^-(aq)+ H^+(aq) \rightarrow H_2O(l)$ for any wholly dissociated acid/base/alkali
Practically ΔH^θ_n can be determined as in the examples below:

To determine the molar enthalpy of neutralization ΔH_n of Hydrochloric acid

Procedure

Place 50cm3 of 2M hydrochloric acid into a calorimeter/200cm3 plastic beaker wrapped in cotton wool/tissue paper. Record its temperature T_1.Using a clean measuring cylinder, measure another 50cm3 of 2M sodium hydroxide. Rinse the bulb of the thermometer in distilled water. Determine the temperature of the sodium hydroxide T_2.Average T_2 andT_1 to get the initial temperature of the mixture T_3.

Carefully add all the alkali into the calorimeter/200cm3 plastic beaker wrapped in cotton wool/tissue paper containing the acid. Stir vigorously the mixture with the thermometer.

Determine the highest temperature change to the nearest 0.5°C T_4 as the final temperature of the mixture. Repeat the experiment to complete table 1.

Table I . **Sample results**

Experiment	I	II
Temperature of acid T_1 (°C)	22.5	22.5
Temperature of base T_2 (°C)	22.0	23.0
Final temperature of solution T_4(°C)	35.5	36.0
Initial temperature of solution T_3(°C)	22.25	22.75

Temperature change(T_5)	13.25	13.75

(a)Calculate T_6 the average temperature change

$T_6 = \frac{13.25 + 13.75}{2} = 13.5\,^{o}C$

(b)Why should the apparatus be very clean?

Impurities present in the apparatus reacts with acid /base lowering the overall temperature change and hence ΔH^{θ}_{n}.

(c)Calculate the:

(i)number of moles of the acid used

number of moles = $\frac{\text{molarity x volume}}{1000}$ => $\frac{2 \text{ x } 50}{1000}$ = **0.1moles**

(ii)enthalpy change ΔH of neutralization.

ΔH = (**m**)mass of solution(acid+base) x (**c**)specific heat capacity of solution x Δ**T**(T_6) => (50 +50) x 4.2 x 13.5 = **5670J**oules = **5.67kJ**

(iii) the molar heat of neutralization the acid.

$\Delta H_n = \frac{\text{Enthalpy change } \Delta H}{\text{Number of moles}}$ => $\frac{5.67\text{kJ}}{0.1\text{moles}}$ = **56.7kJ mole^{-1}**

(c)Write the ionic equation for the reaction that takes place

$OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$

(d)The theoretical enthalpy change is 57.4kJ. Explain the difference with the results above.

The theoretical value is higher

Heat/energy loss to the surrounding/environment lowers Δ**T**/T_6 and thus ΔH_n

Heat/energy is absorbed by the reaction vessel/calorimeter/plastic cup lowers ΔT and hence ΔH_n

(e)Compare the ΔH_n of the experiment above with similar experiment repeated with neutralization of a solution of:

(i) potassium hydroxide with nitric(V) acid

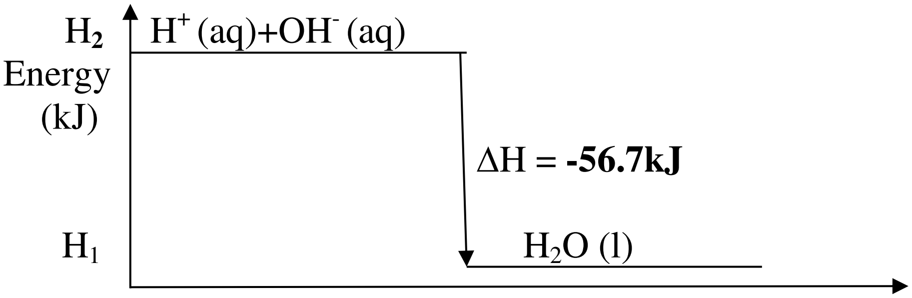
The results would be the same/similar.

Both are neutralization reactions of strong acids and bases/alkalis that are fully /wholly dissociated into many free H^+ / H_3O^+ and OH^- ions.

(ii) ammonia with ethanoic acid

The results would be lower/ΔH_n would be less.
Both are neutralization reactions of weak acids and bases/alkalis that are partially /partly dissociated into few free H^+ / H_3O^+ and OH^- ions. Some energy is used to ionize the molecule.

(f)Draw an energy level diagram to illustrate the energy changes



Reaction path/coordinate/progress

Theoretical examples

1.The molar enthalpy of neutralization was experimentary shown to be 51.5kJ per mole of 0.5M hydrochloric acid and 0.5M sodium hydroxide. If the volume of sodium hydroxide was 20cm3, what was the volume of hydrochloric acid used if the reaction produced a 5.0°C rise in temperature?

Working:

Moles of sodium hydroxide = $\frac{\text{molarity x volume}}{1000}$ => $\frac{0.5\text{ M x }20\text{cm3}}{1000}$ = **0.01 moles**

Enthalpy change ΔH **=** $\frac{\Delta H_n}{\text{Moles sodium hydroxide}}$ => $\frac{51.5}{0.01\text{ moles}}$ = **0.515kJ**

Mass of base + acid = $\frac{\text{Enthalpy change } \Delta H \text{ in Joules}}{\text{Specific heat capacity x } \Delta T}$

=> $\frac{0.515\text{kJ x }1000}{4.2 \text{ x } 5}$ = **24.5238**g

Mass/volume of HCl = Total volume – volume of NaOH

=>24.5238 - 20.0 = **4.5238 cm3**

3. **ΔH_n of potassium hydroxide was practically determined to be 56.7kJmole^{-1}.Calculate the molarity of 50.0 cm3 potassium hydroxide used to neutralize 25.0cm3 of dilute sulphuric(VI) acid raising the temperature of the solution from 10.0°C to 16.5°C.**

ΔH = (**m**)mass of solution(acid+base) x (**c**)specific heat capacity of solution x **ΔT**

=> (50 +25) x 4.2 x 6.5 = **2047.5J**oules

Moles potassium hydroxide = $\frac{\text{Enthalpy change } \Delta H}{\Delta H_n}$

$\frac{2047.5\text{Joules}}{56700\text{Joules}}$ = **0.0361 moles**

Molarity of KOH = $\frac{\text{moles x 1000}}{\text{Volume used}}$ => $\frac{0.0361 \text{ moles x } 1000}{50\text{cm3}}$ = **0.722M**

3.Determine the specific heat capacity of a solution of a solution mixture of 50.0cm3 of 2M potassium hydroxide neutralizing 50.0cm3 of 2M nitric(V) acid if a 13.25^{o}C rise in temperature is recorded.(1mole of potassium hydroxide produce 55.4kJ of energy)

Moles of potassium hydroxide = $\frac{\text{molarity KOH x volume}}{1000}$

=> $\frac{2 \text{ M x } 50\text{cm3}}{1000}$ = **0.1 moles**

Enthalpy change ΔH **=** ΔH_n x Moles potassium hydroxide

=> 55.4kJ x 0.1 moles = 5.54kJ x 1000=**5540J**oules

Specific heat capacity = $\frac{\text{Enthalpy change } \Delta H \text{ in Joules}}{\text{Mass of base + acid x } \Delta T}$

=> $\frac{5540}{(50+50) \text{ x } 13.25}$ = **4.1811J^{-1}g^{-1}K^{-1}**

Graphically ΔH_n can be determined as in the example below:

Procedure

Place 8 test tubes in a test tube rack .Put 5cm3 of 2M sodium hydroxide solution into each test tube.

Measure 25cm3 of 1M hydrochloric acid into 100cm3 plastic beaker.

Record its initial temperature at volume of base =0. Put one portion of the base into the beaker containing the acid.

Stir carefully with the thermometer and record the highest temperature change to the nearest 0.5^{o}C.

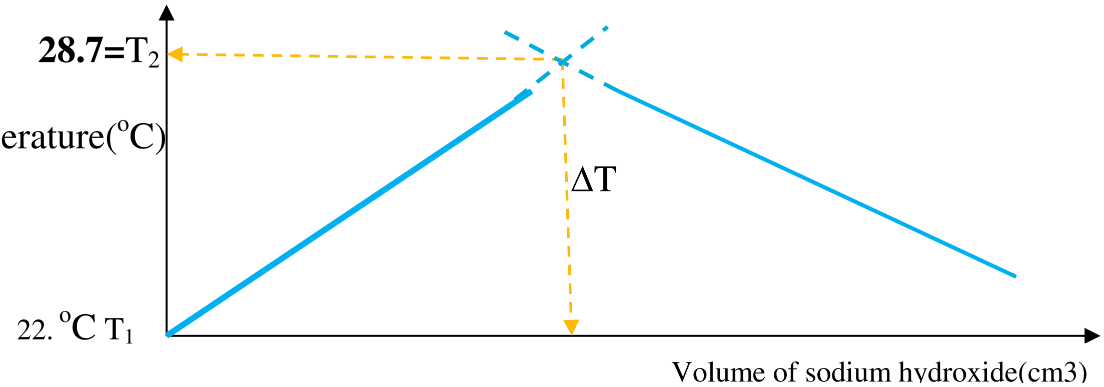
Repeat the procedure above with other portions of the base to complete table 1 below

Table 1:Sample results.

Volume of acid(cm3)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Volume of alkali(cm3)	0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
Final temperature(°C)	**22.0**	**24.0**	**26.0**	**28.0**	**28.0**	**27.0**	**26.0**	**25.0**	**24.0**
Initial temperature(°C)	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**	**22.0**
Change in temperature	**0.0**	**2.0**	**4.0**	**6.0**	**6.0**	**5.0**	**4.0**	**3.0**	**2.0**

(a)Complete the table to determine the change in temperature.

(b)Plot a graph of volume of sodium hydroxide against temperature change.



From the graph show and determine :

(i)the highest temperature change ΔT

ΔT =T_2-T_1 => highest temperature-T_2 (from extrapolating a correctly plotted graph) less lowest temperature at volume of base=0 :T_1

=>ΔT = 6.7 – 0.0 = **6.7°C**

(ii)the volume of sodium hydroxide used for complete neutralization

From a correctly plotted graph – **16.75cm3**

(c)Calculate the number of moles of the alkali used

$$\text{Moles NaOH} = \frac{\text{molarity x volume}}{1000} \Rightarrow \frac{2M \text{ x } 16.75cm3}{1000} = \mathbf{0.0335\ moles}$$

(d)Calculate ΔH for the reaction

ΔH = mass of solution(acid+base) x c x ΔT

$$\Rightarrow (25.0 + 16.75) \text{ x } 4.2 \text{ x } 6.7 = \frac{1174.845\ J}{1000} = \mathbf{1.174845kJ}$$

(e)Calculate the molar enthalpy of neutralization of the alkali.

$$\Delta H_n = \frac{\Delta H_n}{\text{Number of moles}} = \frac{1.174845kJ}{0.0335} = \mathbf{35.0701kJ}$$

(d)Standard enthalpy/heat of solution ΔH^{θ}_{s}

The standard enthalpy of solution $\Delta H^{\theta}_{s}$is defined as the energy change when one mole of a substance is dissolve in excess distilled water to form an infinite dilute solution. An infinite dilute solution is one which is **too** dilute to be diluted further.

Dissolving a solid involves two processes:

(i) **breaking** the **crystal** of the solid into **free ions**(cations and anion).This process is the **opposite** of the **formation** of the crystal itself. The energy required to form one mole of a crystal structure from its **gaseous ions** is called **Lattice energy**/heat/enthalpy of lattice ($\Delta \mathbf{H_l}$). Lattice energy /heat/enthalpy of lattice (ΔH_l) is an endothermic process (+**ΔHl**).

The table below shows some $\Delta \mathbf{H_l}$ in kJ for the process $MX(s) \rightarrow M^+(g) + X^-(g)$

	Li	Na	K	Ca	Mg
F	+1022	+900	+800	+760	+631
Cl	+846	+771	+690	+2237	+2493
Br	+800	+733	+670	+2173	+2226

(ii)**surrounding** the free ions by polar **water** molecules. This process is called **hydration.** The energy produced when one mole of ions are completely hydrated is called **hydration energy**/ heat/enthalpy of hydration($\Delta \mathbf{H_h}$).Hydration energy /enthalpy of hydration(ΔH_h) is an **exothermic** process(ΔH_h).

The table below shows some ΔH_h in kJ for some ions;

ion	Li^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	Br^-
ΔH_h	-1091	-406	-322	-1920	-1650	-506	-364	-335

The **sum** of the **lattice** energy **+**$\Delta \mathbf{H_l}$ (endothermic) and **hydration** energy **-**$\Delta \mathbf{H_h}$ (exothermic) gives the heat of solution**-**$\Delta \mathbf{H_s}$

$\Delta \mathbf{H_s} = \Delta \mathbf{H_l} + \Delta \mathbf{H_h}$

Note

Since ΔH_l is an endothermic process and ΔH_h is an exothermic process then ΔH_s is**:**

(i)**exothermic** if $\Delta \mathbf{H_l}$ is **less** than $\Delta \mathbf{H_h}$ and hence a solid **dissolve** easily in water.

(ii)**endothermic** if $\Delta \mathbf{H_l}$ is **more** than $\Delta \mathbf{H_h}$ and hence a solid does not **dissolve** easily in water.

(a)Dissolving sodium chloride crystal/s:

(i) **NaCl** **----**breaking the crystal into free ions---**>** **Na^+(g)+ Cl^-(g)** ΔH_l **=+771 kJ**

(ii) Hydrating the ions;

$Na^+(g)$ + **aq** -> Na(aq) **ΔHh = - 406 kJ**

$Cl^-(g)$ + aq -> $Cl^-(aq)$ **ΔHh = - 364 kJ**

$\Delta H_s = \Delta H_h + \Delta H_s$ -> (- 406 kJ + - 364 kJ) + +771 kJ = **+ 1.0 $kJmole^{-1}$**

NaCl does not **dissolve** easily in water because overall **ΔH_s** is **endothermic**

Solubility of NaCl therefore increases with increase in temperature.
Increase in temperature increases the energy to break the crystal lattice of NaCl to free $Na^+(g)$+ $Cl^-(g)$

(b)Dissolving magnesium chloride crystal/s// $MgCl_2$ (s) ->$MgCl_2$ (aq)

(i) $MgCl_2$ --breaking the crystal into free ions**-->**$Mg^{2+}(g)$+ $2Cl^-(g)$ ΔH_l =+2493 kJ
(ii) Hydrating the ions;

$Mg^{2+}(g)$ + aq -> $Mg^{2+}(g)$ (aq) ΔHh = - 1920 kJ

$2Cl^-(g)$ + aq -> $2Cl^-(aq)$ ΔHh = (- 364 x 2) kJ

$\Delta H_s = \Delta H_h + \Delta H_s$ -> (- 1920 kJ + (- 364 x 2 kJ)) + +2493 kJ = **-155.0 $kJmole^{-1}$**

$MgCl_2$ (s) **dissolve** easily in water because overall **ΔH_s** is **exothermic** .
Solubility of $MgCl_2$ (s) therefore decreases with increase in temperature.

(c)Dissolving Calcium floride crystal/s// CaF_2 (s) -> CaF_2 (aq)
(i) **CaF_2 -->**$Ca^{2+}(g)$+ $2F^-(g)$ ΔH_l =+760 kJ
(ii) Hydrating the ions;

$Ca^{2+}(g)$ + aq -> $Ca^{2+}(g)$ (aq) ΔHh = - 1650 kJ

$2F^-(g)$ + aq -> $2F^-(aq)$ ΔHh = (- 506 x 2) kJ

$\Delta H_s = \Delta H_h + \Delta H_s$ -> (- 1650 kJ + (- 506 x 2 kJ)) + +760 kJ = **-1902.0 $kJmole^{-1}$**

CaF_2 (s) **dissolve** easily in water because overall **ΔH_s** is **exothermic** .
Solubility of CaF_2 (s) therefore decreases with increase in temperature.

(d)Dissolving magnesium bromide crystal/s// $MgBr_2$ (s) ->$MgBr_2$ (aq)

(i) $MgCl_2$ --breaking the crystal into free ions**-->**$Mg^{2+}(g)$+ $2Br^-(g)$ ΔH_l =+2226 kJ
(ii) Hydrating the ions;

$Mg^{2+}(g)$ + aq -> $Mg^{2+}(g)$ (aq) ΔHh = - 1920 kJ

$2Br^-(g)$ + aq -> $2Br^-(aq)$ ΔHh = (- 335x 2) kJ

$\Delta H_s = \Delta H_h + \Delta H_s$ -> (- 1920 kJ + (- 335 x 2 kJ)) + +2226 kJ = **-364.0 $kJmole^{-1}$**

$MgBr_2$ (s) **dissolve** easily in water because overall **ΔH_s** is **exothermic** .
Solubility of $MgBr_2$(s) therefore decreases with increase in temperature.

Practically the heat of solution can be determined from dissolving known amount /mass/volume of solute in known mass /volume of water/solvent.

From the temperature of solvent **before** and **after** dissolving the change in temperature(ΔT) during dissolution is determined.

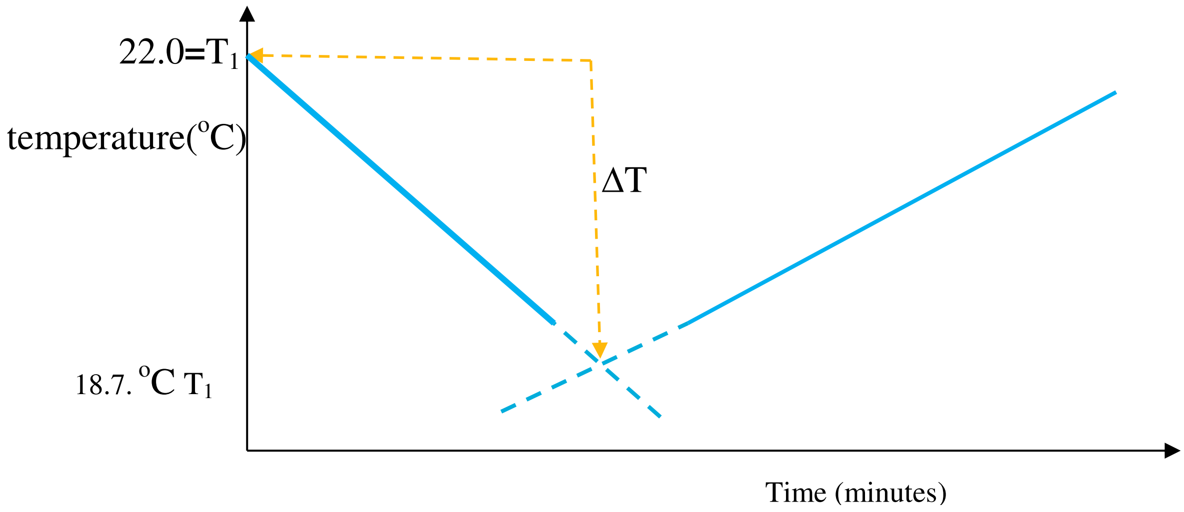
To determine the ΔH_s ammonium nitrate

Place 100cm3 of distilled water into a plastic beaker/calorimeter. Determine its temperature and record it at time =0 in table I below.
Put all the 5.0g of ammonium nitrate (potassium nitrate/ammonium chloride can also be used)provided into the plastic beaker/calorimeter, stir using a thermometer and record the highest temperature change to the nearest 0.5°Cafter every ½ minute to complete table I.
Continue stirring the mixture throughout the experiment.

Sample results: Table I

Time (minutes)	0.0	½	1	1 ½	2	2 ½	3	3 ½
Temperature()°C	**22.0**	**21.0**	**20.0**	**19.0**	**19.0**	**19.5**	**20.0**	**20.5**

(a)Plot a graph of temperature against time(x-axis)



(b)From the graph show and determine the highest temperature change ΔT

$\Delta T = T_2 - T_1$ => lowest temperature-T_2 (from extrapolating a correctly plotted graph) less highest temperature at volume of base=0 :T_1

$=> \Delta T = 18.7 - 22.0 =$ **3.3^0C**

(c)Calculate the number of moles of ammonium nitrate(V) used

$$\text{Moles } NH_4NO_3 = \frac{\text{mass used}}{\text{Molar mass}} => \frac{5.0}{80} = \mathbf{0.0625\ moles}$$

(d)Calculate ΔH for the reaction

$\Delta H = \text{mass of water x c x } \Delta T$

$$-> 100 \text{ x } 4.2 \text{ x } 3.3 = \mathbf{+}\frac{1386\text{ J}}{1000} = \mathbf{+1.386kJ}$$

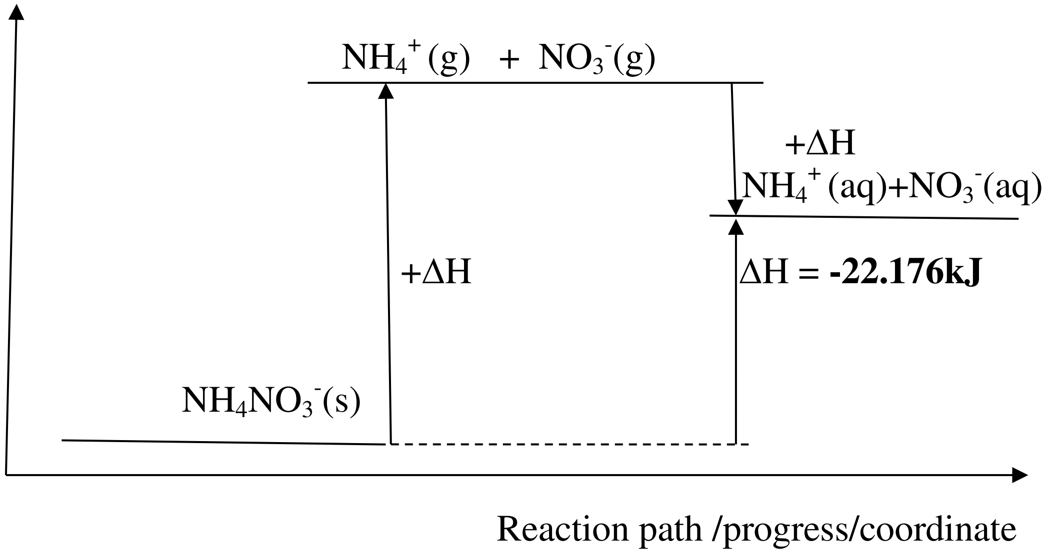
(e)Calculate the molar enthalpy of dissolution of ammonium nitrate(V).

$$\Delta H_s = \frac{\Delta H}{\text{Number of moles}} = \frac{+1.386\text{kJ}}{0.0625\text{ moles}} = +\ 22.176\text{kJ mole}^{-1}$$

(f)What would happen if the distilled water was heated before the experiment was performed.

The ammonium nitrate(V)would take less time to dissolves. Increase in temperature reduces lattice energy causing endothermic dissolution to be faster

(g)Illustrate the process above in an energy level diagram



(h) 100cm3 of distilled water at 25°C was added carefully 3cm3 concentrated sulphuric(VI)acid of density 1.84gcm^{-3}.The temperature of the mixture rose from 25^{0}C to 38°C.Calculate the molar heat of solution of sulphuric(VI)acid (S=32.0,H=1.0,0=16.0)

Working

Molar mass of H_2SO_4 = 98g

Mass of H_2SO_4= Density x volume => $1.84 gcm^{-3}$ x 3cm3 = **5.52 g**

Mass of H_2O = Density x volume => $1.00 gcm^{-3}$ x 100cm3 = **100 g**

Moles of H_2SO_4= $\frac{\text{mass}}{\text{Molar mass of } H_2SO_4}$ => $\frac{5.52\text{ g}}{98\text{g}}$ = **0.0563 moles**

Enthalpy change ΔH= (mass of acid + water) x specific heat capacity of water x ΔT

=> (100 +5.52 g) x 4.2 x 13°C = $\frac{5761.392 \text{ J}}{1000}$ = **5.761392 kJ**

ΔH_s of H_2SO_4= $\frac{\Delta H}{\text{Moles of } H_2SO_4}$ => $\frac{5.761392 \text{ kJ}}{0.0563 \text{ moles}}$ = **-102.33378kJmoles^{-1}**

(e)Standard enthalpy/heat of formation ΔH^{θ}_{f}

The molar enthalpy of formation ΔH^{θ}_{f} is defined as the energy change when one mole of a compound is formed from its elements at 298K(25°C) and 101325Pa(one atmosphere)pressure. ΔH^{θ}_{f} is practically difficult to determine in a school laboratory.

It is determined normally determined by applying Hess’ law of constant heat summation.

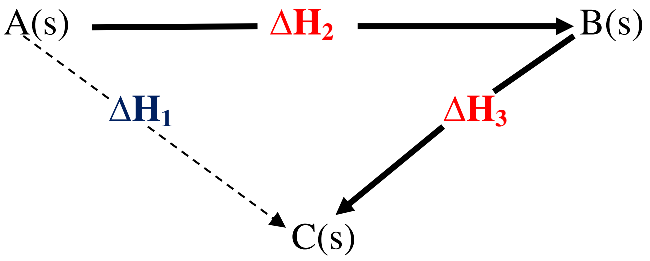
Hess’ law of constant heat summation states that **“the total enthalpy/heat/energy change of a reaction is the same regardless of the route taken from reactants to products at the same temperature and pressure”.**

Hess’ law of constant heat summation is as a result of a series of experiments done by the German Scientist Henri Hess(1802-1850).

He found that the total energy change from the reactants to products was the same irrespective of the intermediate products between. i.e.

$$A(s) \xrightarrow{\Delta \mathbf{H_1}} C(s) \quad = \quad A(s) \xrightarrow{\Delta \mathbf{H_2}} B(s) \xrightarrow{\Delta \mathbf{H_3}} C(s)$$

Applying Hess’ law of constant heat summation then:



The above is called an **energy cycle diagram**. It can be used to calculate any of the missing energy changes since:

(i) $\Delta H_1 = \Delta H_2 + \Delta H_3$
(ii) $\Delta H_2 = \Delta H_1 + -\Delta H_3$
(iii) $\Delta H_3 = -\Delta H_1 + \Delta H_2$

Examples of applying Hess' law of constant heat summation

1.Calculate the molar enthalpy of formation of methane (CH_4) given that ΔH^{θ}_{c} of carbon-graphite is -393.5kJmole^{-1},Hydrogen is -285.7 kJmole^{-1} and that of methane is 890 kJmole^{-1}

Working

Carbon-graphite ,hydrogen and oxygen can react to first form methane.

Methane will then burn in the oxygen present to form carbon(IV)oxide and water.

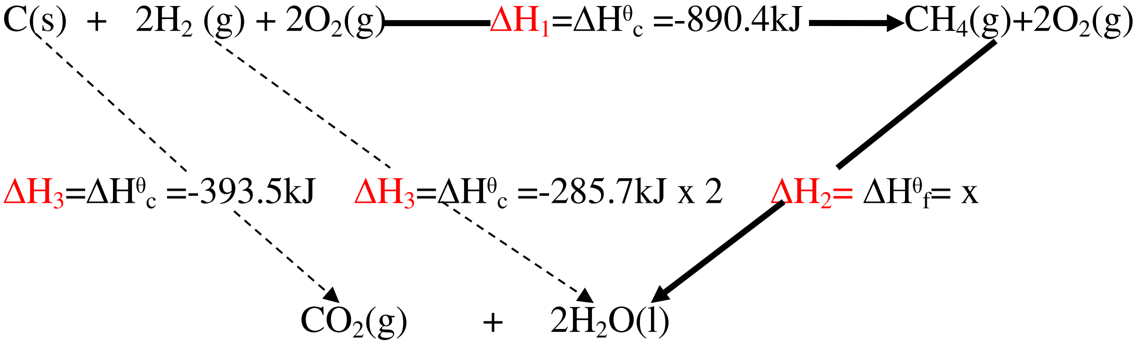
Carbon-graphite can burn in the oxygen to form carbon(IV)oxide.

Hydrogen can burn in the oxygen to form water.

$C(s) + 2H_2(g) + 2O_2(g) \xrightarrow{\Delta H_1} CH_4(g) + 2O_2(g) \xrightarrow{\Delta H_2} \mathbf{CO_2(g) + 2H_2O(l)}$

$C(s) + 2H_2(g) + 2O_2(g) \xrightarrow{\Delta H_3} \mathbf{CO_2(g) + 2H_2O(l)}$

Energy cycle diagram



Substituting:

$\Delta H_3 = \Delta H_1 + \Delta H_2$

$-393.5 + (-285.7 \times 2) = -890.4\text{kJ} + x$

$x = -74.5 \text{ kJ}$

Heat of formation ΔH^{θ}_{f} CH_4 = -74.5 kJmole^{-1}

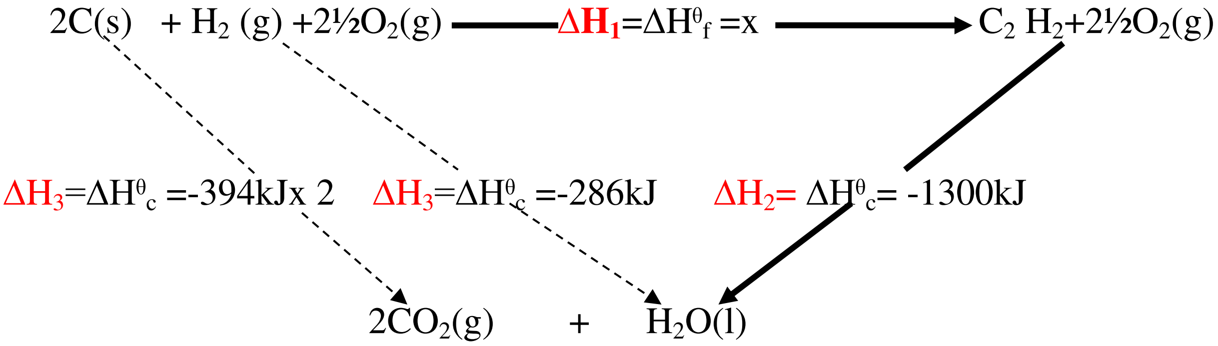
2. Calculate the molar enthalpy of formation of ethyne (C_2H_2) given : ΔH^{θ}_{c} of carbon-graphite = -394kJmole^{-1},Hydrogen = -286 kJmole^{-1} , (C_2H_2) = -1300 kJmole^{-1}

Working

Carbon-graphite ,hydrogen and oxygen can react to first form ethyne.
Ethyne will then burn in the oxygen present to form carbon(IV)oxide and water.
Carbon-graphite can burn in the oxygen to form carbon(IV)oxide.

Hydrogen can burn in the oxygen to form water.
$2C(s) + H_2(g) + 2\frac{1}{2}O_2(g)$ --**ΔH_1**--> $C_2H_2(g) + 2\frac{1}{2}O_2(g)$ --**ΔH_2**--> **$CO_2(g) + H_2O(l)$**
$2C(s) + H_2(g) + 2\frac{1}{2}O_2(g)$ --**ΔH_3**--> 2**$CO_2(g) + H_2O(l)$**

Energy cycle diagram



Substituting:

$\Delta H_3 = \Delta H_1 + \Delta H_2$
(-394 x 2) + -286 = -1300kJ + x
x = +244 kJ
Heat of formation ΔH^{θ}_{f} CH_4 = **+244 kJmole^{-1}**

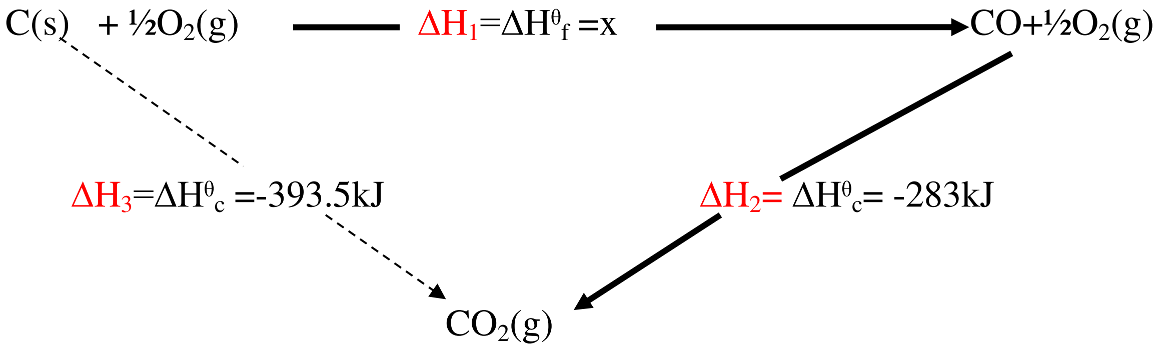
3. Calculate the molar enthalpy of formation of carbon(II)oxide (CO) given : ΔH^{θ}_{c} of carbon-graphite = -393.5kJmole^{-1}, ΔH^{θ}_{c} of carbon(II)oxide (CO)= -283 kJmole^{-1}

Working

Carbon-graphite reacts with oxygen first to form carbon (II)oxide (CO).
Carbon(II)oxide (CO) then burn in the excess oxygen to form carbon(IV)oxide.
Carbon-graphite can burn in excess oxygen to form carbon (IV) oxide.

$C(s) + \frac{1}{2}O_2(g) \text{ --}\mathbf{\Delta H_1}\text{--> } CO(g) + \frac{1}{2}O_2(g) \text{ --}\mathbf{\Delta H_2}\text{--> } \mathbf{CO_2(g)}$
$C(s) + O_2(g) \text{ --}\mathbf{\Delta H_3}\text{--> } \mathbf{CO_2(g)}$

Energy cycle diagram

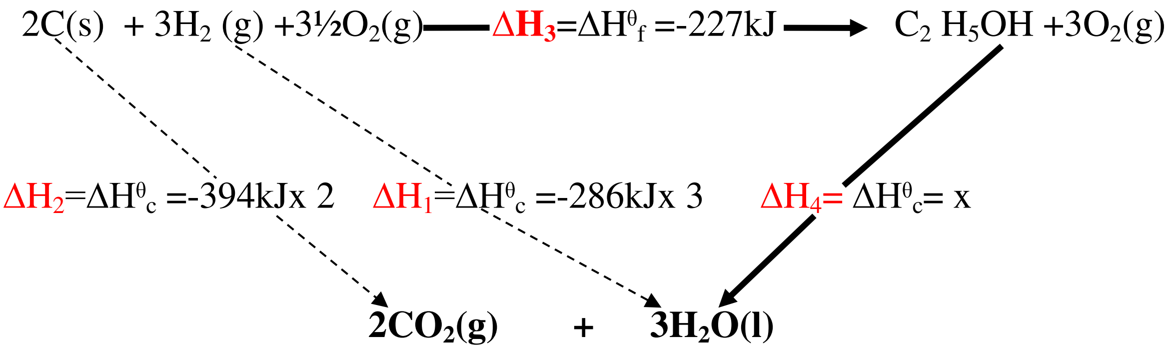


Substituting:

$\Delta H_3 = \Delta H_1 + \Delta H_2$
$-393.5kJ = -283kJ + x$
$x = -110\ kJ$
Heat of formation ΔH^θ_f CO = -110 $kJmole^{-1}$

4.Study the information below:
$\mathbf{H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l) \quad \Delta H_1 = -286\ kJmole^{-1}}$
$\mathbf{C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H_2 = -393\ kJmole^{-1}}$
$\mathbf{2C(s) + H_2(g) + \frac{1}{2} O_2(g) \rightarrow C_2H_5OH(l) \quad \Delta H_3 = -277\ kJmole^{-1}}$
Use the information to calculate the molar enthalpy of combustion ΔH_4 of ethanol

Energy cycle diagram



Substituting:
$\Delta H_1 + \Delta H_2 = \Delta H_3 + \Delta H_4$
$(-394 \times 2) + -286 \times 3 = -277 + x$
$\Delta H_4 = -1369\ kJ$

Heat of combustion ΔH^{θ}_{c} C_2H_5OH = **-1369 kJmole^{-1}**

5.Given the following information below:

$CuSO_4$(s) + (aq) -> $CuSO_4$(aq) ΔH=-66.1 kJmole^{-1}
$CuSO_4$(s) + (aq) + $5H_2O$(l)-> $CuSO_4.5H_2O$ (aq) ΔH=-77.4 kJmole^{-1}

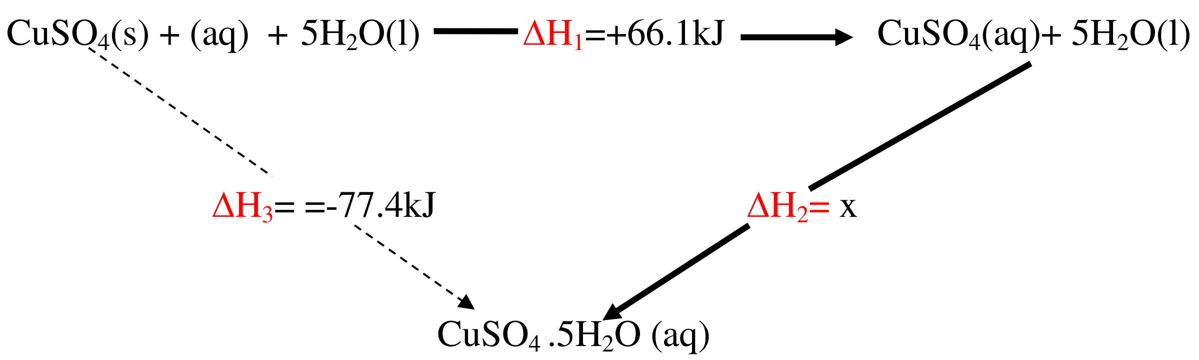
Calculate ΔH for the reaction;

$CuSO_4$(aq) + $5H_2O$-> $CuSO_4.5H_2O$ (aq) ΔH=-77.4 kJmole^{-1}

Working

$CuSO_4$(s) + (aq) + $5H_2O$(l)-> $CuSO_4$(aq)+ $5H_2O$(l)-> $CuSO_4.5H_2O$ (aq)
$CuSO_4$(s) + (aq) + $5H_2O$(l)-> $CuSO_4.5H_2O$ (aq)

Energy cycle diagram



Substituting:

$\Delta H_3 = \Delta H_2 + \Delta H_1$
(-77.4kJ = x + +66.1kJ
ΔH_4 = **-10.9 kJ**
Heat of dissolution of $CuSO_4$ = **-10.9kJmole^{-1}**

Practically, Hess' law can be applied practically as in the following examples

a)Practical example 1

Determination of the enthalpy of formation of $CuSO_4.5H_2O$

Experiment I

Weigh accurately 12.5 g of copper(II)sulphate(VI)pentahydrate. Measure 100cm3 of distilled water into a beaker. Determine its temperature T_1 .Put all the crystals of the copper(II)sulphate(VI)pentahydrate carefully into the beaker. Stir using a thermometer and determine the highest temperature change T_2 Repeat the procedure again to complete table 1.

Table 1:Sample results

Experiment	I	II
Highest /lowest temperature T_2	27.0	29.0
Initial temperature T_1	24.0	25.0
Change in temperature ΔT	3.0	4.0

Experiment II

Weigh accurately 8.0g of anhydrous copper(II)sulphate(VI). Measure 100cm3 of distilled water into a beaker. Determine its temperature T_1 .Put all the crystals of the copper(II)sulphate(VI)pentahydrate carefully into the beaker. Stir using a thermometer and determine the highest temperature change T_2 Repeat the procedure again to complete table II.

Table II :Sample results

Experiment	I	II
Highest /lowest temperature T_2	26.0	27.0
Initial temperature T_1	25.0	25.0
Change in temperature ΔT	1.0	2.0

Questions

(a)Calculate the average ΔT in

(i)Table I

$$\Delta T = T_2 - T_1 \Rightarrow \frac{3.0 + 4.0}{2} = \mathbf{3.5\,^{o}C}$$

(ii)Table II

$$\Delta T = T_2 - T_1 \Rightarrow \frac{1.0 + 2.0}{2} = \mathbf{1.5\,^{o}C}$$

(b)Calculate the number of moles of solid used in:

(i)Experiment I

$$\text{Moles of } CuSO_4.5H_2O = \frac{\text{Mass}}{\text{Molar mass}} \Rightarrow \frac{12.5}{250} = \mathbf{0.05\ moles}$$

(ii)Experiment II

$$\text{Moles of } CuSO_4 = \frac{\text{Mass}}{\text{Molar mass}} \Rightarrow \frac{8.0}{160} = \mathbf{0.05\ moles}$$

(c)Calculate the enthalpy change for the reaction in:

(i)Experiment I

Enthalpy change of $CuSO_4.5H_2O$= mass of Water(**m**) x **c** x **ΔT**

$$\Rightarrow \frac{100cm3 \ \text{x}\ 4.2\ \text{x}\ 3.5\,^{o}C}{1000} = \mathbf{-1.47kJ}$$

(ii)Experiment II

Enthalpy change of $CuSO_4$ = mass of water(**m**) x **c** x **ΔT**

$$\Rightarrow \frac{100cm3 \ \text{x} \ 4.2 \ \text{x} \ 1.5^{o}C}{1000} = \mathbf{-0.63kJ}$$

(c)Calculate the molar enthalpy of solution $CuSO_4.5H_2O$ (s) form the results in (i)experiment I.

$$\Delta Hs = CuSO_4.5H_2O = \frac{\Delta H}{\text{Number of Moles}} \Rightarrow \frac{-1.47kJ}{0.05 \text{ moles}} = \mathbf{29.4kJ}$$

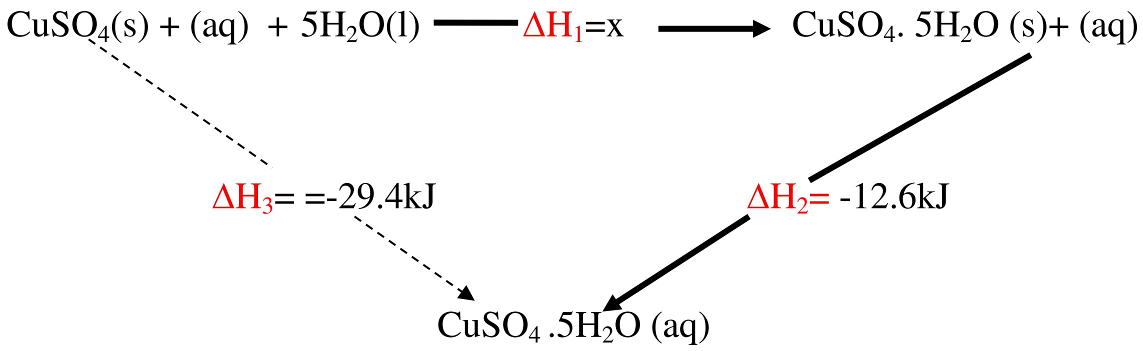
(ii)experiment II.

$$\Delta Hs = CuSO_4 = \frac{\Delta H}{\text{Number of Moles}} \Rightarrow \frac{-0.63kJ}{0.05 \text{ moles}} = \mathbf{12.6kJ}$$

(d) Using an energy level diagram, calculate the molar enthalpy change for the reaction:

$CuSO_4.5H_2O$ (s) -> $CuSO_4$(s) + $5H_2O$(l)

Energy cycle diagram



$\Delta H_3 = \Delta H_1 + \Delta H_2$

=>-29.4kJ = -12.6kJ + x

=>-29.4kJ - (+12.6kJ) = x

x = 16.8kJ

b)Practical example II

Determination of enthalpy of solution of ammonium chloride

Theoretical information.

Ammonium chloride dissolves in water to form ammonium chloride solution. Aqueous ammonia can react with excess dilute hydrochloric acid to form ammonium chloride solution. The heat change taking place can be calculated from the heat of reactions:

(i) $NH_3(aq)$ + $HCl(aq)$ -> $NH_4Cl(s)$
(ii) $NH_4Cl(s)$ + (aq) -> $NH_4Cl(aq)$
(iii) $NH_3(aq)$ + $HCl(aq)$ -> $NH_4Cl(aq)$

Experiment procedure I

Measure 50cm3 of water into a 100cm3 beaker. Record its temperature T_1 as initial temperature to the nearest 0.5°C in table I. Add exactly 5.0g of ammonium chloride crystals weighed carefully into the water. Stir and record the highest temperature change T_2 as the final temperature change. Repeat the above procedure to complete table I.

Sample results TableI

Experiment	I	II
final temperature(°C)	19.0	20.0
initial temperature(°C)	22.0	22.0
temperature change ΔT(°C)	3.0	2.0

Experiment procedure II

Measure 25cm3 of 2M aqueous ammonia into a 100cm3 beaker. Record its temperature T_1 as initial temperature to the nearest 0.5°C in table II. Measure 25cm3 of 2M hydrochloric acid solution. Add the acid into the beaker containing aqueous ammonia. Stir and record the highest temperature change T_2 as the final temperature change. Repeat the above procedure to complete table II.

Sample results:Table II

Experiment	I	II
final temperature(°C)	29.0	29.0
initial temperature(°C)	22.0	22.0
temperature change ΔT(°C)	7.0	7.0

Sample Calculations:

(a)Calculate the average ΔT in

(i)Table I

$$\Delta T = T_2 - T_1 \Rightarrow \frac{-3.0 + -2.0}{2} = \mathbf{2.5\,^{o}C}$$

(ii)Table II

$$\Delta T = T_2 - T_1 \Rightarrow \frac{7.0 + 7.0}{2} = \mathbf{7.0\,^{o}C}$$

(b)Calculate the enthalpy change for the reaction in:

(i)Experiment I

Enthalpy change ΔH = mass of Water(**m**) x **c** x Δ**T**

$$\Rightarrow \frac{50cm3 \ \text{x} \ 4.2 \ \text{x} \ 2.5^{o}C}{1000} = \mathbf{+0.525kJ}$$

(ii)Experiment II

Enthalpy change of $CuSO_4$ = mass of water(**m**) x **c** x Δ**T**

$$\Rightarrow \frac{25+25cm3 \ \text{x} \ 4.2 \ \text{x} \ 7^{o}C}{1000} = \mathbf{+1.47kJ}$$

(c)Write the equation for the reaction taking place in:

(i)Experiment I

NH_4Cl(**s**) + (aq) -> NH_4Cl(**aq**)

(ii)Experiment I

NH_3(aq) + HCl(aq) -> NH_4Cl(aq)

(d)Calculate the enthalpy change ΔH for the reaction:

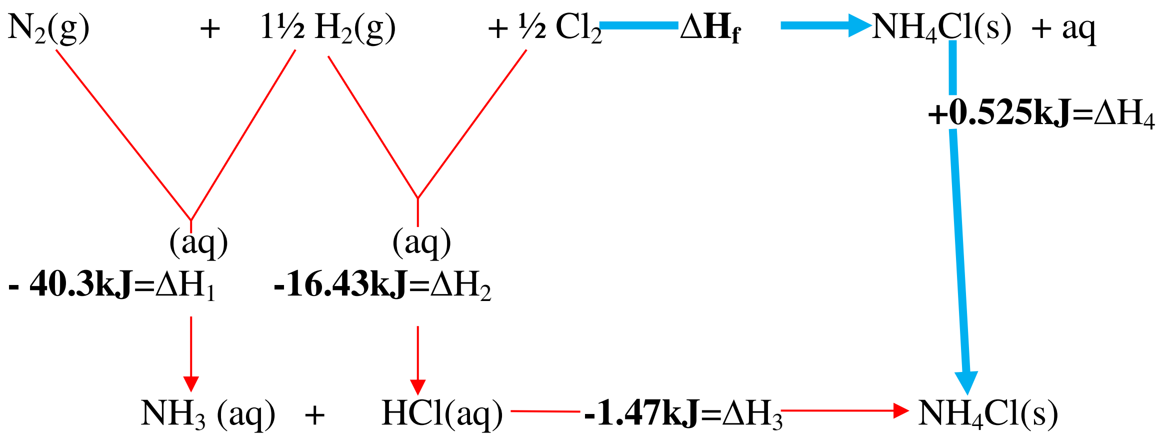
NH_3(g) + HCl(g) -> NH_4Cl(s) given that:

(i) NH_3(g) + (aq) -> NH_3(aq) ΔH= -40.3kJ

(ii) (aq) + HCl(g) -> HCl(aq) ΔH= -16.45kJ

(e)Applying Hess' Law of constant heat summation:

Energy level diagram



$$\Delta H_1 + \Delta H_2 + \Delta H_3 = \Delta H_4 + \Delta H_f$$

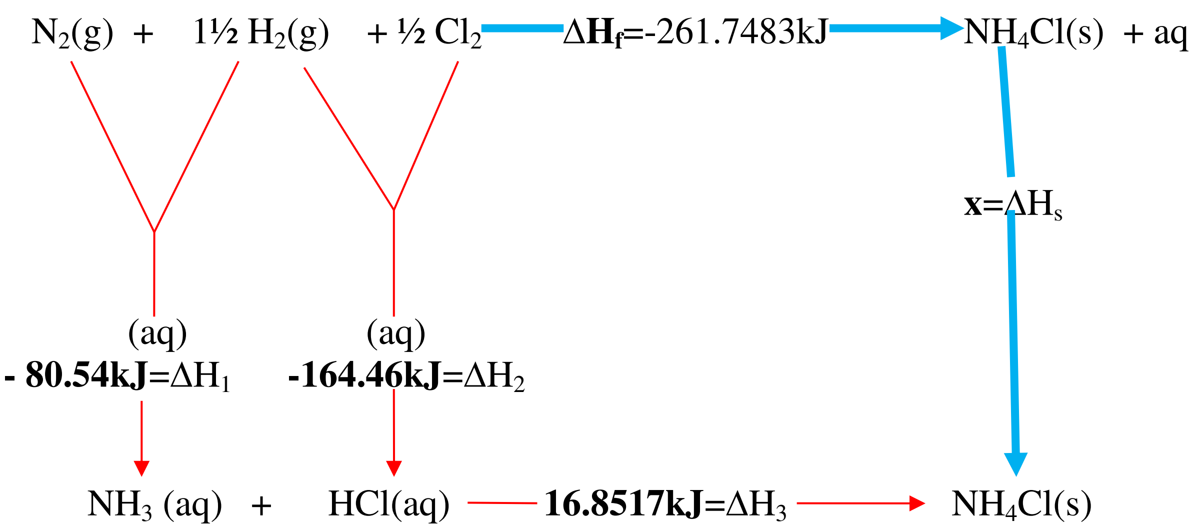
$$\mathbf{-\,40.3kJ + -16.43kJ + -1.47kJ = +0.525kJ + \Delta H_f}$$

$$\Rightarrow \mathbf{\Delta H_f = -58.865kJ.}$$

Practice theoretical examples:

1. Using an energy level diagram calculate the ΔH_s of ammonium chloride crystals given that.

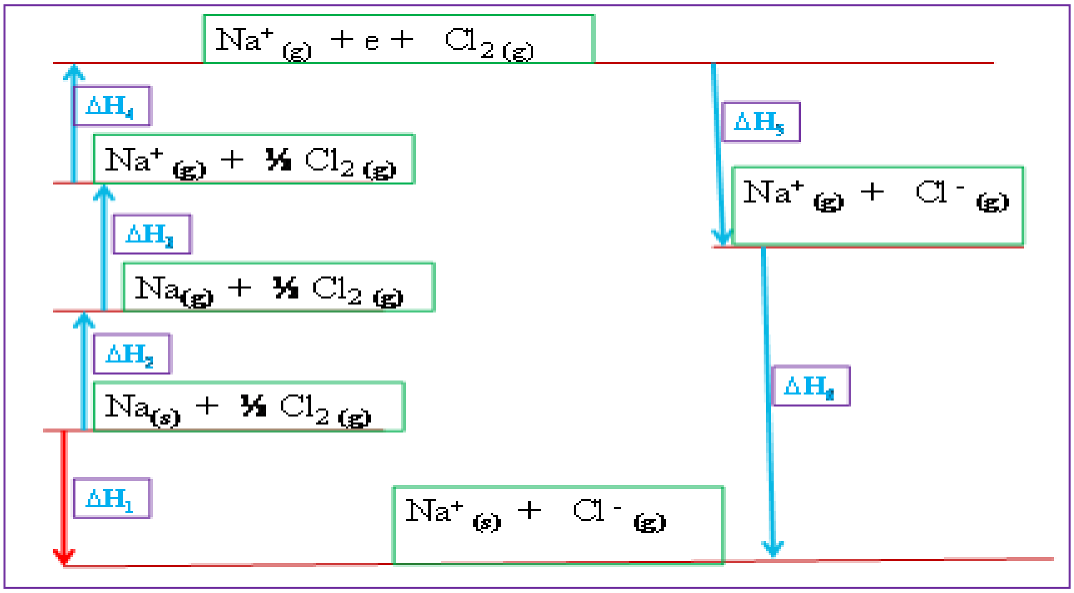
ΔH_f of NH_3 (aq) = -80.54kJ mole^{-1}
ΔH_f of HCl (aq) = -164.46kJ mole^{-1}
ΔH_f of NH_4Cl (aq) = -261.7483kJ mole^{-1}
ΔH_s of NH_4Cl (aq) = -16.8517kJ mole^{-1}



ΔH_1 + ΔH_2 + ΔH_3 = ΔH_4 + ΔH_f
- 80.54kJ + -164.46kJ + -16.8517kJ = -261.7483kJ + ΔH_f
=>ΔH_f = **-33.6kJmole^{-1}**.

Study the energy cycle diagram below and use it to:

(a)Identify the energy changes ΔH_1 ΔH_2 ΔH_3 ΔH_4 ΔH_5 ΔH_6

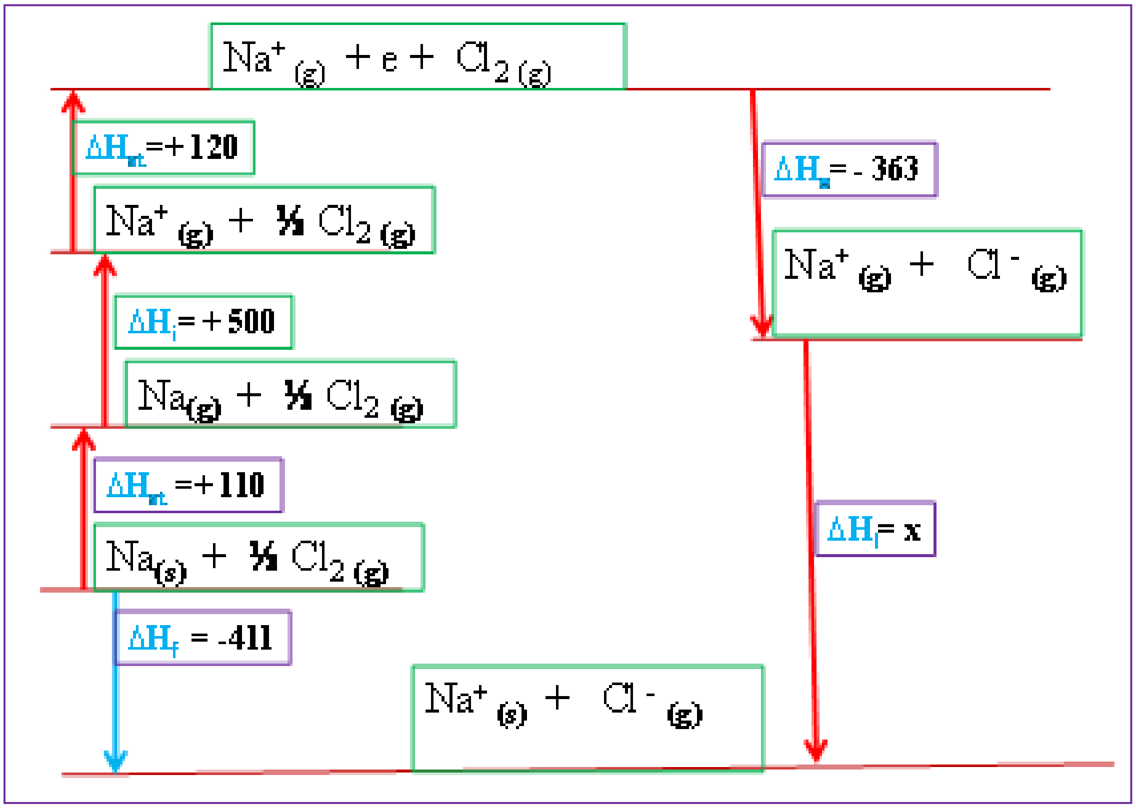


ΔH_1 - enthalpy/heat of formation of sodium chloride (ΔH_f)
ΔH_2 -enthalpy/heat of atomization of sodium (ΔH_{at})
ΔH_3 -enthalpy/heat of ionization/ionization energy of sodium (ΔH_i)
ΔH_4 -enthalpy/heat of atomization of chlorine (ΔH_{at})
ΔH_5 -enthalpy/heat of electron affinity of chlorine (ΔH_e)
ΔH_6 enthalpy/heat of lattice/Lattice energy of sodium chloride(ΔH_l)

(b) Calculate ΔH_1 given that ΔH_2=+108kJ , ΔH_3=+500kJ, ΔH_4=+121kJ ,ΔH_5 =-364kJ and ΔH_6=-766kJ

Working:
$\Delta H_1 = \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5 + \Delta H_6$
Substituting:
ΔH_1= +108kJ + +500kJ + +121kJ +-364kJ + -766kJ
ΔH_1= $\underline{\textbf{-401kJmole}^{-1}}$

(c) Given the that:
(i) Ionization energy of sodium = + 500kJmole^{-1}
(ii)ΔH_{at} of sodium = + 110kJmole^{-1}
(iii) Electron affinity of chlorine = - 363kJmole^{-1}
(iv)ΔH_{at} of chlorine = + 120kJmole^{-1}
(v) ΔH_f of sodium chloride = -411kJ , calculate the lattice energy of sodium chloride using an energy cycle diagram.



Working:

Applying Hess law then:

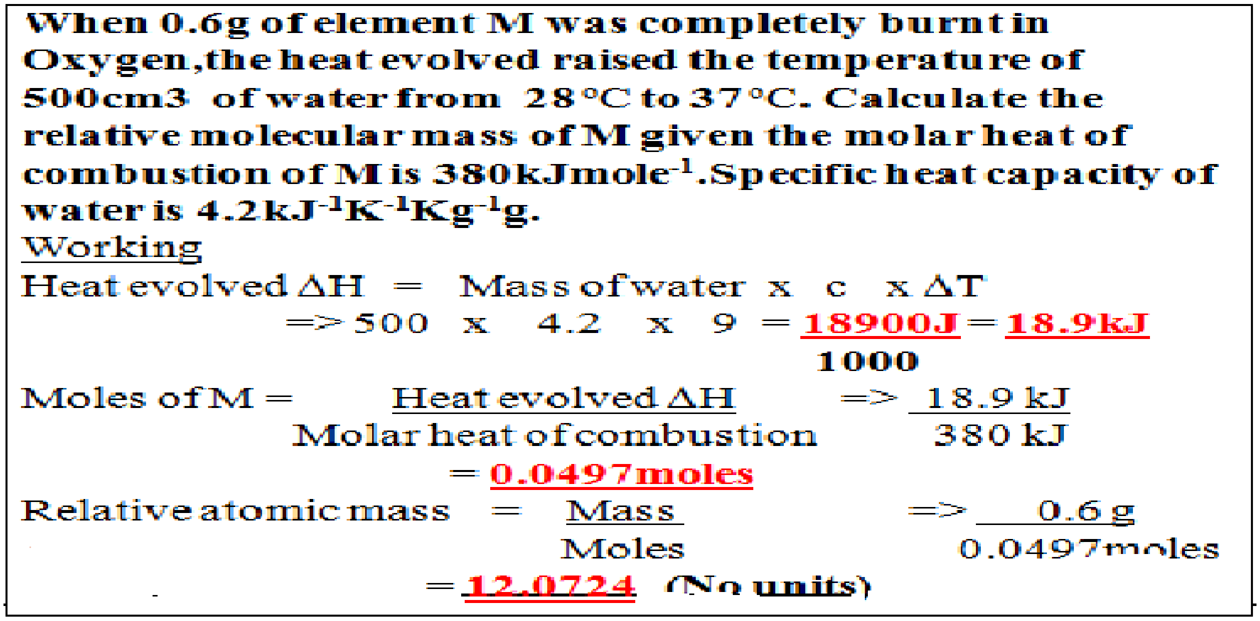
$\Delta H_f = \Delta H_a + \Delta H_i + \Delta H_a + \Delta H_e + \Delta H_l$

Substituting:

-411= +108kJ + +500kJ + +121kJ +-364kJ + x

-411 + -108kJ + -500kJ + -121kJ + +364kJ = x

x= $\underline{\textbf{-776kJmole}^{-1}}$



When 0.6g of element M was completely burnt in Oxygen,the heat evolved raised the temperature of 500cm3 of water from 28°C to 37°C. Calculate the relative molecular mass of M given the molar heat of combustion of M is 380kJmole^{-1}.Specific heat capacity of water is 4.2kJ^{-1}K^{-1}Kg^{-1}g.

Working

Heat evolved ΔH = Mass of water x c x ΔT

$\Rightarrow 500 \text{ x } 4.2 \text{ x } 9 = \frac{\underline{18900J}}{1000} = \underline{18.9kJ}$

Moles of M = $\frac{\text{Heat evolved } \Delta H}{\text{Molar heat of combustion}} \Rightarrow \frac{18.9\text{ kJ}}{380\text{ kJ}}$

$= \underline{0.0497moles}$

Relative atomic mass = $\frac{\text{Mass}}{\text{Moles}} \Rightarrow \frac{0.6\text{ g}}{0.0497\text{moles}}$

$= \underline{12.0724}$ (No units)

20.0.0 REACTION RATES AND REVERSIBLE REACTIONS (15 LESSONS)

A.THE RATE OF CHEMICAL REACTION

(CHEMICAL KINETICS)

1.Introduction

The rate of a chemical reaction is the time taken for a given mass/amount of products to be formed. The rate of a chemical reaction is also the time taken for a given mass/amount of reactant to be consumed /used up.

Some reactions are too slow to be determined. e.g rusting ,decomposition of hydrogen peroxide and weathering.

Some reactions are too fast and instantaneous e.g. neutralization of acid and bases/alkalis in aqueous solution and double decomposition/precipitation.

Other reactions are explosive and very risky to carry out safely e.g. reaction of potassium with water and sodium with dilute acids.

The study of the rate of chemical reaction is useful in knowing the factors that influence the reaction so that efficiency and profitability is maximized in industries.

Theories of rates of reaction.

The rate of a chemical reaction is defined as the rate of change of concentration/amount of reactants in unit time. It is also the rate of formation of given concentration of products in unit time. i.e.

$$\text{Rate of reaction} = \frac{\text{Change in concentration/amount of reactants}}{\text{Time taken for the change to occur}}$$

$$\text{Rate of reaction} = \frac{\text{Change in concentration/amount of products formed}}{\text{Time taken for the products to form}}$$

For the above, therefore the rate of a chemical reaction is rate of decreasing reactants to form an increasing product.
The SI unit of **time** is **second**(s) but minutes and hours are also used.

(a)The collision theory

The collision theory is an application of the Kinetic Theory of matter which assumes matter is made up of small/tiny/minute particles like ions atoms and molecules.
The collision theory proposes that
(i)for a reaction to occur, reacting particles must collide.
(ii)not all collisions between reacting particles are successful in a reaction. Collisions that initiate a chemical reaction are called successful / fruitful/ effective collisions

(iii)the speed at which particles collide is called **collision frequency**.
The higher the collision frequency the higher the **chances** of successful / fruitful/ effective collisions to form products.

(iv)the higher the chances of successful collisions, the faster the reaction.

(v)the average distance between solid particles from one another is too big for them to meet and collide successfully.

(vi)dissolving substances in a solvent ,make the solvent a medium for the reaction to take place.
The solute particle distance is reduced as the particle ions are free to move in the solvent medium.

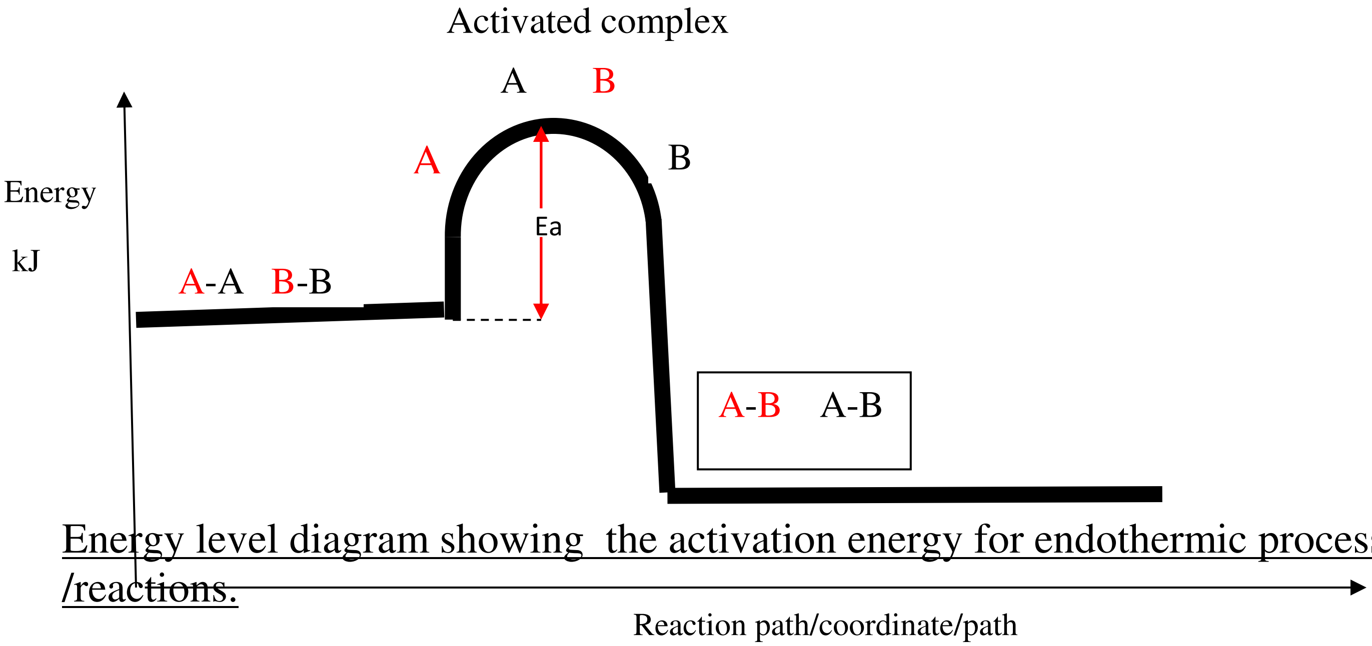
(vii)successful collisions take place if the particles colliding have the required **energy** and right **orientation** which increases their **vibration** and **intensity** of successful / fruitful/ effective collisions to form products.

(b)The Activation Energy(Ea) theory

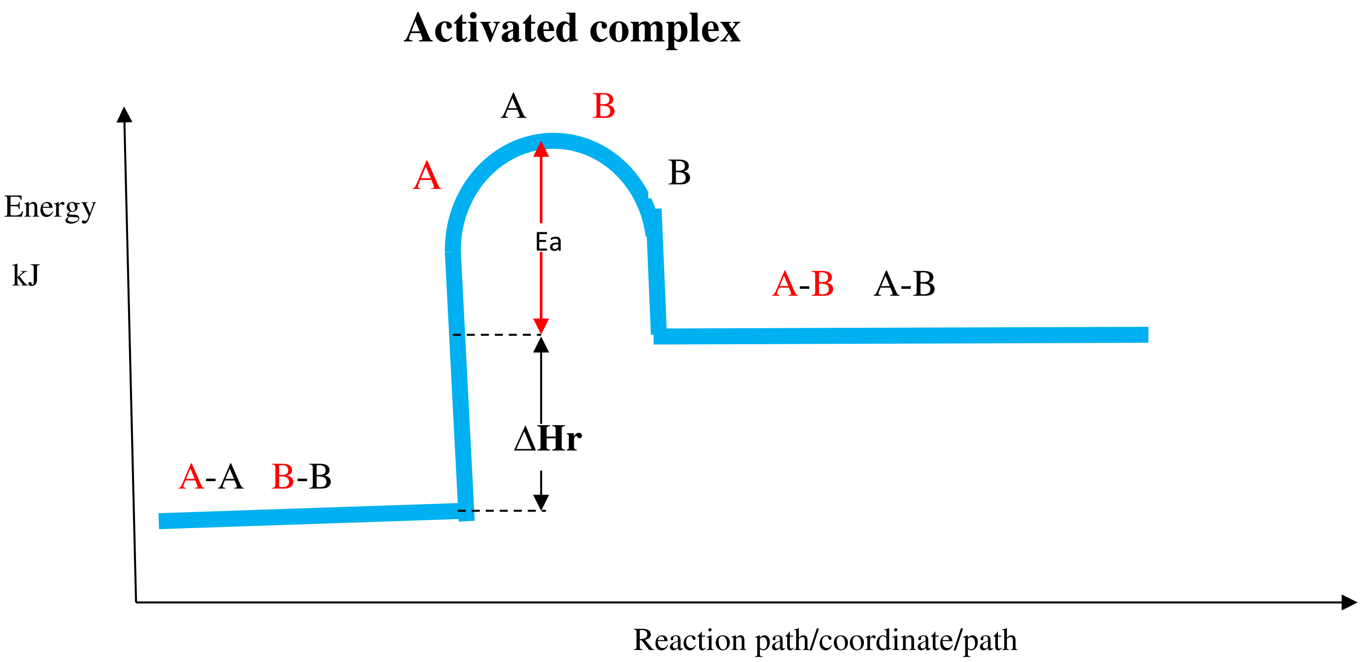
The **Enthalpy of activation(ΔH_a) /Activation Energy(Ea)** is the minimum amount of energy which the reactants must overcome before they react. Activation Energy(Ea) is usually required /needed in bond breaking of the reacting particles.
Bond breaking is an endothermic process that require an energy input.
The higher the bond energy the slower the reaction to **start of**.
Activation energy does not influence whether a reaction is exothermic or endothermic.

The energy level diagrams below shows the activation energy for exothermic and endothermic processes/reactions.

Energy level diagram showing the activation energy for exothermic processes /reactions.



Energy level diagram showing the activation energy for endothermic processes /reactions.



The activated complex is a mixture of many intermediate possible products which may not exist under normal physical conditions ,but can theoretically exist.

Exothermic reaction proceeds without further heating /external energy because it generates its own energy/heat to overcome activation energy.

Endothermic reaction cannot proceed without further heating /external energy because it does not generates its own energy/heat to overcome activation energy. It generally therefore requires continuous supply of more energy/heat to sustain it to completion.

3. Measuring the rate of a chemical reaction.

The rate of a chemical reaction can be measure as:

(i)Volume of a gas in unit time;

- if reaction is producing a gas as one of the products.
- if reaction is using a gas as one reactants

(ii)Change in mass of reactants/products for solid products/reactants in unit time.

(iii)formation of a given mass of precipitate in unit time

(iv)a certain mass of reactants to completely form products/diminish.

Reactants may be homogenous or heterogenous.

-Homogenous reactions involve reactants in the **same phase/state** e.g. solid-solid,gas-gas,liquid-liquid.

-Heterogenous reactions involve reactants in the **different phase/state** e.g. solid-liquid,gas-liquid,solid-gas.

4. Factors influencing/altering/affecting/determining rate of reaction

The following factors alter/influence/affect/determine the rate of a chemical reaction:

(a)Concentration
(b)Pressure
(c) Temperature
(d)Surface area

(e)Catalyst

a) Influence of concentration on rate of reaction

The higher the concentration, the higher the rate of a chemical reaction. An increase in concentration of the reactants reduces the distance between the reacting particles increasing their collision frequency to form products. Practically an increase in concentration **reduces** the time taken for the reaction to take place.

Practical determination of effect of concentration on reaction rate

Method 1(a)

Reaction of sodium thisulphate with dilute hydrochloric acid

Procedure:

Measure 20cm3 of 0.05M sodium thisulphate into a 50cm3 glass beaker. Place the beaker on a white piece of filter paper with ink **mark** 'X' on it. Measure 20cm3 of 0.1M hydrochloric acid solution using a 50cm3 measuring cylinder. Put the acid into the beaker containing sodium thisulphate. Immediately start off the stop watch/clock. Determine the time taken for the ink **mark** 'X' to become invisible /obscured when viewed from above. Repeat the procedure by measuring different volumes of the acid and adding the volumes of the distilled water to complete table 1.

Sample results:Table 1.

Volume of acid(cm3)	**Volume of water(cm3)**	**Volume of sodium thiosulphate(cm3)**	**Time taken for mark 'X' to be invisible/obscured(seconds)**	**Reciprocal of time** $\frac{1}{t}$
20.0	0.0	20.0	20.0	5.0 x 10^{-2}
18.0	2.0	20.0	23.0	4.35 x 10^{-2}
16.0	4.0	20.0	27.0	3.7 x 10^{-2}
14.0	6.0	20.0	32.0	3.13 x 10^{-2}
12.0	8.0	20.0	42.0	2.38 x 10^{-2}
10.0	10.0	20.0	56.0	1.78 x 10^{-2}

For most examining bodies/councils/boards the above results score for:
(a) **complete table** as evidence for all the practical work done and completed.

(b) (i)Consistent use of **a decimal point** on time as evidence of understanding/knowledge of the degree of accuracy of stop watches/clock.

(ii)Consistent use of a minimum of **four decimal points** on inverse/reciprocal of time as evidence of understanding/knowledge of the degree of accuracy of scientific calculator.

(c) **accuracy** against a school value based on **candidate's teachers-results** submitted.

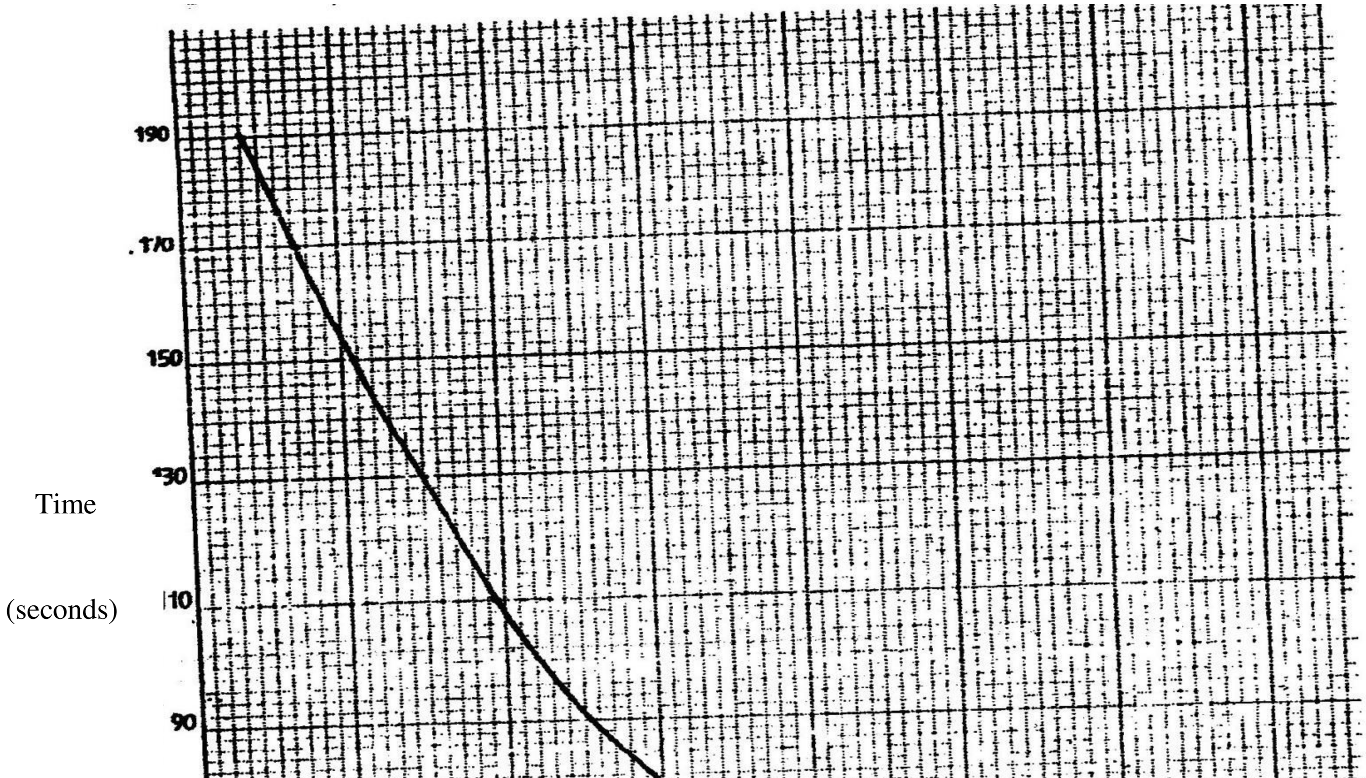
(d) correct **trend** (time increase as more water is added/acid is diluted) in conformity with expected **theoretical** results.

Sample questions

1. On separate graph papers plot a graph of:
   (i)volume of acid used(x-axis) against time. Label this graph I
   (ii) volume of acid used(x-axis) against 1/t. Label this graph II

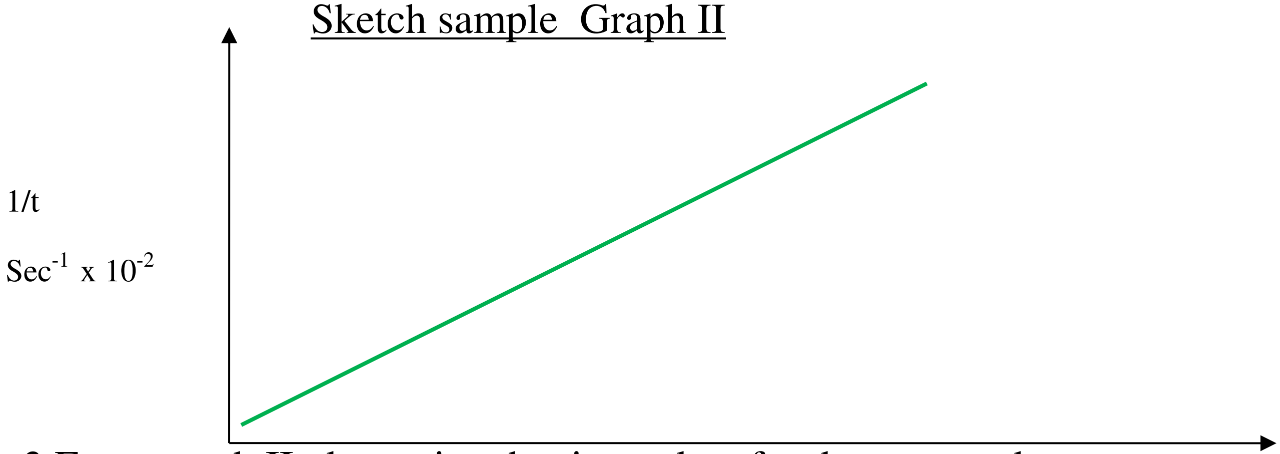
2. Explain the shape of graph I
Diluting/adding water is causes a decrease in concentration.
Decrease in concentration reduces the rate of reaction by increasing the time taken for reacting particle to collide to form products.

Sketch sample Graph I



Volume of acid(cm3)

Sketch sample Graph II



3.From graph II ,determine the time taken for the cross to be obscured/invisible when the volume of the acid is:

(i) 13cm3

From a correctly plotted graph

1/t at 13cm3 on the graph

Volume of acid(cm3)

t = 1 / 2.75 x 10^{-2} = **36.3636 seconds**

(ii) 15cm3

From a correctly plotted graph

1/t at 15cm3 on the grap Volume of acid (cm3)

t = 1 / 3.35 x 10^{-2} = **29.8507 seconds**

(iii) 15cm3

From a correctly plotted graph

1/t at 17cm3 on the graph => **4.0×10^{-2}**
t = 1 / 4.0×10^{-2} = **<u>25.0</u> seconds**

(iv) 19cm3
From a correctly plotted graph
1/t at 19cm3 on the graph => **4.65×10^{-2}**
t = 1 / 4.65×10^{-2} = **<u>21.5054</u> seconds**

4.From graph II ,determine the volume of the acid used if the time taken for the cross to be obscured/invisible is:

(i)25 seconds
1/t => 1/25 = **4.0×10^{-2}**
Reading from a correctly plotted graph;
4.0×10^{-2} correspond to **<u>17.0 cm3</u>**

(ii)30 seconds
1/t => 1/30 = **3.33×10^{-2}**
Reading from a correctly plotted graph;
3.33×10^{-2} correspond to **<u>14.7 cm3</u>**

(iii)40 seconds

1/t => 1/40 = **2.5×10^{-2}**
Reading from a correctly plotted graph;
2.5×10^{-2} correspond to **<u>12.3 cm3</u>**

4. Write the equation for the reaction taking place
$Na_2S_2O_3$ (aq) + 2HCl(aq) -> 2NaCl (aq)+ SO_2 (g) + S(s) + H_2O(l)

Ionically:
$S_2O_3^{2-}$ (aq) + $2H^+$ (aq) -> SO_2 (g) + S(s) + H_2O(l)

5.Name the yellow precipitate
Colloidal sulphur

<u>Method 1(b)</u>

Reaction of sodium thisulphate with dilute hydrochloric acid

You are provided with

2.0M Hydrochloric acid
0.4M sodium thiosulphate solution

Procedure:

Measure 10cm3 of sodium thisulphate into a 50cm3 glass beaker. Place the beaker on a white piece of filter paper with ink **mark** 'X' on it.

Add 5.0cm3 of hydrochloric acid solution using a 10cm3 measuring cylinder into the beaker containing sodium thisulphate.

Immediately start off the stop watch/clock. Determine the time taken for the ink **mark** 'X' to become invisible /obscured when viewed from above.

Repeat the procedure by measuring different volumes of the thiosulphate and adding the volumes of the distilled water to complete table 1.

Sample results:Table 1.

Volume of acid(cm3)	**Volume of water (cm3)**	**Volume of sodium thiosulphate (cm3)**	**Concentation of sodium thisulphate in molesdm^{-3}**	**Time(T) taken for mark 'X' to be invisible/ obscured(seconds)**	**T^{-1}**
5.0	0.0	25.0	0.4	20.0	5.0×10^{-2}
5.0	5.0	20.0	0.32	23.0	4.35×10^{-2}
5.0	10.0	15.0	0.24	27.0	3.7×10^{-2}
5.0	15.0	10.0	0.16	32.0	3.13×10^{-2}

Note concentration of diluted solution is got:

$C_1V_1=C_2V_2$ => $0.4 \times 25 = C_2 \times 25$ =0.4M
$C_1V_1=C_2V_2$ => $0.4 \times 20 = C_2 \times 25$ =0.32M
$C_1V_1=C_2V_2$ => $0.4 \times 15 = C_2 \times 25$ =0.24M
$C_1V_1=C_2V_2$ => $0.4 \times 10 = C_2 \times 25$ =0.16M

Sample questions

1. On separate graph papers plot a graph of:

(i)Concentration of sodium thiosulphate against time. Label this graph I (ii)Concentration of sodium thiosulphate against against **T^{-1}**.Label this graph II

2. Explain the shape of graph I

Diluting/adding water causes a decrease in concentration.

Decrease in concentration reduces the rate of reaction by increasing the time taken for reacting particle to collide to form products.

From graph II

Determine the time taken if

(i)12cm3 of sodium thisulphate is diluted with 13cm3 of water.

At 12cm3 concentration of sodium thisulphate

$= C_1V_1=C_2V_2$ => 0.4 x 1 2 = C_2x 25 =0.192M

From correct graph at concentration 0.192M => 2.4 x10^{-2}

I/t = 2.4 x10^{-2} **t = 41.6667seconds**

(ii)22cm3 of sodium thisulphate is diluted with 3cm3 of water.

At 22cm3 concentration of sodium thisulphate

$= C_1V_1=C_2V_2$ => 0.4 x 22 = C_2x 25 =0.352M

From correct graph at concentration 0.352M => 3.6 x10^{-2}

I/t = 3.6 x10^{-2} **t = <u>27.7778seconds</u>**

Determine the volume of water and sodium thiosulphate if T^{-1} is 3.0 x10^{-1}

From correct graph at T^{-1} = 3.0 x10^{-1} => concentration = 0.65 M

$= C_1V_1=C_2V_2$ => 0.4 x 25 = 0.65 M x V_2 = **15.3846cm3**

Volume of water = 25 - 15.3846cm3 = **9.6154cm3**

Determine the concentration of hydrochloric acid if 12cm3 of sodium thiosulphate and 13cm3 of water was used.

At 12cm3 concentration of sodium thisulphate

$= C_1V_1=C_2V_2$ => 0.4 x 1 2 = C_2x 25 =0.192M

Mole ratio $Na_2S_2O_3$:HCl =1:2

Moles of $Na_2S_2O_3$ = $\frac{0.192M \times 12}{1000}$ => $\underline{2.304 \times 10^{-3}}$ moles

Mole ratio HCl =$\frac{2.304 \times 10^{-1} \text{ moles}}{2}$ = $\underline{1.152 \times 10^{-3}}$ moles

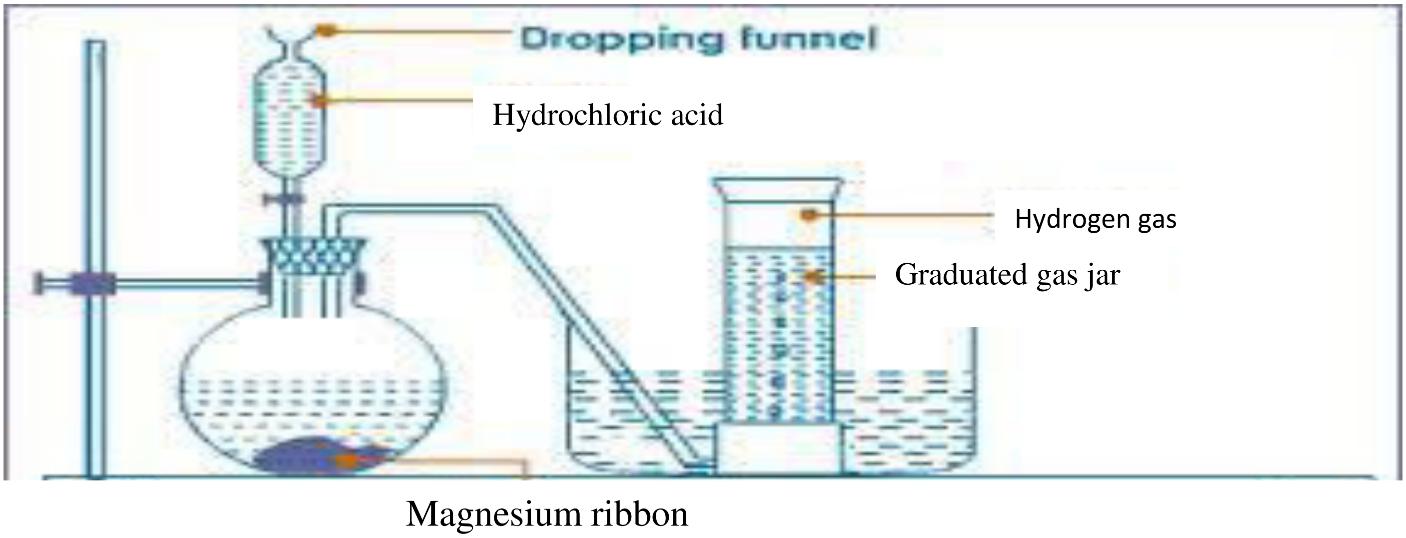
Molarity o f HCl = $\frac{1.152 \times 10^{-3} \text{ moles} \times 1000}{5.0}$ = **<u>0.2304M</u>**

Method 2

Reaction of Magnesium with dilute hydrochloric acid

Procedure

Scub 10centimeter length of magnesium ribbon with sand paper/steel wool. Measure 40cm3 of 0.5M dilute hydrochloric acid into a flask .Fill a graduated gas jar with water and invert it into a trough. Stopper the flask and set up the apparatus to collect the gas produced as in the set up below:



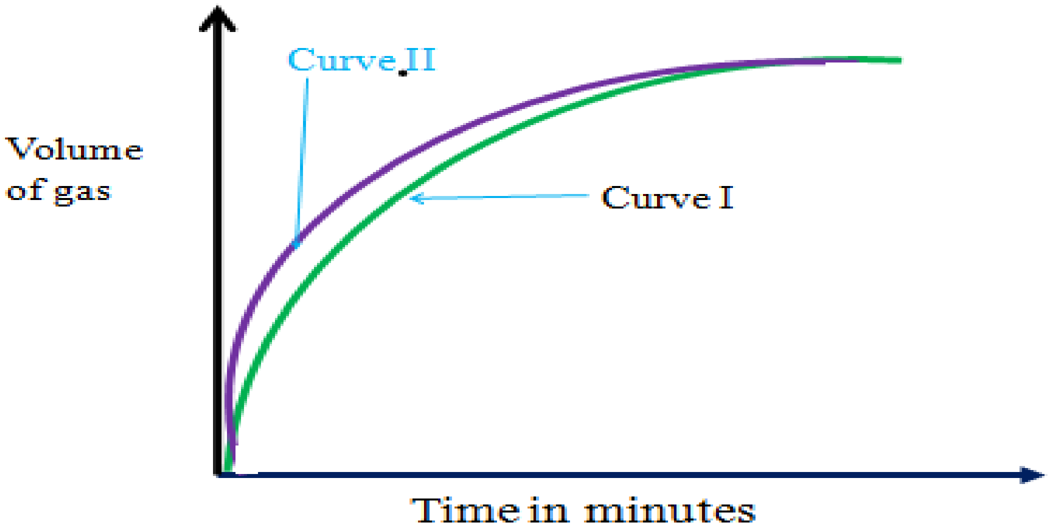
Carefully remove the stopper, carefully put the magnesium ribbon into the flask . cork tightly. Add the acid into the flask. Connect the delivery tube into the gas jar. Immediately start off the stop watch and determine the volume of the gas produced after every 30 seconds to complete table II below.

Sample results: Table II

Time(seconds)	0	30	60	90	120	150	180	210	240
Volume of gas produced(cm3)	**0.0**	**20.0**	**40.0**	**60.0**	**80.0**	**90.0**	**95.0**	**96.0**	**96.0**

Sample practice questions

1.Plot a graph of volume of gas produced (y-axis) against time



Curve showing the effect of concentration on the rate of evolution of a gas with time

2.Explain the shape of the graph.

The rate of reaction is faster when the concentration of the acid is high .

As time goes on, the concentration of the acid decreases and therefore less gas is produced.

When all the acid has reacted, no more gas is produced after 210 seconds and the graph flattens.

3.Calculate the rate of reaction at 120 seconds

From a tangent at 120 seconds rate of reaction = $\frac{\text{Change in volume of gas}}{\text{Change in time}}$

=> **From the tangent** at 120seconds $\frac{V_2 - V_1}{T_2 - T_1} = \frac{96-84}{150-90} = \frac{12}{60} = \underline{\mathbf{0.2cm3sec^{-1}}}$

4. Write an ionic equation for the reaction taking place.

$Mg^{2+}(s) + 2H^{+}(aq) \text{ -> } Mg^{2+}(aq) + H_2(g)$

5. On the same axis sketch then explain the curve that would be obtained if:

(i) 0.1 M hydrochloric acid is used –Label this curve I

(ii)1.0 M hydrochloric acid is used –Label this curve II

Observation:

Curve I is to the right

Curve II is to the left

Explanation

A decrease in concentration shift the rate of reaction graph to the right as more time is taken for completion of the reaction.

An increase in concentration shift the rate of reaction graph to the left as less time is taken for completion of the reaction.

Both graphs **flatten** after some time indicating the **completion** of the reaction.

b)Influence of pressure on rate of reaction

Pressure affects only gaseous reactants.

An increase in pressure reduces the volume(Boyles law) in which the particles are contained.

Decrease in volume of the container bring the reacting particles closer to each other which increases their chances of effective/successful/fruitful collision to form products.

An increase in pressure therefore increases the rate of reaction by reducing the time for reacting particles of gases to react.

At industrial level, the following are some reactions that are affected by pressure:

(a)Haber process for manufacture of ammonia

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

(b)Contact process for manufacture of sulphuric(VI)acid

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

(c)Ostwalds process for the manufacture of nitric(V)acid

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO\ (g) + 6H_2O\ (l)$$

The influence of pressure on reaction rate is not felt in solids and liquids.

This is because the solid and liquid particles have fixed positions in their strong bonds and therefore no degree of freedom (Kinetic Theory of matter)

c)Influence of temperature on rate of reaction

An increase in temperature increases the kinetic energy of the reacting particles by increasing their collision frequency.
Increase in temperature increases the particles which can overcome the activation energy (Ea).
A **10°C rise** in temperature doubles the rate of reaction by reducing the time taken for the reaction to complete by **a half.**

Practical determination of effect of Temperature on reaction rate
Method 1

Reaction of sodium thisulphate with dilute hydrochloric acid

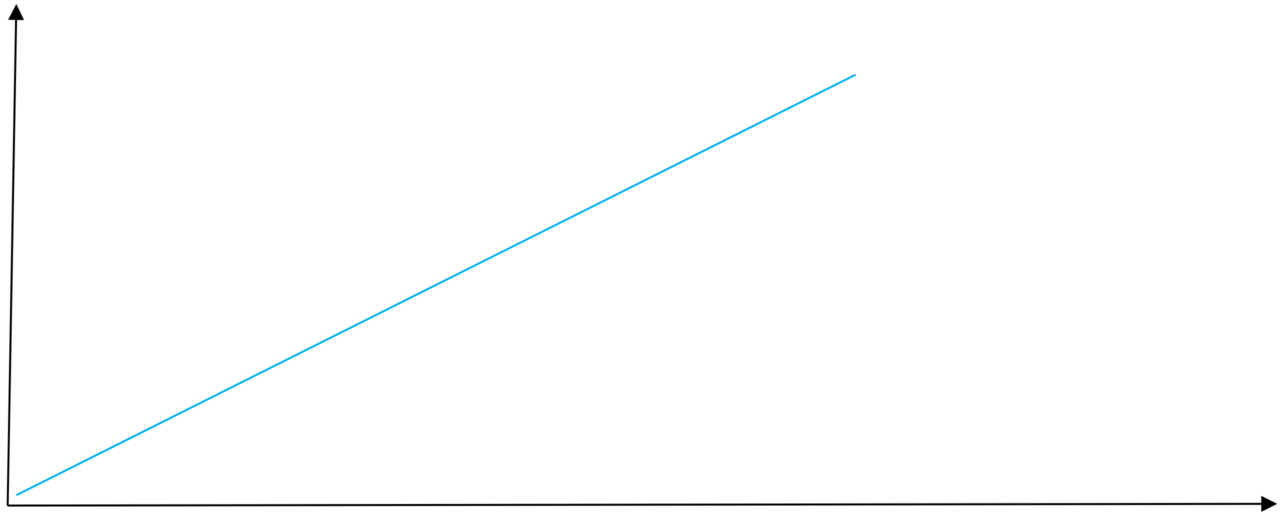
Procedure:
Measure 20cm3 of 0.05M sodium thisulphate into a 50cm3 glass beaker.
Place the beaker on a white piece of filter paper with ink **mark** 'X' on it.
Determine and record its temperature as room temperature in table 2 below.
Measure 20cm3 of 0.1M hydrochloric acid solution using a 50cm3 measuring cylinder.
Put the acid into the beaker containing sodium thisulphate.
Immediately start off the stop watch/clock.
Determine the time taken for the ink **mark** 'X' to become invisible /obscured when viewed from above.
Measure another 20cm3 separate portion of the thisulphate into a beaker, heat the solution to 30°C.
Add the acid into the beaker and repeat the procedure above. Complete table 2 below using different temperatures of the thiosulphate.

Sample results:Table 2.

Temperature of $Na_2S_2O_3$	Room temperature	30	40	50	60
Time taken for mark X to be obscured /invisible (seconds)	50.0	40.0	20.0	15.0	10.0
Reciprocal of time($^1/_t$)	0.02	0.025	0.05	0.0667	0.1

Sample practice questions

1. **Plot a graph of temperature(x-axis) against $^1/_t$**



2(a)From your graph determine the temperature at which:

(i)1/t is ;

I. 0.03

Reading directly from a correctly plotted graph = **32.25 ^{o}C**

II. 0.07

Reading directly from a correctly plotted graph = **48.0 ^{o}C**

(ii) t is;

I. 30 seconds

30 seconds => 1/t =1/30 =**0.033**

Reading directly from a correctly plotted graph 0.033 => **33.5 ^{o}C**

II. 45 seconds

45 seconds => 1/t =1/45 =**0.022**

Reading directly from a correctly plotted graph 0.022 => **29.0 ^{o}C**

III. 25 seconds

25 seconds => 1/t =1/25 =**0.04**

Reading directly from a correctly plotted graph 0.04 => **36.0 ^{o}C**

(b) From your graph determine the time taken for the cross to become invisible at:

(i) 57.5 ^{o}C

Reading directly from a correctly plotted graph at 57.5 ^{o}C= **0.094**

=>1/t = **0.094**

t= 1/0.094 => **10.6383 seconds**

(ii) 45 ^{o}C

Reading directly from a correctly plotted graph at 45 ^{o}C = **0.062**

=>1/t = **0.062**

t= 1/0.094 => **16.1290 seconds**

(iii) 35 ^{o}C

Reading directly from a correctly plotted graph at 35 ^{o}C = **0.047**

=>1/t = **0.047**

t= 1/0.047 => 2**1.2766 seconds**

Method 2

Reaction of Magnesium with dilute hydrochloric acid

Procedure

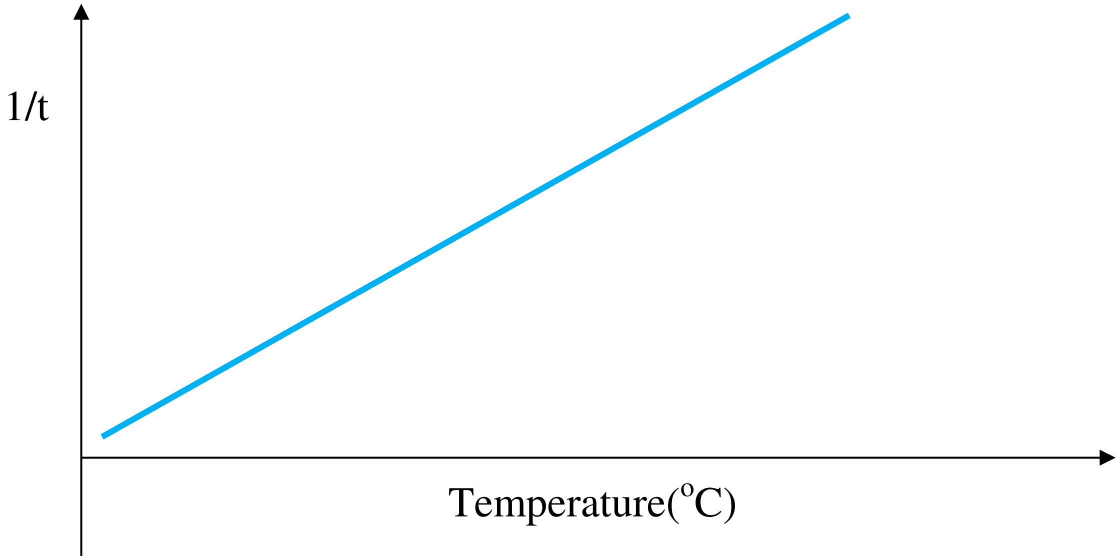
Scub 5centimeter length of magnesium ribbon with sand paper/steel wool.
Cut the piece into five equal one centimeter smaller pieces.
Measure 20cm3 of 1.0M dilute hydrochloric acid into a glass beaker .
Put one piece of the magnesium ribbon into the acid, swirl.
Immediately start off the stop watch/clock.
Determine the time taken for the effervescence/fizzing/bubbling to stop when viewed from above.
Record the time in table 2 at room temperature.
Measure another 20cm3 portions of 1.0M dilute hydrochloric acid into a clean beaker.
Heat separately one portion to 30^{o}C, 40^{o}C , 50^{o}C and 60^{o}C and adding 1cm length of the ribbon and determine the time taken for effervescence /fizzing /bubbling to stop when viewed from above .
Record each time to complete table 2 below using different temperatures of the acid.

Sample results:Table 1.

Temperature of acid(^{o}C)	Room temperature	30	40	50	60
Time taken effervescence to stop (seconds)	80.0	50.0	21.0	13.5	10.0
Reciprocal of time($^{1}/_{t}$)	0.0125	0.02	0.0476	0.0741	0.1

Sample practice questions

1. **Plot a graph of temperature(x-axis) against $^{1}/_{t}$**



2.(a)Calculate the number of moles of magnesium used given that 1cm of magnesium has a mass of 1g.(Mg= 24.0)

$$\text{Moles} = \frac{\text{Mass of magnesium}}{\text{Molar mass of Mg}} \Rightarrow \frac{1.0}{24} = \mathbf{4.167 \times 10^{-2}\ moles}$$

(b)Calculate the number of moles of hydrochloric acid used

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

$$\Rightarrow \frac{1.0 \times 20}{1000} = \mathbf{2.0 \times 10^{-2}\ moles}$$

(c)Calculate the mass of magnesium that remain unreacted

Mole ratio Mg: HCl = 1:2
Moles Mg = ½ moles HCl
=> ½ x 2.0 x 10^{-2} moles = **1.0 x 10^{-2} moles**
Mass of reacted Mg = moles x molar mass
=> 1.0 x 10^{-2} moles x 24 = **0.24 g**
Mass of unreacted Mg = Original total mass - Mass of reacted Mg
=> 1.0 g – 0.24 = **0.76 g**

(b)Calculate the total volume of hydrogen gas produced during the above reactions.

Mole ratio Mg : H_2 = 1:1
Moles of Mg that reacted per experiment = moles H_2 =**1.0 x 10 $^{-2}$ moles**
Volume of Hydrogen at s.t.p produced per experiment = moles x 24 dm3
=> 1.0 x 10 $^{-2}$ moles x 24 dm3 = **0.24dm3**
Volume of Hydrogen at s.t.p produced in 5 experiments =0.24 dm3 x 5
= **1.2 dm3**

3.(a)At what temperature was the time taken for magnesium to react equal to:

(i)70seconds
70 seconds => 1/t =1/70 =**0.01429**
Reading directly from a correctly plotted graph **0.01429** => **28.0 ^{o}C**

(ii)40seconds
40 seconds => 1/t =1/40 =**0.025**
Reading directly from a correctly plotted graph **0.025** => **32.0 ^{o}C**

(b)What is the time taken for magnesium to react if the reaction was done at:

(i) 55.0 ^{o}C
Reading directly from a correctly plotted graph at 55.0 ^{o}C=> 1/t = **8.0 x 10^{-2}**
=> t = 1/8.0 x 10^{-2} = **12.5 seconds**

(ii) 47.0 ^{o}C
Reading directly from a correctly plotted graph at 47.0 ^{o}C=> 1/t = **6.0 x 10^{-2}**
=> t = 1/6.0 x 10^{-2} = **16.6667 seconds**

(iii) 33.0 ^{o}C
Reading directly from a correctly plotted graph at 33.0 ^{o}C=> 1/t = **2.7 x 10^{-2}**
=> t = 1/2.7 x 10^{-2} = **37.037 seconds**

4. Explain the shape of the graph.

Increase in temperature increases the rate of reaction as particles gain kinetic energy increasing their frequency and intensity of collision to form products.

d)Influence of surface area on rate of reaction

Surface area is the area of contact. An increase in surface area is a decrease in particle size. Practically an increase in surface area involves chopping /cutting solid lumps into smaller pieces/chips then crushing the chips into powder. Chips thus have a higher surface area than solid lumps but powder has a highest surface area.

An increase in surface area of solids increases the area of contact with a liquid solution increasing the chances of successful/effective/fruitful collision to form products. The influence of surface area on rate of reaction is mainly in heterogeneous reactions.

Reaction of chalk/calcium carbonate on dilute hydrochloric acid

Procedure

Measure 20cm3 of 1.0 M hydrochloric acid into three separate conical flasks labeled C_1 C_2 and C_3 .

Using a watch glass weigh three separate 2.5g a piece of white chalk. Place the conical flask C_1 on an electronic balance.

Reset the balance scale to 0.0.

Put one weighed sample of the chalk into the acid in the conical flask.

Determine the scale reading and record it at time =0.0.

Simultaneously start of the stop watch.

Determine and record the scale reading after every 30 seconds to complete Table I .

Repeat all the above procedure separately with C_2 and C_3 to complete Table II and Table III by cutting the chalk into small pieces/chips for C_2 and crushing the chalk to powder for C_3

Sample results:Table 1.

Time(seconds)	0.0	30.0	60.0	90.0	120.0	150.0	180.0	210.0	240.0
Mass of $CaCO_3$	**2.5**	**2.0**	**1.8**	**1.4**	**1.2**	**1.0**	**0.8**	**0.5**	**0.5**
Loss in mass	**0.0**	**0.5**	**0.7**	**1.1**	**1.3**	**1.5**	**1.7**	**2.0**	**2.0**

Sample results:Table 1I.

Time(seconds)	0.0	30.0	60.0	90.0	120.0	150.0	180.0	210.0	240.0
Mass of $CaCO_3$	**2.5**	**1.9**	**1.5**	**1.3**	**1.0**	**0.8**	**0.5**	**0.5**	**0.5**
Loss in mass	**0.0**	**0.6**	**1.0**	**1.2**	**1.5**	**1.7**	**2.0**	**2.0**	**2.0**

Sample results:Table III.

Time(seconds)	0.0	30.0	60.0	90.0	120.0	150.0	180.0	210.0	240.0
Mass of $CaCO_3$	**2.5**	**1.8**	**1.4**	**1.0**	**0.8**	**0.5**	**0.5**	**0.5**	**0.5**
Loss in mass	**0.0**	**0.7**	**1.1**	**1.5**	**1.7**	**2.0**	**2.0**	**2.0**	**2.0**

Sample questions:

1.Calculate the loss in mass made at the end of each time from the original to complete table I,II and III

2.On the same axes plot a graph of total loss in mass against time (x-axes) and label them curve I, II, and III from Table I, II, and III.

3.Explain why there is a loss in mass in all experiments.
Calcium carbonate react with the acid to form carbon(IV)oxide gas that escape to the atmosphere.

4.Write an ionic equation for the reaction that take place

$CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$

5.Sulphuric(VI)acid cannot be used in the above reaction. On the same axes sketch the curve which would be obtained if the reaction was attempted by reacting a piece of a lump of chalk with 0.5M sulphuric(VI)acid. Label it curve IV. Explain the shape of curve IV.

Calcium carbonate would react with dilute 0.5M sulphuric(VI)acid to form insoluble calcium sulphate(VI) that coat /cover unreacted Calcium carbonate stopping the reaction from reaching completion.

6.Calculate the volume of carbon(IV)oxide evolved(molar gas volume at room temperature = 24 dm3, C= 12.0, O= 16.O Ca=40.0)
Method I

Mole ratio $CaCO_3(s) : CO_2(g) = 1:1$

Moles $CaCO_3(s)$ used $= \frac{\text{Mass } CaCO_3(s)}{\text{Molar mass } CaCO_3(s)}$ = **0.025 moles**

Moles $CO_2(g)$ = 0.025 moles

Volume of $CO_2(g)$ = moles x molar gas volume

=>0.025 moles x 24 dm3 = **0.600 dm3/600cm3**

Method II

Molar mass of $CaCO_3(s)$ = 100g produce 24 dm3 of $CO_2(g)$

Mass of $CaCO_3(s)$ =2.5 g produce $\frac{2.5 \times 24}{100}$ = **0.600dm3**

7.From curve I ,determine the rate of reaction (loss in mass per second)at time 180 seconds on the curve.

From tangent at 180 seconds on curve I

$$\text{Rate} = \frac{M_2 - M_1}{T_2 - T_1} \Rightarrow \frac{2.08 - 1.375}{222-132} = \frac{0.625}{90} = \mathbf{0.006944g\ sec^{-1}}$$

8.What is the effect of particle size on the rate of reaction?

A larger surface area is a reduction in particle size which increases the area of contact between reacting particles increasing their collision frequency.

Theoretical examples

1. Excess marble chips were put in a beaker containing 100cm3 of 0.2M hydrochloric acid. The beaker was then placed on a balance and total loss in mass recorded after every two minutes as in the table below.

Time(minutes)	0.0	2.0	4.0	6.0	8.0	10.0	12.0
Loss in mass(g)	0.0	1.80	2.45	2.95	3.20	3.25	3.25

(a)Why was there a loss in mass?

Carbon (IV) oxide gas was produced that escape to the surrounding

(b)Calculate the average rate of loss in mass between:

(i) 0 to 2 minutes

$$\text{Average rate} = \frac{M_2 - M_1}{T_2 - T_1} \Rightarrow \frac{1.80 - 0.0}{2.0 - 0.0} = \frac{1.8}{2} = \mathbf{9.00g\ min^{-1}}$$

(i) 6 to 8 minutes

$$\text{Average rate} = \frac{M_2 - M_1}{T_2 - T_1} \Rightarrow \frac{3.20 - 2.95}{8.0 - 6.0} = \frac{0.25}{2} = \mathbf{0.125g\ min^{-1}}$$

(iii) Explain the difference between the average rates of reaction in (i) and(ii) above.

Between 0 and 2 minutes , the concentration of marble chips and hydrochloric acid is high therefore there is a higher collision frequency between the reacting particles leading to high successful rate of formation of products.

Between 6 and 8 minutes , the concentration of marble chips and hydrochloric acid is low therefore there is low collision frequency between the reacting particles leading to less successful rate of formation of products.

(c)Write the equation for the reaction that takes place.

$CaCO_3(s) + 2HCl\ (aq) \rightarrow CaCO_3\ (aq) + H_2O(l) + CO_2(g)$

(d)State and explain three ways in which the rate of reaction could be increased.

(i) Heating the acid- increasing the temperature of the reacting particles increases their kinetic energy and thus collision frequency.

(ii) Increasing the concentration of the acid-increasing in concentration reduces the distances between the reacting particles increasing their chances of effective/fruitful/successful collision to form products faster.

(iii) Crushing the marble chips to powder-this reduces the particle size/increase surface area increasing the area of contact between reacting particles.

(e)If the solution in the beaker was evaporated to dryness then left overnight in the open, explain what would happen.

It becomes wet because calcium (II) chloride absorbs water from the atmosphere and form solution/is deliquescent.

(f)When sodium sulphate (VI) was added to a portion of the contents in the beaker after the reaction , a white precipitate was formed .

(i)Name the white precipitate.

Calcium(II)sulphate(VI)

(ii)Write an ionic equation for the formation of the white precipitate

$Ca^{2+}(aq) + SO_4^{2-}(aq) \rightarrow CaSO_4(s)$

(iii)State one use of the white precipitate

-Making plaster for building

-Manufacture of plaster of Paris

-Making sulphuric(VI)acid

(g)(i) Plot a graph of total loss in mass(y-axes) against time

(**ii**)From the graph, determine the rate of reaction at time 2 minutes.

From a tangent/slope at 2 minutes;

Rate of reaction = Average rate $= \frac{M_2 - M_1}{T_2 - T_1} \Rightarrow \frac{2.25 - 1.30}{3.20 - 0.8} = \frac{0.95}{2.4} = \mathbf{0.3958g\ min^{-1}}$

(**iii**)Sketch on the same axes the graph that would be obtained if 0.02M hydrochloric acid was used. Label it curve II

e) Influence of catalyst on rate of reaction

Catalyst is a substance that alter the rate /speed of a chemical reaction but remain chemically unchanged at the end of a reaction. Biological catalysts are called **enzymes**. A catalyst does not alter the amount of products formed but itself may be altered **physically** e.g. from solid to powder to fine powder. Like biological enzymes, a catalyst only catalyse specific type of reactions

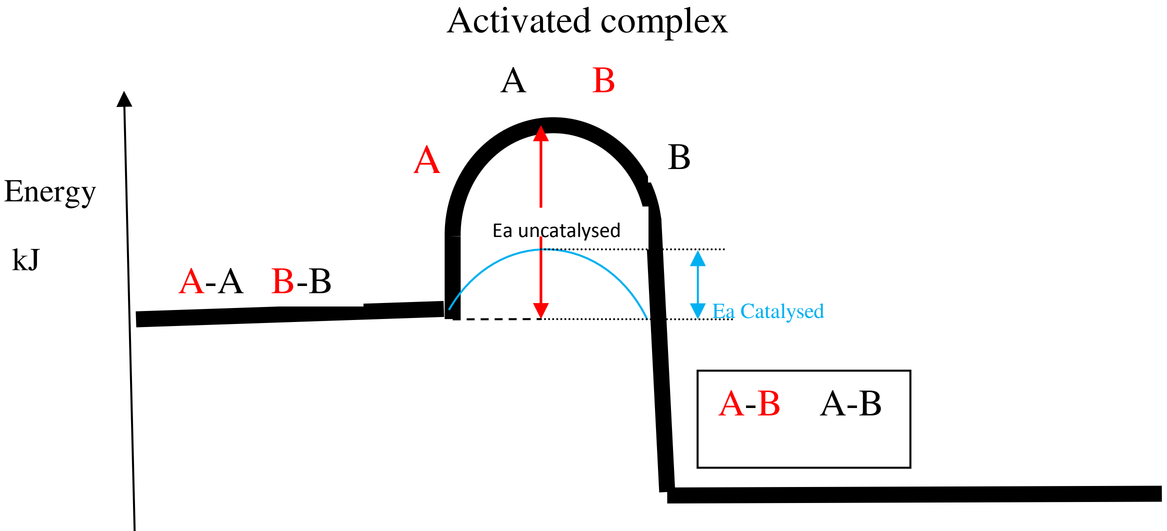
Most industrial catalysts are **transition metals** or their compounds. Catalyst works by lowering the Enthalpy of activation(ΔH_a)/activation energy (Ea) of the reactants .The catalyst lowers the Enthalpy of activation(ΔH_a)/activation energy (Ea) by:

(i) forming short lived intermediate compounds called activated complex that break up to form the final product/s

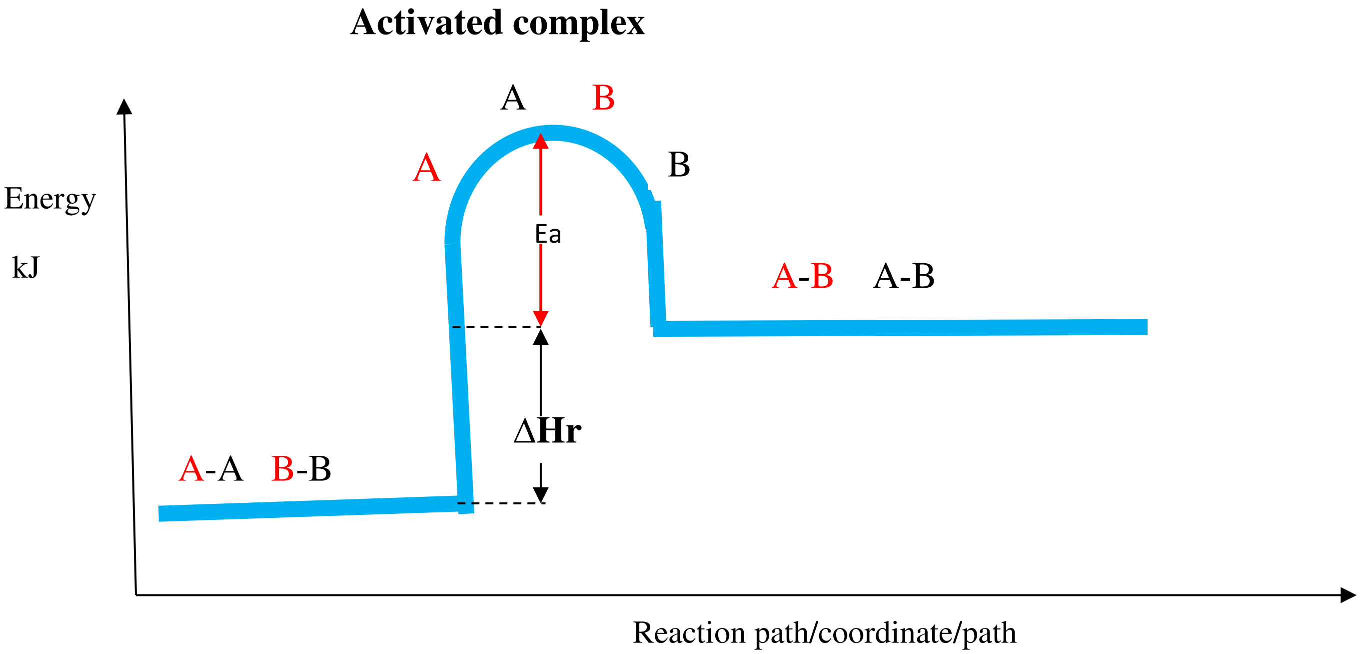
(ii) being absorbed by the reactants thus providing the surface area on which reaction occurs.

A catalyst has no effect on the enthalpy of reaction ΔH_r but only lowers the Enthalpy of activation(ΔH_a)/activation energy (Ea)It thus do not affect/influence whether the reaction is exothermic or endothermic as shown in the energy level diagrams below.

Energy level diagram showing the activation energy for exothermic processes /reactions.



Energy level diagram showing the activation energy for endothermic processes /reactions.



The following are some catalysed reaction processes.

(a)The contact process

Vanadium(V) Oxide(V_2O_5) or platinum(Pt) catalyses the oxidation of sulphur(IV)oxide during the manufacture of sulphuric(VI) acid from contact process.

$$SO_2(g) \quad + \quad O_2(g) \xrightarrow{\mathbf{V_2O_5}} SO_3(g)$$

To **reduce** industrial cost of manufacture of sulphuric (VI) acid from contact process Vanadium(V) Oxide(V_2O_5) is used because it is **cheaper** though it is **easily poisoned** by impurities.

(b)Ostwalds process

Platinum promoted with Rhodium catalyses the oxidation of ammonia to nitrogen(II)oxide and water during the manufacture of nitric(V)acid

$4NH_3(g)$ + $5O_2(g)$ ----**Pt/Rh**--> $4NO$ (g) + $6H_2O(l)$

(c)Haber process

Platinum or iron catalyses the combination of nitrogen and hydrogen to form ammonia gas

$N_2(g)$ + $3H_2(g)$ ---**Pt or Fe**---> $2NH_3(g)$

(d)Hydrogenation/Hardening of oil to fat

Nickel (Ni) catalyses the hydrogenation of unsaturated compound containing - C≡C- or –C=C- to saturated compounds without double or triple bond
This process is used is used in hardening oil to fat.

(e)Decomposition of hydrogen peroxide

Manganese(IV)oxide speeds up the rate of decomposition of hydrogen peroxide to water and oxygen gas.
This process/reaction is used in the school laboratory preparation of Oxygen.

$2H_2O_2$ (g) ----**MnO_2**--> $O_2(g)$ + $2H_2O(l)$

(f)Reaction of metals with dilute sulphuric(VI)acid

Copper(II)sulphate(VI) speeds up the rate of production of hydrogen gas from the reaction of Zinc and dilute sulphuric(VI)acid.
This process/reaction is used in the school laboratory preparation of Hydrogen.

$H_2 SO_4$ (aq) + Zn(s) ----$CuSO_4$--> $ZnSO_4$ (aq) + $H_2(g)$

(g) Substitution reactions

When placed in bright **sunlight** or **U.V /ultraviolet** light , a mixture of a halogen and an alkane undergo substitution reactions **explosively** to form halogenoalkanes. When paced in **diffused** sunlight the reaction is very **slow**.

e.g. $CH_4(g)$ + $Cl_2(g)$ ---**u.v. light**--> $CH_3Cl(g)$ + $HCl(g)$

(h)Photosynthesis

Plants convert carbon(IV)oxide gas from the atmosphere and water from the soil to form glucose and oxygen as a byproduct using sunlight / ultraviolet light.

$6CO_2(g)$ + $6H_2O(l)$ ---**u.v. light**--> $C_6H_{12}O_6(g)$ + $O_2(g)$

(i)Photography

Photographic film contains silver bromide emulsion which decomposes to silver and bromine on exposure to **sunlight**.

$2AgBr(s)$ ---**u.v/sun light**--> $2Ag(s) + Br_2(l)$

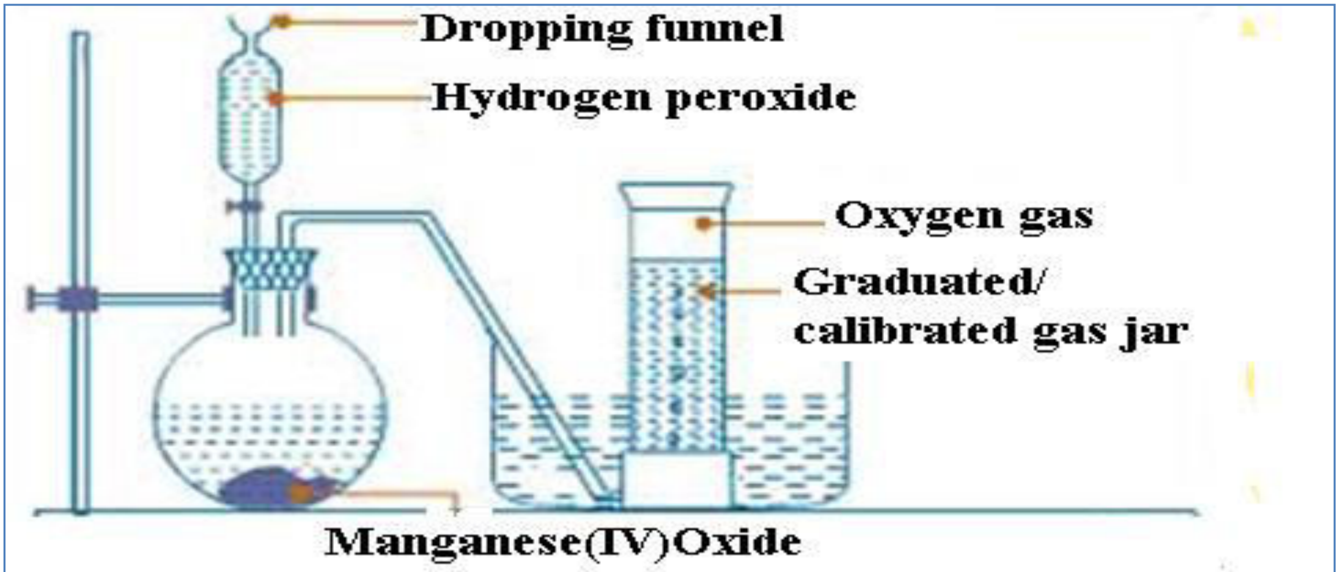
When developed, the silver deposits give the picture of the object whose photograph was taken depending on **intensity** of light. A picture photographed in **diffused** light is therefore **blurred**.

Practical determination of effect of catalyst on decomposition of hydrogen peroxide

Measure 5cm3 of 20 volume hydrogen peroxide and then dilute to make 40cm3 in a measuring cylinder by adding distilled water.
Divide it into two equal portions.
(**i**)Transfer one 20cm3volume hydrogen peroxide into a conical/round bottomed/flat bottomed flask. Cork and swirl for 2 minutes. Remove the cork. Test the gas produced using a glowing splint. Clean the conical/round bottomed/flat bottomed flask.

(**ii**)Put 2.0g of Manganese (IV) oxide into the clean conical/round bottomed/flat bottomed flask. Stopper the flask.
Transfer the second portion of the 20cm3volume hydrogen peroxide into a conical/round bottomed/flat bottomed flask through the dropping/thistle funnel. Connect the delivery tube to a calibrated/graduated gas jar as in the set up below.
Start off the stop watch and determine the volume of gas in the calibrated/graduated gas jar after every 30 seconds to complete Table 1.

(**iii**)Weigh a filter paper .Use the filter paper to filter the contents of the conical conical/round bottomed/flat bottomed flask. Put the residue on a sand bath to dry. Weigh the dry filter paper again .Determine the new mass Manganese (IV) oxide.

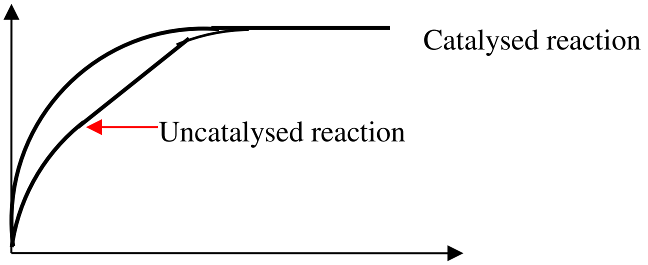


Determining the effect of catalyst on rate of decomposition of Hydrogen peroxide

Time(seconds)	0.0	30.0	60.0	90.0	120.0	150.0	180.0	210.0	240.0	270.0
Volume of gas (cm3)	0.0	20.0	40.0	60.0	80.0	90.0	95.0	96.0	96.0	96.0

Mass of MnO_2 **before** reaction(g)	Mass of MnO_2 **after** reaction(g)
2.0	2.0

Plot a graph of volume of gas produced against time(x-axes)



b) On the same axes, plot a graph of the uncatalysed reaction.

(c) Explain the changes in mass of manganese(IV)oxide before and after the reaction.

The mass of MnO_2 before and after the reaction is the same but a more fine powder after the experiment. A catalyst therefore remains unchanged chemically but may physically change.

B.EQUILIBRIA (CHEMICAL CYBERNETICS)

Equilibrium is a state of balance.
Chemical equilibrium is state of balance between the reactants and products.
As reactants form products, some products form back the reactants.
Reactions in which the reactants form products to completion are said to be reversible i.e.

$$A + B \rightarrow C + D$$

Reactions in which the reactants form products and the products can reform the reactants are said to be reversible.

$$A + B \quad C + D$$

Reversible reactions may be:

(**a**)Reversible physical changes
(**b**)Reversible chemical changes
(**c**)Dynamic equilibrium

(a)Reversible physical changes

Reversible physical change is one which involves:

(i) change of state/phase from solid, liquid, gas or aqueous solutions. States of matter are interconvertible and a reaction involving a change from one state/phase can be reversed back to the original.

(ii) colour changes. Some substances/compounds change their colours without change in chemical substance.

Examples of reversible physical changes

(i) colour change on heating and cooling:

I. Zinc(II)Oxide changes from white when cool/cold to yellow when hot/heated and back.

$$ZnO(\mathbf{s}) \rightleftharpoons ZnO(\mathbf{s})$$

(white when cold) (yellow when hot)

II. Lead(II)Oxide changes from yellow when cold/cool to brown when hot/heated and back.

$$PbO(\mathbf{s}) \rightleftharpoons PbO(\mathbf{s})$$

(brown when hot) (yellow when cold)

(ii)Sublimation

I. Iodine **sublimes** from a grey crystalline solid on heating to purple vapour. Purple vapour undergoes **deposition** back to the grey crystalline solid.

$$I_2(\mathbf{s}) \rightleftharpoons I_2(\mathbf{g})$$

(grey crystalline solid undergo sublimation) (purple vapour undergo deposition)

II. Carbon (IV)oxide gas undergoes **deposition** from a colourless gas to a white solid at very high pressures in a cylinder. It **sublimes** back to the colourless gas if pressure is reduced

$$CO_2(\mathbf{s}) \rightleftharpoons CO_2(\mathbf{g})$$

(white powdery solid undergo sublimation) (colourless/odourless gas undergo deposition)

(iii)Melting/ freezing and boiling/condensation

Ice on heating undergo **melting** to form a liquid/water. Liquid/water on further heating **boil**/vaporizes to form gas/water vapour. Gas/water vapour on cooling, **condenses**/liquidifies to water/liquid. On further cooling, liquid water **freezes** to ice/solid.

$$\boxed{H_2O(\mathbf{s})} \underset{\text{Freezing}}{\overset{\text{Melting}}{\rightleftharpoons}} \boxed{H_2O(\mathbf{l})} \underset{\text{condensing}}{\overset{\text{boiling}}{\rightleftharpoons}} \boxed{H_2O(\mathbf{s})}$$

(iv)Dissolving/ crystallization/distillation

Solid crystals of soluble substances (solutes) dissolve in water /solvents to form a uniform mixture of the solute and solvent/solution. On crystallization /distillation /evaporation the solvent evaporate leaving a solute back. e.g.

$$NaCl(\mathbf{s}) + aq \rightleftharpoons NaCl(\mathbf{aq})$$

(b)Reversible chemical changes

These are reactions that involve a chemical change of the reactants which can be reversed back by recombining the new substance formed/products.

<u>Examples of Reversible chemical changes</u>

(i)Heating Hydrated salts/adding water to anhydrous salts.

When **hydrated** salts are heated they **lose** some/all their **water** of crystallization and become **anhydrous**.Heating an unknown substance /compound that forms a **colourless liquid droplets** on the **cooler** parts of a dry test/boiling tube is in fact a **confirmation** inference that the substance/compound being heated is **hydrated**.
When anhydrous salts are added (back) some water they form hydrated compound/salts.

Heating Copper(II)sulphate(VI)pentahydrate and cobalt(II)chloride hexahydrate

(i)Heat about 5.0g of Copper(II)sulphate(VI) pentahydrate in a clean dry test tube until there is no further colour change on a small Bunsen flame. Observe any changes on the side of the test/boiling tube. Allow the boiling tube to cool.Add about 10 drops of distilled water. Observe any changes.

(ii)Dip a filter paper in a solution of cobalt(II)chloride hexahydrate. Pass one end the filter paper to a small Bunsen flame repeatedly. Observe any changes on the filter paper. Dip the paper in a beaker containing distilled water. Observe any changes.

Sample observations

Hydrated compound	**Observation before heating**	**Observation after heating**	**Observation on adding water**
Copper(II)sulphate (VI) pentahydrate	**Blue** crystalline solid	(i)colour changes from **blue** to **white**. (ii)colourless liquid forms on the cooler parts of boiling / test tube	(i)colour changes from **white** to **blue** (ii)boiling tube becomes warm /hot.
Cobalt(II)chloride hexahydrate	**Pink** crystalline solid/solution	(i)colour changes from **pink** to **blue**. (ii) colourless liquid forms on the cooler parts of boiling / test tube (if crystal are used)	(i)colour changes from **blue** to **pink** (ii)boiling tube becomes warm/hot.

When blue Copper(II)sulphate (VI) pentahydrate is heated, it loses the five molecules of water of crystallization to form white anhydrous Copper(II)sulphate (VI).Water of crystallization form and condenses as colourless droplets on the cooler parts of a dry boiling/test tube.
This is a chemical change that produces a new substance. On adding drops of water to an anhydrous white copper(II)sulphate(VI) the hydrated compound is

formed back. The change from **hydrated** to **anhydrous** and **back** is therefore **reversible chemical change.** Both anhydrous white copper(II)sulphate(VI) and blue cobalt(II)chloride hexahydrate are therefore used to test for the presence of water when they turn to blue and pink respectively.

$$CuSO_4(\mathbf{s}) \quad + \quad 5H_2O(\mathbf{l}) \rightleftharpoons CuSO_4 \cdot 5H_2O(\mathbf{s/aq})$$

(white/anhydrous) (blue/hydrated)

$$CoCl_2(\mathbf{s}) \quad + \quad 6H_2O(\mathbf{l}) \rightleftharpoons CoCl_2 \cdot 6H_2O(\mathbf{s/aq})$$

(blue/anhydrous) (pink/hydrated)

(ii)Chemical sublimation

Some compounds sublime from solid to gas by dissociating into new different compounds. e.g.

Heating ammonium chloride

(**i**)Dip a glass rod containing concentrated hydrochloric acid. Bring it near the mouth of a bottle containing concentrated ammonia solution. Explain the observations made.

When a glass rod containing hydrogen chloride gas is placed near ammonia gas, they react to form ammonium chloride solid that appear as **white fumes**.

This experiment is used interchangeably to test for the presence of hydrogen chloride gas (and hence Cl^- ions) and ammonia gas (and hence NH_4^+ ions)

(**ii**)Put 2.0 g of ammonium chloride in a long dry boiling tube. Place wet / moist /damp blue and red litmus papers separately on the sides of the mouth of the boiling tube. Heat the boiling tube gently then strongly. Explain the observations made.

When ammonium chloride is heated it dissociates into ammonia and hydrogen chloride gases. Since ammonia is less dense, it diffuses faster to turn both litmus papers blue before hydrogen chloride turn red because it is denser. The heating and cooling of ammonium chloride is therefore a **reversible chemical change**.

$$NH_3(g) \quad + \quad HCl(g) \rightleftharpoons NH_4Cl(s)$$

(Turns moist litmus paper blue)	(Turns moist litmus paper red)	(forms white fumes)

(c)Dynamic equilibria

For reversible reactions in a closed system:

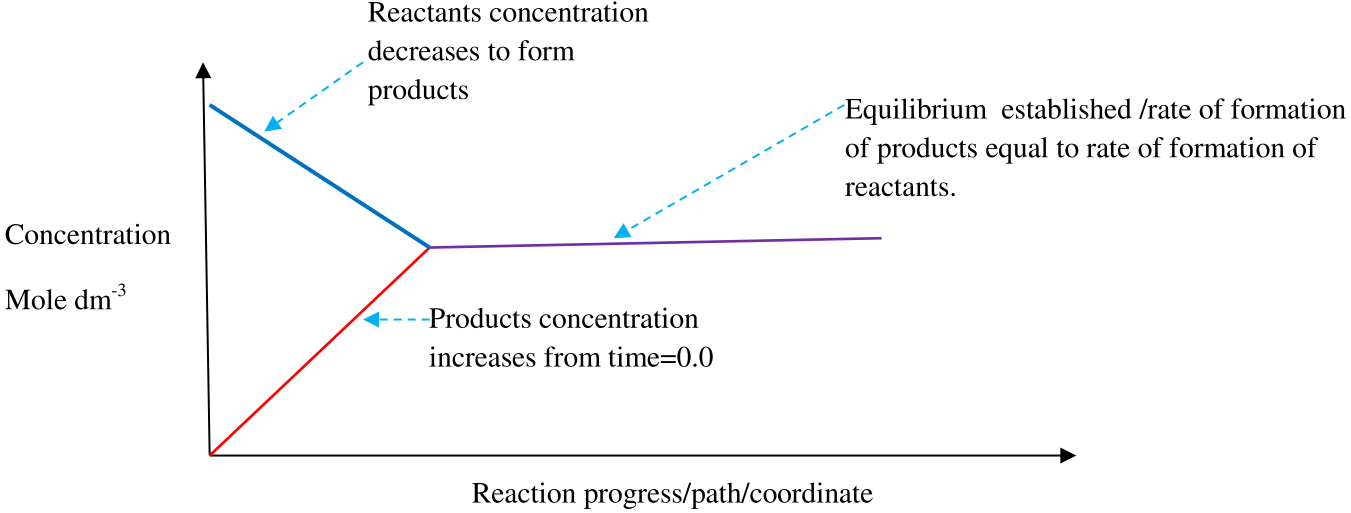
(i) at the beginning;

-the reactants are decreasing in concentration with time

-the products are increasing in concentration with time

(ii) after some time a point is reached when as the reactants are forming products the products are forming reactants. This is called equilibrium.

Sketch showing the changes in concentration of reactants and products in a closed system



For a system in equilibrium:

(i) a reaction from left to right (reactants to products) is called forward reaction.

(ii) a reaction from right to left (products to reactants) is called backward reaction.

(iii)a reaction in which the rate of forward reaction is equal to the rate of backward reaction is called a **dynamic equilibrium.**

A dynamic equilibrium is therefore a balance of the rate of formation of products and reactants. This balance continues until the reactants or products are disturbed/changed/ altered.

The influence of different factors on a dynamic equilibrium was first investigated from 1850-1936 by the French Chemist Louis Henry Le Chatellier. His findings were called Le Chatelliers Principle which states that:

"if a stress/change is applied to a system in dynamic equilibrium, the system readjust/shift/move/behave so as to remove/ reduce/ counteract/ oppose the stress/change"

Le Chatelliers Principle is applied in determining the effect/influence of several factors on systems in dynamic equilibrium. The following are the main factors that influence /alter/ affect systems in dynamic equilibrium:

(a)Concentration
(b)Pressure
(c)Temperature
(d)Catalyst

(a)Influence of concentration on dynamic equilibrium

An increase/decrease in concentration of reactants/products at equilibrium is a stress. From Le Chatelliers principle the system redjust so as to remove/add the excessreduced concentration.

Examples of influence of concentration on dynamic equilibrium

(i)Chromate(VI)/CrO_4^{2-} ions in solution are **yellow**. Dichromate(VI)/$Cr_2O_7^{2-}$ ions in solution are **orange**. The two solutions exist in equilibrium as in the equation:

$$\underset{\text{(Yellow)}}{2H^+(aq) + 2CrO_4^{2-}(aq)} \rightleftharpoons \underset{\text{(Orange)}}{Cr_2O_7^{2-}(aq) + H_2O(l)}$$

I. If an acid is/H^+ (aq) is added to the equilibrium mixture a stress is created on the reactant side where there is already H^+ ions. The equilibrium shift forward to the right to remove/reduce the **excess** H^+ ions added. Solution mixture becomes More $Cr_2O_7^{2-}$ ions formed in the solution mixture make it to be more **orange** in colour.

II. If a base/OH^- (aq) is added to the equilibrium mixture a stress is created on the reactant side on the H^+ ions. H^+ ions react with OH^- (aq) to form water.

$$H^+ (aq) + OH^- (aq) \rightarrow H_2O(l)$$

The equilibrium shift backward to the left to add/replace the H^+ ions that have reacted with the OH^- (aq) ions . More of the CrO_4^{2-} ions formed in the solution mixture makes it to be more **yellow** in colour.

$$2OH^- (aq) + \underset{\text{(Orange)}}{2Cr_2O_7^{2-} (aq)} \rightleftharpoons \underset{\text{(Yellow)}}{CrO_4^{2-} (aq)} + H_2O(l)$$

I. If an acid/ H^+ (aq) is added to the equilibrium mixture a stress is created on the reactant side on the OH^- (aq). H^+ ions react with OH^- (aq) to form water.

$$H^+ (aq) + OH^- (aq) \rightarrow H_2O(l)$$

The equilibrium shift backward to the left to add/replace the $2OH^-$ (aq) that have reacted with the H^+ (aq) ions . More $Cr_2O_7^{2-}$ (aq)ions formed in the solution mixture makes it to be more **Orange** in colour.

II. If a base /OH^- (aq) is added to the equilibrium mixture a stress is created on the reactant side where there is already OH^- (aq) ions. The equilibrium shift forward to the right to remove/reduce the **excess** OH^- (aq) ions added. More of the $Cr_2O_7^{2-}$ ions are formed in the solution mixture making it to be more **orange** in colour.

(i)Practical determination of the influence of alkali/acid on $Cr_2O_7^{2-}$ / CrO_4^{2-} equilibrium mixture

Measure about 2 cm3 of Potassium dichromate (VI) solution into a test tube.

Note that the solution mixture is orange.

Add three drops of 2M sulphuric(VI) acid. Shake the mixture carefully.

Note that the solution mixture is remains orange.

Add about six drops of 2M sodium hydroxide solution. Shake carefully.

Note that the solution mixture is turns yellow.

Explanation

The above observations can be explained from the fact that both the dichromate(VI)and chromate(VI) exist in equilibrium. Dichromate(VI) ions are stable in acidic solutions while chromate(VI)ions are stable in basic solutions. An equilibrium exist thus:

$$Cr_2O_7^{2-} \overset{OH-}{\underset{H+}{\rightleftharpoons}} CrO_4^{2-}$$

When an **acid** is added, the equilibrium shift **forward** to the right and the mixture become more **orange** as more $Cr_2O_7^{2-}$ ions exist.
When a **base** is added, the equilibrium shift **backward** to the left and the mixture become more **yellow** as more CrO_4^{2-} ions exist.

(ii)Practical determination of the influence of alkali/acid on bromine water in an equilibrium mixture

Measure 2cm3 of bromine water into a boiling tube. Note its colour.

Bromine water is yellow

Add three drops of 2M sulphuric(VI)acid. Note any colour change

Colour becomes more yellow

Add seven drops of 2M sodium hydroxide solution. Note any colour change.

Solution mixture becomes colourless/Bromine water is decolourized.

Explanation

When added distilled water,an equilibrium exist between bromine liquid ($Br_2(aq)$) and the bromide ion(Br^-), hydrobromite ion(OBr^-) and hydrogen ion(H^+) as in the equation:

$$H_2O(l) + Br_2(aq) \rightleftharpoons OBr^- (aq) + H^+ (aq) + Br^- (aq)$$

If an acid (H^+)ions is added to the equilibrium mixture, it increases the concentration of the ions on the product side which shift backwards to the left to remove the excess H^+ ions on the product side making the colour of the solution mixture more yellow.

If a base/alkali OH^- is added to the equilibrium mixture, it reacts with H^+ ions on the product side to form water.

$$H^+ (aq) + OH^-(aq) \rightarrow H_2O(l)$$

This decreases the concentration of the H^+ ions on the product side which shift the equilibrium forward to the right to replace H^+ ions making the solution mixture colourless/less yellow (Bromine water is decolorized)

(iii)Practical determination of the influence of alkali/acid on common acid-base indicators.

Place 2cm3 of phenolphthalein ,methyl orange and litmus solutions each in three separate test tubes.
To each test tube add two drops of water. Record your observations in Table 1 below.
To the same test tubes, add three drops of 2M sulphuric(VI)acid. Record your observations in Table 1 below.
To the same test tubes, add seven drops of 2M sodium hydroxide solution. Record your observations in Table 1 below.
To the same test tubes, repeat adding four drops of 2M sulphuric(VI)acid.

Table 1

Indicator	Colour of indicator in		
	Water	Acid(2M sulphuric (VI) acid)	Base(2M sodium hydroxide)
Phenolphthalein	**Colourless**	**Colourless**	**Pink**
Methyl orange	**Yellow**	**Red**	**Orange**
Litmus solution	**Colourless**	**Red**	**Blue**

Explanation
An indicator is a substance which shows whether **another** substance is an **acid** , **base** or **neutral**.
Most indicators can be regarded as very weak acids that are partially dissociated into ions.An equilibrium exist between the undissociated molecules and the dissociated anions. Both the molecules and anions are **coloured**. i.e.

$$HIn(aq) \rightleftharpoons H^+(aq) + In^-(aq)$$

(undissociated indicator molecule(**coloured**)) (dissociated indicator molecule(**coloured**))

When an acid H^+ is added to an indicator, the H^+ ions increase and equilibrium shift backward to remove excess H^+ ions and therefore the **colour** of the undissociated (**HIn**) molecule **shows/appears.**
When a base/alkali OH^- is added to the indicator, the OH^- reacts with H^+ ions from the dissociated indicator to form water.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

(from indicator) (from alkali/base)

The equilibrium shift forward to the right to replace the H^+ ion and therefore the colour of dissociated (**In**$^-$) molecule **shows/appears.**

The following examples illustrate the above.

(i)Phenolphthalein indicator exist as:

$$\underset{\text{(colourless molecule)}}{HPh} \rightleftharpoons H^+(aq) + \underset{\text{(Pink anion)}}{Ph^-(aq)}$$

On adding an acid ,equilibrium shift backward to the left to remove excess H^+ ions and the solution mixture is therefore **colourless.**

When a base/alkali OH^- is added to the indicator, the OH^- reacts with H^+ ions from the dissociated indicator to form water.

$$\underset{\text{(from indicator)}}{H^+(aq)} + \underset{\text{(from alkali/base)}}{OH^-(aq)} \rightarrow H_2O(l)$$

The equilibrium shift forward to the right to replace the removed/reduced H^+ ions. The **pink** colour of dissociated (**Ph^-**) molecule **shows/appears.**

(ii)Methyl Orange indicator exists as:

$$\underset{\text{(Red molecule)}}{HMe} \rightleftharpoons H^+(aq) + \underset{\text{(Yellow/Orange anion)}}{Me^-(aq)}$$

On adding an acid ,equilibrium shift backward to the left to remove excess H^+ ions and the solution mixture is therefore **red.**

When a base/alkali OH^- is added to the indicator, the OH^- reacts with H^+ ions from the dissociated indicator to form water.

$$\underset{\text{(from indicator)}}{H^+(aq)} + \underset{\text{(from alkali/base)}}{OH^-(aq)} \rightarrow H_2O(l)$$

The equilibrium shift forward to the right to replace the removed/reduced H^+ ions. The **Orange** colour of dissociated (**Me^-**) molecule **shows/appears.**

(b)Influence of Pressure on dynamic equilibrium

Pressure affects gaseous reactants/products. Increase in **pressure** shift/**favours** the equilibrium towards the side with **less volume/molecules**. Decrease in pressure shift the equilibrium towards the side with more volume/molecules. More yield of products is obtained if high pressures produce less molecules / volume of products are formed.

If the products and reactants have **equal** volume/molecules then pressure has **no effect** on the position of equilibrium

The following examples show the influence of pressure on dynamic equilibrium:

(i)Nitrogen(IV)oxide /Dinitrogen tetroxide mixture

Nitrogen(IV)oxide and dinitrogen tetraoxide can exist in dynamic equilibrium in a closed test tube. Nitrogen(IV)oxide is a brown gas. Dinitrogen tetraoxide is a yellow gas.

Chemical equation :	$2NO_2(g)$	$\rightleftharpoons$	$N_2O_4(g)$
Gay Lussacs law	**2**Volume		**1**Volume
Avogadros law	**2**molecule		**1**molecule

2 volumes/molecules of Nitrogen(IV)oxide form **1** volumes/molecules of dinitrogen tetraoxide

Increase in pressure shift the equilibrium forward to the left where there is less volume/molecules.The equilibrium mixture become more **yellow**.

Decrease in pressure shift the equilibrium backward to the right where there is more volume/molecules. The equilibrium mixture become more **brown.**

(ii)Iodine vapour-Hydrogen gas/Hydrogen Iodide mixture.

Pure hydrogen gas reacts with Iodine vapour to form Hydrogen Iodide gas.

Chemical equation :	$I_2(g)$	+	$H_2(g)$	$\rightleftharpoons$	$2HI(g)$
Gay Lussacs law	**1**Volume		**1**Volume		**2**Volume
Avogadros law	**1**molecule		**1**molecule		**2**molecule

(1+1) **2** volumes/molecules of Iodine and Hydrogen gasform **2** volumes/molecules of Hydrogen Iodide gas.

Change in pressure thus has no effect on position of equilibrium.

(iii)Haber process.

Increase in pressure of the Nitrogen/Hydrogen mixture favours the formation of **more** molecules of Ammonia gas in Haber process**.**

The yield of ammonia is thus favoured by high pressures

Chemical equation :	$N_2(g)$	+	$3H_2(g)$	->	$2NH_3(g)$
Gay Lussacs law	**1**Volume		**3**Volume		**2**Volume
Avogadros law	**1**molecule		**3**molecule		**2**molecule

(1 + 3) **4** volumes/molecules of Nitrogen and Hydrogen react to form **2** volumes/molecules of ammonia.

Increase in pressure shift the equilibrium forward to the left where there is less volume/molecules.
The yield of ammonia increase.
Decrease in pressure shift the equilibrium backward to the right where there is more volume/molecules.
The yield of ammonia decrease.

(iv)Contact process.

Increase in pressure of the Sulphur(IV)oxide/Oxygen mixture favours the formation of **<u>more</u>** molecules of Sulphur(VI)oxide gas in Contact process**.** The yield of Sulphur(VI)oxide gas is thus favoured by high pressures.

Chemical equation :	$2SO_2(g)$	+	O_2 (g)	->	$2SO_3$ (g)
Gay Lussacs law	**2**Volume		**1**Volume		**2**Volume
Avogadros law	**2**molecule		**1**molecule		**2**molecule

(2 + 1) **3** volumes/molecules of Sulphur(IV)oxide/Oxygen mixture react to form **2** volumes/molecules of Sulphur(VI)oxide gas.
Increase in pressure shift the equilibrium forward to the left where there is less volume/molecules. The yield of Sulphur(VI)oxide gas increase.
Decrease in pressure shift the equilibrium backward to the right where there is more volume/molecules. The yield of Sulphur(VI)oxide gas decrease.

(v)Ostwalds process.

Increase in pressure of the Ammonia/Oxygen mixture favours the formation of **<u>more</u>** molecules of Nitrogen(II)oxide gas and water **vapour** in Ostwalds process**.** The yield of Nitrogen(II)oxide gas and water **vapour** is thus favoured by low pressures.

Chemical equation :	$4NH_3(g)$	+	$5O_2$ (g)	->	4NO(g)	+	$6H_2O$ (g)
Gay Lussacs law	**4**Volume		**5**Volume		**4**Volume		**6**Volume
Avogadros law	**4**molecule		**5**molecule		**4**molecule		**6**Molecule

(4 + 5) **9** volumes/molecules of Ammonia/Oxygen mixture react to form **10** volumes/molecules of Nitrogen(II)oxide gas and water **vapour**.

Increase in pressure shift the equilibrium backward to the left where there is less volume/molecules. The yield of Nitrogen(II)oxide gas and water vapour **decrease**.

Decrease in pressure shift the equilibrium forward to the right where there is more volume/molecules. The yield of Nitrogen(II)oxide gas and water vapour **increase**.

Note

If the water vapour is **condensed** on cooling, then:

Chemical equation :	$4NH_3(g)$	+	$5O_2$ (g)	->	4NO(g)	+	$6H_2O$ (**l**)
Gay Lussacs law	**4**Volume		**5**Volume		**4**Volume		**0**Volume
Avogadros law	**4**molecule		**5**molecule		**4**molecule		**0**Molecule

(4 + 5) **9** volumes/molecules of Ammonia/Oxygen mixture react to form **4** volumes/molecules of Nitrogen(II)oxide gas and no **vapour**.

Increase in pressure shift the equilibrium forward to the right where there is less volume/molecules. The yield of Nitrogen(II)oxide gas **increase**.

Decrease in pressure shift the equilibrium backward to the left where there is more volume/molecules. The yield of Nitrogen(II)oxide gas **decrease**.

(c)Influence of Temperature on dynamic equilibrium

A **decrease** in temperature favours the reaction that liberate/generate more heat thus **exothermic** reaction(**-ΔH**).

An **increase** in temperature favours the reaction that do not liberate /generate more heat thus **endothermic** reaction(**+ΔH**).

Endothermic reaction are thus favoured by high temperature/heating

Exothermic reaction are favoured by low temperature/cooling.

If a reaction/equilibrium mixture is neither exothermic or endothermic, then a change in temperature/cooling/heating has no effect on the equilibrium position.

(i)Nitrogen(IV)oxide /Dinitrogen tetroxide mixture

Nitrogen(IV)oxide and dinitrogen tetraoxide can exist in dynamic equilibrium in a closed test tube. Nitrogen(IV)oxide is a brown gas. Dinitrogen tetraoxide is a yellow gas.

Chemical equation : $2NO_2(g) \rightleftharpoons N_2O_4(g)$

On heating /increasing temperature, the mixture becomes more brown. On cooling the mixture become more yellow.

This show that

(i)the forward reaction to the right is exothermic(**-ΔH**).

On heating an exothermic process the equilibrium shifts to the side that generate /liberate less heat.

(ii)the backward reaction to the right is endothermic(**+ΔH**).

On cooling an endothermic process the equilibrium shifts to the side that do not generate /liberate heat.

(c)Influence of Catalyst on dynamic equilibrium

A catalyst has no effect on the position of equilibrium. It only speeds up the rate of attainment. e.g.

Esterification of alkanols and alkanoic acids naturally take place in fruits.In the laboratory concentrated sulphuric(VI)acid catalyse the reaction.The equilibrium mixture forms the ester faster but the yield does not increase.

$CH_3CH_2OH(l)+CH_3COOH(l) \overset{Conc.H_2SO_4}{\rightleftharpoons} CH_3COOCH_2CH_3(aq) + H_2O(l)$

(d)Influence of rate of reaction and dynamic equilibrium (<u>Optimum conditions</u>) on industrial processes

Industrial processes are commercial profit oriented. All industrial processes take place in closed systems and thus in dynamic equilibrium.

For manufacturers, obtaining the highest yield at minimum cost and shortest time is paramount.

The conditions required to obtain the highest yield of products within the shortest time at minimum cost are called **optimum conditions**

Optimum condition thus require understanding the effect of various factors on:

(i)rate of reaction(**Chemical kinetics**)
(ii)dynamic equilibrium(**Chemical cybernetics**)

1.Optimum condition in Haber process

Chemical equation

$$N_2\,(g) + 3H_2\,(g) \quad ===Fe/Pt=== \quad 2NH_3\,(g) \qquad \Delta H = -92kJ$$

Equilibrium/Reaction rate considerations

(i)**Removing ammonia** gas once formed shift the equilibrium forward to the right to replace the ammonia. More/higher yield of ammonia is attained.

(ii)**Increase in pressure** shift the equilibrium forward to the right where there is less volume/molecules . **More/higher yield** of ammonia is attained. Very **high** pressures raises the **cost** of production because they are **expensive** to produce and maintain. An optimum pressure of about 500atmospheres is normally used.

(iii)**Increase in temperature** shift the equilibrium backward to the left because the reaction is exothermic($\Delta H = -92kJ$) . Ammonia formed **decomposes** back to Nitrogen and Hydrogen to remove excess heat therefore a **less** yield of ammonia is attained. Very **low** temperature decrease the collision frequency of Nitrogen and Hydrogen and thus the rate of reaction **too slow** and **uneconomical**.
An optimum temperature of about 450°C is normally used.

(iv)Iron and platinum can be used as catalyst. **Platinum** is a **better** catalyst but more **expensive** and easily **poisoned** by impurities than Iron. Iron is promoted /impregnated with AluminiumOxide(Al_2O_3) to increase its surface area/area of contact with reactants and thus efficiency.The catalyst does not increase the yield of ammonia but it speed up its rate of formation.

2.Optimum condition in Contact process

Chemical equation

$$2SO_2\,(g) + O_2\,(g) \quad ===V_2O_5/Pt=== \quad 2SO_3\,(g) \qquad \Delta H = -197kJ$$

Equilibrium/Reaction rate considerations (i)**Removing sulphur(VI)oxide** gas once formed shift the equilibrium forward to the right to replace the sulphur(VI)oxide. More/higher yield of sulphur(VI) oxide is attained.

(ii)**Increase in pressure** shift the equilibrium forward to the right where there is less volume/molecules . **More/higher yield** of sulphur(VI)oxide is attained. Very **high** pressures raises the **cost** of production because they are **expensive** to produce and maintain. An optimum pressure of about 1-2 atmospheres is normally used to attain about 96% yield of SO_3.

(iii)**Increase in temperature** shift the equilibrium backward to the left because the reaction is exothermic($\Delta H = -197kJ$) . Sulphur(VI)oxide formed **decomposes** back to Sulphur(IV)oxide and Oxygen to remove excess heat therefore a **less** yield of Sulphur(VI)oxide is attained. Very **low** temperature decrease the collision frequency of Sulphur(IV)oxide and Oxygen and thus the rate of reaction **too slow** and **uneconomical**.
An optimum temperature of about 450°C is normally used.

(iv)Vanadium(V)Oxide and platinum can be used as catalyst. **Platinum** is a **better** catalyst and **less** easily **poisoned** by impurities but more **expensive.** Vanadium(V)Oxide is very cheap even if it is easily poisoned by impurities. The catalyst does not increase the yield of Sulphur (VI)Oxide but it speed up its rate of formation.

3.Optimum condition in Ostwalds process

Chemical equation

$$4NH_3\,(g) + 5O_2\,(g) \;===Pt/Rh===\; 4NO\,(g) + 6H_2O\,(g)\;\Delta H = -950kJ$$

Equilibrium/Reaction rate considerations

(i)**Removing Nitrogen(II)oxide** gas once formed shift the equilibrium forward to the right to replace the Nitrogen(II)oxide. More/higher yield of Nitrogen(II) oxide is attained.

(ii)**Increase in pressure** shift the equilibrium backward to the left where there is less volume/molecules . **Less/lower yield** of Nitrogen(II)oxide is attained.

Very **low** pressures increases the distance between reacting $NH_3$and O_2 molecules.
An optimum pressure of about **9** atmospheres is normally used.

(iii)**Increase in temperature** shift the equilibrium backward to the left because the reaction is exothermic($\Delta H = -950kJ$) . Nitrogen(II)oxide and water vapour formed **decomposes** back to Ammonia and Oxygen to remove excess heat therefore a **less** yield of Nitrogen(II)oxide is attained. Very **low** temperature decrease the collision frequency of Ammonia and Oxygen and thus the rate of reaction **too slow** and **uneconomical**.
An optimum temperature of about $900^{o}C$ is normally used.

(iv)Platinum can be used as catalyst. **Platinum** is very **expensive.**It is:
- promoted with Rhodium to increase the surface area/area of contact.
- added/coated on the surface of asbestos to form platinized –asbestos to reduce the amount/quantity used.

The catalyst does not increase the yield of Nitrogen (II)Oxide but it speed up its rate of formation.

C.SAMPLE REVISION QUESTIONS

1.State two distinctive features of a dynamic equilibrium.

(**i**)the rate of forward reaction is equal to the rate of forward reaction
(**ii**)at equilibrium the concentrations of reactants and products do not change.

2. Explain the effect of increase in pressure on the following:

(i) $N_2(g) \quad + \quad O_2(g) \quad ===== \quad 2NO(g)$

Gay Lussacs law	1Volume	1Volume	2 Volume
Avogadros law	1 molecule	1 molecule	2 molecule

2 volume on reactant side produce 2 volume on product side.
Increase in pressure thus have no effect on position of equilibrium.

(ii) $2H_2(g) \quad + \quad CO(g) \quad ===== \quad CH_3OH\ (g)$

Gay Lussacs law	2Volume	1Volume	1 Volume
Avogadros law	2 molecule	1 molecule	1 molecule

3 volume on reactant side produce 1 volume on product side.
Increase in pressure shift the equilibrium forward to the left. More yield of CH_3OH is formed.

4. Explain the effect of increasing temperature on the following:

$2SO_2(g) \quad + \quad O_2(g) \quad ===== \quad 2SO_3(g) \ \Delta H = -189kJ$

Forward reaction is exothermic. Increase in temperature shift the equilibrium backward to reduce the excess heat.

5.120g of brass an alloy of copper and Zinc was put it a flask containing dilute hydrochloric acid. The flask was placed on an electric balance. The readings on the balance were recorded as in the table below

Time(Seconds)	Mass of flask(grams)	Loss in mass(grams)
0	600	
20	599.50	
40	599.12	
60	598.84	
80	598.66	
100	598.54	
120	598.50	
140	598.50	
160	598.50	

(a)Complete the table by calculating the loss in mass

(b)What does the “600” gram reading on the balance represent

The initial mass of brass and the acid before any reaction take place.

(c)Plot a graph of Time (x-axes) against loss in mass.

(d)Explain the shape of your graph

The reaction produce hydrogen gas as one of the products that escape to the atmosphere. This decreases the mass of flask.After 120 seconds,the

react is complete. No more hydrogen is evolved.The mass of flask remain constant.

(d)At what time was the loss in mass equal to:

(i)1.20g
Reading from a correctly plotted graph =

(ii)1.30g
Reading from a correctly plotted graph =

(iii)1.40g
Reading from a correctly plotted graph =

(e)What was the loss in mass at:

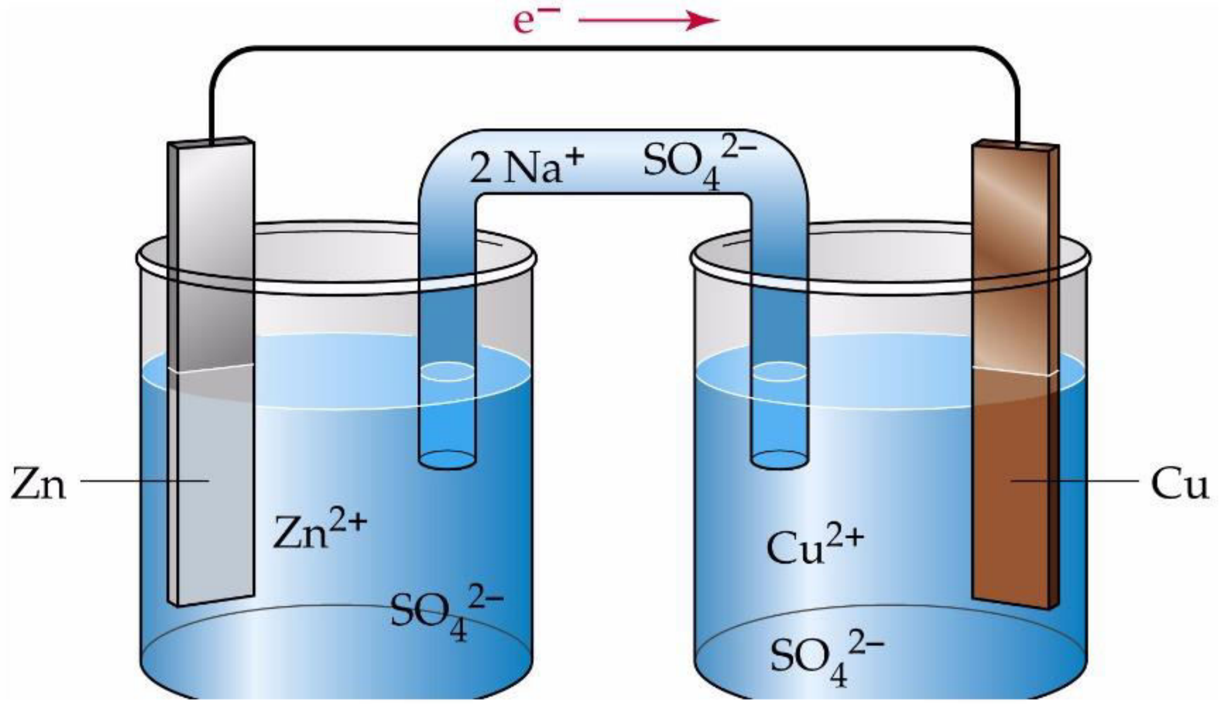
(i)50°C
Reading from a correctly plotted graph =

(ii) 70°C
Reading from a correctly plotted graph =

(iii) 90°C g
Reading from a correctly plotted graph =

21.0.0 ELECTROCHEMISTRY

(25 LESSONS)



Electrochemistry can be defined as the study of the effects of electricity on a substance/ compound and how chemical reactions produce electricity. Electrochemistry therefore deals mainly with:

- i) Reduction and oxidation
- ii) Electrochemical (voltaic) cell
- iii) Electrolysis (electrolytic) cell

(i)REDUCTION AND OXIDATION (REDOX)

1. In teams of oxygen transfer:

i) Reduction is **removal** of oxygen.

ii) Oxidation is **addition** of oxygen.

iii) Redox is **simultaneous** addition and removal of oxygen.

iv) Reducing agent is the species that undergoes **oxidation**, therefore **gains** oxygen.

v) Oxidizing agent is the species that undergoes **reduction**, therefore **looses/donates** oxygen.

e.g. When hydrogen is passed through heated copper (II) oxide, it is **oxidised** to copper metal as in the equation below:

$CuO_{(s)} \quad + \quad H_{2\,(g)} \quad -> \quad Cu_{(s)} \quad + \quad H_2O_{(l)}$

(Oxidising agent) (Reducing agent)

2. In terms of hydrogen transfer:
   i) Oxidation is the **removal** of hydrogen.
   ii) Reduction is the **addition** of hydrogen.
   iii) Redox is **simultaneous** addition and removal of hydrogen.
   iv) Reducing agent is the species that undergoes **oxidation**, therefore **looses/ donates** hydrogen.
   v) Oxidizing agent is the species that undergoes **reduction,** therefore **gains** hydrogen.

e.g. When hydrogen sulphide gas is bubbled into a gas jar containing chlorine gas it is oxidized (loose the hydrogen) to sulphur (yellow solid). The chlorine is reduced (gain hydrogen) to hydrogen chlorine gas.

$Cl_{2\,(g)}$ + $H_2S_{(g)}$ -> $S_{(S)}$ + $2HCl_{(g)}$
(Oxidizing agent) (Reducing agent)

3. In terms of electron transfer:
   i) Oxidation is **donation/ loss/ removal** of electrons.
   ii) Reduction is **gain/ accept/ addition** of electrons.
   iii) Redox is **simultaneous gain/ accept/ addition** and **donation/ loss/ removal** of electrons.
   iv) Reducing agent is the species that undergoes **oxidation,** therefore **looses/ donates** electrons.
   v) Oxidizing agent is the species that undergoes **reduction**, therefore **gains/ accepts** electrons.

Example

a) **Displacement of metals from their solutions:**

Place 5cm^3 each of Iron (II) sulphate (VI) solution into three different test tubes. Add about 1g of copper tunings / powder into one test tube then zinc and magnesium powders separately into the other test tubes. Shake thoroughly for 2 minutes each. Record any colour changes in the table below.

Metal added to Iron (II) sulphate (VI) solution	Colour changes
Copper	**Solution remains green**
Zinc	**Green colour fades**
Magnesium	**Green colour fades**

Explanation

-When a more reactive metal is added to a solution of less reactive metal, it displaces it from its solution.

-When a less reactive metal is added to a solution of a more reactive metal, it does not displace it from its solution.
-Copper is less reactive than iron therefore cannot displace iron its solution.
-Zinc is more reactive than iron therefore can displace iron from its solution.
-Magnesium is more reactive than iron therefore can displace iron from its solution.

In terms of electron transfer:

- the more reactive metal undergoes oxidation (reducing agent) by **donating/loosing** electrons to form **ions**

-the less reactive metal undergoes reduction (oxidizing agent) by its ions in solution gaining /accepting/acquiring the electrons to form the metal.

-displacement of metals involves therefore electron transfer from a more reactive metal to ions of another less reactive metal.

Examples

1. Zn(s) -> Zn^{2+}(aq) + 2e (oxidation/donation of electrons)
   Fe^{2+}(aq) + 2e -> Fe(s) (reduction/gain of electrons)
   Fe^{2+}(aq) + Zn(s) -> Zn^{2+}(aq) + Fe(s) (redox/both donation and gain of electrons)

2. Mg(s) -> Mg^{2+}(aq) + 2e (oxidation/donation of electrons)
   Fe^{2+}(aq) + 2e -> Fe(s) (reduction/gain of electrons)
   Fe^{2+}(aq) + Mg(s) -> Mg^{2+}(aq) + Fe(s) (redox/both donation and gain of electrons)

3. Zn(s) -> Zn^{2+}(aq) + 2e (oxidation/donation of electrons)
   Cu^{2+}(aq) + 2e -> Cu(s) (reduction/gain of electrons)
   Cu^{2+}(aq) + Zn(s) -> Zn^{2+}(aq) + Cu(s) (redox/both donation and gain of electrons)

4. Fe(s) -> Fe^{2+}(aq) + 2e (oxidation/donation of electrons)
   $2Ag^{+}$(aq) + 2e -> 2Ag(s) (reduction/gain of electrons)
   $2Ag^{+}$(aq) + Fe(s) -> Fe^{2+}(aq) + 2Ag(s) (redox/both donation and gain of electrons)

5. **Zn**(s) -> Zn^{2+}(aq) + 2e (oxidation/donation of electrons)
   Cl_2(g) + 2e -> $2Cl^{-}$(aq) (reduction/gain of electrons)
   Cl_2(g) **+ Zn(s) -> Zn^{2+}(aq) +** $2Cl^{-}$(aq) (redox/both donation and gain of electrons)

6. **2Mg**(s) -> $2Mg^{2+}$(aq) + 4e (oxidation/donation of electrons)
   O_2(g) + 4e -> $2O^{2-}$(aq) (reduction/gain of electrons)
   O_2(g) **+ 2Mg**(s) **->** $2Mg^{2+}$(aq) **+** $2O^{2-}$(aq) (redox/both donation and gain of electrons)

Note

(i)The number of electrons donated/lost MUST be equal to the number of electrons gained/acquired.

(i)During displacement reaction, the colour of ions /salts fades but does not if displacement does not take place. e.g

a)Green colour of **Fe^{2+}(aq) fades** if Fe^{2+}(aq) ions are **displaced** from their solution. Green colour of **Fe^{2+}(aq) appear** if Fe/iron **displaces** another salt/ions from their solution.

b)Blue colour of **Cu^{2+}(aq) fades** if Cu^{2+}(aq) ions are **displaced** from their solution and **brown** copper deposits appear. Blue colour of **Cu^{2+}(aq) appear** if Cu/copper **displaces** another salt/ions from their solution.

c)Brown colour of **Fe^{3+}(aq) fades** if Fe^{3+}(aq) ions are **displaced** from their solution. Brown colour of **Fe^{3+}(aq) appear** if Fe/iron **displaces** another salt/ions from their solution to form **Fe^{3+}(aq)**.

(iii)Displacement reactions also produce **energy/heat**. The **closer/nearer** the metals in the reactivity/electrochemical series the **less** energy/heat of displacement.

(iv)The **higher** the metal in the reactivity series therefore the **easier** to loose/donate electrons and thus the **stronger** the reducing agent.

4. (a)In terms of oxidation number:
    i) Oxidation is increase in oxidation numbers.
    ii) Reduction is decrease in oxidation numbers.
    iii) Redox is simultaneous increase in oxidation numbers of one species/substance and a decrease in oxidation numbers of another species/substance.
    iv) Reducing agent is the species that undergoes oxidation, therefore increases its oxidation number.
    v) Oxidizing agent is the species that undergoes reduction, therefore increases its oxidation number.

(b)The idea/concept of oxidation numbers uses/applies the following simple guideline rules:

Guidelines /rules applied in assigning oxidation number

1.Oxidation number of combined Oxygen is always **-2** except in peroxides (Na_2O_2/H_2O_2) where its Oxidation number is -1

2.Oxidation number of combined Hydrogen is always **+1**except in Hydrides (NaH/KH) where its Oxidation number is -1

3.All **atoms** and **molecules** of elements have oxidation number **0** (zero)

Atom	Oxidation number	**Molecule**	**Oxidation number**
Na	0	**Cl_2**	**0**
O	0	**O_2**	**0**
H	0	**H_2**	**0**
Al	0	**N_2**	**0**
Ne	0	**O_3**	**0**
K	0	**P_3**	**0**
Cu	0	**S_8**	**0**

4.All **combined metals** and **non-metals** have oxidation numbers equal to their valency /oxidation state e.g.

Metal/non-metal ion	**Valency**	**Oxidation state**	**Oxidation number**
Fe^{2+}	2	-2	-2
Fe^{3+}	3	-3	-3
Cu^{2+}	2	-2	-2
Cu^{+}	1	+1	+1
Cl^{-}	1	-1	-1
O^{2-}	2	-2	-2
Na^{+}	1	+1	+1
Al^{3+}	3	+3	+3
P^{3-}	3	-3	-3
Pb^{2+}	2	+2	+2

5.Sum of oxidation numbers of atoms of elements making a compound is equal zero(**0**) e.g.
Using this rule ,an unknown oxidation number of an atom in a compound can be determined as below:
a) $CuSO_4$ has-

-one atom of Cu with oxidation number +2(refer to Rule 4)
-one atom of S with oxidation number +6 (refer to Rule 4)
-six atoms of O each with oxidation number -2(refer to Rule 4)

Sum of oxidation numbers of atoms in $CuSO_4$ = (**+2** + **+6** + (**-2** x 6)) **= 0**

b) H_2SO_4 has-

-two atom of H each with oxidation number +1(refer to Rule 2)
-one atom of S with oxidation number +6 (refer to Rule 4)
-four atoms of O each with oxidation number -2(refer to Rule 4)

Sum of oxidation numbers of atoms in H_2SO_4 = (**+2** + **+6** + (**-2** x 4)) **= 0**

c) $KMnO_4$ has-

-one atom of K with oxidation number +1(refer to Rule 4)

-one atom of Mn with oxidation number +7 (refer to Rule 4)

-four atoms of O each with oxidation number -2(refer to Rule 4)

Sum of oxidation numbers of atoms in $KMnO_4$ = (**+1** + **+7** + (**-2** x 4)) **= 0**

Determine the oxidation number of:

I.Nitrogen in;

-NO => x + -2 = 0 thus x = 0 – (-2) = **+ 2**

The chemical name of this compound is thus Nitrogen(**II**)oxide

-NO_2 => x + (-2 x2)= 0 thus x = 0 – (-4) = **+ 4**

The chemical name of this compound is thus Nitrogen(**IV**)oxide

-N_2O => 2x + -2 = 0 thus 2x = 0 – (-2) = **+2/2= +1**

The chemical name of this compound is thus Nitrogen(**I**)oxide

II. Sulphur in;

-SO_2 => x + (-2 x2)= 0 thus x = 0 – (-4) = **+ 4**

The chemical name of this compound is thus Sulphur(**IV**)oxide

-SO_3 => x + (-2 x3)= 0 thus x = 0 – (-6) = **+ 6**

The chemical name of this compound is thus Sulphur(**VI**)oxide

-H_2SO_4 = ((+1 x 2) + x + (-2 x 4)) thus x= 0-(+2 +-8) =**+6**

The chemical name of this compound is thus Sulphuric(**VI**)acid

-H_2SO_3 = ((+1 x 2) + x + (-2 x 3)) thus x= 0-(+2 +-6) =**+4**

The chemical name of this compound is thus Sulphuric(**IV**)acid

III. Carbon in;

-CO_2 => x + (-2 x2)= 0 thus x = 0 – (-4) = **+ 4**

The chemical name of this compound is thus carbon(**IV**)oxide

-CO => x + -2 = 0 thus x = 0 – -2 = **+ 2**

The chemical name of this compound is thus carbon(**II**)oxide

-H_2CO_3 = ((+1 x 2) + x + (-2 x 3)) thus x= 0-(+2 +-6) =**+4**

The chemical name of this compound is thus Carbonic(**IV**)acid

IV.Manganese in;

-MnO_2 => x + (-2 x2)= 0 thus x = 0 – (-4) = **+ 4**

The chemical name of this compound is thus Manganese(**IV**)oxide

-$KMnO_4$ = ((+1 + x + (-2 x 4)) thus x= 0-(+1 +-8) =**+7**

The chemical name of this compound is thus Potassium manganate(**VII**)

V.Chromium in;

- Cr_2O_3 => 2x + (-2 x 3)= 0 thus 2x = 0 – (-6) = **+6 / 2= +3**

The chemical name of this compound is thus Chromium(**III**)oxide

-$K_2Cr_2O_7$ => (+1 x 2) + 2x + (-2 x7)= 0

thus 2x = 0 – +2 +-14 = **+12 / 2= +6**

The chemical name of this compound is thus Potassium **di**chromate(**VI**)

-K_2CrO_4 => (+1 x 2) + x + (-2 x4)= 0

thus 2x = 0 – +2 +-8 = **+12 / 2= +6**

The chemical name of this compound is thus Potassium chromate(**VI**)

6.The sum of the oxidation numbers of atoms of elements making a charged radical/complex ion is equal to its charge.
Using this rule ,the oxidation number of unknown atom of an element in a charged radical/complex ion can be determined as in the examples below;
a) SO_4^{2-} has-
-one atom of S with oxidation number +6(refer to Rule 4)
-four atoms of O each with oxidation number -2(refer to Rule 1)
Sum of oxidation numbers of atoms in SO_4^{2-} = (**+6** + (**-2** x 4)) **= -2**
The chemical name of this radical is thus sulphate(**VI**) ion
b) NO_3^- has-
-one atom of N with oxidation number +4(refer to Rule 4)
-three atoms of O each with oxidation number -2(refer to Rule 1)
Sum of oxidation numbers of atoms in NO_3^- = (**+4** + (**-2** x 3)) **= -1**
The chemical name of this radical is thus nitrate(**IV**) ion.

Determine the oxidation number of:

I.Nitrogen in;
-NO_2^- => x + (-2 x2)= -1 thus x = -1 – (-4) = **+ 3**
The chemical name of this compound/ion/radical is thus Nitrate(**III**)ion
II. Sulphur in;
-SO_3^{2-} => x + (-2 x3)= -2 thus x = -2 – (-6) = **+ 4**
The chemical name of this compound/ion/radical is thus Sulphate(**IV**)ion
III. Carbon in;
-CO_3^{2-} = x + (-2 x 3) = -2 thus x = -2 – (-6) = **+ 4**
The chemical name of this compound/ion/radical is thus Carbonate(**IV**)ion
IV.Manganese in;
-MnO_4^- = x + (-2 x 4)= -1 thus x= -1-(-2 +-8) =**+7**
The chemical name of this compound/ion/radical is thus manganate(**VII**) ion
V.Chromium in
-$Cr_2O_7^{2-}$ => 2x + (-2 x7)= -2
thus 2x = -2 – +2 +-14 = **+12 / 2= +6**
The chemical name of this compound/ion//radical is thus dichromate(**VI**) ion
-CrO_4^{2-} => x + (-2 x4)= -2
thus x = -2 + (-2 x 4) **= +6**
The chemical name of this compound/ion//radical is thus chromate(**VI**) ion

(c)Using the concept/idea of oxidation numbers as increase and decrease in oxidation numbers , the oxidizing and reducing species/agents can be determined as in the following examples;

(i) **Cu^{2+} (aq) + Zn(s) -> Zn^{2+} (aq) + Cu(s)**
Oxidation numbers -> +2 0 +2 0
Oxidizing species/agents =>Cu^{2+} ;its oxidation number decrease from+2 to 0 in Cu(s)

Reducing species/agents => Zn^{2+} ;its oxidation number increase from 0 to +2 in Zn(s)

(ii) **$2Br^-$ (aq) + Cl_2(g) -> $2Cl^-$ (aq) + Br_2 (l)**
Oxidation numbers -> -1 0 -1 0
Oxidizing agent =>Cl_2(g) ;its oxidation number decrease from 0 to-1 in $2Cl^-$ **(aq)**
Reducing agents => Zn^{2+} ;its oxidation number increase from -1 to 0 in Zn(s)

(iii) **Br_2 (l) + Zn(s) -> Zn^{2+} (aq) + $2Br^-$ (aq)**
Oxidation numbers -> 0 0 +2 -1
Oxidizing agent => Br_2 (l) ;its oxidation number decrease from 0 to-1 in $2Br^-$(aq)
Reducing agents => Zn(s) ;its oxidation number increase from 0 to +2 in Zn^{2+}

(iv) **2HCl (aq) + Mg(s) -> $MgCl_2$ (aq) + H_2 (g)**
Oxidation numbers -> 2 (+1 -1) 0 +2 2(-1) 0
Oxidizing agent => **H^+ in HCl**;its oxidation number decrease from +1to 0 in **H_2 (g)**
Reducing agents => Mg(s) ;its oxidation number increase from 0 to +2 in Mg^{2+}

(v) **$2H_2O$ (l) + 2Na(s) -> 2NaOH (aq) + H_2 (g)**
Oxidation numbers -> +1 -2 0 +1 -2 +1 0
Oxidizing agent => **H^+ in** H_2O;its oxidation number decrease from +1to 0 in **H_2 (g)**
Reducing agents => Na(s) ;its oxidation number increase from 0 to +1 in Na^+

(vi) $5Fe^{2+}$ (aq) + $8H^+$ (aq) + MnO_4^- -> $5Fe^{3+}$ (aq) + Mn^{2+} (aq) + $4H_2O$ (l)
+2 +1 +7 -2 +3 +2 +1 -2
Oxidizing agent => **Mn in** MnO_4^- ;its oxidation number decrease from +7to+2 in **Mn^{2+}**
Reducing agents => **Fe^{2+}** ;its oxidation number increase from +2 to +3 in Fe^{3+}

(vii) $6Fe^{2+}$ (aq) + $14H^+$ (aq) + $Cr_2O_7^{2-}$(aq) -> $6Fe^{3+}$ (aq) + Cr^{3+} (aq) + $7H_2O$ (l)
+2 +1 +6 -2 +3 +3 +1 -2
Oxidizing agent:
Cr in $Cr_2O_7^{2-}$;its oxidation number decrease from +6 to+3 in **Cr^{3+}**
Reducing agents => **Fe^{2+}** ;its oxidation number increase from +2 to +3 in Fe^{3+}
(viii) $2Fe^{2+}$ (aq) + $2H^+$ (aq) + H_2O_2(aq) -> $2Fe^{3+}$ (aq) + $2H_2O$ (l)
+2 +1 +1 -1 +3 +1 -2
Oxidizing agent:
O in H_2O_2;its oxidation number decrease from -1 to -2 in H_2O
Reducing agents => **Fe^{2+}** ;its oxidation number increase from +2 to +3 in Fe^{3+}

(ix) $Cr_2O_7^{2-}$(aq) + $6H^+$ (aq) + $5H_2O_2$(aq) -> $2Cr^{3+}$ (aq) + $2H_2O$ (l) + $5O_2$(g)
+6 -2 +1 +1 -1 +3 +1 -2 0
Oxidizing agents:
O in H_2O_2;its oxidation number decrease from -1 to -2 in H_2O
Cr in $Cr_2O_7^{2-}$ its oxidation number decrease from +6 to +3 in Cr^{3+}
Reducing agents

O in H_2O_2;its oxidation number increase from -1 to O in O_2(g)
O in $Cr_2O_7^{2-}$ its oxidation number increase from -2 to O in O_2(g)

(x) $2MnO_4^-$(aq) + $6H^+$ (aq) + $5H_2O_2$(aq) -> $2Mn^{2+}$ (aq) + $8H_2O$ (l) + $5O_2$(g)
+7 -2 +1 +1 -1 +2 +1 -2 0

Oxidizing agents:
O in H_2O_2;its oxidation number decrease from -1 to -2 in H_2O
Mn in MnO_4^- its oxidation number decrease from +7 to +2 in Mn^{2+}

Reducing agents
O in H_2O_2;its oxidation number increase from -1 to O in O_2(g)
O in MnO_4^- its oxidation number increase from -2 to O in O_2(g)

(ii)ELECTROCHEMICAL (VOLTAIC) CELL

1. When a metal rod/plate is put in a solution of its own salt, some of the metal ionizes and dissolve into the solution i.e.

$M(s) \rightarrow M^{+}(aq) + e$ (monovalent metal)
$M(s) \rightarrow M^{2+}(aq) + 2e$ (divalent metal)
$M(s) \rightarrow M^{3+}(aq) + 3e$ (Trivalent metal)

The ions move into the solution leaving electrons on the surface of the metal rod/plate.

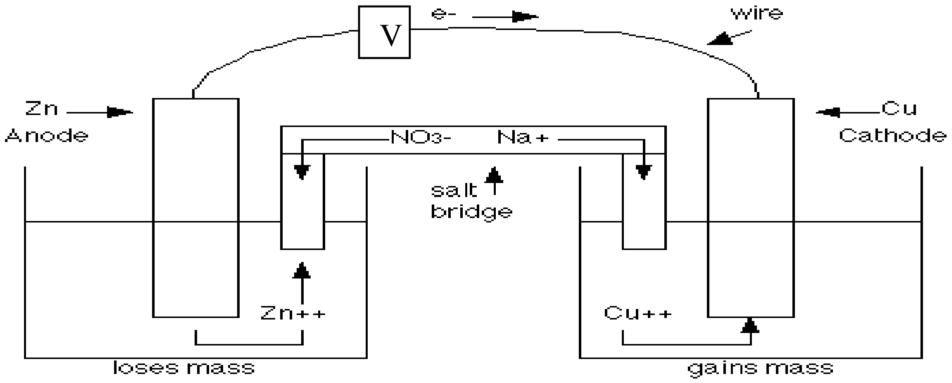
2.The **metal** rod becomes therefore **negatively** charged while its own **solution positively** charged. As the positive charges of the solution increase, some of them recombine with the electrons to form back the metal atoms

$M^{+}(aq) + e \rightarrow M(s)$ (monovalent metal)
$M^{2+}(aq) + 2e \rightarrow M(s)$ (divalent metal)
$M^{3+}(aq) + 3e \rightarrow M(s)$ (Trivalent metal)

3. When a metal rod/plate is put in a solution of its own salt, it constitutes/forms a **half-cell**. The tendency of metals to ionize differ from one metal to the other. The difference can be measured by connecting two half cells to form an electrochemical/voltaic cell as in the below procedure:

To set up an electrochemical /voltaic cell
<u>To compare the relative tendency of metals to ionize</u>

Place 50cm3 of 1M Zinc(II) sulphate(VI) in 100cm3 beaker. Put a clean zinc rod/plate into the solution. Place 50cm3 of 1M Copper(II) sulphate(VI) in another 100cm3 beaker. Put a clean copper rod/plate of equal area (length x width) with Zinc into the solution. Connect/join the two metals(to a voltmeter) using connecting wires. Dip a folded filter paper into a solution of Potassium nitrate(V) or sodium(I) chloride(I) until it soaks. Use the folded soaked filter paper to connect/join the two solutions in the two beakers.The whole set up should be as below



An electrochemical cell of the reaction:
$Zn(s) + Cu^{++}(aq) \rightarrow Zn^{++}(aq) + Cu(s)$

Repeat the above procedure by replacing:

(i)Zinc half cell with Magnesium rod/plate/ribbon dipped in 50cm3 of IM magnesium (II) sulphate(VI) solution (ii)Zinc half cell with Silver rod/plate/coin dipped in 50cm3 of IM silver(I) nitrate(V) solution

(iii)Copper half cell with Iron rod/plate/spoon dipped in 50cm3 of IM Iron (II) sulphate(VI) solution

Record the observations in the table below

Changes on the 1st metal rod (A)	Changes on the 2nd metal rod (B)	Changes on the 1st solution (A(aq))	Changes on the 2nd solution (**B**(aq))	Voltage/voltmeter reading(Volts)
Using Zn/Cu half cell -The rod decrease in size /mass /dissolves/ erodes	-copper rod /plate increase in size /mass/ deposited	Zinc(II)sulphate (VI)colour remain colourless	Blue Copper (II)sulphate (VI)colour fades. Brown solid/residue/ deposit	0.8 (Theoretical value=**1.10V**)
Using Mg/Cu half cell -The rod decrease in size /mass /dissolves/ erodes	-copper rod /plate increase in size /mass/ deposited	Magnesium(II) sulphate(VI) colour remain colourless	Blue Copper (II)sulphate (VI)colour fades Brown solid/residue/ deposit	1.5 (Theoretical value=**2.04V**)
Using Ag/Cu half cell -The rod increase in size /mass /deposited	-silver coin/ rod /plate increase in size /mass/ deposited	Blue Copper (II)sulphate (VI)colour remains	Silver(I)nitrate (V)colour remain colourless	0.20 (Theoretical value=**0.46V**)
Using Fe/Cu half cell -The rod decrease in size /mass /dissolves/ erodes	-copper rod /plate increase in size /mass/ deposited	Iron(II)sulphate (VI)colour becomes more green	Blue Copper (II)sulphate (VI)colour fades.Brown solid/residue/ deposit	0.60 (Theoretical value=**0.78V**)

From the above observations ,it can be deduced that:

(i)in the Zn/Cu half-cell the;

-Zinc rod/plate ionizes /dissolves faster than the copper rod/plate to form Zn^{2+}

Ionic equation **$Zn(s) \rightarrow Zn^{2+}(aq) + 2e$**

-blue copper ions in the Copper (II)sulphate solution gains the donated electrons to form brown copper metal/atoms

Ionic equation **$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$**

This reaction shows /imply the **Zinc** rod has a **higher** tendency to ionize than **copper.**The **Zinc** rod has a **higher net** accumulation of electrons and is more **negative** compared to the copper rod which has **lower** accumulation of electrons. The copper rod is therefore relatively more **positive** with respect to Zinc rod.

When the two half cells are connected , electrons therefore flow from the **negative** Zinc rod through the external wire to be gained by copper **ions**. This means a net accumulation/**increase** of Zn^{2+} positive ions on the negative half cell and a net **decrease** in Cu^{2+} positive ions on the positive half cell.
The purpose of the salt bridge therefore is:

(i)complete the circuit
(ii)maintain balance of charges /ions on both half cells.

For the negative half cell the NO_3^- /Cl^- from salt bridge **decrease/neutralise** the increased **positive**(Zn^{2+}) ion.
For the positive half cell the Na^+ / K^+ from salt bridge **increase** the decreased **positive**(Cu^{2+}) ion.

The voltmeter should theoretically register/read a 1.10Volts as a measure of the electromotive force (**e.m.f**) of the cell .Practically the voltage reading is lowered because the connecting wires have some **resistance** to be overcomed.
A combination of two half cells that can **generate** an electric **current** from a **redox** reaction is called a <u>voltaic</u>/<u>electrochemical cell</u>.

By convention a voltaic/electrochemical cell is represented;

$M(s) \;/\; M^{2+}(aq) \;//\; N^{2+}(aq) \;/\; N(s)$

(metal rod of M)(solution ofM)(solution ofN)(metal rod ofN)

Note;
a)(i)Metal M must be the one **higher** in the reactivity series.
(ii)It forms the **negative** terminal of the cell.
(iii)It must diagrammatically be drawn **first** on the **left hand side** when illustrating the voltaic/electrochemical cell.

b)(i)Metal N must be the one **lower** in the reactivity series.
(ii)It forms the **positive** terminal of the cell.
(iii)It must diagrammatically be drawn second/**after/ right hand side** when illustrating the voltaic/electrochemical cell.

Illustration of the voltaic/electrochemical cell.

(i)Zn/Cu cell

1. Zinc rod ionizes /dissolves to form Zn^{2+} ions at the negative terminal

$$\mathbf{Zn(s) \rightarrow Zn^{2+}(aq) + 2e}$$

2. Copper ions in solution gain the donated electrons to form copper atoms/metal

$$\mathbf{Cu^{2+}(aq) + 2e \rightarrow Cu(s)}$$

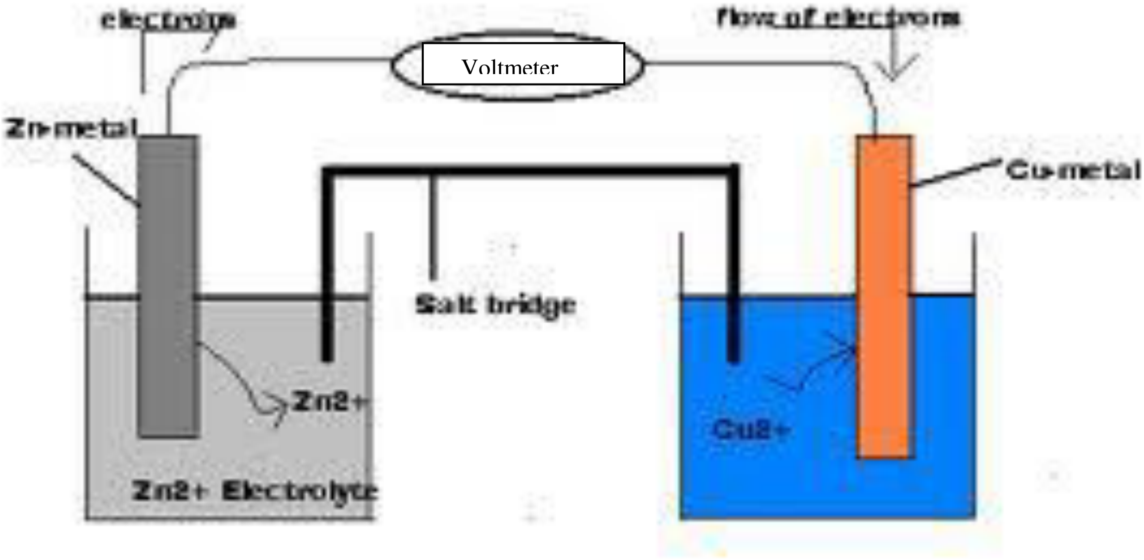
3.Overall redox equation

$$\mathbf{Cu^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Cu(s)}$$

4.cell representation.

$$\mathbf{Zn(s) / 1M, Zn^{2+}(aq) // 1M, Cu^{2+}(aq) / Cu(s) \quad E^0 = +1.10\ V}$$

5.cell diagram



(ii)Mg/Cu cell

1. Magnesium rod ionizes /dissolves to form Mg^{2+} ions at the negative terminal

$$\mathbf{Mg(s) \rightarrow Mg^{2+}(aq) + 2e}$$

2. Copper ions in solution gain the donated electrons to form copper atoms/metal

$$\mathbf{Cu^{2+}(aq) + 2e \rightarrow Cu(s)}$$

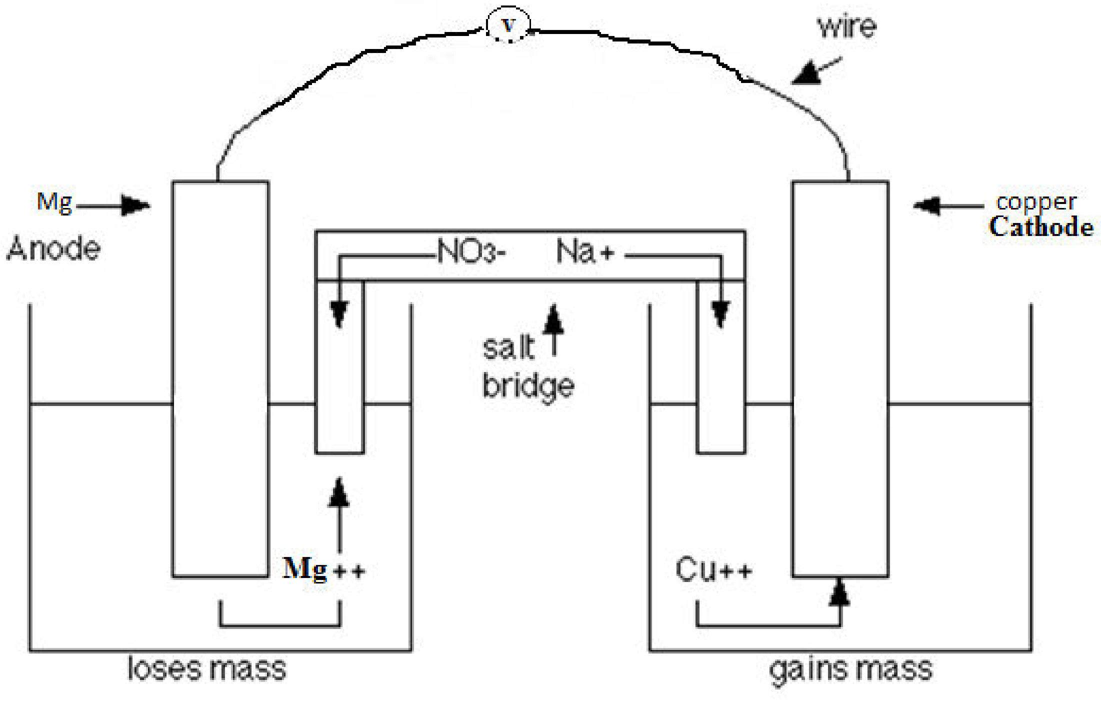
3.Overall redox equation

$$\mathbf{Cu^{2+}(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + Cu(s)}$$

4.cell representation.

$$\mathbf{Mg(s) / 1M, Mg^{2+}(aq) // 1M, Cu^{2+}(aq) / Cu(s) \quad E^0 = +2.04\ V}$$

5.cell diagram.



An electrochemical cell of the reaction:
$Mg(s) + Cu^{++}(aq) \longrightarrow Mg^{++}(aq) + Cu(s)$

(iii)Fe/Cu cell

1. Magnesium rod ionizes /dissolves to form Mg^{2+} ions at the negative terminal

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e$$

2. Copper ions in solution gain the donated electrons to form copper atoms/metal

$$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$$

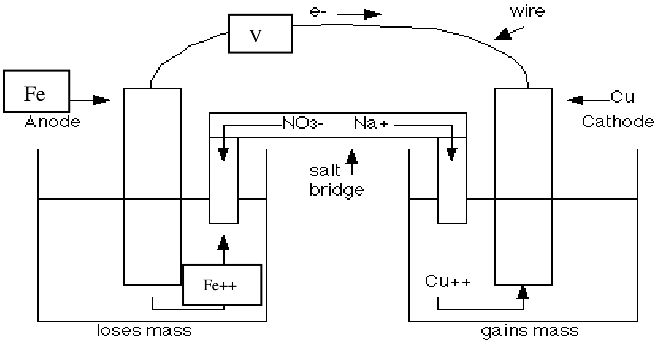
3.Overall redox equation

$$Cu^{2+}(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + Cu(s)$$

4.cell representation.

$$Fe(s) / 1M, Fe^{2+}(aq) // 1M, Cu^{2+}(aq) / Cu(s) \quad E^0 = +0.78\ V$$

5.cell diagram.



An electrochemical cell of the reaction:

(iv)Ag/Cu cell

1. Copper rod ionizes /dissolves to form Cu^{2+} ions at the negative terminal

$$\mathbf{Cu(s) \quad -> \quad Cu^{2+}(aq) \quad + \quad 2e}$$

2. Silver ions in solution gain the donated electrons to form silver atoms/metal

$$\mathbf{2Ag^{+}(aq) \quad + \quad 2e \quad -> \quad 2Ag(s)}$$

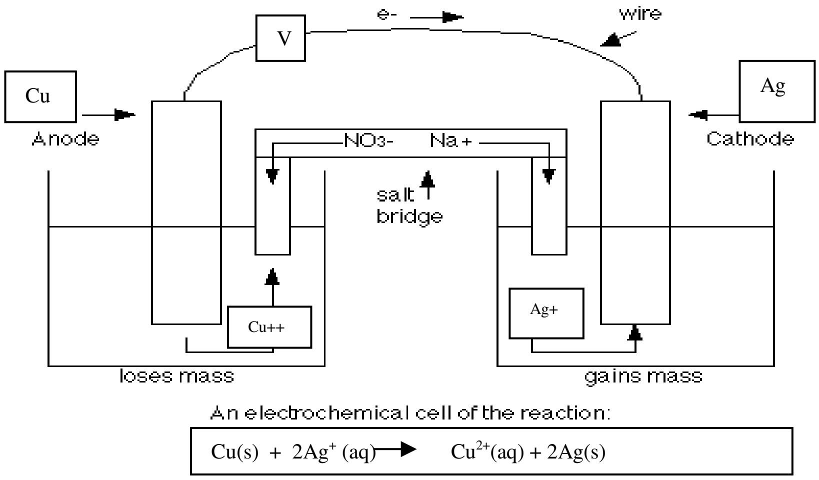
3.Overall redox equation

$$\mathbf{2Ag^{+}(aq) \quad + \quad Cu(s) \quad -> \quad Cu^{2+}(aq) \quad + \quad 2Ag(s)}$$

4.cell representation.

$$\mathbf{Cu(s) / 1M, Cu^{2+}(aq) // 1M,2Ag^{+}(aq) / 2Ag(s) \quad E^{0} = +0.46\ V}$$

5.cell diagram.



Standard electrode potential (E^0)

The **standard** electrode potential (**E^0**) is obtained if the **hydrogen** half cell is used as **reference.** The standard electrode potential (E^0) consist of inert platinum electrode immersed/dipped in 1M solution of (sulphuric(VI) acid) H^+ ions. Hydrogen gas is bubbled on the platinum electrodes at:

(i)a temperature of 25°C

(ii)atmospheric pressure of 101300Pa/101300Nm^{-2}/1atm/760mmHg/76cmHg

(iii)a concentration of 1M(1$moledm^{-3}$) of sulphuric(VI) acid/ H^+ ions and 1M(1$moledm^{-3}$) of the other half cell.

Hydrogen is **adsorbed** onto the **surface** of the platinum. An **equilibrium/balance** exist between the adsorbed layer of molecular hydrogen and H^+ ions in solution to form a half cell.

$$\tfrac{1}{2} H_2 (g) \quad ==== \quad H^{+} (aq) \quad + \quad e$$

The half cell representation is:

$$Pt, \tfrac{1}{2} H_2 (g) \ / \ H^{+} (aq), 1M$$

The standard electrode potential (E^{θ}) is thus defined as **the potential difference for a cell comprising of a particular element in contact with1M solution of its own ions and the standard hydrogen electrode.**

If the other electrode has a **higher/greater** tendency to lose electrons than the hydrogen electrode, the electrode is therefore **negative** with respect to hydrogen electrode and its electrode potential has **negative** (E^{θ}) values.
If the other electrode has a **lower/lesser** tendency to lose electrons than the hydrogen electrode, the electrode is therefore **positive** with respect to hydrogen electrode and its electrode potential has **positive** (E^{θ}) values.

Table showing the standard electrode potential (E^{θ}) of some reactions

Reaction	**(E^{θ}) values in volts**
F_2 (g)+ 2e -> $2F^-$ (aq)	+2.87
H_2O_2 (aq)+ H^+ (aq) +2e -> H_2O (l)	+1.77
MnO_4^- (aq)+ $4H^+$ (aq) +3e -> MnO_2 (s) +H_2O (l)	+1.70
2HClO (aq)+ $2H^+$ (aq) +2e -> Cl_2 (aq) +$2H_2O$ (l)	+1.59
MnO_4^- (aq)+ $4H^+$ (aq) +5e -> Mn^{2+} (aq) +H_2O (l)	+1.51
Cl_2 (g)+ 2e -> $2Cl^-$ (aq)	+1.36
MnO_2 (s)+ $4H^+$ (aq) +2e -> Mn^{2+} (aq) +$2H_2O$ (l)	+1.23
Br_2 (aq)+ 2e -> $2Br^-$ (aq)	+1.09
NO_3^- (aq)+ $2H^+$ (aq) + e -> NO_2 (g) + H_2O (l)	+0.80
Ag^+ (aq) + e -> Ag(s)	+0.80
Fe^{3+} (aq) + e -> Fe^{2+} (aq)	+0.77
$2H^+$ (aq)+ O_2 (g) -> H_2O_2 (aq)	+0.68
I_2 (aq)+ 2e -> $2I^-$ (aq)	+0.54
Cu^{2+} (aq) + 2e -> Cu(s)	+0.34
$2H^+$ (aq) + 2e -> H_2(g)	**+0.00**
Pb^{2+} (aq) + 2e -> Pb(s)	-0.13
Fe^{2+} (aq) + 2e -> Fe(s)	-0.44
Zn^{2+} (aq) + 2e -> Zn(s)	-0.77
Al^{3+} (aq) + 3e -> Al(s)	-1.66
Mg^{2+} (aq) + 2e -> Mg(s)	-2.37
Na^+ (aq) + e -> Na(s)	-2.71
K^+ (aq) + e -> K(s)	-2.92

Note:

(i)**E^{θ}** values generally show the **possibility/feasibility** of a **reduction** process/**oxidizing strength.**

(ii)The **element**/species in the half cell with the **highest** negative **E^{θ}** value easily **gain / acquire** electrons.

It is thus the **strongest oxidizing agent** and its reduction process is highly **possible/feasible.** The **element**/species in the half cell with the **lowest** positive **E^{θ}** value easily **donate / lose** electrons.

It is thus the **strongest reducing agent** and its reduction process is the least **possible/feasible.**

(iii)The **overall** redox reaction is **possible**/feasible is it has a **positive** (+) **E^θ**.

If the **overall** redox reaction is **not** possible/ **not** feasible/ **forced**, it has a **negative** (-) **E^θ**

Calculation examples on E^θ

Calculate the E^θ value of a cell made of:

a)Zn and Cu

From the table above:

$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$ $E^\theta = +0.34V$(higher E^θ /**R**ight **H**and **S**ide diagram)

$Zn^{2+}(aq) + 2e \rightarrow Zn(s)$ $E^\theta = -0.77V$(lower E^θ/ Left **H**and **S**ide diagram)

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e$ $E^\theta = +0.77$(reverse lower E^θ to derive cell reaction / representation)

Overall E^θ = **E^θ higher- E^θ lower / E^θ RHS - E^θ LHS/ E^θoxidized- E^θ reduced**

Substituting:

Overall E^θ = $+0.34 - (-0.77) =$ **+1.10V**

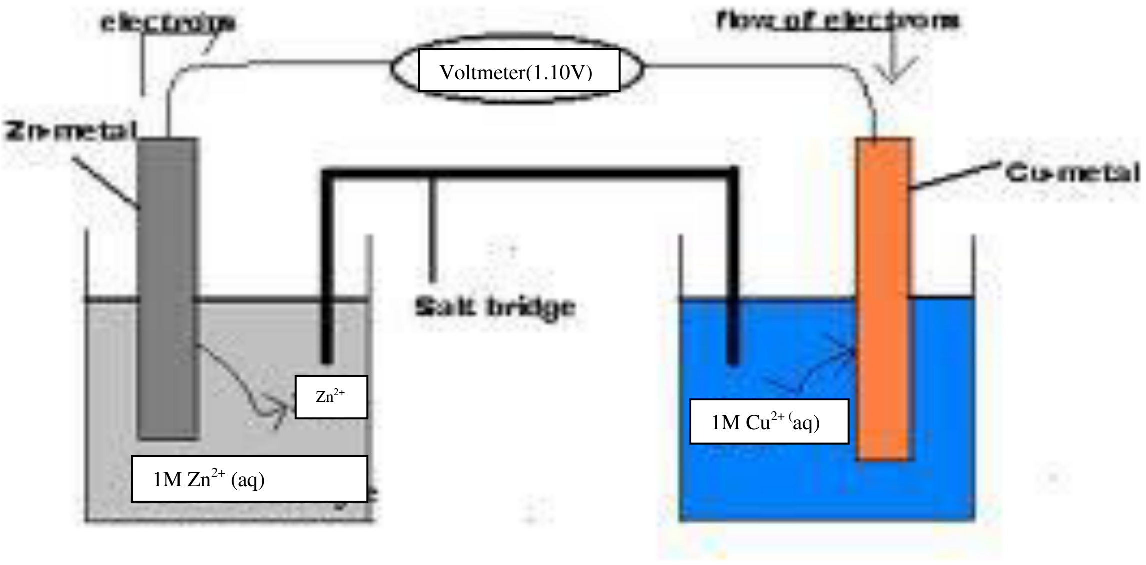
Overall redox equation:

$Cu^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Cu(s)$ $E^\theta = +1.10V$

Overall conventional cell representation:

$Zn(s) / Zn^{2+}(aq)$ 1M, // 1M,$Cu^{2+}(aq) / Cu(s)$ $E^\theta = +1.10V$

Overall conventional cell diagram:



Zinc and copper reaction has a **positive**(+) overall E^θ therefore is possible/feasible and thus Zinc can displace/reduce Copper solution.

b)Mg and Cu
From the table above:
$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$ $E^\theta = +0.34V$(higher E^θ /**R**ight **H**and **S**ide diagram)
$Mg^{2+}(aq) + 2e \rightarrow Mg(s)$ $E^\theta = -2.37V$(lower E^θ/ **L**eft **H**and **S**ide diagram)
$Mg(s) \rightarrow Mg^{2+}(aq) + 2e$ $E^\theta = +2.37$(reverse lower E^θ to derive cell reaction / representation)
Overall E^θ = **E^θ higher- E^θ lower / E^θ RHS - E^θ LHS/ E^θ oxidized- E^θ reduced**
Substituting:
Overall E^θ = +0.34 – (- 2.37) = **<u>+2.71V</u>**

Overall redox equation:
$Cu^{2+}(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + Cu(s)$ $E^\theta = +2.71V$

Overall conventional cell representation:
$Mg(s) / Mg^{2+}(aq)$ 1M, // 1M,$Cu^{2+}(aq) / Cu(s)$ $E^\theta = +2.71V$

c)Ag and Pb
From the table above:
$2Ag^{+}(aq) + 2e \rightarrow 2Ag(s)$ $E^\theta = +0.80V$(higher E^θ /**R**ight **H**and **S**ide diagram)
$Pb^{2+}(aq) + 2e \rightarrow Pb(s)$ $E^\theta = -0.13V$(lower E^θ/ **L**eft **H**and **S**ide diagram)
$Pb(s) \rightarrow Pb^{2+}(aq) + 2e$ $E^\theta = +0.13$(reverse lower E^θ to derive cell reaction / representation)

Overall E^θ = **E^θ higher- E^θ lower / E^θ RHS - E^θ LHS/ E^θ oxidized- E^θ reduced**
Substituting:
Overall E^θ = +0.80 – (- 0.13) = **<u>+0.93V</u>**

Overall redox equation:
$2Ag^{+}(aq) + Pb(s) \rightarrow Pb^{2+}(aq) + 2Ag(s)$ $E^\theta = +0.93V$

Overall conventional cell representation:
$Pb(s) / Pb^{2+}(aq)$ 1M, // 1M,$2Ag^{+}(aq) / Ag(s)$ $E^\theta = +0.93V$

d)Chlorine and Bromine
From the table above:
$2e + Cl_2(g) \rightarrow 2Cl^{-}(aq)$ $E^\theta = +1.36V$(higher E^θ /**R**ight **H**and **S**ide diagram)
$2e + Br_2(aq) \rightarrow 2Br^{-}(aq)$ $E^\theta = +0.13V$(lower E^θ/ **L**eft **H**and **S**ide diagram)
$2Br^{-}(aq) \rightarrow Br_2(aq) + 2e$ $E^\theta = -0.13$(reverse lower E^θ to derive cell reaction / representation)

Overall E^θ = **E^θ higher- E^θ lower / E^θ RHS - E^θ LHS/ E^θ oxidized- E^θ reduced**
Substituting:
Overall E^θ = - 0.13 – (- 1.36) = **<u>+1.23V</u>**

Overall redox equation:

$2Br^-(aq) + Cl_2(g) \rightarrow 2Cl^-(aq) + Br_2(aq)$ $E^\theta = +1.23V$

Overall conventional cell representation:
$Cl_2(g) / 2Cl^-(aq)$ 1M, // 1M, $2Br^-(aq) / Br_2(aq)$ $E^\theta = +1.23V$

Chlorine displaces bromine from bromine water. When chlorine gas is thus bubbled in bromine water, the pale **green** colour **fades** as displacement takes place and a **brown** solution containing dissolved bromine liquid is **formed**. This reaction is feasible /possible because the overall redox reaction has a **positive** E^θ value.

e)Strongest oxidizing agent and the strongest reducing agent.
From the table above:
$2e + F_2(g) \rightarrow 2F^-(aq)$ $E^\theta = +2.87V$(highest E^θ /strongest oxidizing agent)
$2e + 2K^+(aq) \rightarrow 2K(aq)$ $E^\theta = -2.92V$(lowest E^θ/ strongest reducing agent)
$2K(aq) \rightarrow 2K^+(aq) + 2e$ $E^\theta = +2.92V$ (reverse lower E^θ to derive cell reaction / representation)

Overall E^θ = **E^θ higher- E^θ lower / E^θ RHS - E^θ LHS/ E^θ oxidized- E^θ reduced**
Substituting:
Overall E^θ = $+2.87 - (-2.92) = \underline{\mathbf{+5.79V}}$

Overall redox equation:
$F_2(g) + 2K(s) \rightarrow 2F^-(aq) + 2K^+(aq)$ $E^\theta = +5.79V$

Overall conventional cell representation:

$2K(s) / 2K^+(aq)$,1M, // 1M, $2F^-(aq) / F_2(g)$ $E^\theta = +5.79V$

The redox reactions in an electrochemical/voltaic is commercially applied to make the:

(a)Dry /primary/Laclanche cell.

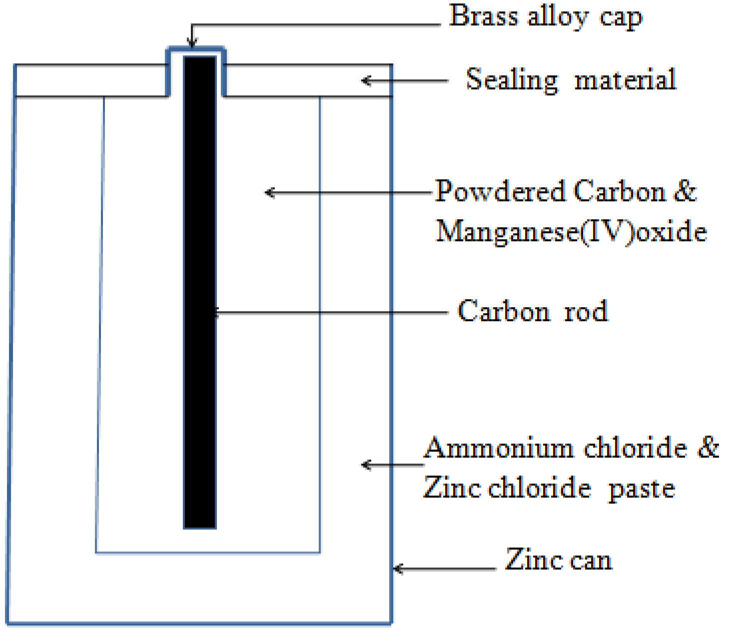
(b)Wet /secondary /accumulators.

(a)Dry/primary/Laclanche cell

Examine a used dry cell.
Note the positive and the negative terminal of the cell. Carefully using a knife cut a cross section from one terminal to the other.
The dry cell consist of a **Zinc can** containing a **graphite rod** at the **centre** surrounded by a **paste** of;

-Ammonium chloride
-Zinc chloride
-powdered manganese (IV) oxide mixed with Carbon.

Zinc acts/serve as the negative terminal where it ionizes/dissociates:



The Le clanche dry cell

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e$

Ammonium ions in ammonium chloride serve as the positive terminal where it is converted to ammonia gas and hydrogen gas.

$$2NH_4^+(aq) + 2e \rightarrow 2NH_3(g) + H_2(g)$$

Ammonia forms a complex salt / compound /$(Zn(NH_3)_4)^{2+}$ (aq) / tetramminezinc(II) complex with the Zinc chloride in the paste.

Manganese (IV) oxide oxidizes the hydrogen produced at the electrodes to water preventing any bubbles from coating the carbon terminal which would reduce the efficiency of the cell.

Ammonium chloride is used as paste because the solid does not conduct electricity because the ions are fused/not mobile.

Since the reactants are used up, the dry /primary /Laclanche cell cannot provide continous supply of electricity.The process of restoring the reactants is called **recharging.**

b)Wet/Secondary/Accumulators

1. Wet/Secondary/Accumulators are **rechargeable** unlike dry /primary /Laclanche cells.Wet/Secondary/Accumulators are made up of:
   (i)**Lead** plate that forms the **negative** terminal
   (ii)**Lead(IV) oxide** that forms the **positive** terminal

2.The two electrodes are dipped in concentrated sulphuric(VI) acid of a relative density 1.2/1.3

3.At the negative terminal,lead ionizes /dissolves;

$$Pb(s) \rightarrow Pb^{2+} + 2e$$

4.At the positive terminal,

(i) Lead(IV) oxide **reacts** with the hydrogen ions in sulphuric(VI)acid to form Pb^{2+} (aq) ions;

$\mathbf{PbO_2(s) + 4H^+(aq) + 2e \rightarrow Pb^{2+}(aq) + H_2O(l)}$

(ii) Pb^{2+} (aq) ions formed **instantly** react with sulphate (VI) ions/ SO_4^{2-} (aq) from sulphuric (VI)acid to form **insoluble** Lead(II) sulphate (VI).

$\mathbf{Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s)}$

5.The **overall** cell reaction is called **discharging**

$\mathbf{PbO_2(s) + Pb(s) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)\ E^0 = +2.0V}$

6.The insoluble Lead(II) sulphate (VI) formed should not be left for long since fine Lead(II) sulphate (VI) will change to a course non-reversible and inactive form making the cell less efficient.

As the battery discharges ,lead and lead(IV)oxide are depleted/finished/reduced and the concentration of sulphuric(VI)acid decreases.

7. During **recharging**, the electrode reaction is reversed as below:

$\mathbf{2PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + Pb(s) + 4H^+(aq) + 2SO_4^{2-}(aq)}$

8. A car battery has six Lead-acid cells making a total of 12 volts.

(iii)ELECTROLYSIS (ELECTROLYTIC CELL)

1.Electrolysis is defined simply as the **decomposition** of a **compound** by an electric current/**electricity**.

A compound that is decomposed by an electric current is called an electrolyte. Some electrolytes are **weak** while others are **strong**.

2.Strong electrolytes are those that are fully ionized/dissociated into (many) ions. Common strong electrolytes include:

(i)all **mineral** acids

(ii)all strong **alkalis**/sodium hydroxide/potassium hydroxide.

(iii)all soluble **salts**

3.Weak electrolytes are those that are partially/partly ionized/dissociated into (few) ions.

Common weak electrolytes include:

(i)all **organic** acids
(ii)all **bases** except sodium hydroxide/potassium hydroxide.
(iii)**Water**

4. A compound that is **not** decomposed by an electric current is called non-electrolyte. Non-electrolytes are those compounds /substances that exist as molecules and thus cannot ionize/dissociate into(any) ions .

Common non-electrolytes include:

(i) most organic solvents (e.g. petrol/paraffin/benzene/methylbenzene/ethanol)
(ii)all hydrocarbons(alkanes /alkenes/alkynes)
(iii)Chemicals of life(e.g. proteins, carbohydrates, lipids, starch, sugar)

5. An electrolytes in **solid** state have **fused** /joined ions and therefore do **not** conduct electricity but the **ions** (cations and anions) are **free** and **mobile** in **molten** and **aqueous** (solution, dissolved in water) state.

6.During electrolysis, the free ions are attracted to the **electrodes**. An electrode is a rod through which current enter and leave the electrolyte during electrolysis. An electrode that does not influence/alter the products of electrolysis is called an **inert electrode.**

Common inert electrodes include:

(i)**Platinum**
(ii)**Carbon graphite**

Platinum is not usually used in a school laboratory because it is very **expensive**. Carbon graphite is **easily**/readily and **cheaply** available (from used dry cells).

7.The **positive** electrode is called **Anode**.The anode is the electrode through which **current enter** the electrolyte/**electrons leave** the electrolyte

8.The **negative** electrode is called **Cathode**. The cathode is the electrode through which **current leave** the electrolyte **/ electrons enter** the electrolyte

9. During the electrolysis, free **anions** are attracted to the **anode** where they **lose /donate** electrons to form **neutral** atoms/molecules. i.e.

$M(l) \rightarrow M^+(l) + e$ (for cations from molten electrolytes)
$M(s) \rightarrow M^+(aq) + e$ (for cations from electrolytes in aqueous state / solution / dissolved in water)

The neutral atoms /molecules form the **products** of electrolysis at the anode. This is called **discharge** at anode

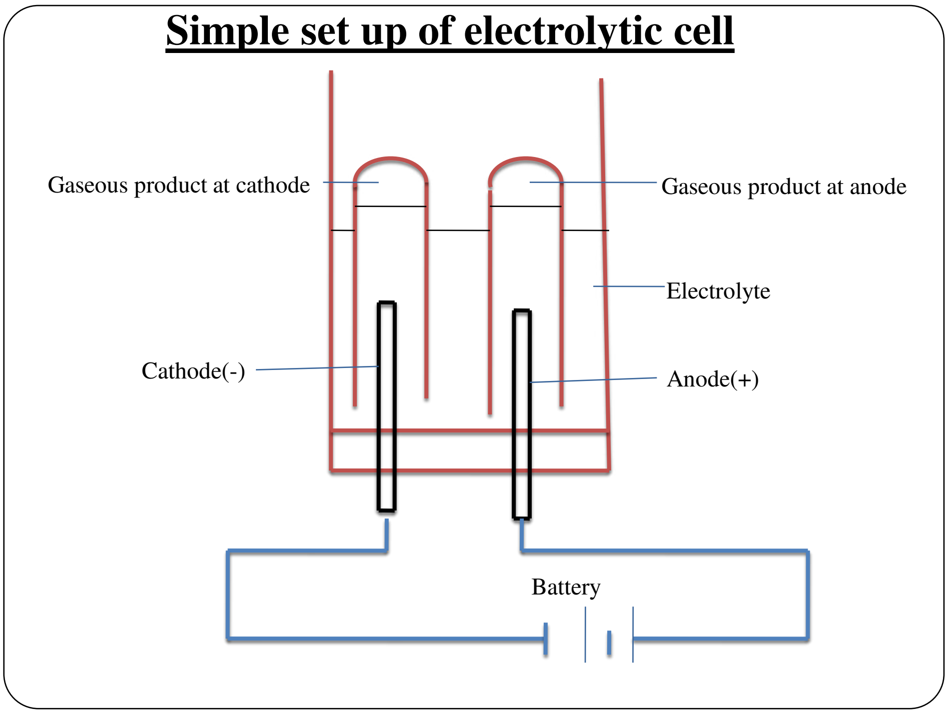
10. During electrolysis, free **cations** are attracted to the **cathode** where they **gain /accept/acquire** electrons to form **neutral** atoms/molecules.

X^{+} (aq) + 2e -> X(s) (for cations from electrolytes in aqueous state / solution / dissolved in water)

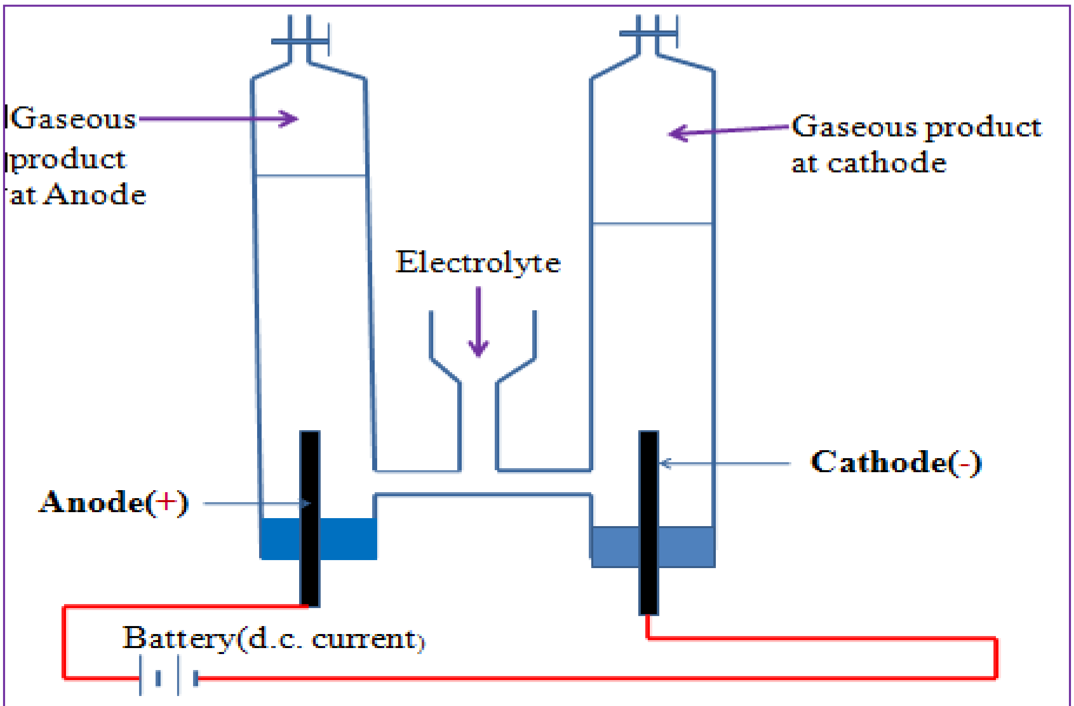
$2X^{+}$ (l) + 2e -> X (l) (for cations from molten electrolytes)

The neutral atoms /molecules form the **products** of electrolysis at the cathode. This is called **discharge** at cathode.

11. The below set up shows an electrolytic cell.

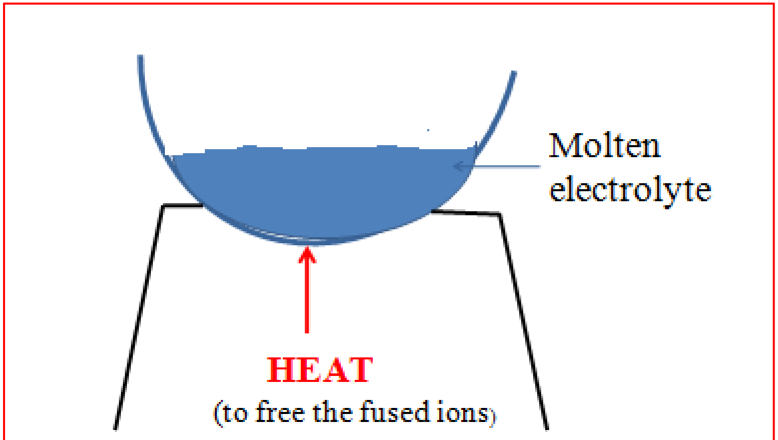


Simple set up of electrolytic cell



Hoffmanns voltameter

12. For a compound /salt containing only two ion/binary salt the products of electrolysis in an electrolytic cell can be determined as in the below examples:



Set up of Electrolytic cell for binary salts

a)<u>To determine the products of electrolysis of molten Lead(II)chloride</u>

(i)Decomposition of electrolyte into free ions;

$PbCl_2$ (l) -> Pb^{2+}(l) + $2Cl^-$(l)

(Compound decomposed into free cation and anion in **liquid** state)

(ii)At the cathode/negative electrode(-);

Pb^{2+}(l) + 2e -> Pb (l)

(Cation / Pb^{2+} gains / accepts / acquires electrons to form free **atom)** (iii)At the anode/positive electrode(+);

$2Cl^-(l) \rightarrow Cl_2(g) + 2e$

(Anion / Cl^- donate/lose electrons to form free **atom** then a gas **molecule)**

(iv)Products of electrolysis therefore are;

I.At the cathode grey beads /solid lead metal.
II.At the anode pale green chlorine gas.

b)To determine the products of electrolysis of molten Zinc bromide

(i)Decomposition of electrolyte into free ions;

$ZnBr_2(l) \rightarrow Zn^{2+}(l) + 2Br^-(l)$

(Compound decomposed into free cation and anion in **liquid** state)

(ii)At the cathode/negative electrode(-);

$Zn^{2+}(l) + 2e \rightarrow Zn(l)$

(Cation / Zn^{2+} gains / accepts / acquires electrons to form free **atom)**

(iii)At the anode/positive electrode(+);

$2Br^-(l) \rightarrow Br_2(g) + 2e$

(Anion / Br^- donate/lose electrons to form free **atom** then a liquid **molecule** which change to **gas** on heating)

(iv)Products of electrolysis therefore are;

I.At the cathode grey beads /solid Zinc metal.
II.At the anode **red** bromine **liquid / red/brown** bromine **gas.**

c)To determine the products of electrolysis of molten sodium chloride

(i)Decomposition of electrolyte into free ions;

$NaCl(l) \rightarrow Na^+(l) + Cl^-(l)$

(Compound decomposed into free cation and anion in **liquid** state)

(ii)At the cathode/negative electrode(-);

$2Na^+(l) + 2e \rightarrow Na(l)$

(Cation / Na^+ gains / accepts / acquires electrons to form free **atom)**

(iii)At the anode/positive electrode(+);

$2Cl^-(l) \rightarrow Cl_2(g) + 2e$

(Anion / Cl^- donate/lose electrons to form free **atom** then a gas **molecule)**

(iv)Products of electrolysis therefore are;

I.At the cathode grey beads /solid sodium metal.
II.At the anode pale green chlorine gas.

d)To determine the products of electrolysis of molten Aluminium (III)oxide

(i)Decomposition of electrolyte into free ions;

$Al_2O_3\ (l) \ \ -> \ \ 2Al^{3+}(l) + 3O^{2-}(l)$

(Compound decomposed into free cation and anion in **liquid** state)

(ii)At the cathode/negative electrode(-);

$4Al^{3+}(l) + 12e \ \ -> \ \ 4Al\ (l)$

(Cation / Al^{3+} gains / accepts / acquires electrons to form free **atom)**

(iii)At the anode/positive electrode(+);

$6O^{2-}(l) \ \ -> \ \ 3O_2\ (g) + 12e$

(Anion /$6O^{2-}$ donate/lose 12 electrons to form free **atom** then three gas **molecule)**

(iv)Products of electrolysis therefore are;

I.At the cathode grey beads /solid aluminium metal.

II.At the anode colourless gas that relights/rekindles glowing splint.

13. For a compound /salt mixture containing **many** ions in an electrolytic cell, the **discharge** of ions in the cell depend on the following **factors**:

a) Position of cations and anions in the electrochemical series

1. Most electropositive cations require more energy to reduce (gain electrons) and thus not readily discharged. The **higher** elements /metals in the electrochemical series the **less easily/readily** it is **discharged** at the cathode in the electrolytic cell.

Table I showing the relative ease of discharge of **cations** in an electrolytic cell

$K^+(aq) + e -> K(s)$ (**least** readily/easily discharged)
$Na^+(aq) + e -> Na(s)$
$Ca^{2+}(aq) + 2e -> Ca(s)$
$Mg^{2+}(aq) + 2e -> Mg(s)$
$Al^{3+}(aq) + 3e -> Al(s)$
$Zn^{2+}(aq) + 2e -> Zn(s)$
$Fe^{2+}(aq) + 2e -> Fe(s)$
$Pb^{2+}(aq) + 2e -> Pb(s)$
$2H^+(aq) + 2e -> H_2(g)$ (hydrogen is usually “metallic”)
$Cu^{2+}(aq) + 2e -> Cu(s)$
$Hg^{2+}(aq) + 2e -> Hg(s)$
$Ag^+(aq) + e -> Ag(s)$ (**most** readily/easily discharged)

2.The **OH^-** ion is the **most** readily/easily **discharged** anion . All the other anionic **radicals**(SO_4^{2-} ,SO_3^{2-} ,CO_3^{2-} ,HSO_4^- ,HCO_3^- ,NO_3^- ,PO_4^{3-})are not/never discharged. The ease of discharge of halogen ions increase down the group.

Table II showing the relative ease of discharge of **anions** in an electrolytic cell

$4OH^-$ (aq) -> $2H_2O$(l) + O_2 (g) + 4e (**most** readily/easily discharged)
2 I^-(aq) -> I_2(aq) + 2e
2 Br^-(aq) -> Br_2(aq) + 2e
2 Cl^-(aq) -> Cl_2(aq) + 2e
2 F^-(aq) -> F_2(aq) + 2e

SO_4^{2-} ,SO_3^{2-} ,CO_3^{2-} ,HSO_4^- ,HCO_3^- ,NO_3^- ,PO_4^{3-} **not/never/rarely** discharged.

3.(a)When **two** or more **cations** are attracted to the **cathode**, the ion **lower** in the electrochemical series is discharged **instead** of that which is **higher** as per the table I above. This is called selective/preferential discharge at cathode.

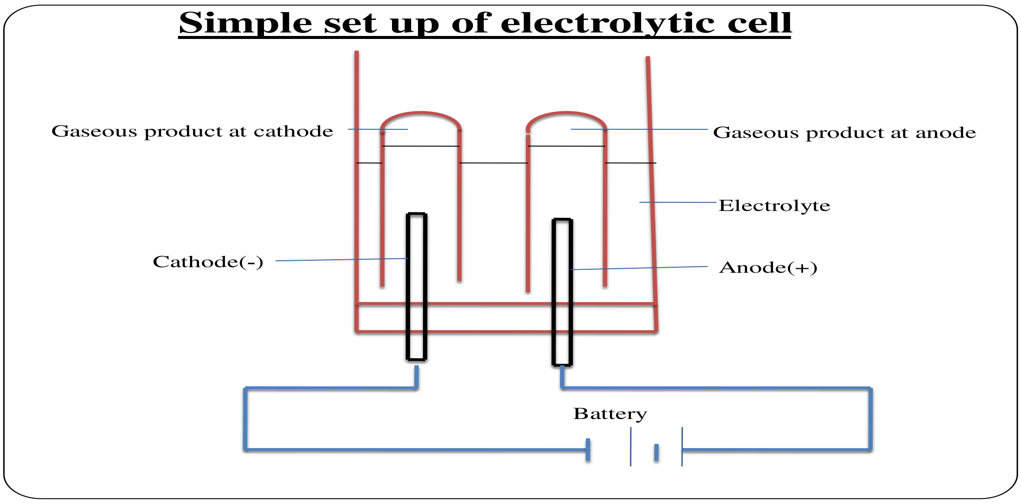
(b)When **two** or more **anions** are attracted to the **anode**, the ion **higher** in the electrochemical series is discharged **instead** of that which is **lower** as per the table I above. This is called selective/preferential discharge at anode.

4.The following experiments shows the influence /effect of selective/preferential discharge on the products of electrolysis:

(i)Electrolysis of acidified water/dilute sulphuric(VI) acid

Fill the Hoffmann voltameter with dilute sulphuric(VI) acid. Connect the Hoffmann voltameter to a d.c. electric supply. Note the observations at each electrode.

Electrolytic cell set up during electrolysis of acidified water/dilute sulphuric(VI) acid



Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

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

$H_2SO_4(aq) \rightarrow SO_4^{2-}(aq) + 2H^+(aq)$

II. Name the ions in acidified water that are attracted/move to:

Cathode- H^+(aq) from **either** sulphuric(VI) acid (H_2SO_4) or water (H_2O)

Anode- **SO_4^{2-}(aq)** from sulphuric (VI) acid (H_2SO_4) and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $4H^+(aq) + 4e \rightarrow 2H_2(g)$

Anode $4OH^-(aq) \rightarrow 2H_2O(l) + O_2(g) + 4e$

($4OH^-$ ions selectively discharged instead of SO_4^{2-} ions at the anode)

IV. Name the products of electrolysis of acidified water.

Cathode-Hydrogen gas (colourless gas that extinguishes burning splint with explosion/ "pop" sound

Anode-Oxygen gas (colourless gas that relights /rekindles glowing splint)

V. Explain the difference in volume of products at the cathode and anode.

The **four**(4) electrons donated/lost by **OH^-** ions to form **1** molecule/**1**volume/**1**mole of **oxygen** (**O_2**)gas at the **anode** are gained/acquired/accepted by the four **H^+(aq)** ions to form **2** molecule/**2**volume/**2**mole of **Hydrogen** (**H_2**)gas at the **cathode.**

The volume of **Oxygen** gas at the anode is thus a **half** the volume of **Hydrogen** produced at the cathode/ The volume of **Hydrogen** gas at the cathode is thus a **twice** the volume of **Oxygen** produced at the anode.

VI. Why is electrolysis of dilute sulphuric(VI) acid called "electrolysis of (acidified) water"?

The ratio of **H_2 (g)**: **O_2 (g)** is **2:1** as they are combined in water. This implies/means that water in the electrolyte is being decomposed into hydrogen and Oxygen gases. The electrolysis of dilute sulphuric acid is therefore called "electrolysis of acidified water."

VI. Explain the changes in concentration of the electrolyte during electrolysis of acidified water"

The concentration of dilute sulphuric (VI) acid **increases.** Water in the electrolyte is decomposed into Hydrogen and Oxygen gases that escape. The concentration /mole of acid present in a given volume of solution thus continue increasing/rising.

(ii)Electrolysis of Magnesium sulphate(VI) solution

Fill the Hoffmann voltameter with dilute sulphuric(VI) acid. Connect the Hoffmann voltameter to a d.c. electric supply. Note the observations at each electrode.

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

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

II. Name the ions in Magnesium sulphate(VI) solution that are attracted/move to:

Cathode- Mg^{2+}(aq) from Magnesium sulphate(VI) solution (Mg SO_4) and **H^+(aq)** from water (H_2O)
Anode- **SO_4^{2-}(aq)** from Magnesium sulphate(VI) solution (Mg SO_4) and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:
Cathode $4H^+$(aq) + 4e -> $2H_2$(g)
H^+ ions selectively discharged instead of Mg^{2+} ions at the cathode)

Anode $4OH^-$ (aq) -> $2H_2O$(l) + O_2 (g) + 4e
($4OH^-$ ions selectively discharged instead of SO_4^{2-} ions at the anode)

IV. Name the products of electrolysis of Magnesium sulphate(VI) solution

Cathode-Hydrogen gas (colourless gas that extinguishes burning splint with explosion/ "pop" sound
Anode-Oxygen gas (colourless gas that relights /rekindles glowing splint)

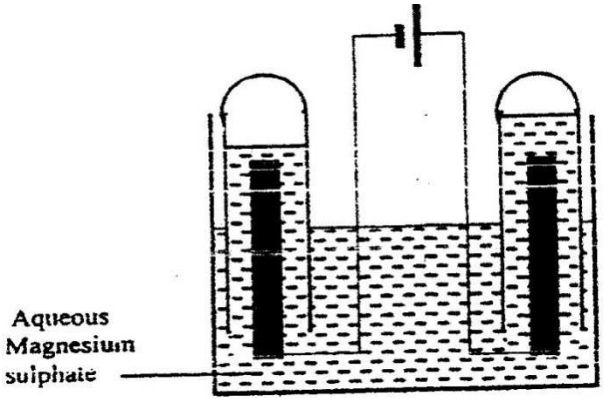
V. Explain the difference in volume of products at the cathode and anode.

The **four**(4) electrons donated/lost by **OH^-** ions to form **1** molecule/**1**volume/**1**mole of **oxygen** (**O_2**)gas at the **anode** are gained/acquired/accepted by the four **H^+(aq)** ions to form **2** molecule/**2**volume/**2**mole of **Hydrogen** (**H_2**)gas at the **cathode.**
The volume of **Oxygen** gas at the anode is thus a **half** the volume of **Hydrogen** produced at the cathode/ The volume of **Hydrogen** gas at the cathode is thus a **twice** the volume of **Oxygen** produced at the anode.

VI. Explain the changes in concentration of the electrolyte during electrolysis of Magnesium sulphate(VI) solution

The concentration of dilute Magnesium sulphate(VI) solution **increases.**
The ratio of **H_2 (g): O_2 (g)** is **2:1** as they are combined in water.
Water in the electrolyte is decomposed into Hydrogen and Oxygen gases that escape as products.
The concentration /mole of acid present in a given volume of Magnesium sulphate(VI) solution thus continue increasing/rising.

The set – up below was used during the electrolysis of aqueous magnesium sulphate using inert electrodes.



Name a suitable pair of electrodes for this experiment

Identify the ions and cations in the solution

On the diagram label the cathode

Write ionic equations for the reactions that took place at the anode.

Explain the change that occurred to the concentration of magnesium sulphate solution during the experience.

During the electrolysis a current of 2 amperes was passed through the solution for 4 hours. Calculate the volume of the gas produced at the anode.(1 faraday 96500 coulombs and volume of a gas at room temperature is 24000cm3)

One of the uses of electrolysis is electroplating
What is meant by electroplating?
Give tow reasons why electroplating is necessary.

b) Concentration of the electrolytes

1.**High** concentrations of cations and/or anions at the electrodes **block** the ion/s that is likely to be discharged at the electrode. This is called **over voltage**. A concentrated solution therefore produces different products of electrolysis from a dilute one.

2. The following experiments show the influence/effect of concentration of electrolyte on the products of electrolysis.

(i)Electrolysis of dilute and concentrated(brine)sodium chloride solution

I. Dissolve about 0.5 g of pure sodium chloride crystals in 100cm3 of water. Place the solution in an electrolytic cell. Note the observations at each electrode for 10 minutes. Transfer the set up into a **fume chamber/open** and continue to make observations for a further 10 minute.

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l)$ -> OH^- (aq) + H^+(aq)
NaCl(aq) -> Cl^-(aq) + Na^+(aq)

II. Name the ions in sodium chloride solution that are attracted/move to:

Cathode- Na^+(aq) from Sodium chloride solution (NaCl) and **H^+(aq)** from water (H_2O)

Anode- **Cl^-(aq)** from sodiumchloride solution (NaCl) and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $4H^+$(aq) + 4e -> $2H_2$(g)
H^+ ions selectively discharged instead of Na^+ ions at the cathode)

Anode $4OH^-$ (aq) -> $2H_2O(l)$ + O_2 (g) + 4e
($4OH^-$ ions selectively discharged instead of Cl^- ions at the anode)

IV. Name the products of electrolysis of dilute sodium chloride solution

Cathode-Hydrogen gas (colourless gas that extinguishes burning splint with explosion/ "pop" sound

Anode-Oxygen gas (colourless gas that relights /rekindles glowing splint)

V. Explain the difference in volume of products at the cathode and anode.

Four(4) electrons donated/lost by **OH^-** ions to form **1** molecule/**1**volume/**1**mole of **oxygen** (**O_2**)gas at the **anode** are gained/acquired/accepted by four **H^+(aq)** ions to form **2** molecule/**2**volume/**2**mole of **Hydrogen** (**H_2**)gas at the **cathode.**

The volume of **Oxygen** gas at the anode is **half** the volume of **Hydrogen** produced at the cathode/ The volume of **Hydrogen** gas at the cathode is **twice** the volume of **Oxygen** produced at the anode.

VI. Explain the changes in concentration of the electrolyte during electrolysis of sodium chloride solution

The concentration of dilute sodium chloride solution **increases.**

The ratio of **H_2 (g)**: **O_2 (g)** is **2:1** as they are combined in water. Water in the electrolyte is decomposed into Hydrogen and Oxygen gases that escape as products. The concentration /moles of salt present in a given volume of sodium chloride solution continue increasing/rising.

II. Dissolve about 20 g of pure sodium chloride crystals in 100cm3 of water. Place the solution in an electrolytic cell. Note the observations continuously at each electrode for 30 minutes in a **fume chamber/open**.

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$

$NaCl(aq) \rightarrow Cl^-(aq) + Na^+(aq)$

II. Name the ions in sodium chloride solution that are attracted/move to:

Cathode- Na^+(aq) from Sodium chloride solution (NaCl) and **H^+(aq)** from water (H_2O)

Anode- **Cl^-(aq)** from sodium chloride solution (NaCl) and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $2H^+(aq) + 2e \rightarrow H_2(g)$

H^+ ions selectively discharged instead of Na^+ ions at the cathode)

Anode $2Cl^-(aq) \rightarrow Cl_2(g) + 4e$

(Cl^- ions with a **higher** concentration **block** the discharge of OH^- ions at the anode)

IV. Name the products of electrolysis of concentrated sodium chloride solution/brine

Cathode-Hydrogen gas (colourless gas that extinguishes burning splint with explosion/ "pop" sound

Anode-Chlorine gas(pale green gas that bleaches damp/moist/wet litmus papers)

V. Explain the difference in volume of products at the cathode and anode.

Two (2) electrons donated/lost by **Cl^-** ions to form **1** molecule/**1**volume/**1**mole of **Chlorine** (**Cl_2**)gas at the **anode** are gained/acquired/accepted by two **H^+(aq)** ions to form **1** molecule/**1**volume/**1**mole of **Hydrogen** (**H_2**)gas at the **cathode.**

The volume of **Chlorine** gas at the anode is **equal to** the volume of **Hydrogen** produced at the cathode/ The volume of **Hydrogen** gas at the cathode is **equal to** the volume of **Chlorine** produced at the anode.

VI. Explain the changes in concentration of the electrolyte during electrolysis of concentrated sodium chloride solution/brine

The concentration of concentrated sodium chloride solution/brine **increases.**

The ratio of **Cl_2 (g)**: **H_2 (g)** is **1:1** as they are combined in water.

Water in the electrolyte is decomposed into only Hydrogen gas that escapes as products at cathode.

The concentration /moles of OH^- (aq) and Na^+ ion (as NaOH) present in a given volume of electrolyte continue increasing/rising.
This makes the electrolyte strongly alkaline with **high pH.**
As the electrolysis of brine continues the concentration of **Cl^-** ions **decrease** and **oxygen** gas start being **liberated** at **anode**.
The electrolyte pH is thus lowered and the concentration of brine starts again increasing.

(ii)Electrolysis of dilute and concentrated Hydrochloric acid solution

I. Prepare about 50cm3 of 0.05 M of dilute Hydrochloric acid in 100cm3 solution. Place the solution in an electrolytic cell. Note the observations at each electrode for 10 minutes.

Answer the following questions:
I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$
$HCl(aq) \rightarrow Cl^-(aq) + H^+(aq)$

II. Name the ions in dilute Hydrochloric acid solution that are attracted/move to:
Cathode- H^+(aq) from dilute Hydrochloric acid (HCl) and **H^+(aq)** from water (H_2O)
Anode- **Cl^-(aq)** from dilute Hydrochloric acid (HCl) and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:
Cathode $4H^+(aq) + 4e \rightarrow 2H_2(g)$
H^+ ions selectively discharged instead of Na^+ ions at the cathode)

Anode $4OH^-(aq) \rightarrow H_2O(l) + O_2 + 4e$
($4OH^-$ ions selectively discharged instead of Cl^- ions at the anode)

IV. Name the products of electrolysis of dilute Hydrochloric acid
Cathode-Hydrogen gas (colourless gas that extinguishes burning splint with explosion/ "pop" sound
Anode-Oxygen gas (colourless gas that relights /rekindles glowing splint)
V. Explain the difference in volume of products at the cathode and anode.
Four(4) electrons donated/lost by **OH^-** ions to form **1** molecule/**1**volume/**1**mole of **oxygen** (**O_2**)gas at the **anode** are gained/acquired/accepted by four **H^+(aq)** ions to form **2** molecule/**2**volume/**2**mole of **Hydrogen** (**H_2**)gas at the **cathode.**
The volume of **Oxygen** gas at the anode is **half** the volume of **Hydrogen** produced at the cathode/ The volume of **Hydrogen** gas at the cathode is **twice** the volume of **Oxygen** produced at the anode.

VI. Explain the changes in concentration of the electrolyte during electrolysis of dilute Hydrochloric acid

The concentration of dilute Hydrochloric acid **increases.**

The ratio of **H_2 (g): O_2 (g)** is **2:1** as they are combined in water. Water in the electrolyte is decomposed into Hydrogen and Oxygen gases that escape as products. The concentration /moles of HCl present in a given volume of dilute Hydrochloric acid continue increasing/rising.

II. Prepare about 50cm3 of 2M of Hydrochloric acid in 100cm3 solution. Place the solution in an electrolytic cell. Note the observations at each electrode for 30 minutes **Caution This experiment should be done in the open/fume chamber**.

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$

$HCl(aq) \rightarrow Cl^-(aq) + H^+(aq)$

II. Name the ions in 2M Hydrochloric acid solution that are attracted/move to:

Cathode- H^+(aq) from dilute Hydrochloric acid (HCl) and **H^+(aq)** from water (H_2O)

Anode- **Cl^-(aq)** from dilute Hydrochloric acid (HCl) and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $4H^+(aq) + 4e \rightarrow 2H_2(g)$

H^+ ions selectively discharged instead of Na^+ ions at the cathode)

Anode $2Cl^-(aq) \rightarrow Cl_2 + 2e$

(OH^- ions concentration is **low**.Cl^- ions concentration is **higher** at the anode thus cause **over voltage/block** discharge of OH^- ions)

IV. Name the products of electrolysis of 2M Hydrochloric acid

Cathode-Hydrogen gas (colourless gas that extinguishes burning splint with explosion/ “pop” sound

Anode-Chlorine gas (Pale green gas that bleaches blue/red moist/wet/damp litmus papers)

V. Explain the difference in volume of products at the cathode and anode.

Two(2) electrons donated/lost by **Cl^-** ions to form **1** molecule/**1**volume/**1**mole of **Chlorine** (**Cl_2**)gas at the **anode** are gained/acquired/accepted by two **H^+(aq)** ions to form **1** molecule/**1**volume/**1**mole of **Hydrogen** (**H_2**)gas at the **cathode.**

The volume of **Chlorine** gas at the anode is **equal to** the volume of **Hydrogen** produced at the cathode/ The volume of **Hydrogen** gas at the cathode is **twice** the volume of **Chlorine** produced at the anode.

VI. Explain the changes in concentration of the electrolyte during electrolysis of 2M Hydrochloric acid

The concentration of Hydrochloric acid **decreases.**

The ratio of **H_2 (g): Cl_2 (g)** is **1:1** as they are combined in Hydrochloric acid.

Water in the electrolyte is decomposed only into Hydrogen gas that escapes as products at the cathode.

There is a net accumulation of excess OH^- (aq) ions in solution.

This makes the electrolyte strongly alkaline with high pH.

c) Nature of electrodes used in the electrolytic cell

Inert electrodes (carbon-graphite and platinum) **do not** alter the expected products of electrolysis in an electrolytic cell. If another/different electrode is used in the electrolytic cell it alters/influences/changes the expected products of electrolysis. The examples below illustrate the influence of the nature of electrode on the products of electrolysis:

(i)Electrolysis of copper(II) sulphate(VI) solution

I. Using carbon-graphite electrodes

Weigh Carbon -graphite electrodes. Record the masses of the electrodes in table I below. Place the electrodes in 1M copper(II) sulphate(VI) solution in a beaker. Set up an electrolytic cell.

Close the switch and pass current for about 20 minutes. Observe each electrode and any changes in electrolyte. Remove the electrodes from the electrolyte. Wash with acetone/propanone and allow them to dry. Reweigh each electrode.

Sample results

Mass of **cathode before** electrolysis	23.4 g	Mass of **anode before** electrolysis	22.4 g
Mass of **cathode after** electrolysis	25.4 g	Mass of **anode after** electrolysis	22.4 g
Brown solid deposit at the cathode **after** electrolysis	-	Bubbles of colourless gas that relight splint	-
Blue colour of electrolyte **fades**/become less blue	-	Blue colour of electrolyte **fades** /become less blue	-

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$

$CuSO_4(aq) \rightarrow SO_4^{2-}(aq) + Cu^{2+}(aq)$

II. Name the ions in 1M copper(II) sulphate(VI) solution that are attracted/move to:

Cathode- Cu^{2+} (aq) from copper(II) sulphate(VI) solution and **H^+(aq)** from water (H_2O)

Anode- **SO_4^{2-}(aq)** from copper(II) sulphate(VI) solution and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $2Cu^{2+}(aq) + 4e \rightarrow 2Cu(g)$

Cu^{2+} ions are **lower** than H^+ ions in the electrochemical series therefore selectively discharged at the cathode.)

Anode $4OH^-(aq) \rightarrow H_2O(l) + O_2 + 4e$

(OH⁻ ions ions are **higher** than SO_4^{2-} ions in the electrochemical series therefore selectively discharged at the cathode.))

IV. Name the products of electrolysis of 1M copper(II) sulphate(VI) solution

Cathode-2 moles of **copper** metal as <u>brown solid coat</u>

Anode-Oxygen gas (Colourless gas that relights /rekindles glowing splint)

V. Explain the changes that take place at the cathode and anode.

Four(4) electrons donated/lost by **OH^-** ions to form **1** molecule/**1**volume/**1**mole of **Oxygen (O_2)**gas at the **anode** are gained/acquired/accepted by two **Cu^{2+}(aq)** ions to form **2** moles of brown **copper** solid that deposit itself at the **cathode.**

The moles of **oxygen** gas at the anode is **equal to** the moles of **copper** produced at the cathode

VI. Explain the changes in electrolyte during electrolysis of 1M copper (II) sulphate(VI) solution.

(i)The **pH** of copper(II) sulphate(VI) solution lowers/**decreases.** The salt becomes **more acidic.** Water in the electrolyte is decomposed only into Oxygen gas (from the OH^- ions) that **escapes** as products at the **anode**. There is a net accumulation of **excess H^+** (aq) ions in solution. This makes the electrolyte strongly **acidic** with **low** pH.

(ii) **Cu^{2+}** (aq) ions are responsible for the **blue** colour of the electrolyte/ copper(II) sulphate (VI) solution. As electrolysis continues, **blue** Cu^{2+} (aq) ions gain electrons to form **brown Copper.** The blue colour of electrolyte therefore fades/become less blue.

(iii)Copper is deposited at the cathode. This increases the mass of the cathode.OH^- ions that produce Oxygen gas at anode come from water. Oxygen escapes out/away without increasing the mass of anode.

II. Using copper electrodes

Weigh clean copper plates electrodes. Record the masses of the electrodes in table I below. Place the electrodes in 1M copper(II) sulphate(VI) solution in a beaker. Set up an electrolytic cell.

Close the switch and pass current for about 20 minutes. Observe each electrode and any changes in electrolyte. Remove the electrodes from the electrolyte. Wash with acetone/propanone and allow them to dry. Reweigh each electrode.

Sample results

Mass of **cathode before** electrolysis	23.4 g	Mass of **anode before** electrolysis	22.4 g
Mass of **cathode after** electrolysis	25.4 g	Mass of **anode after** electrolysis	20.4 g
Brown solid deposit at the cathode **after** electrolysis	-	Anode decrease insize/erodes/wear off	-
Blue colour of electrolyte **remain** blue	-	Blue colour of electrolyte **remain** blue	-

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l) \rightarrow OH^-(aq) + H^+(aq)$

$CuSO_4(aq) \rightarrow SO_4^{2-}(aq) + Cu^{2+}(aq)$

II. Name the ions in 1M copper(II) sulphate(VI) solution that are attracted/move to:

Cathode- Cu^{2+} (aq) from copper(II) sulphate(VI) solution and **H^+(aq)** from water (H_2O)

Anode- **SO_4^{2-}(aq)** from copper(II) sulphate(VI) solution and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $Cu^{2+}(aq) + 2e \rightarrow Cu(s)$

Cu^{2+} ions are **lower** than H^+ ions in the electrochemical series therefore selectively discharged at the cathode.)

Anode $Cu(s) \rightarrow Cu^{2+}(aq) + 2e$

(Both OH^- ions and SO_4^{2-} ions move to the anode but none is discharged. The copper anode itself ionizes/dissolves/dissociate because less energy is used to remove an electron/ionize /dissociate copper atoms than OH^- ions.

IV. Name the products of electrolysis of 1M copper(II) sulphate(VI) solution using copper electrodes.

Cathode-1 moles of **copper** metal as brown solid coat (Cathode increase/deposits)

Anode-Anode erodes/decrease in size

V. Explain the changes that take place during the electrolytic process

(i)Cathode

-Cu^{2+} ions are **lower** than **H^+** ions in the electrochemical series therefore selectively discharged at the cathode. **Cu^{2+}** ions have greater tendency to accept/gain/acquire electrons to form brown **copper** atoms/solid that deposit itself and increase the mass/size of the **cathode.**The copper deposited at the cathode is **pure**

-H^+ ions accumulate around the cathode. Electrolyte thus becomes strongly acidic around the cathode.

-Cu^{2+} ions in solution are responsible for the blue colour of electrolyte. Blue colour of electrolyte **fade** around the cathode.

(ii)**Anode**

Copper atom at the anode easily ionizes to release electrons. The anode therefore keeps decreasing in mass/eroding. The amount of copper that dissolve/erode is **equal** to the mass of copper deposited. This is called **electrode ionization.**

Electrode ionization is where the anode erodes/decrease and the cathode deposits/increase during electrolysis. The overall **concentration** of the electrolyte remains **constant**

14. In industries electrolysis has the following uses/applications:

(a)Extraction of reactive metals from their ores.

Potassium, sodium ,magnesium, and aluminium are extracted from their ores using electrolytic methods.

(b)Purifying copper after exraction from copper pyrites ores.

Copper obtained from copper pyrites ores is not pure. After extraction, the copper is refined by electrolysing copper(II)sulphate(VI) solution using the **impure** copper as **anode** and a thin strip of **pure** copper as **cathode**. Electrode ionization take place there:

(i)At the cathode; **$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$** (Pure copper deposits on the strip

(ii)At the anode; **$Cu(s) \rightarrow Cu^{2+}(aq) + 2e$** (impure copper erodes/dissolves)

(c)Electroplating

The label EPNS(**E**lectro **P**lated **N**ickel **S**ilver) on some steel/metallic utensils mean they are plated/coated with silver and/or Nickel to **improve** their **appearance**(**add** their **aesthetic** value)and **prevent**/slow **corrosion**(**rusting** of iron). Electroplating is the process of coating a metal with another metal using an electric current. During electroplating,the **cathode** is made of the metal to be **coated**/impure.

Example:

During the electroplating of a spoon with silver

(i)the spoon/impure is placed as the cathode(negative terminal of battery)

(ii)the pure silver is placed as the anode(positive terminal of battery)

(iii)the pure silver erodes/ionizes/dissociates to release electrons:

Ag(s) ->Ag^+ (aq) + e (impure silver erodes/dissolves)

(iv) silver (**Ag^+**)ions from electrolyte gain electrons to form pure silver deposits / coat /cover the spoon/impure

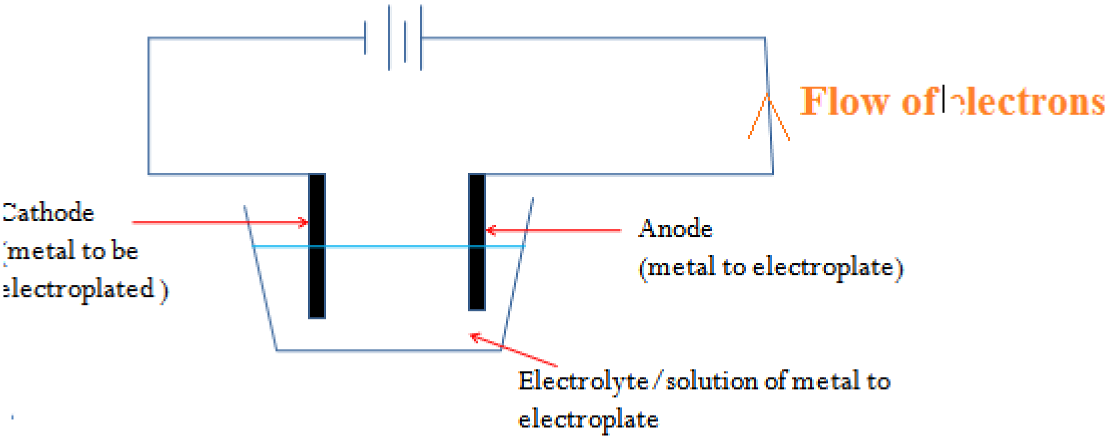
Ag^+ (aq) + e ->Ag(s) (pure silver deposits /coat/cover on spoon)

Ag(s) ->Ag^+ (aq) + e (pure silver erodes/dissolves)

(iv) silver (**Ag^+**)ions from electrolyte gain electrons to form pure silver deposits / coat /cover the spoon/impure

Ag^+ (aq) + e ->Ag(s) (pure silver deposits /coat/cover on spoon)

Electrolytic set up during electroplating



15. The quantitative **amount** of **products** of electrolysis can be determined by applying **Faradays 1st law of electrolysis**.

Faradays 1st law of electrolysis states that **"the mass/amount of substance liberated/produced/used during electrolysis is directly proportional to the quantity of of electricity passed/used."**

(**a**)The **SI** unit of **quantity** of electricity is the <u>coulomb</u>(C). The coulomb may be defined as the quantity of electricity passed/used when a current of one ampere flow for one second.i.e;

1Coulomb = 1 Ampere x 1Second

The Ampere is the **SI** unit of current(I)

The Second is the **SI** unit of time(t) therefore;

Quantity of electricity(in Coulombs) = Current(**I**) x time(**t**)

Practice examples

1. A current of 2 amperes was passed through an electrolytic cell for 20 minutes. Calculate the quantity of electric charge produced.

Working:

Quantity of electricity(in Coulombs) = Current(**I**) x time(**t**)
Substituting /converting time to second = 2 x (20 x 60)
= **2400 C**

2. A current of 2 amperes was passed through an electrolytic.96500 coulombs of charge were produced. Calculate the time taken.

Working:

Time(**t**) in seconds = $\frac{\text{Quantity of electricity(in Coulombs)}}{\text{Current(I) in amperes}}$
Substituting = $\frac{96500}{2}$
= **48250 seconds**

3. 96500 coulombs of charge were produced after 10 minutes in an electrolytic cell . Calculate the amount of current used.

Working:

Current(**I**) in amperes = $\frac{\text{Quantity of electricity(in Coulombs)}}{\text{Time(t) in seconds}}$
Substituting/converting time to second= $\frac{96500}{10 \times 60}$
= **160.8333 Amperes**

(**b**)The quantity of electricity required for **one mole** of **electrons** at the anode/cathode is called the **Faraday constant**(F). It is about **96500 Coulombs.**i.e

The number of **Faradays** used /required is equal to the number of **electrons** used at cathode/anode during the electrolytic process. e.g.
Cu^{2+} require to gain **2** moles of electrons=**2** Faradays =**2** x 96500 coulombs of electricity at the cathode.
Al^{3+} require to gain **3** moles of electrons=**3** Faradays =**3** x 96500 coulombs of electricity at the cathode
Na^{+} require to gain **1** moles of electrons=**1** Faradays =**1** x 96500 coulombs of electricity at the cathode
$2H^{+}$ require to gain **2** moles of electrons=**2** Faradays =**2** x 96500 coulombs of electricity at the cathode to form 1molecule of hydrogen gas

$2O^{2-}$ require to lose/donate **4** moles of electrons=**4** Faradays =**4** x 96500 coulombs of electricity at the anode to form 1molecule of Oxygen O_2 gas.
$4OH^{-}$ require to lose/donate **4** moles of electrons=**4** Faradays =**4** x 96500 coulombs of electricity at the anode to form 1molecule of Oxygen gas and 2 molecules of water.

(**c**)The mass/amount of products at the cathode/anode is related to the molar mass of the substance and/or the volume of gases at standard/room temperature and pressure as in the below examples:

Practice examples

1.Calculate the mass of copper deposited at the cathode when a steady current of 4.0 amperes is passed through copper(II)sulphate(VI) for 30 minutes in an electrolytic cell. (Cu=63.5, 1F = 96500C)

Working:

Quantity of electricity(in Coulombs) = Current(**I**) x time(**t**)
Substituting /converting time to second = 4 x (30 x 60)
= **7200 C**

Equation at the cathode: $Cu^{2+}(aq) + \mathbf{2e} \rightarrow Cu(s)$

2 mole of electrons = 2 Faradays = 2 x 96500 C produce a mass =molar mass of copper thus;

2 x 96500C -> 63.5 g
72000C -> $\frac{7200 \times 63.5}{2 \times 96500}$ = **2.3689 g** of copper

2.a)If 3.2 g of Lead were deposited when a current of 2.5 amperes was passed through an electrolytic cell of molten Lead(II)bromide for 20 minutes, determine the Faraday constant.(Pb = 207)

Working:

Quantity of electricity (in Coulombs) = Current(**I**) x time(**t**)
Substituting /converting time to second = 2.5 x (20 x 60)
= **3000 C**

If 3.2g of Lead -> 3000C
Then 207 g of Lead -> $\frac{207 \times 3000}{3.2}$ = **194062.5** C

Equation at the cathode: $Pb^{2+}(l) + \mathbf{2e} \rightarrow Pb(l)$

From the equation: 2 moles of electrons = 2 Faradays = 194062.5 C
1mole of electrons = 1 Faraday => $\frac{194062.5}{2}$ = **97031.25 C**

b)What is the volume of bromine vapour produced at the anode at room temperature(1mole of gas at room temperature and pressure = 24000cm3)

Method 1

Equation at the anode: $Br^{-}(l) \rightarrow Br_2(g) + \mathbf{2e}$

From the equation: 2 moles of electrons = 2 Faradays = 194062.5 C -> 24000cm3

$$3000\ C \rightarrow \frac{3000 \times 24000}{194062.5}$$

=371.0145cm3

Method 2

Equation at the anode: $Br^-(l) \rightarrow Br_2(g) + \mathbf{2e}$

Mole ratio of products at Cathode: anode = 1:1

Moles of Lead at cathode = $\frac{3.2}{207}$ = 0.0155moles = moles of Bromine

1 moles of bromine vapour -> 24000cm3

0.0155moles of Bromine -> 0.0155 x 24000 = **372 cm3**

Method 3

Equation at the anode: $Br^-(l) \rightarrow Br_2(g) + \mathbf{2e}$

Ratio of Faradays used to form products at Cathode: anode = 2:2

=> 2 x 97031.25 C produce 24000cm3 of bromine vapour

Then: $3000\ C \rightarrow \frac{3000 \times 24000cm3}{2 \times 97031.25}$ = **371.0145cm3**

3.What mass of copper remain from 2.0 at the anode if a solution of copper(II)sulphate(VI) is electrolysed using a current of 1 ampere flowing through an electrolytic cell for 20 minutes.(Cu= 63.5, 1Faraday = 96487 coulombs)

Working:

Quantity of electricity (in Coulombs) = Current(**I**) x time(**t**)

Substituting /converting time to second = 1 x (20 x 60)

= **1200 C**

Equation at the cathode: $Cu^{2+}(aq) + \mathbf{2e} \rightarrow Cu(s)$

2 mole of electrons = 2 Faradays = 2 x 96500 C erode/dissolve a mass =molar mass of copper thus;

2 x 96500C -> 63.5 g

1200C -> $\frac{1200 \times 63.5}{2 \times 96500}$ = **0.3948g** of copper deposited

Mass of copper remaining = Original mass – mass dissolved/eroded

=> 2.0 -0.3948 = **1.6052 g** of copper remain

4. Calculate the current passed if a mass of 0.234 g of copper is deposited in 4 minutes during electrolysis of a solution of copper (II)sulphate(VI). (Cu= 63.5 ,1F = 96500C)

Working:

Equation at the cathode: $Cu(s) \rightarrow Cu^{2+}(aq) + \mathbf{2e}$

2 mole of electrons = 2 Faradays = 2 x 96500 C produce a mass =molar mass of copper thus;

63.5 g -> 2 x 96500C

0.234 g -> $\frac{0.234 \times 2 \times 96500}{63.5}$ = **711.2126 C**

Current(**I**) in amperes = $\frac{\text{Quantity of electricity(in Coulombs)}}{\text{Time(t) in seconds}}$

Substituting/converting time to second= $\frac{711.2126\ \text{C}}{4 \times 60}$

= **2.9634 A**mperes

5. (a)What quantity of electricity will deposit a mass of 2.43 g of Zinc during electrolysis of a solution of Zinc (II)sulphate(VI).
(Zn= 65 ,1F = 96500C)

Working:

Equation at the cathode: $Zn^{2+}(aq) + \mathbf{2e} \rightarrow Zn(s)$

2 mole of electrons = 2 Faradays = 2 x 96500 C erode/dissolve a mass =molar mass of Zinc thus;

65 g -> 2 x 96500

2.43 g -> $\frac{2.43 \times 2 \times 96500}{65}$ = **7215.2308** C

(b)Calculate the time (in minutes) it would take during electrolysis of the solution of Zinc (II)sulphate(VI) above if a current of 4.0 Amperes is used.

Time(**t**) in seconds = $\frac{\text{Quantity of electricity(in Coulombs)}}{\text{Current(I) in amperes}}$

Substituting = $\frac{7215.2308}{4}$ = $\frac{1803.8077\ \text{seconds}}{60}$ = **30.0635** minutes

6.When a current of 1.5 amperes was passed through a cell containing M^{3+} ions of metal M for 15 minutes, the mass at cathode increased by 0.26 g.(Faraday constant = 96500C

a) Calculate the quantity of electricity used.

Quantity of electricity (in Coulombs) = Current(**I**) x time(**t**)

Substituting /converting time to second = 1.5 x (15 x 60)

= **1350 C**

b) Determine the relative atomic mass of metal M

Equation at the cathode: $M^{3+}(aq) + \mathbf{3e} \rightarrow M(s)$

1350 C of electricity -> 0.26 g of metal M

3 mole of electrons = 3 Faradays = 3 x 96500 C produce a mass =molar mass of M thus;

RAM of M = $\frac{0.26\ \text{g} \times 3 \times 96500}{1350}$ = **55.7556**(No units)

7.An element "P" has a relative atomic mass 88.When a current of 0.5 amperes was passed through fused chloride of "P" for 32 minutes and 10seconds ,0.44 g

of “P” was deposited at the cathode. Determine the charge on an ion of “P”(Faraday constant = 96500C)

Working:

Quantity of electricity (in Coulombs) = Current(**I**) x time(**t**)

Substituting /converting time to second = 0.5 x ((32 x 60) + 10)

= **965**C

0.44 g of metal “P” are deposited by 965C

88g of of metal “P” are deposited by: $\frac{88 \text{ x } 965}{0.44}$= **193000** C

96500 C = 1 mole of electrons = 1 Faradays = single charge

193000 C -> $\frac{193000}{96500}$ = **2** moles/Faradays/charges => symbol of ion = $\mathbf{P^{2+}}$

8. During purification of copper by electrolysis 1.48 g of copper was deposited when a current was passed through aqueous copper (II)sulphate(VI) for 2 ½ hours. Calculate the amount of current that was passed. (Cu= 63.5 ,1F = 96500C)

Working:

Equation at the cathode: $Cu^{2+}(aq) + \mathbf{2e} \rightarrow Cu(s)$

2 mole of electrons = 2 Faradays = 2 x 96500 C produce a mass =molar mass of copper thus;

63.5 g -> 2 x 96500C

1.48 g -> $\frac{1.48 \text{ x } 2 \text{ x } 96500}{63.5}$ = **4255.1181** C

Current(**I**) in amperes = $\frac{\text{Quantity of electricity(in Coulombs)}}{\text{Time}(\mathbf{t}) \text{ in seconds}}$

Substituting/converting time to second= $\frac{\mathbf{4255.1181}\text{C}}{((2 \text{ x } 60) + 30) \text{ x}60}$

= **0.4728** **A**mperes

17. Practically Faraday 1st law of electrolysis can be verified as below.

Verifying Faraday 1st law of electrolysis

Procedure.

Weigh clean copper plates electrodes. Record the masses of the electrodes in table I below. Place the electrodes in 1M copper(II) sulphate(VI) solution in a beaker. Set up an electrolytic cell.

Close the switch and pass a steady current of 2 amperes by adjusting the rheostat for exactly 20 minutes.Remove the electrodes from the electrolyte. Wash with acetone/ propanone and allow them to dry. Reweigh each electrode.

Sample results

Mass of **cathode before** electrolysis	7.00 g	Mass of **anode before** electrolysis	7.75 g
Mass of **cathode after**	8.25 g	Mass of **anode after**	6.50 g

electrolysis		electrolysis	
Change in mass at cathode **after** electrolysis	1.25 g	Change in mass at anode **after** electrolysis	1.25 g

Answer the following questions:

I. Write the equation for the decomposition of the electrolytes during the electrolytic process.

$H_2O(l)$ -> $OH^-(aq)$ + $H^+(aq)$
$CuSO_4(aq)$ -> $SO_4^{2-}(aq)$ + $Cu^{2+}(aq)$

II. Name the ions in 1M copper(II) sulphate(VI) solution that are attracted/move to:

Cathode- Cu^{2+} (aq) from copper(II) sulphate(VI) solution and **H^+(aq)** from water (H_2O)

Anode- **SO_4^{2-}(aq)** from copper(II) sulphate(VI) solution and **OH^- (aq)** from water (H_2O)

III. Write the equation for the reaction during the electrolytic process at the:

Cathode $Cu^{2+}(aq) + 2e \rightarrow Cu(s)$

Cu^{2+} ions are **lower** than H^+ ions in the electrochemical series therefore selectively discharged at the cathode.)

Anode $Cu(s) \rightarrow Cu^{2+}(aq) + 2e$

(Both OH^- ions and SO_4^{2-} ions move to the anode but none is discharged. The copper anode itself ionizes/dissolves/dissociate as less energy is used to remove an electron/ionize /dissociate copper atoms than OH^- ions.

IV. Name the products of electrolysis of 1M copper(II) sulphate(VI) solution using copper electrodes.

Cathode-1.25 g of **copper** metal as <u>brown solid coat</u>/deposits

Anode-1.25 g of **copper** metal erodes/decrease in size

V. (i)How many moles of electrons are used to deposit/erode one mole of copper metal at the cathode/anode?

From the equation at anode/cathode= **<u>2 moles</u>**

(ii)How many Faradays are used to deposit/erode one mole of copper metal at the cathode/anode?

From the equation at anode/cathode : 2 moles = **<u>2 Faradays</u>**

(iii)Calculate the quantity of electric charge used

<u>Working:</u>

Quantity of electricity (in Coulombs) = Current(**I**) x time(**t**)
Substituting /converting time to second = 2 x 20 x 60
= **2400**C

VI. (i) Calculate the quantity of electricity required to deposit/erode one mole of copper at the cathode/anode(Cu=63.5)

Since 1.25 g of copper -> 2400C
Then 63.5 g (1mole of copper) -> $\frac{63.5 \times 2400}{1.25}$ = **121920** C

(ii)Determine the Faraday constant from the results in V(i) above

From the equation at;
Cathode $Cu^{2+}(aq) + 2e \rightarrow Cu(s)$
Anode $Cu(s) \rightarrow Cu^{2+}(aq) + 2e$
2 moles = 2 Faradays -> 121920 C
1 moles = 1 Faradays -> $\frac{121920}{2}$ = **60960** C

(iii) The faraday constant obtained above is far lower than theoretical.Explain

-high resistance of the wires used.
-temperatures at 25°C were not kept constant
-plates/electrodes used were not made of pure copper
-plates/electrodes used were not thoroughly clean copper

Further practice

1.**An element P has a relative atomic mass of 88. When a current of 0.5 amperes was passed through the fused chloride of P for 32 minutes and 10 seconds, 0.44g of P were deposited at the cathode. Determine the charge on an ion of P. (1 faraday = 96500 Coulombs).**

2.During electrolysis of aqueous copper (II) sulphate, 144750 coulombs of electricity were used. Calculate the mass of copper metal that was obtained (Cu = 64 ;1 Faraday = 96500 coulombs) (3 mks)

3.A nitrate of a metal M was electrolysed .1.18 g of metal was deposited when a current of 4 ampheres flow for 16 minutes.Determine the formula of the sulphate(VI)salt of the metal.
(Faraday constant = 96500 , RAM of X = 59.0)

Working
Q = It =>(4 x 16 x 60) = **3840** C
1.18 g of X => 3840 C
59.0 g => $\frac{59.0 \times 3840}{1.18}$ = **192000** C
96500 C = 1Faraday
192000 C= $\frac{192000 \text{ C} \times 1}{96500 \text{ C}}$ = **2F** thus charge of M = $\mathbf{M^{2+}}$
Valency of M is **2** thus formula of sulphate(VI)salt $\mathbf{MSO_4}$

4. Below is the results obtained when a current of 2.0amperes is passed through copper(II)sulphate(VI)solution for 15 minutes during electrolysis using copper electrode.

Initial mass of cathode = 1.0 g
Final mass of cathode = 1.6 g
Change in mass of cathode = 0.60 g

(i)Determine the change in mass at the anode. Explain your answer.

Mass decrease = 0.6g.

Electrode ionization take place where the cathode increase in mass form the erosion of the anode

(ii)Calculate the quantity of electricity required to deposit one mole of copper.(Cu =63.5)

Q =It => 2 x 15 x 60 = 1800 coulombs

Method 1

0.60 g of copper ->1800 coulombs

63.5 g -> $\frac{63.5 \times 1800}{0.60}$ = **<u>190500</u>** Coulombs

Method 2

Moles of Copper = $\frac{\text{Mass}}{\text{Molar mass}}$ => $\frac{0.60}{63.5}$ = **9.4488×10^{-3} moles**

9.4488×10^{-3} moles **->** 1800 coulombs

1 Mole -> $\frac{1 \times 1800 \text{ coulombs}}{9.4488 \times 10^{-3} \text{ moles}}$ = **<u>190500.381</u>** coulombs

(iii)Determine the oxidation number of copper produced at the cathode and hence the formula of its nitrate (V)salt (1 Faraday = 96500 Coulombs)

96500 Coulombs -> 1 Faraday

190500.381 coulombs -> $\frac{190500.381 \text{ coulombs} \times 1}{96500 \text{ Coulombs}}$

= 1.9741 Faradays => **<u>2</u>**F(**whole number**)

Charge of copper = **<u>2+</u>** = **Oxidation number**

=> Valency of copper = **2** hence chemical formula of nitrate (V)salt = **<u>$Cu(NO_3)_2$</u>**

22.0.0 METALS (20 LESSONS)

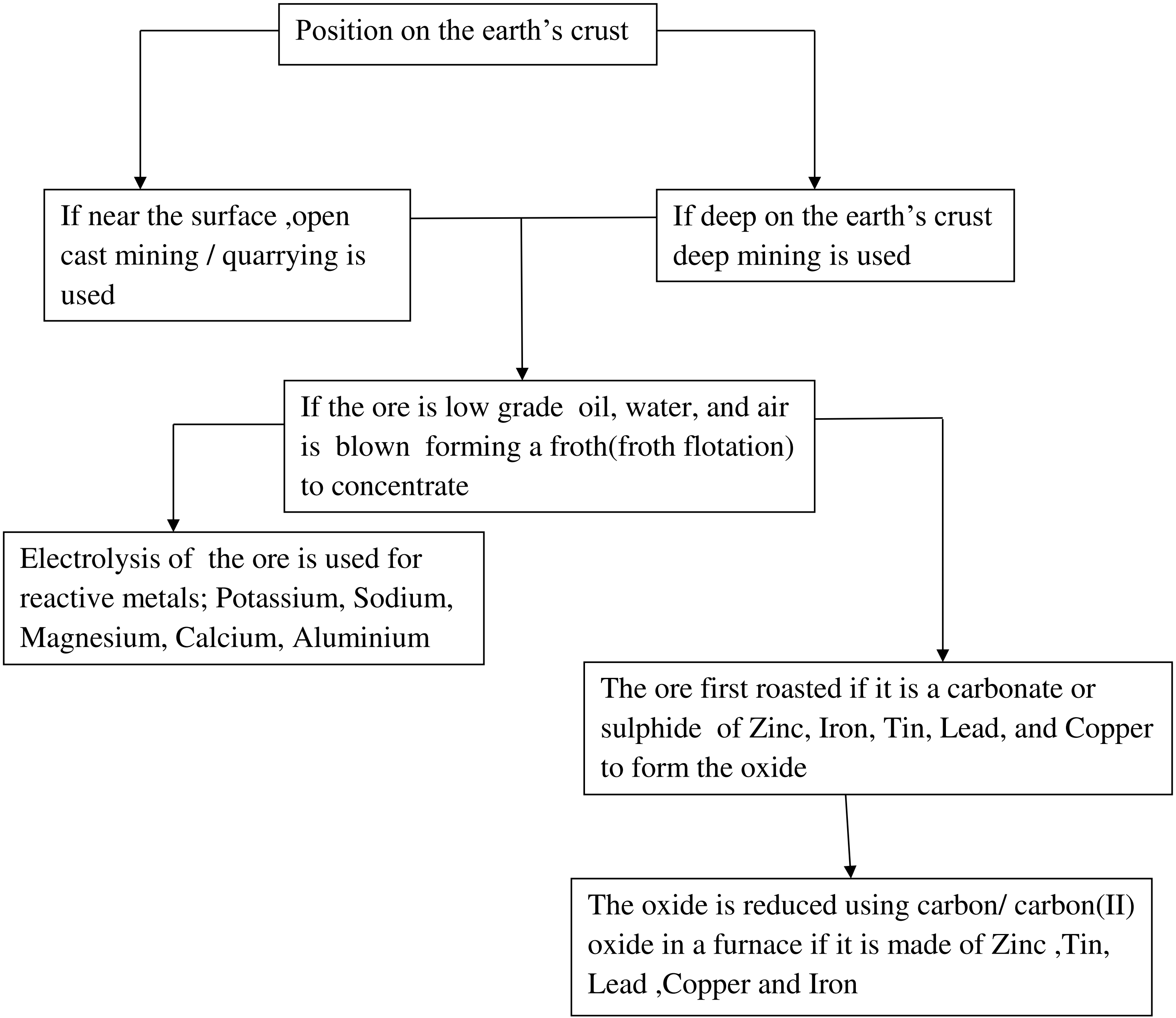
a)Introduction to metals

The rationale of studying metals cannot be emphasized.Since ages, the world over, metals like gold and silver have been used for commercial purposes.
The periodicity of alkali and alkaline earth metals was discussed in year 2 of secondary school education. This topic generally deals with:

(**a**)Natural occurrence of the chief ores of the most useful metals for industrial /commercial purposes.
(**b**)Extraction of these metals from their ores for industrial/ commercial purposes.
(**c**)industrial/ commercial uses of these metals.
(**d**)main physical and chemical properties /characteristic of the metals.

The metals given detailed emphasis here are; **Sodium, Aluminium, Iron, Zinc, Lead** and **Copper.**

The main criteria used in extraction of metals is based on its position in the electrochemical/reactivity series and its occurrence on the earth's crust.



1.SODIUM

a) Natural occurrence

Sodium naturally occurs as:

(i)Brine-a concentrated solution of sodium chloride($NaCl(\mathbf{aq})$) in salty seas and oceans.

(ii)Rock salt-solid sodium chloride($NaCl(\mathbf{s})$)

(iii)Trona-sodium sesquicarbonate($NaHCO_3.Na_2CO_3.2H_2O$) especially in lake Magadi in Kenya.

(iv)Chile saltpeter-sodium nitrate($NaNO_3$)

b)(i)

Extraction of Sodium from brine/Manufacture of Sodium hydroxide/The flowing mercury cathode cell/ TheCaster-Keller process

I.Raw materials

(i) Brine-concentrated solution of sodium chloride (NaCl (**aq**)) from salty seas and oceans.
(ii) Mercury
(iii) Water from river/lakes

II. Chemical processes

Salty lakes, seas and oceans contain large amount of dissolved sodium chloride (NaCl (aq)) solution.
This solution is concentrated to form brine which is fed into an electrolytic chamber made of **suspended** Carbon **graphite**/titanium as the **anode** and a **continuous** flow of Mercury as the **cathode**.Note
Mercury is the only naturally occurring known liquid metal at room temperature and pressure

Questions

I. Write the equation for the decomposition of the electrolyte during the electrolytic process.

$$H_2O(l) \longrightarrow H^+(aq) + OH^-(aq)$$
$$NaCl(aq) \longrightarrow Na^+(aq) + Cl^-(aq)$$

II. Name the ions present in brine that moves to the:
(i)Mercury cathode; **$H^+(aq)$, $Na^+(aq)$**
(ii)Titanium/graphite; **$OH^-(aq)$, $Cl^-(aq)$**

III. Write the equation for the reaction that take place during the electrolytic process at the;

Cathode; $2Na^+(aq) + 2e \longrightarrow 2Na(s)$

Anode; $2Cl^-(aq) \longrightarrow Cl_2(g) + 2e$

Note
(i) Concentration of $2Cl^-(aq)$ ions is higher than OH^- ions causing **overvoltage** thus **block**ing OH^- ions from being discharged at the anode.

(ii) Concentration of $Na^+(aq)$ ions is higher than H^+ ions causing **overvoltage** thus **block**ing H^+ ions from being discharged at the cathode.

IV. Name the products of electrolysis in the flowing mercury-cathode cell.

(i)Mercury cathode; **Sodium metal as grey soft metal/solid**

(ii)Titanium/graphite; **Chlorine gas as a pale green gas that turns moist blue/red litmus papers red then bleaches both.** Chlorine gas is a very useful by-product in;

(i)making (PVC)polyvinylchloride(polychloroethene) pipes.
(ii)chlorination/sterilization of water to kill germs.
(iii)bleaching agent
(iv)manufacture of hydrochloric acid.

Sodium produced at the cathode immediately reacts with the mercury at the cathode forming **sodium amalgam(NaHg)** liquid that flow out of the chamber.

$$Na(s) + Hg(l) \longrightarrow Na\,Hg\,(l)$$

Sodium amalgam is added distilled water and reacts to form sodium hydroxide solution, free mercury and Hydrogen gas.

$$2Na\,Hg\,(l) + 2H_2O(l) \longrightarrow 2NaOH\,(aq) + 2Hg(l) + H_2(g)$$

Hydrogen gas is a very useful by-product in;

(i)making ammonia gas in the Haber process
(ii)manufacture of hydrochloric acid
(iii)in weather balloons to forecast weather
(iv)as rocket fuel

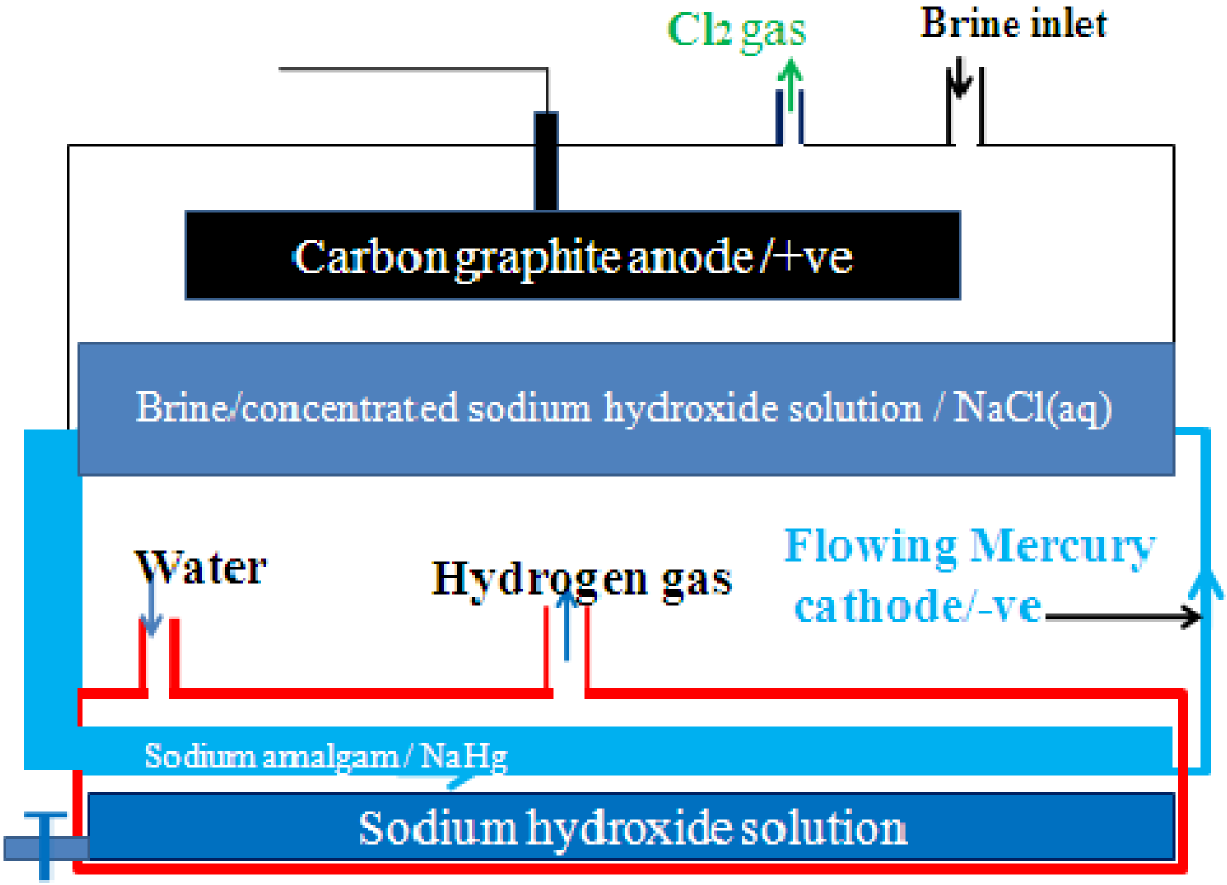
As the electrolysis of brine continues, the concentration of Cl-ions decreases and oxygen gas start being liberated. **Continuous** feeding of the electrolyte is therefore very necessary.

III.Uses of sodium hydroxide

The sodium hydroxide produced is very pure and is used mainly in:

(i)Making soapy and soapless detergents.
(ii)making cellulose acetate/rayon

IV. Diagram showing the Manufacture of Sodium hydroxide from the flowing Mercury-cathode cell.



Flowing mercury cathode cell

V. Environmental effects of Manufacture of Sodium hydroxide from the flowing Mercury-cathode cell.

1.Most of the Mercury used at the cathode is recycled ;

(i)to reduce the cost because mercury is expensive
(ii)to reduce pollution because mercury kills marine life.
(iii)because it causes chromosomal/genetic mutation to human beings.

2.Chlorine produced at the anode;

(i)has a pungent irritating smell that causes headache to human beings.
(ii)bleaches any wet substance.
(iii)dissolves water to form both hydrochloric acid and chloric(I)acid
Both cause marine pollution and stomach upsets.

b)(ii)

Extraction of sodium from rock salt/The Downs cell/process

I. Raw materials

(i)Rock salt/solid sodium chloride
(ii)calcium(II)chloride

II. Chemical processes.

Rock salt/ solid sodium chloride is heated to molten state in a chamber lined with fire bricks on the outside.

Sodium chloride has a melting point of about 800°C. A little calcium (II) chloride is added to lower the melting point of the electrolyte to about 600°C. The molten electrolyte is the electrolyzed in a carbon graphite anode suspended at the centre and surrounded by steel cathode.

Questions

I. Write the equation for the decomposition of the electrolyte during the electrolytic process.

$$NaCl(l) \longrightarrow Na^+(l) + Cl^-(l)$$

Note: In absence of water, the ions are in liquid state.

II. Name the ions present in molten rock salt that move to the;

(i)Steel cathode **-$Na^+(l)$**

(ii)Carbon graphite anode- **$Cl^-(l)$**

III. Write the equation for the reaction that take place during the electrolytic process at the;

(i)Steel cathode

$$2Na^+(l) + 2e \longrightarrow 2Na(l)$$

(ii)Carbon graphite anode

$$2Cl^-(l) \longrightarrow Cl_2(g) + 2e$$

IV. Name the products of electrolysis in the Downs cell at;

(i)Cathode:

Grey solid Sodium metal is less dense than the molten electrolyte and therefore float on top of the cathode to be periodically tapped off.

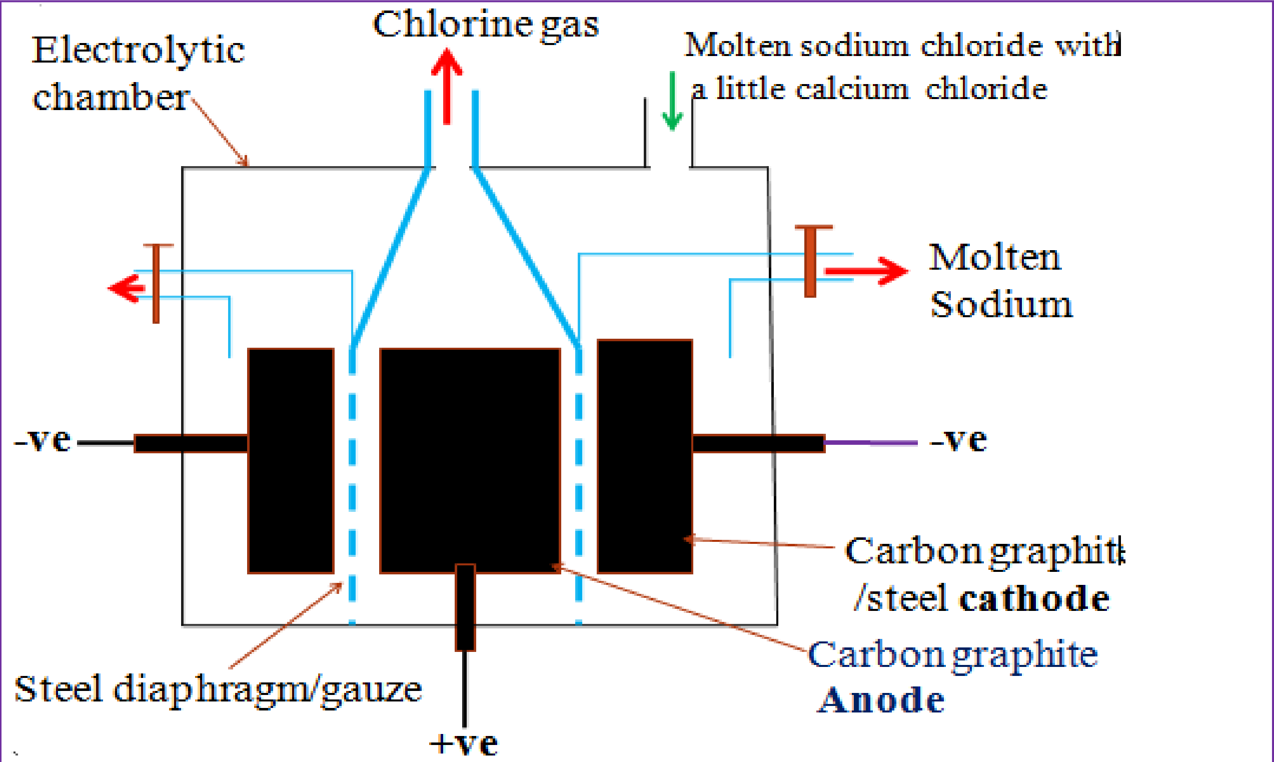
(ii)Anode:

Pale green chlorine gas that turns moist/damp/wet blue/red litmus papers red then bleaches/decolorizes both. Chlorine gas is again a very useful by-product in;

(i)making (PVC)polyvinylchloride(polychloroethene) pipes.
(ii)chlorination/sterilization of water to kill germs.
(iii)bleaching agent
(iv)manufacture of hydrochloric acid.

A **steel diaphragm/gauze** is suspended between the electrodes to **prevent recombination** of sodium at the cathode and chlorine gas at the anode **back** to sodium chloride.

III. Diagram showing the **Downs cell/process for extraction of sodium**



The Downs process for extraction of Sodium from Rock salt

IV. Uses of sodium.

1.Sodium vapour is used as sodium lamps to give a yellow light in street lighting.

2.Sodium is used in making very useful sodium compounds like;

(i)Sodium hydroxide(NaOH)
(ii)Sodium cyanide(NaCN)
(iii)Sodium peroxide(Na_2O_2)
(iv)Sodamide($NaNH_2$)

3.An alloy of Potassium and Sodium is used as **coolant** in nuclear reactors.

V. Environmental effects of Downs cell.

1.Chlorine produced at the anode;

(i)has a pungent irritating smell that causes headache to human beings.
(ii)bleaches any wet substance.
(iii)dissolves water to form both hydrochloric acid and chloric(I)acid
Both cause marine pollution and stomach upsets.

2.Sodium metal rapidly react with traces of water to form alkaline Sodium hydroxide(NaOH(aq))solution. This raises the pH of rivers/lakes killing aquatic lifein case of leakages.

VI. Test for presence of Na.

If a compound has **Na^+** ions in solid/molten/aqueous state then it changes a non-luminous clear/colourless flame to a **yellow coloration** but does not burn

Experiment

Scoop a portion of sodium chloride crystals/solution in a clean metallic spatula. Introduce it to a clear /colourless Bunsen flame.

Observation	Inference
Yellow coloration	Na^+

Practice

(i)Calculate the time taken in hours for 230kg of sodium to be produced in the Downs cell when a current of 120kA is used.
(ii)Determine the volume of chlorine released to the atmosphere.
(Na=23.0),Faraday constant=96500C.I mole of a gas =24dm3 at r.t.p)

Working:

Equation at the cathode:

$$2Na^+(l) + 2e \rightarrow 2Na(l)$$

2 mole of electrons = 2 Faradays = 2 x 96500 C deposits a mass = molar mass of Na = 23.0g thus;

$$23.0\text{ g} \rightarrow 2 \times 96500\text{ C}$$

$$(230 \times 1000)\text{g} \rightarrow \frac{230 \times 1000 \times 2 \times 96500}{23}$$

$$= \underline{1{,}930{,}000{,}000 / 1.93 \times 10^{9}}\text{C}$$

$$\text{Time}(t)\text{ in seconds} = \frac{\text{Quantity of electricity}}{\text{Current}(I)\text{ in amperes}}$$

Substituting

$$= \frac{\underline{1{,}930{,}000{,}000 / 1.93 \times 10^{9}}\text{C}}{120 \times 1000\text{A}}$$

= <u>16,083,3333seconds / 268.0556 minutes</u>

= <u>4.4676hours</u>

<u>Volume of Chlorine</u>

<u>Method 1</u>

Equation at the anode:

$2\,Cl^{-}\,(\mathbf{l}) \rightarrow Cl_2(g) + \mathbf{2e}$

From the equation:

2 moles of electrons = 2 Faradays =2 x 96500C

2 x 96500C -> 24dm3

$$1{,}930{,}000{,}000 / 1.93 \times 10^{9}\text{C} \rightarrow \frac{1{,}930{,}000{,}000 / 1.93\times10^{9}\text{C} \times 24}{2 \times 96500\text{C}}$$

Volume of Chlorine = **<u>240,000dm3</u> <u>/2.4 x 10^{5}dm3</u>**

<u>Method 2</u>

Equation at the anode: $Cl^{-}\,(l) \rightarrow Cl_2(g) + \mathbf{2e}$

Mole ratio of products at Cathode: anode = 1:1

Moles of sodium at cathode $= \frac{(230 \times 1000)\text{g}}{23}$ = **<u>10,000moles</u>**

10,000moles of Na = **<u>10,000moles</u>** moles of Chlorine

1 moles of Chlorine gas = 24000cm3

10,000moles of Chlorine- > 10000 x 24

=<u>240,000dm3 / 2.4x 10^{5}dm3</u>

<u>Method 3</u>

Equation at the anode: $Cl^{-}\,(l) \rightarrow Cl_2(g) + \mathbf{2e}$

Ratio of Faradays of products at Cathode: anode = 2:2

=> 2 x 96500C produce 24000cm3 of chlorine gas Then: <u>1,930,000,000 / 1.93 x 10</u> ^{9}C ->

$$\frac{\underline{1{,}930{,}000{,}000 / 1.93 \times 10}^{9}\text{C} \times 24}{2 \times 96500} = \mathbf{\underline{240{,}000dm3}}$$

(iij)The sodium metal produced was reacted with water to form 25000dm3 solution in a Caster-Keller tank.

(a)Calculate the concentration of the resulting solution in moles per litre.
(b)The volume of gaseous products formed at s.t.p(1 mole of gas =22.4 dm3 at s.t.p)

Chemical equation at Caster-Keller tank

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

Mole ratio Na:NaOH = 2 : 2 => 1:1

Moles Na =10000moles=10000moles of NaOH

25000dm3 ->10000moles of NaOH

$1dm3 \rightarrow \frac{10000 \times 1}{25000} =$ **0.4M / 0.4 moles/dm3**

Mole ratio Na: $H_2(g)$ = 2 : 1

Moles Na = 10000moles = **5000moles of $H_2(g)$**

Volume of $H_2(g)$ = moles x molar gas volume at s.t.p

=> 5000moles x 22.4 dm3

=**120,000dm3**

(iv)The solution formed was further diluted with water for a titration experiment. 25.0 cm3 of the diluted solution required 20.0cm3 of 0.2M sulphuric(VI)acid for complete neutralization. Calculate the volume of water added to the diluted solution before titration.

Chemical equation

$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

Moles ratio NaOH : H_2SO_4 = 2 : 1

Moles ratio $H_2SO_4 = \frac{\text{molarity x volume}}{1000} \Rightarrow \frac{0.2M \times 20}{1000}$

=**4.0×10^{-3} moles**

Moles NaOH = $2 \times 4.0 \times 10^{-3}$ moles= **8.0×10^{-3} moles**

Molarity of NaOH= $\frac{\text{Moles x 1000}}{\text{volume}} \Rightarrow \frac{8.0 \times 10^{-3} \text{ moles} \times 1000}{25}$

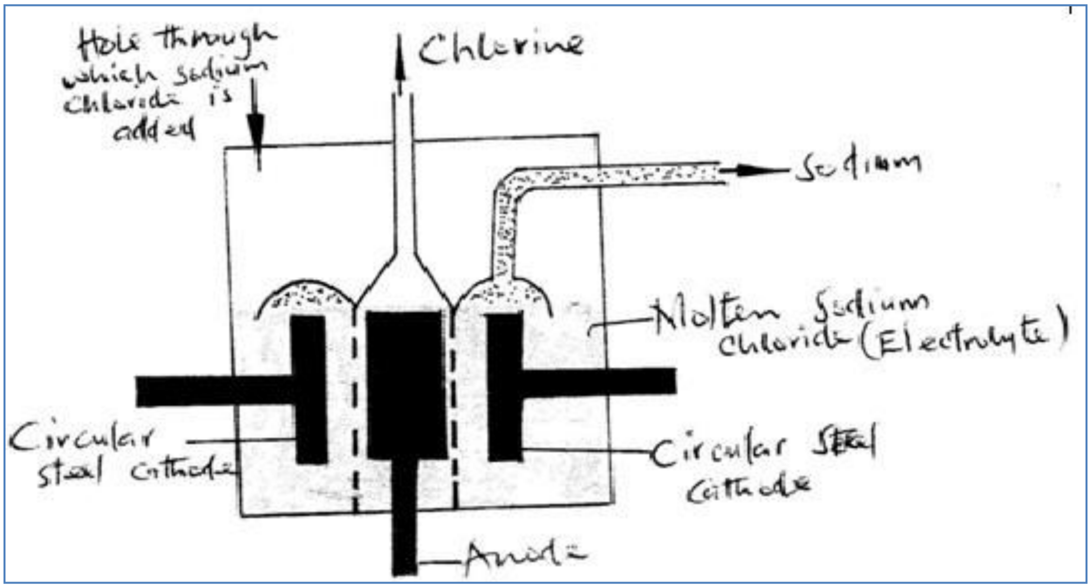
=**0.16 molesdm^{-3} /M**

Volume used during dilution

$C_1V_1 = C_2V_2 \Rightarrow 0.4M \times V_1 = 0.16 M \times 25$

$$= \frac{0.16\ M\ x\ 25}{0.4} \quad = \underline{\textbf{10cm3}}$$

(a) Below is a simplified diagram of the Downs Cell used for the manufacture of sodium. Study it and answer the questions that follow



(i)What material is the anode made of? Give a reason (2 mks)

Carbon graphite/Titanium

This because they are cheap and inert/do not influence/affect the products of electrolysis

(ii) What precaution is taken to prevent chlorine and sodium from re-combination? (1 mks)

Using a steel gauze/diaphragm separating the cathode from anode

(iii) Write an ionic equation for the reaction in which chlorine gas is formed (1mk)

$$2Cl^-(l) \quad -> \quad Cl_2(g) \quad + \quad 2e$$

(b) In the Downs process, (used for manufacture of sodium), a certain salt is added to lower the melting point of sodium chloride from about 800^0C to about 600^0C.

(i) Name the salt that is added (1mk)

Calcium chloride

(ii) State why it is necessary to lower the temperature(1mk)

To reduce the cost of production

(c) Explain why aqueous sodium chloride is not suitable as an electrolyte for the manufacture of sodium in the Downs process(2mk)

The sodium produced react explosively/vigorously with water in the aqueous sodium chloride

(d) Sodium metal reacts with air to form two oxide. Give the formulae of two oxides(1mk)

Na_2O Sodium oxide(in limited air)
Na_2O_2 Sodium peroxide(in excess air)

2.ALUMINIUM

a)Natural occurrence

Aluminium is the most common naturally occurring metal. It makes 7% of the earths crust as:

(i)Bauxite ore- Hydrated aluminium oxide($Al_2O_3.2H_2O$)
(ii)Mica ore-Potassium aluminium silicate($K_2Al_2Si_6O_{16}$)
(iii)China clay ore- aluminium silicate ($Al_2Si_6O_{16}$)
(iv)Corrundum-Anhydrous aluminium oxide(Al_2O_3)

b)Extraction of aluminium from Bauxite/Halls cell/process)

The main ore from which aluminium is extracted is **Bauxite** ore- hydrated aluminium oxide($Al_2O_3.2H_2O$).

The ore is mined by open-caste mining method/quarrying where it is scooped together with silica/sand/silicon(IV)oxide (**SiO_2**) and soil/ iron(III)oxide (**Fe_2O_3**) as **impurities**.

The mixture is first dissolved in hot concentrated sodium/potassium hydroxide solution.

The alkalis dissolve both bauxite and silicon(IV)oxide.

This is because bauxite is **amphotellic** while silicon(IV)oxide is **acidic**.

Iron(III)oxide (**Fe_2O_3**) is filtered of /removed as a residue.

Carbon(IV)oxide is bubbled into the filtrate to precipitate aluminium (III) hydroxide ($Al(OH)_3$) as residue.

The aluminium (III) hydroxide (**$Al(OH)_3$**) residue is filtered off. Silicon (IV)oxide remain in the solution as filtrate. Aluminium (III) hydroxide ($Al(OH)_3$) residue is then heated to form pure aluminium (III)oxide(**Al_2O_3**)

$$2Al(OH)_3\ (s) \longrightarrow Al_2O_3\ (s) + 3H_2O(l)$$

Pure aluminium (III)oxide (**Al_2O_3**) has a very high melting point of **2015°C**. Alot of energy is required to melt the oxide.
It is therefore dissolved first in molten **cryolite** /sodium hexafluoroaluminate (III)/Na_3AlF_6 to **lower** the melting point to about **800°C**.

The molten electrolyte is put in the Hall cell made up of a steel tank lined with carbon graphite and an anode suspended into the electrolyte.
During the electrolysis:

(**i**)At the cathode;

$$4Al^{3+}(\mathbf{l}) + 12e \longrightarrow 4Al(\mathbf{l})$$

(**ii**) At the anode;

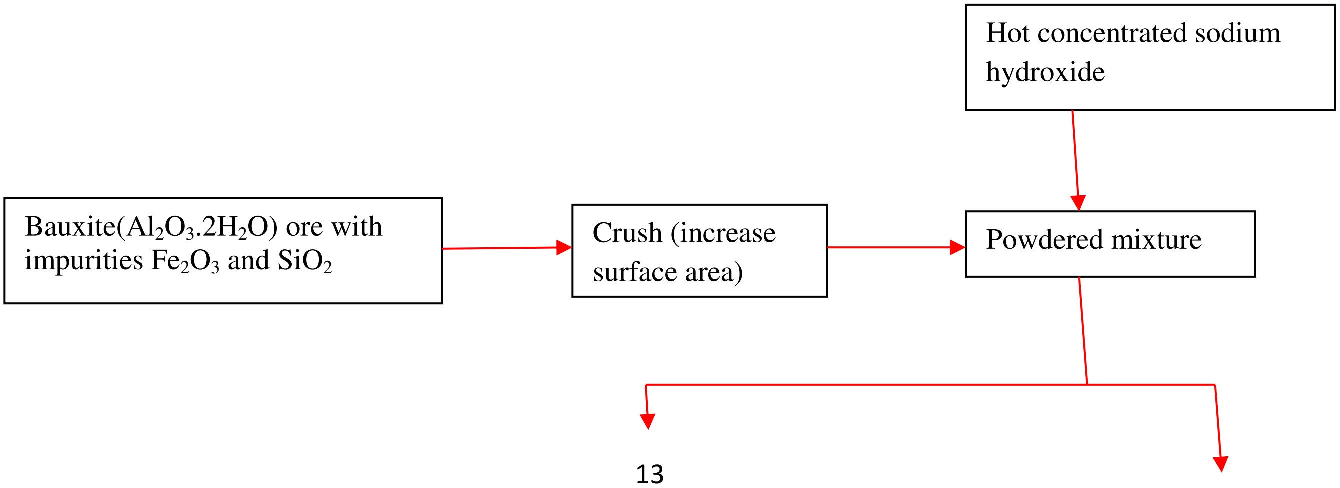
$$6O^{2-}(l) \longrightarrow 3O_2(g) + 12e$$

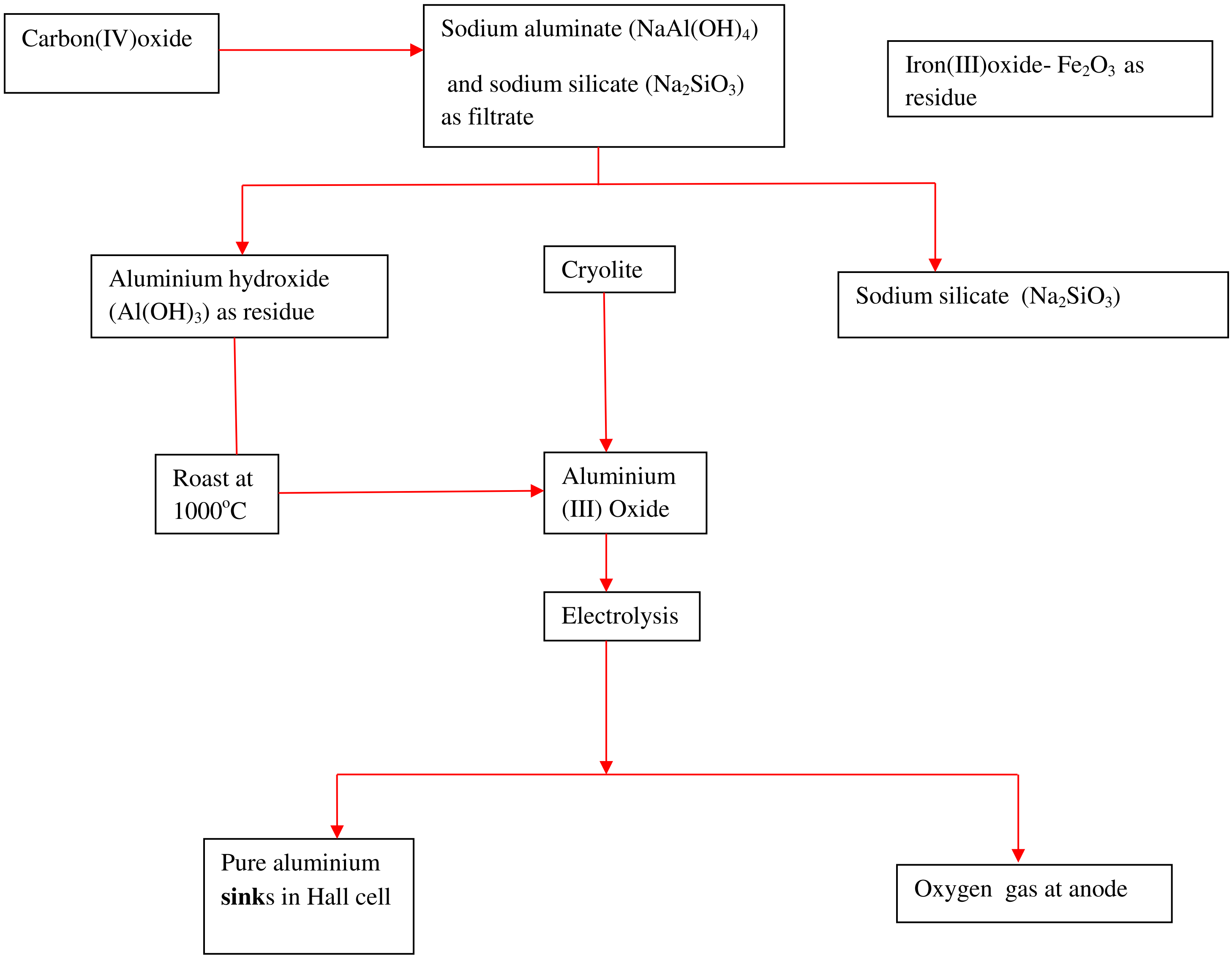
Aluminium is denser than the electrolyte therefore sink to the bottom of the Hall cell.
At this temperature ,the Oxygen evolved/produced at the anode **reacts** with carbon anode to form carbon(IV)oxide gas that **escape** to the atmosphere.

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

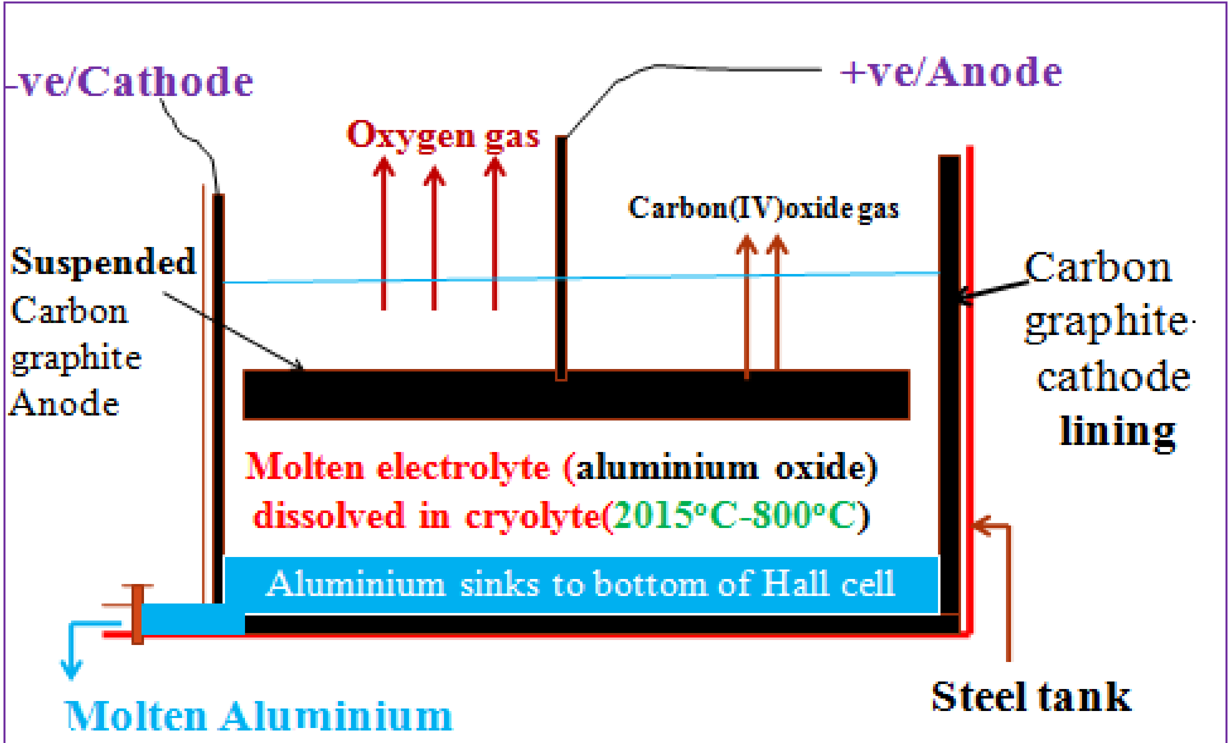
The anode thus should be continuously **replaced** from time to time.

<u>Flow chart summary of extraction of aluminium from Bauxite</u>





c) Diagram showing the **Hall cell / process for extraction of Bauxite**



Hall cell for extraction of Aluminium from Aluminium oxide

d)Uses of aluminium

(i) In making aeroplane parts, buses, tankers, furniture because aluminium is very light.

(ii)Making duralumin-an alloy which is harder and has a higher tensile strength

(iii)Making utensils,sauce pans,spoons because it is light and good conductor of electricity.

(iv)Making overhead electric cables because it is light,ductile and good conductor of electricity.

(iv)Used in the thermite process for production of Manganese, Chromium amd Titanium.

e) Environmental effects of extracting aluminium from Bauxite.

Carbon(IV)oxide gas that **escape** to the atmosphere is a green house gas that causes global warming.

Bauxite is extracted by open caste mining that causes soil/environmental degradation.

f) Test for presence of Al^{3+}

If an ore is suspected to contain Al^{3+} it is;

(i)added hot concentrated sulphuric(VI)/Nitric(V)acid to free the ions present.

(ii)the free ions are then added a precipitating reagent like 2M sodium hydroxide /2M aqueous ammonia.

Observation	Inference
White precipitate in excess 2M NaOH(aq)	Pb^{2+} , Al^{3+}, Zn^{2+}
White precipitate in excess 2M NH_3(aq)	Pb^{2+} , Al^{3+}
No black precipitate on adding Na_2S(aq)	Al^{3+}
No white precipitate on adding either NaCl(aq),HCl(aq),H_2SO_4(aq),Na_2SO_4(aq)	Al^{3+}

Practice

1.An unknown rock X was discovered in Ukraine. Test with dilute sulphuric (VI)acid shows rapid effervescence with production of a colourless gas A that forms a white precipitate with lime water and colourless solution B. On adding 3cm3 of 2M sodium hydroxide, a white precipitate C is formed that dissolves to form a colourless solution D on adding more sodium hydroxide. On adding 2M aqueous ammonia, a white precipitate E is formed which persist in excess aqueous ammonia.On which on adding 5cm3 of 1M Lead(II)nitrate(V) to F a white precipitate G is formed which remains on heating.

Identify:

A

Hydrogen/H_2

B

Aluminium sulphate(VI)/$Al_2(SO_4)_3$

C

Aluminium hydroxide/ $Al(OH_4)_3$

D

Tetrahydroxoaluminate(III)/ $[Al(OH_4)_3]^-$

E

Aluminium hydroxide/ $Al(OH)_3$

F

Aluminium chloride/ $AlCl_3$

2.Aluminium is obtained from the ore with the formula Al_2O_3. $2H_2O$. The ore is first heated and refined to obtain pure aluminium oxide (Al_2O_3). The oxide is then electrolysed to get Aluminium and oxygen gas using carbon anodes and carbon as cathode. Give the common name of the ore from where aluminium is extracted from ½ mark

What would be the importance of heating the ore first before refining it?1 mark

To remove the water of crystallization

The refined ore has to be dissolved in cryolite first before electrolysis. Why is this necessary? 1½ mark

To lower the melting point of aluminium oxide from about 2015°C to 900°C so as to lower /reduce cost of production

Why are the carbon anodes replaced every now and then in the cell for electrolysing aluminium oxide? 1 mark

Oxygen produced at anode react with carbon to form carbon(IV)oxide gas that escape

State two uses of aluminium

In making aeroplane parts, buses, tankers, utensils, sauce pans,spoons

Making overhead electric cables

Making duralumin

3. IRON

a)Natural occurrence

Iron is the second most common naturally occurring metal. It makes 4% of the earths crust as:

(i)Haematite(Fe_2O_3)
(ii)Magnetite(Fe_3O_4)
(iii)Siderite($FeCO_3$)

b)The blast furnace for extraction of iron from Haematite and Magnetite

a)Raw materials:

(i)Haematite(Fe_2O_3)
(ii)Magnetite(Fe_3O_4)
(iii)Siderite($FeCO_3$)
(iv)Coke/charcoal/ carbon
(v)Limestone

b)Chemical processes:

Iron is usually extracted from Haematite (Fe_2O_3), Magnetite(Fe_3O_4) Siderite ($FeCO_3$).These ores contain silicon(IV)oxide(SiO_2) and aluminium(III)oxide (Al_2O_3) as impurities.

When extracted from siderite, the ore must first be roasted in air to decompose the iron(II)Carbonate to Iron(II)oxide with production of carbon(IV)oxide gas:

$$FeCO_3(s) \longrightarrow FeO(s) + CO_2(g)$$

Iron(II)oxide is then rapidly oxidized by air to iron(III)oxide(Haematite).

$$4FeO(s) + O_2(g) \longrightarrow 2Fe_2O_3(s)$$

Haematite (Fe_2O_3), Magnetite(Fe_3O_4), coke and limestone are all then fed from top into a tall (about 30metres in height) tapered steel chamber lined with refractory bricks called a blast furnace.

The furnace is covered with **inverted** double cap to prevent/reduce amount of any gases escaping .

Near the base/bottom, blast of hot air at about 1000K (827^oC) is driven/forced into the furnace through small holes called **Tuyeres**.

As the air enters ,it reacts with coke/charcoal/carbon to form carbon(IV)oxide gas. This reaction is highly exothermic.

$$C(s) + O_2(g) \longrightarrow CO_2(g) \quad \Delta H = -394kJ$$

This raises the temperature at the bottom of the furnace to about 2000K(1650°C).As Carbon(IV)oxide gas rises up the furnace it reacts with more coke to form carbon(II)oxide gas.This reaction is endothermic.

$$CO_2\ (g) + C(s) \longrightarrow 2CO\ (g)\quad \Delta H = +173kJ$$

Carbon(II)oxide gas is a strong reducing agent that reduces the ores at the upper parts of the furnace where temperatures are about 750K(500°C) i.e.
For Haematite;

$$Fe_2O_3\ (s) + 3CO(g) \longrightarrow 2Fe(s) + CO_2(g)$$

For Magnetite;

$$Fe_3O_4\ (s) + 4CO(g) \longrightarrow 3Fe(s) + 4CO_2(g)$$

Iron is denser than iron ore. As it falls to the hotter base of the furnace it melts and can easily be tapped off.
Limestone fed into the furnace decomposes to quicklime/calcium oxide and produce more carbon(IV)oxide gas.

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

Quicklime/calcium oxide reacts with the impurities silicon(IV)oxide(SiO_2) and aluminium(III)oxide(Al_2O_3)in the ore to form calcium silicate and calcium aluminate.

$$CaO(s) + SiO_2(s) \longrightarrow CaSiO_3\ (l)$$
$$CaO(s) + Al_2O_3(s) \longrightarrow Ca\ Al_2O_4\ (l)$$

Calcium silicate and calcium aluminate mixture is called **slag**.Slag is **denser** than iron ore but **less dense** than iron therefore **float** on the pure iron. It is tapped at different levels to be tapped off for use in:

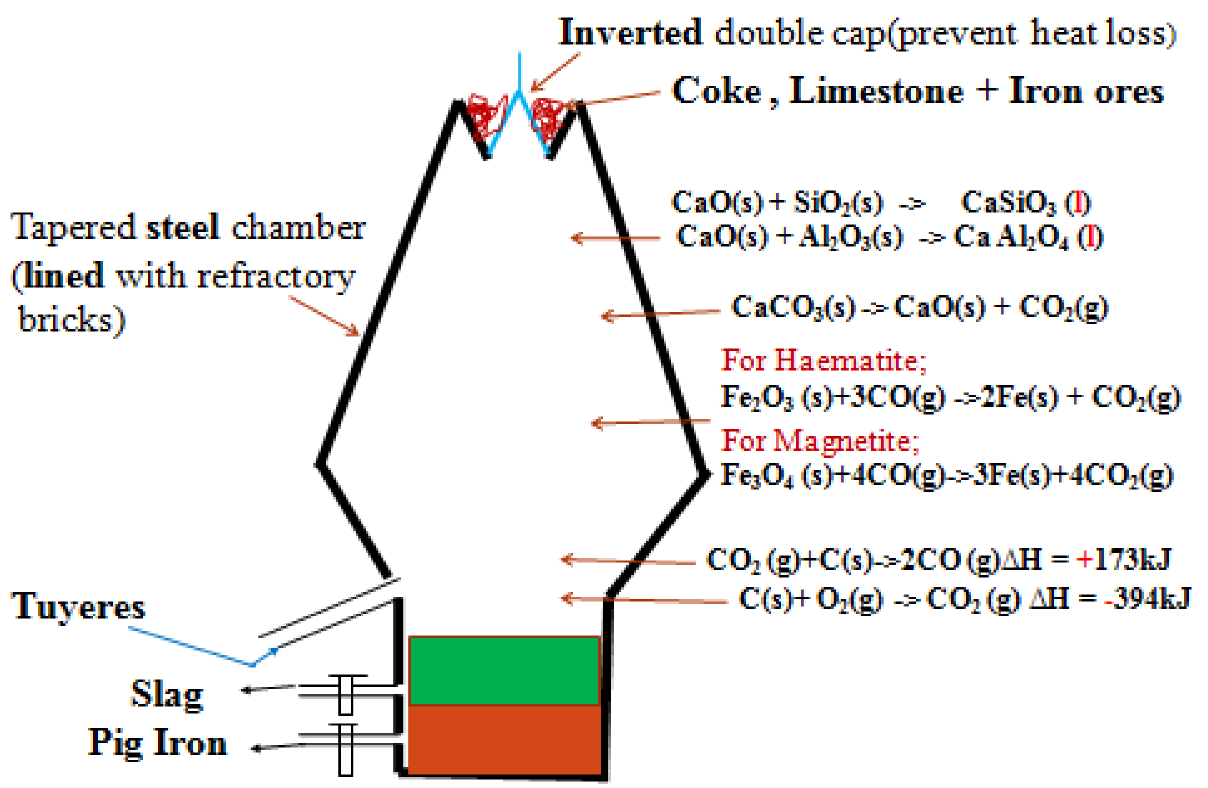
(i)tarmacing roads
(ii) cement manufacture
(iii)as building construction material

(c)Uses of Iron

Iron obtained from the blast furnace is hard and brittle. It is called **Pig iron.** It is remelted, added scrap steel then cooled. This iron is called cast iron.
Iron is mainly used to make:
(i)gates ,pipes, engine blocks, rails, charcoal iron boxes,lamp posts because it is cheap.

(ii)nails, cutlery, scissors, sinks, vats, spanners,steel rods, and railway points from steel.

Steel is an alloy of iron with carbon, and/or Vanadium, Manganese, Tungsten, Nickel ,Chromium. It does **not rust**/corrode like iron.



The Blast furnace for the extraction of Iron

e) Environmental effects of extracting Iron from Blast furnace

(i)Carbon(IV)oxide(CO_2) gas is a green house gas that causes/increases global warming if allowed to escape/leak from the furnace.

(ii)Carbon(II)oxide(CO)gas is a highly poisonous/toxic odourless gas that can kill on leakage.

It is **preferentially** absorbed by the haemoglobin in mammals instead of Oxygen to form a **stable** compound that reduce free hemoglobin in the blood.

(iii) Haematite (Fe_2O_3), Magnetite(Fe_3O_4) and Siderite ($FeCO_3$) are extracted through quarrying /open cast mining that cause soil / environmental degradation .

f) Test for the presence of Iron

Iron naturally exist in its compound as Fe^{2+} /Fe^{3+}

If an ore is suspected to contain Fe^{2+} /Fe^{3+} it is;

(i)added hot concentrated sulphuric(VI)/Nitric(V)acid to free the ions present.

(ii)the free ions are then added a precipitating reagent like 2M sodium hydroxide /2M aqueous ammonia which forms;

I) an insoluble green precipitate in excess of 2M sodium hydroxide /2M aqueous ammonia if Fe^{2+} ions are present.

I) an insoluble brown precipitate in excess of 2M sodium hydroxide /2M aqueous ammonia if Fe^{2+} ions are present.

Observation	Inference
green precipitate in excess 2M NaOH(aq)	Fe^{2+}
green precipitate in excess 2M NH_3(aq)	Fe^{2+}
brown precipitate in excess 2M NaOH(aq)	Fe^{3+}
brown precipitate in excess 2M NH_3(aq)	Fe^{3+}

Practice questions

4.COPPER

a)Natural occurrence

Copper is found as uncombined element/metal on the earths crust in Zambia, Tanzania, USA and Canada .The chief ores of copper are:

(i)Copper pyrites($CuFeS_2$)
(ii)Malachite($CuCO_3.Cu(OH)_2$)
(iii)Cuprite(Cu_2O)

b)Extraction of copper from copper pyrites.

Copper pyrites are first crushed into fine powder. The powdered ore is the added water and oil. The purpose of water is to dissolve hydrophilic substances/particle. The purpose of oil is to make cover copper ore particle so as to make it hydrophobic

Air is blown through the mixture. Air creates bubbles that stick around hydrophobic copper ore. The air bubbles raise through buoyancy small hydrophobic copper ore particles to the surface. A concentrated ore floats at the top as froth. This is called froth flotation. The concentrated ore is then skimmed off.The ore is then roasted in air to form copper(I)sulphide ,sulphur(IV)oxide and iron (II) oxide.

$$2CuFeS_2(s) + 4O_2(g) \longrightarrow Cu_2S(s) + 3SO_2(g) + 2FeO(s)$$

Limestone ($CaCO_3$) and silicon(IV)oxide (SiO_2) are added and the mixture heated in absence of air.Silicon(IV)oxide (SiO_2) reacts with iron (II) oxide to form Iron silicate which constitutes the slag and is removed.

$$FeO(s) + SiO_2(s) \longrightarrow FeSiO_3(s)$$

The slag separates off from the copper(I)sulphide. Copper(I)sulphide is then heated in a regulated supply of air where some of it is converted to copper (I) oxide.

$$2Cu_2S(s) + 3O_2(g) \longrightarrow 2Cu_2S(s) + 2SO_2(g)$$

The mixture then undergo self reduction in which copper(I)oxide is reduced by copper(I)sulphide to copper metal.

$$Cu_2S(s) + 2Cu_2O(s) \longrightarrow 6Cu(s) + SO_2(g)$$

The copper obtained has Iron, sulphur and traces of silver and gold as impurities.It is therefore about 97.5% pure. It is refined by electrolysis/electrolytic method.

During the electrolysis of refining copper, the impure copper is made the anode and a small pure strip is made the cathode.

Electrode ionization takes place where:

At the anode;

$$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e$$

Note: Impure copper anode dissolves/erodes into solution and decreases in size.

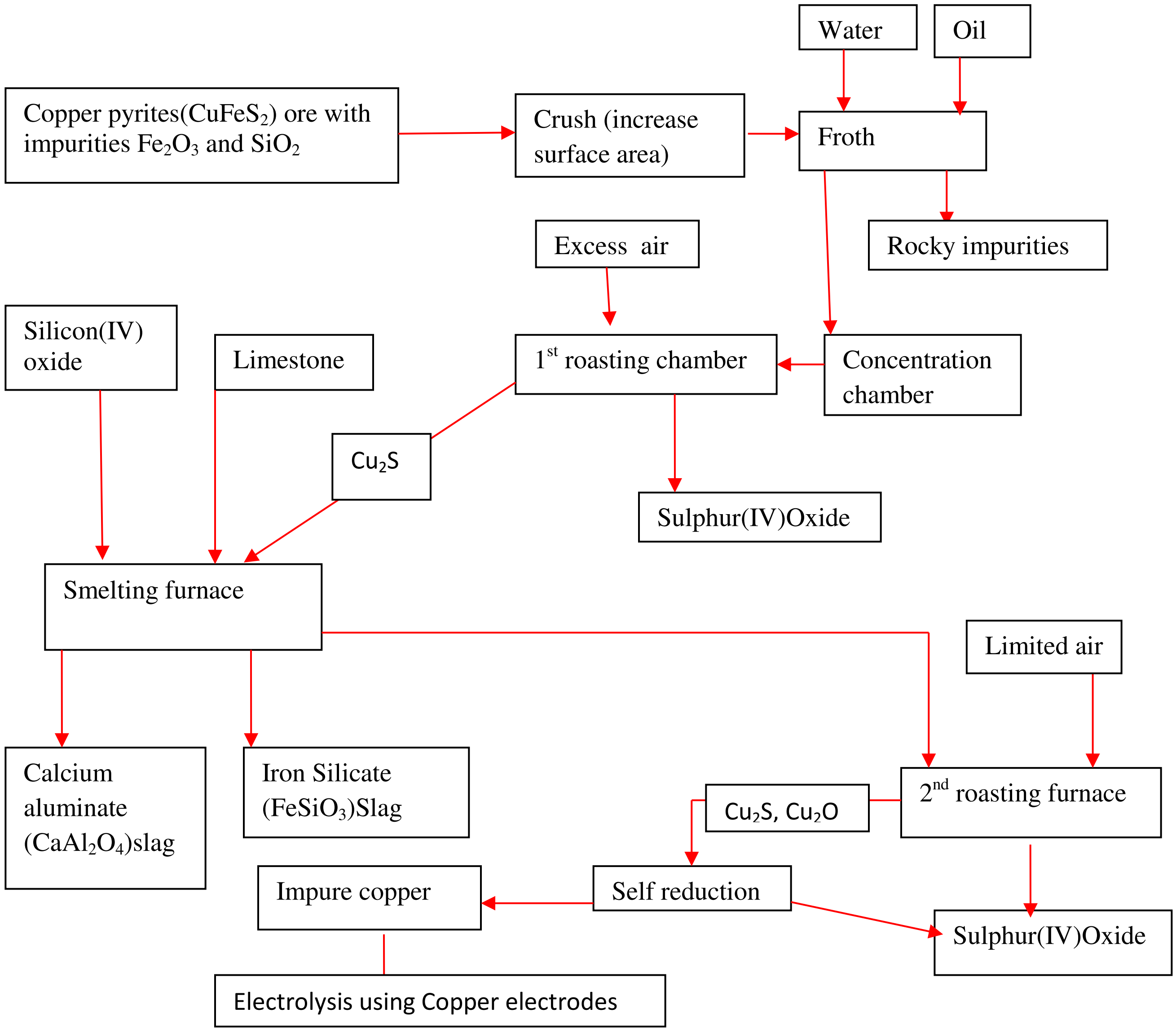
At the Cathode;

$$Cu^{2+}(aq) + 2e \longrightarrow Cu(s)$$

Note: The copper ions in the electrolyte($CuSO_4$) are reduced and deposited as copper metal at the cathode. The copper obtained is 99.98% pure.

Valuable traces of silver and gold collect at the bottom of the electrolytic cell as sludge. It is used to finance the extraction of copper pyrites.

(c)Flow chart summary of extraction of copper from Copper pyrites



Cathode; Pure Copper deposited.

Anode; Impure Copper eroded.

Electrolytic purification of impure copper

d) Uses of copper

Copper is mainly used in:

(i)making low voltage electric cables,contact switches, cockets and plugs because it is a good conductor of electricity.

(ii)Making solder because it is a good thermal conductor.

(iii)Making useful alloys e.g.

-Brass is an alloy of copper and Zinc(Cu/Zn)

-Bronze is an alloy of copper and Tin(Cu/Sn)

-German silver is an alloy of copper ,Zinc and Nickel(Cu/Zn/Ni)

(iv)Making coins and ornaments.

e) Environmental effects of extracting copper from Copper pyrites

(i)Sulphur(IV)oxide is a gas that has a pungent poisonous smell that causes head ache to human in high concentration.

(ii)Sulphur(IV)oxide gas if allowed to escape dissolves in water /rivers/rain to form weak sulphuric(IV)acid lowering the pH of the water leading to marine pollution, accelerated corrosion/rusting of metals/roofs and breathing problems to human beings.

(iii)Copper is extracted by open caste mining leading to land /environmental /soil degradation.

f) Test for the presence of copper in an ore

Copper naturally exist in its compound as Cu^{2+} /Cu^{+}

Copper (I) / Cu^{+} is readily oxidized to copper(II)/ Cu^{2+}

If an ore is suspected to contain Cu^{2+} /Cu^{+} it is;

(i)added hot concentrated sulphuric(VI)/Nitric(V)acid to free the ions present.

(ii)the free ions are then added a precipitating reagent; 2M sodium hydroxide /2M aqueous ammonia which forms;

I) an insoluble blue precipitate in excess of 2M sodium hydroxide if Cu^{2+} ions are present.

I) an insoluble blue precipitate in 2M aqueous ammonia that dissolve to **royal/deep blue solution** in excess if **Cu^{2+}** ions are present.

Observation	Inference
blue precipitate in excess 2M NaOH(aq)	Cu^{2+}
blue precipitate,dissolve to **royal/deep blue solution** in excess 2M NH_3(aq)	**Cu^{2+}**

g)Sample questions

Copper is extracted from copper pyrites as in the flow chart outlined below. Study it and answer the questions that follow

5.ZINC and LEAD

a)Natural occurrence

Zinc occurs mainly as:
(i)Calamine-Zinc carbonate($ZnCO_3$)
(ii)Zinc blende-Zinc sulphide(ZnS)
Lead occurs mainly as Galena-Lead(II)Sulphide mixed with Zinc blende:

b)Extraction of Zinc/Lead from Calamine ,Zinc blende and Galena.

During extraction of Zinc , the ore is first roasted in air:
For Calamine Zinc carbonate decompose to Zinc oxide and carbon(IV) oxide gas.

$$ZnCO_3(s) \longrightarrow ZnO(s) + CO_2(g)$$

Zinc blende does not decompose but reacts with air to form Zinc oxide and sulphur(IV) oxide gas.
Galena as a useful impurity also reacts with air to form Lead(II) oxide and sulphur(IV) oxide gas.

$$2ZnS(s) + 3O_2(g) \longrightarrow 2ZnO(s) + 2SO_2(g)$$
(Zinc blende)

$$2PbS(s) + 3O_2(g) \longrightarrow 2PbO(s) + 2SO_2(g)$$
(Galena)

The oxides are mixed with coke and limestone/Iron(II)oxide/ Aluminium (III) oxide and heated in a blast furnace.
At the furnace temperatures limestone decomposes to quicklime/CaO and produce Carbon(IV)oxide gas.

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

Carbon(IV)oxide gas reacts with more coke to form the Carbon(II)oxide gas.

$$C(s) + CO_2(g) \longrightarrow 2CO(g)$$

Both Carbon(II)oxide and carbon/coke/carbon are reducing agents.

The oxides are reduced to the metals by either coke or carbon (II)oxide.

$$ZnO(s) + C(s) \longrightarrow Zn(g) + CO(g)$$
$$PbO(s) + C(s) \longrightarrow Pb(l) + CO(g)$$

$$PbO(s) + CO(s) \longrightarrow Pb(l) + CO_2(g)$$
$$PbO(s) + CO(s) \longrightarrow Pb(g) + CO_2(g)$$

At the furnace temperature:

(i)Zinc is a gas/vapour and is collected at the **top** of the furnace. It is condensed in a spray of molten lead to prevent reoxidation to Zinc oxide. On further cooling , Zinc collects on the surface from where it can be tapped off

(ii)Lead is a liquid and is ale to trickle to the bottom of the furnace from where it is tapped off.

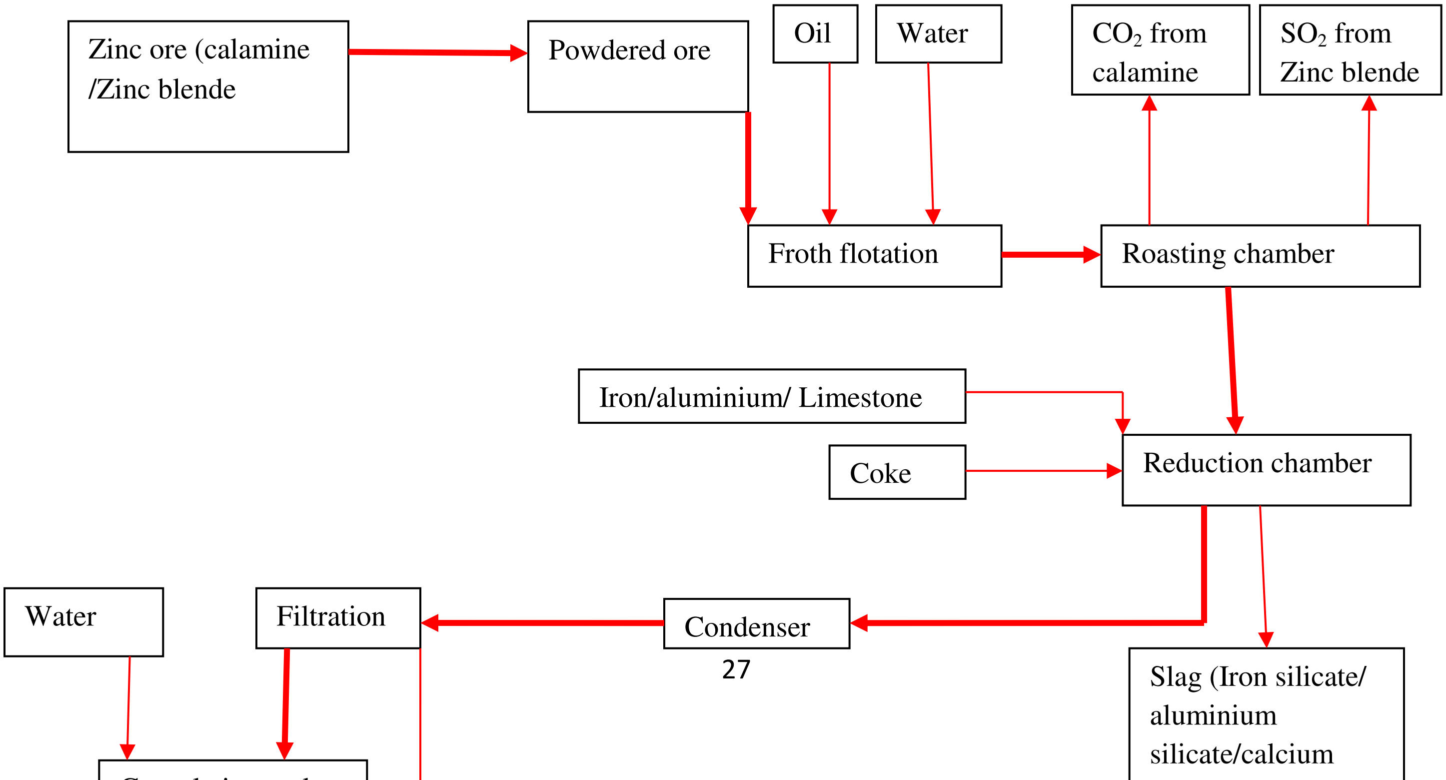
Quicklime/CaO, Iron(II)Oxide, Aluminium(III)oxide are used to remove silica/silicon(IV)oxide as silicates which float above Lead preventing its reoxidation back to Lead(II)Oxide.

$$CaO(s) + SiO_2(s) \longrightarrow CaSiO_3(s/l)$$
(Slag-Calcium silicate)

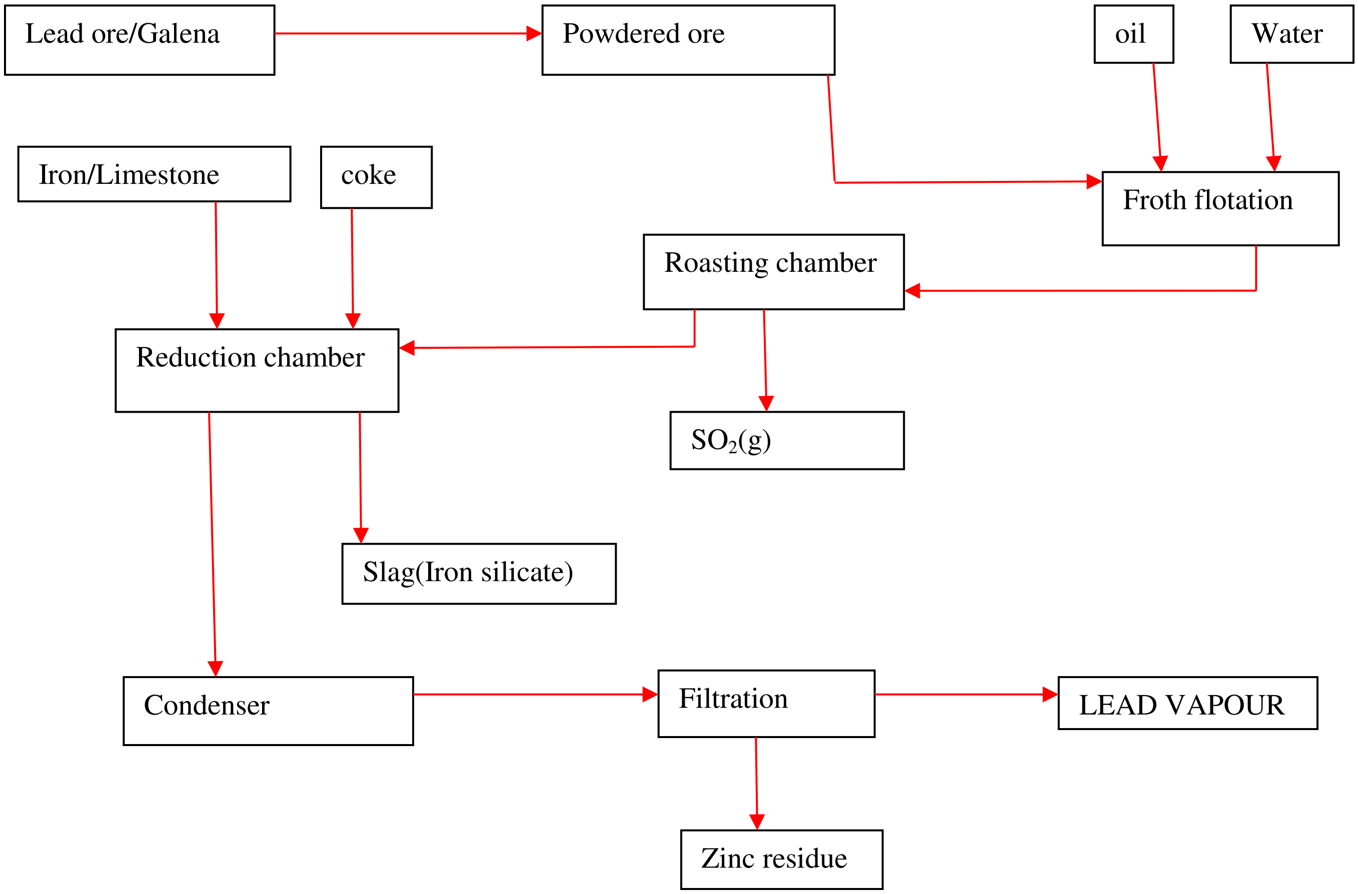
$$FeO(s) + SiO_2(s) \longrightarrow FeSiO_3(s/l)$$
(Slag-Iron silicate)

$$Al_2O_3(s) + SiO_2(s) \longrightarrow Al_2SiO_4(s/l)$$
(Slag-Aluminium silicate)

c)Flow chart on extraction of Zinc from Calamine ,Zinc blende.



d) Flow chart on extraction of Lead from Galena



e) Uses of Lead

Lead is used in:

(i)making gun-burettes.

(ii)making protective clothes against nuclear (alpha rays/particle) radiation in a nuclear reactor.

(iii)Mixed with tin(Sn) to make **solder** alloy

f) Uses of Zinc

Zinc is used in:

(i)Galvanization-when iron sheet is dipped in molten Zinc ,a thin layer of Zinc is formed on the surface.Since Zinc is more reactive than iron ,it reacts with elements of air(CO_2/ O_2 / H_2O) to form basic Zinc carbonate($ZnCO_3.Zn(OH)_2$).This **sacrificial** method protects iron from corrosion/rusting.

(ii)As negative terminal and casing in dry/Laclanche cells.

(iii)Making brass alloy with copper(Cu/Zn)

g) Environmental effects of extracting Zinc and Lead.

(i) Lead and Lead salts are carcinogenic/causes cancer

(ii)Carbon(IV)oxide is a green house gas that causes/accelerate global warming.

(iii)Carbon(II)oxide is a colourless odourless poisonous /toxic gas that combines with haemoglobin in the blood to form stable carboxyhaemoglobin reducing free haemoglobin leading to death.

(iv) Sulphur(IV)oxide is a gas that has a pungent poisonous smell that causes headache to human if in high concentration.

(v)Any leakages in Sulphur(IV)oxide gas escapes to the water bodies to form weak sulphuric(VI)acid lowering the pH of the water. This causes marine pollution /death of aquatic life, accelerated rusting/corrosion of metals/roofs and breathing problems to human beings.

h) Test for presence of Zinc/ Lead.

If an ore is suspected to contain Zinc/Lead it is:

I.added hot concentrated Nitric(V)acid to free the ions present.

Note:

Concentrated Sulphuric(VI)acid forms insoluble $PbSO_4$ thus cannot be used to free the ions in Lead salts.

II.the free ions are then added a precipitating reagent mostly 2M sodium hydroxide or 2M aqueous ammonia with the formation of;

(i)a soluble precipitate in excess of 2M sodium hydroxide if Zn^{2+}, Pb^{2+}, Al^{3+}ions are present.

(ii)a white precipitate that dissolves to form a colorless solution in excess 2M aqueous ammonia if Zn^{2+}ions are present.

(iii)an insoluble white precipitate in excess 2M aqueous ammonia if Pb^{2+}, Al^{3+}ions are present.

(iv) Pb^{2+} ions form a white precipitate when any soluble SO_4^{2-}, SO_3^{2-}, CO_3^{2-}, Cl^-, is added while Al^{3+} ions do not form a white precipitate

(v) Pb^{2+} ions form a yellow precipitate when any soluble I^-(e.g. Potassium/sodium Iodide) is added while Al^{3+} ions do not form a yellow precipitate.

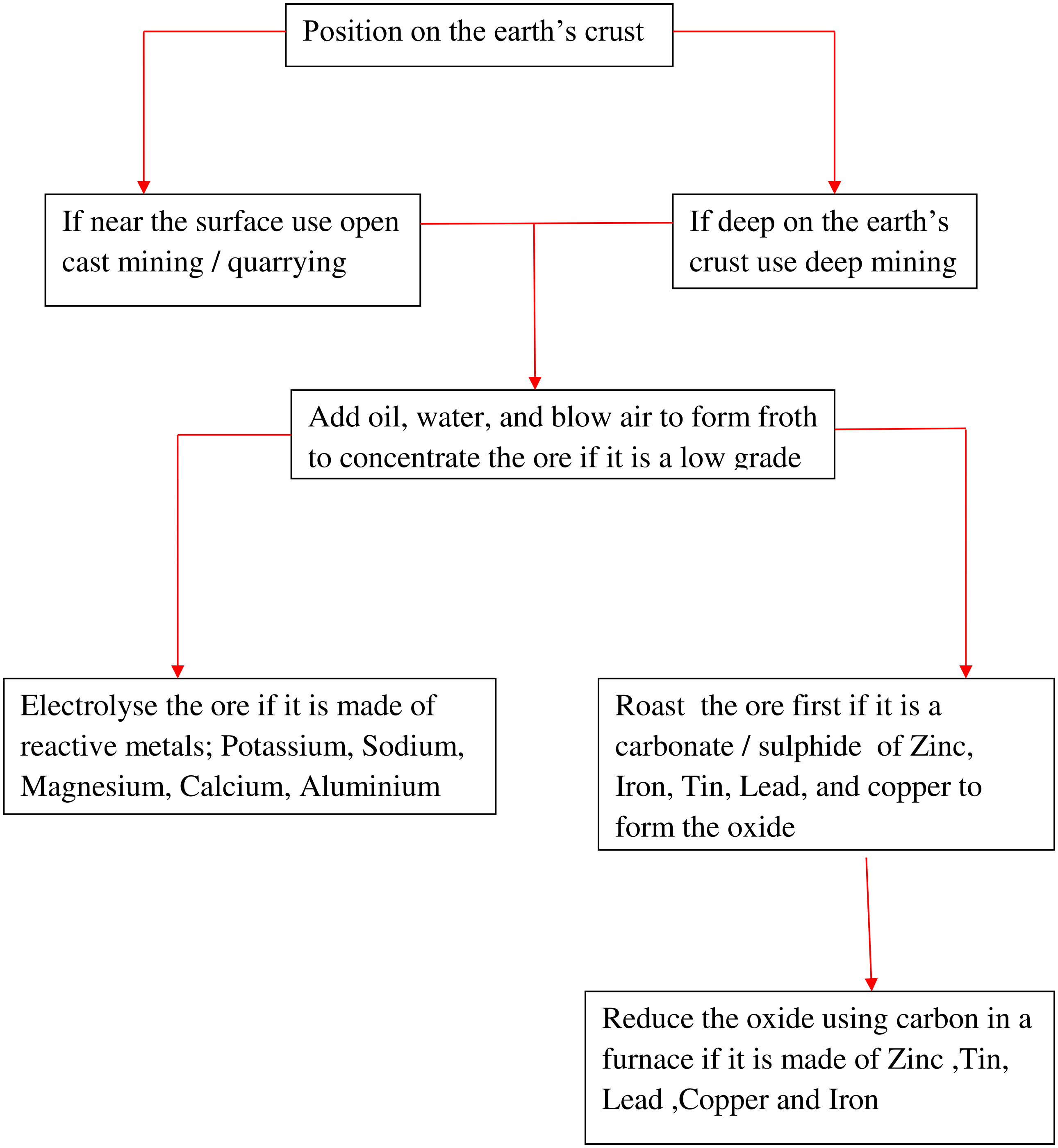
(vi) Pb^{2+} ions form a black precipitate when any soluble S^-(e.g. Potassium/sodium sulphide) is added while Al^{3+} ions do not form a black precipitate.i.e;

Observation	Inference
White precipitate in excess 2M NaOH (aq)	Zn^{2+}, Pb^{2+}, Al^{3+} ions
White precipitate that dissolves to form a colourless solution in excess 2M NH_3(aq)	Zn^{2+} ions
White precipitate in excess 2M NH_3(aq)	Pb^{2+}, Al^{3+} ions
White precipitate on adding about 4 drops of either Na_2CO_3(aq), Na_2SO_3(aq), Na_2SO_4(aq), H_2SO_4(aq), HCl(aq), NaCl(aq)	Pb^{2+}ions
Yellow precipitate on adding about 4 drops of of KI(aq).NaI (aq)	Pb^{2+} ions
Black precipitate on adding aout 4 drops of Na_2S(aq)/K_2S(aq)	Pb^{2+} ions

6.GENERAL SUMMARY OF METALS

a) Summary methods of extracting metal from their ore

The main criteria used in extraction of metals is based on its position in the electrochemical/reactivity series and its occurrence on the earth's crust.



Position on the earth's crust

If near the surface use open cast mining / quarrying

If deep on the earth's crust use deep mining

Add oil, water, and blow air to form froth to concentrate the ore if it is a low grade

Electrolyse the ore if it is made of reactive metals; Potassium, Sodium, Magnesium, Calcium, Aluminium

Roast the ore first if it is a carbonate / sulphide of Zinc, Iron, Tin, Lead, and copper to form the oxide

Reduce the oxide using carbon in a furnace if it is made of Zinc ,Tin, Lead ,Copper and Iron

b) Summary of extraction of common metal.

Metal	Chief ore/s	Chemical formula of ore	Method of extraction	Main equation during extraction
Sodium	Rock salt	NaCl(s)	**Downs process** Through electrolysis of molten NaCl ($CaCl_2$ lower m.pt from 800°C-> 600°C)	**Cathode:** $2Na^+(l) + 2e \rightarrow 2Na(l)$ **Anode:** $2Cl^-(l) \rightarrow Cl_2(g) + 2e$
Sodium/ sodium hydroxide	Brine	NaCl(aq)	**Flowing mercury cathode cell** Through electrolysis of concentrated NaCl(aq)	**Cathode:** $2Na^+(aq)+2e \rightarrow 2Na(aq)$ **Anode:** $2Cl^-(aq) \rightarrow Cl_2(g) + 2e$
Aluminium	Bauxite	$Al_2O_3.2H_2O$	**Halls process** **Through electrolysis of molten** Al_2O_3. (Cryolite lower m.pt from 2015°C -> 800°C)	**Cathode:** $4Al^{3+}(l) + 12e \rightarrow 4Al(l)$ **Anode:** $6O^{2-}(l) \rightarrow 3O_2(g) + 12e$
Iron	Haematite Magnetite	Fe_2O_3 Fe_3O_4	**Blast furnace** Reduction of the ore by carbon(II)oxide	$Fe_2O_3(s)+ 3CO(g) \longrightarrow 2Fe(l) +3CO_2(g)$ $Fe_3O_4(s)+ 4CO(g) \longrightarrow 3Fe(l) +4CO_2(g)$
Copper	Copper pyrites	$CuFeS_2$	**Roasting** the ore in air to get Cu_2S. **Heating** Cu_2S ore in regulated supply of air. **Reduction** of Cu_2O by Cu_2S	$2CuFeS_2 (s)+ 4O_2(g) \rightarrow Cu_2S(s)+3SO_2(g) +2FeO(s)$ $2Cu_2S (s)+ 3O_2(g) \rightarrow 2Cu_2O(s)+2SO_2(g)$ $Cu_2S (s)+ 2Cu_2O(s) \rightarrow 6Cu(s)+ SO_2(g)$
Zinc	Calamine	$ZnCO_3$	**Roasting** the ore in air to get ZnO	$ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$

			Blast furnace /reduction of the oxide by Carbon(II)Oxide/Carbon	$2ZnS(s) +3O_2(g)$ -> $2ZnO(s) + 2SO_2(g)$ $ZnO(s) + CO(g)$-> $Zn(s) + CO_2(g)$
Lead	Galena	PbS	**Blast furnace- Reduction of the oxide by carbon(II)oxide /Carbon**	$PbO(s) + CO(g)$-> $Pb(s) + CO_2(g)$

c) Common alloys of metal.

Alloy name	**Constituents of the alloy**	**Uses of the alloy**
Brass	Copper and Zinc	Making scews and bulb caps
Bronze	Copper and Tin	Making clock springs,electrical contacts and copper coins
Soldier	Lead and Tin	Soldering, joining electrical contacts because of its low melting points and high thermal conductivity
Duralumin	Aluminium, Copper and Magnesium	Making aircraft , utensils ,windows frames because of its light weight and corrosion resistant.
Steel	Iron, Carbon ,Manganese and other metals	Railway lines , car bodies girders and utensils.
Nichrome	Nichrome and Chromium	Provide resistance in electric heaters and ovens
German silver	Copper,Zinc and Nickel	Making coins

d) Physical properties of metal.

Metals form giant metallic structure joined by metallic bond from electrostatic attraction between the metallic cation and free delocalized electrons.
This makes metals to have the following physical properties:

(i)High melting and boiling points

The giant metallic structure has a very close packed metallic lattice joined by strong electrostatic attraction between the metallic cation and free delocalized electrons.The more delocalized electrons the higher the melting/boiling points e.g.
Aluminium has a melting point of about 2015^{o}C while that of sodium is about 98^{o}C.This is mainly because aluminium has more/three delocalized electrons than sodium/has one.
Aluminium has a boiling point of about 2470^{o}C while that of sodium is about 890^{o}C.This is mainly because aluminium has more/three delocalized electrons than sodium/has one.

(ii)High thermal and electrical conductivity

All metals are good thermal and electrical conductors as liquid or solids. The more delocalized electrons the higher the thermal and electrical conductivity. e.g.

Aluminium has an electrical conductivity of about 3.82×19^{-9} ohms per metre. Sodium has an electrical conductivity of about 2.18×19^{-9} ohms per metre.

(iii)Shiny/Lustrous

The free delocalized electrons on the surface of the metal absorb, vibrate and then scatter/re-emit/lose light energy. All metals are therefore usually shades of grey in colour except copper which is shiny brown.e.g.

Zinc is bluish grey while iron is silvery grey.

(iv)High tensile strength

The free delocalized electrons on the surface of the metal atoms binds the surface immediately when the metal is coiled/folded preventing it from breaking /being brittle.

(v)Malleable.

Metals can be made into thin sheet. The metallic crystal lattice on being beaten/pressed/hammered on two sides extend its length and width/bredth and is then immediately bound by the delocalized electrons preventing it from breaking/being brittle.

(vi)Ductile.

Metals can be made into thin wires. The metallic crystal lattice on being beaten/pressed/hammered on all sides extend its length is then immediately bound by the delocalized electrons preventing it from breaking/being brittle.

Revision questions

1.Given some soil , dilute sulphuric(VI)acid,mortar,pestle,filter paper,filter funnel and 2M aqueous ammonia,describe with explanation,how you would show that the soil contain Zinc.

Place the soil sample in the pestle. Crush using the mortar to reduce the particle size/increase its surface area.

Add dilute sulphuric(VI)acid to free the ions in soil sample.

Filter to separate insoluble residue from soluble filtrate

To filtrate,add three drops of aqueous ammonia as precipitating reagent. A white precipitate of $Zn(OH)_2$, $Pb(OH)_2$ or $Al(OH)_3$ is formed

Add excess aqueous ammonia to the white precipitate. If it dissolves the Zn^{2+} ions are present. $Zn(OH)_2$ react with excess ammonia to form soluble $[Zn(OH)_4]^{2+}$ complex.

2.In the extraction of aluminium,the oxide is dissolved in cryolite.

(i)What is the chemical name of cryolite?

Sodium hexafloroaluminate/Na_3AlF_6

(ii)What is the purpose of cryolite?

To lower the melting point of the electrolyte/Aluminium oxide from about 2015°C to 900°C

(iii)Name the substance used for similar purpose in the Down cell

Calcium chloride/$CaCl_2$

(iv)An alloy of sodium and potassium is used as coolant in nuclear reactors.Explain.

Nuclear reactors generate a lot of heat energy. sodium and potassium alloy reduce/lower the high temperature in the reactors.

(v)Aluminium metal is used to make cooking utensils in preference to other metals.Explain.

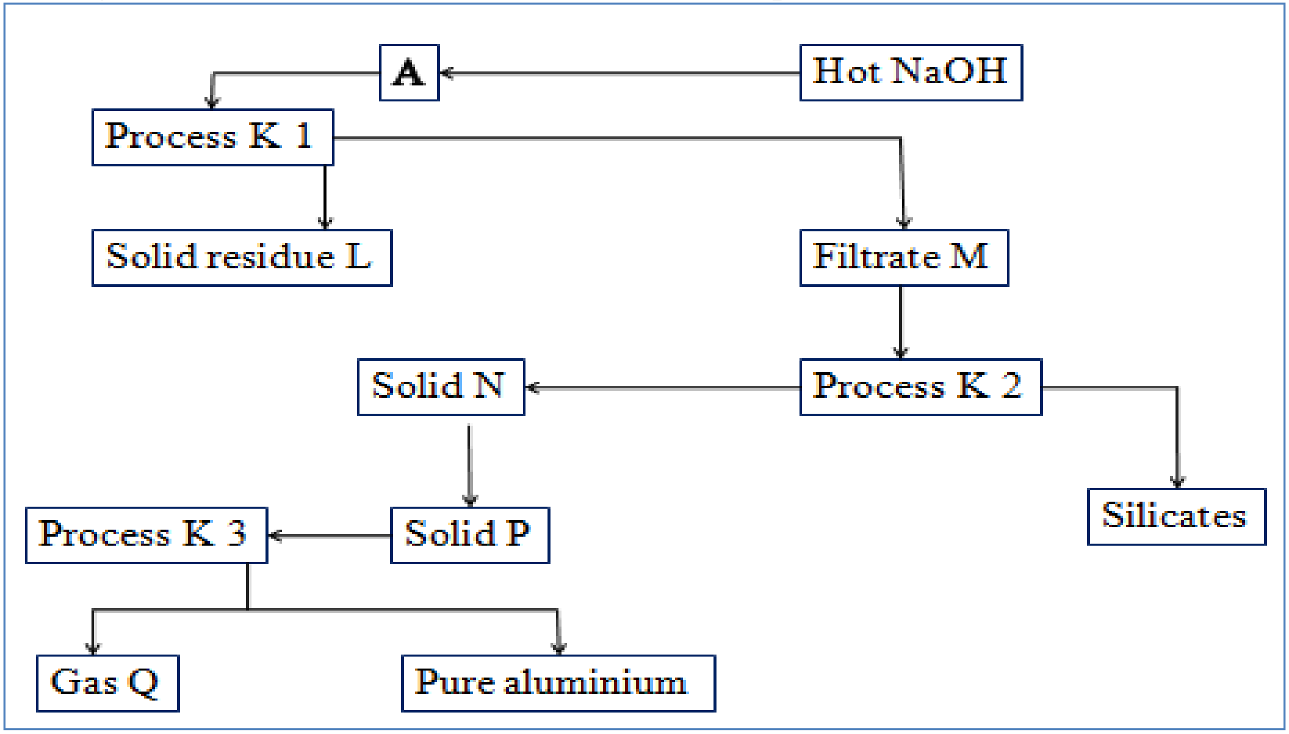
Aluminium

(i) is a very good conductor of electricity because it has three delocalized electrons in its metallic structure

(ii)is cheap,malleable,ductile and has high tensile strength

(iii)on exposure to fire/heat form an impervious layer that prevent it from rapid corrosion.

3.Study the scheme below and use it to answer the questions that follow.



(a)Identify:

(i)solid residue L

Iron(III)Oxide/Fe_2O_3

(ii)Solid N

Aluminium hydroxide /$Al(OH)_3$

(iii)Filtrate M

Sodium tetrahydroxoaluminate/ $NaAl(OH)_4$ and sodium silicate/ $NaSiO_3$

(iv)Solid P

Aluminium oxide/ Al_2O_3

(v)Gas Q

Oxygen/O_2

(vi)Process K1

Filtration

(vii)Process K2

Electrolysis

(b)Write the equation for the reaction taking place in the formation of solid P from solid N

$2Al(OH)_3 \quad -> \quad Al_2O_3\,(s) \quad + \quad 3H_2O(l)$

(c)Name a substance added to solid N before process Process K2 take place.

Cryolite/Sodium tetrahydroxoaluminate/ $NaAl(OH)_4$

(d)State the effect of evolution of gas Q on

(i)process K2

Oxygen produced at the anode reacts with the carbon anode to form carbon(IV) oxide which escape. The electrolytic process needs continuous replacement of the carbon anode.

(ii)the environment

Oxygen produced at the anode reacts with the carbon anode to form carbon(IV) oxide which escape to the atmosphere.CO_2 is a green house gas that cause global warming**.**

(e)An aluminium manufacturing factory runs for 24 hours. If the total mass of aluminium produced is 27000kg,

(i)Calculate the current used. (Faraday constant=96500Coulombs, Al=27.0).

(ii)assuming all the gas produced react with 200kg of anode ,calculate the loss in mass of the electrode.(Molar gas volume at room temperature = 24dm3,C=12.0)

Working

Equation at Cathode

$Al^{3+}(l) \quad + \quad 3e \quad -> \quad Al(l)$

27g Al -> 3 Faradays = 3 x 96500C

$(27000kg \times 1000)\,g \;->\; \frac{(27000kg \times 1000)\,g \times 3 \times 96500C}{27g}$

=<u>289500000000 Coulombs</u>

Current = $\frac{\text{Quantity of electricity}}{\text{Time in seconds}}$ => $\frac{289500000000 \text{ Coulombs}}{24 \times 60 \times 60}$

3350690Amperes

Working

Equation at Anode

$2O^{2-}(l)$ + 4e -> $O_2(g)$

4 Faradays -> 4 x 96500C24dm3 $O_2(g)$ -

289500000000 Coulombs -> $\frac{289500000000 \text{ Coulombs} \times 24\text{dm3}}{4 \times 96500\text{C}}$

18,000,000dm3

Chemical equation at anode

$O_2(g)$ + C (s) -> $CO_2(g)$

Method 1

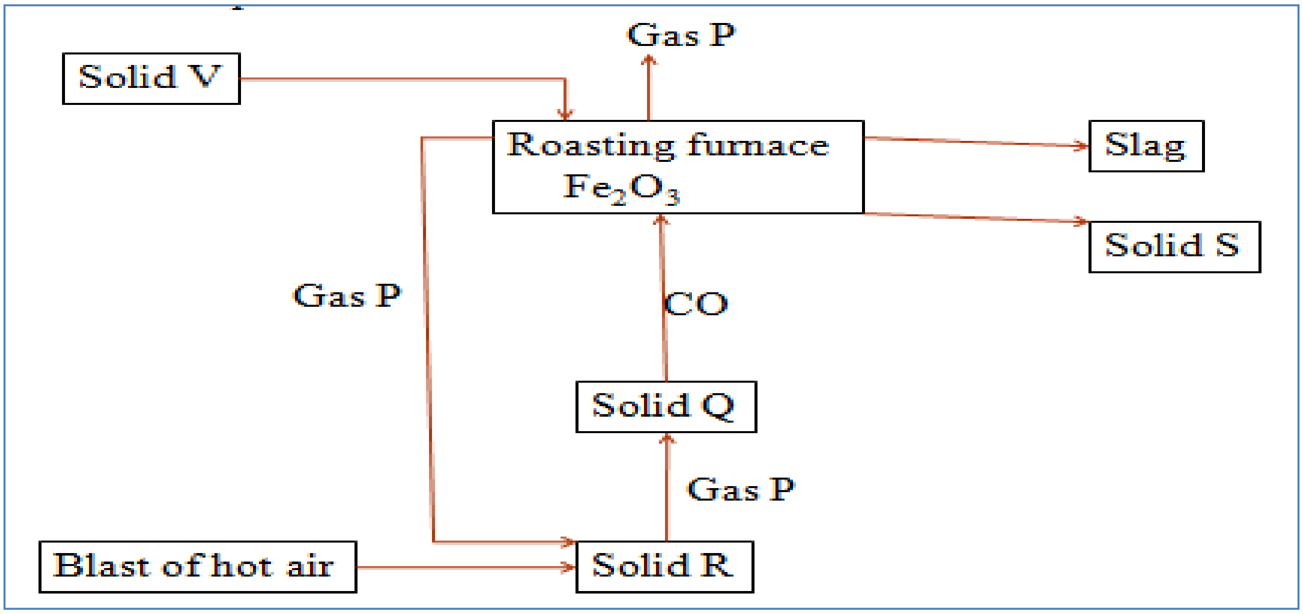
24dm3 of $O_2(g)$ -> 12.0g Carbon

18,000,000dm3 of $O_2(g)$ -> $\frac{18{,}000{,}000\text{dm3} \times 12}{24\text{dm3}}$ = $\frac{9000000\text{g}}{1000\text{g}}$ = **9000kg**

Loss in mass of the carbon graphite anode = **9000kg**

NB: Mass of the carbon graphite anode remaining =27000kg - 9000kg **=18000kg**

The flow chart below shows the extraction of iron metal.Use it to answer the questions that follow.



(a)Identify:

(i)gas P

Carbon(IV)oxide/CO_2

(ii)Solid Q

Carbon/coke/charcoal

(iii)Solid R

Carbon/coke/charcoal

(iv)Solid V

Limestone/calcium carbonate/$CaCO_3$

(v)Solid S

Iron/Fe

(b)Write the chemical equation for the reaction for the formation of:

(i)Solid S

$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$

(ii)Carbon(II)oxide

$C(s) + CO_2(g) \rightarrow 2CO(g)$

(iii)Slag

$SiO_2(s) + CaO(s) \rightarrow CaSiO_3(s)$

$Al_2O_3(s) + CaO(s) \rightarrow Ca\,Al_2O_4(s)$

(iv)Gas P

$C(s) + O_2(g) \rightarrow CO_2(g)$

(c)State two uses of:

(i)Solid S

Iron is used in making:

(i)gates ,pipes, engine blocks, rails, charcoal iron boxes, lamp posts because it is **cheap**.

(ii)nails, cutlery, scissors, sinks, vats, spanners, steel rods, and railway points from steel.

Steel is an alloy of iron with carbon, and/or Vanadium, Manganese, Tungsten, Nickel ,Chromium.

It does **not rust**/corrode like iron.

(ii)Slag

(i) tarmacing roads

(ii) cement manufacture

(iii) as building construction material

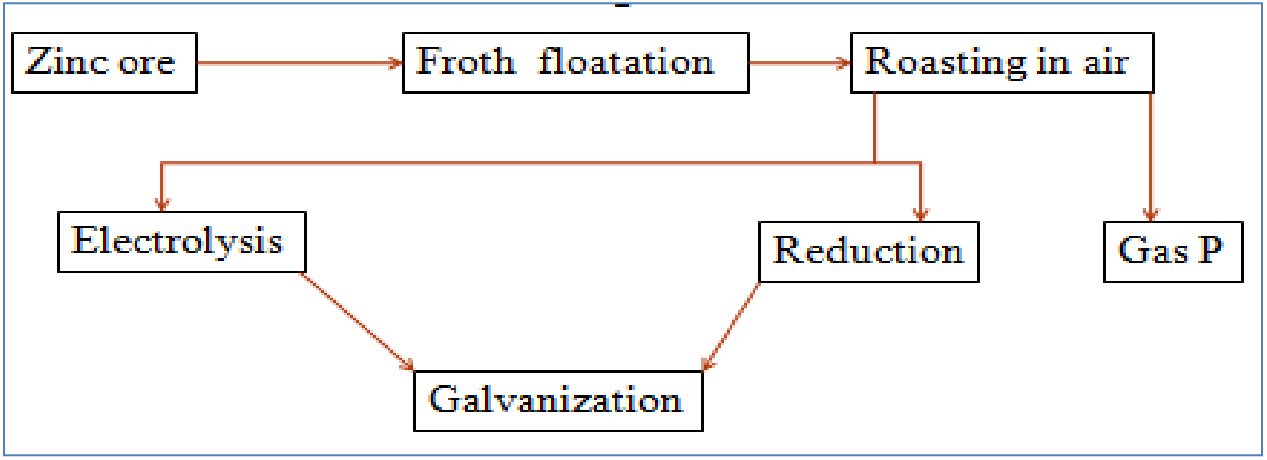
3.You are provided with sulphuric(VI)acid ,2M aqueous ammonia and two ores suspected to contain copper and iron. Describe with explanation how you would differentiate the two ores.

Crush the two ores separately in using a mortar and pestle to reduce the particle size/increase the surface area.

Add sulphuric(VI)acid to separate portion of the ore. Filter.

To a portion of the filtrate,add three drops of 2M aqueous ammonia then axcess
Results
A green precipitate insoluble in excess 2M aqueous ammonia confirms the ore contain Fe^{2+} ion.
A brown precipitate insoluble in excess 2M aqueous ammonia confirms the ore contain Fe^{3+} ion.
A blue precipitate that dissolve in excess 2M aqueous ammonia to form a deep/royal blue solution confirms the ore contain Cu^{2+} ion.

4. Use the flow chart below showing the extraction of Zinc metal to answer the questions that follow



(a)Name:

(i)two ores from which Zinc can be extracted

Calamine($ZnCO_3$)
Zinc blende(ZnS)

(ii)two possible identity of gas P

Sulphur(IV)oxide(SO_2) from roasting Zinc blende
Carbon(IV)oxide(CO_2) from decomposition of Calamine.

(b)Write a possible chemical equation taking place in the roasting chamber.

$2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$
$ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$

(c)Explain the effect of the by-product of the roating on the environment.

Sulphur (IV)oxide from roasting Zinc blende is an acidic gas that causes “acid rain” on dissolving in rain water.
Carbon(IV)oxide(CO_2) from decomposition of Calamine is a green house gas that causes global warming.

(d)(i)Name a suitable reducing agent used in the furnace during extraction of Zinc.

Carbon(II)oxide

(ii)Write a chemical equation for the reduction process

$ZnO(s) + CO(g) \rightarrow Zn(s) + CO_2(g)$

(e)(i)Before electrolysis, the products from roasting is added dilute sulphuric (VI)acid. Write the equation for the reaction with dilute sulphuric(VI)acid.

$ZnO(s) + H_2SO_4 (aq) \rightarrow Zn SO_4(aq) + H_2(g)$

(ii)During the electrolysis for extraction of Zinc,state the

I. Anode used

Aluminium sheet

II. Cathode used

Lead plate coated with silver

(ii)Write the equation for the electrolysis for extraction of Zinc at the:

I.Cathode;

$Zn^{2+}(aq) + 2e \rightarrow Zn(s)$

II.Anode;

$4OH^-(aq) \rightarrow 2H_2O(l) + O_2(s) + 4e$

(f)(i)What is galvanization

Dipping Iron in molten Zinc to form a thin layer of Zinc to prevent iron from rusting.

(ii)Galvanized iron sheet rust after some time. Explain

The thin layer of Zinc protect Iron from rusting through sacrificial protection. When all the Zinc has reacted with elements of air, Iron start rusting.

(g)State two uses of Zinc other than galvanization.

Making brass(Zinc/copper alloy)
Making german silver(Zinc/copper/nickel alloy)
As casing for dry cells/battery

(h)Calculate the mass of Zinc that is produced from the reduction chamber if 6400kg of Calamine ore is fed into the roaster. Assume the process is 80% efficient in each stage(Zn=64.0,C=12.0,O=16.0)

Molar mass $ZnCO_3(s)$	=124g
Molar mass Zn	= 64g
Molar mass ZnO	= 80g

<u>Chemical equation</u>

$ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$

Method 1

$124g\ ZnCO_3 \Rightarrow 80g\ ZnO$

(6400kg x1000)g $ZnCO_3$ => $\frac{(6400 \times 1000) \times 80}{124}$ = **512,000,000** g of ZnO

100% => 512,000,000 g of ZnO

80% => $\frac{80 \times 512{,}000{,}000 \text{ g}}{100}$ = **409600000**g of ZnO

Chemical equation

$ZnO(s) + CO(g) \rightarrow Zn(s) + CO_2(g)$

80g ZnO(s) => 64g Zn(s)

409600000g of ZnO => $\frac{409600000\text{g} \times 64}{80}$ = **327680000 g Zn**

100% => 327680000 g Zn

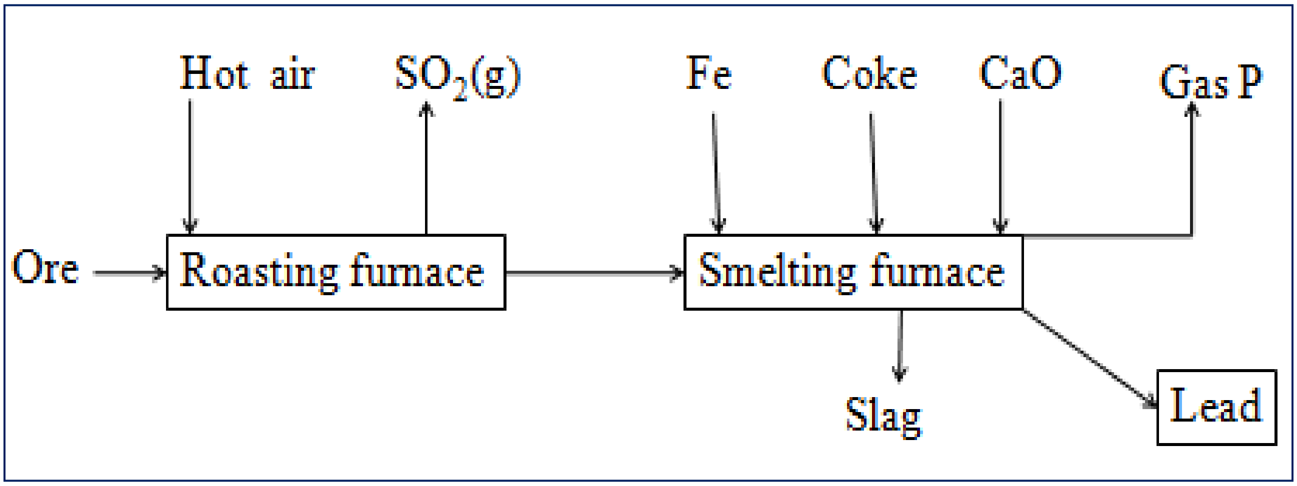
80% => $\frac{80 \times 327680000 \text{ g Zn}}{100}$ = **262144000**g of Zn

Mass of Zinc produced = **262144000g of Zn**

5.An ore is suspected to bauxite. Describe the process that can be used to confirm the presence of aluminium in the ore.

Crush the ore to fine powder to increase surface area/reduce particle size.
Add hot concentrated sulphuric(VI)/nitric(V) acid to free the ions.
Filter. Retain the filtrate
Add excess aqueous ammonia to a sample of filtrate.
A white precipitate confirms presence of either Al^{3+} or Pb^{2+}.
Add sodium sulphate,dilute sulphuric(VI)to another portion of filtrate.
No white precipitate confirms presence of Al^{3+}
Or Add potassium iodide to another portion of filtrate.
No yellow precipitate confirms presence of Al^{3+}

6.The flow chart below illustrate the industrial extraction of Lead metal

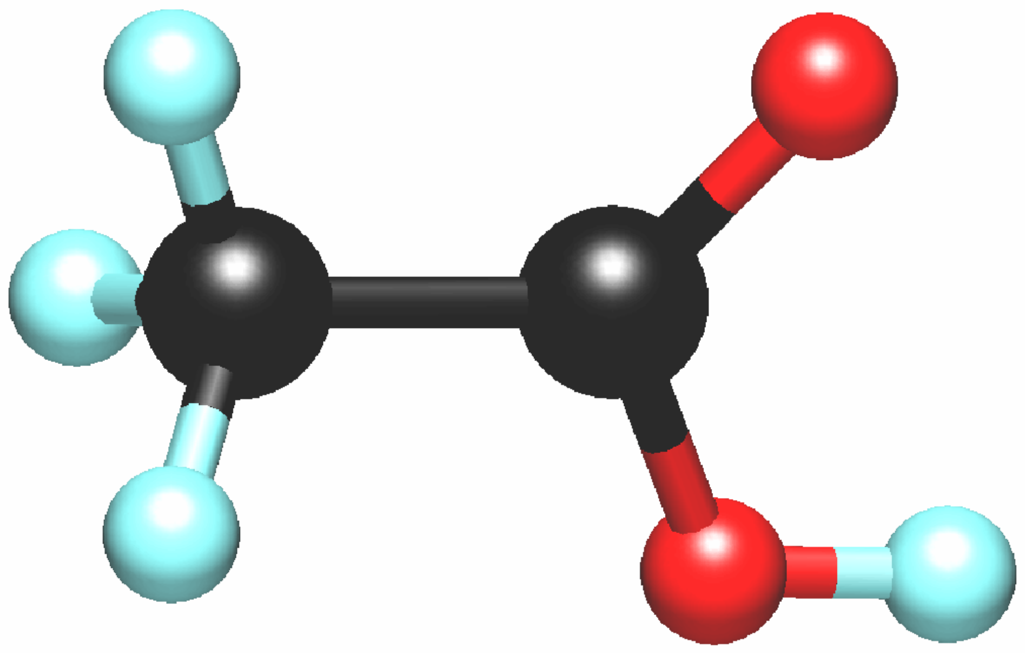


(a)(i)Name the chief ore that is commonly used in this process

Galena(PbS)

(ii)Explain what take place in the roasting furnace

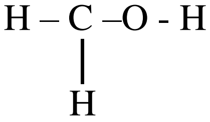
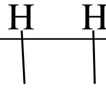
23.0.0 ORGANIC CHEMISTRY II (ALKANOLS AND ALKANOIC ACIDS) (20 LESSONS)

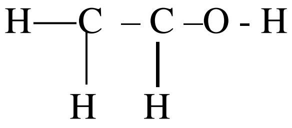
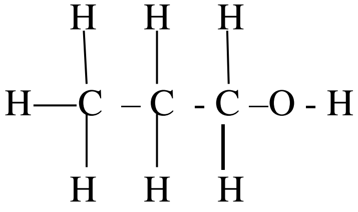
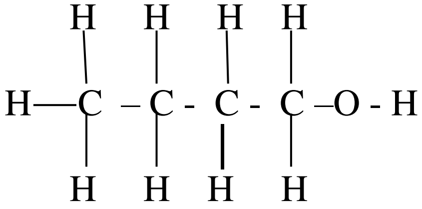
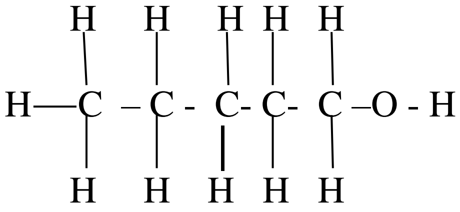
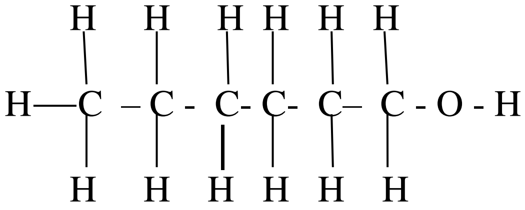
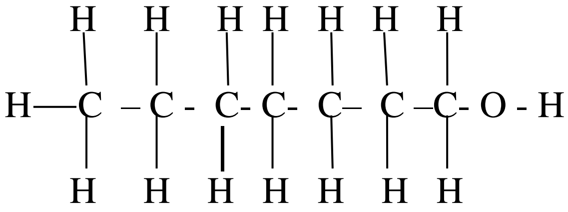
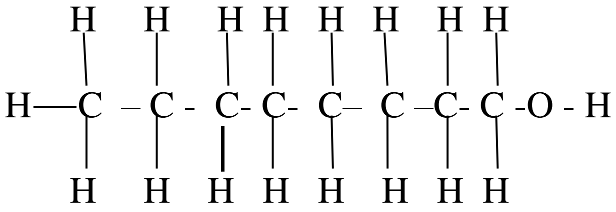


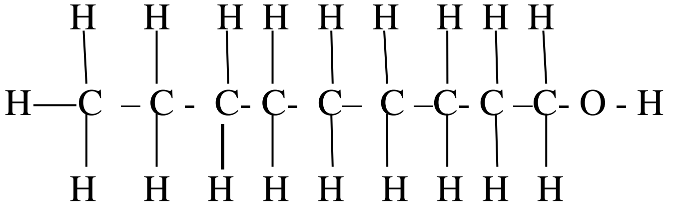
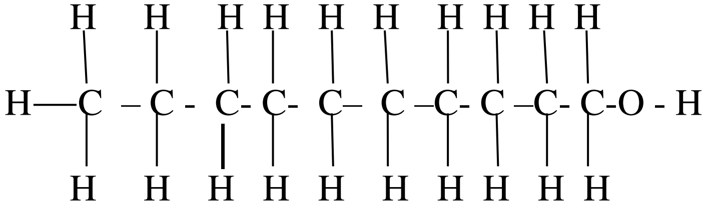
B.ALKANOLS(Alcohols)

(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	 $H - \underset{\underset{H}{\mid}}{C} - O - H$	Methan**ol**
2	$CH_3\,CH_2OH$	 H H	Ethan**ol**

	C_2H_5 OH	 $H-\underset{H}{C}-\underset{H}{C}-O-H$	
3	CH_3 $(CH_2)_2OH$ C_3H_7 OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$	Propan**ol**
4	CH_3 $(CH_2)_3OH$ C_4H_9 OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$	Butan**ol**
5	$CH_3(CH_2)_4OH$ C_5H_{11} OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$	Pentan**ol**
6	$CH_3(CH_2)_5OH$ C_6H_{13} OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$	Hexan**ol**
7	$CH_3(CH_2)_6OH$ C_7H_{15} OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$	Heptan**ol**
8	$CH_3(CH_2)_7OH$ C_8H_{17} OH	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-H$	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.

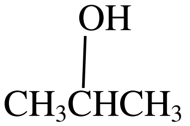
(ii)Identify the position of the **-OH** functional group to give it the **smallest /lowest** position.

(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

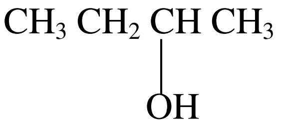


$CH_3\overset{\overset{OH}{|}}{C}HCH_3$ - Propan-2-ol

Propan-2-ol and Propan-1-ol are position isomers because only the position of the –OH functional group changes.

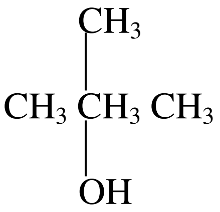
(ii)Isomers of Butanol C_4H_9OH

$CH_3\ CH_2\ CH_3\ CH_2\ OH$ Butan-1-ol



$$CH_3\ CH_2\ \underset{\displaystyle OH}{\underset{|}{CH}}\ CH_3$$

Butan-2-ol



$$CH_3\ \overset{\displaystyle CH_3}{\overset{|}{\underset{\displaystyle OH}{\underset{|}{CH_3}}}}\ CH_3$$

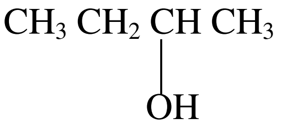
2-methylpropan-2-ol

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.

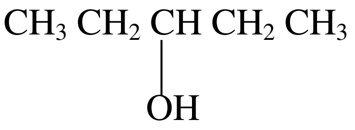
(iii)Isomers of Pentanol $C_5H_{11}OH$

$CH_3\ CH_2\ CH_2CH_2CH_2\ OH$ Pentan-1-ol (Position isomer)



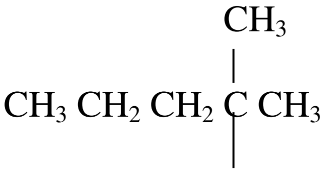
$$CH_3\ CH_2\ \underset{\displaystyle OH}{\underset{|}{CH}}\ CH_3$$

Pentan-2-ol (Position isomer)



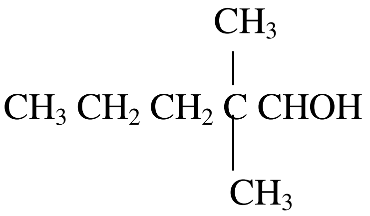
$$CH_3\ CH_2\ \underset{\displaystyle OH}{\underset{|}{CH}}\ CH_2\ CH_3$$

Pentan-3-ol (Position isomer)



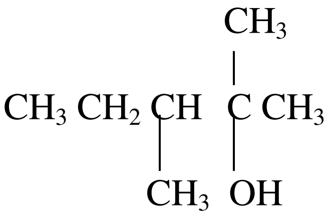
$$CH_3\ CH_2\ CH_2\ \overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}\ CH_3$$

OH 2-methylbutan-2-ol (Position /structural isomer)



$CH_3CH_2CH_2C(CH_3)_2CHOH$

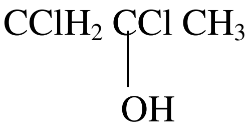
2,2-dimethylbutan-1-ol (Position /structural isomer)



$CH_3CH_2CH(CH_3)C(CH_3)(OH)CH_3$

2,3-dimethylbutan-1-ol (Position /structural isomer)

(iv)1,2-dichloropropan-2-ol



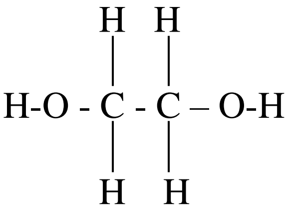
$CClH_2CCl(OH)CH_3$

(v)1,2-dichloropropan-1-ol

$CClH_2CHClCH_2OH$

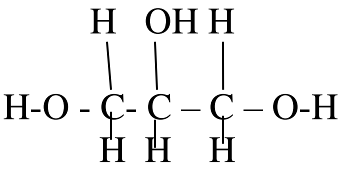
(vi) Ethan1,2-diol

$HOCH_2CH_2OH$



(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

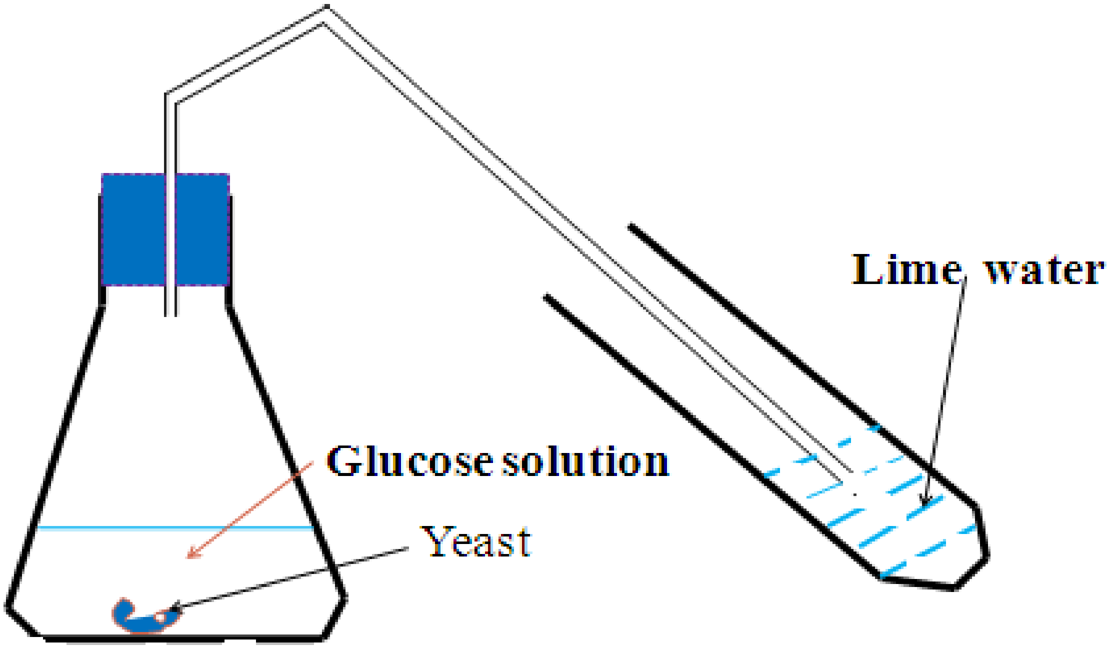
Measure 100cm3 of pure water into a conical flask.

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) Role of yeast

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 (°C)	Boiling point (°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
$2CH_3CH_2OH(l)$ + $2Na(s)$ -> $2CH_3CH_2ONa$ (aq) + H_2 (s)
$2H_2O(l)$ + $2Na(s)$ -> $2NaOH$ (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
$2CH_3CH_2OH(l)$ + $2K(s)$ -> $2CH_3CH_2OK$ (aq) + H_2 (s)
$2H_2O(l)$ + $2K(s)$ -> $2KOH$ (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
$2CH_3CH_2\ CH_2OH(l)$ + $2Na(s)$ -> $2CH_3CH_2\ CH_2ONa$ (aq) + H_2 (s)
$2H_2O(l)$ + $2Na(s)$ -> $2NaOH$ (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 $\xrightarrow{\text{Conc. } H_2SO_4}$ 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 -COO**H** + 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	pH= 4/5/6	Weakly acidic

	$KMnO_4$decolorized (ii) Orange colour of $K_2Cr_2O_7$turns green.	pH = 4/5/6	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°C temperature and 60 atmosphere pressure to form ethanol

Ethene + water ---60 atm/300°C/ H_3PO_4 --> Ethanol

$H_2C = CH_2$ (g) + $\mathbf{H_2O}$(l) --60 atm/300°C/ H_3PO_4 --> $CH_3\ C\mathbf{H_2O}H$(l)

This is the main method of producing <u>large quantities</u> of ethanol instead of fermentation

(ii) Propene + water ---60 atm/300°C/ H_3PO_4 --> Propanol

$CH_3C = CH_2$ (g) + $\mathbf{H_2O}$(l) --60 atm/300°C/ H_3PO_4 --> $CH_3\ CH_2\ C\mathbf{H_2O}H$(l)

(iii) Butene + water ---60 atm/300°C/ H_3PO_4 --> Butanol

$CH_3\ CH_2\ C{=}CH_2$ (g) + $\mathbf{H_2O}$(l) --60 atm/300°C/ H_3PO_4 --> $CH_3\ CH_2\ CH_2\ C\mathbf{H_2O}H$(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°C. i.e

Alkanol --Conc. $H_2\ SO_4$/180°C--> Alkene + Water

Examples

1. At 180°C and in presence of Concentrated sulphuric(VI)acid, ethanol undergoes dehydration to form ethene.

Ethanol ---180°C/ H_2SO_4 --> Ethene + Water

$CH_3\ C\mathbf{H_2O}H$(l) --180°C/ H_2SO_4 --> $H_2C = CH_2$ (g) + $\mathbf{H_2O}$(l)

2. Propanol undergoes dehydration to form propene.

Propanol ---180°C/ H_2SO_4 --> Propene + Water

$CH_3\ CH_2\ C\mathbf{H_2O}H$(l) --180°C/ H_2SO_4 --> $CH_3CH = CH_2$ (g) + $\mathbf{H_2O}$(l)

3. Butanol undergoes dehydration to form Butene.

Butanol ---180°C/ H_2SO_4 --> Butene + Water

$CH_3\ CH_2\ CH_2C\mathbf{H_2O}H$(l) --180°C/ H_2SO_4 --> $CH_3\ CH_2C = CH_2$ (g) + $\mathbf{H_2O}$(l)

3. Pentanol undergoes dehydration to form Pentene.

Pentanol ---180°C/ H_2SO_4 --> Pentene + Water

$CH_3\ CH_2\ CH_2\ CH_2\ CH_2OH(l) \text{--}180^{o}C/\ H_2SO_4\text{-->}CH_3\ CH_2\ CH_2C = CH_2\ (g) + H_2O(l)$

(I)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 $- C \equiv C-$ 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**ol** + [O] -> Ethan**al** + [O] -> Ethan**oic** acid

$CH_3CH_2OH + [O] \rightarrow CH_3CH_2O + [O] \rightarrow CH_3COOH$

2.When ethene is bubbled in a test tube containing acidified $K_2Cr_2O_7$,the orange of acidified $K_2Cr_2O_7$ turns to green. Ethene is oxidized to ethan-1,2-diol.

Ethene + [O] -> Ethan-1,2-diol.

$H_2C{=}CH_2 + [O] \rightarrow HOCH_2\text{-}CH_2OH$

III. Differences with alkenes/alkynes

Alkanols do not decolorize bromine and chlorine water.

Alkenes decolorizes bromine and chlorine water to form halogenoalkanols

Example

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. Differences in melting and boiling point with Hydrocarbons

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.

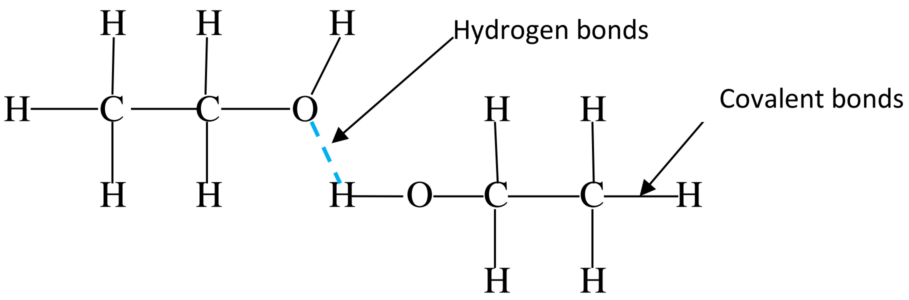
Two alkanol molecules form a dimer joined by hydrogen bonding.

Example

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.



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)

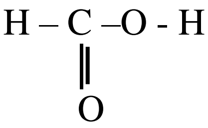
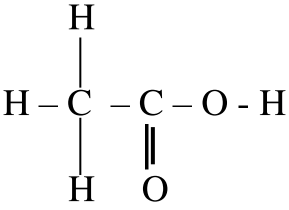
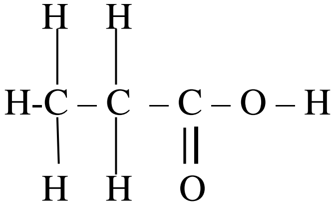
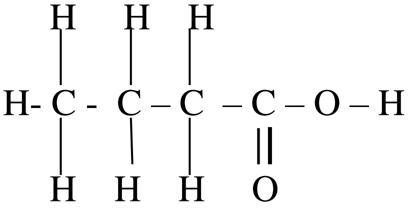
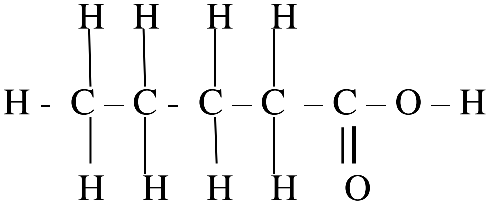
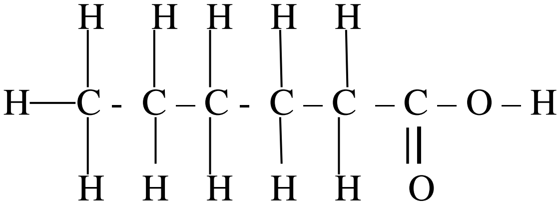
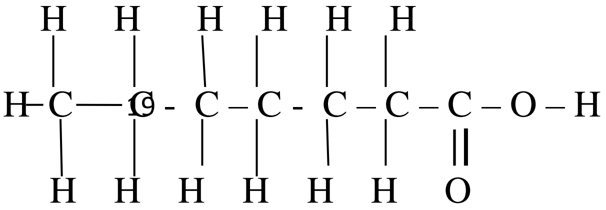
(A) INTRODUCTION.

Alkanoic acids belong to a homologous series of organic compounds with a general formula **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—$\underset{\|}{\mathrm{C}}$-O-H as the functional group.

n	General /molecular formular	Structural formula	IUPAC name
0	HCOOH	 $\mathrm{H-\underset{\underset{O}{\|}}{C}-O-H}$	Methanoic acid
1	$CH_3\ COOH$	 $\mathrm{H-\overset{H}{\underset{H}{C}}-\underset{\underset{O}{\|}}{C}-O-H}$	Ethanoic acid
2	$CH_3\ CH_2\ COOH$ $C_2\ H_5\ COOH$	 $\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{\underset{O}{\|}}{C}-O-H}$	Propanoic acid
3	$CH_3\ CH_2\ CH_2\ COOH$ $C_3\ H_7\ COOH$	 $\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{\underset{O}{\|}}{C}-O-H}$	Butanoic acid
4	$CH_3CH_2CH_2CH_2$ COOH $C_4\ H_9\ COOH$	 $\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{\underset{O}{\|}}{C}-O-H}$	Pentanoic acid
5	$CH_3CH_2\ CH_2CH_2CH_2$ COOH $C_5\ H_{11}\ COOH$	 $\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{\underset{O}{\|}}{C}-O-H}$	Hexanoic acid
6	$CH_3CH_2\ CH_2$ $CH_2CH_2CH_2\ COOH$ $C_6\ H_{13}\ COOH$	 $\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{\underset{O}{\|}}{C}-O-H}$	Pentanoic acid

O

(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 $-\underset{\underset{O}{\|}}{C}-O-H$ functional group to give it the smallest /lowest position.

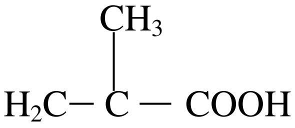
(iii)Identify the type and position of the side group branches.

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



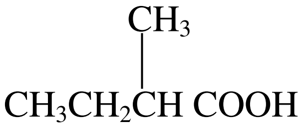
$$H_2C-\overset{\overset{CH_3}{|}}{C}-COOH$$

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.

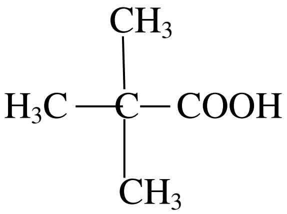
2.Isomers of pentanoic acid C_4H_9COOH

$CH_3CH_2CH_2CH_2\ COOH$ pentan-1-oic acid



$$CH_3CH_2\overset{\overset{CH_3}{|}}{C}H\ COOH$$

2-methylbutan-1-oic acid

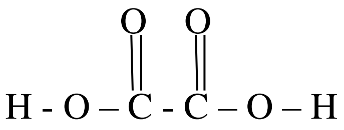


$$H_3C-C(CH_3)_2-COOH$$

2,2-dimethylpropan-1-oic acid

3.Ethan-1,2-dioic acid

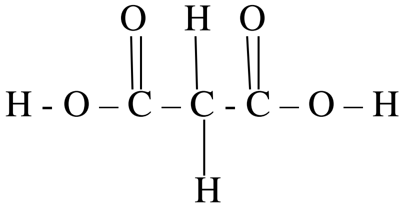
HOOC- COOH //



$$H-O-C(=O)-C(=O)-O-H$$

4.Propan-1,3-dioic acid

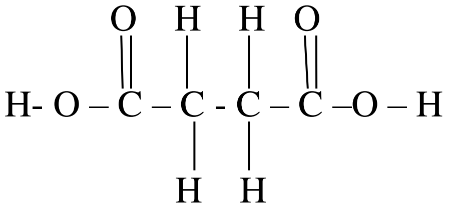
HOOC- CH_2COOH //



$$H-O-C(=O)-CH_2-C(=O)-O-H$$

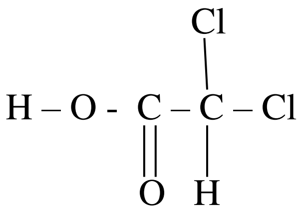
5.Butan-1,4-dioic acid

HOOC CH_2 CH_2 COOH



$$H-O-C(=O)-CH_2-CH_2-C(=O)-O-H$$

6.2,2-dichloroethan-1,2-dioic acid
HOOCCHCl_2



$$H-O-C(=O)-CHCl_2$$

(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**

Example
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(°C)	Boiling point(°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

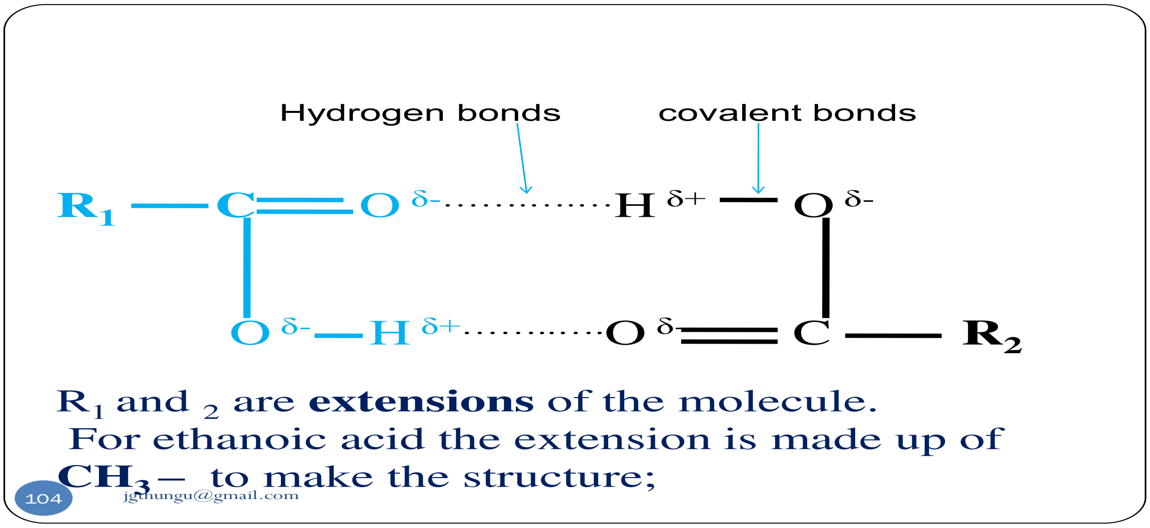
From the table note the following:

(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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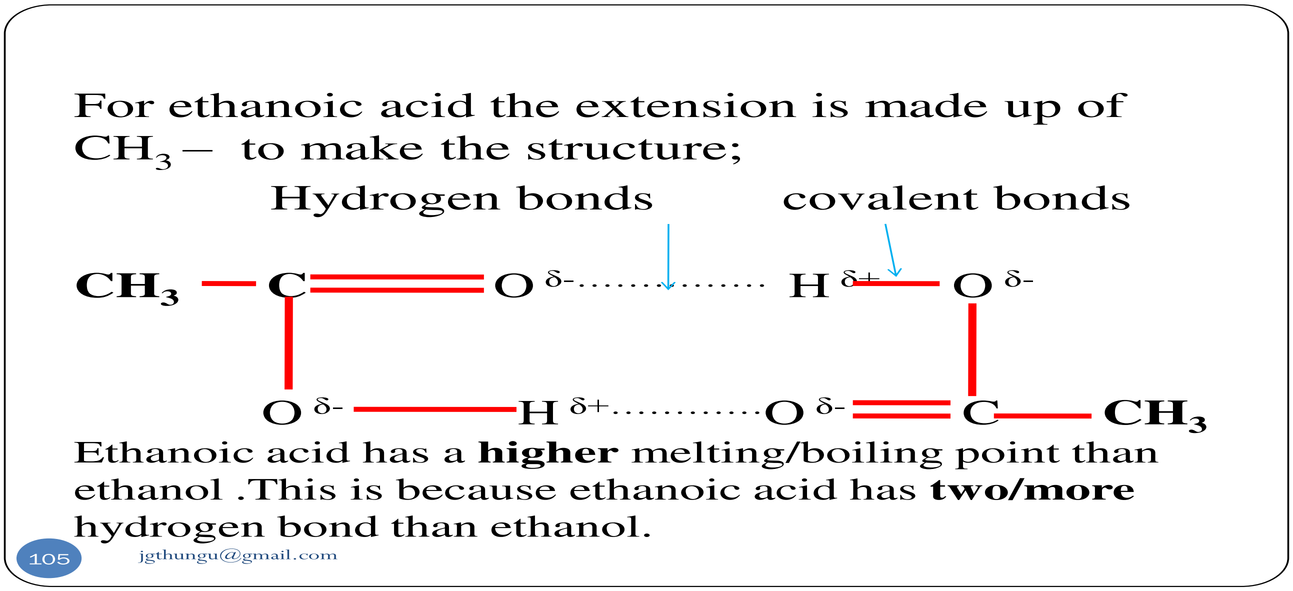
For ethanoic acid the extension is made up of CH_3— to make the structure;

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. $CH_3COO\mathbf{H}(aq) \longleftarrow CH_3COO^-(aq) + H^+(aq)$

$\dashrightarrow$

(ethanoic acid) (ethanoate ion) (few H^+ ion)

2. $CH_3\,CH_2COO\mathbf{H}(aq)$ $\underset{\dashrightarrow}{\longleftarrow}$ $CH_3\,CH_2COO^-(aq)$ + $H^+(aq)$
   (propanoic acid) (propanoate ion) (few H^+ ion)

3. $CH_3\,CH_2\,CH_2COO\mathbf{H}(aq)$ $\overset{\dashrightarrow}{\longleftarrow}$ $CH_3\,CH_2\,CH_2COO^-(aq)$ + $H^+(aq)$
   (Butanoic acid) (butanoate ion) (few H^+ ion)

4. $HOO\mathbf{H}(aq)$ $\underset{\dashrightarrow}{\longleftarrow}$ $HOO^-(aq)$ + $H^+(aq)$
   (methanoic acid) (methanoate ion) (few H^+ ion)

5. $H_2\,SO_4\,(aq)$ $\underset{\dashleftarrow}{\longrightarrow}$ $SO_4^{2-}\,(aq)$ + $2H^+(aq)$
   (sulphuric(VI) acid) (sulphate(VI) ion) (**many** H^+ ion)

6. $HNO_3\,(aq)$ $\underset{\dashleftarrow}{\longrightarrow}$ $NO_3^-\,(aq)$ + $H^+(aq)$
   (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 -**COOH** 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

$2R-\mathbf{COOH} + 2M \rightarrow 2R-\mathbf{COOM} + 2H_2(g)$

2.For a divalent metal with monobasic acid

$2R-\mathbf{COOH} + M \rightarrow (R-COO)_2\mathbf{M} + H_2(g)$

3.For a divalent metal with dibasic acid

$\mathbf{HOOC\text{-}R\text{-}COOH} + M \rightarrow \mathbf{MOOC\text{-}R\text{-}COOM} + H_2(g)$

4.For a monovalent metal with dibasic acid

$\mathbf{HOOC\text{-}R\text{-}COOH} + 2M \rightarrow \mathbf{MOOC\text{-}R\text{-}COOM} + H_2(g)$

5 For mineral acids

(i)Sulphuric(VI)acid is a dibasic acid

$\mathbf{H_2}SO_4(aq) + 2M \rightarrow M_2SO_4(aq) + H_2(g)$

$\mathbf{H_2}SO_4(aq) + M \rightarrow MSO_4(aq) + H_2(g)$

(ii)Nitric(V) and hydrochloric acid are monobasic acid

$\mathbf{H}NO_3(aq) + 2M \rightarrow 2MNO_3(aq) + H_2(g)$

$\mathbf{H}NO_3(aq) + M \rightarrow M(NO_3)_2(aq) + H_2(g)$

Examples

1.Sodium reacts with ethanoic acid to form sodium ethanoate and produce. hydrogen gas.

Caution: This reaction is explosive.

$CH_3\mathbf{COOH}(aq) + Na(s) \rightarrow CH_3COO\mathbf{Na}(aq) + H_2(g)$

(Ethanoic acid) (Sodium ethanoate)

2.Calcium reacts with ethanoic acid to form calcium ethanoate and produce. hydrogen gas.

$2CH_3\mathbf{COOH}(aq) + Ca(s) \rightarrow (CH_3COO)_2\mathbf{Ca}(aq) + H_2(g)$

(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)

$\mathbf{H_2} SO_4 (aq) + Mg \rightarrow MgSO_4 (aq) + H_2(g)$

(ii)Nitric(V) and hydrochloric acid are monobasic acid

$2\mathbf{H}NO_3 (aq) + Mg \rightarrow M(NO_3)_2 (aq) + H_2(g)$

(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.

$\mathbf{H}OOC\text{-}COO\mathbf{H}$+ Na_2CO_3 (s) -> $\mathbf{Na}OOC - COO\mathbf{Na}$ + 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.

$\mathbf{H}OOC\text{-}COO\mathbf{H}$+ $2NaHCO_3$ (s) -> $\mathbf{Na}OOC - COO\mathbf{Na}$ + 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**

Examples

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

$\mathbf{Na}OH(aq) + CH_3(CH_2)_{16}COOH(aq) \rightarrow CH_3(CH_2)_{16}COO^- \mathbf{Na}^+(aq) + H_2O(l)$

Commonly ,soap can thus be represented ;

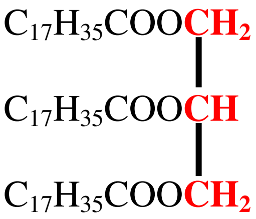
$R\text{-}COO^- \mathbf{Na}^+$ where;

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;



$$\begin{array}{l} C_{17}H_{35}COOCH_2 \\ \qquad\qquad\quad | \\ C_{17}H_{35}COOCH \\ \qquad\qquad\quad | \\ C_{17}H_{35}COOCH_2 \end{array}$$

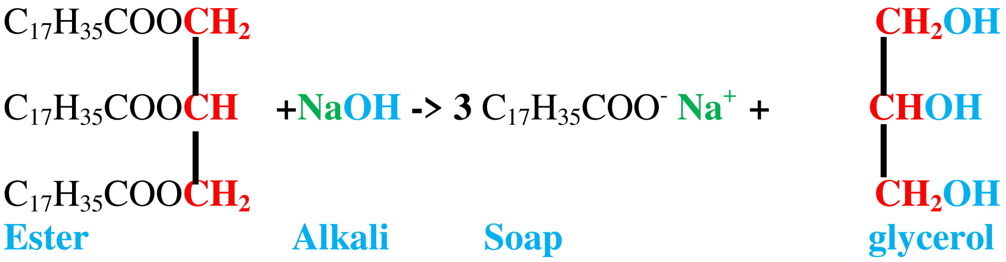
When boiled with concentrated sodium hydroxide solution NaOH;

(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

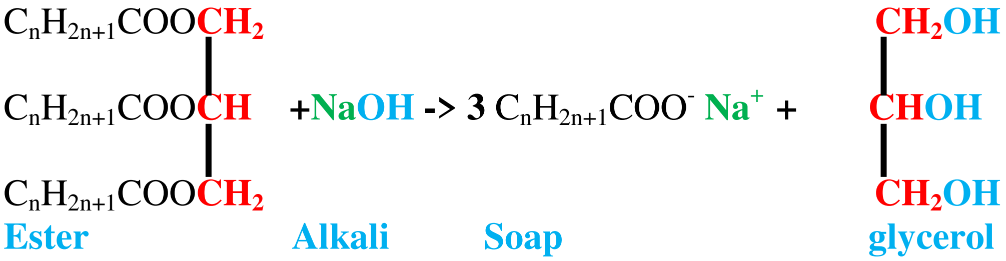
(iii) the three **Na^+** combine with the three $C_{17}H_{35}COO^-$ to form the salt $C_{17}H_{35}COO^-$ **Na^+**

(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)**

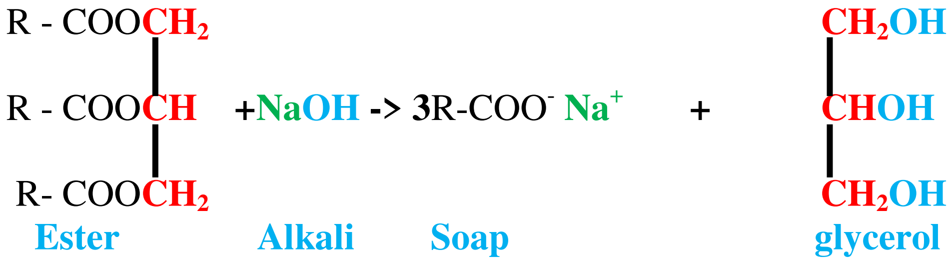


$$\begin{array}{l} C_{17}H_{35}COOCH_2 \\ \qquad\quad | \\ C_{17}H_{35}COOCH \\ \qquad\quad | \\ C_{17}H_{35}COOCH_2 \end{array} + NaOH \rightarrow 3\, C_{17}H_{35}COO^- Na^+ + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Generally:



$$\begin{array}{l} C_nH_{2n+1}COOCH_2 \\ \qquad\quad | \\ C_nH_{2n+1}COOCH \\ \qquad\quad | \\ C_nH_{2n+1}COOCH_2 \end{array} + NaOH \rightarrow 3\, C_nH_{2n+1}COO^- Na^+ + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$



$$\begin{array}{l} R - COOCH_2 \\ \qquad\quad | \\ R - COOCH \\ \qquad\quad | \\ R- COOCH_2 \end{array} + NaOH \rightarrow 3R\text{-}COO^- Na^+ + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

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

$\mathrm{R{-}}\mathbf{OH} + \mathbf{H}_2\mathrm{SO_4} \rightarrow \mathrm{R{-}O{-}SO_3H} + \mathbf{H_2}\mathrm{O}$

(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 + Potassium/sodium -> Sodium/potassium + Water
sulphate(VI) hydroxide alkyl hydrogen sulphate(VI)

$\mathrm{R{-}O{-}SO_3H} + \mathbf{Na}\mathrm{OH} \rightarrow \mathrm{R{-}O{-}SO_3^{-}\,Na^{+}} + \mathbf{H_2}\mathrm{O}$

Example

Step I : Reaction of Octadecanol with Conc.$\mathbf{H}_2\mathrm{SO_4}$

$\mathrm{C_{17}H_{35}CH_2OH\,(aq)} + \mathrm{H_2SO_4} \rightarrow \mathrm{C_{17}H_{35}CH_2{-}}\mathbf{O{-}\,SO_3^{-}\,H^{+}}\,\mathrm{(aq)} + \mathrm{H_2O\,(l)}$

octadecanol + sulphuric(VI)acid -> Octadecyl hydrogen sulphate(VI) + water

Step II: Neutralization by an alkali

$\mathrm{C_{17}H_{35}CH_2{-}}\mathbf{O{-}\,SO_3^{-}\,H^{+}}\,\mathrm{(aq)} + \mathrm{NaOH} \rightarrow \mathrm{C_{17}H_{35}CH_2{-}}\mathbf{O{-}\,SO_3^{-}\,Na^{+}}\,\mathrm{(aq)} + \mathrm{H_2O\,(l)}$

Octadecyl hydrogen + sodium/potassium -> sodium/potassium octadecyl+Water
sulphate(VI) hydroxide hydrogen sulphate(VI)

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-$COO^{-}Na^{+}$

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv-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.

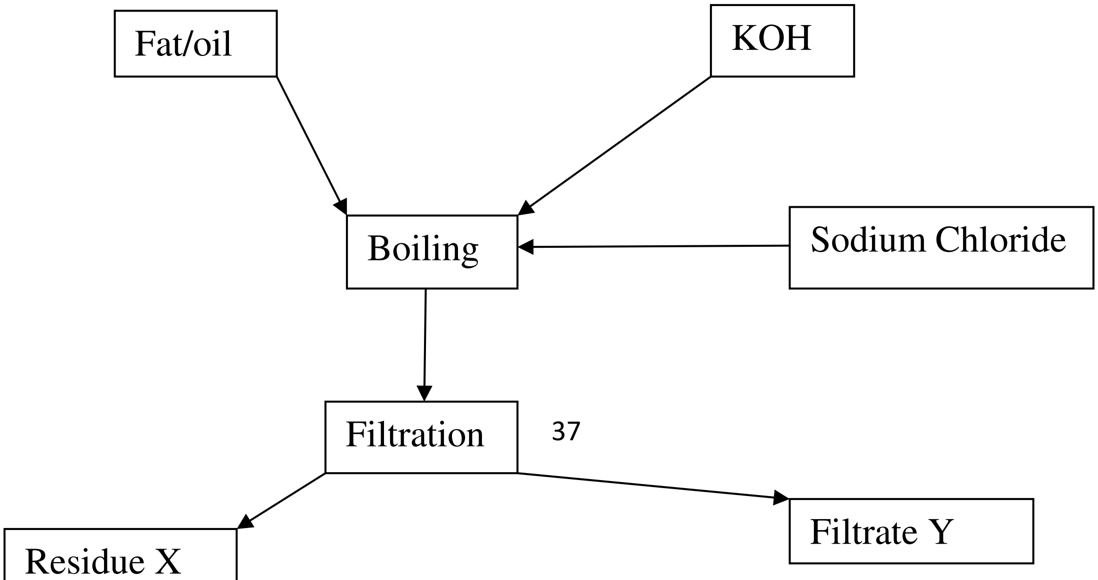
Advantages and disadvantages of using soapless detergents

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

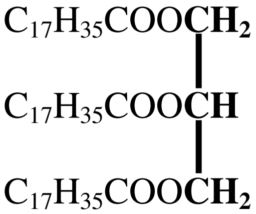
1. Study the scheme below



(a)Identify the process

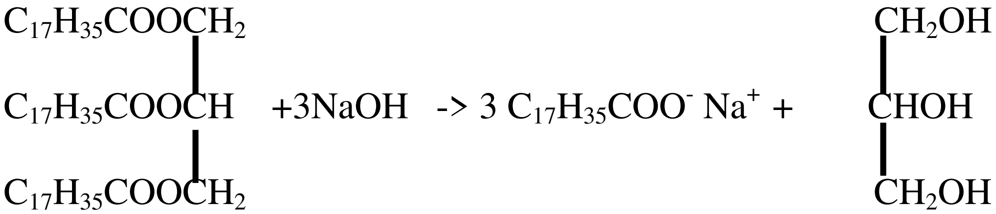
Saponification

(b)Fats and oils are esters. Write the formula of the a common structure of ester



$$\begin{array}{l} C_{17}H_{35}COO\mathbf{CH_2} \\ \qquad\qquad\quad | \\ C_{17}H_{35}COO\mathbf{CH} \\ \qquad\qquad\quad | \\ C_{17}H_{35}COO\mathbf{CH_2} \end{array}$$

(c)Write a balanced equation for the reaction taking place during boiling



$$\begin{array}{l} C_{17}H_{35}COOCH_2 \\ \qquad\qquad\quad | \\ C_{17}H_{35}COOCH \\ \qquad\qquad\quad | \\ C_{17}H_{35}COOCH_2 \end{array} +3NaOH \rightarrow 3\,C_{17}H_{35}COO^-\,Na^+ + \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array}$$

Ester Alkali Soap glycerol

(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.

<u>Chemical equation</u>

$2C_{17}H_{35}COO^{-}\,\mathbf{K}^{+}(aq) + CaSO_4(aq) \rightarrow (C_{17}H_{35}COO^{-})Ca^{2+}(s) + \mathbf{K}_2SO_4(aq)$

(insoluble Calcium octadecanote/scum)

<u>Ionic equation</u>

$2C_{17}H_{35}COO^{-}\,\mathbf{K}^{+}(aq) + Ca^{2+}(aq) \rightarrow (C_{17}H_{35}COO^{-})Ca^{2+}(s) + \mathbf{2K}^{+}(aq)$

(insoluble Calcium octadecanote/scum)

Chemical equation

$2C_{17}H_{35}COO^- \mathbf{K}^+(aq)$ + $MgSO_4(aq)$ -> $(C_{17}H_{35}COO^-)Mg^{2+}(s)$ + $\mathbf{K}_2SO_4(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^- \mathbf{K}^+(aq)$ + $Mg^{2+}(aq)$ -> $(C_{17}H_{35}COO^-)Mg^{2+}(s)$ + $\mathbf{2K}^+(aq)$

(insoluble Magnesium octadecanote/scum)

(iii)Write the equation for the reaction at water sample A before boiling.

Chemical equation

$2C_{17}H_{35}COO^- \mathbf{K}^+(aq)$ + $Ca(HCO_3)(aq)$ ->$(C_{17}H_{35}COO^-)Ca^{2+}(s)$ + $2KHCO_3(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^- \mathbf{K}^+(aq)$ + $Ca^{2+}(aq)$ -> $(C_{17}H_{35}COO^-)Ca^{2+}(s)$ + $2K^+(aq)$

(insoluble Calcium octadecanote/scum)

Chemical equation

$2C_{17}H_{35}COO^- \mathbf{K}^+(aq)$ + $Mg(HCO_3)(aq)$ ->$(C_{17}H_{35}COO^-)Mg^{2+}(s)$ + $2KHCO_3(aq)$

(insoluble Calcium octadecanote/scum)

Ionic equation

$2C_{17}H_{35}COO^- \mathbf{K}^+(aq)$ + $Mg^{2+}(aq)$ -> $(C_{17}H_{35}COO^-)Mg^{2+}(s)$ + $2K^+(aq)$

(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.

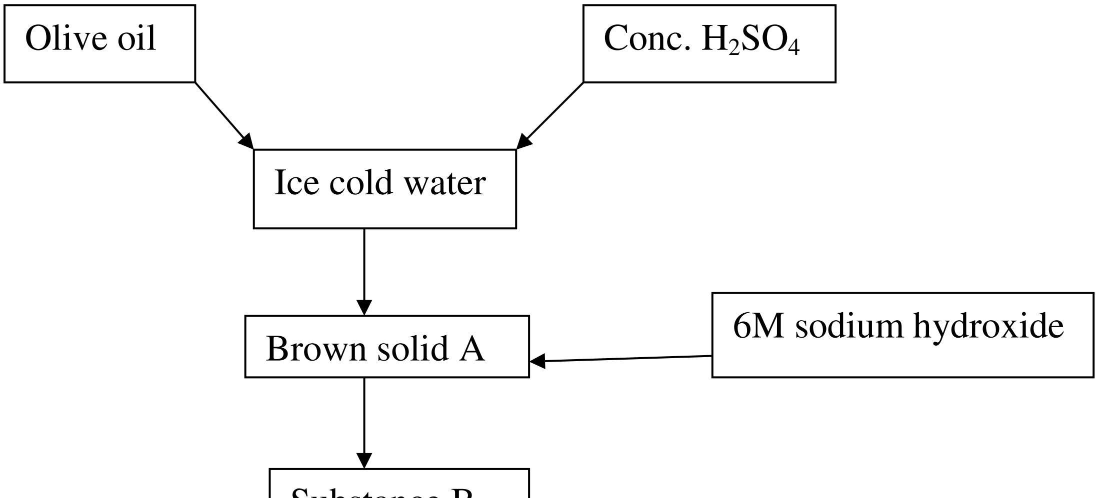
(v)State two useful benefits of hard water

-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)

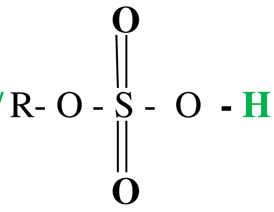
(ii)substance B

Sodium alkyl hydrogen sulphate(VI)

(b)Write a general formula of:

(i)Substance A.

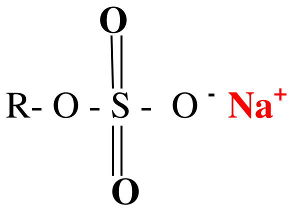
R-O-S O_3 **H** //



$$R\text{-}O\text{-}\overset{O}{\underset{O}{\overset{\|}{\underset{\|}{S}}}}\text{-}O\text{-}H$$

(ii)Substance B

R-O-S O_3^- **Na^+**



$$R\text{-}O\text{-}\overset{O}{\underset{O}{\overset{\|}{\underset{\|}{S}}}}\text{-}O^-\ Na^+$$

(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)

$H_2C=CH_2 + H_2SO_4 \rightarrow H_3C-CH_2-O-SO_3H$

Product B

Ethyl hydrogen sulphate(VI) + sodium hydroxide -> sodium Ethyl hydrogen sulphate(VI) + Water

$H_3C-CH_2-O-SO_3H + \textbf{Na}OH \rightarrow H_3C-CH_2-O-SO_3^-\textbf{Na}^+ + H_2O$

(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

$H_3C-CH_2OH + H_2SO_4 \rightarrow H_3C-CH_2-O-SO_3H + H_2O$

Product B

Ethyl hydrogen sulphate(VI) + sodium hydroxide -> sodium Ethyl hydrogen sulphate(VI) + Water

$H_3C-CH_2-O-SO_3H + \textbf{Na}OH \rightarrow H_3C-CH_2-O-SO_3^-\textbf{Na}^+ + H_2O$

3.Below is part of a detergent

$\mathbf{H_3C-(CH_2)_{16}-O-SO_3^-K^+}$

(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?

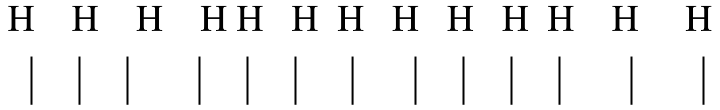
Soapless detergent

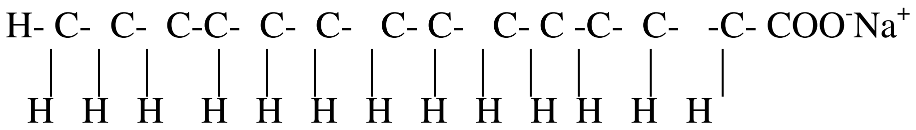
(c)State one advantage of using the above detergent

-does not form scum with hard water

-is cheap to manufacture

4.The structure of a detergent is





$H- C- C- C-C- C- C- C- C- C- C -C- C- -C- COO^-Na^+$

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.

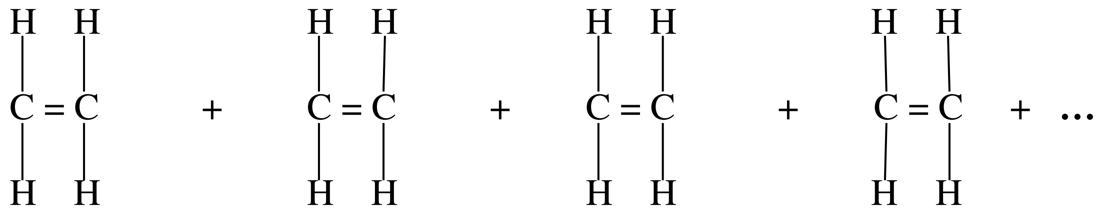
Examples of addition polymerization

1.Formation of Polyethene

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:

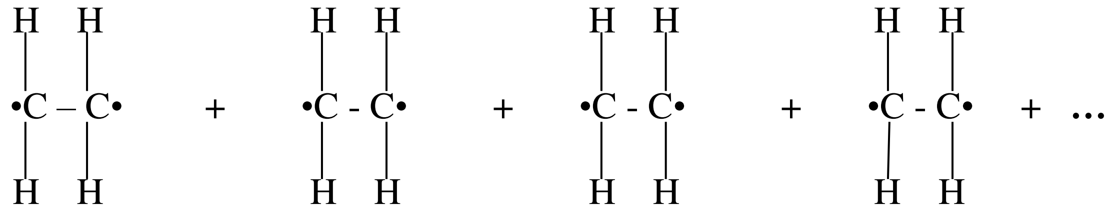
(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting paticles)



$$\begin{matrix} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{matrix} + \begin{matrix} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{matrix} + \begin{matrix} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{matrix} + \begin{matrix} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{matrix} + \ldots$$

Ethene + Ethene + Ethene + Ethene + ...

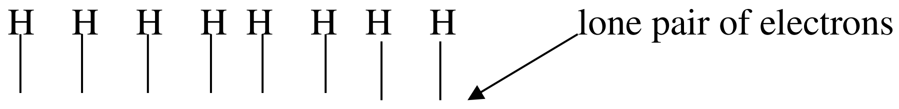
(ii)the double bond joining the ethane molecule break to free readicals

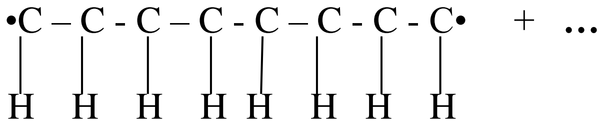


$$\begin{matrix} H & & H \\ | & & | \\ \bullet C & - & C\bullet \\ | & & | \\ H & & H \end{matrix} + \begin{matrix} H & & H \\ | & & | \\ \bullet C & - & C\bullet \\ | & & | \\ H & & H \end{matrix} + \begin{matrix} H & & H \\ | & & | \\ \bullet C & - & C\bullet \\ | & & | \\ H & & H \end{matrix} + \begin{matrix} H & & H \\ | & & | \\ \bullet C & - & C\bullet \\ | & & | \\ H & & H \end{matrix} + \ldots$$

Ethene radical + Ethene radical + Ethene radical + Ethene radical + ...

(iii)the free radicals collide with each other and join to form a larger molecule

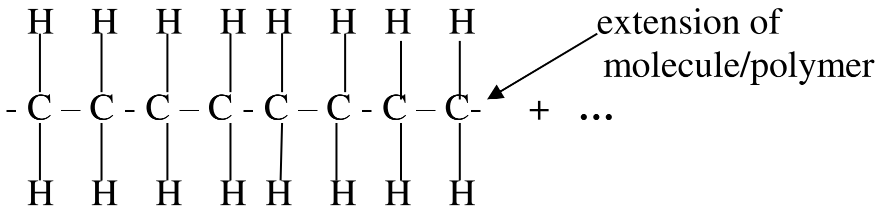




$$\begin{array}{ccccccccccccccc} \bullet C & - & C & - & C & - & C & - & C & - & C & - & C & - & C\bullet \\ | & & | & & | & & | & & | & & | & & | & & | \\ H & & H & & H & & H & & H & & H & & H & & H \end{array} \quad + \ \ldots$$

Lone pair of electrons can be used to join more monomers to form longer polyethene.

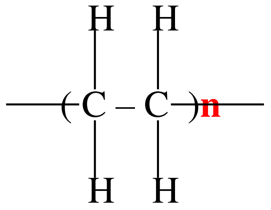
Polyethene molecule can be represented as:



extension of molecule/polymer

$$\begin{array}{ccccccccccccccccc} & H & & H & & H & & H & & H & & H & & H & & H & \\ & | & & | & & | & & | & & | & & | & & | & & | & \\ - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - \\ & | & & | & & | & & | & & | & & | & & | & & | & \\ & H & & H & & H & & H & & H & & H & & H & & H & \end{array} \quad + \ \ldots$$

Since the molecule is a repetition of one monomer, then the polymer is:



$$\begin{array}{ccccc} & H & & H & \\ & | & & | & \\ -(& C & - & C &)_{n}- \\ & | & & | & \\ & H & & H & \end{array}$$

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:

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)

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:

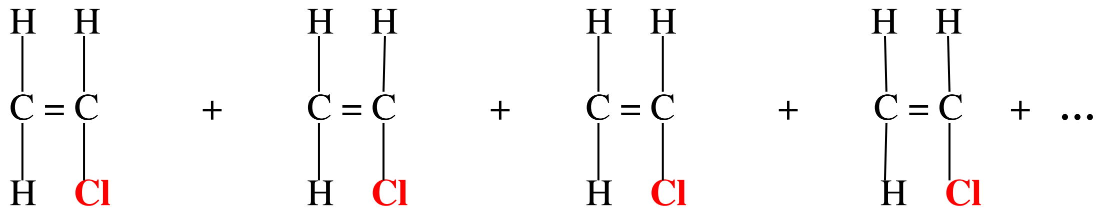
(i)in making plastic bag
(ii)bowls and plastic bags
(iii)packaging materials

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:

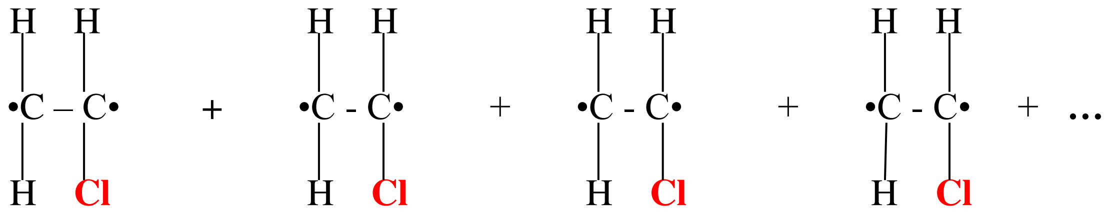
(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)



$$\underset{H}{\overset{H}{C}} = \underset{Cl}{\overset{H}{C}} + \underset{H}{\overset{H}{C}} = \underset{Cl}{\overset{H}{C}} + \underset{H}{\overset{H}{C}} = \underset{Cl}{\overset{H}{C}} + \underset{H}{\overset{H}{C}} = \underset{Cl}{\overset{H}{C}} + \ldots$$

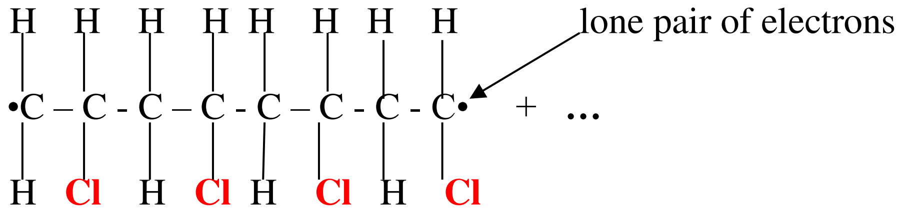
chloroethene + chloroethene + chloroethene + chloroethene + …

(ii)the double bond joining the chloroethene molecule break to free radicals



$$\bullet\underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}}\bullet + \bullet\underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}}\bullet + \bullet\underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}}\bullet + \bullet\underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}}\bullet + \ldots$$

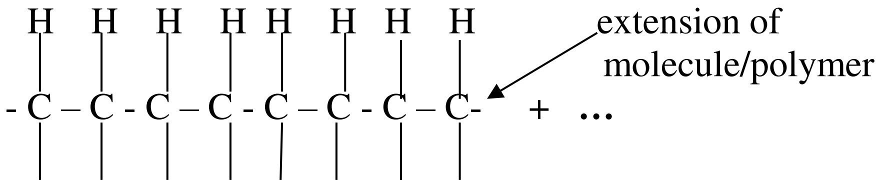
(iii)the free radicals collide with each other and join to form a larger molecule



$$\bullet\underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}} - \underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}} - \underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}} - \underset{H}{\overset{H}{C}} - \underset{Cl}{\overset{H}{C}}\bullet + \ldots$$

Lone pair of electrons can be used to join more monomers to form longer polychloroethene.

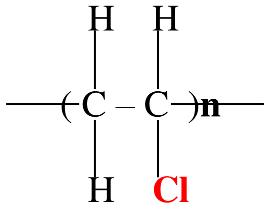
Polychloroethene molecule can be represented as:



$$-\overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}} - \overset{H}{\underset{|}{C}}- + \ldots$$

H Cl H Cl H Cl H Cl

Since the molecule is a repetition of one monomer, then the polymer is:



$$-\!\left(CH_2 - CHCl \right)_n\!-$$

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:

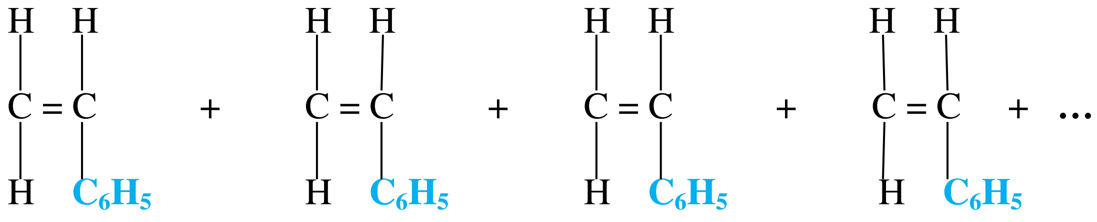
(i)in making plastic rope
(ii)water pipes
(iii)crates and boxes

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:

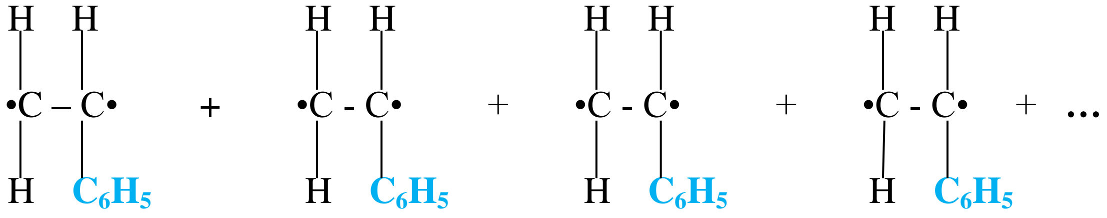
(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)



$$CH_2{=}CHC_6H_5 + CH_2{=}CHC_6H_5 + CH_2{=}CHC_6H_5 + CH_2{=}CHC_6H_5 + \ldots$$

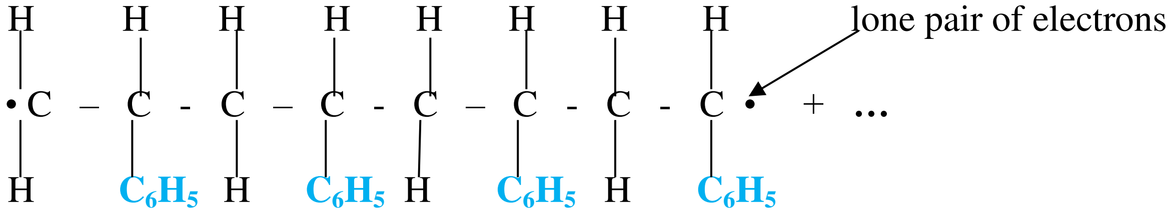
phenylethene + phenylethene + phenylethene + phenylethene + …

(ii)the double bond joining the phenylethene molecule break to free radicals



$$\cdot\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}\cdot + \cdot\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}\cdot + \cdot\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}\cdot + \cdot\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}\cdot + \ldots$$

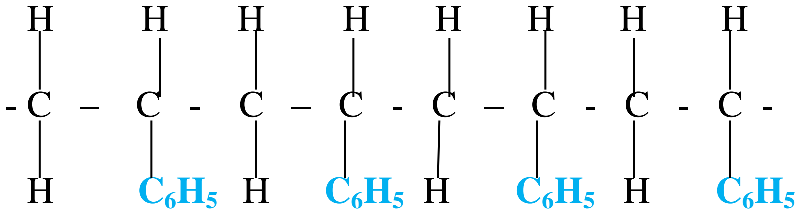
(iii)the free radicals collide with each other and join to form a larger molecule



$$\cdot\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}\cdot + \ldots$$

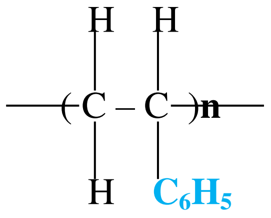
Lone pair of electrons can be used to join more monomers to form longer polyphenylethene.

Polyphenylethene molecule can be represented as:



$$-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}-$$

Since the molecule is a repetition of one monomer, then the polymer is:



$$-\left(\overset{H}{\underset{H}{C}}-\overset{H}{\underset{C_6H_5}{C}}\right)_n-$$

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 $\underline{4760}$ = $\underline{45.7692}$ =>$\underline{\text{45 polyphenylethene molecules}}$**(whole number)**

104

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

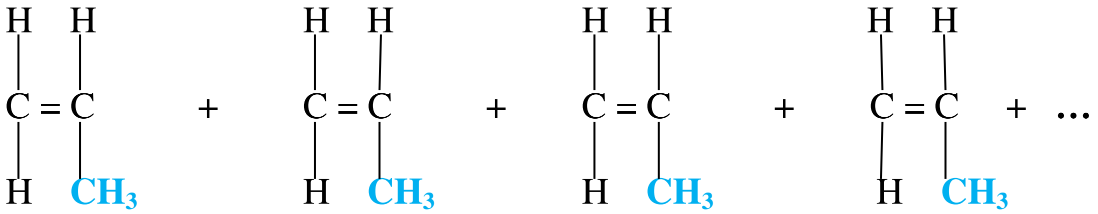
(iii)clothe linings

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.

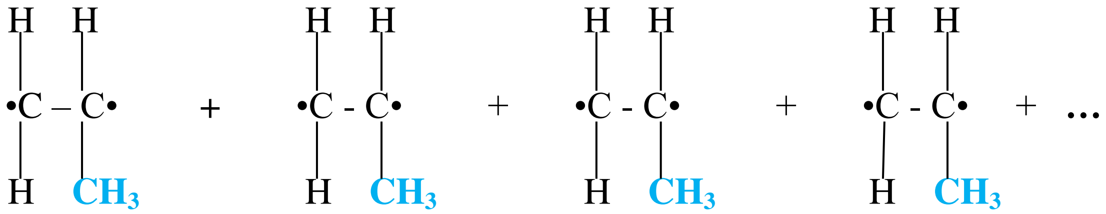
During polymerization:

(i)many molecules are brought nearer to each other by the high pressure(which reduces the volume occupied by reacting particles)

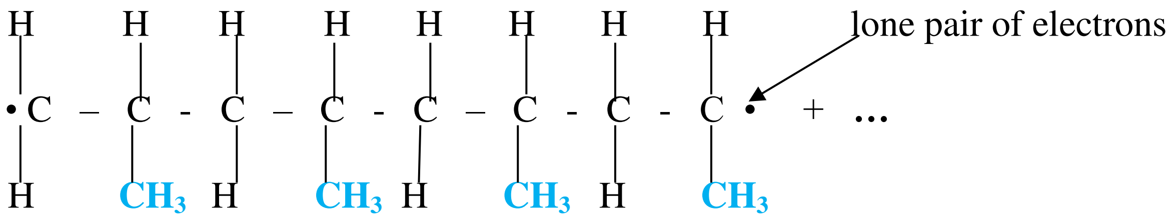


propene + propene + propene + propene + …

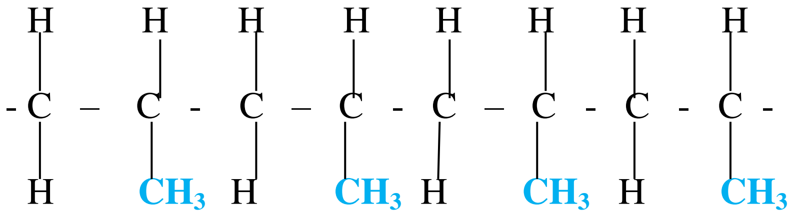
(ii)the double bond joining the phenylethene molecule break to free radicals



(iii)the free radicals collide with each other and join to form a larger molecule

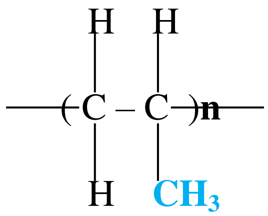


Lone pair of electrons can be used to join more monomers to form longer propene. propene molecule can be represented as:



$$\begin{array}{ccccccccccccccccc} & H & & H & & H & & H & & H & & H & & H & & H & \\ & | & & | & & | & & | & & | & & | & & | & & | & \\ - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - \\ & | & & | & & | & & | & & | & & | & & | & & | & \\ & H & & CH_3 & & H & & CH_3 & & H & & CH_3 & & H & & CH_3 & \end{array}$$

Since the molecule is a repetition of one monomer, then the polymer is:



$$\begin{array}{cccc} & H & & H \\ & | & & | \\ -(& C & - & C &)_n- \\ & | & & | \\ & H & & CH_3 \end{array}$$

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 $\frac{4760}{44}$ = 108.1818 =>108 propene 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

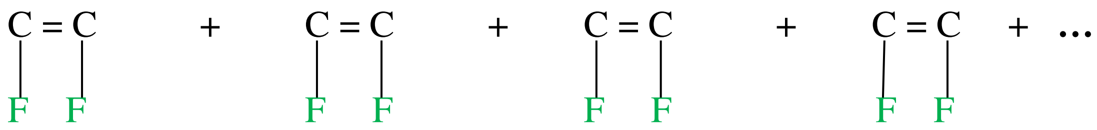
5.Formation of Polytetrafluorothene

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)

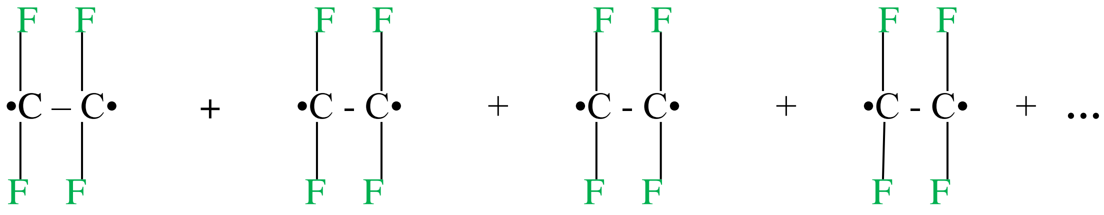
$$\begin{array}{cccccccc} F & F & F & F & F & F & F & F \\ | & | & | & | & | & | & | & | \end{array}$$



$$\underset{F}{C}=\underset{F}{C} + \underset{F}{C}=\underset{F}{C} + \underset{F}{C}=\underset{F}{C} + \underset{F}{C}=\underset{F}{C} + \ldots$$

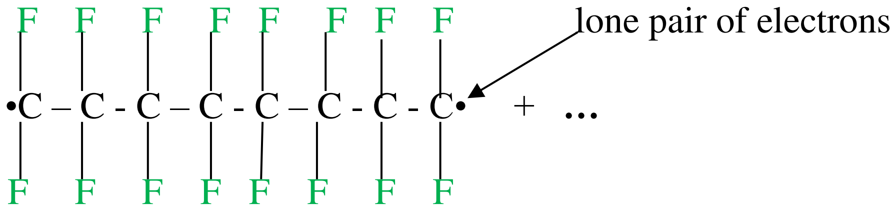
tetrafluoroethene + tetrafluoroethene+ tetrafluoroethene+ tetrafluoroethene + …

(ii)the double bond joining the tetrafluoroethene molecule break to free radicals



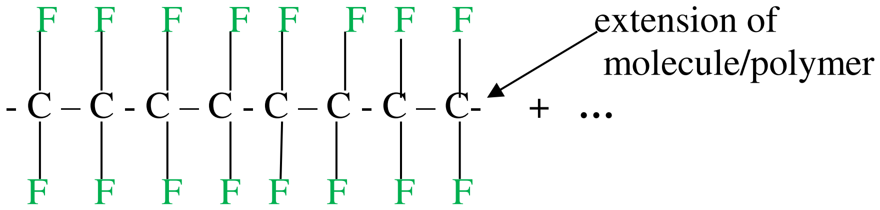
$$\bullet\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}\bullet + \bullet\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}\bullet + \bullet\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}\bullet + \bullet\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}\bullet + \ldots$$

(iii)the free radicals collide with each other and join to form a larger molecule



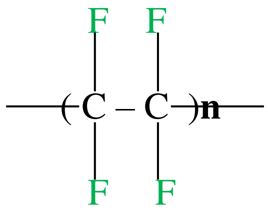
$$\bullet\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}\bullet + \ldots$$

Lone pair of electrons can be used to join more monomers to form longer polytetrafluoroethene.
polytetrafluoroethene molecule can be represented as:



$$-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}- + \ldots$$

Since the molecule is a repetition of one monomer, then the polymer is:



$$-\!\!\left(\overset{F}{\underset{F}{C}}-\overset{F}{\underset{F}{C}}\right)_{\mathbf{n}}\!\!-$$

<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 $\frac{4760}{62.5}$ = 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.

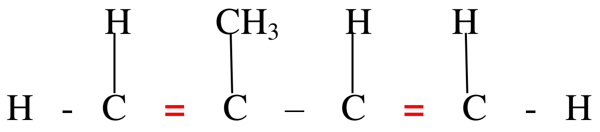
During harvesting an incision is made on the rubber tree to produce a milky white substance called **latex.**

Latex is a mixture of rubber and lots of water.

The latex is then added an acid to coagulate the rubber.

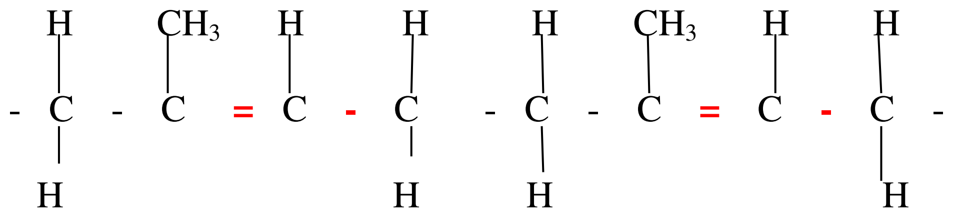
Natural rubber is a polymer of 2-methylbut-1,3-diene ;

$CH_2{=}C\,(CH_3)\,CH = CH_2$



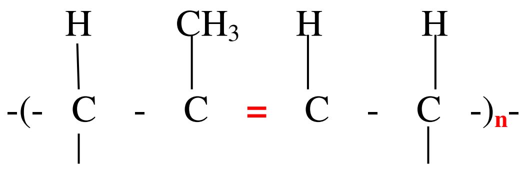
$$\mathrm{H-\overset{H}{C}=\overset{CH_3}{C}-\overset{H}{C}=\overset{H}{C}-H}$$

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;



$$\mathrm{-\underset{H}{\overset{H}{C}}-\overset{CH_3}{C}=\overset{H}{C}-\underset{H}{\overset{H}{C}}\quad-\underset{H}{\overset{H}{C}}-\overset{CH_3}{C}=\overset{H}{C}-\underset{H}{\overset{H}{C}}-}$$

Generally the structure of rubber is thus;

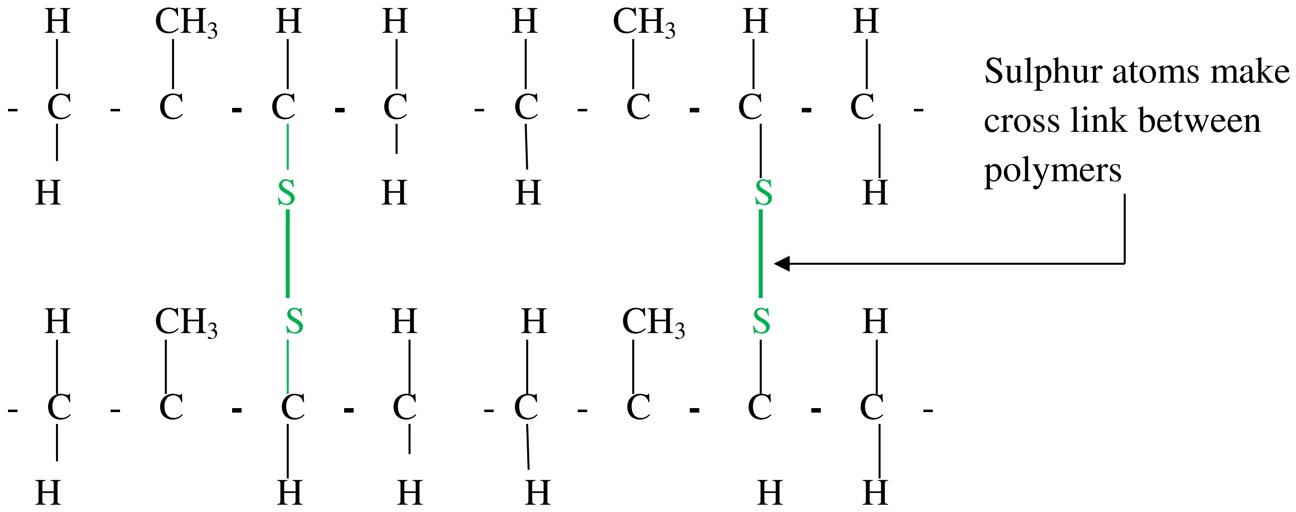


$$\mathrm{-(-\underset{|}{\overset{H}{C}}-\overset{CH_3}{C}=\overset{H}{C}-\underset{|}{\overset{H}{C}}-)_n-}$$

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.



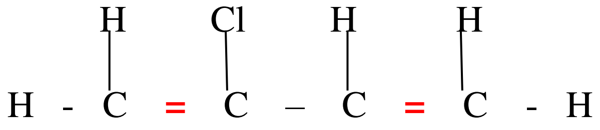
Vulcanized rubber is used to make **tyres**, **shoes** and **valves**.

6.Formation of synthetic rubber

Synthetic rubber is able to resist action of oil,abrasion and organic solvents which rubber cannot.

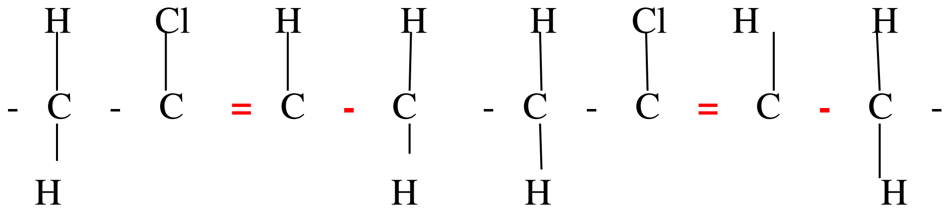
Common synthetic rubber is a polymer of 2-chlorobut-1,3-diene ;

CH_2=C (Cl CH = CH$_2$

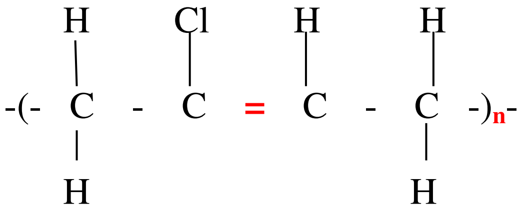


$$\mathrm{H - \overset{H}{\underset{}{C}} = \overset{Cl}{C} - \overset{H}{C} = \overset{H}{C} - H}$$

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;



$$-(-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{Cl}{|}}{C}=\overset{\overset{H}{|}}{C}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-)_n-$$

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

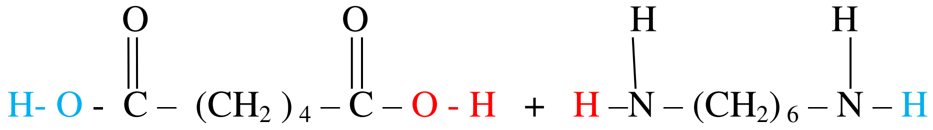
Examples of condensation polymerization

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.

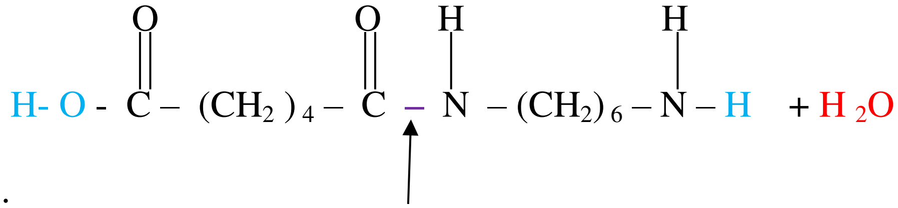
During the formation of Nylon-6,6:

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



$$H-O-\overset{\overset{O}{\|}}{C}-(CH_2)_4-\overset{\overset{O}{\|}}{C}-O-H + H-\overset{\overset{H}{|}}{N}-(CH_2)_6-\overset{\overset{H}{|}}{N}-H$$

(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 .



$$H-O-\overset{O}{\overset{\|}{C}}-(CH_2)_4-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{N}}-(CH_2)_6-\overset{H}{\overset{|}{N}}-H \;+ H_2O$$

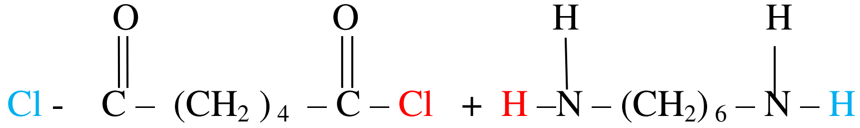
Polymer bond linkage

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

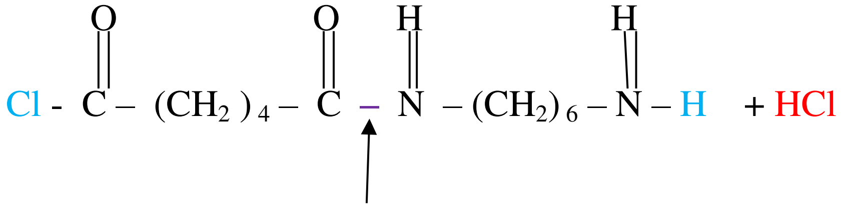
During the formation of Nylon-6,6:

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



$$Cl-\overset{O}{\overset{\|}{C}}-(CH_2)_4-\overset{O}{\overset{\|}{C}}-Cl \;+\; H-\overset{H}{\overset{|}{N}}-(CH_2)_6-\overset{H}{\overset{|}{N}}-H$$

(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 .



$$Cl-\overset{O}{\overset{\|}{C}}-(CH_2)_4-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{\|}{N}}-(CH_2)_6-\overset{H}{\overset{\|}{N}}-H \;+ HCl$$

Polymer bond 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.**

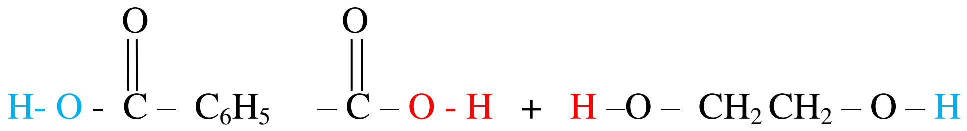
<u>2.Formation of Terylene</u>

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.

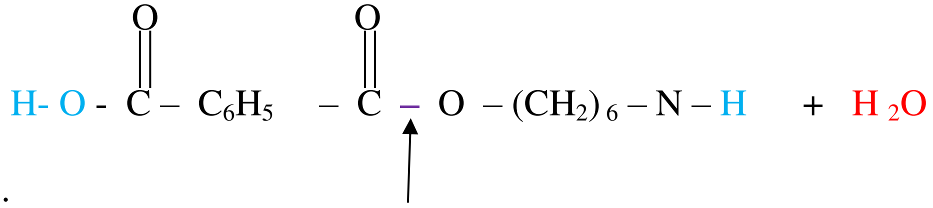
During the formation of Terylene:

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



$$H-O-\overset{O}{\overset{\|}{C}}-C_6H_5-\overset{O}{\overset{\|}{C}}-O-H + H-O-CH_2CH_2-O-H$$

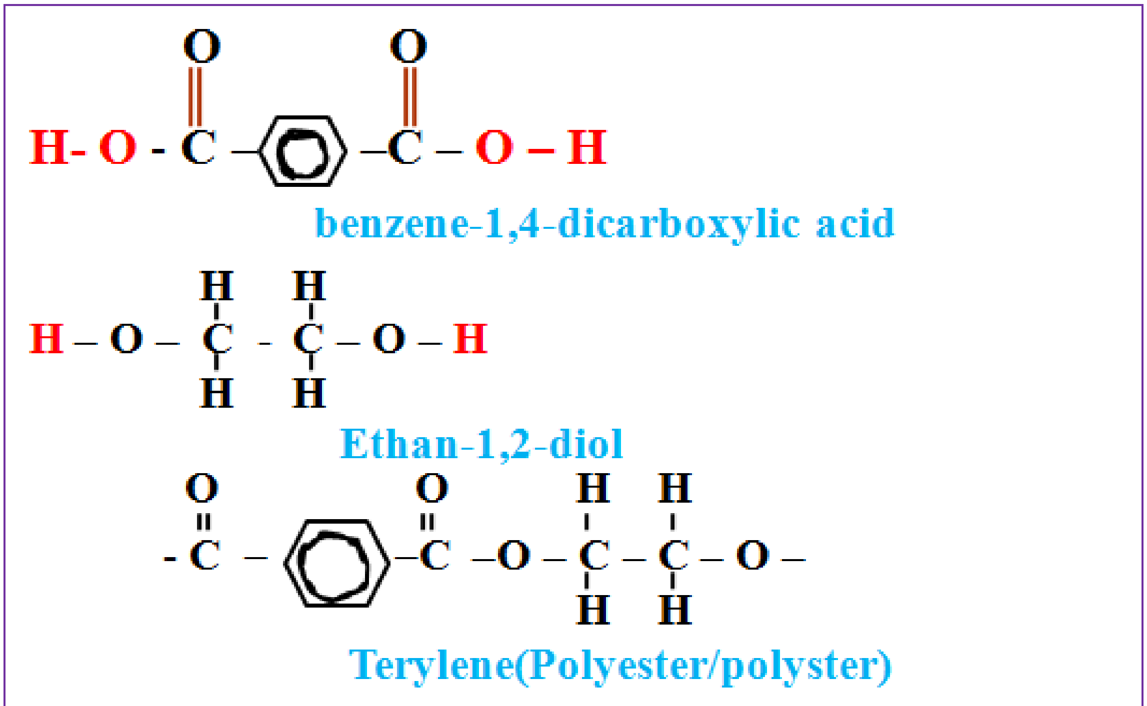
(iii)from each functional group an element is removed so as to form a molecule of H_2O and the two monomers join at the linkage .



$$H-O-\overset{O}{\overset{\|}{C}}-C_6H_5-\overset{O}{\overset{\|}{C}}-O-(CH_2)_6-N-H + H_2O$$

.

Polymer bond linkage of terylene



Condensation polymerization of Benzene-1,4-dicarboxylic acid and Ethan-1,2-diol to form Terylene

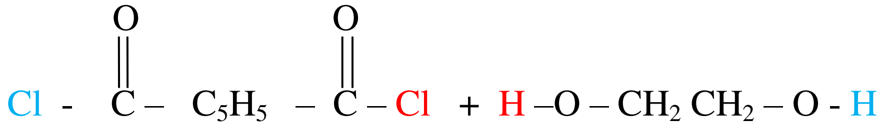
Method 2: Terylene can be made from the condensation polymerization of benzene-1,4-dioyl dichloride with ethan-1,2-diol.

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

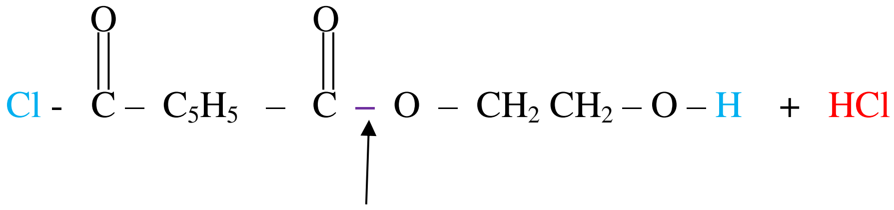
During the formation of Terylene

(i)the two monomers are brought together by high pressure to reduce distance between them and realign themselves at the functional groups.



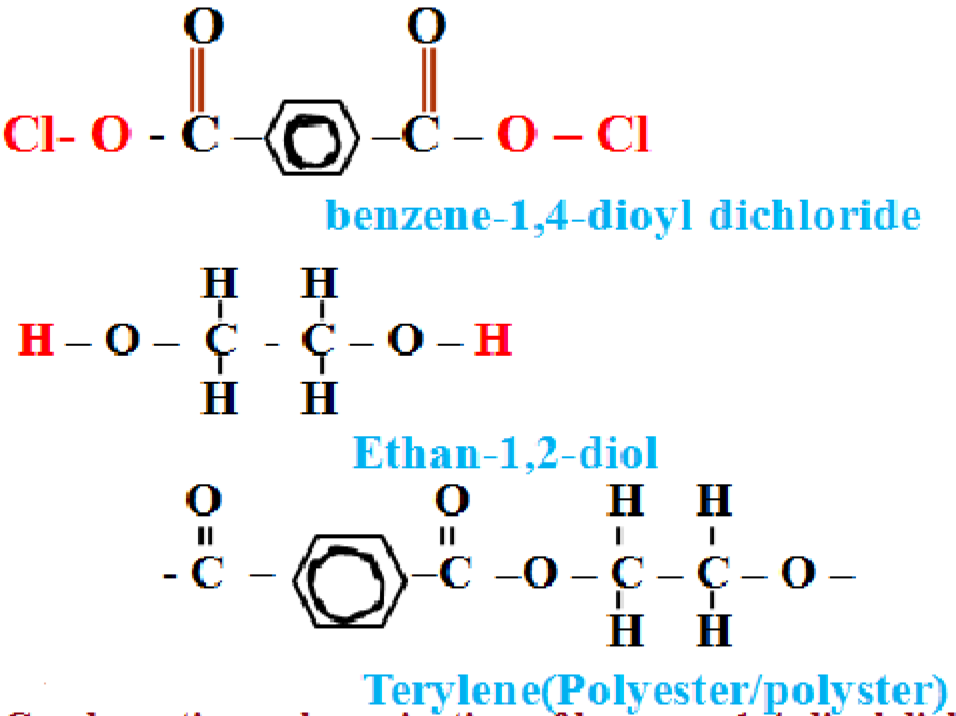
$$Cl - \overset{\overset{O}{\|}}{C} - C_5H_5 - \overset{\overset{O}{\|}}{C} - Cl + H-O-CH_2\,CH_2-O-H$$

(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 .



$$Cl - \overset{\overset{O}{\|}}{C} - C_5H_5 - \overset{\overset{O}{\|}}{C} - O - CH_2\,CH_2 - O - H + HCl$$

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

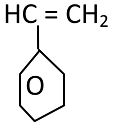
(i) Name and write the formula of the main products

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

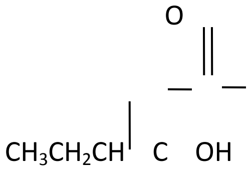
3. Explain the environmental effects of burning plastics in air as a disposal method

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:



$CH_3CH_2CH-\overset{O}{\overset{\|}{C}}-OH$

(a) Write the structural formula of the repeat unit of the polymer

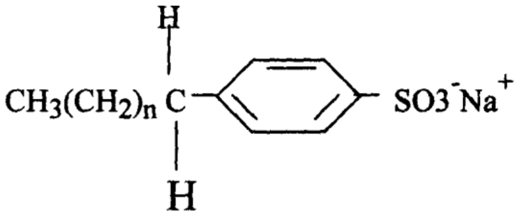
(b) When 5.0 x 10^{-5} moles of the polymer were hydrolysed, 0.515g of the monomer

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**



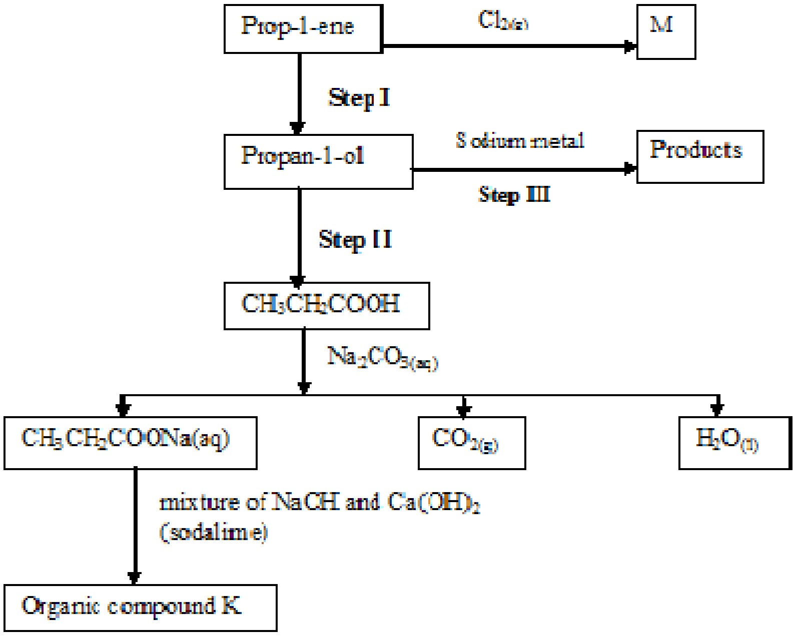
Agent A

$CH_3(CH_2)_6COO^-Na^+$

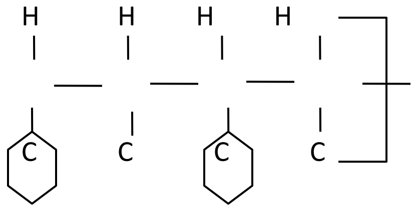
Agent B

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

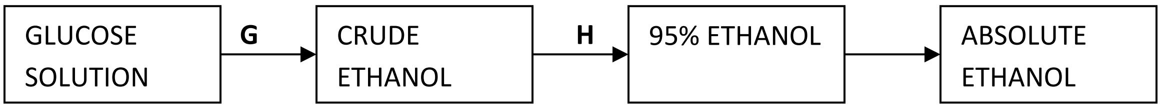
(b) Identify the type of polymerization that takes place

(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

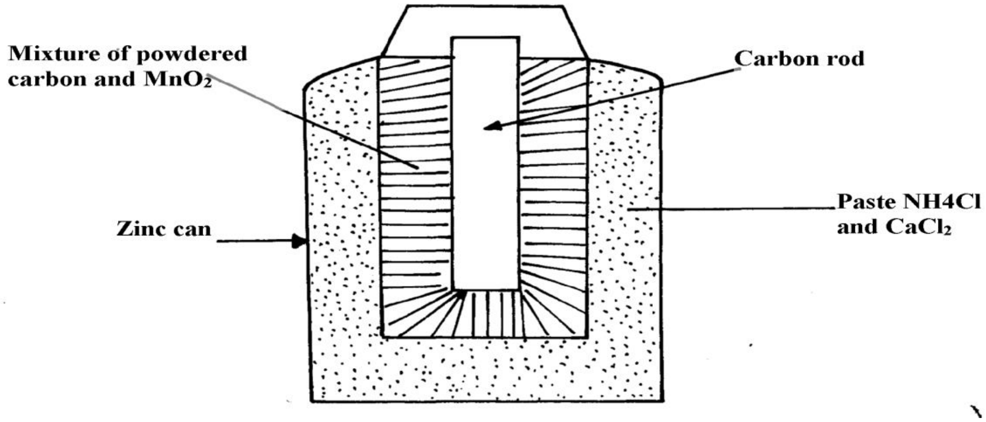
(ii) Determine the rate of reaction at time 156 seconds

(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

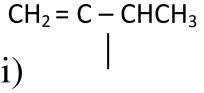
through the above cell for 30minutes (1F =96500c Zn =65)

12. (a) Give the IUPAC names of the following compounds:

(i) $CH_3COOCH_2CH_3$

*

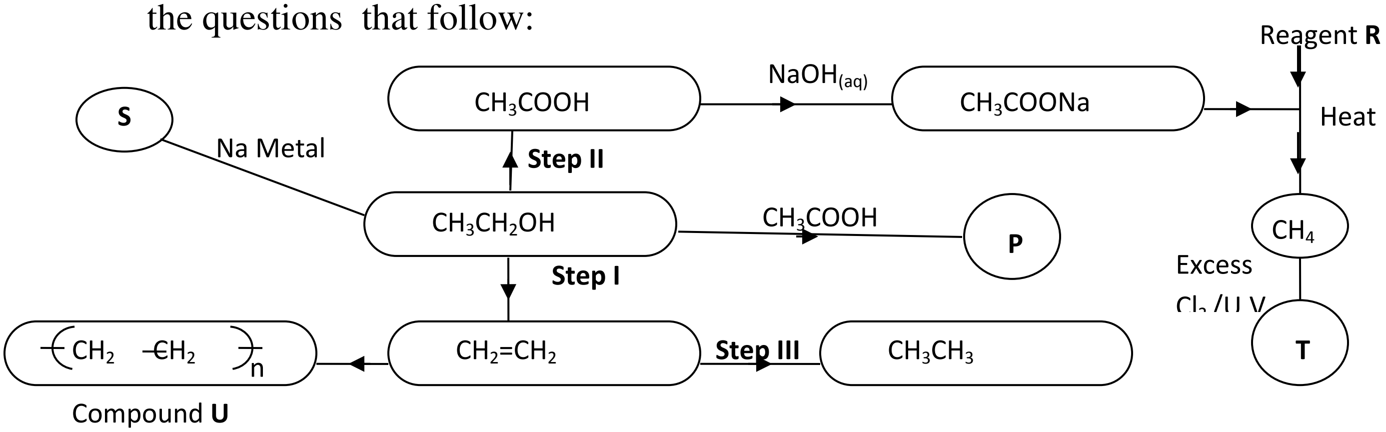
(ii)



$CH_2 = C - CHCH_3$

(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

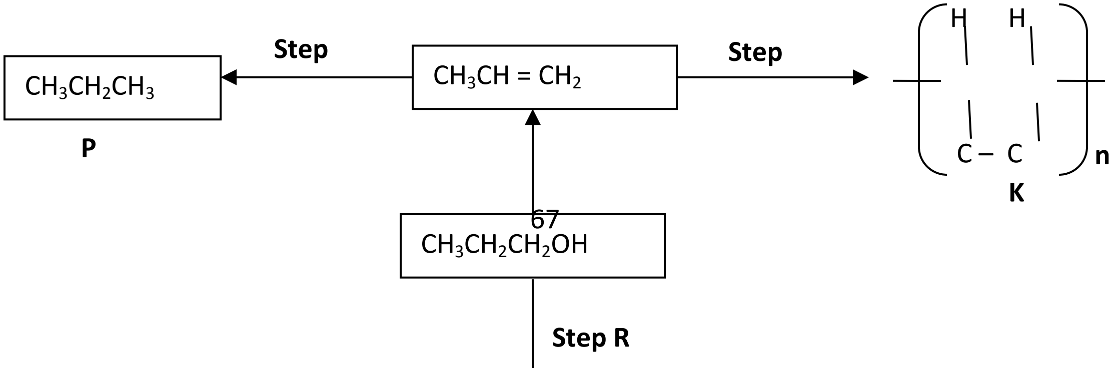
*

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**

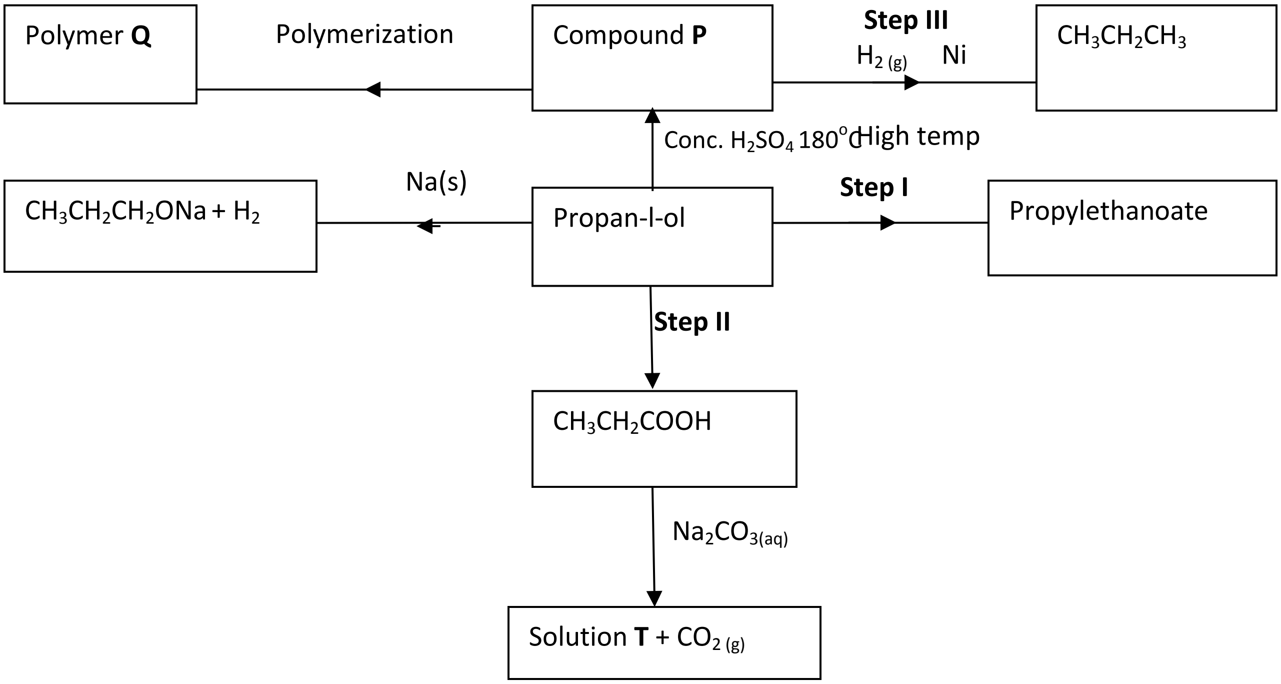
iv) Give **one** use of substance **K**

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

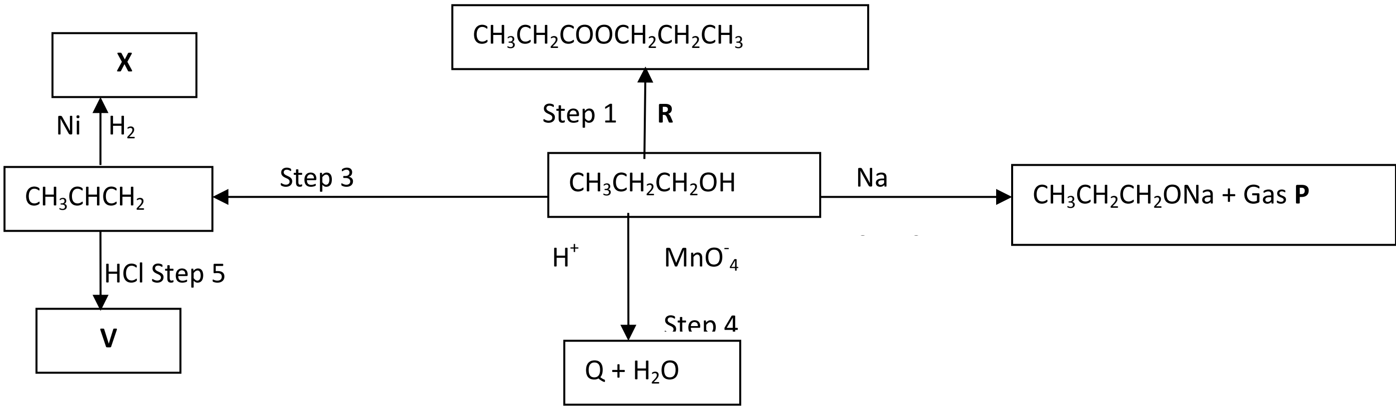
answer

(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:

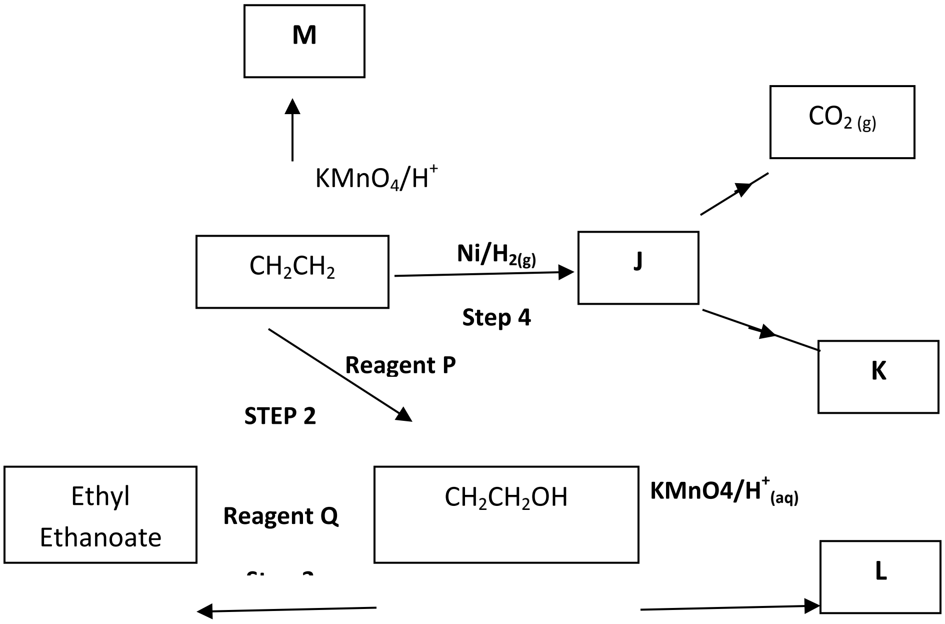
Step 1..

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) $CH_3CH_2CH_2CH_2OH$

……………………………………………………………………

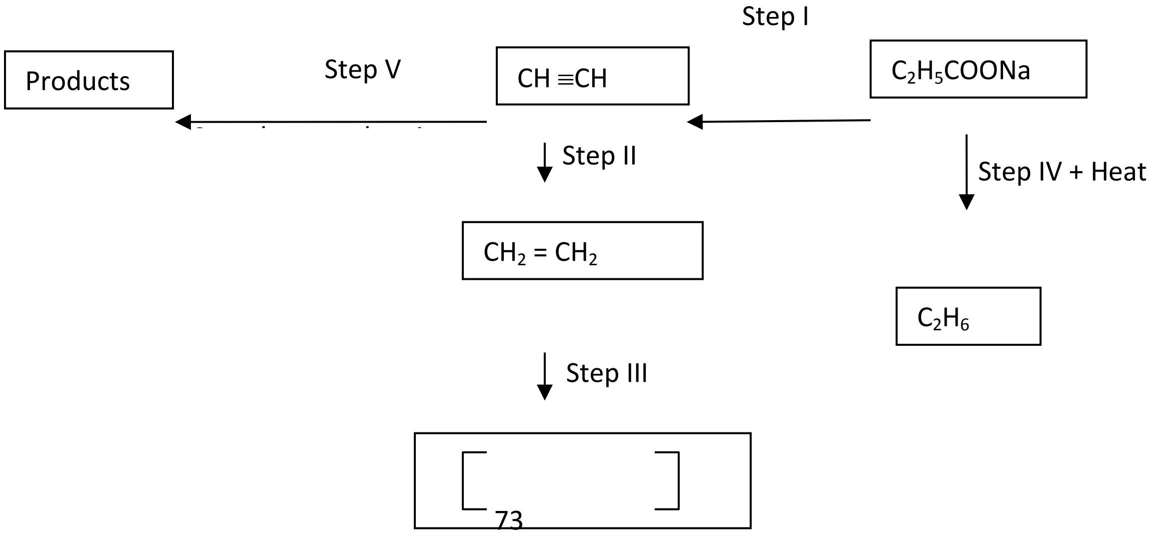
ii) CH_3CH_2COOH

……………………………………………………………………

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)

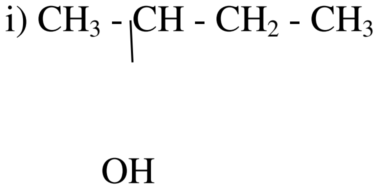
20. Write an equation to show products formed for the complete combustion of CH = CH

iii) Explain **one** disadvantage of continued use of items made form the compound formed

in step III

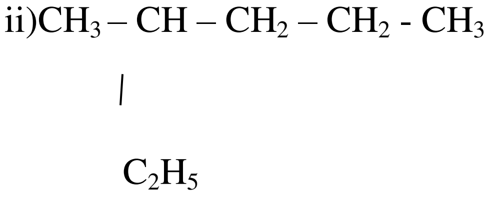
21. Give the IUPAC name for each of the following organic compounds;

i)



$$CH_3-\underset{\substack{|\\ OH}}{CH}-CH_2-CH_3$$

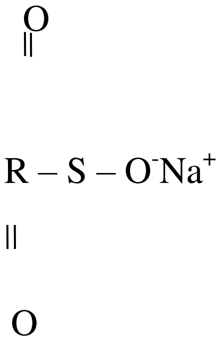
ii)



$$CH_3-\underset{\substack{|\\ C_2H_5}}{CH}-CH_2-CH_2-CH_3$$

iii) $CH_3COOCH_2CH_2CH_3$

22. The structure below represents a cleansing agent.

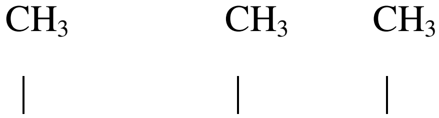


$$R-\overset{\substack{O\\ \|}}{\underset{\substack{\|\\ O}}{S}}-O^-Na^+$$

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.



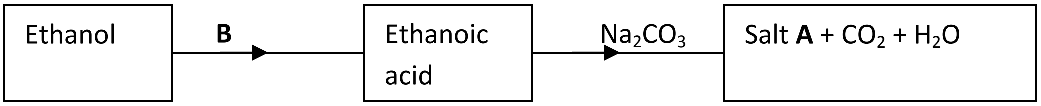
$$\begin{array}{ccc} CH_3 & CH_3 & CH_3 \\ | & | & | \end{array}$$

$— CH\ - CH_2 – CH- CH_2 - CH – CH_2 —$

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

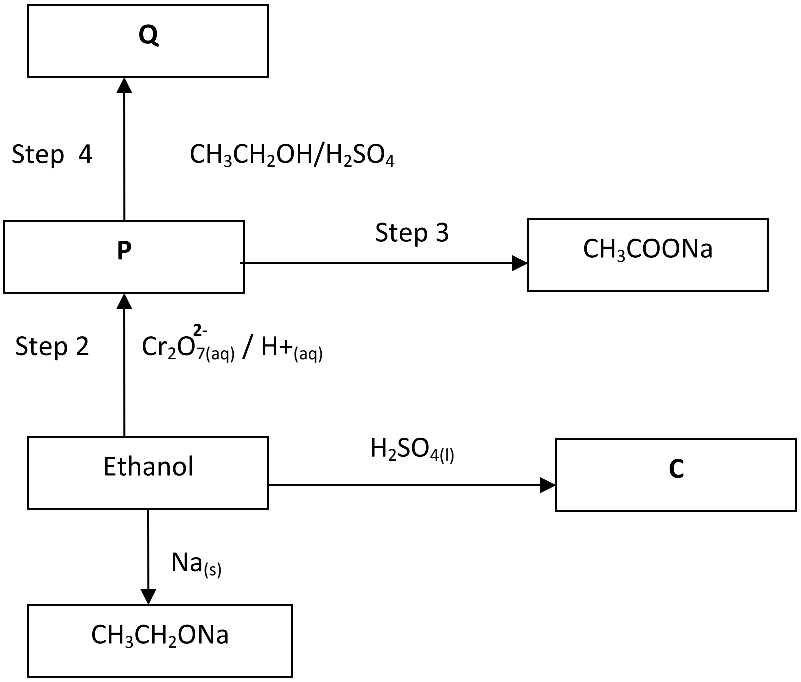
27. (a) Draw the structure of pentanoic acid

(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**

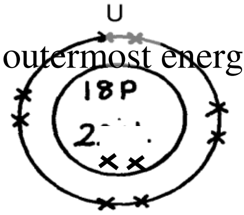
30. Below are structures of particles. Use it to answer questions that follow. In each case only electrons in the outermost energy level are shown

key

P = Proton

N = Neutron

X = Electron



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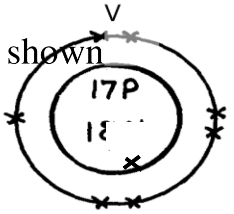

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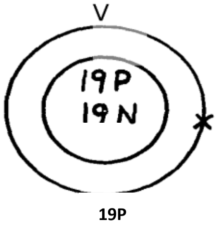
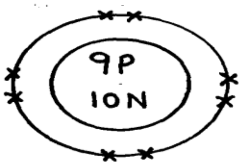
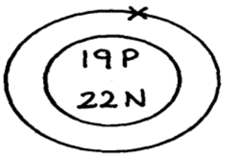


W



Y



Z

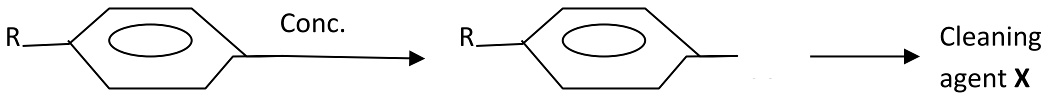
(a) Identify the particle which is an anion

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

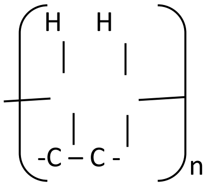
(b) State **one** disadvantage of using **X** as a cleaning agent

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:-



$$\left(-\overset{\overset{H}{|}}{\underset{|}{C}}-\overset{\overset{H}{|}}{\underset{|}{C}}- \right)_n$$

(i) Name the polymer above...

(ii) Determine the value of **n** if giant molecule had relative molecular mass of 4956

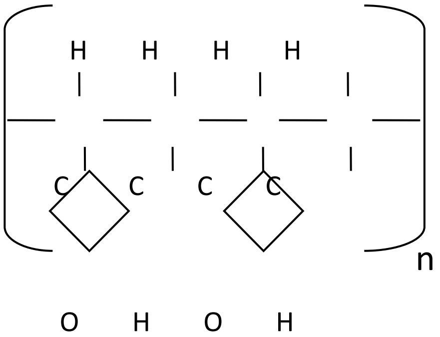
35. $RCOO^-Na^+$ and $RCH_2OSO_3^-Na^+$ are two types of cleansing agents;

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

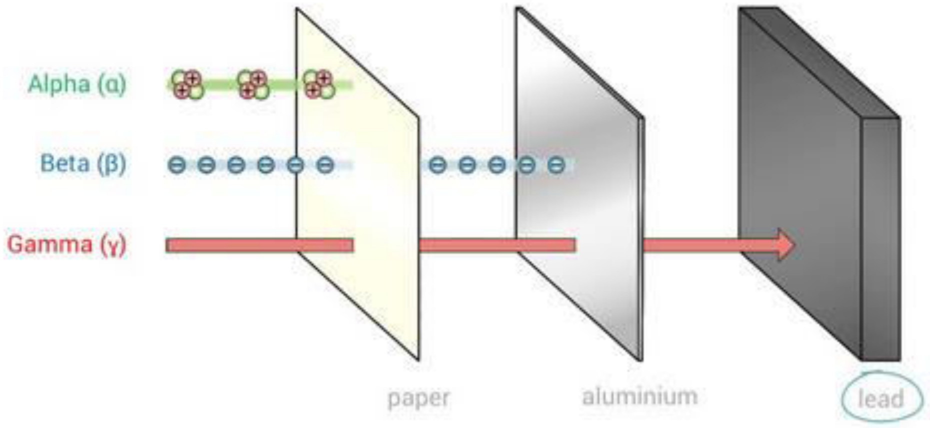
36. The formula given below represents a portion of a polymer



(a) Give the name of the polymer

(b) Draw the structure of the monomer used to manufacture the polymer

24.0.0 RADIOACTIVITY (10 LESSONS)



Contents

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- Beta (β) particle
- Gamma(y) particle

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C. HALF-LIFE PERIOD AND DECAY CURVES

D .CHEMICAL vs NUCLEAR REACTIONS

E .APPLICATION OF RADIOACTIVITY AND RADIO ISOTOPES.

F. DANGERS OF RADIOACTIVITY AND RADIO ISOTOPES.

G. COMPREHENSIVE REVISION QUESTIONS

A: INTRODUCTION / CAUSES OF RADIOCTIVITY

Radioactivity is the spontaneous disintegration/decay of an unstable nuclide.

A nuclide is an atom with defined mass number (number of protons and neutrons), atomic number and definite energy.

Radioactivity takes place in the nucleus of an atom unlike chemical reactions that take place in the energy levels involving electrons.

A nuclide is said to be stable if its neutron: proton ratio is equal to one (n/p = 1)

All nuclide therefore try to **attain n/p = 1** by undergoing radioactivity.

Examples

(i)Oxygen nuclide with $^{16}_{8}O$ has **8** neutrons and **8** protons in the nucleus therefore an **n/p = 1** thus **stable** and do **not** decay/disintegrate.

(ii)Chlorine nuclide with $^{35}_{17}Cl$ has **18** neutrons and **17** protons in the nucleus therefore an n/p = 1.0588 thus **unstable** and **decays**/disintegrates to try to attain n/p = 1.

(ii)Uranium nuclide with $^{237}_{92}U$ has 206 neutrons and 92 protons in the nucleus therefore an n/p = 2.2391 thus more unstable than $^{235}_{92}U$ and thus more readily decays / disintegrates to try to attain n/p = 1.

(iii) Chlorine nuclide with $^{37}_{17}Cl$ has **20** neutrons and **17** protons in the nucleus therefore an n/p = 1.1765 thus **more unstable** than $^{35}_{17}Cl$ and thus more **readily** decays / disintegrates to try to attain n/p = 1.

(iv)Uranium nuclide with $^{235}_{92}U$ has **143** neutrons and **92** protons in the nucleus therefore an n/p = 1.5543 thus more **stable** than $^{237}_{92}U$ but also **readily** decays / disintegrates to try to attain n/p = 1.

All **unstable** nuclides naturally try to attain nuclear **stability** with the production of:

(i)alpha(α) particle decay

The alpha (α) particle has the following main characteristic:

i)is **positive**ly charged(like protons)

ii) has mass number **4** and atomic number **2** therefore equal to a charged Helium atom ($\mathbf{^{4}_{2}He^{2+}}$)

iii) have very **low** penetrating power and thus can be stopped /blocked/shielded by a thin sheet of **paper.**

iv) have **high** ionizing power thus cause a lot of **damage** to living cells.

v) a nuclide undergoing α-decay has its mass number **reduced** by **4** and its atomic number **reduced** by **2**

<u>Examples of alpha decay</u>

$^{210}_{84}Pb \quad \rightarrow \quad ^{x}_{82}Pb \quad + \quad ^{4}_{2}He^{2+}$

$\mathbf{^{210}_{84}Pb \quad \rightarrow \quad ^{206}_{82}Pb \quad + \quad ^{4}_{2}He^{2+}}$

$^{226}_{88}\text{Ra}$ -> $^{222}_{y}\text{Rn}$ + $^{4}_{2}\text{He}^{2+}$
$^{\mathbf{226}}_{\mathbf{88}}\mathbf{Ra}$ **->** $^{\mathbf{222}}_{\mathbf{86}}\mathbf{Rn}$ **+** $^{\mathbf{4}}_{\mathbf{2}}\mathbf{He}^{\mathbf{2+}}$

$^{x}_{y}\text{U}$ -> $^{234}_{90}\text{Th}$ + $^{4}_{2}\text{He}^{2+}$
$^{\mathbf{238}}_{\mathbf{92}}\mathbf{U}$ **->** $^{\mathbf{234}}_{\mathbf{90}}\mathbf{Th}$ **+** $^{\mathbf{4}}_{\mathbf{2}}\mathbf{He}^{\mathbf{2+}}$

$^{x}_{y}\text{U}$ -> $^{230}_{88}\text{Ra}$ + $2\ ^{4}_{2}\text{He}^{2+}$
$^{\mathbf{238}}_{\mathbf{92}}\mathbf{U}$ **->** $^{\mathbf{230}}_{\mathbf{88}}\mathbf{Ra}$ **+** $\mathbf{2}\ ^{\mathbf{4}}_{\mathbf{2}}\mathbf{He}^{\mathbf{2+}}$

$^{210}_{84}\text{U}$ -> $^{x}_{y}\text{W}$ + $10\ \alpha$
$^{\mathbf{210}}_{\mathbf{84}}\mathbf{U}$ **->** $^{\mathbf{170}}_{\mathbf{64}}\mathbf{W}$ **+** $\mathbf{10}\ \boldsymbol{\alpha}$

$^{210}_{92}\text{U}$ -> $^{x}_{y}\text{W}$ + $6\ \alpha$
$^{\mathbf{210}}_{\mathbf{92}}\mathbf{U}$ **->** $^{\mathbf{186}}_{\mathbf{80}}\mathbf{W}$ **+** $\mathbf{6}\ \boldsymbol{\alpha}$

(ii)Beta (β) particle decay

The Beta (β) particle has the following main characteristic:
i)is negatively charged(like electrons)
ii)has no mass number and atomic number negative one(-1) therefore equal to a fast moving electron ($^{\mathbf{0}}_{\mathbf{-1}}\mathbf{e}$)
iii) have medium penetrating power and thus can be stopped /blocked/shielded by a thin sheet of aluminium foil.
iv) have medium ionizing power thus cause less damage to living cells than the α particle.
v) a nuclide undergoing β -decay has its mass number **remain** the same and its atomic number **increase** by **1**

Examples of beta (β) decay

1. $^{23}\mathbf{x}\,\text{Na}$ -> $^{23}_{12}\text{Mg}$ + $^{0}_{-1}\text{e}$
$^{\mathbf{23}}\mathbf{11\ Na}$ **->** $^{\mathbf{23}}_{\mathbf{12}}\mathbf{Mg}$ **+** $^{\mathbf{0}}_{\mathbf{-1}}\mathbf{e}$

2. $^{234}\mathbf{x}\,\text{Th}$ -> $^{\mathbf{y}}_{91}\text{Pa}$ + $^{0}_{-1}\text{e}$
$^{\mathbf{234}}\mathbf{90\ Th}$ **->** $^{\mathbf{y}}_{\mathbf{91}}\mathbf{Pa}$ **+** $^{\mathbf{0}}_{\mathbf{-1}}\mathbf{e}$

3. $^{207}_{70}\text{Y}$ -> $\mathbf{x}_{y}\,\text{Pb}$ + 3^{0}_{-1}e
$^{\mathbf{207}}_{\mathbf{70}}\mathbf{Y}$ **->** $^{\mathbf{207}}_{\mathbf{73}}\mathbf{Pb}$ **+** $\mathbf{3}^{\mathbf{0}}_{\mathbf{-1}}\mathbf{e}$

4. $\mathbf{x}_{y}\text{C}$ -> $^{14}_{7}\text{N}$ + $^{0}_{-1}\text{e}$

$14_{6}C$ -> $^{14}_{7}N$ + $^{0}_{-1}e$

5. ^{1} **x** n -> $^{y}_{1}H$ + $^{0}_{-1}e$
$^{1}0\,n$ -> $^{1}_{1}H$ + $^{0}_{-1}e$

6. $^{4}_{2}He$ -> $4\,^{1}_{1}H$ + **x** $^{0}_{-1}e$
$^{4}_{2}He$ -> $4\,^{1}_{1}H$ + $2\,^{0}_{-1}e$

7. $^{228}_{88}Ra$ -> $^{228}_{90}Th$ + **x** β
$^{228}_{88}Ra$ -> $^{228}_{92}Th$ + $4\,\beta$

8. $^{232}_{90}Th$ -> $^{212}_{82}Pb$ + $2\,\beta$ + **x** α
$^{232}_{90}Th$ -> $^{212}_{82}Pb$ + $2\,\beta$ + $5\,\alpha$

9. $^{238}_{92}U$ -> $^{226}_{88}Ra$ + **x** β + $3\,\alpha$
$^{238}_{92}U$ -> $^{226}_{88}Ra$ + $2\,\beta$ + $3\,\alpha$

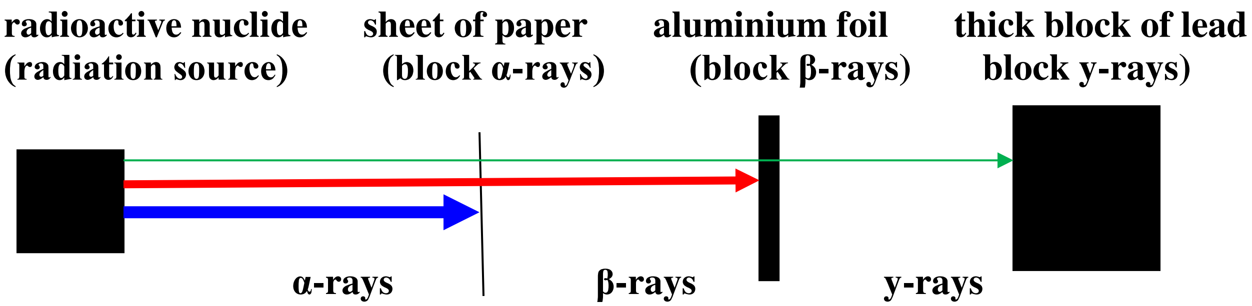
10. $^{218}_{84}Po$ -> $^{206}_{82}Pb$ + **x** β + $3\,\alpha$
$^{218}_{84}Po$ -> $^{206}_{82}Pb$ + 4β + $3\,\alpha$

(iii)Gamma (y) particle decay
The gamma (y) particle has the following main characteristic:
i)is **neither** negatively charged(like electrons/beta) nor positively charged(like protons/alpha) therefore **neutral**.
ii)has **no** mass number and atomic number therefore equal to **electromagnetic waves**.
iii) have very **high** penetrating power and thus can be stopped /blocked/shielded by a thick block of lead..
iv) have very **low** ionizing power thus cause less damage to living cells unless on prolonged exposure..
v) a nuclide undergoing y -decay has its mass number and its atomic number **remain** the **same**.

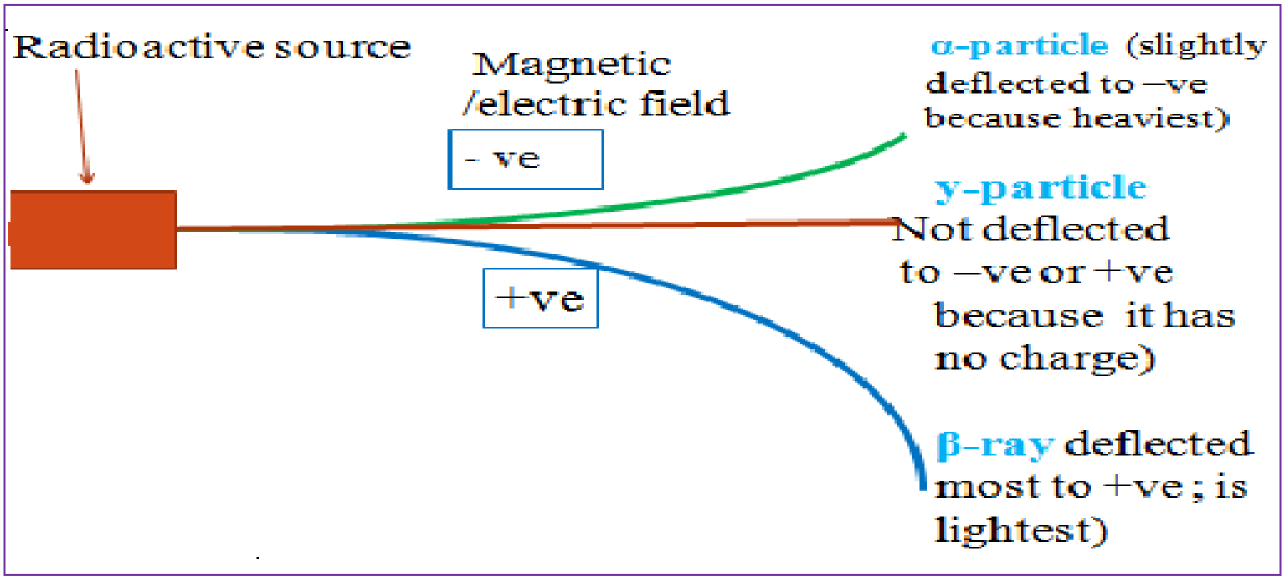
Examples of gamma (y) decay

- $^{37}_{17}Cl$ -> $^{37}_{17}Cl$ + y
- $^{14}_{6}C$ -> $^{14}_{6}C$ + y

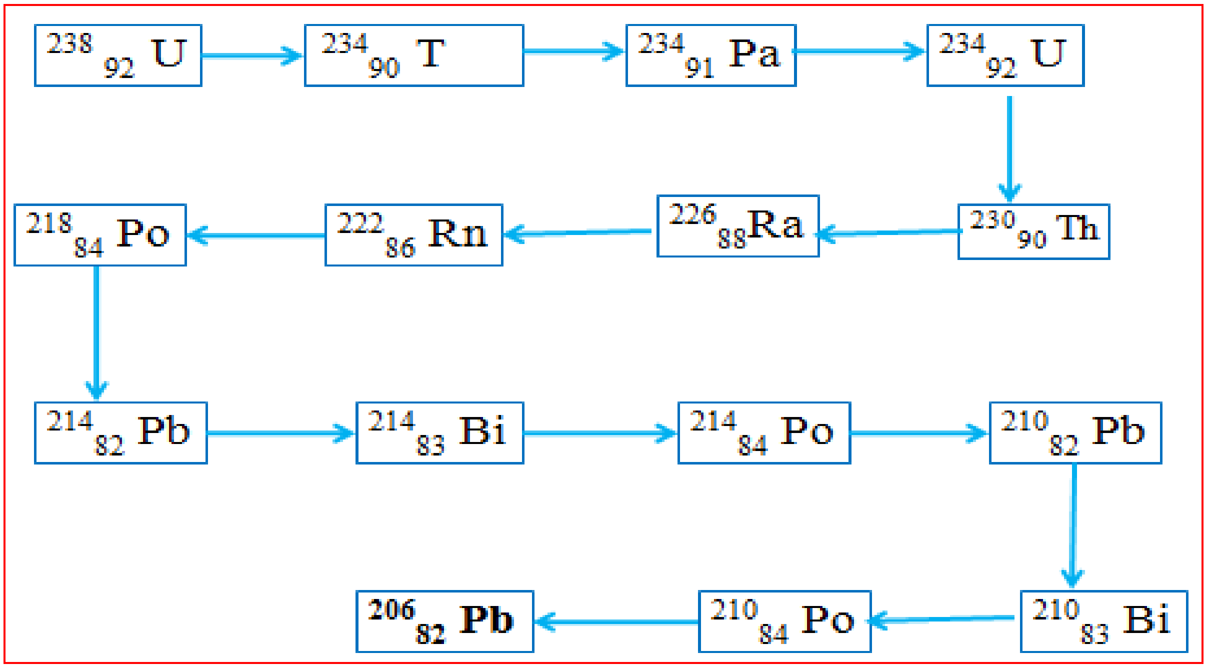
The sketch diagram below shows the **penetrating power** of the radiations from a radioactive nuclide.



The sketch diagram below illustrates the effect of **electric /magnetic field** on the three radiations from a radioactive nuclide



Radioactive disintegration/decay **naturally** produces the stable $^{206}_{82}$Pb nuclide /isotope of lead.Below is the $^{238}_{92}$U natural decay series. Identify the particle emitted in each case



Write the nuclear equation for the disintegration from :

(i) $^{238}_{92}\mathrm{U}$ to $^{234}_{90}\mathrm{T}$

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{T} + {}^{4}_{2}\mathrm{He}^{2+}$$

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{T} + \alpha$$

(ii) $^{238}_{92}\mathrm{U}$ to $^{222}_{84}\mathrm{Rn}$

$$^{238}_{92}\mathrm{U} \rightarrow {}^{222}_{84}\mathrm{Rn} + 4\,{}^{4}_{2}\mathrm{He}^{2+}$$

$$^{238}_{92}\mathrm{U} \rightarrow {}^{222}_{84}\mathrm{Rn} + 4\alpha$$

$^{230}_{90}\mathrm{Th}$ undergoes alpha decay to $^{222}_{86}\mathrm{Rn}$. Find the number of α particles emitted. Write the nuclear equation for the disintegration.

Working

$$^{230}_{90}\mathrm{Th} \rightarrow {}^{222}_{86}\mathrm{Rn} + x\,{}^{4}_{2}\mathrm{He}$$

Method 1

Using mass numbers

$$230 = 222 + 4x \Rightarrow 4x = 230 - 222 = \underline{8}$$

$$x = 8/4 = \underline{2\,\alpha}$$

Using atomic numbers

$$90 = 86 + 2x \Rightarrow 2x = 90 - 86 = \underline{4}$$

$$x = 4/2 = \underline{2\,\alpha}$$

Nuclear equation

$$^{230}_{90}\mathrm{Th} \rightarrow {}^{222}_{86}\mathrm{Rn} + 2\,{}^{4}_{2}\mathrm{He}$$

$^{214}_{82}$Pb undergoes beta decay to $^{214}_{84}$Rn. Find the number of β particles emitted. Write the nuclear equation for the disintegration.

Working

$^{214}_{82}\text{Pb} \rightarrow {}^{214}_{84}\text{Rn} + \mathbf{x\,^{0}_{-1}e}$

Using atomic numbers only

$$82 = 84 - x \Rightarrow -x = 82 - 84 = \underline{-2}$$

$$x = \underline{2\beta}$$

Nuclear equation

$^{214}_{82}\text{Pb} \rightarrow {}^{214}_{84}\text{Rn} + \mathbf{2\,^{0}_{-1}e}$

$^{238}_{92}$U undergoes beta and alpha decay to $^{206}_{82}$Pb. Find the number of β and α particles emitted. Write the nuclear equation for the disintegration.

Working

$^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + \mathbf{x\,^{0}_{-1}e + y\,^{4}_{2}He}$

Using Mass numbers only

$$238 = 206 + 4y \Rightarrow 4y = 238 - 206 = \underline{32}$$

$$y = \frac{32}{4} = \underline{8\alpha}$$

Using atomic numbers only and substituting the 8 α(above)

$^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + 8\,^{4}_{2}\text{He} + x\,^{0}_{-1}\text{e}$

$$92 = 82 + 16 + -x$$

$$\Rightarrow 92 - (82 + 16) = -x$$

$$x = \underline{6\beta}$$

Nuclear equation

$^{238}_{92}\text{U} \rightarrow {}^{206}_{82}\text{Pb} + \mathbf{6\,^{0}_{-1}e + 8\,^{4}_{2}He}$

$^{298}_{92}$U undergoes alpha and beta decay to $^{214}_{83}$Bi. Find the number of α and β particles emitted. Write the nuclear equation for the disintegration.

Working

$^{298}_{92}\text{U} \rightarrow {}^{210}_{83}\text{Bi} + \mathbf{x\,^{4}_{2}He + y\,^{0}_{-1}e}$

Using Mass numbers only

$$298 = 214 + 4x \Rightarrow 4x = 298 - 214 = \underline{84}$$

$$y = \frac{84}{4} = \underline{21\alpha}$$

Using atomic numbers only and substituting the 21 α (above)

$^{238}_{92}\text{U} \rightarrow {}^{214}_{83}\text{Bi} + 21\,^{4}_{2}\text{He} + y\,^{0}_{-1}\text{e}$

$$92 = 83 + 42 + -y$$

=> 92 – (83 + 42) = - x

x = <u>33 ß</u>

<u>Nuclear equation</u>

$$\mathbf{{}^{298}_{92}U \rightarrow {}^{210}_{83}Bi + 21\,{}^{4}_{2}He + 33\,{}^{0}_{-1}e}$$

<u>B:NUCLEAR FISSION AND NUCLEAR FUSION</u>

Radioactive disintegration/decay can be initiated in an industrial laboratory through two chemical methods:

a) nuclear **fission**
b) nuclear **fusion.**

a)<u>Nuclear fission</u>

Nuclear fission is the process which a fast moving neutron bombards /hits /knocks a heavy **unstable** nuclide releasing l**ighter** nuclide, **three** daughter neutrons and a large quantity of **energy.**

Nuclear fission is the basic chemistry behind **nuclear bombs** made in the nuclear reactors.

The three daughter neutrons becomes again fast moving neutron bombarding / hitting /knocking a heavy unstable nuclide releasing lighter nuclides, three more daughter neutrons each and a larger quantity of energy setting of a **chain reaction**

Examples of nuclear equations showing nuclear fission

$${}^{1}_{0}n + {}^{235}_{b}U \rightarrow {}^{90}_{38}Sr + {}^{c}_{54}Xe + 3\,{}^{1}_{0}n + a$$

$${}^{1}_{0}n + {}^{27}_{13}Al \rightarrow {}^{28}_{13}Al + y + a$$

$${}^{1}_{0}n + {}^{28}_{a}Al \rightarrow {}^{b}_{11}Na + {}^{4}_{2}He$$

$${}^{a}_{0}n + {}^{14}_{7}N \rightarrow {}^{14}_{b}C + {}^{1}_{1}H$$

$${}^{1}_{0}n + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + a$$

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{95}_{42}Mo + {}^{139}_{57}La + 2\,{}^{1}_{0}n + 7\,a$$

b) <u>Nuclear fusion</u>

Nuclear fusion is the process which **smaller** nuclides join together to form **larger /** heavier nuclides and releasing a large quantity of **energy**.

Very high temperatures and pressure is required to overcome the repulsion between the atoms.

Nuclear fusion is the basic chemistry behind solar/sun radiation.

Two daughter atoms/nuclides of Hydrogen fuse/join to form Helium atom/nuclide on the surface of the sun releasing large quantity of energy in form of heat and light.

$^{2}_{1}H \quad + \quad ^{2}_{1}H \quad -> \quad ^{a}_{b}He \quad + \quad ^{1}_{0}n$

$^{2}_{1}H \quad + \quad a \quad -> \quad ^{3}_{2}He$

$^{2}_{1}H \quad + \quad ^{2}_{1}H \quad -> \quad a \quad + \quad ^{1}_{1}H$

$4\ ^{1}_{1}H \quad -> \quad ^{4}_{2}He \quad + \quad a$

$^{14}_{7}H \quad + \quad a \quad -> \quad ^{17}_{8}O \quad + \quad ^{1}_{1}H$

C: HALF LIFE PERIOD ($t^{1}/_{2}$)

The half-life period is the **time** taken for a radioactive nuclide to spontaneously decay/ disintegrate to **half** its **original** mass/ amount.

It is usually denoted **$t\ ^{1}/_{2}$**.

The rate of radioactive nuclide disintegration/decay is **<u>constant</u>** for each nuclide.

The table below shows the half-life period of some elements.

Element/Nuclide	**Half-life period($t\ ^{1}/_{2}$)**
$^{238}_{92}U$	4.5×10^{9} years
$^{14}_{6}C$	5600 years
$^{229}_{88}Ra$	1620 years
$^{35}_{15}P$	14 days
$^{210}_{84}Po$	0.0002 seconds

The **less** the half life the **more <u>unstable</u>** the nuclide /element.

The half-life period is determined by using a Geiger-Muller counter (**GM tube**) .A GM tube is connected to ratemeter that records the **count-rates per unit time**.

This is the rate of decay/ disintegration of the nuclide.

If the count-rates per unit time **fall** by **half**, then the **time** taken for this **fall** is the half-life period.

Examples

a)A radioactive substance gave a count of 240 counts per minute but after 6 hours the count rate were 30 counts per minute. Calculate the half-life period of the substance.

If $t\ {}^1/_2 = x$

then 240 --x-->120 –x-->60 –x--->30

From 240 to 30 =3x =6 hours

=>x $= t\ {}^1/_2 = (6 / 3)$

= **2 hours**

b) The count rate of a nuclide fell from 200 counts per second to 12.5 counts per second in 120 minutes.

Calculate the half-life period of the nuclide.

If $t\ {}^1/_2 = x$

then

200 --x-->100 –x-->50 –x--->25 –x--->12.5

From 200 to 12.5 =4x =120 minutes

=>x $= t\ {}^1/_2 = (120 / 4)$

= **30 minutes**

c) After 6 hours the count rate of a nuclide fell from 240 counts per second to 15 counts per second on the GM tube. Calculate the half-life period of the nuclide.

If $t\ {}^1/_2 = x$

then 240 --x-->120 –x-->60 –x--->30 –x--->15

From 240 to 15 =4x =6 hours

=>x $= t\ {}^1/_2 = (6 / 4)$= **1.5 hours**

d) Calculate the mass of nitrogen-13 that remain from 2 grams after 6 half-lifes if the half-life period of nitrogen-13 is 10 minutes.

If $t\ {}^1/_2 = x$ then:

2 --**x**-->1 –**2x**-->0.5 –**3x**--->0.25 –**4x**-->0.125–**5x**--->0.0625–**6x**--->0.03125

After the 6th half life **0.03125 g** of nitrogen-13 remain.

e) What fraction of a gas remains after 1hour if its half-life period is 20 minutes?

If $t\ {}^1/_2 = x$ then:

then 60 /20 = 3x

1 --x--> $^1/_2$ –2x--> $^1/_4$ –3x---> $^1/_8$

After the 3rd half-life **$\underline{^1/_8}$** of the gas remain

f) 348 grams of a nuclide A was reduced to 43.5 grams after 270days.Determine the half-life period of the nuclide.

If $t\,^1/_2 = x$ then:
348 --x-->174 –2x-->87 –3x--->43.5
From 348 to 43.5=3x =270days
=>x $= t\,^1/_2 = (270 / 3)$
= 90 days

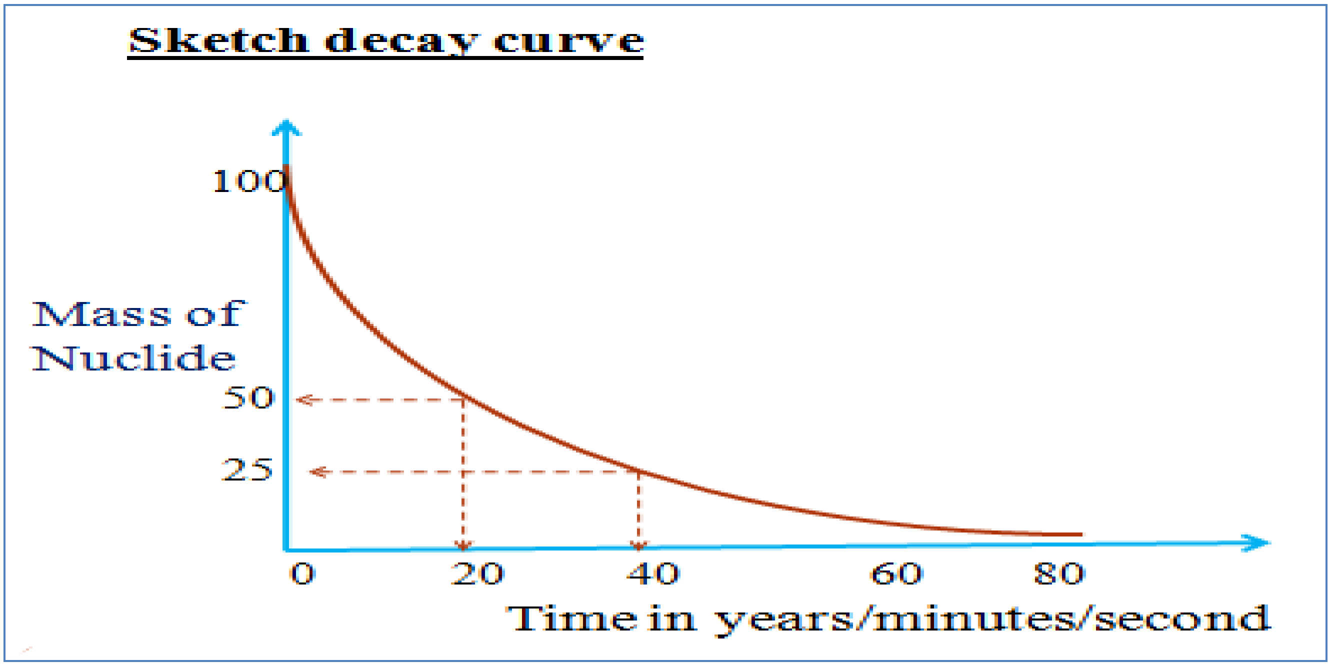
g) How old is an Egyptian Pharaoh in a tomb with 2grams of ^{14}C if the normal ^{14}C in a present tomb is 16grams.The half-life period of ^{14}C is 5600years.

If $t\,^1/_2 = x = 5600$ years then:
16 --x-->8 –2x-->4 –3x--->2
3x = (3 x 5600)
= <u>16800years</u>

h) 100 grams of a radioactive isotope was reduced 12.5 grams after 81days.Determine the half-life period of the isotope.

If $t\,^1/_2 = x$ then:
100 --x-->50 –2x-->25 –3x--->12.5
From 100 to 12.5=3x =81days
=>x $= t\,^1/_2$
= (81 / 3)
= **<u>27 days</u>**

A graph of activity against time is called **decay curve.**
A decay curve can be used to determine the half-life period of an isotope since activity decrease at equal time interval to half the original



(i)From the graph show and determine the half-life period of the isotope.

From the graph $t\ ^{1}/_{2}$ changes in activity from:
(100 – 50) => (20 – 0) = **20** minutes
(50 – 25) => (40 – 20) = **20** minutes
Thus $t^{1/2}$ = **<u>20 minutes</u>**

(ii)Why does the graph tend to 'O'?
Smaller particle/s will disintegrate /decay to half its original.
There can <u>never</u> be 'O'/zero particles

D: CHEMICAL vs NUCLEAR REACTIONS

Nuclear and chemical reaction has the following **similarities**:
(i)-both involve the **subatomic** particles; electrons, protons and neutrons in an atom
(ii)-both involve the subatomic particles trying to make the atom more **stable**.
(iii)-Some for of **energy** transfer/release/absorb from/to the environment take place.

Nuclear and chemical reaction has the following **differences**:

(i) Nuclear reactions mainly involve **protons** and **neutrons** in the **nucleus** of an atom.

Chemical reactions mainly involve outer **electrons** in the **energy levels** an atom.

(ii) Nuclear reactions form a **new element**.

Chemical reactions **do not** form new elements

(iii) Nuclear reactions mainly involve evolution/production of **large** quantity of **heat/energy**.

Chemical reactions produce or absorb **small** quantity of heat/energy.

(iv)Nuclear reactions are accompanied by a **loss** in **mass**/mass defect.Do not obey the **law of conservation of matter**.

Chemical reactions are not accompanied by a loss in mass/ mass defect hence obey the law of conservation of matter.

(v)The **rate** of decay/ disintegration of the nuclide is **independent** of **physical** conditions (temperature/pressure /purityp/article size)

The rate of a chemical reaction is **dependent** on physical **conditions** (temperature/pressure/purity/particle size/ surface area)

E: APPLICATION AND USES OF RADIOCTIVITY.

The following are some of the fields that apply and use radioisotopes;

a)**Medicine: -**Treatment of cancer to **kill** malignant tumors through **radiotherapy.**

-**Sterilizing** hospital /surgical instruments /equipments by exposing them to gamma radiation.

b) Agriculture:

If a plant or animal is fed with radioisotope, the metabolic processes of the plant/animal is better understood by **tracing** the route of the radioisotope.

c) Food preservation:

X-rays are used to kill bacteria in **tinned** food to last for a long time.

d) Chemistry:

To study **mechanisms** of a chemical reaction, one reactant is **replaced** in its structure by a radioisotope e.g.

During esterification the **'O'** joining the ester was discovered comes from the **alkanol** and not alkanoic acid.

During photosynthesis the **'O'** released was discovered comes from **water**.

e) Dating rocks/fossils:

The quantity of ^{14}**C** in living things (plants/animals) is **constant.**

When they die the fixed mass of ^{14}C is t**rapped** in the cells and **continues** to decay/disintegrate.

The half-life period of ^{14}C is 5600 years .

Comparing the mass of ^{14}C in l**iving** and **dead** cells, the age of the dead can be determined.

F: DANGERS OF RADIOCTIVITY.

All rays emitted by radioactive isotopes have **ionizing effect** of changing the **genetic** make up of living cells.

Exposure to theses radiations causes **chromosomal** and /or **genetic** mutation in living cells.

Living things should therefore **not** be exposed for a long time to radioactive substances.

One of the main uses of radioactive isotopes is in generation of large cheap **electricity** in nuclear reactors.

Those who work in these reactors must wear protective devises made of **thick** glass or l**ead** sheet.

Accidental leakages of radiations usually occur

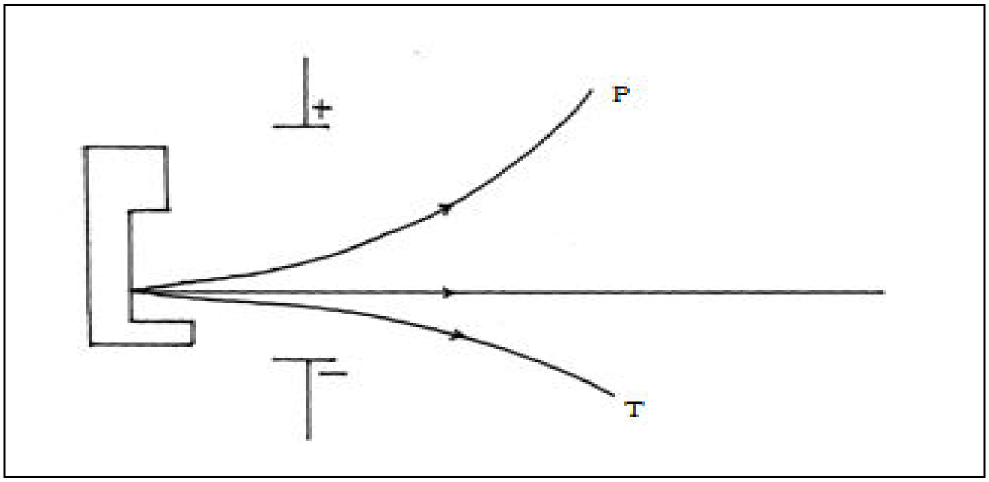
In 1986 the Nuclear reactor at **Chernobyl** in Russia had a major explosion that emitted poisonous nuclear material that caused immediate environmental disaster

In 2011, an **earthquake** in Japan caused a nuclear reactor to leak and release poisonous radioactive waste into the Indian Ocean.

The immediate and long term effects of exposure to these **poisonous** radioactive waste on human being is of major concern to all environmentalists.

G: SAMPLE REVISION QUESTIONS

The figure below shows the behaviour of emissions by a radioactive isotope x. Use it to answer the question follow



(a) Explain why isotope **X** emits radiations. (1mk)

-is unstable //has n/p ratio greater/less than one

(b) Name the radiation labeled **T** (1mk)

alpha particle

(c) Arrange the radiations labeled **P** and **T** in the increasing order of ability to be deflected by an electric filed. (1mk)

T -> P

a) Calculate the mass and atomic numbers of element B formed after $^{212}_{80}X$ has emitted three beta particles, one gamma ray and two alpha particles.

Mass number

= 212 – (0 beta+ o gamma + (2 x 4) alpha = 204

Atomic number

= 80 – (-1 x3) beta + 0 gamma + (2 x 2)) alpha =79

b)Write a balanced nuclear equations for the decay of $^{212}_{80}X$ to B using the information in (a) above.

$$\mathbf{^{212}_{80}X \rightarrow\ ^{204}_{79}B + 2\,^{4}_{2}He + 3\,^{0}_{-1}e + y}$$

Identify the type of radiation emitted from the following nuclear equations.

(i) $^{14}_{6}C \rightarrow\ ^{14}_{7}N + \ldots\ldots\ldots$

β - Beta

(ii) $^{1}_{1}H + \,^{1}_{0}n \rightarrow\ ^{2}_{1}H + \ldots\ldots$

y -gamma

(iii) $^{235}_{92}U \rightarrow\ ^{95}_{42}Mo + \,^{139}_{57}La + \,^{1}_{0}n + \ldots\ldots$

7 β – seven beta particles

(iv) $^{238}_{92}U$ -> $^{234}_{90}Th$ + … …

α-alpha

(v) $^{14}_{6}C$ + $^{1}_{1}H$ -> $^{15}_{7}N$ + ……

y-gamma

X grams of a radioactive isotope takes 100 days to disintegrate to 20 grams. If the half-life period isotope is 25 days, calculate the initial mass X of the radio isotope.

Number of half-lifes = (100 / 25) = 4
20g -----> 40g ----> 80g-----> 160g -----> 320g
Original mass X = <u>320g</u>

Radium has a half-life of 1620 years.
(i)What is half-life?
The half-life period is the time taken for a radioactive nuclide to spontaneously decay/ disintegrate to half its original mass/ amount

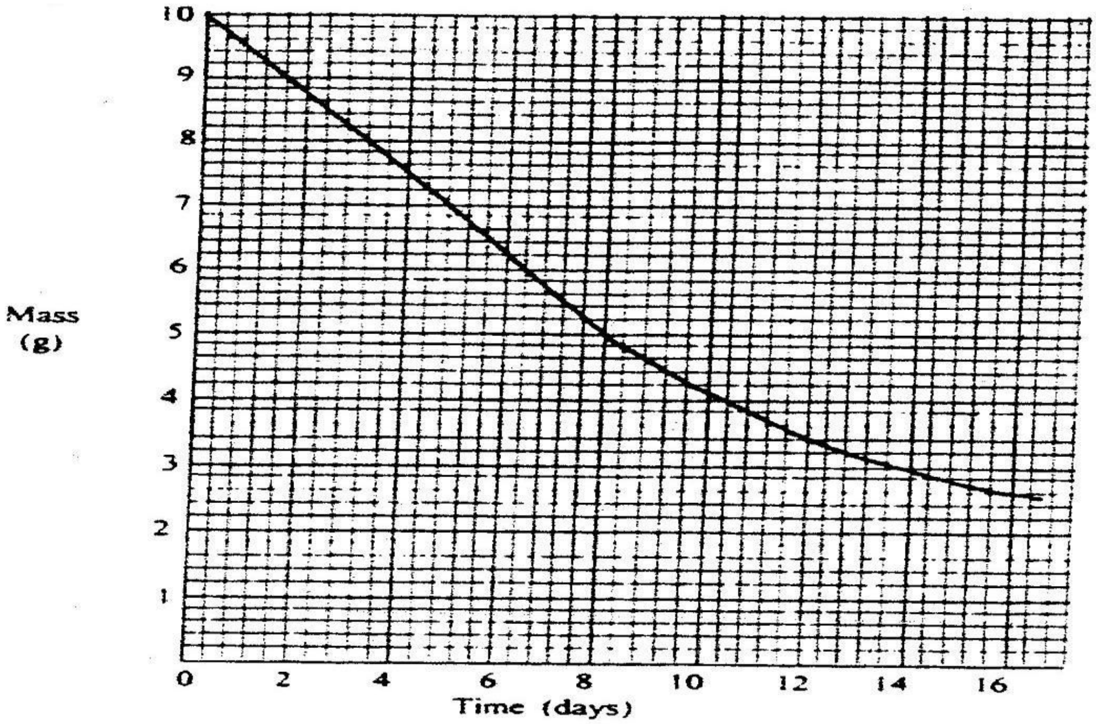
b)If one milligram of radium contains 2.68 x 10 18 atoms ,how many atoms disintegrate during 3240 years.

Number of half-lifes = (3240 / 1620) = 2
1 mg ---1620---> 0.5mg ---1620----> 0.25mg
If 1mg -> <u>2.68×10^{18} atoms</u>

Then 0.25 mg -> ($0.25 \times 2.68 \times 10^{18}$) = 6.7×10^{17}
Number of atoms remaining = <u>6.7×10^{17}</u>

-Number of atoms disintegrated =
($2.68 \times 10^{18} - 6.7 \times 10^{17}$)
= <u>2.01×10^{18}</u>

The graph below shows the mass of a radioactive isotope plotted against time



Using the graph, determine the half – life of the isotope

From graph 10 g to 5 g takes <u>8 days</u>

From graph 5 g to 2.5 g takes 16 – 8 = <u>8 days</u>

Calculate the mass of the isotope dacayed after 32 days

Number of half lifes= 32/8 = 4

Original mass = 10g

10g—1st -->5g—2nd-->2.5—3rd –>1.25—4th --><u>0.625 g</u>

Mass remaining =<u> 0.625 g</u>

Mass decayed after 32 days = 10g - 0.625 g = <u>9.375g</u>

A radioactive isotope X_2 decays by emitting two alpha (a) particles and one beta (β) to form $^{214}{}_{83}Bi$

(a)Write the nuclear equation for the radioactive decay

$^{212}_{86}X \rightarrow {}^{214}_{83}Bi + 2\,^{4}_{2}He + {}^{0}_{-1}e$

(b)What is the atomic number of X_2?

86

(c) After 112 days, 1/16 of the mass of X_2 remained. Determine the half life of X_2

1—x-> $^{1}/_{2}$ –x-> $^{1}/_{4}$ –x-> $^{1}/_{8}$–x-> $^{1}/_{16}$

Number of t $^{1}/_{2}$ in 112 days = <u>4</u>

$$t^{1}/_{2} = \frac{112}{4} = \underline{28\ \text{days}}$$

1.Study the nuclear reaction given below and answer the questions that follow.

$^{12}_{6}C$ --step 1-->$^{12}_{7}N$ --step 2--> $^{12}_{11}Na$

(a)$^{12}_{6}C$ and $^{14}_{6}C$ are isotopes. What does the term isotope mean?

Atoms of the same element with different mass number /number of neutrons.

(b)Write an equation for the nuclear reaction in step II

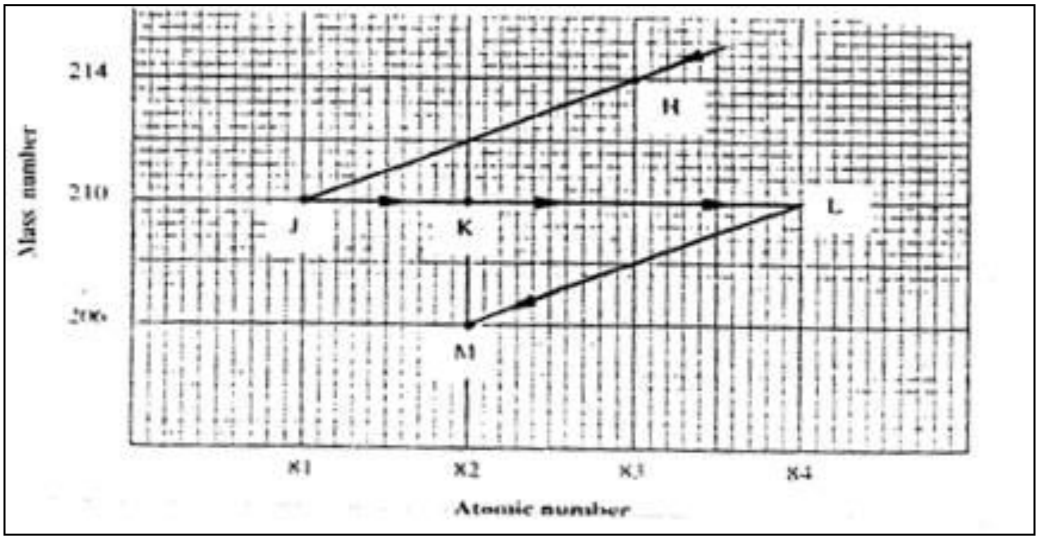
$$^{12}_{7}N \rightarrow\ ^{12}_{11}Na + \ ^{0}_{-1}e$$

(c)Give one use of $^{14}_{6}C$

Dating rocks/fossils:

Study of metabolic pathways/mechanisms on plants/animals

Study the graph of a radioactive decay series for isotope H below.



(a) Name the type of radiation emitted when isotope

(i) H changes to isotope J.

Alpha-Mass number decrease by 4 from 214 to 210(y-axis)

atomic number decrease by 2 from 83 to 81(x-axis)

(ii) J changes to isotope K

Beta-Mass number remains 210(y-axis)

atomic number increase by 1 from 81 to 82(x-axis).

(b) Write an equation for the nuclear reaction that occur when isotope

(i)J changes to isotope L

$$\mathbf{{}^{210}_{81}J \rightarrow {}^{210}_{84}L + 3\,{}^{0}_{-1}e}$$

(i)H changes to isotope M

$$\mathbf{{}^{214}_{83}H \rightarrow {}^{206}_{82}M + 3\,{}^{0}_{-1}e + 2\,{}^{4}_{2}He}$$

Identify a pair of isotope of an element in the decay series

K and M

Have same atomic number 82 but different mass number K-210 and M-206

a)A radioactive substance emits three different particles.

Identify the particle:

(i)with the highest mass.

Alpha/ α

(ii) almost equal to an electron

Beta/ β

1.a)State two differences between chemical and nuclear reactions(2mks)

(i) Nuclear reactions <u>mainly</u> involve **protons** and **neutrons** in the **nucleus** of an atom.Chemical reactions <u>mainly</u> involve outer **electrons** in the **energy levels** an atom.

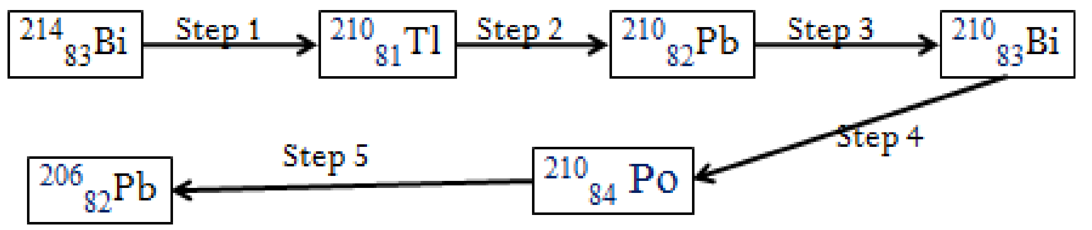
(ii) Nuclear reactions form a **new element**. Chemical reactions <u>**do not**</u> form new elements

(iii) Nuclear reactions <u>mainly</u> involve evolution/production of **large** quantity of **heat/energy.**Chemical reactions produce or absorb **smaller** quantity of heat/energy.

(iv)Nuclear reactions are accompanied by a **loss** in **mass** /mass defect. Chemical reactions <u>are not</u> accompanied by a loss in mass.

(v)**R**ate of decay/ disintegration of nuclide is <u>**independent**</u> of **physical** conditionsThe rate of a chemical reaction is <u>**dependent**</u> on physical **conditions** of temperature/pressure/purity/particle size/ surface area

b)Below is a radioactive decay series starting from $^{214}_{83}$Bi and ending at $^{206}_{82}$ Pb. Study it and answer the question that follows.



Identify the particles emitted in steps I and III (2mks)

I - **α-particle**

III - **β-ray**

ii)Write the nuclear equation for the reaction which takes place in (a) step I

$$^{214}_{83}\mathrm{Bi} \rightarrow {}^{210}_{81}\mathrm{Bi} + {}^{4}_{2}\mathrm{He}$$

(b) step 1 to 3

$$^{214}_{83}\mathrm{Bi} \rightarrow {}^{210}_{81}\mathrm{Bi} + {}^{4}_{2}\mathrm{He} + 2\ {}^{0}_{-1}e$$

(c) step 3 to 5

$$^{210}_{82}\mathrm{Pb} \rightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He} + 2\ {}^{0}_{-1}e$$

(c) step 1 to 5

$$^{214}_{83}\mathrm{Bi} \rightarrow {}^{206}_{82}\mathrm{Pb} + 2\ {}^{4}_{2}\mathrm{He} + 3\ {}^{0}_{-1}e$$

The table below give the percentages of a radioactive isotope of Bismuth that remains after decaying at different times.

Time (min)	0	6	12	22	38	62	100
Percentage of Bismuth	100	81	65	46	29	12	3

i)On the grid below , plot a graph of the percentage of Bismuth remaining(Vertical axis) against time.

ii)Using the graph, determine the:

I. Half – life of the Bismuth isotope

II. Original mass of the Bismuth isotope given that the mass that remained after 70 minutes was 0.16g (2mks)

d) Give one use of radioactive isotopes in medicine (1mk)

14.a)Distinguish between nuclear fission and nuclear fusion. (2mks)

Describe how solid wastes containing radioactive substances should be disposed of. (1mk)

b)(i)Find the values of Z_1 and Z_2 in the nuclear equation below

$$ {}^{Z1}_{92}U + {}^{1}_{0}n \rightarrow {}^{94}_{38}Sr + {}^{140}_{Z2}Xe + 2\,{}^{1}_{0}n $$

iii)What type of nuclear reaction is represented in b (i) above?

A radioactive cobalt ${}^{61}_{28}Co$ undergoes decay by emitting a beta particle and forming Nickel atom,

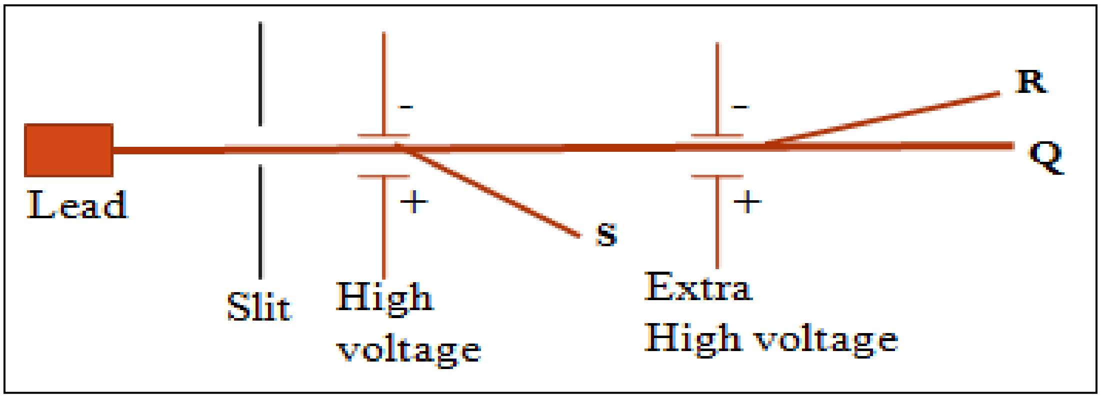
Write a balanced decay equation for the above change

1 mark

If a sample of the cobalt has an activity of 1000 counts per minute, determine the time it would take for its activity to decrease to 62.50 if the half-life of the element is 30years 2 marks

Define the term half-life.

The diagram below shows the rays emitted by a radioactive sample

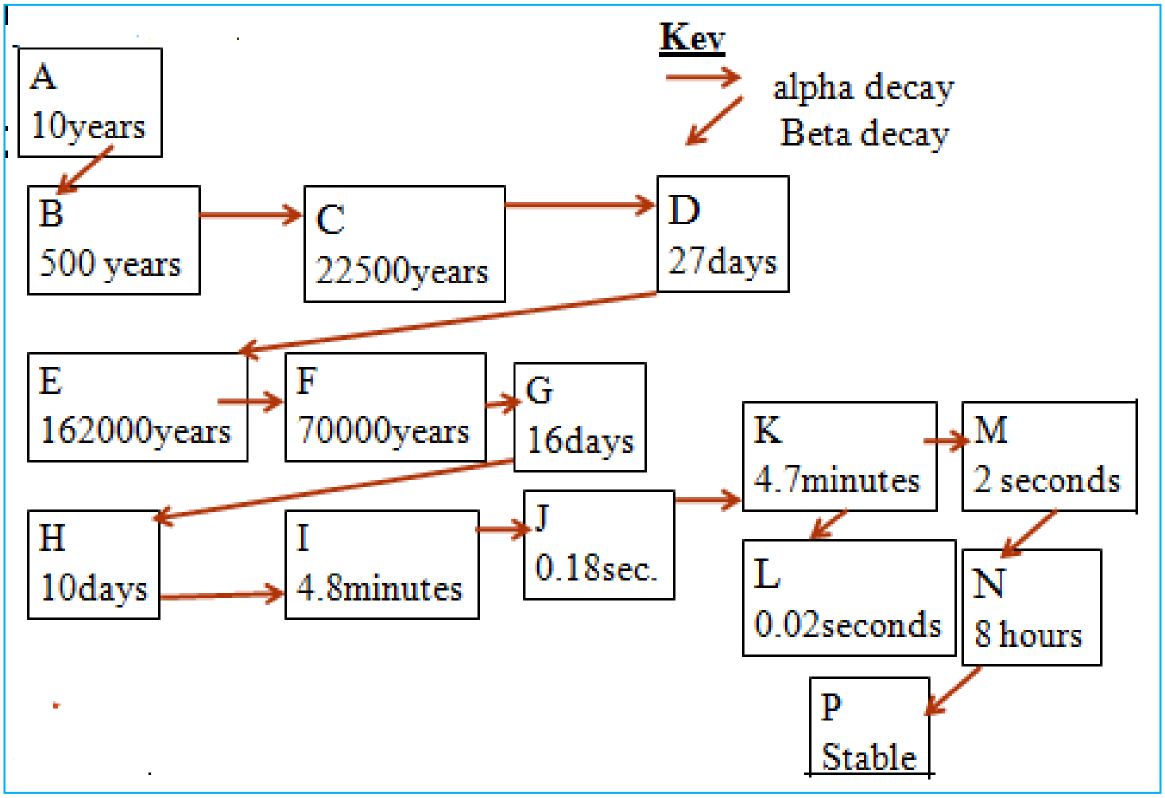


a) Identify the rays S,R and Q
   S- Beta (**β)particle/ray**
   R- Alpha (**α)particle/ray**
   Q- Gamma (**γ)particle/ray**

b) State what would happen if an aluminium plate is placed in the path of ray R,S and Q:

R-is blocked/stopped/do not pass through
Q-is not blocked/pass through
S-is blocked/stopped/do not pass through

(c) The diagram bellow is the radioactive decay series of nuclide A which is $^{241}_{94}$Pu.Use it to answer the questions that follow. The letters are not the actual symbols of the elements.



(a)Which letter represent the : Explain.

(i)shortest lived nuclide

L-has the shortest half life

(ii)longest lived nuclide

P-Is stable

(iii) nuclide with highest n/p ratio

L-has the shortest half life thus most unstable thus easily/quickly decay/disintegrate

(iv) nuclide with lowest n/p ratio

P-is stable thus do not decay/disintegrate

(b)How long would it take for the following:

(i)Nuclide A to change to B

10 years (half life of A)

(ii) Nuclide D to change to H

27days +162000years+70000years+16days

232000 years and 43 days

(iii) Nuclide A to change to P

27days +162000years+70000years+16days

232000 years and 43 days

Study

THE END