Acids ,Bases & Salts

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:

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

(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 <u>base</u>**

(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 <u>conjugate acid</u>**

(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 <u>acid</u>**

(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 <u>conjugate base</u>.**

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

I**I.** 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 <u>base</u>**

(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 <u>conjugate acid</u>**

(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 <u>acid</u>**

(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 <u>conjugate base</u>**.

4. Acids and bases show acidic and alkaline properties/characteristics <u>only</u> 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: $MCO_3(s) + 2H^+(aq) \rightarrow M^{2+}(aq) + H_2O(l) + CO_2(g)$
$M(HCO_3)_2$(**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: $ZnCO_3(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2O(l) + CO_2(g)$
$Mg(HCO_3)_2$(**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(**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

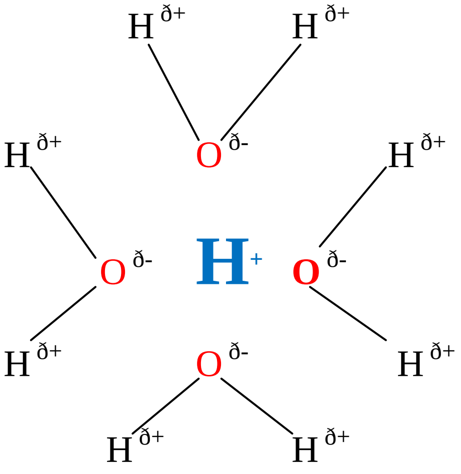
(iii)be a good electrical conductor

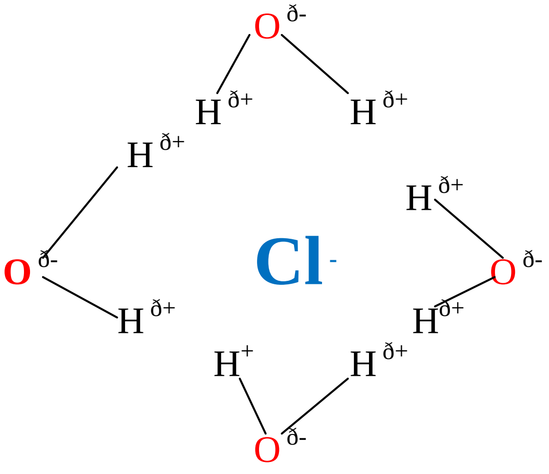
(iv)react with acids to form ammonium salt and water only.

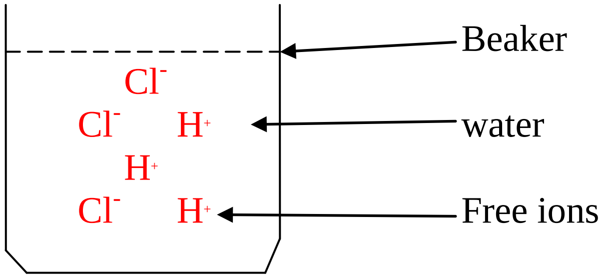
$$NH_4OH(aq) + HCl(aq) \rightarrow NH_4Cl(aq) + H_2O(l)$$

(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:







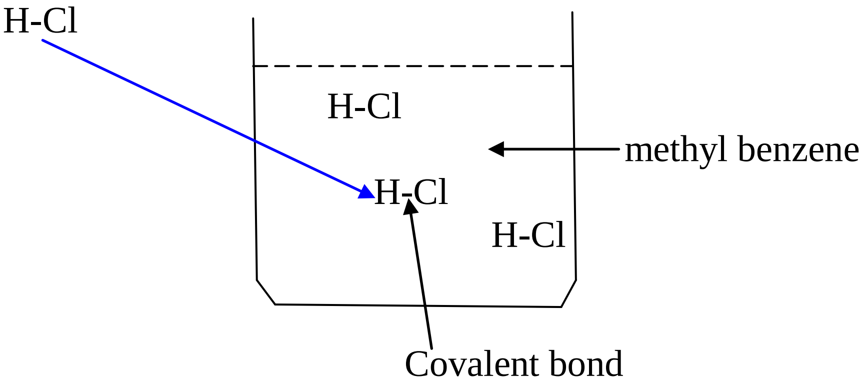
Note:Water is polar .It is made up of :

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 $\mathbf{H^+}$ ions than molecules. e.g.

$$\underset{\text{(molecules)}}{HCl(aq)} \rightleftharpoons \underset{\text{(cation)}}{H^+(aq)} + \underset{\text{(anion)}}{Cl^-(aq)}$$

$$\underset{\text{(molecules)}}{HNO_3(aq)} \rightleftharpoons \underset{\text{(cation)}}{H^+(aq)} + \underset{\text{(anion)}}{NO_3^-(aq)}$$

$$\underset{\text{(molecules)}}{H_2SO_4(aq)} \rightleftharpoons \underset{\text{(cation)}}{2H^+(aq)} + \underset{\text{(anion)}}{SO_4^{2-}(aq)}$$

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

$KOH(aq) \rightleftharpoons K^+(aq) + OH^-(aq)$
(molecules) (cation) (anion)

$NaOH(aq) \rightleftharpoons Na^+(aq) + OH^-(aq)$
(molecules) (cation) (anion)

(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.

$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$
(molecules) (cation) (anion)

$H_3PO_4(aq) \rightleftharpoons 3H^+(aq) + PO_4^{3-}(aq)$
(molecules) (cation) (anion)

$H_2CO_3(aq) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$
(molecules) (cation) (anion)

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

$NH_4OH(aq) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$
(molecules) (cation) (anion)

$Ca(OH)_2(aq) \rightleftharpoons Ca^{2+}(aq) + 2OH^-(aq)$
(molecules) (cation) (anion)

$Mg(OH)_2(aq) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$
(molecules) (cation) (anion)

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.

$PbO(s) + 2NaOH(aq) + H_2O(l) \rightarrow Na_2Pb(OH)_4(aq)$

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

$PbO(s) + 2KOH(aq) + H_2O(l) \rightarrow K_2Pb(OH)_4(aq)$

Ionic equation

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

(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

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

Ionic equation

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

(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.

$$Pb(OH)_2(s) + 2NaOH(aq) \rightarrow Na_2Pb(OH)_4(aq)$$

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

$$Pb(OH)_2(s) + 2KOH(aq) \rightarrow K_2Pb(OH)_4(aq)$$

Ionic equation

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

(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.

$$Al(OH)_3 (s) \quad + \quad NaOH(aq) \quad -> \quad NaAl(OH)_4(aq)$$

2.When aluminium(III) hydroxide is reacted with potassium hydroxide the complex salt is potassium tetrahydroxoaluminate(III) complex salt.

$$Al(OH)_3 (s) \quad + \quad KOH(aq) \quad -> \quad KAl(OH)_4(aq)$$

Ionic equation

$$Al(OH)_3 (s) \quad + \quad OH^-(aq) \quad -> \quad [Al(OH)_4]^- (aq)$$

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 **H**X e.g.
HCl, **H**NO_3,HCOO**H**,CH3COO**H**.

(ii)**di**basic acids ; generally denoted H_2X e.g.
H_2SO_4, H_2SO_3, H_2CO_3,**H**OOCOO**H**.

(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) acid	H_3PO_4	Tribasic	Phosphate(V)(PO_4^{3-})	Dihydrogen 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.

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

Examples

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

(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) -> $2NaNO_3$(aq) + H_2O (l) + CO_2(g)
K_2CO_3 (s) + 2HCl(aq) -> 2KCl(aq) + H_2O (l) + CO_2(g)
$NaHCO_3$ (s) + HNO_3(aq) -> $NaNO_3$(aq) + H_2O (l) + CO_2(g)
$KHCO_3$ (s) + HCl(aq) -> 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) -> $NaNO_3$(aq) + H_2O (l)
KOH (aq) + HNO_3(aq) -> KNO_3(aq) + H_2O (l)
KOH (aq) + HCl(aq) -> KCl(aq) + H_2O (l)
2KOH (aq) + H_2SO_4(aq) -> K_2SO_4(aq) + $2H_2O$ (l)
2 NH_4OH (aq) + H_2SO_4(aq) -> $(NH_4)_2SO_4$(aq) + $2H_2O$ (l)
NH_4OH (aq) + HNO_3(aq) -> 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) -> 2NaCl(s)
2K(s) + Cl_2(g) -> 2KCl(s)
Mg(s) + Cl_2(g) -> Mg Cl_2 (s)
Ca(s) + Cl_2(g) -> 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) -> $2AlCl_3$ (**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)+ $3H_2$ O(g) -> $Al(OH)_3$ (**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

$2Fe(s)$ + $3Cl_2(g)$ -> $2FeCl_3$ (**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.

$FeCl_3(s)$+ $3H_2O(g)$ -> $Fe(OH)_3$ (**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) -> $\mathbf{CuCO_3}$ (s) + Na_2SO_4(aq)
$\mathbf{Ba}Cl_2(aq)$ + $K_2\mathbf{SO_4}$ (aq) -> $\mathbf{BaSO_4}$ (s) + $2KCl$ (aq)
$\mathbf{Pb}(NO_3)_2(aq)$ + $K_2\mathbf{SO_4}$ (aq) -> $\mathbf{PbSO_4}$ (s) + $2KNO_3$ (aq)
$2\mathbf{Ag}NO_3(aq)$ + $Mg\mathbf{Cl_2}$ (aq) -> $2\mathbf{AgCl}$(s) + $Mg(NO_3)_2$ (aq)
$\mathbf{Pb}(NO_3)_2(aq)$ + $(NH_4)_2\mathbf{SO_4}$ (aq) -> $\mathbf{PbSO_4}$ (s) + $2NH_4NO_3$(aq)
$\mathbf{Ba}Cl_2(aq)$ + $K_2\mathbf{SO_3}$ (aq) -> $\mathbf{BaSO_3}$ (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) -> $2KNO_2(s)$ + $O_2(g)$
$2NaNO_3$ (s) -> $2NaNO_2(s)$ + $O_2(g)$

(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. $CuCO_3 (s) \rightarrow CuO(s) + CO_2(g)$
$CaCO_3 (s) \rightarrow CaO(s) + CO_2(g)$
$PbCO_3 (s) \rightarrow PbO(s) + CO_2(g)$
$FeCO_3 (s) \rightarrow FeO(s) + CO_2(g)$
$ZnCO_3 (s) \rightarrow ZnO(s) + CO_2(g)$

(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.

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

$2KHCO_3(s) \rightarrow K_2CO_3(s) + CO_2(g) + H_2O(l)$

(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.

$Ca(HCO_3)_2(\mathbf{aq}) \rightarrow CaCO_3(s) + CO_2(g) + H_2O(l)$

$Mg(HCO_3)_2(\mathbf{aq}) \rightarrow MgCO_3(s) + CO_2(g) + H_2O(l)$

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 $Na^+(aq) + OH^-(aq)$ -> $NaOH(aq)$ $K^+(aq) + OH^-(aq)$ -> $KOH(aq)$
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 $NH_4^+ (aq) + OH^-(aq)$ -> $NH_3 (g) + H_2O(l)$
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. $Ba^{2+}(aq) + 2OH^-(aq)$ -> $Ba(OH)_2$(**s**) $Ca^{2+}(aq) + 2OH^-(aq)$ -> $Ca(OH)_2$(**s**) $Mg^{2+}(aq) + 2OH^-(aq)$ -> $Mg(OH)_2$(**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. $Zn^{2+}(aq) + 2OH^-(aq)$ -> $Zn(OH)_2$(**s**) $Pb^{2+}(aq) + 2OH^-(aq)$ -> $Pb(OH)_2$(**s**) $Al^{3+}(aq) + 3OH^-(aq)$ -> $Al(OH)_3$(**s**) The hydroxides formed react with more OH^- ions to form complex salts/ions. $Zn(OH)_2$(**s**) + $2OH(aq)$ -> $[Zn(OH)_4]^{2-}$(**aq**) $Pb(OH)_2$(**s**) + $2OH(aq)$ -> $[Pb(OH)_4]^{2-}$(**aq**) $Al(OH)_3$(**s**) + $OH(aq)$ -> $[Al(OH)_4]^-$(**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. $Cu^{2+}(aq) + 2OH^-(aq)$ -> **$Cu(OH)_2$**(**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. $Fe^{2+}(aq) + 2OH^-(aq)$ -> **$Fe(OH)_2$**(**s**) Hydrogen peroxide is an oxidizing agent that oxidizes green Fe^{2+} oxidized to brown Fe^{3+} **$Fe(OH)_2$**(**s**) + $2H^+$ -> **$Fe(OH)_3$**(**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**. $Fe^{3+}(aq) + 3OH^-(aq)$ -> **$Fe(OH)_3$**(**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. $Pb^{2+}(aq) + 2OH^-(aq) \rightarrow Pb(OH)_2(\mathbf{s})$ $Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(\mathbf{s})$ $Ba^{2+}(aq) + 2OH^-(aq) \rightarrow Ba(OH)_2(\mathbf{s})$ $Ca^{2+}(aq) + 2OH^-(aq) \rightarrow Ca(OH)_2(\mathbf{s})$ $Mg^{2+}(aq) + 2OH^-(aq) \rightarrow Mg(OH)_2(\mathbf{s})$
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. $Zn^{2+}(aq) + 2OH^-(aq) \rightarrow Zn(OH)_2(\mathbf{s})$ The Zinc hydroxides formed react $NH_3(aq)$ to form a complex salts/ions. $Zn(OH)_2(\mathbf{s}) + 4NH_3(aq)$ $\rightarrow [Zn(NH_3)_4]^{2+}(\mathbf{aq}) + 2OH^-(aq)$
Blue precipitate that dissolves in excess ammonia solution to form a **deep/royal blue solution**	Cu^{2+}	Cu^{2+} ions react with OH^- from 2M aqueous ammonia to form blue precipitate of copper(II) hydroxide. $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow \mathbf{Cu(OH)_2}(\mathbf{s})$ The copper(II) hydroxide formed react $NH_3(aq)$ to form a complex salts/ions.

		$\mathbf{Cu(OH)_2}$ (**s**) + 4NH$_3$(aq) -> $\mathbf{[\ Cu(NH_3)_4]}^{2+}$(**aq**)+ 2OH$^-$(aq)
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 aqueous ammonia to form insoluble green precipitate of Iron(II) hydroxide. Fe^{2+}(aq) + 2OH$^-$(aq) -> $\mathbf{Fe(OH)_2}$(**s**) Hydrogen peroxide is an oxidizing agent that oxidizes green Fe^{2+} oxidized to brown Fe^{3+} $\mathbf{Fe(OH)_2}$(**s**) + 2H$^+$ -> $\mathbf{Fe(OH)_3}$(**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) -> $\mathbf{Fe(OH)_3}$(**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$_4$Cl 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$_4$Cl/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 $\mathbf{Pb^{2+}}$.
No white precipitate on adding Cl^- ions/salts shows $\mathbf{Al^{3+}}$.
Adding a chloride/ Cl^- ions/salts can thus be used to separate the identity of $\mathbf{Al^{3+}}$ **and** $\mathbf{Pb^{2+}}$.

(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 precipitate	Ca^{2+}, Ba^{2+}, Pb^{2+} ions	$CaSO_3$ and $CaSO_4$ do not form a thick precipitate as 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. $Cu^{2+}(aq) + CO_3^{2-}(aq) + 2OH^-(aq)$ $\rightarrow \mathbf{CuCO_3.Cu(OH)_2}(s)$
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+} <u>absent</u>

(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

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

Practice examples

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

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

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

$$\text{Solubility} = \frac{\text{Mass of solute/salt/solid} \times 100}{\text{Mass/volume of water/solvent}} \Rightarrow \left(\frac{50.0 \times 100}{250.0}\right) = \mathbf{20.0\ g\ /100g\ H_2O}$$

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

Mass of solute/salt/solid = 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.

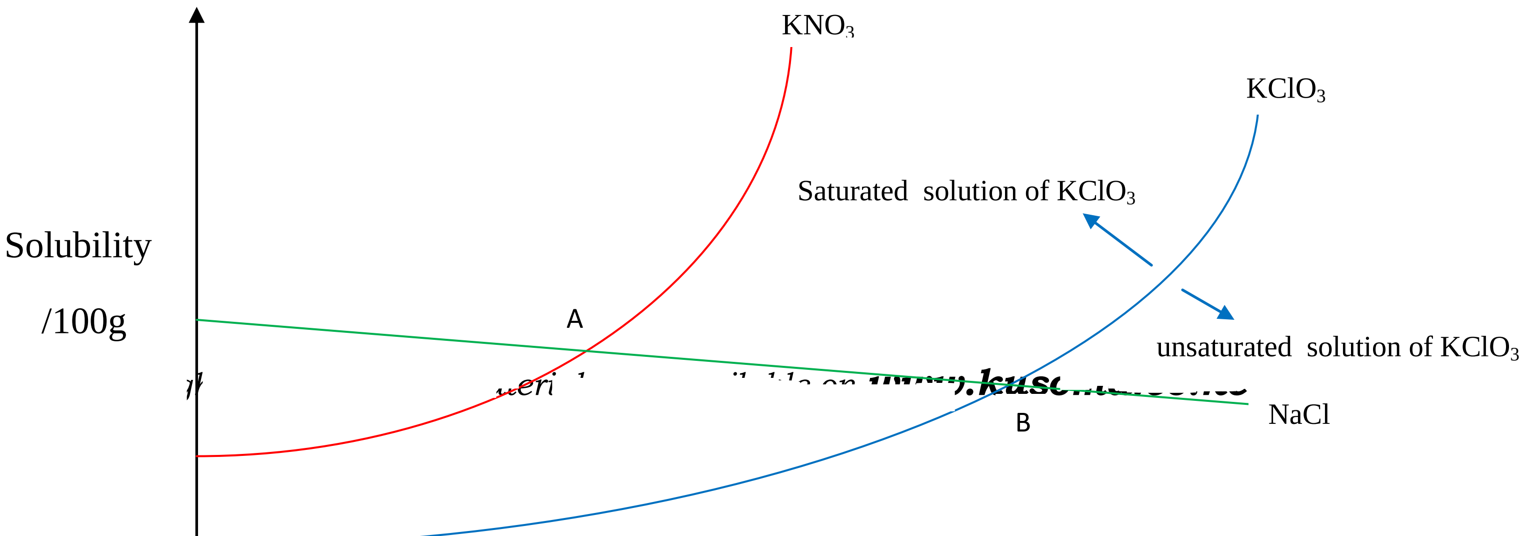
Solubility = $\frac{\text{Mass of solute/salt/solid x 100}}{\text{Mass/volume of water/solvent}}$ =>($\frac{22 \times 100}{40.0.}$) = **55.0 g /100g H_2O**

(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 <u>above</u> the solubility curve of the salt shows a **saturated** /supersaturated solution.

(viii) An area <u>below</u> 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^oC is 60g/100g water .What mass of $KClO_3$ will be deposited at:

(i)75 ^oC 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 ^oC 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**

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

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

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°C	20°C
KNO_3	90	30
$KClO_3$	20	6

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

(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

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

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

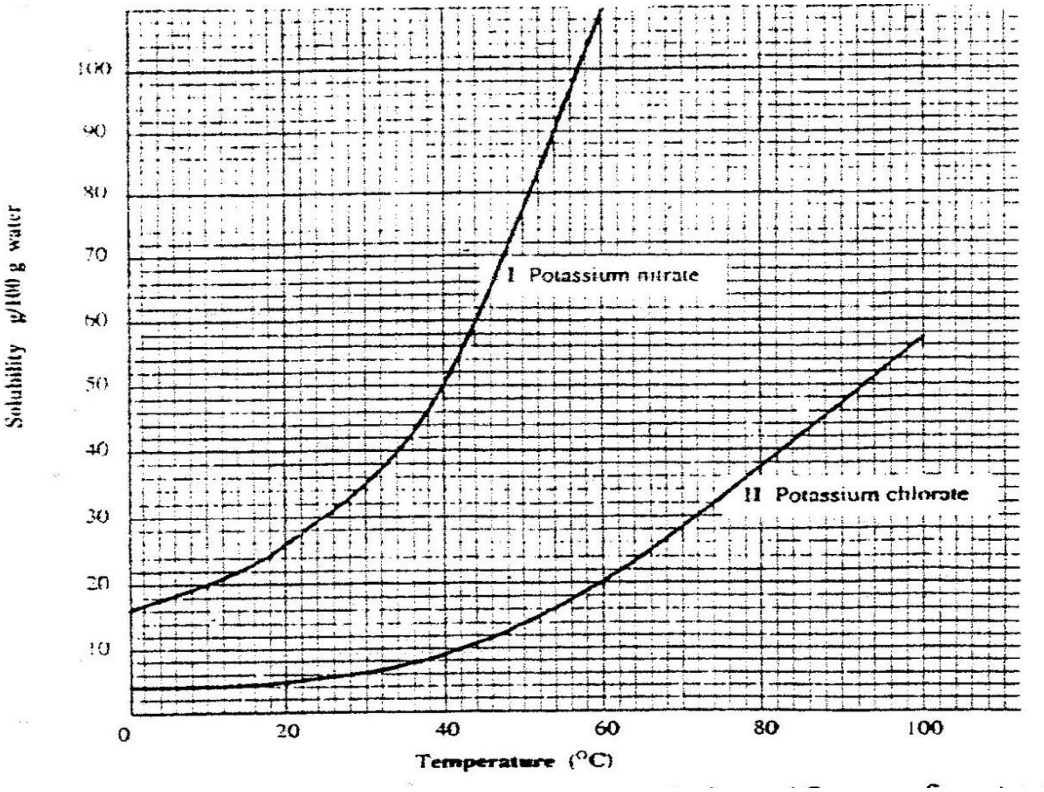
(e)What is the formula of the hydrated salt?
$K_2CO_3 .\underline{2}\, H_2O$

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 ^oC



(b)From the graph show and determine

(i)the mass of KNO_3 dissolved at:

I. 20^oC

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

II. 35^oC

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

III. 55^oC

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^oC**

II. 30g

From a correctly plotted graph =**17.5^oC**

III.100g

From a correctly plotted graph =**54.5^oC**

(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^oC to:

I. 20^oC

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

II. 35^oC

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

III. 55^oC

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(^{o}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^{o}C

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

From the graph, the solubility of B at 80^{o}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^{o}C to 20^{o}C.

Method I.

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

Method II.

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

(From graph) Solubility/mass before cooling at 50^{o}C = 85.0 g
(From graph) Solubility/mass after cooling at 20^{o}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.

I.For salt A

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

$$\Rightarrow \frac{40 \times 100}{10} = \mathbf{400g/100g\ Water}$$

(Theoretical)Solubility of A before heating = 400 g
Less (From graph) Solubility of A after heating at 70^{o}C = 48g
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 = 31g
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 = 369 g

I.For salt B

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

$$\Rightarrow \frac{60 \times 100}{10} = \mathbf{600g/100g\ Water}$$

(Theoretical)Solubility of B before heating = 600 g
Less (From graph) Solubility of B after heating at 70^{o}C = 138g
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 = 21g
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 = 579 g

(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 = $\underline{9.0}$
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(^{o}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 $80^{o}C$ to $40^{o}C$.

(From the graph)Solubility at $80^{o}C$ = 24.0 g
Less (From the graph)Solubility at $40^{o}C$ = 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-$40^{o}C$) 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)

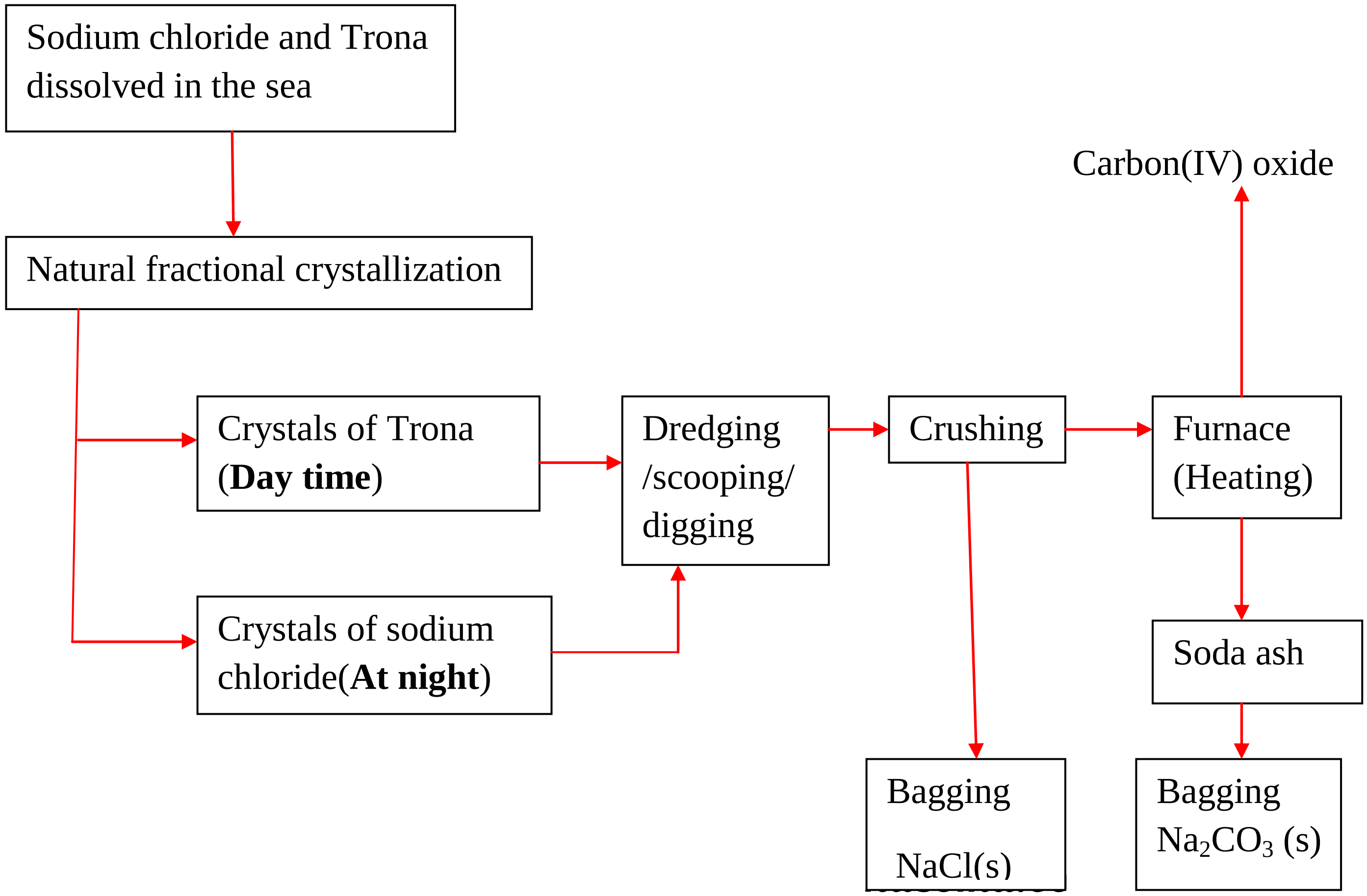
Chemical equation
$2Na_2CO_3.NaHCO_3.2H_2O(s) \rightarrow 3Na_2CO_3(s) + CO_2(g) + 5H_2O(l)$

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.<u>Extraction of common salt from Indian Ocean at Ngomeni in Kenya</u>

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

$Ca(HCO_3)_2(aq) \rightarrow CaCO_3\ (s) + CO_2(g) + H_2O(l)$

$Mg(HCO_3)_2(aq) \rightarrow MgCO_3\ (s) + CO_2(g) + H_2O(l)$

(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

$Na_2CO_3\ (aq) + Ca(HCO_3)_2\ (aq) \rightarrow NaHCO_3(aq) + CaCO_3\ (s)$

$Na_2CO_3\ (aq) + Mg(HCO_3)_2\ (aq) \rightarrow NaHCO_3(aq) + MgCO_3\ (s)$

Ionic equation

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

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

(ii)with permanent hard water

Chemical equation

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

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

Ionic equation

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

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

(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>

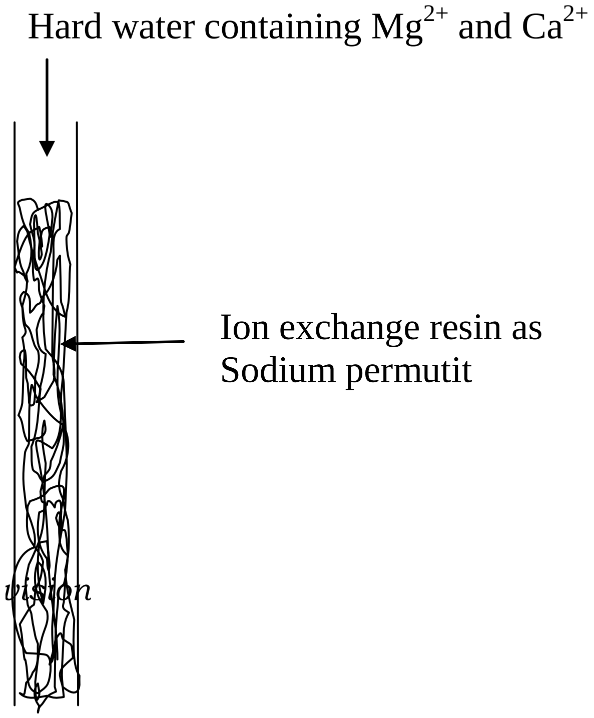
$$2NH_3\ (aq)\ +\ Ca(HCO_3)_2\,(aq)\ \rightarrow\ (NH_4)_2CO_3(aq)\ +\ CaCO_3\ (s)$$
$$2NH_3\ (aq)\ +\ Mg(HCO_3)_2\,(aq)\ \rightarrow\ (NH_4)_2CO_3(aq)\ +\ MgCO_3\ (s)$$

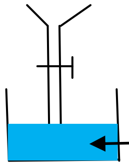
(v)Use of ion-exchange permutit

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.

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

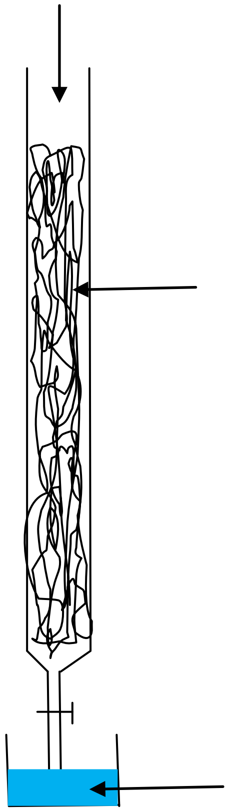




Na^+ ions replace Mg^{2+} and Ca^{2+} to make the water soft.

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.

Hard water containing Mg^{2+} and Ca^{2+}



Ion exchange resin as Sodium permutit

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 cation exchanger which remove /absorb all the **cations** present in water and leave **only H^+** ions.

(ii)An anion exchanger 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 pure 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

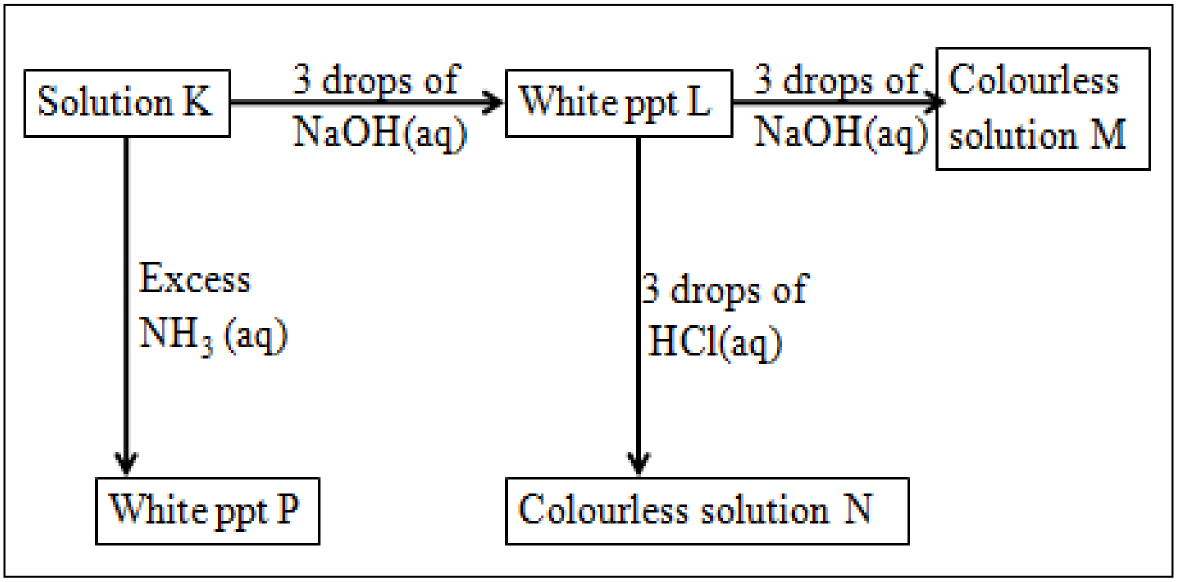
a) Which water sample is likely to be soft? Explain. (2mks)

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

*********************END**********************

- *K.C.S.E past papers.*
- *University past papers.*
- *K.A.S.N.E.B past papers e.g. C.P.A*
- *Primary school schemes of work.*
- *Primary school revision papers to all classes.*
- *Marking schemes to primary school past papers.*
- *K.C.P.E past papers.*