Established in

RAFFLES GIRLS' SCHOOL (SECONDARY)
RAFFLES PROGRAMME
YEAR 4 CHEMISTRY

Name : ________________________ ( ) Class : _______
Date : _____________

QA Notes (2) – Tests for Cations, Anions & Gases

2.1 Tests for Cations

Cations can be distinguished based on their reactions with **aqueous sodium hydroxide** and **aqueous ammonia**.

To test for cations, aqueous sodium hydroxide or aqueous ammonia is added to the unknown solution **dropwise** until it is in **excess**. The **colour of the precipitate** formed and its **solubility in excess alkali** can be used to identify the cation present in the solution.

Cations in syllabus: Zn^{2+}, Al^{3+}, Pb^{2+}, Ca^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, NH_4^+

2.1.1 Sodium hydroxide

- An aqueous solution of sodium hydroxide consists of sodium ions, hydroxide ions and water molecules.

$$NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$$

- Upon addition of aqueous sodium hydroxide to a solution of an unknown cation, the hydroxide ions in sodium hydroxide solution may combine with the cations to form metal hydroxides.

> **Think: Which hydroxides are soluble and which are insoluble?**
>
> **NaOH, KOH (Group I metal hydroxides) are soluble and no precipitate will form.**
>
> **All other metal ions react with hydroxide ions in aqueous sodium hydroxide to form insoluble hydroxides.**

- The formation of insoluble metal hydroxides is a **precipitation** reaction.

- Adding NaOH (aq) to salt solutions containing transition metal ions (Cu^{2+}, Fe^{2+} and Fe^{3+}) usually form **<u>coloured</u>** precipitates while adding NaOH (aq) to salt solutions containing other metal ions such as Ca^{2+}, Zn^{2+}, Pb^{2+}, Al^{3+} (except Group I and ammonium) form **white** precipitates.

- Metal hydroxides as $Al(OH)_3$, $Zn(OH)_2$, and $Pb(OH)_2$ are **amphoteric** in nature i.e. they can **react with both acids and bases**. In this case, they react with excess sodium hydroxide to form complex salts that are soluble to give colourless solutions.

Table 2.1: Test and observations for identifying cations using sodium hydroxide solution

❖ *denotes advanced content for enrichment*

<table>
<tr><th rowspan="2">Cation</th><th colspan="3">Sodium hydroxide solution, NaOH (aq)</th></tr>
<tr><th>Test</th><th>On adding a few drops</th><th>On adding excess</th></tr>
<tr><td rowspan="3">Zn^{2+}</td><td>Observations</td><td>White precipitate is formed.</td><td>White precipitate dissolves in excess NaOH (aq) to form a colourless solution.</td></tr>
<tr><td rowspan="2">Theory</td><td colspan="2">On adding a few drops of NaOH (aq):

$Zn^{2+} (aq) + 2OH^- (aq) \rightarrow \underset{\text{white ppt}}{Zn(OH)_2 (s)}$</td></tr>
<tr><td colspan="2">On adding excess of NaOH (aq):

❖ [Ionic equation] $\underset{\text{white ppt}}{Zn(OH)_2 (s)} + 2OH^- (aq) \rightleftharpoons \underset{\text{colourless solution}}{Zn(OH)_4^{2-} (aq)}$
❖ [Chemical equation] $\underset{\text{white ppt}}{Zn(OH)_2 (s)} + 2NaOH(aq) \rightleftharpoons \underset{\text{colourless solution}}{Na_2Zn(OH)_4 (aq)}$</td></tr>
<tr><td rowspan="3">Al^{3+}</td><td>Observations</td><td>White precipitate is formed.</td><td>White precipitate dissolves in excess NaOH (aq) to form a colourless solution.</td></tr>
<tr><td rowspan="2">Theory</td><td colspan="2">On adding a few drops of NaOH (aq):

$Al^{3+} (aq) + 3OH^- (aq) \rightarrow \underset{\text{white ppt}}{Al(OH)_3 (s)}$</td></tr>
<tr><td colspan="2">On adding excess of NaOH (aq):

❖ [Ionic equation] $\underset{\text{white ppt}}{Al(OH)_3 (s)} + OH^- (aq) \rightleftharpoons \underset{\text{colourless solution}}{Al(OH)_4^- (aq)}$
❖ [Chemical equation] $\underset{\text{white ppt}}{Al(OH)_3 (s)} + NaOH(aq) \rightleftharpoons \underset{\text{colourless solution}}{NaAl(OH)_4 (aq)}$</td></tr>
<tr><td rowspan="3">Pb^{2+}</td><td>Observations</td><td>White precipitate is formed.</td><td>White precipitate dissolves in excess NaOH (aq) to form a colourless solution.</td></tr>
<tr><td rowspan="2">Theory</td><td colspan="2">On adding a few drops of NaOH (aq) :
$Pb^{2+} (aq) + 2OH^- (aq) \rightarrow \underset{\text{white ppt}}{Pb(OH)_2 (s)}$</td></tr>
<tr><td colspan="2">On adding excess of NaOH (aq):

❖ [Ionic equation] $\underset{\text{white ppt}}{Pb(OH)_2 (s)} + 2OH^- (aq) \rightleftharpoons \underset{\text{colourless solution}}{Pb(OH)_4^{2-} (aq)}$
❖ [Chemical equation] $\underset{\text{white ppt}}{Pb(OH)_2 (s)} + 2NaOH(aq) \rightleftharpoons \underset{\text{colourless solution}}{Na_2Pb(OH)_4 (aq)}$</td></tr>
</table>

Ca^{2+}	**Observations**	White precipitate is formed.	White precipitate insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): Ca^{2+} (aq) + $2OH^-$ (aq) → $Ca(OH)_2$ (s) *white ppt* No reaction takes place when excess of NaOH (aq) is added.	
Cu^{2+}	**Observations**	Light blue precipitate is formed.	Light blue precipitate is insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): Cu^{2+} (aq) + $2OH^-$ (aq) → $Cu(OH)_2$ (s) *light blue ppt* No reaction takes place when excess of NaOH (aq) is added.	
Fe^{2+}	**Observations**	Green precipitate is formed.	Green precipitate is insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): Fe^{2+} (aq) + $2OH^-$ (aq) → $Fe(OH)_2$ (s) *green ppt* No reaction takes place when excess of NaOH (aq) is added.	
Fe^{3+}	**Observations**	Reddish-brown precipitate is formed.	Reddish-brown precipitate is insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): Fe^{3+} (aq) + $3OH^-$ (aq) → $Fe(OH)_3$ (s) *reddish brown ppt* No reaction takes place when excess of NaOH (aq) is added.	
NH_4^+	**Observations**	No precipitate is formed. On heating, colourless and pungent gas produced turns moist red litmus paper blue. Gas is NH_3 gas.	No change is observed.

2.1.2 Aqueous ammonia

Like sodium hydroxide, aqueous ammonia also precipitates insoluble hydroxides from salt solutions. As aqueous ammonia is a weak alkali, it dissociates partially in water as follows:

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Table 2.2: Test and observations for identifying cations using aqueous ammonia

<table>
<tr><th rowspan="2">Cation</th><th colspan="3">Aqueous ammonia, NH_3 (aq)</th></tr>
<tr><th>Test</th><th>On adding a few drops</th><th>On adding excess</th></tr>
<tr><td rowspan="3">Zn^{2+}</td><td>Observations</td><td>White precipitate is formed.</td><td>White precipitate dissolves in excess NH_3 (aq) to form a colourless solution.</td></tr>
<tr><td rowspan="2">Theory</td><td colspan="2">On adding a few drops of NH_3 (aq) :
Zn^{2+} (aq) + $2OH^-$ (aq) → $Zn(OH)_2$ (s)
white ppt</td></tr>
<tr><td colspan="2">On adding excess of NH_3 (aq):
❖ $Zn(OH)_2$ (s) + $4NH_3$ (aq) ⇌ $Zn(NH_3)_4^{2+}$ (aq) + $2OH^-$ (aq)
white ppt colourless solution</td></tr>
<tr><td rowspan="2">Al^{3+}</td><td>Observations</td><td>White precipitate is formed.</td><td>White precipitate insoluble in excess NH_3 (aq).</td></tr>
<tr><td>Theory</td><td colspan="2">On adding a few drops of NH_3 (aq) :
Al^{3+} (aq) + $3OH^-$ (aq) → $Al(OH)_3$ (s)
white ppt
No reaction takes place when excess of NH_3 (aq) is added.</td></tr>
<tr><td rowspan="2">Pb^{2+}</td><td>Observations</td><td>White precipitate is formed.</td><td>White precipitate insoluble in excess NH_3 (aq).</td></tr>
<tr><td>Theory</td><td colspan="2">On adding a few drops of NH_3 (aq) :
Pb^{2+} (aq) + $2OH^-$ (aq) → $Pb(OH)_2$ (s)
white ppt
No reaction takes place when excess of NH_3 (aq) is added.</td></tr>
<tr><td rowspan="2">Ca^{2+}</td><td>Observations</td><td>No precipitate is formed.</td><td>No precipitate is formed.</td></tr>
<tr><td>Theory</td><td colspan="2">Recall that $Ca(OH)_2$ is sparingly soluble. Hence, since NH_3 (aq) is a weak base, the concentration of OH^- ions contributed by NH_3 (aq) to the solution will be very low which will result in a very low concentration of $Ca(OH)_2$ to be formed. The small quantity of $Ca(OH)_2$ formed allows it remain soluble.</td></tr>
<tr><td rowspan="3">Cu^{2+}</td><td>Observations</td><td>Light blue precipitate is formed.</td><td>Light blue precipitate dissolves in excess NH_3 (aq) to form a deep blue solution.</td></tr>
<tr><td rowspan="2">Theory</td><td colspan="2">On adding a few drops of NH_3 (aq):
Cu^{2+} (aq) + $2OH^-$ (aq) → $Cu(OH)_2$ (s)
blue ppt</td></tr>
<tr><td colspan="2">On adding excess of NH_3 (aq):
❖ $Cu(OH)_2$ (s) + $4NH_3$ (aq) ⇌ $Cu(NH_3)_4^{2+}$ (aq) + $2OH^-$ (aq)
blue ppt deep blue solution</td></tr>
</table>

Fe^{2+}	**Observations**	Green precipitate is formed.	Green precipitate is insoluble in excess NH_3 (aq).
	Theory	On adding a few drops of NH_3 (aq): Fe^{2+} (aq) + $2OH^-$ (aq) → $Fe(OH)_2$ (s) *green ppt* No reaction takes place when excess of NH_3 (aq) is added.	
Fe^{3+}	**Observations**	Reddish-brown precipitate is formed.	Reddish-brown precipitate is insoluble in excess NH_3 (aq).
	Theory	On adding a few drops of NH_3 (aq): Fe^{3+} (aq) + $3OH^-$ (aq) → $Fe(OH)_3$ (s) *reddish-brown ppt* No reaction takes place when excess of NH_3 (aq) is added.	

Think: What do you observe if an acid is added to the insoluble hydroxide formed? Explain.

Observations:

White (coloured) precipitate is observed to dissolve and form a colourless (coloured) solution.

Theory:

Acid-base neutralisation takes place to form a salt and water. If dilute nitric acid is added, it reacts with the insoluble metal hydroxide to form a soluble salt and water. For example,

Chemical Equation: $Pb(OH)_2$ (s) + $2HNO_3$ (aq) → $Pb(NO_3)_2$ (aq)+ $2H_2O$ (*l*)

Base (*white ppt*) — *Acid* — *Salt* (*colourless solution*) — *Water*

Ionic Equation: $Pb(OH)_2$(s) + $2H^+$(aq) → Pb^{2+}(aq) + 2 H_2O (*l*)

- **Think: What do you observe if an acid is added to the complex salt?**

Observation:

- **A white precipitate is observed. White precipitate dissolves in excess acid to form a colourless solution. (If the complex salt was $Cu(NH_3)_4^{2+}$, then the deep blue solution will be observed to return to a blue solution.)**

Theory:

- Zn^{2+} (aq) + $2OH^-$ (aq) $\rightleftharpoons$ $Zn(OH)_2$ (s) ---- (1)
  $Zn(OH)_2$ (s) + $2OH^-$ (aq) $\rightleftharpoons$ $Zn(OH)_4^{2-}$ ---- (2)

  When acid is first added, the H^+ ions will react with the OH^- ions shifting equilibrium in eqn (2) towards the left-hand side of eqn (2) (c.f. Le Chatelier's principle), regenerating $Zn(OH)_2$. On further addition of the acid, more of the OH^- ions will react with the H^+ ions causing equilibrium in eqn (1) to shift to the left-hand side, regenerating Zn^{2+}.

- Cu^{2+} (aq) + $2OH^-$ (aq) $\rightleftharpoons$ $Cu(OH)_2$ (s) ----- (1)
  $Cu(OH)_2$ (s) + $4NH_3$ (aq) $\rightleftharpoons$ $Cu(NH_3)_4^{2+}$ (aq) + $2OH^-$ (aq) ----- (2)

  Combining eqn (1) to eqn (2), we get the following overall eqn:

  Cu^{2+} (aq) + $4NH_3$ (aq) $\rightleftharpoons$ $Cu(NH_3)_4^{2+}$ (aq)

  When acid is added to the solution, the H^+ ions will react with the NH_3 to form NH_4^+ ions shifting equilibrium towards the left-hand, regenerating the Cu^{2+} ions in the process.

2.2 Tests for Anions

Anions (negatively charged ions) are usually identified by

i. Specific test reagents and confirmatory tests
ii. Gas evolved during heating or reaction with dilute acids

A specific test reagent undergoes a specific reaction with each type of anion. The **colour of precipitate** formed and the **reaction of the precipitate formed with dilute acid** or the **identity of gas evolved** give us valuable clues to the identity of the anion in the unknown solution.

Table 2.3: Test Reagents Used and Observations in Tests for Anions

Test	Reagents	Purpose	Observations	Theory
A	Dilute acids	Test for **CO_3^{2-}**	Effervescence is observed. Colourless and odourless gas evolved forms a white ppt with aqueous calcium hydroxide (limewater). Gas is CO_2.	<u>Acid-carbonate reaction</u> $2H^+ (aq) + CO_3^{2-} (aq) \rightarrow H_2O (l) + CO_2 (g)$ $CO_2 (g) + Ca(OH)_2 (aq) \rightarrow CaCO_3 (s) + H_2O (l)$
		❖ **SO_3^{2-}**	❖ Effervescence is observed. ❖ Colourless and pungent gas evolved forms a white ppt with aqueous calcium hydroxide (limewater). Gas is SO_2.	❖ $2H^+ (aq) + SO_3^{2-} (aq) \rightarrow H_2O (l) + SO_2 (g)$ ❖ $SO_2 (g) + Ca(OH)_2 (aq) \rightarrow CaSO_3 (s) + H_2O (l)$
B	Aq. $BaCl_2$ and dilute HC*l* *OR* Aq. $Ba(NO_3)_2$ and dilute HNO_3	Test for **SO_4^{2-}**	White ppt formed. Ppt is insoluble in acid.	<u>Precipitation reaction</u> $Ba^{2+} (aq) + SO_4^{2-} (aq) \rightarrow BaSO_4 (s)$
		CO_3^{2-}	White ppt formed. Ppt dissolves in acid to form a colourless solution. Effervescence is observed. Colourless and odourless gas produced forms a white ppt with aqueous calcium hydroxide (limewater). Gas is CO_2.	$Ba^{2+} (aq) + CO_3^{2-} (aq) \rightarrow BaCO_3 (s)$ $BaCO_3 (s) + 2H^+ (aq) \rightarrow Ba^{2+} (aq) + H_2O (l) + CO_2 (g)$ $CO_2 (g) + Ca(OH)_2 (aq) \rightarrow CaCO_3 (s) + H_2O (l)$

		❖ **SO_3^{2-}**	❖ White ppt formed. ❖ Ppt dissolves in acid to form a colourless solution. Effervescence is observed. Colourless and pungent gas produced forms a white ppt with aqueous calcium hydroxide (limewater). Gas is SO_2.	❖ Ba^{2+} (aq) + SO_3^{2-} (aq) → $BaSO_3$ (s) ❖ $BaSO_3$ (s) + $2H^+$ (aq) → Ba^{2+} (aq) + H_2O (*l*) + SO_2 (g) ❖ SO_2 (g) + $Ca(OH)_2$ (aq) → $CaSO_3$ (s) + H_2O (*l*)
C	Aq. $AgNO_3$ and divide the precipitate into 2 separate portions i. Add dilute HNO_3 ii. Add aq NH_3	Test for **Cl^-** **I^-** **CO_3^{2-}**	White ppt formed. Ppt is insoluble in acid. Ppt dissolves in aq NH_3 to form a colourless solution. Yellow ppt formed. Ppt is insoluble in acid. Ppt is insoluble in aq NH_3. White ppt formed. Ppt turned pale yellow on standing. Ppt dissolves in dilute acid to form a colourless solution. Effervescence is observed. Colourless and odourless gas produced forms a white ppt with aqueous calcium hydroxide (limewater). Gas is CO_2.	Precipitation reaction, followed by (i) acid-carbonate reaction, or (ii) formation of complex, if any. Ag^+ (aq) + Cl^- (aq) → $AgCl$ (s) ❖ Ag^+ (aq) + $2NH_3$ (aq) ⇌ $Ag(NH_3)_2^+$ (aq) Ag^+ (aq) + I^- (aq) → AgI (s) $2Ag^+$ (aq) + CO_3^{2-} (aq) → Ag_2CO_3 (s) Ag_2CO_3 (s) + $2H^+$ (aq) → $2Ag^+$ (aq) + H_2O (*l*) + CO_2 (g) CO_2 (g) + $Ca(OH)_2$ (aq) → $CaCO_3$ (s) + H_2O (*l*)

		❖ **SO_3^{2-}**	❖ White ppt formed. ❖ Ppt dissolves in dilute acid to form a colourless solution. Effervescence is observed. Colourless and pungent gas produced forms a white ppt with aqueous calcium hydroxide (limewater). Gas is SO_2. ❖ ppt dissolves in excess aq NH_3 to form a colourless solution.	❖ $2Ag^+ (aq) + SO_3^{2-} (aq) \rightarrow Ag_2SO_3 (s)$ ❖ $Ag_2SO_3 (s) + 2H^+ (aq) \rightarrow 2Ag^+ (aq) + H_2O (l) + SO_2 (g)$ ❖ $SO_2 (g) + Ca(OH)_2 (aq) \rightarrow CaSO_3 (s) + H_2O (l)$ ❖ $Ag^+ (aq) + 2NH_3 (aq) \rightleftharpoons Ag(NH_3)_2^+ (aq)$
D	Aq. $Pb(NO_3)_2$, followed by dilute HNO_3	Test for **Cl^-**	White ppt formed. Ppt insoluble in acid.	<u>Precipitation reaction</u> $Pb^{2+} (aq) + 2Cl^- (aq) \rightarrow PbCl_2 (s)$
		I^-	Yellow ppt formed. Ppt insoluble in acid.	$Pb^{2+} (aq) + 2I^- (aq) \rightarrow PbI_2 (s)$
		SO_4^{2-}	White ppt formed Ppt insoluble in acid.	$Pb^{2+} (aq) + SO_4^{2-} (aq) \rightarrow PbSO_4 (s)$
		CO_3^{2-}	White ppt formed. Ppt dissolves in acid to form a colourless solution. Effervescence is observed. Colourless and odourless gas produced forms a white ppt with aqueous calcium hydroxide (limewater). Gas is CO_2.	$Pb^{2+} (aq) + CO_3^{2-} (aq) \rightarrow PbCO_3 (s)$ $PbCO_3 (s) + 2H^+ (aq) \rightarrow Pb^{2+} (aq) + H_2O (l) + CO_2 (g)$ $CO_2 (g) + Ca(OH)_2 (aq) \rightarrow CaCO_3 (s) + H_2O (l)$

E	Aq. NaOH, Devarda's alloy or zinc or aluminium, warm	Test for **NO_3^-**	On warming, effervescence is observed. Colourless and pungent gas produced turns moist red litmus paper blue. Gas is NH_3 gas.	❖ $3NO_3^-$ (aq) + 8A*l* (s) + $5OH^-$ (aq) + $18H_2O$ (*l*) → $3NH_3$ (g) + $8Al(OH)_4^-$ (aq)

2.3 Tests for Gases

You may not be explicitly asked to test for a gas but when you suspect a gas is given off in a reaction e.g. you see effervescence, you are expected to test for it and write down your observations and conclusions. To identify a gas you should note

i. its colour
ii. its smell
iii. its reaction with litmus paper (if any)
iv. its effect on a glowing or lighted wooden splint (if any)

In some cases you may have to carry out a special test to confirm the identity of the gas. Do not waste time testing for a gas unless you have some clues that a gas is being given off.

Table 2: Confirmatory Tests for Common Gases

Gas	**Observations**
Ammonia	Colourless and pungent gas evolved. Moist red litmus paper turned blue or white fumes formed when a glass rod dipped in concentrated HC*l* was brought near the gas.
Chlorine	Pale greenish-yellow and pungent gas evolved. Moist red litmus paper was bleached or moist blue litmus paper turned red and then bleached.
Water vapour	Colourless and odourless gas evolved. Blue cobalt(II) chloride paper turned pink
Sulfur dioxide	Colourless and pungent gas evolved. Purple acidified potassium manganate(VII) turned colourless. *(Additional test: Orange acidified potassium dichromate (VI) turned green)*
Carbon Dioxide	Colourless and odourless gas evolved. White precipitate formed when gas is bubbled into limewater, soluble in excess gas, forming a colourless solution
Oxygen	Colourless and odourless gas evolved. Glowing splint rekindled
Hydrogen	Colourless and odourless gas evolved. Lighted splint was extinguished with a 'pop' sound