



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

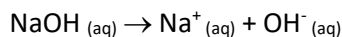
Cations can be distinguished based on their reactions with **aqueous sodium hydroxide** and **aqueous ammonia**.

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.



- 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 **coloured** 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 $\text{Al}(\text{OH})_3$, $\text{Zn}(\text{OH})_2$, and $\text{Pb}(\text{OH})_2$ 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

Cation	Sodium hydroxide solution, NaOH (aq)		
	Test	On adding a few drops	On adding excess
Zn²⁺	Observations	White precipitate is formed.	White precipitate dissolves in excess NaOH (aq) to form a colourless solution.
	Theory	On adding a few drops of NaOH (aq):	
		$\text{Zn}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Zn}(\text{OH})_2(\text{s})$ <i>white ppt</i>	
Al³⁺	Observations	White precipitate is formed.	White precipitate dissolves in excess NaOH (aq) to form a colourless solution.
	Theory	On adding a few drops of NaOH (aq):	
		$\text{Al}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Al}(\text{OH})_3(\text{s})$ <i>white ppt</i>	
Pb²⁺	Observations	White precipitate is formed.	White precipitate dissolves in excess NaOH (aq) to form a colourless solution.
	Theory	On adding a few drops of NaOH (aq) :	
		$\text{Pb}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Pb}(\text{OH})_2(\text{s})$ <i>white ppt</i>	
Al³⁺	Theory	On adding excess of NaOH (aq):	
		❖ [Ionic equation] $\text{Al}(\text{OH})_3(\text{s}) + \text{OH}^{-}(\text{aq}) \rightleftharpoons \text{Al}(\text{OH})_4^{-}(\text{aq})$ <i>white ppt</i> <i>colourless solution</i>	
		❖ [Chemical equation] $\text{Al}(\text{OH})_3(\text{s}) + \text{NaOH}(\text{aq}) \rightleftharpoons \text{NaAl}(\text{OH})_4(\text{aq})$ <i>white ppt</i> <i>colourless solution</i>	
Pb²⁺	Theory	On adding excess of NaOH (aq):	
		❖ [Ionic equation] $\text{Pb}(\text{OH})_2(\text{s}) + 2\text{OH}^{-}(\text{aq}) \rightleftharpoons \text{Pb}(\text{OH})_4^{2-}(\text{aq})$ <i>white ppt</i> <i>colourless solution</i>	
		❖ [Chemical equation] $\text{Pb}(\text{OH})_2(\text{s}) + 2\text{NaOH}(\text{aq}) \rightleftharpoons \text{Na}_2\text{Pb}(\text{OH})_4(\text{aq})$ <i>white ppt</i> <i>colourless solution</i>	

Ca²⁺	Observations	White precipitate is formed.	White precipitate insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): $\text{Ca}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Ca}(\text{OH})_2(\text{s})$ <i>white ppt</i> No reaction takes place when excess of NaOH (aq) is added.	
Cu²⁺	Observations	Light blue precipitate is formed.	Light blue precipitate is insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$ <i>light blue ppt</i> No reaction takes place when excess of NaOH (aq) is added.	
Fe²⁺	Observations	Green precipitate is formed.	Green precipitate is insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): $\text{Fe}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_2(\text{s})$ <i>green ppt</i> No reaction takes place when excess of NaOH (aq) is added.	
Fe³⁺	Observations	Reddish-brown precipitate is formed.	Reddish-brown precipitate is insoluble in excess NaOH (aq).
	Theory	On adding a few drops of NaOH (aq): $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$ <i>reddish brown ppt</i> No reaction takes place when excess of NaOH (aq) is added.	
NH₄⁺	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:

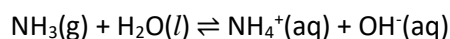


Table 2.2: Test and observations for identifying cations using aqueous ammonia

Cation	Aqueous ammonia, NH ₃ (aq)		
	Test	On adding a few drops	On adding excess
Zn ²⁺	Observations	White precipitate is formed.	White precipitate dissolves in excess NH ₃ (aq) to form a colourless solution.
	Theory	On adding a few drops of NH ₃ (aq) :	
		$\text{Zn}^{2+} (\text{aq}) + 2\text{OH}^{-} (\text{aq}) \rightarrow \text{Zn}(\text{OH})_2 (\text{s})$ <i>white ppt</i>	
		On adding excess of NH ₃ (aq):	
		$\text{Zn}(\text{OH})_2 (\text{s}) + 4\text{NH}_3 (\text{aq}) \rightleftharpoons \text{Zn}(\text{NH}_3)_4^{2+} (\text{aq}) + 2\text{OH}^{-} (\text{aq})$ <i>white ppt</i> <i>colourless solution</i>	
Al ³⁺	Observations	White precipitate is formed.	White precipitate insoluble in excess NH ₃ (aq).
	Theory	On adding a few drops of NH ₃ (aq) :	
		$\text{Al}^{3+} (\text{aq}) + 3\text{OH}^{-} (\text{aq}) \rightarrow \text{Al}(\text{OH})_3 (\text{s})$ <i>white ppt</i>	
		No reaction takes place when excess of NH ₃ (aq) is added.	
Pb ²⁺	Observations	White precipitate is formed.	White precipitate insoluble in excess NH ₃ (aq).
	Theory	On adding a few drops of NH ₃ (aq) :	
		$\text{Pb}^{2+} (\text{aq}) + 2\text{OH}^{-} (\text{aq}) \rightarrow \text{Pb}(\text{OH})_2 (\text{s})$ <i>white ppt</i>	
		No reaction takes place when excess of NH ₃ (aq) is added.	
Ca ²⁺	Observations	No precipitate is formed.	No precipitate is formed.
	Theory	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.	
Cu ²⁺	Observations	Light blue precipitate is formed.	Light blue precipitate dissolves in excess NH ₃ (aq) to form a deep blue solution.
	Theory	On adding a few drops of NH ₃ (aq):	
		$\text{Cu}^{2+} (\text{aq}) + 2\text{OH}^{-} (\text{aq}) \rightarrow \text{Cu}(\text{OH})_2 (\text{s})$ <i>blue ppt</i>	
		On adding excess of NH ₃ (aq):	
		$\text{Cu}(\text{OH})_2 (\text{s}) + 4\text{NH}_3 (\text{aq}) \rightleftharpoons \text{Cu}(\text{NH}_3)_4^{2+} (\text{aq}) + 2\text{OH}^{-} (\text{aq})$ <i>blue ppt</i> <i>deep blue solution</i>	

Fe²⁺	Observations	Green precipitate is formed.	Green precipitate is insoluble in excess NH ₃ (aq).
	Theory	On adding a few drops of NH ₃ (aq): $\text{Fe}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_2(\text{s})$ <i>green ppt</i> No reaction takes place when excess of NH ₃ (aq) is added.	
Fe³⁺	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): $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$ <i>reddish-brown ppt</i> No reaction takes place when excess of NH ₃ (aq) is added.	

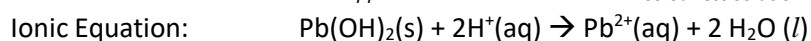
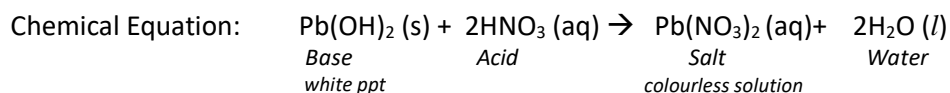
Think: What do you observe if an acid is added to the insoluble hydroxide formed? Explain.

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,

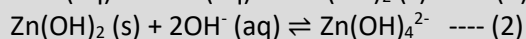
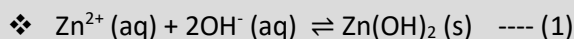


❖ Think: What do you observe if an acid is added to the complex salt?

Observation:

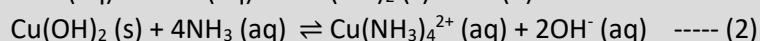
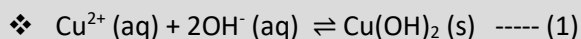
❖ A white precipitate is observed. White precipitate dissolves in excess acid to form a colourless solution. (If the complex salt was $\text{Cu}(\text{NH}_3)_4^{2+}$, then the deep blue solution will be observed to return to a blue solution.)

Theory:

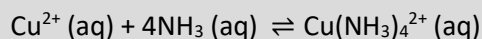


When acid is first added, the H^{+} ions will react with the OH^{-} ions shifting equilibrium in eqn (2) towards the left-hand side of eqn (2) (c.f. Le Chatelier's principle), regenerating $\text{Zn}(\text{OH})_2$.

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+} .



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



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

- Specific test reagents and confirmatory tests
- 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> $2\text{H}^+ (\text{aq}) + \text{CO}_3^{2-} (\text{aq}) \rightarrow \text{H}_2\text{O} (\text{l}) + \text{CO}_2 (\text{g})$ $\text{CO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaCO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$
		❖ SO_3^{2-}	❖ Effervescence is observed. ❖ Colourless and pungent gas evolved forms a white ppt with aqueous calcium hydroxide (limewater). Gas is SO_2 .	❖ $2\text{H}^+ (\text{aq}) + \text{SO}_3^{2-} (\text{aq}) \rightarrow \text{H}_2\text{O} (\text{l}) + \text{SO}_2 (\text{g})$ ❖ $\text{SO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaSO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$
B	Aq. BaCl_2 and dilute HCl OR Aq. $\text{Ba}(\text{NO}_3)_2$ and dilute HNO_3	Test for SO_4^{2-} CO_3^{2-}	White ppt formed. Ppt is insoluble in acid. 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 .	<u>Precipitation reaction</u> $\text{Ba}^{2+} (\text{aq}) + \text{SO}_4^{2-} (\text{aq}) \rightarrow \text{BaSO}_4 (\text{s})$ $\text{Ba}^{2+} (\text{aq}) + \text{CO}_3^{2-} (\text{aq}) \rightarrow \text{BaCO}_3 (\text{s})$ $\text{BaCO}_3 (\text{s}) + 2\text{H}^+ (\text{aq}) \rightarrow \text{Ba}^{2+} (\text{aq}) + \text{H}_2\text{O} (\text{l}) + \text{CO}_2 (\text{g})$ $\text{CO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaCO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$

		❖ 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 .	❖ $\text{Ba}^{2+} (\text{aq}) + \text{SO}_3^{2-} (\text{aq}) \rightarrow \text{BaSO}_3 (\text{s})$ ❖ $\text{BaSO}_3 (\text{s}) + 2\text{H}^+ (\text{aq}) \rightarrow \text{Ba}^{2+} (\text{aq}) + \text{H}_2\text{O} (\text{l}) + \text{SO}_2 (\text{g})$ ❖ $\text{SO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaSO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$
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. $\text{Ag}^+ (\text{aq}) + \text{Cl}^- (\text{aq}) \rightarrow \text{AgCl} (\text{s})$ ❖ $\text{Ag}^+ (\text{aq}) + 2\text{NH}_3 (\text{aq}) \rightleftharpoons \text{Ag}(\text{NH}_3)_2^+ (\text{aq})$ $\text{Ag}^+ (\text{aq}) + \text{I}^- (\text{aq}) \rightarrow \text{AgI} (\text{s})$ $2\text{Ag}^+ (\text{aq}) + \text{CO}_3^{2-} (\text{aq}) \rightarrow \text{Ag}_2\text{CO}_3 (\text{s})$ $\text{Ag}_2\text{CO}_3 (\text{s}) + 2\text{H}^+ (\text{aq}) \rightarrow 2\text{Ag}^+ (\text{aq}) + \text{H}_2\text{O} (\text{l}) + \text{CO}_2 (\text{g})$ $\text{CO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaCO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$

		❖ 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.	❖ $2\text{Ag}^+ (\text{aq}) + \text{SO}_3^{2-} (\text{aq}) \rightarrow \text{Ag}_2\text{SO}_3 (\text{s})$ ❖ $\text{Ag}_2\text{SO}_3 (\text{s}) + 2\text{H}^+ (\text{aq}) \rightarrow 2\text{Ag}^+ (\text{aq}) + \text{H}_2\text{O} (\text{l}) + \text{SO}_2 (\text{g})$ ❖ $\text{SO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaSO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$ ❖ $\text{Ag}^+ (\text{aq}) + 2\text{NH}_3 (\text{aq}) \rightleftharpoons \text{Ag}(\text{NH}_3)_2^+ (\text{aq})$
D	Aq. $\text{Pb}(\text{NO}_3)_2$, followed by dilute HNO_3	Test for Cl^- I^- SO_4^{2-} CO_3^{2-}	White ppt formed. Ppt insoluble in acid. Yellow ppt formed. Ppt insoluble in acid. White ppt formed Ppt insoluble in acid. 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 .	<u>Precipitation reaction</u> $\text{Pb}^{2+} (\text{aq}) + 2\text{Cl}^- (\text{aq}) \rightarrow \text{PbCl}_2 (\text{s})$ $\text{Pb}^{2+} (\text{aq}) + 2\text{I}^- (\text{aq}) \rightarrow \text{PbI}_2 (\text{s})$ $\text{Pb}^{2+} (\text{aq}) + \text{SO}_4^{2-} (\text{aq}) \rightarrow \text{PbSO}_4 (\text{s})$ $\text{Pb}^{2+} (\text{aq}) + \text{CO}_3^{2-} (\text{aq}) \rightarrow \text{PbCO}_3 (\text{s})$ $\text{PbCO}_3 (\text{s}) + 2\text{H}^+ (\text{aq}) \rightarrow \text{Pb}^{2+} (\text{aq}) + \text{H}_2\text{O} (\text{l}) + \text{CO}_2 (\text{g})$ $\text{CO}_2 (\text{g}) + \text{Ca}(\text{OH})_2 (\text{aq}) \rightarrow \text{CaCO}_3 (\text{s}) + \text{H}_2\text{O} (\text{l})$

E	Aq. NaOH, Devarda's alloy or zinc or aluminium, warm	Test for NO₃⁻	On warming, effervescence is observed. Colourless and pungent gas produced turns moist red litmus paper blue. Gas is NH ₃ gas.	❖ $3\text{NO}_3^- (\text{aq}) + 8\text{Al} (\text{s}) + 5\text{OH}^- (\text{aq}) + 18\text{H}_2\text{O} (\text{l}) \rightarrow 3\text{NH}_3 (\text{g}) + 8\text{Al}(\text{OH})_4^- (\text{aq})$
----------	--	--	--	---

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

- its colour
- its smell
- its reaction with litmus paper (if any)
- 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 HCl 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. <i>(Additional test: Orange acidified potassium dichromate (VI) turned green)</i>
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