Topic 22 – Qualitative Analysis

Subject content

Identification of ions and gases

(a) describe the use of aqueous sodium hydroxide and aqueous ammonia to identify the following aqueous cations: aluminium, ammonium, calcium, copper(II), iron(II), iron(III), lead(II) and zinc (formulae of complex ions are not required)

(b) describe tests to identify the following anions: carbonate (by the addition of dilute acid and subsequent use of limewater); chloride (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); iodide (by reaction of an aqueous solution with nitric acid and aqueous silver nitrate); nitrate (by reduction with aluminium in aqueous sodium hydroxide to ammonia and subsequent use of litmus paper) and sulfate (by reaction of an aqueous solution with nitric acid and aqueous barium nitrate)

(c) describe tests to identify the following gases: ammonia (using damp red litmus paper); carbon dioxide (using limewater); chlorine (using damp litmus paper); hydrogen (using a burning splint); oxygen (using a glowing splint) and sulfur dioxide (using acidified potassium manganate(VII))

Qualitative analysis: test for

1. **cations**
2. **anions**
3. **gas**

1 Test for aqueous cations

cation	effect of aqueous sodium hydroxide	effect of aqueous ammonia
aluminium (Al^{3+})	white ppt., soluble in excess giving a colourless solution	white ppt., insoluble in excess
ammonium (NH_4^+)	ammonia produced on warming	–
calcium (Ca^{2+})	white ppt., insoluble in excess	no ppt.
copper(II) (Cu^{2+})	light blue ppt., insoluble in excess	light blue ppt., soluble in excess giving a dark blue solution
iron(II) (Fe^{2+})	green ppt., insoluble in excess	green ppt., insoluble in excess
iron(III) (Fe^{3+})	red-brown ppt., insoluble in excess	red-brown ppt., insoluble in excess
lead(II) (Pb^{2+})	white ppt., soluble in excess giving a colourless solution	white ppt., insoluble in excess
zinc (Zn^{2+})	white ppt., soluble in excess giving a colourless solution	white ppt., soluble in excess giving a colourless solution

[Lead(II) ions can be distinguished from aluminium ions by the insolubility of lead(II) chloride.]

NaOH (aq) and NH_3 (aq) are alkalis → source of OH^- ions
Precipitation reaction of alkalis:

$CuSO_4$ (aq) + 2 NaOH (aq) → $Cu(OH)_2$ (s) + Na_2SO_4 (aq)
Cu^{2+} (aq) + 2 OH^- (aq) → $Cu(OH)_2$ (s) [**blue ppt**]

Note: NH_3 (aq) contains OH^- ions
NH_3 (aq) + H_2O (l) ⇌ NH_4OH (aq)

- NH_3 (aq) is weak alkali → reaction is reversible → low conc of NH_4OH
- X separate NH_4OH from water

2 Test for aqueous anions

anion	test	test result
carbonate (CO_3^{2-})	add dilute acid	effervescence, carbon dioxide produced
chloride (Cl^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	white ppt.
iodide (I^-) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	yellow ppt.
nitrate (NO_3^-) [in solution]	add aqueous sodium hydroxide, then aluminium foil; warm carefully	ammonia produced
sulfate (SO_4^{2-}) [in solution]	acidify with dilute nitric acid, then add aqueous barium nitrate	white ppt.

Theory:

Anion	Explanation
CO_3^{2-}	$CO_3^{2-} + 2\ H^+ \rightarrow H_2O + CO_2$ [**effervescence**] $\rightarrow H_2CO_3$ $Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + H_2O$
Cl^-	$AgNO_3$ (aq) + NaCl (aq) $\rightarrow$ AgCl (s) + $NaNO_3$ (aq) Ag^+ (aq) + Cl^- (aq) $\rightarrow$ AgCl (s) [**white ppt**]
I^-	$AgNO_3$ (aq) + NaI (aq) $\rightarrow$ AgI (s) + $NaNO_3$ (aq) Ag^+ (aq) + I^- (aq) $\rightarrow$ AgI (s) [**yellow ppt**]
NO_3^-	NaOH and Al are reducing agents NO_3^- is reduced to NH_3 [**ammonia gas**]
SO_4^{2-}	$Ba(NO_3)_2$ (aq) + Na_2SO_4 (aq) $\rightarrow$ $BaSO_4$ (s) + 2 $NaNO_3$ (aq) Ba^{2+} (aq) + SO_4^{2-} (aq) $\rightarrow$ $BaSO_4$ (s) [**white ppt**]

Acidify using HNO_3 (aq): ensure that any traces of CO_3^{2-} are reacted away

- Formation of Ag_2CO_3 (s) interferes with observation of Cl^- or I^- or SO_4^{2-} test
- 2 $AgNO_3$ (aq) + Na_2CO_3 (aq) $\rightarrow$ Ag_2CO_3 (s) [**white ppt**] + 2 $NaNO_3$ (aq)

3 Test for gases

gas	test and test result
ammonia (NH_3)	turns damp red litmus paper blue
carbon dioxide (CO_2)	gives white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine (Cl_2)	bleaches damp litmus paper
hydrogen (H_2)	'pops' with a lighted splint
oxygen (O_2)	relights a glowing splint
sulfur dioxide (SO_2)	turns aqueous acidified potassium manganate(VII) from purple to colourless

4 Test for presence of water

Reagent used	Observation
1. **anhydrous cobalt(II) chloride**	blue → pink
2. **anhydrous copper(II) sulfate**	white → blue

Observations

Test for cations

Cation	**Al^{3+}**	**NH_4^+**	**Ca^{2+}**	**Pb^{2+}**	**Zn^{2+}**	**Cu^{2+}**	**Fe^{2+}**	**Fe^{3+}**
NaOH		NH_3						
excess NaOH	sol			sol	sol			
NH_3 (aq)			no ppt					
Excess NH_3 (aq)			no ppt		sol	sol		

Test for anions

Anion	**CO_3^{2-}**	**Cl^-**	**I^-**	**NO_3^-**	**SO_4^{2-}**
Test result	eff.				eff.

Colour of solids

Colour	Substance
black	C, I (s) CuO, FeO, MnO_2
silver / grey	most metals (Mg, Al, Zn, Pb, Fe)
reddish-brown / pink	Cu
reddish-brown	Fe_2O_3, $Fe(OH)_3$
brown	Fe^{3+} salt, PbO_2, $Fe_2(CO_3)_3$
green	Fe^{2+} salt, $CuCO_3$, $Fe(OH)_2$
purple	$KMnO_4$
white / colourless	NH_4^+, K^+, Na^+ salt Ca^{2+}, Mg^{2+}, Zn^{2+}, Pb^{2+}, Al^{3+} salt

Colour of aqueous solutions

Colour	Ion / substance
blue / green	Cu^{2+} (aq)
pale green	Fe^{2+} (aq)
yellow	Fe^{3+} (aq)
orange-brown / reddish-brown	Br_2 (aq)
reddish-brown	I_2 (aq)
purple	MnO_4^- (aq)

Heating solids (in dry test tube)

Heating	Observation	Reaction
Solid contain oxygen	Oxygen gas produced	Some nitrates and oxides give off oxygen upon heating
Hydrated salt	Colourless drops of liquid condense on cold walls of test tube	$CuSO_4 \cdot 5\ H_2O \rightarrow CuSO_4 + 5\ H_2O$
Carbonate	Carbon dioxide gas produced	Sodium, potassium carbonate X decompose upon heating
Copper(II) carbonate	Green solid → black	$CuCO_3 \rightarrow CuO + CO_2$
Zinc carbonate	White solid → yellow → white	$ZnCO_3 \rightarrow ZnO + CO_2$
Ammonium salt	Ammonia gas produced	$NH_4Cl \rightarrow NH_3 + HCl$
Solid X contain metal	No residue left	

Typical questions

Multiple choice questions

1 An aqueous solution of a salt is tested and the following results are obtained.

Test	Result
Addition of a few drops of aqueous sodium hydroxide	white precipitate forms
Addition of excess aqueous sodium hydroxide	precipitate dissolves
Addition of a few drops of aqueous ammonia	white precipitate forms
Addition of excess aqueous ammonia	precipitate remains

What is the cation in the salt? (2021 P1 Q3)

A Al^{3+}
B Ca^{2+}
C NH_4^+
D Zn^{2+}

2 The following substances are used in the laboratory to test for various ions and gases.

acidified potassium manganate(VII)	aqueous ammonia	aqueous barium nitrate
aqueous silver nitrate	aqueous sodium hydroxide	limewater
red litmus paper	blue litmus paper	wooden splint

When testing for ammonia, chlorine, hydrogen and oxygen,
what is the minimum number of items from the table above needed to identify these four gases? (2020 P1 Q3)

A 2
B 3
C 4
D 5

3 Three different experiments with colour changes are carried out.

1. Sulfur dioxide is tested with acidified potassium manganate(VII) solution.
2. Universal Indicator solution is added to a solution of a weak acid.
3. Aqueous potassium iodide and dilute nitric acid are mixed. Then aqueous silver nitrate is added.

Which row correctly identifies the experiments that correspond to the colour changes?

(2019 P1 Q4)

	colourless solution to a yellow precipitate	purple to colourless	green to orange
A	1	2	3
B	2	1	3
C	3	2	1
D	3	1	2

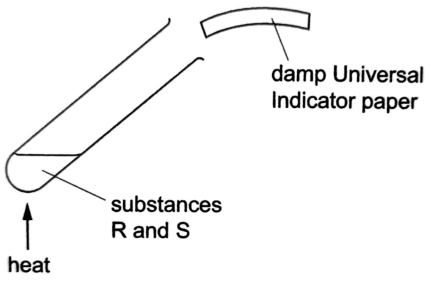
4 Y is a white solid mixture that has the following properties:

- Y dissolves in water.
- When dilute hydrochloric acid is added to an aqueous solution of Y, bubbles are produced.
- When chlorine is bubbled through an aqueous solution of Y, the solution turns red-brown.

What is present in Y? (2019 P1 Q21)

A calcium carbonate ($CaCO_3$) and potassium bromide (KBr)
B copper(II) carbonate ($CuCO_3$) and magnesium iodide (MgI_2)
C sodium carbonate (Na_2CO_3) and sodium bromide (NaBr)
D sodium nitrate ($NaNO_3$) and ammonium bromide (NH_4Br)

5 The diagram shows two substances, **R** and **S**, being heated together.



Which row is correct? (2019 P1 Q22)

	substance **R**	substance **S**	colour change of damp Universal Indicator paper
A	ammonium chloride	aqueous sodium hydroxide	turns blue
B	ammonium chloride	hydrochloric acid	turns red
C	aluminium	aqueous sodium hydroxide	turns blue
D	aluminium	hydrochloric acid	turns red

6 Two solutions, **W** and **X**, were tested as shown.

	W	**X**
Dilute sulfuric acid added	white precipitate	no reaction
Dilute nitric acid added, then aqueous barium nitrate	no reaction	white precipitate
Aqueous ammonia added	white precipitate, insoluble in excess	white precipitate, soluble in excess forming a colourless solution
Aqueous sodium hydroxide and aluminium foil added, then warmed	gas given off which turns red litmus paper blue	no gas given off

What are solutions **W** and **X**? (2018 P1 Q3)

	W	**X**
A	ammonium sulfate	zinc sulfate
B	lead(II) nitrate	aluminium sulfate
C	lead(II) nitrate	zinc sulfate
D	zinc nitrate	aluminium sulfate

7 A salt **G** dissolves in water to give a green solution.

- On adding chlorine, the green solution turns yellow.
- On adding aqueous ammonia, the green solution gave a green precipitate and the yellow solution gave a red-brown precipitate.
- On adding dilute nitric acid followed by aqueous barium nitrate, the green solution gave a white precipitate.

What is the chemical formula of **G**? (2017 P1 Q26)

A $CuCl_2$
B $CuSO_4$
C $FeCl_2$
D $FeSO_4$

8 A gas **R** has the following properties:

- A choking smell
- Turns damp blue litmus paper red, then white
- Does not react with acidified potassium manganate(VII)

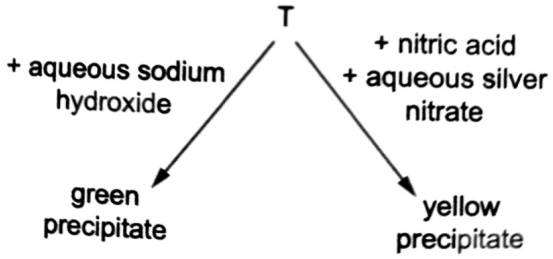
What is **R**? (2016 P1 Q1)

A ammonia
B carbon dioxide
C chlorine
D sulfur dioxide

9 A salt Q, on warming with excess aqueous sodium hydroxide, evolved a gas that turned damp red litmus paper blue. When no more gas was evolved, aluminium powder was added and a further evolution of the same gas occurred.
What was salt Q? (2016 P1 Q2)

A $(NH_4)_2CO_3$
B NH_4Cl
C $(NH_4)_2SO_4$
D NH_4NO_3

10 An aqueous solution of a compound **T**, undergoes the following reactions.



What is **T**? (2016 P1 Q21)

A iron(II) carbonate
B iron(III) chloride
C iron(II) iodide
D iron(III) nitrate

11 The following observations were made by separately reading three solutions containing metal ions with an excess of aqueous sodium hydroxide and an excess of aqueous ammonia.

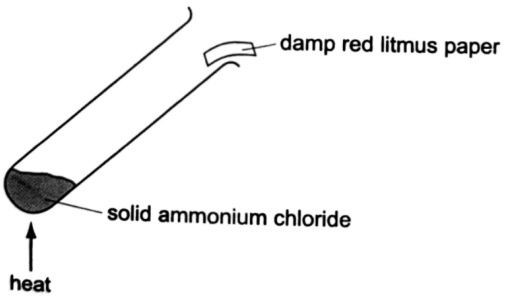
Solution	1	2	3
Add excess aqueous sodium hydroxide	colourless solution	colourless solution	white ppt.
Add excess aqueous ammonia	white ppt.	colourless solution	colourless solution

Which metal ions are present in each solution? (2015 P1 Q24)

	1	2	3
A	Al^{3+}	Ca^{2+}	Zn^{2+}
B	Al^{3+}	Zn^{2+}	Ca^{2+}
C	Ca^{2+}	Zn^{2+}	Al^{3+}
D	Zn^{2+}	Al^{3+}	Ca^{2+}

12 Solid ammonium chloride decomposes on heating according to the following equation.

$$NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$$



Which change occurs to the damp red litmus paper in the experiment above? (2013 P1 Q2)

A remains red
B turns blue and is then bleached
C turns blue and remains blue
D turns blue and then turns red

13 Which one of the following tests can be used to distinguish between potassium iodide and potassium chloride?

A Heat strongly.
B Use litmus paper.
C Add aqueous ammonia.
D Add dilute nitric acid, followed by aqueous silver nitrate.

14 A solution of an unknown substance produces a white precipitate with acidified silver nitrate solution. When added to aqueous ammonia, a white precipitate that dissolves in excess alkali is produced. What is the unknown substance?

A Zinc chloride
B Calcium iodide
C Lead(II) chloride
D Aluminium iodide

15 A sample of an unknown powder is added to dilute hydrochloric acid. Effervescence is observed and a colourless and odourless gas is produced. It is neutral to moist litmus paper but extinguishes a burning splint with a 'pop' sound. When aqueous ammonia is added, a white precipitate is formed which is insoluble in excess alkali. When acidified potassium iodide is reacted with the powder, a yellow precipitate is formed. What is the unknown powder?

A Zinc
B Lead
C Calcium
D Aluminium

Structured questions

1 Different metal ores may also contain impurities of compounds of lead, zinc or aluminium.
The reaction of a sample of ore with nitric acid results in the formation of a solution containing one of these metal ions. (2019 P2 A3)

(a) Explain why aqueous ammonia can be used to identify **only** one of the ions in the solution. [2]

- For both Al^{3+} and Pb^{2+} ions, white ppt. is formed which is insoluble in excess aqueous ammonia.
- For Zn^{2+} ion, white ppt. is formed which is soluble in excess ammonia to give a colourless solution.

(b) Describe another test and result that can be used to distinguish between the **other** two ions. [1]

To distinguish between Al^{3+} and Pb^{2+} ions, add aqueous potassium iodide (KI).

- If Pb^{2+} is present, yellow ppt. of PbI_2 (s) is formed.
- If Al^{3+} is present, no ppt. is seen.

(c) Describe how you would carry out a test to show the presence of nitrate ions in a solution. Include the observations you would expect. [3]

- Add aqueous sodium hydroxide and then add a small piece of aluminium foil. Warm the mixture gently.
- If nitrate ion is present, a pungent gas is produced,
- which turns moist red litmus paper blue. The gas is ammonia.

2 A student did some tests using four reagents A, B, C and D.
In each test, he added a different reagent to separate fresh samples of aqueous copper(II) chloride and aqueous copper(II) sulfate.
The table shows what reagents he used. (2016 P2 B9 EITHER)

	reagent
A	zinc powder
B	acidified aqueous silver nitrate
C	acidified aqueous barium nitrate
D	aqueous sodium hydroxide

(a) Which **two** reagents give the **same** observations for both aqueous copper(II) chloride and aqueous copper(II) sulfate? [1]

A and **D**

(b) Describe what the student would **observe** when he adds each of the four reagents to separate fresh samples of aqueous copper(II) chloride and aqueous copper(II) sulfate. [5]

Reagent	Copper(II) chloride	Copper(II) sulfate
A	Blue solution turns colourless with a reddish-brown deposit of copper	
B	White precipitate of silver chloride is formed in blue solution	No visible change observed
C	No visible change observed	White precipitate of barium sulfate is formed in blue solution
D	Light blue precipitate of copper(II) hydroxide, insoluble in excess of D	

3 When a certain green powder is heated, it produces a black powder X and a gas Y. Gas Y gives a white precipitate in limewater.

Black powder X is added to dilute sulfuric acid and a blue solution is formed after filtering. This solution is heated to remove most of the solvent. Upon cooling, blue crystals Z are formed. Upon addition of concentrated sulfuric acid, they turn white.

(a) Suggest what the green powder was.

copper(II) carbonate

(b) Identify black powder X, gas Y and blue crystals Z.

X: copper(II) oxide

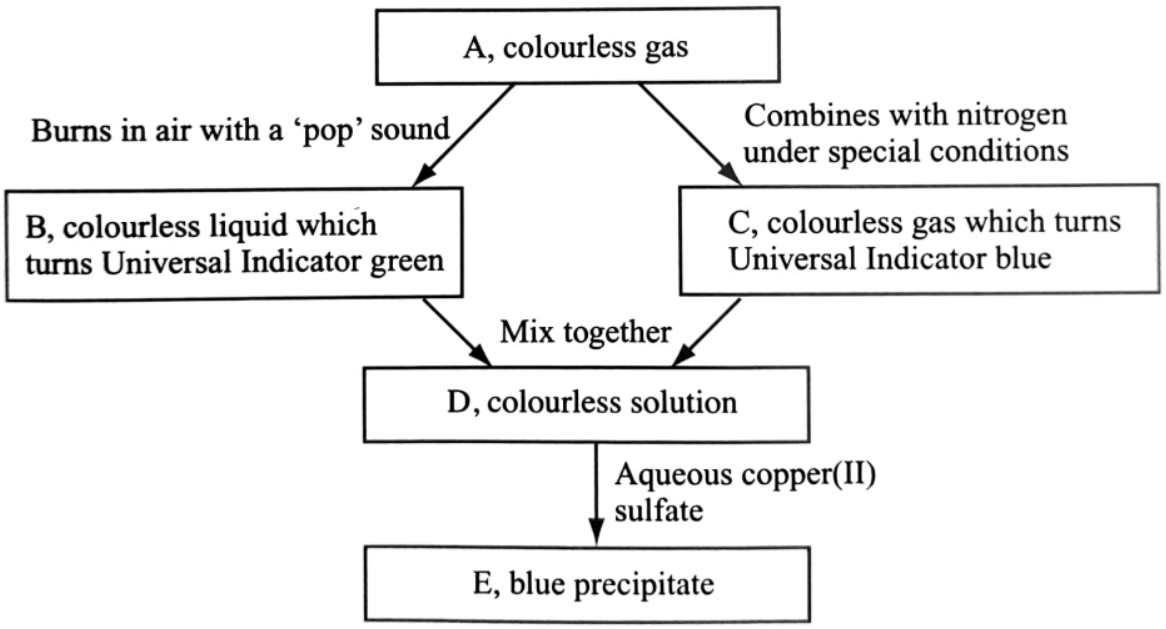
Y: carbon dioxide

Z: copper(II) sulfate

(c) Explain why the blue crystals turn white.

They lose their water of crystallisation and become anhydrous. Copper(II) sulfate is used to test for the presence of water vapour.

4 Substance A is a colourless gas. Substance B is a colourless liquid. The diagram below shows some properties and reactions of substances A, B, C, D and E.



(a) Identify A, B, C and D.

A: hydrogen gas

B: water

C: ammonia gas

D: aqueous ammonia

(b) Suggest an ion present in solution D.

Hydroxide ion (OH^-)

(c) Suggest the identity of E.

copper(II) hydroxide ($Cu(OH)_2$)

3 An alloy which contains two metals was divided into two samples.

- When the first sample was added to excess dilute hydrochloric acid, a pink solid and a colourless solution were formed. When excess aqueous ammonia was added to the colourless solution, a white precipitate was formed.
- The second sample was heated with excess nitric acid to form a blue solution. In the presence of excess sodium hydroxide solution, a blue precipitate was observed.

(a) Name the pink solid and blue solution.

The pink solid is copper and the blue solution is a mixture of copper(II) nitrate and aluminium nitrate solution.

The first test shows the presence of aluminium. Aluminium can react with dilute acid to form a colourless solution and hydrogen gas. The pink solid is a metal that does not react with dilute hydrochloric acid. The second test shows that the pink solid is copper. Copper does not react with dilute acids but can be oxidised by nitric acid.

(b) Explain why zinc cannot be present in the alloy.

If zinc were present, it would form a white precipitate with aqueous ammonia that would react in the presence of excess alkali.

(c) The colourless solution from the first sample was reacted with acidified potassium iodide. No reaction was observed. What are the two metals present in the alloy?

Aluminium and copper

(d) Name the white precipitate formed in the first sample. Write the equation for the reaction leading to its formation.

The white precipitate is aluminium hydroxide.

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

4 Given some test tubes and Universal Indicator paper, explain how you can distinguish the identity of four bottles containing dilute hydrochloric acid, magnesium carbonate solution, propanoic acid and ammonia solution.

Step 1: Add Universal Indicator paper to the solutions.

- The two acids change the colour of the Universal Indicator paper to red.
- The two alkalis change the colour of the Universal Indicator paper to blue or purple.

Step 2: Add acid to each of the two alkaline solutions.

- The one that gives a gas is magnesium carbonate solution.
- The other is ammonia solution.

Step 3: Add magnesium carbonate solution to the two acids. A gas (carbon dioxide) is evolved.

- The acid with the faster reaction is dilute hydrochloric acid.
- The other acid is propanoic acid.

5 When an ammonium compound is heated in potassium hydroxide solution, a gas is produced. Suggest a suitable ammonium compound and write a balanced chemical equation for the reaction. Identify the gas and describe a test to distinguish it.

Any ammonium salt when heated with any alkali will form ammonia gas. Ammonia is commonly prepared in the laboratory by heating solid ammonium chloride together with solid sodium hydroxide.

$$NH_4Cl\ (s) + NaOH\ (s) \rightarrow NaCl\ (s) + NH_3\ (g) + H_2O\ (l)$$

To test for ammonia gas, hold a piece of moist red litmus paper to the gas. The colour of the litmus paper changes from red to blue.

6 Describe one chemical test to distinguish between $Zn(OH)_2$ (s) and $Mg(OH)_2$ (s).

Add excess aqueous sodium hydroxide.

- $Zn(OH)_2$ dissolve to form colourless solution
- $Mg(OH)_2$ does not dissolve.