Topic 6: **Answers**
Identification of Ions & Gases

SYLLABUS RELEVANCE & TEXTBOOK CHAPTERS		
O-LEVEL PURE (5072)	✓	Chapter 12.3
O-LEVEL SCIENCE (5116)	✓	Chapter 11.3
N-LEVEL SCIENCE (5155)[1]	✓	Chapter 10

Lesson Package & Accompanying Slides Designed by Alex Lee (2007)
Last Modified by Alex Lee (2011)

[1]only tests for gases (pages 6|1 & 6|2)

1. Tests for Gases

When testing for an unknown gas in a science laboratory, we do this in three steps:

Step 1: Colour & Odour
Step 2: Moist Litmus Test
Step 3: Confirmatory Test (except ammonia and chlorine)

It is important, however, to note that a negative observation is still an observation. For example, do not neglect the fact that a gas is colourless, odourless, or has no effect on moist litmus paper!

Complete the table below with the experimental observations for the following gases.

Gas	Colour	Odour	Litmus Test	Confirmatory Test
H_2 hydrogen gas	colourless	odourless	no effect on moist litmus paper	extinguishes a lighted splint with a 'pop' sound
O_2 oxygen gas	colourless	odourless	no effect on moist litmus paper	rekindles a glowing splint
CO_2 carbon dioxide	colourless	odourless	turns moist blue litmus paper red	white ppt produced when bubbled through limewater (ppt dissolves in excess CO_2)
NH_3 ammonia gas	colourless	pungent smell	turns moist red litmus paper blue	
SO_2 sulfur dioxide	colourless	choking smell	turns moist blue litmus paper red	turns acidified potassium dichromate(VI) [$K_2Cr_2O_7$] from orange to green
Cl_2 chlorine gas	greenish-yellow	irritating smell	turns moist blue litmus paper red and then bleaches it / and then white	
H_2O water vapour	colourless	odourless	no effect on moist litmus paper	turns cobalt(II) chloride paper from blue to pink

(a) Explain why, in the test for gases, the litmus paper must be moist.

Water must be present in order for dissociation to occur; without which the litmus will be unable to change colour.

(b) Suggest why the litmus test alone is sufficient, and that a separate confirmatory test is unnecessary when testing for

(i) ammonia,

Ammonia is the only alkaline gas.

(ii) chlorine.

Chlorine already exhibits a distinctive bleaching effect during the litmus test.

(c) Carbon dioxide can be tested by bubbling through limewater. A white precipitate should be formed in the limewater.

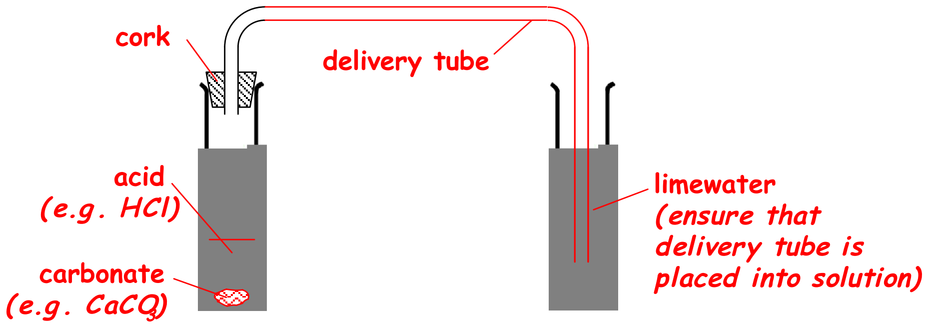
(i) What is limewater?

aqueous calcium hydroxide

(ii) What is the white precipitate that is formed?

calcium carbonate

(iii) Complete the experimental set-up, in the drawing below, for testing of carbon dioxide gas, labeling your diagram appropriately.



(d) Construct chemical equations, including state symbols for

(i) the reaction that occurs when hydrogen is tested with a lighted splint,

$2\ H_2\ (g) + O_2\ (g) \longrightarrow 2\ H_2O\ (g)$

(ii) the reaction that occurs when carbon dioxide is bubbled through limewater.

$CO_2\ (g) + Ca(OH)_2\ (aq) \longrightarrow CaCO_3\ (s) + H_2O\ (l)$

2. Tests for Water

The presence of water (whether liquid or vapour) can be tested by using certain anhydrous salts such as copper(II) sulfate and cobalt(II) chloride. This is because these salts have different colours when in anhydrous form and when in hydrated form.

Anhydrous copper(II) sulfate is a white powder. When it comes in contact with water, it is able to form hydrated copper(II) sulfate, which is blue.

$$CuSO_4 + 5\,H_2O \longrightarrow CuSO_4.5H_2O$$

$CuSO_4$	+	$5\ H_2O$	$\longrightarrow$	$CuSO_4.5H_2O$
white (anhydrous)				*blue (hydrated)*

Another salt, anhydrous cobalt(II) chloride, is a blue powder. When it comes in contact with water, it is able to form hydrated cobalt(II) chloride, which is pink.

$CoCl_2$	+	$6\ H_2O$	$\longrightarrow$	$CoCl_2.6H_2O$
blue (anhydrous)				*pink (hydrated)*

Complete the table below with two possible tests to prove that an unknown liquid is water.

No	Procedure	Observations
1	Place a few drops of the unknown liquid in a sample of anhydrous copper(II) sulfate.	The white anhydrous copper(II) sulfate will turn to blue.
2	Place a few drops of the unknown liquid in a sample of anhydrous cobalt(II) chloride.	The blue anhydrous cobalt(II) chloride will turn to pink.

It is important to note that this tests for the ......presence...... of water, and not ......purity...... . This means the tests will continue to give a positive result for impure samples – for example, salt water. (To test for purity, we have to test melting and boiling points.)

Hydrated salts can be converted back into anhydrous salts simply by gentle heating. The water of crystallization is lost as water vapour.

$CuSO_4.5H_2O$	$\xrightarrow{\text{heat}}$	$CuSO_4$	+	$5\ H_2O$
blue (hydrated)		*white (anhydrous)*		*water vapour evolved*

3. **Tests for Anions**

Complete the table below with the various tests and experimental observations for the following aqueous anions (negative ions).

Anion	Property	Test	Observation
CO_3^{2-} carbonate ion	reacts with acids to form carbon dioxide*	add dilute ......nitric acid...... ......(or hydrochloric acid)......	effervescence, CO_2 evolved
NO_3^- nitrate ion	reacts with alkalis and aluminium to produce ammonia	add aqueous sodium hydroxide, ...aluminium foil......, and warm gently	NH_3 evolved
SO_4^{2-} sulfate ion	forms insoluble salts with calcium, barium and lead(II) ions	add dilute nitric acid, then add aqueous ......barium nitrate......	white precipitate of $BaSO_4$ formed
Cl^- chloride ion	forms insoluble salts with silver and lead(II) ions	add dilute nitric acid, then add aqueous ......silver nitrate......	white precipitate of AgCl formed
I^- iodide ion	forms insoluble salts with silver and lead(II) ions	add dilute nitric acid, then add aqueous ......lead(II) nitrate......	yellow precipitate of PbI_2 formed

** also works on solid metal carbonates.*

(a) Suggest why nitrates are commonly used reagents when testing for anions.

As nitrates are all soluble, by adding a nitrate of the desired metal salt we can ensure that no additional precipitates are formed unintentionally.

(b) Acidified lead(II) nitrate is also able to form a precipitate with chloride ions. Explain why it is not a suitable reagent to test for chlorine ions.

Acidified lead(II) nitrate forms white precipitates in the presence of both chloride and sulfate ions, and hence it will not help us to conclude which anion is present.

(c) Explain why, in the test for chloride ions, acid must first be added.

Silver nitrate is able to form precipitates with chloride, carbonate and hydroxide ions. By adding an acid, we can remove the carbonate and hydroxide ions so that any precipitate formed will allow us to conclude that chloride ions are present.

4. **Review Questions**

(a) Complete the qualitative analysis table below:

No	Procedure	Observations	Conclusions
1	To a 2 cm^3 sample of **P** (aqueous potassium sulfate), add 2 cm^3 of dilute nitric acid followed by 2 cm^3 of aqueous barium nitrate.	A white precipitate is formed.	Sulfate ions are present.
2	To a 2 cm^3 sample of **Q** (aqueous potassium chloride), add 2 cm^3 of dilute nitric acid followed by 2 cm^3 of aqueous barium nitrate.	There is no visible change.	Sulfate ions are not present.
3	(a) To a 2 cm^3 sample of **Q** (aqueous potassium chloride), add 2 cm^3 of dilute nitric acid. (b) Then add 2 cm^3 of aqueous silver nitrate.	There is no visible change. A white precipitate is formed.	Chloride ions are present.
4	(a) To a 2 cm^3 sample of **P** (aqueous potassium sulfate), add 2 cm^3 of barium nitrate. (b) Then add 2 cm^3 of dilute nitric acid.	A white precipitate is formed. There is no visible change.	Sulfate ions are present.
5	(a) To a 2 cm^3 sample of **R** (aqueous potassium hydroxide), add 2 cm^3 of dilute nitric acid. (b) Then add 2 cm^3 of aqueous silver nitrate.	There is no visible change. There is no visible change.	Chloride ions are not present.
6	(a) To a 2 cm^3 sample of **R** (aqueous potassium hydroxide), add 2 cm^3 of silver nitrate. (b) Then add 2 cm^3 of dilute nitric acid.	A white precipitate is formed. White precipitate dissolves to form a colourless solution.	Chloride ions are not present.

(b) (i) Construct a balanced chemical equation, including state symbols, for the reaction between magnesium carbonate and nitric acid.

$MgCO_3\ (s) + 2\ HNO_3\ (aq) \longrightarrow Mg(NO_3)_2\ (aq) + H_2O\ (l) + CO_2\ (g)$

(ii) Construct a balanced chemical equation, including state symbols, for the precipitation reaction between potassium iodide and lead(II) nitrate.

$2\ KI\ (aq) + Pb(NO_3)_2\ (aq) \longrightarrow 2\ KNO_3\ (aq) + PbI_2\ (s)$

5. **Tests for Cations**

Study the table below with the various experimental observations when testing for aqueous cations by adding (i) aqueous sodium hydroxide, and (ii) aqueous ammonia.

	TEST #1: *add a few drops of* ***sodium hydroxide****, followed by excess*	**TEST #2:** *add a few drops of* ***aqueous ammonia****, followed by excess*
Cations of Amphoteric Oxides ("ALZ")		
Al^{3+} aluminium ion	white precipitate of $Al(OH)_3$ formed, which **dissolves in excess NaOH**, forming a colourless solution	white precipitate of $Al(OH)_3$ formed, insoluble in excess NH_4OH
Pb^{2+} lead(II) ion	white precipitate of $Pb(OH)_2$ formed, which **dissolves in excess NaOH**, forming a colourless solution	white precipitate of $Pb(OH)_2$ formed, insoluble in excess NH_4OH
Zn^{2+} zinc ion	white precipitate of $Zn(OH)_2$ formed, which **dissolves in excess NaOH**, forming a colourless solution	white precipitate of $Zn(OH)_2$ formed, which **dissolves in excess NH_4OH**, forming a colourless solution
Cations of Transition Metals		
Cu^{2+} copper(II) ion	**light blue** precipitate of $Cu(OH)_2$ formed, insoluble in excess NaOH	**light blue** precipitate of $Cu(OH)_2$ formed, which **dissolves in excess NH_4OH**, forming a dark blue solution
Fe^{2+} iron(II) ion	**green** precipitate of $Fe(OH)_2$ formed, insoluble in excess NaOH	**green** precipitate of $Fe(OH)_2$ formed, insoluble in excess NH_4OH
Fe^{3+} iron(III) ion	**reddish-brown** precipitate $Fe(OH)_3$ formed, insoluble in excess NaOH	**reddish-brown** precipitate $Fe(OH)_3$ formed, insoluble in excess NH_4OH
Other Cations		
Ca^{2+} calcium ion	white precipitate of $Ca(OH)_2$ formed, insoluble in excess NaOH	no visible change
NH_4^+ ammonium ion	**ammonia produced on warming**	no visible change

(a) In the table below, write down the **chemical formulae** of the metal hydroxides that are able to dissolve in aqueous sodium hydroxide and aqueous ammonia.

dissolves in excess aqueous sodium hydroxide	**dissolves in excess aqueous ammonia**
$Al(OH)_3$	$Zn(OH)_2$
$Pb(OH)_2$	$Cu(OH)_2$
$Zn(OH)_2$	

(b) (i) Which two cations can not be distinguished from each other through these tests?

aluminium ion (Al^{3+}) and lead(II) ion (Pb^{2+})

(ii) Suggest an additional test that can be done to distinguish between these two ions, stating your observations for each cation.

Add an aqueous chloride/iodide/sulfate compound, e.g. sodium chloride / hydrochloric acid. If lead(II) ions are present, a white precipitate will be formed. If aluminium ions are present, there will be no precipitate formed.

(c) State the common feature in the reaction between sodium hydroxide and

(i) cations of amphoteric oxides: a white precipitate is formed, soluble in excess

(ii) cations of transition metals: a coloured (i.e. non-white) precipitate is formed

The tests for the ammonium ion and the nitrate ion are very similar:

Ion	**Ammonium Ion (NH_4^+)**	**Nitrate Ion (NO_3^-)**
Procedure	To a sample of the unknown solution, add aqueous sodium hydroxide. Warm the mixture gently.	To a sample of the unknown solution, add aqueous sodium hydroxide. Then add **aluminium** foil. Warm the mixture gently.
Observations	A colourless, pungent-smelling gas is evolved which turns moist red litmus paper blue. Gas is ammonia.	A colourless, pungent-smelling gas is evolved which turns moist red litmus paper blue. Gas is ammonia.

(d) (i) State the main difference between the tests for ammonium and nitrate ions.

In the test for the nitrate ion, aluminium foil is added. However, in the test for the ammonium ion, aluminium foil is not added.

(ii) Will the presence of ammonium ions affect the test for nitrates ions? Why?

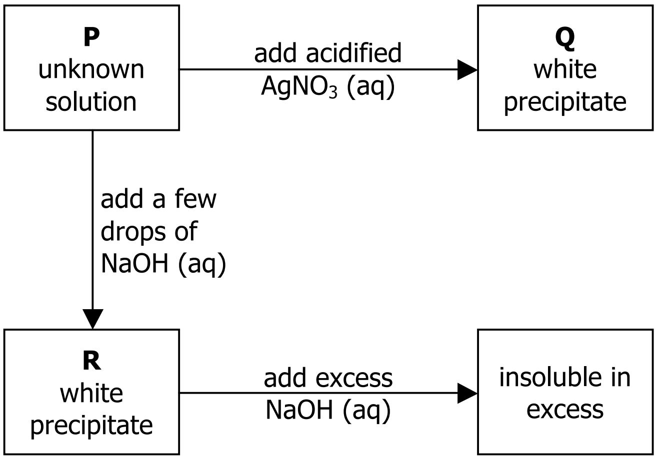
Yes. If ammonium ions are present, the test for nitrate ions will be positive even if nitrate ions are not present.

(iii) Describe how should we accurately test that an unknown solution contains nitrate ions and not ammonium ions.

To a sample of the unknown solution, add aqueous sodium hydroxide and warm. Test that no ammonia gas is evolved. Then add aluminium foil and warm again.

6. **Review Questions**

(a) Deduce the identities of the three unknown substances, **P**, **Q** and **R** below:

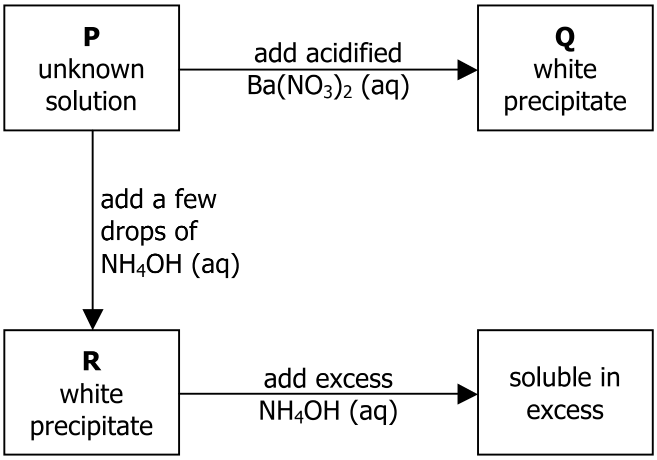


Substance P Name: calcium chloride Formula: $CaCl_2$

Substance Q Name: silver chloride Formula: AgCl

Substance R Name: calcium hydroxide Formula: $Ca(OH)_2$

(b) Deduce the identities of the three unknown substances, **P**, **Q** and **R** below:



Substance P Name: zinc sulfate Formula: $ZnSO_4$

Substance Q Name: barium sulfate Formula: $BaSO_4$

Substance R Name: zinc hydroxide Formula: $Zn(OH)_2$

7. Thermal Decomposition

Sometimes, the action of heat alone is able to break up a **solid salt** into smaller compounds. This reaction is known as thermal decomposition (thermal - heat, decomposition - break apart).

This is **not to be confused with combustion**, where the substance reacts with oxygen to form **oxides of the various elements** in the initial compound.

Salts that decompose easily on heating are said to be thermally unstable, while salts that are unable to be decomposed even by strong heat are said to be thermally stable.

Type of Compound	Occurs In	Products of Decomposition
Hydroxides (OH^-)	All hydroxides, except Group I hydroxides	**Water vapour evolved** e.g. $Ca(OH)_2 \longrightarrow CaO + H_2O$
Carbonates (CO_3^{2-})	All carbonates, except Group I carbonates	**Carbon dioxide evolved** e.g. $CaCO_3 \longrightarrow CaO + CO_2$
Nitrates (NO_3^-)	All nitrates can decompose	*Group I nitrates:* **Oxygen evolved** e.g. $2\ KNO_3 \longrightarrow 2\ KNO_2 + O_2$ *Other nitrates:* **Nitrogen dioxide and oxygen evolved** e.g. $Ca(NO_3)_2 \longrightarrow 2CaO + 4NO_2 + O_2$

(a) Construct chemical equations, including state symbols, for the **decomposition** of

(i) solid copper(II) hydroxide

$Cu(OH)_2\ (s) \longrightarrow CuO\ (s) + H_2O\ (g)$

(ii) solid zinc carbonate

$ZnCO_3\ (s) \longrightarrow ZnO\ (s) + CO_2\ (g)$

(iii) solid silver nitrate

$4\ AgNO_3\ (s) \longrightarrow 2\ Ag_2O\ (s) + 4\ NO_2\ (g) + O_2\ (g)$

(b) Construct chemical equations, including state symbols, for the **combustion** of

(i) liquid ethanol (C_2H_6O)

$C_2H_6O\ (s) + 3\ O_2\ (g) \longrightarrow 2\ CO_2\ (g) + 3\ H_2O\ (g)$

(ii) solid magnesium sulfide (MgS)

$2\ MgS\ (s) + 3\ O_2\ (g) \longrightarrow 2\ MgO\ (s) + 2\ SO_2\ (g)$

8. **Review Questions**

(a) A solid sample of zinc nitrate is gently heated over an open flame. Two different gases were evolved in the process.

(i) Suggest the identities of these two gases.

Nitrogen dioxide and oxygen

(ii) Write down the name and chemical formula of the residue from this reaction.

Zinc oxide, ZnO

(iii) Predict the experimental observation that would be made if aqueous sodium hydroxide is added, slowly until in excess, to a solution of zinc nitrate.

A white precipitate would be formed, which would be soluble in excess sodium hydroxide, forming a colourless solution.

(iv) Describe how you would prove the presence of the nitrate ion in an aqueous solution of zinc nitrate, stating the predicted observations.

To a sample of the solution, add an equal volume of sodium hydroxide and warm gently. Test for any gas evolved with a moist red blue litmus paper. There should be no visible change. Then add a few pieces of aluminium foil and warm again. A colourless, pungent-smelling gas should be evolved which turns moist red litmus paper blue.

(b) A green compound, **P**, was heated strongly in a test-tube. A colourless gas, **Q**, was evolved and a black solid, **R**, remained in the test-tube.

When gas **Q** was bubbled through aqueous calcium hydroxide, a white precipitate, **S**, formed.

When **R** was dissolved in excess nitric acid, a blue solution, **T**, formed.

A few drops of aqueous ammonia is added to **T**, which produces a light blue precipitate **U**. An excess of aqueous ammonia added to **U** produces a dark blue solution.

(i) Deduce the chemical formulae, **with state symbols**, of **P**, **Q**, **R**, **S**, **T** and **U**.

P: $CuCO_3$ (s) **S:** $CaCO_3$ (s)

Q: CO_2 (g) **T:** $Cu(NO_3)_2$ (aq)

R: CuO (s) **U:** $Cu(OH)_2$ (s)

(ii) Construct an equation, including state symbols, for the thermal decomposition of **P**.

$CuCO_3$ (s) $\longrightarrow$ CuO (s) + CO_2 (g)

9. **Colours of Common Substances**

Generally, salts of Group I and Group II metals form **white-coloured compounds**. Similarly, salts of transition metals from **coloured compounds**.

Colour	Substances / Ions Present
Grey	All metals, except copper and gold
Black	CuO, CuS, CoO, FeO, FeS, PbS, MnO_2, I_2 crystals
Blue	Cu^{2+} (aq), $CoCl_2$ (anhydrous)
Green	Fe^{2+}, Ni^{2+}, $CuCl_2$ (anhydrous), $CuCO_3$
Reddish-brown	Fe^{3+} (solid), I_2 (aqueous), Br_2 (aqueous/liquid)
Yellow	Fe^{3+} (aq), PbI_2, AgBr, AgI
Orange	$Cr_2O_7^{2-}$, PbO
Pink	$CoCl_2$ (hydrated), Cu (pure metal)
Purple	MnO_4^-, I_2 (solid/gas)

(a) Complete the table below which summarizes the colours of copper and its compounds.

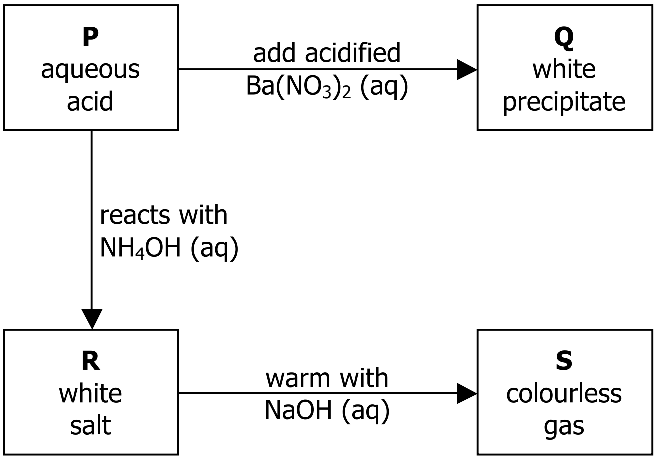
Substance	Colour
copper metal	pink
anhydrous copper(II) sulfate	white
aqueous copper(II) sulfate	blue
anhydrous copper(II) chloride	green
aqueous copper(II) chloride	blue
solid copper(II) carbonate	green
solid copper(II) oxide	black

(b) Complete the table below which summarizes the colours of iodine and its compounds.

Substance	Colour
iodine crystals	purple
iodine vapour	purple
aqueous iodine	brown
aqueous potassium iodide	colourless
solid lead(II) iodide	yellow
solid silver iodide	pale yellow

10. **Review Questions**

(a) The diagram below shows a reaction scheme involving four unknown substances.



State the **names** and **formulae** of the unknown substances **P**, **Q**, **R** and **S**, as shown above.

P: sulfuric acid, H_2SO_4

R: ammonium sulfate, $(NH_4)_2SO_4$

Q: barium sulfate, $BaSO_4$

S: ammonia gas, NH_3

(b) Substance **V** is a blue solution. When aqueous sodium hydroxide is added to **V**, a blue precipitate **W** is formed.

When **W** is heated, a vapour **X** and a black solid **Y** are formed. The vapour condenses to a colourless liquid **Z** that boils at a temperature of 100 °C.

When **Y** is reacted with dilute hydrochloric acid, **V** is obtained again.

(i) Deduce the chemical formulae, **with state symbols**, of **V**, **W**, **X**, **Y** and **Z**.

V: $CuCl_2$ (aq)

Y: CuO (s)

W: $Cu(OH)_2$ (s)

Z: H_2O (l)

X: H_2O (g)

(ii) Construct a balanced chemical equation, with state symbols, for the action of aqueous sodium hydroxide on **V**.

$CuCl_2 (aq) + 2\ NaOH (aq) \longrightarrow Cu(OH)_2 (s) + 2\ NaCl (aq)$

(iii) Why did **W** turn black upon heating?

The copper(II) hydroxide undergoes thermal decomposition to form copper(II) oxide, a black solid.

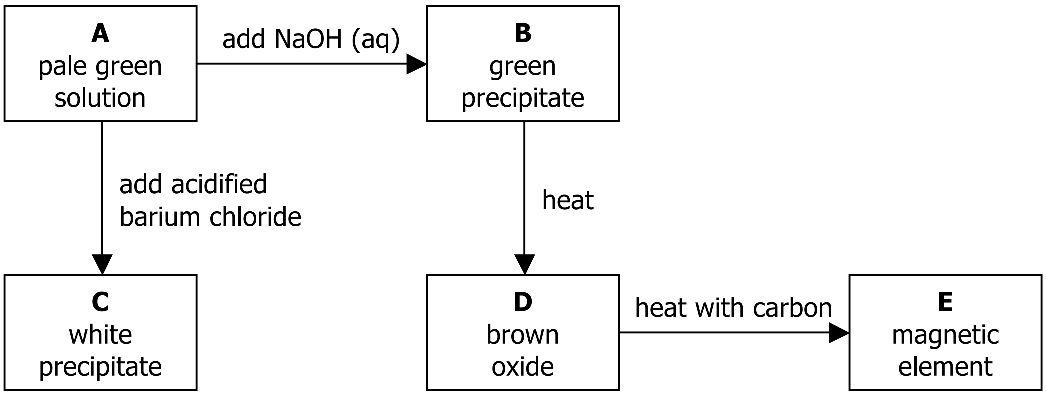
(iv) Construct a balanced chemical equation, with state symbols, for the action of heating **W**.

$Cu(OH)_2 (s) \longrightarrow CuO (s) + H_2O (g)$

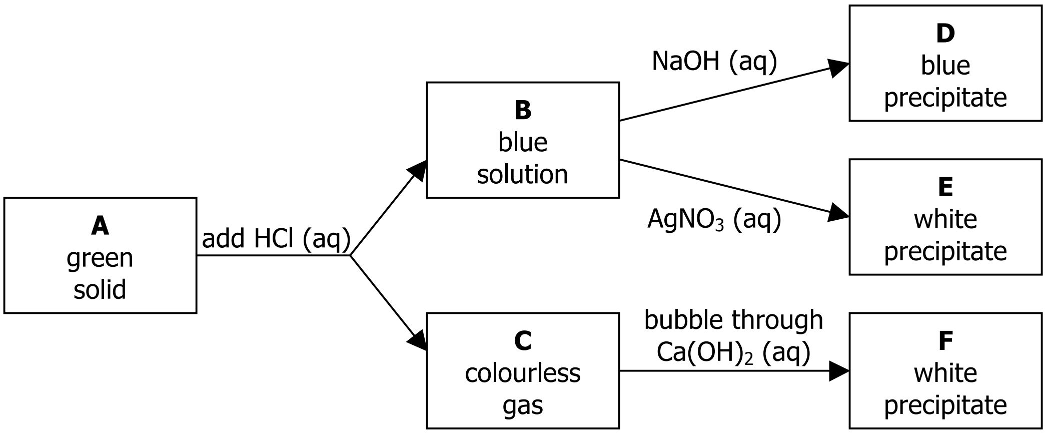
Self-Designed Summary

Supplementary Questions

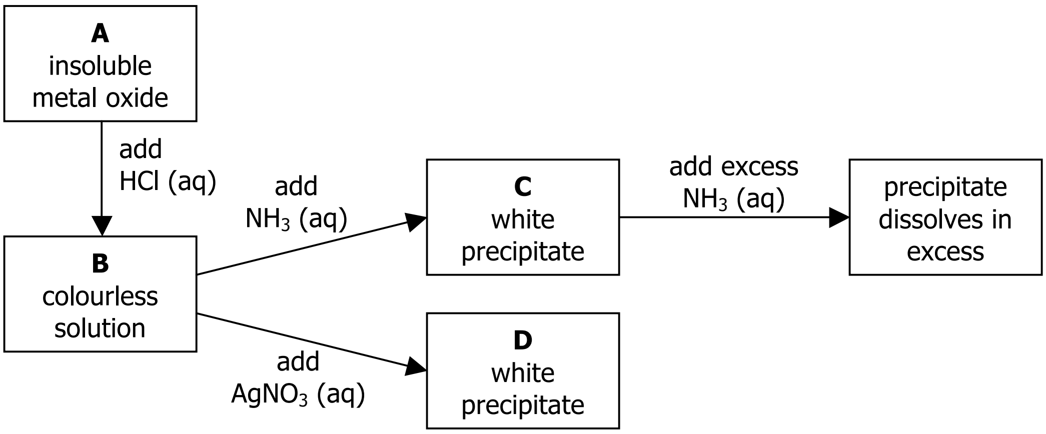
1. State the formulae and state symbols of the unknown substances in the reaction diagram below.



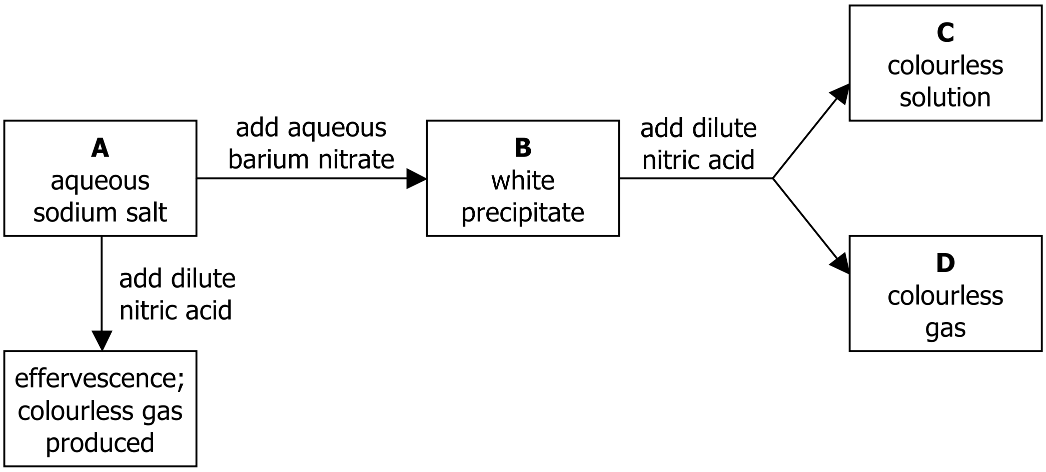
2. State the formulae and state symbols of the unknown substances in the reaction diagram below.



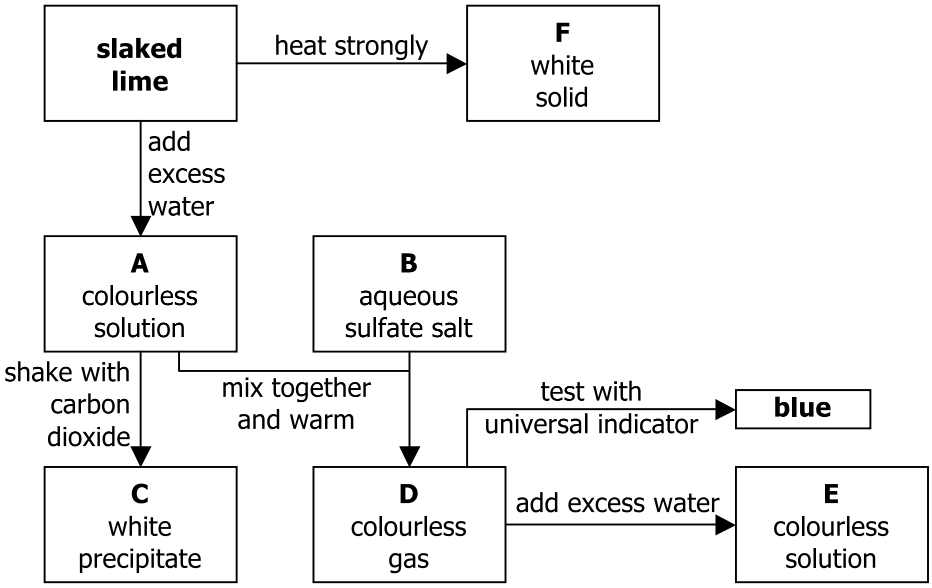
3. State the formulae and state symbols of the unknown substances in the reaction diagram below.



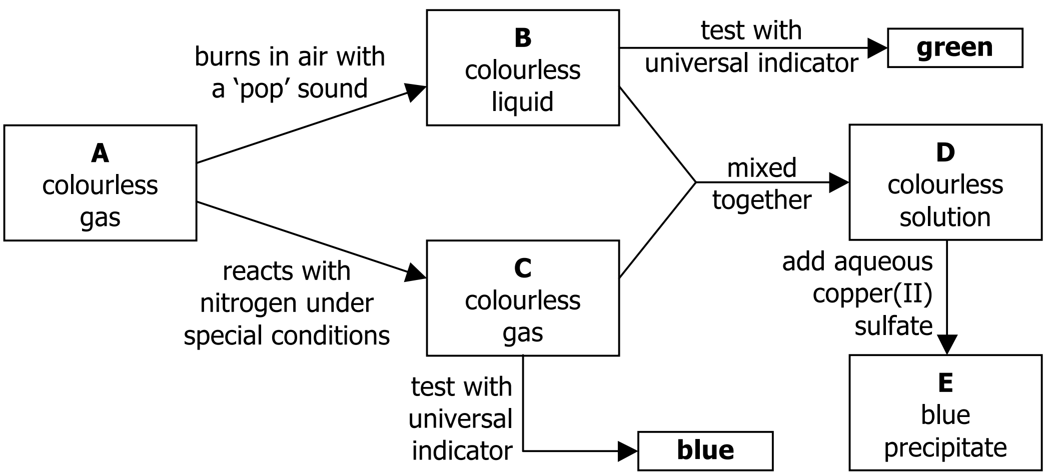
4. State the formulae and state symbols of the unknown substances in the reaction diagram below.



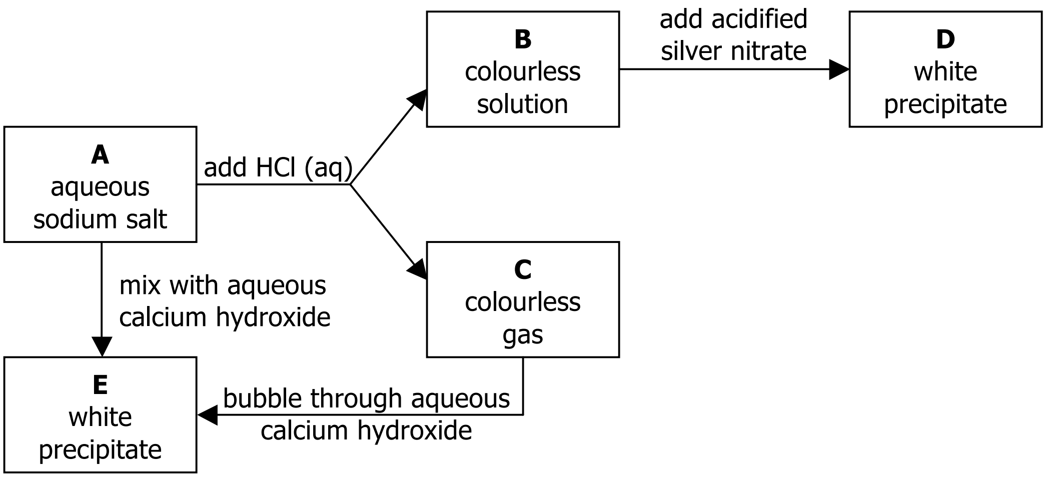
5. State the formulae and state symbols of the unknown substances in the reaction diagram below.



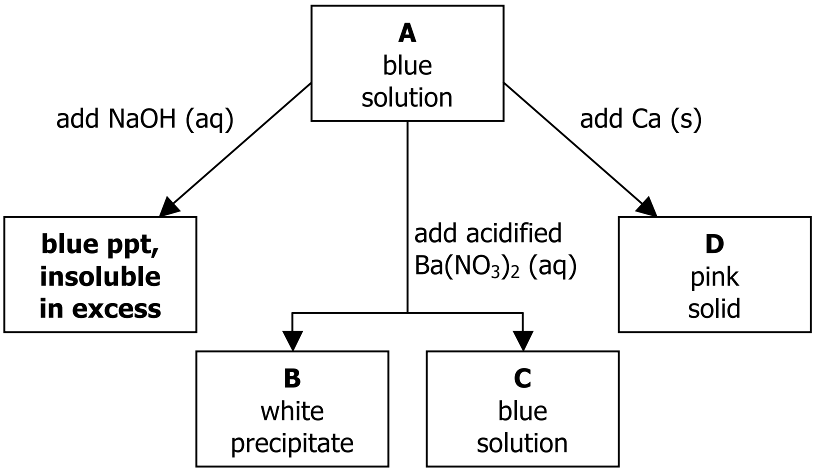
6. State the formulae and state symbols of the unknown substances in the reaction diagram below.



7. State the formulae and state symbols of the unknown substances in the reaction diagram below.



8. State the formulae and state symbols of the unknown substances in the reaction diagram below.



Supplementary Questions (Answers)

Question 1

A: $FeSO_4$ (aq)
B: $Fe(OH)_2$ (s)
C: $BaSO_4$ (s)
D: Fe_2O_3 (s)
E: Fe (s)

Question 2

A: $CuCO_3$ (s)
B: $CuCl_2$ (aq)
C: CO_2 (g)
D: $Cu(OH)_2$ (s)
E: AgCl (s)
F: $CaCO_3$ (s)

Question 3

A: ZnO (s)
B: $ZnCl_2$ (aq)
C: $Zn(OH)_2$ (s)
D: AgCl (s)

Question 4

A: Na_2CO_3 (aq)
B: $BaCO_3$ (s)
C: $Ba(NO_3)_2$ (aq)
D: CO_2 (g)

Question 5

A: $Ca(OH)_2$ (aq)
B: $(NH_4)_2SO_4$ (aq)
C: $CaCO_3$ (s)
D: NH_3 (g)
E: NH_4OH (aq)
F: CaO (s)

Question 6

A: H_2 (g)
B: H_2O (l)
C: NH_3 (g)
D: NH_4OH (aq) / NH_3 (aq)
E: $Cu(OH)_2$ (s)

Question 7

A: Na_2CO_3 (aq)
B: NaCl (aq)
C: CO_2 (g)
D: AgCl (s)
E: $CaCO_3$ (s)

Question 8

A: $CuSO_4$ (aq)
B: $BaSO_4$ (s)
C: $Cu(NO_3)_2$ (aq)
D: Cu (s)

Lecture Slides

Identification of Ions & Gases

Anglo-Chinese School (Barker Road)

CHEMISTRY
Prepared by Alex Lee

Chapter Overview

In This Chapter, We Will Learn …

Tests for Gases

- In our syllabus, we have to conduct the tests for various gases, including:
  - H_2, hydrogen gas
  - O_2, oxygen gas
  - CO_2, carbon dioxide gas
  - Cl_2, chlorine gas
  - SO_2, sulfur dioxide gas
  - NH_3, ammonia gas
- The knowledge of such tests are examined in both practical and theory papers.

Tests for Gases

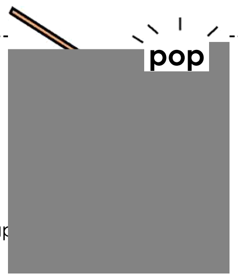
Step 1: **Sensory Observations** → **COLOUR**: colourless? greenish-yellow? ; **ODOUR**: odourless? pungent smell?

Step 2: **Litmus (Acidity) Test** → **MOIST LITMUS**: no effect? moist blue litmus turns red?

Step 3: **Confirmatory Test** → **DEPENDS ON GAS**, e.g.
hydrogen – lighted splint test
oxygen – glowing splint test
carbon dioxide – limewater test
chlorine – bleaching effect
sulfur dioxide – reducing agent test

Tests for Gases

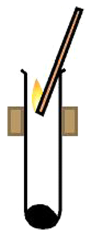
HYDROGEN GAS



- **Sensory Observations:**
  Colourless, odourless gas
- **Moist Litmus Test:**
  No effect on moist litmus paper
- **Confirmatory Test:**
  Extinguishes a **lighted** splint with a 'pop' sound.

Tests for Gases

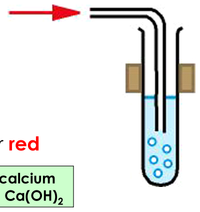
OXYGEN GAS



- **Sensory Observations:**
  Colourless, odourless gas
- **Moist Litmus Test:**
  No effect on moist litmus paper
- **Confirmatory Test:**
  Relights a **glowing** splint.

Tests for Gases

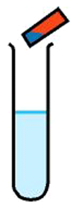
CARBON DIOXIDE GAS



- **Sensory Observations:**
  Colourless, odourless gas
- **Moist Litmus Test:**
  Turns moist blue litmus paper **red**
- **Confirmatory Test:** [aqueous calcium hydroxide, $Ca(OH)_2$]
  When bubbled through **limewater**, a **white precipitate** is formed. [white precipitate dissolves in excess of carbon dioxide!] [calcium carbonate, $CaCO_3$]

Tests for Gases

AMMONIA GAS



- **Sensory Observations:**
  Colourless, **pungent-smelling** gas
- **Moist Litmus Test:**
  Turns moist red litmus paper **blue**
- **Confirmatory Test:**
  (no confirmatory test necessary: ammonia is the only alkaline gas)

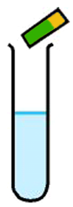
Tests for Gases

CHLORINE GAS

- **Sensory Observations:**
  Greenish-yellow, **irritating-smelling** gas
- **Moist Litmus Test:**
  Turns moist blue litmus paper **red**
- **Confirmatory Test:**
  (Litmus paper is eventually **bleached**, i.e. it turns white.)

Tests for Gases

SULFUR DIOXIDE GAS



- **Sensory Observations:**
  Colourless, **choking-smelling** gas
- **Moist Litmus Test:**
  Turns moist blue litmus paper **red**
- **Confirmatory Test:** [Potassium Dichromate(VI)]
  Filter paper soaked in **acidified** $K_2Cr_2O_7$ changes from **orange to green**.

Tests for Gases

WATER VAPOUR

- **Sensory Observations:**
  Colourless, odourless gas
- **Moist Litmus Test:**
  No effect on moist litmus paper
- **Confirmatory Test:**
  Turns **anhydrous cobalt(II) chloride** paper from blue to pink.

Writing Observations

- When we record our observations, we should include all steps in our observations, including effervescence, sensory observations and the litmus test.
- For example, when testing for sulfur dioxide:
  "Effervescence observed. A colourless, choking-smelling gas is evolved which turns moist blue litmus paper red. When tested with a piece of filter paper soaked in potassium dichromate, filter paper turns from orange to green. Therefore gas is sulfur dioxide."

[Step 1: Sensory Observations] [Step 2: Moist Litmus Test] [Step 3: Confirmatory Test] [Step 4: Conclusion]

Tests for Gases

- **Why do we need to moisten the litmus paper?**
  Water must be present in order for dissociation to occur; without which the litmus will be unable to change colour.

- **Why is no confirmatory test necessary for ammonia?**
  Ammonia is the only alkaline gas.

- **Why is no confirmatory test necessary for chlorine?**
  Chlorine already exhibits a distinctive bleaching effect during the litmus test.

Tests for Water

- Many salts have different colours when hydrated and when anhydrous.

- Two common examples are copper(II) sulfate and cobalt(II) chloride:

	anhydrous	hydrated
copper(II) sulfate	**white**	**blue**
cobalt(II) chloride	**blue**	**pink**

Tests for Water

- An anhydrous salt can be converted into a hydrated salt by the addition of water:

  e.g. adding water to anhydrous copper(II) sulfate

  $CuSO_4$ (s) + 5 H_2O (l) ⟶ $CuSO_4.5H_2O$ (s)

  white → blue

- A hydrated salt can be converted back into an anhydrous salt by gentle heating:

  e.g. heating hydrated copper(II) sulfate

  $CuSO_4.5H_2O$ (s) ⟶ $CuSO_4$ (s) + 5 H_2O (g)

  blue → white

Tests for Water

Water being poured onto white anhydrous copper(II) sulfate, which turns blue.

Image: Source Unknown

Tests for Water

- We can hence use these colour changes as a test for the presence of water!

No	Procedure	Observations
1	Place a few drops of the unknown liquid in a sample of **anhydrous copper(II) sulfate**.	The **white** anhydrous copper(II) sulfate will turn to **blue**.
2	Place a few drops of the unknown liquid in a sample of **anhydrous cobalt(II) chloride**.	The **blue** anhydrous cobalt(II) chloride will turn to **pink**.

Tests for Water

- We should note, however, that these tests test for the **presence** of water, and not **purity**.

- To test for purity, we should check for melting and boiling points instead.

Test for Anions

- In our syllabus, we learn to test for the following anions:
  - CO_3^{2-} carbonate ion
  - NO_3^- nitrate ion
  - SO_4^{2-} sulfate ion
  - Cl^- chloride ion
  - I^- iodide ion
- Let's look at some special properties of these anions.

Test for Anions

CARBONATE ION

- We can use the reaction between acids and metal carbonates to test for the carbonate ion.

Test	Observation
Add dilute **nitric acid** (**or hydrochloric acid**).	**Effervescence, carbon dioxide evolved.** *(A colourless, odourless gas evolved which produces a white precipitate when bubbled through limewater.)*

Effervescence refers to the 'fizzing' that occurs.

Test for Anions

NITRATE ION

- Nitrates can be tested by a special reaction with hydroxide ions and aluminium metal.

Test	Observation
Add **aqueous sodium hydroxide**, a few pieces of **aluminium foil** and **warm** gently.	**Ammonia evolved.** *(A colourless, pungent-smelling gas evolved which is able to turn moist red litmus paper blue.)*

No effervescence for the evolution of ammonia.

Test for Anions

SULFATE ION

- We can test for sulfate ions through precipitation – since only three sulfate salts are insoluble!

Test	Observation
First add dilute **nitric acid**, followed by **aqueous barium nitrate**.	A **white precipitate** of barium sulfate is formed.

Why is nitric acid added?
*Aqueous barium nitrate can precipitate with **sulfate**, **carbonate** and **hydroxide** ions. Adding an acid **removes any possible carbonate and hydroxide ions**.*

Test for Anions

SULFATE ION (Continued)

- Sometimes, the dilute nitric acid and aqueous barium nitrate can be added as separate steps:

Test	*If Sulfate Ions Present*	*If Carbonate Ions Present*
① Add dilute **nitric acid**. ② Add **aqueous barium nitrate**.	No visible change. A **white precipitate** is formed.	**Effervescence** … No visible change.
① Add **aqueous barium nitrate**. ② Add dilute **nitric acid**.	A **white precipitate** is formed. ($BaSO_4$) White precipitate **does not dissolve** in dilute nitric acid.	A **white precipitate** is formed. ($BaCO_3$) White precipitate **dissolves** in dilute nitric acid.

Test for Anions

CHLORIDE ION

- We can test for chloride ions through precipitation – since only two chloride salts are insoluble!

Test	Observation
First add dilute **nitric acid**, followed by **aqueous silver nitrate**.	A **white precipitate** of silver chloride is formed.

Why is nitric acid added?
*Aqueous silver nitrate can precipitate with **chloride**, **carbonate** and **hydroxide** ions. Adding an acid **removes any possible carbonate and hydroxide ions**.*

Test for Anions

CHLORIDE ION (Continued)

- Sometimes, the dilute nitric acid and aqueous silver nitrate can be added as separate steps:

Test	*If Chloride Ions Present*	*If Carbonate Ions Present*
① Add dilute **nitric acid**.	No visible change.	**Effervescence** ...
② Add **aqueous silver nitrate**.	A **white precipitate** is formed.	No visible change.
① Add **aqueous silver nitrate**.	A **white precipitate** is formed. → AgCl	A **white precipitate** is formed. → Ag_2CO_3
② Add dilute **nitric acid**.	White precipitate **does not dissolve** in dilute nitric acid.	White precipitate **dissolves** in dilute nitric acid.

Test for Anions

- **Why is lead(II) nitrate not used to test for precipitation with sulfate or chloride ions?**

Lead(II) nitrate forms white precipitates with both sulfate and chloride ions and hence the two ions may not be distinguished from each other!

Insoluble Sulfates		Insoluble Chlorides		Insoluble Iodides	
$PbSO_4$	white	$PbCl_2$	white	PbI_2	yellow
$BaSO_4$	white	AgCl	white	AgI	pale yellow
$CaSO_4$	white				

However, **lead(II) nitrate** can be used to **test for iodide ions** due to the distinctive yellow colour of lead(II) iodide!

Test for Anions

IODIDE ION

- We can test for iodide ions through precipitation – since only two iodide salts are insoluble!

Test	Observation
First add dilute **nitric acid**, followed by **aqueous lead(II) nitrate**.	A **yellow precipitate** of lead(II) iodide is formed.

Aqueous silver nitrate can also be used, although lead(II) nitrate provides **better contrast** with chloride ions!

Iodides		Chlorides	
PbI_2	yellow	$PbCl_2$	white
AgI	pale yellow	AgCl	white

Test for Anions: Summary

Anion	Test	Observation
CO_3^{2-} carbonate	add dilute **nitric acid** (or hydrochloric acid)	**effervescence**, carbon dioxide evolved
NO_3^- nitrate	add **aqueous sodium hydroxide**, **aluminium foil**, and **warm** gently	**ammonia** evolved (test with moist red litmus)
SO_4^{2-} sulfate	add dilute **nitric acid**, then add aqueous **barium nitrate**	**white precipitate** of $BaSO_4$ formed
Cl^- chloride	add dilute **nitric acid**, then add aqueous **silver nitrate**	**white precipitate** of AgCl formed
I^- iodide	add dilute **nitric acid**, then add aqueous **lead(II) nitrate**	**yellow precipitate** of PbI_2 formed

Tests for Cations

- In our syllabus, we learn to test for the following cations:
  - Al^{3+} aluminium ion
  - Pb^{2+} lead(II) ion
  - Zn^{2+} zinc ion
  - Cu^{2+} copper(II) ion
  - Fe^{2+} iron(II) ion
  - Fe^{3+} iron(III) ion
  - Ca^{2+} calcium ion
  - NH_4^+ ammonium ion

"ALZ" Remember these? **Cations of amphoteric oxides**! (Al^{3+}, Pb^{2+}, Zn^{2+})

Cations of transition metals! (Cu^{2+}, Fe^{2+}, Fe^{3+})

Tests for Cations

- We can test for these cations by first adding an alkali:
  - aqueous **sodium hydroxide**, NaOH
  - aqueous **ammonia** (ammonium hydroxide), NH_4OH

- Most cations, except Group I and ammonium cations, would form a **metal hydroxide precipitate**.

  e.g. $Zn^{2+} (aq) + OH^- (aq) \longrightarrow Zn(OH)_2 (s)$

Why would Group I and ammonium ions not form a precipitate?
This is because all Group I and ammonium hydroxides are soluble, and hence would not form a precipitate when mixed with a solution containing hydroxide ions.

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Tests for Cations

- We can identify some of the metal hydroxides by their colour (i.e. **colour of precipitate**):

hydroxide	colour
aluminium hydroxide	white
lead(II) hydroxide	white
zinc hydroxide	white
copper(II) hydroxide	**light blue**
iron(II) hydroxide	**green**
iron(III) hydroxide	**reddish-brown**
calcium hydroxide	white

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Tests for Cations

- We can identify some of the metal hydroxides by their colour (i.e. **colour of precipitate**):

hydroxide	colour
aluminium hydroxide	white
lead(II) hydroxide	white
zinc hydroxide	white
copper(II) hydroxide	**light blue**
iron(II) hydroxide	**green**
iron(III) hydroxide	**reddish-brown**
calcium hydroxide	white

Transition metals form coloured compounds.

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Tests for Cations

- We can identify other metal hydroxides by their **solubility in sodium hydroxide and aqueous ammonia**:

hydroxide	NaOH	NH_4OH
aluminium hydroxide	**soluble**	insoluble
lead(II) hydroxide	**soluble**	insoluble
zinc hydroxide	**soluble**	**soluble**
copper(II) hydroxide	insoluble	**soluble**
iron(II) hydroxide	insoluble	insoluble
iron(III) hydroxide	insoluble	insoluble
calcium hydroxide	insoluble	n/a

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Tests for Cations

- We can identify other metal hydroxides by their **solubility in sodium hydroxide and aqueous ammonia**:

hydroxide	NaOH	NH_4OH
aluminium hydroxide	**soluble**	insoluble
lead(II) hydroxide	**soluble**	insoluble
zinc hydroxide	**soluble**	
copper(II) hydroxide	insoluble	
iron(II) hydroxide	insoluble	
iron(III) hydroxide	insoluble	
calcium hydroxide	insoluble	insoluble

Amphoteric oxides are soluble in strong alkalis.

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Tests for Cations

- **<u>Memory Tip!</u>**

We can remember the solubility of the various metal hydroxides in both aqueous sodium hydroxide and aqueous ammonia using a mnemonic:

"<u>A</u>nother <u>L</u>azy <u>Z</u>ebra <u>C</u>atches <u>Z</u>zzs."

Aluminium → Another; Lead(II) → Lazy; Zinc → Zebra; Copper(II) → Catches; Zinc → Zzzs

←— Soluble in Aqueous Sodium Hydroxide —→ (Aluminium, Lead(II), Zinc)

←Soluble in Aqueous Ammonia→ (Copper(II), Zinc)

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Tests for Cations

- **Hence each cation test comes in four steps:**

Unknown Solution

① To one portion of the unknown solution, add a **few drops** of **aqueous sodium hydroxide**. *(to form precipitate)*

② Then add **excess aqueous sodium hydroxide**. *(to test solubility)*

③ To a separate portion of the unknown solution, add a **few drops** of **aqueous ammonia.** *(to form precipitate)*

④ Then add **excess aqueous ammonia**. *(to test solubility)*

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Tests for Cations

	add a few drops of sodium hydroxide, followed by excess	*add a few drops of aqueous ammonia, followed by excess*
Al^{3+} aluminium	white precipitate formed, which **dissolves in excess**, forming a **colourless solution**	white precipitate of formed, insoluble in excess
Pb^{2+} lead(II)	white precipitate formed, which **dissolves in excess**, forming a **colourless solution**	white precipitate formed, insoluble in excess
Zn^{2+} zinc	white precipitate formed, which **dissolves in excess**, forming a **colourless solution**	white precipitate formed, which **dissolves in excess**, forming a **colourless solution**
Cu^{2+} copper(II)	**light blue** precipitate formed, insoluble in excess	**light blue** precipitate formed, which **dissolves in excess**, forming a **dark blue solution**

Tests for Cations

	add a few drops of sodium hydroxide, followed by excess	*add a few drops of aqueous ammonia, followed by excess*
Fe^{2+} iron(II)	**green** precipitate formed, insoluble in excess	**green** precipitate formed, insoluble in excess
Fe^{3+} iron(III)	**reddish-brown** precipitate formed, insoluble in excess	**reddish-brown** precipitate formed, insoluble in excess
Ca^{2+} calcium	white precipitate formed, insoluble in excess	no visible change

Test for Cations

AMMONIUM ION

- We can use the reaction between ammonium salts and alkalis to test for the ammonium ion.

Test	Observation
Add **aqueous sodium hydroxide** and **warm** gently.	**Ammonia evolved.** *(A colourless, pungent-smelling gas evolved which is able to turn moist red litmus paper blue.)*

No effervescence for the evolution of ammonia.

Tests for Ammonium & Nitrate Ions

- The tests for the ammonium ion and nitrate ion are very similar:

Ion	**Ammonium Ion (NH_4^+)**	**Nitrate Ion (NO_3^-)**
Procedure	To a sample of the unknown solution, add aqueous sodium hydroxide. Warm the mixture gently.	To a sample of the unknown solution, add aqueous sodium hydroxide. **Then add aluminium foil.** Warm the mixture gently.
Observations	A colourless, pungent-smelling gas is evolved which turns moist red litmus paper blue.	A colourless, pungent-smelling gas is evolved which turns moist red litmus paper blue.

Tests for Ammonium & Nitrate Ions

- **What is the main difference between the tests for ammonium and nitrate ions.**

  *In the test for the nitrate ion, **aluminium foil is added**. However, in the test for the ammonium ion, aluminium foil is not added.*

- **Will the presence of ammonium ions affect the test for nitrates ions? Why?**

  Yes. If ammonium ions are present, the test for nitrate ions will be positive even if nitrate ions are not present.

Tests for Ammonium & Nitrate Ions

- **How then should we accurately test that an unknown solution contains nitrate ions and not ammonium ions?**

  To a sample of the unknown solution, add aqueous sodium hydroxide and warm. Test that no ammonia gas is evolved. Then add aluminium foil and warm again. Test that ammonia gas is evolved.

Thermal Decomposition

- Some compound can be **broken down by heat alone**.
- This is known as **thermal decomposition**, and this can be used to help us identify a compound.
- Thermal decomposition is **not** to be confused with **combustion**.

Thermal Decomposition

- **Thermal decomposition** should not be confused with **combustion**.

Thermal Decomposition	Combustion
Single reactant	More than one reactant
Absorbs heat	Produces heat
Example: **$Ca(OH)_2 \longrightarrow CaO + H_2O$**	*Example:* **$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$**

Thermal Decomposition

Type of Compound	Occurs In	Products of Decomposition
Hydroxides (OH^-)	All hydroxides, except Group I hydroxides	**Water vapour evolved** e.g. $Ca(OH)_2 \longrightarrow CaO + H_2O$
Carbonates (CO_3^{2-})	All carbonates, except Group I carbonates	**Carbon dioxide evolved** e.g. $CaCO_3 \longrightarrow CaO + CO_2$
Nitrates (NO_3^-)	All nitrates can decompose	*Group I nitrates:* **Oxygen evolved** e.g. $2\ KNO_3 \longrightarrow 2\ KNO_2 + O_2$ *Other nitrates:* **Nitrogen dioxide and oxygen evolved** e.g. $Ca(NO_3)_2 \longrightarrow 2CaO + 4NO_2 + O_2$

Colours of Common Substances

- The physical appearance of a substance can help us narrow down its identity.
- Generally, all **pure metals are grey**, with the exception of gold (yellow) and copper (pink).
- Also, most **Group I and Group II salts are white**, while salts of transition metals have various colours.

Colours of Common Substances

- Below are the colours of some common chemicals:

Colour	Substances / Ions Present
Black	CuO, CuS, CoO, FeO, FeS, PbS, MnO_2
Blue	Cu^{2+} (aq), $CoCl_2$ (anhydrous)
Green	Fe^{2+}, Ni^{2+}, $CuCl_2$ (anhydrous), $CuCO_3$
Reddish-brown	Fe^{3+} (solid), I_2 (aqueous), Br_2 (liquid)
Yellow	Fe^{3+} (aq), PbI_2, $AgBr$, AgI
Orange	$Cr_2O_7^{2-}$, PbO
Pink	$CoCl_2$ (hydrated), Cu (pure metal)
Purple	MnO_4^-, I_2 (solid/gas)