Qualitative Analysis Part One: Cations

Qualitative Analysis

- Qualitative analysis is a structured set of methods used to determine the identities (but not the amounts) of the components that make up a mixture.

Qualitative Analysis

Qualitative Analysis

- Qualitative inorganic analysis is used to establish the presence or absence of particular elements or inorganic ions or compounds in an unknown sample. For example, an environmental technician might test a water sample to determine if arsenic, barium, or mercury is present.

Qualitative Analysis

- Qualitative organic analysis is used to establish the presence or absence of particular organic compounds or functional groups in an unknown sample. For example, a medical technician might test a urine sample to determine if glucose is present.

Qualitative Analysis

Qualitative Analysis

- In modern university and corporate laboratories, many qualitative analyses are done instrumentally, using methods such as infrared and mass spectroscopy, nuclear magnetic resonance, neutron activation analysis, x-ray diffraction, spectrophotometry, chromatography, electrophoresis, and others.

Qualitative Analysis

- Before such instruments were introduced, chemists did qualitative analyses using wet-chemistry procedures, reacting the unknown substance with various reagents and observing the results. Such wet-chemistry procedures remain important today, both for field tests or initial screening preliminary to instrumental analysis and as a learning tool.

Qualitative Analysis

A dead body has been found in the kitchen of a five star hotel. Upon close examination, the victim is found to have traces of a white powder under their fingernails. A brief survey of the kitchen reveals that containers of the following ingredients are easily assessable on the work surface. All five of the ingredients are identical in appearance:

- Baking powder
- Citric acid
- Flour
- Sugar
- Table salt

You are the senior forensic scientist at the crime scene. As part of the investigation, you are required to identify the unknown white powder found under the victim’s fingernails. Using your learning device, go online and research information on each ingredient. Give the name and formula of the active chemical that is present in each ingredient and state a qualitative test(s) for each chemical.

Qualitative Analysis

- **Possible test for table salt** (sodium chloride – $\mathrm{NaC}l$):

Add an aqueous solution of silver nitrate to an aqueous solution of the sodium chloride. A *white precipitate* of *silver chloride* will be observed. This confirms the presence of chloride ions in aqueous solution (all chlorides are soluble *except* silver chloride and lead(II) chloride):

$$\mathrm{AgNO_3(aq)} + \mathrm{NaC}l\mathrm{(aq)} \rightarrow \mathrm{AgC}l\mathrm{(s)} + \mathrm{NaNO_3(aq)}$$

$$\mathrm{Ag^+(aq)} + \mathrm{C}l^-\mathrm{(aq)} \rightarrow \mathrm{AgC}l\mathrm{(s)}$$

Note: A small amount of dilute nitric acid should be added to the white precipitate to ensure that it is silver chloride and *not silver carbonate*. Silver carbonate would react with the nitric acid to produce effervescence and the soluble salt, silver nitrate:

$$\mathrm{2HNO_3(aq)} + \mathrm{Ag_2CO_3(s)} \rightarrow \mathrm{2AgNO_3(aq)} + \mathrm{H_2O}(l) + \mathrm{CO_2(g)}$$

There would be no observed reaction if the white precipitate was silver chloride.

Note: Silver ions can be used to test for chloride ions and chloride ions can be used to test for silver ions.

Qualitative Analysis

- **Possible test for sugar** (sucrose – $C_{12}H_{22}O_{11}$):

When solid sucrose is heated, it will undergo a thermal decomposition known as *caramelisation*, turning into a brown viscous liquid. Sucrose is a simple covalent molecule. Consequently, when dissolved in water, it will *not* conduct electricity as there are no mobile charge carrying particles present.

- **Possible test for flour** (starch – $(C_6H_{10}O_5)_n$):

Add an aqueous solution of iodine to the solid starch. The formation of a blue/black complex confirms the presence of starch.

Note: Just as iodine can be used to test for the presence of starch, starch can be used to test for the presence of iodine.

Qualitative Analysis

- **Possible test for baking powder**

(sodium hydrogencarbonate – $NaHCO_3$):

Add dilute nitric acid to the solid baking powder. Effervescence will be observed as carbon dioxide gas is produced:

$$HCl(aq) + NaHCO_3(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

$$H^+(aq) + HCO_3^-(aq) \rightarrow H_2O(l) + CO_2(g)$$

The presence of carbon dioxide should be confirmed by bubbling the gas through limewater. A white precipitate of calcium carbonate will be observed:

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

Note: Acids can be used to test for carbonates and hydrogencarbonates. Carbonates and hydrogencarbonates can be used to test for acids.

Qualitative Analysis

- **Possible test for citric acid** (citric acid – $C_6H_8O_7$):

The most straightforward test for an acid is to use either universal indicator paper / solution or blue litmus paper / solution. Firstly, the solid citric acid must be dissolved in distilled water so that it can exhibit its acidic properties. Blue litmus paper will turn red when dipped into the aqueous solution of citric acid.

Alternatively, an aqueous solution of sodium carbonate could be added to the aqueous solution of citric acid. Effervescence will be observed due to the production of carbon dioxide gas:

$$2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$$

The gas that is produced should be bubbled through limewater. The formation of a white precipitate confirms that the gas is carbon dioxide:

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

Qualitative Analysis

In a nutshell,
what is
qualitative
analysis?

Qualitative Analysis

Qualitative Analysis

- Qualitative analysis is the *identification* of anions, cations and gases based upon their *unique chemical properties*.
- *Cations* can be identified using the alkaline solutions *aqueous sodium hydroxide* and *aqueous ammonia*.
- All cations (with the exception of Na^+, K^+ and NH_4^+) produce *precipitates* with aqueous sodium hydroxide and aqueous ammonia.
- The cation can then be identified by observing:

i) The colour of the precipitate formed (important for the identification of transition metal cations).

ii) Whether the precipitate is soluble or insoluble in an excess of the test reagent (important for the identification of cations of elements with amphoteric properties).

Qualitative Analysis

What is a *precipitate*? How is it different from a *solution*?

Qualitative Analysis

Precipitate Formation

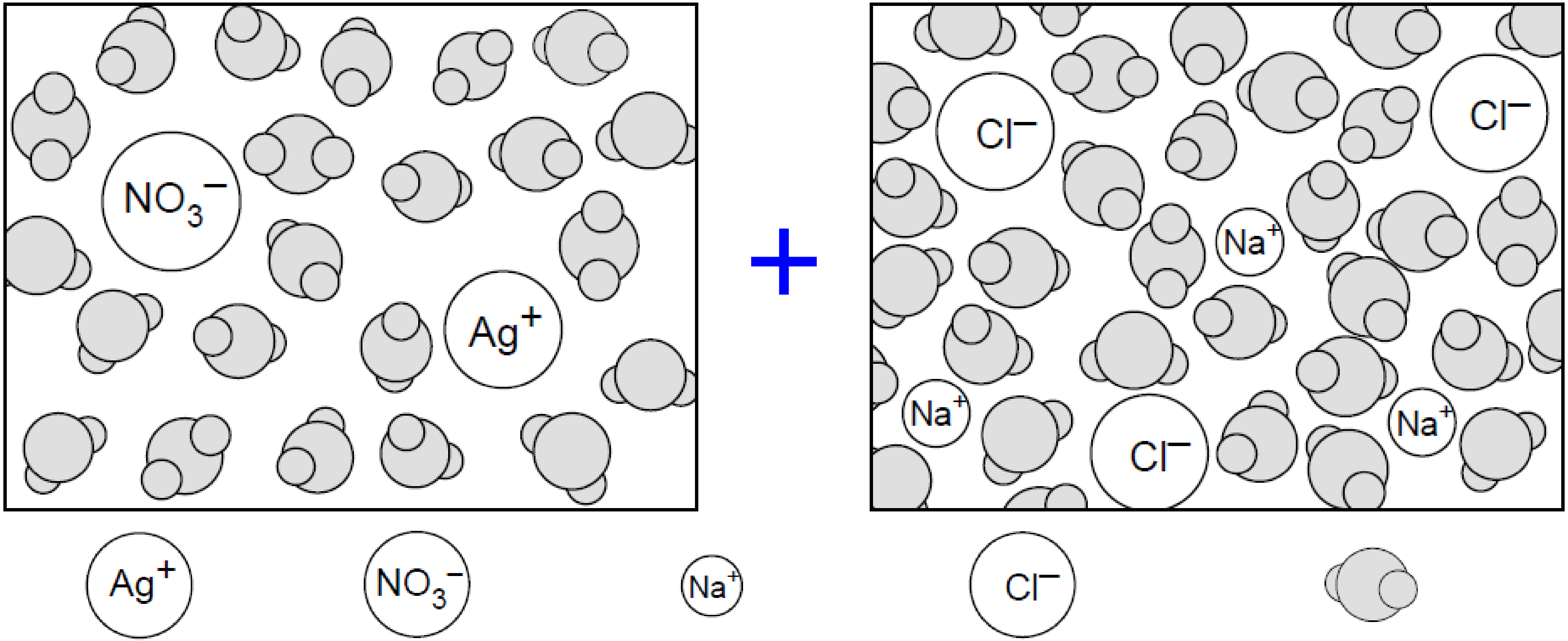
A precipitate is formed when two *clear solutions* react together to form an *opaque solid* product.

- All solutions are *clear*.
- Solutions may be *coloured*, *e.g*. we may refer to a “blue solution of copper(II) sulfate.”
- All precipitates are *opaque*. There is no such thing as a clear precipitate!
- Precipitates may be *coloured*, *e.g*. we may refer to a “yellow precipitate of lead(II) iodide.”

Qualitative Analysis

Precipitate Formation

Aqueous Silver Nitrate + Aqueous Sodium Chloride

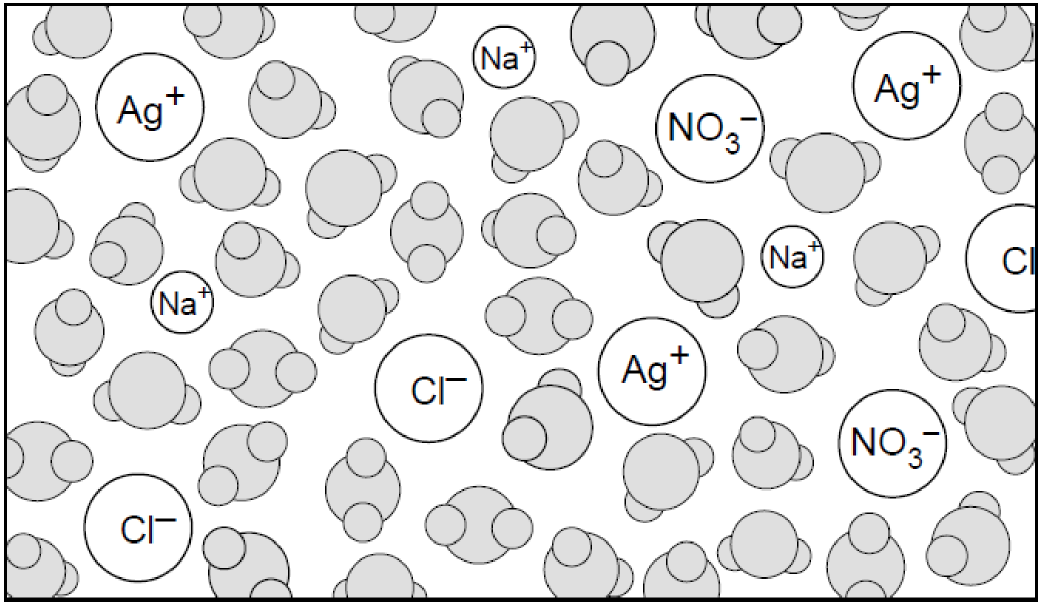


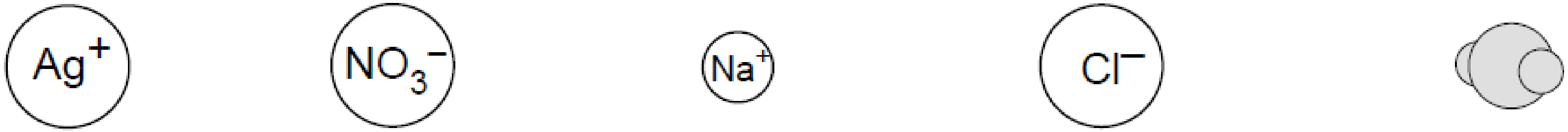
Silver Ion | Nitrate Ion | Sodium Ion | Chloride Ion | Water Molecule

Qualitative Analysis

Precipitate Formation

Mixture of Aqueous Silver Nitrate and Aqueous Sodium Chloride



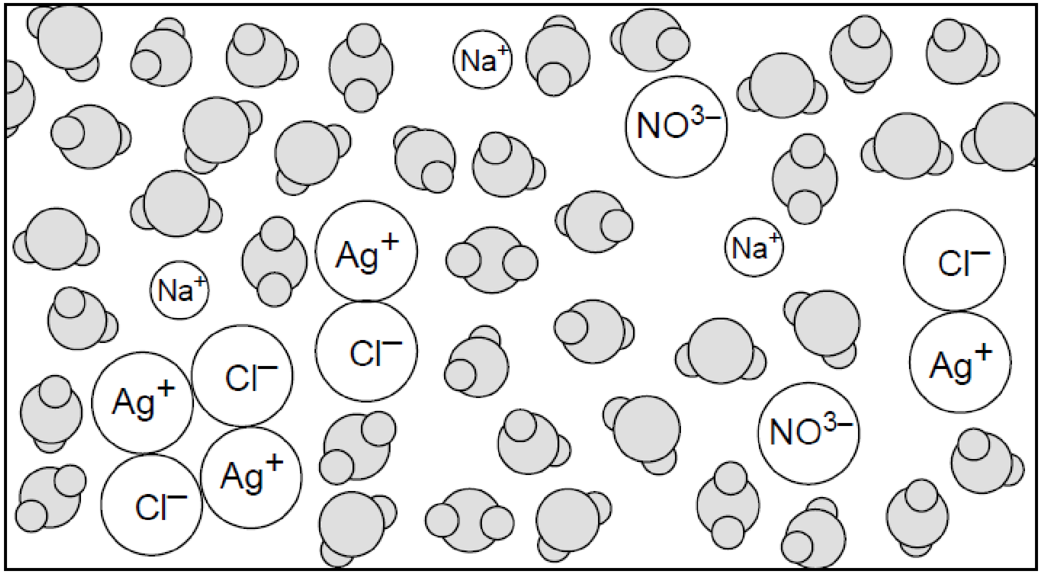


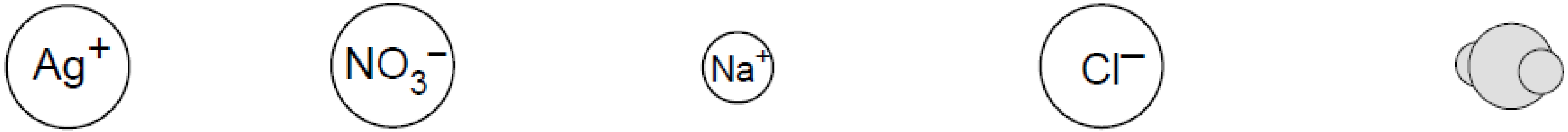
Silver Ion Nitrate Ion Sodium Ion Chloride Ion Water Molecule

Qualitative Analysis

Precipitate Formation

Silver Chloride Precipitating from a Solution of Sodium Nitrate





Silver Ion

Nitrate Ion

Sodium Ion

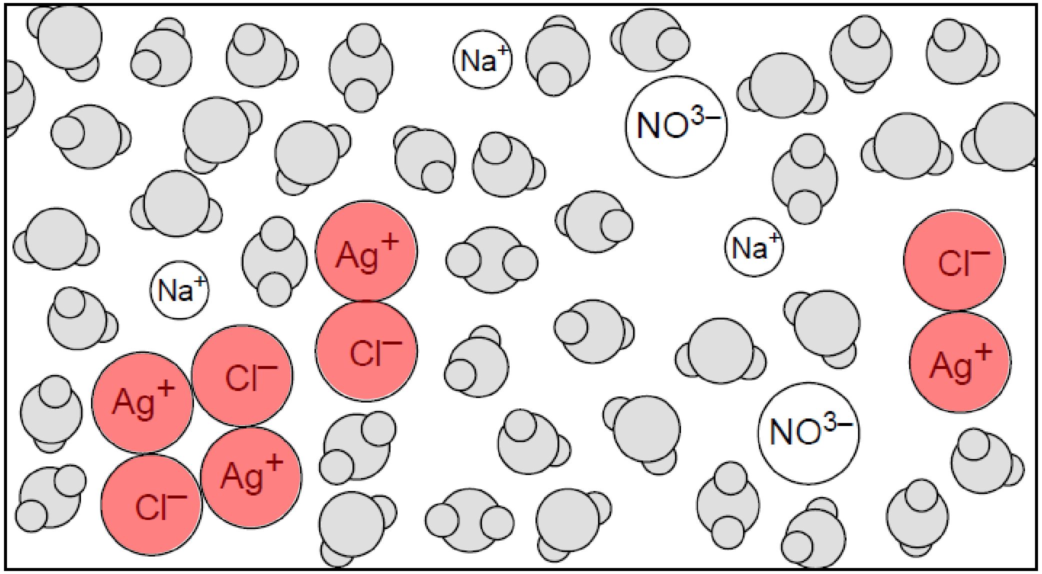
Chloride Ion

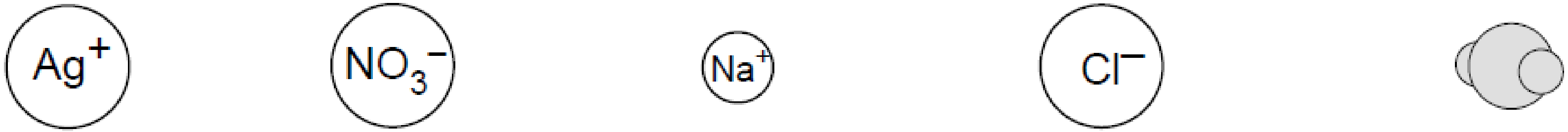
Water Molecule

Qualitative Analysis

Precipitate Formation

Silver Chloride Precipitating from a Solution of Sodium Nitrate





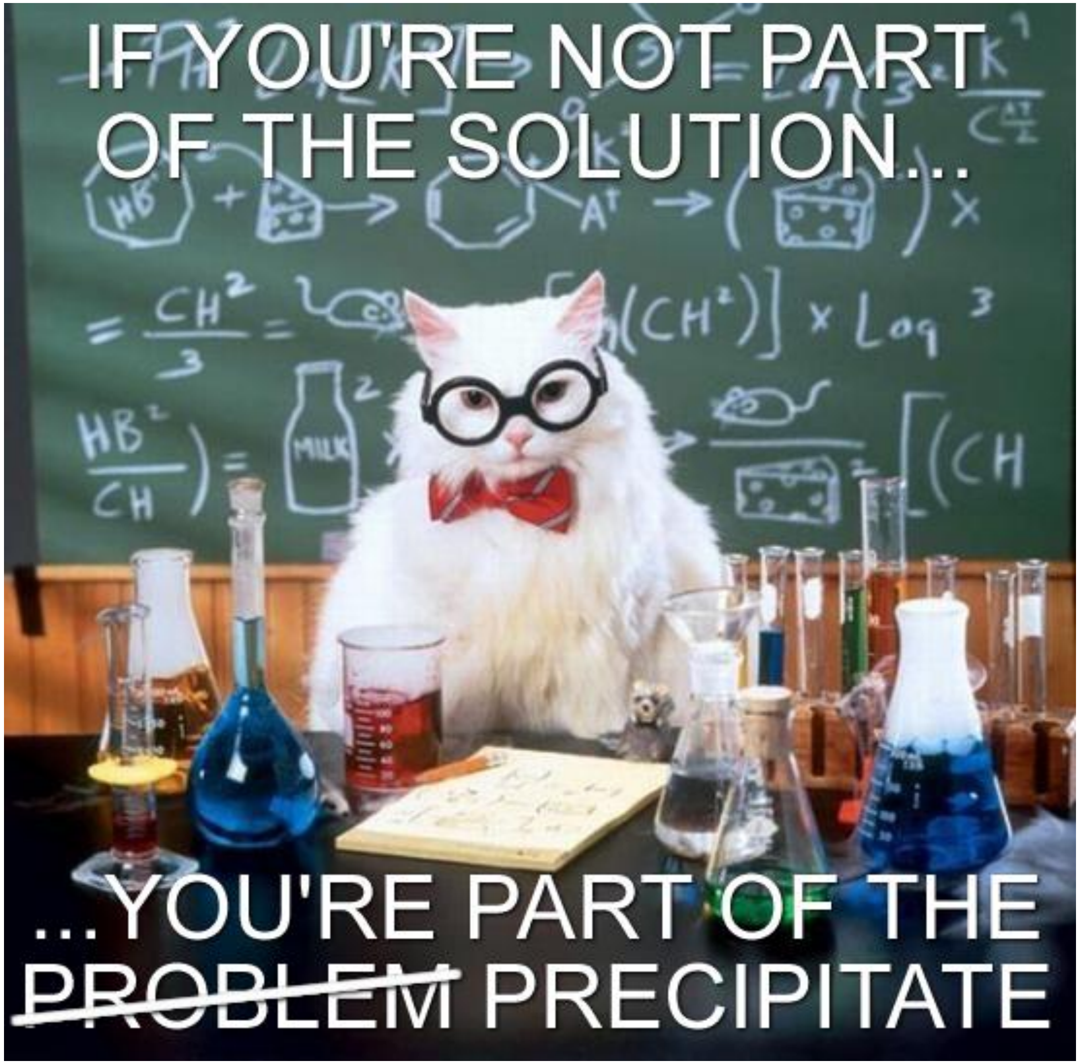
Silver Ion
Nitrate Ion
Sodium Ion
Chloride Ion
Water Molecule

Qualitative Analysis

Precipitate Formation

White Precipitate of Silver Chloride

Qualitative Analysis



Qualitative Analysis

Precipitate Formation

- The word equation for the reaction between aqueous silver nitrate and aqueous sodium chloride is:

Silver Nitrate + Sodium Chloride → Silver Chloride + Sodium Nitrate

- The balanced chemical equation for the reaction between aqueous silver nitrate and aqueous sodium chloride is:

$$\mathrm{AgNO_3(aq)} \;+\; \mathrm{NaC}l\mathrm{(aq)} \;\rightarrow\; \mathrm{AgC}l\mathrm{(s)} \;+\; \mathrm{NaNO_3(aq)}$$

- The ionic equation for the reaction between aqueous silver nitrate and aqueous sodium chloride is:

$$\mathrm{Ag^+(aq)} \;+\; \mathrm{C}l^-\mathrm{(aq)} \;\rightarrow\; \mathrm{AgC}l\mathrm{(s)}$$

- Pay attention to the state symbols!

Qualitative Analysis

Solubility Rules

- All ammonium salts are ________ in water.
- All potassium salts are ________ in water.
- All sodium salts are ________ in water.
- All carbonates are ________ in water, except ______________________
- All chlorides are ________ in water, except _____________________
- All hydroxides are ________ in water, except _____________________
- All nitrates are ________ in water.
- All sulfates are ________ in water, except ______________________

Qualitative Analysis

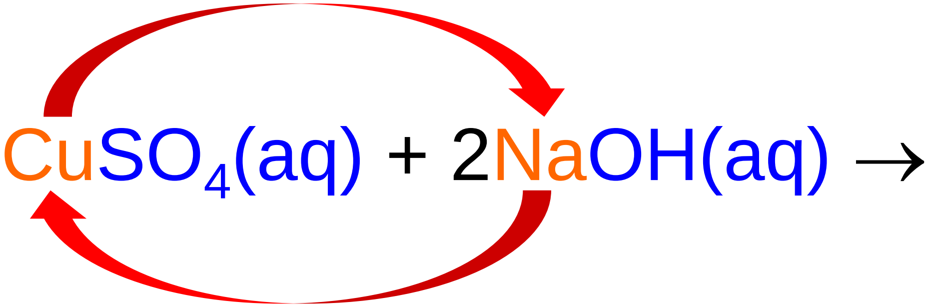
Solubility Rules

- All ammonium salts are soluble in water.
- All potassium salts are soluble in water.
- All sodium salts are soluble in water.
- All carbonates are insoluble in water, except Na_2CO_3, K_2CO_3, $(NH_4)_2CO_3$
- All chlorides are soluble in water, except $AgCl$, $PbCl_2$
- All hydroxides are insoluble in water, except $NaOH$, KOH, NH_4OH
- All nitrates are soluble in water.
- All sulfates are soluble in water, except $BaSO_4$, $CaSO_4$, $PbSO_4$

Qualitative Analysis

Determining the Products of a Reaction

The products of the precipitation reactions can be easily determined by *swapping the cations*:

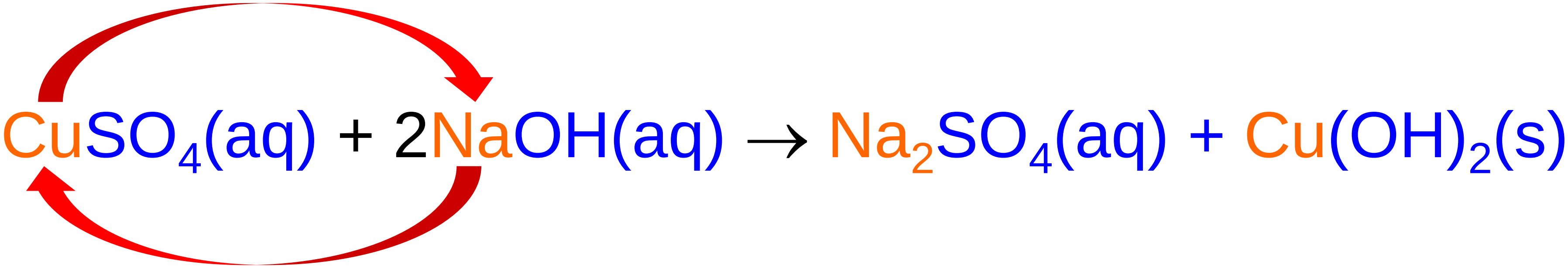


$CuSO_4(aq) + 2NaOH(aq) \rightarrow$

Qualitative Analysis

Determining the Products of a Reaction

The products of the precipitation reactions can be easily determined by *swapping the cations*:

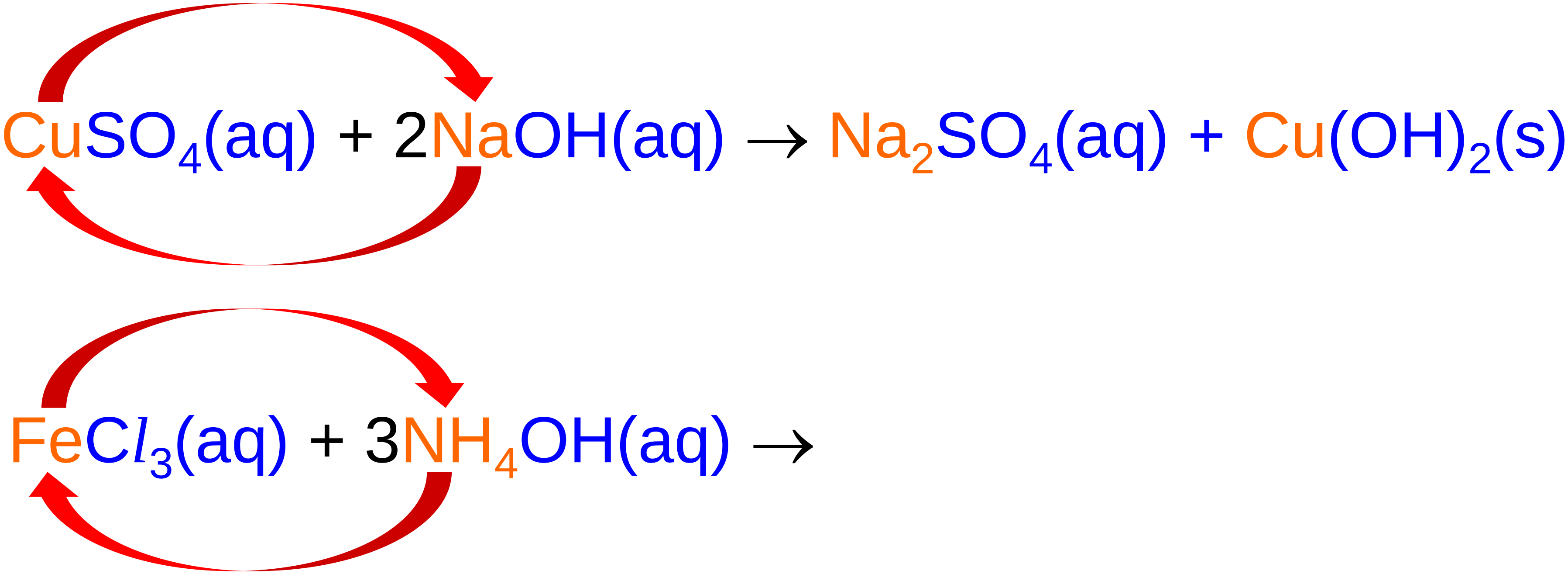


$$CuSO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + Cu(OH)_2(s)$$

Qualitative Analysis

Determining the Products of a Reaction

The products of the precipitation reactions can be easily determined by *swapping the cations*:



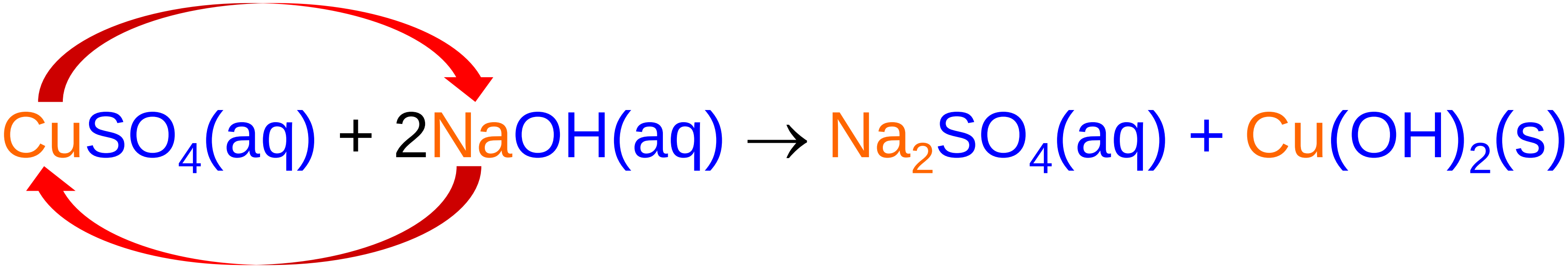
$$CuSO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + Cu(OH)_2(s)$$

$$FeCl_3(aq) + 3NH_4OH(aq) \rightarrow$$

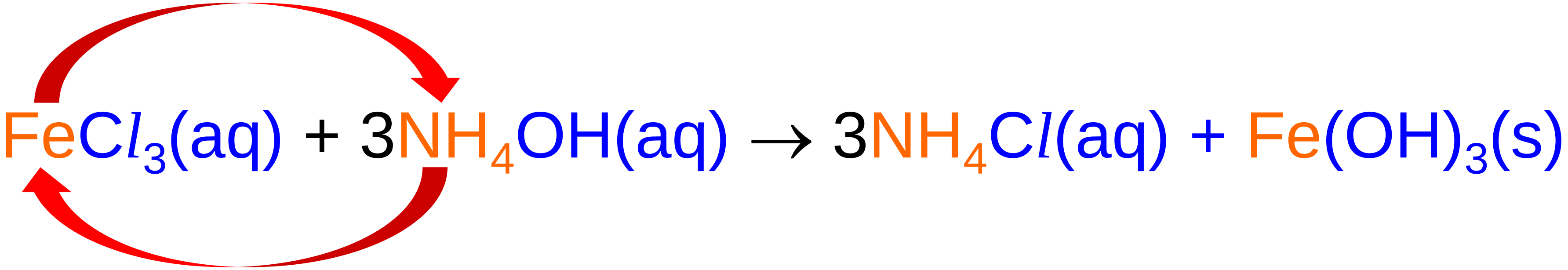
Qualitative Analysis

Determining the Products of a Reaction

The products of the precipitation reactions can be easily determined by *swapping the cations*:



$CuSO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + Cu(OH)_2(s)$



$FeC\mathit{l}_3(aq) + 3NH_4OH(aq) \rightarrow 3NH_4C\mathit{l}(aq) + Fe(OH)_3(s)$

Qualitative Analysis

Quick test – what are the formulae of the following chemicals?

1) Aluminium hydroxide ___________

2) Ammonium sulfate ___________

3) Calcium hydroxide ___________

4) Copper(II) sulfate ___________

5) Iron(II) nitrate ___________

6) Iron(III) chloride ___________

7) lead(II) hydroxide ___________

8) Zinc nitrate ___________

Qualitative Analysis

Quick test – what are the formulae of the following chemicals?

1) Aluminium hydroxide $\underline{\quad Al(OH)_3 \quad}$

2) Ammonium sulfate $\underline{\quad (NH_4)_2SO_4 \quad}$

3) Calcium hydroxide $\underline{\quad Ca(OH)_2 \quad}$

4) Copper(II) sulfate $\underline{\quad CuSO_4 \quad}$

5) Iron(II) nitrate $\underline{\quad Fe(NO_3)_2 \quad}$

6) Iron(III) chloride $\underline{\quad FeCl_3 \quad}$

7) lead(II) hydroxide $\underline{\quad Pb(OH)_2 \quad}$

8) Zinc nitrate $\underline{\quad Zn(NO_3)_2 \quad}$

Qualitative Analysis

Writing Balanced Chemical and Ionic Equations

copper(II) nitrate + sodium hydroxide → copper(II) hydroxide + sodium nitrate

$$Cu(NO_3)_2(aq) + NaOH(aq) \rightarrow Cu(OH)_2(s) + NaNO_3(aq)$$

$$Cu(NO_3)_2(aq) + \mathbf{2}NaOH(aq) \rightarrow Cu(OH)_2(s) + \mathbf{2}NaNO_3(aq)$$

Ionic compounds that are dissolved in water can be split into their individual ions. This rule does not apply to insoluble solids:

$$Cu^{2+}{}_{(aq)} + \cancel{\mathbf{2}NO_3{}^-}{}_{(aq)} + \cancel{\mathbf{2}Na^+}{}_{(aq)} + \mathbf{2}OH^-{}_{(aq)} \rightarrow Cu(OH)_{2(s)} + \cancel{\mathbf{2}Na^+}{}_{(aq)} + \cancel{\mathbf{2}NO_3{}^-}{}_{(aq)}$$

Identify the ions that are responsible for formation of the *precipitate*, and delete the *spectator ions* from the equation:

$$Cu^{2+}(aq) + \mathbf{2}OH^-(aq) \rightarrow Cu(OH)_2(s)$$

Qualitative Analysis

Writing Balanced Chemical and Ionic Equations

lead(II) nitrate + potassium iodide → lead(II) iodide + potassium nitrate

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

$$Pb(NO_3)_2(aq) + \mathbf{2}KI(aq) \rightarrow PbI_2(s) + \mathbf{2}KNO_3(aq)$$

Ionic compounds that are dissolved in water can be split into their individual ions. This rule does not apply to insoluble solids:

$$Pb^{2+}{}_{(aq)} + \cancel{\mathbf{2}NO_3{}^-}{}_{(aq)} + \cancel{\mathbf{2}K^+}{}_{(aq)} + \mathbf{2}I^-{}_{(aq)} \rightarrow PbI_{2(s)} + \cancel{\mathbf{2}K^+}{}_{(aq)} + \cancel{\mathbf{2}NO_3{}^-}{}_{(aq)}$$

Identify the ions that are responsible for formation of the *precipitate*, and delete the *spectator ions* from the equation:

$$Pb^{2+}(aq) + \mathbf{2}I^-(aq) \rightarrow PbI_2(s)$$

Qualitative Analysis

Writing Balanced Chemical and Ionic Equations

aluminium chloride + aqueous ammonia → aluminium hydroxide + ammonium chloride

$$\mathrm{A}l\mathrm{C}l_3(aq) + NH_4OH(aq) \rightarrow \mathrm{A}l(OH)_3(aq) + NH_4\mathrm{C}l(aq)$$

$$\mathrm{A}l\mathrm{C}l_3(aq) + \mathbf{3}NH_4OH(aq) \rightarrow \mathrm{A}l(OH)_3(s) + \mathbf{3}NH_4\mathrm{C}l(aq)$$

Ionic compounds that are dissolved in water can be split into their individual ions. This rule does not apply to insoluble solids:

$$\mathrm{A}l^{3+}{}_{(aq)} + \cancel{\mathbf{3}\mathrm{C}l^{-}}{}_{(aq)} + \cancel{\mathbf{3}NH_4^{+}}{}_{(aq)} + \mathbf{3}OH^{-}{}_{(aq)} \rightarrow \mathrm{A}l(OH)_{3(s)} + \cancel{\mathbf{3}NH_4^{+}}{}_{(aq)} + \cancel{\mathbf{3}\mathrm{C}l^{-}}{}_{(aq)}$$

Identify the ions that are responsible for formation of the *precipitate*, and delete the *spectator ions* from the equation:

$$\mathrm{A}l^{3+}(aq) + \mathbf{3}OH^{-}(aq) \rightarrow \mathrm{A}l(OH)_3(s)$$

Qualitative Analysis

A Note About State Symbols

(s) indicates that the chemical is a *solid*,
e.g. sand is $SiO_2(s)$

(*l*) indicates that the chemical is a *liquid*,
e.g. water is $H_2O(l)$

(g) indicates that the chemical is a *gas*,
e.g. carbon dioxide is $CO_2(g)$

(aq) indicates that the chemical is *dissolved in water*,
e.g. an aqueous solution of sodium chloride is $NaCl(aq)$

Qualitative Analysis

Test for Cations Using Aqueous Sodium Hydroxide

Qualitative Analysis

Which cations must I know the tests for?

Qualitative Analysis

Describe the use of *aqueous sodium hydroxide* and *aqueous ammonia* to identify the following aqueous cations:

- Aluminium cation – $Al^{3+}(aq)$
- Ammonium cation – $NH_4^+(aq)$
- Calcium cation – $Ca^{2+}(aq)$
- Copper(II) cation – $Cu^{2+}(aq)$
- Iron(II) cation – $Fe^{2+}(aq)$
- Iron(III) cation – $Fe^{3+}(aq)$
- Lead(II) cation – $Pb^{2+}(aq)$
- Zinc cation – $Zn^{2+}(aq)$

Note: The formulae of complex ions are not required.

Qualitative Analysis

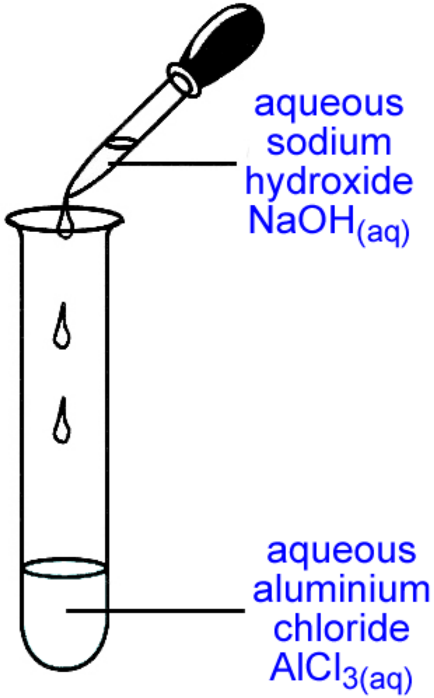
- Remember that the qualitative tests are for *aqueous cations* and *not* for a *pure solid metal*.

- What does that mean…?

- If adding aqueous sodium hydroxide to an unknown solution results in the formation of a blue precipitate that is insoluble in excess reagent, *it confirms the presence of copper(II) cations in aqueous solution* – $Cu^{2+}(aq)$ – *not the presence of copper* – $Cu(s)$.

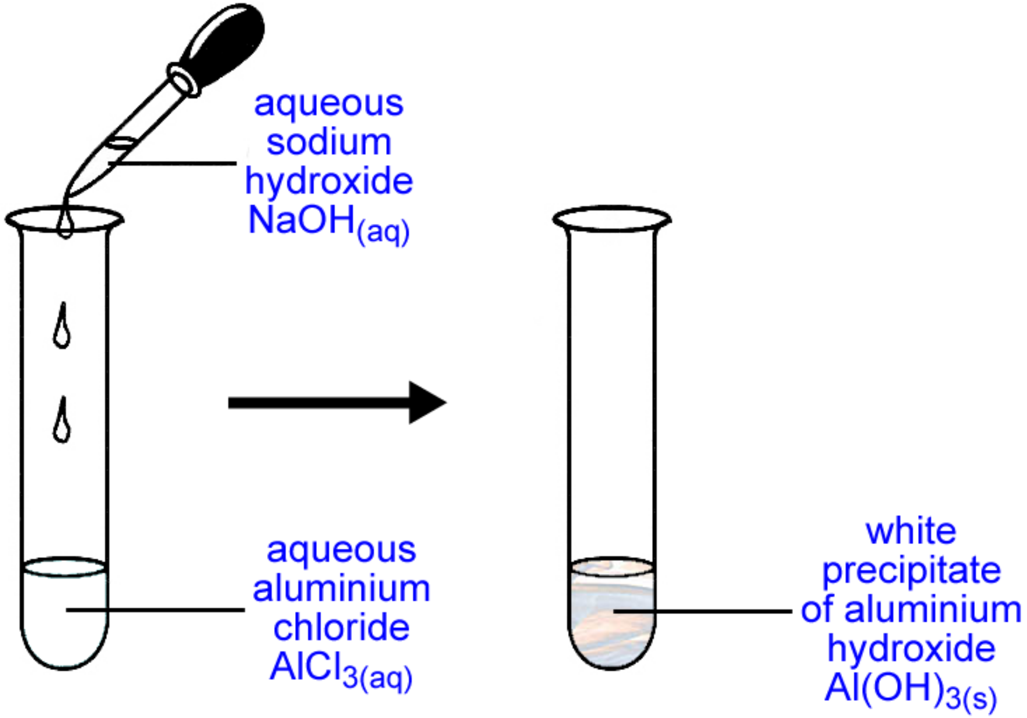
Qualitative Analysis

Test for Al^{3+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

Test for $\mathrm{A}l^{3+}$(aq) – Addition of NaOH(aq)



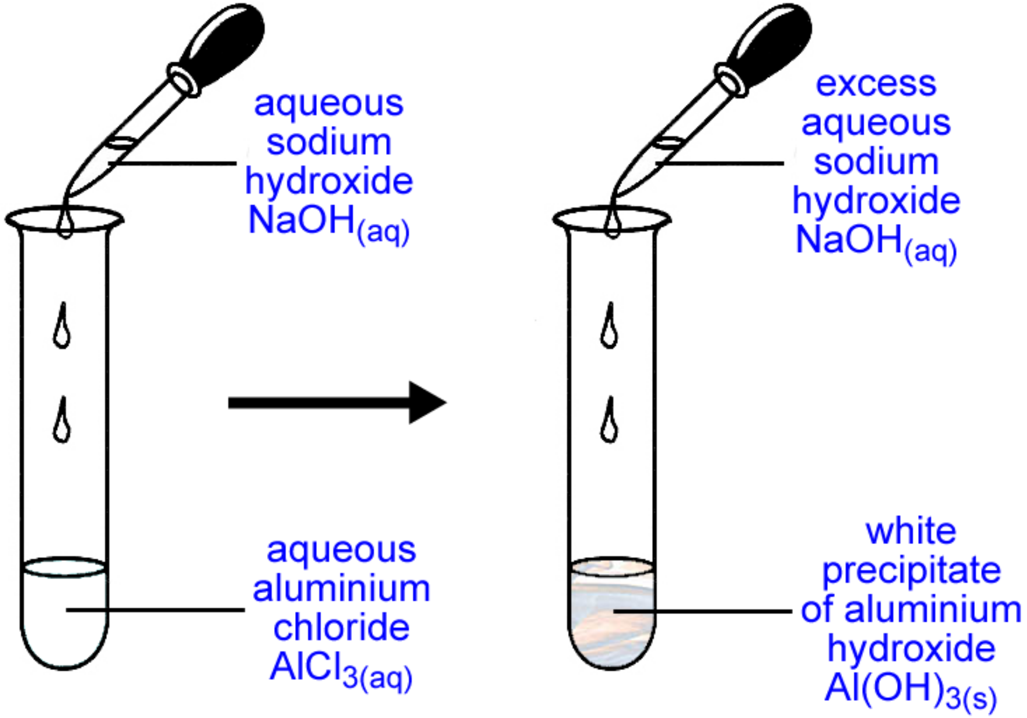
Aluminium Chloride + Sodium Hydroxide → Aluminium Hydroxide + Sodium Chloride

$$\mathrm{A}l\mathrm{C}l_3\mathrm{(aq)} + 3\mathrm{NaOH(aq)} \rightarrow \mathrm{A}l\mathrm{(OH)_3(s)} + 3\mathrm{NaC}l\mathrm{(aq)}$$

$$\mathrm{A}l^{3+}\mathrm{(aq)} + 3\mathrm{OH^{-}(aq)} \rightarrow \mathrm{A}l\mathrm{(OH)_3(s)}$$

Qualitative Analysis

Test for Al^{3+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

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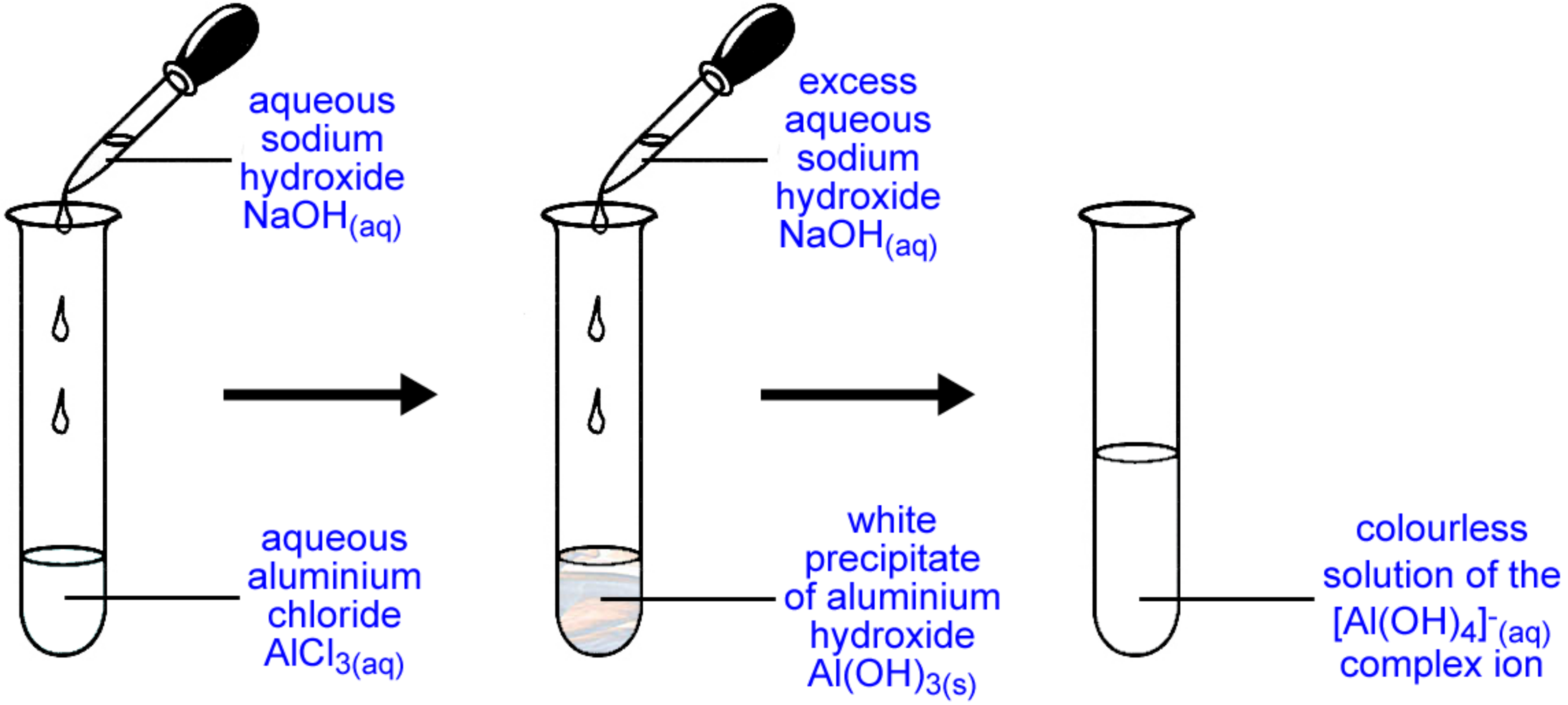
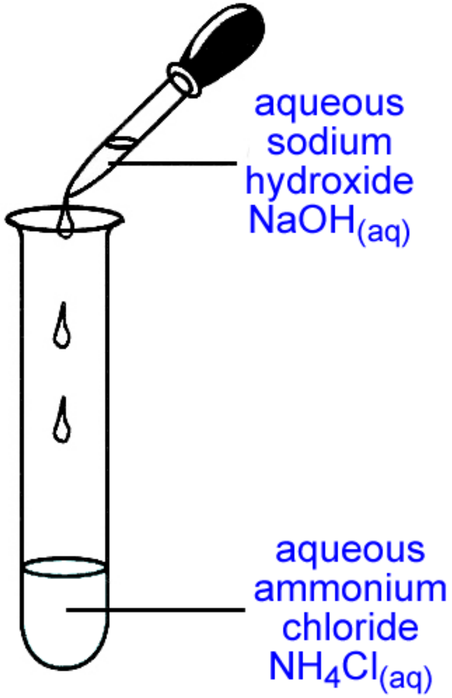


The white precipitate of Al(OH)$_3$ dissolves in excess aqueous sodium hydroxide to produce a colourless solution.

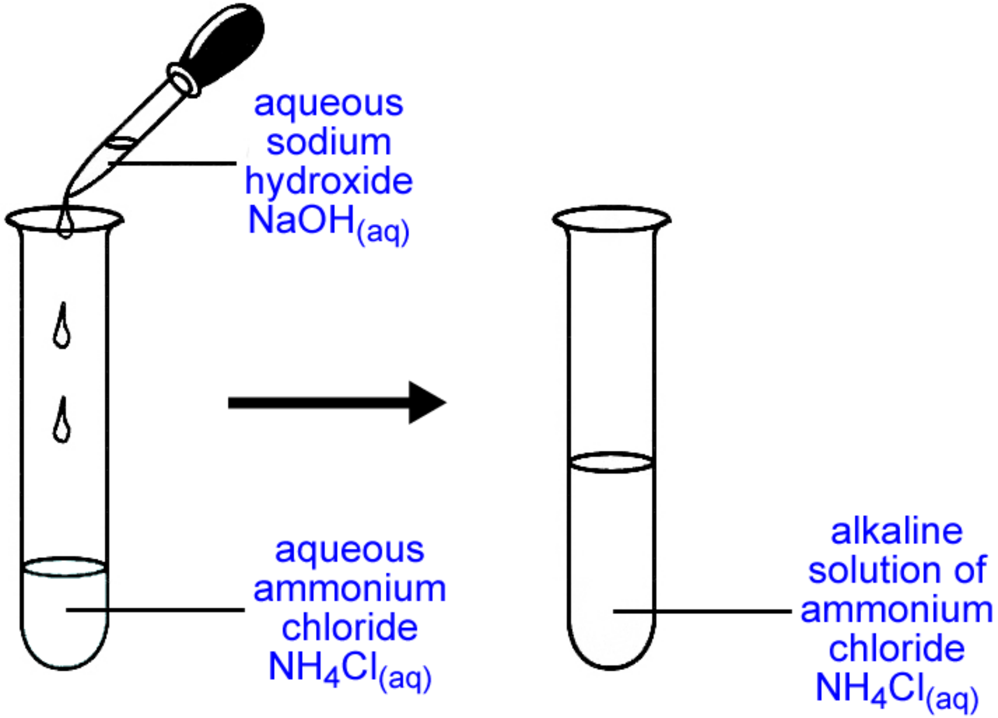
Qualitative Analysis

Test for NH_4^+(aq) – Addition of NaOH(aq)



Qualitative Analysis

Test for $NH_4^+(aq)$ – Addition of NaOH(aq)



Qualitative Analysis

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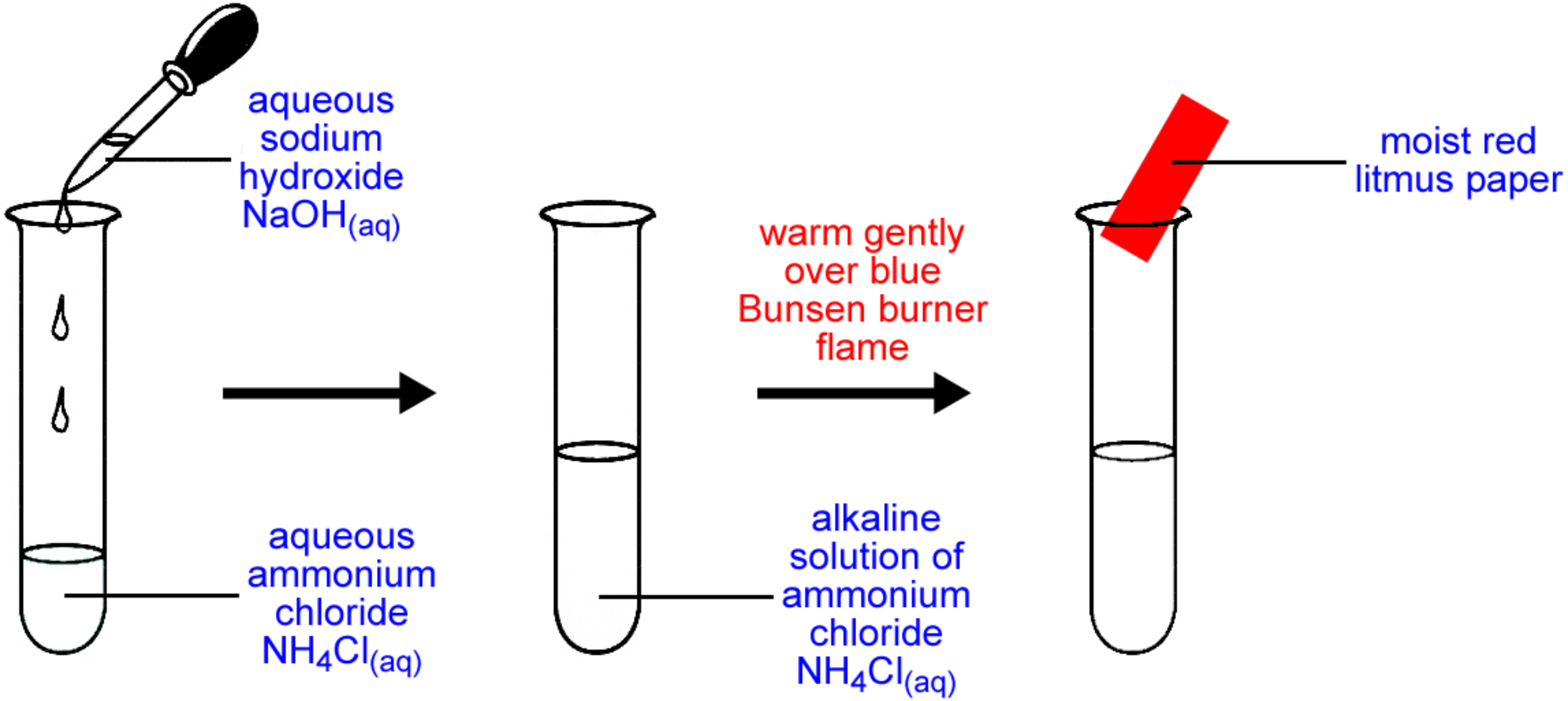
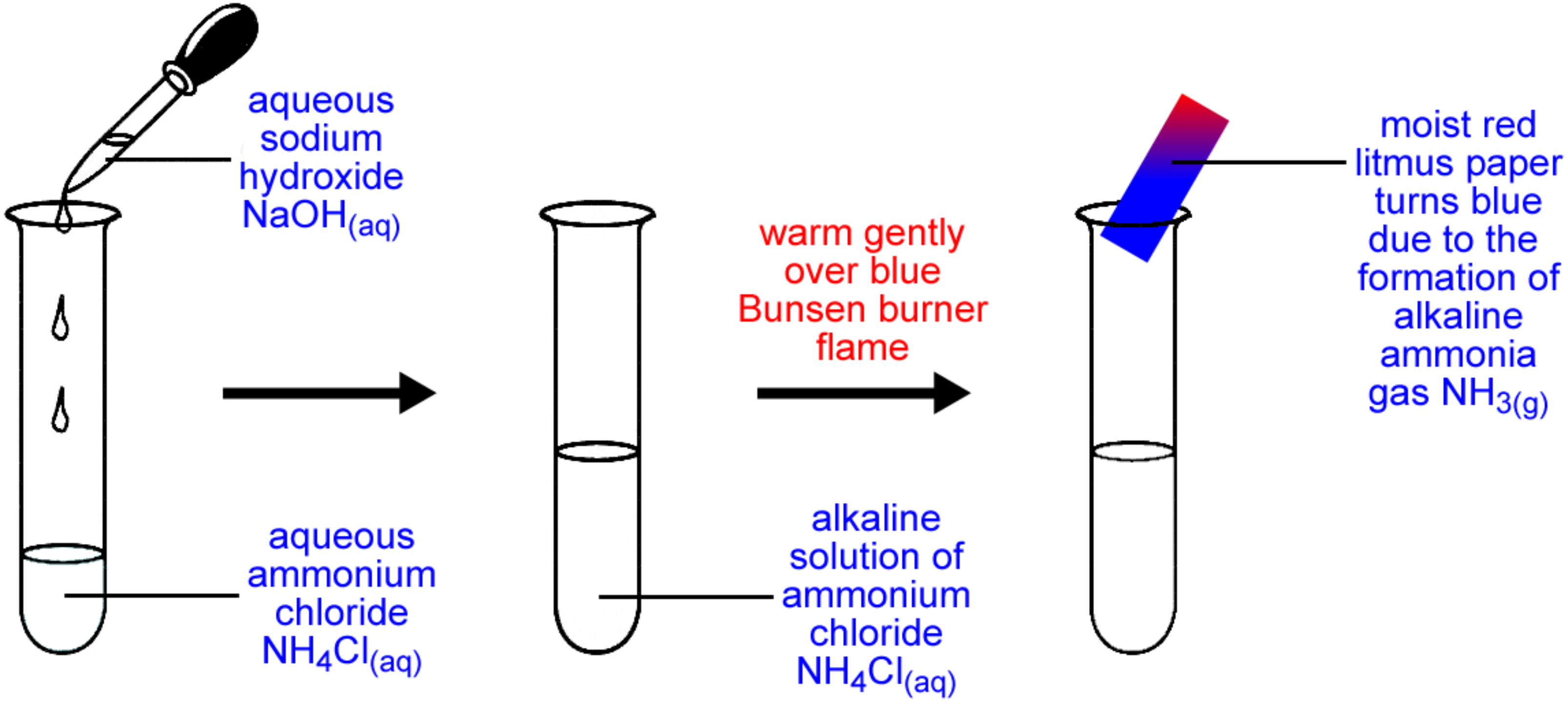


Qualitative Analysis

Test for $NH_4^+(aq)$ – Addition of NaOH(aq)



aqueous sodium hydroxide $NaOH_{(aq)}$

aqueous ammonium chloride $NH_4Cl_{(aq)}$

warm gently over blue Bunsen burner flame

alkaline solution of ammonium chloride $NH_4Cl_{(aq)}$

moist red litmus paper turns blue due to the formation of alkaline ammonia gas $NH_{3(g)}$

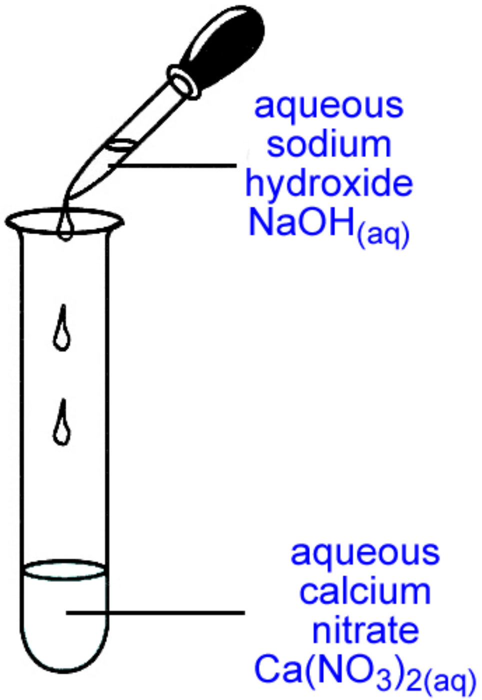
Ammonium Chloride + Sodium Hydroxide → Sodium Chloride + Water + Ammonia

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

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

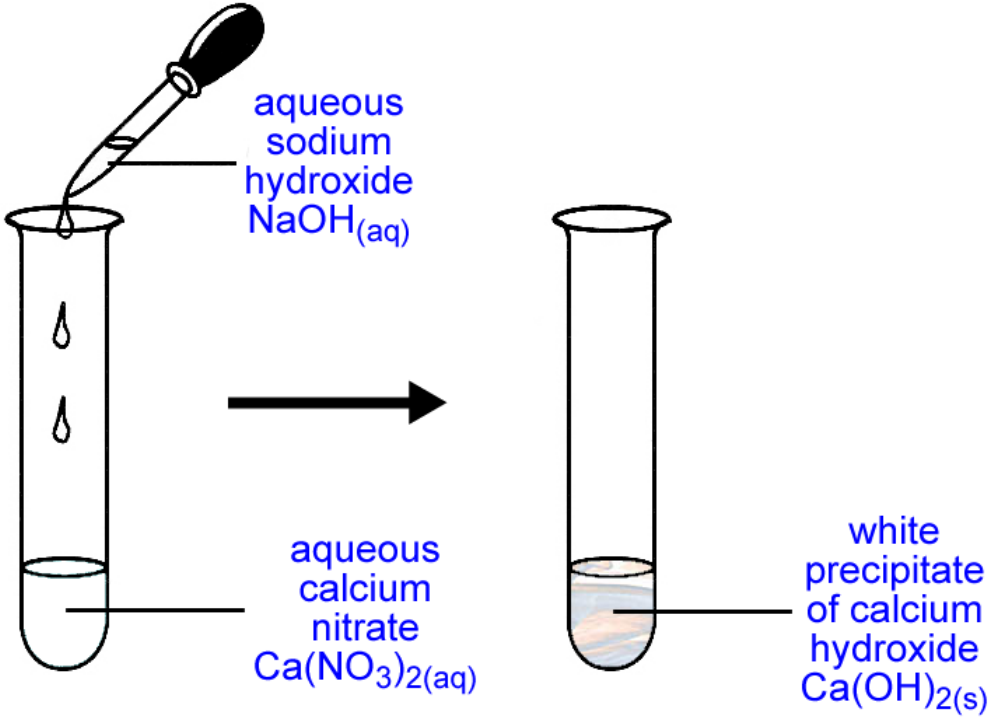
Qualitative Analysis

Test for Ca^{2+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

Test for Ca^{2+}(aq) – Addition of NaOH(aq)



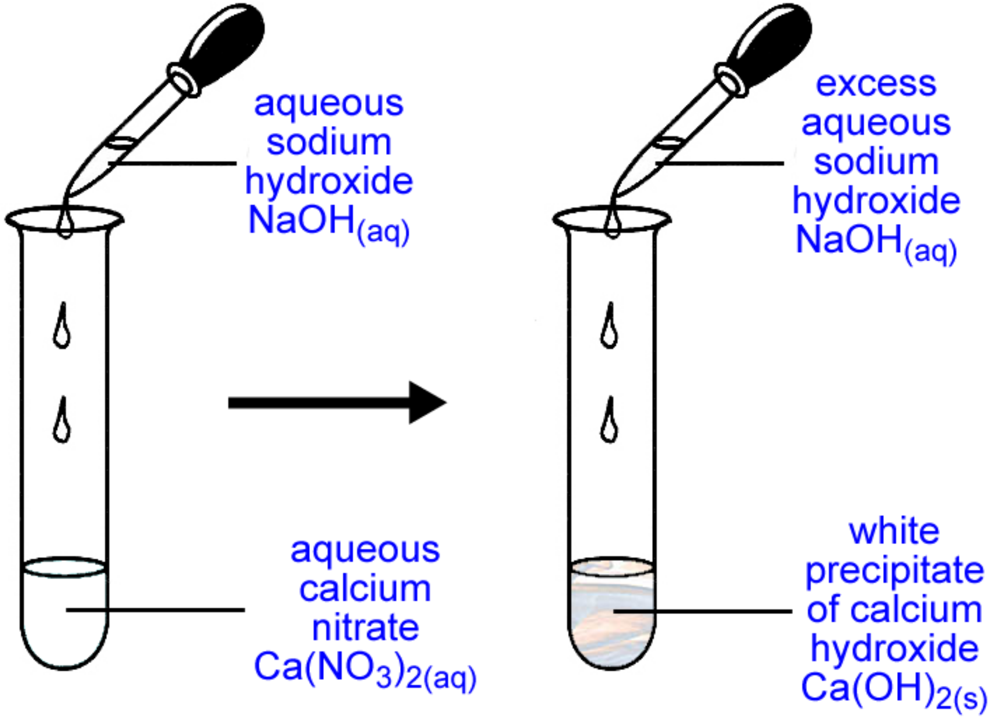
Calcium Nitrate + Sodium Hydroxide → Calcium Hydroxide + Sodium Nitrate

$$Ca(NO_3)_2(aq) + 2NaOH(aq) \rightarrow Ca(OH)_2(s) + 2NaNO_3(aq)$$

$$Ca^{2+}(aq) + 2OH^{-}(aq) \rightarrow Ca(OH)_2(s)$$

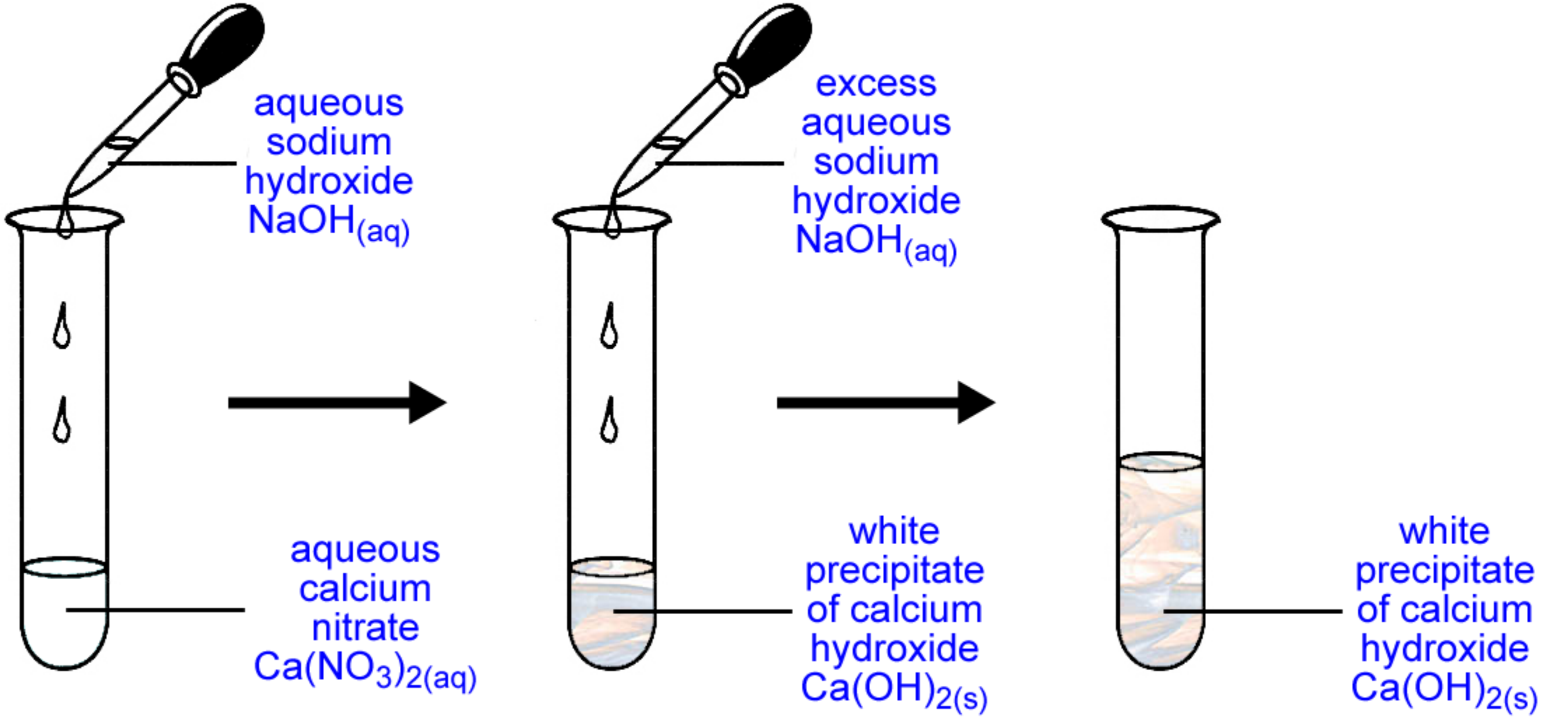
Qualitative Analysis

Test for Ca^{2+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

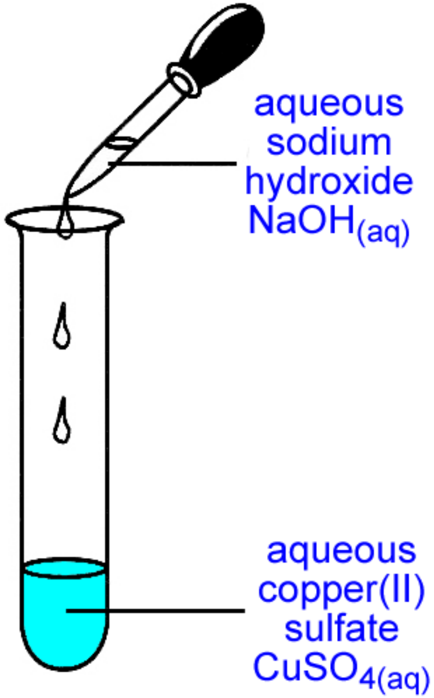
Test for Ca^{2+}(aq) – Addition of NaOH(aq)



The white precipitate of $Ca(OH)_2$ is insoluble in excess aqueous sodium hydroxide.

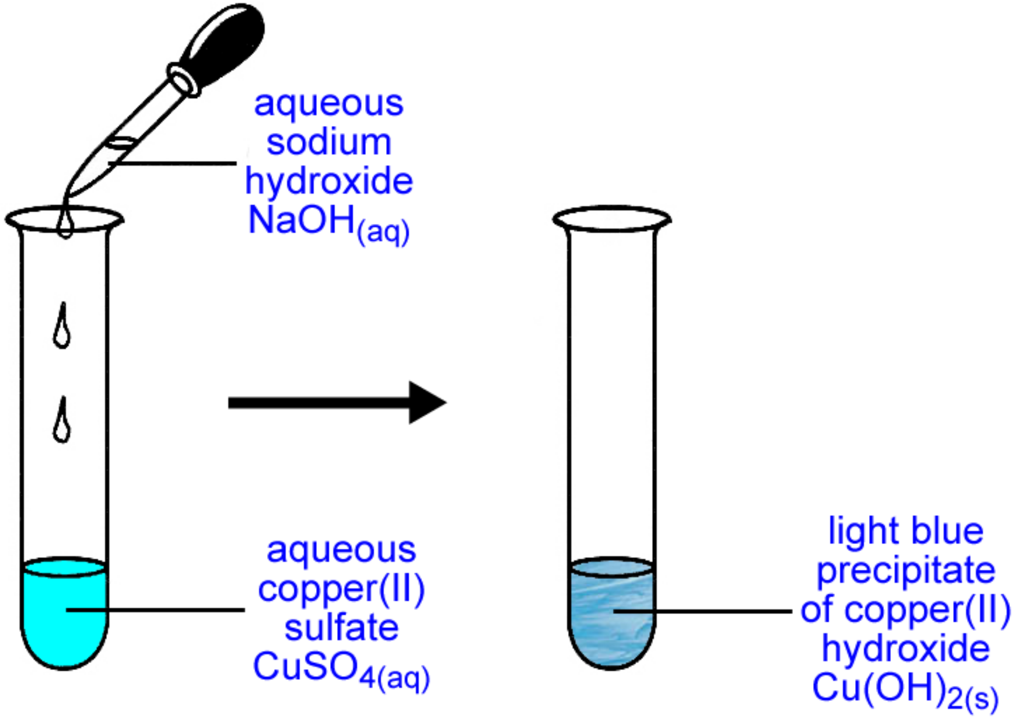
Qualitative Analysis

Test for $Cu^{2+}(aq)$ – Addition of $NaOH(aq)$



Qualitative Analysis

Test for Cu^{2+}(aq) – Addition of NaOH(aq)



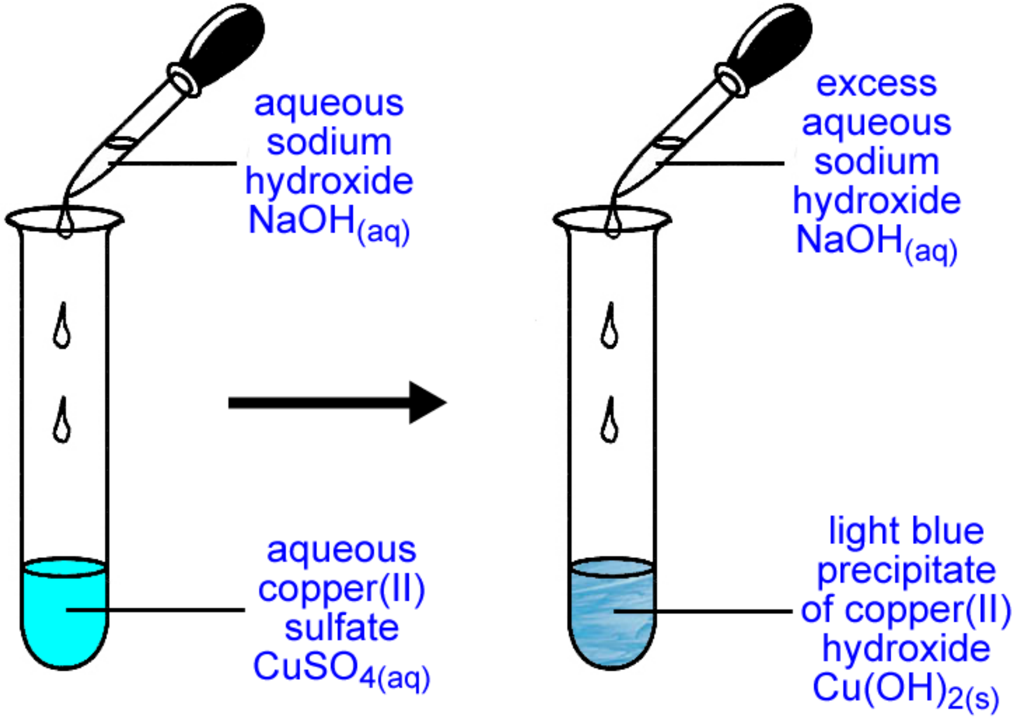
Copper(II) Sulfate + Sodium Hydroxide → Copper(II) Hydroxide + Sodium sulfate

$$CuSO_4(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$$

$$Cu^{2+}(aq) + 2OH^{-}(aq) \rightarrow Cu(OH)_2(s)$$

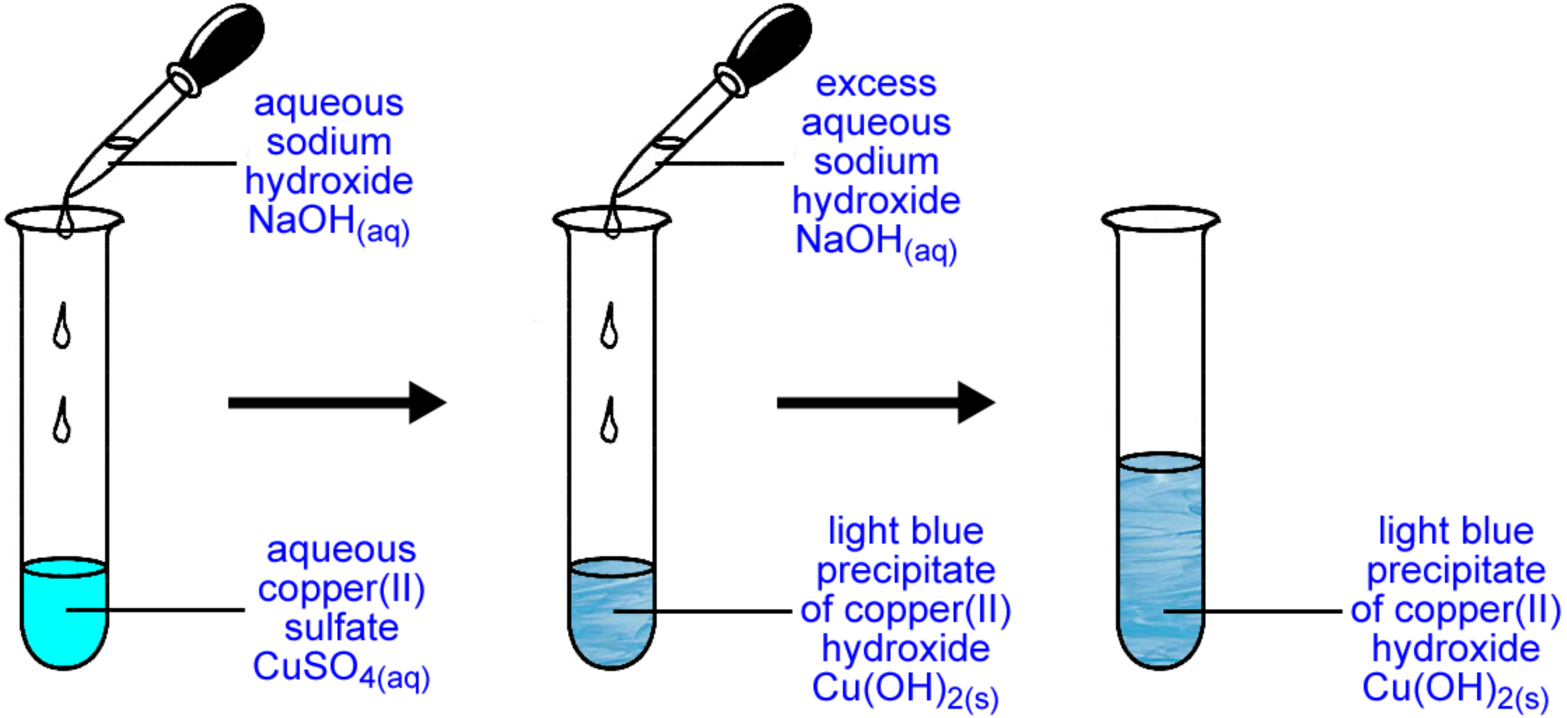
Qualitative Analysis

Test for $Cu^{2+}(aq)$ – Addition of NaOH(aq)



Qualitative Analysis

Test for Cu^{2+}(aq) – Addition of NaOH(aq)



aqueous sodium hydroxide $NaOH_{(aq)}$

aqueous copper(II) sulfate $CuSO_{4(aq)}$

excess aqueous sodium hydroxide $NaOH_{(aq)}$

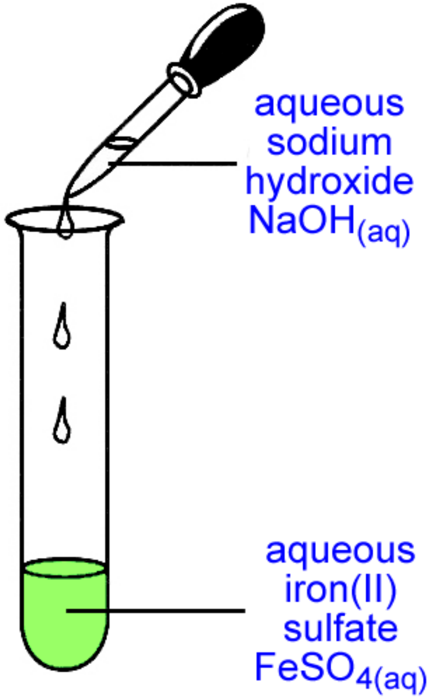
light blue precipitate of copper(II) hydroxide $Cu(OH)_{2(s)}$

light blue precipitate of copper(II) hydroxide $Cu(OH)_{2(s)}$

The blue precipitate of $Cu(OH)_2$ is insoluble in excess aqueous sodium hydroxide.

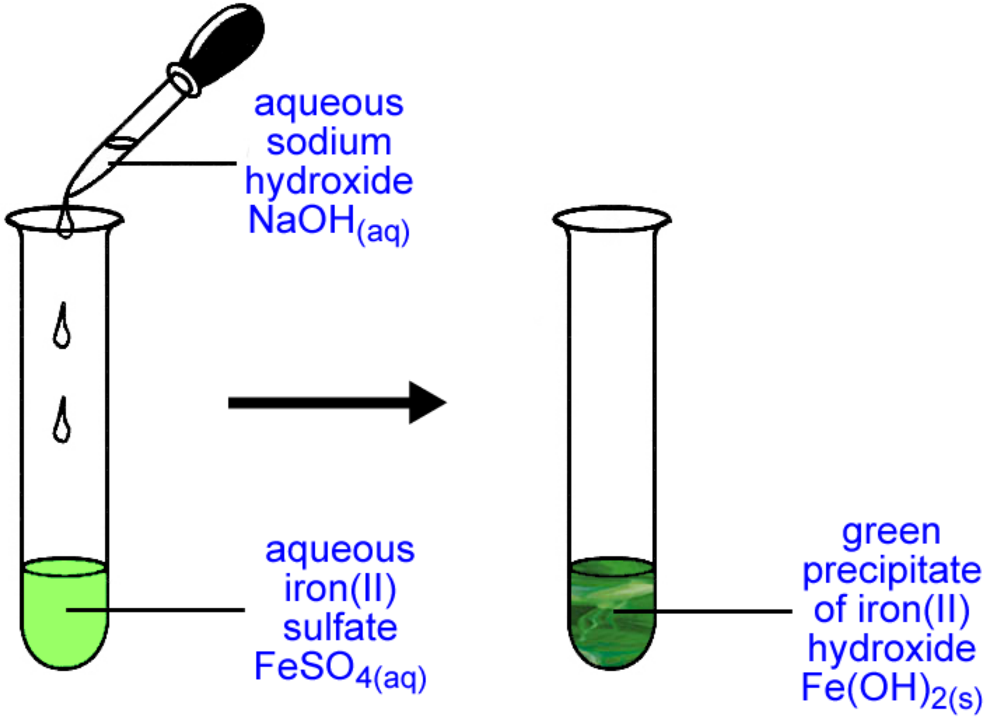
Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NaOH(aq)



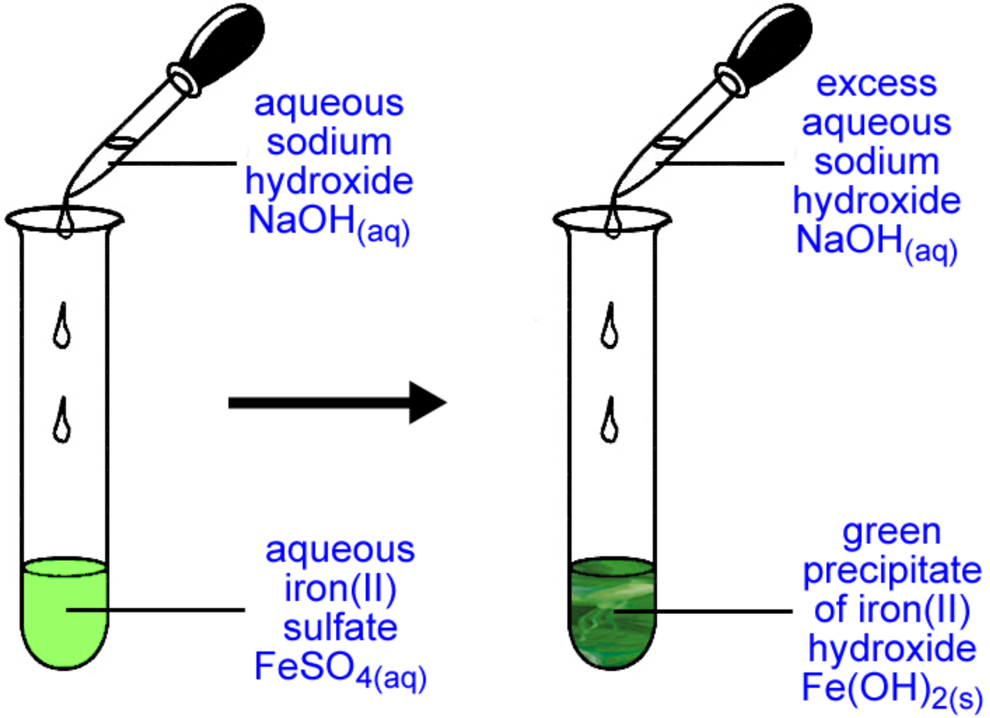
Iron(II) Sulfate + Sodium Hydroxide → Iron(II) Hydroxide + Sodium Sulfate

$$FeSO_4(aq) + 2NaOH(aq) \rightarrow Fe(OH)_2(s) + Na_2SO_4(aq)$$

$$Fe^{2+}(aq) + 2OH^{-}(aq) \rightarrow Fe(OH)_2(s)$$

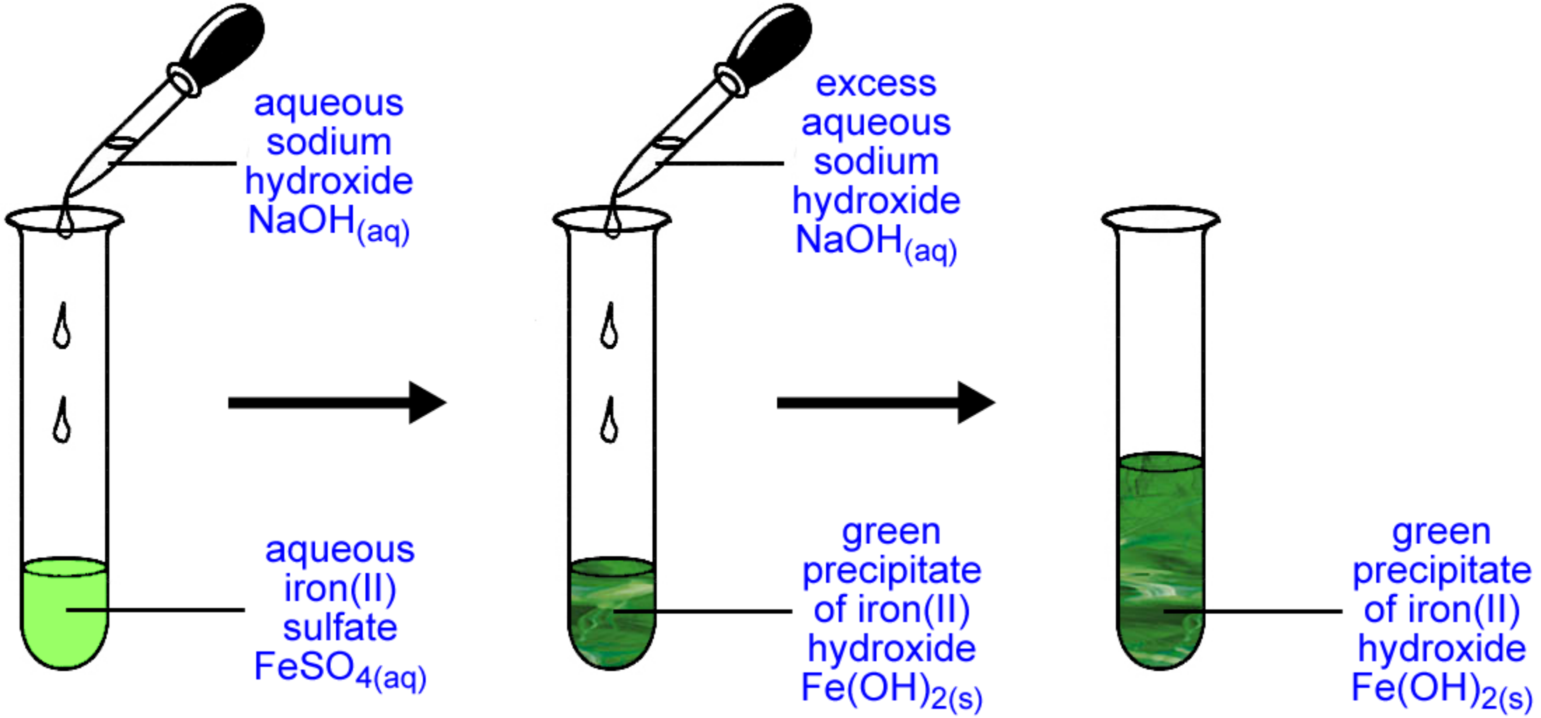
Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

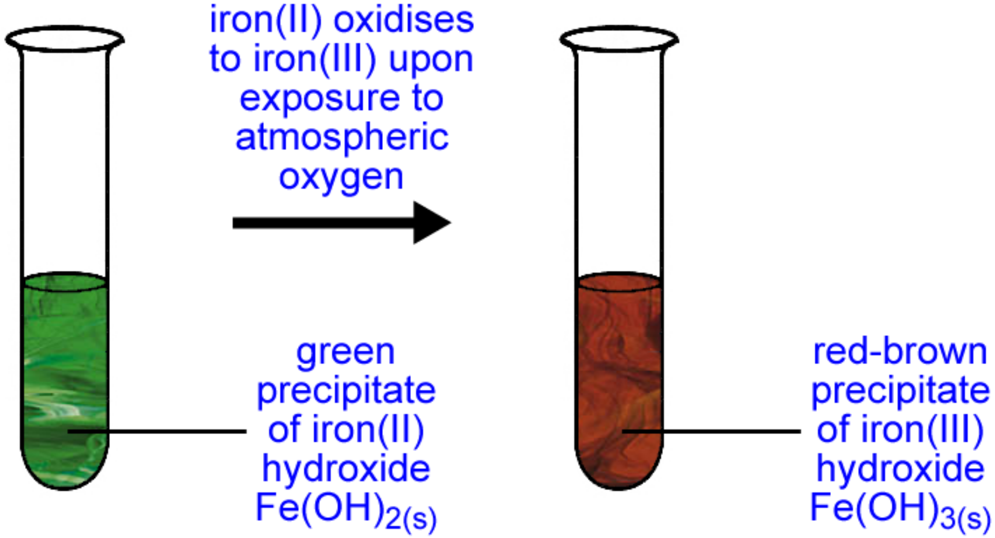
Test for Fe^{2+}(aq) – Addition of NaOH(aq)



The green precipitate of $Fe(OH)_2$ is insoluble in excess aqueous sodium hydroxide.

Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NaOH(aq)



iron(II) oxidises to iron(III) upon exposure to atmospheric oxygen

green precipitate of iron(II) hydroxide $Fe(OH)_{2(s)}$

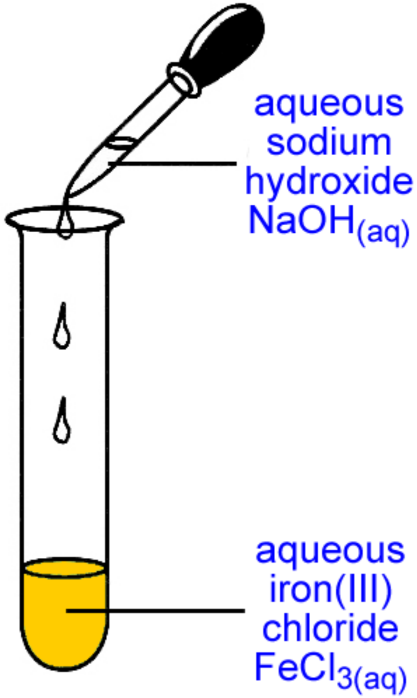
red-brown precipitate of iron(III) hydroxide $Fe(OH)_{3(s)}$

Note: Iron(II) can oxidise to iron(III) upon exposure to atmospheric oxygen.

When this happens, the green precipitate of $Fe(OH)_2$ changes into a red-brown precipitate of $Fe(OH)_3$.

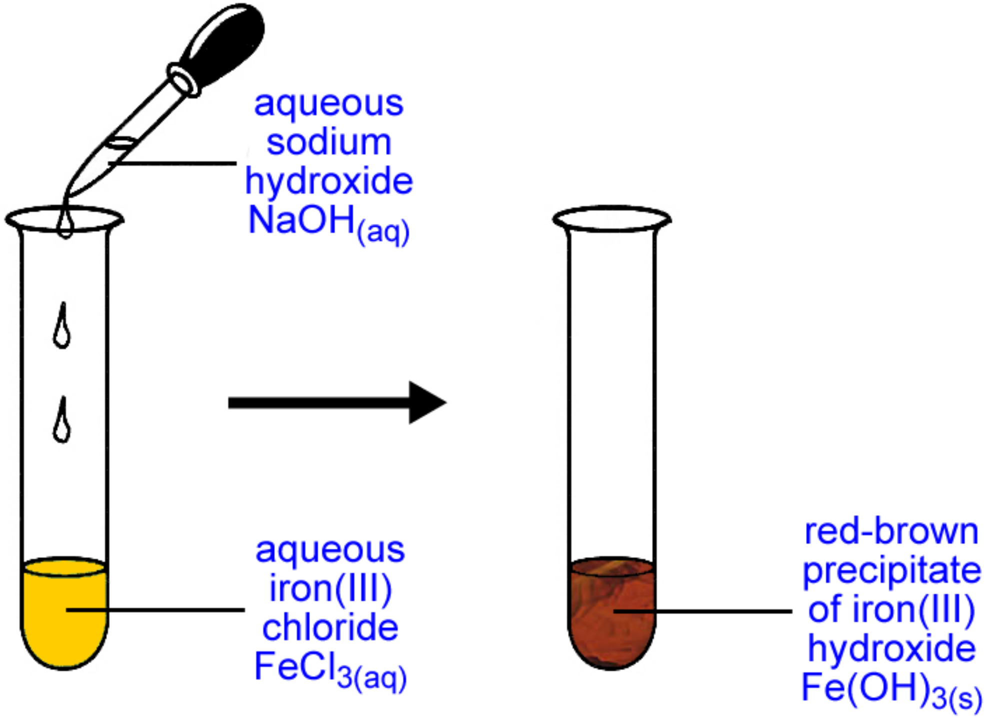
Qualitative Analysis

Test for Fe^{3+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

Test for $\mathrm{Fe^{3+}(aq)}$ – Addition of NaOH(aq)



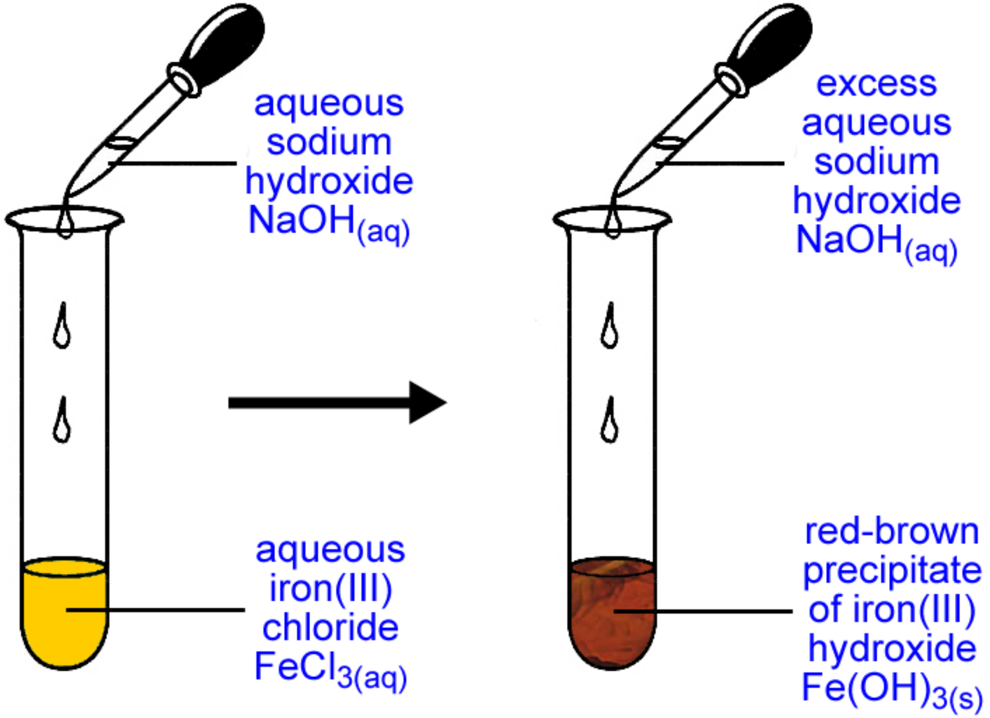
Iron(III) Chloride + Sodium Hydroxide → Iron(III) Hydroxide + Sodium Chloride

$$\mathrm{FeC}l_3\mathrm{(aq)} + 3\mathrm{NaOH(aq)} \rightarrow \mathrm{Fe(OH)_3(s)} + 3\mathrm{NaC}l\mathrm{(aq)}$$

$$\mathrm{Fe^{3+}(aq)} + 3\mathrm{OH^{-}(aq)} \rightarrow \mathrm{Fe(OH)_3(s)}$$

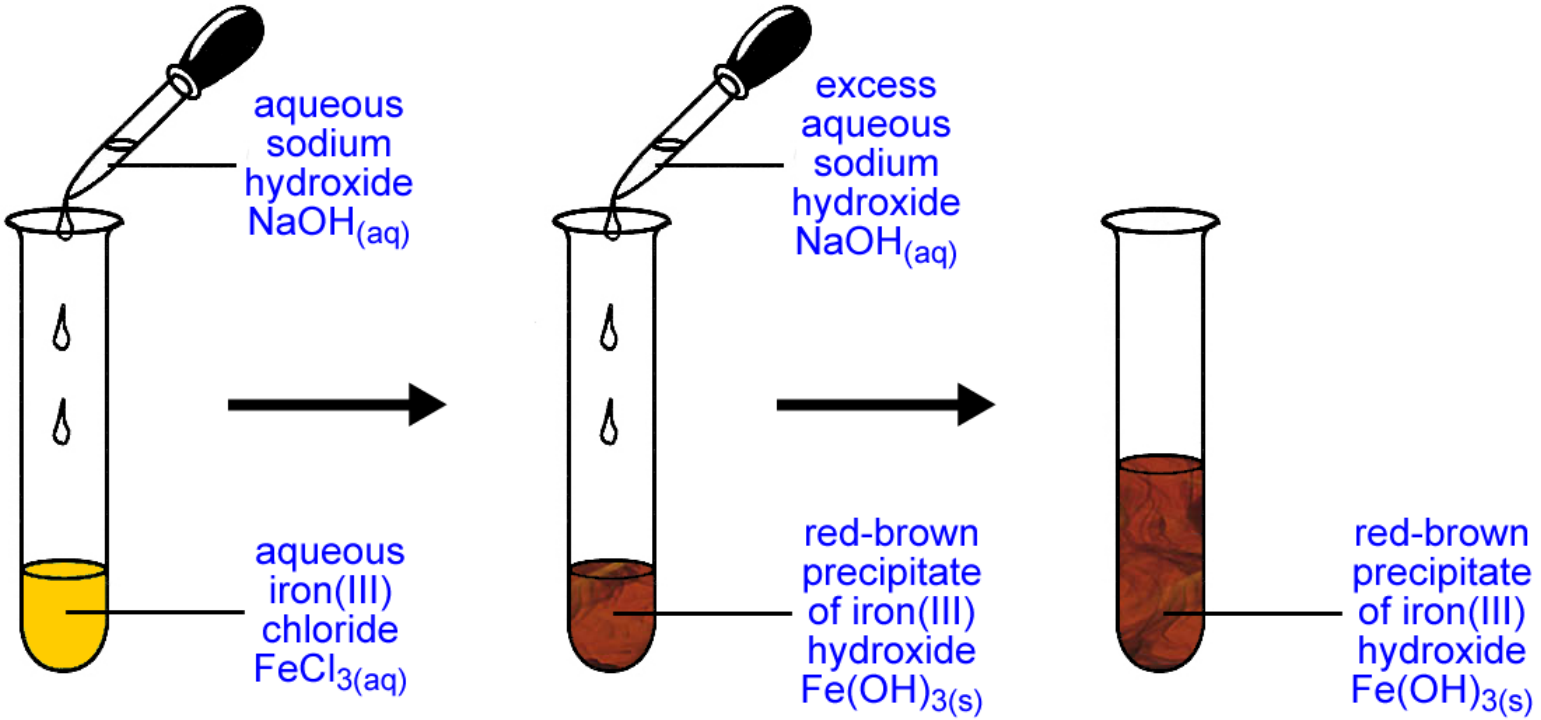
Qualitative Analysis

Test for Fe^{3+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

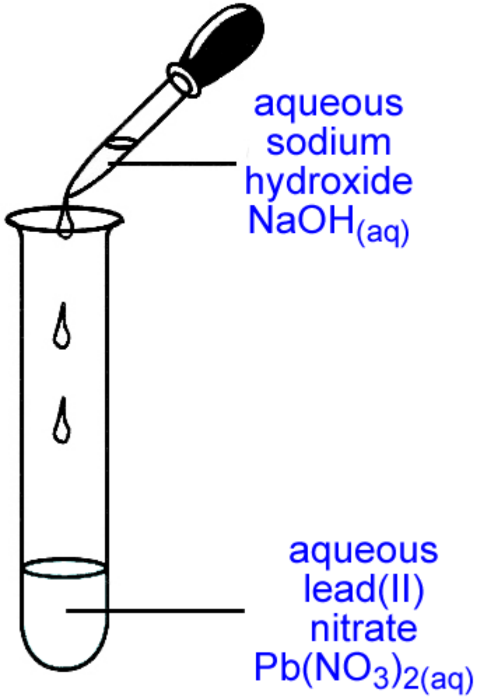
Test for Fe^{3+}(aq) – Addition of NaOH(aq)



The red-brown precipitate of $Fe(OH)_3$ is insoluble in excess aqueous sodium hydroxide.

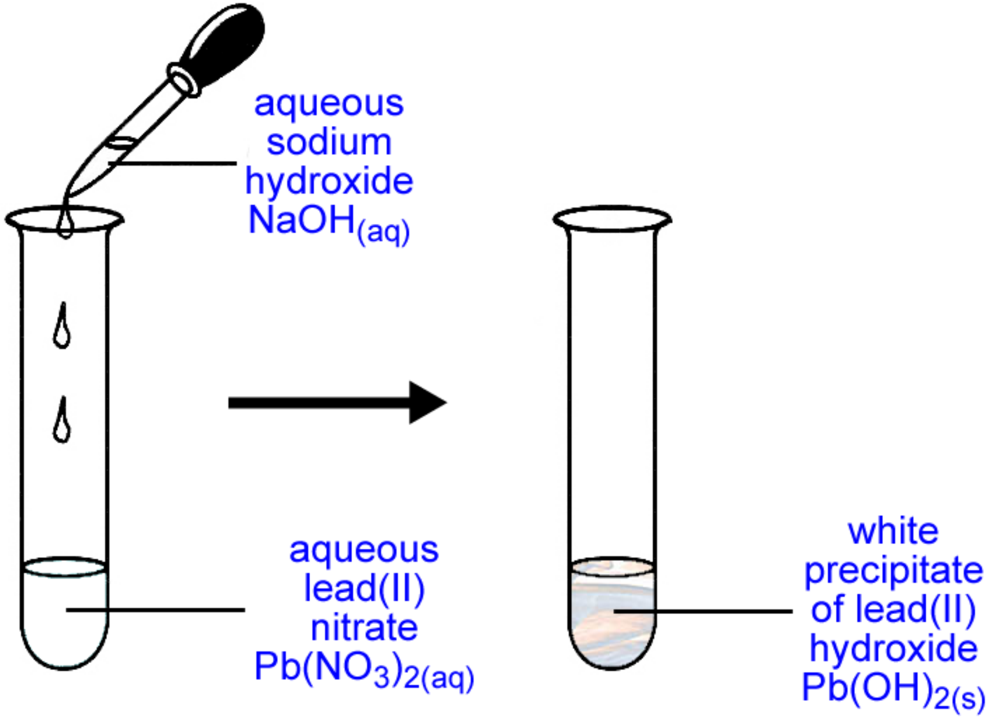
Qualitative Analysis

Test for $Pb^{2+}(aq)$ – Addition of NaOH(aq)



Qualitative Analysis

Test for Pb^{2+}(aq) – Addition of NaOH(aq)



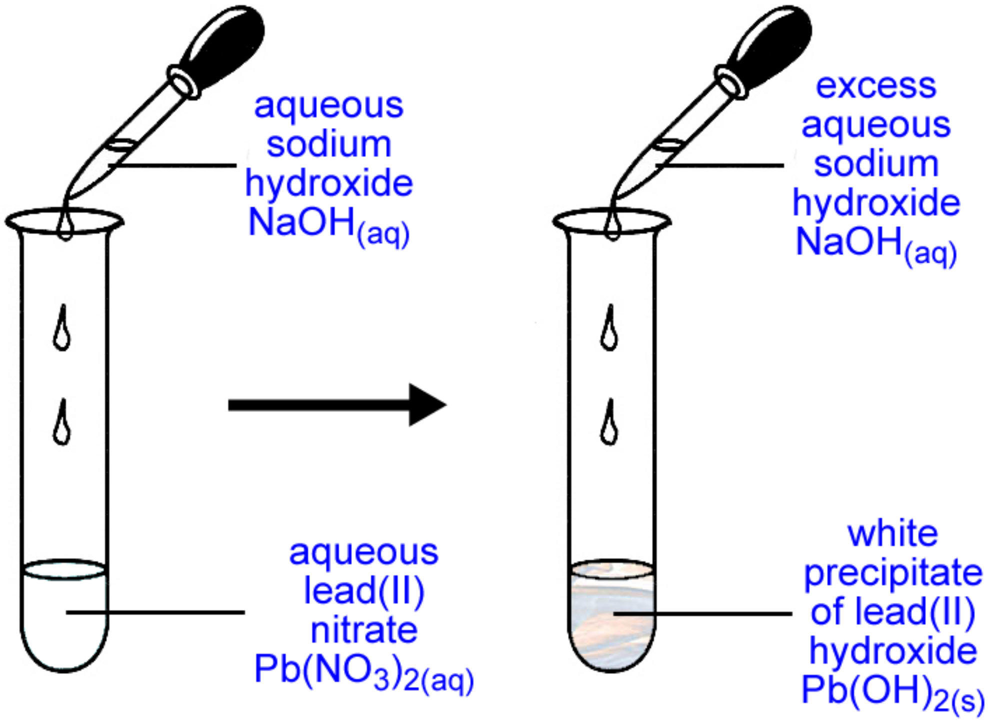
Lead(II) Nitrate + Sodium Hydroxide → Lead(II) Hydroxide + Sodium Nitrate

$$Pb(NO_3)_2(aq) + 2NaOH(aq) \rightarrow Pb(OH)_2(s) + 2NaNO_3(aq)$$

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

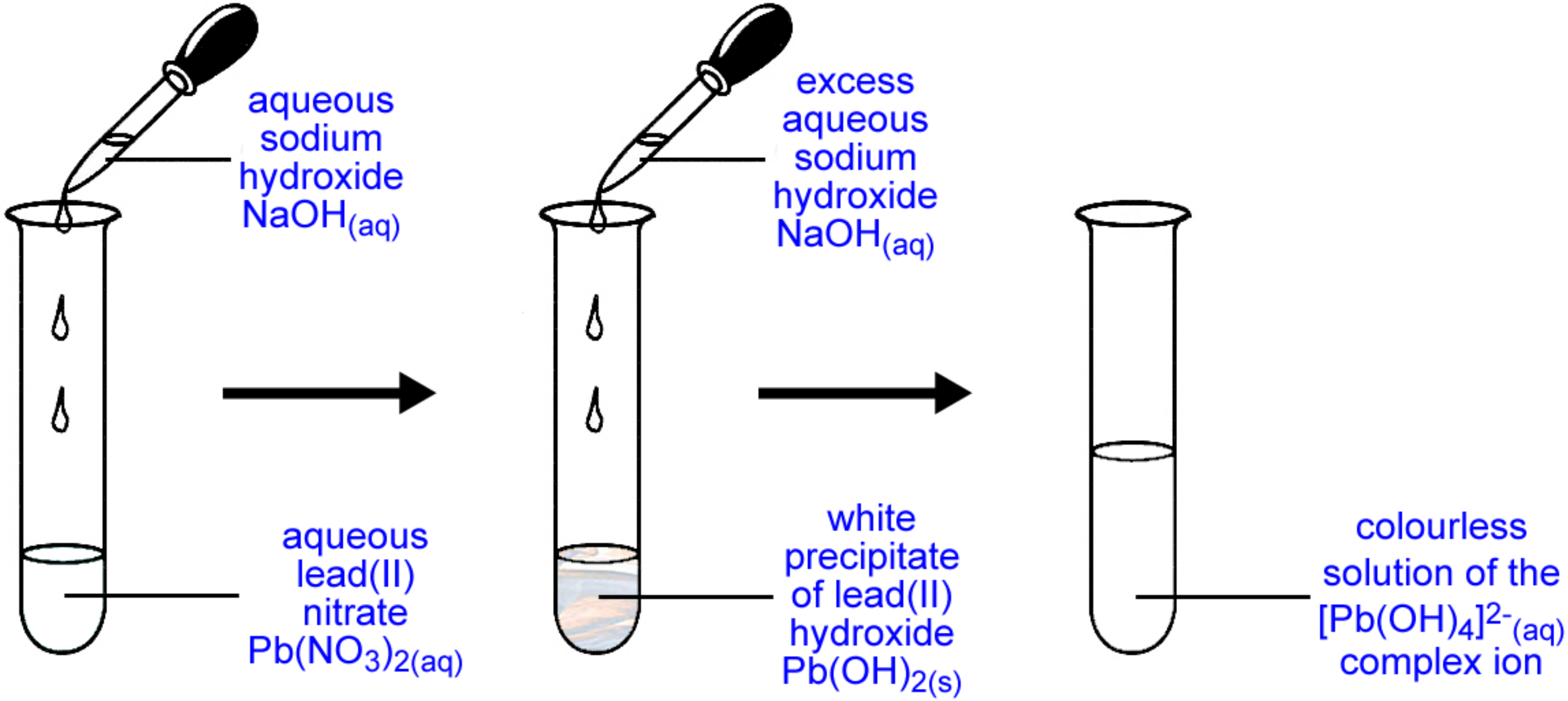
Qualitative Analysis

Test for Pb^{2+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

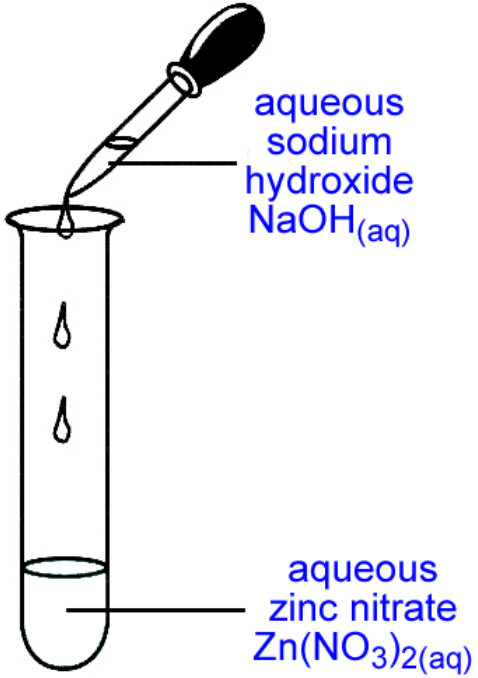
Test for $Pb^{2+}(aq)$ – Addition of NaOH(aq)



The white precipitate of $Pb(OH)_2$ dissolves in excess aqueous sodium hydroxide to produce a colourless solution.

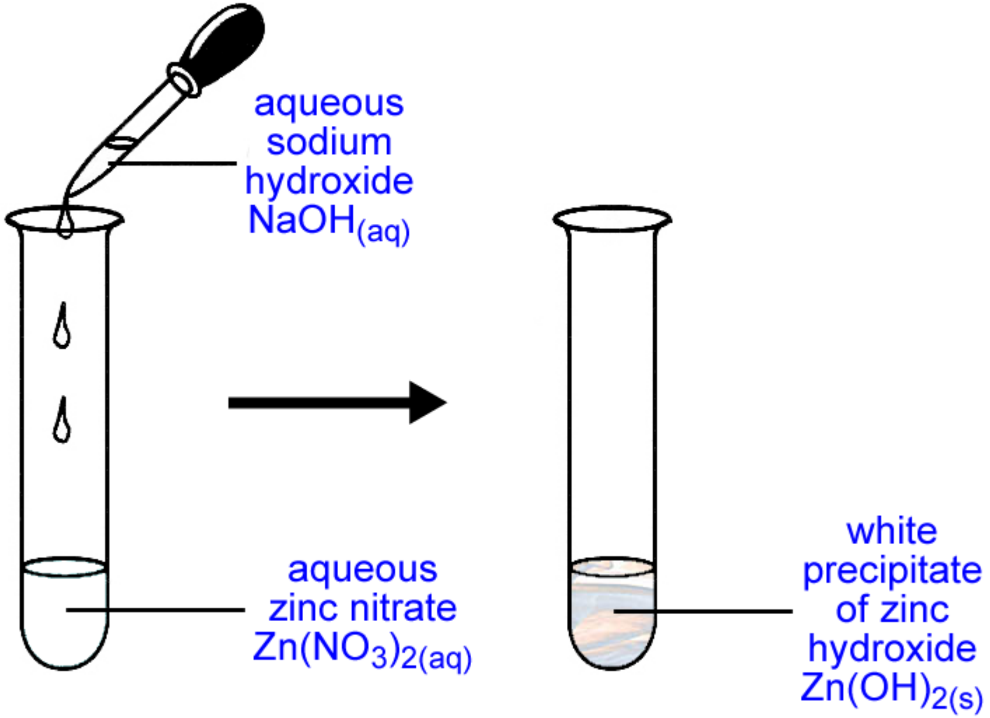
Qualitative Analysis

Test for Zn^{2+}(aq) – Addition of NaOH(aq)



Qualitative Analysis

Test for Zn^{2+}(aq) – Addition of NaOH(aq)



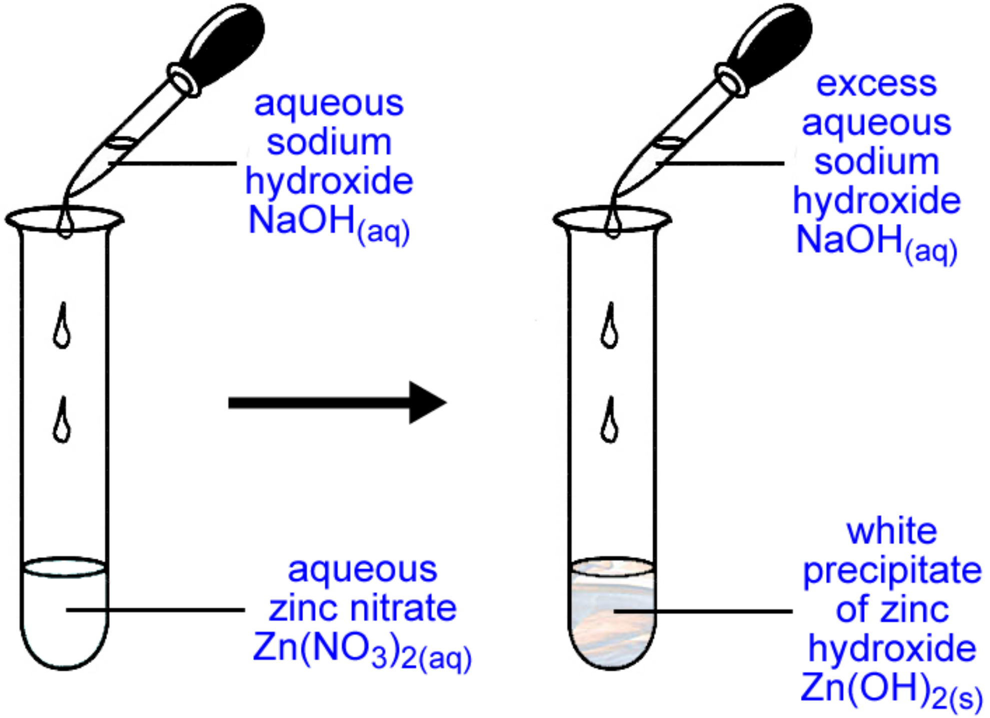
Zinc Nitrate + Sodium Hydroxide → Zinc Hydroxide + Sodium Nitrate

$$Zn(NO_3)_2(aq) + 2NaOH(aq) \rightarrow Zn(OH)_2(s) + 2NaNO_3(aq)$$

$$Zn^{2+}(aq) + 2OH^{-}(aq) \rightarrow Zn(OH)_2(s)$$

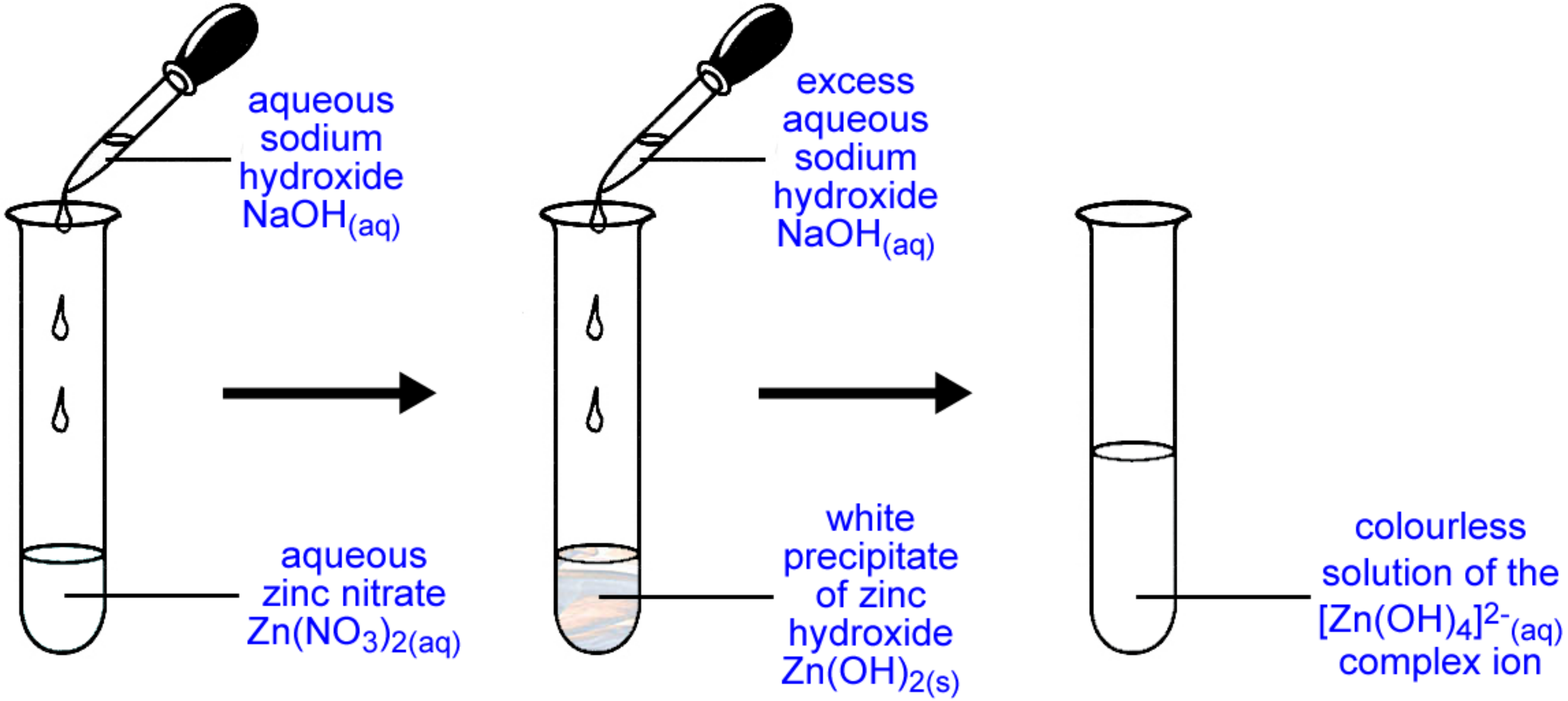
Qualitative Analysis

Test for $Zn^{2+}(aq)$ – Addition of NaOH(aq)



Qualitative Analysis

Test for $Zn^{2+}(aq)$ – Addition of $NaOH(aq)$



aqueous sodium hydroxide $NaOH_{(aq)}$

aqueous zinc nitrate $Zn(NO_3)_{2(aq)}$

excess aqueous sodium hydroxide $NaOH_{(aq)}$

white precipitate of zinc hydroxide $Zn(OH)_{2(s)}$

colourless solution of the $[Zn(OH)_4]^{2-}{}_{(aq)}$ complex ion

The white precipitate of $Zn(OH)_2$ dissolves in excess aqueous sodium hydroxide to produce a colourless solution.

Qualitative Analysis

Can I please have a summary?

Qualitative Analysis

Summary – Test for Cations Using Aqueous Sodium Hydroxide

Cation	Effect of Aqueous Sodium Hydroxide
Aluminium cation – Al^{3+}(aq)	White ppt., soluble in excess giving a colourless solution.
Ammonium cation – NH_4^+(aq)	Ammonia produced on warming.
Calcium cation – Ca^{2+}(aq)	White ppt., insoluble in excess.
Copper(II) cation – Cu^{2+}(aq)	Light blue ppt., insoluble in excess.
Iron(II) cation – Fe^{2+}(aq)	Green ppt., insoluble in excess.
Iron(III) cation – Fe^{3+}(aq)	Red-brown ppt., insoluble in excess.
Lead(II) cation – Pb^{2+}(aq)	White ppt., soluble in excess giving a colourless solution.
Zinc cation – Zn^{2+}(aq)	White ppt., soluble in excess giving a colourless solution.

Qualitative Analysis

Summary – Test for Cations Using Aqueous Sodium Hydroxide

“Chunk” your thinking to help you remember:

- *Cu^{2+}(aq)*, *Fe^{2+}(aq)* and *Fe^{3+}(aq)* form *coloured precipitates* which are *insoluble* in excess aqueous sodium hydroxide. **Note:** *copper* and *iron* are both *transition metals*.

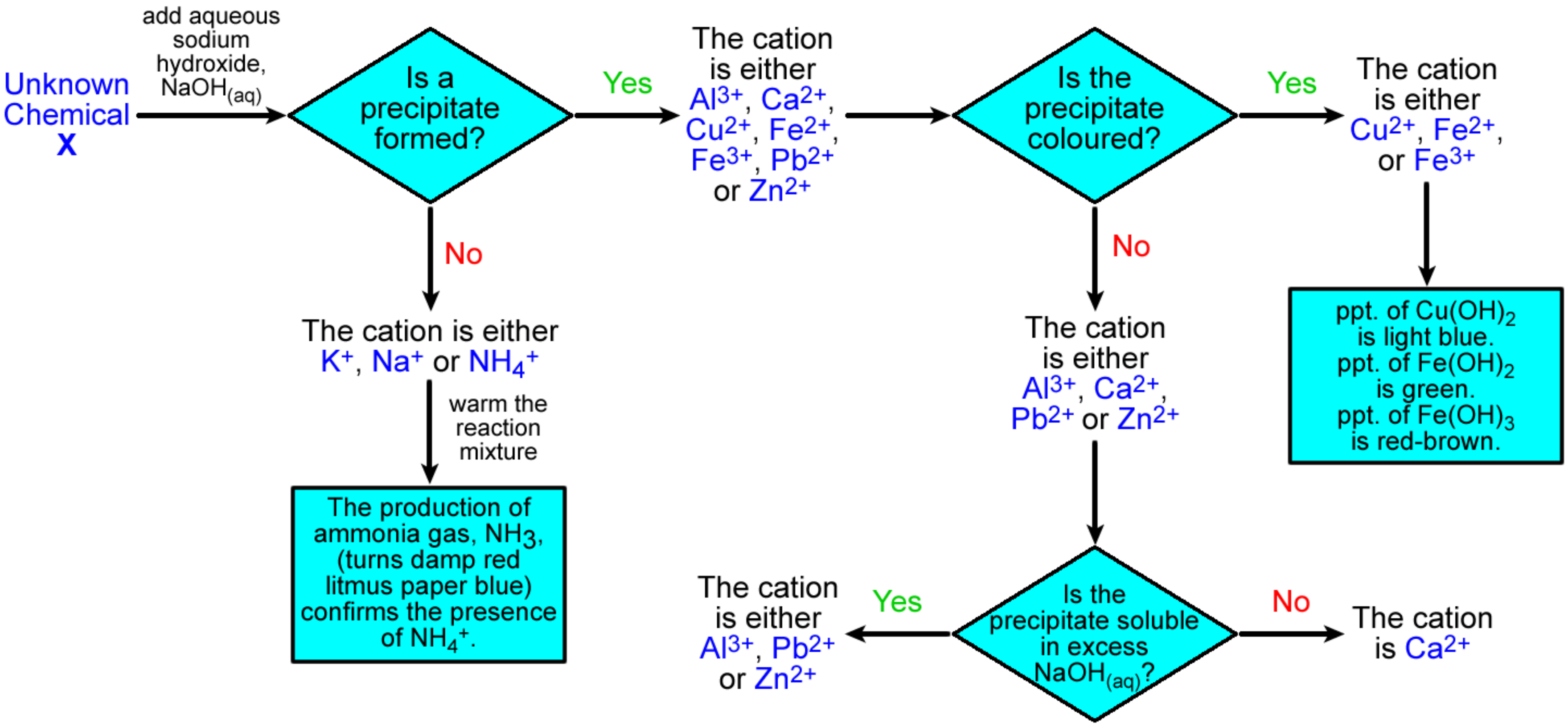
- *Al^{3+}(aq)*, *Pb^{2+}(aq)* and *Zn^{2+}(aq)* form *white precipitates* which *dissolve* in excess aqueous sodium hydroxide to produce *colourless solutions*. **Note:** *Al^{3+}(aq)*, *Pb^{2+}(aq)* and *Zn^{2+}(aq)* are described as *amphoteric* which means they demonstrate both acidic and basic character.

- *Ca^{2+}(aq)* forms a *white precipitate* which is *insoluble* in excess aqueous sodium hydroxide.

- *NH_4^+(aq)* reacts with aqueous sodium hydroxide to form *ammonia gas* which turns moist red litmus paper *blue* when the reaction is warmed gently.

Qualitative Analysis

Summary – Test for Cations Using Aqueous Sodium Hydroxide



Unknown Chemical **X**

add aqueous sodium hydroxide, $NaOH_{(aq)}$

Is a precipitate formed?

Yes

The cation is either Al^{3+}, Ca^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Pb^{2+} or Zn^{2+}

Is the precipitate coloured?

Yes

The cation is either Cu^{2+}, Fe^{2+}, or Fe^{3+}

ppt. of $Cu(OH)_2$ is light blue.
ppt. of $Fe(OH)_2$ is green.
ppt. of $Fe(OH)_3$ is red-brown.

No

The cation is either Al^{3+}, Ca^{2+}, Pb^{2+} or Zn^{2+}

Is the precipitate soluble in excess $NaOH_{(aq)}$?

Yes

The cation is either Al^{3+}, Pb^{2+} or Zn^{2+}

No

The cation is Ca^{2+}

No

The cation is either K^+, Na^+ or NH_4^+

warm the reaction mixture

The production of ammonia gas, NH_3, (turns damp red litmus paper blue) confirms the presence of NH_4^+.

Qualitative Analysis

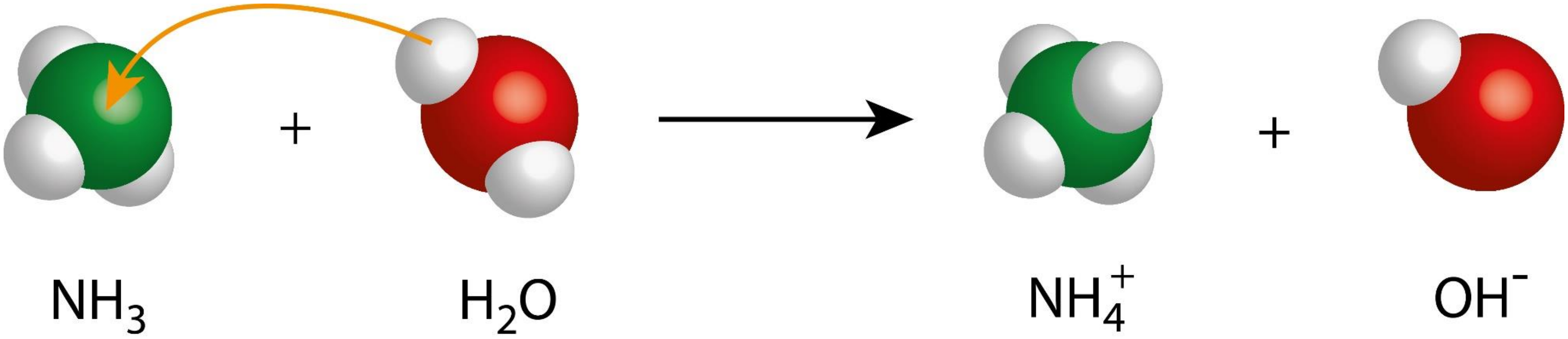
Test for Cations Using Aqueous Ammonia

Qualitative Analysis

What exactly is *aqueous ammonia?*

Qualitative Analysis

- Ammonia gas is very soluble in water. Approximately 500 g of ammonia will dissolve in 1000g of water at 25 °C.



- When ammonia gas dissolves in water, some of the ammonia molecules and water molecules react to form an alkaline solution of ammonium hydroxide.

ammonia + water $\rightleftharpoons$ ammonium hydroxide

$NH_3(g) + H_2O(\mathit{l}) \rightleftharpoons NH_4OH(aq)$

Qualitative Analysis

Aqueous Ammonia – $NH_3(aq)$

Aqueous ammonia is a solution of ammonia gas dissolved in water.

When ammonia gas is bubbled into water, some of the ammonia *reacts* with the water to form an aqueous solution of *ammonium hydroxide* – *$NH_4OH(aq)$*:

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4OH(aq) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

As a consequence of this, an aqueous solution of ammonia is actually a mixture of *ammonia molecules* (NH_3), *water molecules* (H_2O), *ammonium ions* (NH_4^+) and *hydroxide ions* (OH^-).

Note: The hydroxide ions can react with soluble metal cations to produce precipitates of the insoluble metal hydroxide.

Qualitative Analysis

- What is the essential difference between aqueous ammonia and aqueous sodium hydroxide?

- Aqueous sodium hydroxide is a *strong alkali*. This means that it *completely ionises* when dissolved in water:

$$NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$$

- Aqueous ammonia is a *weak alkali*. Ammonia molecules only *partially react* and *ionise* in water to form ammonium hydroxide:

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

Qualitative Analysis

- The consequence is that 1.00 mol/dm^3 aqueous sodium hydroxide and 1.00 mol/dm^3 aqueous ammonia contain *different* concentrations of hydroxide ions.

→ 1.00 mol/dm^3 aqueous sodium hydroxide contains 1.00 mol/dm^3 hydroxide ions.

→ 1.00 mol/dm^3 aqueous ammonia contains approximately 0.004 mol/dm^3 hydroxide ions.

- Reactions that take place when aqueous sodium hydroxide is used may *not* take place when aqueous ammonia is used, because the concentration of hydroxide ions in the aqueous ammonia is too low for a reaction to occur.

Qualitative Analysis

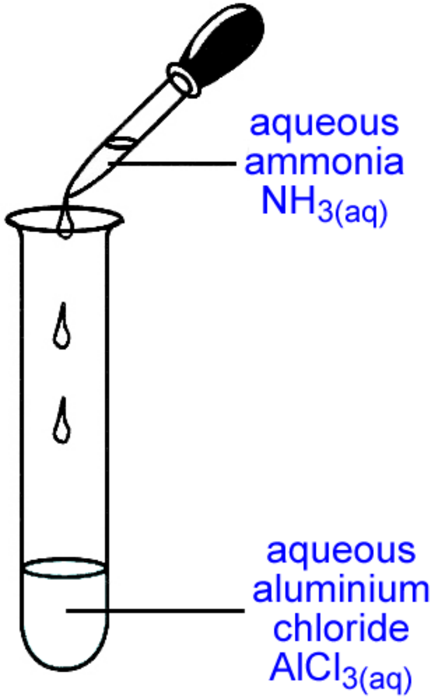
- When *aqueous sodium hydroxide* is added to Ca^{2+}(aq), the relatively high concentration of OH^-(aq) ensures that sufficient $Ca(OH)_2$(s) is formed to precipitate from the solution.

- However, when *aqueous ammonia* is added to Ca^{2+}(aq), the relatively low concentration of OH^-(aq) means that not enough $Ca(OH)_2$(s) is formed for a precipitate to be formed.

- For a similar reason, $\mathrm{A}l(\mathrm{OH})_3$(s) and $Pb(OH)_2$(s) both dissolve in excess aqueous sodium hydroxide, but are both insoluble in excess aqueous ammonia.

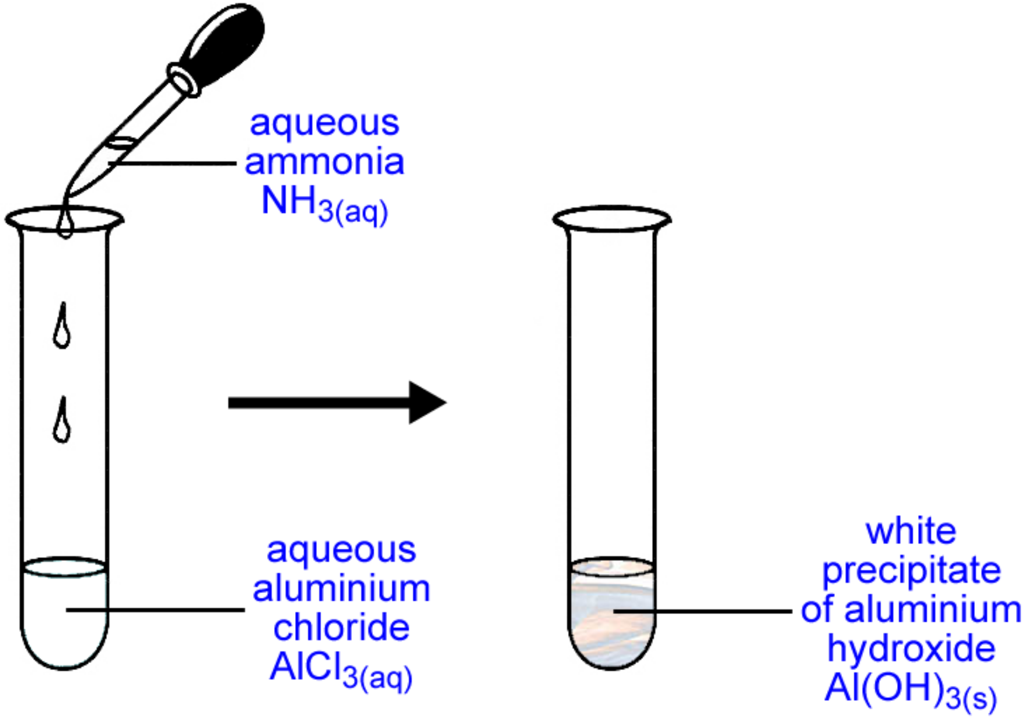
Qualitative Analysis

Test for A*l*$^{3+}$(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for $\mathrm{Al^{3+}(aq)}$ – Addition of $\mathrm{NH_3(aq)}$



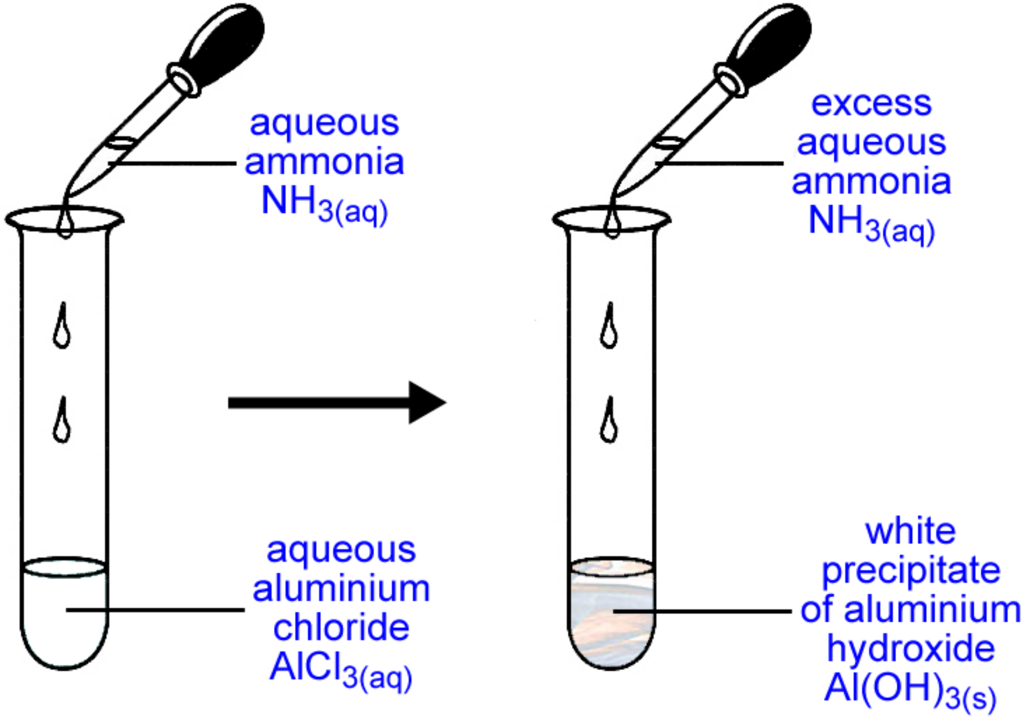
Aluminium Chloride + Aqueous Ammonia → Aluminium Hydroxide + Ammonium Chloride

$$\mathrm{AlCl_3(aq) \;+\; 3NH_4OH(aq) \;\rightarrow\; Al(OH)_3(s) \;+\; 3NH_4Cl(aq)}$$

$$\mathrm{Al^{3+}(aq) \;+\; 3OH^{-}(aq) \;\rightarrow\; Al(OH)_3(s)}$$

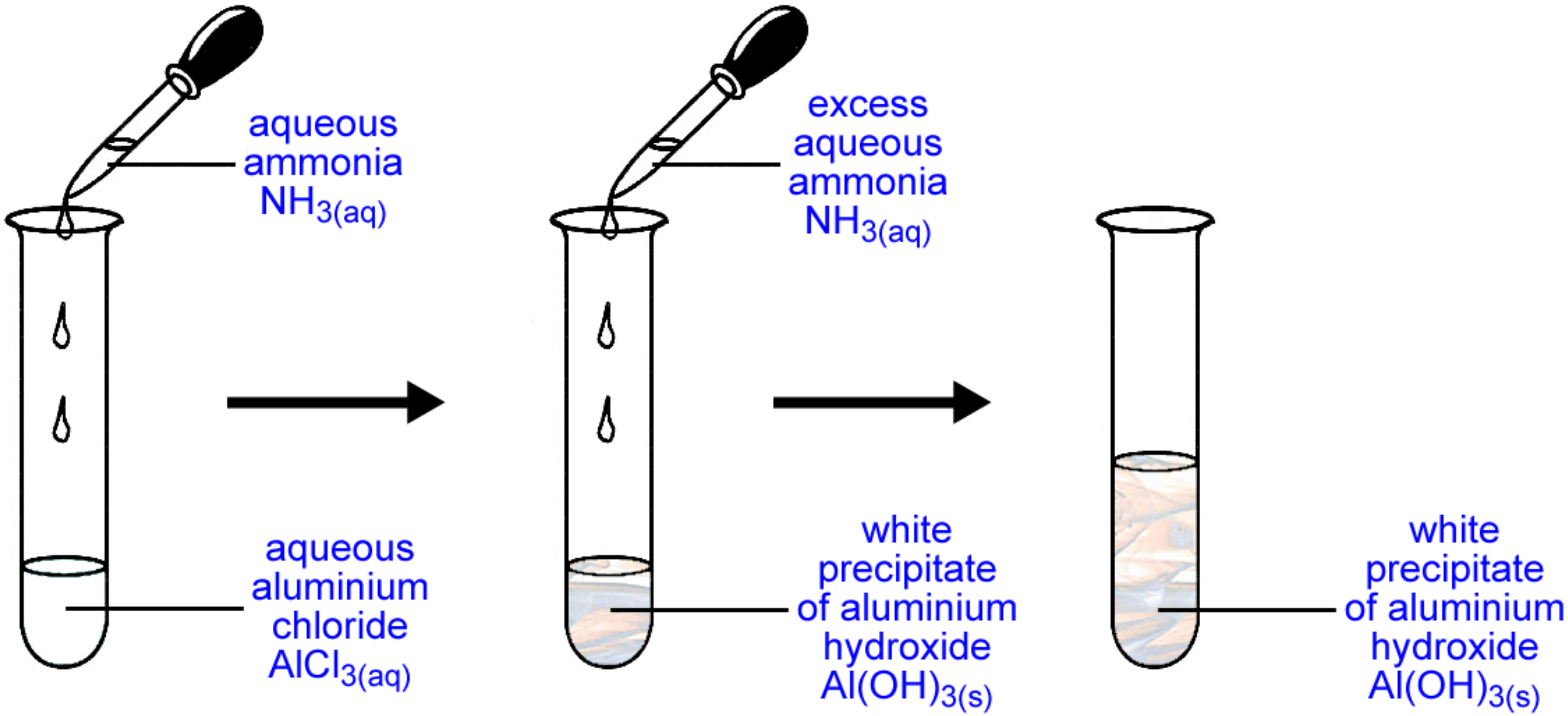
Qualitative Analysis

Test for A*l*$^{3+}$(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for Al^{3+}(aq) – Addition of NH_3(aq)



aqueous ammonia $NH_{3(aq)}$

aqueous aluminium chloride $AlCl_{3(aq)}$

excess aqueous ammonia $NH_{3(aq)}$

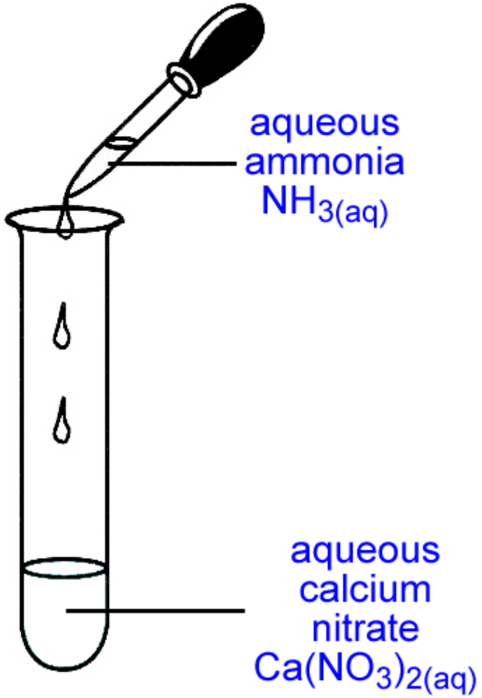
white precipitate of aluminium hydroxide $Al(OH)_{3(s)}$

white precipitate of aluminium hydroxide $Al(OH)_{3(s)}$

The white precipitate of $Al(OH)_3$ is insoluble in excess aqueous ammonia.

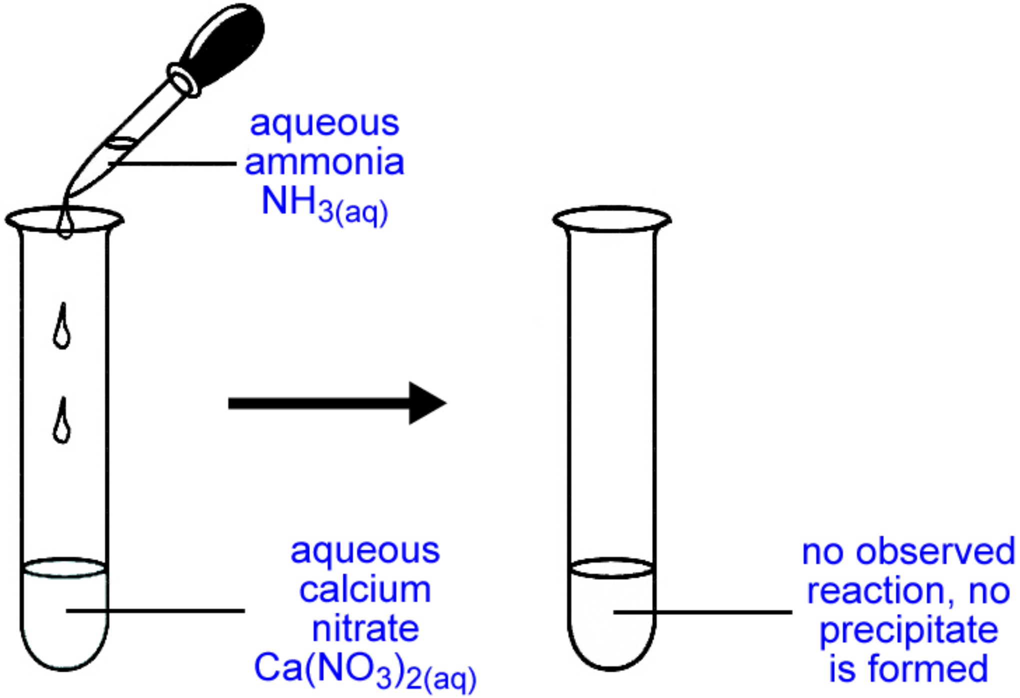
Qualitative Analysis

Test for Ca^{2+}(aq) – Addition of NH_3(aq)



Qualitative Analysis

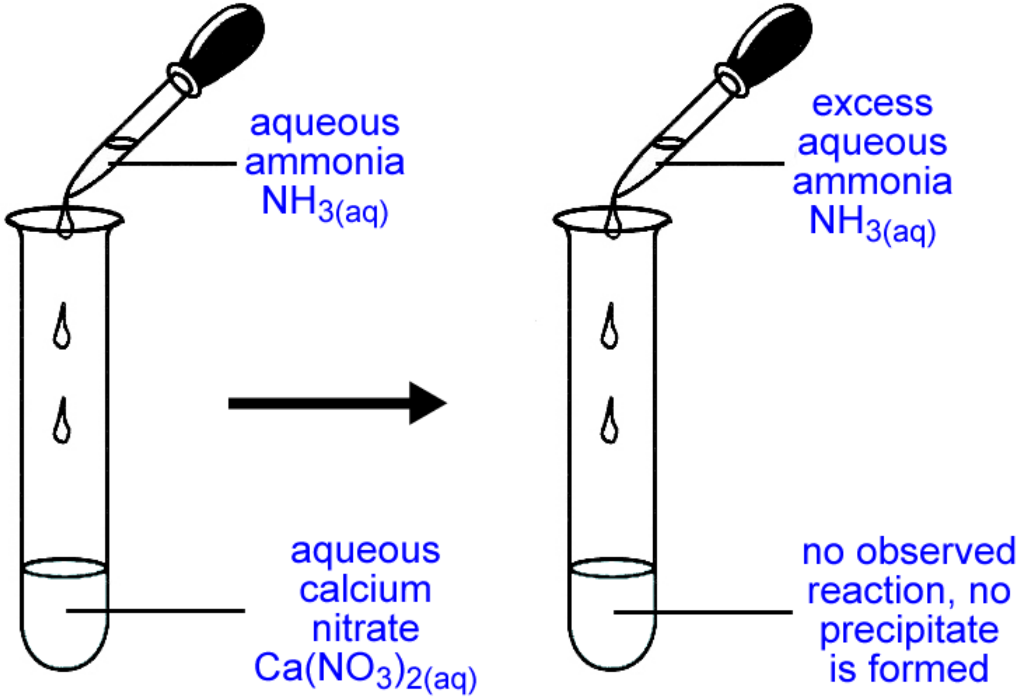
Test for Ca^{2+}(aq) – Addition of NH_3(aq)



There is no observed reaction between the calcium nitrate and aqueous ammonia – no precipitate is formed.

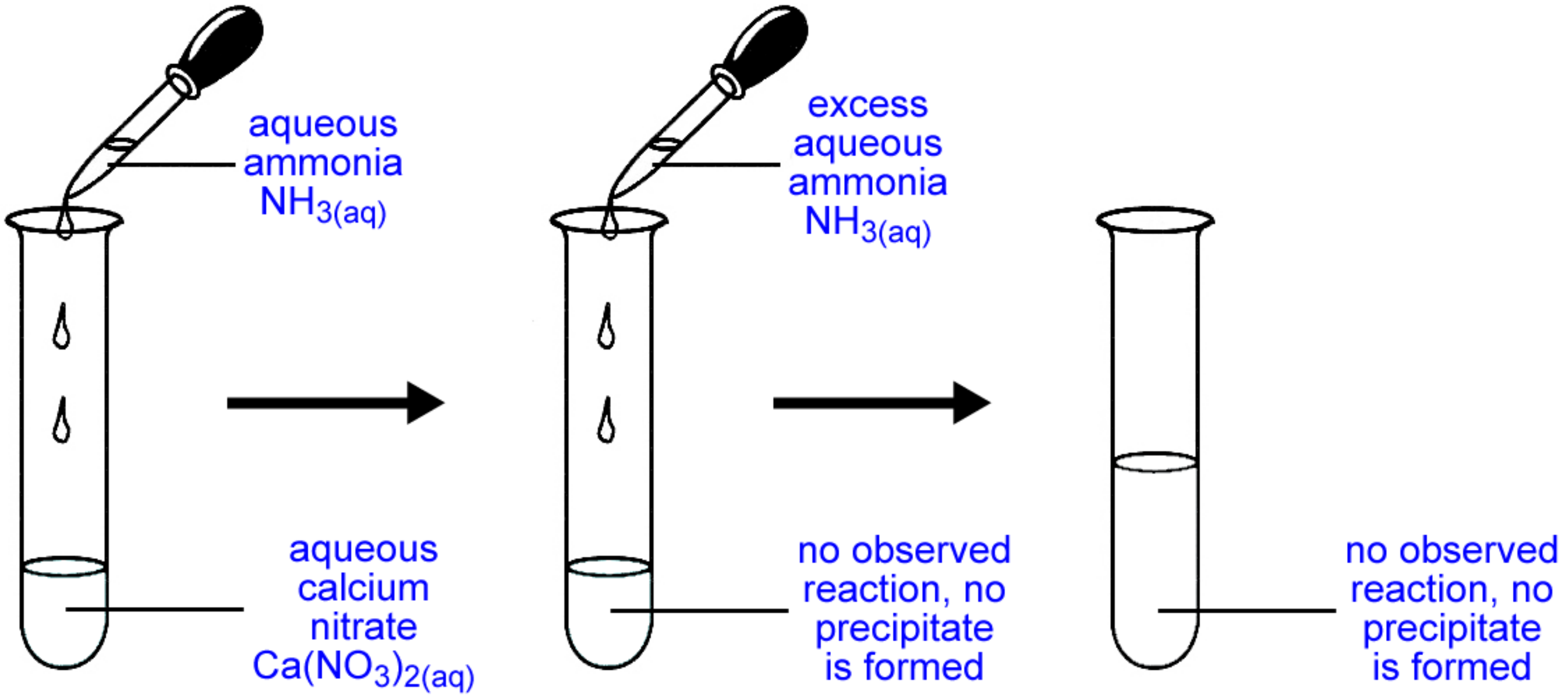
Qualitative Analysis

Test for $Ca^{2+}(aq)$ – Addition of $NH_3(aq)$



Qualitative Analysis

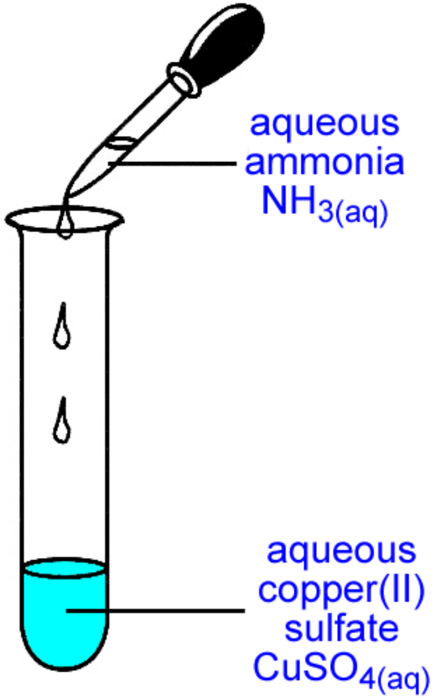
Test for Ca^{2+}(aq) – Addition of NH_3(aq)



There is no observed reaction between the calcium nitrate and aqueous ammonia – no precipitate is formed.

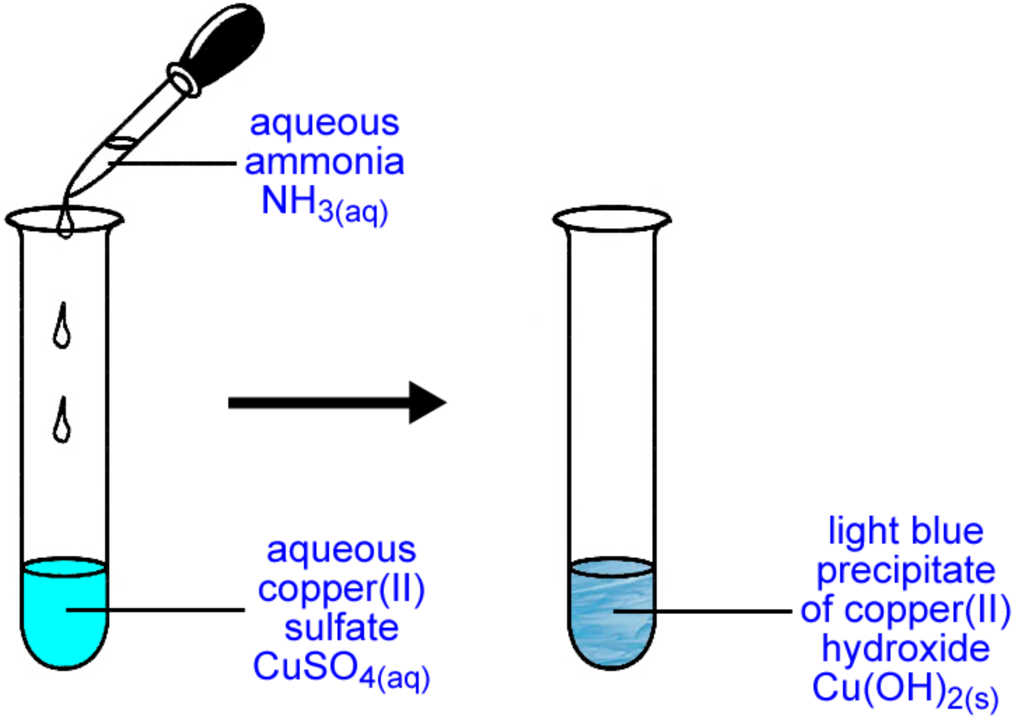
Qualitative Analysis

Test for $Cu^{2+}(aq)$ – Addition of $NH_3(aq)$



Qualitative Analysis

Test for Cu^{2+}(aq) – Addition of NH_3(aq)



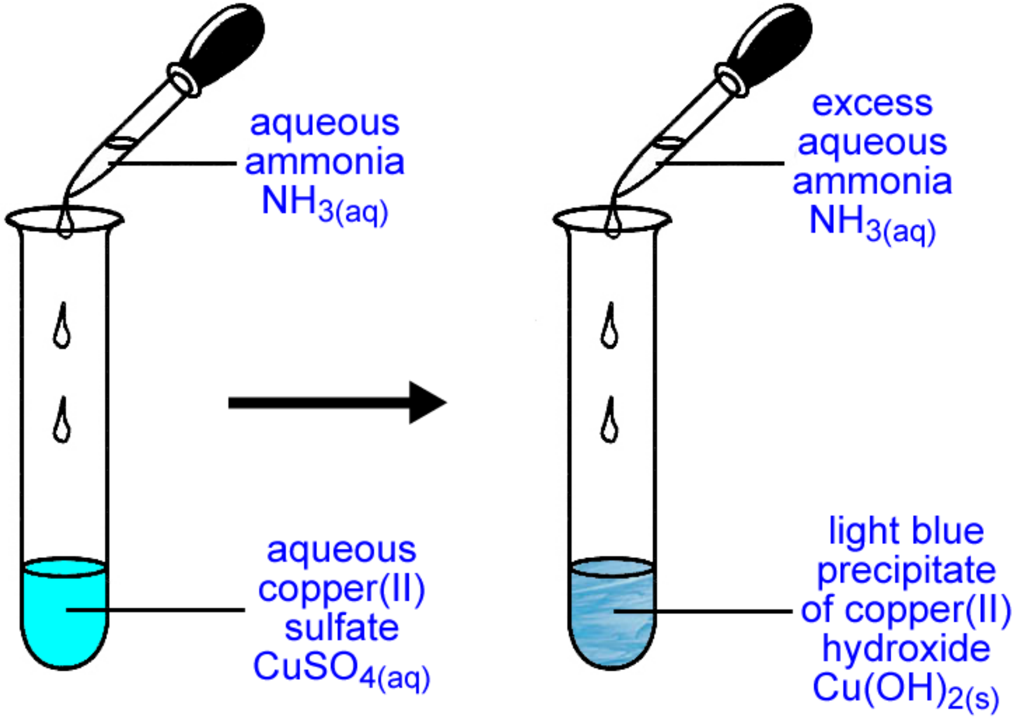
Copper(II) Sulfate + Aqueous Ammonia → Copper(II) Hydroxide + Ammonium Sulfate

$$CuSO_4(aq) + 2NH_4OH(aq) \rightarrow Cu(OH)_2(s) + (NH_4)_2SO_4(aq)$$

$$Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$$

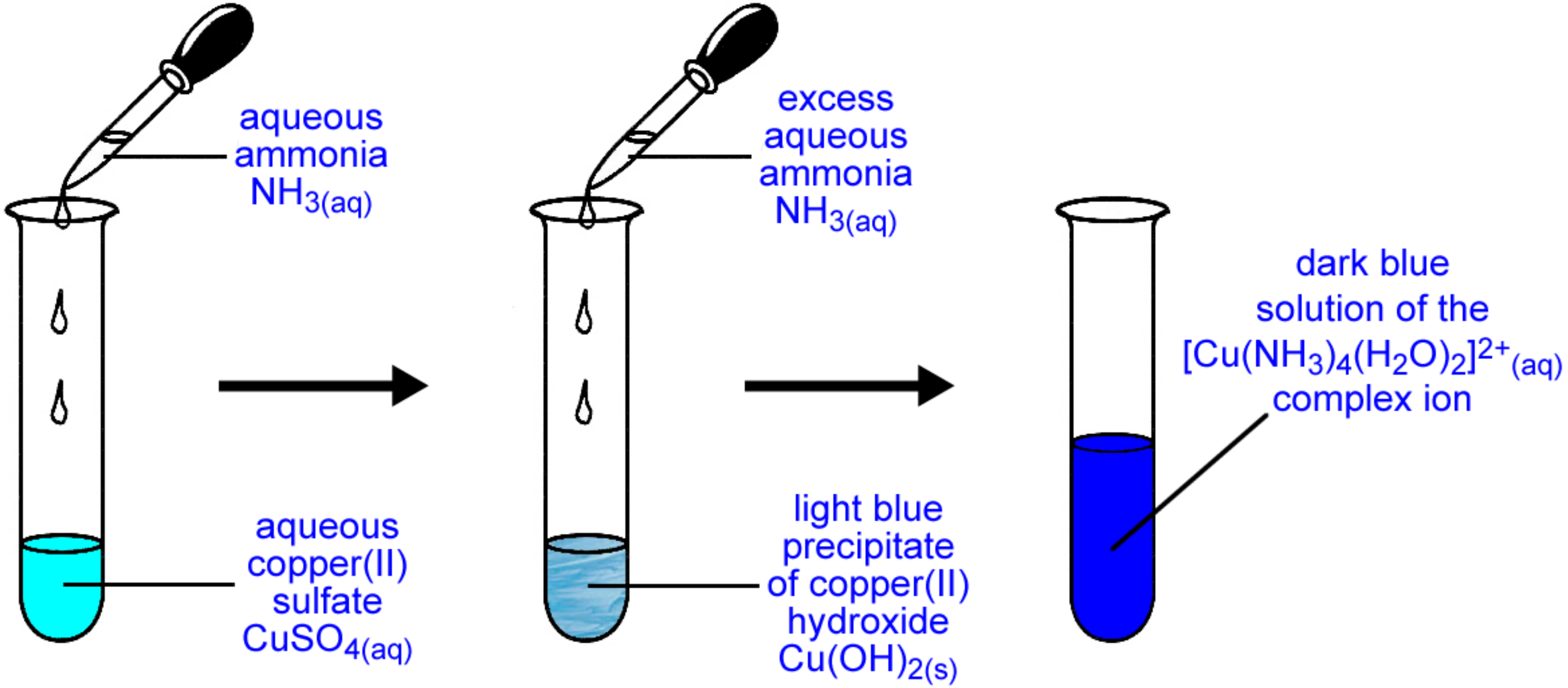
Qualitative Analysis

Test for $Cu^{2+}(aq)$ – Addition of $NH_3(aq)$



Qualitative Analysis

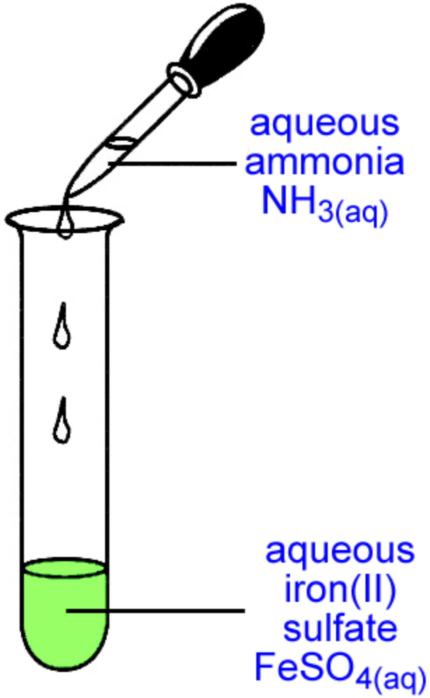
Test for Cu^{2+}(aq) – Addition of NH_3(aq)



The blue precipitate of $Cu(OH)_2$ dissolves in excess aqueous ammonia to produce a dark blue solution.

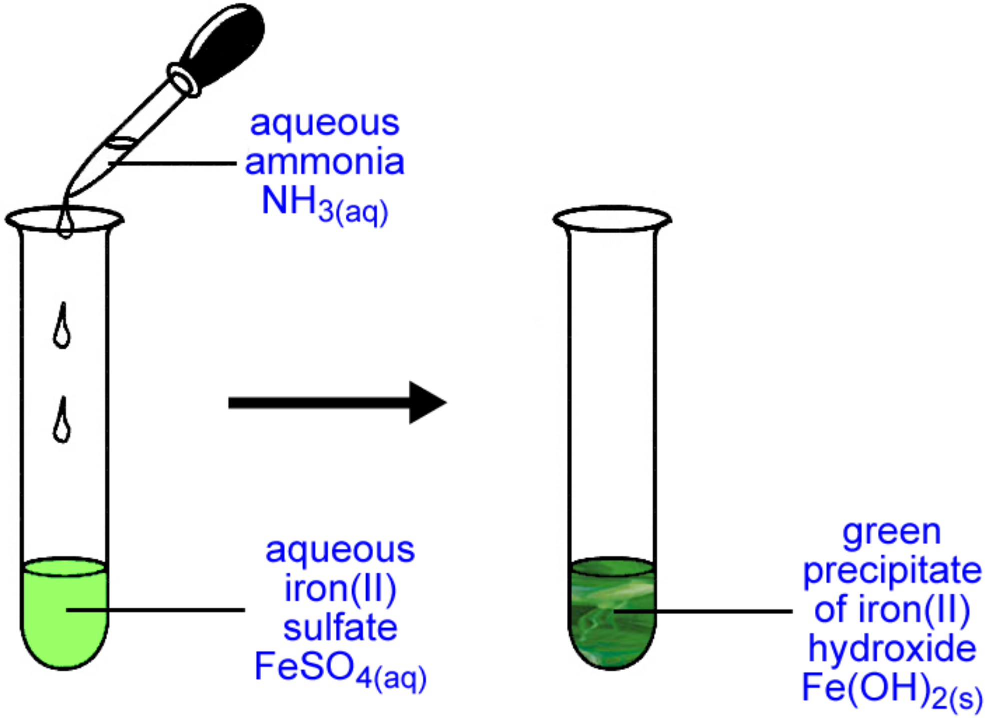
Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NH_3(aq)



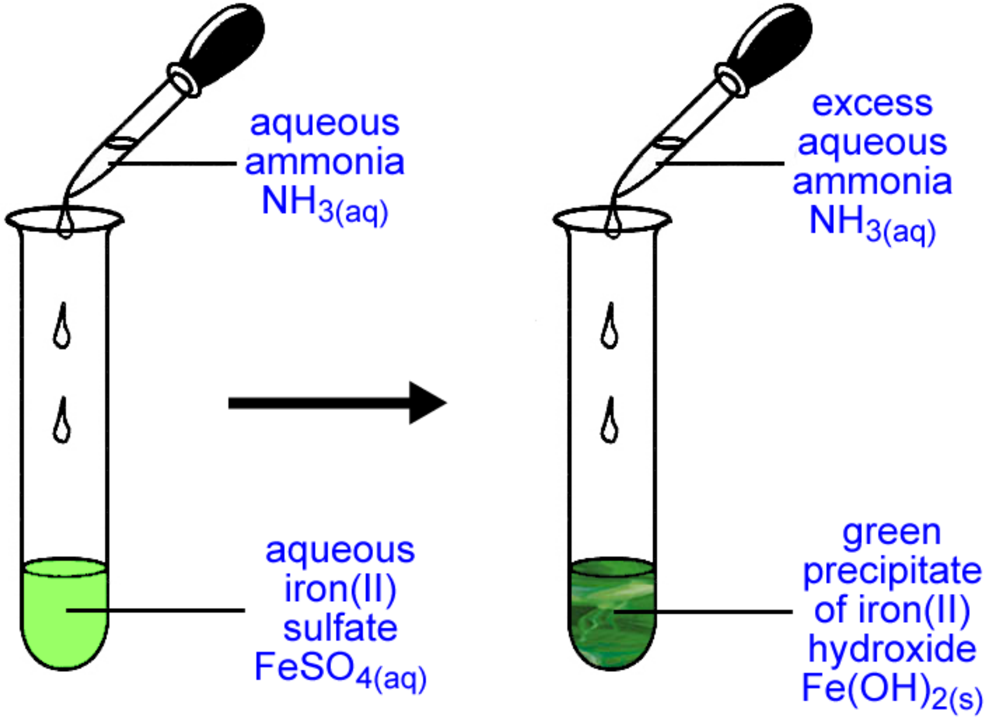
Iron(II) Sulfate + Aqueous Ammonia → Iron(II) Hydroxide + Ammonium Sulfate

$$FeSO_4(aq) + 2NH_4OH(aq) \rightarrow Fe(OH)_2(s) + (NH_4)_2SO_4(aq)$$

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$$

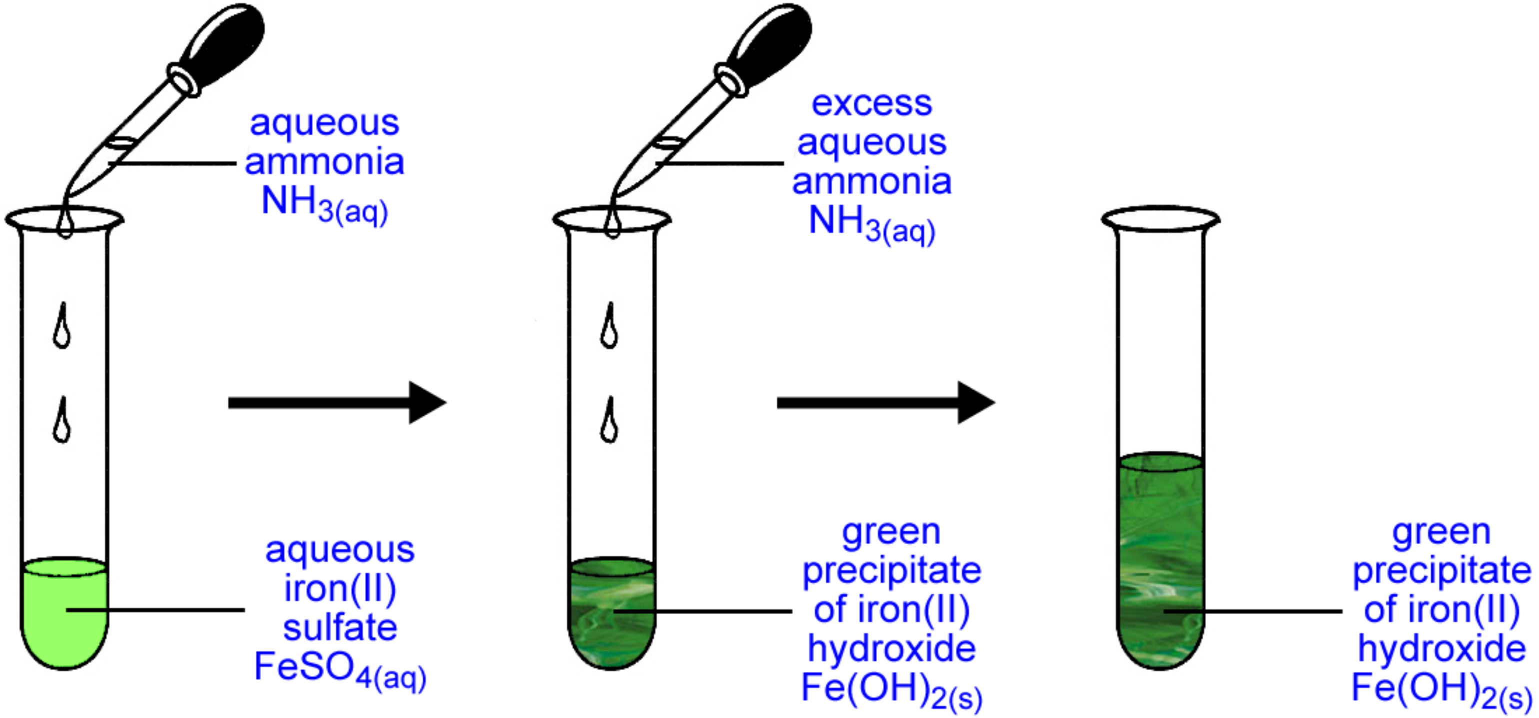
Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for Fe^{2+}(aq) – Addition of NH_3(aq)



aqueous ammonia $NH_{3(aq)}$

aqueous iron(II) sulfate $FeSO_{4(aq)}$

excess aqueous ammonia $NH_{3(aq)}$

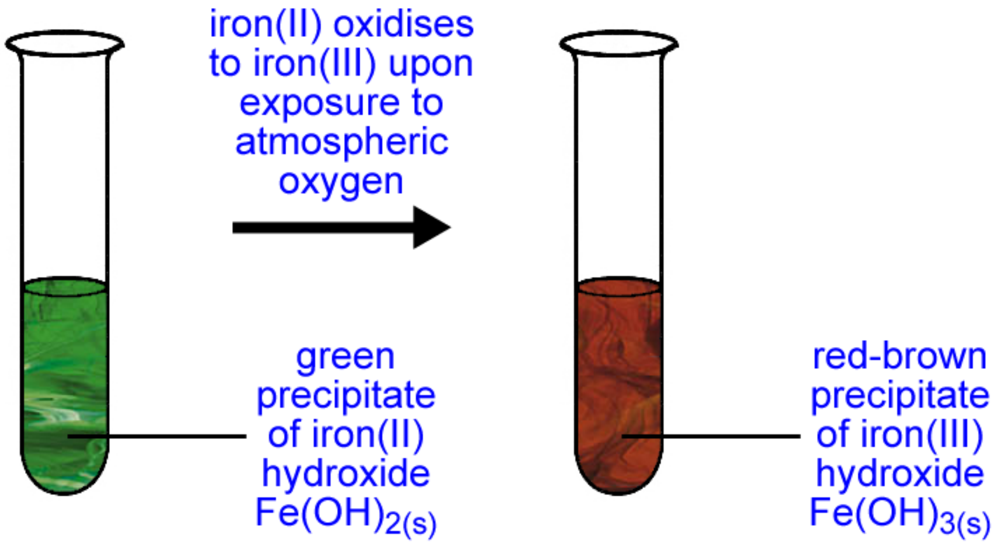
green precipitate of iron(II) hydroxide $Fe(OH)_{2(s)}$

green precipitate of iron(II) hydroxide $Fe(OH)_{2(s)}$

The green precipitate of $Fe(OH)_2$ is insoluble in excess aqueous ammonia.

Qualitative Analysis

Test for $Fe^{2+}(aq)$ – Addition of $NH_3(aq)$



iron(II) oxidises to iron(III) upon exposure to atmospheric oxygen

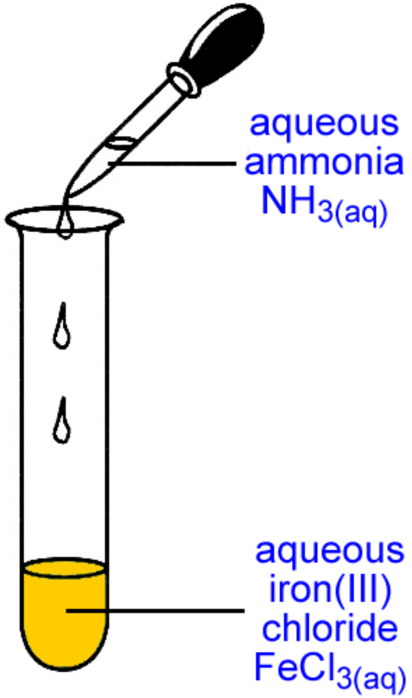
green precipitate of iron(II) hydroxide $Fe(OH)_{2(s)}$

red-brown precipitate of iron(III) hydroxide $Fe(OH)_{3(s)}$

Note: Iron(II) can oxidise to iron(III) upon exposure to atmospheric oxygen.
When this happens, the green precipitate of $Fe(OH)_2$ changes into a red-brown precipitate of $Fe(OH)_3$.

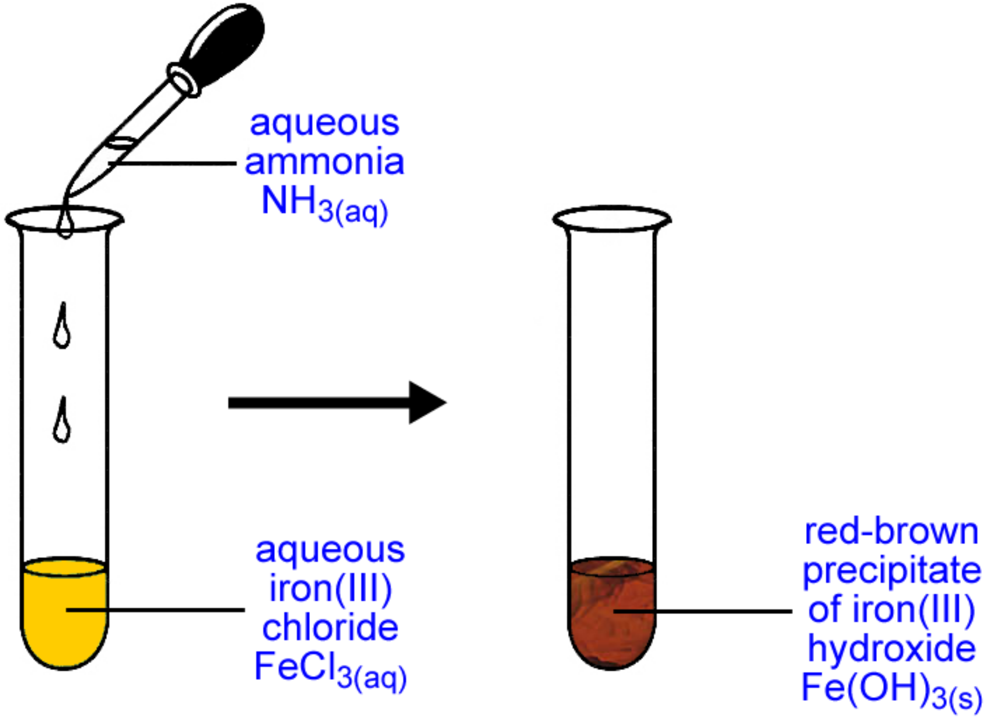
Qualitative Analysis

Test for Fe^{3+}(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for $Fe^{3+}(aq)$ – Addition of $NH_3(aq)$



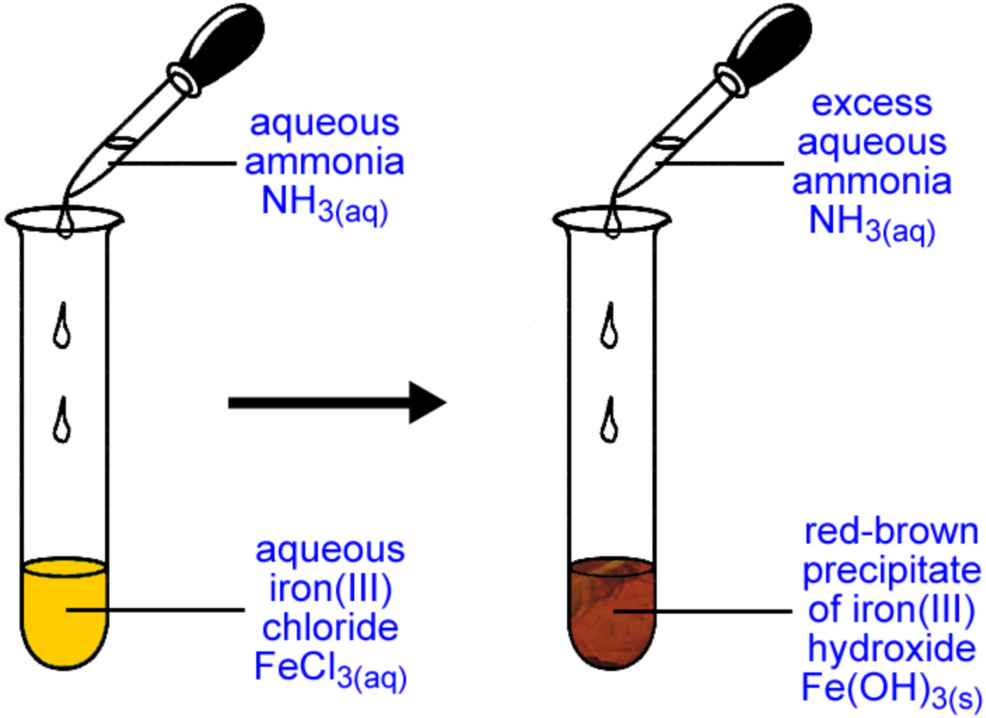
Iron(III) Chloride + Aqueous Ammonia → Iron(III) Hydroxide + Ammonium Chloride

$$FeCl_3(aq) + 3NH_4OH(aq) \rightarrow Fe(OH)_3(s) + 3NH_4Cl(aq)$$

$$Fe^{3+}(aq) + 3OH^{-}(aq) \rightarrow Fe(OH)_3(s)$$

Qualitative Analysis

Test for Fe^{3+}(aq) – Addition of NH_3(aq)



aqueous ammonia $NH_{3(aq)}$

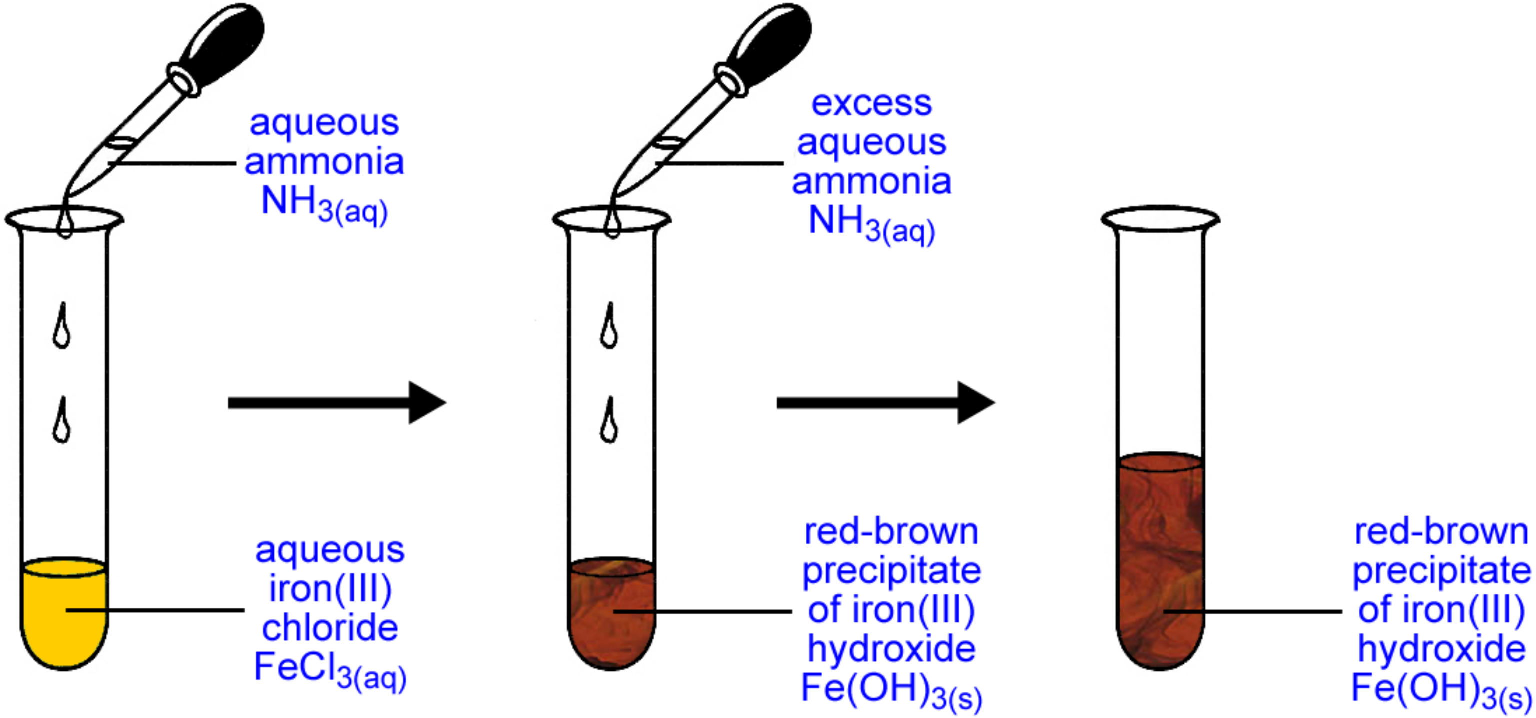
excess aqueous ammonia $NH_{3(aq)}$

aqueous iron(III) chloride $FeCl_{3(aq)}$

red-brown precipitate of iron(III) hydroxide $Fe(OH)_{3(s)}$

Qualitative Analysis

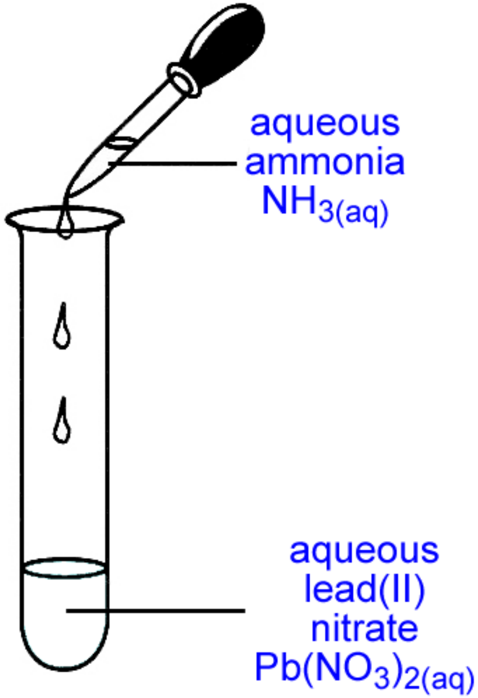
Test for $Fe^{3+}(aq)$ – Addition of $NH_3(aq)$



The red-brown precipitate of $Fe(OH)_3$ is insoluble in excess aqueous ammonia.

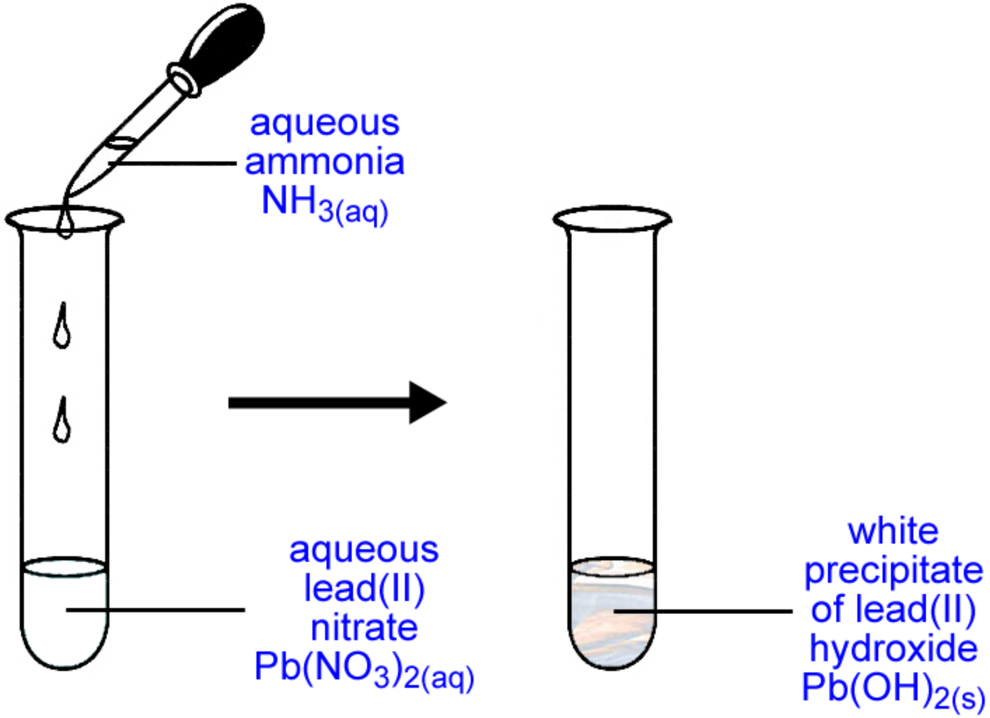
Qualitative Analysis

Test for $Pb^{2+}(aq)$ – Addition of $NH_3(aq)$



Qualitative Analysis

Test for $Pb^{2+}(aq)$ – Addition of $NH_3(aq)$



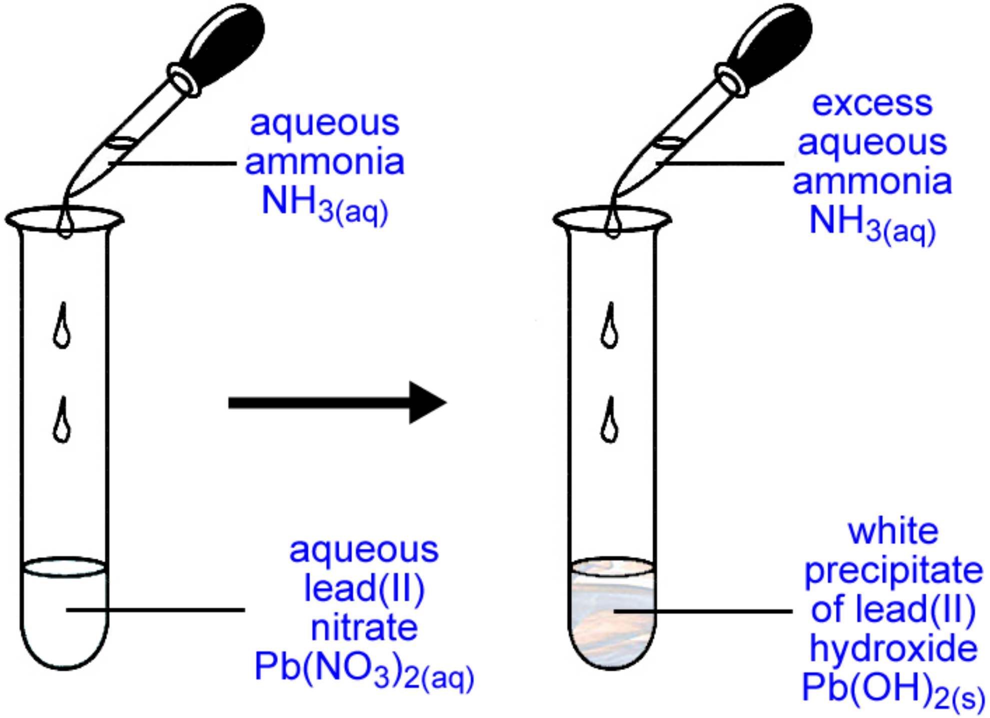
Lead(II) Nitrate + Aqueous Ammonia → Lead(II) Hydroxide + Ammonium Nitrate

$$Pb(NO_3)_2(aq) + 2NH_4OH(aq) \rightarrow Pb(OH)_2(s) + 2NH_4NO_3(aq)$$

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

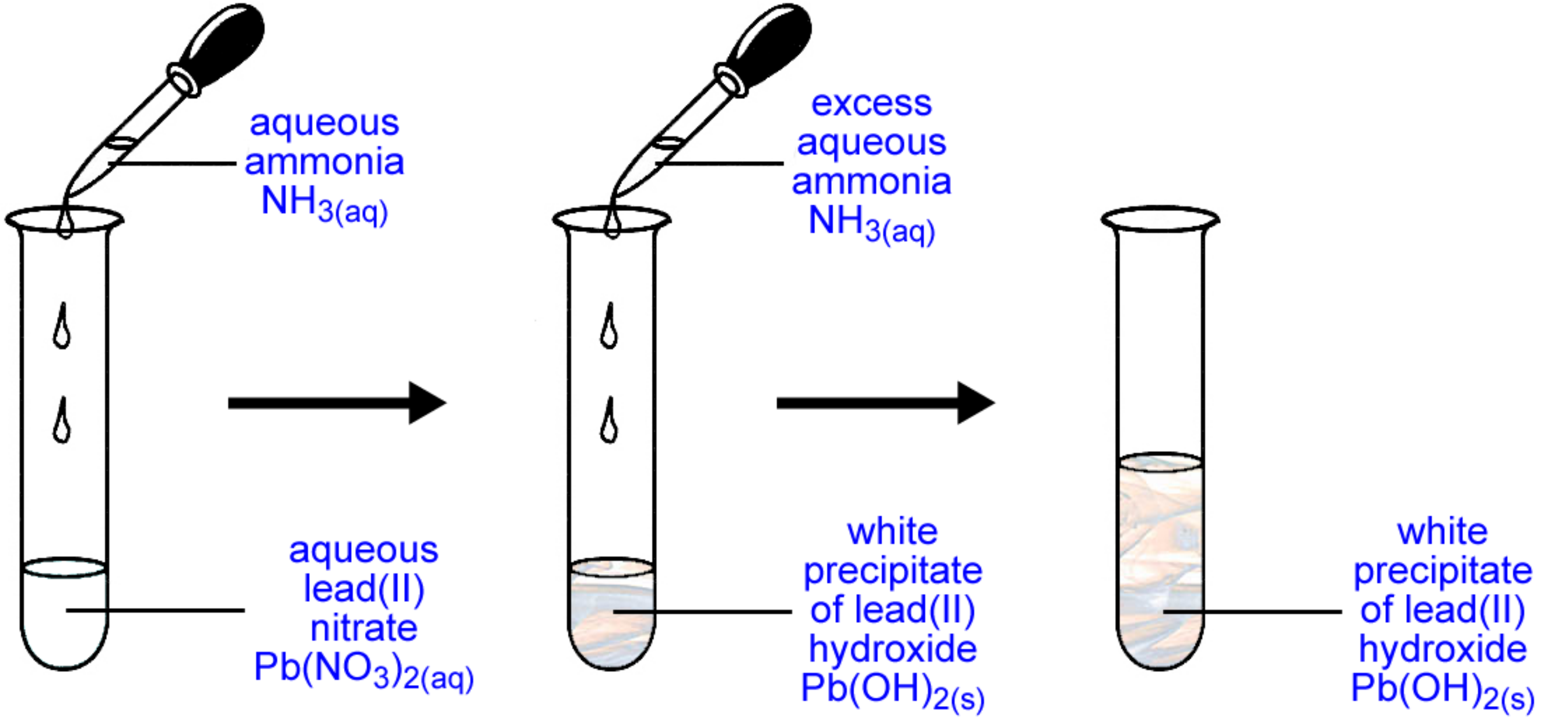
Qualitative Analysis

Test for $Pb^{2+}(aq)$ – Addition of $NH_3(aq)$



Qualitative Analysis

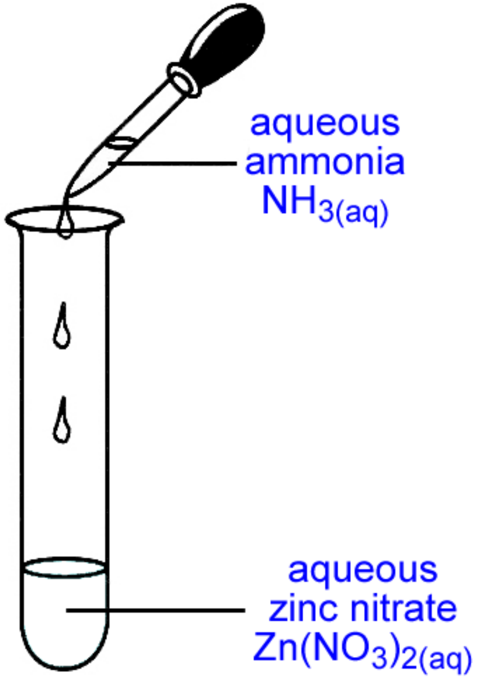
Test for $Pb^{2+}(aq)$ – Addition of $NH_3(aq)$



The white precipitate of $Pb(OH)_2$ is insoluble in excess aqueous ammonia.

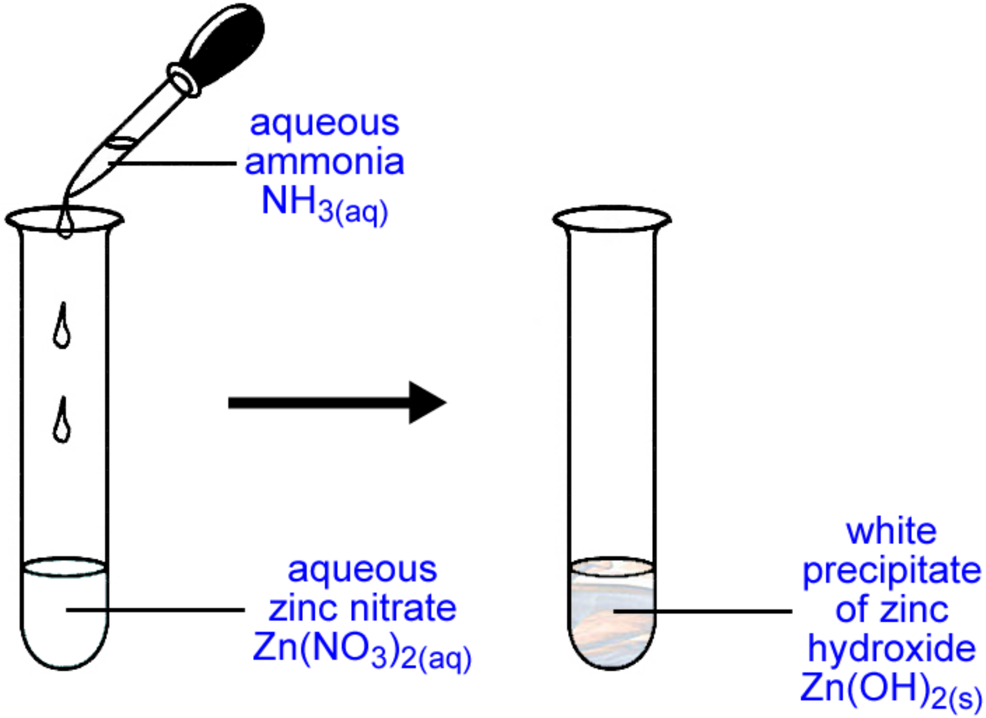
Qualitative Analysis

Test for Zn^{2+}(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for Zn^{2+}(aq) – Addition of NH_3(aq)



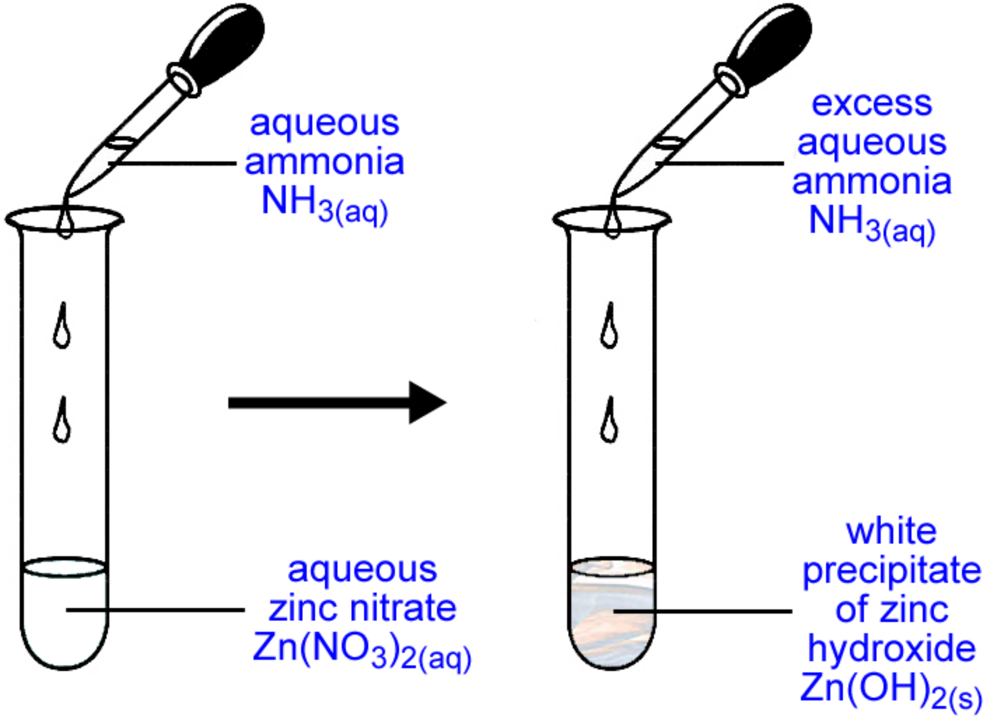
Zinc Nitrate + Aqueous Ammonia → Zinc Hydroxide + Ammonium Nitrate

$$Zn(NO_3)_2(aq) + 2NH_4OH(aq) \rightarrow Zn(OH)_2(s) + 2NH_4NO_3(aq)$$

$$Zn^{2+}(aq) + 2OH^-(aq) \rightarrow Zn(OH)_2(s)$$

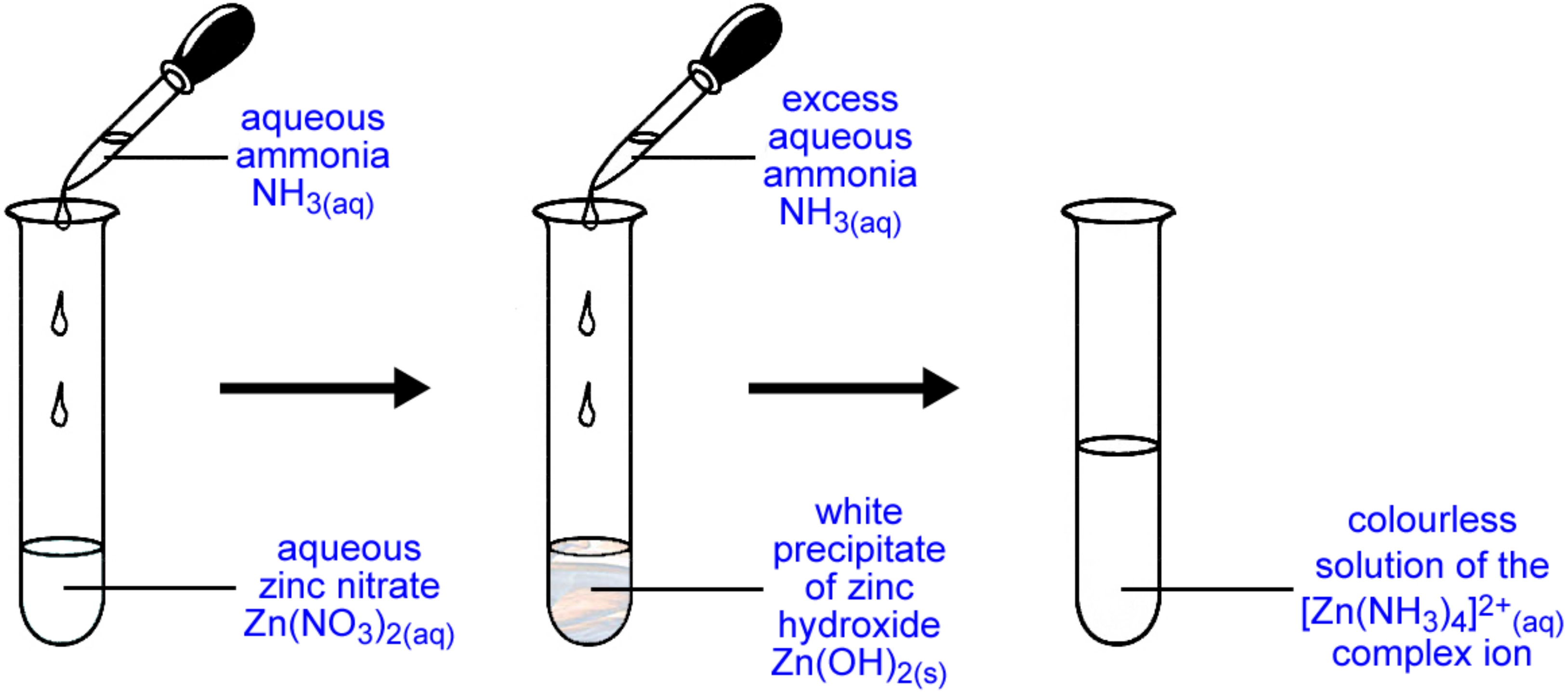
Qualitative Analysis

Test for Zn^{2+}(aq) – Addition of NH_3(aq)



Qualitative Analysis

Test for $Zn^{2+}(aq)$ – Addition of $NH_3(aq)$



The white precipitate of $Zn(OH)_2$ dissolves in excess aqueous ammonia to produce a colourless solution.

Qualitative Analysis

Can I please have a summary?

Qualitative Analysis

Summary – Test for Cations Using Aqueous Ammonia

Cation	Effect of Aqueous Ammonia
Aluminium cation – Al^{3+}(aq)	White ppt., insoluble in excess.
Ammonium cation – NH_4^+(aq)	Not applicable.
Calcium cation – Ca^{2+}(aq)	No observed reaction, no ppt. observed.
Copper(II) cation – Cu^{2+}(aq)	Light blue ppt., soluble in excess giving a dark blue solution.
Iron(II) cation – Fe^{2+}(aq)	Green ppt., insoluble in excess.
Iron(III) cation – Fe^{3+}(aq)	Red-brown ppt., insoluble in excess.
Lead(II) cation – Pb^{2+}(aq)	White ppt., insoluble in excess.
Zinc cation – Zn^{2+}(aq)	White ppt., soluble in excess giving a colourless solution.

Qualitative Analysis

Summary – Test for Cations Using Aqueous Ammonia

"Chunk" your thinking to help you remember:

- *$Cu^{2+}(aq)$*, *$Fe^{2+}(aq)$* and *$Fe^{3+}(aq)$* form *coloured precipitates* which are *insoluble* in excess aqueous ammonia. **Note:** *copper* and *iron* are both *transition metals*.

- *$Al^{3+}(aq)$* and *$Pb^{2+}(aq)$* form *white precipitates* which are *insoluble* in excess aqueous ammonia.

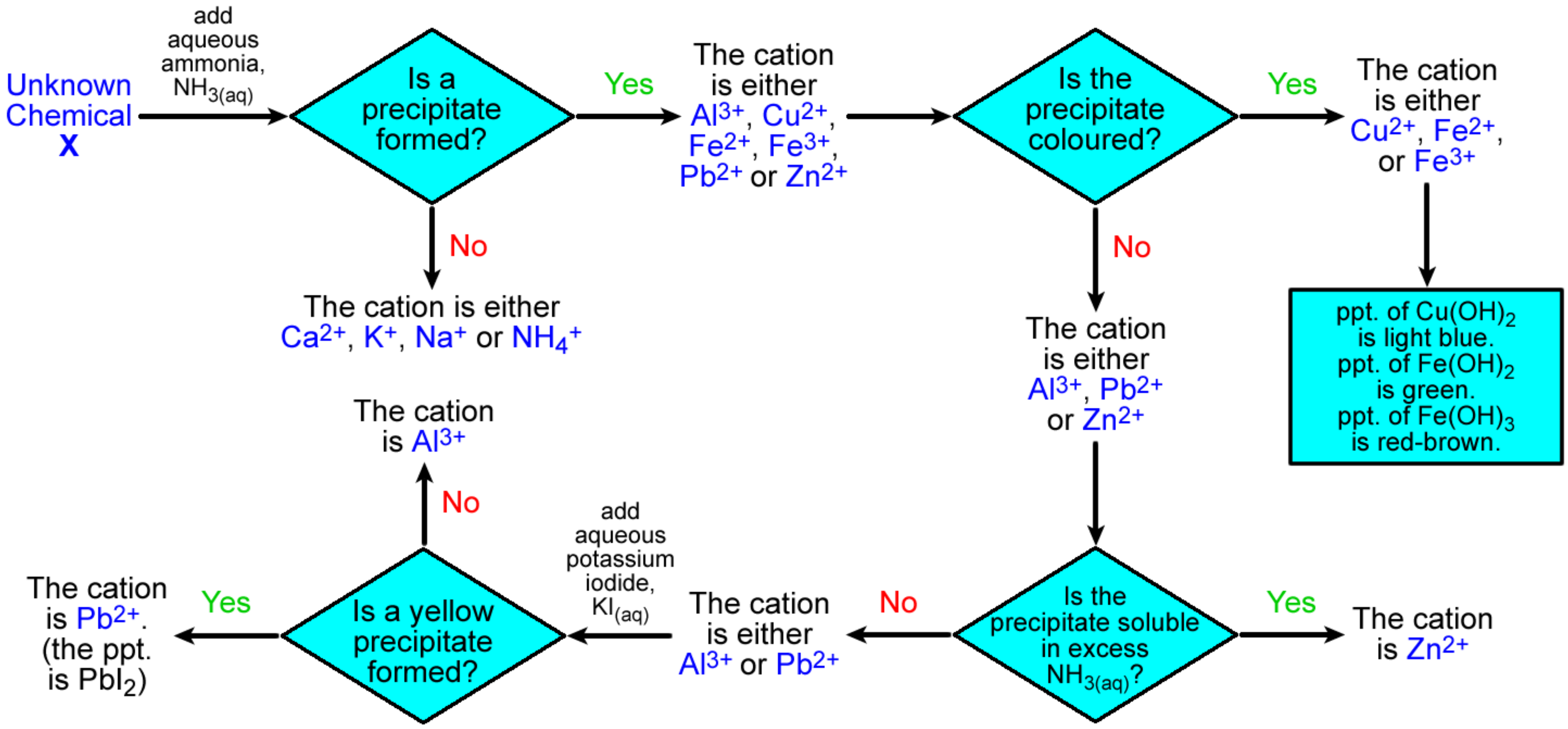
- *$Ca^{2+}(aq)$* is not seen to react with either aqueous ammonia or excess aqueous ammonia, *i.e.* no precipitate is formed.

- *$Zn^{2+}(aq)$* forms a *white precipitate* which *dissolves* in excess aqueous ammonia to form a *colourless solution*.

NANYANG GIRLS' HIGH

Qualitative Analysis

Summary – Test for Cations Using Aqueous Ammonia



Unknown Chemical **X**

add aqueous ammonia, $NH_{3(aq)}$

Is a precipitate formed?

Yes

The cation is either Al^{3+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Pb^{2+} or Zn^{2+}

Is the precipitate coloured?

Yes

The cation is either Cu^{2+}, Fe^{2+}, or Fe^{3+}

ppt. of $Cu(OH)_2$ is light blue.
ppt. of $Fe(OH)_2$ is green.
ppt. of $Fe(OH)_3$ is red-brown.

No

The cation is either Ca^{2+}, K^+, Na^+ or NH_4^+

No

The cation is either Al^{3+}, Pb^{2+} or Zn^{2+}

Is the precipitate soluble in excess $NH_{3(aq)}$?

Yes

The cation is Zn^{2+}

No

The cation is either Al^{3+} or Pb^{2+}

add aqueous potassium iodide, $KI_{(aq)}$

Is a yellow precipitate formed?

Yes

The cation is Pb^{2+}. (the ppt. is PbI_2)

No

The cation is Al^{3+}

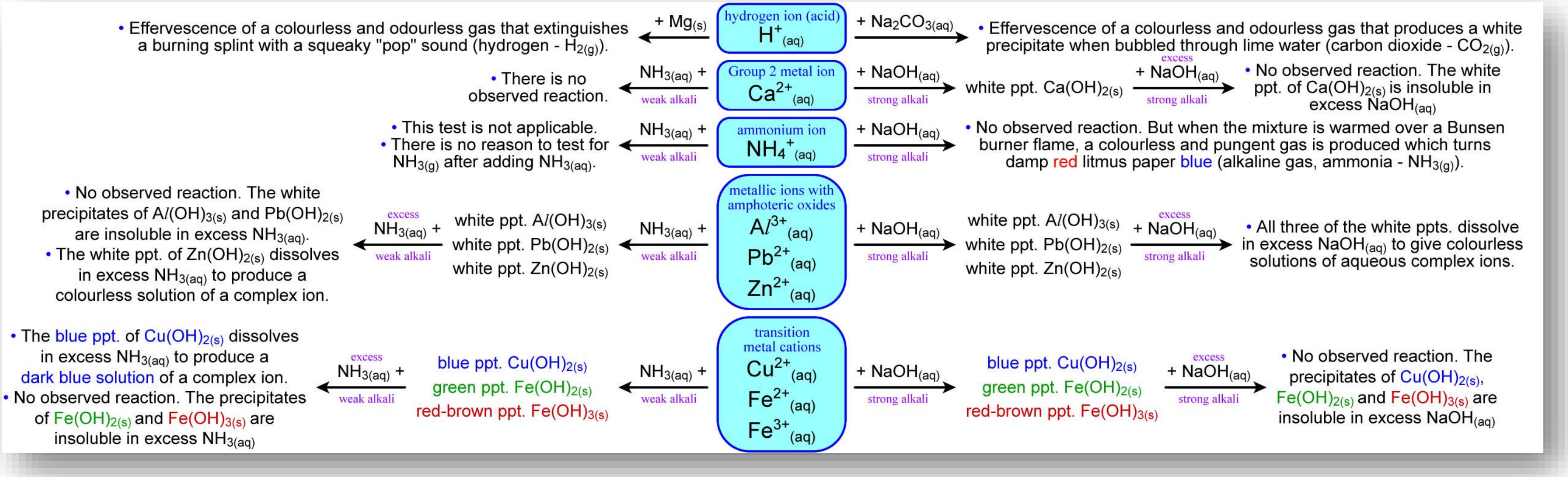
Qualitative Analysis

Summary – Test for Cations Using NaOH(aq) and NH_3(aq)

Cation	Effect of Aqueous Sodium Hydroxide	Effect of Aqueous Ammonia
Aluminium cation – $Al^{3+}(aq)$	White ppt., soluble in excess giving a colourless solution.	White ppt., insoluble in excess.
Ammonium cation – $NH_4^+(aq)$	Ammonia produced on warming.	Not applicable.
Calcium cation – $Ca^{2+}(aq)$	White ppt., insoluble in excess.	No observed reaction, no ppt. observed.
Copper(II) cation – $Cu^{2+}(aq)$	Light blue ppt., insoluble in excess.	Light blue ppt., soluble in excess giving a dark blue solution.
Iron(II) cation – $Fe^{2+}(aq)$	Green ppt., insoluble in excess.	Green ppt., insoluble in excess.
Iron(III) cation – $Fe^{3+}(aq)$	Red-brown ppt., insoluble in excess.	Red-brown ppt., insoluble in excess.
Lead(II) cation – $Pb^{2+}(aq)$	White ppt., soluble in excess giving a colourless solution.	White ppt., insoluble in excess.
Zinc cation – $Zn^{2+}(aq)$	White ppt., soluble in excess giving a colourless solution.	White ppt., soluble in excess giving a colourless solution.

Qualitative Analysis

Summary – Test for Cations Using NaOH(aq) and NH_3(aq)



hydrogen ion (acid) $H^+_{(aq)}$

- Effervescence of a colourless and odourless gas that extinguishes a burning splint with a squeaky "pop" sound (hydrogen - $H_{2(g)}$). $\xleftarrow{+\ Mg_{(s)}}$ $H^+_{(aq)}$ $\xrightarrow{+\ Na_2CO_{3(aq)}}$
- Effervescence of a colourless and odourless gas that produces a white precipitate when bubbled through lime water (carbon dioxide - $CO_{2(g)}$).

Group 2 metal ion $Ca^{2+}_{(aq)}$

- There is no observed reaction. $\xleftarrow[\text{weak alkali}]{NH_{3(aq)}\ +}$ $Ca^{2+}_{(aq)}$ $\xrightarrow[\text{strong alkali}]{+\ NaOH_{(aq)}}$ white ppt. $Ca(OH)_{2(s)}$ $\xrightarrow[\text{strong alkali}]{\text{excess}\ +\ NaOH_{(aq)}}$
- No observed reaction. The white ppt. of $Ca(OH)_{2(s)}$ is insoluble in excess $NaOH_{(aq)}$

ammonium ion $NH_4^+{}_{(aq)}$

- This test is not applicable.
- There is no reason to test for $NH_{3(g)}$ after adding $NH_{3(aq)}$.

$\xleftarrow[\text{weak alkali}]{NH_{3(aq)}\ +}$ $NH_4^+{}_{(aq)}$ $\xrightarrow[\text{strong alkali}]{+\ NaOH_{(aq)}}$

- No observed reaction. But when the mixture is warmed over a Bunsen burner flame, a colourless and pungent gas is produced which turns damp red litmus paper blue (alkaline gas, ammonia - $NH_{3(g)}$).

metallic ions with amphoteric oxides $Al^{3+}_{(aq)}$ $Pb^{2+}_{(aq)}$ $Zn^{2+}_{(aq)}$

- No observed reaction. The white precipitates of $Al(OH)_{3(s)}$ and $Pb(OH)_{2(s)}$ are insoluble in excess $NH_{3(aq)}$.
- The white ppt. of $Zn(OH)_{2(s)}$ dissolves in excess $NH_{3(aq)}$ to produce a colourless solution of a complex ion.

$\xleftarrow[\text{weak alkali}]{\text{excess}\ NH_{3(aq)}\ +}$ white ppt. $Al(OH)_{3(s)}$ white ppt. $Pb(OH)_{2(s)}$ white ppt. $Zn(OH)_{2(s)}$ $\xleftarrow[\text{weak alkali}]{NH_{3(aq)}\ +}$ $Al^{3+}_{(aq)}$ $Pb^{2+}_{(aq)}$ $Zn^{2+}_{(aq)}$ $\xrightarrow[\text{strong alkali}]{+\ NaOH_{(aq)}}$ white ppt. $Al(OH)_{3(s)}$ white ppt. $Pb(OH)_{2(s)}$ white ppt. $Zn(OH)_{2(s)}$ $\xrightarrow[\text{strong alkali}]{\text{excess}\ +\ NaOH_{(aq)}}$

- All three of the white ppts. dissolve in excess $NaOH_{(aq)}$ to give colourless solutions of aqueous complex ions.

transition metal cations $Cu^{2+}_{(aq)}$ $Fe^{2+}_{(aq)}$ $Fe^{3+}_{(aq)}$

- The blue ppt. of $Cu(OH)_{2(s)}$ dissolves in excess $NH_{3(aq)}$ to produce a dark blue solution of a complex ion.
- No observed reaction. The precipitates of $Fe(OH)_{2(s)}$ and $Fe(OH)_{3(s)}$ are insoluble in excess $NH_{3(aq)}$

$\xleftarrow[\text{weak alkali}]{\text{excess}\ NH_{3(aq)}\ +}$ blue ppt. $Cu(OH)_{2(s)}$ green ppt. $Fe(OH)_{2(s)}$ red-brown ppt. $Fe(OH)_{3(s)}$ $\xleftarrow[\text{weak alkali}]{NH_{3(aq)}\ +}$ $Cu^{2+}_{(aq)}$ $Fe^{2+}_{(aq)}$ $Fe^{3+}_{(aq)}$ $\xrightarrow[\text{strong alkali}]{+\ NaOH_{(aq)}}$ blue ppt. $Cu(OH)_{2(s)}$ green ppt. $Fe(OH)_{2(s)}$ red-brown ppt. $Fe(OH)_{3(s)}$ $\xrightarrow[\text{strong alkali}]{\text{excess}\ +\ NaOH_{(aq)}}$

- No observed reaction. The precipitates of $Cu(OH)_{2(s)}$, $Fe(OH)_{2(s)}$ and $Fe(OH)_{3(s)}$ are insoluble in excess $NaOH_{(aq)}$

- Click on the diagram above to view an enlarged copy.

Qualitative Analysis

Do not forget the qualitative tests for the H^+(aq) cation in an acidic solution!

Qualitative Analysis

- Blue litmus paper turning red *is not* considered as a chemical test for the H^+(aq) cation.
- Universal indicator solution turning from green to red or orange or yellow *is not* considered as a chemical test for the H^+(aq) cation.

Qualitative Analysis

- Adding a reactive metal, *e.g.* magnesium or zinc, to the acid, observing effervescence, and then testing the gas with a burning splint (it should be extinguished with a “pop” sound) *is* considered as a chemical test for the $H^+(aq)$ cation.

acid + metal → salt + hydrogen

nitric acid + zinc → zinc nitrate + hydrogen

$$2HNO_3(aq) + Zn(s) \rightarrow Zn(NO_3)_2(aq) + H_2(g)$$

$$2H^+(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + H_2(g)$$

Qualitative Analysis

- Adding a carbonate, *e.g.* sodium carbonate, to the acid, observing effervescence, and then testing the gas with limewater (a white precipitate should be produced) *is* considered as a chemical test for the $H^+(aq)$ cation.

acid + carbonate → salt + water + carbon dioxide

sulfuric acid + sodium carbonate
↓
sodium sulfate + water + carbon dioxide

$$H_2SO_4(aq) + Na_2CO_3(aq)$$
$$\downarrow$$
$$Na_2SO_4(aq) + H_2O(l) + CO_2(g)$$

$$2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$$

Qualitative Analysis

What other qualitative tests for cations are there?

- It is possible to identify some metal cations by performing a *flame test*.

Qualitative Analysis

Qualitative Analysis

Copper (green)

Lithium (red)

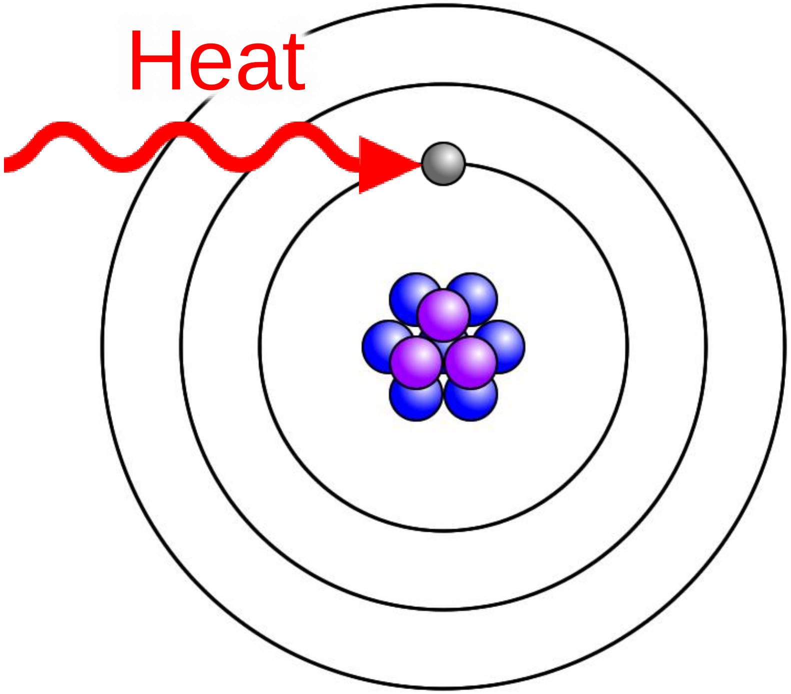
Calcium (brick red)

Sodium (orange)

Barium (apple green)

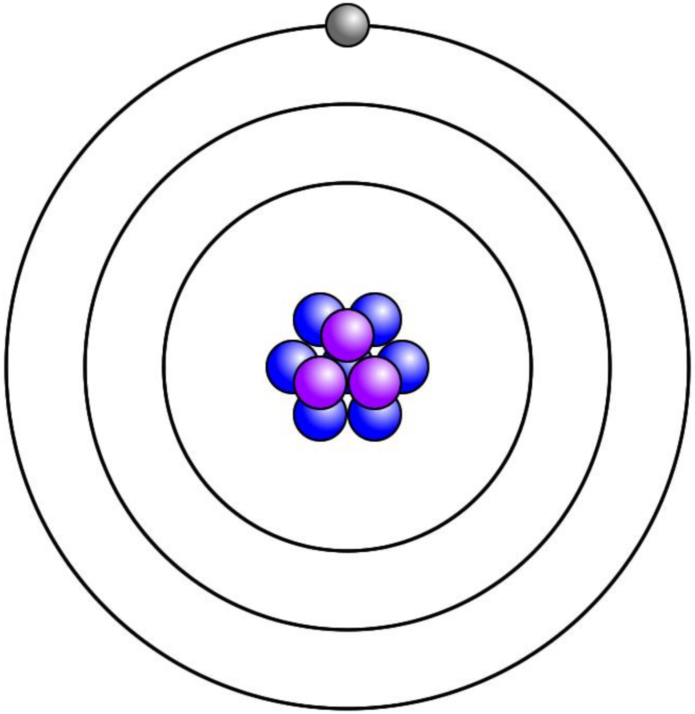
Potassium (lilac)

Qualitative Analysis



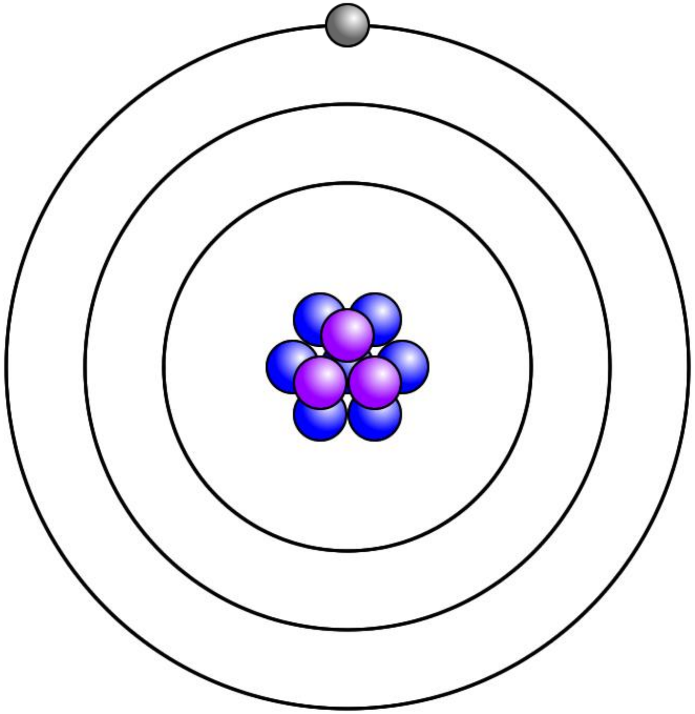
- During a flame test, a sample of an unknown salt (ionic compound) is heated in a non-luminous Bunsen burner flame. Electrons in the metal cation *absorb heat energy* from the flame and are *excited* into higher energy electron shells.

Qualitative Analysis



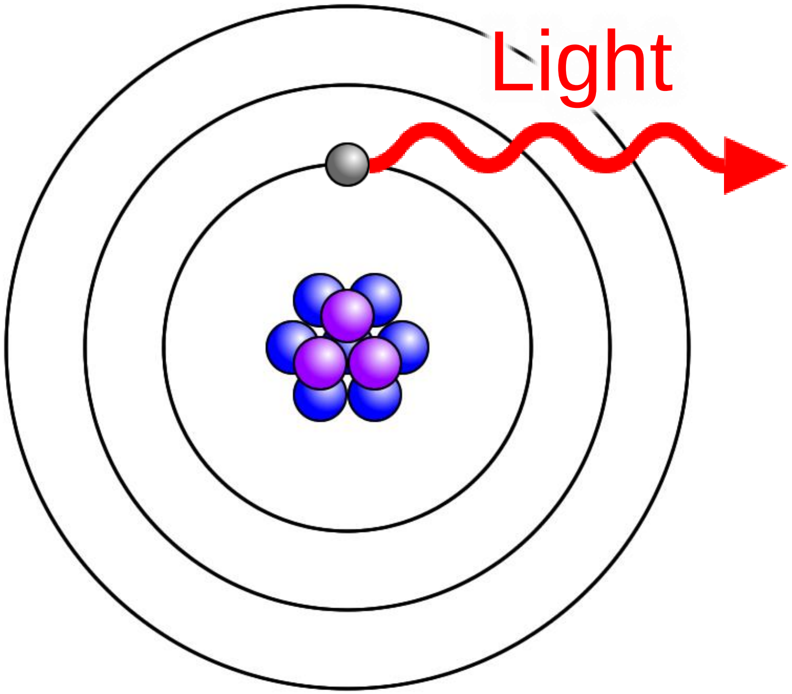
- During a flame test, a sample of an unknown salt (ionic compound) is heated in a non-luminous Bunsen burner flame. Electrons in the metal cation *absorb heat energy* from the flame and are *excited* into higher energy electron shells.

Qualitative Analysis



- When the excited electrons *relax* back to their original electron shells (ground state) they *release energy* in the form of *visible light*. Each metal cation, with its own unique electronic configuration, produces light of different wavelengths (colours).

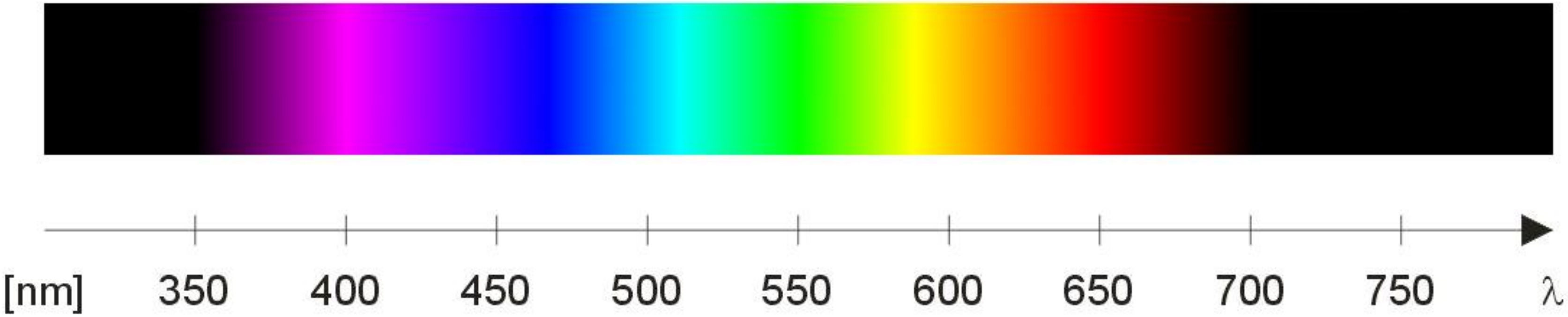
Qualitative Analysis



- When the excited electrons *relax* back to their original electron shells (ground state) they *release energy* in the form of *visible light*. Each metal cation, with its own unique electronic configuration, produces light of different wavelengths (colours).

Qualitative Analysis

The Visible Spectrum



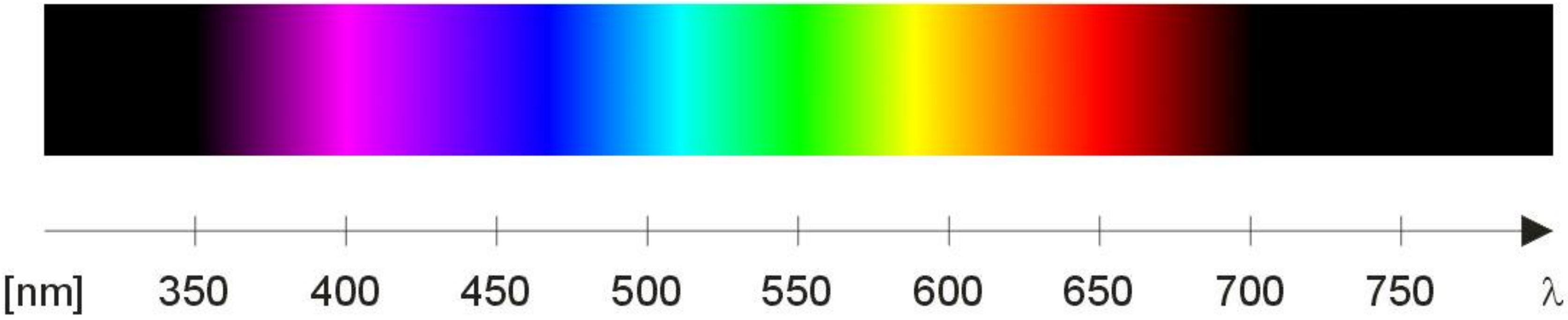
- The wavelength (colour) of light emitted by the metal cation is *inversely proportional* to the change in energy as the electron moves between electron shells.

$$E \propto \frac{1}{\lambda}$$

E = energy / J and λ = wavelength / nm

Qualitative Analysis

The Visible Spectrum



- The electrons in a calcium ion, Ca^{2+}, which produces a red flame colour of wavelength *650 nm*, undergo *relatively low energy transitions* when heated.

- The electrons in a potassium ion, K^{+}, which produces a lilac flame colour of wavelength *400 nm*, undergo *relatively high energy transitions* when heated.

Qualitative Analysis

Qualitative Analysis

Qualitative Analysis

RED
STRONTIUM
COMPOUNDS

BLUE
COPPER COMPOUNDS

ORANGE
CALCIUM COMPOUNDS

VIOLET
STRONTIUM + COPPER

GREEN
BARIUM OR
BORON COMPOUNDS

WHITE
BURNING MAGNESIUM,
ALUMINUM OR TITANIUM

SILVER
SUPERHEATED MAGNESIUM
OR ALUMINUM

YELLOW
-SODIUM COMPOUNDS
-CALCIUM + BARIUM

Qualitative Analysis

RED

STRONTIUM SALTS
Strontium Nitrate
Strontium Carbonate
Strontium Sulfate

ORANGE

CALCIUM SALTS
Calcium Carbonate
Calcium Chloride
Calcium Sulfate

YELLOW

SODIUM SALTS
Sodium Nitrate
Sodium Oxalate
Cryolite

GREEN

BARIUM SALTS
Barium Nitrate
Barium Carbonate
Barium Chloride
Barium Chlorate

BLUE

COPPER SALTS
Copper (I) Chloride
Copper Carbonate
Copper Oxide

PURPLE

COMBINE COPPER & STRONTIUM COMPOUNDS

SILVER

WHITE HOT MAGNESIUM & ALUMINIUM

WHITE

BURNING METAL
Magnesium
Aluminium
Titanium

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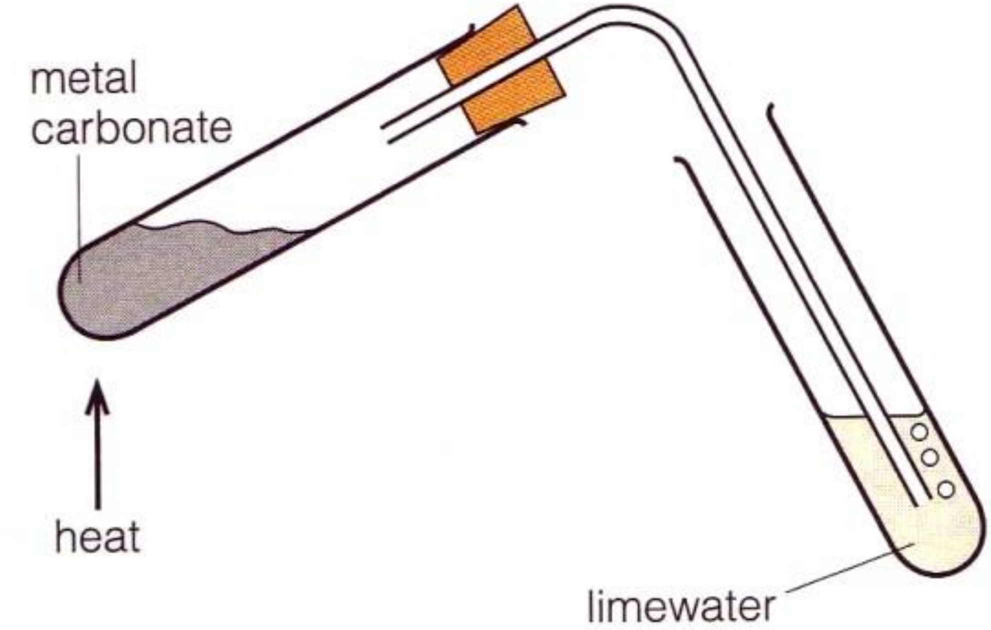
Qualitative Analysis

How else can heating a chemical help me to determine its composition?

Qualitative Analysis

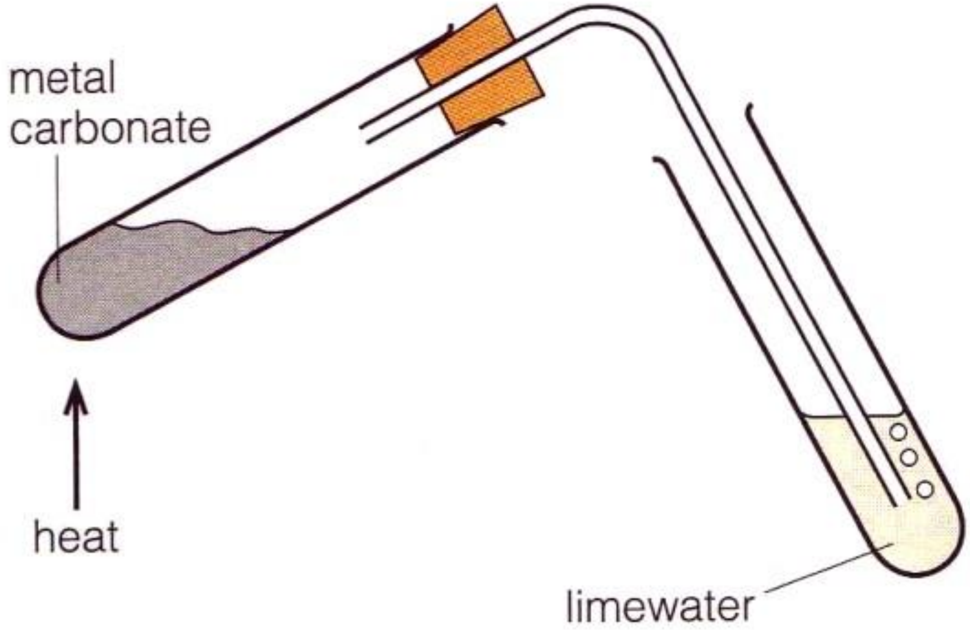
Thermal Decomposition of Carbonates



- Many metal carbonates *decompose on heating* to produce the metal oxide and carbon dioxide gas.

Qualitative Analysis

Thermal Decomposition of Carbonates

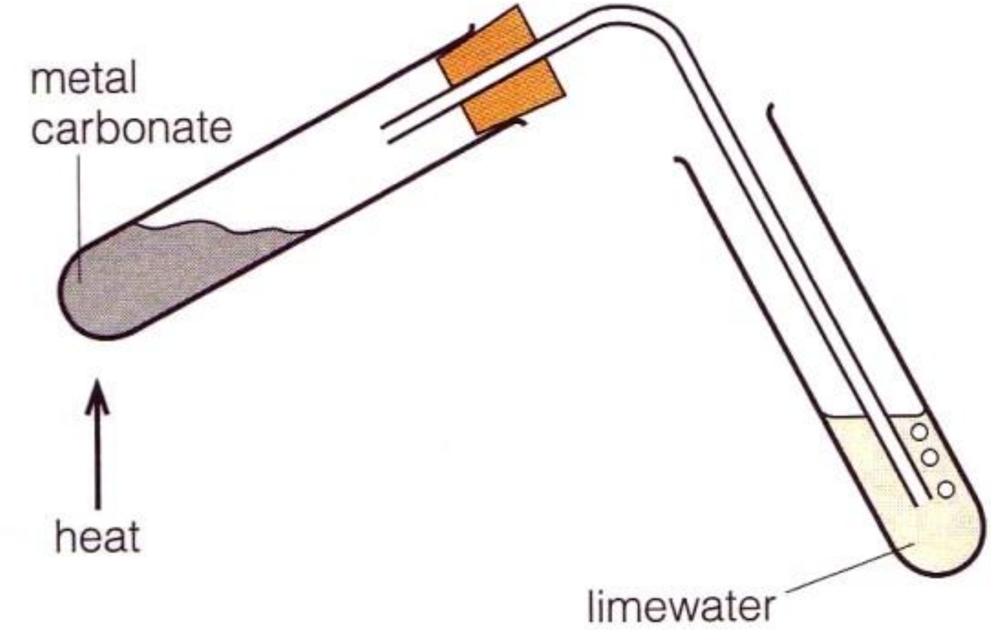


- Carbon dioxide gas produces a white precipitate of calcium carbonate when bubbled through limewater:

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

Qualitative Analysis

Thermal Decomposition of Carbonates



- The *more reactive* the metal, the *more stable* its carbonate, and the *less likely* it is to undergo thermal decomposition.

Qualitative Analysis

Thermal Decomposition of Carbonates

Reactivity	Element	Thermal Stability of CO_3^{2-}	Thermal Stability of NO_3^{-}
Most Reactive	Potassium – K	↓ Metal carbonates become less stable ↓ ↓ and decompose more readily ↓ ↓ on heating ↓	↓ Metal nitrates become less stable ↓ ↓ and decompose more readily ↓ ↓ on heating ↓
↓	Sodium – Na		
↓	Calcium – Ca		
↓	Magnesium – Mg		
↓	Aluminium – A*l*		
↓	(Carbon – C)		
↓	Zinc – Zn		
↓	Iron – Fe		
↓	Lead – Pb		
↓	(Hydrogen – H)		
↓	Copper – Cu		
Least Reactive	Silver – Ag		

Qualitative Analysis

Thermal Decomposition of Carbonates

- With the exception of lithium carbonate, Li_2CO_3, *Group 1 metal carbonates* do *not* decompose on heating in a non-luminous Bunsen burner flame. Note that lithium is the least reactive of the Group 1 metals.

- Carbonates of other metals (including lithium carbonate) *decompose* on heating in a non-luminous Bunsen burner flame to produce a metal oxide and carbon dioxide gas as the products. In general, the temperature at which metal carbonates decompose *decreases* upon *descending* the reactivity series of metals.

Qualitative Analysis

Thermal Decomposition of Carbonates

- Calcium carbonate (white) decomposes into calcium oxide (white) and carbon dioxide at 890 °C.

  $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

- Zinc carbonate (white) decomposes into zinc oxide (yellow when hot, white when cold) and carbon dioxide at 400 °C.

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

- Lead(II) carbonate (white) decomposes into lead(II) oxide (yellow) and carbon dioxide at 350 °C.

  $PbCO_3(s) \rightarrow PbO(s) + CO_2(g)$

Qualitative Analysis

Thermal Decomposition of Carbonates

- Reversible Decomposition of Zinc Oxide

- Zinc oxide is white when cold, but yellow when hot. When heated, the white zinc oxide loses oxygen to form a yellow *non-stoichiometric** oxide. On cooling, the compound absorbs oxygen from the atmosphere to form white zinc oxide once again.

*A compound whose proportions cannot be written using integers.

Qualitative Analysis

Thermal Decomposition of Carbonates

- Reversible Decomposition of Zinc Oxide

- Zinc oxide is white when cold, but yellow when hot. When heated, the white zinc oxide loses oxygen to form a yellow *non-stoichiometric** oxide. On cooling, the compound absorbs oxygen from the atmosphere to form white zinc oxide once again.

*A compound whose proportions cannot be written using integers.

Qualitative Analysis

Thermal Decomposition of Carbonates

- Copper(II) carbonate (green) decomposes into copper(II) oxide (black) and carbon dioxide at 300 °C.

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

- Silver carbonate (yellow) decomposes into silver oxide (black) and carbon dioxide at 210 °C.

  $Ag_2CO_3(s) \rightarrow Ag_2O(s) + CO_2(g)$

The silver oxide (black) undergoes further thermal decomposition at 280 °C to form elemental silver and oxygen.

$2Ag_2O(s) \rightarrow 4Ag(s) + O_2(g)$

Qualitative Analysis

Thermal Decomposition of Carbonates

- Thermal Decomposition of Copper(II) Carbonate

- When heated by a non-luminous Bunsen burner flame, green copper(II) carbonate decomposes to form black copper(II) oxide and carbon dioxide gas. The carbon dioxide gas produces a white precipitate when bubbled through limewater.

Qualitative Analysis

Thermal Decomposition of Carbonates

- Thermal Decomposition of Copper(II) Carbonate

- When heated by a non-luminous Bunsen burner flame, green copper(II) carbonate decomposes to form black copper(II) oxide and carbon dioxide gas. The carbon dioxide gas produces a white precipitate when bubbled through limewater.

Qualitative Analysis

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Qualitative Analysis

Thermal Decomposition of Nitrates

- With the exception of lithium nitrate, most Group I metal nitrates decompose on heating in a non-luminous Bunsen burner flame to produce the metal *nitrite* and oxygen gas only.

$$2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$$

- Most other metal nitrates (including lithium nitrate) decompose on heating in a non-luminous Bunsen burner flame to produce the metal oxide, reddish-brown nitrogen dioxide gas (acidic) and oxygen gas (relights a glowing splint).

$$2Mg(NO_3)_2(s) \rightarrow 2MgO(s) + 4NO_2(g) + O_2(g)$$

Qualitative Analysis

Thermal Decomposition of Nitrates

- Thermal Decomposition of Copper(II) Nitrate

- Copper(II) nitrate decomposes on heating in a non-luminous Bunsen burner flame:

$$2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$$

Qualitative Analysis

Thermal Decomposition of Nitrates

- Thermal Decomposition of Copper(II) Nitrate

- The reddish-brown nitrogen dioxide gas is acidic and turns damp blue litmus paper red.

$$2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$$

Qualitative Analysis

Thermal Decomposition of Nitrates

- Thermal Decomposition of Copper(II) Nitrate

- Oxygen gas supports combustion and relights a glowing splint.

$$2Cu(NO_3)_2(s) \rightarrow 2CuO(s) + 4NO_2(g) + O_2(g)$$

Qualitative Analysis

Thermal Decomposition of Nitrates

- Lead(II) nitrate decompose into lead(II) oxide, nitrogen dioxide and oxygen. The decomposition is accompanied by a loud cracking sound called *decrepitation*.

$$2Pb(NO_3)_2(s) \rightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$$

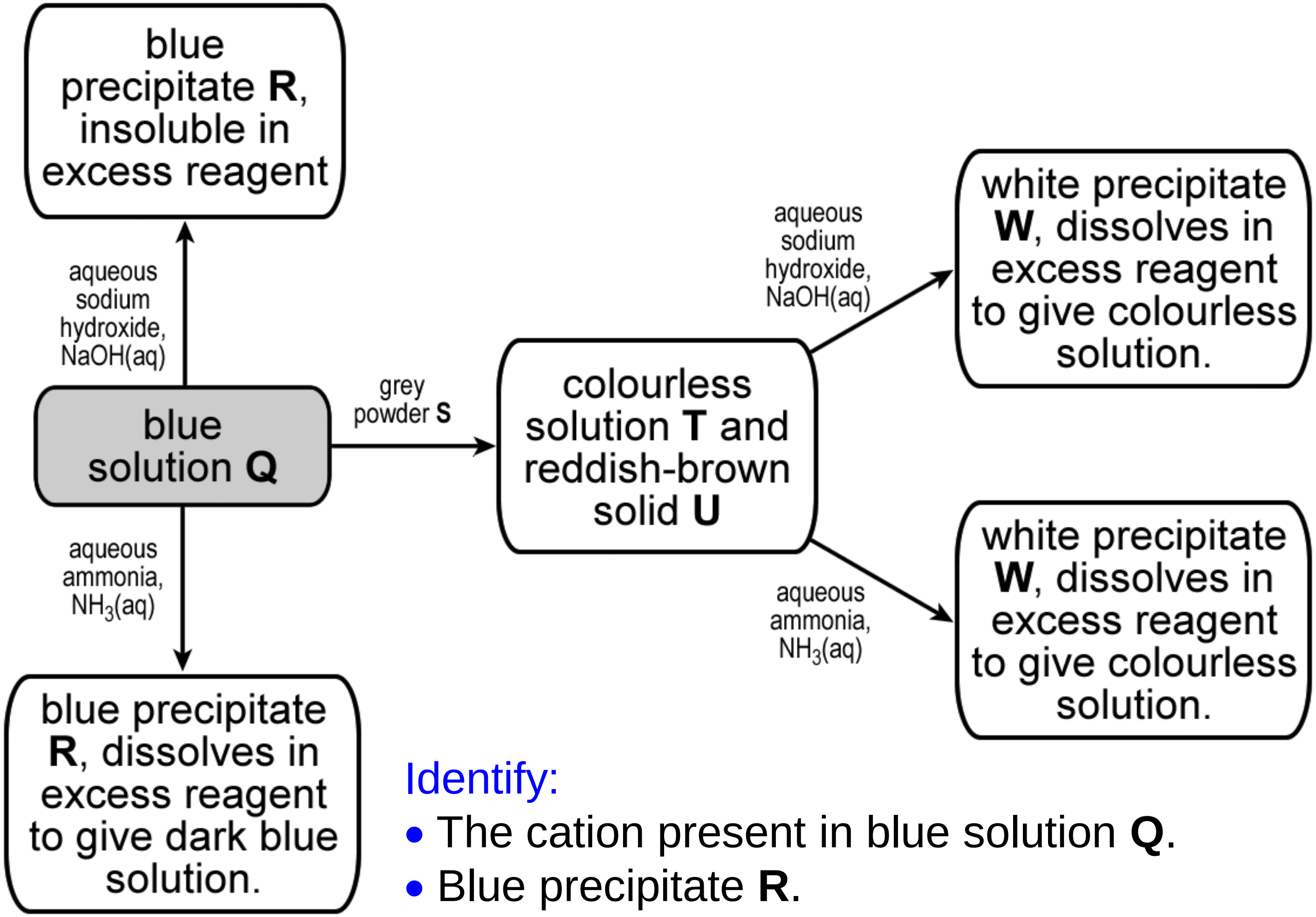
- Silver nitrate starts to decompose into silver, nitrogen dioxide and oxygen at 250°C, and decomposes completely at 440°C.

$$2AgNO_3(s) \rightarrow 2Ag(s) + 2NO_2(g) + O_2(g)$$

Qualitative Analysis

Can I please have some questions to check my understanding?

Qualitative Analysis



blue precipitate **R**, insoluble in excess reagent

aqueous sodium hydroxide, NaOH(aq)

blue solution **Q**

grey powder **S**

aqueous ammonia, NH_3(aq)

blue precipitate **R**, dissolves in excess reagent to give dark blue solution.

colourless solution **T** and reddish-brown solid **U**

aqueous sodium hydroxide, NaOH(aq)

white precipitate **W**, dissolves in excess reagent to give colourless solution.

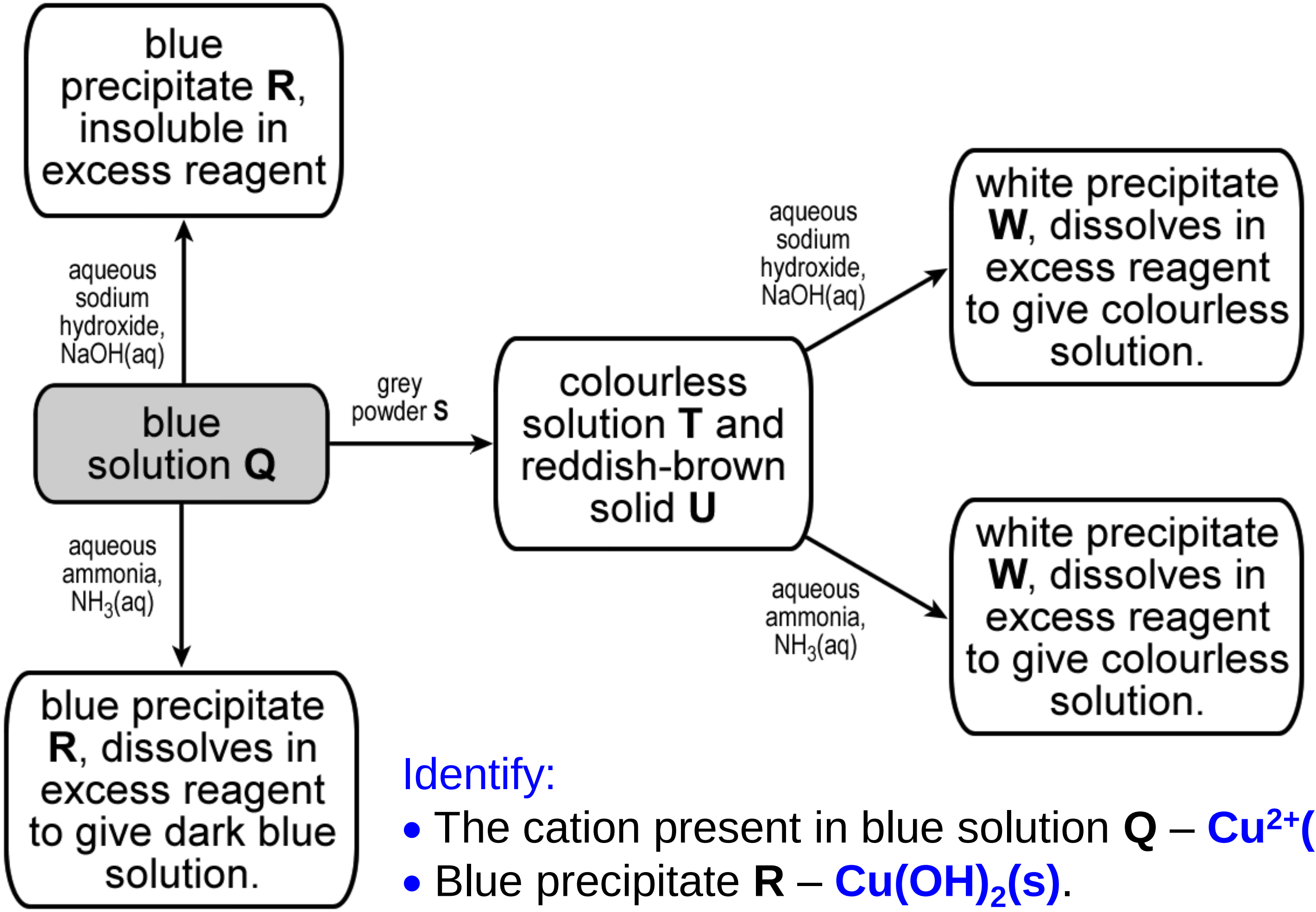
aqueous ammonia, NH_3(aq)

white precipitate **W**, dissolves in excess reagent to give colourless solution.

Identify:

- The cation present in blue solution **Q**.
- Blue precipitate **R**.
- The grey powder **S**.
- The cation present in colourless solution **T**.
- Reddish-brown solid **U**.
- White precipitate **W**.

Qualitative Analysis



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white precipitate **W**, dissolves in excess reagent to give colourless solution.

aqueous ammonia, $NH_3(aq)$

white precipitate **W**, dissolves in excess reagent to give colourless solution.

Identify:

- The cation present in blue solution **Q** – **$Cu^{2+}(aq)$**.
- Blue precipitate **R** – **$Cu(OH)_2(s)$**.
- The grey powder **S** – **Zn(s)**
- The cation present in colourless solution **T** – **$Zn^{2+}(aq)$**.
- Reddish-brown solid **U** – **Cu(s)**.
- White precipitate **W** – **$Zn(OH)_2(s)$**.

Qualitative Analysis

The Reactions

Formation of blue precipitate **R**:

$Cu^{2+}(aq) + 2OH^{-}(aq) \rightarrow Cu(OH)_2(s)$

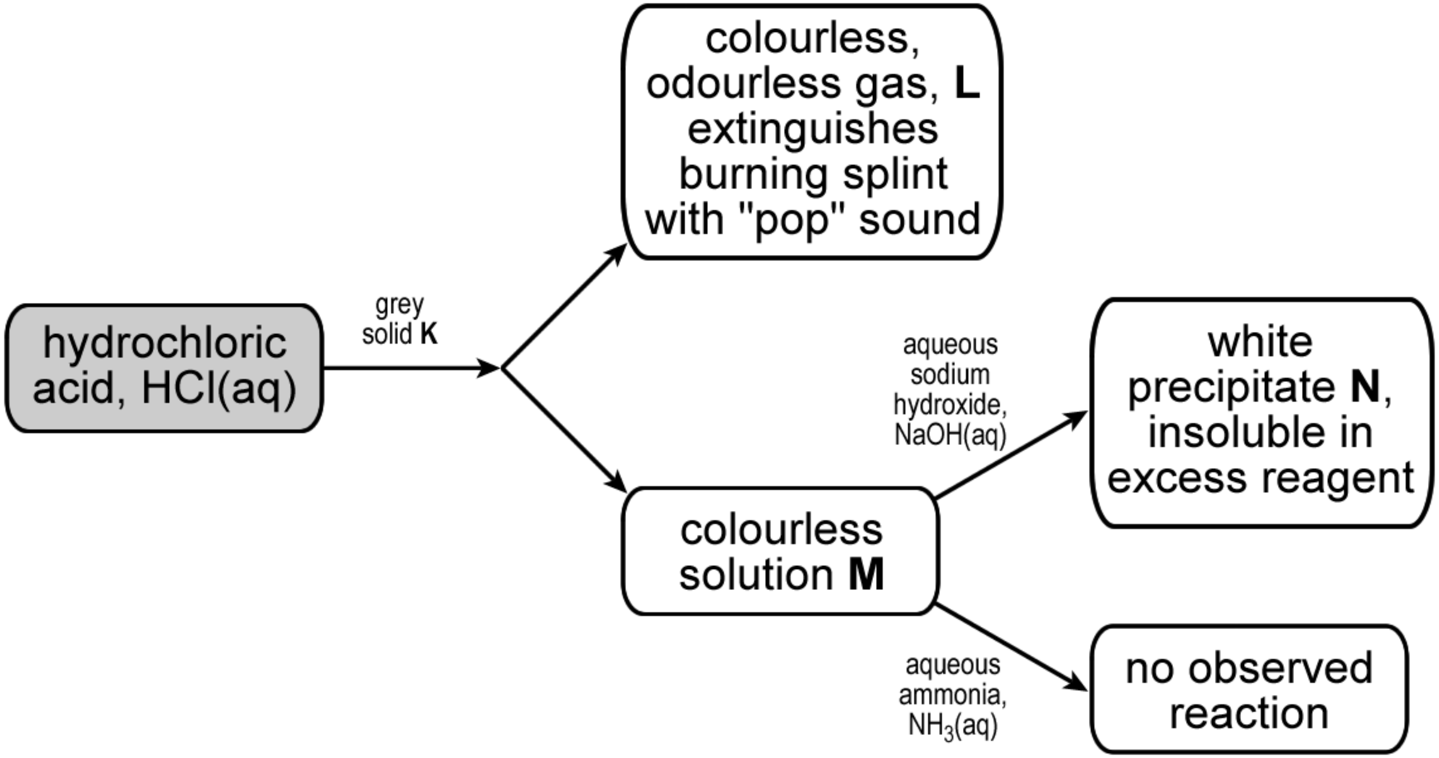
Formation of solution **T** and solid **U**:

$Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$

Formation of white precipitate **W**:

$Zn^{2+}(aq) + 2OH^{-}(aq) \rightarrow Zn(OH)_2(s)$

Qualitative Analysis



hydrochloric acid, HCl(aq)

grey solid **K**

colourless, odourless gas, **L** extinguishes burning splint with "pop" sound

colourless solution **M**

aqueous sodium hydroxide, NaOH(aq)

white precipitate **N**, insoluble in excess reagent

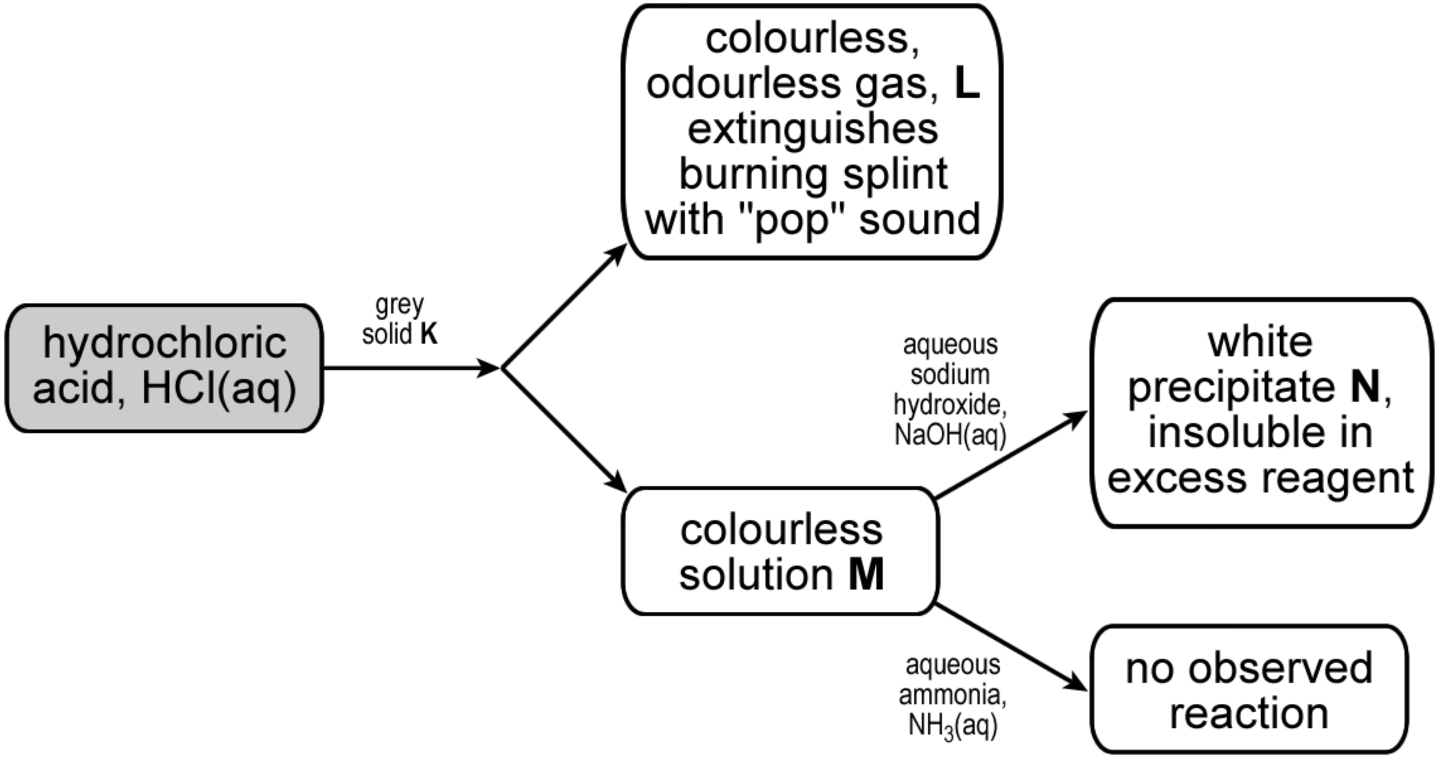
aqueous ammonia, NH_3(aq)

no observed reaction

Identify:

- Grey solid **K**.
- Colourless gas **L**.
- Colourless solution **M**.
- White precipitate **N**.

Qualitative Analysis



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colourless solution **M**

aqueous sodium hydroxide, NaOH(aq)

white precipitate **N**, insoluble in excess reagent

aqueous ammonia, NH_3(aq)

no observed reaction

Identify:

- Grey solid **K** – **Ca(s)**.
- Colourless gas **L** – $\mathbf{H_2(g)}$.
- Colourless solution **M** – $\mathbf{CaCl_2(aq)}$.
- White precipitate **N** – $\mathbf{Ca(OH)_2(s)}$.

Qualitative Analysis

The Reactions

Formation of gas **L** and solution **M**:

$$\mathrm{Ca(s)} + 2\mathrm{HC}l\mathrm{(aq)} \rightarrow \mathrm{CaC}l_2\mathrm{(aq)} + \mathrm{H_2(g)}$$

ionic equation:

$$\mathrm{Ca(s)} + 2\mathrm{H^+(aq)} \rightarrow \mathrm{Ca^{2+}(aq)} + \mathrm{H_2(g)}$$

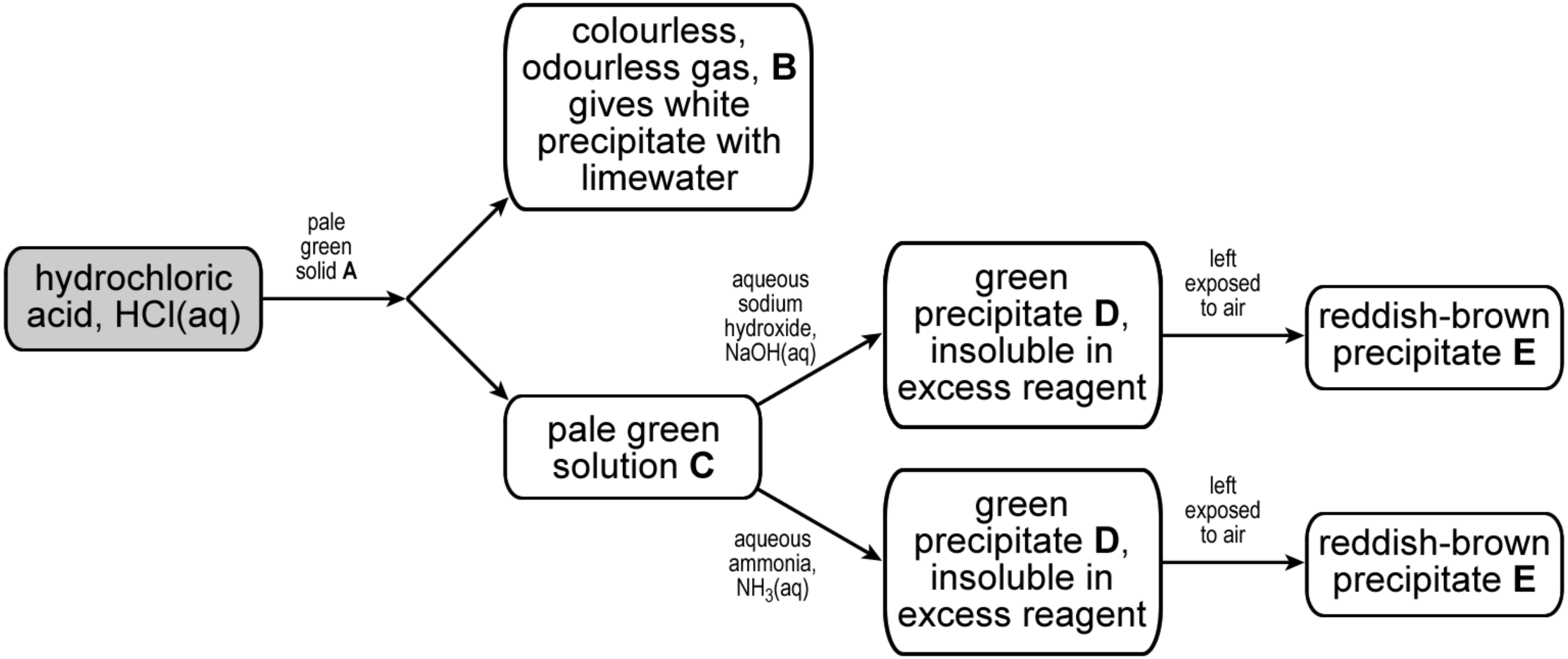
Formation of white precipitate **N**:

$$\mathrm{CaC}l_2\mathrm{(aq)} + 2\mathrm{NaOH(aq)} \rightarrow \mathrm{Ca(OH)_2(s)} + 2\mathrm{NaC}l\mathrm{(aq)}$$

ionic equation:

$$\mathrm{Ca^{2+}(aq)} + 2\mathrm{OH^-(aq)} \rightarrow \mathrm{Ca(OH)_2(s)}$$

Qualitative Analysis



hydrochloric acid, HCl(aq)

pale green solid **A**

colourless, odourless gas, **B** gives white precipitate with limewater

pale green solution **C**

aqueous sodium hydroxide, NaOH(aq)

green precipitate **D**, insoluble in excess reagent

left exposed to air

reddish-brown precipitate **E**

aqueous ammonia, $NH_3(aq)$

green precipitate **D**, insoluble in excess reagent

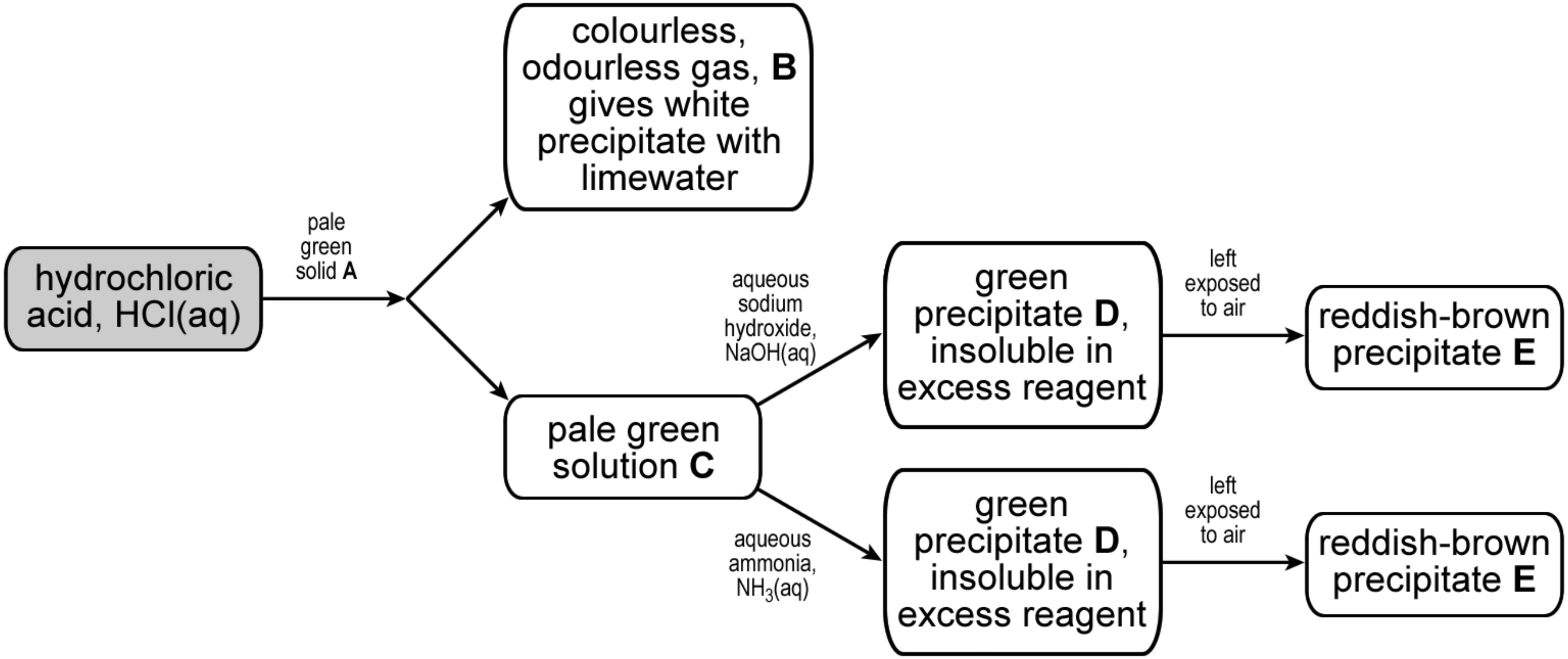
left exposed to air

reddish-brown precipitate **E**

Identify:

- Pale green solid **A**.
- Colourless gas **B**.
- Pale green solution **C**.
- Green precipitate **D**.
- Reddish-brown precipitate **E**.

Qualitative Analysis



hydrochloric acid, HCl(aq)

pale green solid **A**

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pale green solution **C**

aqueous sodium hydroxide, NaOH(aq)

green precipitate **D**, insoluble in excess reagent

left exposed to air

reddish-brown precipitate **E**

aqueous ammonia, NH_3(aq)

green precipitate **D**, insoluble in excess reagent

left exposed to air

reddish-brown precipitate **E**

Identify:

- Pale green solid **A** – **$FeCO_3(s)$**.
- Colourless gas **B** – **$CO_2(g)$**.
- Pale green solution **C** – **$FeCl_2(aq)$**.
- Green precipitate **D** – **$Fe(OH)_2(s)$**.
- Reddish-brown precipitate **E** – **$Fe(OH)_3(s)$**.

Qualitative Analysis

The Reactions

Formation of gas **B** and solution **C**:

$$\mathrm{FeCO_3(s) + 2HC}\mathit{l}\mathrm{(aq) \rightarrow FeC}\mathit{l}_2\mathrm{(aq) + H_2O(}\mathit{l}\mathrm{) + CO_2(g)}$$

ionic equation:

$$\mathrm{FeCO_3(s) + 2H^+(aq) \rightarrow Fe^{2+}(aq) + H_2O(}\mathit{l}\mathrm{) + CO_2(g)}$$

Qualitative Analysis

The Reactions

Formation of green precipitate **D**:

with aqueous sodium hydroxide:

$$\mathrm{FeC}l_2\mathrm{(aq)} + \mathrm{2NaOH(aq)} \rightarrow \mathrm{Fe(OH)_2(s)} + \mathrm{2NaC}l\mathrm{(aq)}$$

ionic equation

$$\mathrm{Fe^{2+}(aq)} + \mathrm{2OH^{-}(aq)} \rightarrow \mathrm{Fe(OH)_2(s)}$$

Formation of green precipitate **D**:

with aqueous ammonia:

$$\mathrm{FeC}l_2\mathrm{(aq)} + \mathrm{2NH_4OH(aq)} \rightarrow \mathrm{Fe(OH)_2(s)} + \mathrm{2NH_4C}l\mathrm{(aq)}$$

ionic equation

$$\mathrm{Fe^{2+}(aq)} + \mathrm{2OH^{-}(aq)} \rightarrow \mathrm{Fe(OH)_2(s)}$$

Qualitative Analysis

Presentation on
Qualitative Analysis
Part One: Cations

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17th August 2015