

Carry out an investigation into chemical species present in a sample using qualitative analysis 3 credits

This activity requires you to carry out a comprehensive investigation, using qualitative analysis, of an aqueous sample.

You will be given an ion identification chart, solubility rules and complex ion formulae.

You are to identify the species (cation and anion) that are present in the sample and then *put these together* to identify the ionic substance.

The identification of ions is limited to:

- Cations: Ag^+ , Al^{3+} , Ba^{2+} , Cu^{2+} , Fe^{2+} , Fe^{3+} , Mg^{2+} , Pb^{2+} , Na^+ , Zn^{2+}
- Anions: Cl^- , CO_3^{2-} , I^- , NO_3^- , OH^- , SO_4^{2-}

You also need to be able to explain the solubility of species, applying the solubility rules.

You will be assessed on how well you collect primary data using an identification procedure, use this to identify the chemical species and link this to the purpose of the investigation.

The report will include a justification of the identification process of the two ions identified in the solution, and discuss the significance of ONE of the identified chemical species (ions) for people and the environment.

The Solubility Rules

1. All **Group 1** compounds are soluble
2. All **nitrate** compounds are soluble
3. Most **sulfates** are soluble **except** for calcium sulfate, barium sulfate and lead sulfate
4. Most halides (chlorides & iodides) are soluble **except** for those salts with silver and lead
5. All **carbonates** are insoluble **except** those of Group 1
6. All **oxides** and **hydroxides** are insoluble **except** those of Group 1

Formulae of Potential Complex ions

- $[\text{FeSCN}]^{2+}(\text{aq})$
- $[\text{Zn}(\text{OH})_4]^{2-}(\text{aq})$
- $[\text{Pb}(\text{OH})_4]^{2-}(\text{aq})$
- $[\text{Al}(\text{OH})_4]^{-}(\text{aq})$
- $[\text{Ag}(\text{NH}_3)_2]^{+}(\text{aq})$
- $[\text{Zn}(\text{NH}_3)_4]^{2+}(\text{aq})$
- $[\text{Cu}(\text{NH}_3)_4]^{2+}(\text{aq})$

Tests for Anions

You will be provided with this flowchart (or similar) - see page 3

Start with a small sample of the solution provided, say 0.5 mm depth in a test tube.

Testing with red litmus will tell you whether the solution is alkaline / basic or not.

- The two anions that cause alkalinity are carbonate and hydroxide.
- Adding dilute HCl will release small bubbles of colourless carbon dioxide gas from the carbonate anion.
- Because no precipitates are formed there is no need to write any equations.

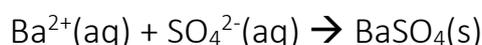
If the litmus remains red it is because you have sulfate, chloride, iodide or nitrate.

Adding barium nitrate solution, Ba(NO₃)₂ will identify the sulfate ion, SO₄²⁻.

Barium nitrate solution contains Ba²⁺(aq) and NO₃⁻(aq).

A white precipitate forms if the solution contains SO₄²⁻(aq) ions because barium sulfate is insoluble in water – see the solubility rules on page 1 (rule 3).

We need to write an equation for the formation of this precipitate (solid).



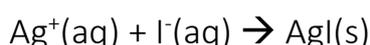
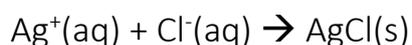
In the equation, remember that the (aq) means dissolved in water and the (s) means solid – the insoluble material you see as the precipitate.

Barium chloride and barium iodide are soluble (rule 4) and barium nitrate is soluble (rule 2) so if the sample contains chloride or iodide or nitrate this is why there will be NO precipitate.

A **new sample** is now needed as your original sample has been contaminated with Ba²⁺(aq) and NO₃⁻(aq) ions.

Adding silver nitrate solution, AgNO₃ will identify the chloride ion Cl⁻ and iodide ion I⁻. Silver nitrate solution contains both Ag⁺(aq) and NO₃⁻(aq). A precipitate forms if the solution contains chloride or iodide because both silver chloride and silver iodide are insoluble (rule 4).

We need to write an equation for the formation of these precipitates.



Since silver nitrate is soluble (rule 2), if the sample contains nitrate then there will be NO precipitate.

Although silver chloride and silver iodide precipitates are different colours, to distinguish more conclusively between chloride and iodide needs as additional test. This relies on the fact that the silver chloride makes a complex ion with dilute ammonia solution, NH_3 BUT silver iodide does not. You are NOT expected to be able to explain the chemistry ideas of complex ion formation, but we need to write an equation for the formation of the soluble complex ion.

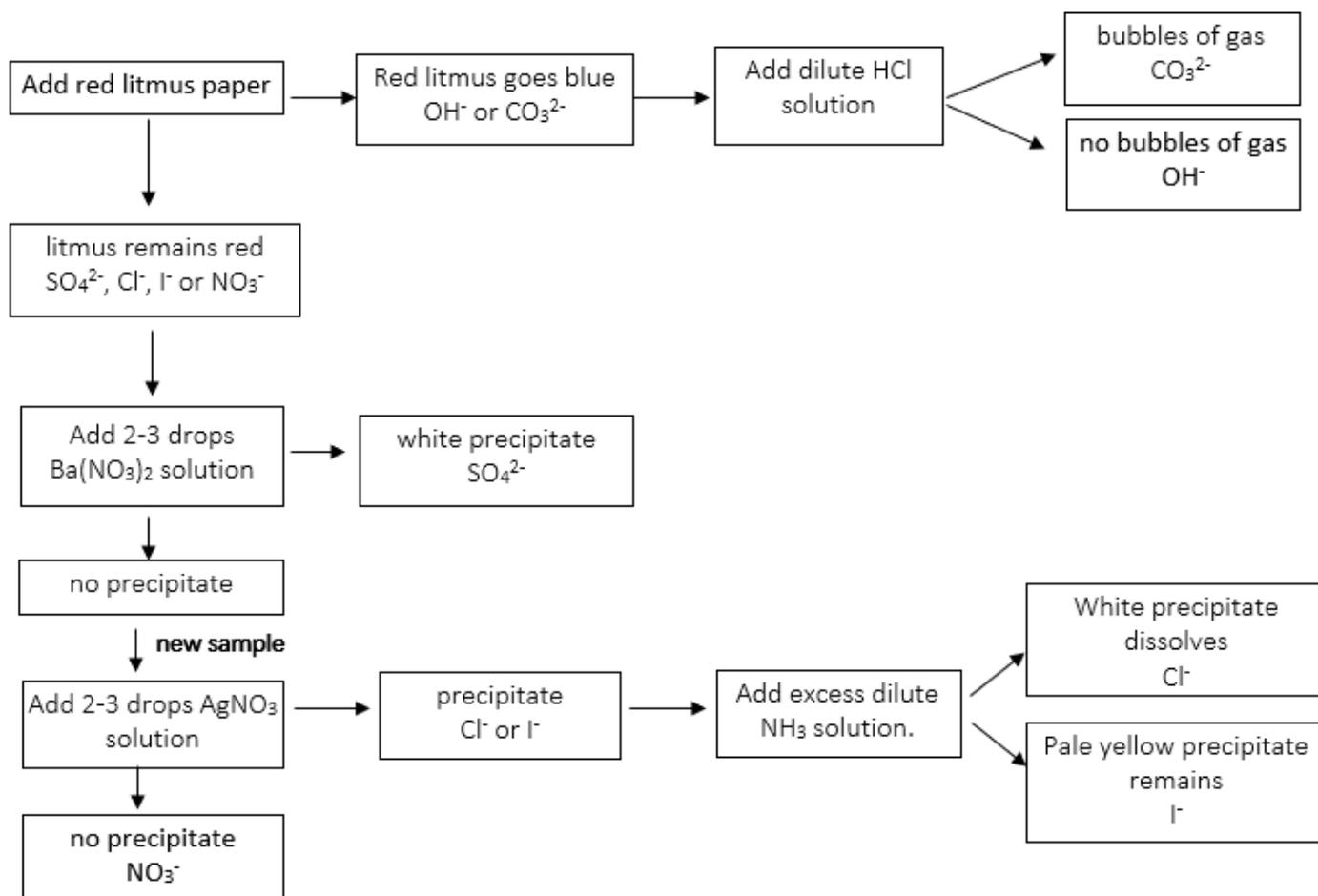


A simpler alternative is: $\text{Ag}^+(\text{aq}) + 2\text{NH}_3(\text{aq}) \rightarrow [\text{Ag}(\text{NH}_3)_2]^+(\text{aq})$

Since the products, $[\text{Ag}(\text{NH}_3)_2]^+(\text{aq})$ and $\text{Cl}^-(\text{aq})$, are both soluble, the precipitate of AgCl disappears / dissolves.

AgI(s) does not do a similar reaction.

Flow Chart for Anions



Tests for Cations

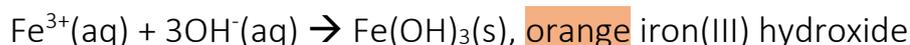
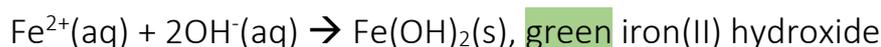
Start with a small sample of the solution provided, say 0.5 mm depth in a test tube.

You will be provided this flowchart (or similar) - see page 7

Adding sodium hydroxide solution will either result in no precipitate or a white or coloured precipitate forming. Sodium hydroxide contains $\text{Na}^+(\text{aq})$ ions and $\text{OH}^-(\text{aq})$ ions. If no precipitate forms, then the cation is Na^+ . This is because sodium is found in group 1 and group 1 compounds are soluble (rule 1) as well as sodium hydroxide being soluble (rule 6).

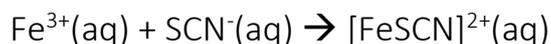
The colour of any metal hydroxide precipitate formed is then very useful. A coloured precipitate suggests a transition metal compound; iron, copper and silver are transition metals.

These are all insoluble (rule 6).



The different colours of the metal hydroxides and metal oxide would be sufficient, but there are some additional tests that should be done to confirm the ion identity.

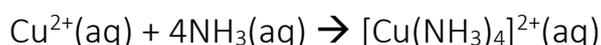
To confirm $\text{Fe}^{3+}(\text{aq})$, adding 2 drops of KSCN solution forms a **dark red** solution due to the formation of a complex ion.



To confirm $\text{Cu}^{2+}(\text{aq})$, adding excess NH_3 solution to the blue precipitate of copper hydroxide forms a **dark blue** solution due to the formation of a complex ion.



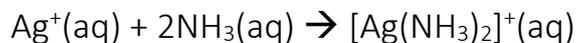
or



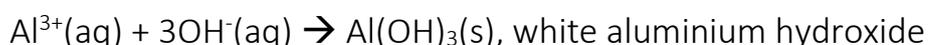
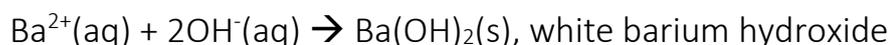
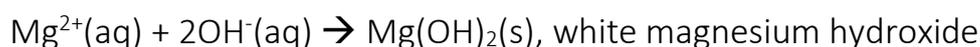
To confirm $\text{Ag}^+(\text{aq})$, adding excess NH_3 solution to the brown precipitate of silver oxide, Ag_2O , forms a colourless solution due to the formation of a complex ion.



Or



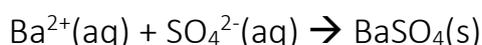
The white colour of any metal hydroxide precipitate formed suggests Mg^{2+} , Ba^{2+} , Al^{3+} , Pb^{2+} or Zn^{2+} . All these hydroxides are insoluble (rule 6)



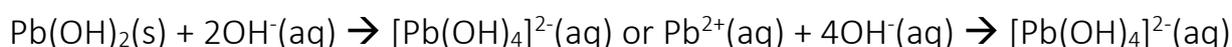
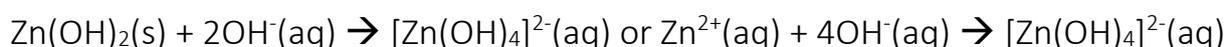
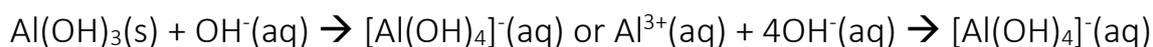
Adding excess NaOH solution to these white precipitates enables them to be divided into 2 groups – those that dissolve in excess $\text{NaOH}(\text{aq})$ and those that do not.

Addition of excess NH_3 to magnesium hydroxide and barium hydroxide has no effect on the precipitate. Neither dissolve because no soluble complex ion is formed.

To distinguish between Mg^{2+} and Ba^{2+} needs a new sample. Addition of 2 drops of dilute sulfuric acid solution (which contains $\text{H}^+(\text{aq})$ and $\text{SO}_4^{2-}(\text{aq})$ ions) produces a white precipitate with $\text{Ba}^{2+}(\text{aq})$ because barium sulfate is insoluble (rule 3), but not with $\text{Mg}^{2+}(\text{aq})$ because magnesium sulfate is soluble (also rule 3).



The white precipitates of aluminium hydroxide, lead hydroxide and zinc hydroxide all dissolve in excess sodium hydroxide solution because they form soluble complex ions.

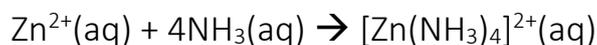


Since $\text{Al}(\text{OH})_3(\text{s})$, $\text{Zn}(\text{OH})_2(\text{s})$ and $\text{Pb}(\text{OH})_2(\text{s})$ ALL dissolve in excess NaOH solution additional tests are needed.

Adding 2 drops then excess NH₃ solution will identify Zn²⁺(aq) because a white precipitate form (on addition of the 2 drops) and then dissolves (on addition of excess NH₃(aq)

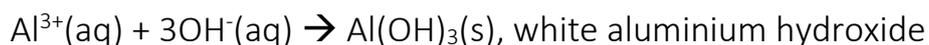


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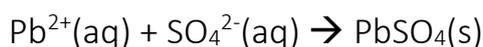


*The first equation is written with hydroxide because ammonia solution contains a small amount of hydroxide ions, and the white precipitate that forms is that of insoluble zinc hydroxide (rule 6). On addition of excess NH₃(aq) the precipitate dissolves because the soluble complex ion is made, this time containing NH₃, The formula is [Zn(NH₃)₄]²⁺(aq).

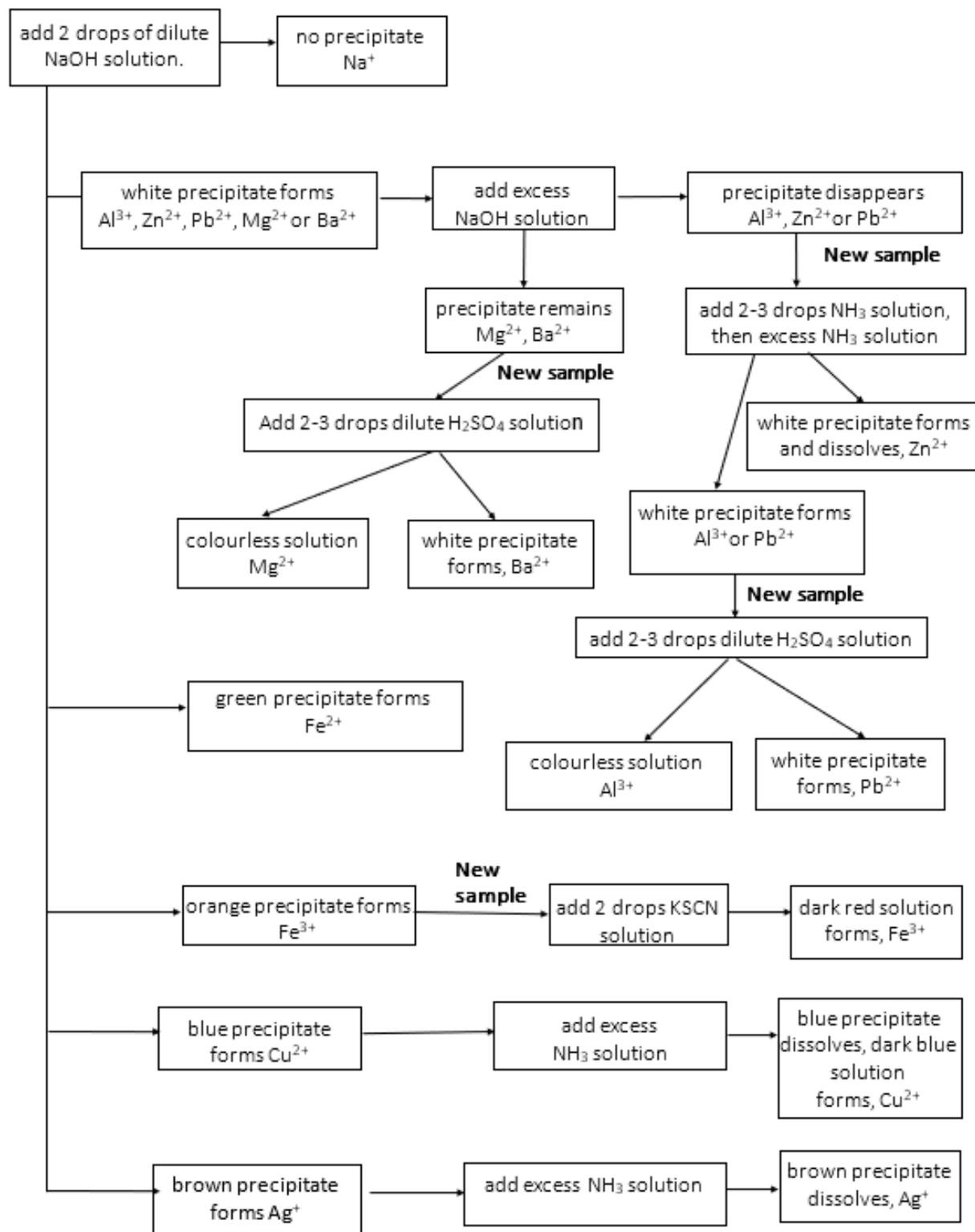
Adding 2 drops then excess NH₃ solution will NOT distinguish between Al³⁺(aq) and Pb²⁺(aq) because both form a white precipitate but neither precipitates dissolve to make soluble complex ions in excess NH₃(aq). Again this equation is written with hydroxide because ammonia solution contains a small amount of hydroxide ions.



Adding 2-3 drops of dilute sulfuric acid to a new sample allows Al³⁺(aq) and Pb²⁺(aq) to be distinguished from each other. Dilute sulfuric acid solution (which contains H⁺(aq) and SO₄²⁻(aq) ions) produces a white precipitate with Pb²⁺(aq) because lead sulfate is insoluble (rule 3), but not with Al³⁺(aq) because aluminium sulfate is soluble (also rule 3).



Flow Chart for Cations



Once you have identified your anion and cation you MUST 'put the ions together' to name the ionic substance you have analysed. E.g. anion identified as SO_4^{2-} and cation identified as Cu^{2+} , the substance identified is **copper sulfate**.

Report.

The report will include a justification of the identification process of the ions identified in the solutions, and **discuss the significance of the identified chemical species for people and the environment** linked to the purpose of the investigation. E.g. the water sample might have been collected from a local stream beside a winery where children are known to swim.

You only have to write about one ion; you may be advised which one by your teacher e.g. cation or anion. Some websites may be provided.

Sample report.

Significance of copper for humans and the environment

Since the early nineteenth century, copper containing chemicals have been commonly used as fungicides in vineyards kill mildew infections. Copper metal, in the form of copper sulfate solution, is an effective control for downy mildew and blackspot when it is sprayed on the vines. It is also known as Bordeaux mixture.

Copper degrades extremely slowly. It can lead to 'lifeless soils' if the substance is allowed to accumulate when it is washed off the plants into the soil. In the soil the copper strongly attaches to organic matter and minerals so it does not travel very far, rarely entering groundwater. However if it enters surface water, the same copper can travel great distances, either suspended on sludge particles or as free ions, in streams and rivers.

Although copper is essential to the proper functioning of organs and metabolic processes (copper is essential for human and animal health), it may become a pollutant that can affect our health when the concentrations of copper increase in our water. Copper is needed as a 'trace element' and for red blood cells, healthy bones, blood vessels and nerves and also plays an important part in our immune systems.. It is needed in some enzyme systems, which are responsible for the metabolic processes required in the body. The WHO (World Health Organisation) recommendation for Cu^{2+} concentration in drinking water is 1.3 mg per litre of water. Too little copper and we show symptoms that include fatigue and weakness. A copper deficiency in cattle can cause weak bones and wobbly gaits. Deficiency in plants can lead to stunted growth.

The main targets for copper toxicosis on a regular basis are the gastrointestinal, hepatic (liver), renal (kidneys), haematological (blood) and cardiovascular, and the central nervous systems. If the Cu^{2+} ion concentration is too high then it can cause symptoms such as cramps, nausea, vomiting and diarrhoea. The negative effects include damage to liver function, and damage the heart and kidneys. The copper can build up in soft tissues of the liver where it interacts with the liver enzymes. This disrupts the liver's important metabolic processes and its vital ability to detoxify and cleanse the blood.

Only a limited number of plants are able to thrive on copper-rich soils, which makes copper a threat to certain farmlands. Sheep are particularly vulnerable to copper poisoning. Copper also has an adverse effect on soil fertility as it affects microbes and earthworms, both of which have a vital role in the breakdown of organic matter.

When pollutants enter the river up-stream, the water can make its way into a reservoir. The pollutant is then distributed to humans who use drinking water from the reservoir. Toxic effects could potentially be seen over time in the population that are consuming the water.

<https://www.lenntech.com/periodic/elements/cu.htm#:~:text=Long%2Dterm%20exposure%20to%20copper,has%20not%20been%20determined%20yet.>

<https://ods.od.nih.gov/factsheets/Copper-HealthProfessional/>

<https://pubmed.ncbi.nlm.nih.gov/22890509/#:~:text=The%20use%20of%20copper%2Dbased,microbial%20function%20in%20vineyard%20soils>

<https://www.healthline.com/health/copper-toxicity#causes>

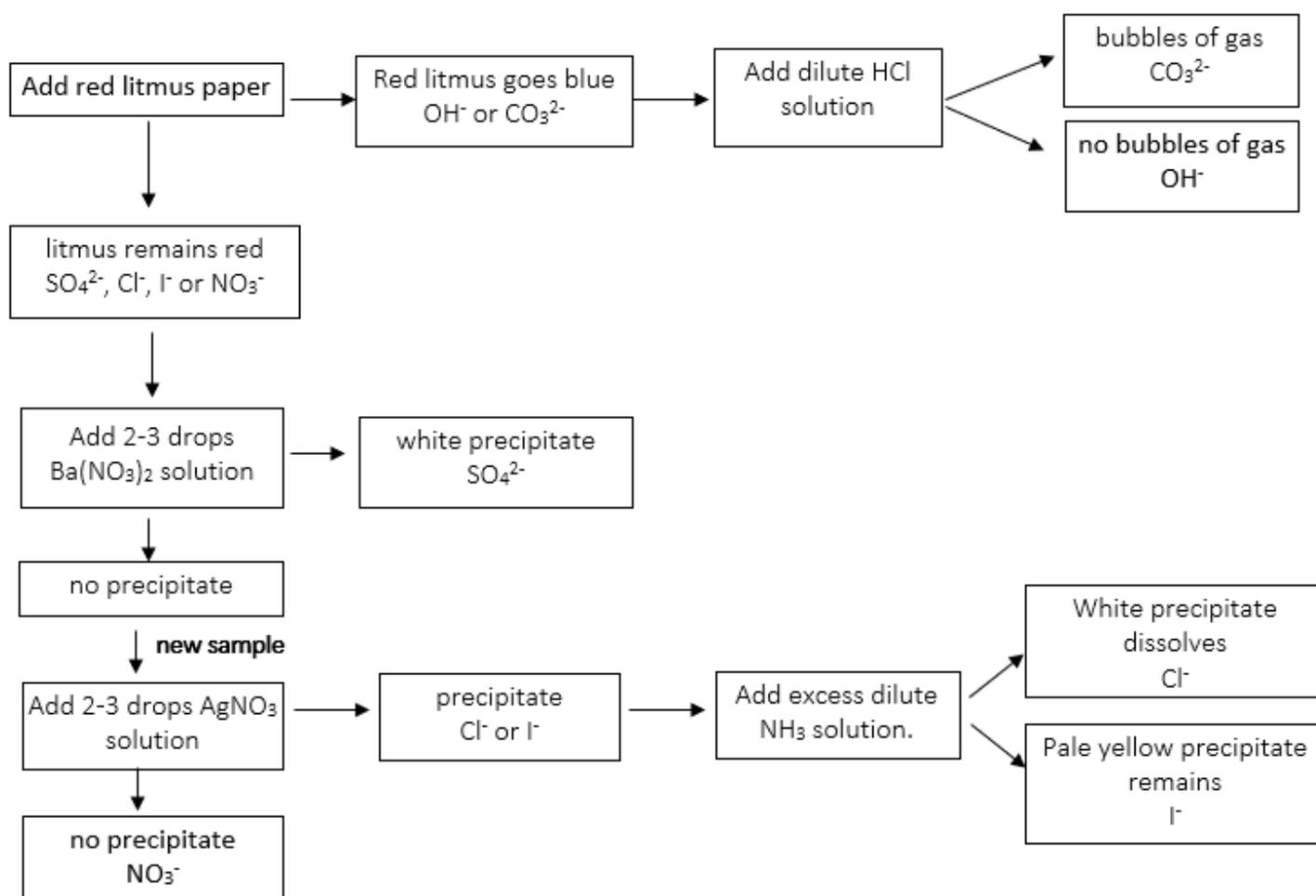
<https://vetsouth.co.nz/about-us/news/stock-die-due-copper-toxicity>

<https://store.nzfarmsource.co.nz/enrichplus/pasture-cropping/dont-come-a-cropper-with-copper>

RESOURCE SHEETS

The Solubility Rules	Formulae of Potential Complex ions
<ol style="list-style-type: none"> All Group 1 compounds are soluble All nitrate compounds are soluble Most sulfates are soluble except for calcium sulfate, barium sulfate and lead sulfate Most halides (chlorides & iodides) are soluble except for those salts with silver and lead All carbonates are insoluble except those of Group 1 All oxides and hydroxides are insoluble except those of Group 1 	<ul style="list-style-type: none"> $[\text{FeSCN}]^{2+}(\text{aq})$ $[\text{Zn}(\text{OH})_4]^{2-}(\text{aq})$ $[\text{Pb}(\text{OH})_4]^{2-}(\text{aq})$ $[\text{Al}(\text{OH})_4]^{-}(\text{aq})$ $[\text{Ag}(\text{NH}_3)_2]^{+}(\text{aq})$ $[\text{Zn}(\text{NH}_3)_4]^{2+}(\text{aq})$ $[\text{Cu}(\text{NH}_3)_4]^{2+}(\text{aq})$

Flow Chart for Anions



Flow Chart for Cations

