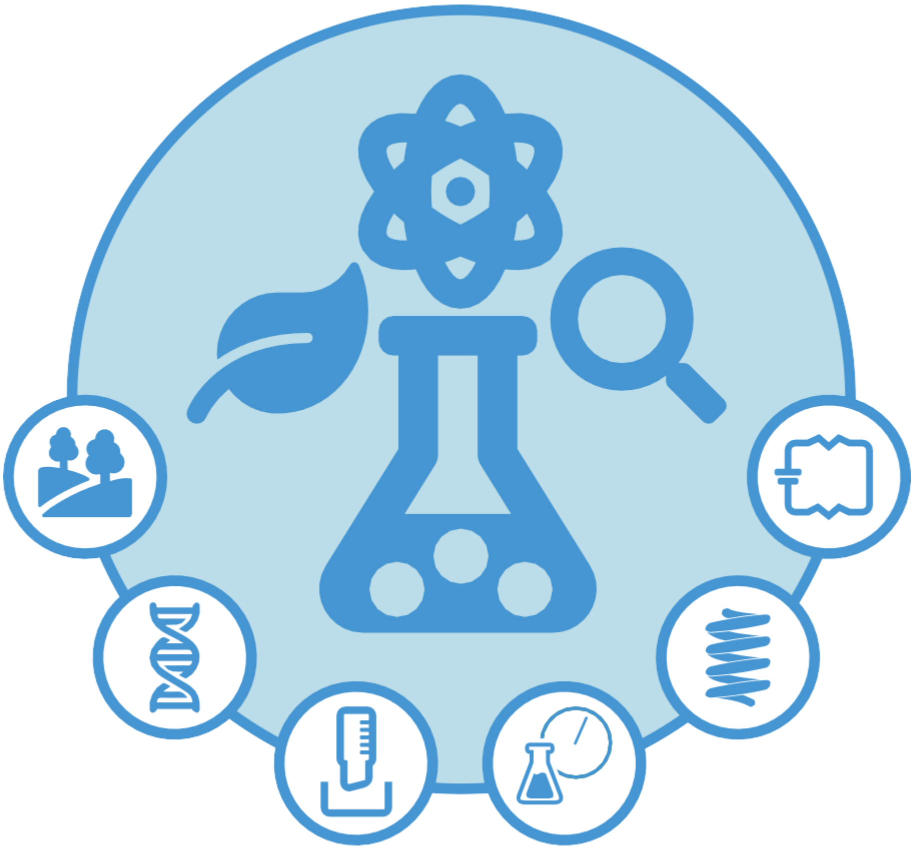
EXEMPLAR LESSON

OpenSTEM Africa

QUALITATIVE CHEMICAL ANALYSIS: CHEMICAL TESTS FOR CATIONS



Acknowledgements

Ministry of Education

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For information on OpenSTEM Africa see: www.open.edu/openlearncreate/OpenSTEM_Africa

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.

Contents

Exemplar lessons for the OpenSTEM Africa Virtual Laboratory applications

All the exemplar lessons are examples of lessons which could be used both individually and by whole classes of Senior High School (SHS) students in the elective sciences of Biology, Chemistry and Physics. Each of the lessons is linked specifically to one of the applications in the OpenSTEM Africa Virtual Laboratory. The exemplar lesson is created to give, both to SHS students and to SHS teachers, a clear example of the ways in which the applications can be used in the learning and teaching of practical science. There is a focus throughout the lesson on the student's development of the practical and experimental skills which, along with knowledge and understanding, are integral to the profile of learning, teaching and assessment in SHS sciences.

The 'you' in this lesson is 'you', the Senior High School student. Remember that you can repeat the experiments and activities in this lesson as often as you have time for in class. This freedom to repeat experiments and activities is also important if you are accessing the lesson outside the classroom, for example for homework. Every application in the OpenSTEM Africa Virtual Laboratory contains real data – the experiments are real experiments. This means you might make mistakes the first or second or third time you try an experiment or an activity – and that is exactly what often happens in the real world in the sciences. So, it is helpful for you as a student to share in some of the real-world trial and error of science as you develop your skills as a scientist.

The exemplar lesson also contains a set of teaching notes at the end of this document for 'you' the SHS science teacher, to suggest how you might want to set up this particular lesson with one of your classes. Hopefully it will also generate ideas for other lessons on the same topic, or other lessons which use the same OpenSTEM Africa Virtual Laboratory application.

Qualitative chemical analysis: Chemical tests for cations

Lesson objectives

By the end of this lesson, you will be able to:

- Identify ionic compounds
- Understand the chemistry behind qualitative tests for metal ions in solution using alkali solutions (sodium hydroxide and ammonia solutions).
- Write net ionic chemical equations
- Identify an unknown metal ion in solution.

The following practical and experimental skills will be developed:

- Carrying out qualitative observation
- Recording qualitative data
- Interpreting results.

Background

Ionic compounds

The elements in the Periodic Table can be divided in two groups (Figure 1):

- metals (including sodium, calcium, copper, aluminium and iron)
- non-metals (including oxygen, carbon, hydrogen, nitrogen, sulfur and chlorine).

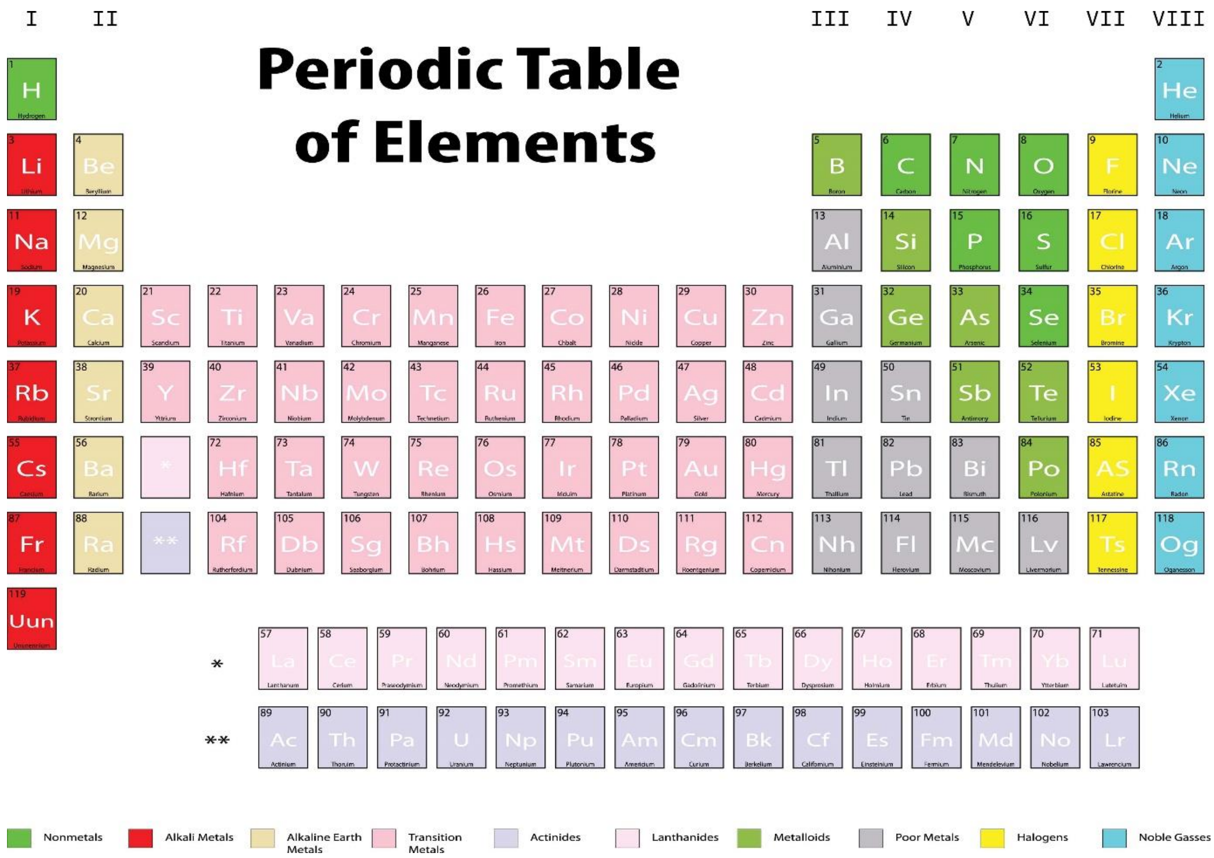

Figure 1. Periodic Table showing metals and non-metals.

When a metal atom comes into contact with a non-metal atom, the metal atom has a tendency to lose an **electron** (some metals atoms lose more than one) and donate it to the non-metal atom. The atoms losing or gaining electrons become charged particles called **ions.**

What is an electron and what charge does it carry?
Go to Appendix 3 for the answer.

Metal atoms form positively charged ions, also known as **cations**. And the non-metal atom that receives the extra electron will become negatively charged because it has gained a negatively charged electron. These negatively charged ions are also known as **anions**. Cations and anions are attracted to each other by their opposite charges; this type of interaction is known as an **ionic bond**.

Figure 2 shows the ions formed when sodium interacts with chlorine to form the **ionic compound** sodium chloride (NaCl), known as common table salt. Electrons are shown orbiting the atomic nucleus in electron shells. The sodium atom loses one electron to form a positively charged sodium ion with chemical symbol Na^{+}. The electron that the sodium atom loses is transferred to the chlorine atom, which becomes a negatively charged chloride ion (with chemical symbol Cl^{-}). Note that the charged of an ion is shown as a superscript plus '$^{+}$' or superscript minus '$^{-}$' sign to the right of the chemical symbol.

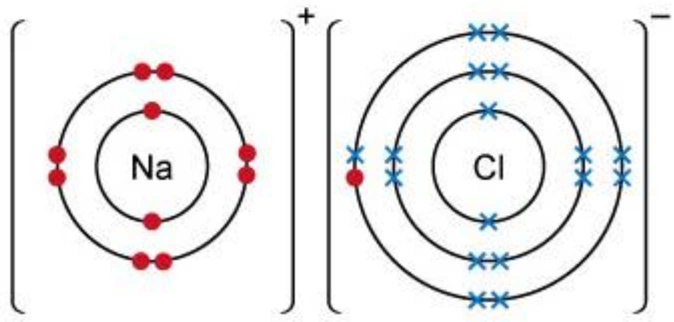

Figure 2. Sodium chloride (NaCl) is an ionic compound formed by ionic bonding between a positively charged sodium ion (written as Na^{+}) and a negatively charged chloride ion (written as Cl^{-}). Electrons of the sodium atom are represented by red dots and electrons of the chlorine atom are represented by blue crosses.

Chemists use the term 'salt' to refer not only to sodium chloride, but also to any ionic compound formed in that way. The general rule is that ionic compounds form when metals bond with non-metals.

In calcium chloride ($CaCl_2$), the calcium forms a positive ion by losing two electrons (one to each of the two chlorine atoms). What is the charge on the calcium ion and on each chloride ion?
Go to Appendix 3 for the answer.

Not all ions are formed from a single charged atom. **Molecular ions** are larger charge particles consisting of a group of atoms that has lost or gained some electrons. For example, sodium hydroxide (NaOH) is an ionic compound formed by ionic bonding between a positively charged sodium ion (Na^{+}) and a negatively charged hydroxide ion (OH^{-}). A hydroxide ion is a negatively charged group in which oxygen shares an electron with hydrogen (to form a **covalent bond** between the oxygen and hydrogen atoms), but also gains an electron from the sodium atom (Figure 3).

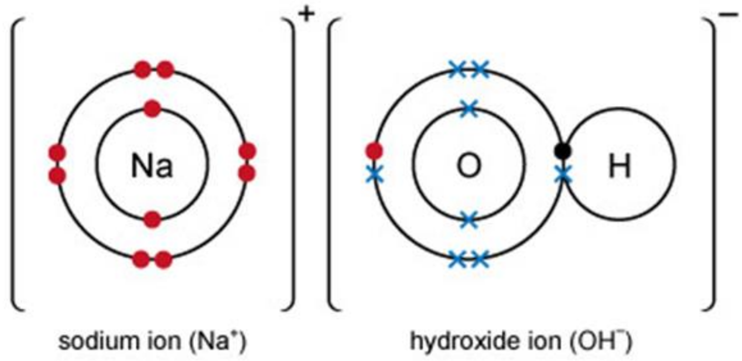

Figure 3. Sodium hydroxide (NaOH) is an ionic compound formed by ionic bonding between a sodium ion (Na^+) and a hydroxide ion (OH^-). Electrons of the sodium atom are represented by red dots, electrons of the chlorine atom are represented by blue crosses and the electron of the hydrogen atom is represented by a black dot.

What is the main difference between ionic and covalent bonds?
Go to Appendix 3 for the answer.

Other examples of 'molecular ions' you will come across are:

- The nitrate ion (NO_3^-) which has an overall charge of -1 and forms ionic compounds such as sodium nitrate ($NaNO_3$) where the nitrate group gains an electron from a sodium atom.
- The sulfate ion (SO_4^{2-}), which has an overall charge of -2 and forms ionic compounds such as sodium sulfate (Na_2SO_4), which has an overall charge of -2 and forms ionic compounds such as sodium sulfate (Na_2SO_4) where the sulfate group gains one electron from each of the sodium atoms.

The carbonate ion forms ionic compounds such as sodium carbonate (Na_2CO_3). Which is the overall charge of the carbonate ion?
Go to Appendix 3 for the answer.

Water as a solvent

In chemistry, a **solution** is a homogeneous (uniform) mixture in which a substance (known as the **solute**) dissolves in another substance (known as the **solvent**). A solvent is usually a liquid, but it could also be a gas. Water (H_2O) is an excellent solvent and it is also called the universal solvent.

Although a water molecule has a neutral charge overall, it has some areas that are slightly more negative (the oxygen atom) and some areas that are slightly more positive (the hydrogen atoms). The electrons shared between the oxygen and hydrogen atoms in a water molecule are more strongly attracted to the oxygen. The term **polarisation** is commonly used to describe this partial separation of charge and can be represented as δ^- (delta minus) and δ^+ (delta plus). In Figure 4 the oxygen atom has a partial negative charge δ^- and the hydrogen atoms has a partial positive charge δ^+. Due to its bent geometry, water is a **polar molecule**.

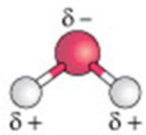

Figure 4. Uneven distribution of charge between the oxygen atom (red) and hydrogen atoms (white) in a water molecule.

The slightly negative area of one water molecule (the oxygen atom) is attracted to the slightly positive area of an adjacent water molecule (the hydrogen atoms) as shown in Figure 5.

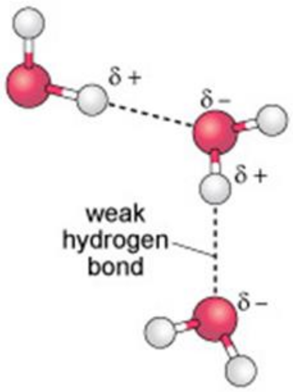

Figure 5. Hydrogen bonds holding adjacent molecules together. The polarised charges are shown.

This attraction between water molecules (known as **hydrogen bonds**) are a tenth the strength of the covalent bonding within a water molecule between the hydrogen and oxygen atoms. These hydrogen bonds between different water molecules are constantly being broken and reformed as the molecules move around.

Water molecules can also form interactions with many other polar molecules. This is what makes water a good solvent. For example, when salt dissolves in water, the electrical attraction between the Na^+ and Cl^- ions in the salt crystals is replaced by electrical attraction between the Na^+ and Cl^- ions and the polarised water molecules. The regular structure of the salt crystals (known as an **ionic lattice**) then starts to break down as the crystals dissolve in the water.

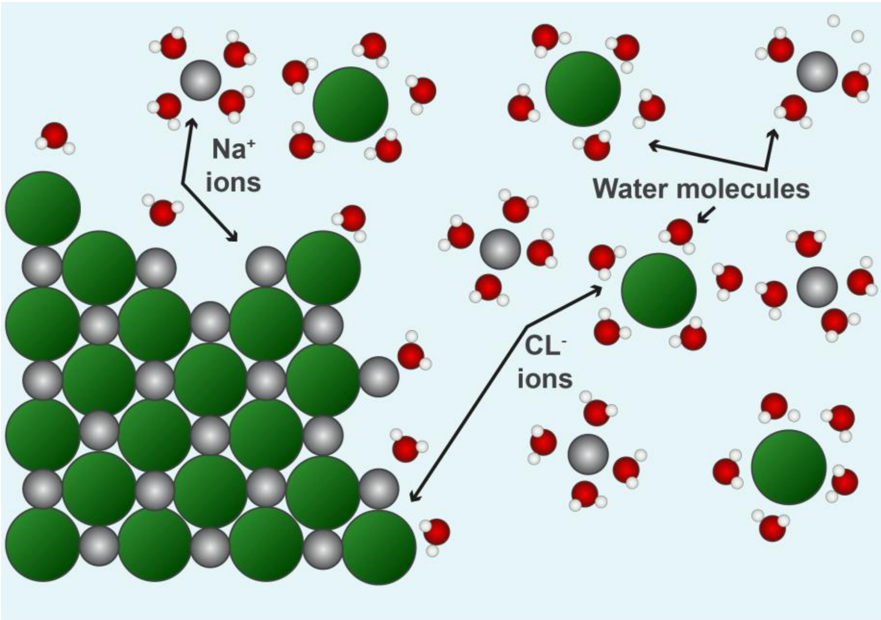

Figure 6. Solubility of sodium chloride crystal in water.

When salts are dissolved in water, the ions separate, and you should treat them individually. Some ions may react with other ions however few ions may be only spectators to those reactions.

Representing ionic chemical reactions

A **chemical equation** provides a shorthand way of writing out what happens when the substances present at the beginning of a chemical reaction (the **reactants**) are transformed into new chemical substances (the **products**). Similarly, ionic **chemical equations** can be written for chemical reactions involving ions. Dissolving table salt in water can be represented by:

$$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$$

In a balanced ionic chemical equation, the number of atoms of each element must be the same on both sides of the equation (the same as when balancing chemical equations for neutral species). Note that the simple ionic equation for dissolving table salt in water, is already balanced with one sodium and one chlorine atom on both sides of the equation. For more complex chemical equations, a good way to see this more clearly is to make a table of the number of atoms present on each side of the equation.

There is an extra check to ensure an ionic chemical equation is balanced; the total charge on each side of the ionic equation must be the same. The total charge on each side of the balanced ionic equation for dissolving table salt in water is zero. Finally, remember to include the state symbols for both reactants and products.

Write the balanced chemical equation for dissolving lead nitrate, $Pb(NO_3)_2$ in water.
Go to Appendix 3 for the answer.

Precipitation reactions

A **precipitation reaction** is when substances in solution are mixed, resulting in the formation of a product that cannot be dissolved in the solvent, and so it deposits in solid form from the solution (this deposit is known as a **precipitate**).

Precipitation reactions are frequently used in **qualitative chemical analysis**, for example when chemists are tasked with the identification of an ion in an unknown solution.

The chemical equation below represents the precipitation reaction between copper ions and hydroxide ions (both in solution) to form solid copper (II) hydroxide:

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

The pale blue precipitate $Cu(OH)_2$ formed is used as a test for the identification of copper ion, Cu^{2+}.

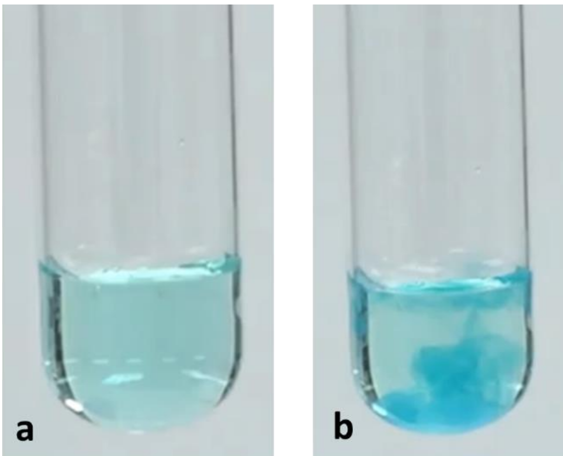

Figure 7. Test tubes containing (a) a diluted solution of copper ions and (b) a solid precipitate of copper (II) hydroxide after adding hydroxide ions to the solution of copper ions.

What is the difference between qualitative versus quantitative chemical analysis?
Go to Appendix 3 for the answer.

Reactions of metal ions with sodium hydroxide and ammonia solutions

Sodium hydroxide (NaOH) and ammonia (NH_3) solutions are both **alkalis** (soluble bases), giving hydroxide ions (OH^-) in their solutions.

NaOH is a **strong base** and dissociates completely to form sodium ions and hydroxide ions.

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

On the other hand, NH_3 is a **weak base**, and it does not fully dissociate in water.

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

Note that this is a reversible reaction (represented in the chemical equation with the two arrows but each with just half an arrowhead, the top one pointing right and the bottom one pointing left). In a reversible reaction, the products can react to produce the original reactants again. In this equilibrium the concentration of ammonia is much higher than the concentration of ammonium NH_4^+ ions and OH^- ions.

Why do strong bases have a higher pH than weak bases?
Go to Appendix 3 for the answer.

Many metal ions in solution with a charge of n+ (Me^{n+}) react with hydroxide ion (OH^-) to form different coloured precipitates of their **metal hydroxide**, $Me(OH)_n$:

$Me^{n+}(aq) + n\ OH^-(aq) \rightarrow Me(OH)_n\ (s)$

However, when adding more OH^- some of these precipitates re-dissolve in excess alkali. For example, you will observe that when a few drops of sodium hydroxide is added to a solution containing aluminium ions, the precipitate formed will re-dissolve when adding excess sodium hydroxide:

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

$Al(OH)_3(s) + OH^-(aq) \rightarrow Al(OH)_4^-(aq)$

Both observations (precipitates forming with few drops of alkali and any effect of adding excess alkali) are important in qualitative chemical analysis for the identification of metal ions.

The observations with sodium hydroxide solution are usually similar (but not always) to the observations with ammonia solution; any similarities and/or differences can be important clues to the identification of metal ions.

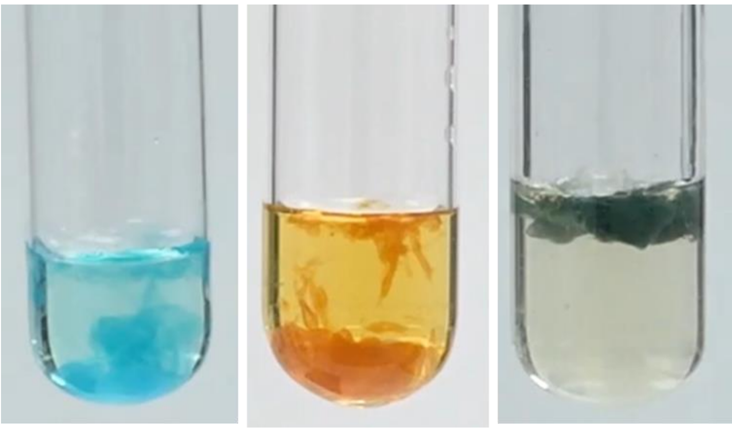

Figure 8. Test tubes containing precipitates of different metal hydroxides.

Write the ionic chemical equation for zinc ion (Zn^{2+}) in solution reacting with hydroxide ion (OH^-) in solution to form a precipitate of zinc hydroxide.
Go to Appendix 3 for the answer.

Complete versus net ionic chemical equations

The ionic equations discussed in the previous sections only included the ions involved in the formation of a precipitate. This is known as **net ionic chemical equation**. In this section, you will practice how to write a net ionic equation for precipitation reactions of metal ions with a soluble base.

First, you write the complete balanced molecular chemical equation, representing all the reagents and products in the precipitation reaction. You continue rewriting the chemical equation, substituting any soluble ionic compound with its dissociated ions and obtaining the **complete ionic chemical equation**. There are some ions on both sides of the complete ionic chemical equation that do not undergo any chemical reaction themselves. These are called **spectator ions.** Cancelling out the spectator ions leaves you with the net ionic chemical equation.

It takes practice to be able to write balanced ionic chemical equations. Look at the following example for the reaction of copper (II) sulfate solution and sodium hydroxide solution to form solid copper (II) hydroxide:

Copper (II) sulfate + sodium hydroxide → copper (II) hydroxide + sodium sulfate

There are few essential steps to follow:

Step 1: Write the molecular chemical equation using the chemical formula for reactants and products including their state of matter:

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

Table – The numbers of atoms in the unbalanced equation

Type of atom	Reactants	Products
Cu	1	1
S	1	1
O	5	6
Na	1	2
H	1	2

Step 2: Write the balanced molecular chemical equation:

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

Table – The numbers of atoms in the balanced equation

Type of atom	Reactants	Products
Cu	1	1
S	1	1
O	6	6
Na	2	2
H	2	2

STEP 3: Separate the soluble ionic compounds into their ions:

$Cu^{2+}(aq) + SO_4^{2-}(aq) + 2\ Na^+(aq) + 2\ OH^-(aq) \rightarrow Cu(OH)_2(s) + 2\ Na^+(aq) + SO_4^{2-}(aq)$

Note that $Cu(OH)_2$ is a precipitate and it is an insoluble product so it is not separated.

SO_4^{2-} and Na^+ are on both side of the equation so these spectator ions are cancelled out.

STEP 4: Write the **net ionic chemical equation** for the precipitation of copper (II) hydroxide, showing the actual chemical change (without the spectator ions):

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

This reaction is used for the identification of copper ion (Cu^{2+}).

What is the molecular, ionic and net ionic chemical equation for the precipitation reaction between a solution of aluminum nitrate and a solution of sodium hydroxide to form a precipitate of aluminum hydroxide and sodium nitrate?
Go to Appendix 3 for the answer.

Practical activity

Chemists have created a series of chemical tests that will identify which metal ion is present. Similarly, there is another series of chemical tests for negative ions, so that the overall identity of an unknown salt can be discovered. Many of these tests involve a precipitation reaction. In the online experiment you will identify metal ions in solution.

Task 1: You will perform a series of chemical tests by mixing a metal ion in solution with one reagent.

Task 2: Using observations of chemical tests, you will identify the unknown metal ion present in a solution.

Task 1: Chemical tests for metal ions in solution

First, you will examine the outcome of individually mixing a metal ion in solution with one reagent. Tests will be performed with two different reagents (sodium hydroxide and ammonia solutions). You should look very carefully at what happens to each metal ion solution when adding a reagent (starting with a few drops and then adding reagent in excess). Remember that all your observations should be recorded in your laboratory notebook.

A possible change occurring during the tests is the formation of a coloured precipitate, but don't be disappointed if you don't see a change when performing some tests. Remember that negative results are often as important as positive ones and they should be also recorded in your laboratory notebook.

Your observations will show that each metal ion reacts in a different way with each reagent and so these tests provide a means of identifying which metal is present in an unknown solution, which is your second task.

Detailed instructions are provided within the experiment. In preparation, read and reflect on the following summary of the steps you will need to take:

1. Using the dropping pipette, transfer a small volume of a metal ion solution into an empty test tube. Ensure you note down which metal ion is being transferred into each test tube (numbered 1–6).
2. Select one of the reagents (sodium hydroxide solution or ammonia solution) and using the dropper pipette initially add a few drops of your selected reagent into the test tube containing the metal ion solution. Ensure you note down which reagent is being added to each test tube.
3. After watching video showing chemical reaction, record the results of the test by giving a brief description of what has been observed. Don't be disappointed if you don't see a change when performing some tests. Remember that negative results are often as important as positive ones, and they should be also recorded.
4. Add excess of your selected reagent.
5. Ensure that the metal ion solution and the reagent solution are mixed well by using a glass stirring rod before recording your final observations.
6. Repeat this test using the second reagent and record your observations.

7. Repeat steps 1–6 for each of the other six metal ion solutions available and record all results

Tables 1 and 2 show templates you could use to record your observations.

Table 1 Qualitative data from reactions of positively charged metal ions in solution with a solution of dilute sodium hydroxide.

	Observations	
Cations	After adding few drops of NaOH	After adding a large excess of NaOH
Zn^{2+}		
Ca^{2+}		
Al^{3+}		
Pb^{2+}		
Cu^{2+}		
Fe^{2+}		
Fe^{3+}		

Table 2 Qualitative data from reactions of positively charged metal ions in solution with a solution of dilute ammonia.

	Observations	
Cations	After adding few drops of NH_3(aq)	After adding a large excess of NH_3(aq)
Zn^{2+}		
Ca^{2+}		
Al^{3+}		
Pb^{2+}		
Cu^{2+}		
Fe^{2+}		
Fe^{3+}		

Click on the icon to access the OpenSTEM Africa Virtual Laboratory (Chemical tests) homepage. Watch the introductory video before entering the experiment to carry out Task 1.

Qualitative chemical analysis

Go to the OpenSTEM Africa Virtual Laboratory.

Click on the icon to access the Chemical tests homepage.

Watch the introductory video before entering the experiment.

When cleaning laboratory glassware, you will finish up with a couple of rinses of deionised water. Why is it not desirable to use tap water for the final rinses when carrying out chemical tests for metal ions?

Go to Appendix 3 for the answer.

Task 2: Identification of an unknown metal ion in a water sample

Once you completed chemical tests for the six metal ions in solution, select one of the unknown solutions a–d.

1. Using the dropping pipette, transfer a small volume of the unknown solution into an empty test tubes.
2. Select one of the reagents (sodium hydroxide solution or ammonia solution) and using the dropper pipette initially add a few drops of your selected reagent into the test tube containing the unknown solution.
3. After watching video showing chemical reaction, record the results of the test by giving a brief description of what has been observed.
4. Add excess of your selected reagent.
5. Ensure that the metal ion solution and the reagent solution are mixed well by using a glass stirring rod before recording your final observations.
6. Repeat this test using the second reagent and record observations.

The colour of an unknown solution may provide a clue in the identification of a metal ion however you should always carry out the chemical tests to conclusively confirm which metal ion is present. Table 3 shows a template you could use to record your observations.

Table 3 Qualitative data from the reaction of an unknown sample containing a metal ion with different reagents

Unknown sample allocated:	
Reagent	**Observations**
Few drops of NaOH	
A large excess of NaOH	
Few drops of NH_3(aq)	

A large excess of $NH_3(aq)$	

Which metal ion do you think is present in your allocated water sample? Explain your choice

Note that unknows samples are randomly allocated and yours will be different to those allocated to your fellow students. Check with your teacher if an identification of a metal ion is a bit challenging.

Summary

When salts dissolved in water, the positively and negatively charged ions in the crystal salt separate and disperse throughout the solution. These ions in solution should be treat individually; some may react with other ions to form a new compound.

Precipitation reactions are used for the identification of positively charged metal ions in solution. Each metal ion reacts in a different way with hydroxide ion (OH^-) to form precipitates of metal hydroxide and these tests provide a means of identifying which metal is present in an unknown sample. Qualitative data from reactions of metal ions with sodium hydroxide solution is usually similar (but not always) to observations from reactions of metal ions with ammonia solution; any similarities and/or differences can be important clues to the identification some metal ions.

Quiz

Answer the questions, then search for the correct answers in Appendix 4.

Question 1

Select the correct answer:

What type of bonding occurs between the positively charged ion and the negatively charged ion forming a 'salt'?

a) Covalent bonding

b) Ionic bonding

c) Hydrogen bonding

Question 2

Select the correct answer:

Which of the following ionic chemical equation is correctly balanced and represents the chemical reaction of dissolving sodium sulfate in water?

a) $Na_2SO_4(s) \rightarrow 2Na^+(l) + SO_4^{2-}(l)$

b) $Na_2SO_4(s) \rightarrow 2Na^+(aq) + SO_4^{2-}(aq)$

c) $NaSO_4(s) \rightarrow Na^+(aq) + SO_4^-(aq)$

Question 3

Which of the following statements is correct?

1. Spectator ions are negatively charged ions that remain unchanged on both sides of a chemical equation and can be ignored when writing a net ionic equation.
2. Reactions of metal ions with a solution of sodium hydroxide are always similar to reactions of metal ions with a solution of ammonia because both reagents are alkalis.
3. An alkali is a base that dissolves in water and has a pH higher than 7.

Question 4

How does dilute sodium hydroxide solution react with metal ions in solution? Complete the paragraph below by selecting <u>one</u> option to fill in the gap.

Dilute sodium hydroxide solution reacts with metal ions forming metal _______ that are insoluble and appear as precipitates.

[oxides, hydroxides, alloys]

Glossary

Alkalis – Soluble bases

Anions – Positively charged ions

Cations – Negatively charged ions

Chemical equation – A representation of a chemical reaction in which reactants and products are expressed in terms of their chemical formulae (by using symbols for its constituent elements).

Covalent bond – A link between atoms where electrons are shared

Electron – A negatively charged subatomic particle that surrounds the atom nucleus

Hydrogen bond – The attraction between molecules due to the interaction of hydrogen with another atom that already are participating in other chemical bonds

Ionic bond – A linking between ions with opposite electrical charge

Ionic chemical equation – A way of writing out what happens for a chemical reaction involving ions in solution

Ionic compound – Chemical compound composed of ions held together by ionic bonding (such as table salt, NaCl)

Ionic lattice – The regular arrangement of oppositely charged ions in an ionic compound

Ions – Charged particles due to the loss or gain of electrons

Metal hydroxide – A chemical compound containing a metal ion and a hydroxide ion, OH^-

Molecular ion – An ion formed by removing or adding electrons from a molecule

Net ionic chemical equation – A shortened version of the complete ionic chemical equation showing only the species undergoing chemical changes

Polarisation – Partial separation of charge

Polar molecule – A molecule with a slightly negative end and a slightly positive end

Precipitate – An insoluble solid emerging from a liquid solution

Precipitation reaction – A chemical reaction in which substances in solution are mixed and an insoluble product is formed

Products – Substances formed as a result of a chemical reaction

Qualitative chemical analysis – A branch of chemistry dealing with the identification of elements or grouping of elements present in a sample

Reactants – Starting materials in a chemical reaction

Solution – A homogeneous mixture of two or more substances, consisting of a solute and a solvent

Solute – A substance dissolved in another substance (known as the solvent)

Solvent – A substance (usually a liquid) in which another substance (known as the solute) is dissolved

Spectator ion – An ion existing in the same form on both the reactant and products sides of the chemical equation and are excluded from the net ionic equation because do not participate in the chemical reaction

Strong base – A base that completely dissociates to give hydroxide ions in an aqueous solution

Weak base – A base that does not completely dissociate to give hydroxide ions in an aqueous solution

Appendix 1: Teacher notes – organisation of the lesson

Teaching notes for the Chemical tests application and the exemplar lesson on identification of cations in solution.

Combined with using the Chemical tests application, this lesson links to the following units in the Teaching Syllabus for Chemistry:

- SHS 1 Section 2 Atomic Structure, Unit 1: Particulate nature of matter
- SHS 1 Section 2 Atomic Structure, Unit31: Periodicity
- SHS 1 Section 3 Chemical bonds, Unit 1: Interatomic bonding
- SHS 2 Section 4 Conservation of matter and stoichiometry, Unit 3: Stoichiometry and chemical equations
- SHS 2 Section 4 Acids and Bases, Unit 6: Solubility of Substances
- SHS 2 Section 4 Acids and Bases, Unit 7: Salt and Chemicals from salt

Ideas for organising this exemplar lesson link directly to activities and teaching examples in the OpenSTEM Africa CPD units *Organising practical work*, *Collaborative learning*, and *Using ICT to support learning*.

Overview

If it can be arranged through your Head of Science and the Head of ICT, this lesson should take place in the ICT Lab in your school. If the lesson takes place in the ICT Lab, it may be possible for each student to work individually at a computer; otherwise divide the class so that students are in small groups at a computer.

If it is not possible to use the ICT Lab for this lesson, then try to set up this lesson in your classroom. You may be lucky enough in your school to have a set of 'empty' tablets or mobile phones which students can use, or you may be able to bring a laptop connected to the internet/your school intranet, and perhaps connected to a projector to make it possible for the whole class to view at once. If access to ICT is a real challenge in your school but you want your students to view an experiment, you might be able demonstrate it to small groups of your students at a time using your own mobile phone.

Whatever way(s) you set up the class, it would still be helpful to the students to be able to work in pairs or small groups for at least some of the lesson. Do remember as well that students need desk space to be able to write in their notebooks and to draw diagrams.

Steps in Organising the lesson

Step 1: This takes place in one (or more) of the lessons before the one where you and your class access the OpenSTEM Africa Virtual Laboratory Chemical tests application. Have students work in pairs to pre-read the Background section of the exemplar lesson. They should ask each other the questions in the Background section and check with each other that each understands the answers. You may want students to complete their reading of the Background section for homework or continue into a second lesson. If you do allocate more than one lesson to the Background work, consider changing the pairs of students around. In that way each student can check their understanding of what they have learned with a new partner. While they are doing so, you may want to walk round the class, checking they can identify ionic compounds and which elements in the Periodic Table form cations and anions. It is important that students can write ionic equations and understand the chemistry of precipitation reactions of metal ions in solution with alkali solutions.

Step 2: At the beginning of this exemplar lesson, check students' understanding of relevant chemistry by asking (again!) the questions in the Background section. You could organise the class to work in the same pairs as in the previous lesson or change them again. Have each person in the pair create the tables for their experimental data in their own laboratory notebook in preparation for their data collection from the practical activity.

Step 3: Within each pair, have them check each other's work and that each has set the tables out correctly with the correct headings.

Step 4: Make sure that each pair has access to/can see the computer screen to begin the actual investigation and observation and carry out the chemical tests. Ensure that each pair knows how to perform the qualitative tests **–** or if you are using a laptop/projector, that you draw on the expertise of the class as you go through each step of the investigation, transferring metal solutions to test tubes, adding reagents, recording observations **–** i.e., ask them what the next step is.

Step 5: Have the class follow the instructions. Make sure, if working in a pair on a PC, that each student in the pair gets to follow all the steps; if working in a group on a PC, have the group leader ensure that everyone in the group is involved.

Step 6: Ten minutes before the end of the lesson, tell the students to complete the quiz.

Appendix 2: Teacher notes – outputs from the lesson

Task 1

Completed tables for Task 1 are given below.

Table 1 Qualitative data from reactions of positively charged metal ions in solution with a solution of dilute sodium hydroxide.

Cations	Add a few drops of NaOH	Add large excess of NaOH
Zn^{2+}	White precipitate forms (gelatinous)	Precipitate redissolves
Ca^{2+}	White precipitate forms	No change
Al^{3+}	White precipitate forms (gelatinous)	Precipitate redissolves
Pb^{2+}	White precipitate forms	Precipitate redissolves
Cu^{2+}	Pale blue precipitate forms (gelatinous)	No change
Fe^{2+}	Green precipitate (gelatinous)	No change
Fe^{3+}	Reddish-brown precipitate (gelatinous)	No change

Table 2 Qualitative data from reactions of positively charged metal ions in solution with a solution of dilute ammonia.

Cations	Add a few drops of $NH_3(aq)$	Add large excess of $NH_3(aq)$
Zn^{2+}	White precipitate forms (gelatinous)	Precipitate redissolves
Ca^{2+}	No precipitate forms	No precipitate formed
Al^{3+}	White precipitate forms (gelatinous)	No change
Pb^{2+}	White precipitate forms	No change
Cu^{2+}	Pale blue precipitate forms (gelatinous)	Precipitate redissolves
Fe^{2+}	Green precipitate (gelatinous)	No change
Fe^{3+}	Reddish brown precipitate (gelatinous)	No change

Task 2

The application will allocate four random unknown samples of metal ions in solution to each student. The colour of some unknown solutions may provide a clue in the identification of a metal ion. However, you should ask your students to always carry out the chemical tests to conclusively confirm which metal ion is present.

Appendix 3: In-text question answers

What is an electron and what charge does it carry?

Answer: An electron is a negatively charged particle that circles around the atomic nucleus of an atom (where the protons reside). The electron is regarded as having a negative charge (-1)**.**

In calcium chloride ($CaCl_2$), the calcium forms a positive ion by losing two electrons (one to each of the two chlorine atoms). What is the charge on the calcium ion an on each chloride ion?

Answer: The calcium ion has lost two electrons, so it has a charge of plus two, written as Ca^{2+}. To balance this positive charge, each chloride atom gains one electron and therefore the chloride ion has a charge of minus one (Cl^-).

What is the main difference between ionic and covalent bonds?

Answer: In a covalent bond, atoms are bound by sharing electrons. In an ionic bond, one atom donates one or more electrons to another atom and these oppositely-charged ions formed are attracted to each other.

The carbonate ion forms ionic compounds such as sodium carbonate (Na_2CO_3). Which is the overall charge of the carbonate ion?

Answer: The carbonate ion (CO_3^{2-}) has an overall charge of -2 where it gains one electron from each of the sodium atoms**.**

Write the balanced chemical equation for dissolving lead nitrate, $Pb(NO_3)_2$ in water.

Answer: $Pb(NO_3)_2$ (s) → Pb^{2+} (aq) + 2 NO_3^- (aq)

Table – The numbers of atoms in the balanced ionic equation

Type of atom	Reactants	Products
Pb	1	1
N	2	2
O	6	6

Look at the subscripts to the right of the symbol to find the number of each type of atom. The total charge on both sides of the ionic equation is zero.

What is the difference between qualitative versus quantitative chemical analysis?

Answer: Qualitative chemical analysis aims at finding out if a substance is present in a sample. Quantitative chemical analysis finds out how much of a substance is present in a sample. Only quantitative chemical analysis produces numerical data. The data gather in a qualitative analysis is descriptive.

Why do strong bases have a higher pH than weak bases?

Answer: Strong bases completely dissociated to produce higher concentrations of OH^- ions compared to weak bases that only partially dissociate to give OH^- ions. A higher concentration of OH^- ions in solution results in a higher pH value, A pH closer to 14 indicates a strong base. Weak bases have a pH value closer to 7 but always higher than 7 (neutral value).

Write the ionic chemical equation for zinc ion (Zn^{2+}) in solution reacting with hydroxide ion (OH^-) in solution to form a precipitate of zinc hydroxide.

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

Write the net ionic chemical equation for the precipitation reaction between a solution of aluminum nitrate and a solution of sodium hydroxide to form a precipitate of aluminum hydroxide and sodium nitrate.

Answer:

Aluminium nitrate + sodium hydroxide → aluminum (II) hydroxide + sodium nitrate

Step 1: Write the molecular chemical equation using the chemical formula for reactants and products:

$Al(NO_3)_3(aq) + NaOH(aq) \rightarrow Al(OH)_3\ (s) + NaNO_3(aq)$

Table – The numbers of atoms in the unbalanced equation

Type of atom	Reactants	Products
Al	1	1
N	3	1
O	7	6
Na	1	1
H	1	3

Step 2: Write the balanced molecular chemical equation:

$Al(NO_3)_3(aq) + 3\ NaOH(aq) \rightarrow Al(OH)_3(s) + 3\ NaNO_3(aq)$

Table – The numbers of atoms in the balanced equation

Type of atom	Reactants	Products
Al	1	1
N	3	3
O	9	9
Na	3	3
H	3	3

Step 3: Separate the soluble ionic compounds into their ions:

$Al^{3+(}aq) + 3\ NO_3^-(aq) + 3\ Na^+(aq) + 3\ OH^-(aq) \rightarrow Al(OH)_3(s) + 3\ Na^+(aq) + 3\ NO_3^-(aq)$

Note that $Al(OH)_3$ is a precipitate and it is an insoluble product so it is not separated. Ions on both side of the chemical can be cancelled out.

Step 4: Write the **net ionic chemical equation** for the precipitation of aluminium (III) hydroxide, showing the actual chemical change (without the spectator ions) for the identification of aluminium ion (Al^{3+}) is as follows:

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

When cleaning laboratory glassware, you will finish up with a couple of rinses of deionised water. Why is not desirable to use tap water for the final rinses when carrying out chemical tests for metal ions?

Answer: Cations such as Ca^{2+} and Mg^{2+} exist in tap water.

To avoid interferences in the chemical analysis, deionised water should be used in any final rising of laboratory glassware. Deionisation is a very cost-effective water filtration process removing ions from solution through ion exchange. Distilled water does not contain metal ions and could be also used for this purpose, but the process of distillation is more expensive than deionisation.

Appendix 4: Quiz answers

Correct answers are **highlighted in green**.

Question 1

Select the correct answer:

1. What type of bonding occurs between the positively charged ion and the negatively charged ion forming a 'salt'?

   a) Covalent bonding

   b) Ionic bonding

   c) Hydrogen bonding

Question 2

Select the correct answer:

Which of the following ionic chemical equation is correctly balanced and represents the chemical reaction of dissolving sodium sulfate in water?

a) $Na_2SO_4(s)$ -> $2Na^+(l)$ + $SO_4^{2-}(l)$

b) $Na_2SO_4(s)$ -> $2Na^+(aq)$ + $SO_4^{2-}(aq)$

c) $NaSO_4(s)$ -> $Na^+(aq)$ + $SO_4^-(aq)$

Question 3

Which of the following statements is correct?

1. Spectator ions are negatively charged ions that remain unchanged on both sides of a chemical equation and can be ignored when writing a net ionic equation.
2. Reactions of metal ions with a solution of sodium hydroxide are always similar to reactions of metal ions with a solution of ammonia because both reagents are alkalis.
3. **An alkali is a base that dissolves in water and has a pH higher than 7**.

Question 4

How does dilute sodium hydroxide solution react with metal ions in solution? Complete the paragraph below by selecting <u>one</u> option to fill in the gap.

Dilute sodium hydroxide solution reacts with metal ions forming metal **<u>hydroxides</u>** that are insoluble and appear as precipitates.

[oxides, **hydroxides**, alloys]

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