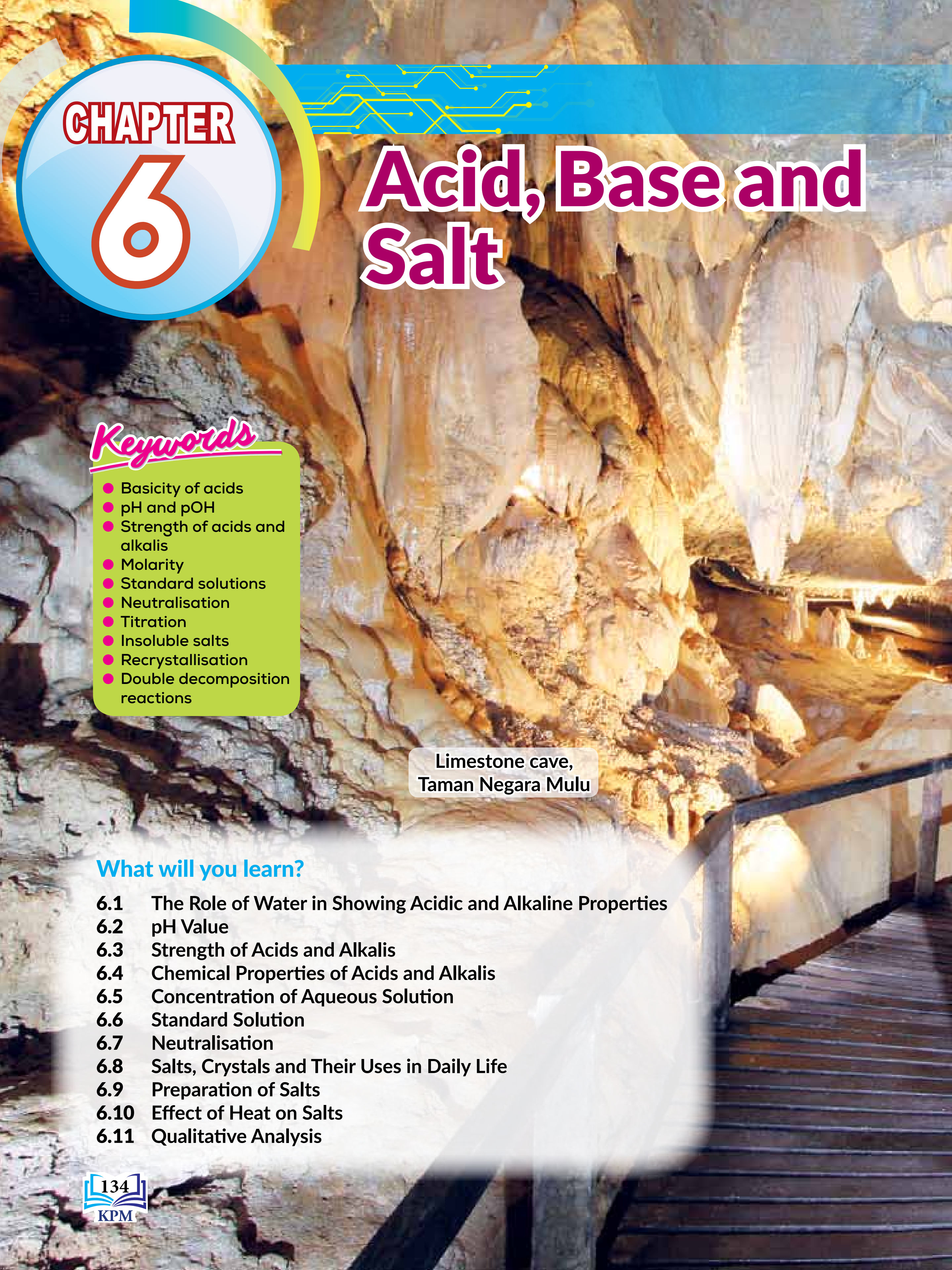
CHAPTER 6

Acid, Base and Salt



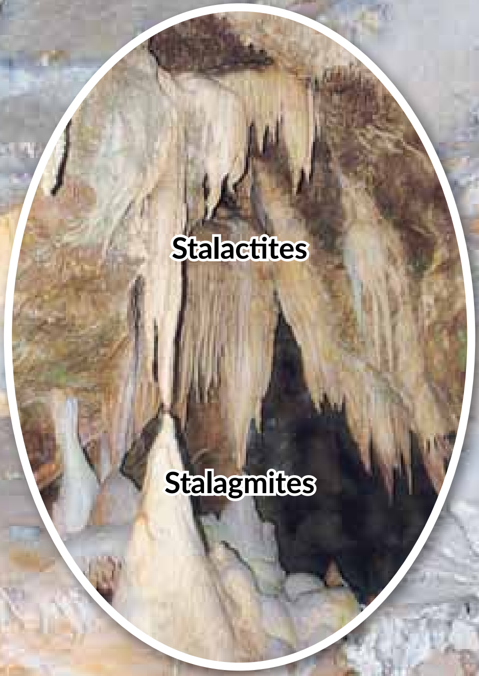
Limestone cave,
Taman Negara Mulu

Keywords

- Basicity of acids
- pH and pOH
- Strength of acids and alkalis
- Molarity
- Standard solutions
- Neutralisation
- Titration
- Insoluble salts
- Recrystallisation
- Double decomposition reactions

What will you learn?

6.1 The Role of Water in Showing Acidic and Alkaline Properties
6.2 pH Value
6.3 Strength of Acids and Alkalis
6.4 Chemical Properties of Acids and Alkalis
6.5 Concentration of Aqueous Solution
6.6 Standard Solution
6.7 Neutralisation
6.8 Salts, Crystals and Their Uses in Daily Life
6.9 Preparation of Salts
6.10 Effect of Heat on Salts
6.11 Qualitative Analysis



Bulletin

How are stalactites and stalagmites formed in limestone caves? Limestone caves consist of calcium carbonate, $CaCO_3$. When rainwater falls on the caves seep through the limestone, the following reaction takes place to produce calcium bicarbonate salt, $Ca(HCO_3)_2$.

$$H_2O(l) + CO_2(g) + CaCO_3(s) \rightarrow Ca(HCO_3)_2(aq)$$

The flowing water will carry the soluble calcium bicarbonate, $Ca(HCO_3)_2$ through the crevices at the roof of the caves. When the water comes in contact with air in the caves, a small portion of calcium bicarbonate, $Ca(HCO_3)_2$ reverts back to calcium carbonate, $CaCO_3$, due to water and carbon dioxide losses. Calcium carbonate, $CaCO_3$ starts to precipitate on these crevices. Hence, the formation of stalactites begins gradually. Water that drips from the ends of the stalactites will fall on the floor of the cave. Over the time, stalagmites will form in the same way as stalactites. This is why stalactites and stalagmites are found together in the caves.

Formation of stalactites and stalagmites

http://bit.ly/2ISEfPQ

What is the relationship between pH value and concentration of hydrogen ions, H^+?

Why are all alkalis bases but not all bases are alkalis?

How does a laboratory assistant prepare a standard solution?

6.1 The Role of Water in Showing Acidic and Alkaline Properties

Situation in Figure 6.1 shows the uses of acidic and alkaline substances in daily life. Identify which subtances are acidic and which substances are alkaline.

Figure 6.1 *Acidic and alkaline substances in daily life*

Acids

When acid is dissolved in water, the hydrogen atoms in acid molecules are released in the form of **hydrogen ions, H^+**. Therefore, based on the Arrhenius theory, acid is defined as follows:

> Chemical substances ionise in water to produce hydrogen ions, H^+.

$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$ $HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$

When hydrogen chloride gas is dissolved in water, hydrogen chloride molecules will ionise in water to produce hydrogen ions, H^+ and chloride ions, Cl^-. However, do the hydrogen ions, H^+ remain in the aqueous solution? Literally, **hydrogen ions, H^+** produced will combine with the water molecules, H_2O to form **hydroxonium ions, H_3O^+**.

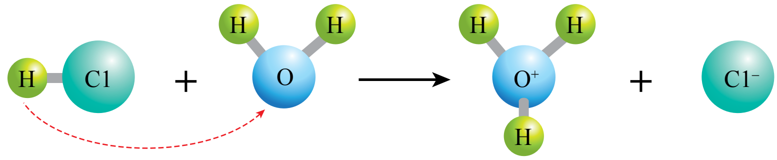


Figure 6.2 *Formation of hydroxonium ion, H_3O^+*

Learning Standard

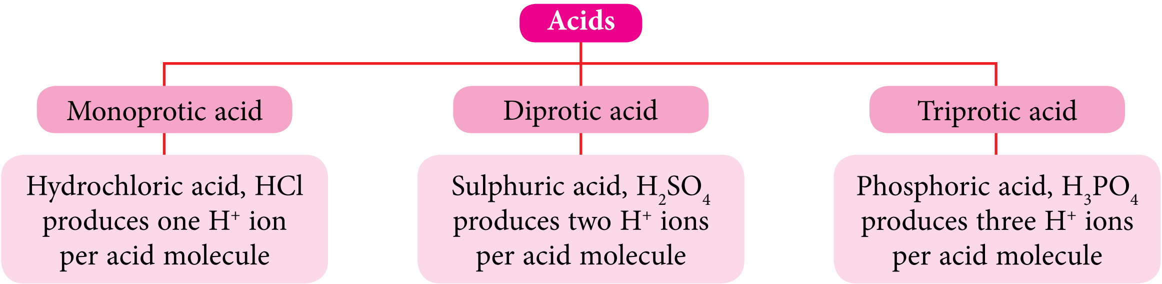
At the end of the lesson, pupils are able to:
6.1.1 Define acid and alkali
6.1.2 State the meaning of basicity of an acid
6.1.3 Investigate the role of water in showing acidic and alkaline properties through experiment

Chemistry Lens

Although hydroxonium ions, H_3O^+ are the actual ions existing in the aqueous solution that gives the acidic properties, to simplify explanation, we often use hydrogen ion, H^+ to represent hydroxonium ions, H_3O^+.

Basicity of Acids

Basicity of acids refers to the **number of hydrogen ions, H^+** that can be produced by an acid molecule that ionises in water. Hydrochloric acid, HCl is monoprotic acid because it can produce one hydrogen ion, H^+ per acid molecule. How about diprotic acid and triprotic acid?



Acids

Monoprotic acid

Hydrochloric acid, HCl produces one H^+ ion per acid molecule

Diprotic acid

Sulphuric acid, H_2SO_4 produces two H^+ ions per acid molecule

Triprotic acid

Phosphoric acid, H_3PO_4 produces three H^+ ions per acid molecule

Figure 6.3 *The classification of acids based on the basicity of the acids*

Formic acid, HCOOH is used in the coagulation of latex. Is formic acid, HCOOH a diprotic acid? Why?

Alkalis

Base is a substance that reacts with acids to produce **salt and water** only. Metal oxides and metal hydroxides are bases. For example, magnesium oxide, MgO and calcium hydroxide, $Ca(OH)_2$ are bases because they react with acids to produce salt and water only.

$$MgO(s) + H_2SO_4(aq) \rightarrow \underset{\text{Salt}}{MgSO_4(aq)} + H_2O(l)$$

$$Ca(OH)_2(aq) + 2HNO_3(aq) \rightarrow \underset{\text{Salt}}{Ca(NO_3)_2(aq)} + 2H_2O(l)$$

Brain Teaser

Observe the chemical equation below.
$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
Is magnesium a base? Why?

A base that is soluble in water is called an **alkali**. Potassium hydroxide, KOH and sodium hydroxide, NaOH are alkalis because they are soluble in water. When sodium hydroxide pellets, NaOH is dissolved in water, sodium ions, Na^+ and hydroxide ions, OH^- that can move freely in water are produced.

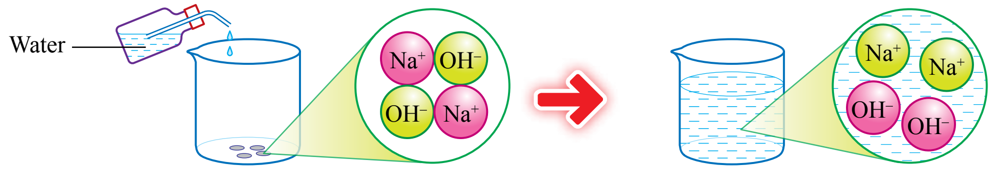
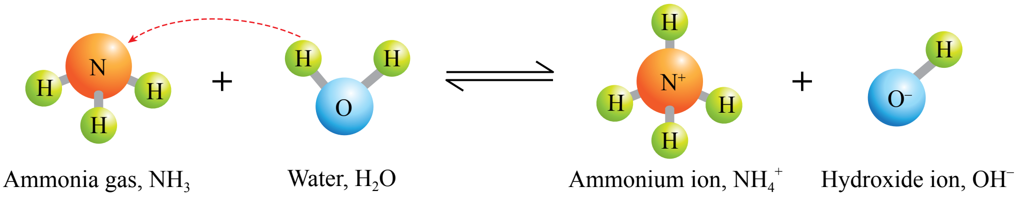


Figure 6.4 *Dissociation of sodium hydroxide, NaOH into ions that move freely in water*

An alkali is defined as follows:

Chemical substances that ionise in water to produce hydroxide ions, OH^-.

What will happen to ammonia molecule when ammonia gas is dissolved in water? Why is aqueous ammonia produced an alkali?



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

Figure 6.5 *Formation of hydroxide ion, OH^- from ammonia molecule*

By dissolving ammonia gas in water, aqueous ammonia is produced. Aqueous ammonia is an alkali because the ammonia molecules ionise partially to produce hydroxide ions, OH^-.

Uses of Acids, Bases and Alkalis

Acids, bases and alkalis are not just chemical substances in the laboratory but they are also widely found in daily life. Toothpaste which is alkaline, functions to neutralise acid on the teeth, while vinegar is an acidic substance used to make pickled chillies.

Photograph 6.1 *Uses of acid and alkali in daily life*

Activity 6.1

Discussing the uses of acids and alkalis in daily life using examples of acidic and alkaline substances

21st Century Skills CT

1. Carry out the activity in groups.
2. Gather information from reading materials or websites on examples of acidic and alkaline substances as well as their uses in various fields.

Agriculture

Industries

Medicine

Food industry

3. Based on the information gathered, discuss the followings:
   (a) Identify the acid, base or alkali in each substance that you have found
   (b) State the use of acid, base or alkali found in the substance
4. Pin up your group work on the bulletin board to share the information and references with the other groups.

The Role of Water to Show Acidity and Alkalinity

Figure 6.6 *Role of water to show alkalinity*

Based on the conversation in Figure 6.6, why is the water added to the soap? Is water needed to allow acids or alkalis to show acidic or alkaline properties?

Experiment 6.1

Aim: To study the role of water in showing acidic properties.

Problem statement: Is water needed to allow an acid to show its acidic properties?

Hypothesis: Water is needed for an acid to show its acidic properties.

Variables:

(a) Manipulated : Presence of water
(b) Responding : Colour change on blue litmus paper
(c) Fixed : Type of acid

Materials: Solid oxalic acid, $C_2H_2O_4$, distilled water and blue litmus paper

Apparatus: Test tubes and test tube rack

Procedure:

1. Add a spatula of solid oxalic acid, $C_2H_2O_4$ in a test tube.
2. Insert a piece of dry blue litmus paper into the test tube.

3. Observe any changes to the colour of the blue litmus paper. Record your observations.
4. After that, add 2 cm^3 distilled water and shake well.
5. Observe any changes to the colour of the blue litmus paper. Record your observations.

CAUTION

Acid is corrosive. Be careful when handling acid. If in contact with acid, run continuous flow of water on the affected area.

Results:

Table 6.1

Contents	Observations
Solid oxalic acid, $C_2H_2O_4$	
Solid oxalic acid, $C_2H_2O_4$ + water	

Interpreting data:

1. State the change in colour of the blue litmus paper that is used to detect acidic properties.
2. Based on the observations, state a suitable inference.
3. What are the conditions needed for an acid to show its acidic properties?

Conclusion:

Is the hypothesis acceptable? What is the conclusion of this experiment?

Discussion:

1. Name the ion that is responsible for showing the acidic properties.
2. Solid oxalic acid, $C_2H_2O_4$ had differences in observation compared to the solid oxalic acid, $C_2H_2O_4$ that has been dissolved in water. Give a reason.
3. What is the operational definition for **acid** in this experiment?

Prepare a complete report after carrying out this experiment.

Acids only show acidic properties in the presence of water. When an acid is dissolved in water, acid molecules will ionise to produce hydrogen ions, H^+. The presence of hydrogen ions H^+ allows the acid to show its acidic properties. Therefore, blue litmus paper changes to red. Without water, solid oxalic acid, $C_2H_2O_4$ only exist as molecules. Hydrogen ions, H^+ are not present. Thus, the colour of blue litmus paper remains unchanged.

Literacy Tips

Reflect on the properties of acid:
- Sour taste
- Corrosive
- Has pH value less than 7
- Changes moist blue litmus paper to red

Experiment 6.2

Aim: To study the role of water in showing alkaline properties.

Problem statement: Is water needed to allow an alkali to show its alkaline properties?

Hypothesis: Make a suitable hypothesis for this experiment.

Variables: State all the variables involved in this experiment.

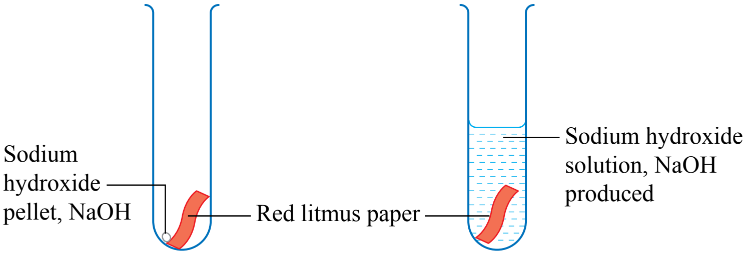


Figure 6.7 Method to test the alkaline properties of sodium hydroxide, NaOH

CAUTION

Sodium hydroxide, NaOH is corrosive. A pellet of sodium hydroxide, NaOH is sufficient to carry out this experiment. If in contact with the alkaline solution, run water over the area continuously until it no longer feels slippery.

Procedure:

1. Based on Figure 6.7, list out the apparatus and materials required for this experiment.
2. Plan the procedure for this experiment with your group members.
3. Determine the method used to collect data and prepare a suitable table.
4. Carry out the experiment with your teacher's permission.
5. Record your observations in the table provided.

Results:

Record your observation in a table.

Interpreting data:

1. Based on the observations, state a suitable inference.
2. What is the condition of the litmus paper needed to detect alkaline properties?

Conclusion:

Is the hypothesis acceptable? What is the conclusion of this experiment?

Discussion:

1. Name the ion responsible to show alkaline properties.
2. Explain the difference in observation between using a pellet of sodium hydroxide, NaOH and sodium hydroxide solution, NaOH.
3. Give the operational definition for **alkali** in this experiment.

Prepare a complete report after carrying out this experiment.

Akalis only shows alkaline properties when they are dissolved in water. Without water, hydroxide ions, OH^- in the sodium hydroxide pellet, NaOH cannot move freely and are still tied in its lattice structure. So, the pellet of sodium hydroxide, NaOH does not show alkaline properties. The red litmus paper cannot change colour. When a pellet of sodium hydroxide, NaOH is dissolved in water, hydroxide ions, OH^- are produced and able to move freely in water. Thus, sodium hydroxide solution, NaOH shows alkaline properties. Hence, the moist red litmus paper turns blue.

Literacy Tips

Reflect on the properties of an alkali:
- Tastes bitter and feels slippery
- Corrosive
- Has pH value more than 7
- Changes moist red litmus paper to blue

The presence of water also enables ammonia gas, NH_3 to ionise and produce hydroxide ions, OH^- that are responsible for its alkaline properties. Therefore, the moist red litmus paper turns blue. Without water, ammonia gas, NH_3 only exists as molecules. Hydroxide ions, OH^- are not present. So, red litmus paper remains unchanged.

Test Yourself 6.1

1. State the meaning of the following terms:
   (a) Acid
   (b) Alkali
2. Carbonic acid is a mineral acid with the formula, H_2CO_3. What is the basicity of carbonic acid? Explain why.
3. Figure 6.8 shows a conversation between Khairul and his teacher.

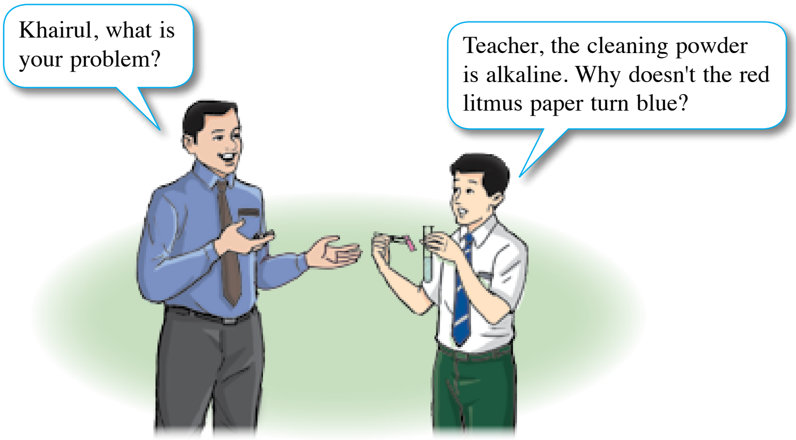


Figure 6.8

   (a) What possible mistake was committed by Khairul in his test?
   (b) How can you help Khairul in his test? Explain why.

6.2 pH Value

The pH Values of Acids and Alkalis

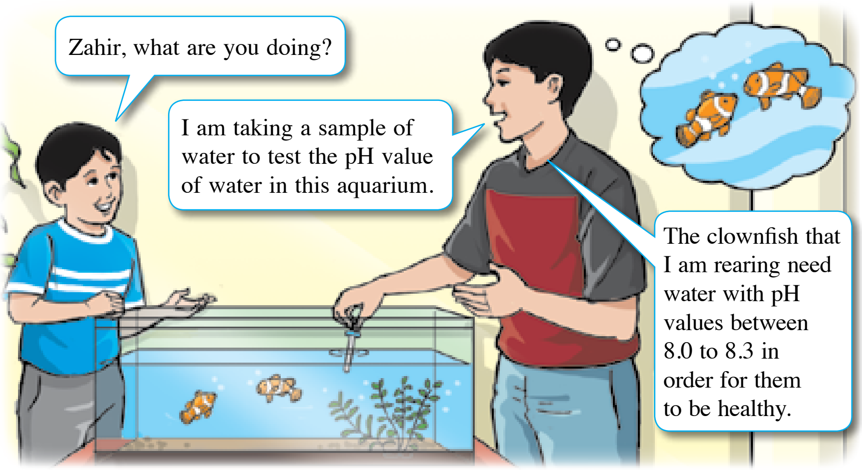


Figure 6.9 *Clownfish need water with specific pH values*

Learning Standard

At the end of the lesson, pupils are able to:

- 6.2.1 State the meaning of pH and its uses
- 6.2.2 Calculate pH values of acids and alkalis
- 6.2.3 Investigate the relationship between pH value and the concentration of hydrogen ions and hydroxide ions through experiment

Based on the pH value mentioned by Zahir, do clownfish require acidic or alkaline water? Why do you say so?

The pH scale which ranges from 0 to 14 is used to show the acidity and alkalinity of an aqueous solution. Solutions with pH **value less than 7** is **acidic** while solutions with pH value **more than 7** is **alkaline**. Universal indicator, pH meter or pH paper is commonly used to determine the pH value. Referring to Figure 6.10, what is the relationship between pH value and degree of acidity or alkalinity?

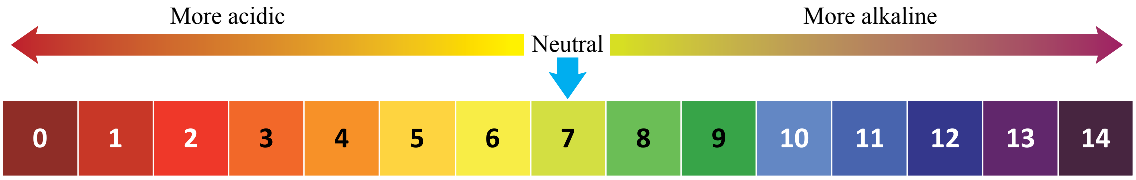


Figure 6.10 *The pH scale*

What is actually 'pH'? In chemistry, pH is a logarithmic measure of the **concentration of hydrogen ions** in an **aqueous solution**.

$$\boxed{pH = -\log [H^+]}$$

where log is logarithm of base 10 and $[H^+]$ is the concentration of hydrogen ions in mol dm^{-3} of the solution. Using that formula, we can determine the pH value of an acid by calculation.

Example 1

Calculate the pH value of nitric acid, HNO_3 with 0.5 mol dm^{-3} of hydrogen ion, H^+.

Solution

Given the concentration of H^+ = 0.5 mol dm^{-3}

$$\begin{aligned} pH &= -\log [0.5] \longleftarrow \text{Use the formula } pH = -\log [H^+] \\ &= -(-0.301) \\ &= 0.301 \end{aligned}$$

pH value of nitric acid, HNO_3 = 0.3

Example 2

Determine the molarity of hydrochloric acid, HCl with pH value of 2.0.

Solution

$$\begin{aligned} pH &= -\log [H^+] \\ 2.0 &= -\log [H^+] \\ \log [H^+] &= -2.0 \\ [H^+] &= 10^{-2} \\ &= 0.01 \text{ mol dm}^{-3} \end{aligned}$$

Molarity of hydrochloric acid, HCl = 0.01 mol dm^{-3}

The concentration of hydroxide ion, OH^- is used to calculate the value of pOH of an alkali based on the following formula, where $[OH^-]$ represents the concentration of hydroxide ions in mol dm^{-3} of the alkali solution.

$$pOH = -\log [OH^-]$$

Given that the sum of pH value and pOH value is 14, the pH value of an alkali can be calculated by using the following relationship:

$$\begin{aligned} pH + pOH &= 14 \\ pH &= 14 - pOH \end{aligned}$$

Example 3

Calculate the pOH value for sodium hydroxide solution, NaOH with 0.1 mol dm^{-3} hydroxide ions, OH^-.

Solution

Given that the concentration of hydroxide ion, OH^- = 0.1 mol dm^{-3}

$$\begin{aligned} pOH &= -\log [0.1] \longleftarrow \text{Use the formula } pOH = -\log [OH^-] \\ &= -(-1) \\ &= 1 \end{aligned}$$

pOH value of sodium hydroxide solution, NaOH = 1.0

Example 4

Calculate the pH value for potassium hydroxide, KOH that has 0.01 mol dm^{-3} hydroxide ions, OH^-.

Solution

Given concentration of hydroxide ion, OH^- = 0.01 mol dm^{-3}

$$\begin{aligned} pOH &= -\log [0.01] \\ &= -(-2) \\ &= 2 \end{aligned}$$

Use the formula $pOH = -\log [OH^-]$

pOH value of potassium hydroxide solution, KOH = 2.0

$$\begin{aligned} \text{pH value of potassium hydroxide solution, KOH} &= 14.0 - pOH \\ &= 14.0 - 2.0 \\ &= 12.0 \end{aligned}$$

Consider the relationship:
$pH + pOH = 14$

Example 5

Determine the molarity of lithium hydroxide solution, LiOH with pH value 12.0.

Solution

$$\begin{aligned} pH + pOH &= 14.0 \\ 12.0 + pOH &= 14.0 \\ pOH &= 14.0 - 12.0 \\ &= 2.0 \\ pOH &= -\log [OH^-] \\ 2.0 &= -\log [OH^-] \\ \log [OH^-] &= -2.0 \\ [OH^-] &= 10^{-2} \\ &= 0.01 \text{ mol dm}^{-3} \end{aligned}$$

Molarity of lithium hydroxide solution, LiOH = 0.01 mol dm^{-3}

Did you know that the decimal place of pH is related to the significant numbers in the concentration of hydrogen ions given?

If the value of given concentration has two significant numbers, the pH value should be rounded to two decimal places.

The pH value can be calculated based on the concentration of hydrogen ions, H^+ in an acid, or the concentration of hydroxide ions, OH^- in an alkali. So, the pH scale allows us to compare the concentration of hydrogen ions, H^+ or the hydroxide ions, OH^- in an aqueous solution. The relationship between hydrogen ions, H^+ or hydroxide ions, OH^- with the pH value can be studied in Experiment 6.3.

Experiment 6.3

Aim: To study the relationship between the concentration of hydrogen ions, H^+ and pH value of acid.

Problem statement: Does the concentration of hydrogen ions, H^+ of an acid affect its pH value?

Hypothesis: The higher the concentration of hydrogen ion, H^+, the lower the pH value of the acid.

Variables:

(a) Manipulated : Concentration of hydrogen ions, H^+
(b) Responding : pH value
(c) Fixed : Type of acid

Materials: 0.1 mol dm^{-3}, 0.01 mol dm^{-3} and 0.001 mol dm^{-3} hydrochloric acid, HCl

Apparatus: 100 cm^3 beaker and pH meter

Procedure:

1. Pour 20 cm^3 of hydrochloric acid, HCl of different concentrations into three beakers.
2. Measure the pH value of each hydrochloric acid, HCl with the pH meter.
3. Record the pH values in Table 6.2.

Results:

Table 6.2

Concentration of hydrochloric acid, HCl (mol dm^{-3})	0.1	0.01	0.001
Concentration of hydrogen ions, H^+ (mol dm^{-3})			
pH value			

Interpreting data:

1. Based on the results obtained, how does the pH value change when the concentration of hydrochloric acid, HCl decreases?
2. State the changes in the concentration of hydrogen ions, H^+ when the concentration of hydrochloric acid, HCl decreases.
3. What is the relationship between the concentration of hydrogen ions, H^+ and pH value?

Conclusion:

Is the hypothesis acceptable? What is the conclusion of this experiment?

Discussion:

1. When an acidic solution is diluted, what are the changes in the:
   (a) Concentration of hydrogen ions, H^+?
   (b) pH value?
   (c) Degree of acidity of the aqueous solution?
2. State the relationship between the concentration of hydrogen ions, H^+, pH values and degree of acidity of an acidic aqueous solution.

Prepare a complete report after carrying out this experiment.

Experiment 6.4

Aim: To study the relationship between the concentration of hydroxide ions, OH^- and pH value of an alkali.

Problem statement: Does the concentration of hydroxide ions, OH^- of an alkali affect its pH value?

Hypothesis: Make a suitable hypothesis for this experiment.

Variables: State all variables involved in this experiment.

Materials: 0.1 mol dm^{-3}, 0.01 mol dm^{-3} and 0.001 mol dm^{-3} sodium hydroxide solution, NaOH

Apparatus: 100 cm^3 beaker and pH meter

Procedure:

1. Plan the procedure to measure the pH value of sodium hydroxide solution, NaOH.
2. Your plan should include the pH meter.
3. Carry out the experiment with your teacher's permission.
4. Record the pH values obtained in your report book.

Results:

Record the pH values in a table.

Interpreting data:

1. Based on the data obtained, how does the pH value change when the concentration of sodium hydroxide solution, NaOH decreases?
2. When the concentration of sodium hydroxide solution, NaOH decreases, what are the changes that occur to the:
   (a) Concentration of hydroxide ions, OH^-?
   (b) pH value?
   (c) Degree of alkalinity of sodium hydroxide solution, NaOH?
3. State the relationship between the concentration of hydroxide ions, OH^-, pH value and degree of alkalinity of sodium hydroxide, solution NaOH.

Conclusion:

Is the hypothesis acceptable? What is the conclusion of this experiment?

Prepare a complete report after carrying out this experiment.

When the concentration of acid increases, more acid molecules ionise to produce hydrogen ions, H^+. The higher the concentration of hydrogen ions, H^+, the lower the pH value. Acidity increases when the pH value of the acid solution decreases.

Concentration of hydrogen ions, H^+ ↑, pH value ↓

On the other hand, the higher the concentration of hydroxide ions, OH^-, the higher the pH value. Alkalinity increases when the pH value of the alkaline solution increases.

Concentration of hydroxide ions, OH^- ↑, pH value ↑

Most substances found in our daily lives contain acids or alkalis. The determination of pH values for these substances can be done in Activity 6.2.

Chemistry & Us

Purple cabbages change colour at different pH values.

Activity 6.2

Determining the pH values of various items in daily life

1. You are supplied with the following items:
    - Soap water
    - Lime juice
    - Milk tea
    - Coffee
    - Carbonated drink
    - Tap water
2. In pairs, measure the pH value of each item using the universal indicator.
3. Record the items with similar pH values.
4. Prepare a pH indicator using a purple cabbage. Visit websites to know how to prepare this pH indicator. Use the pH indicator that you have prepared to measure the pH value of each of the above items.
5. Using a suitable graphic management tools, present your findings.
6. Pin up your work in class to share with others.

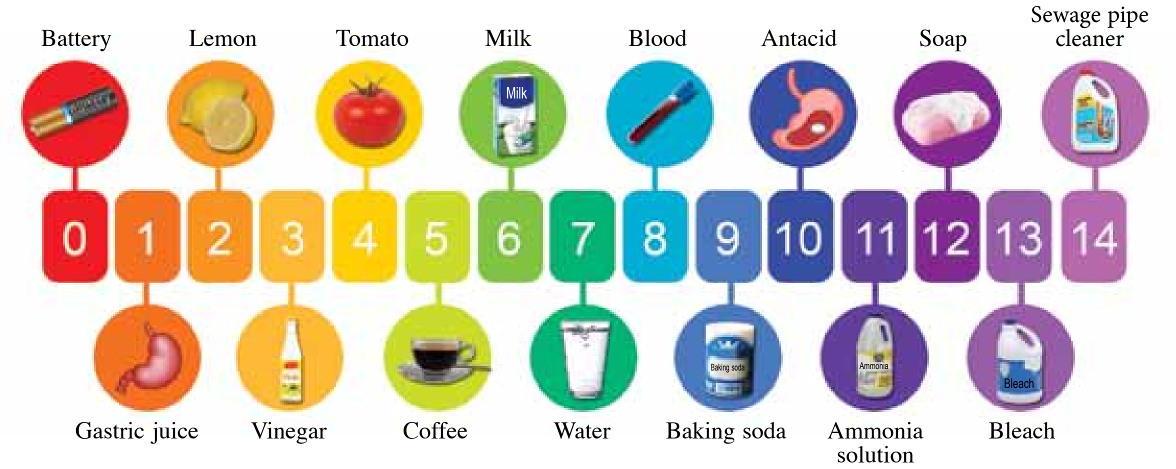


Figure 6.11 The pH value of few items in daily life tested with the universal indicator

Test Yourself 6.2

1. Write the formula to calculate the pH value of acid.
2. Calculate the pH value for hydrochloric acid, HCl that contains 0.001 mol dm^{-3} hydrogen ions, H^+.
3. Determine the pH value for calcium hydroxide, $Ca(OH)_2$ with concentration of 0.05 mol dm^{-3}. [pH + pOH = 14].

6.3 Strength of Acids and Alkalis

Observe Figure 6.12. What is meant by a strong acid and a weak acid?

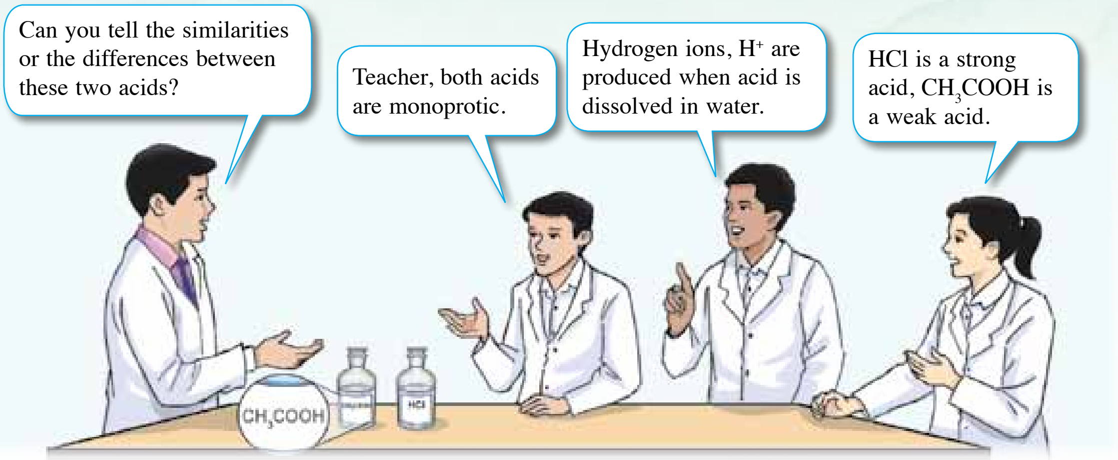


Figure 6.12 Similarities and differences between two acids

Strong Acids and Weak Acids

The strength of an acid depends on the degree of dissociation or ionisation of the acid in water.

Strong Acids

A **strong acid** is an acid that **ionises completely** in water to produce a high concentration of hydrogen ions, H^+. Hydrochloric acid, HCl is a strong acid because **all molecules** of hydrogen chloride, HCl that dissolve in water are **ionised completely** to hydrogen ions, H^+ and chloride ions, Cl^-. No molecule of hydrogen chloride, HCl exists in this solution.

$$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

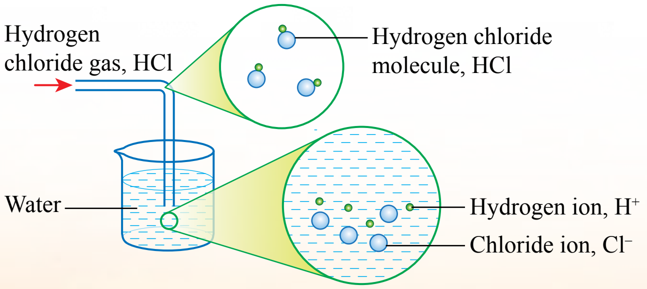


Figure 6.13 Complete ionisation of hydrogen chloride, HCl

Learning Standard

At the end of the lesson, pupils are able to:

6.3.1 Define strong acid, weak acid, strong alkali and weak alkali
6.3.2 Explain the strength of acid and alkali based on its degree of dissociation in water

Chemistry Lens

Hydrogen ions, H^+ produced from acid molecules will combine with water molecules to form hydroxonium ions, H_3O^+. The hydroxonium ions, H_3O^+ is the product of a dative bond formed between hydrogen ion, H^+ with water molecule.

Weak Acids

A **weak acid** is an acid that **ionises partially** in water to produce low concentration of hydrogen ions, H^+. Ethanoic acid, CH_3COOH is a weak acid because the molecules of ethanoic acid, CH_3COOH **ionise partially** in water. The degree of dissociation of ethanoic acid molecules is 1.54%. In other words, from 100 molecules of ethanoic acid, CH_3COOH, only one molecule of ethanoic acid, CH_3COOH ionises to hydrogen ions, H^+ and ethanoate ions, CH_3COO^-. The rest still exist as molecules of ethanoic acid, CH_3COOH.

$$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$$

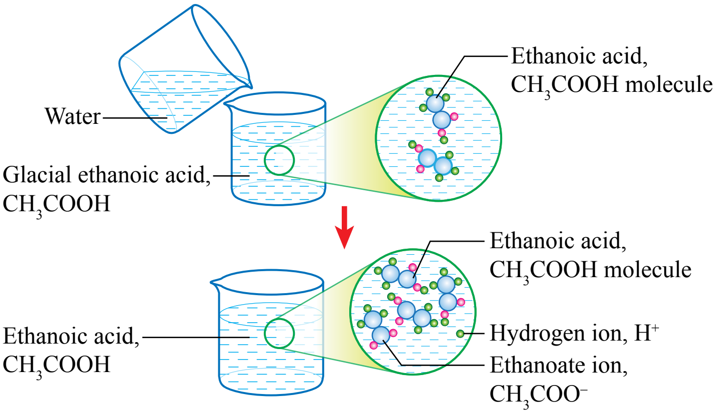


Figure 6.14 Partial ionisation of ethanoic acid, CH_3COOH

The reversible arrow shows that ethanoic acid, CH_3COOH molecule can form hydrogen ions, H^+ and ethanoate ions, CH_3COO^-. These ions can also combine again to form the acid molecules.

Strong Alkalis and Weak Alkalis

Alkalis also consist of strong alkalis and weak alkalis depending on their degree of ionisation in water.

Strong Alkalis

A **strong alkali** is an alkali that **ionises completely** in water to produce a high concentration of hydroxide ions, OH^-. Sodium hydroxide, NaOH is a strong alkali that undergoes complete dissociation when dissolved in water. Only sodium ions, Na^+ and hydroxide ions, OH^- are present in the solution.

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

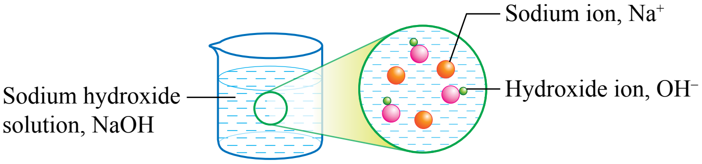


Figure 6.15 Complete ionisation of sodium hydroxide solution, NaOH

Literacy Tips

Dissociation is also known as ionisation.

Weak Alkalis

A **weak alkali** is an alkali that **ionises partially** in water to produce a low concentration of hydroxide ions, OH^-. Ammonia solution, NH_3 is a weak alkali because ammonia molecules, NH_3 ionise partially in water. The degree of dissociation of ammonia, NH_3 is 1.3%. In other words, from 100 molecules of ammonia, NH_3 only one molecule of ammonia, NH_3 will receive hydrogen ion, H^+ from water molecule. So, only a small number of hydroxide ions, OH^- is present in the solution.

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

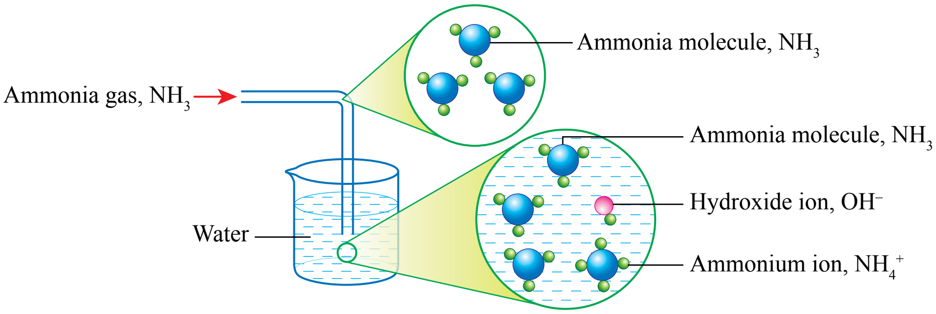


Figure 6.16 *Partial ionisation of ammonia solution, NH_3*

Activity 6.3

Carry out a simulation to explain the strength of acids and alkalis

21st Century Skills CT

1. Visit the website given.
2. Vary the regulator for acid strength and observe the degree of dissociation and number of hydrogen ions, H^+ present.
3. Repeat step 2 for alkali and observe the degree of dissociation and number of hydroxide ions, OH^- present.
4. Interpret the information on strength of acids and alkalis based on the degree of dissociation.
5. Relate the concentration of hydrogen ions, H^+ and hydroxide ions, OH^- with the degree of dissociation of the acid and alkali.
6. Display your findings in an interesting presentation.

Simulation on acid and alkali

http://bit.ly/31cGoMQ

Test Yourself 6.3

1. Give the meaning of the following terms:
   (a) Strong acid
   (b) Weak acid
   (c) Strong alkali
   (d) Weak alkali
2. Why does ammonia solution, NH_3 that has the same concentration as potassium hydroxide, KOH have a lower pH value?
3. The pH value 0.1 mol dm^{-3} nitric acid, HNO_3 is different from the pH value 0.1 mol dm^{-3} oxalic acid, $H_2C_2O_4$? Explain.

6.4 Chemical Properties of Acids and Alkalis

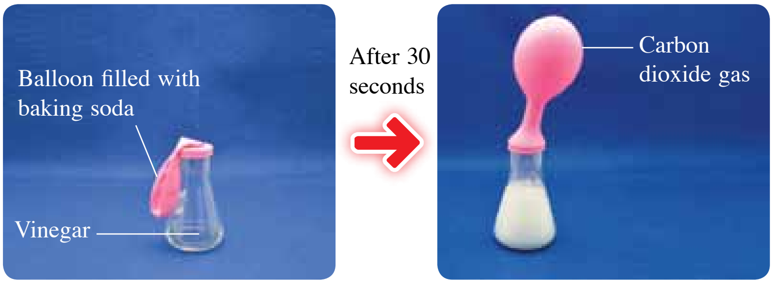


Figure 6.17 *To inflate the balloon using vinegar and baking soda*

Have you ever inflated a balloon using vinegar and baking soda? Is this process related to the chemical properties of acid?

Chemical Properties of Acid

The properties of acid is divided into **physical** and **chemical properties**. The properties of acid such as having a sour taste, changing moist blue litmus paper to red and having pH values less than 7 are the physical properties of acid. The chemical properties of acid on the other hand refer to the reactions between acid and other substances. Carry out activity 6.4 to study the chemical properties of acid.

Learning Standard

At the end of the lesson, pupils are able to:

6.4.1 Summarise the chemical properties of acids by carrying out the reactions between:
  - Acid and base
  - Acid and reactive metal
  - Acid and metal carbonate

6.4.2 Summarise the chemical properties of alkalis by carrying out the reactions between:
  - Alkali and acid
  - Alkali and metal ion
  - Alkali and ammonium salt

Balloon inflation

http://bit.ly/2Mh3M7y

Activity 6.4

Aim: To study the chemical properties of acids.

Materials: Copper(II) oxide powder, CuO, zinc powder, Zn, marble chips, $CaCO_3$, 1.0 mol dm^{-3} sulphuric acid, H_2SO_4, 2.0 mol dm^{-3} nitric acid, HNO_3, 2.0 mol dm^{-3} hydrochloric acid, HCl, limewater, wooden splinter and filter papers

Apparatus: 100 cm^3 beaker, glass rod, filter funnel, retort stand with clamp, evaporating dish, Bunsen burner, pipeclay triangle, delivery tube and rubber stopper, tripod stand, spatula, test tubes and test tube holder

A Reaction between acid and base

Procedure:

1. Pour 20 cm^3 of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 into a beaker. Heat the acid by using a small flame.
2. Add copper(II) oxide powder, CuO gradually into the acid by using a spatula. Stir the mixture with a glass rod.
3. Observe the change that takes place on copper(II) oxide, CuO that reacts with acid. Record your observation on the solution produced.

4. Continue adding copper(II) oxide powder, CuO until it can no longer dissolve.
5. Filter out the excess copper(II) oxide, CuO from the mixture.
6. Pour the filtrate into an evaporating dish and heat the filtrate until one third of its initial volume remains.
7. Allow the saturated solution produced to cool until salt crystals are formed.
8. Filter the contents of the evaporating dish to obtain the salt crystals. Rinse the crystals with distilled water.
9. Dry the salt crystals between two pieces of filter papers.
10. Observe the physical properties of the salt crystals and record your findings.

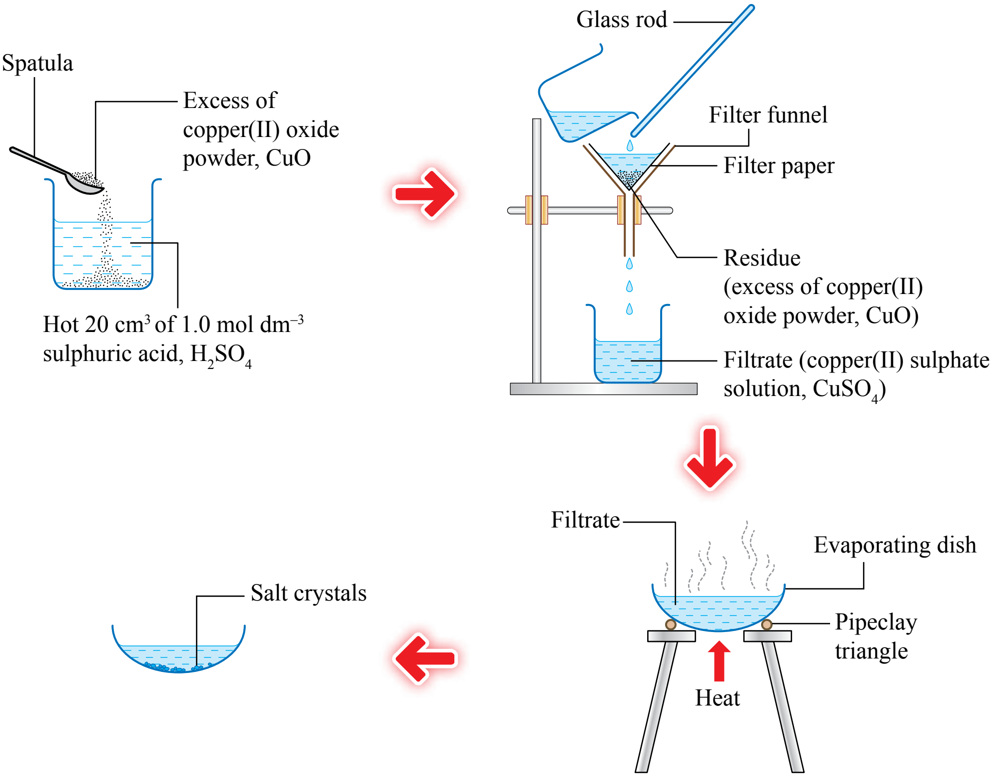


Figure 6.18 *Preparation of salt crystals from the reaction between acid and base*

Discussion:

1. What happens to the copper(II) oxide powder, CuO when added to sulphuric acid, H_2SO_4?
2. What is the colour of the solution produced from the reaction between sulphuric acid, H_2SO_4 and copper(II) oxide, CuO?
3. Write a chemical equation for the reaction between sulphuric acid, H_2SO_4 and copper(II) oxide, CuO.
4. From the chemical equation written above, complete the following equation in words:

Acid + Base → ☐ + ☐

B Reaction between acid and reactive metal

Procedure:

1. Plan a procedure to study the reaction between hydrochloric acid, HCl and zinc powder, Zn as shown in Figure 6.19.

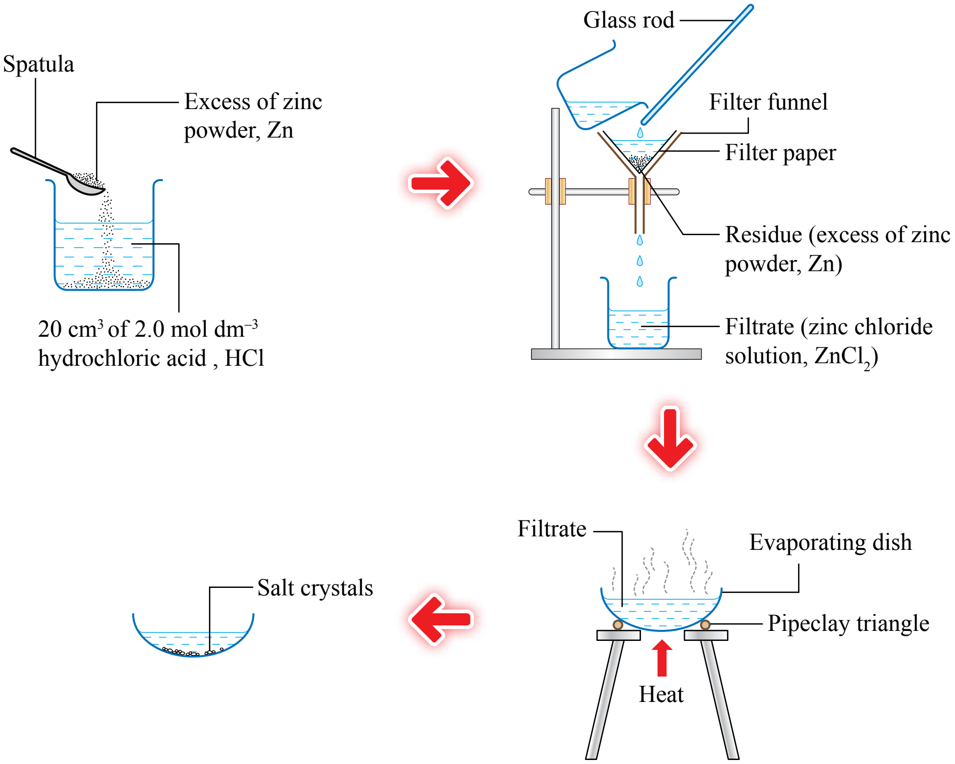


Figure 6.19 *Preparation of salt crystals from the reaction between acid and reactive metal*

2. Discuss with your teacher if you have encountered any problems when planning the procedure.
3. Make sure that you carry out the chemical test on the gas released as shown in Figure 6.20.
4. Carry out this test with your teacher's permission.
5. Record your observations.

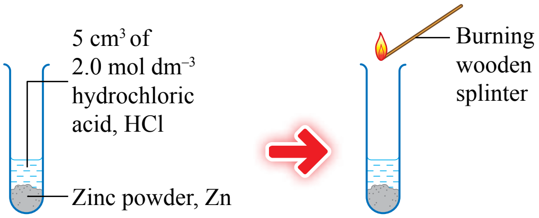


Figure 6.20

Discussion:

1. What is the observation that indicates acid has reacted with metal when zinc powder, Zn is added to hydrochloric acid, HCl?
2. Name the gas released in this activity.
3. Write a chemical equation for the reaction between hydrochloric acid, HCl and zinc, Zn.
4. From the chemical equation written above, complete the following equation in words:

Acid + Reactive metal → ▭ + ▭

Ⓒ Reaction between acid and metal carbonate

Procedure:

1. Plan a procedure to carry out this activity to study the reaction between nitric acid, HNO_3 and marble chips, $CaCO_3$.
2. Include safety measures taken in your procedure.
3. Discuss with your teacher if you have encountered any problems when planning the procedure.
4. Make sure that you carry out the chemical test on the gas released as shown in Figure 6.21.

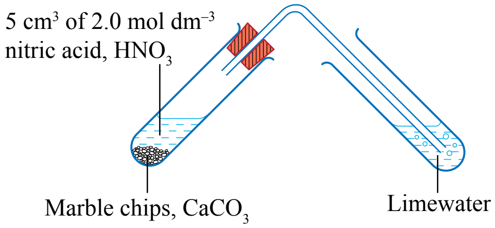


Figure 6.21

5. Carry out this test with your teacher's permission.
6. Record your observations.

Discussion:

1. What is the reason for using excess marble chips, $CaCO_3$ to react with nitric acid, HNO_3?
2. How do you remove the excess marble chips, $CaCO_3$ from the salt solution produced?
3. For the reaction in this activity:
   (a) Name the salt produced
   (b) Name the gas released
4. Write a chemical equation for the reaction between nitric acid, HNO_3 and marble chips, $CaCO_3$.
5. From the chemical equation written above, complete the following equation in words:

Acid + Metal carbonate → ☐ + ☐ + ☐

Prepare a complete report after carrying out this activity.

From Activity 6.4 that was carried out, it can be summarised that acids have the following chemical properties:

- ☆ Acids react with bases to produce salt and water
- ☆ Acids react with reactive metals to produce salt and hydrogen gas, H_2
- ☆ Acids react with metal carbonates to produce salt, water and carbon dioxide gas, CO_2

Chemical Properties of Alkalis

Chemical properties of alkalis can be determined through Activity 6.5.

Activity 6.5

Aim: To study the chemical properties of alkali.

Materials: Benzoic acid powder, C_6H_5COOH, 1.0 mol dm^{-3} sodium hydroxide solution, NaOH, ammonium chloride powder, NH_4Cl, copper(II) sulphate solution, $CuSO_4$, distilled water, filter paper and red litmus paper

Apparatus: 100 cm^3 beaker, glass rod, filter funnel, retort stand with clamp, evaporating dish, Bunsen burner, pipeclay triangle, tripod stand, dropper, spatula, test tube, boiling tube and test tube holder

Figure 6.22, Figure 6.23 and Figure 6.24 show three reactions involving alkalis.

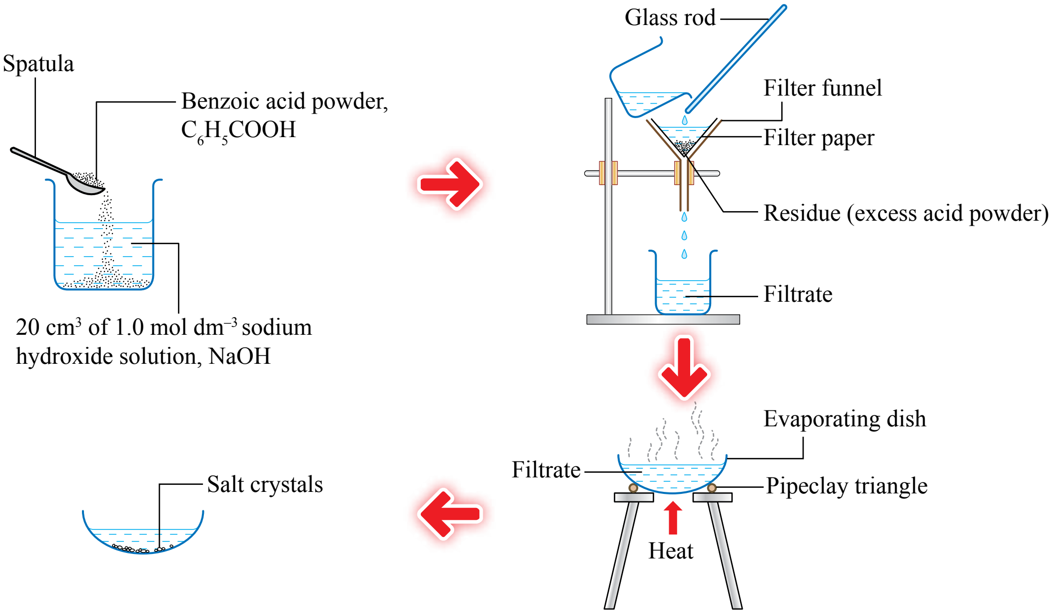


Figure 6.22 *Preparation of salt crystals from the reaction between alkali and acid*

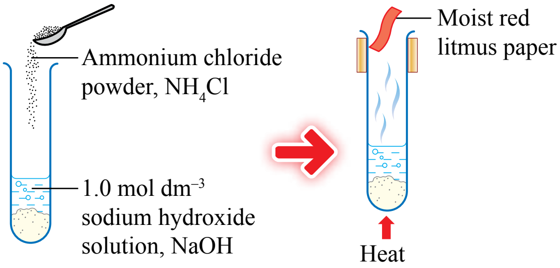


Figure 6.23 *Heating the mixture of alkali and ammonium salt to produce ammonia gas*

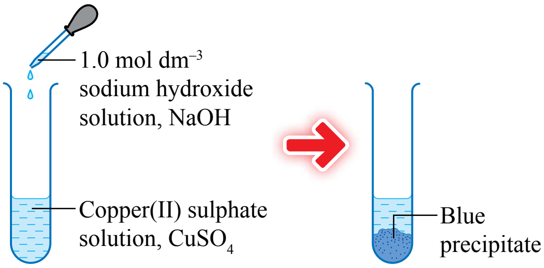


Figure 6.24 *Addition of alkali to metal ions to produce insoluble metal hydroxide precipitate*

Procedure:

1. Based on Figure 6.22 to Figure 6.24, plan a laboratory activity to study the chemical properties of alkalis.
2. Plan and write out the procedure for the laboratory activity to be discussed with your teacher.
3. Record your observations in a report book.
4. Write an equation in words to summarise the chemical properties of alkalis.

Prepare a complete report after carrying out this activity.

From Activity 6.5 that was carried out, we can summarise that alkalis have the following chemical properties:

- ☆ Alkalis react with acids to produce salt and water
- ☆ When a mixture of alkali and ammonium salt is heated, ammonia gas, NH_3 is released
- ☆ Addition of an alkali to most metal ions, will produce an insoluble metal hydroxide precipitate

Table 6.3 summarises the chemical properties of acids and alkalis

***Table 6.3** Chemical properties of acids and alkalis*

Chemical properties of acids	☆ Acid + Base → Salt + Water
	Example: $\underset{\text{Nitric acid}}{2HNO_3(aq)} + \underset{\text{Copper(II) oxide}}{CuO(s)} \rightarrow \underset{\text{Copper(II) nitrate}}{Cu(NO_3)_2(aq)} + \underset{\text{Water}}{H_2O(l)}$
	☆ Acid + Reactive metal → Salt + Hydrogen gas
	Example: $\underset{\text{Sulphuric acid}}{H_2SO_4(aq)} + \underset{\text{Zinc}}{Zn(s)} \rightarrow \underset{\text{Zinc sulphate}}{ZnSO_4(aq)} + \underset{\text{Hydrogen gas}}{H_2(g)}$
	☆ Acid + Metal carbonate → Salt + Water + Carbon dioxide gas
	Example: $\underset{\text{Hydrochloric acid}}{2HCl(aq)} + \underset{\text{Calcium carbonate}}{CaCO_3(s)} \rightarrow \underset{\text{Calcium chloride}}{CaCl_2(aq)} + \underset{\text{Water}}{H_2O(l)} + \underset{\text{Carbon dioxide gas}}{CO_2(g)}$
Chemical properties of alkalis	☆ Alkali + Acid → Salt + Water
	Example: $\underset{\text{Potassium hydroxide}}{2KOH(aq)} + \underset{\text{Sulphuric acid}}{H_2SO_4(aq)} \rightarrow \underset{\text{Potassium sulphate}}{K_2SO_4(aq)} + \underset{\text{Water}}{2H_2O(l)}$
	☆ Alkali + Ammonium salt → Salt + Water + Ammonia gas
	Example: $\underset{\text{Potassium hydroxide}}{KOH(aq)} + \underset{\text{Ammonium chloride}}{NH_4Cl(aq)} \rightarrow \underset{\text{Potassium chloride}}{KCl(aq)} + \underset{\text{Water}}{H_2O(l)} + \underset{\text{Ammonia gas}}{NH_3(g)}$
	☆ Alkali + Metal ion → Insoluble metal hydroxide + Cation from alkali
	Example: $\underset{\text{Sodium hydroxide}}{2NaOH(aq)} + \underset{\text{Magnesium ion}}{Mg^{2+}(aq)} \rightarrow \underset{\text{Magnesium hydroxide}}{Mg(OH)_2(s)} + \underset{\text{Sodium ion}}{2Na^+(aq)}$

Test Yourself 6.4

1. Write a chemical equation for the reaction between hydrochloric acid, HCl and:
   (a) Barium hydroxide, $Ba(OH)_2$
   (b) Magnesium, Mg
   (c) Zinc carbonate, $ZnCO_3$
2. Write an equation in words to summarise the reaction of an alkali solution and the following substances:
   (a) Dilute acids
   (b) Ammonium salts
   (c) Metal ions

6.5 Concentration of Aqueous Solution

Figure 6.25 *Concentration of tea affects its colour*

Learning Standard

At the end of the lesson, pupils are able to:
6.5.1 State the meaning of concentration of aqueous solution
6.5.2 Solve numerical problems involving concentration of solution

Concentration of a solution is a **measurement** that shows the **quantity of solute** dissolved in **a unit volume of solution**, normally in 1 dm^3 solution. The higher the quantity of solute, the higher the concentration of the solution. The quantity of solute dissolved can be measured in gram or mole, hence the concentration of a solution can be measured in unit **$g\ dm^{-3}$** or **$mol\ dm^{-3}$**.

- ☆ Concentration in unit $g\ dm^{-3}$, is the **mass of solute** found in 1 dm^3 solution.

$$\text{Concentration } (\text{g dm}^{-3}) = \frac{\text{Mass of solute (g)}}{\text{Volume of solution } (\text{dm}^3)}$$

- ☆ Concentration in unit $mol\ dm^{-3}$, is the **number of moles of solute** found in 1 dm^3 solution. This concentration is called **molarity**.

$$\text{Molarity } (\text{mol dm}^{-3}) = \frac{\text{Number of moles of solute (mole)}}{\text{Volume of solution } (\text{dm}^3)}$$

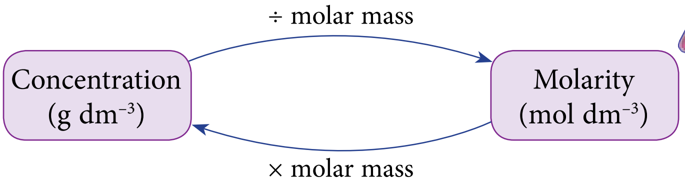


Figure 6.26 *Relationship between concentration and molarity*

Literacy Tips

The unit for molarity is mol dm^{-3} or molar (M). You have to remember that mole is not the same as molar. Mole is the unit for measuring matter while molar is the number of moles of solute in a given volume of solution.

Example 6

Calculate the concentration in g dm^{-3}, for each solution produced.

(a) 40 g of solid copper(II) sulphate, $CuSO_4$ is dissolved in water to produce 20 dm^3 solution.

(b) 18 g of sodium hydroxide pellets, NaOH is dissolved in water to produce 750 cm^3 solution.

Solution

(a) Concentration of copper(II) sulphate, $CuSO_4$

$$= \frac{\text{Mass of solute (g)}}{\text{Volume of solution (dm}^3\text{)}}$$

$$= \frac{40 \text{ g}}{20 \text{ dm}^3}$$

$$= 2.0 \text{ g dm}^{-3}$$

(b) Concentration of sodium hydroxide, NaOH

$$= \frac{\text{Mass of solute (g)}}{\text{Volume of solution(dm}^3\text{)}}$$

$$= \frac{18 \text{ g}}{0.75 \text{ dm}^3}$$

$$= 24.0 \text{ g dm}^{-3}$$

750 cm^3 is converted to dm^3 by dividing the volume with 1000. ➡ $\frac{750}{1000}$ dm^3 = 0.75 dm^3

Example 7

Calculate the molarity of each solution prepared.

(a) 10 mol of solid zinc chloride, $ZnCl_2$ dissolved in water to produce 5 dm^3 of solution.

(b) 0.1 mol of solid calcium chloride, $CaCl_2$ is dissolved in 500 cm^3 of distilled water.

Solution

(a) Molarity of zinc chloride solution, $ZnCl_2$

$$= \frac{\text{Number of moles of solute (mol)}}{\text{Volume of solution (dm}^3\text{)}}$$

$$= \frac{10 \text{ mol}}{5 \text{ dm}^3}$$

$$= 2.0 \text{ mol dm}^{-3}$$

(b) Molarity of calcium chloride solution, $CaCl_2$

$$= \frac{\text{Number of moles of solute (mol)}}{\text{Volume of solution (dm}^3\text{)}}$$

$$= \frac{0.1 \text{ mol}}{0.5 \text{ dm}^3}$$

$$= 0.2 \text{ mol dm}^{-3}$$

500 cm^3 is converted to dm^3 by dividing the volume with 1000. ➡ $\frac{500}{1000}$ dm^3 = 0.5 dm^3

Example 8

What is the concentration of nitric acid, HNO_3 with a molarity of 0.5 mol dm^{-3} in unit g dm^{-3}?
[Relative atomic mass: H = 1, N = 14, O = 16]

Solution

Concentration = Molarity × Molar mass HNO_3

$$= 0.5\text{ mol dm}^{-3} \times [\overset{\text{RAM H}}{1} + \overset{\text{RAM N}}{14} + \overset{\text{RAM O}}{3(16)}]\text{ g mol}^{-1}$$
$$= 0.5\text{ mol dm}^{-3} \times 63\text{ g mol}^{-1}$$
$$= 31.5\text{ g dm}^{-3}$$

Example 9

Convert the concentration of 3.6 g dm^{-3} lithium hydroxide solution, LiOH to molarity, mol dm^{-3}.
[Relative atomic mass: H = 1, Li = 7, O = 16]

Solution

$$\text{Molarity} = \frac{\text{Concentration}}{\text{Molar mass LiOH}}$$
$$= \frac{3.6\text{ g dm}^{-3}}{(\underset{\text{RAM Li}}{7} + \underset{\text{RAM O}}{16} + \underset{\text{RAM H}}{1})\text{ g mol}^{-1}}$$
$$= 0.15\text{ mol dm}^{-3}$$

We can calculate **number of moles** of solute dissolved in the solution if its molarity and the volume of the solution are known.

$$\text{Molarity} = \frac{\text{Number of moles of solute (mol)}}{\text{Volume of solution (dm}^3\text{)}}$$
$$M = \frac{n}{V}$$

Therefore, $\boxed{n = MV}$

Volume of solution is in **dm^3**.

If the volume of the solution is in cm^3, thus, unit of volume needs to be converted to dm^3.

$$n = M\left(\frac{V}{1000}\right)$$

Therefore, $\boxed{n = \frac{MV}{1000}}$

Volume of solution is in **cm^3**.

Example 10

Calculate the number of moles of potassium hydroxide, KOH found in 2 dm^3 of 0.5 mol dm^{-3} potassium hydroxide solution, KOH.

Solution

Number of moles, $n = MV$

$$= 0.5\text{ mol dm}^{-3} \times 2\text{ dm}^3$$
$$= 1\text{ mol KOH}$$

This formula is applied because the volume of solution is in **dm^3**.

Example 11

A beaker contains 200 cm^3 of 0.2 mol dm^{-3} lead(II) nitrate solution, $Pb(NO_3)_2$. How many moles of lead(II) nitrate, $Pb(NO_3)_2$, is in the beaker?

Solution

$$\text{Number of moles, } n = \frac{MV}{1000}$$

This formula is applied because the volume of solution is in **cm³**.

$$= \frac{0.2 \text{ mol dm}^{-3} \times 200 \text{ cm}^3}{1000}$$

$$= 0.04 \text{ mol } Pb(NO_3)_2$$

Activity 6.6

Solving numerical problems related to concentration of solutions CT

1. 6 g of solid magnesium sulphate, $MgSO_4$ is added into a beaker containing 200 cm^3 of water. Calculate the concentration in g dm^{-3}, for the solution produced.
2. 0.4 mol of zinc chloride, $ZnCl_2$ is dissolved in water to produce 2 dm^3 of solution. Calculate the molarity of the solution prepared.
3. What is the concentration of 0.5 mol dm^{-3} sulphuric acid, H_2SO_4 in g dm^{-3}?
   [Relative atomic mass: H = 1, O = 16, S = 32]
4. The concentration of sodium chloride solution, NaCl is 1.989 g dm^{-3}. Calculate the molarity of the solution in mol dm^{-3}.
   [Relative atomic mass: Na = 23, Cl = 35.5]
5. Calculate the number of moles of sodium hydroxide, NaOH in 2.5 dm^3 of 0.2 mol dm^{-3} sodium hydroxide solution, NaOH.
6. Given the molarity of 250 cm^3 of barium hydroxide solution, $Ba(OH)_2$ is 0.1 mol dm^{-3}. How many moles of hydroxide ion, OH^- is in the solution?

Test Yourself 6.5

1. What is meant by concentration in unit g mol^{-1}?
2. State two units to measure concentration.
3. 0.03 mol of potassium nitrate, KNO_3 is dissolved in 1.2 dm^3 of distilled water. What is the molarity of the potassium nitrate solution, KNO_3 produced?
4. Calculate the concentration of sulphuric acid, H_2SO_4 that has the molarity of 2.0 mol dm^{-3} in unit g dm^{-3}.
   [Relative atomic mass: H = 1, O = 16, S = 32]
5. 1.9 g MgY_2 is dissolved in 100 cm^3 of water to produce a solution with the molarity of 0.2 mol dm^{-3}. What is the relative atomic mass of *Y*?
   [Relative atomic mass: Mg = 24]

6.6 Standard Solution

Have you seen the syrup dispenser as shown in Photograph 6.2? Did you know that the dispenser is filled with a standard solution of sugar so that the machine can dispense sugar at an amount requested by customers? What do you know about standard solution?

Syrup dispenser
http://bit.ly/35Ajhiv

Photograph 6.2
Syrup dispenser

Learning Standard

At the end of the lesson, pupils are able to:
6.6.1 State the meaning of standard solution
6.6.2 Describe the preparation of a standard solution through activity:
- From a solid substance
- Through dilution of an aqueous solution

6.6.3 Solve numerical problems involving preparation of standard solution and dilution

Meaning of Standard Solution

Most chemical reactions involve reactants in aqueous solution. In that case, the preparation of aqueous solution with specific concentrations is very important. **Standard solution** is a **solution with known concentration**. In the preparation of standard solutions, mass of solute and volume of distilled water are two parameters that have to be measured accurately.

Preparation of a Standard Solution from a Solid

Activity 6.7

Aim: To prepare 250 cm^3 of standard solution of 1.0 mol dm^{-3} sodium carbonate, Na_2CO_3.

Materials: Distilled water and solid sodium carbonate, Na_2CO_3

Apparatus: Electronic balance, filter funnel, 250 cm^3 volumetric flask, dropper, wash bottle, 250 cm^3 beaker and glass rod

Procedure:

1. Determine the mass of sodium carbonate, Na_2CO_3 needed using the formula $n = \frac{MV}{1000}$.
2. Weigh the mass calculated using the electronic balance.
3. Add 100 cm^3 of distilled water to the solid sodium carbonate, Na_2CO_3 in a beaker.
4. Stir the mixture with a glass rod until all the solid sodium carbonate, Na_2CO_3 is completely dissolved in the distilled water.
5. Transfer the sodium carbonate solution, Na_2CO_3 into a 250 cm^3 volumetric flask via a filter funnel.
6. Rinse the beaker with distilled water. Make sure all the remaining solution is transferred into the volumetric flask.
7. Then, rinse the filter funnel with a little distilled water. All the remaining solution is transferred into the volumetric flask.
8. Remove the filter funnel. Add distilled water until it approaches the calibration mark on the volumetric flask.

9. Using a dropper, add distilled water slowly until the meniscus level is aligned exactly on the calibration mark of the volumetric flask.
10. Close the volumetric flask with a stopper. Shake well by inverting the volumetric flask several times until the solution is homogenous.

Note: Keep the standard solution of sodium carbonate, Na_2CO_3 that you have prepared for Activity 6.8.

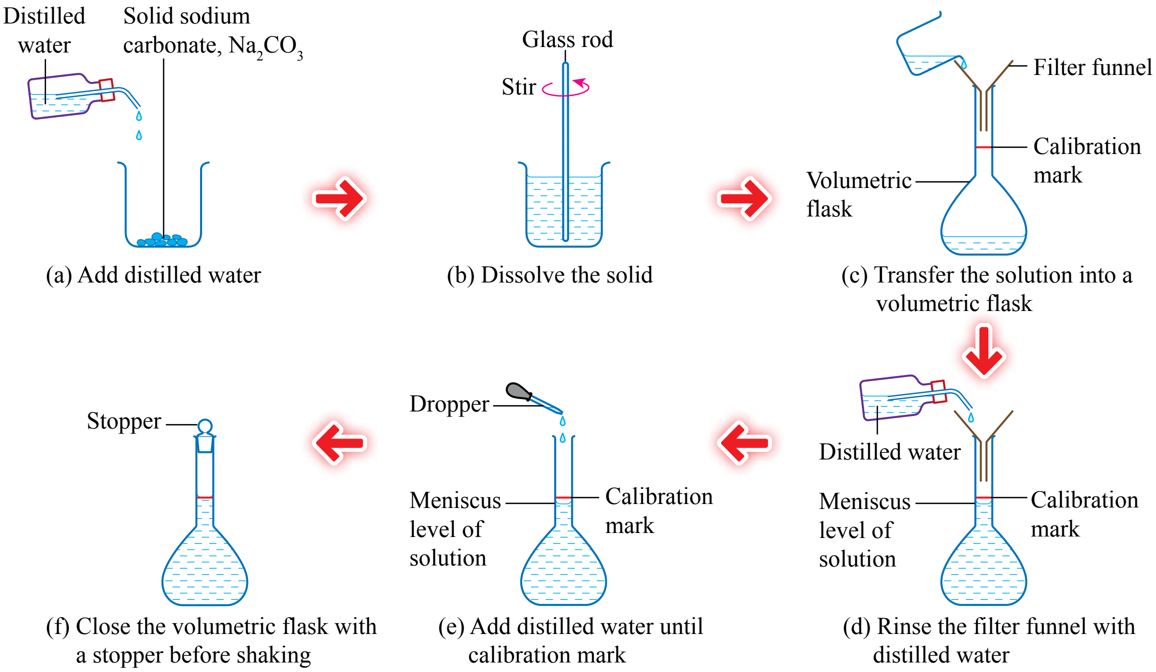


Figure 6.27 *Preparation of 1.0 mol dm*$^{-3}$ *sodium carbonate solution,* Na_2CO_3 *from a solid*

Discussion:

1. Why must the beaker and filter funnel be rinsed with distilled water?
2. Why must all the remaining solution be transferred into the volumetric flask?
3. How can you ensure that the meniscus level aligns with the calibration mark of the volumetric flask?
4. Why does the volumetric flask need to be closed after the standard solution is prepared?

Prepare a complete report after carrying out this activity.

Sodium hydroxide, NaOH is not suitable to be used for the preparation of a standard solution because sodium hydroxide, NaOH is hygroscopic (absorbs water or moisture in the air). Sodium hydroxide, NaOH also absorbs carbon dioxide gas, CO_2 in the air to form sodium carbonate, Na_2CO_3.

$$2NaOH(s) + CO_2(g) \rightarrow Na_2CO_3(s) + H_2O(l)$$

This causes difficulty to determine the exact mass of sodium hydroxide, NaOH. Therefore, the preparation of a standard solution of sodium hydroxide, NaOH with a known concentration could not be made.

Solid oxalic acid $H_2C_2O_4.2H_2O$ can be used to prepare a standard solution in the laboratory.

Chemistry Lens

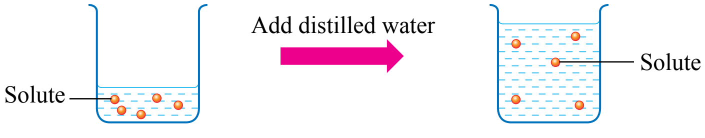
Sodium carbonate, Na_2CO_3 that is used to prepare standard solutions is alkaline. When sodium carbonate, Na_2CO_3 is dissolved in distilled water, carbonate ions, CO_3^{2-} react with water molecules to produce bicarbonate ions, HCO_3^- and hydroxide ions, OH^-. The presence of hydroxide ions, OH^- gives the alkaline properties to the solution.

$$CO_3^{2-}(aq) + H_2O(l) \rightarrow HCO_3^-(aq) + OH^-(aq)$$

Preparation of a Standard Solution by Diluting Aqueous Solution

Another method of preparing solutions of known concentration is by **dilution method**. This method involves adding water to a concentrated standard solution, or known as stock solution, to produce a more diluted solution.

During dilution, water that is added to the aqueous solution will alter **the concentration of the solution** but it would **not alter the number of moles of solute** contained in the solution.



(a) Concentrated solution (b) Dilute solution

Figure 6.28 *Quantity of solute remains the same in both solutions of different concentrations*

Hence,

Number of moles of solute before dilution = Number of moles of solute after dilution

$$n_1 = n_2$$

$$\frac{M_1V_1}{1000} = \frac{M_2V_2}{1000}$$

$$\boxed{M_1V_1 = M_2V_2}$$

where M_1 is the molarity of aqueous solution (stock solution) before dilution.
V_1 is the volume of aqueous solution (stock solution) before dilution.
M_2 is the molarity of aqueous solution (prepared solution) after dilution.
V_2 is the volume of aqueous solution (prepared solution) after dilution.

As an example, you wish to prepare 500 cm^3 of 0.1 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$ from the stock solution of 2.0 mol dm^{-3} copper(II) sulphate, $CuSO_4$. Use the following formula:

$$M_1V_1 = M_2V_2$$
$$(2.0)(V_1) = (0.1)(500)$$
$$V_1 = \frac{(0.1)(500)}{2.0}$$
$$= 25\ cm^3$$

Hence, 25 cm^3 of stock solution of copper(II) sulphate, $CuSO_4$ needs to be diluted using distilled water until 500 cm^3 solution of copper(II) sulphate, $CuSO_4$ is obtained.

The preparation of a standard solution by dilution method can be carried out through Activity 6.8 using sodium carbonate solution, Na_2CO_3 prepared in Activity 6.7.

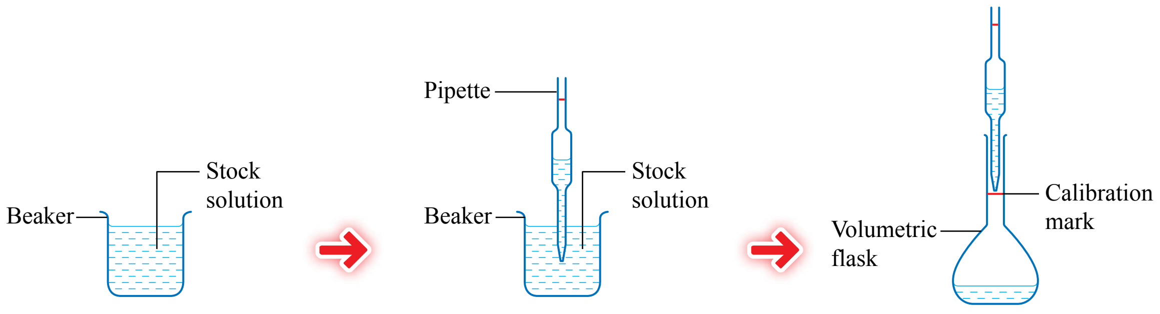
Activity 6.8

Aim: To prepare 100 cm^3 of standard solution of 0.2 mol dm^{-3} sodium carbonate, Na_2CO_3.

Materials: Distilled water and 1.0 mol dm^{-3} sodium carbonate solution, Na_2CO_3 from Activity 6.7

Apparatus: 100 cm^3 volumetric flask, dropper, filter funnel, pipette, wash bottle, pipette filler and 100 cm^3 beaker

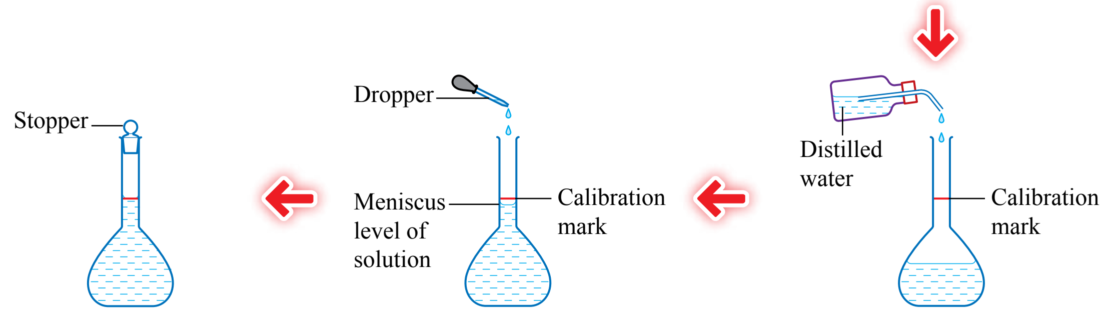
Procedure:



(a) Pour stock solution from Activity 6.7 into a beaker

(b) Take out calculated volume of solution, V_1 cm^3 with a pipette

(c) Transfer V_1 cm^3 of solution into a volumetric flask



(d) Add distilled water until the solution level approaches the calibration mark

(e) Add distilled water slowly with a dropper

(f) Close the volumetric flask and shake well by inverting it several times until the solution is homogenous

Figure 6.29 *Preparation of 0.2 mol* dm^{-3} *sodium carbonate solution,* Na_2CO_3 *by dilution method*

1. Based on Figure 6.29, plan a procedure to prepare a standard solution of 0.2 mol dm^{-3} sodium carbonate, Na_2CO_3 by dilution method.
2. Include precautionary steps in the process of solution preparation.
3. Show your procedure to your teacher before carrying out this activity.
4. Carry out the procedure as planned.
5. Clean and keep the apparatus at their proper places after carrying out this activity.

Brain Teaser

Why is the pipette not rinsed with distilled water but rinsed with 1.0 mol dm^{-3} sodium carbonate solution, Na_2CO_3?

Discussion:

1. What is the volume of the standard solution of 1.0 mol dm^{-3} sodium carbonate solution, Na_2CO_3 needed to prepare 100 cm^3 of 0.2 mol dm^{-3} sodium carbonate solution, Na_2CO_3?
2. What is the size of pipette needed in this preparation process?
3. Why is the beaker not suitable to be used in preparing a standard solution by the dilution method?
4. Do you need to remove the last drop of the solution in the pipette? Why?

Prepare a complete report after carrying out this activity.

Examples 12 and 13 show samples of calculations involved in the preparation of a standard solution by dilution.

Example 12

Figure 6.30 shows 75 cm^3 of 2.0 mol dm^{-3} nitric acid, HNO_3 that is diluted to x mol dm^{-3} when 25 cm^3 distilled water is added. Calculate the value of x.

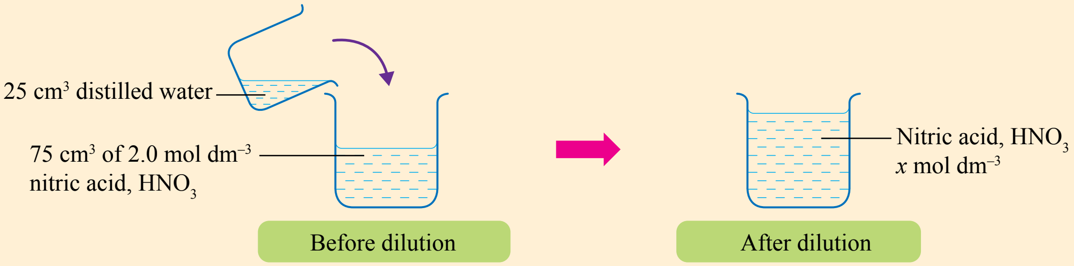


Figure 6.30

Solution

M_1 = 2.0 mol dm^{-3} ; V_1 = 75 cm^3

M_2 = x mol dm^{-3} ; V_2 = (75 + 25) cm^3 ← Volume of solution = Volume of HNO_3 + Volume of distilled water

= 100 cm^3

2.0 mol dm^{-3} × 75 cm^3 = x mol dm^{-3} × 100 cm^3 ← Use the formula $M_1V_1 = M_2V_2$

$$x \text{ mol dm}^{-3} = \frac{2.0 \text{ mol dm}^{-3} \times 75 \text{ cm}^3}{100 \text{ cm}^3}$$

$$= 1.5 \text{ mol dm}^{-3}$$

Then, x = 1.5

Example 13

Determine the volume of 2.0 mol dm^{-3} hydrochloric acid, HCl needed to be pipetted into a volumetric flask 250 cm^3 to produce 0.2 mol dm^{-3} hydrochloric acid, HCl.

Solution

M_1 = 2.0 mol dm^{-3} ; V_1 = ?

M_2 = 0.2 mol dm^{-3} ; V_2 = 250 cm^3

2.0 mol dm^{-3} × V_1 = 0.2 mol dm^{-3} × 250 cm^3 ← Use the formula $M_1V_1 = M_2V_2$

$$V_1 = \frac{0.2 \text{ mol dm}^{-3} \times 250 \text{ cm}^3}{2.0 \text{ mol dm}^{-3}}$$

$$= 25 \text{ cm}^3$$

Activity 6.9

Solving calculation problems involved in the preparation of a standard solution by dilution

CT

1. Calculate the volume of 2.0 mol dm^{-3} sodium carbonate solution, Na_2CO_3 needed to prepare 50 cm^3 of 0.1 mol dm^{-3} sodium carbonate solution, Na_2CO_3.
2. What is the molarity of sodium hydroxide solution, NaOH when 30 cm^3 distilled water is added to 50 cm^3 of 0.5 mol dm^{-3} sodium hydroxide solution, NaOH?
3. Calculate the volume of solution produced when 50 cm^3 of 1.2 mol dm^{-3} sodium nitrate solution, $NaNO_3$ is diluted to 0.5 mol dm^{-3}.
4. When 200 cm^3 water is added to 50 cm^3 concentrated sulphuric acid, H_2SO_4, sulphuric acid, H_2SO_4 with concentration 0.2 mol dm^{-3} is produced. Calculate the molarity of the initial concentration of sulphuric acid, H_2SO_4.

Test Yourself 6.6

1. What is meant by standard solution?
2. *X* cm^3 of 0.15 mol dm^{-3} zinc nitrate solution, $Zn(NO_3)_2$ is pipetted into a 500 cm^3 volumetric flask to produce 500 cm^3 of 0.018 mol dm^{-3} zinc nitrate solution, $Zn(NO_3)_2$. Determine the value of *X*.
3. Calculate the new molarity of hydrochloric acid, HCl produced if 25 cm^3 of 1.5 mol dm^{-3} hydrochloric acid, HCl is diluted to produce 150 cm^3 of hydrochloric acid, HCl.
4. Determine the volume of distilled water needed to add to 50 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ so that a 0.025 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ is produced.

6.7 Neutralisation

When stung by a bee, the area that had been stung can be treated with baking soda. Vinegar, on the other hand, is used to treat the area that had been stung by a wasp. Why?

***Photograph 6.3** Bee and wasp*

Learning Standard

At the end of the lesson, pupils are able to:
- 6.7.1 State the meaning of neutralisation
- 6.7.2 Determine the concentration of an unknown solution through titration method
- 6.7.3 Solve numerical problems involving neutralisation

Definition of Neutralisation

Neutralisation is a reaction between an acid and an alkali (base) to produce **salt** and **water** only. In the reaction, the salt and water produced are neutral because the acid lose its acidity and the alkali lose its alkalinity.

$$\boxed{\text{Acid} + \text{Alkali} \rightarrow \text{Salt} + \text{Water}}$$

For example, the neutralisation reaction between nitric acid, HNO_3 with potassium hydroxide, KOH to produce potassium nitrate solution, KNO_3 and water, H_2O.

$$\boxed{HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l)}$$

In neutralisation, the actual reaction that occurs only involves the combination of hydrogen ions, H^+, from the acid and the hydroxide ions, OH^- from the alkali to produce water molecules, H_2O. Hence, the ionic equation for the reaction is as follows:

$$\boxed{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$$

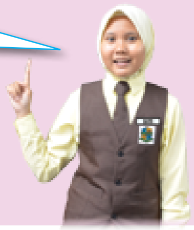
The following shows how the ionic equations for neutralisation reaction can be obtained.

Chemical equation:

$$\boxed{HNO_3(aq) \quad + \quad KOH(aq) \quad \rightarrow \quad KNO_3(aq) \quad + \quad H_2O(l)}$$

$$\underbrace{H^+(aq) + \cancel{NO_3^-}(aq)}_{\text{Ions in nitric acid}} + \underbrace{\cancel{K^+}(aq) + OH^-(aq)}_{\text{Ions in potassium hydroxide solution}} \rightarrow \underbrace{\cancel{K^+}(aq) + \cancel{NO_3^-}(aq)}_{\text{Ions in potassium nitrate solution}} + \underset{\text{Water molecules}}{H_2O(l)}$$

K^+ and NO_3^- are considered as spectator ions that do not change in the reaction. Thus, these ions are cancelled out in the equation.



Ionic equation:

$$\boxed{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$$

Activity 6.10

Write chemical equations and ionic equations for neutralisation reactions CT

1. Complete and balance the following equations. After that, write the relevant ionic equation.
   (a) $HCl(aq) + Ba(OH)_2(aq) \rightarrow$
   (b) $H_2SO_4(aq) + KOH(aq) \rightarrow$
   (c) $HNO_3(aq) + NaOH(aq) \rightarrow$
2. Play the role as a chemistry teacher by explaining your findings in front of your classmates.

Applications of Neutralisation in Daily Life

Figure 6.31 shows the application of neutralisation for a variety of uses in daily life.

Medicine

Milk of magnesia $Mg(OH)_2$ relieves gastric pain by neutralising the excessive hydrochloric acid in the stomach.

Hair health

Weak alkali in the shampoo neutralises acid on hair.

Dental health

Toothpaste contains a base that neutralises lactic acid produced by bacteria in our mouth.

Agriculture

Slaked lime, $Ca(OH)_2$ which is alkaline, is used to treat acidic soil.

Figure 6.31 *Applications of neutralisation in daily life*

Activity 6.11

STEM 21st Century Skills CT

Solving problems on soil fertility using suitable fertilisers

1. Carry out this activity in groups.
2. Study the following problem statement:

> Apart from treating acidic soil, fertilisers need to be added to soil to replace nutrients such as nitrogen, potassium and phosphorus that have been absorbed by plants. There is a variety of fertilisers in the market. Which fertilisers are suitable for plants?

3. Gather information concerning the problem given above.
   (a) What type of crops were planted?
   (b) What are the type of elements required by the crops?
   (c) Identify the fertiliser that is suitable for the crops by considering the percentage of elements such as nitrogen, phosphorus, and other needs, fertiliser cost and the quantity needed for the area.
4. Present your group findings in a multimedia presentation.

Neutralisation reaction is also applied in the production of fertilisers such as urea, potassium sulphate, K_2SO_4, ammonium nitrate, NH_4NO_3 and others. For example, urea can be produced from the neutralisation reaction between ammonia, NH_3 and carbon dioxide, CO_2. How about other fertilisers? Try to list out the acids and alkalis involved in the production of that fertilisers.

Activity 6.12

Gather information on various types of fertilisers

CT

1. Carry out this activity in groups.
2. Visit the websites or refer to printed materials in the library and resource centre to gather information about:
   (a) Ways to produce urea through the reaction between ammonia and carbon dioxide. Include the chemical equations involved
   (b) Types of ammonium fertilisers available in the market
   (c) Calculate the percentage by mass of nitrogen for urea and ammonium fertilisers in the market. Then, compare and determine the quality of fertiliser based on the percentage of nitrogen
3. Use suitable graphic organisers to present your group work to your classmates.

Titration Method

Titration method is a **quantitative analysis method** to determine the volume of acid needed to completely neutralise a given volume of alkali and vice versa.

In acid-base titration, a solution of known concentration is slowly added from a burette into a conical flask that contains a volume of alkali of unknown concentration. Titration stops as soon as the acid-base indicator changes colour. The point in the titration at which the acid-base indicator changes colour is known as the **end point**.

Activity 6.13

Aim: To determine the concentration of potassium hydroxide solution, KOH by acid-base titration.

Materials: 1.0 mol dm^{-3} nitric acid, HNO_3, potassium hydroxide, KOH (unknown concentration), phenolphthalein indicator and distilled water

Apparatus: Burette, 25 cm^3 pipette, pipette filler, 250 cm^3 conical flask, white tile and retort stand with clamp

Procedure:

1. Rinse a 25 cm^3 pipette with a little potassium hydroxide solution, KOH. Remove the solution.
2. Pipette exactly 25 cm^3 of potassium hydroxide solution, KOH. Transfer it into a conical flask.
3. Add a few drops of phenolphthalein indicator into the potassium hydroxide solution, KOH and swirl the flask.
4. Rinse a burette with 1.0 mol dm^{-3} nitric acid, HNO_3. Then, remove the whole solution.
5. Fill the burette with 1.0 mol dm^{-3} nitric acid, HNO_3 and clamp the burette onto a retort stand. Record the initial reading of the burette.
6. Drip 1.0 mol dm^{-3} nitric acid, HNO_3 slowly into the conical flask while swirling it.

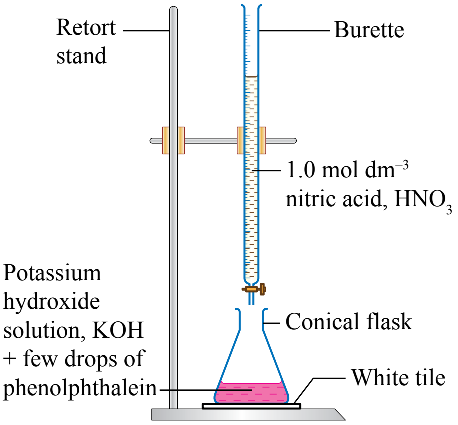


Figure 6.32

7. Stop adding 1.0 mol dm^{-3} nitric acid, HNO_3 as soon as the colour of the solution in the conical flask changes from pink to colourless. Record the final burette reading.
8. Calculate the rough volume, V cm^3 of 1.0 mol dm^{-3} nitric acid, HNO_3 that is needed for titration.
9. Repeat steps 2 and 3.
10. Flow 1.0 mol dm^{-3} nitric acid, HNO_3 until (V – 5) cm^3 into the conical flask containing 25 cm^3 of potassium hydroxide solution, KOH. Then, stop the flow of 1.0 mol dm^{-3} nitric acid, HNO_3.
11. Subsequently add 1.0 mol dm^{-3} nitric acid, HNO_3, drop by drop, into the conical flask while swirling the flask.
12. Occasionally, rinse the inner surface of the conical flask with distilled water to ensure all the 1.0 mol dm^{-3} nitric acid, HNO_3 has been titrated into the potassium hydroxide solution, KOH.
13. Stop the titration as soon as the colour of the solution turns colourless.
14. Record the final burette reading.
15. Repeat steps 9 – 14 twice.
16. Record your readings in Table 6.4.

Safety Precaution

Make sure the eye position is parallel to the meniscus level of the solution while taking a burette reading.

Literacy Tips

Although, the addition of distilled water to rinse the inner part of a conical flask changes the concentration of the mixture solution, the number of moles of acid and alkali reacted remain unchanged. Thus, the volume of acid needed to neutralise alkali is not affected.

Titration procedure

http://bit.ly/2Bev0Fq

Results:

Table 6.4

Number of titration	**Rough**	**1**	**2**	**3**
Initial burette reading (cm^3)				
Final burette reading (cm^3)				
Volume of nitric acid, HNO_3 needed (cm^3)				

Interpreting data:

1. What is the average volume of nitric acid, HNO_3, that is needed to neutralise 25 cm^3 of potassium hydroxide solution, KOH by ignoring the rough volume?
2. Write the ionic equation for the reaction between nitric acid, HNO_3 and the potassium hydroxide solution, KOH.
3. Calculate the number of moles of nitric acid, $HNO_{3,}$ needed in this neutralisation reaction.
4. Calculate the number of moles of potassium hydroxide solution, KOH needed to react completely with the number of moles of nitric acid, HNO_3 calculated in question 3.
5. Determine the molarity of potassium hydroxide solution, KOH.

Discussion:

1. Why is a white tile used in this activity?
2. Why should not we rinse the inside of the conical flask with potassium hydroxide solution, KOH before beginning the titration?
3. What is the operational definition for the **end point** in this activity?

Prepare a complete report after carrying out this activity.

The end point of the neutralisation process can be determined when the acid-base indicator changes colour. When the end point is achieved, all the hydrogen ions, H^+ **completely neutralise** all the hydroxide ions, OH^- to produce water molecules. Table 6.5 shows the phenolphthalein indicator and methyl orange in acidic, neutral and alkaline conditions.

***Table 6.5** Colours of indicators in acidic, neutral and alkaline conditions*

Indicator	Colour in medium		
	Acidic	Neutral	Alkaline
Phenolphthalein	Colourless	Colourless	Pink
Methyl orange	Red	Orange	Yellow

Solving Numerical Problems Involving Neutralisation

If ***a*** mol acid A is completely neutralised by ***b*** mol of alkali B, then the formula $\frac{M_aV_a}{M_bV_b} = \frac{a}{b}$ can be used to solve the calculation related to the neutralisation reaction.

$$\overset{a\text{ mol}}{a}\,\boxed{\text{Acid A}} + \overset{b\text{ mol}}{b}\,\boxed{\text{Alkali B}} \rightarrow c\,\boxed{\text{Salt}} + d\,\boxed{\text{Water}}$$

Molarity of acid A $= M_a$
Volume of acid A $= V_a$

Molarity of alkali B $= M_b$
Volume of alkali B $= V_b$

Based on the equation above, the mole ratio of acid A to alkali B is *a*:*b*.

Example 14

20 cm^3 of 0.25 mol dm^{-3} sodium hydroxide solution, NaOH is neutralised with 0.2 mol dm^{-3} hydrochloric acid, HCl. Calculate the volume of hydrochloric acid, HCl needed for this neutralisation reaction.

Solution

$$\overset{a = 1\text{ mol}}{\bigcirc}\text{HCl} + \overset{b = 1\text{ mol}}{\bigcirc}\text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$$

Write this chemical equation and determine the value of ***a*** and ***b*** based on the coefficients of this chemical equation.

$M_a = 0.2$ mol dm^{-3} ; $V_a = ?$
$M_b = 0.25$ mol dm^{-3} ; $V_b = 20$ cm^3

$$\frac{0.2(V_a)}{0.25(20)} = \frac{1}{1}$$

Use the formula $\frac{M_aV_a}{M_bV_b} = \frac{a}{b}$

$$0.2(V_a) = \frac{1}{1} \times (0.25)(20)$$

$$V_a = \frac{0.25(20)}{0.2}$$

$$= 25\text{ cm}^3$$

Volume of hydrochloric acid, HCl that is needed = 25 cm^3

Further examples
http://bit.ly/35UzBuQ

Example 15

4.05 g of zinc oxide, ZnO is needed to complete the neutralisation of 50 cm³ of nitric acid, HNO_3. Calculate the concentration of the acid in mol dm⁻³.
[Relative atomic mass: H = 1, N = 14, O = 16, Zn = 65]

Solution

$$\overset{a\,=\,2\text{ mol}}{2}HNO_3 + \overset{b\,=\,1\text{ mol}}{}ZnO \rightarrow Zn(NO_3)_2 + H_2O$$

Write a balanced chemical equation.

$$\text{Number of moles of ZnO, } n = \frac{4.05\text{ g}}{(\underset{\text{RAM Zn}}{65} + \underset{\text{RAM O}}{16})\text{ g mol}^{-1}}$$

$$= 0.05\text{ mol}$$

Convert the given quantity (4.05 g) to number of moles.

Based on the chemical equation,
2.0 mol of HNO_3 reacts with 1.0 mol of ZnO
0.1 mol of HNO_3 reacts with 0.05 mol of ZnO

Based on the mol ratio, determine the number of moles of HNO_3.

$$\text{Number of moles of } HNO_3,\ n = \frac{MV}{1000}$$

$$0.1\text{ mol} = \frac{(M)(50)}{1000}$$

$$M = 2.0\text{ mol dm}^{-3}$$

Convert the number of moles of HNO_3 to molarity.

Molarity of nitric acid, HNO_3 = 2.0 mol dm⁻³

Activity 6.14

Solving numerical problems involving neutralisation

CT

1. 25 cm³ of 0.2 mol dm⁻³ sodium hydroxide solution, NaOH is titrated with 0.1 mol dm⁻³ sulphuric acid, H_2SO_4. What is the volume of sulphuric acid, H_2SO_4 needed to neutralise sodium hydroxide solution, NaOH?
2. Sulphuric acid, H_2SO_4, reacts with ammonia solution, NH_3 according to the following chemical equation:

$$H_2SO_4(aq) + 2NH_3(aq) \rightarrow (NH_4)_2SO_4(aq)$$

   It is given that *T* cm³ of 0.125 mol dm⁻³ sulphuric acid, H_2SO_4 exactly neutralises 25 cm³ of 1.0 mol dm⁻³ ammonia solution, NH_3. Determine the total volume of solution in the conical flask at the end point of titration.
3. 50 cm³ of nitric acid, HNO_3 completely neutralises 50 cm³ of 0.25 mol dm⁻³ calcium hydroxide, $Ca(OH)_2$. Calculate the molarity of the nitric acid, HNO_3.
4. In a titration, 15 cm³ of 0.5 mol dm⁻³ sulphuric acid, H_2SO_4 neutralises 20 cm³ of potassium hydroxide solution, KOH. Calculate the concentration of potassium hydroxide solution, KOH.

Test Yourself 6.7

1. What is the meaning of neutralisation?
2. State the changes in the methyl orange indicator inside the conical flask containing potassium hydroxide solution, KOH when it reaches end point.
3. 50 cm^3 of 0.75 mol dm^{-3} ammonia solution, NH_3 is titrated with 1.0 mol dm^{-3} nitric acid, HNO_3. What is the volume of 1.0 mol dm^{-3} nitric acid, HNO_3 that is needed to neutralise the ammonia solution, NH_3?
4. Calculate the volume of 0.05 mol dm^{-3} hydrochloric acid, HCl that exactly neutralises 25 cm^3 of 0.1 mol dm^{-3} barium hydroxide solution, $Ba(OH)_2$.
5. Based on the following chemical equation, 20 cm^3 monoprotic acid, H*X* reacts completely with 10 cm^3 of 0.1 mol dm^{-3} potassium hydroxide solution, KOH.

   $$HX(aq) + KOH(aq) \rightarrow KX(aq) + H_2O(l)$$

   What is the molarity of this acid?
6. A student dissolves hydrogen chloride gas, HCl in water to produce 500 cm^3 of acidic solution. Calculate the molarity of the solution if 6 g of copper(ll) oxide, CuO is used for a complete reaction with the solution produced.
   [Relative atomic mass: O = 16, Cu = 64]

6.8 Salts, Crystals and Their Uses in Daily Life

The common table salt used in cooking is made up of sodium ions, Na^+ and chloride ions, Cl^-. The egg shell is made up of calcium ions, Ca^{2+} and carbonate ions, CO_3^{2-}. Is calcium carbonate a type of salt too?

Learning Standard

At the end of the lesson, pupils are able to:
- 6.8.1 State the meaning of salt
- 6.8.2 Characterise the physical properties of salt crystals
- 6.8.3 Give examples of salt and their uses in daily life

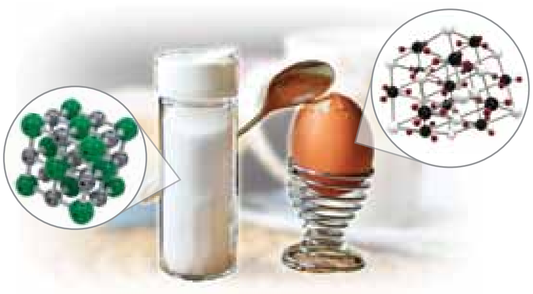


Figure 6.33 *Salt and egg shell*

Definition of Salt

Salt is an **ionic compound**. Salt can be produced from the neutralisation reaction between acid and alkali (base).

Reaction between acid and alkali

Anion from acid

$$\mathrm{H\,Cl(aq) + Na\,OH(aq) \rightarrow NaCl(aq) + H_2O(l)}$$

Cation from base

Sodium chloride salt

Can salt only be produced from acid and base reaction? Look at the following chemical equations to find out further on the salt production concept.

Reaction between acid and reactive metals

Anion from acid

$$\mathrm{2H\,Cl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)}$$

Cation from metal

Zinc chloride salt

Reaction between acid and metal carbonate

Anion from acid

$$\mathrm{2H\,Cl(aq) + Ca\,CO_3(s) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)}$$

Cation from metal carbonate

Calcium chloride salt

Reaction between acid and aqueous ammonia

Anion from acid

$$\mathrm{H\,Cl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq)}$$

Cation from aqueous ammonia

Ammonium chloride salt

Based on the chemical equations above, salt can be defined as follow:

Salt is an ionic compound formed when the hydrogen ion, H^+ from the acid is replaced with the **metal ion** or the **ammonium ion**, NH_4^+.

Activity 6.15

Gathering and interpreting information on the existence of salts that exist naturally

1. Carry out this activity in groups.
2. Gather information on salts that exist naturally. Your information should include the following:
   (a) Name of the salts
   (b) Source or location of the salts
   (c) Relevant photograph of the salts
3. Interpret the information gathered with suitable graphic organisers.
4. Present the information in front of your class.

Physical Properties of Salt Crystals

All salt crystals have specific features. Can you state the physical properties of a salt crystal? Activity 6.16 can assist you in showing characteristics of a salt crystal.

Activity 6.16

Carrying out a crystal growth activity

1. Carry out this activity in pairs.
2. Watch the video clip on the steps taken to produce a large crystal through the growth of crystal.
3. Discuss with your partner on the important procedures in producing copper(II) sulphate crystal, $CuSO_4$.
4. Carry out the crystal growth activity of copper(II)sulphate, $CuSO_4$ in a time frame of two weeks with your teacher's permission.
5. Dry the crystal produced and observe the crystal under a microscope.
6. Record the physical properties of the crystal and sketch its shape in your notebook.

Crystal growth

http://bit.ly/2IOG7ZY

Figure 6.34 *Physical properties of salt crystal*

A crystal has specific properties because the particles in the crystal are arranged in compact and orderly manner according to a specific design arrangement.

Examples of Salts and Their Uses

Besides sodium chloride salt, NaCl that we use everyday, there are more salts that exist naturally as minerals in the Earth's crust. These salts have their own uses in various fields.

Activity 6.17

Making a multimedia presentation on the uses of various salts

1. Carry out this activity in groups.
2. Surf the Internet or refer to printed materials at the library to gather information on the various uses of salt in the following fields:

Agriculture | Medicine | Preservation | Food preparation

3. Interpret the information obtained and present your group's work using multimedia presentations.

Agriculture

Ammonium nitrate, NH_4NO_3 as fertiliser while iron(II) sulphate, $FeSO_4$ is used in pesticides to kill pests and grass.

Medicine

Calcium sulphate, $CaSO_4$ as plaster of Paris to support broken bones while potassium manganate(VII) is used as antiseptic to treat wounds.

Food preparation

Sodium chloride, NaCl is used as flavour.
Sodium bicarbonate, $NaHCO_3$ is used for raising dough.

Preservation

Sodium benzoate, C_6H_5COONa is used to preserve chilli sauce, tomato sauce and oyster sauce. Sodium nitrate, $NaNO_3$ is used to preserve processed meat such as sausages.

Figure 6.35 *Various uses of salt in daily life*

Activity 6.18

Debating the effects of salt on humans

1. Read and understand the following extract:

> Table salt, Himalayan salt and bamboo salt are among the salts found on Earth. Humans need salt to maintain the fluid balance in their body, prevent muscle cramps and others. However, a high salt content will cause high blood pressure, stroke, kidney failure and other diseases.

2. Gather information on the effects of salt on humans.
3. Debate the effects of salt on human health.

Test Yourself 6.8

1. Define the meaning of salt.
2. List out the physical properties of a salt crystal.
3. Give examples of salts and their uses in the following fields:
   (a) Agriculture (b) Medicine

6.9 Preparation of Salts

Learning Standard

At the end of the lesson, pupils are able to:

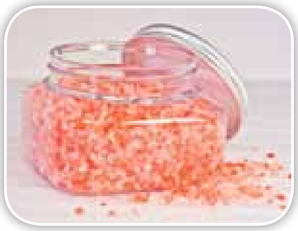
6.9.1 Test the solubility of salt in water and classify them into soluble and insoluble salts through experiment

6.9.2 Describe the preparation of a soluble salt through activity

6.9.3 Describe the preparation of an insoluble salt through activity

6.9.4 Construct an ionic equation using the continuous variation method through experiment

The solid as shown in Photograph 6.4 is the Himalayan salt. Does the Himalayan salt dissolve in water? Is it true that all types of salt dissolve in water?



Photograph 6.4 *Himalayan salt*

Solubility of Salt in Water

Salt is an ionic compound. The solubility of various salts in water is investigated in Experiment 6.5.

Experiment 6.5

Aim: Investigate the solubility of various salts in water.

Problem statement: Do all salts dissolve in water?

Hypothesis: Some salts dissolve in water, some salts do not.

Variables:

(a) Manipulated : Types of nitrate, sulphate, chloride, carbonate and ammonium salt

(b) Responding : Solubility of salt in water

(c) Fixed : Volume and temperature of water, mass of salt

Procedure:

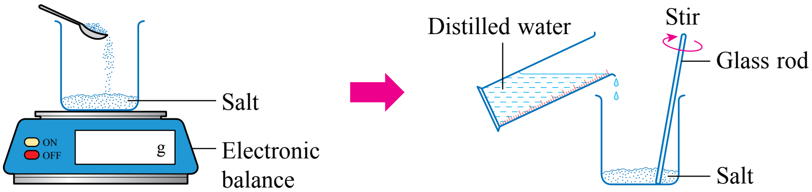


Figure 6.36 *Apparatus set-up to investigate the solubility of salt*

1. Based on Figure 6.36, list out the apparatus and materials/substances used in this experiment.

2. Plan the experiment procedure with the members of your group.
3. Prepare an appropriate table to record your observation.
4. Carry out the experiment with your teacher's permission.
5. Record the observation obtained in the table you have prepared.

CAUTION

Do not taste the salts. There are salts that are poisonous.

Interpreting data:

1. Based on the results of the experiment, list out:
   (a) Nitrate, sulphate, chloride, carbonate and ammonium salts that dissolve in water
   (b) Sulphate, chloride and carbonate salts that do not dissolve in water
2. Formulate and classify the types of salt that dissolve or do not dissolve in water in an appropriate table.

Conclusion:

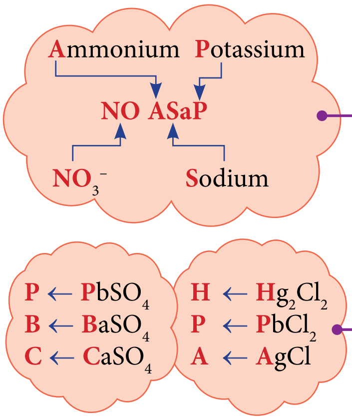
Is the hypothesis acceptable? What is the conclusion of this experiment?

Prepare a complete report after carrying out this experiment.

Soluble salts are salts that **dissolve** in water at room temperature and **non-soluble salts** are salts that **do not dissolve** at room temperature. Table 6.6 shows the types of salts and their solubilities in water.

Table 6.6 Solubility of salts in water

Types of salts	Soluble in water		Insoluble in water
Nitrate salt (NO_3^-)	All nitrate salts		None
Sulphate salt (SO_4^{2-})	All sulphate salts	**except**	Lead(II) sulphate, $PbSO_4$ Barium sulphate, $BaSO_4$ Calcium sulphate, $CaSO_4$
Chloride salt (Cl^-)	All chloride salts	**except**	Mercury(I) chloride, Hg_2Cl_2 Lead(II) chloride, $PbCl_2$ Silver chloride, AgCl
Carbonate salt (CO_3^{2-})	Sodium carbonate, Na_2CO_3 Potassium carbonate, K_2CO_3 Ammonium carbonate, $(NH_4)_2CO_3$		Other carbonate salts
Ammonium, sodium and potassium salts	All ammonium, sodium and potassium salts		None

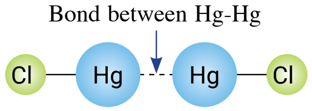


Literacy Tips

Mnemonics:
All **NO ASaP** salts dissolve in water.
PBC sulphates and **HPA** chlorides do not dissolve in water.

Chemistry Lens

The empirical formula for mercury(I) chloride is HgCl. Because mercury atoms, Hg tend to form Hg-Hg bonds, therefore the chemical formula for mercury(I) chloride is Hg_2Cl_2.



Lead(II) chloride, $PbCl_2$ and lead(II) iodide, PbI_2 are two types of salts that are special. These salts are initially insoluble in water, but can be dissolved in hot water to produce a colourless solution. Solids are reformed when water is cooled.

Brain Teaser

Are lead(II) chloride, $PbCl_2$ and lead(II) iodide, PbI_2 classified as soluble or insoluble salts? Why?

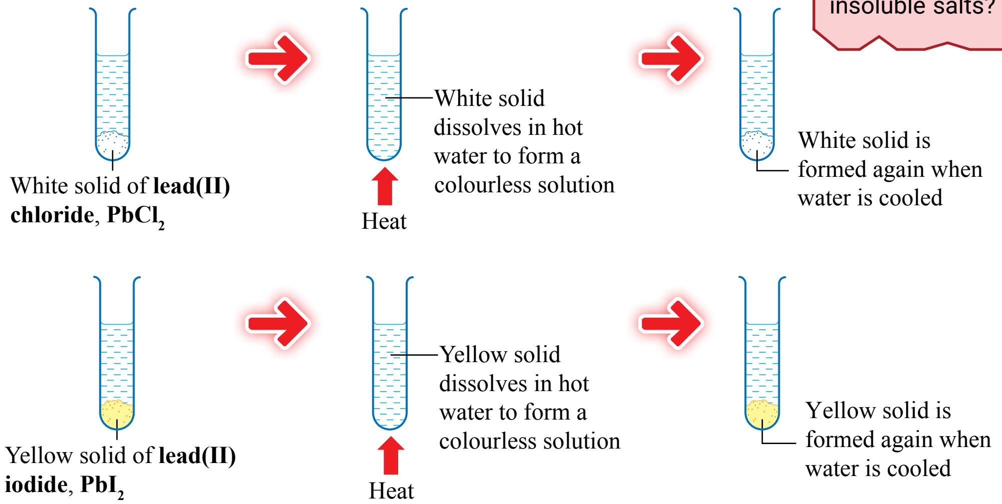


Figure 6.37 *Special properties of lead(II) chloride, $PbCl_2$ and lead(II) iodide, PbI_2*

Preparation of Soluble Salts

The method to prepare salts depends on the solubility of the salt in water and the type of salt required. Figure 6.38 shows the various methods for the preparation of soluble and insoluble salts.

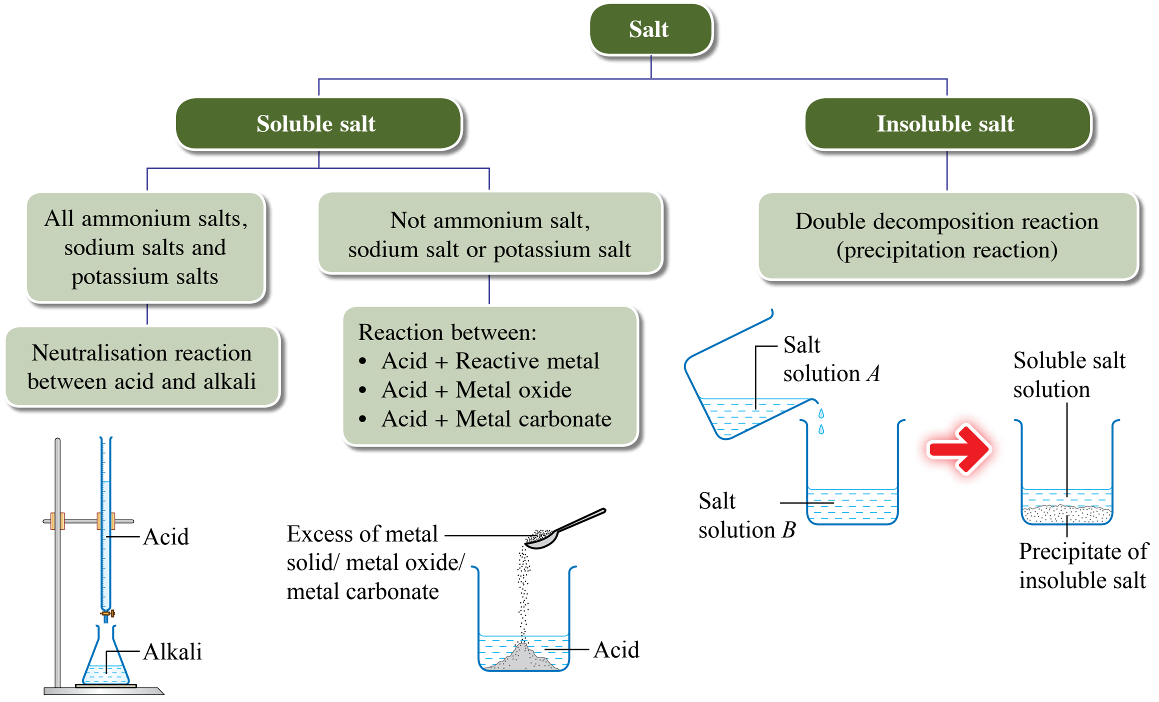


Figure 6.38 *Methods for preparing soluble and insoluble salts*

A Preparation of Soluble Ammonium, Sodium and Potassium Salts

Activity 6.19

Aim: To prepare soluble salts through a neutralisation reaction between an acid and an alkali.

Materials: 2.0 mol dm^{-3} hydrochloric acid, HCl, 2.0 mol dm^{-3} potassium hydroxide solution, KOH, phenolphthalein indicator, filter papers and distilled water

Apparatus: 250 cm^3 beaker, glass rod, filter funnel, retort stand with clamp, 25 cm^3 pipette, pipette filler, burette, evaporating dish, Bunsen burner, pipeclay triangle, conical flask, tripod stand, white tile and wash bottle

Procedure:

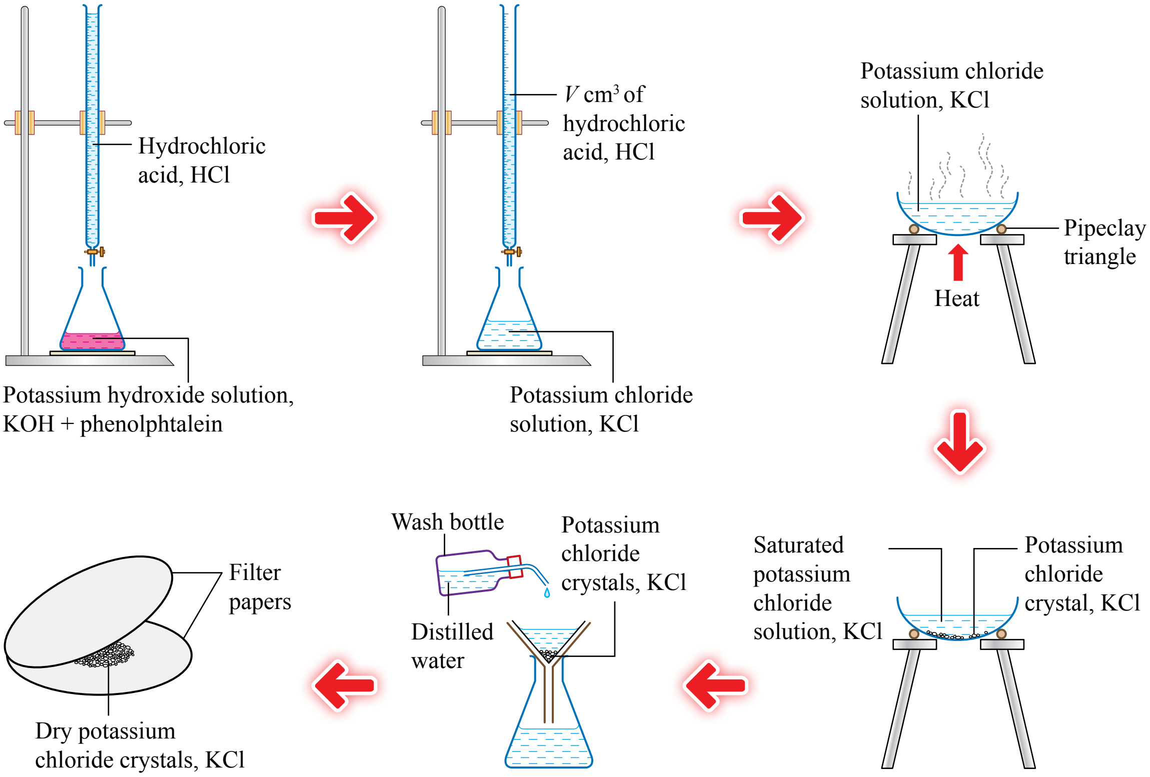


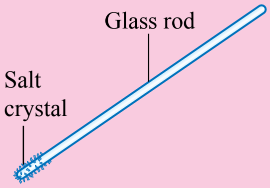
Figure 6.39 Apparatus set-up to obtain potassium chloride crystals, KCl

1. Rinse a 25 cm^3 pipette with a small amount of 2.0 mol dm^{-3} potassium hydroxide, KOH. Then, discard the solution.
2. Pipette accurately 25 cm^3 of 2.0 mol dm^{-3} potassium hydroxide solution, KOH and transfer into a conical flask.
3. Add a few drops of phenolphthalein indicator and swirl the flask.
4. Rinse a burette with 2.0 mol dm^{-3} hydrochloric acid, HCl. Then, discard the solution.
5. Fill the burette with 2.0 mol dm^{-3} hydrochloric acid, HCl and clamp the burette to the retort stand. Record the initial reading of the burette.

6. Add acid into the conical flask slowly while swirling it.
7. Continue adding acid until the colour of the solution in the conical flask changes from pink to colourless.
8. Record the final reading of the burette. Then, determine the volume of 2.0 mol dm^{-3} hydrochloric acid, HCl required to neutralise 25 cm^3 of 2.0 mol dm^{-3} potassium hydroxide solution, KOH (assuming the acid volume is V cm^3).
9. Refill a new 25 cm^3 of 2.0 mol dm^{-3} potassium hydroxide solution, KOH into a conical flask without phenolphthalein indicator.
10. Add V cm^3 of 2.0 mol dm^{-3} hydrochloric acid, HCl from a burette into the conical flask and swirl the mixture to ensure the mixture is even.
11. Pour the content of the conical flask into an evaporating dish.
12. Heat the solution slowly to evaporate the water so that a saturated solution is obtained.
13. Let the saturated salt solution cool down to allow crystallisation to occur.
14. Filter the contents of the evaporating dish to obtain potassium chloride crystals, KCl.
15. Rinse the crystals with a little amount of distilled water.
16. Dry the salt crystals by pressing them between two pieces of filter papers.

Safety Precaution

To know whether the salt is saturated or not, dip the glass rod into the solution and then remove the glass rod. If crystals are produced, a saturated solution has been obtained.



Discussion:

1. Why is phenolphthalein indicator needed in titration?
2. Why should not phenolphthalein indicator be added to V cm^3 of hydrochloric acid, HCl to 25 cm^3 of potassium hydroxide solution, KOH?
3. Explain why the resulting crystals can only be rinsed with a little amount of distilled water.
4. Write a balanced chemical equation for this neutralisation reaction.
5. Give two other types of soluble salts that can be prepared by this method.

Prepare a complete report after carrying out this activity.

B Preparation of Soluble Salts which are not Ammonium, Sodium and Potassium Salts

Activity 6.20

Aim: To prepare a soluble salt based on the reaction between an acid and a metal oxide.

Materials: 2.0 mol dm^{-3} nitric acid, HNO_3, copper(II) oxide powder, CuO, filter papers and distilled water

Apparatus: 250 cm^3 beaker, spatula, glass rod, filter funnel, evaporating dish, Bunsen burner, pipeclay triangle, conical flask, tripod stand, wash bottle, 20 cm^3 measuring cylinder and retort stand with clamp

Procedure:

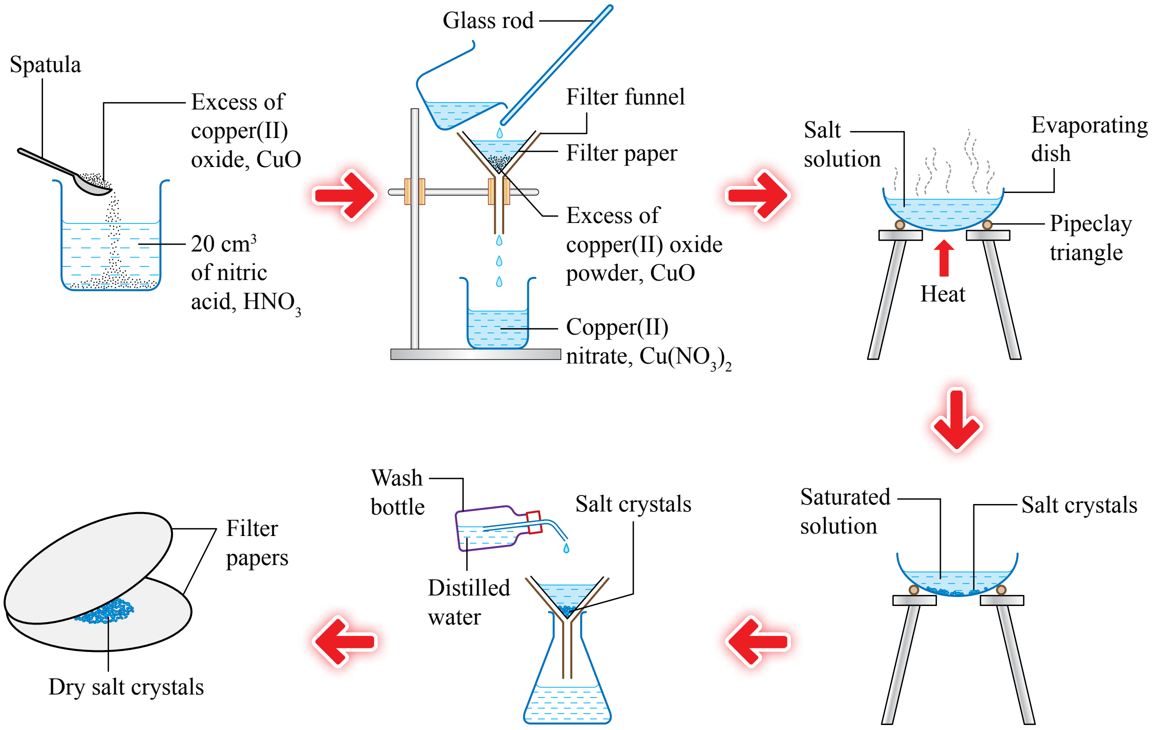


Figure 6.40 Apparatus set-up to obtain copper(II) nitrate crystal, $Cu(NO_3)_2$

1. Pour 20 cm^3 of 2.0 mol dm^{-3} nitric acid, HNO_3 into a beaker. Heat the acid using medium heat.
2. Add copper(II) oxide powder, CuO gradually into the acid using a spatula. Stir the mixture with a glass rod.
3. Continue adding copper(II) oxide, CuO until it is no longer dissolved.
4. Filter the excess copper(II) oxide powder, CuO from the mixture.
5. Pour the filtrate into an evaporating dish and heat the filtrate till a saturated salt solution is obtained.
6. Let the resulting saturated solution cool until salt crystals are formed.
7. Filter the content of the evaporating dish to obtain the salt crystals. Rinse the crystals with a little amount of distilled water.
8. Dry the salt crystals by pressing them between two pieces of filter papers.

Discussion:

1. Why is copper(II) oxide, CuO added in excess to the solution?
2. The filtration is done twice in this activity. Explain why.
3. Write a chemical equation for the reaction between nitric acid, HNO_3 and copper(II) oxide, CuO.
4. Is the reaction between nitric acid, HNO_3 and copper(II) oxide, CuO also considered a neutralisation reaction? Give a reason.

Prepare a complete report after carrying out this activity.

Activity 6.21

Aim: To prepare a soluble salt based on the reaction between an acid and a reactive metal.

Materials: 2.0 mol dm^{-3} sulphuric acid, H_2SO_4, zinc powder, Zn, filter paper and distilled water

Apparatus: 250 cm^3 beaker, spatula, glass rod, filter funnel, evaporating dish, Bunsen burner, pipeclay triangle, conical flask, tripod stand, wash bottle and retort stand with clamp

Procedure:

1. In pair, study Activity 6.20 on pages 182 and 183. Then, plan the procedures for the lab activity to prepare soluble salts of zinc sulphate, $ZnSO_4$ based on the reaction between an acid and a metal.
2. Discuss with your teacher if you encounter any problem when planning the procedures.

Discussion:

1. Does zinc powder, Zn, have to be added in excess to the sulphuric acid, H_2SO_4? Why?
2. Write a chemical equation for the reaction between sulphuric acid, H_2SO_4 and the metal zinc, Zn.
3. Copper powder is not suitable to prepare copper(II) sulphate salt, $CuSO_4$ by using the method in this activity. Give the reason why.

Prepare a complete report after carrying out this activity.

Activity 6.22

Aim: To prepare a soluble salt based on the reaction between an acid and a metal carbonate.

Procedure:

1. In groups, determine a soluble salt that needs to be prepared.
2. Based on the chosen soluble salt, determine the materials and apparatus needed for this activity.
3. Plan and carry out the activity to prepare the soluble salt based on the reaction between an acid and an insoluble metal carbonate.

Discussion:

1. Name the gas that is produced.
2. Describe the chemical test for the gas released.
3. Write the chemical equation involved.

Prepare a complete report after carrying out this activity.

Purification of Soluble Salts by the Recrystallisation Method

The soluble salt produced might contain impurities during preparation. Therefore, the soluble salt can be purified by the recrystallisation method. Carry out Activity 6.23 to find out how to purify a soluble salt.

Activity 6.23

Aim: To prepare a pure soluble salt through the recrystallisation method.

Materials: Copper(II) sulphate crystals, $CuSO_4$, filter papers and distilled water

Apparatus: 250 cm^3 beaker, spatula, glass rod, filter funnel, evaporating dish, Bunsen burner, wire gauze, pipeclay triangle, conical flask, tripod stand, wash bottle and retort stand with clamp

Procedure:

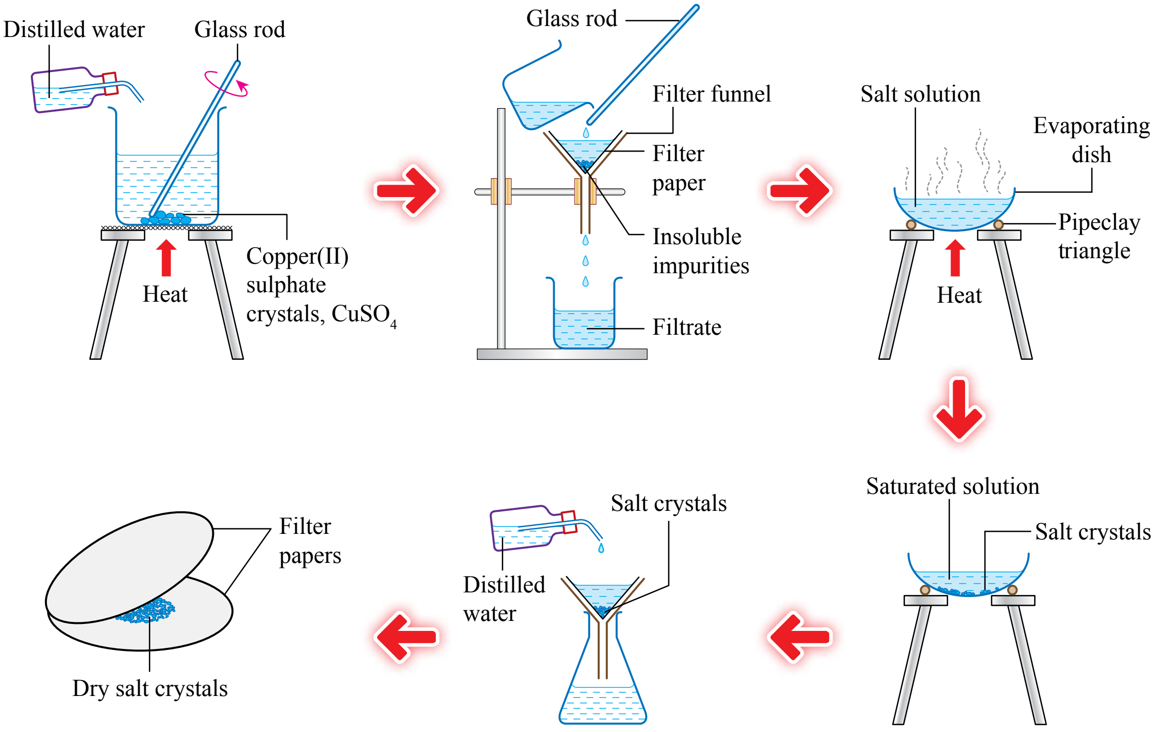


Figure 6.41 Apparatus set-up to purify copper(II) sulphate salt, $CuSO_4$

Safety Precaution

Make sure the distilled water added is just enough to dissolve all the crystals.

1. Put the copper(II) sulphate crystals, $CuSO_4$ into a beaker.
2. Add distilled water gradually while stirring. Heat the solution to speed up the process of dissolving the salt.
3. Filter the hot salt solution to remove insoluble impurities.
4. Then, pour the filtrate into an evaporating dish and heat the filtrate until a saturated salt solution is obtained.
5. Let the saturated solution cool until salt crystals are formed.
6. Filter the contents of the evaporating dish to get the salt crystals. Rinse the crystals with a little amount of distilled water.
7. Dry the salt crystals by pressing them between two pieces of filter papers.

Discussion:

1. What is the purpose of rinsing the crystals formed with distilled water?
2. State the method used to increase the size of the crystals formed.
3. Can recrystallisation be used to purify insoluble salts? Why?

Prepare a complete report after carrying out the activity.

Preparation of Insoluble Salts

Insoluble salts can be prepared through **double decomposition reaction.** In this process, two salt solutions that contain insoluble salt ions are needed.

Preparing Insoluble Salts by Double Decomposition Reaction

Activity 6.24

Aim: To prepare an insoluble salt by double decomposition reaction.

Materials: 2.0 mol dm^{-3} sodium sulphate solution, Na_2SO_4, 2.0 mol dm^{-3} barium chloride solution, $BaCl_2$, filter papers and distilled water

Apparatus: 250 cm^3 beaker, measuring cylinder, glass rod, filter funnel, evaporating dish, conical flask and wash bottle

Procedure:

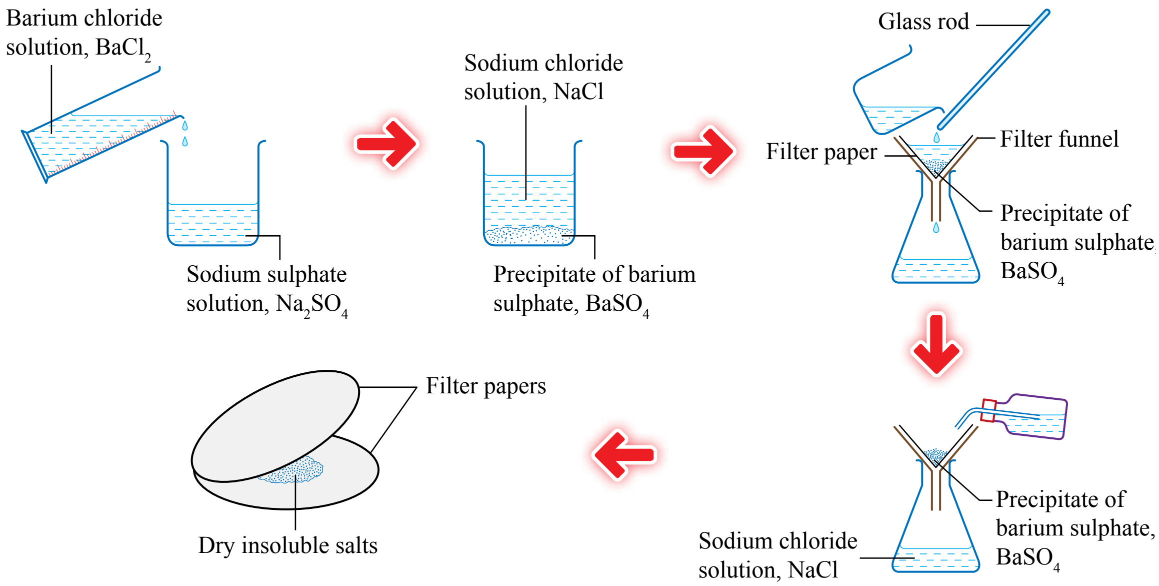


***Figure 6.42** Apparatus set-up in the preparation of insoluble salt*

1. Based on Figure 6.42, plan the activity with your group members to prepare the insoluble salt of barium sulphate, $BaSO_4$.
2. Discuss with your teacher if you encounter any problems while planning the procedure.
3. Carry out the activity with your teacher's permission.

Discussion:

1. Write a balanced chemical equation for the preparation of barium sulphate salt, $BaSO_4$.
2. Write an ionic equation for the preparation of barium sulphate salt, $BaSO_4$.
3. Why must the filtered barium sulphate salt, $BaSO_4$ precipitate rinsed with distilled water?
4. In your opinion, is it suitable to prepare barium sulphate salt, $BaSO_4$ based on the reaction between sulphuric acid, H_2SO_4 and barium carbonate, $BaCO_3$? Explain your answer.
5. Name two other salts that can be prepared by the double decomposition reaction. Then, suggest suitable aqueous solutions for the preparation of the salts mentioned.

Prepare a complete report after carrying out this activity.

In the double decomposition reaction, the ions in both aqueous solutions exchange with each other to form a new aqueous solution and a precipitate. The ionic equation for the formation of barium sulphate, $BaSO_4$ can be derived from the balanced chemical equations as shown below:

Chemical equation:

$$BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$$

$$\underbrace{Ba^{2+}(aq) + \cancel{2Cl^-}(aq)}_{\text{Ions in barium chloride}} + \underbrace{\cancel{2Na^+}(aq) + SO_4^{2-}(aq)}_{\text{Ions in sodium sulphate}} \rightarrow \underbrace{BaSO_4(s)}_{\text{Precipitate}} + \underbrace{\cancel{2Na^+}(aq) + \cancel{2Cl^-}(aq)}_{\text{Ions in sodium chloride}}$$

The Na^+ ion and Cl^- ion are spectator ions which do not take part in the reaction. Thus, these ions are cancelled out in the equation.

Ionic equation:

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$$

Activity 6.25

Writing the ionic equation for the formation of insoluble salts

1. Write the ionic equation for the following reactions:
   - (a) The reaction between silver nitrate, $AgNO_3$ and magnesium chloride, $MgCl_2$
   - (b) Mixing potassium chromate(VI), K_2CrO_4 with lead(II) nitrate, $Pb(NO_3)_2$
   - (c) Copper(II) chloride solution, $CuCl_2$ is added to sodium carbonate solution, Na_2CO_3

Construction of Ionic Equations through the Continuous Variation Method

The **continuous variation method** is used to construct the ionic equation for the formation of insoluble salts. In this method, the volume of one solution, *A* is fixed, while solution *B* is added to the solution *A* by increasing the volume as shown in Figure 6.43.

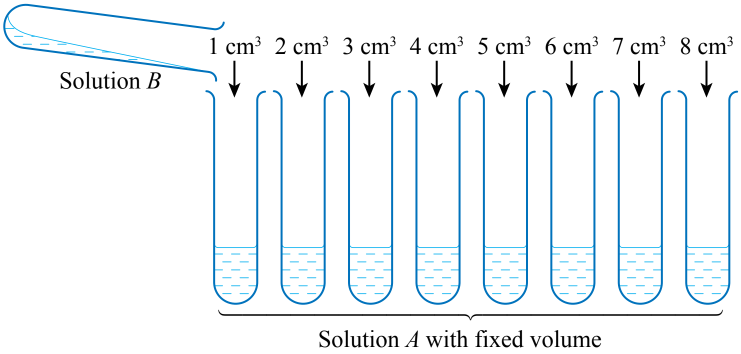


Figure 6.43 *Continuous variation method*

The height of the precipitate formed increases gradually for the first few test tubes and then becomes constant as shown in Figure 6.44.

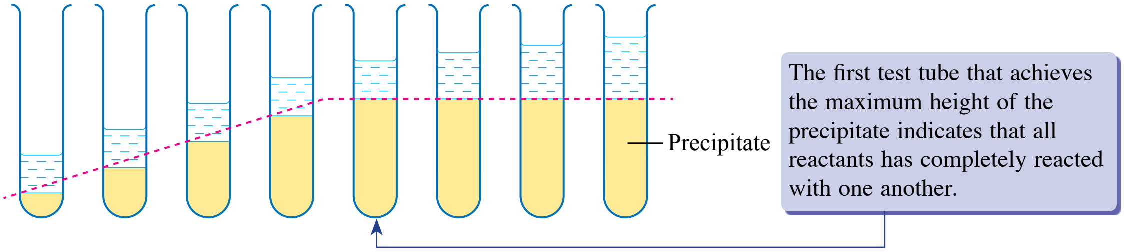


Figure 6.44 *Changes of the height of the precipitate*

Experiment 6.6

Aim: To construct an ionic equation for the formation of lead(II) iodide.

Problem statement: How to construct an ionic equation for the formation of lead(II) iodide?

Hypothesis: As the volume of potassium iodide solution, KI added to lead(II) nitrate solution, $Pb(NO_3)_2$ increases, the height of the precipitate will increase and then remain constant.

Variables:

(a) Manipulated : Volume of potassium iodide solution, KI

(b) Responding : Height of the precipitate

(c) Fixed : Volume and concentration of lead(II) nitrate solution, $Pb(NO_3)_2$, concentration of potassium iodide solution, KI

Materials: 0.5 mol dm^{-3} lead(II) nitrate solution, $Pb(NO_3)_2$, 0.5 mol dm^{-3} potassium iodide solution, KI and distilled water

Apparatus: Test tubes of the same size, glass rod, test tube rack, burette, retort stand with clamp and ruler

Safety Precaution

Make sure all the test tubes used are of the same size.

Procedure:

1. Label eight test tubes from 1 to 8 and place all the test tubes in a test tube rack.
2. Using a burette, fill each test tube with 5 cm^3 of 0.5 mol dm^{-3} lead(II) nitrate solution, $Pb(NO_3)_2$.
3. Using a second burette, add 0.5 mol dm^{-3} potassium iodide solution, KI into each test tube according to the volume stated in Table 6.7.
4. Place a glass rod into the test tube. Swirl the glass rod with both palms to ensure even mixing of the two solutions.
5. Slowly remove the glass rod. Rinse the precipitate that is stuck to the glass rod and the walls of the test tubes with distilled water.
6. Repeat steps 4 and 5 for the rest of the test tubes.
7. Leave the test tubes to stand for 30 minutes for the precipitate to settle to the bottom.
8. Record the colour of the precipitate formed and the solution on top of the precipitate.
9. Measure and record the height of the precipitate in each test tube.

Results:

Table 6.7

Test tube	1	2	3	4	5	6	7	8
Volume of lead(II) nitrate solution, $Pb(NO_3)_2$ (cm^3)	5	5	5	5	5	5	5	5
Volume of potassium iodide solution, KI (cm^3)	1	2	3	4	5	6	7	8
Height of precipitate (cm)								
Colour of the solution on top of the precipitate								

Interpreting data:

1. Plot a graph of the height of the precipitate against the volume of potassium iodide, KI.
2. From the graph, determine the volume of the potassium iodide solution, KI that completely reacts with 5 cm^3 of lead(II) nitrate solution, $Pb(NO_3)_2$.
3. Calculate the number of moles for:
   (a) Lead(II) ions, Pb^{2+} in 5 cm^3 of 0.5 mol dm^{-3} lead(II) nitrate solution, $Pb(NO_3)_2$
   (b) Iodide ions, I^- that reacts with 5 cm^3 of 0.5 mol dm^{-3} lead(II) nitrate solution, $Pb(NO_3)_2$
4. Determine the number of moles of iodide ion, I^- that reacts completely with 1 mol of lead(II) ion, Pb^{2+}.
5. Based on your answer in questions 3 and 4, construct an ionic equation for the formation of the lead(II) iodide precipitate, PbI_2.

Conclusion:

Is the hypothesis acceptable? What is the conclusion of the experiment?

Discussion:

1. Why should the test tubes be of the same size?
2. Explain why the height of the precipitate increases gradually and then remains constant.

Prepare a complete report after carrying out this experiment.

In the continuous variation method, fixing the volume of lead(II) nitrate solution, $Pb(NO_3)_2$ while manipulating the volume of potassium iodide, KI is to determine the mole ratio of lead(II) ions, Pb^{2+} that will react completely with the iodide ions, I^-. If x mol of lead(II) ions, Pb^{2+} reacts with y mole of iodide ions, I^-, then the empirical formula of the insoluble salt is Pb_xI_y.

$$x(\text{ion } Pb^{2+}) + y(\text{ion } I^-) \rightarrow Pb_xI_y$$

Brain Teaser

If 2 moles of silver ions, Ag^+ reacts with 1 mole of carbonate ions, CO_3^{2-}, can you write the ionic equation for the formation of silver carbonate salt?

Test Yourself 6.9

1. Classify the following into soluble and insoluble salts.

$NaNO_3$
$Pb(NO_3)_2$
$(NH_4)_2SO_4$
$BaSO_4$
$MgSO_4$
PbI_2
$CaCO_3$
K_2CO_3
$BaCrO_4$
$NaCl$
$AgCl$
$ZnCl_2$

2. Suggest suitable aqueous solutions for the preparation of calcium sulphate salt, $CaSO_4$. Then, write an ionic equation for the formation of the salt.

3. Using a diagram, show how zinc nitrate crystals, $Zn(NO_3)_2$ can be prepared. In your diagram, include the reagents that are needed.

6.10 Effect of Heat on Salts

Based on the conversation in Figure 6.45, can you identify the anion based on the gas released?

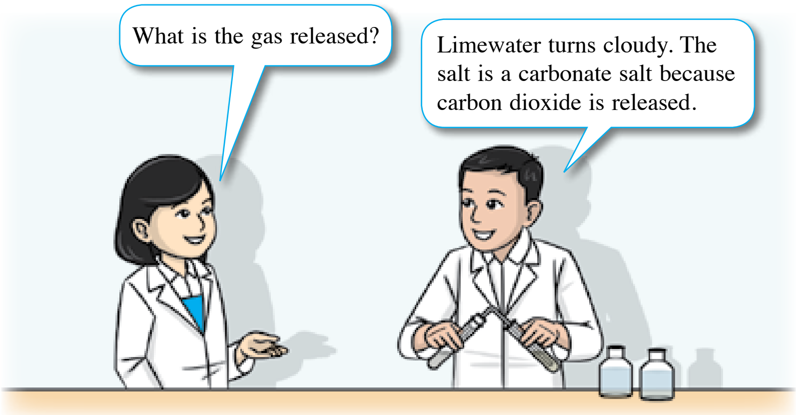


Figure 6.45 *Carbon dioxide gas turns limewater cloudy*

Learning Standard

At the end of the lesson, pupils are able to:
6.10.1 Describe briefly chemical tests to identify gases
6.10.2 Investigate the effects of heat on salts through experiment

Gas Tests

The process to identify a gas can be carried out by the gas test in Activity 6.26.

Activity 6.26

Aim: Identifying the gases released.

Materials: Solid potassium chlorate(V), $KClO_3$, dilute sulphuric acid, H_2SO_4, zinc powder, Zn, solid zinc carbonate, $ZnCO_3$, dilute sodium hydroxide solution, NaOH, solid ammonium chloride, NH_4Cl, solid manganese(IV) oxide, MnO_2, concentrated hydrochloric acid, HCl, solid sodium chloride, NaCl, concentrated sulphuric acid, H_2SO_4, concentrated ammonia solution, NH_3, solid sodium sulphite, Na_2SO_3, dilute hydrochloric acid, HCl, acidified potassium manganate(VII) solution, $KMnO_4$, solid lead(II) nitrate, $Pb(NO_3)_2$, red litmus paper, blue litmus paper and limewater

Apparatus: Test tubes, test tube holder, wooden splinter, rubber stopper with delivery tube, glass rod, spatula, tongs, Bunsen burner and 10 cm^3 measuring cylinder

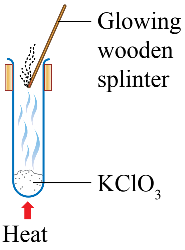
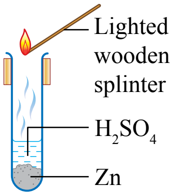
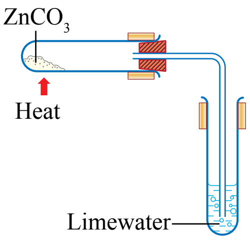
Procedure:

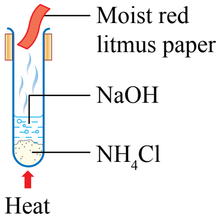
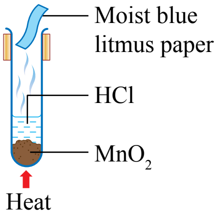
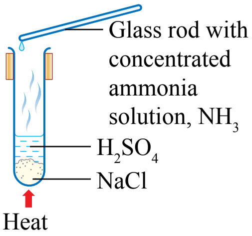
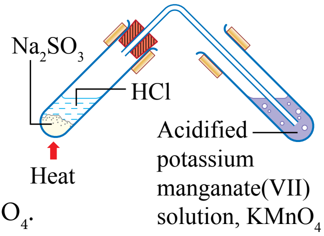
Carry out the test for gases and record your observations.

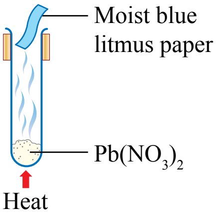
CAUTION

This activity has to be carried out in the fume chamber.

Table 6.8

Gas test	Observation	Inference
A: Test for oxygen gas, O_2 **1.** Put two spatulas of solid potassium chlorate(V), $KClO_3$ into a test tube. **2.** Heat the solid with high heat. **3.** Insert a glowing wooden splinter into the test tube. 		
B: Test for hydrogen gas, H_2 **1.** Put some a few pieces of zinc powder, Zn into a test tube. **2.** Add 4 cm^3 of dilute sulphuric acid, H_2SO_4 into the test tube. **3.** Place a lighted wooden splinter near the mouth of the test tube. 		
C: Test for carbon dioxide gas, CO_2 **1.** Put a spatula of solid zinc carbonate, $ZnCO_3$ into a test tube. **2.** Heat the solid with high heat. **3.** Flow the gas produced into limewater. 		

Gas test	Observation	Inference
D: Test for ammonia gas, NH_3 **1.** Put a spatula of solid ammonium chloride, NH_4Cl into a test tube. **2.** Add 4 cm^3 of dilute sodium hydroxide solution, NaOH into the test tube. **3.** Heat the mixture slowly. **4.** Then, place a piece of moist red litmus paper to the mouth of the test tube. 		
E: Test for chlorine gas, Cl_2 **1.** Put a spatula of powdered manganate(IV) oxide, MnO_2 into a test tube. **2.** Carefully add 2 cm^3 of concentrated hydrochloric acid, HCl. **3.** Heat the mixture slowly. **4.** Then, place a piece of moist blue litmus paper to the mouth of the test tube. 		
F: Test for hydrogen chloride gas, HCl **1.** Put a spatula of solid sodium chloride, NaCl into a test tube. **2.** Add 2 cm^3 of concentrated sulphuric acid, H_2SO_4 carefully. **3.** Heat the mixture slowly. **4.** Dip a glass rod into concentrated ammonia solution, NH_3. **5.** Then, hold the dipped glass rod to the mouth of the test tube. 		
G: Test for sulphur dioxide gas, SO_2 **1.** Put a spatula of solid sodium sulphite, Na_2SO_3 into a test tube. **2.** Add 4 cm^3 of dilute hydrochloric acid, HCl. **3.** Heat the mixture slowly. **4.** Flow the gas released into acidified potassium manganate(VII) solution, $KMnO_4$.  **Note:** Acidified potassium manganate(VII) solution, $KMnO_4$ can be replaced with acidified potassium dichromate(VI) solution, $K_2Cr_2O_7$.		

Gas test	Observation	Inference
H: Test for nitrogen dioxide gas, NO_2 1. Put a spatula of solid lead(II) nitrate, $Pb(NO_3)_2$ into a test tube. 2. Heat the mixture with high heat. 3. Then, place a piece of moist blue litmus paper to the mouth of the test tube. 		

Interpreting data:

1. Based on the observations, write the corresponding inference.
2. Why should the litmus paper be moistened before testing for the gases released?
3. Copy and complete Table 6.9 to summarise the method used for gas test.

Table 6.9

Gas	Chemical tests	
	Method	**Observation**
Oxygen gas, O_2	Place a glowing wooden splinter into a test tube filled with the gas.	The glowing wooden splinter rekindles.
Hydrogen gas, H_2		
Carbon dioxide gas, CO_2		
Ammonia gas, NH_3		
Chlorine gas, Cl_2		
Hydrogen chloride gas, HCl		
Sulphur dioxide gas, SO_2		
Nitrogen dioxide gas, NO_2		

Discussion:

1. What is the expected observation if a glass rod that is dipped into concentrated hydrochloric acid, HCl, is brought closer to the gas released in test D?
2. Name the white fumes formed in test F.
3. The gas released in test G is acidic. Predict the observation when a moist litmus paper is used.

Prepare a complete report after carrying out this activity.

Effect of Heat

Most salts decompose when heated. By comparing the colour of the salt and the residue left behind and the gas released, we can identify the **cation** and **anion** that might be present in the salt. Experiment 6.7 investigates the action of heat on carbonate salt and nitrate salt.

Experiment 6.7

Aim: To investigate the action of heat on carbonate salts.

Problem statement: Do all carbonate salts decompose when heated to produce carbon dioxide gas?

Hypothesis: All carbonate salts decompose when heated to produce carbon dioxide gas.

Variables:

(a) Manipulated : Types of carbonate salts
(b) Responding : Products of decomposed carbonate salts
(c) Fixed : Two spatulas of carbonate salts

Materials: Solid sodium carbonate, Na_2CO_3, solid calcium carbonate, $CaCO_3$, solid zinc carbonate, $ZnCO_3$, solid lead(II) carbonate, $PbCO_3$, solid copper(II) carbonate, $CuCO_3$ and limewater

Apparatus: Test tubes, boiling tubes, test tube holder, Bunsen burner and rubber stopper with delivery tube

Procedure:

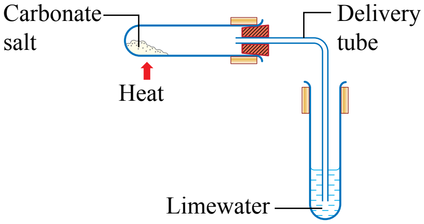


Figure 6.46

1. Place two spatulas of solid sodium carbonate, Na_2CO_3 into a dry boiling tube. Observe the colour of salt and record the observation.
2. Connect the rubber stopper with the delivery tube to the mouth of the boiling tube. Ensure that the other end of the delivery tube is placed into the limewater as shown in Figure 6.46.
3. Heat the carbonate salt with high heat.
4. Observe the changes that occur in the limewater and the colour of the residue in the boiling tube when it is hot and when it is cool. Record the observation.
5. Repeat steps 1 to 4 using other carbonate salts to replace sodium carbonate salt, Na_2CO_3.

Results:

Table 6.10

Carbonate salt	Colour of the salt before heating	Colour of the residue		Effect on limewater
		When hot	When cool	
Sodium carbonate, Na_2CO_3				
Calcium carbonate, $CaCO_3$				
Zinc carbonate, $ZnCO_3$				
Lead(II) carbonate, $PbCO_3$				
Copper(II) carbonate, $CuCO_3$				

Interpreting data:

1. What is the function of the limewater in the experiment?
2. What gas is released when carbonate salts are decomposed by heat?
3. Identify the carbonate salts that cannot be decomposed by heat.

Conclusion:

Is the hypothesis acceptable? What is the conclusion of the experiment?

Discussion:

1. Write an equation for the action of heat on carbonate salts that can be decomposed by heat.
2. Generally, the decomposition of carbonate salts by heat can be represented by the word equation below. Complete the word equation.

Carbonate salt $\xrightarrow[\text{Heat}]{}$ ☐ + ☐

3. Name another carbonate salt that cannot be decomposed by heat.

Prepare a complete report after carrying out this experiment.

Experiment 6.8

Aim: To investigate the action of heat on nitrate salts.

Problem statement: Do nitrate salts decompose when heated to release nitrogen dioxide gas and oxygen gas?

Hypothesis: Propose a suitable hypothesis for the experiment.

Variables: List all the variables involved in the experiment.

Materials: Solid sodium nitrate, $NaNO_3$, solid magnesium nitrate, $Mg(NO_3)_2$, solid zinc nitrate, $Zn(NO_3)_2$, solid lead(II) nitrate, $Pb(NO_3)_2$, solid copper(II) nitrate, $Cu(NO_3)_2$, wooden splinter and blue litmus paper

Apparatus: Boiling tube, test tube holder, Bunsen burner and spatula

Procedure:

1. Discuss the experimental procedure with your group members. Your discussion should include chemical tests for the gases released.
2. Identify the safety precautions when carrying out the experiment.
3. Carry out the experiment with your teacher's permission.
4. Record the salt colour before heating, the colour of the residue when it is hot and cool, the colour of the gas released and its effect on the moist blue litmus paper and the glowing wooden splinter in a table.

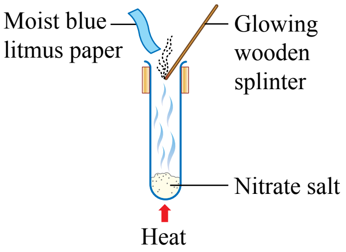


Figure 6.47 *Apparatus set-up for heating a nitrate salt*

Interpreting data:

1. Identify the nitrate salts that are not decomposed by heat.
2. Name the brown coloured gas released in the experiment.
3. What are the changes observed on the glowing wooden splinter? State the corresponding inference.

Conclusion:

Is the hypothesis acceptable? What is the conclusion of the experiment?

Discussion:

1. Write equations for the actions of heat on the nitrate salts that decompose other than sodium nitrate.
2. Generally, the thermal decomposition of nitrate is represented by the word equation below. Complete the equation.

$$\text{Nitrate salt} \xrightarrow[\text{Heat}]{} \square + \square + \square$$

Prepare a complete report after carrying out this experiment.

When heated, most carbonate salts decompose to produce metal oxides and carbon dioxide gas. For example, decomposition of zinc carbonate salt, $ZnCO_3$ produces zinc oxide, ZnO and carbon dioxide gas, CO_2.

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

When heated, nitrate salts decompose to produce metal oxides, nitrogen dioxide gas and oxygen gas. The following equation shows the thermal decomposition of lead(II) nitrate salt, $Pb(NO_3)_2$.

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

Only several sulphate salts and chloride salts can be decomposed when heated.

- Ammonium chloride: $NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$
- Zinc sulphate : $ZnSO_4(s) \rightarrow ZnO(s) + SO_3(g)$
- Iron(II) sulphate : $2FeSO_4(s) \rightarrow Fe_2O_3(s) + SO_2(g) + SO_3(g)$

The cation or anion of a salt can be identified based on the gases released when the salt undergoes thermal decomposition.

- Carbon dioxide gas → Carbonate salt
- Nitrogen dioxide gas + Oxygen gas → Nitrate salt
- Ammonia gas → Ammonium salt

Chemistry Lens

The cation presents in some salts can be identified from the colour of the residue after heating.

Colour of residue		Metal oxide	Cation present in the salt
Hot	Cold		
Yellow	White	Zinc oxide, ZnO	Zinc ion, Zn^{2+}
Brown	Yellow	Lead(II) oxide, PbO	Lead(II) ion, Pb^{2+}
Black	Black	Copper(II) oxide, CuO	Copper(II) ion, Cu^{2+}

Example 16

Salt *X* decomposes when heated. A brown coloured gas is released and turns moist blue litmus paper to red. The colour of the residue is brown when it is hot and yellow when it is cool. Name salt *X*.

Solution:

The brown coloured gas is nitrogen dioxide. Salt *X* contains nitrate ion, NO_3^-.
The residue is lead(II) oxide, PbO. Salt *X* contains lead(II) ion, Pb^{2+}.
Salt *X* is lead(II) nitrate, $Pb(NO_3)_2$.

TestYourself 6.10

1. Identify the colourless gas that turns the colour of acidified potassium dichromate(VI) solution, $K_2Cr_2O_7$ from orange to green.
2. Copper(II) nitrate salt, $Cu(NO_3)_2$ is heated with high heat in a boiling tube. State the observations on the colour of the residue and the gas released.
3. The following results are obtained in a laboratory activity to investigate the effect of heat on a sample of salt *Y*.

   - Colourless gas turns limewater cloudy.
   - The colour of the residue is yellow when it is hot and white when it is cooled.

   Identify salt *Y*.

6.11 Qualitative Analysis

Qualitative Analysis to Identify Cations and Anions in Salts

Qualitative analysis of a salt is a technique used to identify the cation and anion present in a salt by analysing its physical and chemical properties. Figure 6.48 shows the steps that are involved in the qualitative analysis of a salt.

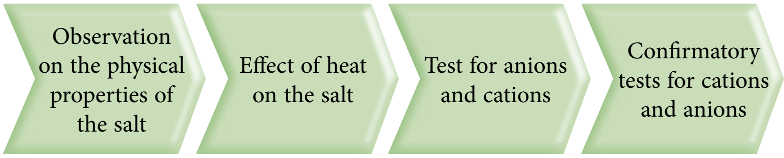


Figure 6.48 *Steps in the qualitative analysis of a salt*

Learning Standard

At the end of the lesson, pupils are able to:
6.11.1 Identify the cation and anion present in a salt through experiment
6.11.2 Describe the confirmatory tests to identify cations and anions

A Observations of the Physical Properties of Salts

Observing the physical properties of salts such as colour and solubility in water is the first step to make inferences on the possibility of the presence of cations and anions in the salt. Even though the solubility test of the salts does not confirm the identities of the ions present, it helps us narrow down the possible identities of the ions present.

For example, salt *X* is soluble in water. Hence, salt *X* might contain NO ASaP ions, but definitely not HPA chloride or PBC sulphate and most probably does not contain the carbonate ion, CO_3^{2-}.

The colour of the salt is one of the physical properties that enables us to make inference on the cation present in the salt. How is this possible? Carry out Activity 6.27 below.

Activity 6.27

Aim: To investigate the colour of the salts and their solubility in water.

Materials: Solid ammonium nitrate, NH_4NO_3, solid potassium nitrate, KNO_3, solid sodium chloride, NaCl, solid calcium carbonate, $CaCO_3$, solid calcium nitrate, $Ca(NO_3)_2$, solid magnesium sulphate, $MgSO_4$, solid magnesium carbonate, $MgCO_3$, solid zinc sulphate, $ZnSO_4$, solid zinc chloride, $ZnCl_2$, solid iron(II) sulphate, $FeSO_4$, solid iron(III) chloride, $FeCl_3$, solid lead(II) nitrate, $Pb(NO_3)_2$, solid lead(II) chloride, $PbCl_2$, solid lead(II) sulphate, $PbSO_4$, solid copper(II) sulphate, $CuSO_4$, solid copper(II) chloride, $CuCl_2$, solid copper(II) nitrate, $Cu(NO_3)_2$, solid copper(II) carbonate, $CuCO_3$ and distilled water

Apparatus: Test tubes, test tube rack, glass rod, spatula and wash bottle

Procedure:

1. Observe and record the colour of each solid salt.
2. Put a little amount of the salt into a test tube. Fill the test tube with distilled water and stir the mixture.
3. Observe the solubility of the salt and the colour of the solution formed.
4. Record all observations in Table 6.11.

Results:

Table 6.11

Type of salt	Colour of the salt	Solubility in water		Colour of the salt solution
		Yes	No	
Ammonium nitrate, NH_4NO_3				
Potassium nitrate, KNO_3				

Interpreting data:

1. Name solid salts that are coloured:
   (a) Green (b) Brown (c) Blue (d) White
2. Name green salts that are:
   (a) Insoluble in water
   (b) Soluble in water to form a blue solution
   (c) Soluble in water to form a light green solution

Discussion:

1. Is the colour of the salt suitable to identify the cation presents in the salt? Explain.
2. What is the colour of the solution formed when the white salt dissolves in water?
3. Classify each salt as soluble salts or insoluble salts.
4. What is the operational definition of **insoluble salts**?

Prepare a complete report after carrying out this activity.

All white soluble salts dissolve in water to form colourless salt solutions. Salts form coloured solutions due to the presence of ions in transition elements.
For example,

- ☆ Blue solution : possibly contains copper(II) ion, Cu^{2+}
- ☆ Brown solution: possibly contains iron(III) ion, Fe^{3+}
- ☆ Green solution : possibly contains iron(II) ion, Fe^{2+}

Chemistry Lens

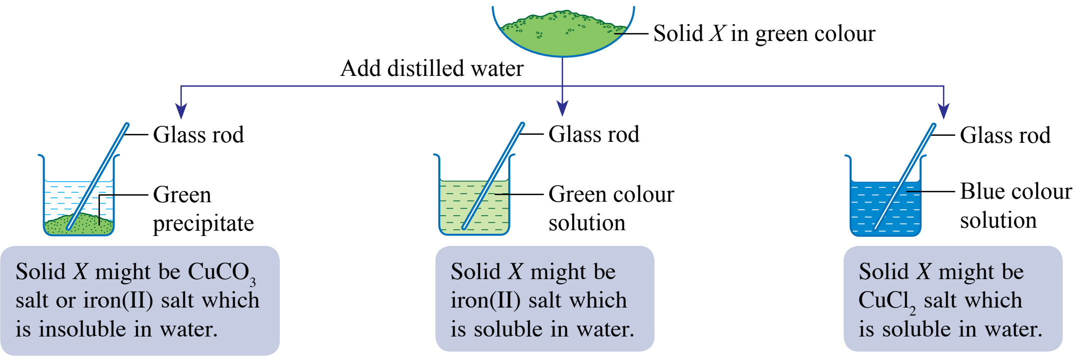
Other than iron(II) ion, Fe^{2+}, nickel(II) ion, Ni^{2+} and chromium(III) ion, Cr^{3+} also give green colour in aqueous solutions.

Table 6.12 shows the colour of some salts in the solid state and in aqueous solution.

***Table 6.12** Colour of salts in solid state and in aqueous solution*

Salt	Colour	
	Solid state	Aqueous solution
Salts containing iron(II) ion, Fe^{2+}	Green	Green/light green
Salts containing iron(III), Fe^{3+}	Brown	Brown/yellowish brown
Copper(II) sulphate, $CuSO_4$ Copper(II) nitrate, $Cu(NO_3)_2$	Blue	Blue
Copper(II) chloride salt, $CuCl_2$	Green	Blue
Copper(II) carbonate salt, $CuCO_3$	Green	Insoluble in water

Figure 6.49 shows the example on the qualitative analysis of a solid *X* which is green in colour and three possible results.



Solid *X* might be $CuCO_3$ salt or iron(II) salt which is insoluble in water.

Solid *X* might be iron(II) salt which is soluble in water.

Solid *X* might be $CuCl_2$ salt which is soluble in water.

***Figure 6.49** Qualitative analysis based on the solubility of the salt and its colour*

B Effect of Heat on Salts and Gas Tests

The gas released when a salt is heated can be identified through its colour, smell, action on moist litmus paper or best, by conducting a gas test. After heating the salt, we can make an inference on the ions that might be present based on the colour of the residue and the gas identified, as shown in Table 6.13 and Table 6.14.

Table 6.13

Colour of residue	Inference
Black	Salt contains Cu^{2+} ion
Brown	Salt contains Fe^{3+} ion
Yellow when hot, white when cool	Salt contains Zn^{2+} ion
Brown when hot, yellow when cool	Salt contains Pb^{2+} ion

Table 6.14

Gas produced	Inference
Gas turns limewater cloudy	Carbonate salt
Gas is brown and acidic	Nitrate salt
Gas is pungent and alkaline	Ammonium salt
Gas ignites the glowing wooden splinter	Might be nitrate salt or Ag_2CO_3

Figure 6.50 and 6.51 show the examples of qualitative analysis based on the effect of heat on salts *X* and *Y* and the corresponding gas tests. However, the qualitative analysis carried out could not identify the presence of cation in the salts.

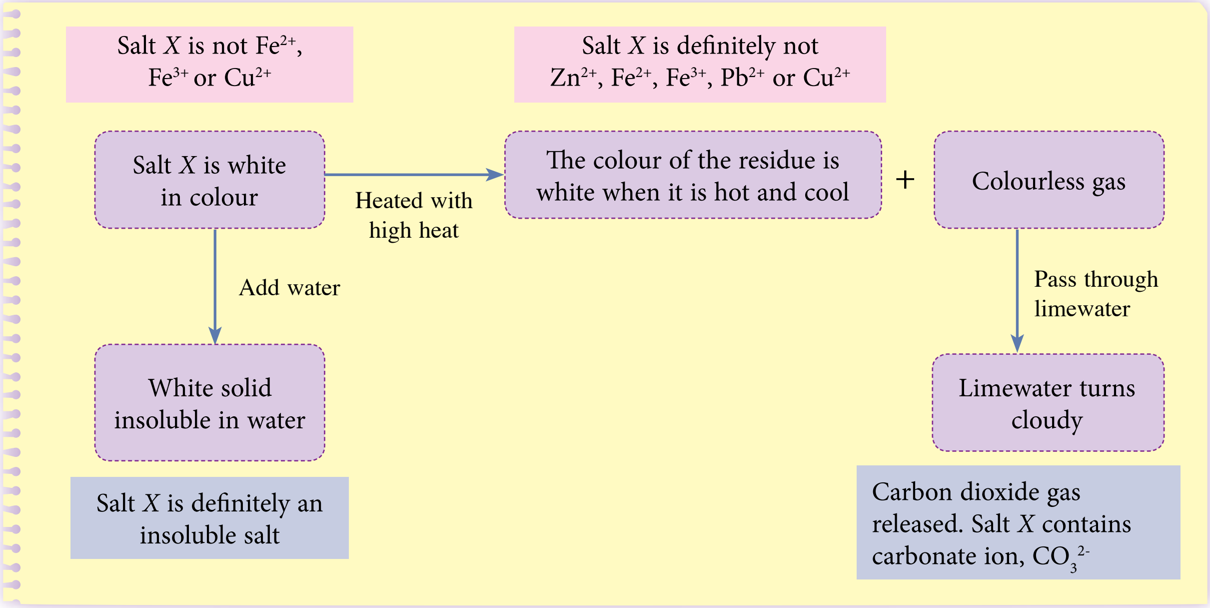


Figure 6.50 *Qualitative analysis based on the effects of heat on salt X and gas test*

Salt *X* is a carbonate salt that possibly contains Ca^{2+} ion, Mg^{2+} ion or Al^{3+} ion and not K^+ ion or Na^+ ion because potassium carbonate and sodium carbonate are not decomposed by heat.

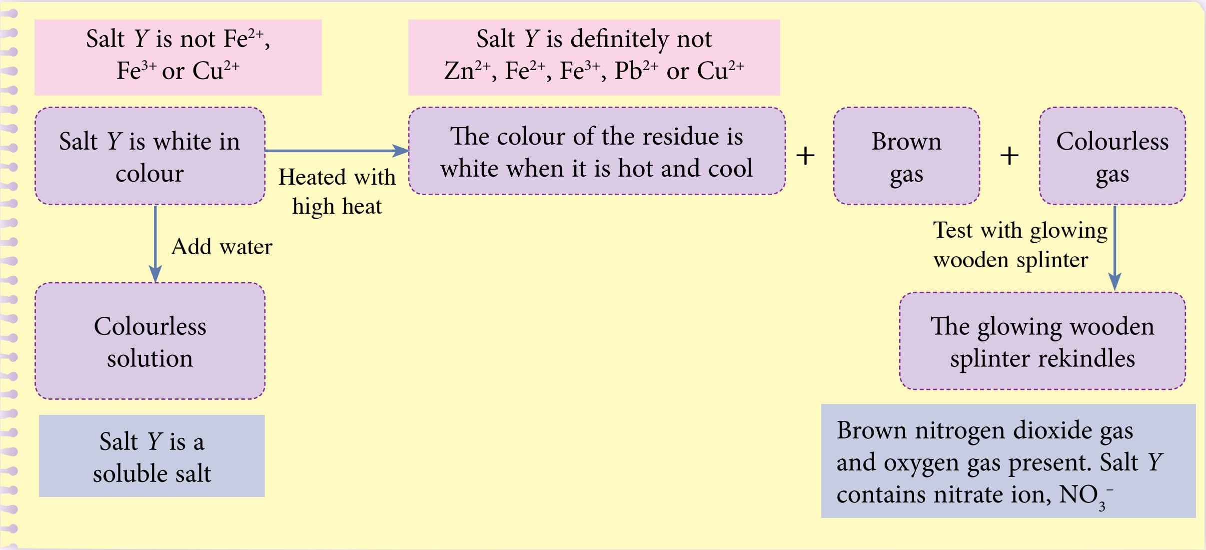


Figure 6.51 *Qualitative analysis based on the effects of heat on salt Y and gas tests*

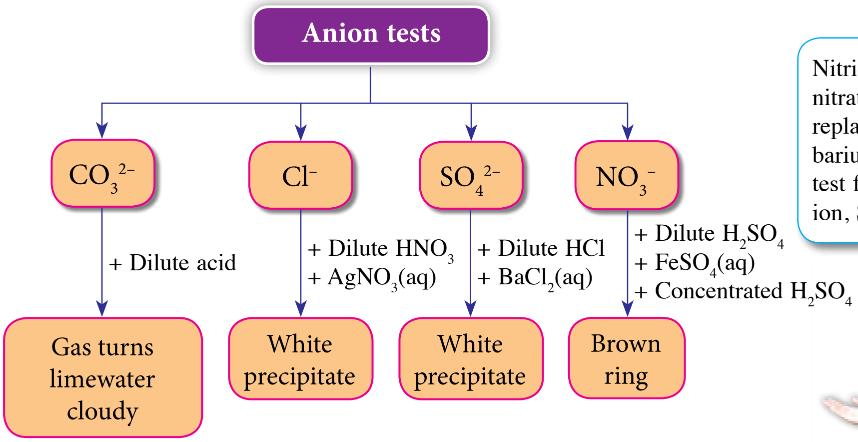
Salt Y is a nitrate salt that possibly contains Ca^{2+} ion, Mg^{2+} ion or Al^{3+} ion and not K^+ ion and Na^+ ion because potassium nitrate and sodium nitrate do not produce a brown gas.

C Anion Tests

Only four anions are needed to be identified at this level, which are:

- ✩ Carbonate ion, CO_3^{2-}
- ✩ Sulphate ion, SO_4^{2-}
- ✩ Chloride ion, Cl^-
- ✩ Nitrate ion, NO_3^-

Certain anions can be identified from testing the gases released when the salt undergoes decomposition by heat. However, the identity of the anion in a salt still needs to be confirmed through anion tests. Figure 6.52 shows the flow chart of the anion tests.



Nitric acid, HNO_3 and barium nitrate solution, $Ba(NO_3)_2$ can replace hydrochloric acid, HCl and barium chloride solution, $BaCl_2$ to test for the presence of sulphate ion, SO_4^{2-}.

Figure 6.52 *Summary of the anion tests*

The test for anions in an aqueous solution of the salt can be performed as in Experiment 6.9.

Experiment 6.9

Aim: To identify the anions present in aqueous salt solutions.

Problem statement: How to identify the anions that are present in aqueous solutions?

Hypothesis: The anions present can be identified through observations from the chemical tests on anions.

Variables:

(a) Manipulated : Types of anions present in the solution
(b) Responding : Observations made
(c) Fixed : Volume of aqueous salt solution

Materials: 2.0 mol dm^{-3} nitric acid, HNO_3, 0.1 mol dm^{-3} silver nitrate solution, $AgNO_3$, 2.0 mol dm^{-3} hydrochloric acid, HCl, 1.0 mol dm^{-3} barium chloride solution, $BaCl_2$, 1.0 mol dm^{-3} sulphuric acid, H_2SO_4, 1.0 mol dm^{-3} iron(II) sulphate solution, $FeSO_4$, concentrated sulphuric acid, H_2SO_4, sample of salt *A* (solid sodium carbonate, Na_2CO_3), sample of salt *B* (solid sodium chloride, NaCl), sample of salt *C* (solid sodium sulphate, Na_2SO_4), sample of salt *D* (solid sodium nitrate, $NaNO_3$), distilled water and limewater

Apparatus: Test tubes, test tube holder, test tube rack, glass rod, dropper, rubber stopper with delivery tube, spatula, 100 cm^3 beaker, 10 cm^3 measuring cylinder

Procedure:

Preparing aqueous solutions of the salts

1. Put salt sample *A* provided by the teacher into a beaker.
2. Dissolve salt sample *A* with distilled water to produce 20 cm^3 of salt *A* solution.
3. Pour 2 cm^3 of salt *A* solution into 4 test tubes. Label the test tubes as A1, A2, A3 and A4.
4. Repeat steps 1 until 3 using salt samples *B*, *C* and *D*.

(I) Test for carbonate ion, CO_3^{2-}

1. Add 2 cm^3 of 2.0 mol dm^{-3} hydrochloric acid, HCl into the test tube labelled A1. If effervescence occurs, flow the gas into limewater as shown in Figure 6.53.
2. Record the observation.
3. Repeat steps 1 and 2 using solutions B1, C1 and D1.

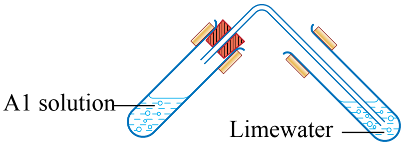


Figure 6.53

(II) Test for chloride ion, Cl^-

1. Add excess of 2.0 mol dm^{-3} nitric acid, HNO_3 into the test tube labelled A2, followed by 2 cm^3 of 0.1 mol dm^{-3} silver nitrate solution, $AgNO_3$.
2. Record the observation.
3. Repeat steps 1 and 2 using solutions B2, C2 and D2.

CAUTION

Be careful when using silver nitrate solution, $AgNO_3$. Skin that comes into contact with silver nitrate solution, $AgNO_3$ would turn brown. The brown spots would disappear only after a few days.

(III) Test for sulphate ion, SO_4^{2-}

1. Add 2.0 mol dm^{-3} hydrochloric acid, HCl into the test tube labelled A3, followed by 2.0 mol dm^{-3} barium chloride solution, $BaCl_2$.
2. Record the observation.
3. Repeat steps 1 and 2 with solutions B3, C3 and D3.

(IV) Test for nitrate ion, NO_3^-

1. Add 2 cm^3 of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 into the test tube labelled A4, followed by 2 cm^3 of 1.0 mol dm^{-3} iron(II) sulphate solution, $FeSO_4$.
2. Shake the mixture.
3. Carefully, drip a few drops of concentrated sulphuric acid, H_2SO_4 slowly down the wall of the tilted test tube as shown in Figure 6.54.
4. Slowly set the test tube upright.
5. Record the observation.
6. Repeat steps 1 to 5 using solutions B4, C4 and D4.

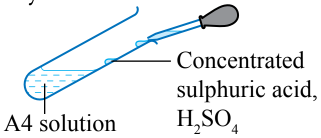


Figure 6.54

Results:

Table 6.15

Test	Observation			
	Salt *A* solution	**Salt *B* solution**	**Salt *C* solution**	**Salt *D* solution**
Carbonate ion, CO_3^{2-}				
Chloride ion, Cl^-				
Sulphate ion, SO_4^{2-}				
Nitrate ion, NO_3^-				

Interpreting data:

1. What was the gas released that causes the effervescence?
2. (a) Name the white precipitate formed in the test for chloride ion, Cl^-.
   (b) Write the ionic equation for the formation of the precipitate in 2(a).
3. (a) What is the name of the white precipitate formed in the test for sulphate ion, SO_4^{2-}.
   (b) Write the ionic equation for the formation of the white precipitate in 3(a).
4. Identify the anion in the following samples:
   (a) Salt *A* (b) Salt *B* (c) Salt *C* (d) Salt *D*

Conclusion:

Is the hypothesis accepted? What is the conclusion of the experiment?

Discussion:

1. What is the purpose of adding excess acid in the test for chloride ion, Cl^- and sulphate ion, SO_4^{2-} before adding the other reagents?
2. A student performs a test for the chloride ion, Cl^- in a sample of salt solution. He added the silver nitrate solution, $AgNO_3$ without first adding an excess of nitric acid, HNO_3. He then made the inference of the presence of chloride ions, Cl^- in the sample when he observed a white precipitate being formed. Was the inference correct? Why?

Prepare a complete report after carrying out this experiment.

Based on the test for the carbonate ion, CO_3^{2-} the reaction between acid and carbonate ions, CO_3^{2-} produces carbon dioxide gas that turns limewater cloudy.

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

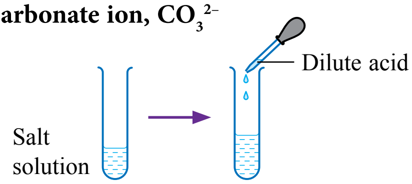
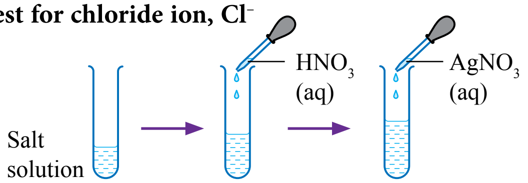
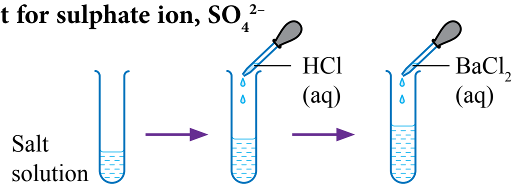
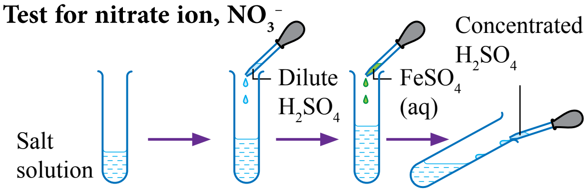
In the test for chloride ion, Cl^-, silver ion, Ag^+ is used to detect the presence of chloride ions, Cl^-. If chloride ions, Cl^- is present, hence the white precipitate of silver chloride, AgCl is produced. However, the carbonate ion, CO_3^{2-} also gives the same observation when reacting with silver ion, Ag^+ due to the formation of a white precipitate of silver carbonate, Ag_2CO_3. Therefore, an excess of nitric acid, HNO_3 has to be added before adding silver nitrate solution, $AgNO_3$. If effervescence occurs when nitric acid, HNO_3 was added, then, the presence of carbonate ion, CO_3^{2-} is confirmed. However, if no effervescence occurs, the formation of white precipitate confirms the presence of the chloride ion, Cl^-.

Chemistry Lens

Reaction between concentrated sulphuric acid, H_2SO_4 and nitrate ion, NO_3^- produces nitrogen monoxide, NO. When nitrogen monoxide, NO combines with iron(II) sulphate, $FeSO_4$, a complex compound of nitrosyliron(II) sulphate, $FeSO_4.NO$, which is a brown ring, is observed.

For the test of sulphate ion, SO_4^{2-}, barium ion, Ba^{2+} used to detect the presence of sulphate ion, SO_4^{2-} because the reaction between the barium ion, Ba^{2+} and sulphate ion, SO_4^{2-} produces a white precipitate of barium sulphate, $BaSO_4$. Hydrochloric acid, HCl was added in excess before adding barium chloride solution, $BaCl_2$ for the same reason as in the test for chloride ion, Cl^-, that is to detect and eliminate the carbonate ion, CO_3^{2-} that might be present.

Table 6.16 Qualitative analysis based on anion tests

Anion test	Observation	Inference
Test for carbonate ion, CO_3^{2-}  	Effervescence occurs. The gas released turns limewater cloudy.	Carbonate ion, CO_3^{2-} is present. Ionic equation: $2H^+(aq) + CO_3^{2-}(aq) \rightarrow CO_2(g) + H_2O(l)$
Test for chloride ion, Cl^-  	White precipitate is formed.	Chloride ion, Cl^- is present. Ionic equation: $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
Test for sulphate ion, SO_4^{2-}  	White precipitate is formed.	Sulphate ion, SO_4^{2-} is present. Ionic equation: $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$
Test for nitrate ion, NO_3^-  	Brown ring is formed.	Nitrate ion, NO_3^- is present.

D Cation Tests

Alkalis such as sodium hydroxide solution, NaOH, and ammonia solution, NH_3 are two main reagents used to test the presence of cations. The hydroxide ion, OH^- from both solutions combine with most metal ions to form a precipitate of metal hydroxide. For example,

$Zn^{2+}(aq)$	+	$2OH^-(aq)$	→	$Zn(OH)_2(s)$
Metal ion		Hydroxide ion		Metal hydroxide precipitate

Inference about the cations present can be made based on the observation on the colour of the precipitate and its solubility in an excess of alkali solution.

Experiment 6.10

Aim: To identify the cations present in aqueous solutions.

Problem statement: How to identify the cations present in aqueous solutions?

Hypothesis: Types of cations present in a solution can be identified through observations of the cation tests.

Variables:

(a) Manipulated : Types of cations present in aqueous solutions
(b) Responding : Observations made
(c) Fixed : Volume of aqueous salt solution

Materials: 2.0 mol dm^{-3} sodium hydroxide solution, NaOH, 2.0 mol dm^{-3} ammonia solution, NH_3, 1.0 mol dm^{-3} calcium nitrate solution, $Ca(NO_3)_2$, 1.0 mol dm^{-3} magnesium nitrate solution, $Mg(NO_3)_2$, 1.0 mol dm^{-3} aluminium nitrate solution, $Al(NO_3)_3$, 1.0 mol dm^{-3} zinc nitrate solution, $Zn(NO_3)_2$, 1.0 mol dm^{-3} iron(II) sulphate solution, $FeSO_4$, 1.0 mol dm^{-3} iron(III) chloride solution, $FeCl_3$, 1.0 mol dm^{-3} lead(II) nitrate solution, $Pb(NO_3)_2$, 1.0 mol dm^{-3} copper(II) sulphate solution, $CuSO_4$ and 1.0 mol dm^{-3} ammonium nitrate solution, NH_4NO_3

Apparatus: Test tubes, test tube holder, test tube rack, dropper, 100 cm^3 beaker, red litmus paper, Bunsen burner and 10 cm^3 measuring cylinder

Procedure:

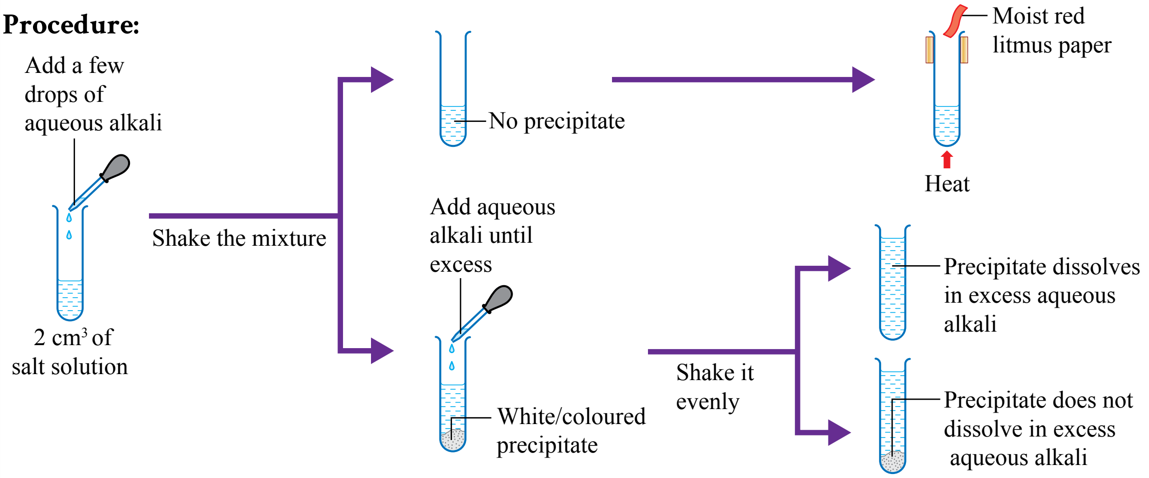


Figure 6.55 *Steps in identifying the cations in aqueous solutions*

A **Using sodium hydroxide solution, NaOH**

1. Based on Figure 6.55, discuss the experimental procedures with your group members.
2. Determine the safety precautions needed in carrying out the experiment.
3. Carry out the experiment with your teacher's permission.
4. Record all the observations in Table 6.17.

B **Using ammonia solution, NH_3**

1. Repeat the procedure in A by using ammonia solution, NH_3 to replace sodium hydroxide solution, NaOH.
2. Record all the observations in Table 6.17.

Results:

Table 6.17

Salt solution	Cation	Observation			
		Small amount of sodium hydroxide solution, NaOH	Excess amount of sodium hydroxide solution, NaOH	Small amount of ammonia solution, NH_3	Excess amount of ammonia solution, NH_3
Calcium nitrate, $Ca(NO_3)_2$					
Magnesium nitrate, $Mg(NO_3)_2$					
Aluminium nitrate, $Al(NO_3)_3$					
Zinc nitrate, $Zn(NO_3)_2$					
Iron(II) sulphate, $FeSO_4$					
Iron(III) chloride, $FeCl_3$					
Lead(II) nitrate, $Pb(NO_3)_2$					
Copper(II) sulphate, $CuSO_4$					
Ammonium nitrate, NH_4NO_3					

Interpreting data:

Based on the experiment in part A:

1. List the cations that produce precipitates which are:
   (a) Green (b) Brown (c) Blue (d) White
2. Which salt solution does not show any changes on the addition of sodium hydroxide solution, NaOH. What is the gas released upon heating?
3. Name the cations that produce white precipitates which are:
   (a) Soluble in an excess amount of sodium hydroxide solution, NaOH
   (b) Insoluble in an excess amount of sodium hydroxide solution, NaOH

Based on the experiment in part B:

1. List the cations that produce precipitates which are:
   (a) Green (c) Blue
   (b) Brown (d) White
2. Which salt solution does not show any changes on the addition of ammonia solution, NH_3?
3. Name the cations that produce white precipitates which are:
   (a) Soluble in excess amount of ammonia solution, NH_3
   (b) Insoluble in excess amount of ammonia solution, NH_3
4. Which cations form a precipitate that is soluble in excess amount of ammonia, NH_3 to produce a dark blue solution?

Conclusion:

Is the hypothesis accepted? What is the conclusion of this experiment?

Discussion:

1. Identify the cations that react with both alkalis to produce white precipitates that are soluble in an excess amount of the alkali.
2. Based on the cations identified in question 1, write ionic equations for the formation of the precipitates.

Prepare a complete report after carrying out this experiment.

Figure 6.56 shows the flow chart that summarises the reactions between cations and sodium hydroxide solution, NaOH.

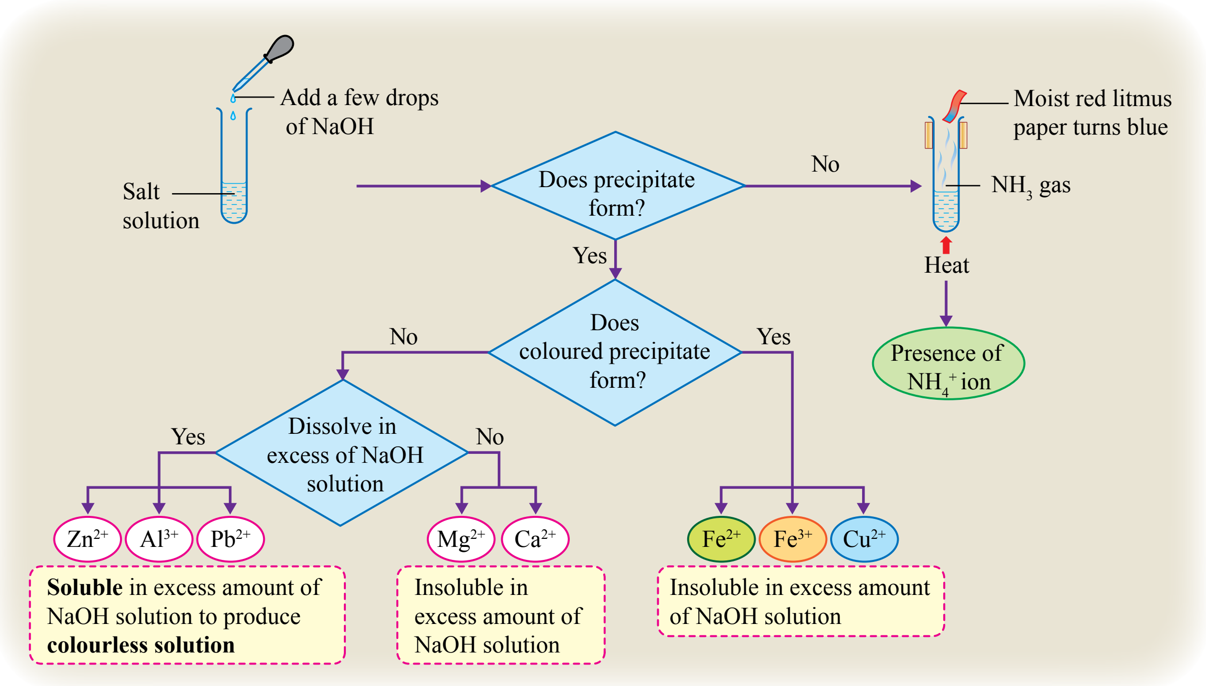


Figure 6.56 *Reactions between cations and sodium hydroxide solution, NaOH*

Figure 6.57 shows the flow chart that summarises the reaction between cations and ammonia solution, NH_3.

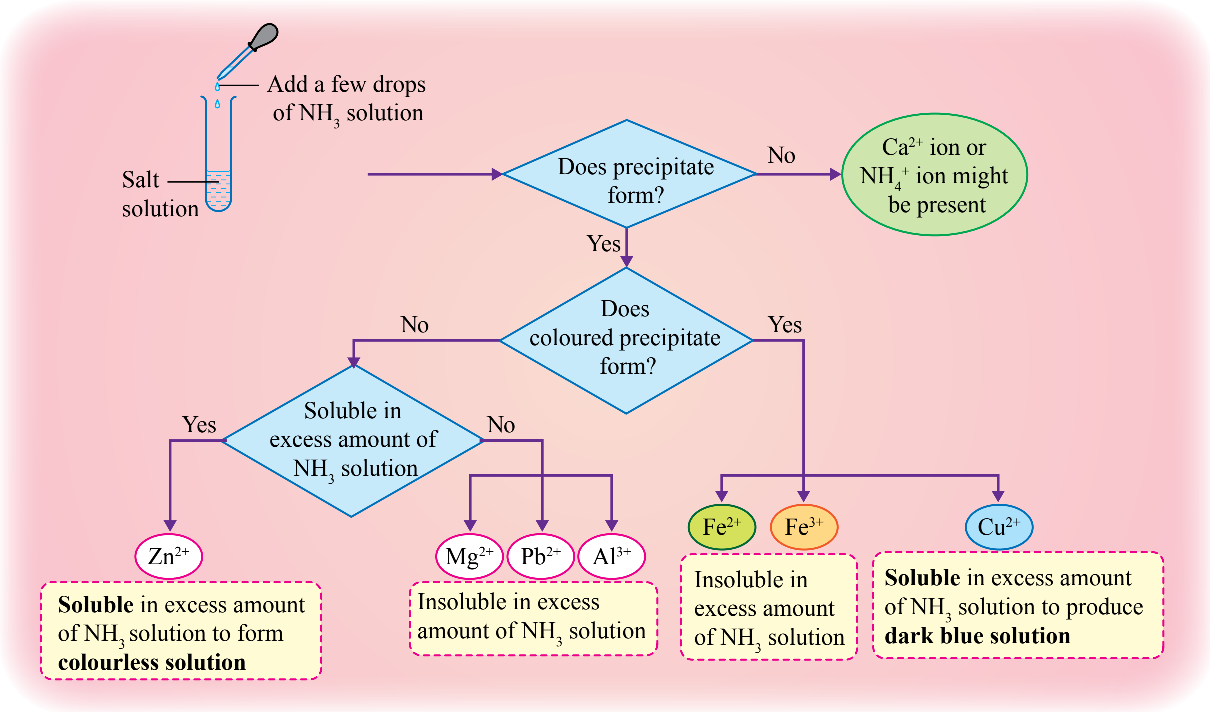
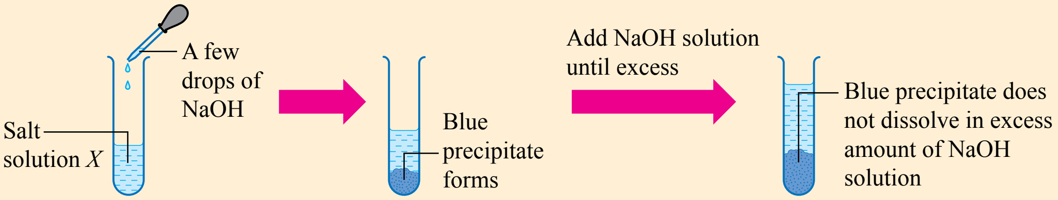


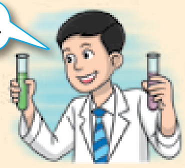
Figure 6.57 Reaction between cations and ammonia solution, NH_3

Example 17

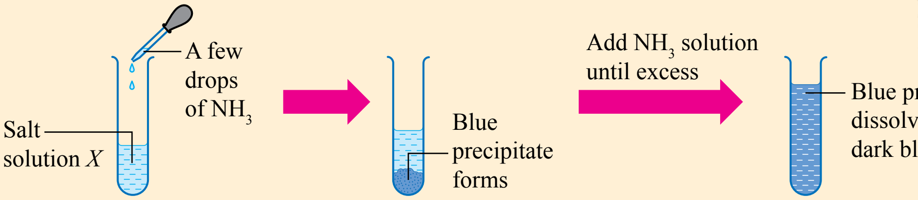
Salt solution *X* is blue.
Test for cations with sodium hydroxide solution, NaOH:



Cu²⁺ ion is present.

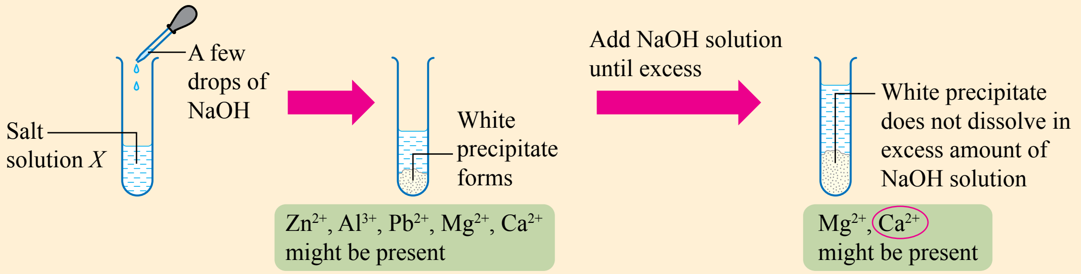


Test for cations with ammonia solution, NH_3:

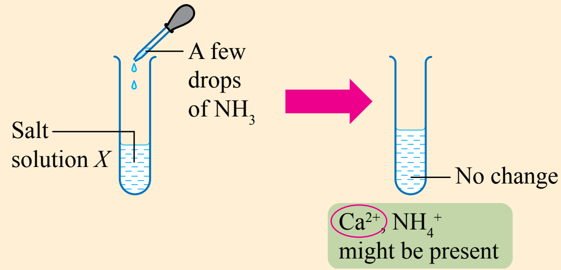


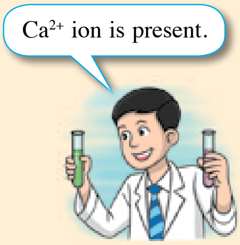
Example 18

Salt solution *X* is colourless.
Test for cations with sodium hydroxide solution, NaOH:



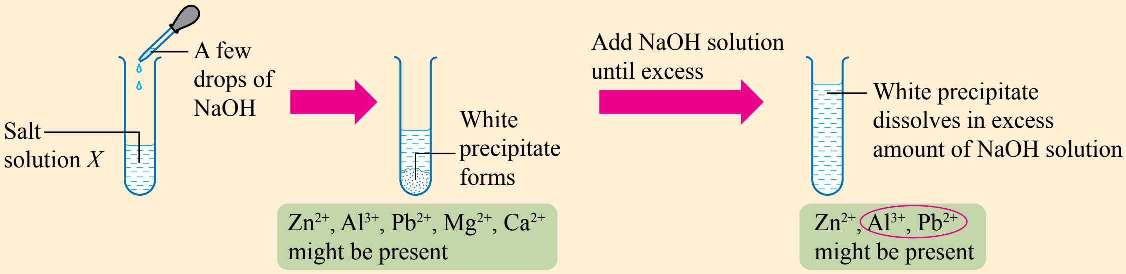
Test for cations with ammonia solution, NH_3:



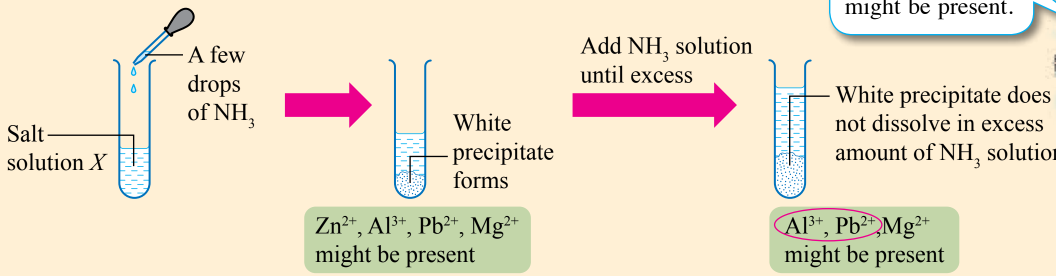


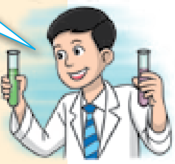
Example 19

Salt solution *X* is colourless.
Test for cations with sodium hydroxide solution, NaOH:



Test for cations with ammonia solution, NH_3:





E Confirmatory Tests for Cations

Both Al^{3+} ion and Pb^{2+} ion give the same observations when tested with sodium hydroxide solution, NaOH and ammonia solution, NH_3. Thus, a confirmatory test is required to differentiate between Pb^{2+} ion and Al^{3+} ion. Other than that, ions such as Fe^{2+}, Fe^{3+} and NH_4^+ too can be confirmed using specific reagents.

Experiment 6.11

Aim: To confirm the presence of cations (NH_4^+, Fe^{2+}, Fe^{3+}, Pb^{2+}) in aqueous solutions.

Problem statement: How to confirm the presence of cations (NH_4^+, Fe^{2+}, Fe^{3+}, Pb^{2+}) in aqueous solutions?

Hypothesis: Construct a hypothesis which is suitable for this experiment.

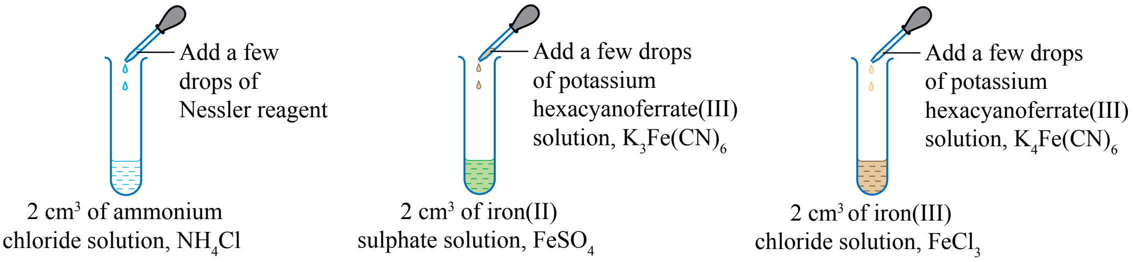
Variables: Name all variables involved in this experiment.

Procedure:

Method I: Confirmation of ammonium ion, NH_4^+

Method II: Confirmation of iron(II) ion, Fe^{2+}

Method III: Confirmation of iron(III) ion, Fe^{3+}



Method IV: Confirmation of lead(II) ion, Pb^{2+}

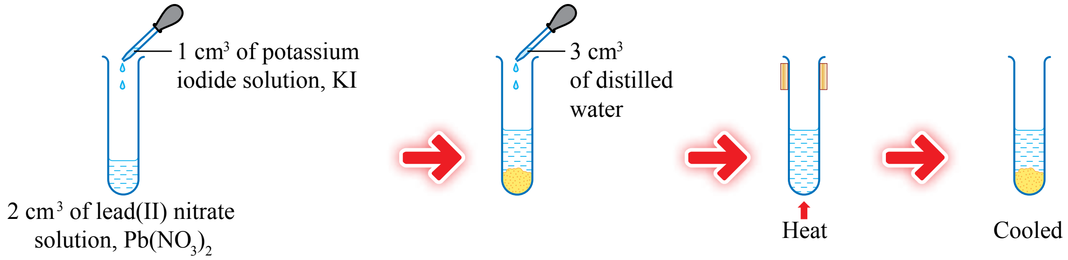


***Figure 6.58** Confirmatory tests for ammonium ion, iron(II) ion, iron(III) ion and lead(II) ion*

1. Based on Figure 6.58, list the apparatus and reagents that are needed for this experiment.
2. Discuss the experimental procedure for the experiment with your group members. Make sure you repeat Method III by using potassium thiocyanate solution, KSCN instead of potassium hexacyanoferate(II), $K_4Fe(CN)_6$.
3. Carry out the experiment with your teacher's permission.
4. Record your observations in Table 6.18.

Results:

Table 6.18

Confirmatory test	Observation
Method I: Confirmatory test for ammonium ion, NH_4^+	
Method II: Confirmatory test for iron(II) ion, Fe^{2+}	
Method III: Confirmatory test for iron(III) ion, Fe^{3+} (a) Using potassium hexacyanoferate(II) solution, $K_4Fe(CN)_6$ (b) Using potassium thiocyanate solution, KSCN	
Method IV: Confirmatory test for lead(II) ion, Pb^{2+}	

Conclusion:

Is the hypothesis accepted? What is the conclusion of this experiment?

Discussion:

1. Write an ionic equation for the reaction between potassium iodide solution, KI and lead(II) nitrate solution, $Pb(NO_3)_2$.
2. Other than Nessler reagent, what are other reagents that can be used to confirm the presence of ammonium ion, NH_4^+? Briefly explain how the chemical test is carried out.
3. Predict the observation obtained if potassium chloride solution, KCl is used instead of potassium iodide solution, KI in Method IV.

Prepare a complete report after carrying out this experiment.

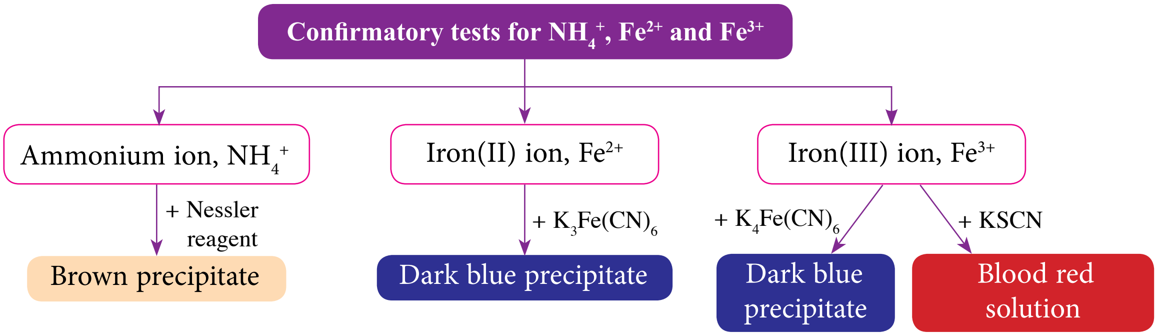


***Figure 6.59** Confirmatory tests for NH_4^+ ion, Fe^{2+} ion and Fe^{3+} ion*

Chemistry Lens

- Potassium hexacyanoferate(II) solution, $K_4Fe(CN)_6$ is used to confirm the presence of iron(III) ion, Fe^{3+}. If this solution is added to an aqueous solution that contains iron(II) ion, Fe^{2+}, a **light blue precipitate** is formed.
- Potassium hexacyanoferate(III) solution, $K_3Fe(CN)_6$ is used to confirm the presence of iron(II) ion, Fe^{2+}. If this solution is added to an aqueous solution containing iron(III), Fe^{3+}, a **greenish brown colour** is obtained.

Al^{3+} ion and Pb^{2+} ion form white precipitates that are insoluble in an excess of alkali solution. Thus, potassium iodide solution, KI is used to differentiate between these two ions.

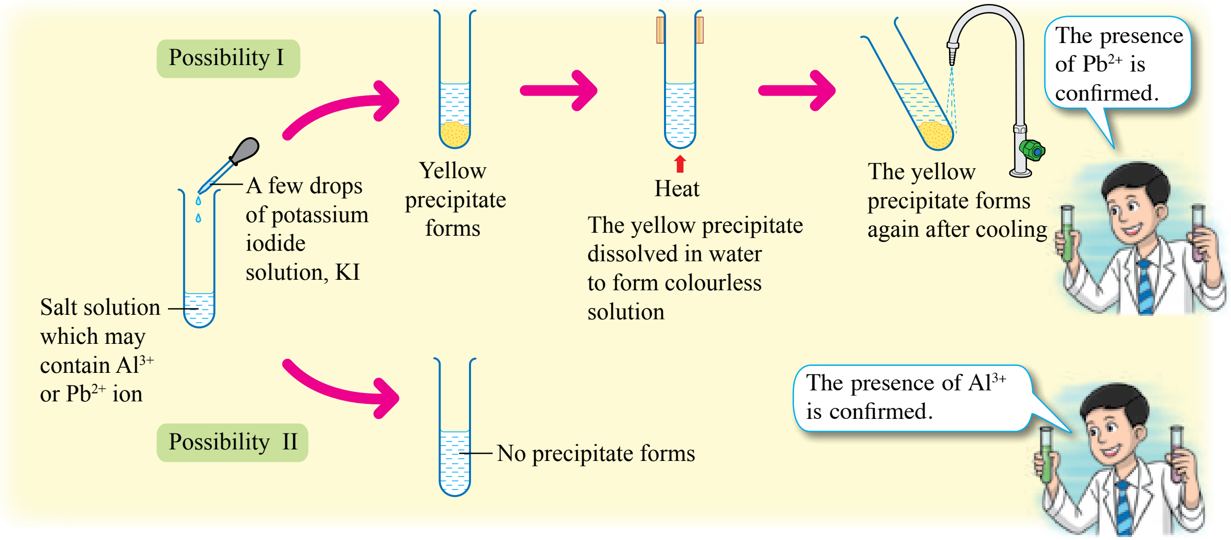


Figure 6.60 *Confirmatory tests for Al^{3+} ion and Pb^{2+} ion*

Qualitative Analysis on Unknown Salts

In order to identify the cations and anions in an unknown salt, you need to perform a systematic analysis according to the order of the test.

Figure 6.61 shows the steps that are involved in the qualitative analysis of salts. Carry out Activity 6.28 to identify the anions and cations in the given salt.

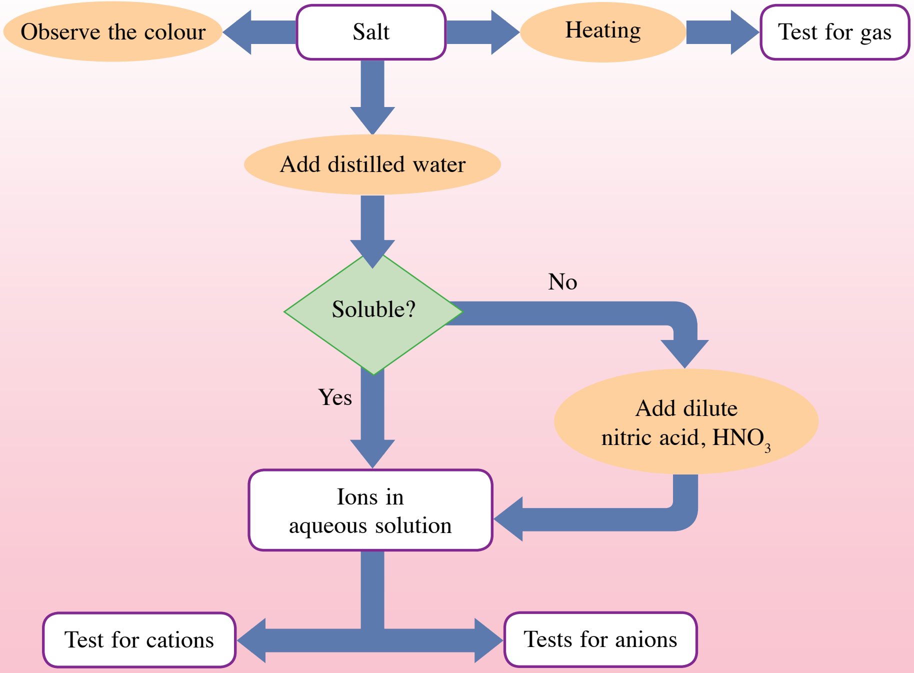


Figure 6.61 *Qualitative analysis of salts*

Activity 6.28

Aims: To identify the cation and anion in L2 solid. CT

Materials: L2 solid, 2.0 mol dm^{-3} sodium hydroxide solution, NaOH, 2.0 mol dm^{-3} ammonia solution, NH_3, 2.0 mol dm^{-3} nitric acid, HNO_3, 0.1 mol dm^{-3} silver nitrate solution, $AgNO_3$, 2.0 mol dm^{-3} hydrochloric acid, HCl, 1.0 mol dm^{-3} barium chloride solution, $BaCl_2$, distilled water, blue litmus paper and wooden splinter

Apparatus: Test tubes, dropper, test tube rack, test tube holder, Bunsen burner, 10 cm^3 measuring cylinder, 100 cm^3 beaker, spatula and glass rod

Procedure:

1. Carry out qualitative analysis to identify the cation and anion in L2 solid.
2. Put half a spatula of L2 solid into a test tube. Add the remaining L2 solid into a beaker. Add 25 cm^3 of distilled water into the beaker to dissolve the L2 solid.
3. Divide the L2 solution into four portions to be used for the chemical tests below:
   - **Tests to identify the cation**

Table 6.19

Chemical test	Observation	Inference
(a) Pour 2 cm^3 of L2 solution into a test tube. Add 2.0 mol dm^{-3} sodium hydroxide solution, NaOH until excess.		
(b) Add 2 cm^3 of L2 solution into a test tube. Add 2.0 mol dm^{-3} ammonia solution, NH_3 until excess.		

- **Tests to identify the anion**

Table 6.20

Chemical test	Observation	Inference
(a) Heat L2 solid with high heat in a test tube. Test the gas released with a glowing wooden splinter and moist blue litmus paper.		
(b) Pour 2 cm^3 of L2 solution into a test tube. Add 2.0 mol dm^{-3} hydrochloric acid, HCl followed by 1.0 mol dm^{-3} barium chloride solution, $BaCl_2$.		
(c) Pour 2 cm^3 of L2 solution into a test tube. Add 2.0 mol dm^{-3} nitric acid, HNO_3 followed by 0.1 mol dm^{-3} silver nitrate solution, $AgNO_3$.		

4. Record the observations for the activity.

Interpreting data:

1. State the inference that corresponds to each observation.
2. Based on the chemical tests, name L2.

Teacher's note
http://bit.ly/2P6Cu5G

Prepare a complete report after carrying out the activity.

While conducting qualitative analysis of salts, systematic and conscientious attitudes are very important in order to identify the cation and anion in a salt correctly.

Activity 6.29

To identify the cations and anions in an unknown salt

21st Century Skills CT

You are provided with salt Q1 that contains one cation and anion. Plan a series of chemical tests to identify the cation and anion in salt Q1.

1. Build a flow chart to help you plan your qualitative technique of salt analysis.
2. Identify and list the reagents and apparatus needed.
3. Discuss with your teacher before carrying out the experiment.
4. Carry out the qualitative analysis of salts in the correct order.
5. Write a report on the qualitative analysis of the salt as described in Activity 6.28. Identify salt Q1 in your report.

Teacher's note

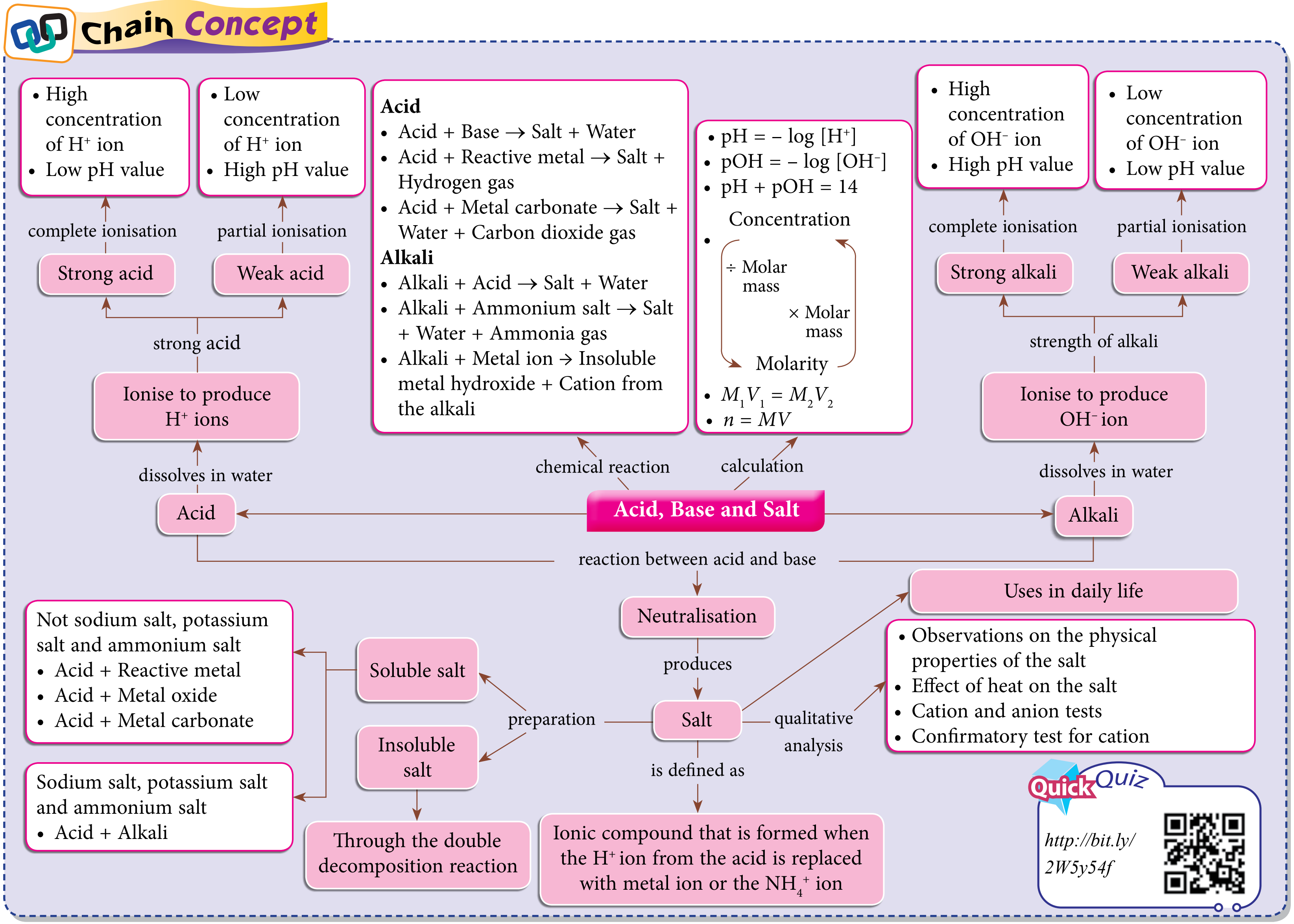
http://bit.ly/2J6jrVl

TestYourself 6.11

1. The aqueous solution of a salt is pale green. What cation might be present in the salt?
2. When a sulphate salt is decomposed by heat, the gas released decolourises the purple colour of potassium manganate(VII) solution, $KMnO_4$. What inference can be made on the gas released?
3. When an aqueous solution of a salt Q was tested with alkali solutions, the following observations was obtained.
   - A white precipitate that is insoluble in an excess of sodium hydroxide solution, NaOH
   - No change on the addition of ammonia solution, NH_3 to the salt solution.

   What cation may be present in the salt?
4. Three salt samples S1, S2 and S3 contain the zinc ion, Zn^{2+}, aluminium ion, Al^{3+} and lead(II) ion, Pb^{2+} respectively. Describe the qualitative analysis carried out to confirm the presence of the ions in each solution.

Chain Concept



Acid, Base and Salt

Acid

Acid, Base and Salt → Acid

Acid — dissolves in water → Ionise to produce H^+ ions

Ionise to produce H^+ ions — strong acid → Strong acid, Weak acid

Strong acid — complete ionisation →
- High concentration of H^+ ion
- Low pH value

Weak acid — partial ionisation →
- Low concentration of H^+ ion
- High pH value

Alkali

Acid, Base and Salt → Alkali

Alkali — dissolves in water → Ionise to produce OH^- ion

Ionise to produce OH^- ion — strength of alkali → Strong alkali, Weak alkali

Strong alkali — complete ionisation →
- High concentration of OH^- ion
- High pH value

Weak alkali — partial ionisation →
- Low concentration of OH^- ion
- Low pH value

Acid, Base and Salt — chemical reaction →

Acid
- Acid + Base → Salt + Water
- Acid + Reactive metal → Salt + Hydrogen gas
- Acid + Metal carbonate → Salt + Water + Carbon dioxide gas

Alkali
- Alkali + Acid → Salt + Water
- Alkali + Ammonium salt → Salt + Water + Ammonia gas
- Alkali + Metal ion → Insoluble metal hydroxide + Cation from the alkali

Acid, Base and Salt — calculation →
- pH = – log [H^+]
- pOH = – log [OH^-]
- pH + pOH = 14
- Concentration ⇄ Molarity (Concentration ÷ Molar mass → Molarity; Molarity × Molar mass → Concentration)
- $M_1V_1 = M_2V_2$
- $n = MV$

Acid, Alkali — reaction between acid and base → Neutralisation

Neutralisation — produces → Salt

Salt — is defined as → Ionic compound that is formed when the H^+ ion from the acid is replaced with metal ion or the NH_4^+ ion

Salt → Uses in daily life

Salt — qualitative analysis →
- Observations on the physical properties of the salt
- Effect of heat on the salt
- Cation and anion tests
- Confirmatory test for cation

Salt — preparation → Soluble salt, Insoluble salt

Soluble salt →

Not sodium salt, potassium salt and ammonium salt
- Acid + Reactive metal
- Acid + Metal oxide
- Acid + Metal carbonate

Sodium salt, potassium salt and ammonium salt
- Acid + Alkali

Insoluble salt → Through the double decomposition reaction

Quick Quiz

http://bit.ly/2W5y54f

SELF Reflection

1. What new knowledge have you learned in **Acid, Base and Salt**?
2. Which is the most interesting subtopic in **Acid, Base and Salt**? Why?
3. Give a few examples on the application of **Acid, Base and Salt** in daily life.
4. Rate your performance in **Acid, Base and Salt** on a scale of 1 to 10; 1 being the lowest and 10 the highest. Why would you rate yourself at that level?
5. What can you do to improve your mastery in **Acid, Base and Salt**?

http://bit.ly/2OSLFXq

Achievement Test 6

1. Table 1 shows the properties of two acids, *P* and Q.

Table 1

Type of acid	*P*	*Q*
Formula of the acid	H_2SO_4	CH_3COOH
pH value of 0.1 mol dm^{-3} solution	0.7	2.9

Based on the information above, answer the following questions:

(a) What is the basicity of the acid:

(i) *P*? (ii) *Q*?

(b) Explain your answer in (a).

(c) Explain why acid *P* and acid *Q* have different pH values.

(d) When 10 cm^3 of acid *P* is added into a test tube containing zinc, effervescence occurs.

(i) Write a chemical equation for the reaction that occurs.

(ii) Calculate the volume of gas released at room conditions.
[Molar volume: 24 dm^3 mol^{-1} at room conditions]

(e) You are required to prepare 100 cm^3 of 0.05 mol dm^{-3} acid *P*. Explain briefly how you would prepare dilute acid *P*.

2. An experiment was carried out to determine the concentration of sodium hydroxide solution, NaOH by titrating 0.5 mol dm^{-3} sulphuric acid, H_2SO_4 with 25 cm^3 of sodium hydroxide solution, NaOH.

Table 2

Titration	I	II	III
Final burette reading (cm^3)	25.55	48.20	28.50
Initial burette reading (cm^3)	0.45	23.00	3.20
Volume of sulphuric acid, H_2SO_4 used (cm^3)			

(a) Complete Table 2. Determine the average volume of sulphuric acid, H_2SO_4 used.

(b) Write a chemical equation for the neutralisation reaction between sulphuric acid, H_2SO_4 and sodium hydroxide solution, NaOH.

(c) Determine the concentration of the sodium hydroxide solution, NaOH used in this experiment.

3. Figure 1 shows the flow chart for a series of reactions that occurs on solid *X* salt.

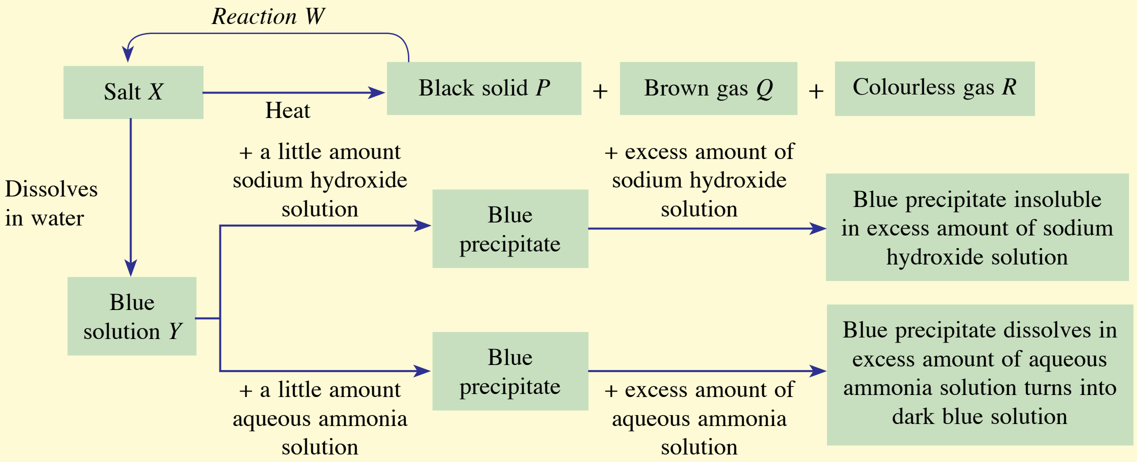


Figure 1

(a) Based on the flow chart above, identify:
  (i) Black solid *P*
  (ii) Brown gas *Q*
  (iii) Colourless gas *R*
  (iv) Blue solution *Y*

(b) Write a chemical equation to represent the decomposition of salt *X* by heat.

(c) Explain briefly how you would confirm the anion presence in salt *X*?

(d) The black solid *P* can be changed into salt *X* through reaction *W*. Suggest a chemical that is suitable for changing the black solid *P* to salt *X*. Then, explain briefly how the black solid *P* can be changed to salt *X* through reaction *W*.

Enrichment Corner

1. Hooi See's mother is very fond of capstone because she loves blue crystals. However, the price of the capstone is very expensive. As a student studying chemistry, how can you help Hooi See to prepare a large and beautiful blue crystal in the laboratory as a present to Hooi See's mother? Prepare the crystal by including the labelled diagram.

Check Answers

http://bit.ly/2pHAdTW