KEMENTERIAN
PENDIDIKAN
MALAYSIA

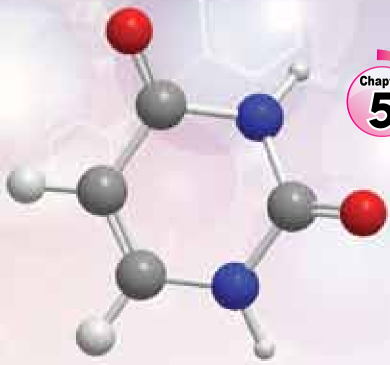
DUAL LANGUAGE PROGRAMME

CHEMISTRY

Form 4

KURIKULUM STANDARD SEKOLAH MENENGAH
KSSM
KEMENTERIAN PENDIDIKAN MALAYSIA

Contents



RUKUN NEGARA

Bahawasanya Negara Kita Malaysia
mendukung cita-cita hendak;

Mencapai perpaduan yang lebih erat dalam kalangan
seluruh masyarakatnya;

Memelihara satu cara hidup demokrasi;

Mencipta satu masyarakat yang adil di mana kemakmuran negara
akan dapat dinikmati bersama secara adil dan saksama;

Menjamin satu cara yang liberal terhadap
tradisi-tradisi kebudayaannya yang kaya dan pelbagai corak;

Membina satu masyarakat progresif yang akan menggunakan
sains dan teknologi moden;

MAKA KAMI, rakyat Malaysia,
berikrar akan menumpukan
seluruh tenaga dan usaha kami untuk mencapai cita-cita tersebut
berdasarkan prinsip-prinsip yang berikut:

KEPERCAYAAN KEPADA TUHAN
KESETIAAN KEPADA RAJA DAN NEGARA
KELUHURAN PERLEMBAGAAN
KEDAULATAN UNDANG-UNDANG
KESOPANAN DAN KESUSILAAN

(Sumber: Jabatan Penerangan, Kementerian Komunikasi dan Multimedia Malaysia)

KURIKULUM STANDARD SEKOLAH MENENGAH

CHEMISTRY

FORM 4

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KEMENTERIAN
PENDIDIKAN
MALAYSIA

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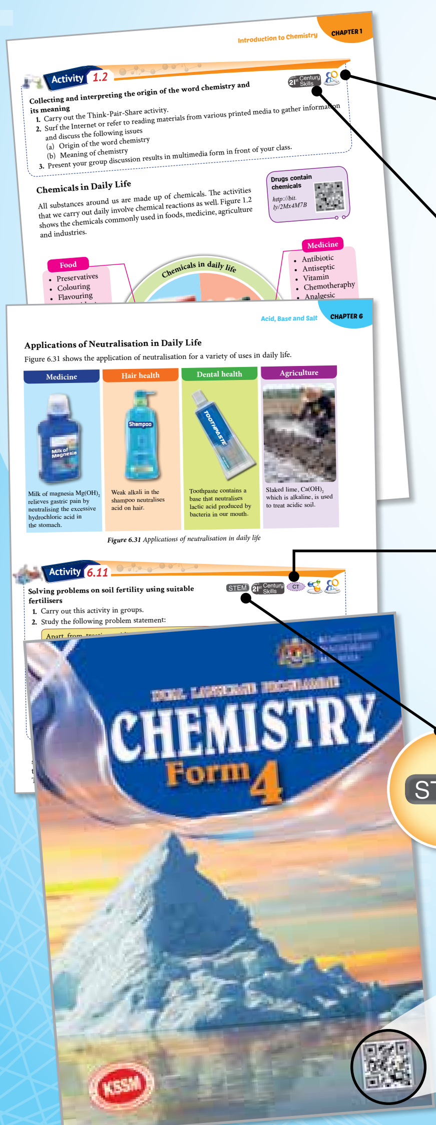
Introduction

This *Kurikulum Standard Sekolah Menengah (KSSM)* Form 4 Chemistry textbook is written based on Form 4 Chemistry *Dokumen Standard Kurikulum dan Pentaksiran (DSKP)* that is prepared by the Ministry of Education Malaysia. In order to successfully implement and fulfil the needs of DSKP, this book is written based on three domains: Knowledge, Skills and Values through methods of inquiry. There are four themes to be discussed, namely the Importance of Chemistry, Fundamentals of Chemistry, Interaction between Matter and Industrial Chemistry.

This book is equipped with various special features that focus on instilling Science, Technology, Engineering and Mathematics (STEM), thinking skills, scientific skills and computational thinking so that students can master skills that are needed for the 21st century and to be individuals who are science-oriented. Special features in this book are as follows:



21st Century Skills
Activities that involve 21st century skills:
- Thinking & problem-solving skills
- Interpersonal and intrapersonal skills
- Information and communication skills

21st Century Learning Activities
Various activities that emphasise student-centered learning based on Higher Order Thinking Skills (HOTS).

Computational Thinking
Activities that involve computational thinking:
- Decomposition
- Pattern recognition
- Logical reasoning
- Abstraction
- Algorithm
- Evaluation

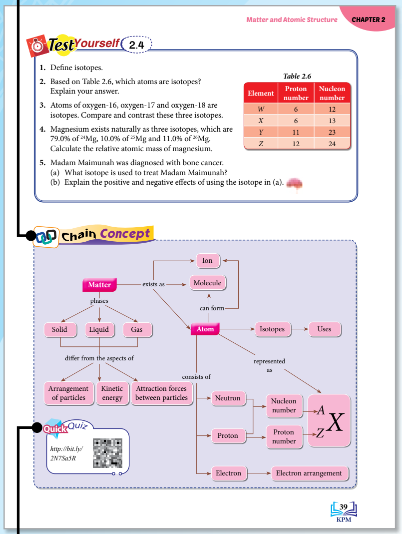
STEM (Science, Technology, Engineering and Mathematics)
Activities that involve project-based learning through STEM approach. STEM approach is based on teaching and learning that applies knowledge, skills and STEM values through inquiry, daily problem solving, environment, as well as local and global communities.

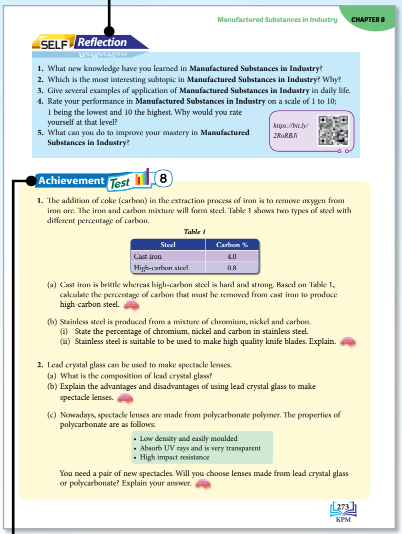
Information in the QR code on the front cover:
- Explanations of book themes
- Authors biodata
- Updated information and facts (if any)

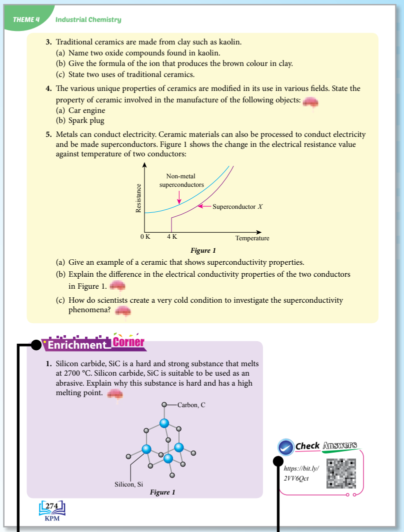
Components at the end of each chapter:

Chain Concept
Brief summary at the end of each chapter in the form of a concept map.

Self-reflection
Reflection to evaluate students' learning on the chapter. Students can download Self-reflection by scanning the given QR code.







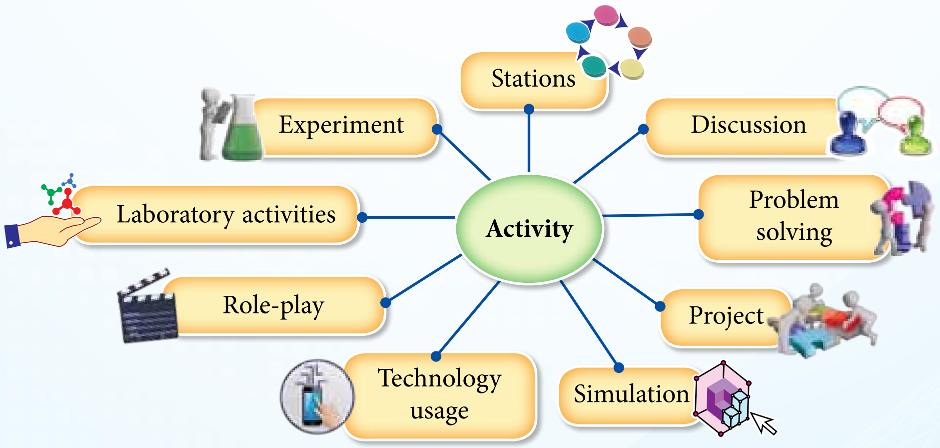
Quick Quiz
Scan the QR code to take the interactive quiz at the end of each chapter.

Achievement Test
Questions to test students' understanding at the end of each chapter. HOTS questions at the application, analysis, evaluation and creation level are marked with the HOTS icon .

Check Answers
Scan the QR code to get the complete answer on that chapter.

Enrichment Corner
Enrichment exercises with HOTS questions at the evaluation and creation level.

Activities in this book:



Icons in this book:

Chemistry & Us

Relates chemical concepts with our daily life.

MY MALAYSIA is Great

Gives information about patriotic elements, cultural or Malaysians' achievements.

Career Kiosk

Gives information about careers related to the chemistry field.

Chemistry Lens

Gives extra information regarding the topic.

Brain Teaser

Questions that hone students' thinking skills.

Literacy Tips

Learning or problem solving tips.

Safety Precaution

Steps that need to be taken to ensure the results of the experiment or lab activity are accurate.

CAUTION

A reminder to students about the dangers while carrying out the experiment or laboratory activity.

e-Portal

Provides the link to the website or the QR code to get additional information.

HISTORY INTEGRATION **PHYSICS INTEGRATION** **MATHEMATICS INTEGRATION**

Cross-curriculum element

Gives cross-curriculum information related to the topic.

Guide to Scan AR (Augmented Reality) for Interactive 3-Dimensional Animation

In this book, there are several pages that contain AR (Augmented Reality) to explain the contents with interactive three dimensional animation. The pages involved are 25, 29, 113, 115 and 259. The following guides on how to scan the AR:

1. Scan [Google Play] or [App Store] to download the app.
2. Scan the whole page that contains AR

Laboratory Rules and Safety Measures

Before entering the laboratory

- Do not enter the laboratory without the teacher's permission.
- Do not bring bags or any food and drinks into the laboratory.

While in the laboratory

- Do not run or play in the laboratory.
- Do not eat or drink in the laboratory.
- Do not taste or smell any chemical substances.
- Avoid touching chemical substances with your hand.
- Do not carry out any experiments without the teacher's permission.
- Understand all instructions before starting the experiment.
- Read all labels and safety symbols on reagent bottles before using them.
- Wear safety equipment such as safety goggles, gloves and laboratory coats while carrying out experiments.
- Do not direct the opening of the boiling tube to one's self or to others while heating chemical substances with a Bunsen burner.
- Keep all chemical substances away from the fire. Tie your hair and tidy your clothes so that it does not come into contact with fire.
- Use the required amount of chemical substances only.

If there is an emergency

- Know the location of safety equipment such as a fire extinguisher and fire hose and ways to use them.
- If a chemical substance comes into contact with your eyes, skin or clothing, wash immediately with plenty of water.
- If you accidentally swallowed a chemical substance, remove it from your mouth and gargle with plenty of water.
- Report to the teacher as soon as possible to get treatment.
- Report any accident or injury to the teacher as soon as possible.

Before exiting the laboratory

- Switch off all water, gas and electrical supplies.
- Return all used equipments to their original places.
- Clean and tidy up all used equipments.
- Throw all used chemical substances as instructed by the teacher. Do not throw chemical substances into the sink.
- Wash your hands before leaving the laboratory.

The List of Chemical Symbols


Explosive


Flammable


Oxidant


Corrosive


Toxic


Health hazard


Irritant


Gas under pressure


Environmental hazard

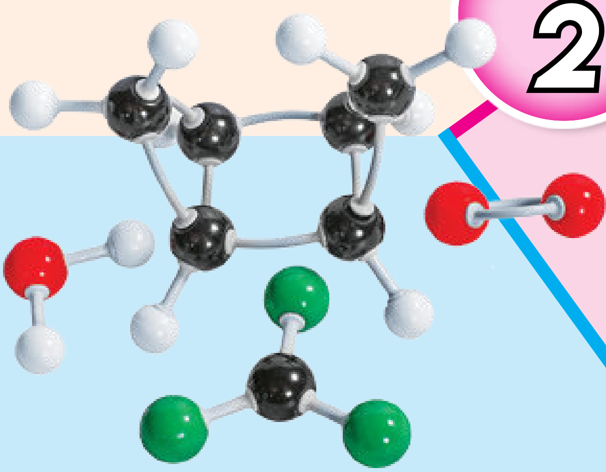
(Source: Department of Occupational Safety and Health (DOSH), Malaysia)

THEME 1

The Importance of Chemistry

This theme introduces students to the meaning of chemistry, importance of chemistry and careers in the chemical field as well as chemicals in daily life. Besides, the application of scientific skills and problem-solving methods in chemistry are also strengthened from chemical perspective.

THEME 2



Fundamentals of Chemistry

This theme aims to introduce chemistry from the microscopic aspect which includes particles, the mole concept, chemical formulae and equations. The Periodic Table of Elements and chemical bonds are also emphasised for a better understanding of the fundamentals of chemistry.

THEME 3

Interaction between Matter

This theme aims to introduce acids, bases and salts as well as the rate of reaction.

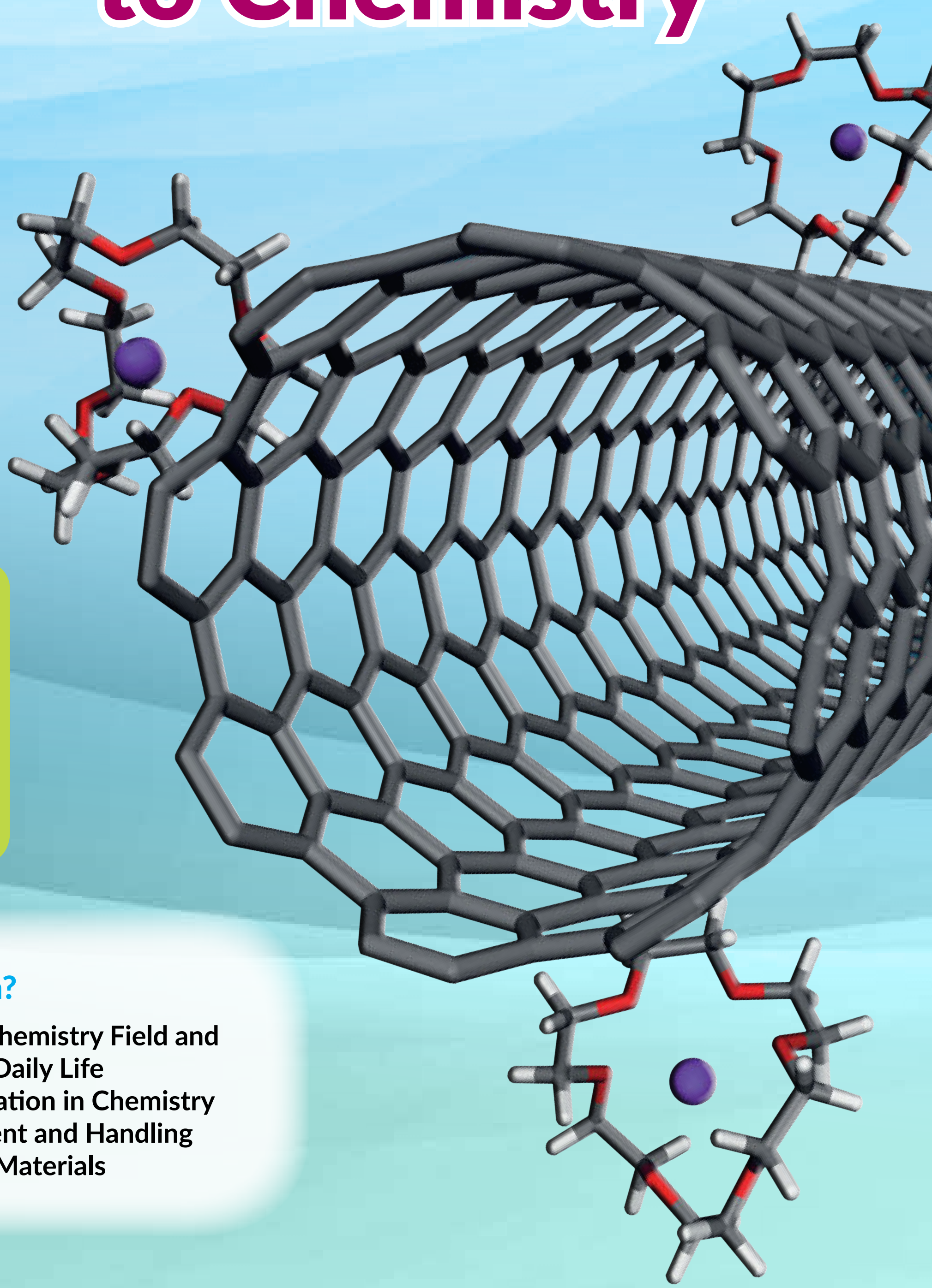
THEME 4

Industrial Chemistry

This theme introduces properties of materials that are widely used in the development and growth of current technology.

CHAPTER 1

Introduction to Chemistry



Keywords

- Chemistry
- Chemical technology
- Scientific method
- Personal protective equipment
- Safety in the laboratory
- Management of laboratory accidents

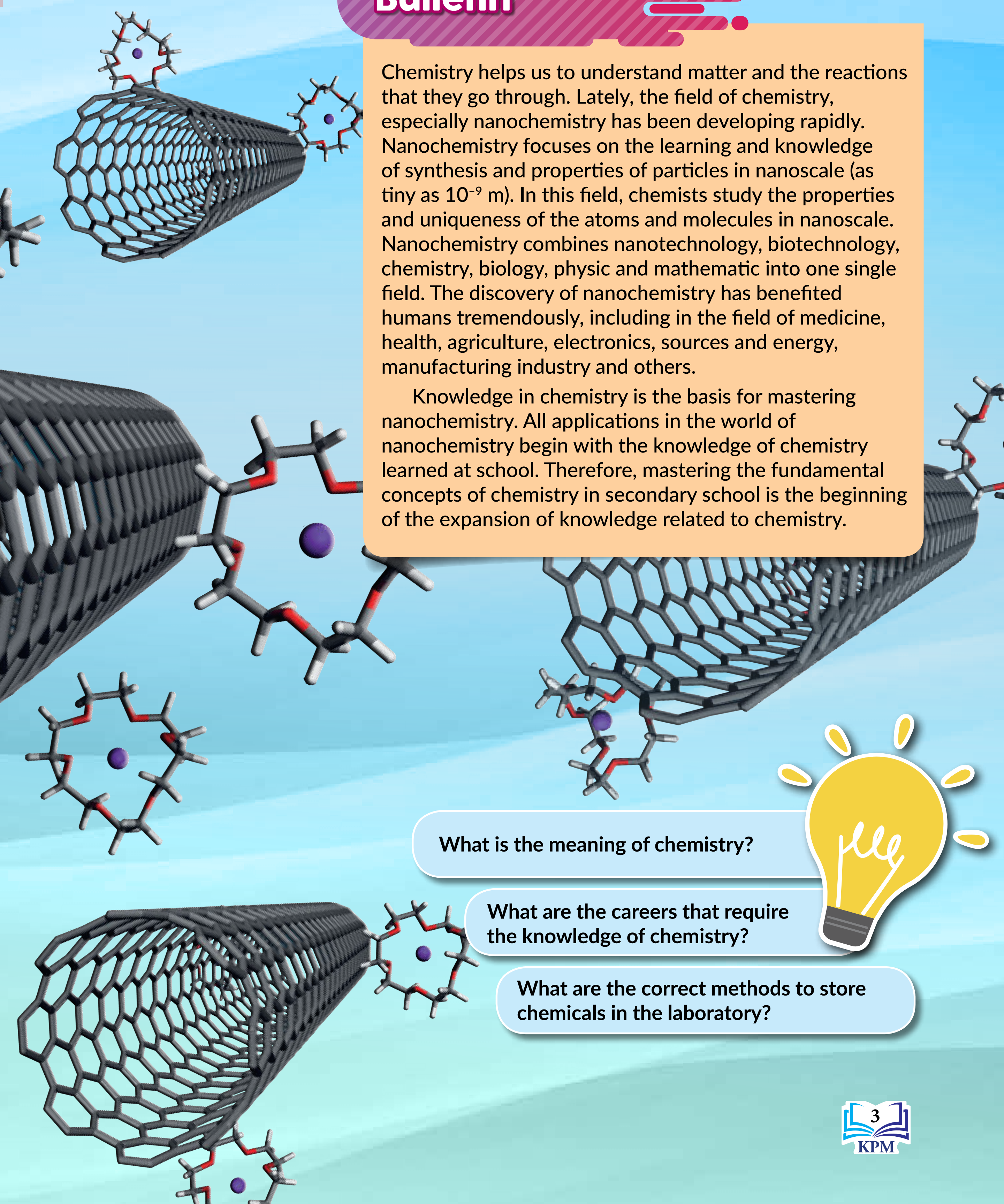
What will you learn?

1.1 Development in Chemistry Field and Its Importance in Daily Life
1.2 Scientific Investigation in Chemistry
1.3 Usage, Management and Handling of Apparatus and Materials

Bulletin

Chemistry helps us to understand matter and the reactions that they go through. Lately, the field of chemistry, especially nanochemistry has been developing rapidly. Nanochemistry focuses on the learning and knowledge of synthesis and properties of particles in nanoscale (as tiny as 10^{-9} m). In this field, chemists study the properties and uniqueness of the atoms and molecules in nanoscale. Nanochemistry combines nanotechnology, biotechnology, chemistry, biology, physic and mathematic into one single field. The discovery of nanochemistry has benefited humans tremendously, including in the field of medicine, health, agriculture, electronics, sources and energy, manufacturing industry and others.

Knowledge in chemistry is the basis for mastering nanochemistry. All applications in the world of nanochemistry begin with the knowledge of chemistry learned at school. Therefore, mastering the fundamental concepts of chemistry in secondary school is the beginning of the expansion of knowledge related to chemistry.



What is the meaning of chemistry?

What are the careers that require the knowledge of chemistry?

What are the correct methods to store chemicals in the laboratory?

1.1 Development in Chemistry Field and Its Importance in Daily Life

Based on Figure 1.1, what do you understand about chemistry?

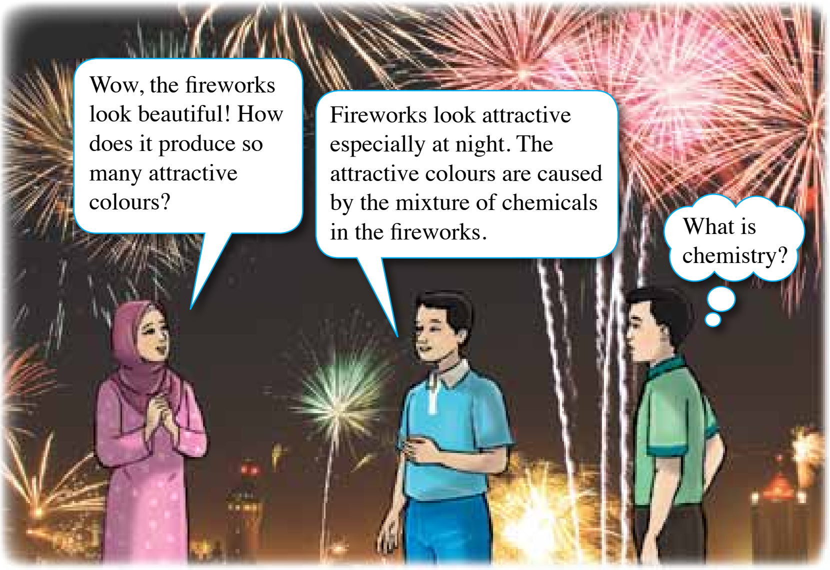


Figure 1.1 *Fireworks and chemistry*

Learning Standard

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

1.1.1 State the meaning of chemistry
1.1.2 State examples of chemicals commonly used in daily life
1.1.3 Generate ideas on the development of chemistry field and the contributions of chemical technology towards mankind
1.1.4 State examples of careers related to chemistry field

Activity 1.1

Discussing the meaning of chemistry based on students' understanding 21st Century Skills

1. Carry out the Round Table activity.
2. Take turns to state the meaning of chemistry according to your understanding on a piece of blank paper based on:
   (a) The science knowledge that you have learned from Form 1 to Form 3
   (b) Your experience outside the classroom
3. Present your group findings to your classmates.

Meaning of Chemistry

Chemistry is a field of science that studies the structures, properties, compositions and interactions between matters. Learning of chemistry is not limited to chemicals found in the laboratory but also substances commonly found in daily life such as salt and soap. Chemistry helps us to understand matter around us. The word chemistry originated from the Arabic word 'al-kimiya'. Carry out Activity 1.2 to study the origin of the word chemistry and its meaning.

Father of Arabic chemistry

http://bit.ly/2qruQIF

Activity 1.2

Collecting and interpreting the origin of the word chemistry and its meaning

21st Century Skills

1. Carry out the Think-Pair-Share activity.
2. Surf the Internet or refer to reading materials from various printed media to gather information and discuss the following issues:
   (a) Origin of the word chemistry
   (b) Meaning of chemistry
3. Present your group discussion results in multimedia form in front of your class.

Chemicals in Daily Life

All substances around us are made up of chemicals. The activities that we carry out daily involve chemical reactions as well. Figure 1.2 shows the chemicals commonly used in foods, medicine, agriculture and industries.

Drugs contain chemicals

http://bit.ly/2Mx4M7B

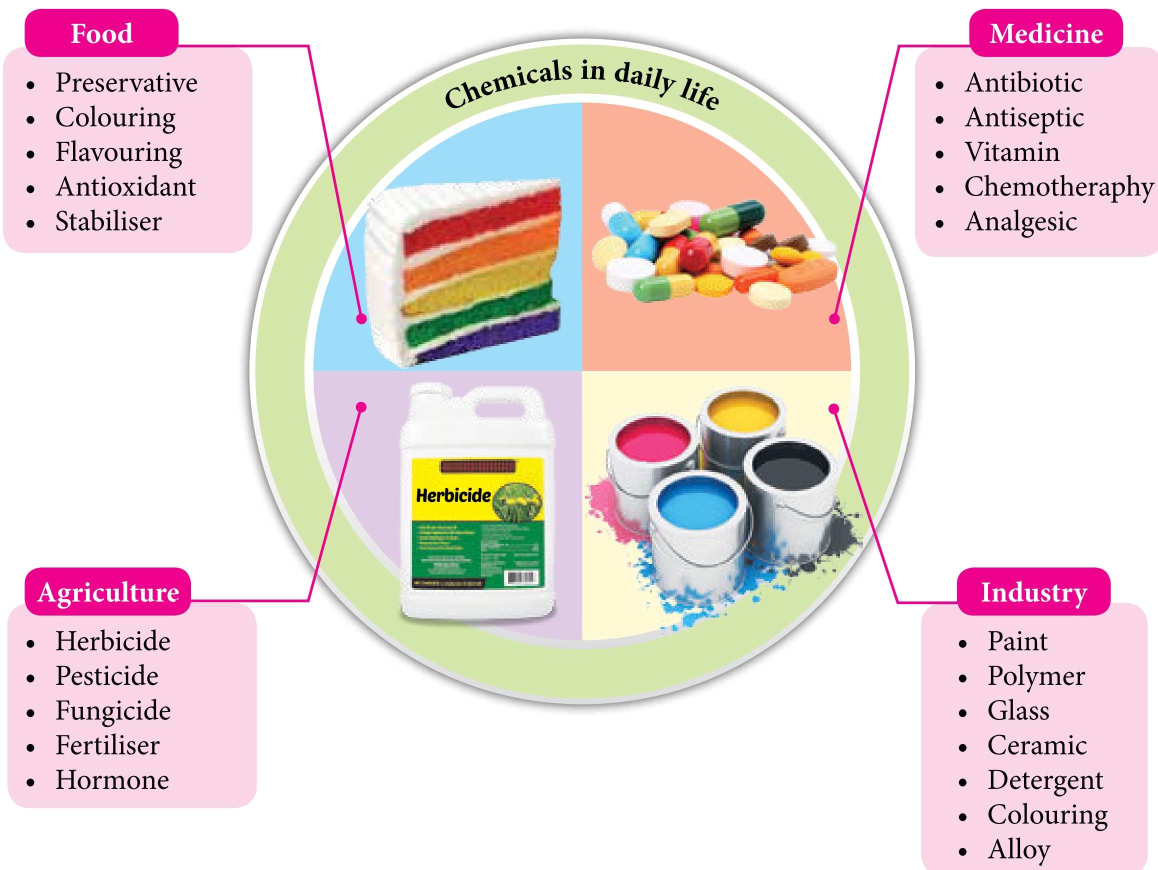


***Figure 1.2** Commonly used chemicals*

The Development in Chemistry Field and the Contributions of Chemical Technology

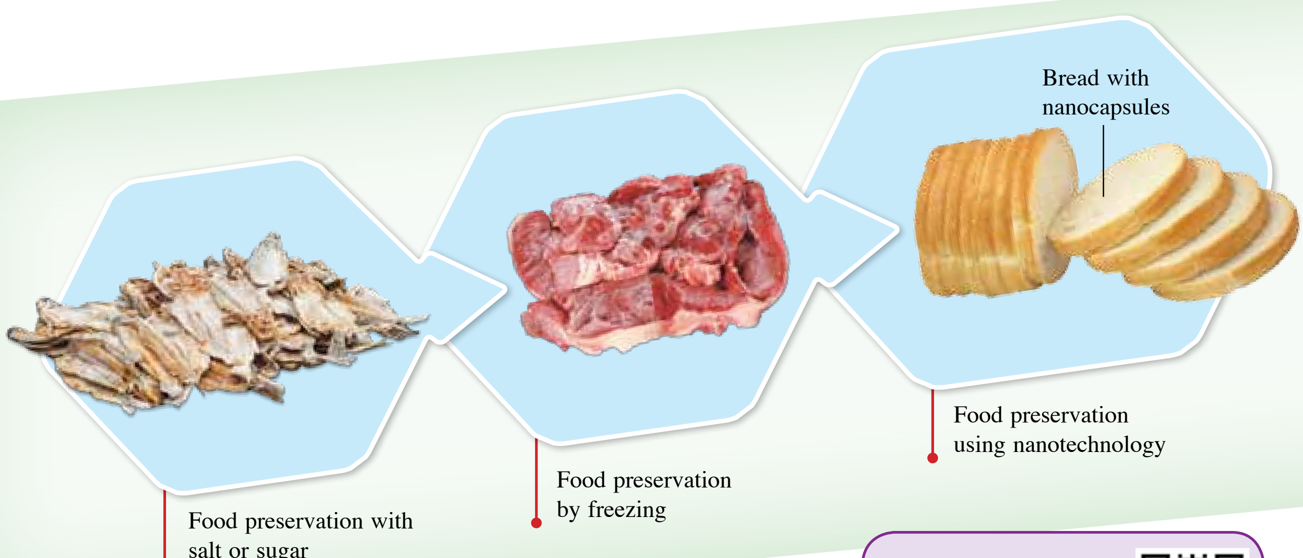
Researches in various chemical fields are constantly being carried out covering various disciplines. For examples, biochemistry, botany and forensics which require chemical knowledge to solve problems. The need for chemical technology to solve problems spurs the development of chemical technology. Technologies used in the 60s and 70s might not be suitable to be applied in this era. Based on your knowledge, what are the contributions of chemical technology to mankind? Carry out Activity 1.3.

Activity 1.3

Searching for information and making a poster

21st Century Skills

1. Carry out the Gallery Walk activity.
2. Gather information on the following aspects:
   (a) Contribution of chemists
   (b) Development of chemical technology
   (c) Careers in the field of chemistry
   (d) Chemicals in daily life
3. Prepare the results of your group in an attractive poster.
4. Display your group's results in the class.
5. Each group has to move around to look at the other groups' posters. Write your comments about the results of the other groups on sticky notes and paste them on the posters.



Food preservation using nanotechnology
http://bit.ly/2OKV8jj

Figure 1.3 *Development of technology in food preservation*

Careers Related to Chemistry

In the era of rapid industrial development, most careers require knowledge in chemistry. For example, careers in the cosmetics, pharmaceutical, biotechnology, nanotechnology and green technology fields are shown in Figure 1.4.

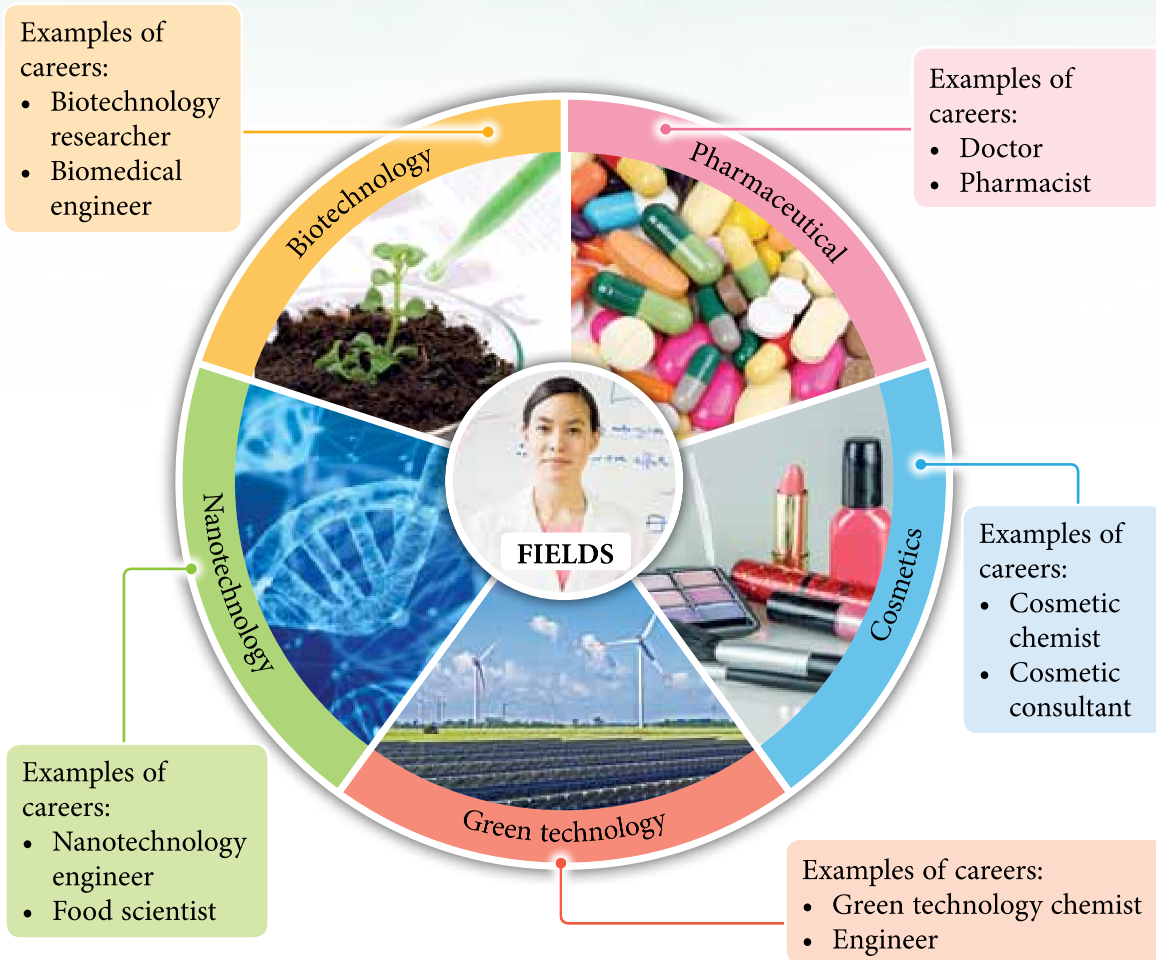


Figure 1.4 *Several careers related to chemistry*

Activity 1.4

Role-playing activity on careers in the field of chemistry 21st Century Skills CT

1. Carry out the Role-Play activity.
2. Gather information from suitable reading resources or websites on careers in the field of chemistry.
3. Assign the members of the groups to various careers.
4. Prepare the acting script and suitable props.
5. Present your group's act in front of your class.

Test Yourself 1.1

1. What is meant by chemistry?
2. List out five types of chemicals used in daily life.
3. Give one example of development of chemistry in industries.
4. List out at least three careers related to chemistry in the following situations:
   (a) Searching for an antidote for dengue fever
   (b) Producing palm trees with a high content of oil

1.2 Scientific Investigation in Chemistry

Learning Standard

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

1.2.1 Design an experiment to test a hypothesis

1.2.2 Investigate through experiment the effect of temperature on the solubility of salt in water using a scientific method

A scientific investigation is a scientific method used in solving problems in science. Generally, a scientific investigation begins with the observation of a problem. Look at Figure 1.5 and identify the problem that occurs. We can carry out an investigation to solve the problem by using a scientific method.

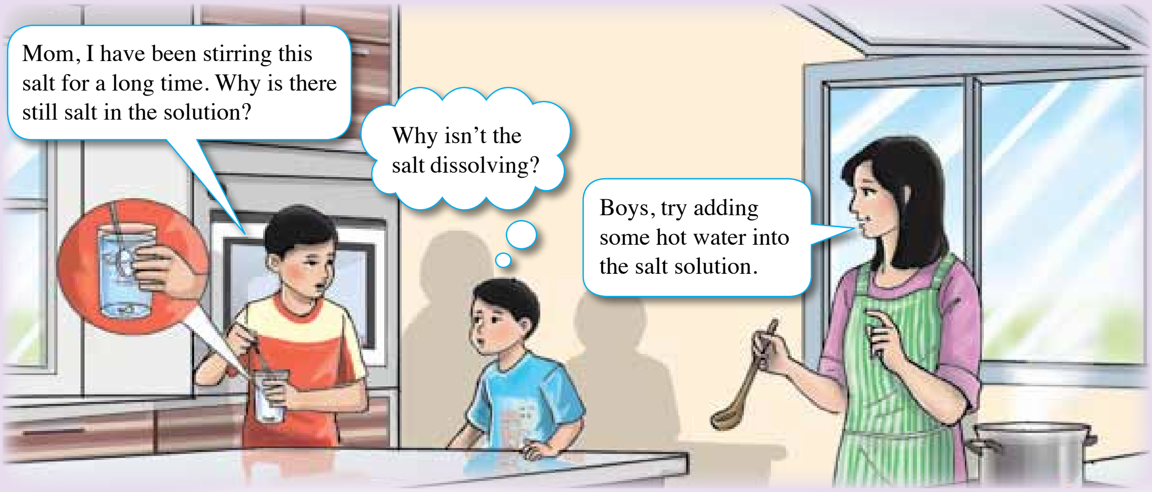
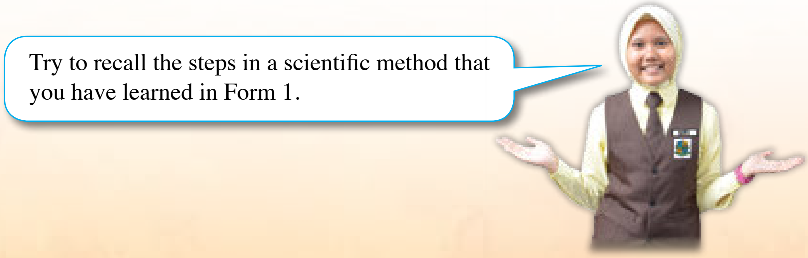


Figure 1.5 *The solubility of salt in hot water*



Scientific Method

Scientific method is a systematic method used by scientists or researchers to solve problems related to science. This method involves several general steps to solve a problem using the correct methods.

Making observations	Using senses of sight, hearing, touch, taste or smell to gather information about an object or a phenomenon taking place.
Making an inference	Using data collection and past experience to make a conclusion and explanation about an event.
Identifying the problem	Asking questions based on the inference made.
Making a hypothesis	Making a general statement about the relationship between a manipulated variable and a responding variable to explain an event or observation. This statement can be tested to prove its validity.
Identifying the variables	Identifying the manipulated variable, responding variable and fixed variable(s) in an experiment to test the hypothesis that is formed.
Controlling the variables	In an investigation, a variable is manipulated to observe its relationship with the responding variable. Simultaneously, other variables are fixed.
Planning an experiment	Determining the materials and apparatus to be used, procedure of the experiment, method of collecting data and the ways to analyse and interpret the data.
Collecting data	Making observations or measurements and recording the data systematically.
Interpreting data	Organising and interpreting the data collected. Data can be interpreted through calculations, graphs or charts to find and determine the relationship between the variables.
Making a conclusion	Making a statement on the results of the experiment on whether the hypothesis made is accepted or rejected.
Preparing a report	Communicating in detail on all aspects of the experiment so that the outcome of the experiment can be shared for the development of chemistry knowledge.

Figure 1.6 *Steps in a scientific method*

Based on the scientific method that you have learned, carry out Experiment 1.1 to study the effect of temperature on the solubility of salt in water.

Experiment 1.1

Aim: To study the effect of temperature on the solubility of salt in water.

Problem statement: Does the temperature of water affect the solubility of salt in water?

Hypothesis: The increase in temperature of water will increase the solubility of salt in water.

Variables:
(a) Manipulated : Temperature of water
(b) Responding : Solubility of salt in water
(c) Fixed : Volume of water, mass of salt, time

Materials: Distilled water and salt

Apparatus: 150 cm^3 beaker, 100 cm^3 measuring cylinder, thermometer, electronic scale, glass rod, Bunsen burner, stopwatch, wire gauze and tripod stand

Procedure:
1. Measure 50 cm^3 of distilled water at temperature 10 °C with a measuring cylinder and pour it into a beaker.
2. Add 40 g of salt into the beaker and stir the solution with a glass rod for 2 minutes.
3. Observe the solubility of salt in the beaker.
4. Repeat steps 1 to 3 with distilled water heated at 30 °C and 80 °C.
5. Record your observations in Table 1.1.

Brain Teaser

How can you obtain distilled water at 10 °C?

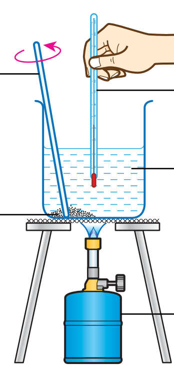


Figure 1.7

Results:

Table 1.1

Temperature (°C)	10	30	80
Observation			

Interpreting data:
At which temperature does all the salt dissolve in water?

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

Prepare a complete report after carrying out this experiment.

Test Yourself 1.2

1. What is meant by scientific method?
2. Why is a scientific method important in chemistry? State your opinion.
3. You are given a bucket of ice cubes, a little sugar, a measuring cylinder and a stopwatch. Plan an experiment to determine whether sugar increases the melting rate of the ice.

1.3 Usage, Management and Handling of Apparatus and Materials

The laboratory is an important place for learning chemistry, and it is a dangerous place too. All the rules and safety measures in the laboratory should be obeyed. Do you still remember the rules and safety measures you have learned in Form 1? Figure 1.8 shows a poster of general rules in the laboratory.

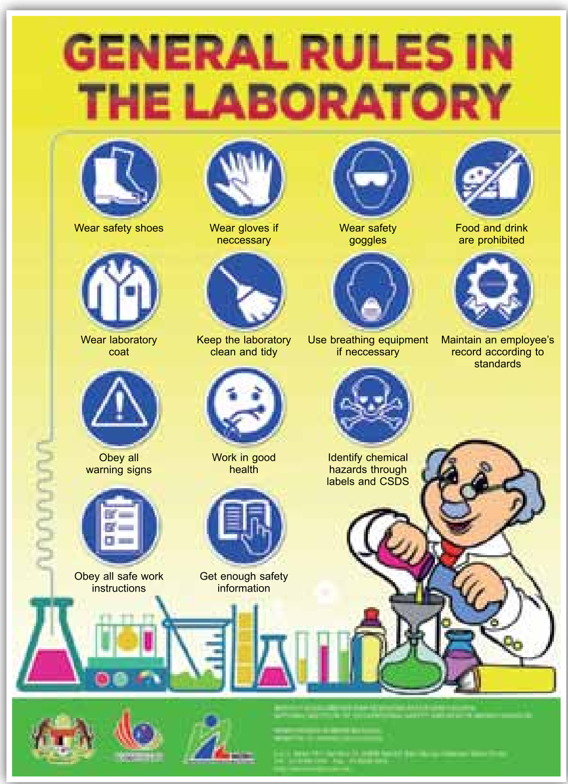


Figure 1.8 *A poster of general rules in the laboratory*

(Source: National Institute of Occupational Safety and Health (NIOSH), Malaysia)

Learning Standard

At the end of the lesson, pupils are able to:
- 1.3.1 Explain the types and functions of self protective equipments and safety in the laboratory
- 1.3.2 Demonstrate methods of managing and handling apparatus and materials
- 1.3.3 Communicate about emergency management procedure in laboratory

Chemistry Lens

CSDS (Chemical Safety Data Sheet) is a data sheet that gives information about chemicals to assist consumers in managing the risks of using dangerous chemicals. This data sheet contains complete information on chemical poisoning besides providing information on management and storage methods, and handling methods during an emergency.

Personal Protective Equipment

Wearing personal protective equipment while carrying out experiments in the laboratory is necessary to protect yourself from accidents. Figure 1.9 shows personal protective equipment in the laboratory and their functions. Other than the personal protective equipment, the chemistry laboratory is also equipped with various safety equipment. Figure 1.10 shows the safety equipment in the laboratory and their functions.

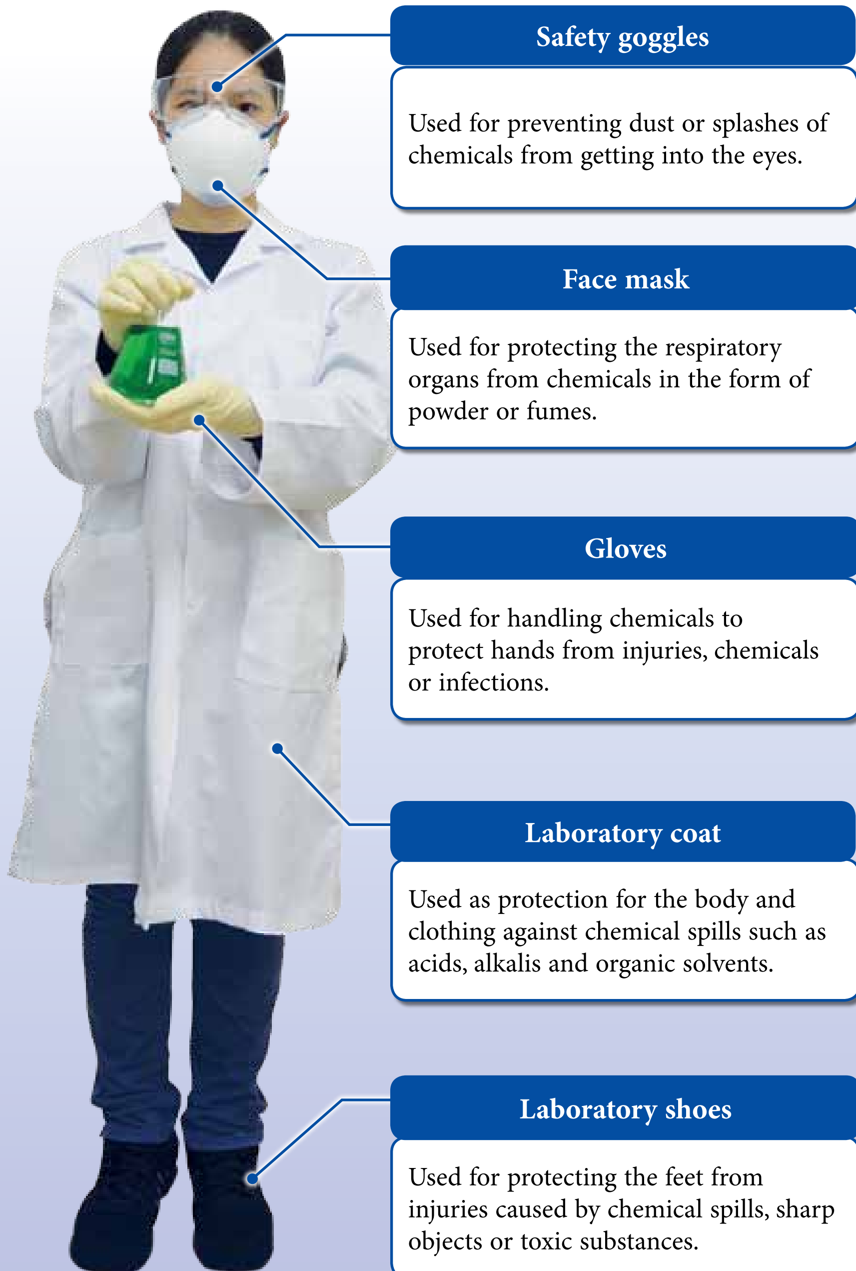


Figure 1.9 *Personal protective equipment in the laboratory and their functions*

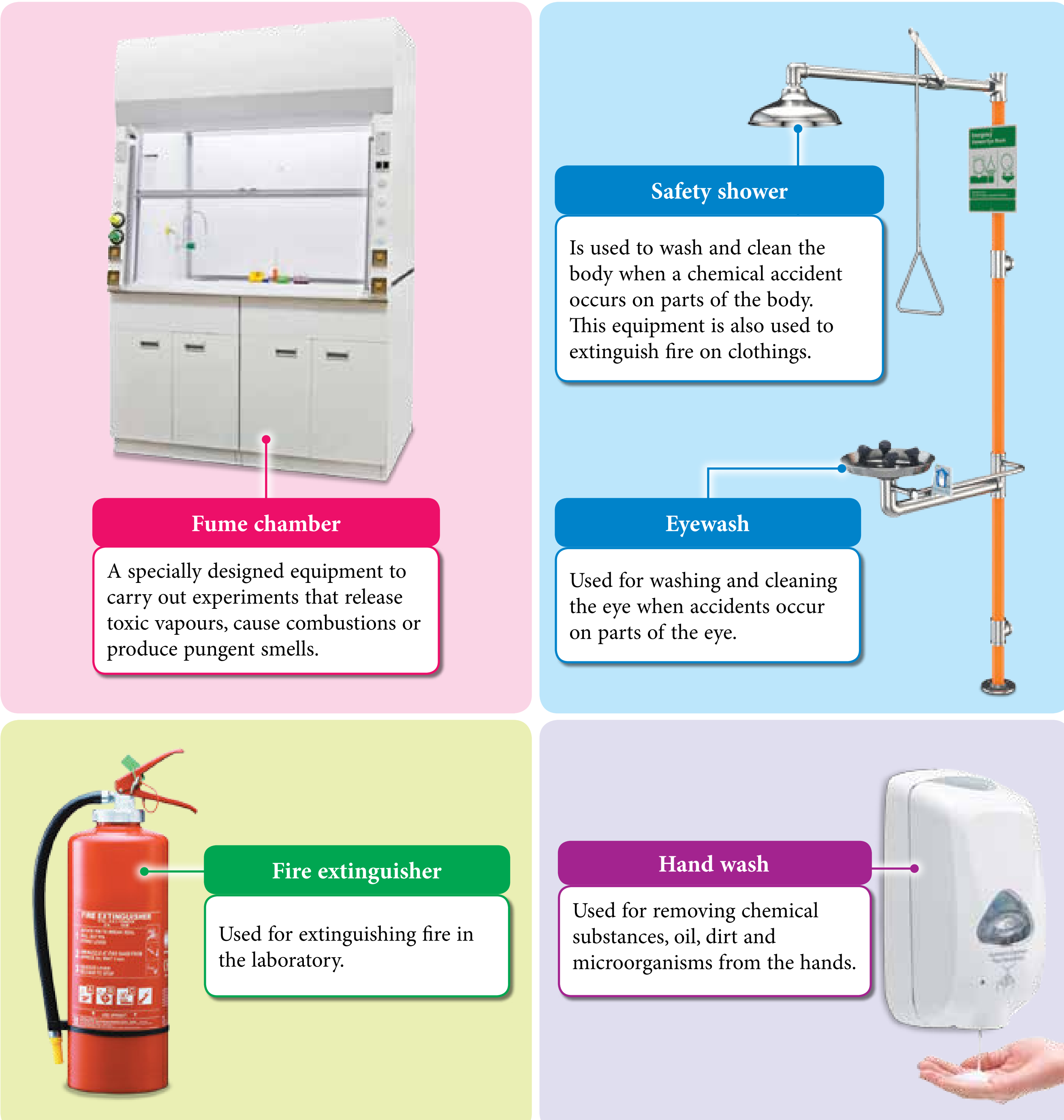


Figure 1.10 *Safety equipment in the laboratory and their functions*

Chemistry Lens

Examples of substances that release toxic vapour, cause combustion or produce pungent smell:
- Concentrated sulphuric acid
- Chlorine gas
- Ammonia gas
- Bromine gas
- Alcohol
- Benzene

Methods of Managing and Handling Apparatus and Chemicals

Skills in using and handling apparatus and materials are important and very useful in carrying out a scientific investigation. Carry out Activity 1.5 to find out the correct methods of managing and handling apparatus.

Activity 1.5

Using and handling apparatus correctly

1. Carry out this activity in groups.
2. Each group should take turns in carrying out the four activities according to the stations by using and handling apparatus and chemicals with the correct methods. Visit the website or scan the QR code for each station.
   (a) Station 1 - Weighing and heating of solid

   Station 1
   http://bit.ly/2MzE6Do

   (b) Station 2 - Filtration and distillation

   Station 2
   http://bit.ly/2pI0scC

   (c) Station 3 - Electrolysis, gas collection and gas test

   Station 3
   http://bit.ly/2MzEMbU

   (d) Station 4 - Titration

   Station 4
   http://bit.ly/2W3RLpl

Storage and Disposal of Chemicals

What do you understand about the storage and disposal of chemicals based on the conversation in Figure 1.11? Most chemicals in the laboratory are hazardous. Chemicals should be stored properly so that they do not endanger the user nor cause accidents. Therefore, chemicals should be stored in their designated places according to their categories.

Disposal of chemicals is equally important as the storage of chemicals. Disposal of chemicals without following the correct disposal procedures not only causes environmental pollution but also destroys the habitats of flora and fauna and endangers human health as well. Hence, the storage and disposal of chemicals should be taken seriously by all parties.

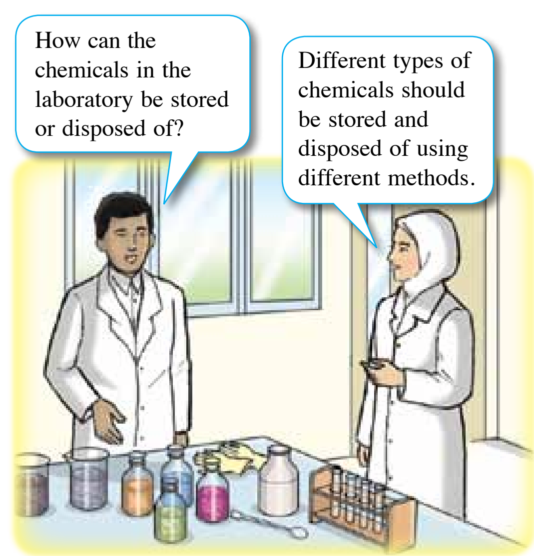


Figure 1.11 *Storage and disposal of chemicals*

Storage of Chemicals

Chemicals have specific storage methods according to the types of substances. Look at the following examples:

Reactive substances

Reactive metals such as lithium, sodium and potassium are stored in paraffin oil to prevent reaction with the moisture in the air.

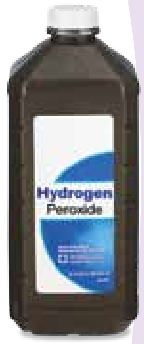
Photograph 1.1 *Sodium in paraffin oil*

Hydrocarbons and organic solvents

Volatile and inflammable liquids like hydrocarbons and organic solvents should be stored in shady areas far from sunlight and heat source.

Substances that decompose easily

Substances that decompose easily in the presence of light, for example concentrated nitric acid, hydrogen peroxide solution, silver nitrate solution, liquid bromine and liquid chlorine are stored in dark bottles.



Photograph 1.2 *Hydrogen peroxide stored in a dark bottle*

Substances with pH<5 and pH>9

Corrosive chemicals (pH<5 and pH>9) are usually stored in special storage cabinets that are kept locked.

Heavy metals and toxic substances

Toxic substances and heavy metals should be kept in special labelled containers and kept in a locked room which is heat free.

Photograph 1.3 *Cabinet for keeping corrosive chemicals*

Guidelines on storage of hazardous substances

http://bit.ly/2MfxBoT

Disposal of Chemicals

Laboratory wastes have specific disposal methods according to the types of substances.

Brain Teaser

Can all the chemical wastes in the laboratory be disposed of into the sink or dustbin? Justify.

Hydrogen peroxide

Hydrogen peroxide wastes with a low concentration can be poured directly into the laboratory's sink. However, hydrogen peroxide with a high concentration has to be diluted with water and added with sodium sulphite for the decomposition process to take place before being poured into the sink.

Solid wastes

Solid wastes like glass and rubber have to be disposed into special containers.

Photograph 1.4
A closed container for disposing hazardous wastes

Organic solvents and hydrocarbons

Most organic solvents and hydrocarbons are toxic, carcinogenic, volatile and inflammable. This type of wastes cannot be disposed directly into the sink or the laboratory drain because it would pollute the water source and the environment. Organic solvent and hydrocarbon wastes should be kept in special containers made of glass or plastic.

Substances with pH<5 and pH>9

Substances with a pH value of pH<5 and pH>9 are strong acids and strong alkalis respectively. Strong acid and alkali wastes can cause damage to the sink and react with water to release high heat and toxic gases. Strong acid and alkali wastes should be kept in closed labelled containers during disposal.

Chemistry Lens

According to Malaysian regulations, chemicals that are classified as listed wastes should be disposed according to standard procedures. The guidelines for listed wastes can be obtained from the Department of Environment of Malaysia.

Heavy metals and toxic substances

Solutions containing heavy metals and toxic substances have to be kept in plastic bags and the solutions be left to evaporate in the fume chamber. Then, the bag of heavy metal residue is tied carefully and is put into the container of heavy metal waste. This type of substances should be discarded and disposed according to standard procedures.

Volatile substances

Substances such as alcohol, ammonia and bromine are volatile, that is easily converted to gas at room temperature. Some of the gases produced from volatile substances are hazardous to humans and can be fatal if inhaled in large amounts. Volatile wastes should be stored in closed containers and kept away from sun and heat.

Chemical wastes and apparatus contaminated by chemicals should be disposed of into bins or bottles labelled with the types of wastes. Then, the waste will be sent to disposal centres.

Photograph 1.5 *Bin and bottle for chemical waste disposal*

Emergency Management Procedure in the Laboratory

Waste spills continue to occur in laboratories even with safety measures in place. When these accidents happen, you should act according to the correct procedure as shown below:

1. Inform your teacher or the laboratory assistant about the accident immediately.
2. Prohibit other students from entering the accident site.
3. Stop the spill from spreading to other areas by using sand to border it.
4. Clean the chemical spill.
5. Dispose of the chemical spill by following the correct procedures.

Mercury thermometers are often used to carry out experiments in the school laboratory. If the mercury thermometer breaks, a pupil faces the risk of mercury spill. Although the quantity of mercury in the thermometer is very minimal, it is enough to cause mercury poisoning. Mercury poisoning occurs when a person is exposed to mercury in certain amount.

News on mercury spill

http://bit.ly/2MxQZh9

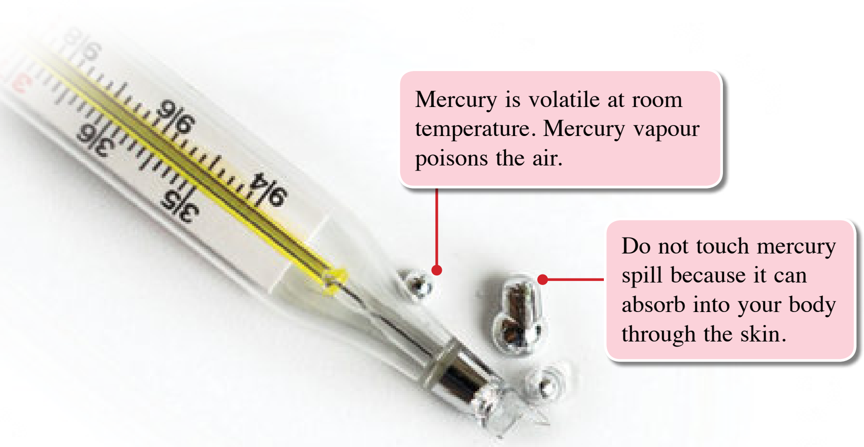


Figure 1.12 *Mercury spill*

Symptoms of mercury poisoning:
- Nausea
- Coughing
- Vomiting
- Diarrhoea
- Chest pain
- Sore throat
- Difficulty in breathing
- Headache
- Eye irritation
- Vision problem
- Increase in blood pressure

Steps to be taken the moment mercury spill occurs.

1. Inform your teacher or the laboratory assistant about the accident.
2. Make the spill site as the prohibited area.
3. Sprinkle sulphur powder to cover up the spill.
4. Contact the Fire and Rescue Department for further action.

If you are exposed to mercury poisoning, you should:
- Stay away from the mercury source to prevent further exposure to it
- Go to the hospital for treatment

Guidelines on handling mercury spill

http://bit.ly/2MJRqng

Activity 1.6

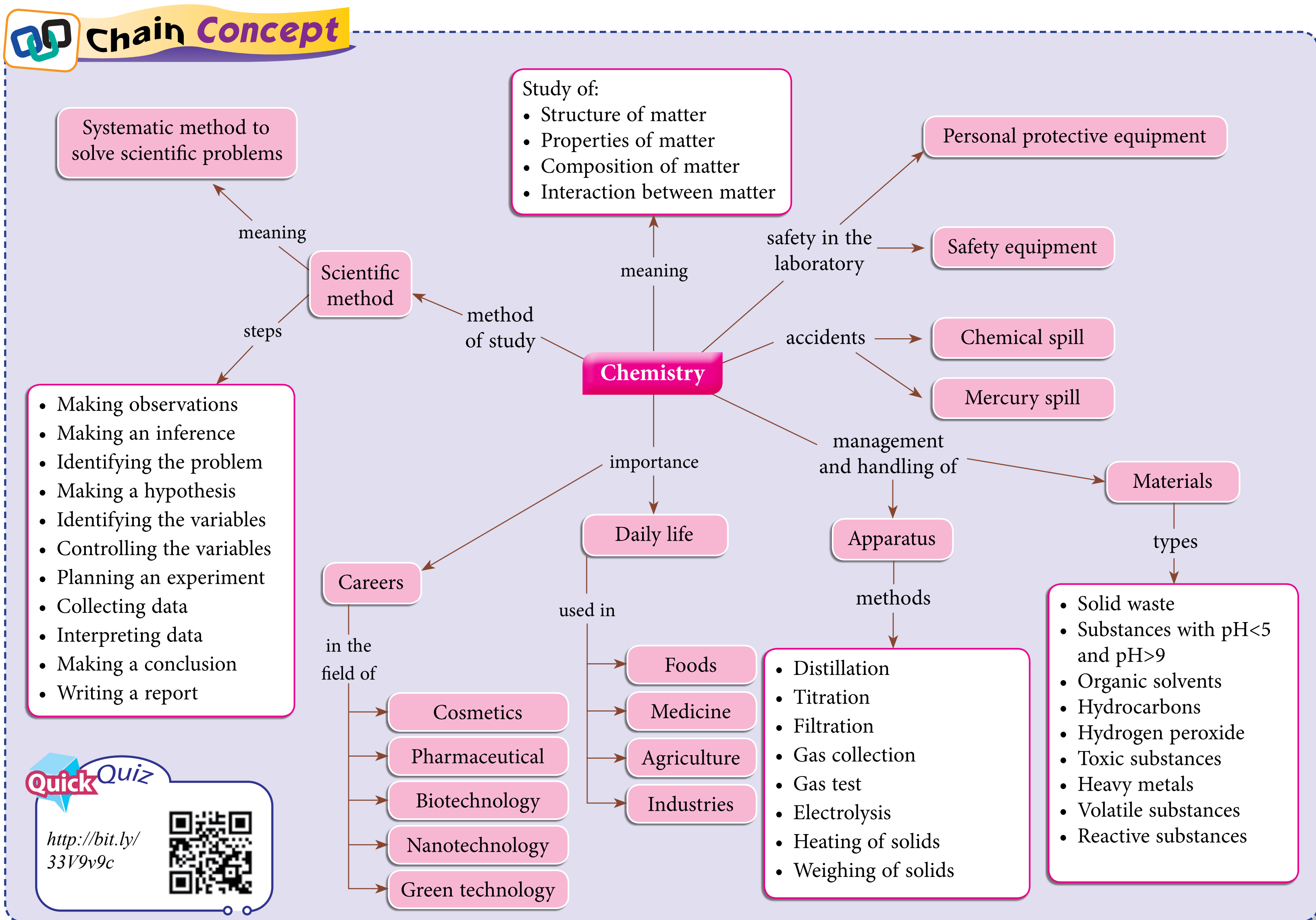
Discussing the emergency management procedures in the laboratory

21st Century Skills

1. Carry out the Gallery Walk activity.
2. Surf the Internet to gather information on the types of accidents that commonly occur in the laboratory and emergency management procedures.
3. Prepare a presentation of your information.
4. Display the information in the class.
5. Each group should move to observe the information of the other groups. Write comments on the other groups' information on sticky notes and paste them.

Test Yourself 1.3

1. List out three safety steps while in the laboratory.
2. Give the functions of the following equipment:
   (a) Fume chamber
   (b) Safety shower
   (c) Laboratory coat
3. How would you manage solid wastes such as glass and rubber in the laboratory?
4. Explain how you would test the presence of oxygen and hydrogen gases.
5. Explain how you can get the most accurate reading in titration.


Chain Concept
Chemistry
meaning
Study of:
• Structure of matter
• Properties of matter
• Composition of matter
• Interaction between matter
method of study
Scientific method
meaning
Systematic method to solve scientific problems
steps
• Making observations
• Making an inference
• Identifying the problem
• Making a hypothesis
• Identifying the variables
• Controlling the variables
• Planning an experiment
• Collecting data
• Interpreting data
• Making a conclusion
• Writing a report
safety in the laboratory
Personal protective equipment
Safety equipment
accidents
Chemical spill
Mercury spill
management and handling of
Apparatus
methods
• Distillation
• Titration
• Filtration
• Gas collection
• Gas test
• Electrolysis
• Heating of solids
• Weighing of solids
Materials
types
• Solid waste
• Substances with pH<5 and pH>9
• Organic solvents
• Hydrocarbons
• Hydrogen peroxide
• Toxic substances
• Heavy metals
• Volatile substances
• Reactive substances
importance
Daily life
used in
Foods
Medicine
Agriculture
Industries
Careers
in the field of
Cosmetics
Pharmaceutical
Biotechnology
Nanotechnology
Green technology
Quick Quiz
http://bit.ly/33V9v9c

SELF Reflection

1. What new knowledge have you learned in **Introduction to Chemistry**?
2. Which is the most interesting subtopic in **Introduction to Chemistry**? Why?
3. Why is the learning of **Introduction to Chemistry** important in the next chemistry lesson?
4. Rate your performance in **Introduction to Chemistry** 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 else would you like to know about **Introduction to Chemistry**?

http://bit.ly/2MEAuyw

Achievement Test 1

1. Chemicals are substances that cannot be ignored in our daily lives.
   (a) State five types of chemicals that are commonly used in daily life.
   (b) For each chemical stated in (a), state its use.
2. (a) Name three industries in Malaysia that use knowledge of chemistry.
   (b) How do the industries stated in (a) benefit our country?
3. List out three types of personal protective equipment and state the function of each equipment.
4. Complete the following flow chart on the steps involved in a scientific method.

Making observation → Making an inference → Identifying the problem → ______ → ______ → ______ → ______ → ______ → ______ → ______ → Writing a report

5. State the safety measures that should be taken to overcome mercury spill accidents that occur in the school laboratory.

6. Three pieces of cloth with a size of 10 cm × 10 cm each are sprinkled with 20 cm^3 of distilled water. Then, all the three pieces of cloth are folded in different styles and left to dry at room temperature. The time taken for each piece to dry is recorded.
   (a) Explain why the three pieces of cloth are folded in different styles.
   (b) Suggest a hypothesis for this experiment.
   (c) Make an inference for this experiment.
   (d) Determine the variables involved in this experiment.
   (e) Construct a suitable table to record the readings in this experiment.

Enrichment Corner

1. Figure 1 shows several examples of waste substances in the school laboratory.

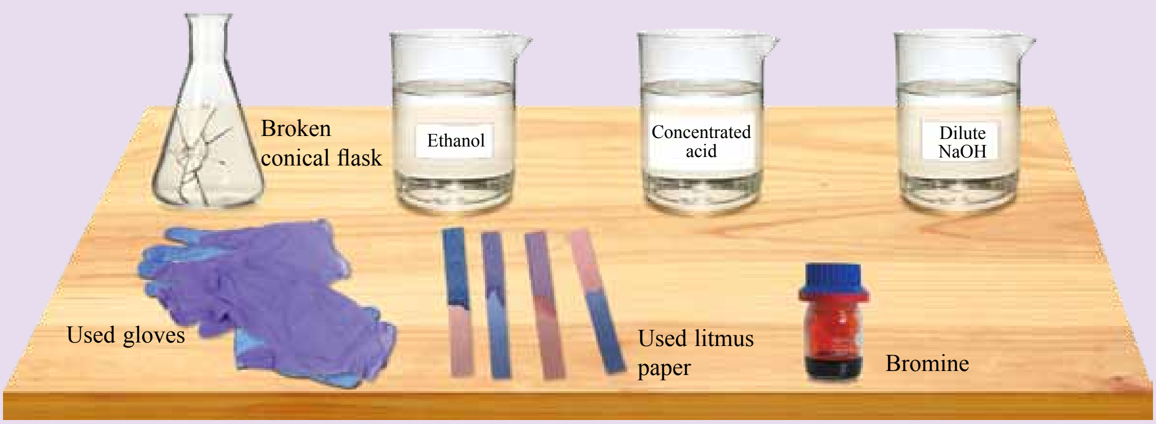


Figure 1

   (a) Based on Figure 1, list out wastes that cannot be disposed of into the school sink or the rubbish bin.
   (b) Explain how to manage the waste substances listed in (a) correctly.

2. Halim is a farmer. He plants various types of vegetables to supply the local market. However, lately, Halim realised that the produce was unsatisfactory and the growth of vegetables was stunted, or the vegetables had died off. He suspected the soil to be acidic. As a scientist, you are asked to help Halim to determine the most suitable pH value of the soil for planting vegetables. Suggest a suitable hypothesis and state briefly how you can control the variables in this experiment. STEM

Check Answers

http://bit.ly/3442zGX

CHAPTER 2

Matter and the Atomic Structure

Keywords

- Atom
- Ion
- Molecule
- Proton number
- Nucleon number
- Electron arrangement
- Isotopes
- Natural abundance

What will you learn?

2.1 Basic Concepts of Matter
2.2 The Development of the Atomic Model
2.3 Atomic Structure
2.4 Isotopes and Its Uses

Bulletin

Have you heard of patients undergoing PET-CT scanning? PET-CT is the abbreviation for Positron Emission Tomography-Computed Tomography. PET-CT scanning can give accurate information on the position of a disease in the patient's body, especially to detect and treat diseases such as cancer, inflammation and infection. PET-CT is an imaging technique that combines CT scan and PET scan. CT is able to visualise the image of a tissue or organ through the anatomical cross section of organs. PET is able to show the metabolism level of cells and tissues in the body of a patient using radioisotopes as a tracer.

Did you know that radioisotopes are isotopes that exhibit radioactivity? What are isotopes? Do isotopes have the same subatomic particles like other atoms of their elements?

Who is the scientist that proved the existence of neutrons in the nucleus?

How many valence electrons are there in $^{12}_{6}C$?

What is the use of isotope cobalt-60?

2.1 Basic Concepts of Matter

Learning Standard

At the end of the lesson, pupils are able to:
2.1.1 Describe matter briefly
2.1.2 Explain the changes in the states of matter
2.1.3 Determine the melting point and freezing point of naphthalene through activity

Meaning of Matter

Try to recall what matter is based on the conversation in Figure 2.1.

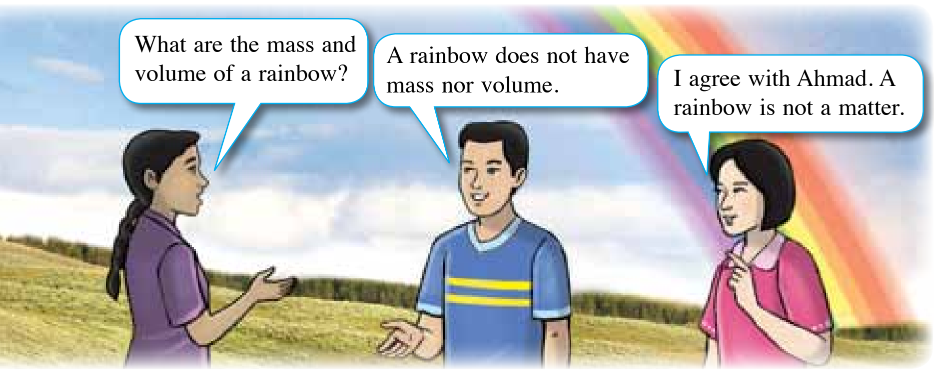


Figure 2.1 *Rainbow is not a matter*

Matter is something that has mass and occupies space. Matter consists of particles that are tiny and discrete. Matter can exist in three states, namely solid, liquid and gas. What are other examples of matter that you encounter in your daily life?

Chemistry Lens

Plasma is the fourth state of matter besides solid, liquid and gas. A plasma is an ionised gas. Although plasma in its natural state is rarely found on Earth, plasma is the state of matter most found in the universe. Most stars exist as plasma.

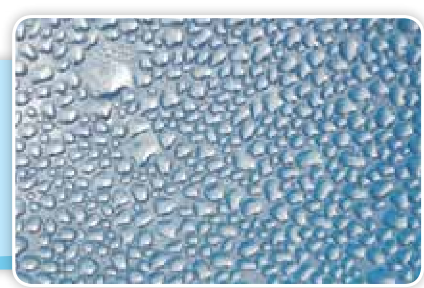
Changes in the State of Matter

The change in the state of matter is caused by **heating** or **cooling**.

Photograph 2.1 *Ice cream*

Ice cream that is left at room temperature absorbs heat energy and changes from solid to liquid state.

At night, glass windows release heat to the surroundings causing the surface of the glass window to become cold. Water vapour in the air that comes in contact with the cold surface loses heat and forms water droplets on the surface of the glass window.

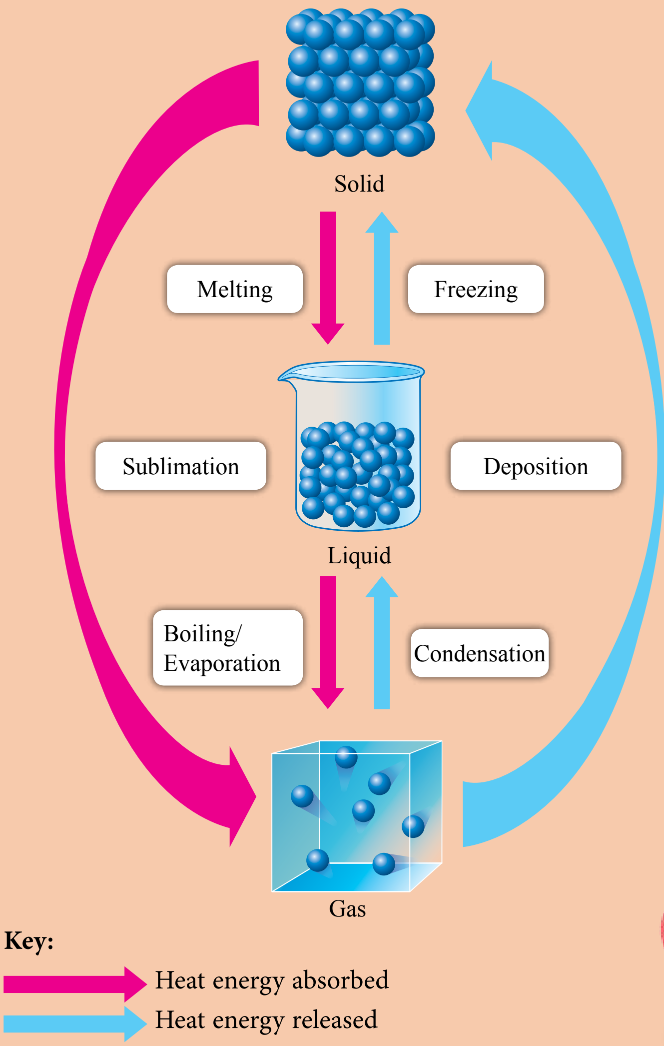


Photograph 2.2 *Water droplets on the surface of a glass window*

Figure 2.2 shows the conversion among states of matter through the process of heat absorbed or heat released. When heat energy is absorbed or released, changes occur in kinetic energy, arrangement of particles and attraction force between particles, causing the state of matter to change.

The difference between deposition and sublimation process

http://bit.ly/2IJ8b0X



Solid

- Particles are closely packed in an orderly manner
- Kinetic energy of particles is low
- Attraction force between particles is strong

Liquid

- Particles are closely packed but not in an orderly manner
- Kinetic energy of particles is higher than solid state
- Attraction force between particles is strong, but less than solid state

Gas

- Particles are far apart
- Kinetic energy of particles is very high
- Attraction force between particles is weak

AR

Figure 2.2 *Conversion between states of matter*

Activity 2.1

Drawing the arrangement of particles in 2D form

1. Based on Figure 2.2, draw the arrangement of particles in solid, liquid and gas in 2D form.
2. Display your work on the notice board in your class.

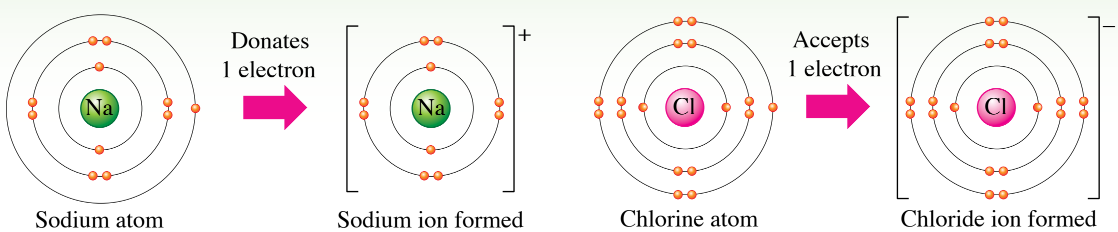
Matter can exist in the form of elements or compounds. Elements consist of particles of atoms or molecules while compounds are made up of molecules or ions. Figure 2.3 shows the classification of matter.

- **Matter**
  - Element
    - Atom: Carbon, C
    - Molecule: Oxygen, O_2
  - Compound
    - Molecule: Water, H_2O
    - Ion: Sodium chloride, NaCl

***Figure 2.3** Classification of matter*

Chemistry Lens

Ions are formed by transfer of electrons between atoms.



Melting Point and Freezing Point

How do scientists determine the melting point and freezing point of a substance? Carry out Activity 2.2 to determine the melting point and freezing point of naphthalene, $C_{10}H_8$.

Literacy Tips

- Melting point is the constant temperature when a substance changes from solid state to become liquid at a specific pressure.
- Freezing point is the constant temperature when a substance changes from liquid state to become solid at a specific pressure.

Activity 2.2

Aim: To determine the melting point and freezing point of naphthalene, $C_{10}H_8$.

Materials: Naphthalene, $C_{10}H_8$ and water

Apparatus: Boiling tube, 250 cm^3 beaker, thermometer, tripod stand, retort stand with clamp, Bunsen burner, stopwatch, conical flask, wire gauze and spatula

Procedure:

1. Fill up one third of a boiling tube with naphthalene, $C_{10}H_8$.
2. Place a thermometer in the boiling tube.
3. Pour water into a beaker until it is half filled.
4. Immerse the boiling tube into the beaker as shown in Figure 2.4. Ensure the level of naphthalene, $C_{10}H_8$ in the boiling tube is below the level of water in the beaker.

CAUTION

Avoid touching the naphthalene, $C_{10}H_8$ or inhaling the naphthalene gas.

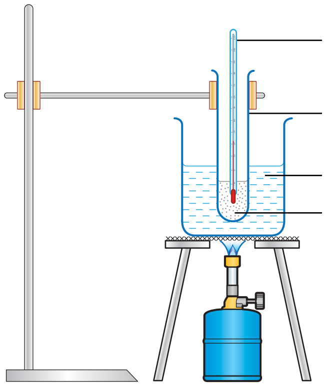


Figure 2.4 Heating of naphthalene, $C_{10}H_8$

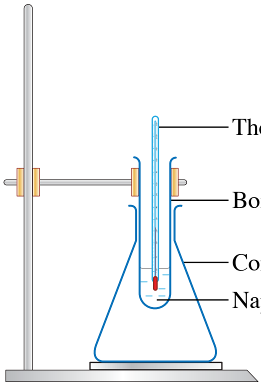


Figure 2.5 Cooling of naphthalene, $C_{10}H_8$

5. Heat water and stir the naphthalene, $C_{10}H_8$ slowly using the thermometer. When the temperature of the napthalene, $C_{10}H_8$ reaches 60 °C, start the stopwatch.
6. Record the temperature and state of matter of naphthalene, $C_{10}H_8$ at 30 seconds intervals until the temperature reaches 90 °C.
7. Remove the boiling tube from the water bath. Dry the outer surface of the boiling tube and put it into a conical flask as shown in Figure 2.5.
8. Stir the naphthalene, $C_{10}H_8$ continuously.
9. Record the temperature and state of matter of naphthalene, $C_{10}H_8$ at 30 seconds intervals until the temperature decreases to 60 °C.
10. Record your observations.

CAUTION

Deficiency of glucose-6-phosphate dehydrogenase (G6PD) is a genetic disease. Exposure to naphthalene, $C_{10}H_8$ to a patient with G6PD will cause haemolysis, that is destruction of red blood cells. This situation will cause the patient to feel tired and dizzy.

Interpreting data:

1. Plot a graph of temperature against time for the following:
   (a) Heating of naphthalene, $C_{10}H_8$
   (b) Cooling of naphthalene, $C_{10}H_8$
2. On the graphs, label the states of matter of naphthalene, $C_{10}H_8$ whether solid, liquid or both.
3. Determine the melting point and freezing point of naphthalene, $C_{10}H_8$ from the graphs plotted.

Discussion:

1. During the heating of naphthalene, $C_{10}H_8$:
   (a) Why is naphthalene, $C_{10}H_8$ not heated directly using the Bunsen burner?
   (b) Why is a water bath used?
2. During the cooling of naphthalene, $C_{10}H_8$:
   (a) Why is the boiling tube put into a conical flask?
   (b) Why is naphthalene, $C_{10}H_8$ stirred continuously?
   (c) Predict what would happen if naphthalene, $C_{10}H_8$ is not stirred continuously.
3. Explain why the temperature becomes constant when melting and freezing of naphthalene, $C_{10}H_8$ take place.

Prepare a complete report after carrying out this activity.

The graph of temperature against time for heating of naphthalene, $C_{10}H_8$ is shown in Figure 2.6 and the graph of temperature against time for cooling of naphthalene, $C_{10}H_8$ is shown in Figure 2.7.

Chemistry Lens

Lauric acid, $C_{12}H_{24}O_2$ is a type of fatty acid that can be obtained from coconuts. This acid is also suitable to be used as a substitute for naphthalene, $C_{10}H_8$ in Activity 2.2.

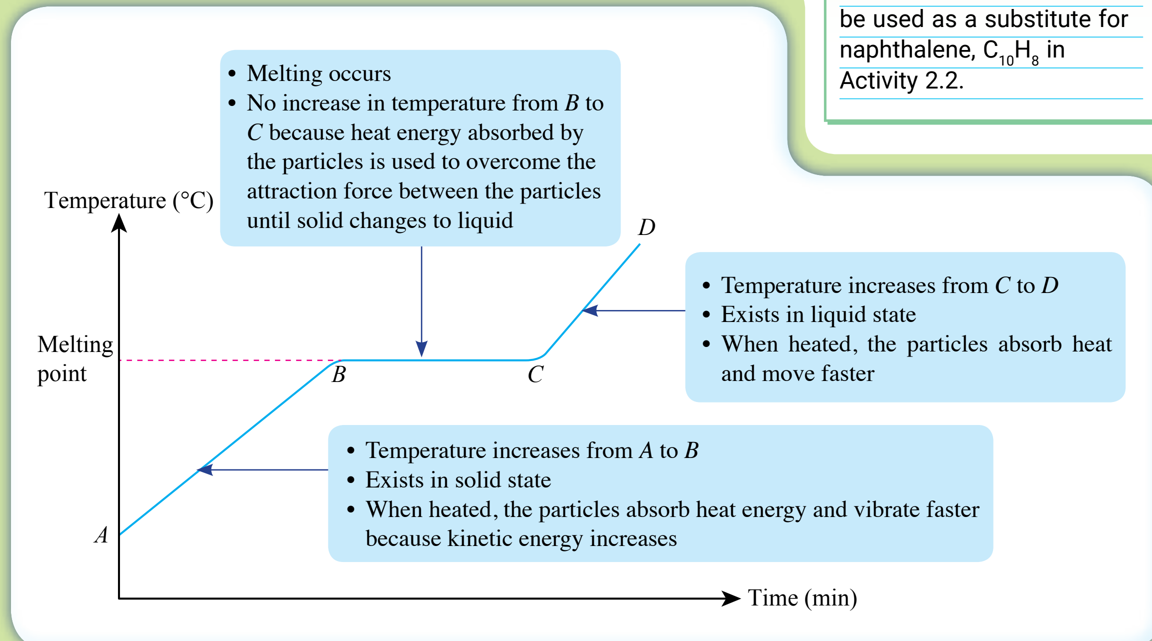


***Figure 2.6** Heating curve of naphthalene, $C_{10}H_8$*

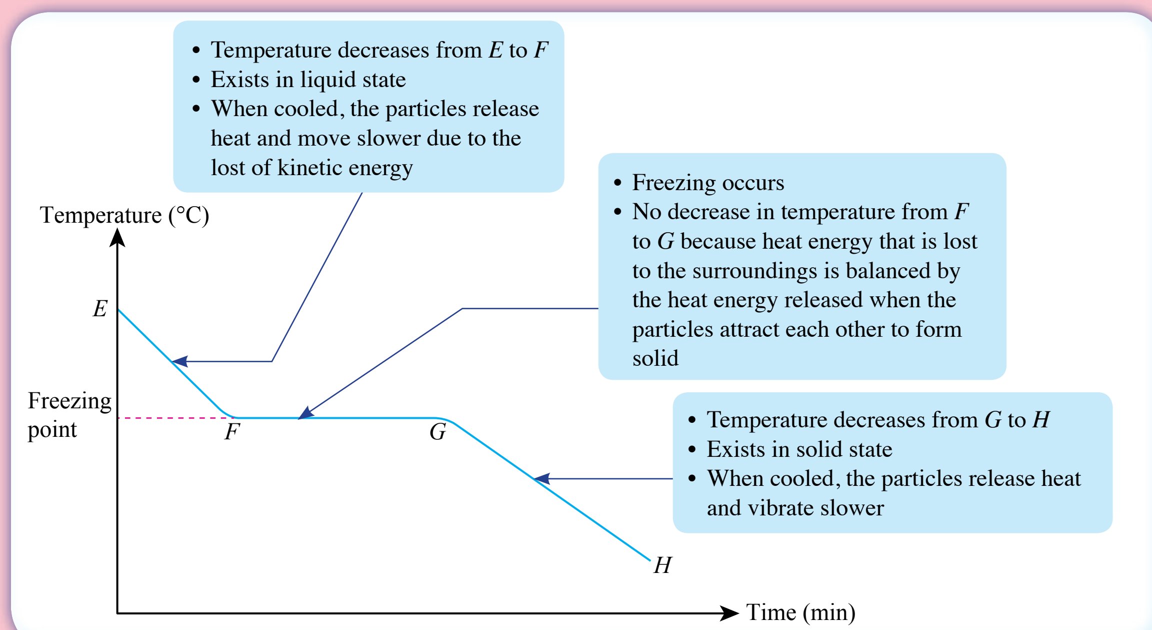


***Figure 2.7** Cooling curve of naphthalene, $C_{10}H_8$*

Test Yourself 2.1

1. State the types of particles that exist in a copper wire.
2. Lily dries her hair with a hair dryer.
   (a) Name the process involved during hair drying.
   (b) State the changes in the movement of water particles when hair is dried.
3. Lauric acid, $C_{12}H_{24}O_2$ is heated from room temperature to 50 °C. At 43 °C, lauric acid, $C_{12}H_{24}O_2$ starts to melt.
   (a) Draw a heating curve for lauric acid, $C_{12}H_{24}O_2$.
   (b) Why is the temperature constant at 43 °C?

2.2 The Development of the Atomic Model

Learning Standard

At the end of the lesson, pupils are able to:
2.2.1 State the subatomic particles in atoms of various elements
2.2.2 Compare and contrast the relative mass and relative charge of proton, electron and neutron
2.2.3 Sequence the atomic structure models based on Atomic Models of Dalton, Thomson, Rutherford, Bohr and Chadwick

Subatomic Particles

Figure 2.8 shows the subatomic particles found in an atom which is made up of protons, neutrons and electrons. What are the similarities and differences in these three types of subatomic particles?

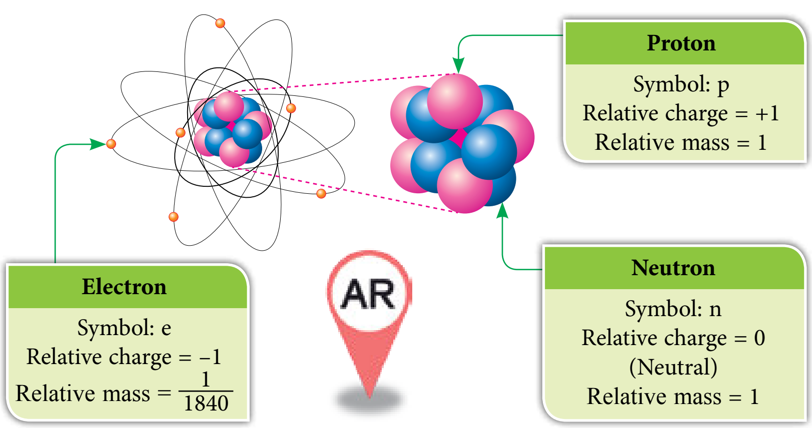


Figure 2.8 *Subatomic particles*

Brain Teaser

How are the relative charge and relative mass of subatomic particles determined?

Activity 2.3

Comparing and contrasting the subatomic particles

1. Watch a video clip on subatomic particles by searching the Internet.
2. Based on the video, compare and contrast the relative masses and charges of protons, electrons and neutrons.
3. Present your findings using a suitable graphic presentation software and upload your work to social media.

Development of the Atomic Structure Model

Atoms can neither be seen with the naked eye nor the microscope. Have you ever thought how the atomic structure model is produced? The atomic structure model that we know now is the product of many scientists' efforts. Studies on atoms started since the introduction of atomic theory by Democritus, a Greek philosopher, around 500 B.C. Figure 2.9 shows the historical development of the atomic structure model.

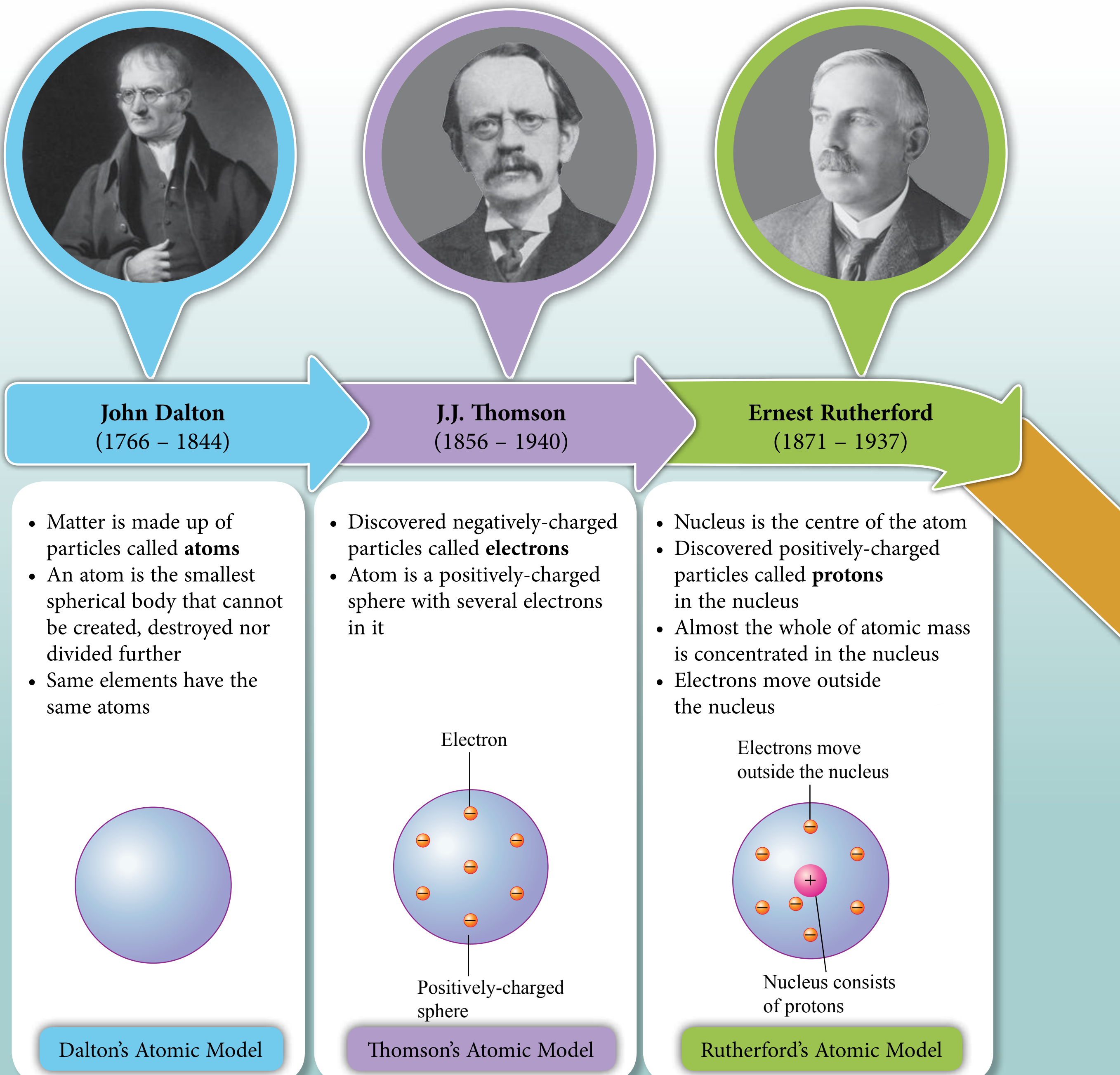


Figure 2.9 *Historical development of the atomic model*

Activity 2.4

Role-playing on the development of the atomic structure model 21st Century Skills CT

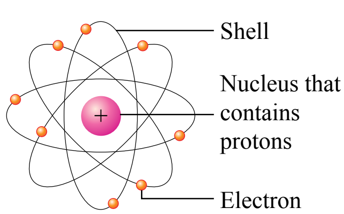
1. Carry out the Role-Play activity in groups.
2. In your group, find information on the atomic structure model explained by one of the following scientists:

John Dalton | Ernest Rutherford | James Chadwick | J.J. Thomson | Niels Bohr

3. Prepare the acting scripts and suitable props.
4. Present the group act in front of the class.

Niels Bohr
(1885 – 1962)

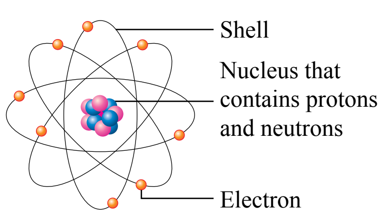
- Electrons in an atom move in **shells** around the nucleus



Bohr's Atomic Model

James Chadwick
(1891 – 1974)

- Discovered neutral particles, that are **neutrons** in the nucleus
- Neutrons contribute almost half of the mass of an atom



Chadwick's Atomic Model

Test Yourself 2.2

1. Figure 2.10 shows the atomic structure of nitrogen.
   (a) Name *X*.
   (b) State the subatomic particles found in the nucleus of nitrogen atom.
   (c) Compare *X* and subatomic particles mentioned in (b) from the aspect of relative charge and relative mass.

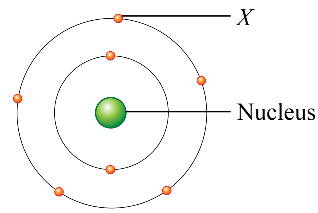


Figure 2.10

2.
   - Electrons move around the nucleus in shells.
   - Nucleus of an atom consists of protons and neutrons.

   The statements above show the information on an atomic structure model.
   (a) Which scientist identified it?
   (b) Draw this atomic structure model.

2.3 Atomic Structure

Proton Number and Nucleon Number

Look at Table 2.1, what is the relationship between the number of protons and proton number, and the relationship between the nucleon number and the proton number?

Table 2.1 *Proton numbers and nucleon numbers of oxygen atom, sodium atom and chlorine atom*

Atom	Number of protons	Number of neutrons	Proton number	Nucleon number
Oxygen	8	8	8	16
Sodium	11	12	11	23
Chlorine	17	18	17	35

The number of protons in the nucleus of an atom is known as the **proton number**. The total number of protons and neutrons in the nucleus of an atom is known as the **nucleon number**.

Nucleon number = number of protons + number of neutrons
or
Nucleon number = proton number + number of neutrons

Atoms of different elements have different proton numbers. For example, sodium atom has a proton number of 11 and chlorine atom has a proton number of 17.

Learning Standard

At the end of the lesson, pupils are able to:
2.3.1 Define proton number and nucleon number
2.3.2 Determine the nucleon number, proton number and number of electrons in an atom
2.3.3 Write the standard representation of an atom
2.3.4 Construct an atomic structure diagram and electron arrangement

Brain Teaser

Are there any two elements with the same proton number? Explain.

An atom is neutral when the number of electrons is the same with the number of protons. For example, an oxygen atom has 8 protons and also 8 electrons. The examples and solutions are shown in Example 1 and 2.

Example 1

An aluminium atom has 13 protons and 14 neutrons. What are the proton number and nucleon number of an aluminium atom?

Solution

Proton number = number of protons
= 13

Nucleon number = proton number + number of neutrons
= 13 + 14
= 27

Example 2

The nucleon number of a potassium atom is 39. A potassium atom has 19 protons. How many neutrons and electrons are there in a potassium atom?

Solution

Number of electrons = number of protons
= 19

Number of neutrons = nucleon number – number of protons
= 39 – 19
= 20

Table 2.2 shows the comparison among the number of protons, neutrons and electrons when a chlorine atom accepts an electron to form a chloride ion. What are the changes in the number of protons, neutrons and electrons?

Table 2.2 *Number of subatomic particles of chlorine atom and chloride ion*

Type of particle	Chlorine atom, Cl	Chloride ion, Cl^-
Number of proton	17	17
Number of neutron	18	18
Number of electron	17	18

A chlorine atom accepts one electron to form a chloride ion, thus a chloride ion has one electron more than a chlorine atom. The number of protons and neutrons in a chlorine atom and chloride ion are the same. Therefore, during the formation of ion from an atom, the number of protons and neutrons in the nucleus remain the same.

Literacy Tips

When the number of electron increases, an anion is formed, which is a negatively-charged ion. However, when the number of electron decreases, a cation is formed, which is a positively-charged ion.

Standard Representation of an Atom

An atom can be represented using a standard representation as shown in Figure 2.11.

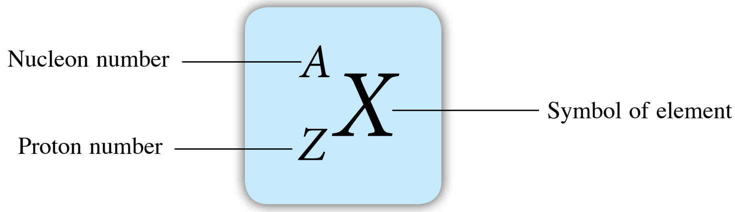
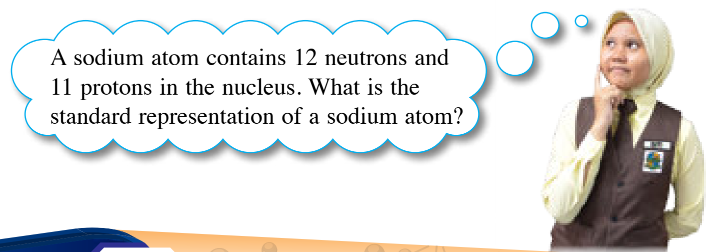


***Figure 2.11** Standard representation of an atom*

What information can you obtain from $^{12}_{6}C$? The symbol of carbon element is C, the nucleon number of a carbon atom is 12, while the proton number of a carbon atom is 6.



Activity 2.5

Finding the mystery code

CT

1. In groups, answer the following questions:
   (a) The nucleon number and the proton number of fluorine element are 19 and 9 respectively. Is the following statement true or false?

   The atom of this element has 9 electrons and 9 neutrons in its nucleus.

   (b) Atom *X* has 11 protons and 12 neutrons. Find the nucleon number of this atom.
   (c) What is the proton number of an atom of nitrogen element that has 7 electrons?
   (d) The standard representation of an atom of oxygen element is $^{16}_{8}O$. This atom accepts electrons to form an oxide ion, O^{2-}. How many electrons are accepted by an oxygen atom to form an oxide ion, O^{2-}?
   (e) The nucleus of atom *Y* has the charge +4 and contains 5 neutrons. State the nucleon number of element *Y*.
   (f) A calcium atom has 20 protons and its nucleon number is 40. A calcium ion, Ca^{2+} is formed when a calcium atom donates 2 electrons. State the number of neutrons in a calcium ion, Ca^{2+}.
   (g) $^{7}_{\square}W$ An atom of element *W* has 3 electrons and 4 neutrons. What should the number in the box be, to represent the atom of element *W*?
2. Scan QR Code or visit the website provided to obtain the code guidance.
3. Get the mystery code.

Code guidance
http://bit.ly/2P8zNQV

Atomic Structure and Electron Arrangement

Electrons of an atom orbit around the nucleus in their respective shells. Electrons will fill the shell closest to the nucleus first. When the shell closest to the nucleus is full, electrons will fill the next shell. The maximum number of electrons in the first three shells for elements with proton numbers 1 to 20 are shown in Figure 2.12.

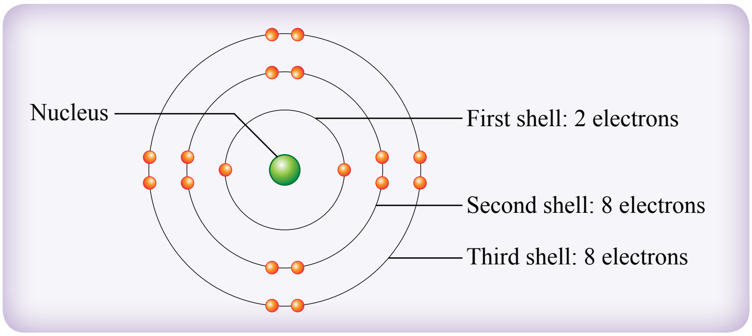


Figure 2.12 *Numbers of maximum electrons in the first three shells for elements with proton numbers 1 to 20*

Chemistry Lens

The third shell can be filled with a maximum of 18 electrons for elements with proton number exceeding 20.

For example, the proton number of aluminium is 13. This shows that an aluminium atom has 13 electrons. The electron arrangement of aluminium atom is, 2 electrons filled in the first shell, 8 electrons filled in the second shell and 3 electrons filled in the third shell. The electron arrangement of aluminium atom can be written as follows:

2.8.3 ← Number of valence electrons = 3

The outermost shell filled with electrons is the valence shell. Electrons in the valence shell are known as valence electrons. The chemical properties of an element depend on the number of valence electrons of the atom. Elements with the same number of valence electrons have similar chemical properties.

Chemistry Lens

The valence shell is the outermost shell of an atom.

The **electron arrangement** shows the nucleus and electron arrangement of an atom. For example, the electron arrangement of aluminium atom is shown in Figure 2.13.

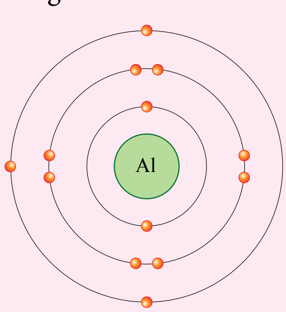


Figure 2.13 *Electron arrangement of aluminium atom*

The **atomic structure** shows the number of protons and neutrons in the nucleus and electron arrangement of an atom. For example, the atomic structure of aluminium is shown in Figure 2.14.

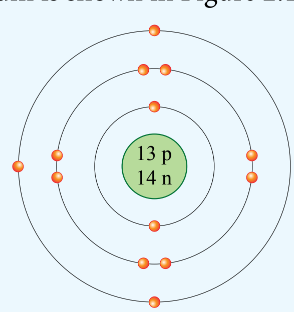


Figure 2.14 *Atomic structure of aluminium atom*

Activity 2.6

Writing the electron arrangement and drawing the atomic structure CT

1. Get the standard representation of atoms of the first 20 elements in the Periodic Table of Elements from the QR code or the given website.
   Based on the information:
   (a) Write the electron arrangement of the 20 elements
   (b) Draw the atomic structure of the 20 elements
2. Display your work on the notice board in your class.

Standard representation of atoms
http://bit.ly/2qusDfC

Activity 2.7

Illustrating the atomic structure using a model CT

1. Carry out this activity in groups.
2. Choose an element from the elements with proton numbers 1 to 20. Produce a model to illustrate the atomic structure using recycled materials.
3. The model that is produced must include the following:
   (a) Protons and neutrons in the nucleus
   (b) Electron arrangement in the shells
4. Present the model in front of the class.

TestYourself 2.3

Table 2.3 shows the number of protons and the number of neutrons for elements *X*, *Y* and *Z*.

Table 2.3

Element	Number of protons	Number of neutrons
X	10	10
Y	11	12
Z	19	20

1. What is the nucleon number of atom *Y*?
2. Write the standard representation of element *Z*.
3. Atom *Y* donates one electron to form ion Y^+. State the number of protons, neutrons and electrons for ion Y^+.
4. (a) Write the electron arrangement of atom *X*.
   (b) Draw the electron arrangement for atom *X*.
   (c) Draw the atomic structure of atom *X*. Label all the subatomic particles in the diagram.

2.4 Isotopes and Its Uses

Learning Standard

At the end of this lesson, pupils are able to:
2.4.1 Deduce the meaning of isotopes
2.4.2 Calculate the relative atomic mass of isotopes
2.4.3 Justify the usage of isotopes in various fields

Meaning of Isotopes

Figure 2.15 shows three atoms of hydrogen element. All these three atoms of hydrogen have the same proton number but different nucleon numbers. These hydrogen atoms are known as **isotopes**.

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

Figure 2.15

Activity 2.8

Generalising the meaning of isotopes

1. Carry out this activity in groups.
2. Compare and contrast the number of protons, electrons and neutrons in the isotopes of silicon, magnesium and phosphorus.

   $^{28}_{14}Si$ $^{29}_{14}Si$ $^{30}_{14}Si$ $^{24}_{12}Mg$ $^{25}_{12}Mg$ $^{26}_{12}Mg$ $^{31}_{15}P$ $^{32}_{15}P$

3. Interpret the information obtained and generalise the meaning of isotopes.

Isotopes are atoms of the same element with the same number of protons but different number of neutrons. For example, chlorine has two isotopes, chlorine-35 and chlorine-37. Table 2.4 shows the number of subatomic particles for the isotopes of chlorine. Atoms of chlorine-35 and chlorine-37 have different masses because the number of neutrons in the nucleus are different.

Chemistry Lens

Chlorine atom with the nucleon number 35 can be represented by Cl-35, $^{35}_{17}Cl$ or ^{35}Cl.

***Table 2.4** Number of subatomic particles for the isotopes of chlorine*

Isotope	Atomic standard representation	Number of protons	Number of neutrons	Number of electrons
Chlorine-35	$^{35}_{17}Cl$	17	18	17
Chlorine-37	$^{37}_{17}Cl$	17	20	17

Relative Atomic Mass of Isotopes

Most elements exist naturally as a mixture of two or more isotopes. Relative atomic mass of these elements depend on the natural abundance of isotopes in a sample. **Natural abundance** is the percentage of isotopes present in a natural sample of element. The relative atomic mass can be calculated from the natural abundance of an element containing isotopes using the following formula:

$$\text{Relative atomic mass} = \frac{\sum(\%\ \text{isotope} \times \text{mass of isotope})}{100}$$

Example 3

Chlorine consists of two isotopes, ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$. The natural abundance of ${}^{35}_{17}Cl$ is 75% and ${}^{37}_{17}Cl$ is 25%. Calculate the relative atomic mass of chlorine.

Solution

$$\text{Relative atomic mass of chlorine} = \frac{(\%\text{ isotope } {}^{35}_{17}Cl \times \text{mass } {}^{35}_{17}Cl) + (\%\text{ isotope } {}^{37}_{17}Cl \times \text{mass } {}^{37}_{17}Cl)}{100}$$

$$= \frac{(75 \times 35) + (25 \times 37)}{100}$$

$$= 35.5$$

Uses of Isotopes

Isotopes are used widely in various fields as listed in Table 2.5.

***Table 2.5** Uses of isotopes in various fields*

Field	Isotope	Uses
Medicine	Cobalt-60	• In radiotherapy to kill cancer cells without surgery • Sterilising surgical tools
	Iodine-131	• Treatment of thyroid disorders such as hyperthyroidism and thyroid cancer
Agriculture	Phosphorus-32	• Study of plant metabolism
Nuclear	Uranium-235	• Generating electricity through nuclear power generator
Archaeology	Carbon-14	• Estimation of artifacts or fossils' age
	Lead-210	• In determining the age of sand and earth layers up to 80 years
Industry	Hydrogen-3	• As a detector to study sewage and liquid wastes
Engineering	Sodium-24	• In detecting leakage in underground pipes

Development in the field of science, specifically chemistry has maximised the use of isotopes in various fields. Isotopes are used for sustainability of life. The use of isotopes causes both positive and negative effects on the environment and society.

Uses of isotopes

http://bit.ly/32zUJUP

Activity 2.9

Holding a forum on the issues of using isotopes

21st Century Skills

1. Carry out this activity in groups.
2. Each group is given a role as a chemist, medical representative, enforcer and others. Based on the role given, search for information concerning issues involving isotopes.
3. Hold a forum to discuss the positive and negative effects of using isotopes.
4. Record the forum proceedings and upload to social media.

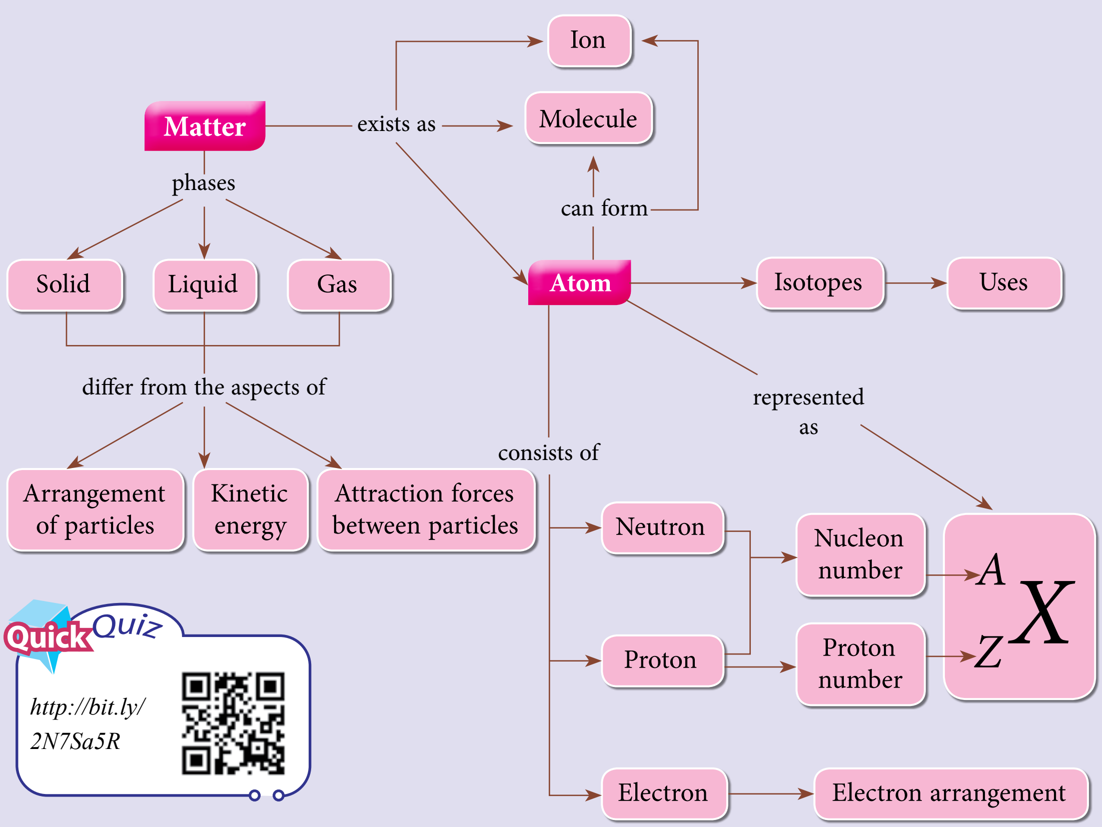
Test Yourself 2.4

1. Define isotopes.
2. Based on Table 2.6, which atoms are isotopes? Explain your answer.
3. Atoms of oxygen-16, oxygen-17 and oxygen-18 are isotopes. Compare and contrast these three isotopes.
4. Magnesium exists naturally as three isotopes, which are 79.0% of ^{24}Mg, 10.0% of ^{25}Mg and 11.0% of ^{26}Mg. Calculate the relative atomic mass of magnesium.
5. Madam Maimunah was diagnosed with bone cancer.
   (a) What isotope is used to treat Madam Maimunah?
   (b) Explain the positive and negative effects of using the isotope in (a).

Table 2.6

Element	Proton number	Nucleon number
W	6	12
X	6	13
Y	11	23
Z	12	24

Chain Concept



Quick Quiz

http://bit.ly/2N7Sa5R

SELF Reflection

1. What new knowledge have you learned in **Matter and Atomic Structure**?
2. Which is the most interesting subtopic in **Matter and Atomic Structure**? Why?
3. Give a few examples on the application of **Matter and Atomic Structure** in daily life.
4. Rate your performance in **Matter and Atomic Structure** 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 else would you like to know about **Matter and Atomic Structure**?

http://bit.ly/2Mkz7Xa

Achievement Test 2

1. Table 1 shows the melting point and boiling point of substances *A*, *B*, *C*, *D* and *E*.

Table 1

Substance	Melting point (°C)	Boiling point (°C)
A	–101.0	–35.0
B	–94.0	65.0
C	17.8	290.0
D	97.8	883.0
E	801.0	1413.0

(a) Classify substances *A*, *B*, *C*, *D* and *E* according to states of matter at room temperature.
(b) State the substance that will change from liquid to solid when placed in the freezer at temperature 2 °C.
(c) Describe the changes that take place on the particles of substance *B* with relation to energy and attraction force between particles when cooled from 80 °C to –2 °C.

2. A group of students carried out an experiment to determine the melting point of lauric acid, $C_{12}H_{24}O_2$. Figure 1 shows the heating curve obtained.
(a) Copy Figure 1 and label the melting point of lauric acid, $C_{12}H_{24}O_2$ on the diagram.
(b) Draw the arrangement of particles in lauric acid, $C_{12}H_{24}O_2$ between *R* and *S*.
(c) The melting point of lauric acid, $C_{12}H_{24}O_2$ is 43 °C. Suggest a suitable method of heating lauric acid, $C_{12}H_{24}O_2$.
(d) Draw a labelled diagram to show the set-up of apparatus for the method suggested in (c).

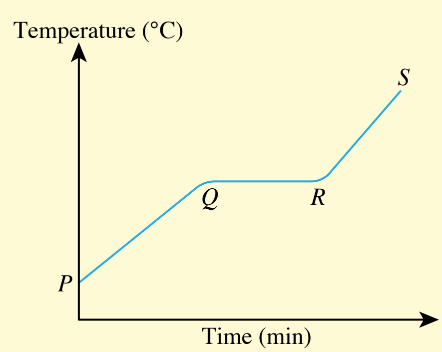


Figure 1

3. Chen Ling cleans her wound using alcohol as shown in Photograph 1. Chen Ling's skin feels cool when wiped with alcohol. Explain this situation.

Photograph 1

4. Figure 2 shows the nucleus charges of the atoms of elements *X*, *Y* and *Z*.

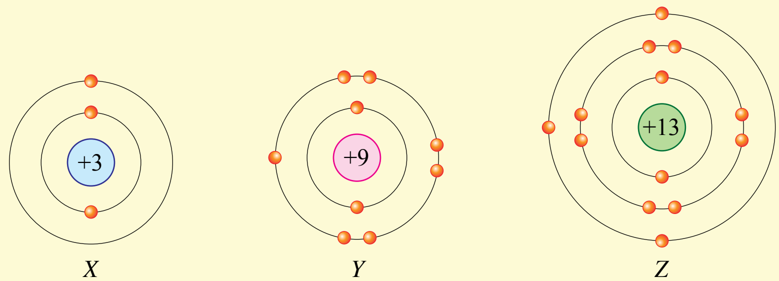


Figure 2

(a) State the subatomic particle that provides the charges in the atoms of the elements.
(b) State the other subatomic particle found in the nucleus of the atoms.
(c) Write the electron arrangement of the atoms for elements *X*, *Y* and *Z*.
(d) Atom *Z* contains 14 neutrons. Calculate the nucleon number of atom *Z*.

5. Figure 3 shows the information on boron. Boron has two isotopes, namely isotope ^{11}B and isotope ^{y}B. Based on the information given, calculate the nucleon number of isotope ^{y}B.

Relative atomic mass of boron = 10.81
80% ^{11}B
20% isotope Boron-Y

Figure 3

6. Figure 4 shows the standard representation of a platinum atom. A platinum ion contains 74 electrons and has a nucleon number of 195.
(a) What are the number of protons and neutrons in the platinum ion?
(b) What is the charge of the platinum ion?

$^{195}_{78}\text{Pt}$

Figure 4

7. Justify the use of iodine-131 in the treatment for hyperthyroidism.

Enrichment Corner

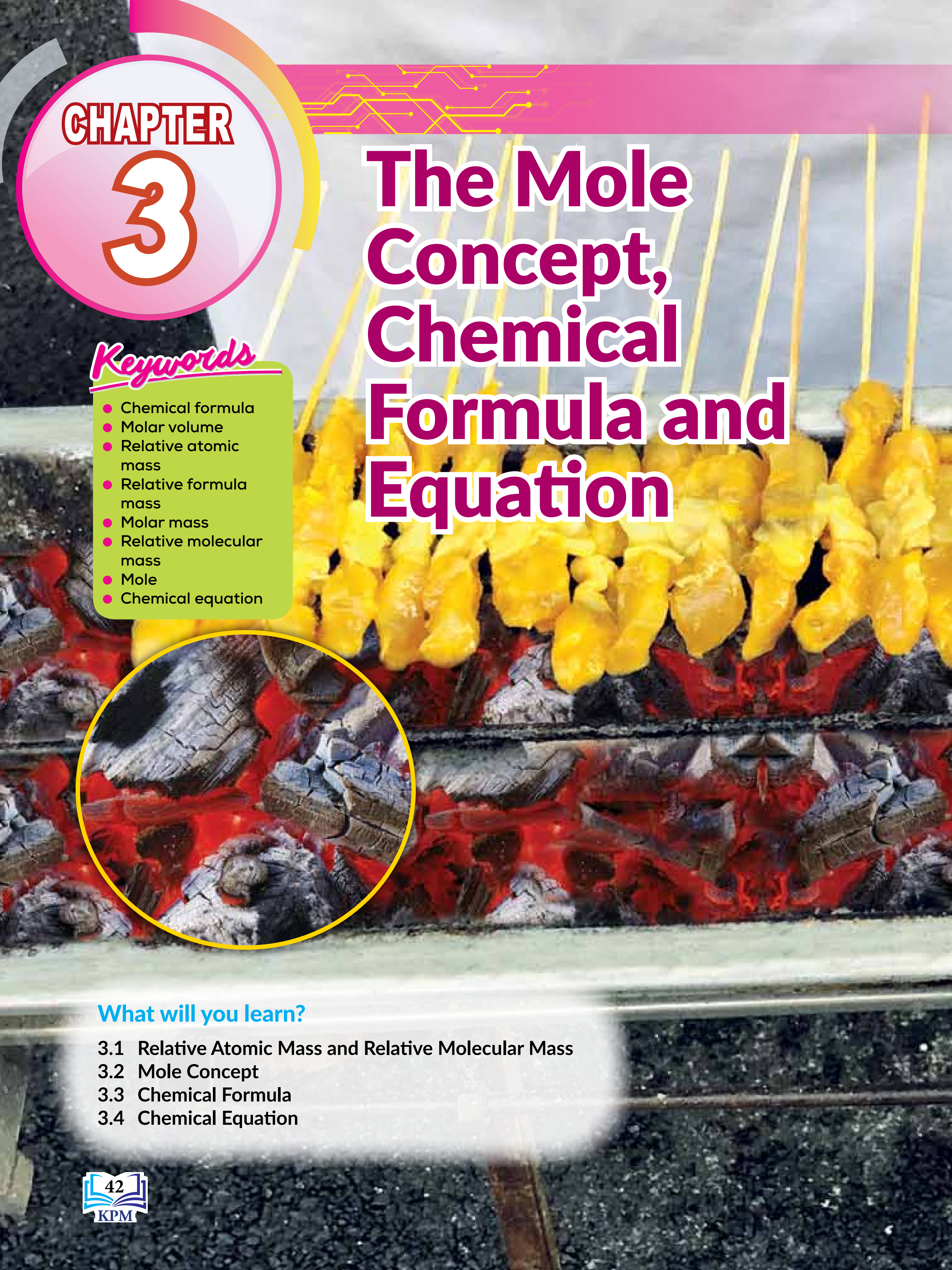
1. You lost your way while camping in a jungle. You felt thirsty but could not find a water source. In your bag, there were a transparent plastic bag and a string. Using the available things, describe how you could produce water through the condensation process. STEM

Check Answers

http://bit.ly/2odL87q

CHAPTER 3

The Mole Concept, Chemical Formula and Equation



Keywords

- Chemical formula
- Molar volume
- Relative atomic mass
- Relative formula mass
- Molar mass
- Relative molecular mass
- Mole
- Chemical equation

What will you learn?

3.1 Relative Atomic Mass and Relative Molecular Mass
3.2 Mole Concept
3.3 Chemical Formula
3.4 Chemical Equation

Bulletin

Satay is a favourite food among Malaysians. Satay is made from pieces of spiced meat skewered on coconut or bamboo skewers and grilled over burning charcoal.

Did you know that the burning of charcoal is a form of chemical reaction? This reaction can be represented by the following chemical equation.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

The symbol 'C' in the equation shows the chemical formula of carbon element in the charcoal. What is a chemical formula? What are the meanings of the other letters and numbers in the above equation?

How do you write the formula of a chemical substance?

What information is found in a chemical equation?

How do you measure the quantity of a chemical substance?

3.1 Relative Atomic Mass and Relative Molecular Mass

Photograph 3.1 Rice

Have you ever tried counting the number of rice grains in a sack of rice? Rice grains cannot be counted because their size is extremely small. Chemists face a similar problem too. As atoms are too small, it is difficult to determine their number and the mass of each atom. How do chemists overcome this problem?

Learning Standard

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

3.1.1 Conceptualise relative atomic mass and relative molecular mass based on the carbon-12 scale

3.1.2 Calculate relative molecular mass and relative formula mass

Relative Atomic Mass, RAM

Chemists use the concept of 'relative atomic mass' by comparing the mass of atom of an element to the mass of atom of another element that is chosen as the standard. Therefore, we do not need to know the actual mass of an atom.

Initially, the hydrogen atom was used as the standard atom because it is the lightest atom. Masses of atoms of all other elements were compared with the hydrogen atom. For example, one carbon atom is as heavy as 12 hydrogen atoms. Hence, the relative atomic mass of carbon is 12 while the relative atomic mass of hydrogen is assigned as one as shown in Figure 3.1.

However, in 1961, chemists across the world agreed to use **carbon-12 atom as the standard atom** after finding that the usage of hydrogen atom as the standard atom encountered various problems. The **relative atomic mass, RAM** of an element is defined as the average mass of an atom of the element compared to $\frac{1}{12}$ of the mass of one carbon-12 atom.

$$\text{Relative atomic mass of an element} = \frac{\text{Average mass of one atom of the element}}{\frac{1}{12} \times \text{Mass of one carbon-12 atom}}$$

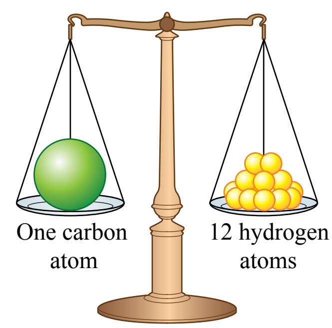
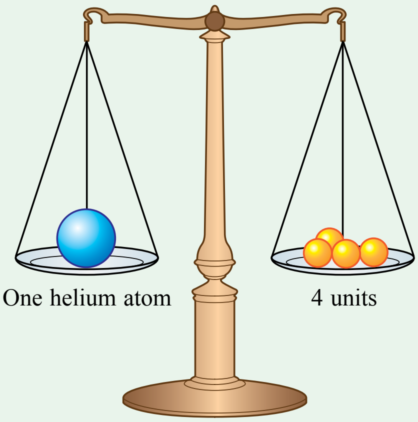


Figure 3.1
Mass of carbon atom compared to hydrogen atom

Brain Teaser

Determining the relative atomic mass of hydrogen atom as the standard atom has encountered various problems. Try to investigate what the problems are.



The relative atomic mass of helium is 4. This means the average mass of one atom of helium is 4 times the mass of $\frac{1}{12}$ of carbon-12 atom.

Figure 3.2 *Relative atomic mass of helium*

Brain Teaser

One magnesium atom is twice as heavy as one atom of carbon-12. What is the RAM of magnesium?

Literacy Tips

The relative atomic masses of elements are given in the Data Table of Elements on page 276. Since the relative atomic mass is a comparative value, it has no unit.

Activity 3.1

Discussing why carbon-12 is used as the standard to determine RAM

1. Carry out the activity in groups.
2. Gather information from printed reference materials or surf the Internet and discuss why carbon-12 is used as the standard to determine the relative atomic mass.
3. Present your group discussion results in a suitable thinking map.

Carbon-12 is chosen as the standard because it is a solid at room temperature and thus can be handled easily. Carbon-12 combines easily with other elements. Therefore, this element is found in most substances. Although carbon has three isotopes, carbon-12 is the major isotope with the abundance of 99%. This makes the relative atomic mass of carbon-12 exactly 12.0.

Relative Molecular Mass, RMM

Similarly, we can compare the molecular mass of a substance with the standard carbon-12 atom. The **relative molecular mass, RMM** of a molecule is the average mass of the molecule compared to $\frac{1}{12}$ of the mass of one carbon-12 atom.

$$\text{Relative molecular mass of a substance} = \frac{\text{Average mass of one molecule}}{\frac{1}{12} \times \text{Mass of one carbon-12 atom}}$$

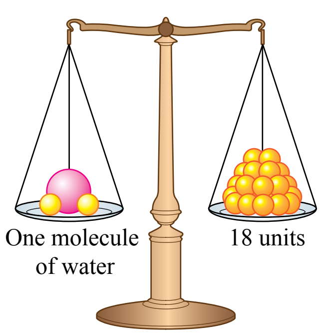


Figure 3.3 *Relative molecular mass of water*

Figure 3.3 shows water molecule that has a relative molecular mass of 18. This means the mass of a water molecule is 18 times the mass of $\frac{1}{12}$ of carbon-12 atom. Activity 3.2 can strengthen your understanding on the concepts of relative atomic mass and relative molecular mass based on the carbon-12 scale as an analogy.

Activity 3.2

Studying the concepts of relative atomic mass and relative molecular mass by analogy

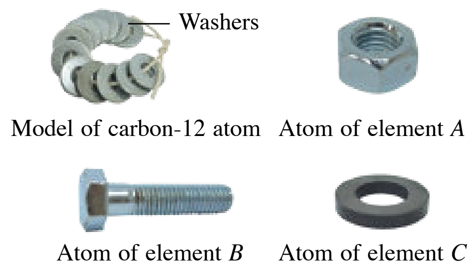
Materials: 36 washers, one 5 cm bolt, five nuts, one flat magnet and strings

Apparatus: Two-pan balance

A Relative atomic mass based on the carbon-12 scale

Procedure:

1. You are given three models of carbon-12 atom. Calculate the number of washers required to form each model of carbon-12 atom.
2. Separate the washers in each model and use them for the following steps.
3. Place an atom of element A on a two-pan balance as shown in Figure 3.4.
4. Place the washers on the other pan one by one until they are balanced.
5. Count and record the number of washers used in Table 3.1.
6. Repeat steps 3 to 5 using atom of element *B* and atom of element *C*.
7. Calculate the relative mass of each washer in the model by assuming that each atom of carbon-12 is given the accurate mass of 12 units. Then, deduce the relative atomic masses of elements *A*, *B* and *C*.



Photograph 3.2
A model of carbon-12 atom and three elements A, B and C

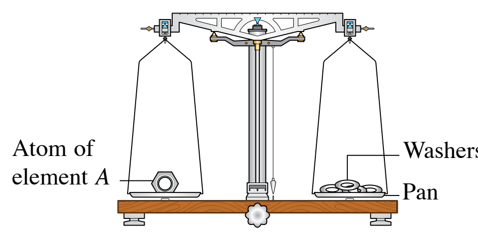


Figure 3.4 *Studying the relative mass by analogy*

Results:

Table 3.1

Atom of element	Number of washers used	Relative atomic mass
A		
B		
C		

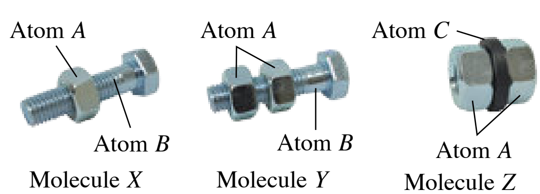
Discussion:

1. How many washers form a model of carbon-12 atom?
2. What is represented by $\frac{1}{12}$ of the mass of carbon-12 atom in this activity?
3. Define the relative atomic mass of an element based on the carbon-12 scale.

B Relative molecular mass based on the carbon-12 scale

Procedure:

1. Prepare models of molecules *X*, *Y* and *Z* as in Photograph 3.3.
2. Place molecule *X* on one of the pans of the balance.
3. Place washers on the other pan one by one until they are balanced.



Photograph 3.3 *Models of molecules X, Y and Z*

4. Count and record the number of washers used in Table 3.2.
5. Repeat steps 2 to 4 using molecule *Y* and *Z*.
6. Deduce the relative molecular masses of *X*, *Y* and *Z*.

Results:

Table 3.2

Molecule	Composition of molecule	Number of washers used	Relative molecular mass
X	1 atom *A* + 1 atom *B*		
Y			
Z			

Discussion:

1. Based on Activity B, give the definition of relative molecular mass based on the carbon-12 scale.
2. Calculate the relative atomic masses of all the elements that form molecules *X*, *Y* and *Z*.
3. Compare the answers from question 2 with the relative molecular masses you obtained in Activity B. What inference can you make about the relationship between the relative molecular mass and the relative atomic mass?
4. Molecule *W* is formed from one atom of element *A*, one atom of element *B* and one atom of element *C*. Predict the relative molecular mass of *W*.

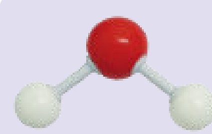
Prepare a complete report after carrying out this activity.

The relative molecular mass of a molecule can be calculated by **adding up the relative atomic masses of all the atoms** that form the molecule, as shown in Figure 3.5 and Example 1.

Literacy Tips

Relative molecular mass of a molecule is similar to the total of relative atomic mass of all atoms in the molecule.

RMM of oxygen gas, O_2
= 2(RAM of O)
= 2(16)
= 32



RMM of water, H_2O
= 2(RAM of H) + RAM of O
= 2(1) + 16
= 18

Figure 3.5 *Calculation of the relative molecular mass, RMM*

Example 1

Calculate the relative molecular mass of glucose, $C_6H_{12}O_6$.
[Relative atomic mass: H = 1, C = 12, O = 16]

Solution

RMM of glucose, $C_6H_{12}O_6$ = 6(RAM of C) + 12(RAM of H) + 6(RAM of O)
= 6(12) + 12(1) + 6(16)
= 72 + 12 + 96
= 180

Relative Formula Mass, RFM

The concept of relative mass is also used for ionic substances. The relative mass of an ionic substance is called the **relative formula mass, RFM**. The relative formula mass is calculated by summing up the relative atomic masses of all the atoms shown in the formula of the ionic substance. This is because the mass of an ion does not differ much from the mass of its atom that forms the ion. Check out Example 2.

Example 2

Calculate the relative formula mass of zinc chloride, $ZnCl_2$ and aluminium sulphate, $Al_2(SO_4)_3$.
[Relative atomic mass: O = 16, Al = 27, S = 32, Cl = 35.5, Zn = 65]

Solution

RFM of zinc chloride, $ZnCl_2$ = RAM of Zn + 2(RAM of Cl)
= 65 + 2(35.5)
= 65 + 71
= 136

RFM of aluminium sulphate, $Al_2(SO_4)_3$ = 2(RAM of Al) + 3[RAM of S + 4(RAM of O)]
= 2(27) + 3[32 + 4(16)]
= 54 + 3[96]
= 342

Activity 3.3

Calculating the relative molecular mass and relative formula mass CT

Determine the relative molecular mass or the relative formula mass of each of the following substances. Refer to the Data Table of Elements on page 276 to obtain the relative atomic mass.

1. H_2
2. O_3
3. CO
4. NH_3
5. N_2O_4
6. C_4H_{10}
7. $CuCl_2$
8. $Zn(OH)_2$
9. $K_2Cr_2O_7$
10. $Fe(NO_3)_3$

Activity 3.4

Tic-tac-toe with relative masses CT

Materials: 10 pieces of formula cards and a tic-tac-toe card

1. Carry out the activity in pairs.
2. Each pair is given a tic-tac-toe card and 10 pieces of formula cards. Each card has the formula of a specific substance and its relative mass.
3. Shuffle the cards and put them at the centre of the table with the written side of the cards facing down.
4. The first player will take a piece of card. Without showing it to the second player, the first player will read the formula of the substance on the card to the second player.

Material for Activity 3.4
http://bit.ly/2PeH6a5

5. Referring to the Data Table of Elements on page 276, the second player will calculate the relative mass of the substance and show the answer to the first player. If the answer is correct, the second player is allowed to mark the tic-tac-toe card. If the answer is wrong, the second player will lose the chance to mark the tic-tac-toe card.
6. Repeat steps 3 to 4 with the second player taking the card while the first player calculates the relative mass of the substance.
7. Continue to take turns until one of the players succeeds in marking a complete line vertically, horizontally or diagonally or until all spaces are filled up.

Test Yourself 3.1

1. Define relative atomic mass based on the carbon-12 scale.
2. Refer to the Data Table of Elements on page 276 to get the relative atomic masses.
   (a) How many atoms of lithium are required to equalise the mass of one atom of krypton?
   (b) How many atoms of helium are required to equalise the mass of a silver atom?
3. Calculate the relative molecular mass or the relative formula mass of each of the following substances:
   (a) Methane, CH_4
   (b) Magnesium nitrate, $Mg(NO_3)_2$
   (c) Sulphuric acid, H_2SO_4
   (d) Formic acid, HCOOH

3.2 Mole Concept

Learning Standard

At the end of the lesson, pupils are able to:
3.2.1 Define mole
3.2.2 Interrelate the Avogadro constant, N_A, the number of particles and the number of moles
3.2.3 State the meaning of molar mass
3.2.4 Interrelate the molar mass, mass and the number of moles
3.2.5 State the meaning of molar volume
3.2.6 Interrelate the molar volume, volume of gas and the number of moles
3.2.7 Solve numerical problems involving the number of particles, number of moles, mass of the substances and volume of gases

In our daily lives, we use units such as pairs and dozens to represent the quantity or number of objects. Photograph 3.4, shows the objects that can be quantified using the units pair and dozen. The unit pair represents 2 objects while the unit dozen represents 12 objects.

Photograph 3.4 *Uses of units in daily life*

In the field of chemistry, we use the unit **mole** to measure the amount of substance. What is the amount of substance represented by the unit mole?

According to the International Union of Pure and Applied Chemistry (IUPAC), the new definition of mole is as follows:

> The **mole**, with the symbol mol, is the SI unit of amount of substance. One mole of substance contains $6.02214076 \times 10^{23}$ elementary entities of the substance. This number is a fixed value known as the Avogadro constant, N_A that is expressed in mol^{-1}. The Avogadro constant, N_A is also called the Avogadro number.

The Avogadro constant, N_A is defined as the number of particles contained in one mole of substance, that is 6.02×10^{23} mol^{-1}. In other words, **1 mol of a substance contains 6.02×10^{23} particles** that form the substance. The type of particles depends on the type of substance, namely atomic substance, molecular substance or ionic substance as shown in Figure 3.6.

MATHEMATICS INTEGRATION

For calculation at this level, Avogadro constant, N_A is taken as 6.02×10^{23} mol^{-1}, to three significant figures.

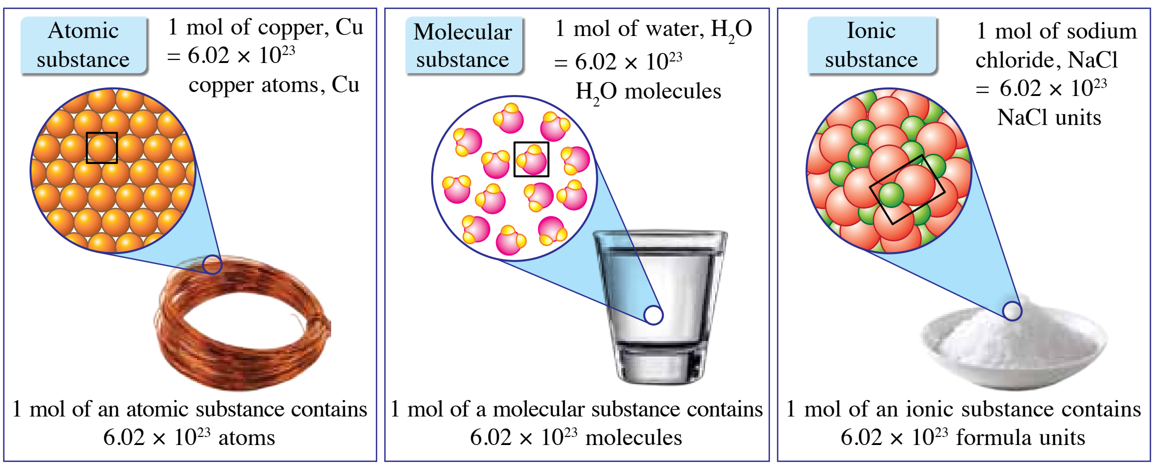


***Figure 3.6** Numbers of particles in 1 mol of substance*

Number of Moles and Number of Particles

The way to use mole is similar to the way of using the unit dozen. For example, 2 dozens of pencils represent 2 × 12 or 24 pencils. Similarly, the Avogadro constant, N_A is used as the conversion factor between the number of moles and the number of particles.

$$\text{Number of moles, } n = \frac{\text{Number of particles}}{N_A}$$

Diagrammatically, the relationship between the number of mole and the number of particles by using Avogadro constant as the conversion factor is shown below:

$$\text{Number of moles} \underset{\div N_A}{\overset{\times N_A}{\rightleftarrows}} \text{Number of particles}$$

HISTORY INTEGRATION

The Avogadro constant is named after a famous Italian scientist, Amedeo Avogadro (1776 – 1856).

The example of conversion between the number of mole and the number of particles by using Avogadro constant, N_A are shown in Examples 3, 4 and 5.

[Note: Assume Avogadro constant, N_A: 6.02×10^{23} mol^{-1}]

Example 3

How many atoms are there in 0.2 mol of magnesium, Mg?

Solution

Number of magnesium atoms, Mg = 0.2 mol × 6.02×10^{23} mol^{-1}
= 1.204×10^{23} atoms

Use the equation:
Number of particles
= Number of moles × N_A

Example 4

A sample of zinc chloride, $ZnCl_2$ contains 3.01×10^{24} $ZnCl_2$ units. Calculate the number of moles of zinc chloride, $ZnCl_2$ found in the sample.

Solution

Number of moles of zinc chloride, $ZnCl_2$ $= \dfrac{3.01 \times 10^{24}}{6.02 \times 10^{23}\ \text{mol}^{-1}}$
= 5 mol

Use the equation:
Number of moles
$= \dfrac{\text{Number of particles}}{N_A}$

Example 5

A gas jar is filled with 2 mol of oxygen gas, O_2.
(a) How many molecules of oxygen are there in the gas jar?
(b) How many atoms of oxygen are there in the gas jar?

Solution

(a) Number of oxygen molecules, O_2 = 2 mol × 6.02×10^{23} mol^{-1}
= 1.204×10^{24} molecules

Use the equation:
Number of particles
= Number of moles × N_A

(b) Each oxygen molecule, O_2 has 2 oxygen atoms, O.
Hence, the number of oxygen atoms, O = Number of O_2 molecules × 2
= $1.204 \times 10^{24} \times 2$
= 2.408×10^{24} atoms

Activity 3.5

Calculating the number of moles and number of particles CT

[Avogadro constant, N_A: 6.02×10^{23} mol^{-1}]

1. Calculate the number of atoms found in
(a) 0.1 mol of carbon, C
(b) 3.5 mol of neon gas, Ne
2. Calculate the number of molecules found in
(a) 1.2 mol of hydrogen gas, H_2
(b) 0.8 mol of ammonia, NH_3
3. Calculate the number of formula units found in
(a) 3 mol of sodium chloride, NaCl
(b) 0.25 mol of potassium nitrate, KNO_3

4. Calculate the number of moles of each of the following substances:
   (a) 6.02×10^{24} lead atoms, Pb
   (b) 3.02×10^{23} magnesium oxide units, MgO
   (c) 9.03×10^{22} bromine molecules, Br_2
   (d) 3.612×10^{24} carbon dioxide molecules, CO_2
5. A reagent bottle contains 1.806×10^{25} units of copper(II) oxide, CuO.
   (a) How many moles of copper(II) oxide, CuO are found in the bottle?
   (b) Calculate the number of ions found in that bottle.
6. A sample contains 0.2 mol of ethene gas, C_2H_4.
   (a) How many ethene molecules, C_2H_4 are found in the sample?
   (b) How many hydrogen atoms, H are found in the sample?
   (c) Calculate the total number of atoms found in the sample.

Number of Moles and Mass of Substances

The number of moles of a substance is impossible to be determined by counting the number of particles in the substance. Therefore, to get the number of moles, the mass of a substance must be measured and we also need to know its molar mass. What is molar mass?

Molar mass is the mass of one mole of substance.

The unit for molar mass is gram/mol or g mol^{-1}. Chemists found that the **value of molar mass of a substance is the same as its relative mass**. For example, the relative atomic mass of carbon, C is 12. Thus, the molar mass of carbon is 12 g mol^{-1} because 12 g of carbon, C contains 1 mol of carbon, C, that is 6.02×10^{23} atoms of carbon, C. Look at Figure 3.7 to strengthen your understanding.

- Copper consists of copper atoms.
- RAM of copper = 64
- Molar mass of copper = 64 g mol^{-1}

- Water consists of H_2O molecules.
- RMM of water = 2(1) + 16 = 18
- Molar mass of water = 18 g mol^{-1}

- Sodium chloride consists of NaCl units.
- RFM of sodium chloride = 23 + 35.5 = 58.5
- Molar mass of sodium chloride = 58.5 g mol^{-1}

***Figure 3.7** Determining the molar mass of substances*

The mass of any fraction of a mole of a substance can be weighed. For example, 12 g of carbon for 1 mol of carbon, 6 g of carbon powder for 0.5 mol of carbon and so on. The molar mass is used as the conversion factor between the number of moles and the mass of substance. The formula and the relationship between the number of moles and the mass of substance by using molar mass as the conversion factor is as follows:

$$\text{Number of moles, } n = \frac{\text{Mass (g)}}{\text{Molar mass (g mol}^{-1}\text{)}}$$

$$\text{Number of moles} \underset{\div \text{ Molar mass}}{\overset{\times \text{ Molar mass}}{\rightleftarrows}} \text{Mass (g)}$$

PHYSICS INTEGRATION

Why is g used as the unit for mass in the formula?
Mass
= Number of moles × Molar mass
= $\cancel{mol} \times \frac{g}{\cancel{mol}}$
= g

Examples of the conversion between the number of moles and the mass of the particles using molar mass are shown in Examples 6, 7 and 8.

Example 6

What is the mass of 1.5 mol of aluminium, Al?
[Relative atomic mass: Al = 27]

Solution

Molar mass of aluminium, Al = 27 g mol^{-1} ← Value of the molar mass of an atomic substance is equal to RAM.

Mass of aluminium, Al = 1.5 mol × 27 g mol^{-1} ← Use the formula: Mass = Number of moles × Molar mass

= 40.5 g

Example 7

How many moles of molecules are found in 32 g of sulphur dioxide gas, SO_2?
[Relative atomic mass: O = 16, S = 32]

Solution

Relative molecular mass of sulphur dioxide, SO_2 = 32 + 2(16)
= 64

Thus, the molar mass of sulphur dioxide, SO_2 = 64 g mol^{-1} ← Value of the molar mass of a molecular substance is equal to RMM.

Number of moles of sulphur dioxide molecules, SO_2 = $\frac{32 \text{ g}}{64 \text{ g mol}^{-1}}$ ← Use the formula: Number of moles = $\frac{\text{Mass}}{\text{Molar mass}}$

= 0.5 mol

Example 8

How many moles are found in 4.7 g of potassium oxide, K_2O?
[Relative atomic mass: O = 16, K = 39]

Solution

Relative formula mass of potassium oxide, K_2O = 2(39) + 16
= 94

Thus, the molar mass of potassium oxide, K_2O = 94 g mol^{-1} ← Value of the molar mass of an ionic substance is equal to RFM.

Number of moles of potassium oxide, K_2O = $\frac{4.7 \text{ g}}{94 \text{ g mol}^{-1}}$ ← Use the formula: Number of moles = $\frac{\text{Mass}}{\text{Molar mass}}$

= 0.05 mol

Activity 3.6

Calculating the number of moles and mass

CT

[Relative atomic mass: H = 1, C = 12, N = 14, O = 16, Mg = 24, S = 32, Fe = 56;
Avogadro constant, N_A: 6.02 × 10^{23} mol^{-1}]

1. Calculate the mass of each of the following substances:
   (a) 0.4 mol of iron fillings, Fe
   (b) 2.2 mol of carbon monoxide, CO
2. Calculate the number of moles in each of the following substances:
   (a) 49 g of sulphuric acid, H_2SO_4
   (b) 8.88 g of magnesium nitrate, $Mg(NO_3)_2$

3. An experiment requires 0.05 mol of ammonium sulphate crystals, $(NH_4)_2SO_4$. What is the mass of ammonium sulphate, $(NH_4)_2SO_4$ that should be used?
4. 0.2 mol of substance *Y* has the mass of 11 g. What is the molar mass of substance *Y*?

Number of Moles and Volume of Gases

Measuring the volume of a gas is easier compared to measuring its mass because gas is very light. How are the number of moles and the volume of a gas related?

From studies, chemists found that the volume of 1 mol of any gas has similar value under the same conditions of temperature and pressure. Thus, the concept of molar volume was explained.

Molar volume is the volume occupied by 1 mol of a gas. The molar volume of any gas depends on the condition, that is 22.4 $dm^3\ mol^{-1}$ at STP or 24 $dm^3\ mol^{-1}$ at room conditions.

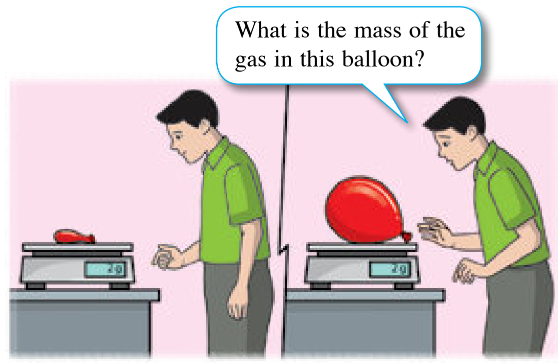


Figure 3.8 *Weighing the mass of a gas*

This means at STP,
- 1 mol of neon gas, Ne occupies 22.4 dm^3
- 1 mol of nitrogen dioxide gas, NO_2 occupies 22.4 dm^3

While at room conditions,
- 1 mol of neon gas, Ne occupies 24 dm^3
- 1 mol of nitrogen dioxide gas, NO_2 occupies 24 dm^3

How do we use the molar volume to measure the number of moles of a gas? The formula and relationship between the number of moles and the volume of gas by using molar volume as a conversion factor are as follow:

$$\text{Number of moles, } n = \frac{\text{Volume of gas}}{\text{Molar volume}}$$

$$\text{Number of moles} \underset{\div \text{ Molar volume}}{\overset{\times \text{ Molar volume}}{\rightleftarrows}} \text{Volume of gas}$$

Chemistry Lens

- STP is the abbreviation for standard temperature and pressure, the condition where temperature is at 0 °C and pressure of 1 atm.
- Room conditions refer to the condition where temperature is at 25 °C and pressure of 1 atm.

The conversion between the number of moles and the volume of gas using molar volume are shown in Examples 9, 10 and 11.

Example 9

Calculate the volume of 2.2 mol of hydrogen gas, H_2 in dm^3 at STP.
[Molar volume = 22.4 dm^3 mol^{-1} at STP]

Solution

Volume of hydrogen gas, H_2
= Number of moles × Molar volume at STP
= 2.2 mol × 22.4 dm^3 mol^{-1}
= 49.28 dm^3

PHYSICS INTEGRATION

Volume of gas
= Number of moles × Molar volume
$= \cancel{mol} \times \frac{dm^3}{\cancel{mol}}$
$= dm^3$

Example 10

What is the volume of 0.01 mol of ammonia gas, NH_3 in cm^3 at room conditions?
[Molar volume = 24 dm^3 mol^{-1} at room conditions]

Solution

Volume of ammonia gas, NH_3 = Number of moles × Molar volume at room conditions
= 0.01 mol × 24 dm^3 mol^{-1}
= 0.24 dm^3
= 0.24 × 1 000 cm^3 ← Convert unit of volume: 1 dm^3 = 1 000 cm^3
= 240 cm^3

Example 11

How many moles of oxygen gas, O_2 has the volume of 600 cm^3 at room conditions?
[Molar volume = 24 dm^3 mol^{-1} at room conditions]

Solution

Volume of oxygen gas, O_2 = 600 cm^3
$= \frac{600}{1\ 000}\ dm^3$ ← Convert unit of volume: 1 dm^3 = 1 000 cm^3
= 0.6 dm^3

Number of moles of oxygen gas, $O_2 = \frac{\text{Volume of gas}}{\text{Molar volume at room conditions}}$
$= \frac{0.6\ dm^3}{24\ dm^3\ mol^{-1}}$
= 0.025 mol

Alternative solution
http://bit.ly/2MyrUmi

Activity 3.7

CT

Calculating the number of moles and volume of gases

[Molar volume of gas = 22.4 dm^3 mol^{-1} at STP or 24 dm^3 mol^{-1} at room conditions]

1. Calculate the volume of 0.6 mol of chlorine gas, Cl_2 at STP and room conditions.
2. Calculate the number of moles of each of the following gases:
   (a) 48 cm^3 of argon gas, Ar at room conditions
   (b) 39.2 dm^3 of carbon dioxide gas, CO_2 at STP
3. A sample contains 0.2 mol of methane gas, CH_4 and 0.3 mol of ethane gas, C_2H_6. What is the volume of the sample at room conditions?

Activity 3.8

Building a chart showing the relationship between the number of particles, number of moles, mass of substances and volume of gases at STP and room conditions

1. Carry out the activity in groups.
2. Discuss among the group members and build a chart on a flip chart paper that shows the relationship between the number of moles, number of particles, mass of substances and volume of gases.
3. Each member needs to copy the chart onto a small, pocket-sized card to produce a memory card.
4. Use this memory card to solve all the following numerical problems.

The relationship between the number of moles, number of particles, mass of substances and volume of gases is shown in Figure 3.9.

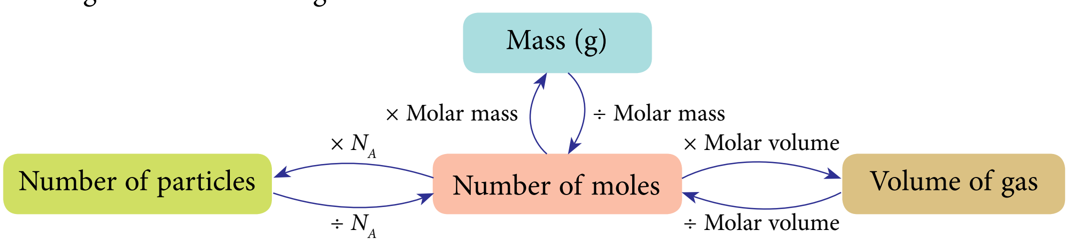


***Figure 3.9** Relationship between the number of moles, number of particles, mass and volume of gases*

Examples 12 and 13 show the function of the number of moles as a medium to convert from one quantity to another.

Example 12

What is the volume of 26.4 g of carbon dioxide, CO_2 at room conditions?
[Relative atomic mass: C = 12, O = 16; Molar volume of gas = 24 dm^3 mol^{-1} at room conditions]

Solution

Question analysis and solution plan

Information from the question: Mass = 26.4 g → Volume of gas at room conditions?

Solution plan: $\underbrace{\text{Mass} \xrightarrow{\div \text{ Molar mass}} \text{Number of moles}}_{\text{Step 1}}$ $\underbrace{\xrightarrow{\times \text{ Molar volume}} \text{Volume of gas}}_{\text{Step 2}}$

RMM of carbon dioxide, CO_2 = 12 + 2(16)
= 44

Thus, the molar mass of carbon dioxide, CO_2 = 44 g mol^{-1} ← Before carrying out step 1, the molar mass must first be determined.

Number of moles of carbon dioxide, CO_2 $= \dfrac{\text{Mass}}{\text{Molar mass}}$ ← Step 1: Mass → Number of moles

$= \dfrac{26.4\text{ g}}{44\text{ g mol}^{-1}}$

= 0.6 mol

Volume of carbon dioxide, CO_2 = Number of moles × Molar volume
= $0.6 \text{ mol} \times 24 \text{ dm}^3 \text{ mol}^{-1}$
= 14.4 dm^3

Step 2:
Number of moles → Volume

Hence, 26.4 g of carbon dioxide gas, CO_2 occupies a volume of 14.4 dm^3 at room conditions.

Example 13

How many molecules are there in 672 cm^3 of hydrogen gas, H_2 at STP?
[Avogadro constant, N_A: $6.02 \times 10^{23} \text{ mol}^{-1}$; Molar volume = $22.4 \text{ dm}^3 \text{ mol}^{-1}$ at STP]

Solution

Question analysis and solution plan

Information from the question: Volume of gas = 672 cm^3 → Number of molecules?

Solution plan:

$$\underbrace{\text{Volume of gas} \xrightarrow{\div \text{ Molar volume}} \text{Number of moles}}_{\text{Step 1}} \underbrace{\xrightarrow{\times N_A} \text{Number of molecules}}_{\text{Step 2}}$$

Number of moles of hydrogen gas, H_2 = $\dfrac{\text{Volume of gas}}{\text{Molar volume}}$

$= \dfrac{672 \text{ cm}^3}{22.4 \times 1\,000 \text{ cm}^3 \text{ mol}^{-1}}$

$= 0.03 \text{ mol}$

Step 1:
Volume → Number of moles

Number of hydrogen molecules, H_2 = Number of moles × N_A
= $0.03 \text{ mol} \times 6.02 \times 10^{23} \text{ mol}^{-1}$
= 1.806×10^{22} molecules

Step 2:
Number of moles →
Number of molecules

Hence, 672 cm^3 of hydrogen gas, H_2 at STP consists of 1.806×10^{22} molecules.

Further example
http://bit.ly/2MBDA7Z

Nandini, you need to determine the number of moles of a substance before determining the number of particles, mass or volume of a gas that is required.

Yes, teacher. I always refer to my memory card from Activity 3.8 to solve numerical problems until I can really understand and remember all the relationships.

Activity 3.9

CT

Solving problems involving the number of particles, number of moles, mass of substances and volume of gases at STP or room conditions

1. Carry out this activity in groups.
2. Read and answer the following questions.
   [Relative atomic mass: H = 1, He = 4, C = 12, N = 14, O = 16, Al = 27, S = 32; Avogadro constant, N_A: 6.02×10^{23} mol^{-1}; Molar volume = 22.4 dm^3 mol^{-1} at STP or 24 dm^3 mol^{-1} at room conditions]
   (a) Calculate the number of atoms found in the following substances:
      (i) 6.75 g of aluminium, Al
      (ii) 5.1 g of ammonia gas, NH_3
   (b) Calculate the volume of the following gases at STP.
      (i) 5.6 g of nitrogen gas, N_2
      (ii) 1.204×10^{22} helium atoms, He
   (c) What is the mass of oxygen gas, O_2 that has the same number of molecules as in 8 g of sulphur trioxide gas, SO_3?
   (d) A sample of methane gas, CH_4 occupies a volume of 9.84 dm^3 at room conditions. How many molecules are found in that sample? Calculate the mass of the sample.
   (e) A reaction releases 120 cm^3 of carbon dioxide gas, CO_2 per minute at room conditions. Calculate the total mass of carbon dioxide, CO_2 released after 10 minutes.
3. Write the calculation steps for questions (a) to (e) clearly and systematically on a piece of flip chart paper.
4. Present your group solution in front of the class.

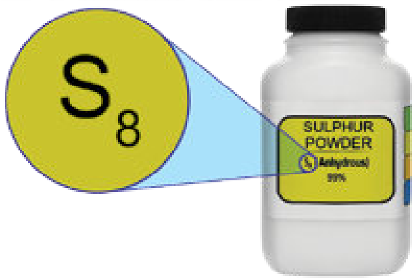
Test Yourself 3.2

[Relative atomic mass: H = 1, C = 12, N = 14, O = 16, Na = 23, Cl = 35.5, K = 39, Fe = 56, Pb = 207; Avogadro constant, N_A: 6.02×10^{23} mol^{-1}; Molar volume = 22.4 dm^3 mol^{-1} at STP or 24 dm^3 mol^{-1} at room conditions]

1. Calculate the molar mass of each of the following substances:
   (a) Lead metal, Pb
   (b) Chloroform, $CHCl_3$
   (c) Sodium nitrate, $NaNO_3$
   (d) Iron(III) oxide, Fe_2O_3
2. Calculate the number of molecules found in 8 mol of water.
3. What is the mass of 0.5 mol of ammonia, NH_3?
4. How many moles of K_2O units are found in 14.1 g of potassium oxide, K_2O?
5. Calculate the volume of 16 g of oxygen gas, O_2 at STP.
6. The mass of 4 dm^3 of a gas is 12 g at room conditions. Calculate the molar mass of the gas.
7. 4 g of hydrogen gas, H_2 has greater number of molecules than 14 g of nitrogen gas, N_2

   Do you agree with the above statement? Give your reason.

3.3 Chemical Formula



***Photograph 3.5** A chemical formula represents a chemical substance*

Chemical formula is a representation of a chemical substance using alphabets to represent the atoms and subscript numbers to show the number of each type of atoms found in the elementary entities of the substance.

Examples of chemical formulae of elements and compounds are shown in Figure 3.10.

Elements

Substance: Magnesium Chemical formula: Mg	The chemical formula shows that magnesium consists of magnesium atoms only.
Substance: Oxygen gas Chemical formula: O_2	The chemical formula shows that oxygen gas molecule consists of two oxygen atoms.

Compounds

Substance: Water Chemical formula: H_2O	The subscript number shows that two atoms of hydrogen combine with one atom of oxygen.
Substance: Aluminium oxide Chemical formula: Al_2O_3	The subscript number shows that two atoms of aluminium combine with three atoms of oxygen.

***Figure 3.10** Chemical formulae of elements and compounds*

Learning Standard

At the end of the lesson, pupils are able to:
- 3.3.1 State the meaning of chemical formula, empirical formula and molecular formula
- 3.3.2 Determine the empirical formula of magnesium oxide, MgO through an activity
- 3.3.3 Determine the empirical formula of copper(II) oxide, CuO through an activity
- 3.3.4 Solve numerical problems involving empirical formula and molecular formula
- 3.3.5 Construct chemical formulae of compounds

Chemistry Lens

Elements are substances that consist of only one type of atoms. Elements like metals and inert gases are atomic substances while elements such as oxygen gas are molecular substances.

Literacy Tips

The subscript number 1 need not be written in a chemical formula.

Empirical Formula and Molecular Formula

In general, compounds can be represented by two types of chemical formulae, namely the empirical formula and the molecular formula. What are the empirical formula and the molecular formula?

Activity 3.10

Gathering and interpreting information involving chemical formulae, empirical formulae and molecular formulae

CT

1. Carry out this activity in groups.
2. Gather information on chemical formulae, empirical formulae and molecular formulae by referring to reading materials or surfing the Internet.
3. Based on the information gathered, construct a suitable thinking map to show the difference between the empirical formula and the molecular formula using a suitable computer software.
4. List out the examples of chemical formulae in a table and use this list throughout your lesson.

The **empirical formula** is the chemical formula that shows the **simplest ratio** of the number of atoms of each element in a compound. The **molecular formula**, on the other hand, is the chemical formula that shows the **actual number** of atoms of each element found in a molecule of a compound. Figure 3.11 shows the difference between the empirical formula and the molecular formula.

Molecular formula of glucose: $C_6H_{12}O_6$

The formula shows one molecule of glucose consists of 6 carbon atoms, 12 hydrogen atoms and 6 oxygen atoms.

Ratio of number of atoms

C atom	:	H atom	:	O atom
= 6	:	12	:	6
= 1	:	2	:	1

Empirical formula of glucose: CH_2O

The formula shows that the simplest ratio of the number of carbon atoms to hydrogen atoms and oxygen atoms is 1:2:1.

Figure 3.11 *Molecular formula and empirical formula of glucose*

Table 3.3 *Molecular formulae and empirical formulae of several substances*

Substance	Molecular formula	Empirical formula
Water	H_2O	H_2O
Ammonia	NH_3	NH_3
Hydrazine	N_2H_4	NH_2
Propene	C_3H_6	CH_2
Benzene	C_6H_6	CH

Brain Teaser

Some compounds have the same empirical formula and molecular formula. However, there are some other compounds that have different empirical formula and molecular formula. Try to think why it is so.

Determination of an Empirical Formula

The empirical formula is obtained by the analysis of percentage composition of a substance. This is done by determining the **simplest whole number ratio of atoms** of each element that combines through an experiment. Example 14 is used as a guide to solve Activity 3.11.

Brain Teaser

Hexane is an organic solvent that is widely used in the food industry. The molecular formula of hexane is C_6H_{14}. What is its empirical formula?

Example 14

1.35 g of aluminium combines with 1.2 g of oxygen to form aluminium oxide. What is the empirical formula of aluminium oxide?
[Relative atomic mass: O = 16; Al = 27]

Solution

Element	Al	O	
Mass (g)	1.35	1.2	Determine the mass of each element.
Number of moles of atoms	$\frac{1.35}{27} = 0.05$	$\frac{1.2}{16} = 0.075$	$n = \frac{\text{Mass}}{\text{Molar mass}}$
Mole ratio	$\frac{0.05}{0.05} = 1$	$\frac{0.075}{0.05} = 1.5$	Divide each number with the smallest number, that is 0.05.
Simplest mole ratio of atom	2	3	Multiply each answer by 2 to get the simplest whole number ratio.

2 mol of aluminium atoms combine with 3 mol of oxygen atoms.
Thus, the empirical formula of aluminium oxide is Al_2O_3.

Activity 3.11

Determining the empirical formulae

CT

[Relative atomic mass: H = 1, C = 12, O = 16, Cl = 35.5, K = 39, Br = 80, Sn = 119, I = 127]

1. A sample of potassium bromide contains 6.24 g of potassium and 12.8 g of bromine. What is the empirical formula of potassium bromide?
2. A sample of 26.1 g of tin chloride contains 11.9 g of tin. State the empirical formula of the tin chloride.
3. 0.03 mol of element *Y* combines with 7.62 g of iodine to produce an iodide salt. State the empirical formula of the iodide salt.
4. A chemist analysed the compound that gives smell to fully ripe bananas. He found that the compound contains 64.62% carbon, 10.77% hydrogen and 24.61% oxygen. What is the empirical formula of that compound?

Photograph 3.6 *Bananas*

Using the calculation skills learned, the determination of the empirical formulae of magnesium oxide and copper(II) oxide can be carried out through Activity 3.12 and 3.13.

Activity 3.12

Aim: To determine the empirical formula of magnesium oxide.

Materials: 10 cm magnesium ribbon and sand paper

Apparatus: Crucible with lid, tongs, Bunsen burner, tripod stand, pipeclay triangle and electronic balance

Procedure:

1. Weigh and record the mass of a crucible together with its lid.
2. Rub 10 cm magnesium ribbon with a sand paper until shiny. Coil the magnesium ribbon and put it in the crucible.
3. Weigh and record the mass of the crucible together with its lid and the coil of magnesium ribbon.
4. Set up the apparatus as shown in Figure 3.12.
5. First, heat the crucible without its lid.
6. When magnesium ribbon starts to burn, close the crucible with its lid.
7. Using a pair of tongs, lift the lid slightly from time to time and quickly place it back.
8. When the burning of magnesium ribbon is complete, take off the lid and heat the crucible with high temperature for 1 to 2 minutes.
9. Put back the lid of the crucible and allow it to cool to room temperature.
10. Weigh the mass of crucible together with its lid and its contents again.
11. Repeat the heating, cooling and weighing process until a constant mass is obtained.
12. Record the constant mass in Table 3.4.

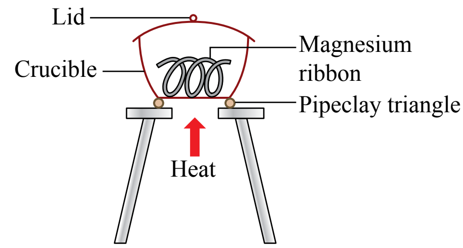


Figure 3.12

Safety Precaution

Prevent white fumes in the crucible from escaping when carrying out Step 7.

Results:

Table 3.4

Description	Mass (g)
Crucible + lid	
Crucible + lid + magnesium ribbon	
Crucible + lid + magnesium oxide	

Interpreting data:

1. Based on your results, determine the masses of magnesium and oxygen that combine.
2. Determine the empirical formula of magnesium oxide.

Discussion:

1. What is the purpose of rubbing the magnesium ribbon with a sand paper before using it?
2. Name the white fumes that are produced.
3. Why are steps 6, 7 and 11 performed?
4. What will happen if the white fumes are released into the environment?

Prepare a complete report after carrying out this activity.

Activity 3.13

Aim: To determine the empirical formula of copper(II) oxide.

Materials: Water, copper(II) oxide powder, zinc granules, 1.0 mol dm^{-3} hydrochloric acid, wooden splinter and cotton buds

Apparatus: Boiling tube, rubber stoppers, rubber tube, 12 cm glass tube, 10 cm glass tube, spirit lamp, retort stand with clamp, wooden block, electronic balance and spatula

Procedure:

1. Weigh the mass of 12 cm glass tube using an electronic balance and record its mass.
2. Put some copper(II) oxide powder into the glass tube. Use the wooden splinter to move copper(II) oxide powder to the middle of the glass tube. Weigh the mass of the glass tube together with its contents and record the mass.
3. Fill $\frac{2}{3}$ of the boiling tube with water.
4. Close the boiling tube with a rubber stopper that has a 12 cm glass tube. Clamp the boiling tube onto the retort stand.
5. Insert a few zinc granules into another boiling tube. Add 1.0 mol dm^{-3} hydrochloric acid into the boiling tube until it is $\frac{1}{3}$ full.
6. Close the boiling tube with a rubber stopper that has a 10 cm glass tube. Clamp the boiling tube onto the other retort stand.
7. Connect the glass tube that contains copper(II) oxide powder as shown in Figure 3.13.

> **Guideline to determine the empirical formula of copper(II) oxide**
> *http://bit.ly/2VLQHq6*

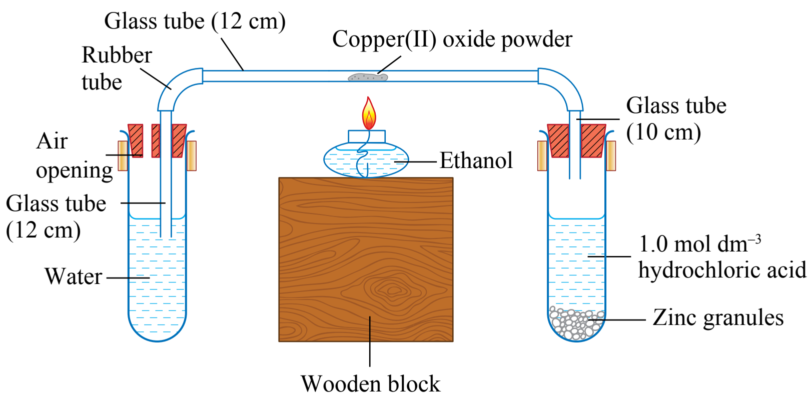


Figure 3.13

8. Let the hydrogen gas flow for 10 seconds by allowing the air bubbles to be released in the water before starting the heating process.
9. Heat copper(II) oxide using a spirit lamp with a continuous flow of hydrogen gas through the glass tube.
10. Stop the heating when the black colour of copper(II) oxide turns brown completely.
11. Keep a continuous flow of hydrogen gas until the glass tube is cooled back to room temperature.

> **Safety Precaution**
> If necessary, hold the spirit lamp by moving it under the glass tube to heat the remaining powder that is still black so that all black powder turns brown.

12. Remove the glass tube that contains brown powder. Eliminate water drops at the end of the glass tube with a cotton bud.
13. Weigh the mass of the glass tube together with its contents and record its mass.
14. Repeat the heating, cooling and weighing processes from steps 9 to 13 until a constant mass reading is obtained.
15. Record the constant mass in Table 3.5.

Another method of determining the empirical formula of copper(II) oxide

http://bit.ly/2BeHBbY

Results:

Table 3.5

Description	Mass (g)
Glass tube	
Glass tube + copper(II) oxide	
Glass tube + copper	
Copper	
Oxygen	

Interpreting data:

1. Determine the empirical formula of copper(II) oxide in this activity.

Discussion:

1. What is the purpose of using zinc granules and hydrochloric acid in this activity?
2. Why does the hydrogen gas need to flow continuously for a while before starting the heating process?
3. The hydrogen gas is allowed to flow until the product of heating is at room temperature in step 11. Why?
4. Why do the heating, cooling and weighing processes need to be repeated until a constant mass is obtained?

Prepare a complete report after carrying out this activity.

For reactive metals like magnesium, the metal needs to be heated only slightly before it can react with the oxygen in the air. Figure 3.14 shows how the mass of magnesium and oxygen that combine are calculated to determine the simplest mole ratio of atom.

Can you name another reactive metal oxide which empirical formula can be determined using the same method?

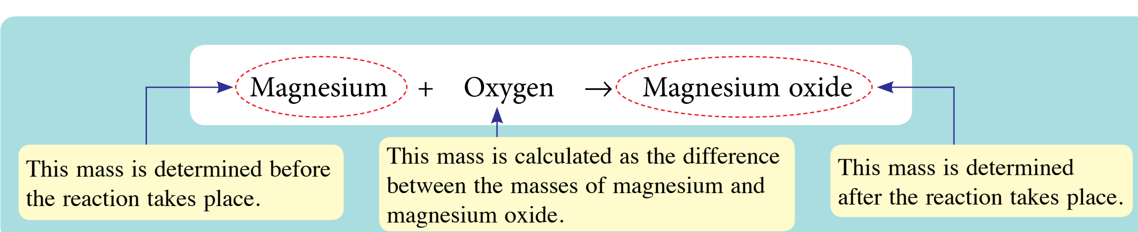


Figure 3.14 *Calculation of the mass of magnesium and oxygen in magnesium oxide*

However, this method is not suitable in determining the empirical formula of copper(II) oxide because copper is less reactive towards oxygen. Hence, copper(II) oxide is heated in a stream of hydrogen gas so that hydrogen can remove oxygen from the oxide as shown in Figure 3.15.

Reactivity series of metals

http://bit.ly/2pFVTQb

Copper(II) oxide + Hydrogen → Copper + Water

This mass is determined before the reaction takes place.

The mass of oxygen is calculated as the difference between the masses of copper(II) oxide and copper.

This mass is determined after the reaction takes place.

Figure 3.15 *Calculation of the masses of copper and oxygen in copper(II) oxide*

Determination of a Molecular Formula

The molecular formula of a compound is its multiplied empirical formula.

Molecular formula = (Empirical formula)$_n$

The value of n is a positive integer. Table 3.6 shows several examples.

Table 3.6 *Relationship between the molecular formula and the empirical formula*

Substance	Water	Hydrazine	Propene	Benzene
Empirical formula	H_2O	NH_2	CH_2	CH
Molecular formula	$(H_2O)_1 = H_2O$	$(NH_2)_2 = N_2H_4$	$(CH_2)_3 = C_3H_6$	$(CH)_6 = C_6H_6$
n	1	2	3	6

Therefore, to determine the molecular formula of a compound, we first need to know its empirical formula. Examples 15 and 16 show solutions regarding chemical formula.

Example 15

A compound has the empirical formula CH_2. Its relative molecular mass is 56. What is the molecular formula of the compound? [Relative atomic mass: H = 1; C = 12]

Solution

Assume that the molecular formula of the compound is $(CH_2)_n$.

Based on its molecular formula, the RMM of compound $= n[12 + 2(1)]$
$= 14n$

Given the RMM of compound, $14n = 56$ ← Equate the calculated RMM with the given one.

$$n = \frac{56}{14} = 4$$

Hence, the molecular formula of the compound is C_4H_8.

Example 16

1.2 g of element *Y* reacts with bromine to form 6 g of a compound with the empirical formula YBr_2. Determine the relative atomic mass of *Y*. [Relative atomic mass: Br = 80]

Solution

The compound consists of element *Y* and bromine.

Therefore, the mass of element *Y* + mass of bromine = mass of compound formed

$$\begin{aligned} 1.2\text{ g} + \text{mass of bromine} &= 6\text{ g} \\ \text{Mass of bromine} &= (6 - 1.2)\text{ g} \\ &= 4.8\text{ g} \end{aligned}$$

Assume that the RAM of element *Y* is *x*.

Element	*Y*	Br
Mass (g)	1.2	4.8
Number of moles of atoms	$\frac{1.2}{x} = ?$	$\frac{4.8}{80} = 0.06$

Further example
http://bit.ly/32BiQ5J

Based on the empirical formula YBr_2,
2 mol of Br atoms combine with 1 mol of atom *Y* or
1 mol of Br atoms combine with 0.5 mol of atom *Y* or
0.06 mol of Br atoms combine with 0.03 mol of atom *Y*.

Based on the empirical formula, calculate using the right ratio.

Hence, the number of moles of atom *Y* that reacts = 0.03 mol

$$\begin{aligned} \frac{1.2}{x} &= 0.03 \\ x &= \frac{1.2}{0.03} \\ &= 40 \end{aligned}$$

The RAM of element *Y* is 40.

Activity 3.14

CT

Solving numerical problems involving empirical formulae and molecular formulae

[Relative atomic mass: H = 1, C = 12, N = 14, O = 16, Ca = 40, Zn = 65]

1. Ethanoic acid has a molar mass of 60 g mol^{-1}. If its empirical formula is CH_2O, determine the molecular formula of ethanoic acid.
2. Hydrocarbons consist of carbon and hydrogen. 5.7 g of a hydrocarbon contains 4.8 g of carbon. If the relative molecular mass of the hydrocarbon is 114, determine its molecular formula.
3. What is the mass of zinc required to combine with 0.5 mol of chlorine to produce zinc chloride, $ZnCl_2$?
4. Assume you are a farmer. You want to choose a fertiliser with a high nitrogen content for your plants. Three types of commonly used fertilisers are as follows.

   Ammonium nitrate, NH_4NO_3 | Urea, $CO(NH_2)_2$ | Nitrosol, $Ca(NO_3)_2$

   Which fertiliser would you choose? Give reasons for your choice. Show the steps used in the calculation.

Chemical Formulae of Ionic Compounds

Ionic compounds are made up of cations (positively-charged ions) and anions (negatively-charged ions). In order to write the chemical formulae of ionic compounds, you need to know the formulae of cations and anions. Table 3.7 shows the examples of formulae for cations and anions that are commonly used. Figure 3.16 explains how the chemical formula of an ionic compound is constructed.

Table 3.7 *Formulae of common cations and anions*

Cation	Formula of cation	Anion	Formula of anion
Sodium ion	Na^+	Oxide ion	O^{2-}
Potassium ion	K^+	Chloride ion	Cl^-
Aluminium ion	Al^{3+}	Bromide ion	Br^-
Zinc ion	Zn^{2+}	Iodide ion	I^-
Magnesium ion	Mg^{2+}	Hydroxide ion	OH^-
Iron(II) ion	Fe^{2+}	Carbonate ion	CO_3^{2-}
Iron(III) ion	Fe^{3+}	Nitrate ion	NO_3^-
Copper(II) ion	Cu^{2+}	Sulphate ion	SO_4^{2-}
Calcium ion	Ca^{2+}	Phosphate ion	PO_4^{3-}
Silver ion	Ag^+	Manganate(VII) ion	MnO_4^-
Lead(II) ion	Pb^{2+}	Thiosulphate ion	$S_2O_3^{2-}$
Ammonium ion	NH_4^+	Dichromate(VI) ion	$Cr_2O_7^{2-}$

Name: **Zinc chloride**

Cation: Zinc ion Anion: Chloride ion

Zn^{2+} **Cl^-**

1. Based on the name of the compound, determine the cation and anion.

Zn^{2+} **Cl^-**

2. Cross-change the cation charge and anion charge to determine the number of cations and anions.

The number of ion:

1 **2**

Check: Positive charge : $1 \times (+2) = +2$
Negative charge : $2 \times (-1) = -2$
Total charge : 0

Formula: **$ZnCl_2$**

3. Write the chemical formula of the compound. The formula is **neutral**. The charges of ions are not written in the formula. The subscript number is used to show the number of ions.

Figure 3.16 *Constructing the chemical formula of zinc chloride via cross-change method*

Further example on cross-change method

http://bit.ly/32DGbUu

The basic concept of constructing a chemical formula of an ionic compound

http://bit.ly/35WMLam

Activity 3.15

Constructing the chemical formulae of ionic compounds

CT

1. Carry out this activity individually.
2. Scan the QR code and download the diagram of ionic formula cards.
3. Print and cut out the ionic formula cards.
4. Use the ion formula cards to help you determine the chemical formula of each of the following ionic compounds:

Potassium oxide	Sodium hydroxide	Magnesium nitrate	Calcium nitrate
Sodium chloride	Aluminium oxide	Potassium carbonate	Aluminium chloride
Calcium bromide	Zinc sulphate	Copper(II) sulphate	Sodium carbonate

5. Record your answers systematically in a table.

Diagram of ionic formula cards
http://bit.ly/2N4JVaG

Naming of Chemical Compounds

For ionic compounds, the name of the cation is written first followed by the name of the anion as in Table 3.8.

***Table 3.8** Examples in the naming of ionic compounds*

Cation	Anion	Name of ionic compound
Sodium ion	Chloride ion	Sodium chloride
Zinc ion	Bromide ion	Zinc bromide
Magnesium ion	Nitrate ion	Magnesium nitrate

Chemistry Lens

Chemical compounds are named systematically as recommended by the International Union of Pure and Applied Chemistry (IUPAC).

Some metals form more than one type of ions. In order to distinguish these ions, Roman numerals are used in their naming. For example, iron forms two types of cations, namely Fe^{2+} and Fe^{3+}. Fe^{2+} ion is named as iron(II) ion while Fe^{3+} ion is named as iron(III) ion. Take a look at the names of the following compounds:

Shows iron(II) ion, Fe^{2+}

Iron(II) oxide
Iron(III) oxide

Shows iron(III) ion, Fe^{3+}

When naming simple molecular compounds, the more electropositive element is named first followed by the name of the more electronegative element. The name of the first element remains the same while the second element ends with 'ide'. Greek prefixes are used to represent the number of atoms of each element in simple molecular compounds. Look at the examples below.

CO – Carbon monoxide
NO_2 – Nitrogen dioxide
SO_3 – Sulphur trioxide

Greek prefixes like 'mono', 'di' and 'tri' show the numbers one, two and three respectively.

Literacy Tips

Other Greek prefixes are as follows:

tetra – 4	hex – 6
pent – 5	hept – 7

Activity 3.16

CT

Naming compounds

1. Name the ionic compounds with the following formulae:
(a) $CaCl_2$ (c) $Mg(NO_3)_2$ (e) Na_2SO_4
(b) KBr (d) $ZnCO_3$ (f) NH_4Cl
2. Name the molecular compounds with the following formulae:
(a) NO (c) SO_3 (e) BF_3
(b) CO_2 (d) CCl_4 (f) CS_2
3. The molecule of a compound consists of two nitrogen atoms and three oxygen atoms. Name the compound.

TestYourself 3.3

1. What is meant by empirical formula and molecular formula?
2. Caffeine, $C_8H_{10}N_4O_2$ is a natural stimulant found in coffee, tea and cocoa. What is the empirical formula of caffeine?
3. Calcium carbonate and sodium fluoride are two compounds found in toothpaste. Write the chemical formulae of both compounds.
4. A sample of 5.04 g of oxide for phosphorus contains 2.48 g of phosphorus.
[Relative atomic mass: O = 16, F = 31]
(a) If the relative molecular mass of the oxide is 126, determine its empirical formula and molecular formula.
(b) Name the oxide of the phosphorus.

3.4 Chemical Equation

Learning Standard

At the end of the lesson, pupils are able to:
3.4.1 Write balanced chemical equations
3.4.2 Interpret chemical equations quantitatively and qualitatively
3.4.3 Solve stoichiometry numerical problems

Photograph 3.7 *Burning of an oil lamp*

Did you know that the burning of fuel and the digestion of food in our bodies are all chemical reactions? Chemists have a simple and accurate way to describe chemical reactions, that is through **chemical equations**.

How to Write Chemical Equations

Chemical equations can be written in the form of words or using chemical formulae. The starting substances or **reactants** are written on the left-hand side of the equation while the new substances formed or **products** are written on the right-hand side of the equation. The arrow '→' means 'produces'. The physical state of each substance, whether solid(s), liquid(l), gas(g) or aqueous solution(aq) is usually indicated in a chemical equation. Figure 3.17 shows the examples of writing the chemical equation for the reaction between hydrogen and oxygen.

Reactants				Product	
Hydrogen	+	Oxygen	→	Water	**1.** Write the equation in words.
H_2	+	O_2	→	H_2O	**2.** Write down the chemical formula of each reactant and product.
H_2 (2 H atoms)	+	O_2 (2 O atoms)	→	H_2O (2 H atoms, 1 O atom) Equation is not balanced	**3.** Check whether the equation is balanced.
$2H_2$ (4 H atoms)	+	O_2 (2 O atoms)	→	$2H_2O$ (4 H atoms, 2 O atoms)	**4. Balance** the equation by adjusting the **coefficient** in front of the chemical formula.
$2H_2(g)$	+	$O_2(g)$	→	$2H_2O(l)$	**5.** Write the physical state of each reactant and product.

Figure 3.17 *Writing the chemical equation for the reaction between hydrogen and oxygen*

Chemical equations need to be **balanced**. Based on the law of conservation of mass, matter can neither be created nor destroyed. Therefore, the number of atoms of each element on both sides of the equation must be the same.

Simulation on balancing chemical equation
http://bit.ly/33vr5QQ

Activity 3.17

Balancing chemical equations CT

1. Write a balanced chemical equation for each of the following reactions:
   (a) Nitrogen gas + Hydrogen gas → Ammonia gas
   (b) Sodium metal + Water → Aqueous solution of sodium hydroxide + Hydrogen gas
   (c) Solid copper(II) carbonate decomposes into solid copper(II) oxide and carbon dioxide gas when heated.
   (d) Burning of aluminium powder in excess oxygen produces white aluminium oxide powder.
2. Balance the following chemical equations:
   (a) $KI(aq) + Br_2(aq) \rightarrow I_2(s) + KBr(aq)$
   (b) $Zn(s) + AgNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + Ag(s)$
   (c) $C_3H_8(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$
   (d) $AgNO_3(s) \xrightarrow[\Delta]{} Ag(s) + NO_2(g) + O_2(g)$

Chemistry Lens

Sometimes, chemical equations also show the condition of the reactions. For example, the Greek letter delta (Δ) below the arrow shows that heating is required in the chemical reaction.

Activity 3.18

Aim: To write balanced chemical equations.

Materials: Copper(II) carbonate powder, $CuCO_3$, concentrated hydrochloric acid, HCl, concentrated ammonia solution, NH_3, lead(II) nitrate solution, $Pb(NO_3)_2$, potassium iodide solution, KI and limewater

Apparatus: Test tubes, delivery tube and rubber stopper, test tube holder, Bunsen burner, 10 cm^3 measuring cyclinder, test tube stoppers and glass tube

CAUTION

Concentrated hydrochloric acid and concentrated ammonia are corrosive. Handle them with care and carry out Activity 3.18 in the fume chamber.

Procedure:

A Heating of copper(II) carbonate, $CuCO_3$

1. Fill a spatula of copper(II) carbonate powder, $CuCO_3$ into a test tube. Observe the colour of the powder.
2. Set up the apparatus as shown in Figure 3.18.
3. Heat copper(II) carbonate, $CuCO_3$ and let the gas produced flow into the test tube filled with limewater. Observe the changes that take place in both test tubes.
4. When the reaction is completed, remove the test tube of limewater. Then, stop the heating.
5. Record your observations.

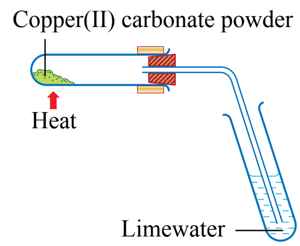


Figure 3.18

B Formation of ammonium chloride, NH_4Cl

1. Using a glass tube, put 3 or 4 drops of concentrated hydrochloric acid, HCl into a test tube. Close the test tube with a stopper and leave it for a few minutes.
2. Repeat step 1 using concentrated ammonia solution, NH_3 in another test tube.
3. Remove the stoppers from both test tubes. Quickly bring the mouths of both test tubes together as shown in Figure 3.19.
4. Observe and record the changes that take place.

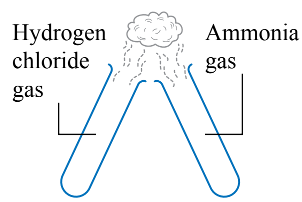


Figure 3.19

C Precipitation of lead(II) iodide, PbI_2

1. Pour 2 cm^3 of lead(II) nitrate solution, $Pb(NO_3)_2$ into a test tube.
2. Pour 2 cm^3 of potassium iodide solution, KI into another test tube.
3. Pour potassium iodide solution, KI into lead(II) nitrate solution, $Pb(NO_3)_2$ as shown in Figure 3.20. Shake the mixture.
4. Observe and record the changes that take place.

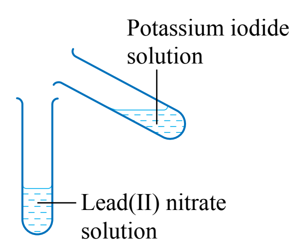


Figure 3.20

Discussion:

1. For each reaction in experiments A, B and C, state:
   (a) The reactants and products
   (b) The physical state of each reactant and product
   (c) The chemical formula of each reactant and product
2. Write a balanced chemical equation for each of the reactions.

Prepare a complete report after carrying out this activity.

Using Chemical Equations

Chemical equation can be interpreted qualitatively and quantitatively. From the **qualitative aspect**, chemical equations enable us to identify the reactants and products as well as their physical states.

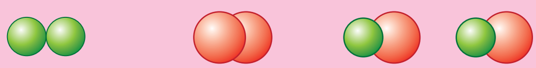
$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

Reactants: Sodium metal and chlorine gas

Product: Solid sodium chloride

From the **quantitative aspect**, we can study the stoichiometry of chemical equations. Stoichiometry is the quantitative study of the composition of substances involved in a chemical reaction. **Coefficients** in chemical equations show the ratio of substances involved, either as the ratio of elementary entities of substance or the mole ratio. Take a look at the following example:

$2Na(s)$	+	$Cl_2(g)$	$\rightarrow$	$2NaCl(s)$
(2 atoms)		(1 molecule)		(2 formula units)



or		or		or
(2 mol)		(1 mol)		(2 mol)

Ratio of basic entities (particles):
Two sodium atoms react with one molecule of chlorine to produce two NaCl units.

Mole ratio:
2 mol of sodium react with 1 mol of chlorine gas to produce 2 mol of sodium chloride.

Activity 3.19

Interpreting chemical equations qualitatively and quantitatively

21st Century Skills

1. Carry out the Think-Pair-Share activity.
2. Based on the chemical equations obtained from Activity 3.18, interpret each equation qualitatively and quantitatively, from the aspects of ratio of elementary entities and mole ratio.
3. Discuss with your partner.
4. Share the results of your discussion with the class.

Based on the mole ratio of substances from a balanced chemical equation, we can solve various numerical problems by calculating the number of moles of substances required in the right ratio.

$2Na(s)$	+	$Cl_2(g)$	$\rightarrow$	$2NaCl(s)$	
(2 mol)		(1 mol)		(2 mol)	Initial mole ratio from the stoichiometry
(1 mol)		(0.5 mol)		(1 mol)	All values are divided by 2
⋮		⋮		⋮	Calculated in the right ratio for other values

The number of moles determined can be converted to mass, number of particles or volume of gas using the molar mass, Avogadro constant or molar volume like all the relationships you have learned before.

Example 17

Burning of aluminium in air is as follows:

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

What is the mass of aluminium oxide produced if 5.4 g of aluminium is burnt completely in air?
[Relative atomic mass: O = 16, Al = 27]

Solution

Question analysis and solution plan

Equation:	$4Al(s)$	+	$3O_2(g)$	$\rightarrow$	$2Al_2O_3(s)$
Information from the equation:	(4 mol)				(2 mol)
Information from the question:	(5.4 g)				(? g – question to be answered)

Step 1 How many moles? → Step 2 Mole ratio? → Step 3 What is the mass?

Number of moles in 5.4 g of aluminium, Al $= \dfrac{\text{Mass}}{\text{Molar mass}}$

$= \dfrac{5.4 \text{ g}}{27 \text{ g mol}^{-1}}$

$= 0.2$ mol

Step 1:
Mass of Al $\rightarrow$ Number of moles of Al

Based on the equation, 4 mol of aluminium, Al produces 2 mol of aluminium oxide, Al_2O_3. Therefore, 0.2 mol of aluminium, Al produces 0.1 mol of aluminium oxide, Al_2O_3.

Step 2:
Calculate the mole ratio of Al_2O_3.

Hence, the mass of aluminium oxide, Al_2O_3 produced
= Number of moles × Molar mass
$= 0.1 \text{ mol} \times [2(27) + 3(16)] \text{ g mol}^{-1}$
$= 0.1 \text{ mol} \times 102 \text{ g mol}^{-1}$
$= 10.2$ g

Step 3:
Number of moles of Al_2O_3 $\rightarrow$ Mass of Al_2O_3

Activity 3.20

Solving numerical stoichiometry problems

CT

[Relative atomic mass: H = 1, C = 12, O = 16, Cl = 35.5, Ca = 40, Fe = 56, Zn = 65; Avogadro constant, N_A: 6.02×10^{23} mol^{-1}; Molar volume = 22.4 dm^3 mol^{-1} at STP or 24 dm^3 mol^{-1} at room conditions]

1. Decomposition of calcium carbonate by heating is as follows:

$$CaCO_3(s) \xrightarrow[\Delta]{} CaO(s) + CO_2(g)$$

What is the mass of calcium carbonate required to produce 1.2 dm^3 of carbon dioxide gas, CO_2 at room conditions?

2. Zinc reacts with hydrochloric acid as follows:

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

What is the mass of zinc that should be used to produce 0.5 mol of hydrogen gas, H_2?

3. A sample of iron(III) oxide, Fe_2O_3 is heated in a stream of excess hydrogen gas, H_2 to produce 5.6 g of iron metal according to the following equation:

$$Fe_2O_3(g) + 3H_2(g) \rightarrow 2Fe(s) + 3H_2O(l)$$

Calculate the mass of the iron(III) oxide sample.

4. Nitrogen and hydrogen gases react according to the following equation:

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

How many molecules of ammonia, NH_3 are produced if 6.72 dm^3 of nitrogen gas at STP reacts completely with hydrogen gas?

Activity 3.21

Creating a computer worksheet

CT

Decomposition of potassium chlorate(V), $KClO_3$ by heat is often used to produce oxygen gas in the laboratory.

$$2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$$

Assume you are a laboratory assistant. You are required to prepare different amounts of oxygen gas from time to time. Repeated calculations using chemical equations can be simplified using a computer worksheet. Use Microsoft Excel or other suitable programmes to prepare a computer worksheet involving the equation above to solve the following problems:
[Relative atomic mass: O = 16, Cl = 35.5, K = 39; Molar volume = 24 dm^3 mol^{-1} at room conditions]

1. What are the masses of potassium chlorate(V), $KClO_3$ needed to produce 1 dm^3, 5 dm^3, 10 dm^3, 20 dm^3 and 50 dm^3 of oxygen gas?

2. What are the volumes of oxygen gas produced if 0.25 kg, 0.5 kg, 1 kg, 1.5 kg and 2 kg of potassium chlorate(V), $KClO_3$ are used?

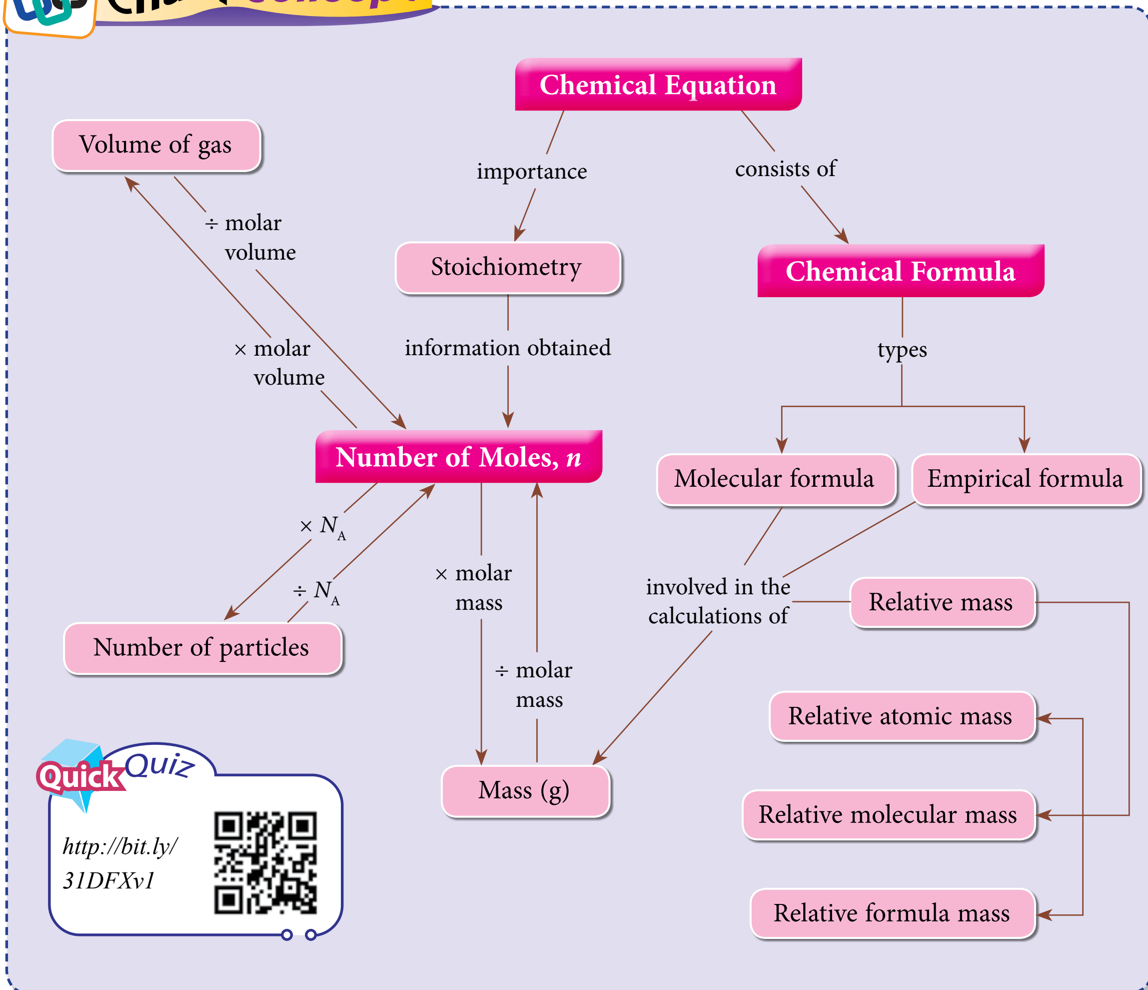
TestYourself 3.4

1. Write the chemical equations for the following reactions:
   (a) Copper + Silver nitrate solution → Copper(II) nitrate solution + Silver
   (b) Hot zinc metal will react with chlorine gas to produce solid zinc chloride
2. Decomposition of hydrogen peroxide, H_2O_2 occurs according to the following equation:

$$2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$$

   (a) What are the products of the decomposition of hydrogen peroxide, H_2O_2?
   (b) Calculate the volume of oxygen produced at STP from the decomposition of 30.6 g of hydrogen peroxide, H_2O_2.

Chain Concept



SELF Reflection

1. What is interesting about **The Mole Concept**, **Chemical Formula and Equation**?
2. Why is the learning of **The Mole Concept**, **Chemical Formula and Equation** important in the next chemistry lesson?
3. Rate your performance in **The Mole Concept**, **Chemical Formula and Equation** on a scale of 1 to 10; 1 being the lowest and 10 the highest. Why would you rate yourself at that level?
4. What can you do to improve your mastery in **The Mole Concept**, **Chemical Formula and Equation**?
5. What else would you like to know about **The Mole Concept**, **Chemical Formula and Equation**?

http://bit.ly/2MiTOIY

Achievement Test 3

Refer to the Data Table of Elements on page 276.
[Avogadro constant, N_A: 6.02×10^{23} mol^{-1}; Molar volume = 22.4 dm^3 mol^{-1} at STP or 24 dm^3 mol^{-1} at room conditions]

1. What is meant by molar mass and molar volume?

2. What is the relationship between Avogadro constant, number of particles and number of moles?

3. Relative atomic mass of nitrogen is 14

   State the meaning of the above statement based on the carbon-12 scale.

4. Vitamin C or ascorbic acid is an important antioxidant required for our health. Vitamin C has the molecular formula $C_6H_8O_6$.
   (a) What is the empirical formula of vitamin C?
   (b) What is the relative molecular mass of vitamin C?

5. Antacid functions to relieve gastric problems. Figure 1 shows the label on a bottle of antacid.

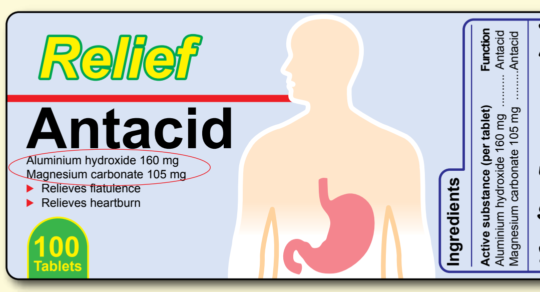


Figure 1

   Give the chemical formulae of the two active ingredients in the antacid.

6. Figure 2 shows the aerobic respiration in our body cells to produce energy from glucose, $C_6H_{12}O_6$. Write a balanced chemical equation for the process of aerobic respiration.

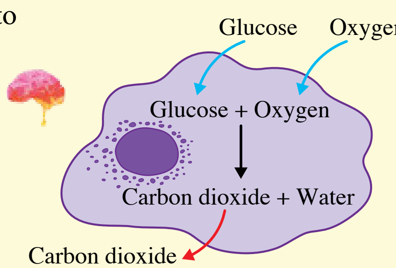


Figure 2

7. Iron(II) sulphate heptahydrate, $FeSO_4.7H_2O$ is often used to treat anaemic patients suffering from the lack of iron mineral.
   (a) What is the molar mass of iron(II) sulphate heptahydrate?
   (b) Calculate the percentage of iron in iron(II) sulphate heptahydrate.

8. Figure 3 shows the weighing steps taken in the determination of the empirical formula of the oxide of metal *Y*.

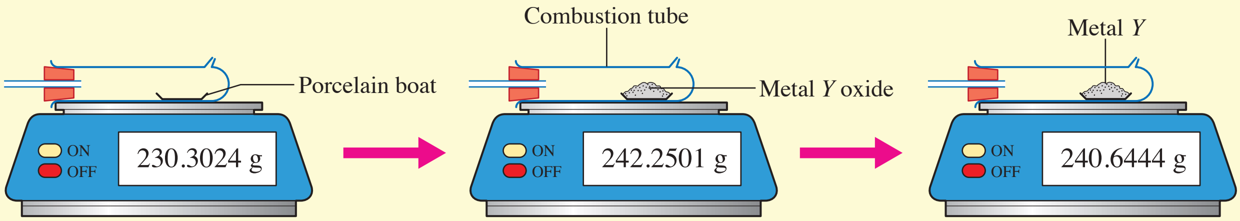


Figure 3

Determine the empirical formula of metal *Y* oxide.
[Relative atomic mass: O = 16, *Y* = 207]

9. *P*, *Q* and *R* are three samples of chemical substances.

P – 0.2 mol of calcium chloride
Q – 12 dm^3 of nitrogen monoxide gas at room conditions
R – 2.408×10^{23} carbon dioxide molecules

Arrange the three samples in ascending order of mass.

10. In your opinion, between the empirical formula and the molecular formula, which formula is more suitable to be used when writing chemical equations? Give your reasons.

Enrichment Corner

1. When steam is passed over a hot iron metal, hydrogen gas and iron(III) oxide are formed. What is the mass of steam required to react completely with 100 g of iron?
[Relative atomic mass: H = 1, O = 16, Fe = 56]

2. Lithium hydroxide, LiOH is used to remove carbon dioxide from the exhaled air in the cabin of a spaceship. [Relative atomic mass: H = 1, Li = 7, C = 12, O = 16]

$$2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$$

An outer space mission is carried out for a period of 18 days involving five people on board. If each person is expected to exhale on the average of 42 g of carbon dioxide per hour and each absorption tube can contain 750 g of LiOH, calculate the number of absorption tubes that should be loaded into the spaceship.

Check Answers
https://bit.ly/32OHQGV

CHAPTER 4

The Periodic Table of Elements

Keywords

- Periodic Table of Elements
- Groups
- Periods
- Noble gases
- Alkali metals
- Halogens
- Metalloids
- Transition elements

What will you learn?

4.1 The Development of the Periodic Table of Elements
4.2 The Arrangement in the Periodic Table of Elements
4.3 Elements in Group 18
4.4 Elements in Group 1
4.5 Elements in Group 17
4.6 Elements in Period 3
4.7 Transition Elements

Bulletin

Is the chlorine content in the swimming pool harmful to the health of users? The answer is no. You need not worry because water treated with chlorine only kills bacteria or dangerous organisms. Users of the swimming pool do not get infected with contagious diseases. In fact, you need not worry about the effects of accidentally swallowing 100 cm^3 of chlorinated water each day during your swimming activity.

The strong smell in the swimming pool results from the reaction of urea (from sweat) with chlorine. This reaction produces a substance called trichloramine (nitrogen trichloride). This substance may be harmful to health. Therefore, before entering the swimming pool, it is advisable for you to clean yourself first so that the urea due to sweat on the surface of the skin is removed.

Did you know that the characteristics of chlorine element can be obtained by studying the position of chlorine in the Periodic Table of Elements? This is because all the elements in the Periodic Table of Elements are arranged systematically, therefore we are able to know the characteristics of chlorine element.

Who invented the Periodic Table of Elements?

How are elements classified in the Periodic Table of Elements?

What are the special characteristics of transition elements?

4.1 The Development of the Periodic Table of Elements

The **Periodic Table of Elements** classifies known chemical elements in a table according to certain characteristics. Many theories were explained by scientists before the modern Periodic Table of Elements was produced. What were those theories? Do you know the scientists involved in the development of the Periodic Table of Elements?

Learning Standard

At the end of the lesson, pupils are able to:
4.1.1 Describe the historical development of the Periodic Table of Elements
4.1.2 Deduce the basic principle of arrangement of elements in the Periodic Table of Elements

Antoine Lavoisier (1743 – 1794)

Lavoisier classified elements according to certain groups such as gases, non-metals, metals and metal oxides. However, his classification was less accurate because he also classified light, heat and a few compounds into the groups as elements. Besides, there were several elements that were classified into the same group but showed different chemical properties.

Dobereiner found that the atomic mass of strontium atom, Sr was similar to the average mass of calcium atom, Ca and barium atom, Ba. These elements had the same chemical properties. A similar condition occurred with chlorine, Cl, bromine, Br and iodine, I. The group consisting of these three elements was named **triad**. Dobereiner's classification was limited to several elements only. However, his classification showed the relationship between the chemical properties of elements and atomic mass.

Johann W. Dobereiner (1780 – 1849)

John Newlands (1837 – 1898)

Newlands arranged elements according to their increasing atomic masses. He arranged seven elements in a row because he found that the chemical and physical properties of the first element recurred at every eighth element. He named the arrangement as the **Law of Octaves**. The Law of Octaves had only been conformed by the first 17 elements. However, the recurrence in properties of the eighth element showed the presence of periodic pattern in the properties of elements.

Lothar Meyer
(1830 – 1895)

Meyer plotted the graph of atomic volume against atomic mass of elements. He found that the elements at equivalent positions on the curve of the graph had similar chemical properties. For example, referring to the alkali metals such as lithium, sodium, potassium and rubidium that were located at the peaks of the curve. Meyer also proved the recurrence in properties of elements similar to Newlands.

Mendeleev arranged the elements according to their increasing atomic masses. Only elements with similar chemical properties were arranged in the same vertical columns. He had left several empty spaces in his periodic table to be filled by elements, yet to be discovered. He was successful in predicting the properties of undiscovered elements based on the properties of elements located above and below an element in the table.

Dmitri Mendeleev
(1834 – 1907)

Henry Moseley
(1887 – 1915)

Moseley studied the frequencies of X-ray released by various elements and eventually found a relationship between the X-ray spectrum and proton numbers. He proposed that each element ought to have its own proton number. Then, he arranged the elements in the Periodic Table of Elements according to their increasing proton numbers. Moseley also left empty spaces in his periodic table like Mendeleev and successfully predicted four elements, namely technetium, Tc, promethium, Pm, hafnium, Hf and rhenium, Re which were discovered later.

Basic Principle of Arrangement of Elements in the Periodic Table of Elements

Elements in the Periodic Table of Elements are arranged in **ascending order of proton numbers**, ranging from 1 to 118. Elements with similar chemical properties are placed in the same vertical columns.

Several new elements which were discovered such as nihonium, Nh, moscovium, Mc, tennessine, Ts and oganesson, Og were added into Period 7 of the Periodic Table of Elements.

113	115	117	118
Nh	**Mc**	**Ts**	**Og**
Nihonium	Moscovium	Tennessine	Oganesson

Figure 4.1 *The new elements*

Brain Teaser

From the historical development of the Periodic Table of Elements learned, predict the basic principle in the arrangement of the elements.

HISTORY INTEGRATION

New elements discovered are named after the location or the name of the scientist.

Activity 4.1

21st Century Skills CT

Discussing the importance of classifying the elements

1. Carry out the Think-Pair-Share activity.
2. Scan the QR code on the right on the development of the Periodic Table of Elements and think of the importance of classifying the elements.
3. Discuss with your partner.
4. Share your outcomes in front of the class.

Development of the Periodic Table of Elements

http://bit.ly/35Sgp0A

Test Yourself 4.1

1. Name the scientists that made the following discoveries:
   (a) Classified elements into four groups according to their chemical properties, that is gases, non-metals, metals and metal oxides
   (b) Proposed the Law of Octaves
   (c) Constructed the triad groups consisting of three elements with similar chemical properties
2. In the historical development of the Periodic Table of Elements, Moseley arranged the elements in ascending order of proton numbers. However, before the modern Periodic Table of Elements was used, scientists made their own discoveries. Compare how Dobereiner and Newlands arranged the elements in the Periodic Table of Elements before Moseley.

4.2 The Arrangement in the Periodic Table of Elements

Learning Standard

At the end of the lesson, pupils are able to:
4.2.1 Describe briefly the modern Periodic Table of Elements
4.2.2 Generalise the relationship between the proton number and the position of elements in the Periodic Table of Elements

The modern **Periodic Table of Elements** is a form of systematic classification of elements in ascending order of proton numbers from left to right and from top to bottom. The arrangement of elements is discussed from the aspects of groups, periods, proton number and electron arrangement.

The vertical columns in the Periodic Table of Elements are called **Groups**. There are 18 groups in the Periodic Table of Elements. The number of valence electrons will determine the position of the group of an element. Figure 4.2 shows the position of the group of an element based on the number of valence electrons.

Literacy Tips

You have learned the positions of metals, non-metals and noble gases in the Periodic Table of Elements in Form 1.

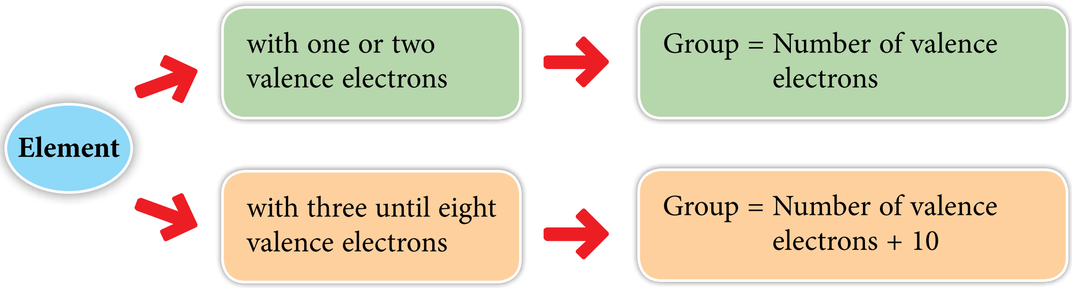


***Figure 4.2** Position of the group of an element*

The horizontal rows in the Periodic Table of Elements are called **Periods**. There are seven periods in the Periodic Table of Elements. The number of shells filled with electrons will determine the position of an element in a period.

Table 4.1 explains the relationship between the proton number and the position of an element in the Periodic Table of Elements based on the aspects of groups and periods.

***Table 4.1** Relationship between the proton number and the position of elements in the Periodic Table of Elements.*

Element	Proton number	Electron arrangement	Valence electron	Group	Number of shells filled with electrons	Period
Lithium, Li	3	2.1	1	1	2	2
Calcium, Ca	20	2.8.8.2	2	2	4	4
Aluminium, Al	13	2.8.3	3	3 + 10 = 13	3	3
Silicon, Si	14	2.8.4	4	4 + 10 = 14	3	3
Nitrogen, N	7	2.5	5	5 + 10 = 15	2	2
Oxygen, O	8	2.6	6	6 + 10 = 16	2	2
Bromine, Br	35	2.8.18.7	7	7 + 10 = 17	4	4
Krypton, Kr	36	2.8.18.8	8	8 + 10 = 18	4	4

Activity 4.2

Predicting the group and period of an element based on its electron arrangement

21st Century Skills CT

1. Carry out the Round Table activity.
2. Choose a representative to speak out the proton number of an element.
3. Group members take turns to note down the electron arrangement, group and period of that element on a piece of paper.
4. Discuss the correct answer.
5. Pin up your outcomes on the class notice board as a reference for other groups.

Test Yourself 4.2

1. Write the symbols for magnesium, copper and fluorine.
2. State the electron arrangement and group, for each of the following elements. Refer the Data Table of Elements on page 276 to get the proton number of each element.
   (a) Potassium, K
   (b) Carbon, C
   (c) Chlorine, Cl
   (d) Argon, Ar
3. Draw the electron arrangements of lithium, Li and carbon, C.

4.3 Elements in Group 18

Learning Standard

At the end of the lesson, pupils are able to:
4.3.1 Relate the inert nature of Group 18 elements to its stability
4.3.2 Generalise the changes in physical properties of elements when going down Group 18
4.3.3 Describe briefly the uses of Group 18 elements in daily life

Group 18 consists of elements of helium, He, neon, Ne, argon, Ar, krypton, Kr, xenon, Xe, radon, Rn and oganesson, Og. Elements in Group 18 are known as noble gases or inert gases. Activity 4.3 shows the relationship between the inert nature and the stability of the electron arrangement in an element.

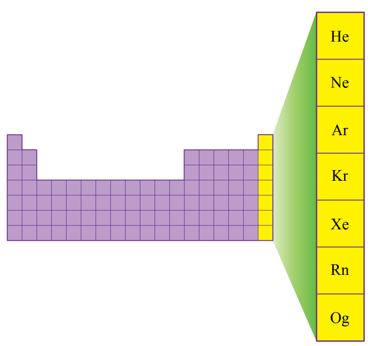


***Figure 4.3** Positions of Group 18 elements in the Periodic Table of Elements*

More information on inert properties of neon
http://bit.ly/33zc7cm

Activity 4.3

Relating the inert nature with the stability of duplet and octet electron arrangements of Group 18 elements

1. Carry out this activity in groups.

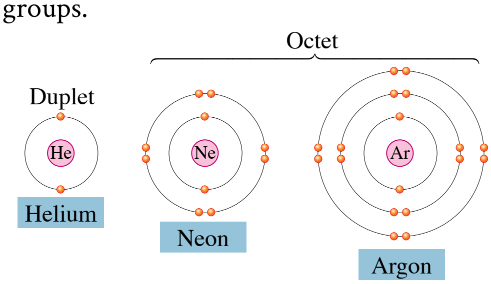


Figure 4.4

2. Based on Figure 4.4, discuss the relationship between the inert nature of Group 18 elements and the stability of electron arrangement in an element.
3. Present your findings in front of the class.

Noble gases are chemically unreactive due to valence shells that are fully filled with electrons. Noble gases have achieved a stable duplet or octet electron arrangement, causing the atoms of noble gases to not donate, accept nor share electrons with the atoms of other elements. The atoms of noble gases exist as monoatoms.

Chemistry Lens

Noble gas is also known as inert gas.

Changes in Physical Properties of Elements When Going Down Group 18

Going down Group 18, the size of atomic radius increases due to the increase in the number of electrons and electron filled shells.

***Table 4.2** Physical properties of Group 18 elements*

Element	Atomic radius (nm)	Melting point (°C)	Boiling point (°C)	Density (g cm^{-3})
Helium, He	0.050	–270	–269	0.00017
Neon, Ne	0.070	–248	–246	0.00080
Argon, Ar	0.094	–189	–186	0.00170
Krypton, Kr	0.109	–156	–152	0.00350
Xenon, Xe	0.130	–122	–108	0.00550
Radon, Rn	–	–71	–62	–

Going down the group, the melting point and boiling point of the elements increase. Increase in the atomic size of elements will increase the attraction force between the atoms. Therefore, the attraction force becomes stronger and more heat energy is required to overcome this force.

Brain Teaser

Try to relate the increase in the density of the elements with the atomic mass and atomic size of each element, when going down the group.

Activity 4.4

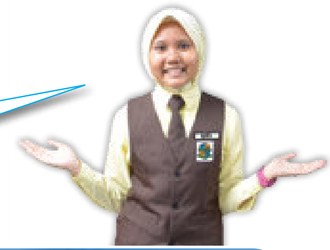
Constructing a model to compare the physical properties and changes in the physical properties of Group 18 elements

21st Century Skills

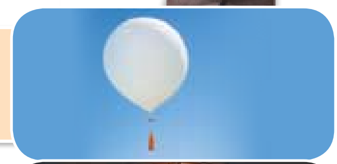
1. Carry out the Three Stray One Stay activity.
2. Construct a 2D or 3D model to compare the physical properties of at least two elements in Group 18.
3. Prepare an exhibition corner in class and display the models from each group.
4. Choose a representative to give explanations on the comparison and changes in the physical properties of the selected Group 18 elements. The rest of the members will move around to seek information from other groups on their selected Group 18 elements.

Uses of Group 18 Elements in Daily Life

You have identified the list of elements found in Group 18 and studied the changes in the physical properties of the elements as you go down the group. Did you know that Group 18 elements have many uses in our daily life?

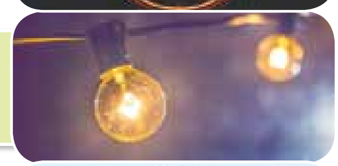


Helium
- Used to fill weather balloons
- Used in the oxygen tanks of divers

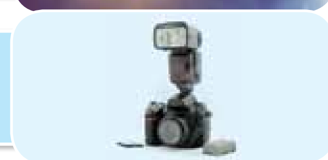


Neon
- Used in advertising board lights

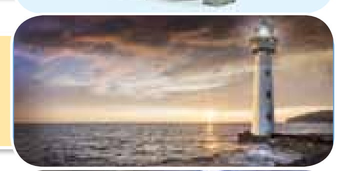
Argon
- Used to fill in electric bulbs
- Used to provide an inert atmosphere for welding in high temperature



Krypton
- Used in flashlight of cameras
- Used in lasers for eye retina treatment



Xenon
- Used in lighthouse lamps
- Used for anesthesia



Radon
- Used to treat cancer

Figure 4.5 *Uses of Group 18 elements*

Activity 4.5

Summarising the uses of Group 18 elements in daily life

1. Carry out this activity in groups.
2. Watch a video clip on the uses of Group 18 elements in our daily lives by searching the Internet or visiting the link given.
3. Based on the video, discuss with your group members and summarise the uses of Group 18 elements in graphic form.
4. Present your group work in front of the class.

Group 18 elements
http://bit.ly/2Be9EIw

Test Yourself 4.3

1. State the electron arrangement of helium, He.
2. What is the type of electron arrangement of argon atom, Ar?
3. Explain why neon, Ne does not react with other elements.
4. Compare the boiling point of helium and argon. Explain.

4.4 Elements in Group 1

Group 1 is made up of lithium, Li, sodium, Na, potassium, K, rubidium, Rb, caesium, Cs and francium, Fr. Group 1 elements are also known as alkali metals.

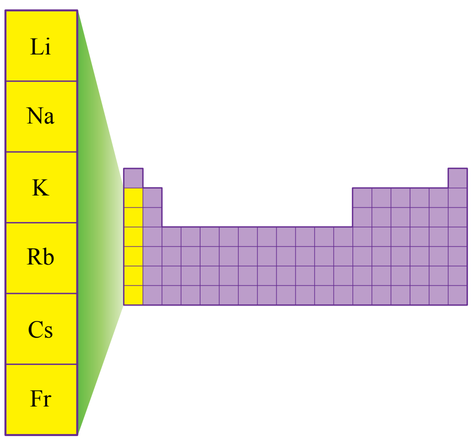


***Figure 4.6** Positions of Group 1 elements in the Periodic Table of Elements*

Learning Standard

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

4.4.1 Generalise the changes in physical properties of elements when going down Group 1

4.4.2 Investigate through experiment the chemical properties of Group 1 elements with:
- Water
- Oxygen gas
- Chlorine

4.4.3 Generalise the changes in the reactivity of elements when going down Group 1

4.4.4 Reason out the physical and chemical properties of the other elements in Group 1

Photograph 4.1 shows the uses of several Group 1 elements. What other uses of these elements that you know?

Lithium, Li is used in battery production.

Sodium, Na is used in sodium vapour lamps.

Potassium, K is used in fertilisers.

***Photograph 4.1** Uses of Group 1 elements*

Changes in Physical Properties of Elements When Going Down Group 1

Going down Group 1, the atomic radius of elements increases as shown in Table 4.3.

Table 4.3 *Physical properties of several Group 1 elements*

Element	Atomic radius (nm)	Melting point (°C)	Boiling point (°C)
Lithium, Li	0.133	186	1342
Sodium, Na	0.186	98	880
Potassium, K	0.203	64	760

Group 1 elements have low melting point and boiling point if compared to other metals like iron that has a melting point of 1 540 °C and boiling point of 2 760 °C. Why do the melting point and boiling point of elements decrease when going down the group? The increase in the atomic size down the group will weaken the attraction force between the atoms. Therefore, less heat energy is required to overcome the attraction forces between the metal atoms.

Group 1 elements are soft metals, with low density and float on the surface of water. These alkali metals also have a grey shiny surface at room temperature.

Chemical Properties of Group 1 Elements

Group 1 elements have one electron in the valence shell. In a chemical reaction, these atoms donate one electron and form an ion with the +1 charge.

$$M \rightarrow M^{+} + e^{-}$$

What will happen when Group 1 elements react with water, oxygen gas or chlorine gas?

Experiment 4.1

Aim: To study the chemical properties of Group 1 elements.

Problem statement: What are the chemical properties of Group 1 elements, when they react with water, oxygen gas and chlorine gas?

Materials: Lithium, sodium, potassium, distilled water, filter paper, red litmus paper, oxygen and chlorine gas

Apparatus: Forceps, white tile, basin, knife, combustion spoon, gas jar with lid, 10 cm^3 measuring cylinder and Bunsen burner

A Reaction of Group 1 elements with water (Demonstration by the teacher)

Hypothesis: Going down the group, the reactivity of alkali metals with water will increase.

Variables:

(a) Manipulated : Type of alkali metal
(b) Responding : Reactivity of alkali metal with water
(c) Fixed : Size of alkali metal

Safety Precaution

Be careful when putting the alkali metal into the water. Only small quantities should be used.

Procedure:

1. Cut lithium into small pieces using a knife and forceps. Dry a piece of the metal on a filter paper.
2. Put the piece of lithium slowly into a basin filled with water as shown in Figure 4.7.

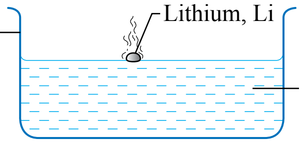


Figure 4.7

3. When the reaction is complete, test the solution with a red litmus paper.
4. Record your observations in Table 4.4.
5. Repeat steps 1 to 4 with sodium and potassium.

B Reaction of Group 1 elements with oxygen gas

Make a hypothesis and state all the variables for part B.

Procedure:

1. Cut lithium into small pieces using a knife and forceps. Dry a piece of the metal on a filter paper.
2. Put the piece of lithium onto a combustion spoon.
3. Heat until it starts to burn and immediately insert the spoon into a gas jar filled with oxygen gas as shown in Figure 4.8.
4. When the reaction is complete, add 10 cm^3 of water into the gas jar and shake.
5. Test the solution using a red litmus paper.
6. Record your observations in Table 4.4.
7. Repeat steps 1 to 6 with sodium and potassium.

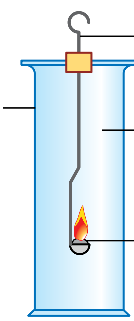


Figure 4.8

C Reaction of Group 1 elements with chlorine gas

Make a hypothesis and state all the variables for part C.

Procedure:

1. Cut lithium into small pieces using a knife and forceps. Dry a piece of the metal on a filter paper.
2. Put the piece of lithium onto a combustion spoon.
3. Heat until it starts to burn and immediately insert the spoon into a gas jar filled with chlorine gas as shown in Figure 4.8.
4. Record your observations in Table 4.4.
5. Repeat steps 1 to 4 with sodium and potassium.

Results:

Table 4.4

Metal	Observation		
	With water	With oxygen gas	With chlorine gas
Lithium			
Sodium			
Potassium			

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

Discussion:

1. Write the chemical equation for the reaction of lithium, sodium and potassium with:
   (a) Water
   (b) Oxygen gas
   (c) Chlorine gas
2. Arrange the reactivity of alkali metals lithium, sodium and potassium with water, oxygen gas and chlorine gas in ascending order.

Prepare a complete report after carrying out this experiment.

Reaction of Group 1 Elements with Water, Oxygen Gas and Chlorine Gas

Lithium, sodium and potassium have the same chemical properties but different reactivity.

When alkali metals react with water, alkaline hydroxide solution and hydrogen gas is formed. For example, reaction of lithium with water will produce lithium hydroxide and hydrogen gas.

EduwebTV: Alkali metal
http://bit.ly/31h4LZN

$$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$$

When alkali metals burn in oxygen gas, a white solid that is metal oxide will be formed. For example, reaction of lithium with oxygen gas will produce lithium oxide.

$$4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$$

Solid metal oxide will form an alkaline solution when dissolved in water. For example, reaction of lithium oxide with water will produce lithium hydroxide.

$$Li_2O(s) + H_2O(l) \rightarrow 2LiOH(aq)$$

When alkali metals burn in chlorine gas, a white solid, that is metal chloride will be formed. For example, reaction of sodium with chlorine gas will produce sodium chloride.

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$

Changes in Reactivity of Elements Going Down Group 1

Experiment 4.1 shows the reactivity of elements increases when going down Group 1. Why do the changes occur?

The reactivity of alkali metals in Group 1 is due to the tendency of an atom to donate its valence electrons. The number of shells filled with electrons increases when going down Group 1. This causes the increase in atomic size.

The position of valence electrons is placed further away from the nucleus of an atom. When the nuclear attraction force towards the valence electrons weakens, the electrons are more easily donated.

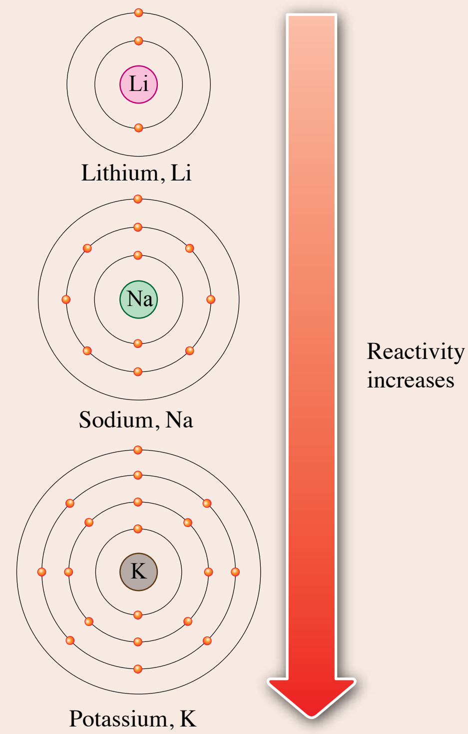


Figure 4.9 *Reactivity of elements increases when going down Group 1*

Physical and Chemical Properties of Other Elements in Group 1

You have studied the properties of lithium, sodium and potassium. How about the properties of other atoms such as rubidium, caesium and francium?

Like other alkali metals, rubidium, caesium and francium elements are soft metals with shiny surfaces and have low melting point and boiling point. Rubidium and caesium are metals that are very reactive and burn easily. Rubidium and caesium are usually combined with other elements. Thus, they are difficult to be isolated chemically. Francium element is an unstable radioactive isotope with a short half-life. All three elements are very reactive with water and oxygen.

Reactions of elements in Group 1 with water

http://bit.ly/2MhYybu

Chemistry & Us

Lithium batteries like those used in smartphones can explode when charged excessively because it accepts current rapidly. So, only original and good quality chargers should be used to charge your devices.

TestYourself 4.4

1. Give two examples of Group 1 elements.
2. Table 4.5 shows the electron arrangement for elements *X*, *Y* and *Z*.

Table 4.5

Elements	Electron arrangement
X	2.1
Y	2.8.8.1
Z	2.8.18.8.1

(a) Give two differences in physical properties between elements *X*, *Y* and *Z*.

(b) Element *X* reacts with oxygen when heated. Write the chemical equation for this reaction.

(c) Arrange the reactivity of elements *X*, *Y* and *Z* in ascending order. Explain the difference in reactivity.

4.5 Elements in Group 17

Group 17 consists of fluorine, F, chlorine, Cl, bromine, Br, iodine, I, astatine, At and tennessine, Ts. Group 17 elements are known as halogens and exist as diatomic molecules.

Learning Standard

At the end of the lesson, pupils are able to:
- 4.5.1 Generalise the changes in the physical properties of elements when going down Group 17
- 4.5.2 Summarise the chemical properties of Group 17 elements
- 4.5.3 Generalise the changes in the reactivity of elements when going down Group 17
- 4.5.4 Reason out the physical and chemical properties of other elements in Group 17

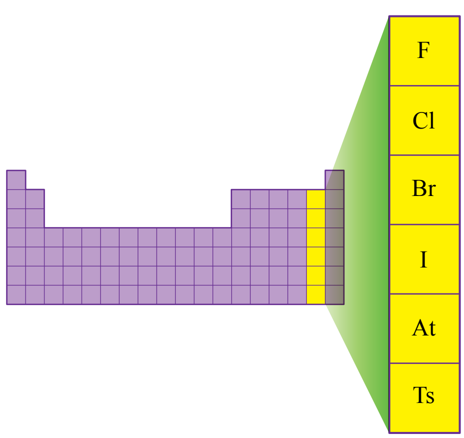


***Figure 4.10** Position of Group 17 elements in the Periodic Table of Elements*

Do you know the uses of Group 17 elements in our daily lives? Photograph 4.2 shows the examples of daily uses for elements chlorine, bromine and iodine.

Chlorine in bleach

Bromine as a substance in fire extinguishers

Iodine as a disinfectant

Photograph 4.2 *Uses of Group 17 elements*

Changes in Physical Properties of Elements When Going Down Group 17

Going down Group 17, the physical state of halogens at room temperature changes from gas to liquid and finally to solid as shown in Table 4.6.

Table 4.6 *Physical properties of several Group 17 elements*

Element	Physical state	Melting point (°C)	Boiling point (°C)	Density ($g\ cm^{-3}$)
Chlorine, Cl	Gas	–101	–34	0.00300
Bromine, Br	Liquid	–7	59	3.11900
Iodine, I	Solid	114	184	4.95000

Going down the group, the increase in molecular size will cause the attraction force between molecules to become stronger. The melting point and boiling point of halogens will increase because more heat energy is required to overcome the intermolecular forces. The density of elements also increases with the increase in mass when going down the group.

Group 17 elements have different colours. Chlorine gas is greenish yellow, liquid bromine is reddish brown while solid iodine is purplish black.

Chemical Properties of Group 17 Elements

Group 17 elements have seven electrons in the valence shell. In chemical reactions, these atoms receive one electron and form ions with –1 charge.

$$X + e^- \rightarrow X^-$$

What will happen if Group 17 elements react with water, metals or alkalis?

Activity 4.6

21st Century Skills

Watching the reactions of Group 17 elements

1. Carry out the activity in groups.
2. Based on Internet search, watch the video clips on the reactions of Group 17 elements with water, metal and alkali.

Reaction of halogen with water
http://bit.ly/2ILzLdZ

Reaction of halogen with iron, Fe
http://bit.ly/2VJzpcR

Reaction of halogen with sodium hydroxide, NaOH
http://bit.ly/32kGWS4

3. Based on the videos above, discuss the following questions:
   (a) Write chemical equations for the reactions of chlorine with water, iron and sodium hydroxide.
   (b) Arrange the reactivity of chlorine, bromine and iodine with iron in ascending order.
   (c) Halogens are reactive non-metal elements. Explain.

Reaction of Group 17 Elements with Water, Metal and Alkali

Chlorine, bromine and iodine have the same chemical properties but different reactivity.

When halogens react with water, an acidic solution is formed. For example, the reaction of chlorine with water will produce hydrochloric acid and hypochlorous acid.

$$Cl_2(g) + H_2O(l) \rightleftharpoons HCl(aq) + HOCl(aq)$$

When halogens react with metal, a metal halide is formed. For example, the reaction of iron with bromine will produce iron(III) bromide.

$$2Fe(s) + 3Br_2(l) \rightarrow 2FeBr_3(s)$$

HISTORY INTEGRATION

Antoine Balard discovered hypochlorous acid when he added a dilute suspension of mercury(II) oxide into a flask filled with chlorine gas.

When halogens react with an alkaline solution, metal halide, metal halate and water will be formed. For example, the reaction of iodine with sodium hydroxide will produce sodium iodide, sodium iodate(I) and water.

$$I_2(s) + 2NaOH(aq) \rightarrow NaI(aq) + NaOI(aq) + H_2O(l)$$

Changes in Reactivity of Elements Down Group 17

Did you know that the reactivity of elements decreases when going down Group 17? Increasing atomic size will cause the valence shell to be further from the nucleus. This will cause the nuclear attraction force towards the electrons to become weaker. Thus, the difficulty in attracting electrons to fill the valence shell will increase.

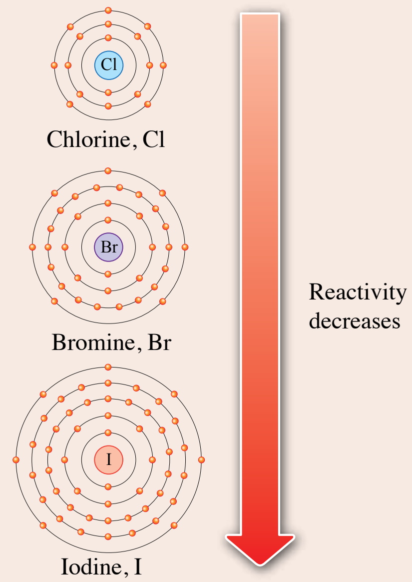


Figure 4.11 *Reactivity of elements decreases when going down Group 17*

Activity 4.7

Watching the safety precautions in handling Group 17 elements

1. Carry out the activity in groups.
2. Watch the video clip on safety precautions on handling Group 17 elements by surfing the Internet.
3. Based on the video, carry out a forum titled 'Safety Precautions in Handling Group 17 Elements'. Discuss the following questions:
   (a) Group 17 elements are dangerous. Explain.
   (b) What are the safety precautions taken when handling halogens like chlorine and bromine in the laboratory?

Example on safety measures in handling halogens

http://bit.ly/33vshDO

CAUTION

Be careful when handling Group 17 elements because they are dangerous.

Physical and Chemical Properties of Other Elements in Group 17

Based on what you have learned, can you predict the physical and chemical properties of fluorine and astatine? Generally, all halogens are soluble in organic solvents and do not conduct heat nor electricity. Fluorine is a light-yellow poisonous gas. This gas which is very reactive and corrosive will cause a strong explosion when combined with hydrogen gas. Astatine is a rare radioactive element because it is not chemically stable.

Test Yourself 4.5

1. State three physical properties of elements down the Group 17.
2. Fluorine is very reactive compared to iodine. The reaction of fluorine with almost all other elements is very vigorous. Why is fluorine more reactive compared to iodine?
3. Give two examples of substances that contain Group 17 elements.
4. Astatine is not used in the science laboratory. Explain.

4.6 Elements in Period 3

Learning Standard

At the end of the lesson, pupils are able to:
- 4.6.1 Describe the trends in physical properties of elements across Period 3
- 4.6.2 Conduct an experiment to observe changes in the properties of the oxides of elements across Period 3
- 4.6.3 Describe briefly the uses of semi-metals

Period 3 consists of elements sodium, Na, magnesium, Mg, aluminium, Al, silicon, Si, phosphorus, P, sulphur, S, chlorine, Cl, and argon, Ar.

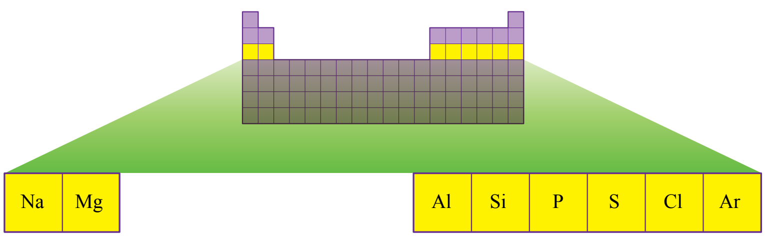


Figure 4.12 *Position of Period 3 elements in the Periodic Table of Elements*

You have learned about the uses of sodium, Na, chlorine, Cl, and argon, Ar. The uses of several other elements in Period 3 are shown in Photograph 4.3.

Photograph 4.3 *Uses of Period 3 elements*

Changes in Physical Properties of Elements Across Period 3

Going across Period 3 from left to right, the atomic size will decrease because the atomic radius decreases.

Table 4.7 Physical properties of Period 3 elements

Elements	Sodium, Na	Magnesium, Mg	Aluminium, Al	Silicon, Si	Phosphorus, P	Sulphur, S	Chlorine, Cl	Argon, Ar
Atomic radius (nm)	0.186	0.160	0.143	0.118	0.110	0.104	0.100	0.094
Electronegativity	0.9	1.2	1.5	1.8	2.1	2.5	3.0	–
Physical state	Solid						Gas	

Atomic size decreases

Increase in the number of protons across Period 3 will increase the charge in the atom's nucleus. The electronegativity of elements will increase because the nuclear attraction force towards the electrons increases.

The physical state of Period 3 elements will change from solid to gas from left to right across the period. The same goes to metal elements, semi-metal elements and non-metal elements. Sodium, Na, magnesium, Mg and aluminium, Al are metal elements, silicon, Si is a semi-metal element or metalloid while phosphorus, P, sulphur, S, chlorine, Cl and argon, Ar are non-metal elements.

Changes in Chemical Properties of Oxides of Elements Across Period 3

You have learned the properties of metal elements, semi-metal elements and non-metal elements in Period 3. How about the chemical properties of oxides of elements across Period 3?

Experiment 4.2

Aim: To study the change of chemical properties of oxides of elements across Period 3.

Problem statement: How does the chemical properties of oxides of elements change across Period 3?

Materials: Sodium oxide, Na_2O, magnesium oxide, MgO, aluminium oxide, Al_2O_3 sulphur dioxide gas, SO_2, silicon(IV) oxide, SiO_2, distilled water, 2.0 mol dm^{-3} sodium hydroxide, NaOH and 2.0 mol dm^{-3} nitric acid, HNO_3

Apparatus: Test tube, stopper, test tube holder, 10 cm^3 measuring cylinder, pH meter, Bunsen burner, glass rod and spatula

A Reaction of oxides of Period 3 elements with water

Hypothesis: Across Period 3, oxides of elements will change from basic to acidic.

Variables:

(a) Manipulated : Type of oxide of Period 3 elements
(b) Responding : Change in oxide property
(c) Fixed : Volume of water

Procedure:

1. Pour 10 cm^3 distilled water into a test tube containing half spatula of sodium oxide, Na_2O and shake.
2. Measure the pH value of the solution in the test tube using a pH meter.

3. Record your observations.
4. Repeat steps 1 to 3 using magnesium oxide, MgO, aluminium oxide, Al_2O_3 and sulphur dioxide, SO_2.

Results:

Table 4.8

Oxide	Sodium oxide, Na_2O	Magnesium oxide, MgO	Aluminium oxide, Al_2O_3	Sulphur dioxide, SO_2
With water				
pH value				

B Reaction of oxides of Period 3 elements with sodium hydroxide and nitric acid

Make hypothesis and state all the variables for part B.

Procedure:

1. Fill $\frac{1}{4}$ spatula of magnesium oxide powder, MgO into two different test tubes.
2. Add 5 cm^3 of 2.0 mol dm^{-3} sodium hydroxide solution, $NaOH$ into the first test tube.
3. Add 5 cm^3 of 2.0 mol dm^{-3} nitric acid, HNO_3 into the second test tube.

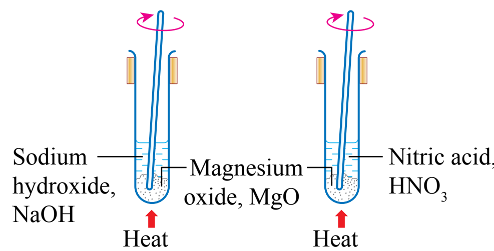


Figure 4.13

4. Heat both test tubes gently and stir using a glass rod as shown in Figure 4.13.
5. Observe the solubility of oxide in both solutions and record your observations.
6. Repeat steps 1 to 5 by using aluminium oxide Al_2O_3 and silicon(IV) oxide, SiO_2.

Results:

Table 4.9

Oxide	Solubility	
	With sodium hydroxide, $NaOH$	**With nitric acid, HNO_3**
Magnesium oxide, MgO		
Aluminium oxide, Al_2O_3		
Silicon(IV) oxide, SiO_2		

Conclusion:

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

Discussion:

1. List the basic oxides, amphoteric oxides and acidic oxides.
2. Write the chemical equation for the reaction between basic oxide and nitric acid, HNO_3.
3. Write the chemical equation for the reaction between amphoteric oxide and sodium hydroxide, $NaOH$.
4. List the elements that have basic oxides and acidic oxides across Period 3.

Prepare a complete report after carrying out this experiment.

Going across Period 3, the properties of oxide change from basic oxide to amphoteric oxide and then to acidic oxide.

Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2	Cl_2O_7
Basic oxide		Amphoteric oxide	Acidic oxide			

Figure 4.14 *Properties of oxides of elements across Period 3*

Group 1 and 2 elements form metal oxides that are basic. When dissolved in water, both basic oxides will produce alkaline solutions. Basic oxides also react with acid to form salt and water.

Aluminium forms metal oxide that is amphoteric in property. Aluminium oxide reacts with both acid and alkali to form salt and water.

Elements from Groups 14, 15, 16 and 17 form non-metal oxides that are acidic in property. When dissolved in water, oxides of elements from these groups will produce acidic solutions. Acidic oxides will also react with alkali to form salt and water.

You have learned the change of physical and chemical properties of elements across Period 3. Can you predict the change of properties for elements across Period 2?

Activity 4.8

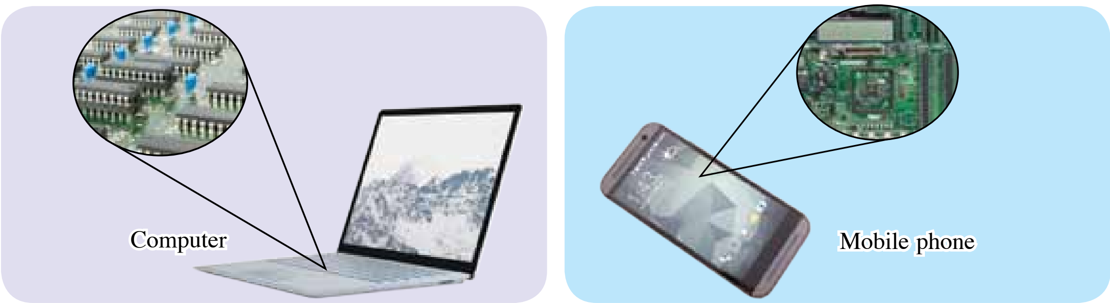
Predicting the change of properties for elements in Period 2

21st Century Skills

1. Carry out the Round Table activity.
2. Based on the change of properties of elements across Period 3, discuss and predict the change of properties for elements across Period 2.
3. Take turns to record the information on a piece of paper.
4. Pin up the outcome of your group discussion on the class bulletin board as a reference to others.

Uses of Semi-Metallic Elements

Semi-metallic elements or metalloid have both the properties of metals and non-metals. These elements are weak conductors of electricity. However, metalloids are good electrical conductors at high temperatures. Based on that property, metalloids like silicon are used as semiconductors in the manufacture of electronic microchips. Photograph 4.4 shows the uses of electronic microchips in the production of computers and mobile phones.



Photograph 4.4 *Electronic microchips used in the making of computers and mobile phones*

Activity 4.9

Discussing the uses of semi-metals in the microelectronic industry

21st Century Skills

1. Carry out the Gallery Walk activity.
2. Collect information from reading materials or suitable websites on the uses of the following semi-metals in the microelectronic industry.

Silicon, Si

Germanium, Ge

3. Discuss among your group members and prepare a presentation.
4. Display your group work in the class. Move around in groups to see the work of other groups.
5. Write comments on their work and paste them.

Test Yourself 4.6

1. Why are the elements sodium, Na, magnesium, Mg, aluminium, Al, silicon, Si, phosphorus, P, sulphur, S, chlorine, Cl and argon, Ar in the same period?
2. Silicon exists as a solid at room temperature while non-metals like chlorine exists as a gas. Explain.
3. Figure 4.15 shows several elements in the Periodic Table of Elements.

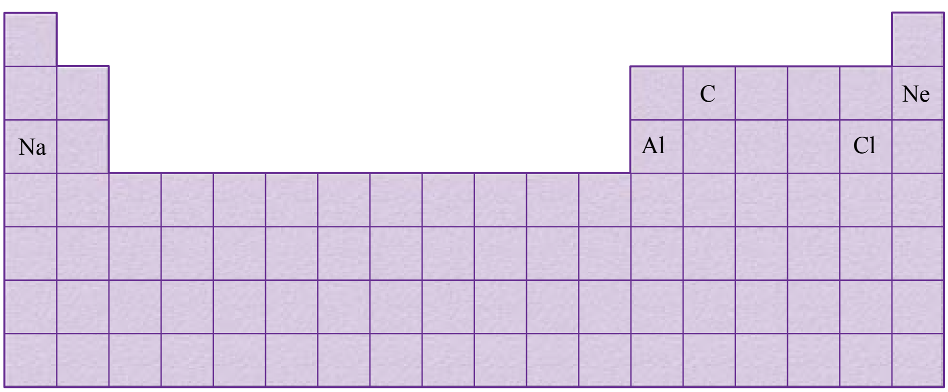


Figure 4.15

(a) When aluminium and chlorine are compared, which element has a smaller atomic size? Explain.

(b) Which element forms an amphoteric oxide?

(c) Arrange all the elements in accending order of atomic size.

4.7 Transition Elements

Learning Standard

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

4.7.1 Determine the position of transition elements in the Periodic Table of Elements
4.7.2 Explain the special characteristics of a few transition elements with examples
4.7.3 List the uses of transition elements in industry

Position of Transition Elements

Transition elements are placed in Group 3 and 12 in the Periodic Table of Elements. Examples of transition elements include chromium, Cr, manganese, Mn, iron, Fe, and copper, Cu. The yellow portion in Figure 4.16 shows the position of transition elements in the Periodic Table of Elements.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 – 71 Lanthanides	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 – 103 Actinides	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Figure 4.16 *Position of transition elements in the Periodic Table of Elements*

Position of transition elements

http://bit.ly/2B8OlYG

All transition elements are metals with the following properties:

- Solids with shiny surfaces
- Very hard compared to metals in Groups 1 and 2
- Have high densities
- Have high melting points and boiling points

Chemistry Lens

Scandium and zinc are not considered as transition elements because both do not show characteristics of transition elements.

Special Characteristics for Several Transition Elements in the Periodic Table of Elements

Transition elements are metals with high melting point and boiling point, hard, shiny surfaces, malleable and ductile. Transition elements also have special characteristics unknown to other metals. What are the special characteristics possessed by transition elements?

1. Transition elements function as a catalyst to increase the rate of reaction without undergoing chemical change at the end of the reaction. For example, iron filings are used as a catalyst in the Haber Process.

$$N_2(g) + 3H_2(g) \underset{450\,-\,550\,^{\circ}C,\ Fe}{\overset{200\,-\,300\ atm}{\rightleftharpoons}} 2NH_3(g)$$

2 Transition elements form coloured ions or compounds.

Photograph 4.5 *Coloured compounds of transition elements*

Table 4.10

Transition element ions	Colour of solution
Chromium(III) ion, $Cr^{3+}(aq)$ Dichromate(VI) ion, $Cr_2O_7^{2-}(aq)$	Green Orange
Manganese(II) ion, $Mn^{2+}(aq)$ Manganate(VII) ion, $MnO_4^{-}(aq)$	Pink Purple
Iron(II) ion, $Fe^{2+}(aq)$ Iron(III) ion, $Fe^{3+}(aq)$	Green Brown
Copper(II) ion, $Cu^{2+}(aq)$	Blue

EduwebTV: Transition elements
http://bit.ly/2BcvM5Z

Activity 4.10

Observing the colour of the transition element compounds

1. Observe the colour of the following transition element compounds:
   (a) Chromium(III) chloride, $CrCl_3$
   (b) Potassium dichromate(VI), $K_2Cr_2O_7$
   (c) Manganese(II) chloride, $MnCl_2$
   (d) Manganese(IV) oxide, MnO_2
   (e) Potassium manganate(VII), $KMnO_4$
   (f) Iron(II) sulphate, $FeSO_4$
   (g) Iron(III) chloride, $FeCl_3$
   (h) Copper(I) oxide, Cu_2O
   (i) Copper(II) oxide, CuO
2. Present your findings in the form of a suitable mind map to share with your friends.

3 Transition elements have more than one oxidation number.

Table 4.11

Transition element	Oxidation number	Compound
Chromium, Cr	+3 +6	Chromium(III) chloride, $CrCl_3$ Potassium dichromate(VI), $K_2Cr_2O_7$
Mangan, Mn	+2 +4 +7	Manganese(II) chloride, $MnCl_2$ Manganese(IV) oxide, MnO_2 Potassium manganate(VII), $KMnO_4$
Iron, Fe	+2 +3	Iron(II) sulphate, $FeSO_4$ Iron(III) chloride, $FeCl_3$
Copper, Cu	+1 +2	Copper(I) oxide, Cu_2O Copper(II) oxide, CuO

4 Transition elements can form complex ions.

Table 4.12

Ion of transition element	Formula
Tetraaminecopper(II) ion	$[Cu(NH_3)_4]^{2+}$
Hexacyanoferrate(III) ion	$[Fe(CN)_6]^{3-}$
Hexacyanoferrate(II) ion	$[Fe(CN)_6]^{4-}$
Hexaaquaferrate(II) ion	$[Fe(H_2O)_6]^{2+}$

Activity 4.11

21st Century Skills CT

Conducting the learning activity based on the problems related to the special characteristics of transition elements

1. Carry out the activity in groups.
2. Read and understand the following passage:

> Scientists found a special characteristic of certain transition elements that can 'remember' their form. For example, an alloy called Nitinol is a mixture of nickel and titanium that can return to its original form after the alloy is bent. This alloy is used in making spectacle frames and treating broken bones.

3. Gather information on problems that can be solved using transition elements and their special characteristics.
4. Justify the use of transition elements and relate them to their special characteristics.
5. Prepare a multimedia presentation based on your findings.
6. Present your group work in front of the class.

Uses of Transition Elements in Industry

One of the special characteristics of transition elements is their use as a catalyst in industries. Do you know which transition elements are involved in that function? Figure 4.17 shows the examples of transition elements that function as a catalyst in industries.

Transition Elements

Iron, Fe is used in the Haber Process to produce ammonia, NH_3.

Platinum, Pt is used in the Ostwald Process to produce nitric acid, HNO_3.

Vanadium(V) oxide, V_2O_5 is used in the Contact Process to produce sulphuric acid, H_2SO_4.

Nickel, Ni or **platinum, Pt** is used in the hydrogenation process on vegetable oils to produce margarine.

Figure 4.17 *Transition elements as catalysts in industries*

Apart from catalyst, other uses of transition elements are shown in Photograph 4.6.

Manganese is used to make stained glass windows

Iron is used to build bridges

Titanium is used to make paints

***Photograph 4.6** Uses of transition elements*

Activity 4.12

Making a scrap book/ brochure/ pamphlet/ poster to show the uses of several transition elements in various industries

1. Carry out this activity in groups.
2. Gather information from various reading materials and search relevant websites for the use of several transition elements in various industries.
3. Discuss with your group members and present your findings in a scrap book/ brochure/ pamphlet/ poster.
4. Exhibit the scrap book/ brochure/ pamphlet/ poster in the laboratory or class.

TestYourself 4.7

1. Table 4.13 shows three transition elements that exist in gems.

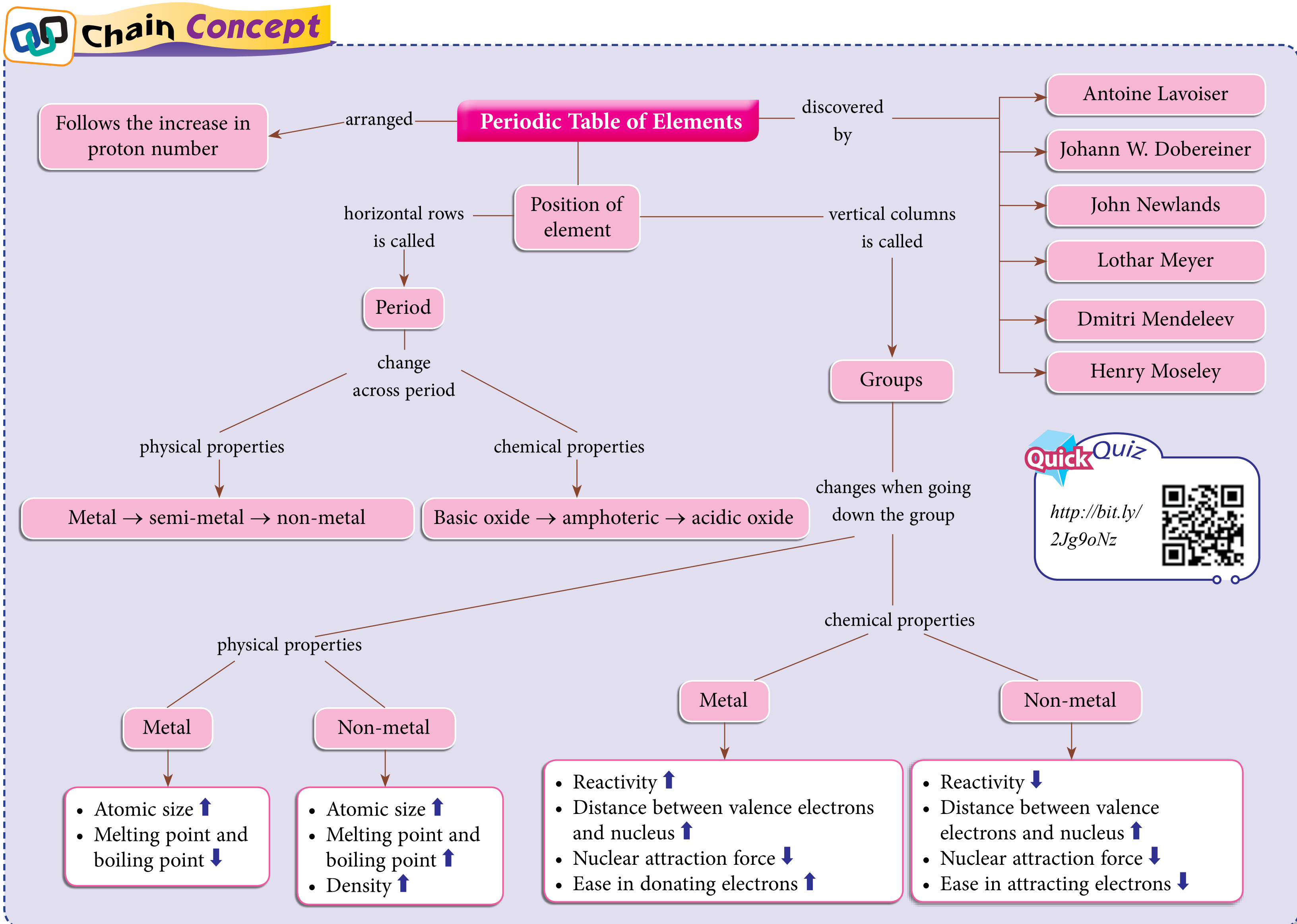
Table 4.13

Gem	Transition element
Ruby	Chromium
Sapphire	Iron, titanium
Amethyst	Manganese

   (a) What are the special characteristics of the transition elements shown in Table 4.13?

   (b) Apart from the characteristics given in 1(a), what are the other characteristics found in transition elements?

2. Give examples of several transition elements used in industry.


Chain Concept
Periodic Table of Elements
arranged
Follows the increase in proton number
discovered by
Antoine Lavoiser
Johann W. Dobereiner
John Newlands
Lothar Meyer
Dmitri Mendeleev
Henry Moseley
Position of element
horizontal rows is called
Period
change across period
physical properties
Metal → semi-metal → non-metal
chemical properties
Basic oxide → amphoteric → acidic oxide
vertical columns is called
Groups
changes when going down the group
physical properties
Metal
• Atomic size ↑
• Melting point and boiling point ↓
Non-metal
• Atomic size ↑
• Melting point and boiling point ↑
• Density ↑
chemical properties
Metal
• Reactivity ↑
• Distance between valence electrons and nucleus ↑
• Nuclear attraction force ↓
• Ease in donating electrons ↑
Non-metal
• Reactivity ↓
• Distance between valence electrons and nucleus ↑
• Nuclear attraction force ↓
• Ease in attracting electrons ↓
Quick Quiz
http://bit.ly/2Jg9oNz

SELF Reflection

1. What new knowledge have you learned in **The Periodic Table of Elements**?
2. Which is the most interesting subtopic in **The Periodic Table of Elements**? Why?
3. Give a few examples of elements in **The Periodic Table of Elements** that you use in your daily life.
4. Rate your performance in **The Periodic Table of Elements** 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 else would you like to know about **The Periodic Table of Elements?**

http://bit.ly/31kIQk8

Achievement Test 4

1. How did Moseley arrange the elements in the Periodic Table of Elements?

2. Figure 1 shows the chemical symbol for element *X*.

$$^{35}_{17}X$$

Figure 1

   (a) Which group does element *X* belong to in the Periodic Table of Elements?
   (b) Which period does element *X* belong to in the Periodic Table of Elements?

3. A restaurant owner uses colourful electric lights to attract his customers. What is the substance suitable for making such lights?

4. State the physical and chemical properties of the element with electron arrangement 2.8.8.1.

5. State the element in Period 3 that forms an amphoteric oxide.

6. Figure 2 shows several elements in the Periodic Table of Elements that are represented by alphabets *X* and *Y*.

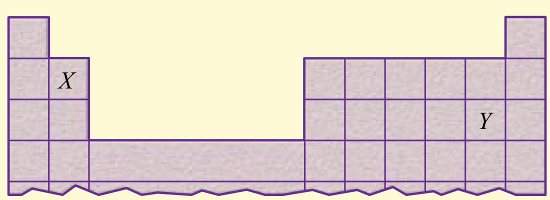


Figure 2

   (a) Write the electron arrangement for atom *X* and atom *Y*.
   (b) Explain two differences in chemical properties between element *X* and element *Y*.
   (c) Why does the reactivity of elements in the same group as *X*, increase when going down the group, but the reactivity of elements in the same group as *Y* decreases?

7. Chlorine, Cl_2 reacts with sodium, Na to form a compound. Write the chemical equation for the reaction.

8. Figure 3 shows the electron arrangement for the element *G*.

(a) Which group does element *G* belong to in the Periodic Table of Elements?

(b) Which period does element *G* belong to in the Periodic Table of Elements?

(c) State a physical property of element *G*.

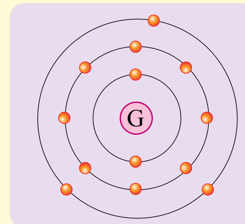


Figure 3

9.

Na Mg Al Si P S Cl Ar

(a) State which element is a metal, metalloid or non-metal from the list of elements given above.

(b) Explain the change in atomic radius across the Period from left to right.

(c) Which element is a noble gas?

(d) Write the chemical equation when a metal reacts with water.

10. Give the colour of the following transition element ions:

(a) Iron(II) ion

(b) Iron(III) ion

Enrichment Corner

1. Photograph 1 shows a few microchips. Silicon element is widely used in the manufacture industries of microchips.

Photograph 1 *Microchips*

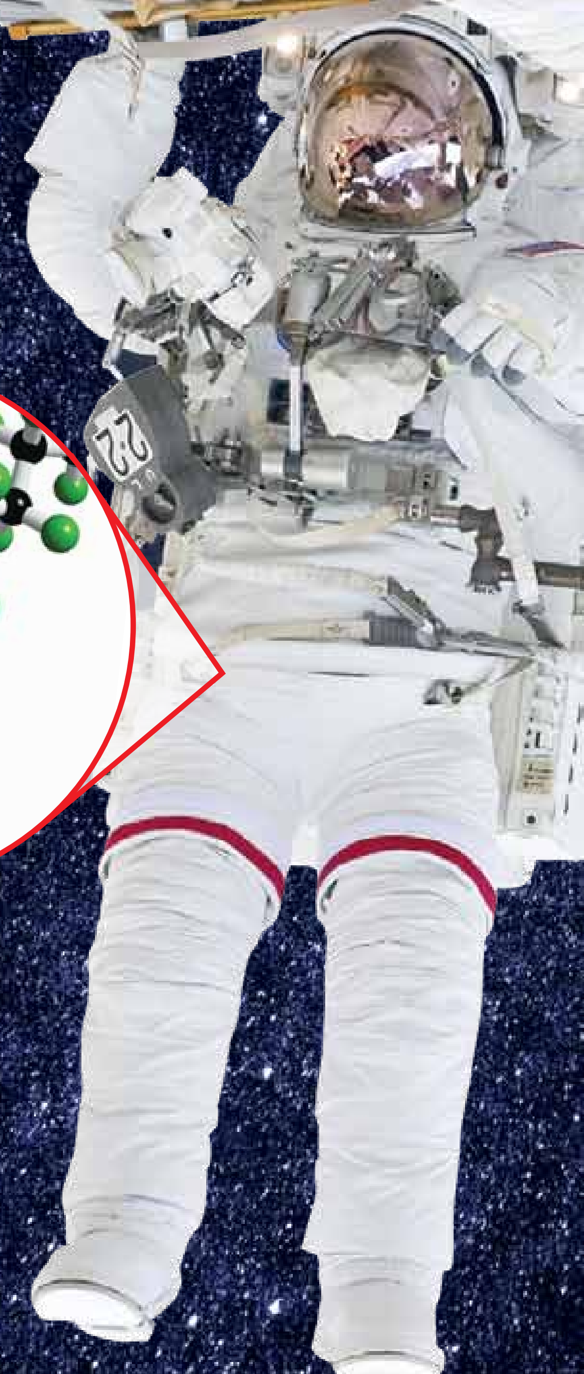
What is the property of silicon that enables this element to be used in the manufacture of microchips instead of a metal like lithium? Explain.

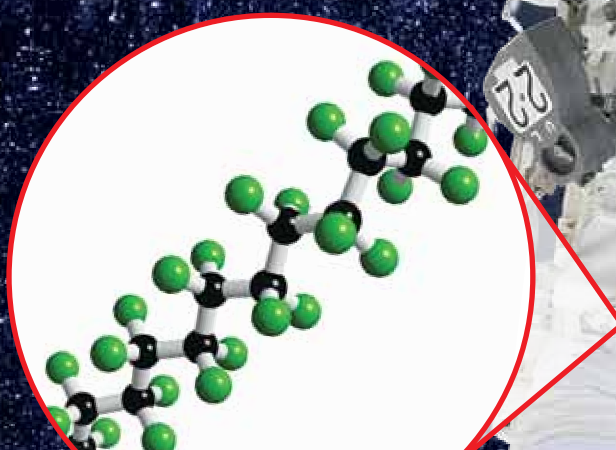
Check Answers

https://bit.ly/2pHzJ04

CHAPTER 5

Chemical Bond





Teflon

Keywords

- Chemical bonds
- Ionic bonds
- Electrostatic attraction force
- Covalent bonds
- Hydrogen bonds
- Dative bonds
- Van der Waals attraction force

What will you learn?

5.1 Basics of Compound Formation
5.2 Ionic Bond
5.3 Covalent Bond
5.4 Hydrogen Bond
5.5 Dative Bond
5.6 Metallic Bond
5.7 Properties of Ionic Compounds and Covalent Compounds

Bulletin

Dato' Dr. Sheikh Muszaphar Shukor is the first Malaysian astronaut sent to the outer space. During his stay in the outer space, he needs to wear an astronaut suit.

The astronaut suit is created specifically to protect the astronaut's body from the space environment. Did you know that the astronaut suit is made up of five layers? The layers consist of an inner layer of cotton, followed by a layer of blue nylon, a layer of black nylon, Teflon layer and lastly white nylon on the outer side. All layers of nylon and Teflon are macromolecules made from covalent compounds by covalent bonds, a type of chemical bond that is very strong.

What is meant by chemical bond?

Why is ethanol soluble in water?

How are dative bonds formed?

5.1 Basics of Compound Formation

Learning Standard

At the end of the lesson, pupils are able to:
5.1.1 Explain the basics of compound formation

Sodium, Na is reactive towards chlorine gas, Cl_2 when heated and forms a white solid. Did you know that this white solid is the table salt that you use in your daily life? However, no compound is formed when sodium, Na is heated with neon gas, Ne. Why?

Compounds are formed when two or more elements are combined. Do you know how elements are combined to produce compounds?

Activity 5.1

Watching a video on the formation of compounds

1. Carry out the activity in groups.
2. Watch video clips on the formation of compounds by electron transfer (ionic bonds) and by sharing of electrons (covalent bonds) from your Internet search.
3. Based on those videos, discuss the following:
   (a) Formation of compounds by transfer of electrons to achieve a stable octet or duplet electron arrangement
   (b) Formation of compounds by sharing of electrons to achieve a stable octet or duplet electron arrangement
4. Present the findings of your discussion on a flip chart paper in front of the class.

Ionic bond
http://bit.ly/2MfCmit

Covalent bond
http://bit.ly/2BeDXi1

Noble gases exist as monoatomic gases and are not reactive chemically because they have achieved a stable duplet or octet electron arrangement. However, for atoms of other elements, stability of electron arrangement can be achieved by transferring or sharing of electrons. **Chemical bonds** are formed when electron transfer or electron sharing takes place. There are two types of chemical bonds; **ionic bond** and **covalent bond**. Chemical bonds only involve the **valence electrons**.

Brain Teaser

Why are electrons in the inner shells not involved in chemical bonds?

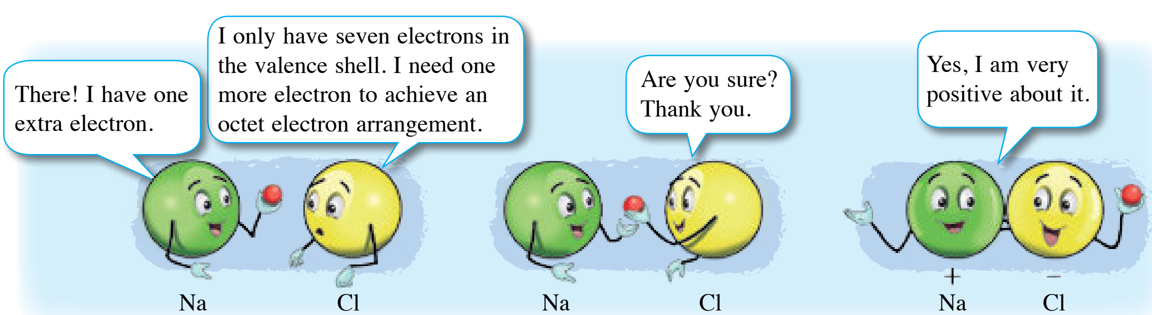


***Figure 5.1** Formation of ionic bond*

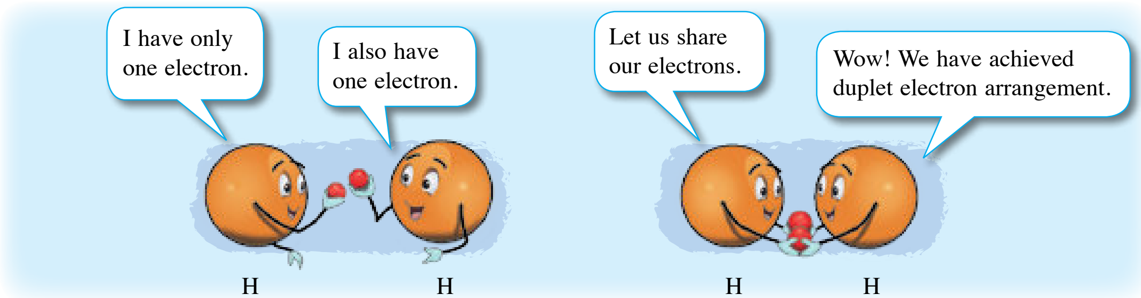


Figure 5.2 *Formation of covalent bond*

TestYourself 5.1

1. What is chemical bond?
2. State two types of chemical bonds.
3. Why noble gases do not form compounds?
4. Is the electron arrangement of sodium atom, Na stable? If not, explain how the electron arrangement can become stable.

5.2 Ionic Bond

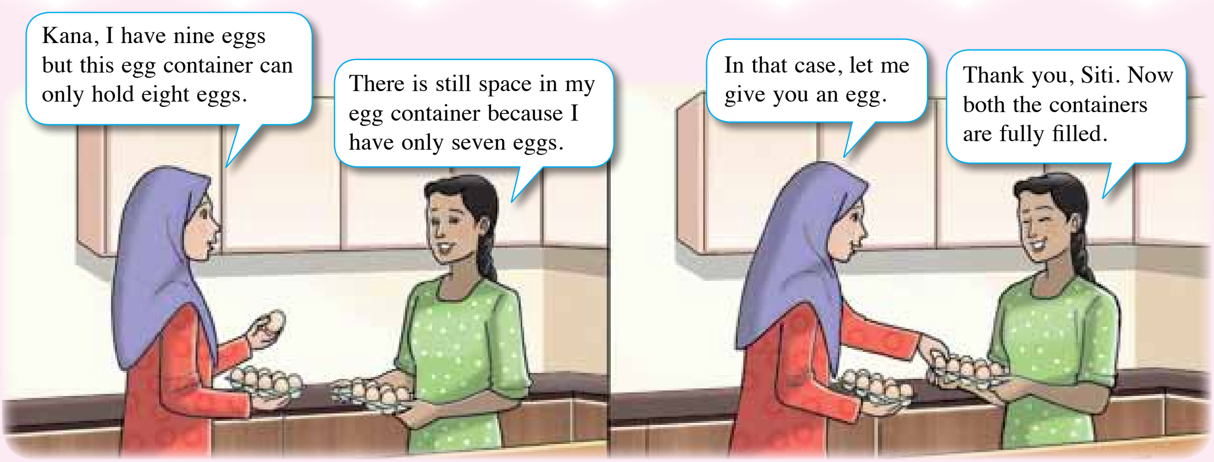


Figure 5.3 *Analogy for the formation of ionic bond*

Learning Standard

At the end of the lesson, pupils are able to:
5.2.1 Explain with examples the formation of ionic bond

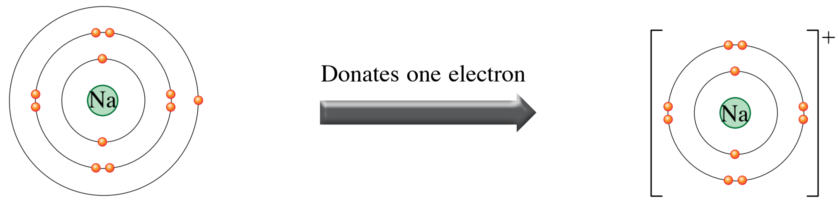
Situation in Figure 5.3 gives the analogy for the formation of ionic bond. **Ionic bond** is formed by the **transfer** of electrons between a metal atom and a non-metal atom.

Formation of Ions

Metal atom **donates** valence electron to form a positively-charged ion or cation. Figure 5.4 shows the formation of sodium ion, Na^+.

To achieve a stable electron arrangement, sodium atom, Na needs to donate an electron. The process of donating an electron from the valence shell of sodium atom, Na is much easier compared to accepting seven electrons from another atom.

After donating its valence electron, sodium ion, Na^+ achieves a stable octet electron arrangement. Sodium ion, Na^+ has 11 protons and 10 electrons, thus the charge for a sodium ion, Na^+ is +1.



2.8.1
Sodium atom, Na

2.8
Sodium ion, Na^+

Half-equation for the formation of sodium ion, Na^+:

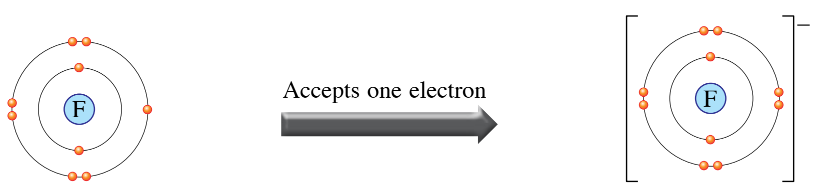
$$Na \longrightarrow Na^+ + e^-$$

***Figure 5.4** Formation of sodium ion, Na^+*

Non-metal atom **receives** electron from a metal atom to form a negatively-charged ion or anion. Figure 5.5 shows the formation of fluoride ion, F^-.

To achieve a stable electron arrangement, fluorine atom, F will accept an electron. The process of accepting one electron to the valence shell of fluorine atom, F is easier compared to donating its seven valence electrons to another atom.

After receiving one valence electron, fluoride ion, F^- achieves a stable octet electron arrangement. Fluoride ion, F^- has 9 protons and 10 electrons, so the charge of fluoride ion, F^- is –1.



2.7
Fluorine atom, F

2.8
Fluoride ion, F^-

Half-equation for the formation of fluoride ion, F^-:

$$F + e^- \longrightarrow F^-$$

***Figure 5.5** Formation of fluoride ion, F^-*

Formation of Ionic Bond

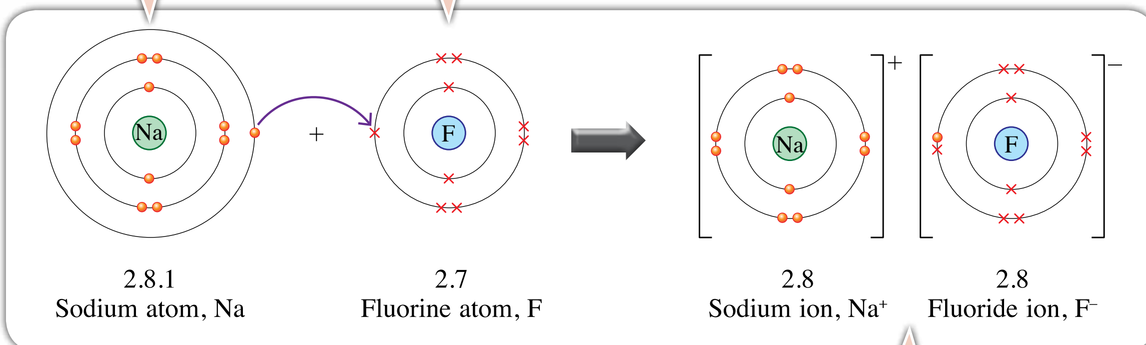
An ionic compound is formed when ions of opposite charges attract one another to form an ionic bond. How do ions of opposite charges attract one another?

Chemistry & Us

Besides calcium carbonate, $CaCO_3$, sodium fluoride, NaF is also added to toothpaste to strengthen the teeth.

Sodium atom, Na will donate one electron to achieve a stable octet electron arrangement. Sodium ion, Na^+ is formed.

Fluorine atom, F will accept one electron from sodium atom, Na to achieve a stable octet electron arrangement. Fluoride ion, F^- is formed.



Sodium ion, Na^+ and fluoride ion, F^- of opposite charges will attract one another by strong electrostatic attraction force. Electrostatic attraction forces are known as **ionic bonds**. A compound sodium fluoride, NaF is formed.

Figure 5.6 *Formation of sodium fluoride, NaF*

Activity 5.2

Discussing the formation of ionic bonds

21st Century Skills CT

AR

1. Carry out the Gallery Walk activity.
2. Gather information from various reading resources and websites on the formation of ionic bonds for the following compounds:

   Magnesium oxide, MgO | Sodium chloride, NaCl | Sodium oxide, Na_2O

3. Scan the AR code to see the formation of ionic compound of sodium chloride, NaCl.
4. Discuss the formation of ionic bonds with your group members and prepare a presentation. You need to write half-equations for the formation of ions in each compound.
5. Display your group work in class. Move around to see the outcome of other groups' discussion.
6. Write comments on their work on sticky notes and paste them.

Test Yourself 5.2

1. Aluminium atom, Al has 13 protons while fluorine atom, F has 9 protons.
   (a) Write the formulae of ions formed from the two atoms respectively.
   (b) Write half-equations for the formation of ions in (a).
   (c) Draw the electron arrangement to show the transfer of electrons in the formation of ionic bonds in aluminium fluoride compound.
2. *Muriate of Potash* is a type of fertiliser that has a high content of potassium chloride compound. [Proton number: Cl = 17, K = 19]
   (a) Write the chemical formula for potassium chloride.
   (b) Describe the formation of ionic bonds in potassium chloride compound.

5.3 Covalent Bond

Learning Standard

At the end of the lesson, pupils are able to:
5.3.1 Explain with examples the formation of covalent bond
5.3.2 Compare ionic bond and covalent bond

Did you know that diamond is one of the hardest substances in the world? The property of diamond is caused by the formation of **covalent bonds** between carbon atoms.

Covalent bonds are formed when non-metal atoms **share** their electrons to achieve a stable duplet or octet electron arrangement. There are three types of covalent bonds; single bond, double bond and triple bond.

Single Bond

A single bond is formed when two atoms share a **pair of electrons**.

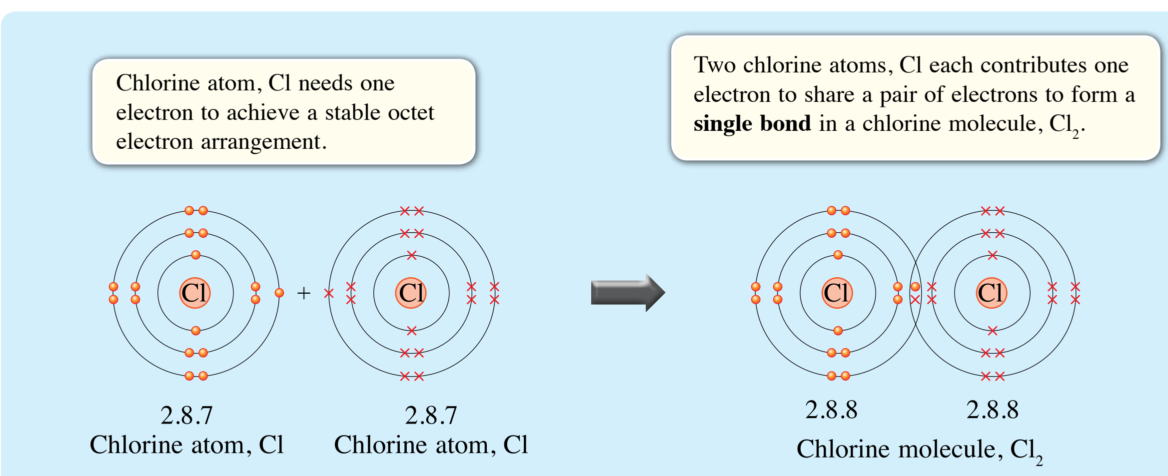


***Figure 5.7** Formation of single bond in chlorine molecule, Cl_2*

The formation of covalent bond can be visualised using the **Lewis structure**. Lewis structure only shows the valence electrons of the atoms involved. A pair of electrons shared, is represented with a line between the two atoms.

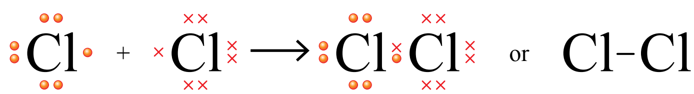
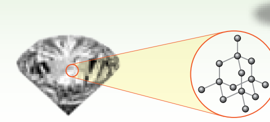


Figure 5.8 *Lewis structure for the formation of chlorine molecule,* Cl_2

Chemistry Lens AR



Diamond consists of carbon atoms, C. Each carbon atom, C forms four covalent bonds with another four carbon atoms.

Double Bond

A double bond is formed when two atoms share **two pairs of electrons.**

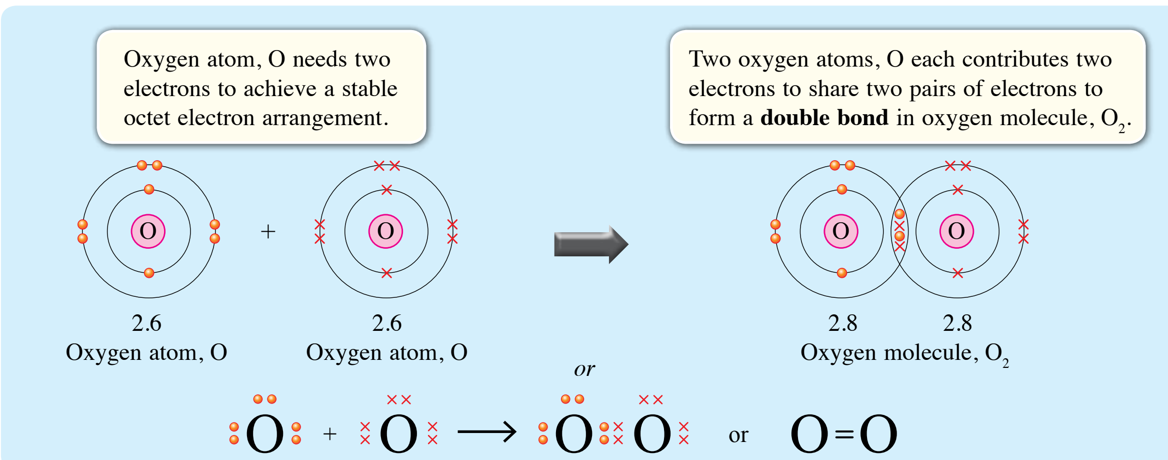


Figure 5.9 *Formation of double bond in oxygen molecule,* O_2

Triple Bond

A triple bond is formed when two atoms share **three pairs of electrons**.

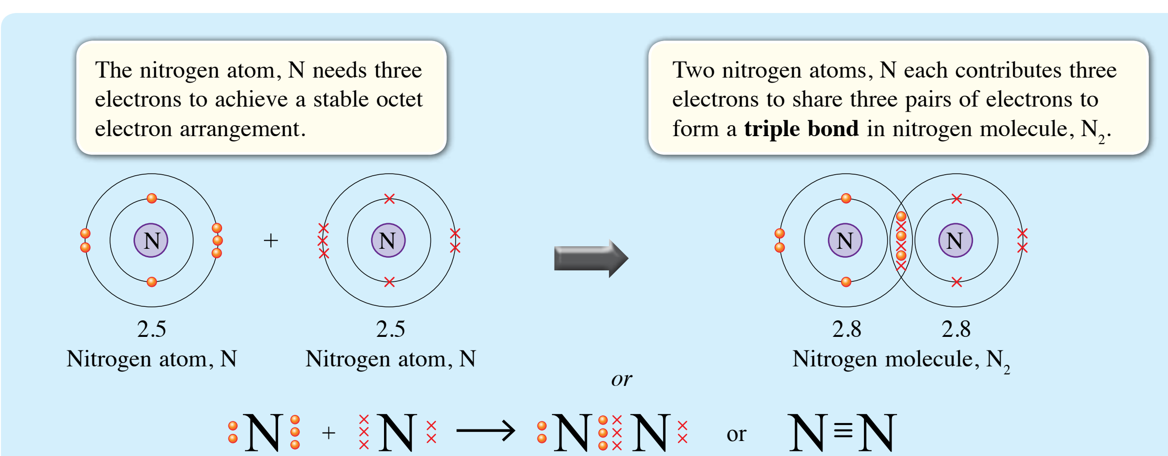


Figure 5.10 *Formation of triple bond in nitrogen molecule,* N_2

Activity 5.3

21st Century Skills CT

Visualising the formation of covalent bonds

1. Carry out the Three Stray One Stay activity.
2. Build a model to visualise the formation of covalent bonds in the following compounds.

Hydrogen, H_2 | Hydrogen chloride, HCl | Oxygen, O_2 | Carbon dioxide, CO_2 | Nitrogen, N_2

3. Prepare an exhibition corner in the class and display the models from each group.
4. Choose a representative to give an explanation on the formation of covalent bond in a chosen compound. The rest of the members will move around to seek information from other groups.

Comparison between Ionic Bond and Covalent Bond

Similarities and differences between ionic bond and covalent bond are shown in Figure 5.11.

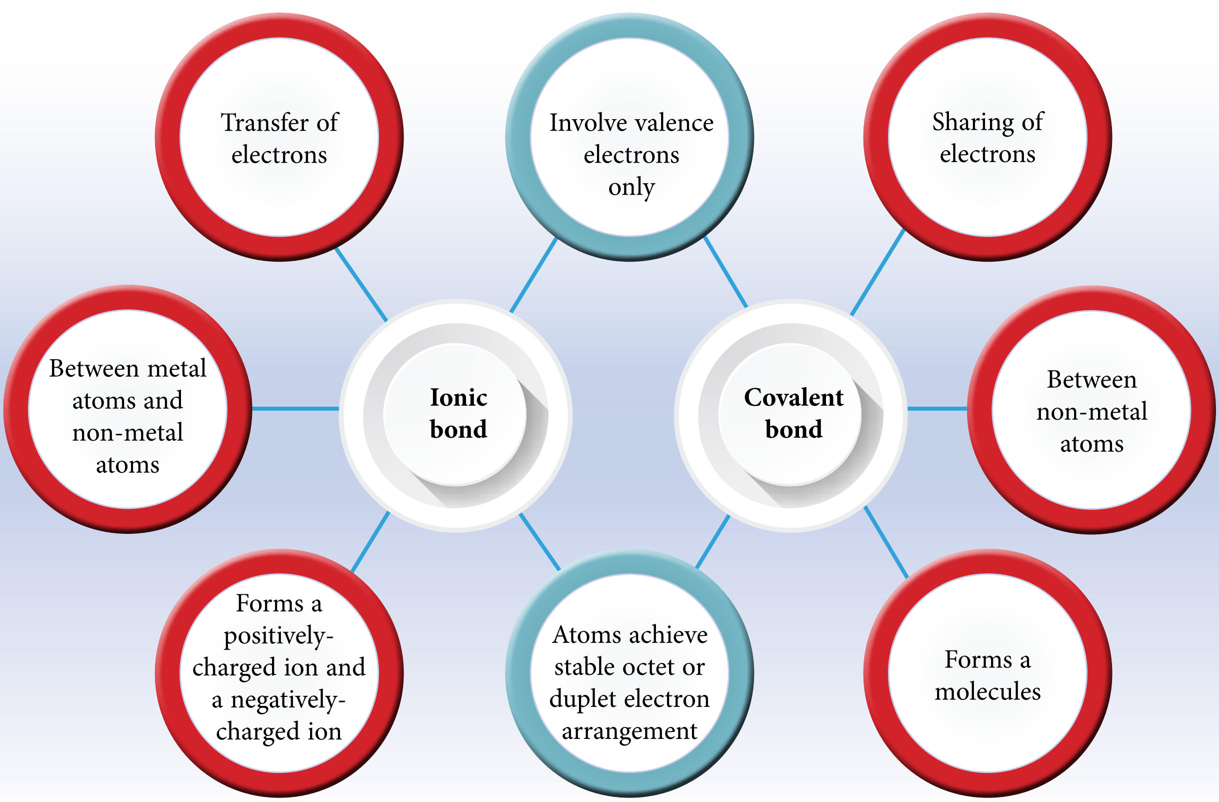


Figure 5.11 Comparison between ionic bond and covalent bond

Test Yourself 5.3

1. State three types of covalent bonds.
2. How are covalent bonds formed?
3. Draw the formation of covalent bonds in a water molecule, H_2O.
4. Can carbon atoms, C share electrons with four hydrogen atoms, H to form a methane molecule? Explain. [Proton number: H = 1, C = 6]
5. State one similarity and two differences between ionic bond and covalent bond.

5.4 Hydrogen Bond

Have you ever thought why an iceberg weighing thousands of tonnes is able to float on the surface of the sea? This is because the density of ice is lower compared with water. Why is water denser than ice? To answer this question, the concept of hydrogen bonds needs to be understood.

Hydrogen bonds are attraction forces between hydrogen atom, H that has bonded with an atom of high electronegativity, such as nitrogen, N, oxygen, O or fluorine, F with nitrogen, N, oxygen, O or fluorine, F in another molecule. For example, water molecule, H_2O can form hydrogen bonds among water molecules, H_2O.

Learning Standard

At the end of the lesson, pupils should be able to:
5.4.1 Explain with examples the formation of a hydrogen bond
5.4.2 Explain the effect of the hydrogen bond on physical properties of substances

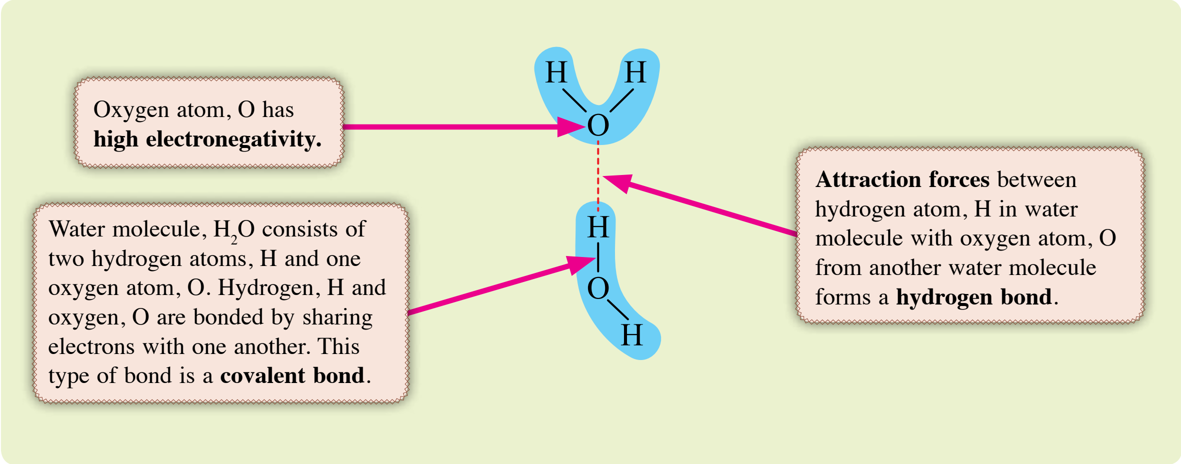


Figure 5.12 Formation of hydrogen bonds between water molecules, H_2O

Activity 5.4

21st Century Skills CT

Discussing the formation of hydrogen bonds in hydrogen fluoride, HF and ammonia, NH_3

1. Carry out the Think-Pair-Share activity.
2. Based on Figure 5.12, think about how hydrogen bonds are formed in hydrogen fluoride, HF and ammonia, NH_3.
3. Discuss with your partner.
4. Share your findings in front of the class.

Role of Hydrogen Bonds in Daily Life

Observe Figure 5.13. There are protein molecules that form hydrogen bonds among one another in the hair structure. Do you know why hair sticks together when wet?

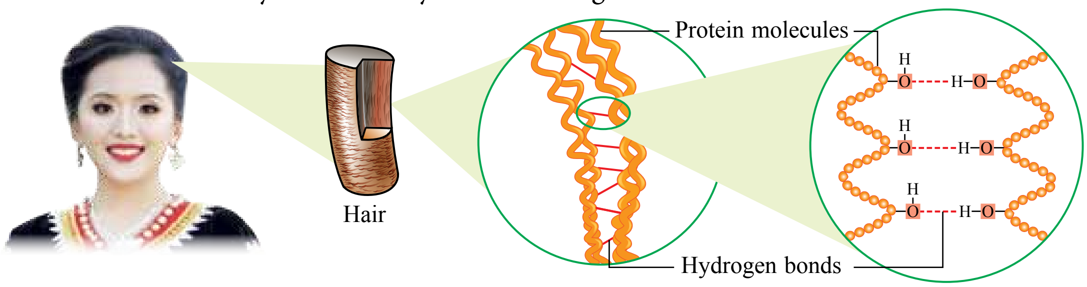


Figure 5.13 Hydrogen bonds between protein molecules in the hair structure

When hair is wet, protein molecules no longer form hydrogen bonds among themselves. Instead, protein molecules will form hydrogen bonds with water molecules, H_2O. Water molecules, H_2O will also form hydrogen bonds with other hair protein molecules. This causes hair to stick together.

Have you ever come across the problem of turning the pages of a book where the pages stick together? To overcome this problem, you lick your finger before turning the pages. Why does a wet finger help to turn the pages of a book? Explanation on this is given in Figure 5.15.

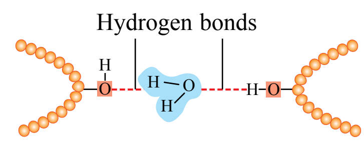


Figure 5.14
Formation of hydrogen bond between protein molecule and water molecule

Brain Teaser

Why does wavy hair look straight when wet?

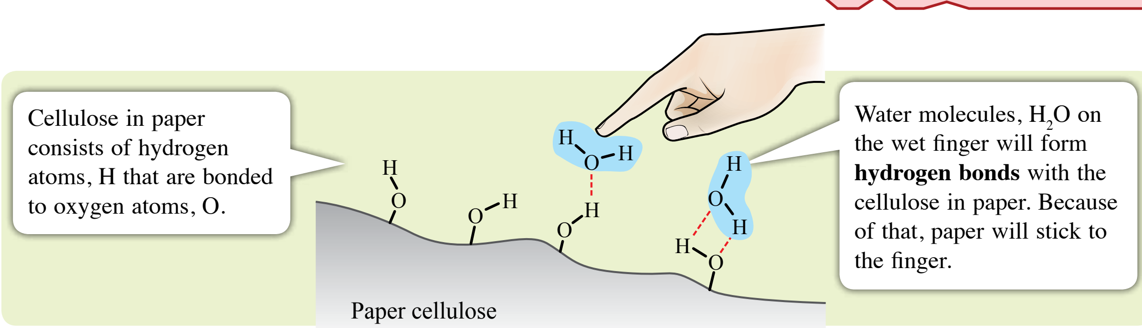


Figure 5.15 *Hydrogen bonds formed between cellulose in paper and water molecule, H_2O on the finger*

Effect of Hydrogen Bonds on The Physical Properties of Substances

Compounds in the form of liquids reach boiling point when the attraction forces between molecules are overcomed. In the covalent compound of ethanol, C_2H_5OH, there are hydrogen bonds formed between molecules, other than weak Van der Waals attraction forces. Strong hydrogen bonds are difficult to break. More heat energy is required to overcome the weak Van der Waals attraction forces, besides breaking the hydrogen bonds. As a result, the boiling point of ethanol, C_2H_5OH is high. On the other hand, molecules like chlorine, Cl_2 which do not form hydrogen bonds have lower boiling point compared to ethanol.

Ethanol, C_2H_5OH is also soluble in water. The solubility of ethanol, C_2H_5OH in water is due to the formation of hydrogen bonds between the ethanol molecule, C_2H_5OH and water molecule, H_2O.

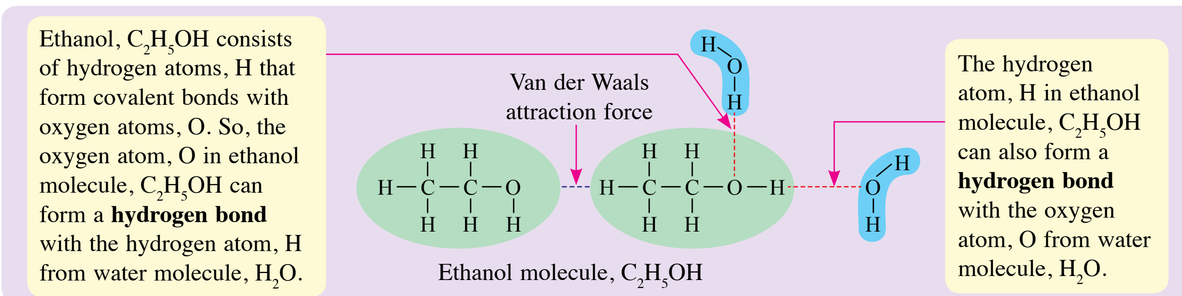


Figure 5.16 *Solubility of ethanol, C_2H_5OH in water, H_2O*

Activity 5.5

Discussing the solubility in water and boiling point of covalent compounds

21st Century Skills CT

1. Carry out the Round Table activity.
2. Gather information on the solubility in water and boiling point for hydrogen fluoride, HF and ammonia, NH_3 from various reading materials and websites.
3. Compare the solubility and boiling point for these compounds with molecules that do not form hydrogen bonds.
4. Take turns to record the related information on a piece of paper.
5. Pin up your group work on the classroom bulletin board to share the information and references with other groups.

TestYourself 5.4

1. State the meaning of hydrogen bond.
2. Hydrogen fluoride, HF exists as liquid at room temperature. Explain this phenomenon based on the formation of hydrogen bonds.
3. Can hydrogen bonds form among hydrogen chloride molecules, HCl? Justify your answer.
4. Explain why paper sticks together when wet.

5.5 Dative Bond

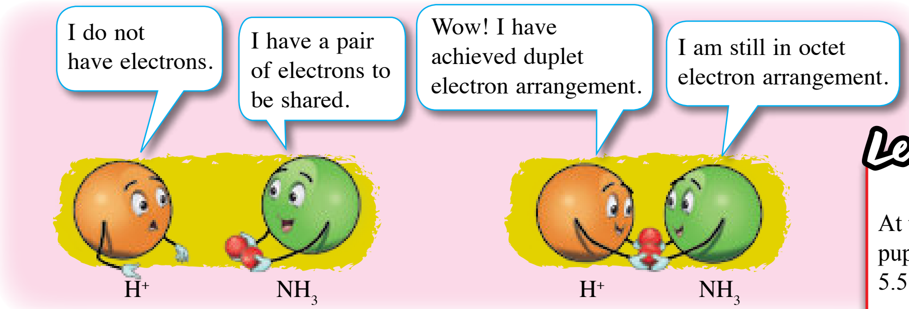


Figure 5.17 *Formation of dative bond*

Learning Standard

At the end of the lesson, pupils should be able to:
5.5.1 Explain with examples the formation of dative bond

Dative bond or coordinate bond is a type of covalent bond where the electron pair that is shared comes from one atom only. How does such sharing take place? Figure 5.18 shows the formation of dative bond in hydroxonium ion, H_3O^+.

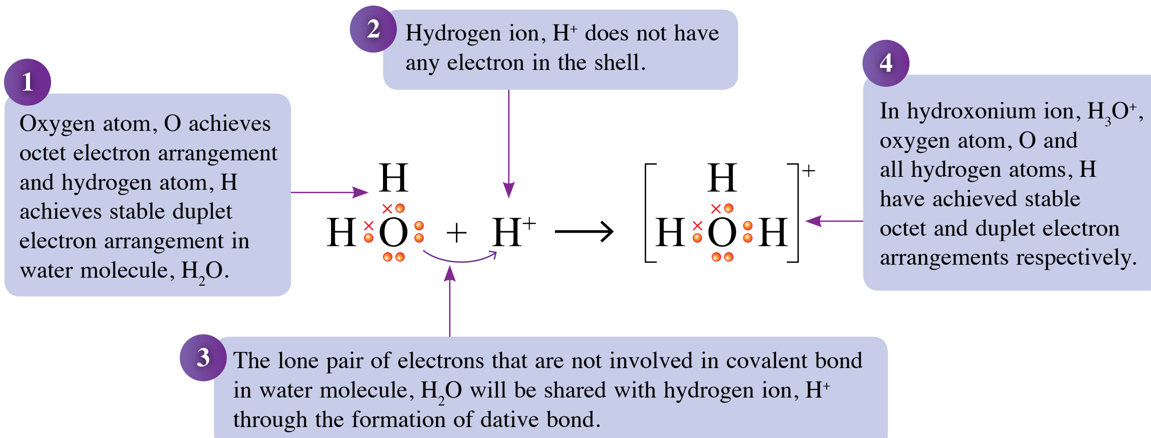


Figure 5.18 *Formation of dative bond in hydroxonium ion, H_3O^+*

Activity 5.6

Discussing the formation of dative bond in ammonium ion, NH_4^+

1. Carry out this activity in groups.
2. Based on the statement below, discuss the formation of dative bonds in ammonium ion, NH_4^+.

   When hydrogen chloride gas, HCl and ammonia gas, NH_3 are mixed, white fumes of ammonium chloride, NH_4Cl is formed as shown in Photograph 5.1.

3. Present your discussion results in an attractive presentation in front of the class.

Photograph 5.1
Formation of white fumes of ammonium chloride, NH_4Cl

Test Yourself 5.5

1. What is dative bond?
2. Explain the formation of ammonium ion through the formation of dative bond between hydrogen ion, H^+ and nitrogen atom, N in ammonia, NH_3.
3. Boron atom, B found in the compound boron trifluoride, BF_3 has not achieved octet electron arrangement because it has only six valence electrons. Can boron atoms, B form dative bonds with nitrogen atoms, N in the compound ammonia, NH_3? Explain your answer.

5.6 Metallic Bond

Learning Standard

At the end of the lesson, pupils should be able to:
5.6.1 Explain the formation of a metallic bond
5.6.2 Reason out the electrical conductivity of metal

Did you know that exposed electrical wires can cause electric shock? Electrical wires made from metal can conduct electricity. Why can metals conduct electricity?

Metal atoms are arranged closely packed and orderly in the solid state. Valence electrons of metal atoms can be donated easily and **delocalised** although in the solid state. Metal ions that are positively-charged are formed when valence electrons are delocalised. All delocalised valence electrons can move freely between the metal structure and form a **sea of electrons**. Electrostatic attraction force between the sea of electrons and the positively-charged metal ions form the **metallic bond**.

Chemistry Lens

Delocalised electron means electron that moves freely and is not owned by any atom nor ion. A sea of electron is formed when the valence shells of metal atoms overlap, resulting in electron delocalisation.

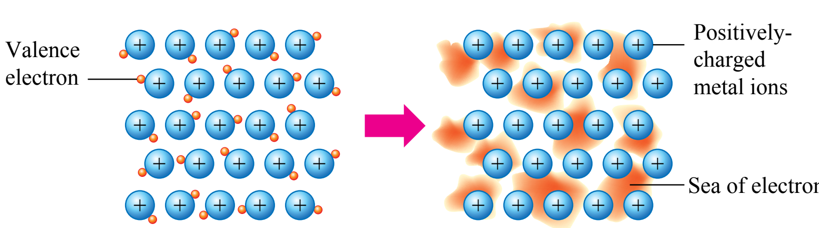


Figure 5.19 *Formation of metallic bond*

When electrons of metal atoms are delocalised in the sea of electrons, the metal can conduct electricity. Electrons that move freely in the metal structure carry the charges from the negative terminal to the positive terminal when electricity is supplied, as shown in Figure 5.20.

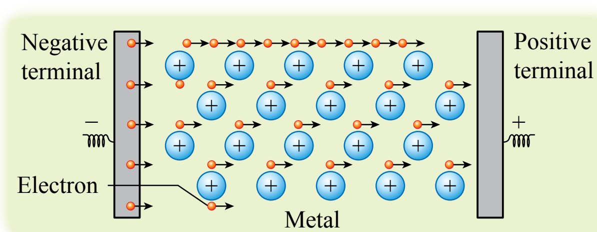


Figure 5.20 *Electrical conductivity of metals*

Activity 5.7

21st Century Skills CT

Comparing and contrasting the formation of bonds

1. Carry out the Think-Pair-Share activity.
2. Using suitable mind maps, compare and contrast the formation of all bonds studied from the following aspects:
   (a) Sharing or transfer of electrons
   (b) Attraction forces formed
   (c) Examples of compounds or elements
3. Pin up your mind maps produced on the classroom bulletin board.

Test Yourself 5.6

1. What is meant by a delocalised electron?
2. How a metallic bond is formed in metals?
3. Using aluminium, Al metal as an example, explain how metals can conduct electricity.

5.7 Properties of Ionic Compounds and Covalent Compounds

Learning Standard

At the end of the lesson, pupils should be able to:
5.7.1 Compare the properties of ionic compounds and covalent compounds through experiment
5.7.2 Explain with examples the uses of ionic compounds and covalent compounds in daily life

Observe salt (sodium chloride, NaCl) and ice in Photograph 5.2. Are both substances in the same physical state? Which substance will melt at room temperature?

Salt is an ionic compound

Ice is a covalent compound

***Photograph 5.2** Example of ionic compound and covalent compound*

Different compounds have different properties. The different properties of ionic compounds and covalent compounds can be studied through Experiment 5.1.

Experiment 5.1

Aim: To study the difference in properties between ionic compounds and covalent compounds.

Problem statement: What are the difference in properties between ionic compounds and covalent compounds?

Materials: Solid lead(II) bromide, $PbBr_2$, naphthalene, $C_{10}H_8$, magnesium chloride, $MgCl_2$, cyclohexane, C_6H_{12} and distilled water

Apparatus: Test tubes, spatula, evaporating dish, Bunsen burner, pipeclay triangle, wire gauze, beaker, 10 cm^3 measuring cylinder, tripod stand, battery, switch, light bulb and carbon electrodes

A Electrical conductivity of compounds

CAUTION

Carry out this experiment in the fume chamber.

Hypothesis: Ionic compounds can conduct electricity in molten state but not in the solid state while covalent compounds cannot conduct electricity in both states.

Safety Precaution

- Naphthalene, $C_{10}H_8$ is a flammable substance.
- Bromine gas, Br_2 produced during the heating of lead(II) bromide, $PbBr_2$ is poisonous.

Variables:

(a) Manipulated : Type of compound

(b) Responding : Electrical conductivity

(c) Fixed : Carbon electrode

Procedure:

1. Put lead(II) bromide, $PbBr_2$ powder into the crucible until half full.
2. Set up the apparatus as shown in Figure 5.21.
3. Switch on and observe whether the bulb lights up.
4. Switch off and heat the lead(II) bromide, $PbBr_2$ powder until all solids have melted.
5. Switch on once again and observe whether the bulb lights up.
6. Repeat steps 1 to 5 using naphthalene, $C_{10}H_8$ powder.
7. Record your observations on the condition of the bulb in Table 5.1

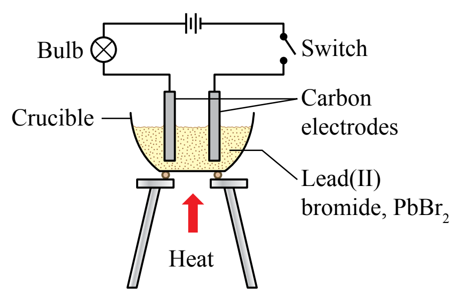


Figure 5.21

Results:

Table 5.1

Compound	Physical state	Condition of bulb
Lead(II) bromide, $PbBr_2$	Solid	
	Molten	
Naphthalene, $C_{10}H_8$	Solid	
	Molten	

Chemistry & Us

Excessive exposure to naphthalene, $C_{10}H_8$ can cause haemolytic anaemia, liver and nervous system failure, cataract and bleeding of the retina.

B Solubility of compound in water and organic solvents

Make hypothesis and state all variables.

Procedure:

1. Put half spatula of magnesium chloride, $MgCl_2$ powder into the test tube.
2. Add 5 cm^3 of distilled water into the test tube and shake gently.
3. Observe the solubility of magnesium chloride, $MgCl_2$ in water.
4. Repeat steps 1 to 3 using cyclohexane, C_6H_{12} as the solvent.
5. Repeat steps 1 to 4 and substitute magnesium chloride, $MgCl_2$ with naphthalene, $C_{10}H_8$.
6. Record your observations on the solubility of compounds in Table 5.2.

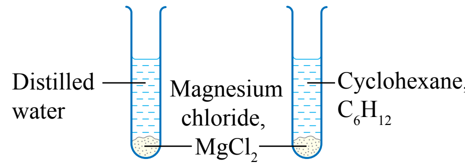


Figure 5.22

Results:

Table 5.2

Compounds	Solubility in distilled water	Solubility in cyclohexane, C_6H_{12}
Magnesium chloride, $MgCl_2$		
Naphthalene, $C_{10}H_8$		

C Melting point and boiling point of compound

Make hypothesis and state all variables.

Procedure:

1. Put half spatula of magnesium chloride, $MgCl_2$ powder and naphthalene, $C_{10}H_8$ into separate test tubes.
2. Heat both test tubes in the water bath as shown in Figure 5.23.
3. Observe and record the change in physical states and make inference of both substances in Table 5.3.

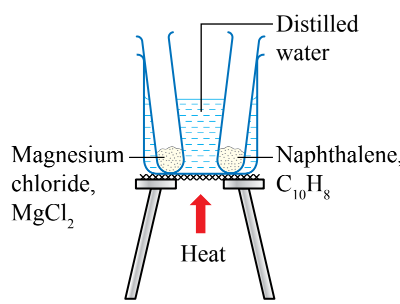


Figure 5.23

Results:

Table 5.3

Compound	Observation	Inference
Magnesium chloride, $MgCl_2$		
Naphthalene, $C_{10}H_8$		

Conclusion:

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

Discussion:

1. What type of compound is lead(II) bromide, $PbBr_2$, magnesium chloride, $MgCl_2$ and naphthalene, $C_{10}H_8$?
2. Predict the electrical conductivity, solubility, melting point and boiling point of sodium chloride, NaCl.

Prepare a complete report after carrying out this experiment.

Electrical Conductivity

Based on Experiment 5.1, ionic compounds and covalent compounds have different electrical conductivity. Ionic compounds cannot conduct electricity in the solid state but can conduct electricity in the molten state and aqueous solution while covalent compounds cannot conduct electricity in all states.

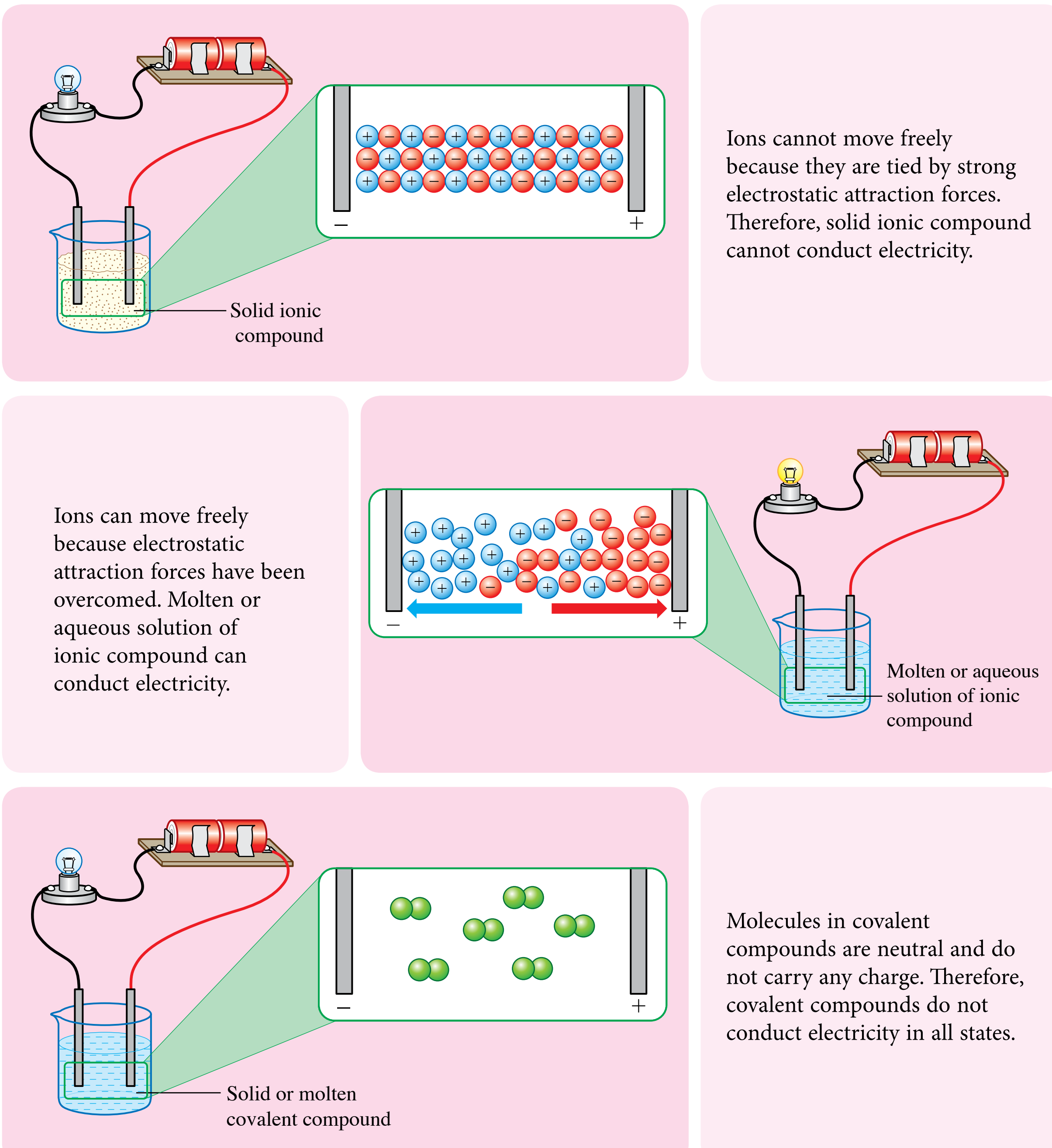


Figure 5.24 *Electrical conductivity of ionic compounds and covalent compounds*

Solubility in Water and Organic Solvents

Most ionic compounds are soluble in water but are not soluble in organic solvents. On the other hand, most covalent compounds are not soluble in water but are soluble in organic solvents.

When dissolved in water, water molecules help to overcome electrostatic attraction force between ions and break down the lattice structure of the solid compound. As a result, ions can move freely in water.

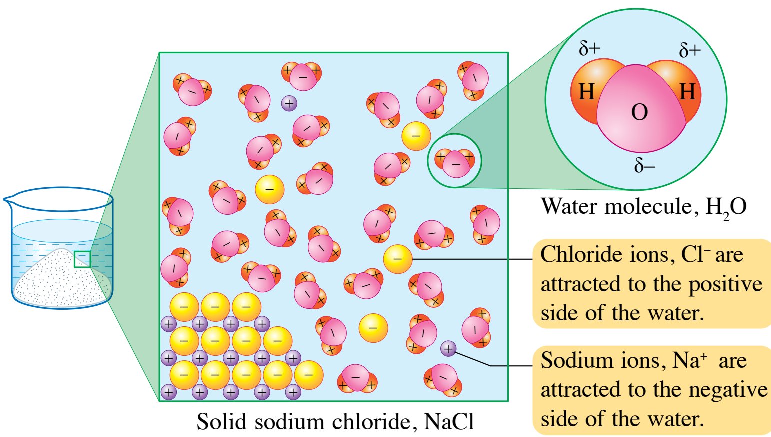
Chemistry Lens

Lattice structure is the orderly arrangement of atoms, ions or molecules of a compound in a solid crystal.

Chemistry Lens

The figure below shows the solubility of sodium chloride, NaCl in water. Water is a polar solvent that has partial negative charge at the oxygen atom and partial positive charge at the hydrogen atom. Positive ion, Na^+ will be attracted to the oxygen atom of water molecule which is negatively-charged while negative ion, Cl^- will be attracted to the hydrogen atom of water molecule which is positively-charged.

Attraction force between atom of water molecules with the ions of ionic compound are strong enough to overcome electrostatic attraction force between ions themselves. This enables most solid ionic compounds to be soluble in water.



Literacy Tips

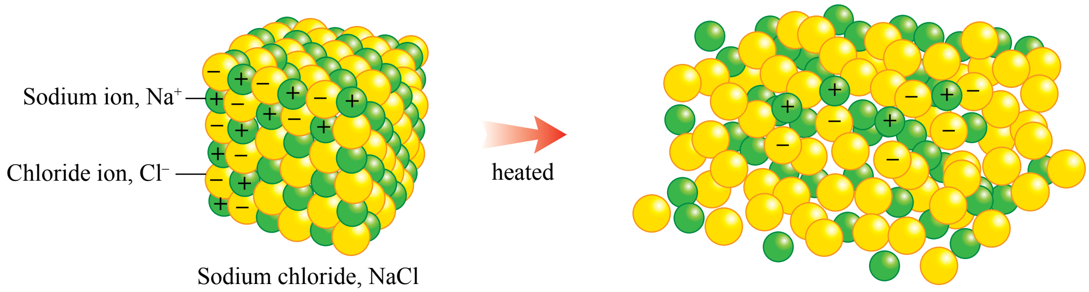
In a water molecule, oxygen atom has a higher electronegativity than hydrogen atom. This causes the electrons shared in the covalent bond to be pulled towards the oxygen atom. The unequal sharing of electrons creates partial negative charge, δ– at the oxygen atom and partial positive charge, δ+ at the hydrogen atom.

Organic solvents cannot overcome electrostatic forces between ions in a solid ionic compound. So, ionic compounds are not soluble in organic solvents. Molecules in a covalent compound are neutral and do not carry any charges. So, molecules in a covalent compound are soluble in an organic solvent but not soluble in water.

Melting Point and Boiling Point

You have learned that ionic compounds and covalent compounds are formed by ionic bonds and covalent bonds respectively. Do you know that both the chemical bonds influence the melting point and boiling point of a compound? Are these chemical bonds overcomed when compounds are melted or boiled?

Ionic compounds have **high melting point and boiling point**. Therefore, ionic compounds are not easily volatile.

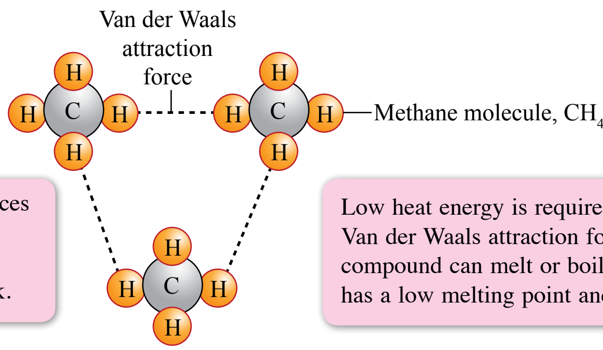


An ionic compound like sodium chloride, NaCl consists of positive ions, Na^+ and negative ions, Cl^- that attract one another by strong electrostatic attraction forces.

High heat energy is required to overcome the strong electrostatic attraction forces so that the ionic compound can melt or boil. Thus, sodium chloride, NaCl has a high melting point and boiling point.

Figure 5.25 *Ionic compounds have high melting point and boiling point*

Covalent compounds with simple molecules have **low melting point and boiling point**. Hence, covalent compounds with simple molecules are easily volatile.



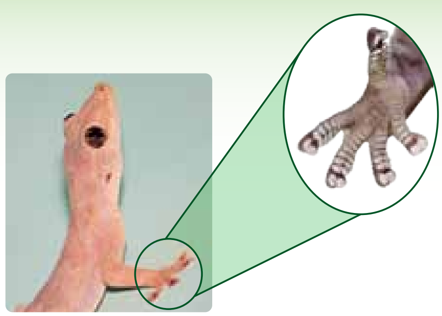
Van der Waals attraction forces between simple molecules in covalent compounds like methane, CH_4 are very weak.

Low heat energy is required to overcome the weak Van der Waals attraction forces so that the covalent compound can melt or boil. Thus, methane, CH_4 has a low melting point and boiling point.

Figure 5.26 *Covalent compounds with simple molecules have low melting point and boiling point*

Chemistry Lens

Lizards can stick to the surface of walls. This is due to the reaction between some electrons from the molecules of the hundreds of fine hairs found on the sole of the lizard's feet and some electrons from the molecules of the wall. This reaction forms the electromagnetic attraction known as Van der Waals attraction forces.



Structure of Covalent Compounds

There are two types of molecular structure for covalent compounds which are simple molecular structure and giant molecular structure. What is the difference between the simple molecular structure and giant molecular structure in covalent compounds?

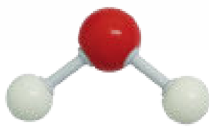
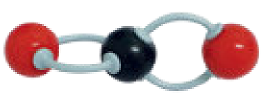
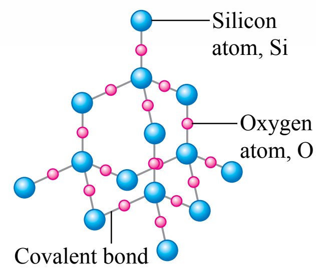
Simple molecule	Covalent compound	Giant molecule
 Water, H_2O  Carbon dioxide, CO_2	Example	 Silicon dioxide, SiO_2
Small and simple structures can be found in the form of solids, liquids or gases.	Structure	Very large structure, usually exists as solids.
Covalent bonds are strong in the molecules and Van der Waals attraction forces between molecules are weak.	Chemical bond	Strong covalent bonds in the molecules only. No Van der Waals attraction forces between molecules because of its giant structure.
Low because only little heat is required to overcome the weak Van der Waals attraction forces between molecules.	Melting point and boiling point	High because a lot of heat is required to break the strong covalent bonds.

Figure 5.27 *Difference between simple molecule and giant molecule in covalent compounds*

Uses of Ionic Compounds and Covalent Compounds in Our Daily Lives

Most ionic compounds and covalent compounds used in our daily lives are in the industrial sector, agriculture, medicine and domestic use.

Industrial sector

The ionic compound of lithium iodide, LiI is used in batteries.

Paint contains covalent compounds such as pigment and turpentine solvent.

Agricultural sector

The ionic compounds of ammonium nitrate, NH_4NO_3 and potassium chloride, KCl are used in fertilisers.

Pesticides used to kill weeds and insects contain covalent compounds such as bromoethane, C_2H_5Br and chloropicrin, CCl_3NO_2.

The uses of ionic compounds and covalent compounds in daily life

Medical sector

The ionic compound of sodium bicarbonate, $NaHCO_3$ is used in antacids to relieve gastric pain.

Paracetamol, $C_8H_9NO_2$ is a covalent compound used to treat fevers and irritation.

Domestic use

Detergents contain the ionic compound, sodium chlorate(V), $NaClO_3$, which is used for domestic cleaning.

Glycerol, $C_3H_5(OH)_3$ is a covalent compound added to skincare products to moisturise skin and help to prevent dry skin.

Figure 5.28 *Uses of ionic compounds and covalent compounds in our daily lives*

Activity 5.8

Carry out a problem-solving project on the use of ionic compounds and covalent compounds in daily life

21st Century Skills CT

1. Carry out this activity in groups.
2. Read and understand the following passage:

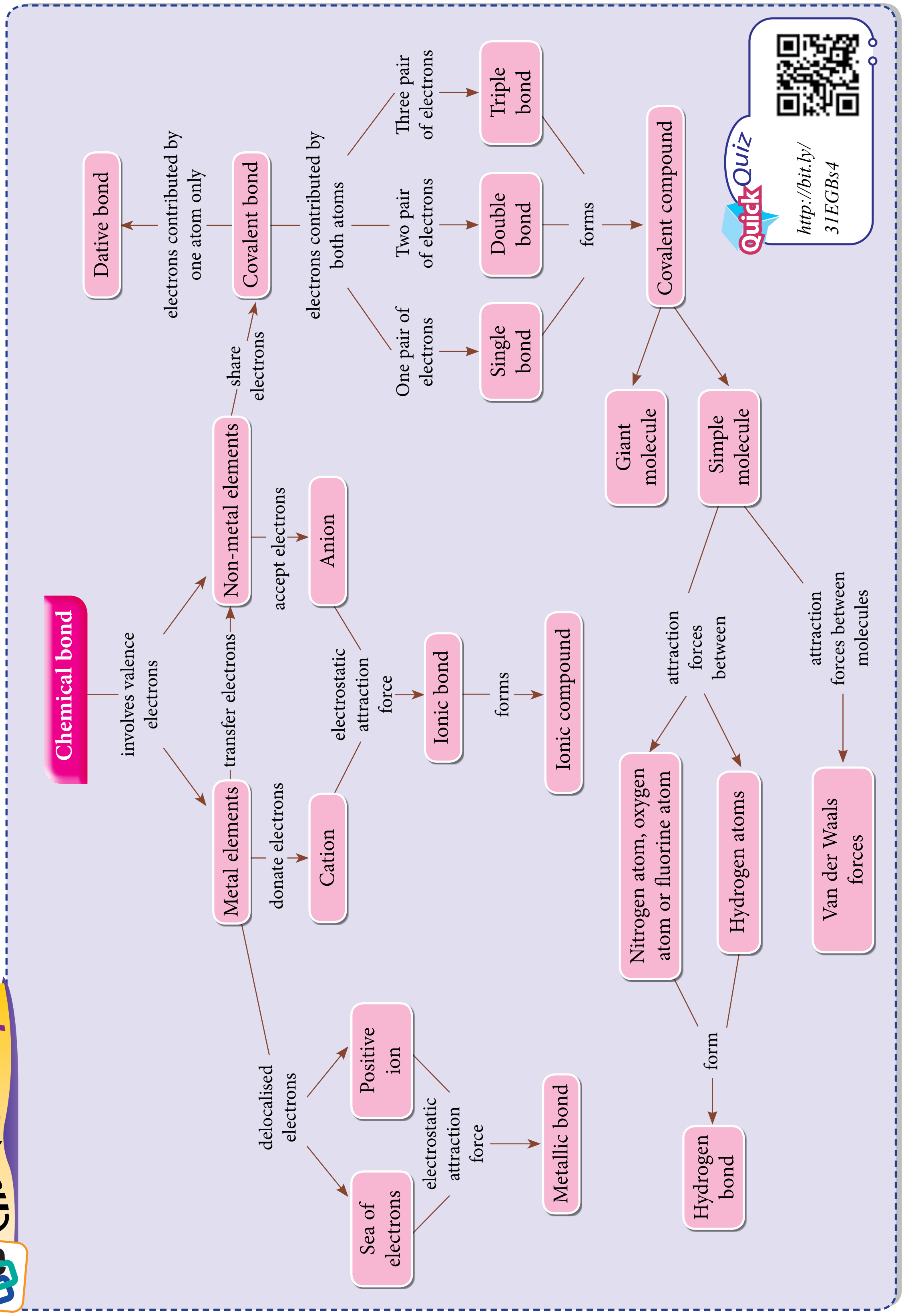
> Plastic particles in the sea can cause problems to aquatic life ranging from plankton, fish to big animals like turtles, dolphins and whales. The problem of aquatic life is not only the direct intake of plastics but also the chemicals in the plastics that can be absorbed into the tissues of these aquatic life.

3. Apart from the problem above, surf the Internet to find information about the problems of using ionic compounds and covalent compounds in one of the following fields:
   (a) Industry
   (b) Agriculture
   (c) Medicine
   (d) Domestic
4. Discuss the ways to solve the problems.
5. Present your findings in front of the class and carry out a question and answer session to improve the proposals of each group.

Test Yourself 5.7

1. Compare the melting point and boiling point of ionic compounds and covalent compounds.
2. Give one similarity between simple molecule and giant molecule of covalent compounds.
3. Magnesium hydroxide, $Mg(OH)_2$ known as milk of magnesia, is a type of ionic compound used to relieve gastric pain.
   (a) State the solubility of magnesium hydroxide, $Mg(OH)_2$ in water.
   (b) Can magnesium hydroxide, $Mg(OH)_2$ conduct electricity in the solid state?
   (c) Explain your answer in 3(b).
4. Diamond is a giant molecule of covalent compound while methane, CH_4 is a simple molecule of covalent compound.
   (a) Compare the melting point and boiling point of diamond and methane, CH_4. Explain.
   (b) Predict the electrical conductivity of diamond. Explain your prediction.

Chain Concept



SELF Reflection

1. What new knowledge have you learned in **Chemical Bond?**
2. Which is the most interesting subtopic in **Chemical Bond**? Why?
3. Give a few examples on the application of **Chemical Bond** in daily life.
4. Rate your performance in **Chemical Bond** 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 else would you like to know about **Chemical Bond**?

http://bit.ly/31le1ft

Achievement Test 5

1. What is the meaning of covalent bond?

2. Why does silicon dioxide, SiO_2 have a high melting point and boiling point?

3. Figure 1 shows several elements in the Periodic Table of Elements that are represented by letters *A*, *D*, *E*, *G* and *H*.

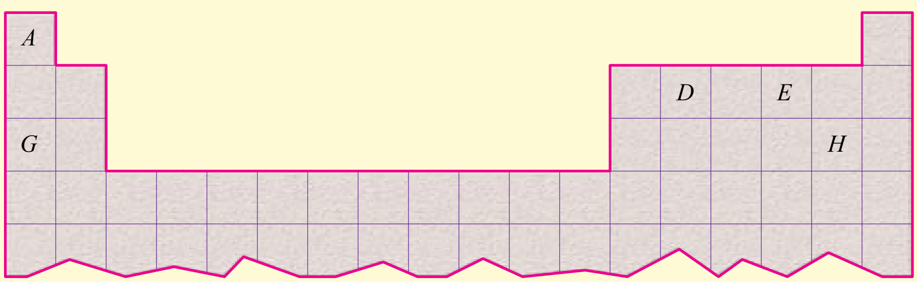


Figure 1

   (a) State the elements that can combine to form ionic compounds.
   (b) Element *D* reacts with element *E* to form a covalent compound. Write the chemical formula of the covalent compound formed.
   (c) Atoms of element *H* combine to form diatomic molecules at room temperature. Explain the melting point and boiling point of molecule *H*.

4. Figure 2 shows the chemical symbols for elements *Q* and *R*.
   (a) Write the electron arrangement for atom *Q* and atom *R*.
   (b) Element *Q* and element *R* react to form compound *S*.
      (i) State the type of chemical bond formed.
      (ii) Explain the process of formation of compound *S*.

$^{24}_{12}Q$ $^{16}_{8}R$

Figure 2

5.
- Atom of element *J* has 12 neutrons and 23 nucleon number
- Atom of element *K* has 9 protons

   (a) Which element is a metal?
   (b) Explain how element *J* combines with element *K* to form white solid *T*.

6. Element *D* combines with element *E* to form a covalent compound with chemical formula ED_3. Element *D* has a proton number of 17. Predict the electron arrangement of the atom of element *E* with reasonable explanation.

7. Water, H_2O exists as liquid while hydrogen chloride, HCl exists as gas at room temperature. Explain this phenomenon based on the formation of hydrogen bonds.

8. Copper, Cu is a metal that is commonly used in the manufacturing of electric wires. Explain briefly how this metal can conduct electricity.

9. Kevin found a beaker filled with white solid left on top of the table in a laboratory. He would like to know what type of compound the white solid is. He carried out several tests to investigate the physical properties of the white solid and obtained the following results:

- Soluble in water
- Can conduct electricity in liquid state

   Based on your observation and knowledge, predict the type of compound of this white solid. Explain your prediction.

Enrichment Corner

1. Deoxyribonucleic acid, DNA in organism is a complex macromolecule that stores genetic information. DNA consists of polynucleotides that coil around each other to form the double helix structure as shown in Figure 1(a). Based on the DNA structure as shown in Figure 1(b), explain how polynucleotides coil around each other using the concept of hydrogen bonds.

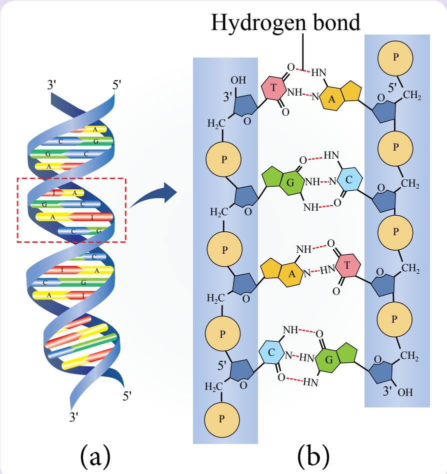


Figure 1

Check Answers

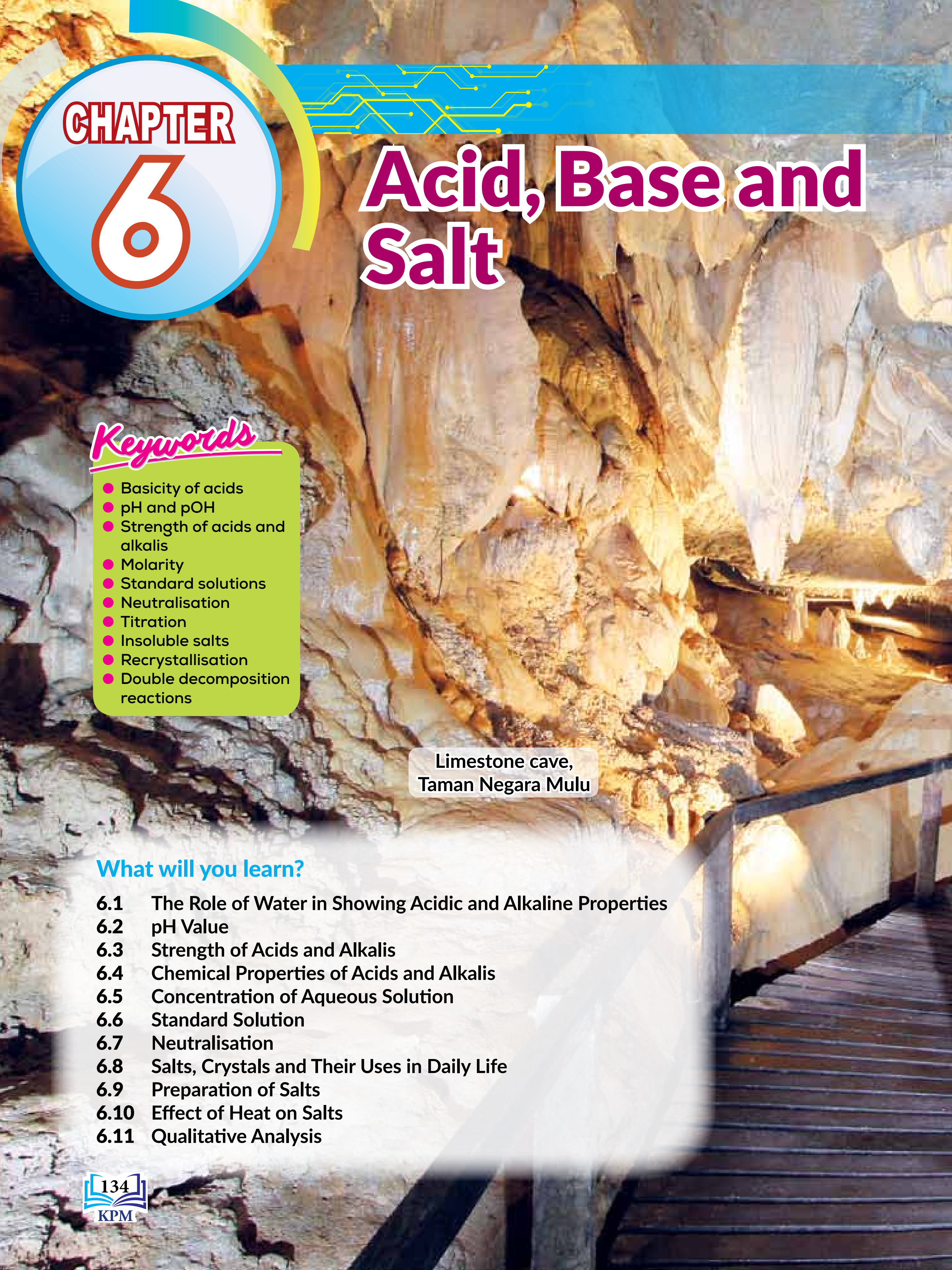
https://bit.ly/2PbIFFq

CHAPTER 6

Acid, Base and Salt

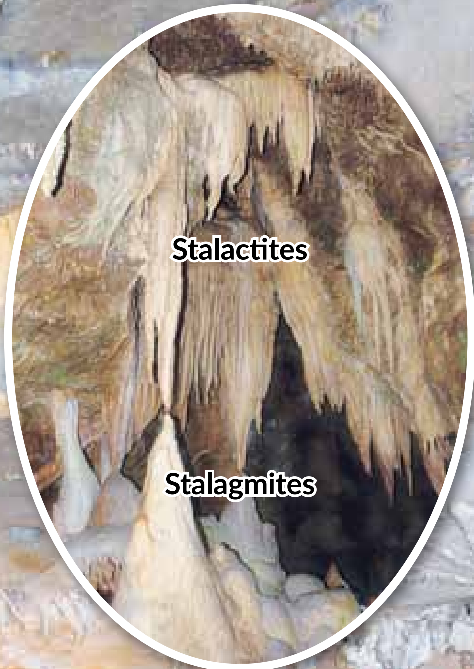
Keywords

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



Limestone cave, Taman Negara Mulu

What will you learn?



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*

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

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^+.

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

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^+**.

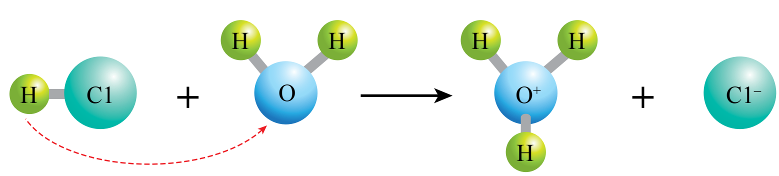


***Figure 6.2** Formation of hydroxonium ion, H_3O^+*

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.

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

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

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.

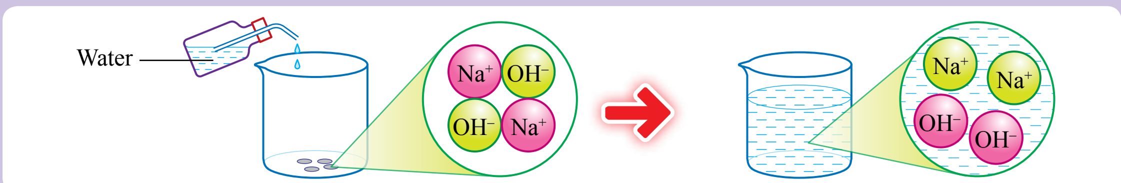
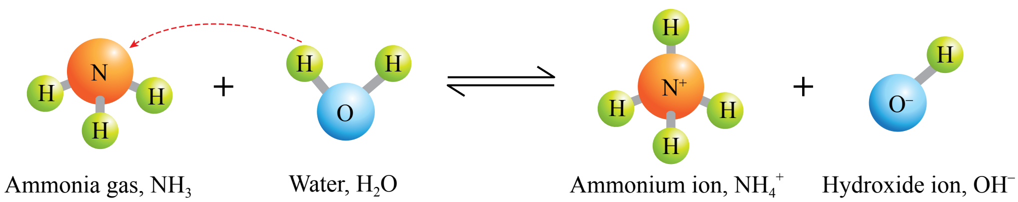


Figure 6.4 *Dissociation of sodium hydroxide, NaOH into ions that move freely in water*

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.

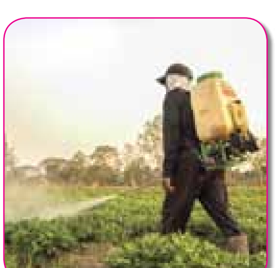
Photograph 6.1 *Uses of acid and alkali in daily life*

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.

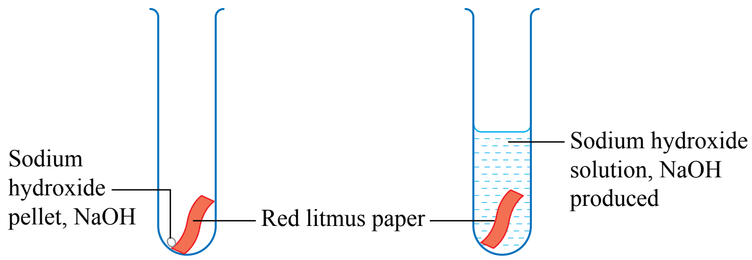


Figure 6.7 *Method to test the alkaline properties of sodium hydroxide, NaOH*

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.

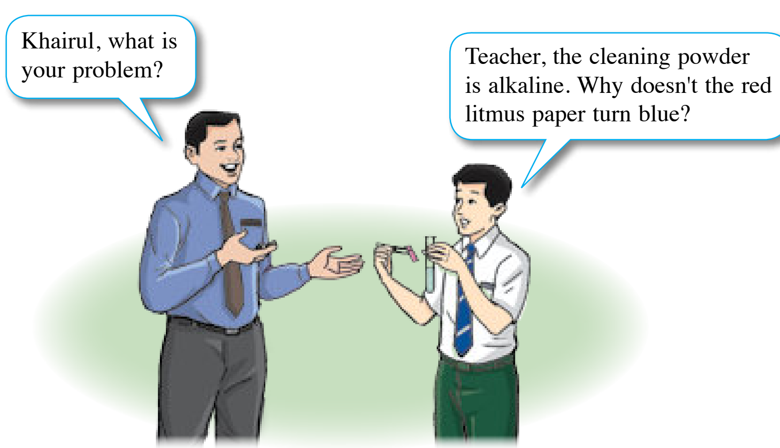


Figure 6.8

   (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

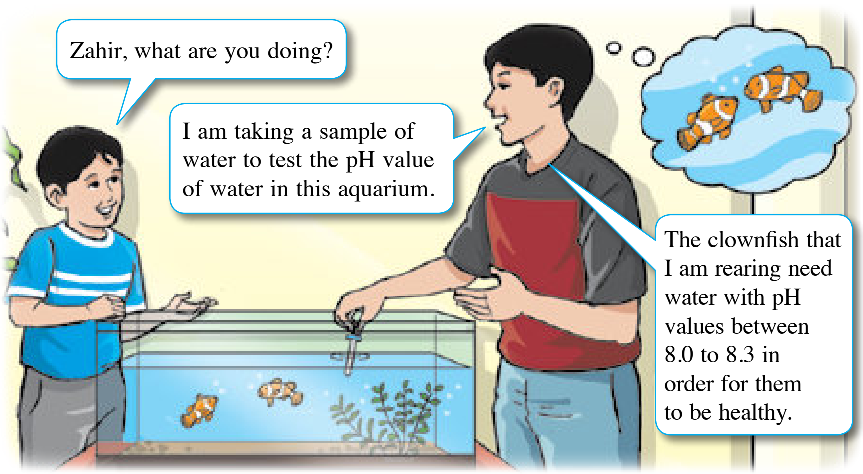


Figure 6.9 *Clownfish need water with specific pH values*

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?

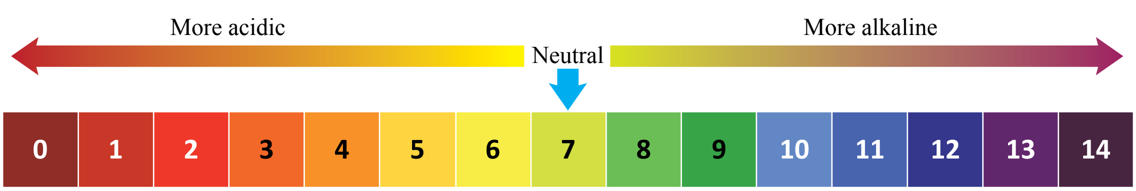


Figure 6.10 *The pH scale*

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

$$pH = -\log [H^+]$$

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}

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

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}

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

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

pH value of potassium hydroxide solution, KOH $= 14.0 - pOH$
$= 14.0 - 2.0$
$= 12.0$

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	• Milk tea	• Carbonated drink
• Lime juice	• Coffee	• 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.

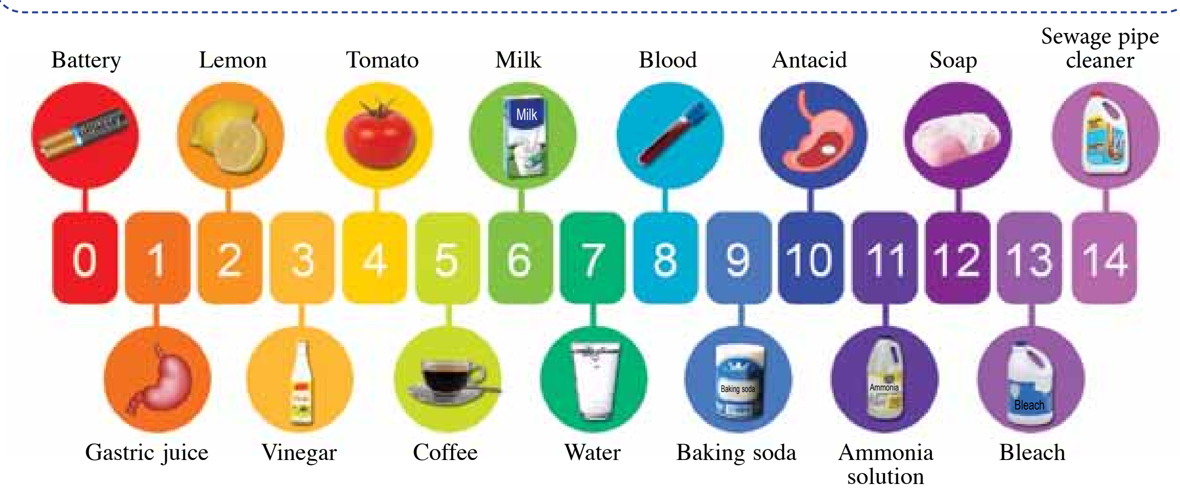


***Figure 6.11** The pH value of few items in daily life tested with the universal indicator*

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?

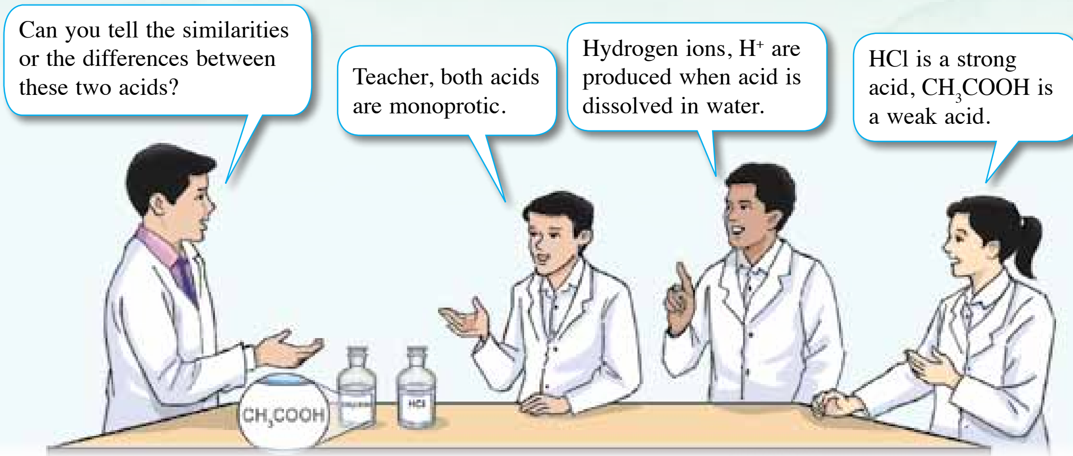


Figure 6.12 Similarities and differences between two acids

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.

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

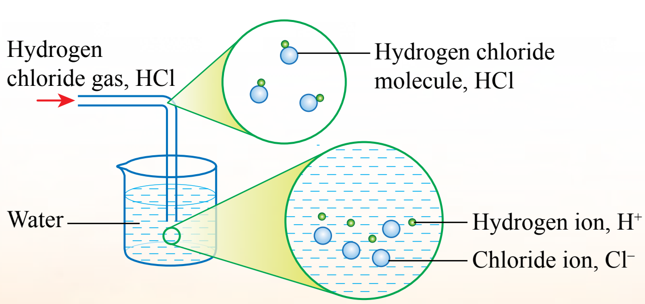


Figure 6.13 Complete ionisation of hydrogen chloride, HCl

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.

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

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.

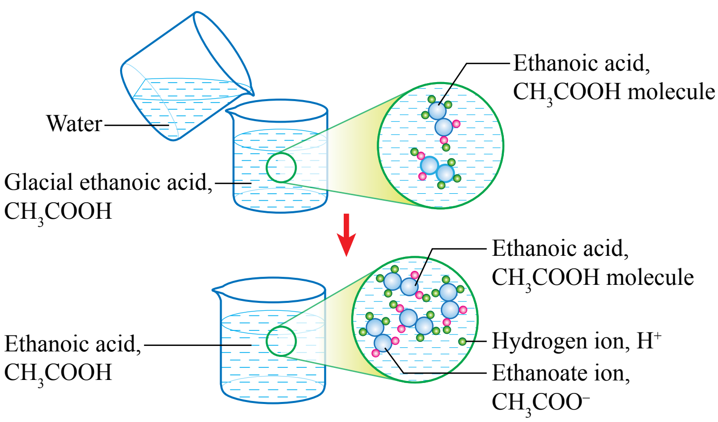


Figure 6.14 Partial ionisation of ethanoic acid, CH_3COOH

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.

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

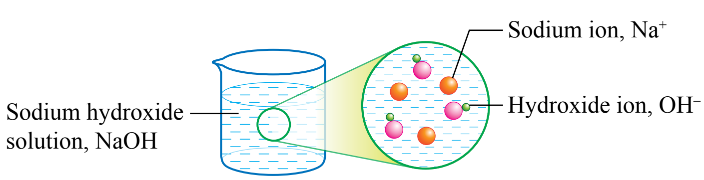


Figure 6.15 Complete ionisation of sodium hydroxide solution, NaOH

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.

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

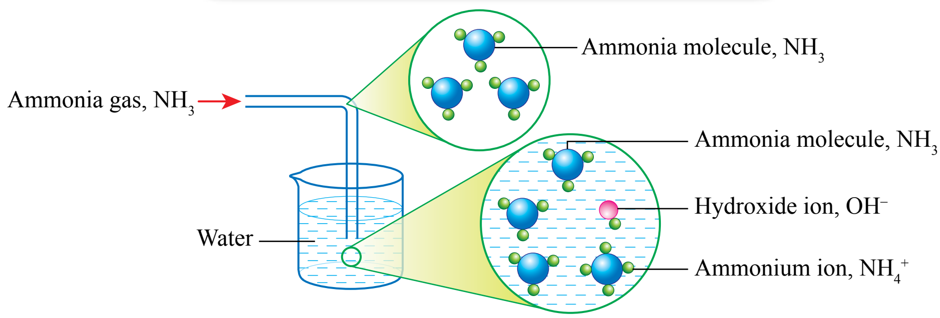


Figure 6.16 *Partial ionisation of ammonia solution, NH_3*

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

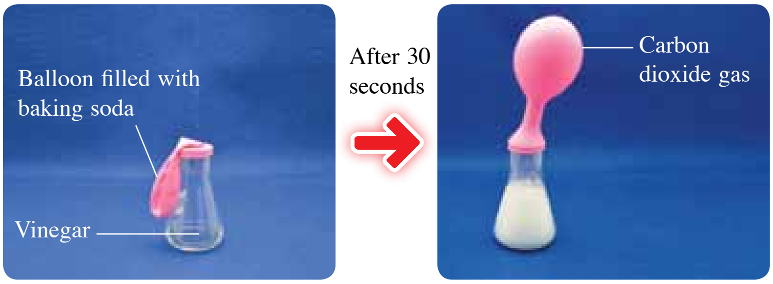


***Figure 6.17** To inflate the balloon using vinegar and baking soda*

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

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.

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.

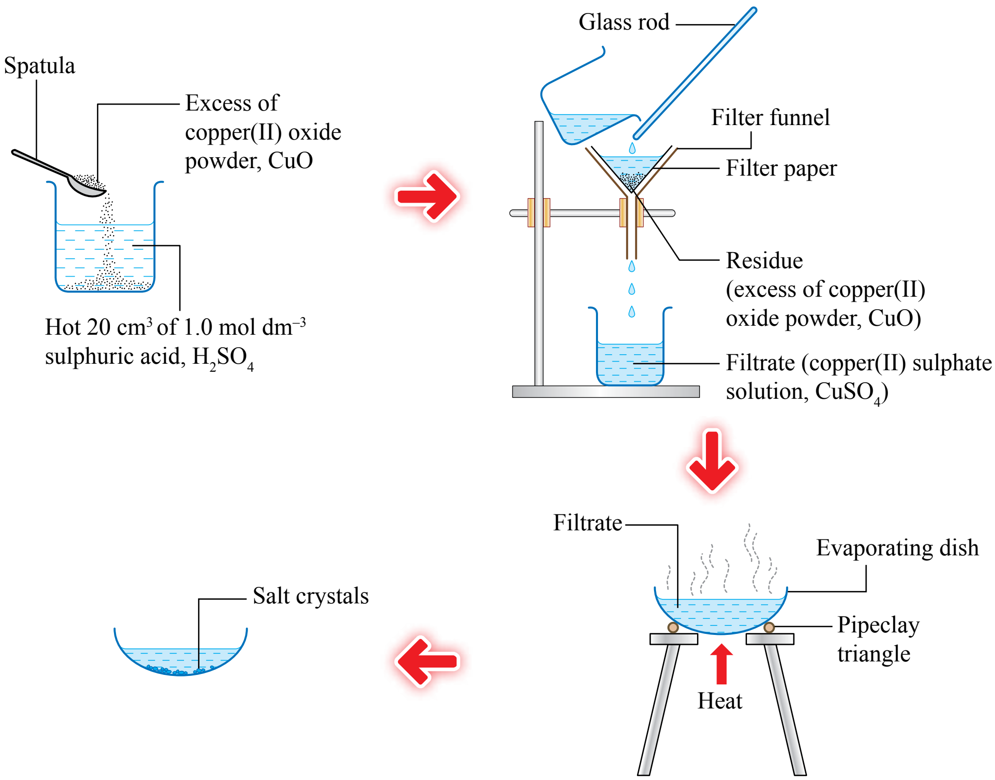


Figure 6.18 *Preparation of salt crystals from the reaction between acid and base*

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.

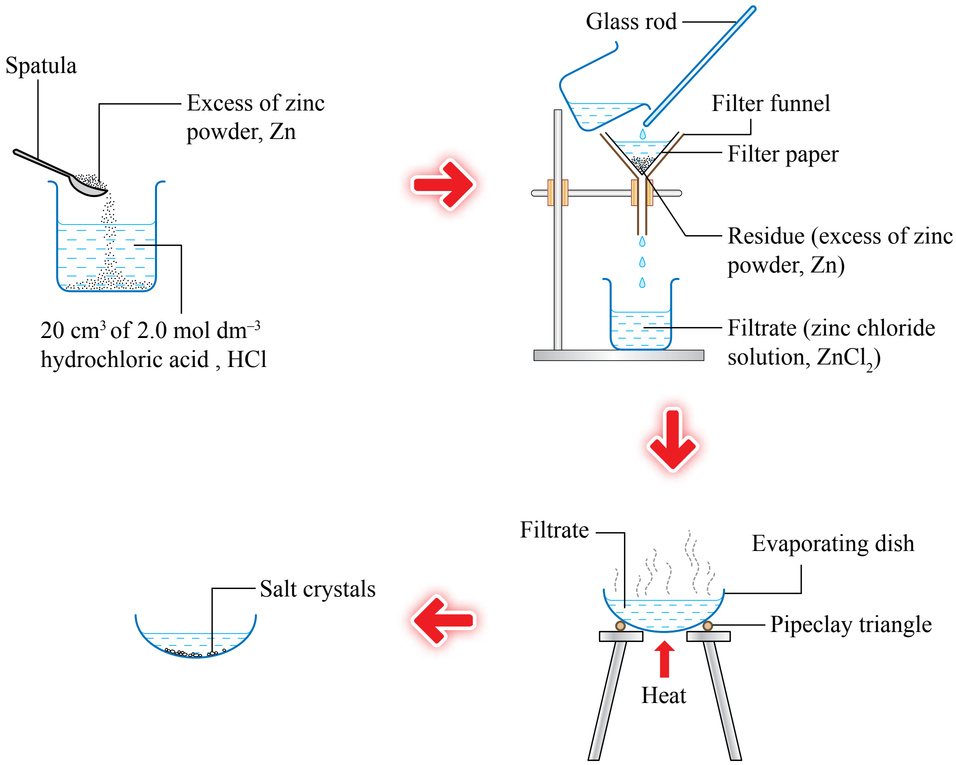


Figure 6.19 *Preparation of salt crystals from the reaction between acid and reactive metal*

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.

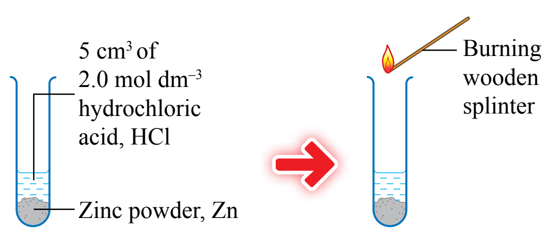


Figure 6.20

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 → ______ + ______

C 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.

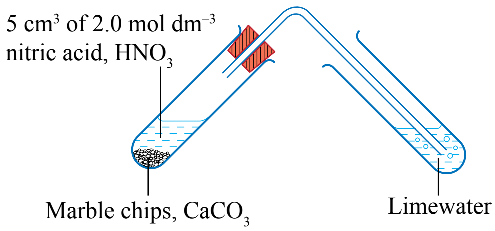


Figure 6.21

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.

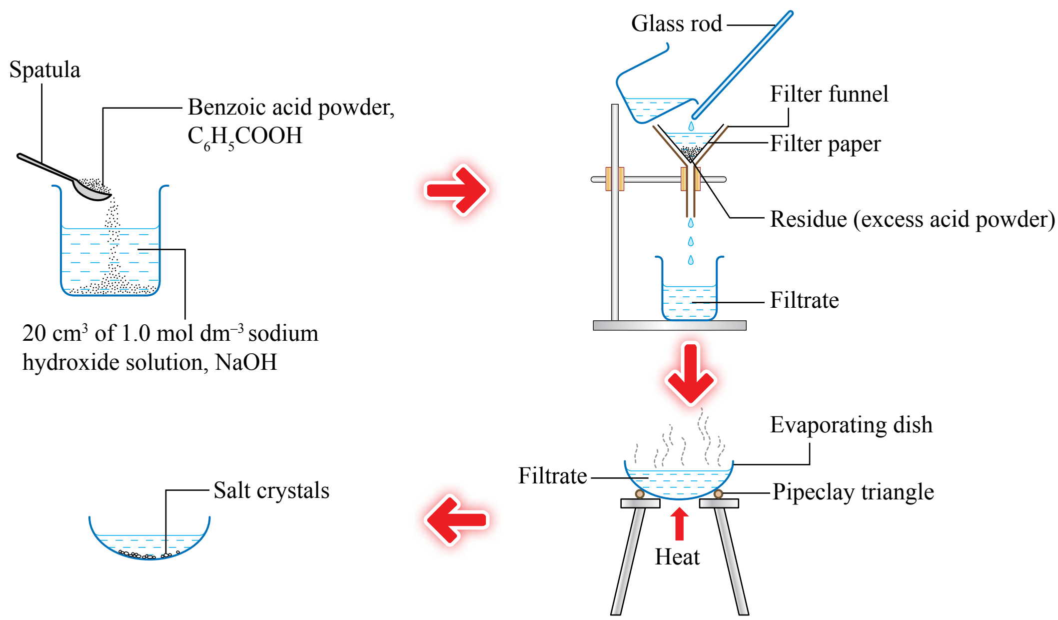


***Figure 6.22** Preparation of salt crystals from the reaction between alkali and acid*

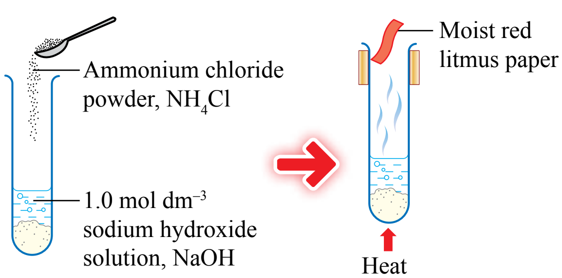


***Figure 6.23** Heating the mixture of alkali and ammonium salt to produce ammonia gas*

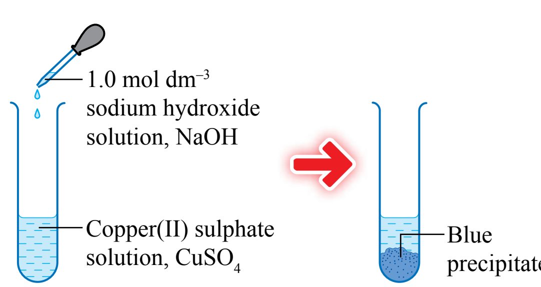


***Figure 6.24** Addition of alkali to metal ions to produce insoluble metal hydroxide precipitate*

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

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.

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

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

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

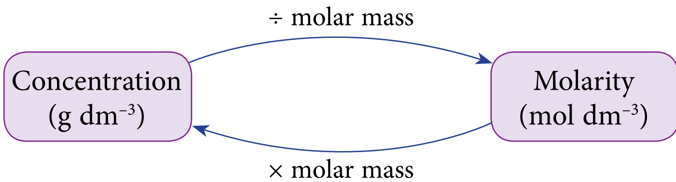


Figure 6.26 *Relationship between concentration and molarity*

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, $CuSO_4$ $= \dfrac{\text{Mass of solute (g)}}{\text{Volume of solution (dm}^3\text{)}}$

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

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

(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, $ZnCl_2$ $= \dfrac{\text{Number of moles of solute (mol)}}{\text{Volume of solution (dm}^3\text{)}}$

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

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

(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

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

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 **dm³**.

If the volume of the solution is in cm³, thus, unit of volume needs to be converted to dm³.

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

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

Volume of solution is in **cm³**.

Example 10

Calculate the number of moles of potassium hydroxide, KOH found in 2 dm³ of 0.5 mol dm^{-3} potassium hydroxide solution, KOH.

Solution

Number of moles, $n = MV$

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

$= 1$ mol KOH

This formula is applied because the volume of solution is in **dm³**.

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

Number of moles, $n = \dfrac{MV}{1000}$ ← This formula is applied because the volume of solution is in **cm³**.

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

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

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.

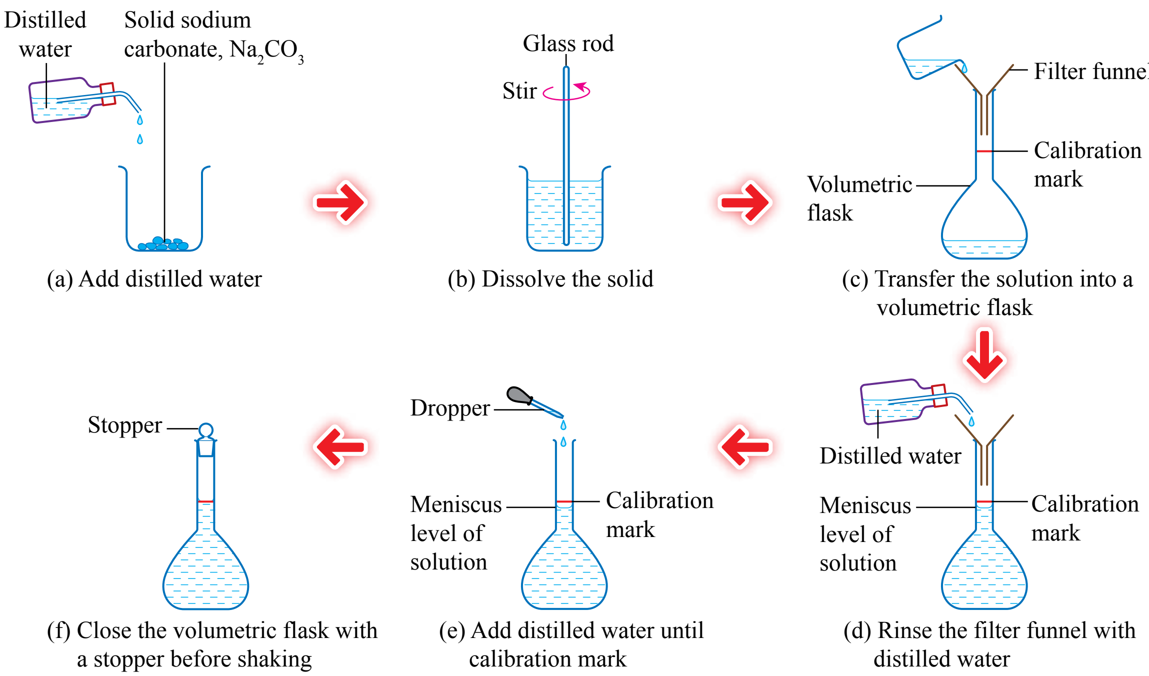


Figure 6.27 *Preparation of 1.0 mol dm*$^{-3}$ *sodium carbonate solution,* Na_2CO_3 *from a solid*

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.

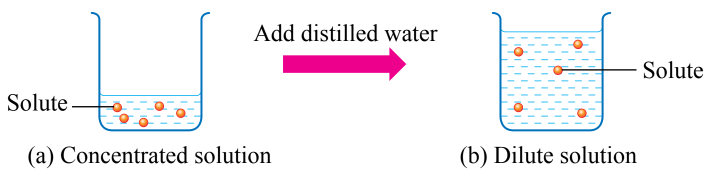


Figure 6.28 *Quantity of solute remains the same in both solutions of different concentrations*

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 cm³ 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 cm³ volumetric flask, dropper, filter funnel, pipette, wash bottle, pipette filler and 100 cm³ beaker

Procedure:

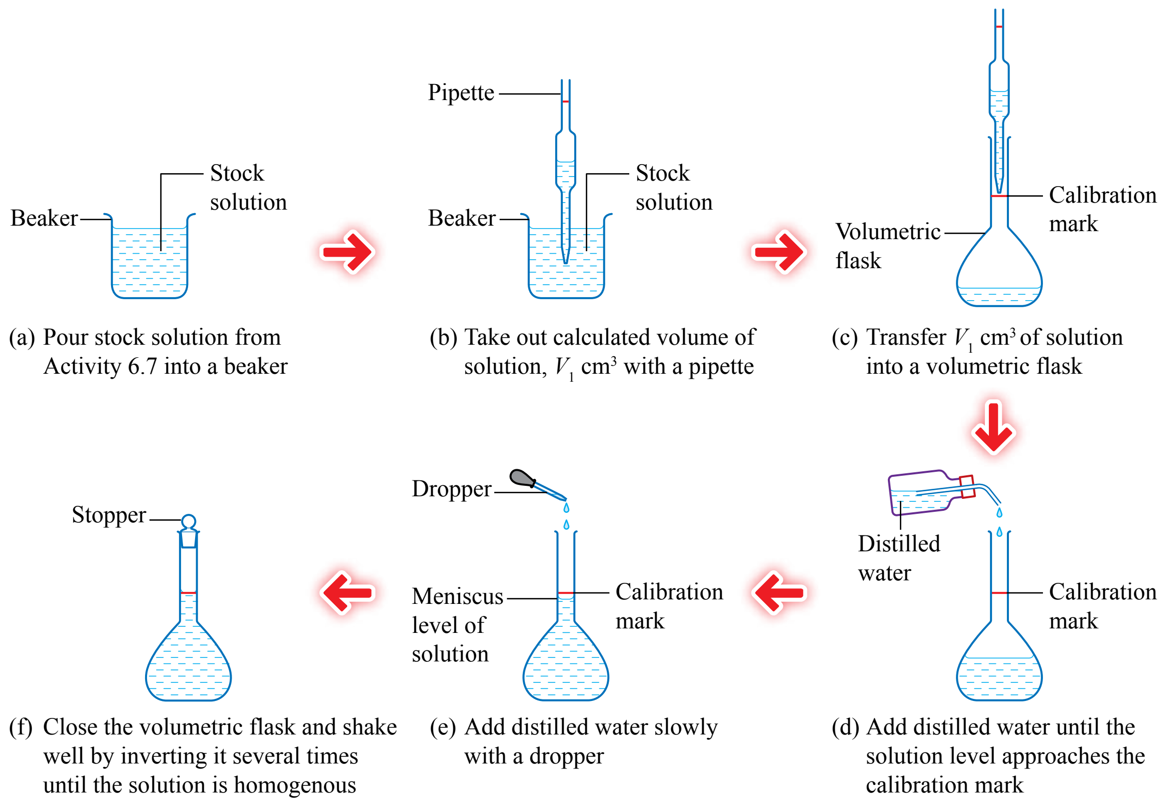


***Figure 6.29** Preparation of 0.2 mol dm⁻³ sodium carbonate solution, Na_2CO_3 by dilution method*

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.

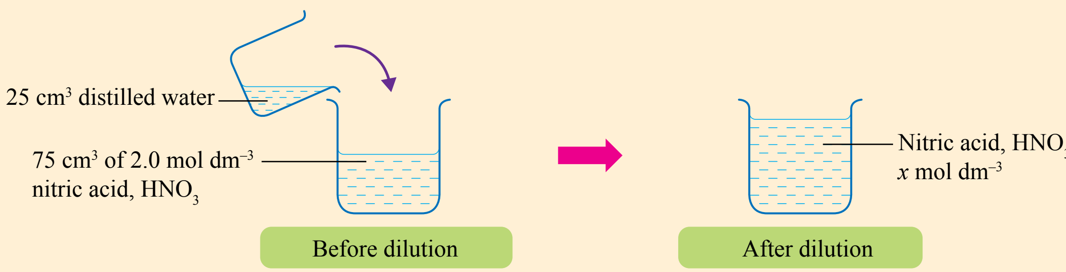


Figure 6.30

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 = 100 cm^3

Volume of solution = Volume of HNO_3 + Volume of distilled water

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

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

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*

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.

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

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.

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

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:

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

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

Chemical equation:

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

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

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:

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

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.

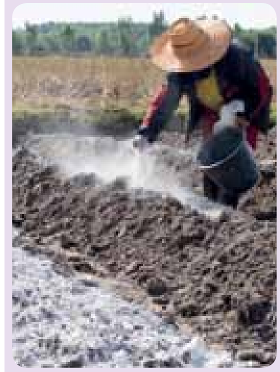
Hair health

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

CT

Gather information on various types of fertilisers

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.

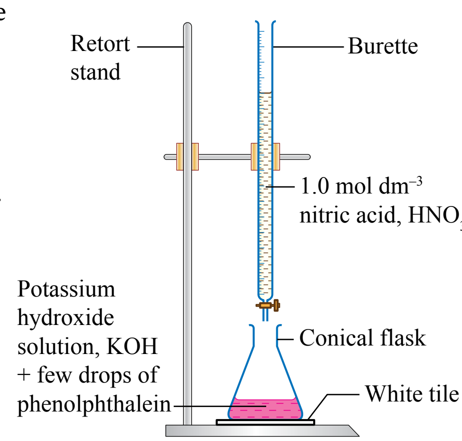


Figure 6.32

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 Molarity of alkali B = M_b
Volume of acid A = V_a 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

$$\overset{a\,=\,1 \text{ mol}}{HCl} + \overset{b\,=\,1 \text{ mol}}{NaOH} \rightarrow NaCl + H_2O$$

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.

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

$= 0.05$ 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.

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

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

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

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

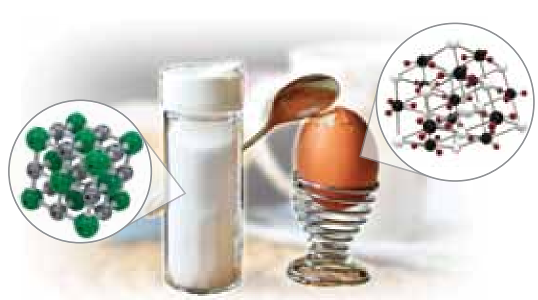


Figure 6.33 *Salt and egg shell*

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

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

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

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

Cation from metal

Zinc chloride salt

Reaction between acid and metal carbonate

Anion from acid

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

Cation from metal carbonate

Calcium chloride salt

Reaction between acid and aqueous ammonia

Anion from acid

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

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.

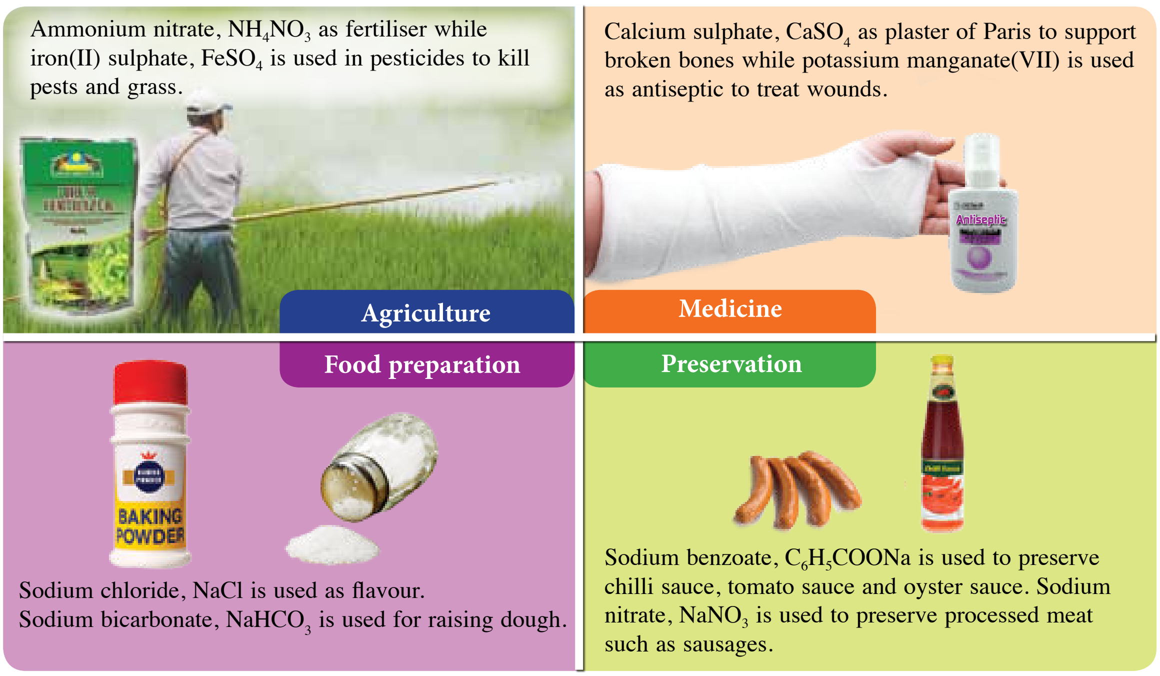


***Figure 6.35** Various uses of salt in daily life*

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:

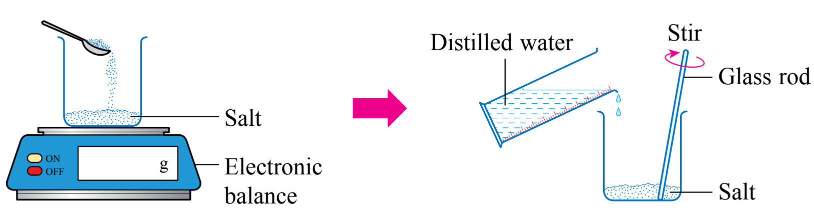


Figure 6.36 *Apparatus set-up to investigate the solubility of salt*

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:

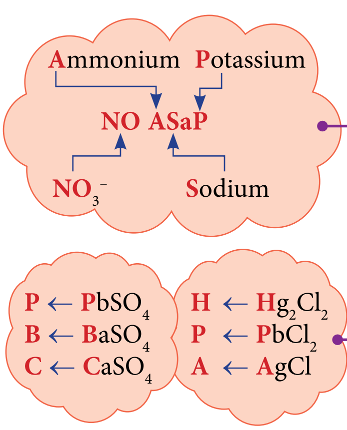
Is the hypothesis acceptable? What is the conclusion of this experiment?

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

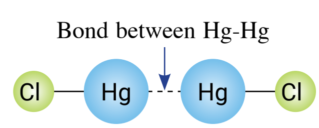


Literacy Tips

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?

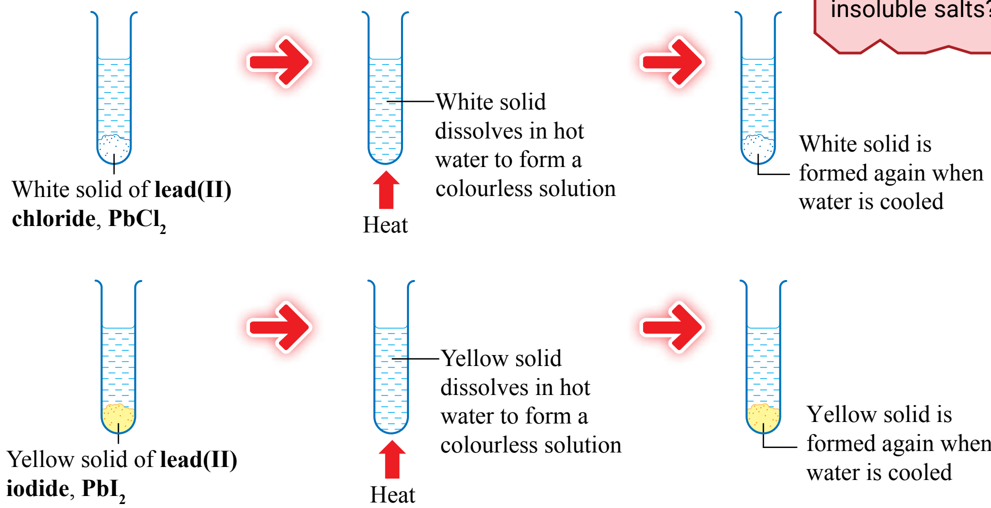


Figure 6.37 *Special properties of lead(II) chloride, $PbCl_2$ and lead(II) iodide, PbI_2*

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.

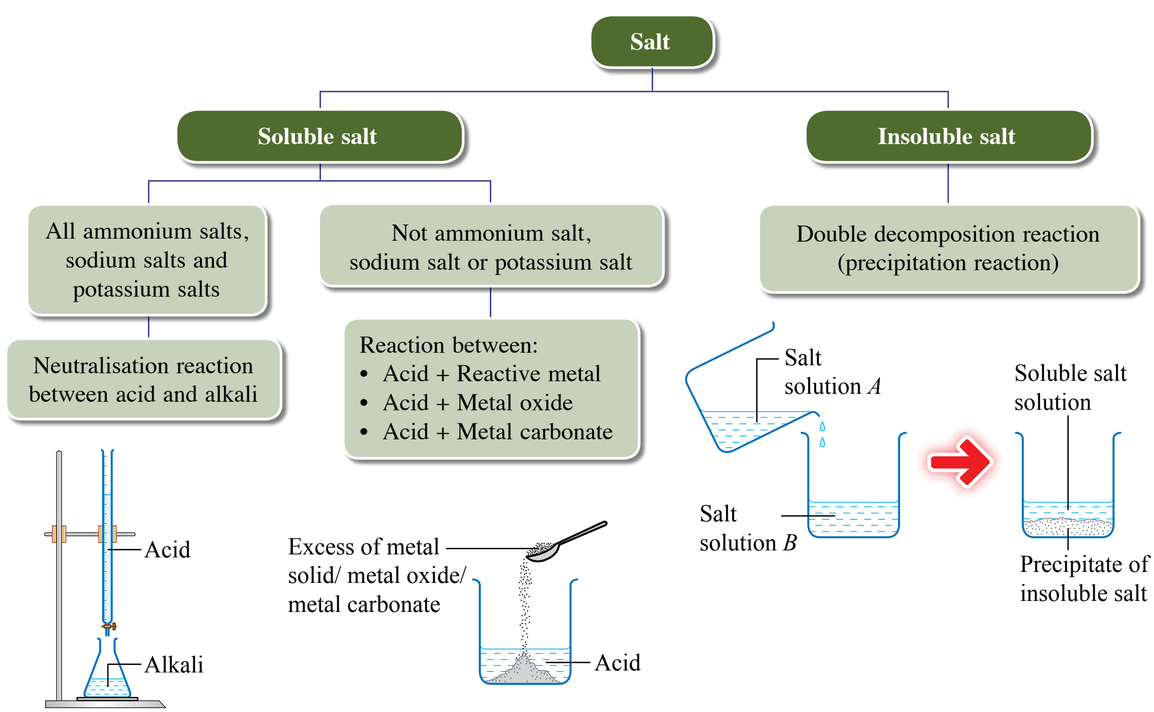


Figure 6.38 *Methods for preparing soluble and insoluble salts*

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:

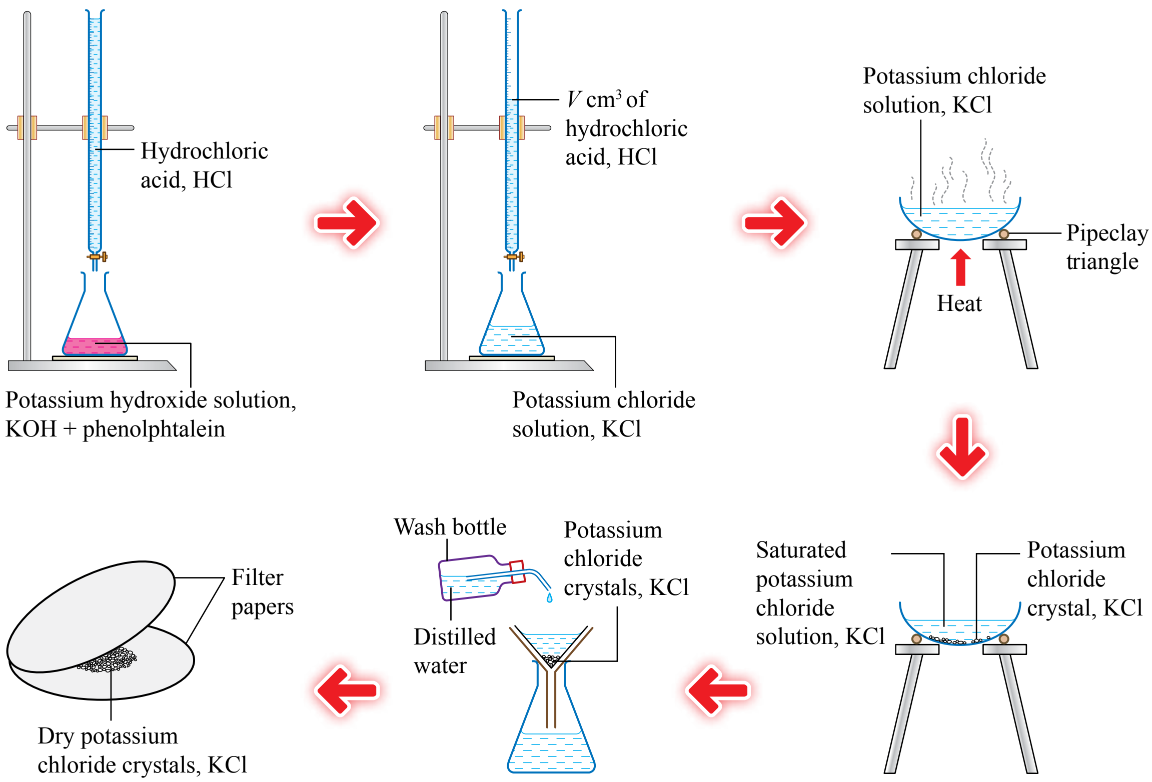


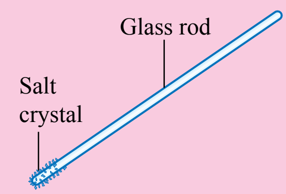
***Figure 6.39** Apparatus set-up to obtain potassium chloride crystals, KCl*

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:

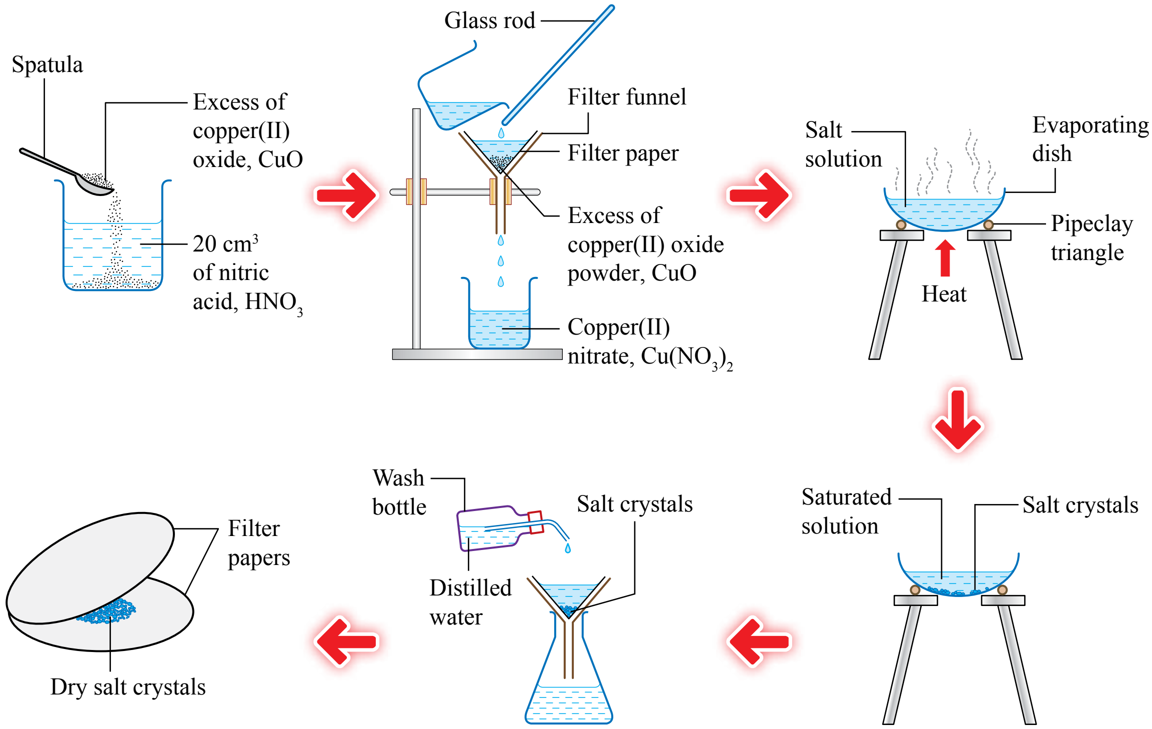


***Figure 6.40** Apparatus set-up to obtain copper(II) nitrate crystal, $Cu(NO_3)_2$*

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:

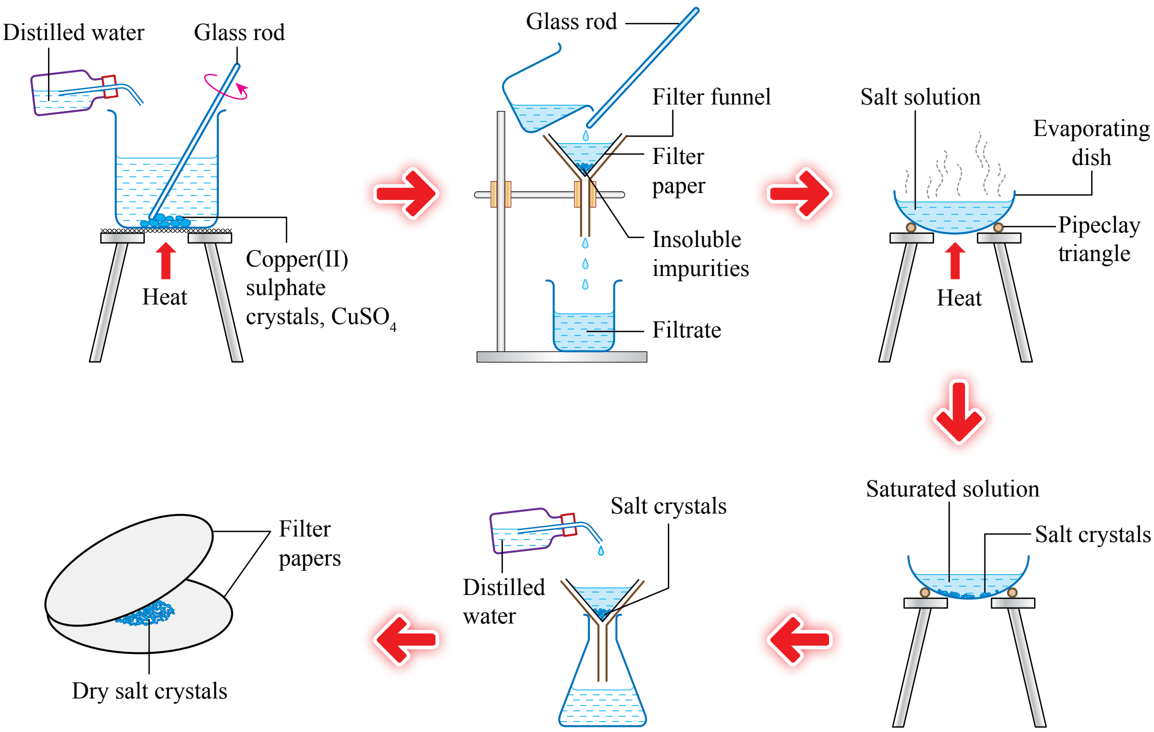


Figure 6.41 Apparatus set-up to purify copper(II) sulphate salt, $CuSO_4$

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.

Safety Precaution

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

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:

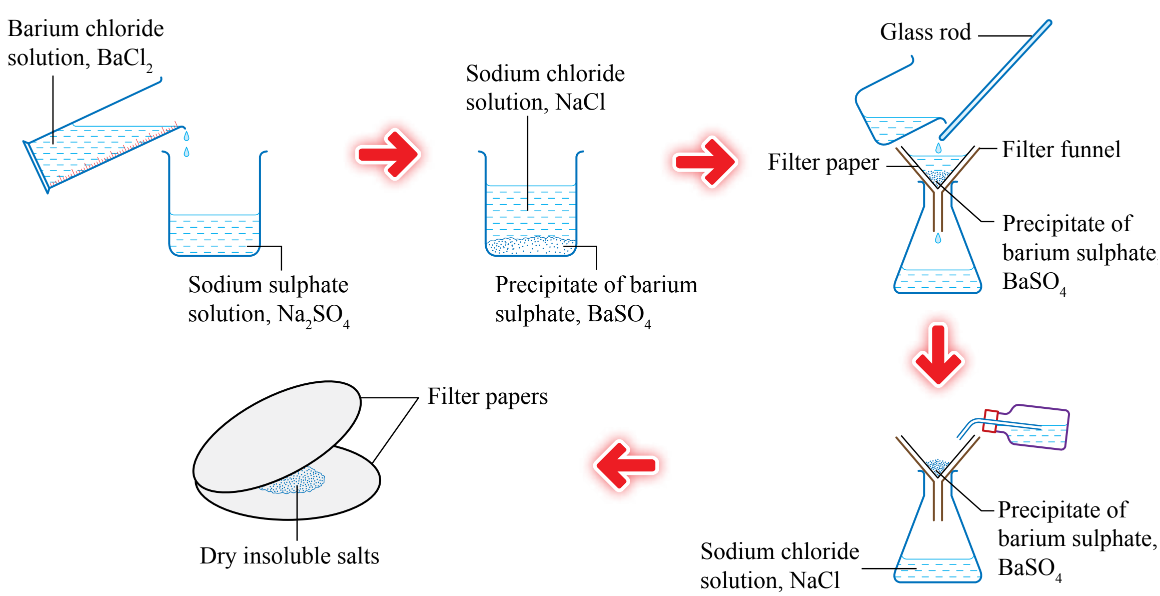


***Figure 6.42** Apparatus set-up in the preparation of insoluble salt*

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.

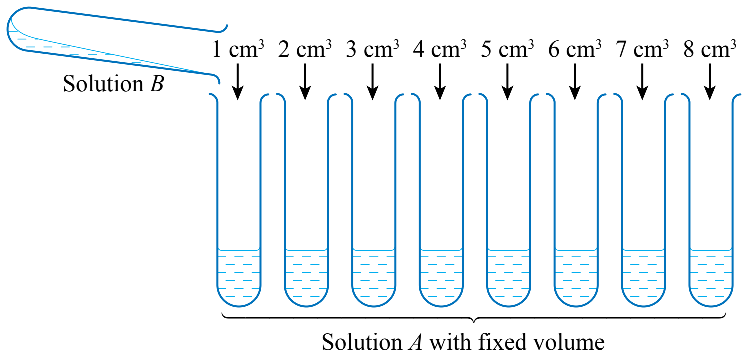


Figure 6.43 *Continuous variation method*

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

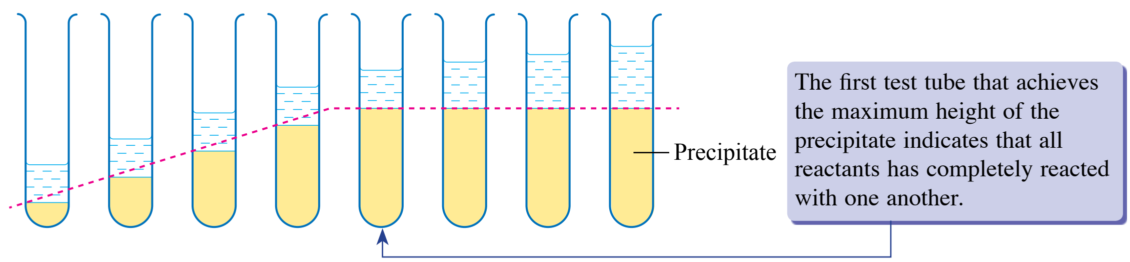


Figure 6.44 *Changes of the height of the precipitate*

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

Procedure:

Safety Precaution

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

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.

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

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

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

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

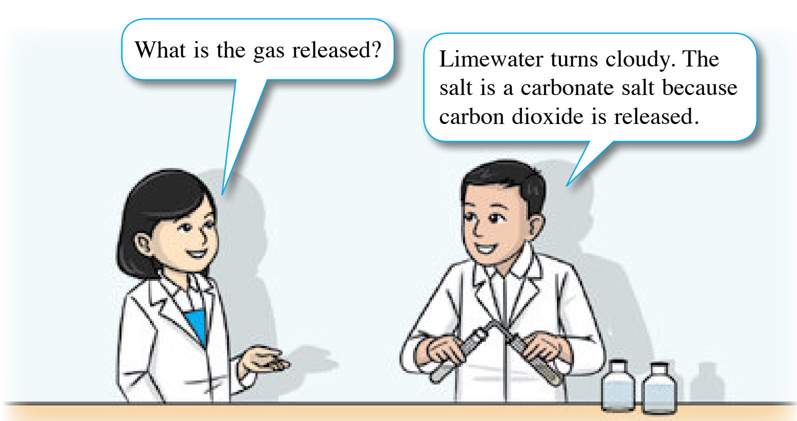


Figure 6.45 Carbon dioxide gas turns limewater cloudy

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.

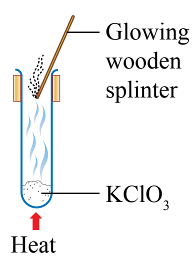
CAUTION
This activity has to be carried out in the fume chamber.

Table 6.8

<table>
<tr><th>Gas test</th><th>Observation</th><th>Inference</th></tr>
<tr><td>

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.



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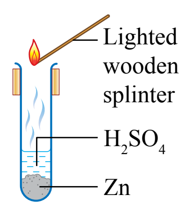
B: Test for hydrogen gas, H_2

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.



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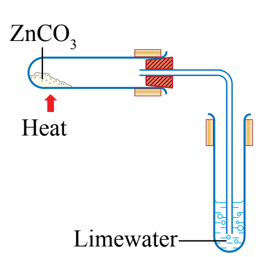
C: Test for carbon dioxide gas, CO_2

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.



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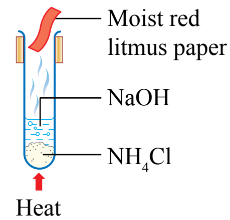
<table>
<tr><th>Gas test</th><th>Observation</th><th>Inference</th></tr>
<tr><td>

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.



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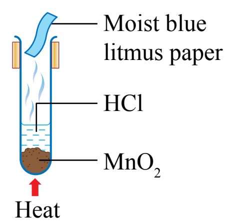
E: Test for chlorine gas, Cl_2

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.



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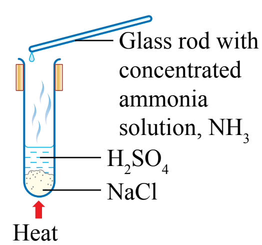
F: Test for hydrogen chloride gas, HCl

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.



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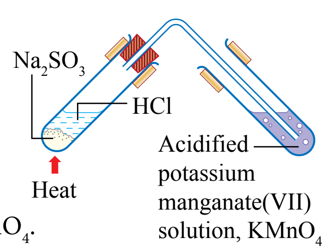
G: Test for sulphur dioxide gas, SO_2

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, $K_2Cr_2O_7$.

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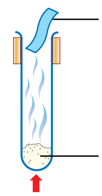
</table>

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:

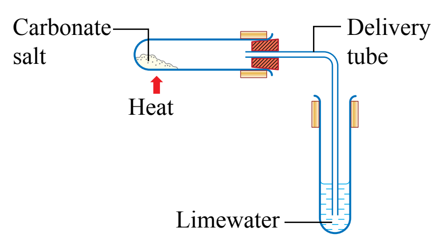


Figure 6.46

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.

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

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.

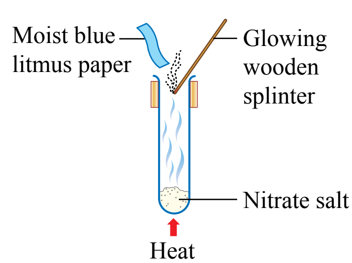


Figure 6.47 *Apparatus set-up for heating a nitrate salt*

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.

Nitrate salt $\xrightarrow{\text{Heat}}$ ______ + ______ + ______

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.

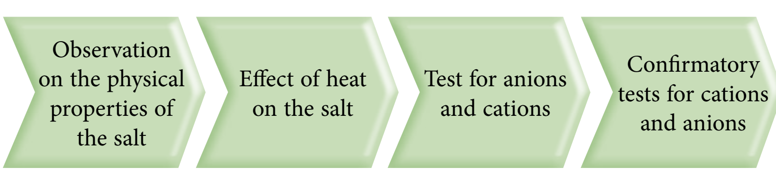


***Figure 6.48** Steps in the qualitative analysis of a salt*

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.

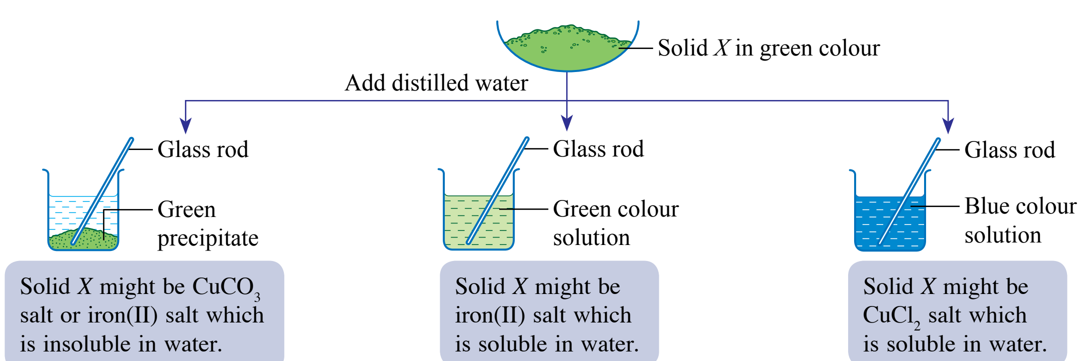


***Figure 6.49** Qualitative analysis based on the solubility of the salt and its colour*

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.

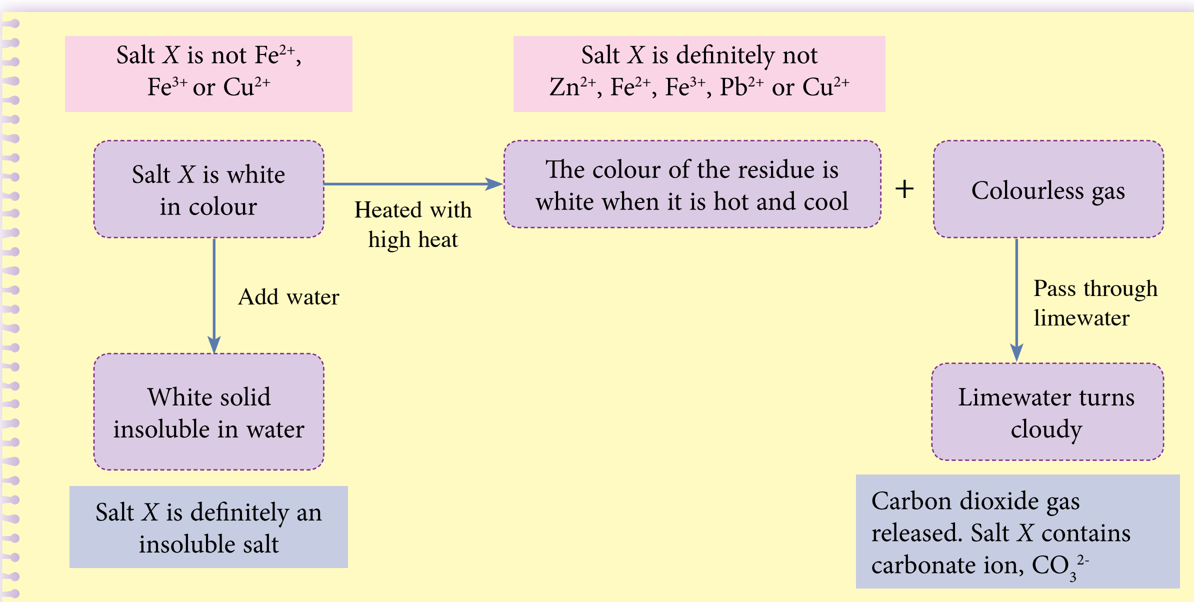


***Figure 6.50** Qualitative analysis based on the effects of heat on salt X and gas test*

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.

Salt Y is not Fe^{2+}, Fe^{3+} or Cu^{2+}

Salt Y is definitely not Zn^{2+}, Fe^{2+}, Fe^{3+}, Pb^{2+} or Cu^{2+}

Salt Y is white in colour $\xrightarrow{\text{Heated with high heat}}$ The colour of the residue is white when it is hot and cool + Brown gas + Colourless gas

Salt Y is white in colour $\xrightarrow{\text{Add water}}$ Colourless solution

Salt Y is a soluble salt

Colourless gas $\xrightarrow{\text{Test with glowing wooden splinter}}$ The glowing wooden splinter rekindles

Brown nitrogen dioxide gas and oxygen gas present. Salt Y contains nitrate ion, NO_3^-

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-}
- Chloride ion, Cl^-
- Sulphate ion, SO_4^{2-}
- 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.

Anion tests

- CO_3^{2-} $\xrightarrow{\text{+ Dilute acid}}$ Gas turns limewater cloudy
- Cl^- $\xrightarrow{\text{+ Dilute } HNO_3 \text{ + } AgNO_3(aq)}$ White precipitate
- SO_4^{2-} $\xrightarrow{\text{+ Dilute HCl + } BaCl_2(aq)}$ White precipitate
- NO_3^- $\xrightarrow{\text{+ Dilute } H_2SO_4 \text{ + } FeSO_4(aq) \text{ + Concentrated } H_2SO_4}$ Brown ring

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.

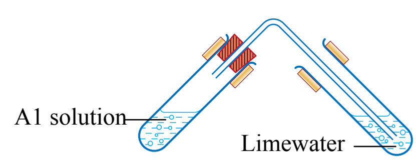


Figure 6.53

(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.

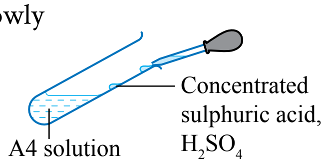


Figure 6.54

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.

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

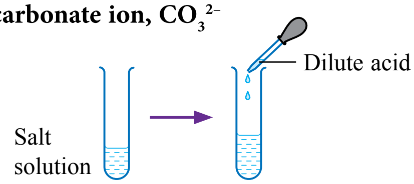
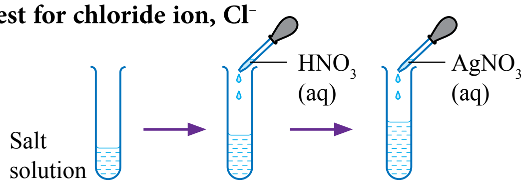
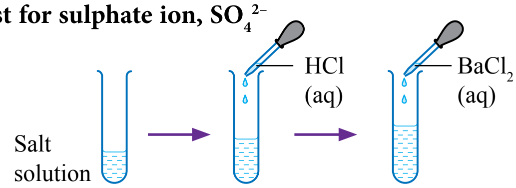
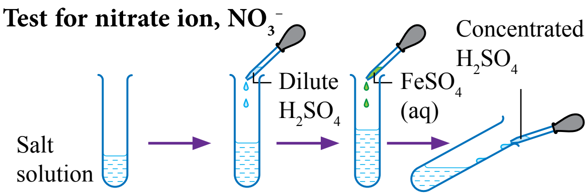
In the test for chloride ion, Cl^-, silver ion, Ag^+ is used to detect the presence of chloride ions, Cl^-. If chloride ions, Cl^- is present, hence the white precipitate of silver chloride, AgCl is produced. However, the carbonate ion, CO_3^{2-} also gives the same observation when reacting with silver 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:

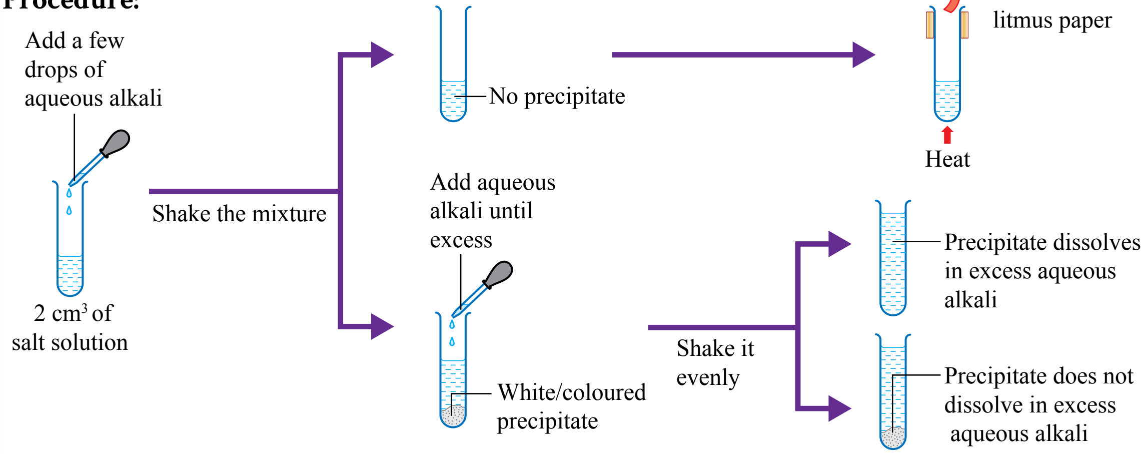


Figure 6.55 *Steps in identifying the cations in aqueous solutions*

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.

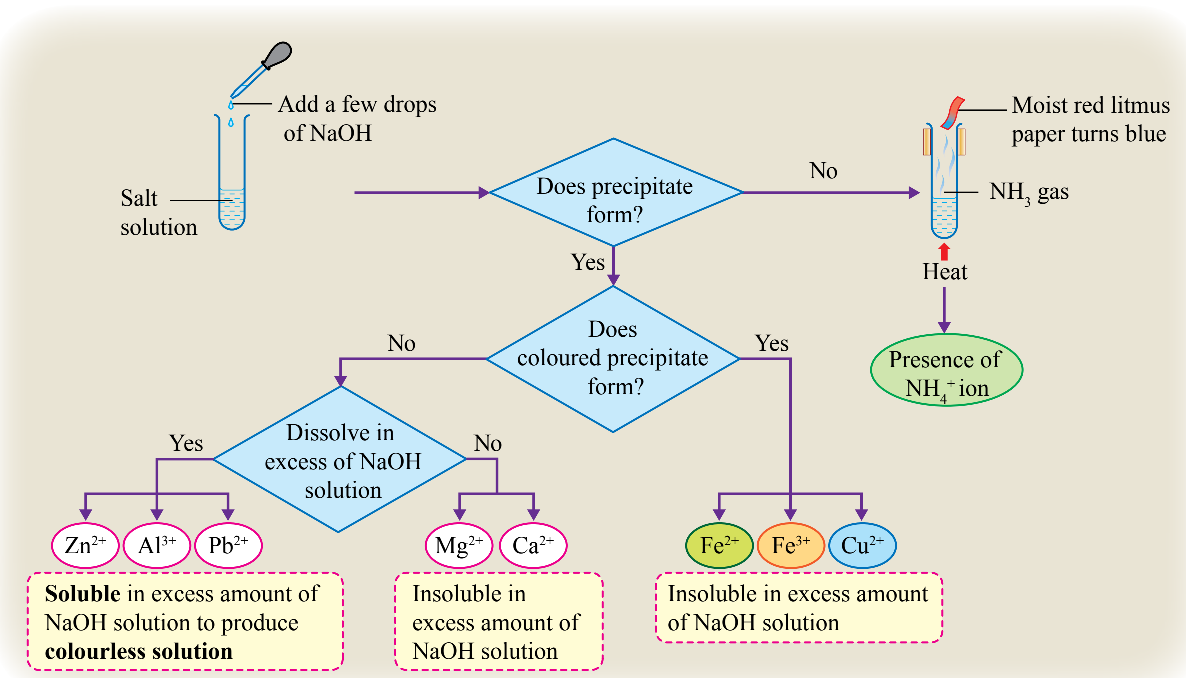


Figure 6.56 *Reactions between cations and sodium hydroxide solution, NaOH*

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

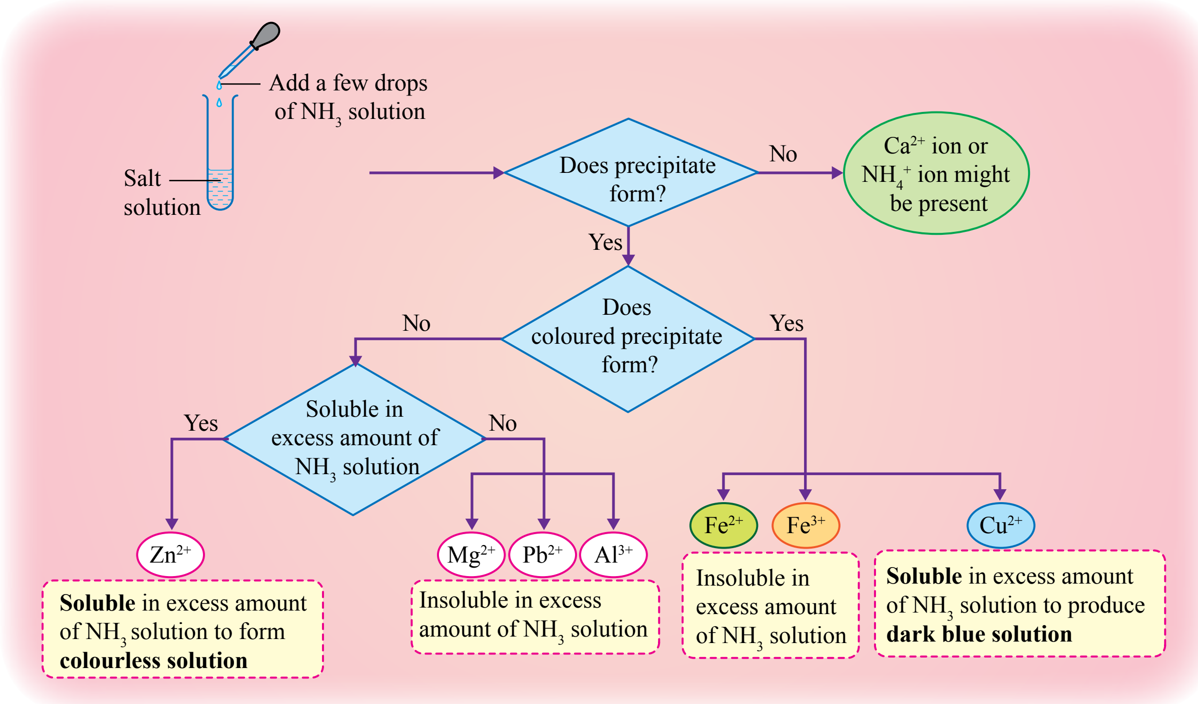
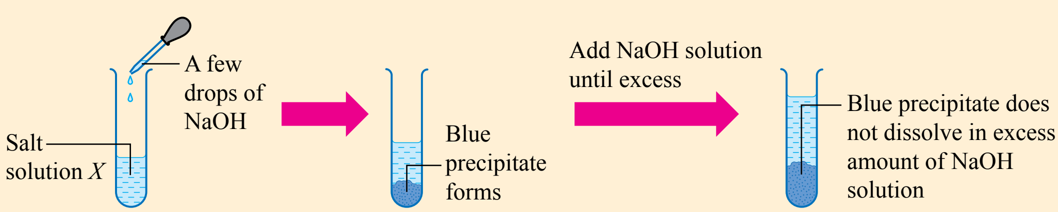


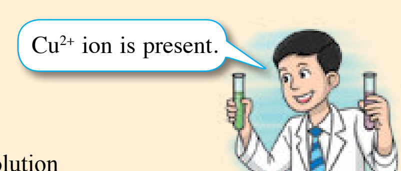
Figure 6.57 *Reaction between cations and ammonia solution, NH_3*

Example 17

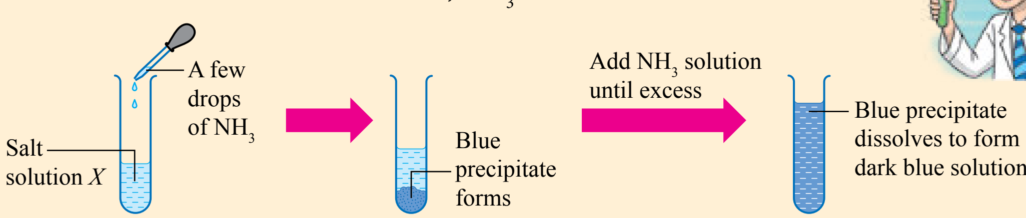
Salt solution *X* is blue.

Test for cations with sodium hydroxide solution, NaOH:



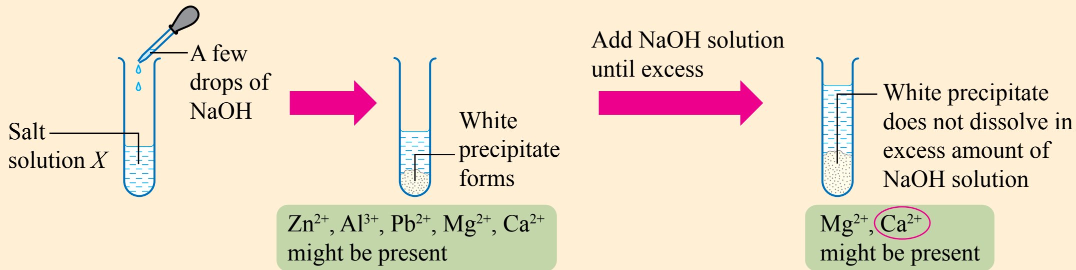


Test for cations with ammonia solution, NH_3:

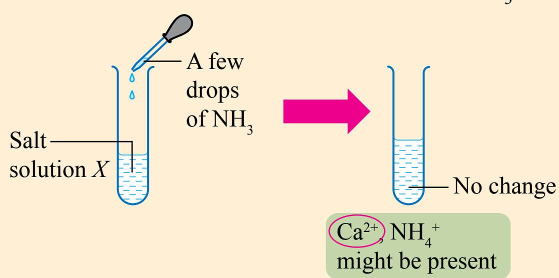


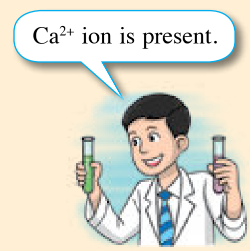
Example 18

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



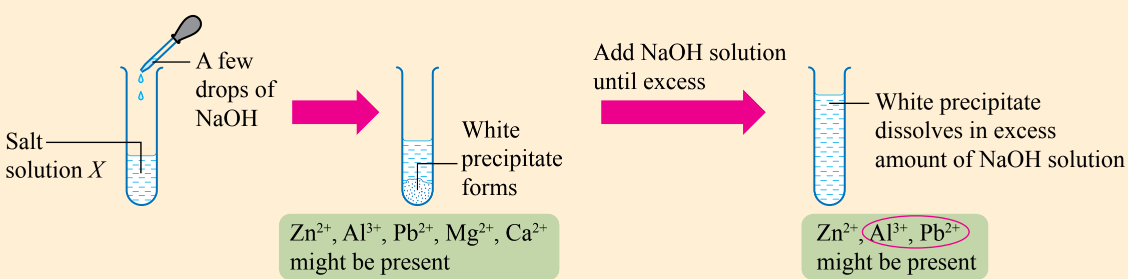
Test for cations with ammonia solution, NH_3:



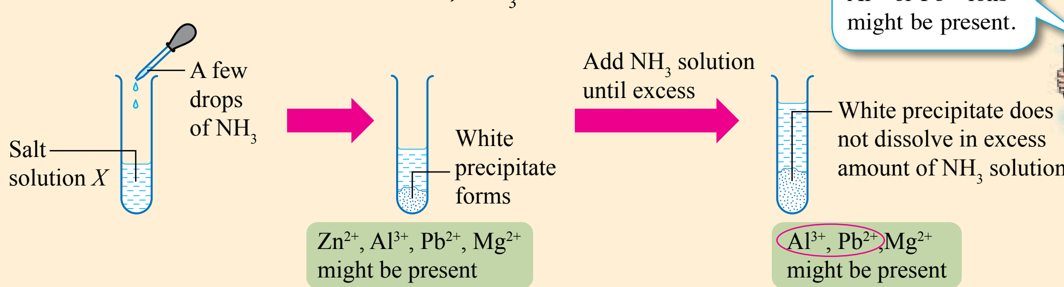


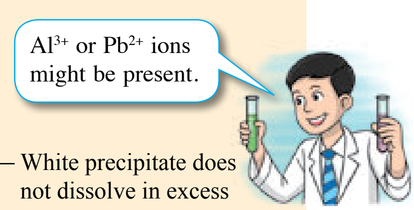
Example 19

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.

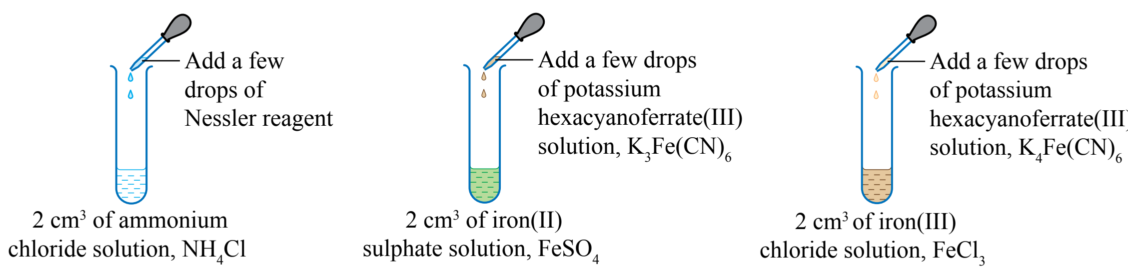
Problem statement: How to confirm the presence of cations (NH_4^+, Fe^{2+}, Fe^{3+}, Pb^{2+}) in aqueous solutions?

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+}

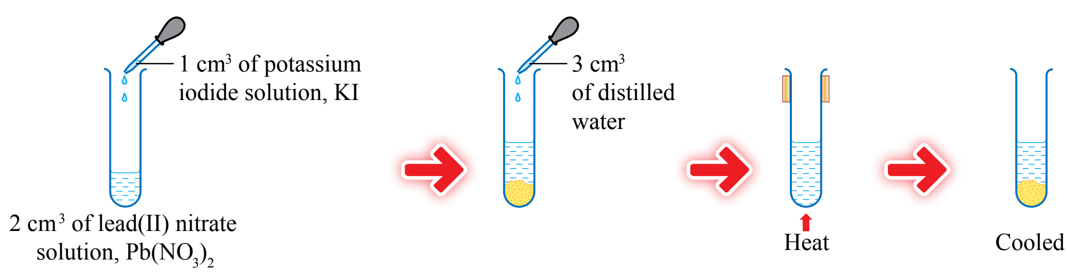


***Figure 6.58** Confirmatory tests for ammonium ion, iron(II) ion, iron(III) ion and lead(II) ion*

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.

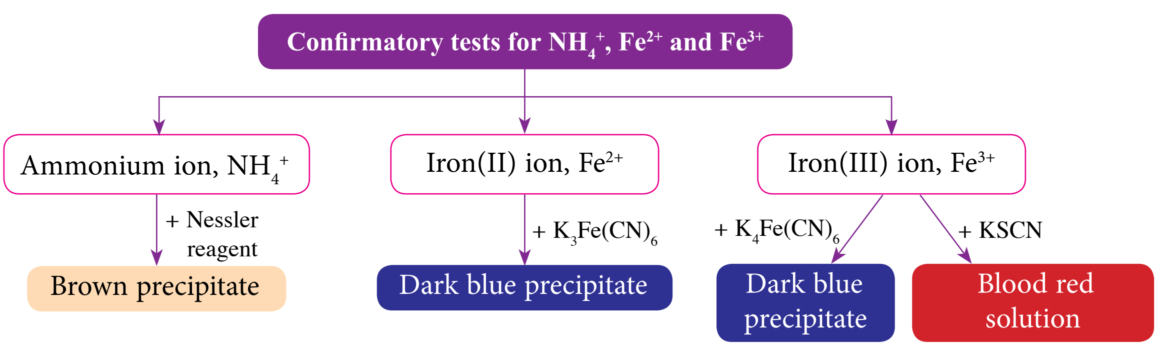


***Figure 6.59** Confirmatory tests for NH_4^+ ion, Fe^{2+} ion and Fe^{3+} ion*

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.

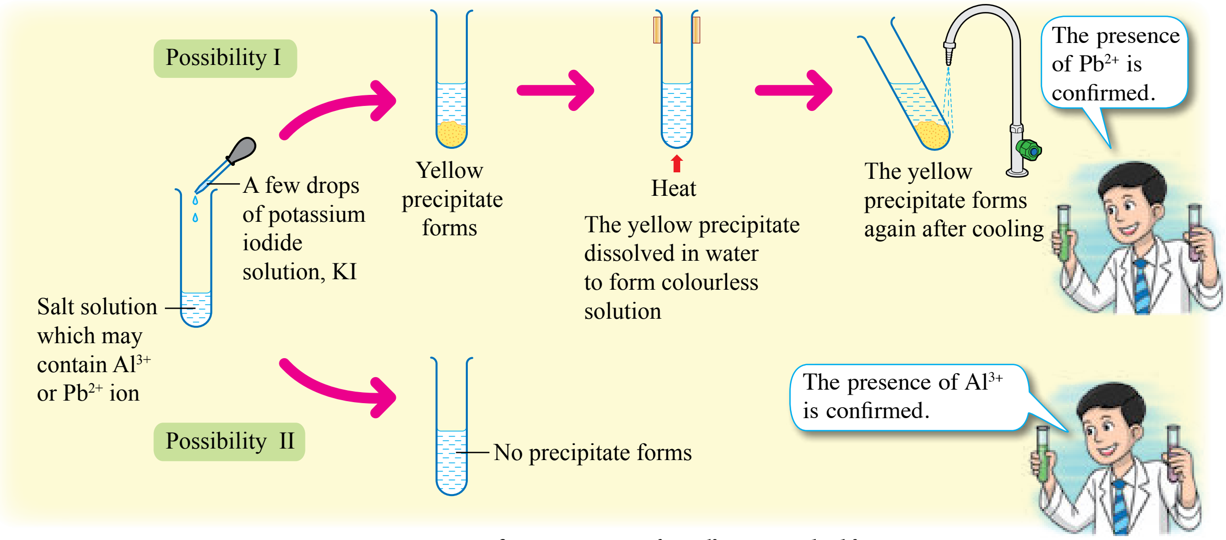


Figure 6.60 *Confirmatory tests for Al^{3+} ion and Pb^{2+} ion*

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.

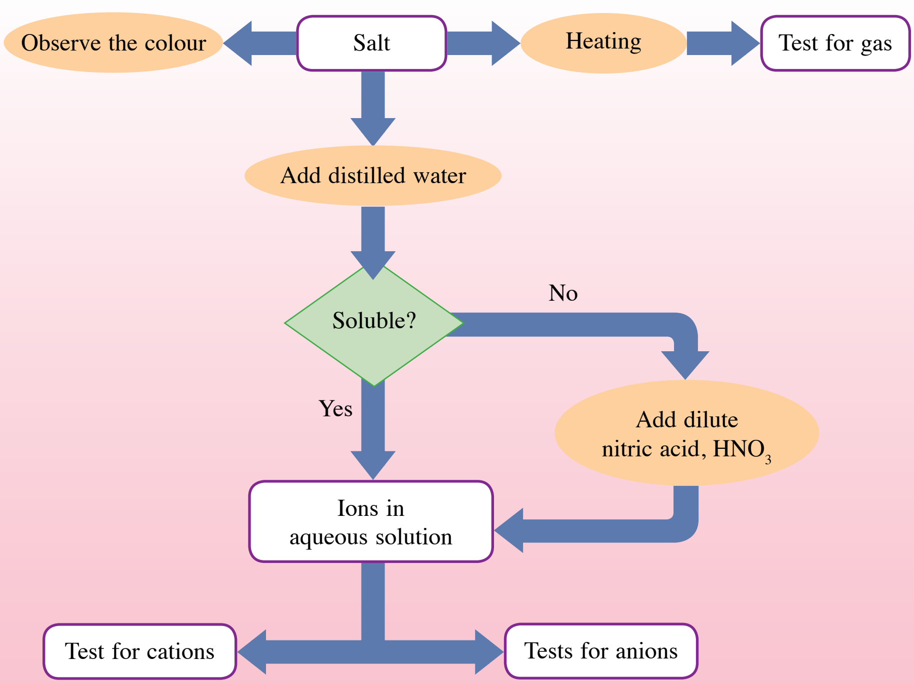


Figure 6.61 *Qualitative analysis of salts*

Activity 6.28

CT

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

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.

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 — dissolves in water → Ionise to produce H^+ ions → strong 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 — dissolves in water → Ionise to produce OH^- ion → strength of 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

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

calculation →
- $pH = -\log [H^+]$
- $pOH = -\log [OH^-]$
- $pH + pOH = 14$
- Concentration $\xrightarrow{\div \text{ Molar mass}}$ Molarity; Molarity $\xrightarrow{\times \text{ Molar mass}}$ Concentration
- $M_1V_1 = M_2V_2$
- $n = MV$

reaction between acid and base → **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 →
  - 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.

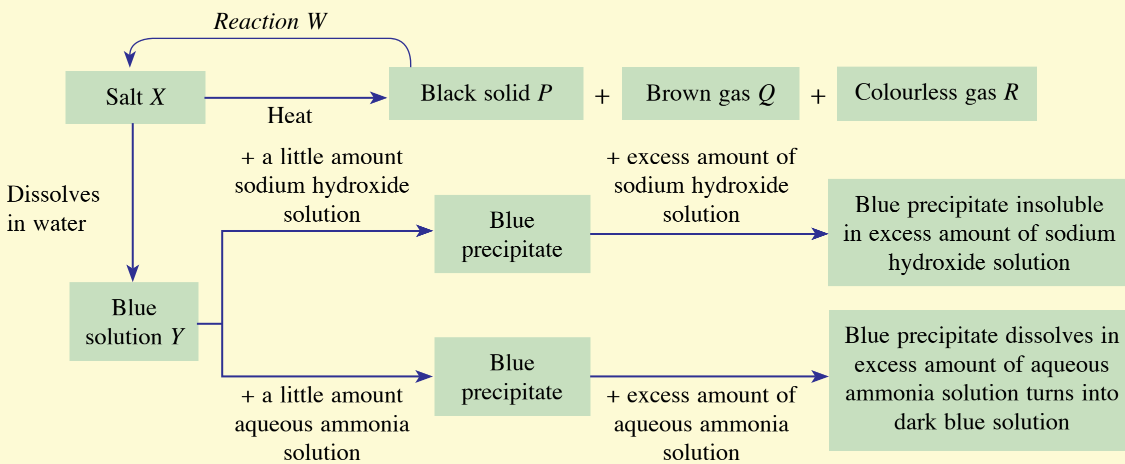


Figure 1

(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

CHAPTER 7

Rate of Reaction

Keywords

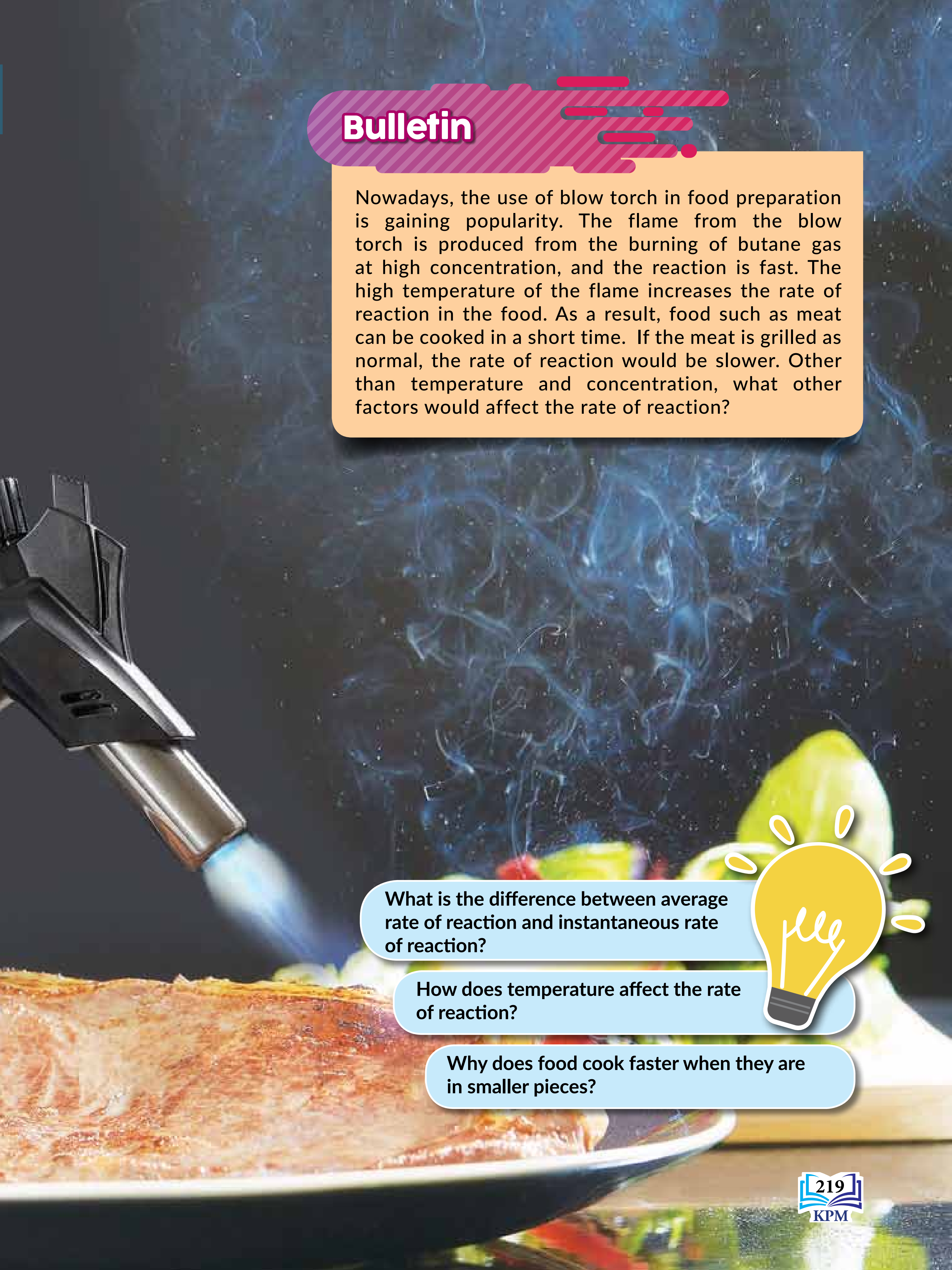
- Reactant
- Product
- Rate of reaction
- Catalyst
- Collision theory
- Activation energy
- Effective collision
- Energy profile diagram

What will you learn?

7.1 Determining Rate of Reaction
7.2 Factors Affecting Rate of Reactions
7.3 Application of Factors that Affect the Rate of Reaction in Daily Life
7.4 Collision Theory

Bulletin

Nowadays, the use of blow torch in food preparation is gaining popularity. The flame from the blow torch is produced from the burning of butane gas at high concentration, and the reaction is fast. The high temperature of the flame increases the rate of reaction in the food. As a result, food such as meat can be cooked in a short time. If the meat is grilled as normal, the rate of reaction would be slower. Other than temperature and concentration, what other factors would affect the rate of reaction?



What is the difference between average rate of reaction and instantaneous rate of reaction?

How does temperature affect the rate of reaction?

Why does food cook faster when they are in smaller pieces?

7.1 Determining Rate of Reaction

Classification of Rate of Reactions

There are a variety of chemical reactions that occur in our surroundings. Did you realise that chemical reactions also occur in our bodies? Do such reactions occur at a fast or slow rate? Figure 7.1 shows several chemical reactions taking place.

Learning Standard

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

7.1.1 Classify fast and slow reactions that occur in daily life

7.1.2 Explain the meaning of the rate of reaction

7.1.3 Identify changes which can be observed and measured during chemical reactions through activity

7.1.4 Determine the
- average rate of reaction
- instantaneous rate of reaction

7.1.5 Solve numerical problems based on the average and instantaneous rate of reaction

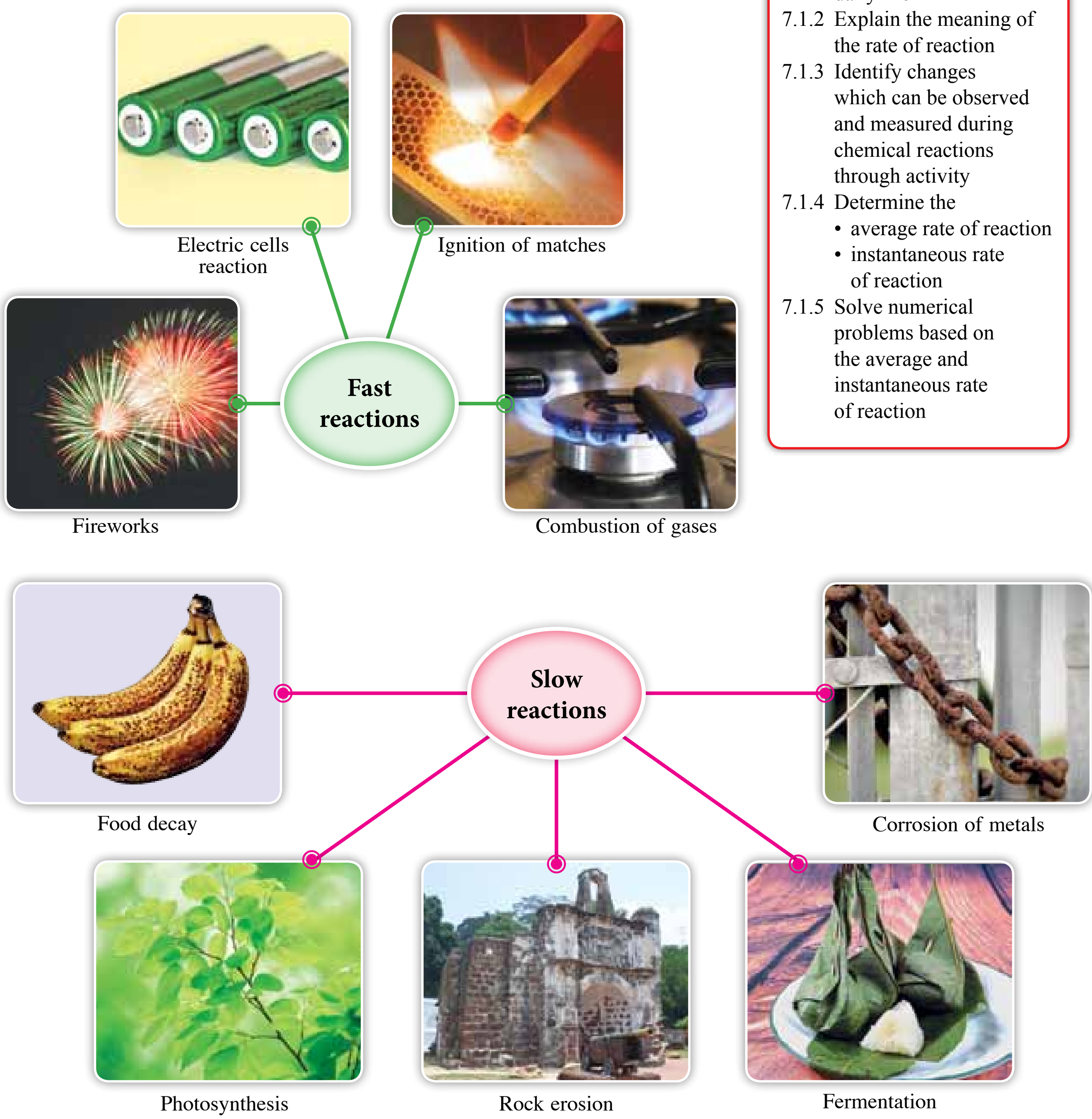


Figure 7.1 Examples of fast and slow reactions

Meaning of the Rate of Reaction

What do you understand by the rate of a reaction? The rate of reaction is the changes in the quantity of the reactant per unit time or the changes in the quantity of product per unit time.

$$\text{Rate of reaction} = \frac{\text{Change in the quantity of reactant or product}}{\text{Time taken for the change to occur}}$$

Chemistry & Us.

In the chemical manufacturing factory, a chemical engineer needs to know accurately about the rate of reaction that happens or the duration of time that is needed for the reaction to complete. In other words, a chemical engineer needs to be proficient in rate of reaction.

During the reaction, the quantity of reactant used decreases, while the quantity of product formed increases.

The unit for mass of solids is measured in g, while the volume of gases in cm^3 or dm^3. For the quantity of soluble substances, the concentration is measured in mol dm^{-3}. The choice in unit of time depends on the rate of reaction. For fast reactions, the time is measured in seconds, while for slow reactions, minutes is used. Therefore, the units for rate of reaction that are commonly used are:

Unit for rate of reaction:
- g s^{-1} or g minute^{-1}
- cm^3 s^{-1} or cm^3 minute^{-1}
- mol dm^{-3} s^{-1} or mol dm^{-3} minute^{-1}

Changes that Occur during Reactions

Determining rate of reaction must be made based on the changes that are observable and can be measured in a certain period of time. What are these changes?

Formation of precipitate occurs in reactions that produce insoluble salts. Photograph 7.1 shows before and after reaction between silver nitrate solution, $AgNO_3$ and sodium chloride solution, NaCl. In this reaction, silver chloride, AgCl and sodium nitrate, $NaNO_3$ are formed. The formation of silver chloride, AgCl can be seen and the precipitate causes the '×' mark to disappear, and the amount of precipitate can be measured.

Photograph 7.1
The reaction between silver nitrate solution, $AgNO_3$ and sodium chloride solution, NaCl

Photograph 7.2
The reaction between nitric acid, HNO_3 and limestone, $CaCO_3$

Decrease in the mass of the reactants also occurs in reactions that produce gases. Photograph 7.2 shows the reaction between nitric acid, HNO_3 and limestone, $CaCO_3$ that produces calcium nitrate, $Ca(NO_3)_2$, carbon dioxide, CO_2 and water, H_2O.
The loss in the mass of limestone can be measured by using an electronic balance.

Increase in volume of gases occurs for reactions that produce gases. Photograph 7.3 shows the reaction between hydrochloric acid, HCl, and magnesium, Mg. In this reaction, magnesium chloride, $MgCl_2$ and hydrogen gas, H_2 are produced. The hydrogen gas, H_2 is collected and the volume of the gas measured using a gas syringe.

Photograph 7.3
The reaction between hydrochloric acid, HCl and magnesium, Mg

Chemistry Lens

Other observable and measurable changes:
- Changes in pressure in reactions involving gases. The change in pressure is measured using a pressure meter
- Changes in the electrical conductivity of electrolytes in reactions involving mobile ions. An ammeter is used to measure the change in the electrical conductivities in the electrolyte
- Changes in pH values for reactions involving acids or bases in aqueous solutions. A pH meter is used to measure the changes in the pH values with time

Activity 7.1

Aim: Determining the time for reaction with reference to some observable and measurable changes.

Materials: Zinc powder, Zn, 0.1 mol dm^{-3} sulphuric acid, H_2SO_4, marble chips, $CaCO_3$, 2.0 mol dm^{-3} nitric acid, HNO_3, potassium iodide powder, KI, lead(II) nitrate powder, $Pb(NO_3)_2$ and distilled water

Apparatus: Retort stand with clamp, burette, basin, 250 cm^3 conical flask, 10 cm^3 and 100 cm^3 measuring cylinders, rubber stopper, delivery tube, electronic balance, stopwatch, cotton wool, petri dish, weighing bottle, filter funnel, ruler and filter paper

A Reaction between zinc, Zn and sulphuric acid, H_2SO_4

Procedure:

1. Add 20 cm^3 of 0.1 mol dm^{-3} sulphuric acid, H_2SO_4 into a conical flask.
2. Fill a burette with water and invert it into a basin of water. Clamp the burette vertically.
3. Adjust the water level in the burette so that the level of water is at the 50 cm^3 mark.
4. Arrange the apparatus as in Figure 7.2.

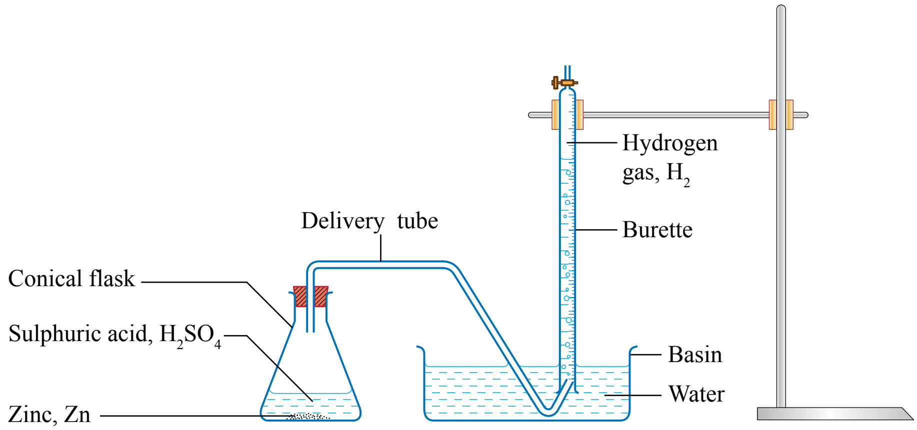


Figure 7.2

5. Add 5 g of zinc powder, Zn into the conical flask that contains sulphuric acid, H_2SO_4.
6. Immediately close the conical flask with the rubber stopper that is connected to the delivery tube. Start the stopwatch.
7. Record the burette reading at 0.5 minute intervals for 5 minutes.
8. Record your results in Table 7.1 given below.

Safety Precaution

Make sure the extension on the apparatus is tight so that the released gas flows to the burette.

Results:

Table 7.1

Time (minute)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burette reading (cm^3)	50.00										
Volume of gas (cm^3)	0.00										

Discussion:

1. State the observable changes and the measurement made in the activity.
2. Name the gas released.
3. Write a chemical equation for the reaction that occurred.
4. How would you know that the reaction is completed?

B **Reaction between nitric acid, HNO_3 and marble chips, $CaCO_3$**

Procedure:

1. Put 100 cm^3 of 2.0 mol dm^{-3} nitric acid, HNO_3 into a conical flask.
2. Close the mouth of the conical flask loosely with cotton wool.
3. Set up the apparatus as shown in Figure 7.3.
4. Add 10 g of marble chips, $CaCO_3$ into the conical flask.
5. Immediately close the conical flask and start the stopwatch.
6. Record the reading of the electronic balance at intervals of 30 seconds.
7. Observe the changes that occur in the conical flask and record all observations.
8. Record your data in a table.

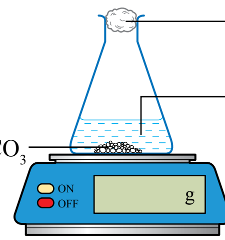


Figure 7.3

Discussion:

1. State the observable changes that was recorded in the activity.
2. Why does such a change occur? Explain your answer with the aid of a suitable chemical equation.
3. How would you know that the reaction is completed?

C **Reaction between potassium iodide solution, KI and lead(II) nitrate solution, $Pb(NO_3)_2$**

Procedure:

1. Using separate weighing bottles, weigh 2 g of potassium iodide powder, KI and 2 g of lead(II) nitrate powder, $Pb(NO_3)_2$ by using two different bottles.
2. Pour distilled water into the petri dish to a depth of 0.5 cm.
3. Add the potassium iodide powder, KI into the water at the edge of the petri dish.
4. Add lead(II) nitrate powder, $Pb(NO_3)_2$ diagonally across from the potassium iodide powder, KI as shown in Figure 7.4.
5. Start the stopwatch immediately.
6. Record the time when the reaction is completed, that is, when no more precipitate is formed.
7. Filter the contents in the petri dish and wash the precipitate with distilled water.
8. Dry and weigh the precipitate.
9. Record your data in a table.

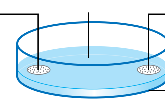


Figure 7.4

Discussion:

1. What is the colour of the precipitate formed?
2. Write an equation for the reaction that occurred.

Prepare a complete report after carrying out this activity.

Determine the time of reaction based on the observable and measurable changes shown through Activity 7.1. How would you determine the rate of reaction?

Average Rate of Reaction and Instantaneous Rate of Reaction

There are two types of rate of reaction, the average rate of reaction and instantaneous rate of reaction. The analogy for the average of reaction and instantaneous rate of reaction is shown in Figure 7.5.

A car intends to travel for 400 km. Due to the ever changing traffic conditions, the driver is not able to maintain a constant speed and took 4 hours to reach the destination. The average speed of the car is 100 km $hour^{-1}$. This is equated as the **average rate of reaction**.

A police officer aims the speed camera in the direction of the car because it is travelling at a speed above the speed limit. At that instant, the camera recorded a speed of 140 km $hour^{-1}$. The speed at that moment is equated to the **instantaneous rate**.

Figure 7.5 *Analogy of average rate of reaction and instantaneous rate of reaction*

The average rate of reaction is the average value for the rate of reaction that occurs in a particular time interval. The following explains the way to calculate the average rate of reaction for reactions that release gases.

☆ The overall average rate of reaction

$$= \frac{\text{Total volume of gas collected}}{\text{Time taken}}$$

$$= \frac{V}{t}\ \text{cm}^3\ \text{s}^{-1}$$

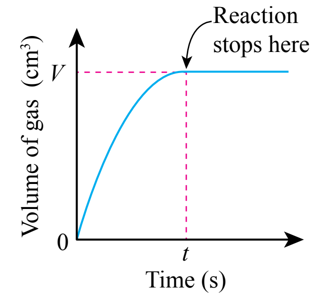


Figure 7.6 *The overall average rate of reaction*

☆ The average rate of reaction for the first t_1 seconds

$$= \frac{\text{Total volume of gas collected in the first } t_1 \text{ seconds}}{\text{Time taken}}$$

$$= \frac{V_1 - 0}{t_1 - 0}\ \text{cm}^3\ \text{s}^{-1}$$

$$= \frac{V_1}{t_1}\ \text{cm}^3\ \text{s}^{-1}$$

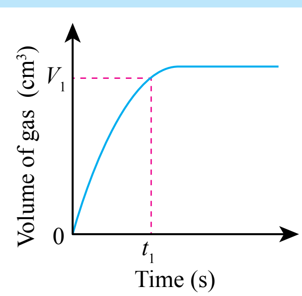


Figure 7.7 *The average rate of reaction for the first t_1 seconds*

☆ The average rate from t_1 to t_2

$$= \frac{\text{Total volume of gas collected from } t_1 \text{ to } t_2}{\text{Time taken}}$$

$$= \frac{V_2 - V_1}{t_2 - t_1} \text{ cm}^3 \text{ s}^{-1}$$

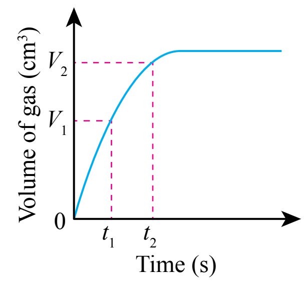
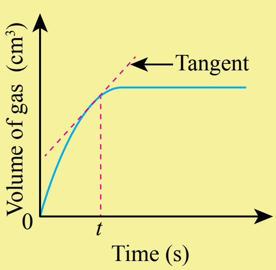


Figure 7.8 *The average rate of reaction from t_1 to t_2*

The instantaneous rate of reaction is the rate of reaction at a particular point of time. It is determined from the experimental data by plotting a graph of changes in the quantity of the reactants or products against time, and measuring the tangent gradient to the curve at that point of time. Figure 7.9 shows the way to calculate the instantaneous rate of reaction.

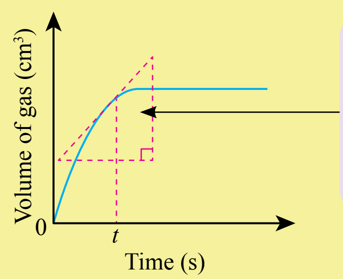
Method 1

Draw a tangent to the curve at time *t*.



Method 2

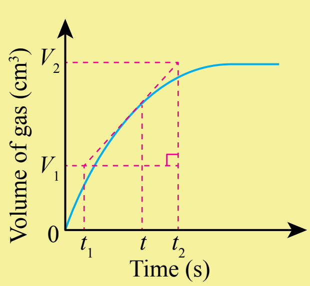
Use the tangent to complete a vertically-angled triangle.



The triangle can be drawn in various sizes. The bigger the triangle, the more accurate it can be to determine the tangent gradient.

Method 3

Calculate the gradient of the tangent to the curve.



Rate of reaction at time t

= Gradient of the tangent at time t

$$= \frac{\Delta V}{\Delta t}$$

$$= \frac{V_2 - V_1}{t_2 - t_1} \text{ cm}^3 \text{ s}^{-1}$$

Figure 7.9 *Methods to calculate the instantaneous rate of reaction*

For reactions that involve a decrease in the total mass of the reactants, a graph as shown in Figure 7.10 is obtained.

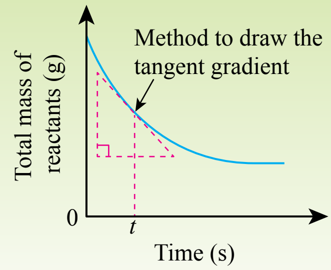


Figure 7.10 *The instantaneous rate of reaction that involves the decreasing of reactants*

Activity 7.2

Determining the average rate of reaction and instantaneous rate of reaction

Answer the following questions based on the data obtained from Activity 7.1.

1. For the reaction between zinc, Zn and sulphuric acid, H_2SO_4:
   (a) Plot a graph of gas volume against time.
   (b) Calculate the following average rates of reaction:
      (i) For the first minute
      (ii) For the fifth minute
      (iii) For the overall reaction
   (c) Based on the graph plotted, calculate the rate of reaction at the following time:
      (i) At the first minute
      (ii) At the third minute
      (iii) At the end of the reaction
2. For the reaction between potassium iodide solution, KI and lead(II) nitrate solution, $Pb(NO_3)_2$:
   (a) Calculate the average rate of reaction.
   (b) Can you determine the rate of reaction at 30 seconds? Explain.

Solving Numerical Problems Based on Rate of Reactions

Example 1

A student adds magnesium carbonate crystals, $MgCO_3$ until excess into sulphuric acid, H_2SO_4. The volume of carbon dioxide, CO_2 released is collected in a gas syringe and the volume of gas recorded in Table 7.2 for 1 minute intervals for 10 minutes.

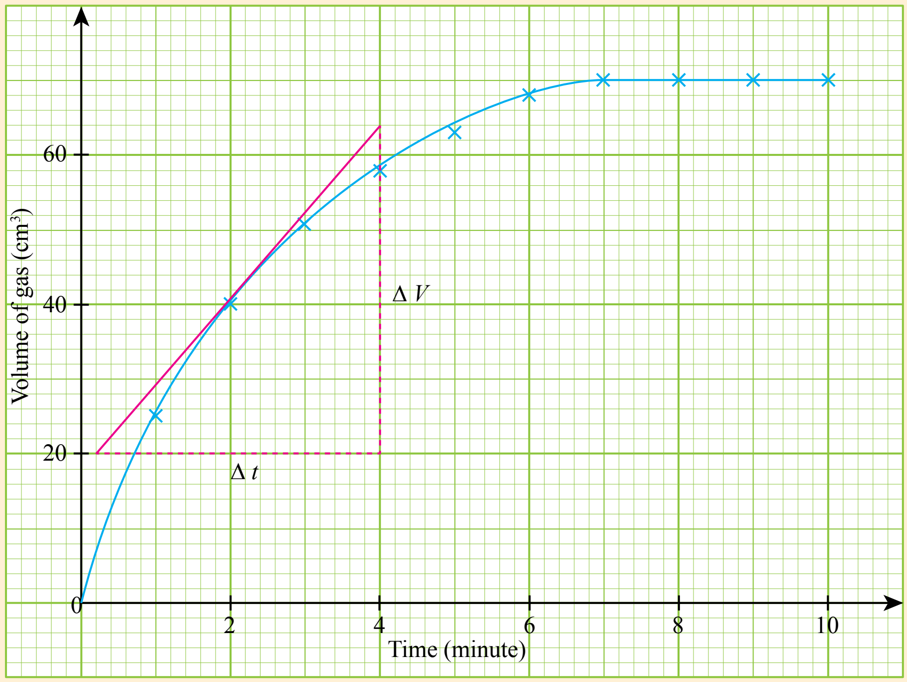
Table 7.2

Time (minute)	0	1	2	3	4	5	6	7	8	9	10
Volume of gas (cm^3)	0	25	40	51	58	63	68	70	70	70	70

(a) Based on Table 7.2, plot a graph of the volume of gas against time.
(b) Calculate the following average rate of reactions:
   (i) For the fifth minute
   (ii) For the overall reaction
(c) Based on the plotted graph, calculate the rate of reaction for the second minute.

Solution

(a)



(b) (i) Average rate of reaction for the 5th minute

$$= \frac{\text{Total volume of gas collected from the 4}^{\text{th}}\text{ minute to the 5}^{\text{th}}\text{ minute}}{\text{Time taken}}$$

$$= \frac{(63 - 58)\text{ cm}^3}{(5 - 4)\text{ minute}}$$

$$= \frac{5\text{ cm}^3}{1\text{ minute}}$$

$= 5\text{ cm}^3\text{ minute}^{-1}$

The average rate of reaction from the 4th to the 5th minute.

(ii) The overall average rate of reaction

$$= \frac{\text{Total volume of gas collected}}{\text{Time of reaction}}$$

$$= \frac{70\text{ cm}^3}{7\text{ minute}}$$

$= 10\text{ cm}^3\text{ minute}^{-1}$

The reaction ends at the 7th minute and not 10th minute.

(c) The rate of reaction at the second minute

= Gradient of the tangent to the curve at the second minute

$$= \frac{\Delta V}{\Delta t}$$

$$= \frac{(64 - 20)\text{ cm}^3}{(4 - 0.2)\text{ minute}}$$

$= 11.58\text{ cm}^3\text{ minute}^{-1}$

Activity 7.3

Solving numerical problems related to rate of reactions CT

In the presence of manganese(IV) oxide, MnO_2, hydrogen peroxide, H_2O_2 decomposes to water and oxygen. The oxygen gas released is collected in a gas syringe and the volume recorded at intervals of 0.5 minute. The data collected is shown in Table 7.3.

Table 7.3

Time (minute)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Volume of gas (cm^3)	0.0	13.5	22.0	28.0	33.0	37.0	40.5	43.0	45.0	47.0	48.0	49.0	50.0	50.0	50.0

1. Based on Table 7.3, plot a graph of volume of gas against time.
2. Calculate the following average rate of reaction:
   (a) For the first minute
   (b) For the fifth minute
   (c) For the whole reaction
3. Calculate the rate of reaction at the following time:
   (a) 1.5 minute   (b) 4.0 minute

Test Yourself 7.1

1. Explain the meaning of rate of reaction.
2. Classify the following reactions as fast or slow:
   (a) Photosynthesis
   (b) Combustion of petrol in car engines
   (c) Rusting of iron gate
   (d) Explosion at oil factory
3. State the observable and measurable change(s) to determine the rate of reaction in the following examples of reactions:
   (a) $2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
   (b) $H_2SO_4(aq) + Na_2S_2O_3(aq) \rightarrow Na_2SO_4(aq) + H_2O(l) + SO_2(g) + S(s)$
   (c) $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
   (d) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
4. Metals react with acids at different rates.

   Metal + Acid → Salt + Hydrogen gas

   Three different metals, *P*, *Q* and *R* react separately with 100 cm^3 of acid. The time taken to collect 50 cm^3 of hydrogen gas for each of the metal is recorded in Table 7.4

   Table 7.4

Metal	Time (s)
P	60
Q	95
R	20

   (a) Calculate the average rates of reaction for each of the metal with acid.
   (b) Based on your answer in 4(a), arrange the three metals in order of descending reactivity. Explain your answer.

7.2 Factors Affecting Rate of Reactions

Different chemical substances have different chemical properties. As a result, different chemicals have different reactions and occur at different rates. What are the factors that affect the rate of reactions?

Learning Standard

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

7.2.1 Investigate factors affecting the rate of reactions through experiment, based on:
- Size of reactants
- Concentration
- Temperature
- Presence of catalyst

Size of Reactants

Solid reactants can undergo change in sizes. A piece of marble chip can be cut into smaller pieces. The total surface area of all the smaller pieces is larger than the total surface area of the original piece of marble as shown in Figure 7.11

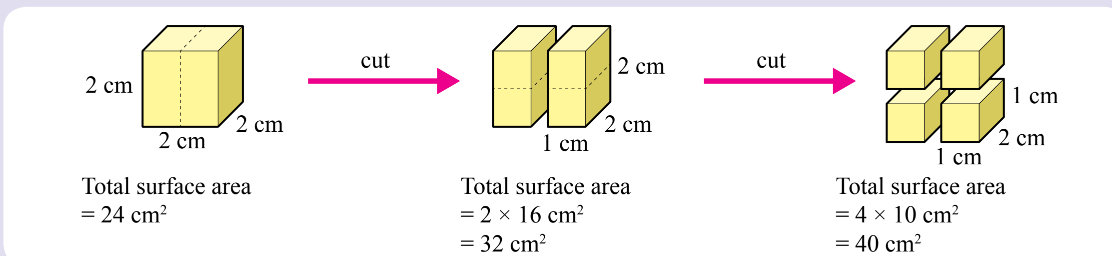


Figure 7.11 *Total surface area of different sizes of reactant*

For a fixed mass, the powdered form has a larger total surface area than the original pieces of the solid. Experiment 7.1 shows the effect of size of reactants on the rate of reaction.

Experiment 7.1

Aim: To study the effect of size of reactants on the rate of reaction.

Problem statement: How can size of reactant affect the rate of reaction?

Hypothesis: The smaller the size of the marble chips, $CaCO_3$, the higher the rate of reaction.

Variables:

(a) Manipulated : Size of marble chips, $CaCO_3$

(b) Responding : Rate of reaction

(c) Fixed : Mass of marble chips, $CaCO_3$, temperature, volume and concentration of hydrochloric acid, HCl

Materials: 0.1 mol dm^{-3} hydrochloric acid, HCl, large pieces of marble chips, $CaCO_3$ and small pieces of marble chips, $CaCO_3$

Apparatus: Conical flask 250 cm^3, retort stand with clamp, burette, basin, 100 cm^3 measuring cylinder, rubber stopper, delivery tube, electronic balance and stopwatch

Procedure:

1. Put 80 cm^3 of 0.1 mol dm^{-3} hydrochloric acid, HCl into a conical flask.
2. Fill the burette with water and invert it into a basin filled with water. Clamp the burette vertically.
3. Adjust the water level in the burette so that the water level reading is 50 cm^3.
4. Set up the apparatus as shown in Figure 7.12.
5. Weigh 5 g of large pieces of marble chips, $CaCO_3$ and add them into the conical flask.
6. Immediately close the conical flask with the rubber stopper which is connected to a delivery tube. At the same time, start the stopwatch.
7. Slowly swirl the conical flask throughout the experiment.
8. Record the burette reading at intervals of 30 seconds until the burette is completely filled with gas.
9. Repeat steps 1 to 8 by using smaller pieces of 5 g of marble chips, $CaCO_3$.
10. Record all the data in table form.

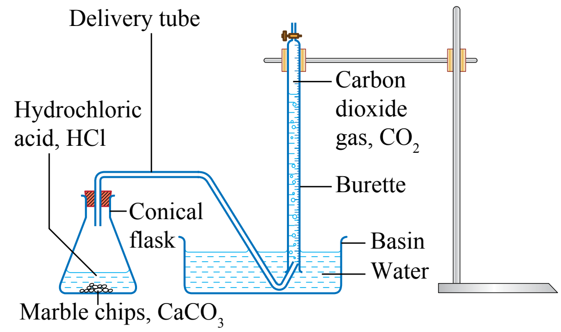


Figure 7.12

CAUTION

Acids are corrosive. Wear gloves and safety glasses when handling acids.

Interpreting data:

1. Based on the data obtained, plot two graphs of volume of gas against time on a same set of axis.
2. Based on the graph, determine:
   (a) The tangent gradient at $t = 0$ (initial rate of reaction).
   (b) The time taken for the complete reaction.

Conclusion:

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

Prepare a complete report after carrying this experiment.

Concentration

The concentration of a solute in a solution can be changed. The concentration of the solution can be changed by adding solvent or solute.

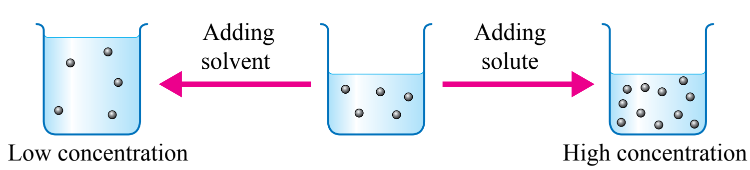


Figure 7.13 *Concentration of solution*

What is the effect of concentration of reactant on the rate of reaction?

Experiment 7.2

Aim: To investigate the effect of concentration of reactants on the rate of reaction.

Problem statement: How does the concentration of the reactants affect the rate of reaction?

Hypothesis: The higher the concentration of sodium thiosulphate solution, $Na_2S_2O_3$, the shorter the time taken for the '×' mark to disappear from view.

Variables:
(a) Manipulated : Concentration of sodium thiosulphate solution, $Na_2S_2O_3$
(b) Responding : Time taken for the '×' mark to disappear from view
(c) Fixed : Temperature, total volume of mixture, concentration and volume of sulphuric acid, H_2SO_4 and the size of the conical flask

Materials: 1.0 mol dm^{-3} sulphuric acid, H_2SO_4, 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$, distilled water and white piece of paper with a '×' mark at the centre

Apparatus: 150 cm^3 conical flask, stopwatch, 10 cm^3 and 50 cm^3 measuring cylinders

Procedure:
1. Put 45 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ into a conical flask.
2. Place the conical flask on the '×' mark on the white paper as shown in Figure 7.14.
3. Swiftly, pour 5 cm^3 of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 into the conical flask carefully and at the same time start the stopwatch.
4. Swirl the conical flask gently and place it again on the '×' mark.

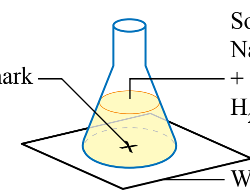


Figure 7.14

5. Observe the '×' mark vertically from the mouth of the conical flask.
6. Stop the stopwatch once the '×' mark disappears from view. Record the time taken.
7. Repeat the experiment by using 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ that has been diluted with distilled water as given in Table 7.5. The volume of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 is fixed at 5 cm^3.
8. Record all data in Table 7.5.

Results:

Table 7.5

Experiment	I	II	III	IV	V
Volume of sodium thiosulphate solution, $Na_2S_2O_3$ (cm^3)	45	40	30	20	10
Volume of distilled water (cm^3)	0	5	15	25	35
Volume of sulphuric acid, H_2SO_4 (cm^3)	5	5	5	5	5
Total volume of mixture (cm^3)	50	50	50	50	50
Time taken for the '×' mark to disappear from view (s)					

Interpreting data:

1. The concentration of dilute sodium thiosulphate solution, $Na_2S_2O_3$ is calculated using the formula $M_1V_1 = M_2V_2$.

   M_1 = The original concentration of sodium thiosulphate solution, $Na_2S_2O_3$
   V_1 = The volume of sodium thiosulphate solution, $Na_2S_2O_3$ used
   M_2 = Concentration of the dilute sodium thiosulphate solution, $Na_2S_2O_3$
   V_2 = Volume of the dilute sodium thiosulphate solution, $Na_2S_2O_3$

   Use the given formula and the data collected to calculate the concentration of the dilute sodium thiosulphate solution, $Na_2S_2O_3$.
2. In the experiment, the rate of reaction is inversely proportional to the time taken for the '×' mark to disappear from view. Thus, rate of reaction = $\frac{1}{\text{time}}$. Use this formula and the data collected to calculate the rate of reaction for all the five experiments.
3. Record all answers from (1) and (2) in Table 7.6.

Table 7.6

Experiment	I	II	III	IV	V
Concentration of dilute sodium thiosulphate, $Na_2S_2O_3$ solution (mol dm^{-3})					
Rate of reaction, $\frac{1}{\text{time}}$ (s^{-1})					

4. Use the data in Table 7.6 to plot a graph of rate of reaction, $\frac{1}{\text{time}}$ against concentration of sodium thiosulphate solution, $Na_2S_2O_3$, M_2.
5. Based on the graph, state the relationship between rate of reaction and concentration of sodium thiosulphate solution, $Na_2S_2O_3$.

Conclusion:

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

Discussion:

1. Why does the solution in the conical flask turn cloudy?
2. Name the substance that causes the solution to turn cloudy.
3. The '×' mark disappears from view when the solution in the conical flask reaches a certain level of cloudiness. What are the steps required in this experiment so that the same level of cloudiness is achieved in all the five experiments?
4. What are the changes being measured in the experiment to determine the rate of reaction?

Prepare a complete report after carrying out this experiment.

Temperature

Most reactions occur faster at high temperatures, that is, the rate of reaction increases with increasing temperature. For reactions that occur at room temperature, each increase of 10 °C will increase the reaction rate by two times.

Experiment 7.3

Aim: To investigate the effect of temperature on the rate of reaction.

Problem statement: How does temperature affect the rate of reaction?

Hypothesis: The higher the temperature of the sodium thiosulphate solution, $Na_2S_2O_3$, the shorter the time taken for the '×' mark to disappear from view.

Variables:
(a) Manipulated : Temperature of sodium thiosulphate solution, $Na_2S_2O_3$
(b) Responding : Time taken for the '×' mark to disappear from view
(c) Fixed : Volume and concentration of sulphuric acid, H_2SO_4

Materials: 1.0 mol dm^{-3} sulphuric acid, H_2SO_4, 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ and a piece of white paper with an '×' mark in the middle

Apparatus: 150 cm^3 conical flask, 10 cm^3 and 50 cm^3 measuring cylinders, stopwatch, thermometer, Bunsen burner, wire gauze and tripod stand

Procedure:
1. Put 50 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ into a conical flask. Leave it for 5 minutes.
2. Record the temperature of the 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$.
3. Place the conical flask on the '×' mark of the white paper.
4. Quickly, add in 5 cm^3 of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 into the conical flask carefully. At the same time, start the stopwatch.
5. Swirl the conical flask gently and place it again on the '×' mark.
6. Observe the '×' mark vertically from the mouth of the conical flask.
7. Stop the stopwatch once the '×' mark disappears from view.
8. Record the time taken when the '×' mark disappears from view.
9. Repeat steps 1 until 8 by using 50 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ that has been heated to 40 °C, 45 °C, 50 °C, and 55 °C.

Interpreting data:
1. Use the data obtained to plot a graph of rate of reaction, $\frac{1}{\text{time}}$ against temperature of sodium thiosulphate solution, $Na_2S_2O_3$.
2. Based on the graph, state the relationship between rate of reaction and the temperature of sodium thiosulphate solution, $Na_2S_2O_3$.

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

Discussion:
1. Write the ionic equation for the reaction between sodium thiosulphate solution, $Na_2S_2O_3$ and sulphuric acid, H_2SO_4.
2. Can sulphuric acid, H_2SO_4 be replaced with hydrochloric acid, HCl? Explain.

Prepare a complete report after carrying out this experiment.

Presence of Catalyst

Catalysts are chemical substances that alter the rate of chemical reactions without undergoing any chemical changes at the end of the reaction. Although the chemical properties of the catalyst does not change, but its physical properties can change. For example, a lump of catalyst can turn into powder.

Catalysts do not change the quantity of products. Does the addition of a catalyst increase the rate of reaction?

Experiment 7.4

Aim: To investigate the effect of catalyst on the rate of reaction.

Problem statement: How does the presence of catalyst affect the rate of reaction?

Hypothesis: Presence of catalyst increases the rate of reaction.

Variables:
(a) Manipulated : Presence of catalyst
(b) Responding : Rate of reaction
(c) Fixed : Mass of manganese(IV) oxide, MnO_2, temperature and volume of hydrogen peroxide solution, H_2O_2

Materials: 20-volume hydrogen peroxide solution, H_2O_2, manganese(IV) oxide powder, MnO_2 and distilled water

Apparatus: 10 cm^3 measuring cylinder, test tubes, test tube rack, glowing wooden splinter, filter funnel, filter paper, 150 cm^3 beaker, spatula and electronic balance

Procedure:
1. Label two test tubes as I and II.
2. Put 5 cm^3 hydrogen peroxide solution, H_2O_2 into test tube I and test tube II separately.
3. Place the two test tubes in the test tube rack.
4. Add 0.5 g manganese(IV) oxide powder, MnO_2 into test tube II. Place a glowing wooden splinter into the mouth of both test tubes quickly.
5. Observe the changes that occur to the wooden splinter and record your observations.

Concentration of hydrogen peroxide solution
http://bit.ly/2W0iIKD

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

Discussion:
1. What are the changes observed and measured in this experiment?
2. Explain how the observation in (1) can assure your hypothesis.

Prepare a complete report after carrying out this experiment.

Chemistry Lens

The mass of catalyst does not change before and after the reaction. You can compare the mass of manganese(IV) oxide, MnO_2 before and after Experiment 7.4 for confirmation.

Diagram 7.15 summarises the effect of concentration, size of reactants, temperature and catalyst on the rate of reaction.

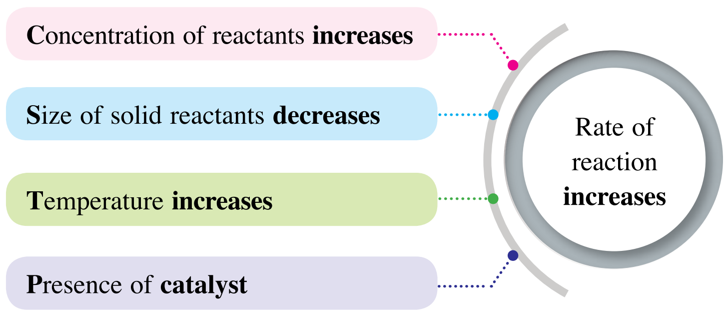


Figure 7.15 *Factors affecting rates of reactions*

Literacy Tips

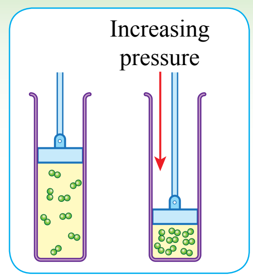
Acronym **CSTP** can help you to remember the factors that affect the rate of reaction.

Effect of pressure on the rate of reaction

http://bit.ly/33zfz6O

Chemistry Lens

Pressure is another factor that affects the rates of reactions. Increasing the pressure on reactions involving gases will affect the rate of reaction. When a gas is compressed at constant temperature, the gas particles are pushed into a smaller volume of space. Increasing pressure, increases the concentration of the gas and the rate of reaction. Changes in pressure does not affect the rate of reaction involving solids and liquids reactants as the volume does not change with pressure.

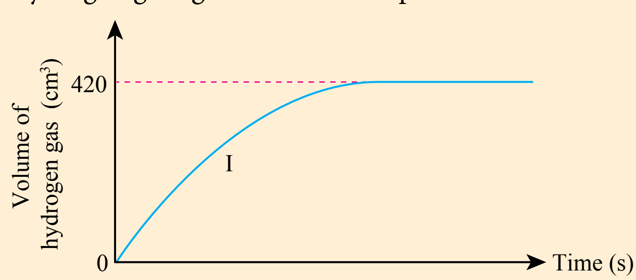


Example 2

Reactive metals such as potassium reacts with water to release hydrogen gas.

$$Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$$

Two experiments are carried out to determine the rate of reaction between 0.7 g of calcium and 200 cm^3 of water at different temperatures. Experiment I is carried out at room temperature. In experiment II, the temperature of water is increased by 10 °C. The diagram below shows the graph of volume of hydrogen gas against time for experiment I.

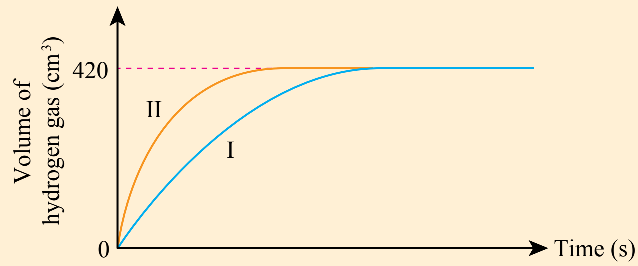


(a) What is the total volume of hydrogen gas produced in experiment II? Explain your answer.
(b) Copy the graph above and sketch the curve for experiment II.
(c) What is the effect of temperature on the rate of reaction?

Solution

(a) Total volume of hydrogen gas produced in experiment II = 420 cm^3.
The quantity of reactants (calcium and water) is the same in both experiments.
So, the results of (hydrogen gas) reaction must be the same.

(b)



(c) Increase in water temperature increases the rate of reaction.

Example 3

Gastric is caused by the production of too much acid in the stomach. Doctors use antacid tablets to neutralise the acid in the stomach. Table 7.7 shows the time taken by each antacid tablet to react completely in excess hydrochloric acid, HCl under different conditions.

Table 7.7

Experiment	Volume of hydrochloric acid, HCl (cm^3)	Concentration of hydrochloric acid, HCl (mol dm^{-3})	Temperature of hydrochloric acid, HCl (°C)	Time of reaction (s)
I	50	1.0	30	120
II	50	2.0	30	60
III	100	2.0	30	60
IV	50	2.0	40	30

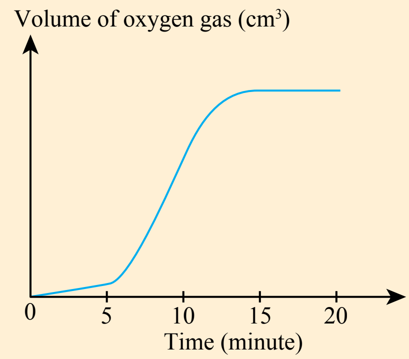
(a) Why the time of reaction is different for experiment I and II?
(b) Which of the following experiment shows that the change in volume of hydrochloric acid, HCl does not affect the rate of reaction?
(c) Why is the rate of reaction for experiment IV higher than experiment II?
(d) Other than temperature and concentration of the hydrochloric acid, HCl, what changes can be made to increase the rate of reaction in experiment I?

Solution

(a) Experiment I uses 1.0 mol dm^{-3} hydrochloric acid, HCl while experiment II uses 2.0 mol dm^{-3} hydrochloric acid, HCl. The concentration of hydrochloric acid is different.
(b) Experiment II and III.
(c) The temperature of the hydrochloric acid, HCl in experiment IV is higher than in experiment II.
(d) The size of the antacid tablet. Crush the tablet into smaller pieces so as to increase the total surface area.

Example 4

Adnan carries out an experiment to investigate the decomposition of hydrogen peroxide, H_2O_2. He records the volume of oxygen gas released. At the 5th minute, he adds one spatula full of black powder into the hydrogen peroxide solution, H_2O_2. The diagram shows the graph of volume of oxygen gas released against time.



(a) What is the effect of the black powder on the rate of reaction?

(b) What is the function of the black powder?

Solution

(a) The addition of the black powder increases the rate of reaction.

(b) The black powder acts as a catalyst.

Activity 7.4

CT

Discussing the solution involving the rate of reactions and determine the variables involved in the reactions

As a group, solve the following problems:

1. Figure 7.16 shows the graph of volume of carbon dioxide against time for the two experiments, I and II.

   Table 7.7 shows the conditions of the two experiments.

Table 7.7

Experiment	Reactants
I	1.0 g of marble chips, $CaCO_3$ + 50 cm^3 of 0.5 mol dm^{-3} hydrochloric acid, HCl at room temperature
II	Marble, $CaCO_3$ + 50 cm^3 of 0.5 mol dm^{-3} hydrochloric acid, HCl

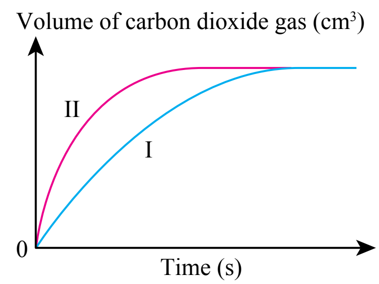


Figure 7.16

Suggest two ways to carry out experiment II so that a similar graph as in Figure 7.16 can be obtained. State all the variables involved.

2. Hydrogen peroxide, H_2O_2 decomposes slowly at room temperature to produce water and oxygen. The decomposition of hydrogen peroxide, H_2O_2 can be accelerated by the presence of a catalyst. Three experiments are carried out to determine the effect of three different catalysts on the complete decomposition of 50 cm^3 of 10-volume hydrogen peroxide solution, H_2O_2. Table 7.8 shows the results of the experiments.

Table 7.8

Type of catalyst \ Time(s)	10	20	30	40	50	60
	Volume of oxygen gas collected (cm^3)					
Manganese(IV) oxide, MnO_2	57	82	93	100	100	100
Copper(II) oxide, CuO	12	19	25	28	30	31
Iron, Fe	33	47	55	58	59	60

(a) Write the chemical equation for the decomposition of hydrogen peroxide, H_2O_2.
(b) Explain briefly how the experiment was conducted. Include the following in your explanation:
   (i) Problem statement
   (ii) Hypothesis
   (iii) All the variables
   (iv) Diagram for the set-up of the apparatus
(c) Which catalyst is more effective in speeding up the rate of decomposition of hydrogen peroxide, H_2O_2? Explain your answer.

Test Yourself 7.2

1. The rate of reaction is affected by various factors.
   (a) State four factors that would affect the rate of reaction.
   (b) Zinc, Zn reacts with excess sulphuric acid, H_2SO_4 according to the following equation:

$$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$$

   State four ways to speed up the reaction. In your answer, state the manipulated and the fixed variables.

2. Four experiments to study the reaction between 2 g of marble, $CaCO_3$ with 15 cm^3 of hydrochloric acid, HCl is shown in Figure 7.17.

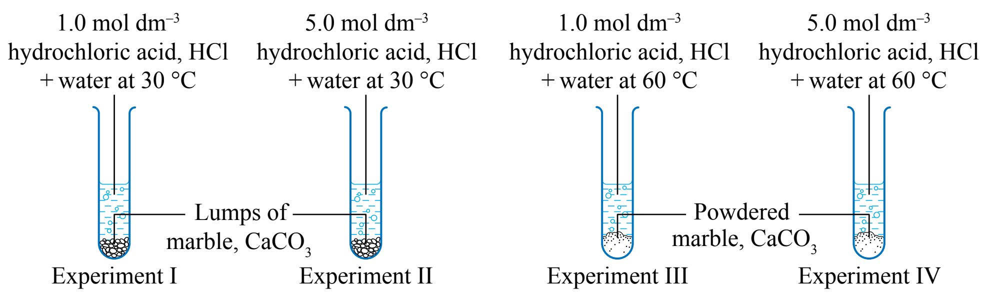


Figure 7.17

   (a) State the variable that can be observed and measured to determine the rate of reaction.
   (b) What is the manipulated variable in the experiment?
   (c) Which experiment has the highest initial rate of reaction? Explain your answer.

7.3 Application of Factors that Affect the Rate of Reaction in Daily Life

Learning Standard

At the end of the lesson, pupils are able to:
7.3.1 Explain with examples the application of factors that affect the rate of reaction in daily life

Rate of reactions are important in daily life whether at home or in industry. Have you ever wondered how to cook food fast?

Activity 7.5

Solving problems in various daily life activities

21st Century Skills CT

1. Carry out the Role-Play activity.
2. Collect information from various sources to solve the following problems:
   (a) How to cook food fast?
   (b) How to maintain the freshness of milk?
   (c) How to remove a blood stain on a shirt?
3. Discuss and prepare the script with suitable equipment.
4. Present your group performance in front of the class within the time allocated.

The Size Factor

Action of medicines

Antacid tablets are used to treat gastric. Doctors advise patients to chew the tablet instead of swallowing. Breaking up the tablet into smaller pieces increases the total surface area exposed and increases the rate of reaction between the medicine and the acid in the stomach.

Cooking food

Potatoes are cut into thin slices or long strips so that it can be cooked faster. Thin slices or long strips increases the total surface area exposed to the cooking oil compared to uncut potatoes.

Photograph 7.4 *Potato strips*

Concentration Factor

Corrosion due to acid rain

Buildings made of iron that are located near the industrial areas will corrode fast due to acid rain. The atmosphere around industrial areas contains a high concentration of sulphur dioxide. When the concentration of the acidic pollutants increases, the level of acid rain increases and the rate of corrosion increases.

Combustion of petrol in car engines

Petrol vapour and air are compressed in the car engine combustion chamber before being burned. The compression increases the concentration of the petrol vapour allowing the petrol to burn very quickly until it explodes. The energy released from the combustion of petrol will make the car move.

Photograph 7.5 *Combustion of petrol in a car engine*

Temperature Factor

Cleaning

Washing clothes using detergent powder and hot water combines two factors that increase the rate of reaction. The process of washing clothes will be even quicker in this situation.

Photograph 7.6 *Washing clothes*

Cooking food

Other than decreasing the size, food also cooks faster at high temperatures. Water boils at 100 °C while cooking oil would not boil even the temperature reaches 180 °C. Therefore, frying food in oil will cook the food even faster.

Catalyst Factor

Catalytic converter

Modern cars are fitted with catalytic converters as shown in Photograph 7.7 to cut down atmospheric pollution. Exhaust gas from car engines contains pollutants. Figure 7.18 shows how catalytic converters change pollutants into non-harmful products that are safe to be released into the atmosphere in the presence of platinum catalyst, Pt.

Photograph 7.7 *Catalytic converter*

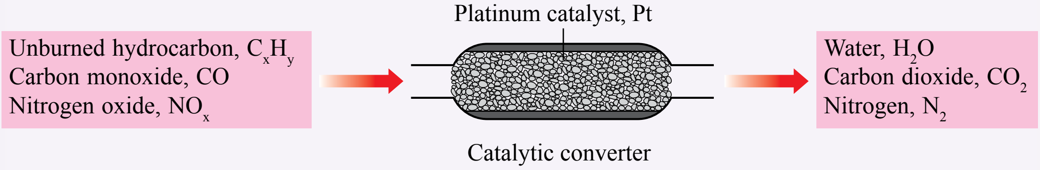


Figure 7.18

Making alcohol

Ethanol, C_2H_5OH, is the main ingredient in alcoholic drinks. Ethanol is produced through the fermentation of glucose with the help of enzyme in yeast as a catalyst at 37 °C.

Activity 7.6

CT

Discussing the application of the knowledge on the factors that affect the rate of reactions in daily activities

1. Carry out the activity in groups.
2. Find information from various reading sources and the internet related to the application of the knowledge on the factors that affect the rate of reactions in the following daily activities.
   (a) Burning of coal
   (b) Food storage in the refrigerator
   (c) Cooking using pressure cooker
   (d) Fermentation process in the making of '*tapai*'
3. Based on the information collected, start a forum titled 'Rate of Reaction in Daily Life'.

Test Yourself 7.3

1. Fill in the blanks.
   (a) Meat cooks faster if it is cut into ___________ sizes.
   (b) In the refrigerator, the ___________ temperature decreases the growth of bacteria that causes food decay.
   (c) Food cooks faster in a pressure cooker because of high ___________.
   (d) Coal burns faster in small chips because of the large surface area that is ___________.

2. In industry, ammonia, NH_3 is produced by the direct combination between nitrogen, N_2 and hydrogen, H_2. Ammonia, NH_3 is used to make nitrogeneous fertilisers. Figure 7.19 shows the percentage yield of ammonia, NH_3 under different conditions.

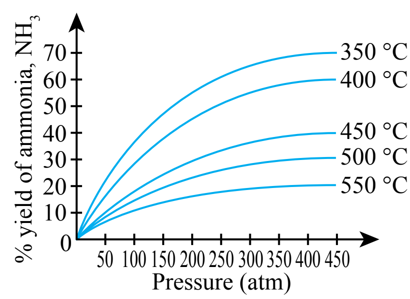


Figure 7.19

   (a) State the effect on the percentage yield of ammonia, NH_3 with increasing:
      (i) Temperature (ii) Pressure
   (b) Explain the advantages and disadvantages of using 350 °C and 550 °C in the process of producing ammonia, NH_3. How can the disadvantages be overcome?

3. Car exhaust gas contains polluting gases formed from the burning of fossil fuels in the car engine.
   (a) Name three polluting gases in the car exhaust.
   (b) In the car engine, nitrogen, N_2 combines with oxygen, O_2 to produce nitrogen monoxide, NO. At room temperature and pressure, this reaction occurs very slow. Why can this reaction occur in the car engine?

7.4 Collision Theory

According to the kinetic theory of matter, matter is made up of tiny and discrete particles that are constantly moving; vibrating at fixed positions for solid, and moving freely for liquids and gasses. As a result, particles collide with one another.

During collision, transfer of energy occurs. Fast moving particles transfer some of their energy to slow moving particles and increases their kinetic energy. This process is repeated with other particles. As a result, particles do not have the same kinetic energy and are constantly changing.

The collision theory explains how reactant particles interact with one another to cause reactions to occur and form products.

According to the collision theory,
- reactant particles must collide with one another for reaction to occur
- the rate of reaction depends on the frequency of **effective collisions**

Not all collisions between reactant particles result in reactions and the formation of products. Only effective collisions would cause reactions to occur. To produce effective collisions, the reactant particles must have energy equal to or more than the **activation energy** and collide in the **correct orientation**.

Activation Energy

Reactant particles need to have enough energy to initiate a reaction. In other words, activation energy is required to start a reaction. Activation energy is like an energy barrier that needs to be overcomed before a reaction can take place. Photograph 7.8 shows the analogy of such a barrier. The energy required for a horse to overcome the barrier is identical to the activation energy that the particles require to initiate a reaction.

Reactant particles need to acquire the minimum energy known as activation energy so as to break the bonds in the reactant particles and form new bonds in the products. Different reactions have different activation energy.

Learning Standard

At the end of the lesson, pupils are able to:
7.4.1 Describe the collision theory
7.4.2 Explain activation energy using examples
7.4.3 Interpret an energy profile diagram for exothermic reaction and endothermic reaction

Chemistry Lens

Collision between particles with energy less than the activation energy or in the wrong orientation is called an ineffective collision.

Collision theory
http://bit.ly/35RRzhl

Photograph 7.8
Analogy of activation energy

The activation energy is represented by the symbol E_a. In the energy profile diagram, the activation energy is the difference in energy between the energy level of the reactants and the energy at the peak of the curve in the graph.

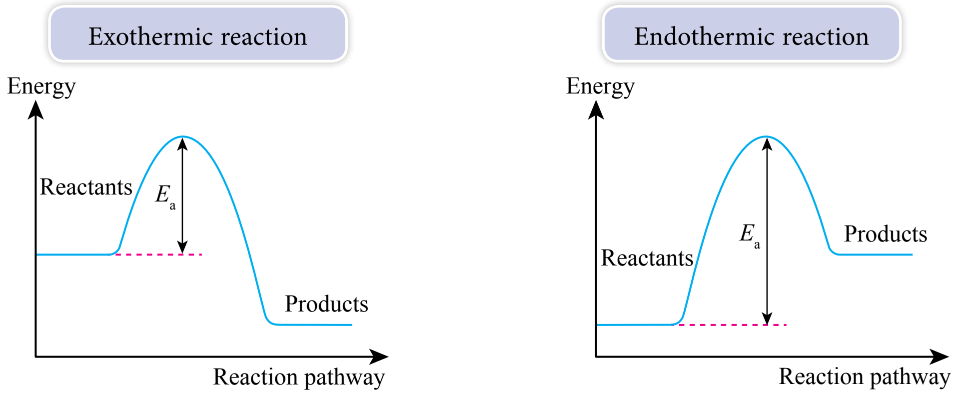


Figure 7.20 *Energy profile diagram*

In an exothermic reaction, the total energy of the reactants is higher than the total energy of the products. In an endothermic reaction, the total energy of the products is higher than the total energy of the reactants.

Collision Orientation

Reactant particles must be in a specific orientation to result in effective collisions. Figure 7.21 shows the collision between reactant particles in the correct orientation to allow old bonds to be broken and new bonds to form.

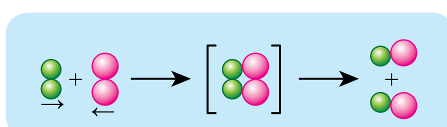


Figure 7.21

If the reactant particles collide in incorrect orientations, the particles will bounce back and no reaction occurs. Figure 7.22 shows the collision between reactant particles in the wrong orientation.

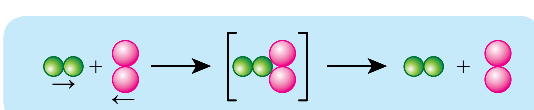


Figure 7.22

Collision theory (Part 2)

http://bit.ly/35Q8DnZ

Collision theory (Part 3)

http://bit.ly/35RRRor

Effective Collision and Rate of Reaction

The rate of reaction depends on the rate of successful collisions between the reactant particles. The higher the frequency of collision between reactant particles with enough energy and in the correct orientation, the faster the reaction occurs. In other words, the rate of reaction depends on the frequency of effective collisions.

The higher the frequency of effective collisions, the higher the rate of reaction.
The lower the frequency of effective collisions, the lower the rate of reaction.

Effect of Concentration on the Rate of Reaction

Based on Figure 7.23, which has a higher frequency of collision?

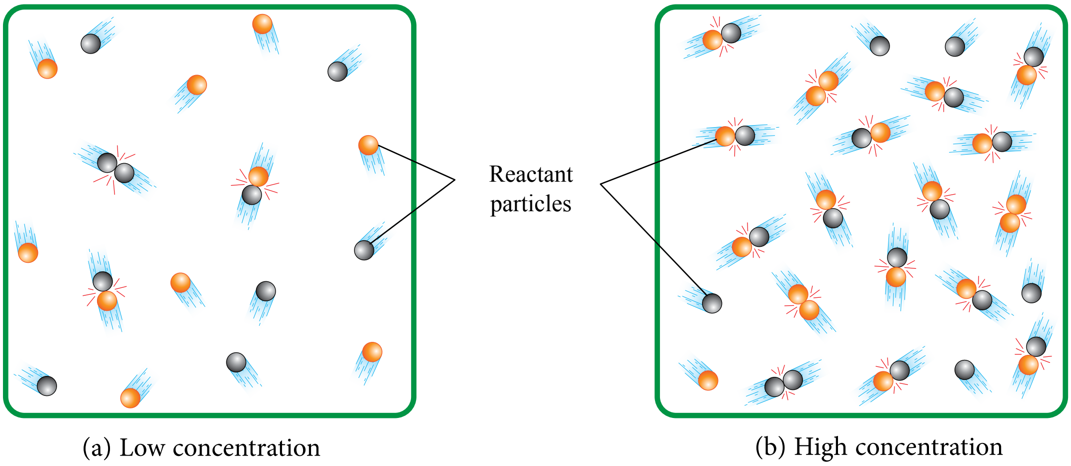


Figure 7.23 *The effect of concentration of reactants on the rate of reaction*

When the **concentration** of the reactant particles increases,
- the number of particles per unit volume increases
- the frequency of collisions between particles increases
- the frequency of effective collisions between particles increases
- the rate of reaction increases

For reactions involving gases, changes in pressure is the same as changing the concentration of the gas. What is the effect of gas pressure on the rate of reaction?

When the **pressure of a gas** increases,
- the number of particles per unit volume increases
- the frequency of collisions between particles increases
- the frequency of effective collisions between particles increases
- the rate of reaction increases

Effect of Size of Reactant on the Rate of Reaction

When a large piece of a solid reactant is broken up into smaller pieces, the total volume of the substance remains the same. However, the total surface area of the reactant increases. Figure 7.24 explains the effect of particle size on the rate of reaction.

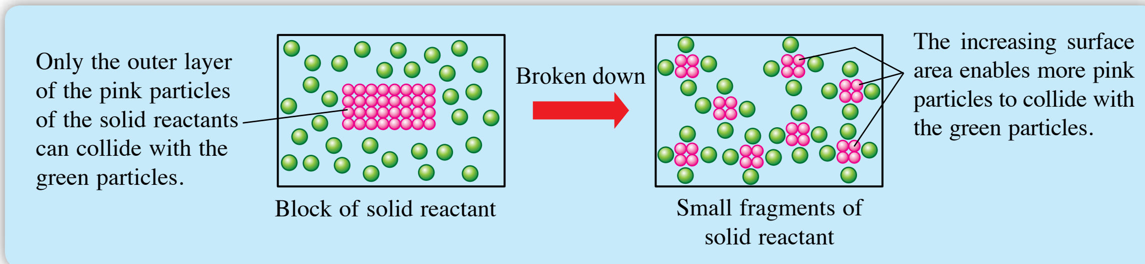
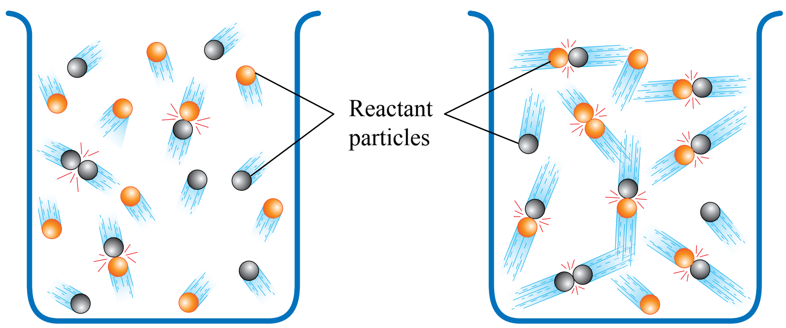


Figure 7.24 The effect of size of reactant on the rate of reaction

When the **total surface area** of the reactant increases,
- the total surface area exposed to collision increases
- the frequency of collisions between particles increases
- the frequency of effective collision increases
- the rate of reaction increases

Effect of Temperature on the Rate of Reaction

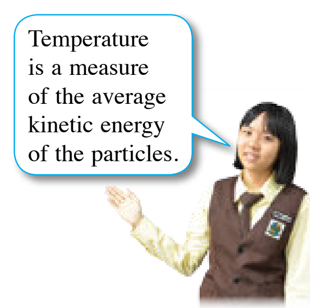
When the temperature increases, the rate of reaction increases. This phenomenon is explained in Figure 7.25.



(a) Low temperature (b) High temperature

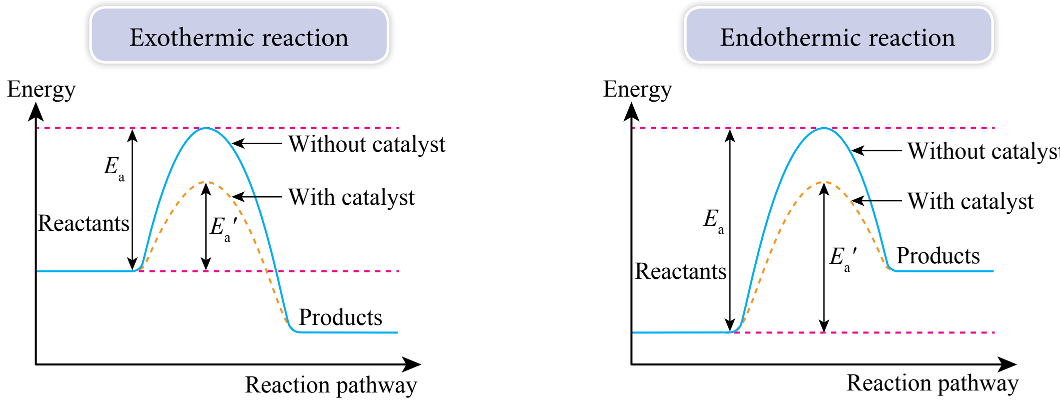
Figure 7.25 The effect of temperature on the rate of reaction

When **temperature** increases,
- the kinetic energy of the reactant particles increases
- more particles have energy to overcome the activation energy
- the frequency of effective collisions between particles increases
- the rate of reaction increases



Effect of Catalyst on the Rate of Reaction

A catalyst is involved in a reaction but remains chemically unchanged at the end of the reaction. The catalyst allows the reaction to occur by providing an alternative pathway with lower activation energy, E_a' as compared to the original activation energy, E_a.



Key: E_a = Activation energy without catalyst E_a' = Activation energy with catalyst

Figure 7.26 *The effect of catalyst on the magnitude of the activation energy*

In the presence of a **catalyst**,
- the catalyst provides an alternative pathway by lowering the activation energy
- more reactant particles can achieve the activation energy
- the frequency of effective collisions between the particles increases
- the rate of reaction increases

Activity 7.7

21st Century Skills CT

Conceptualising the collision theory in reactions that are affected by temperature, reactant size, pressure, concentration and catalyst

1. Carry out the Gallery Walk activity.
2. Get the following information from various reading and search the Internet.
   (a) Collision theory
   (b) Use of the collision theory to explain the effect of the following factors on the rate of reaction

Concentration | Pressure | Size of reactant | Temperature | Catalyst

3. Discuss with your group members and prepare an interesting presentation.
4. Present your group's work in the class. Move in groups to see the works of other groups.
5. Write two stars and a wish about the works of the other groups on sticky notes and paste on the work.

Exothermic Reaction and Endothermic Reaction

Changes in energy can occur during chemical reactions. Reactions that release heat energy to the surroundings are called **exothermic reactions**. Otherwise, reactions that absorb heat energy from the surroundings are called **endothermic reactions**. All exothermic reactions or endothermic reactions have activation energy, E_a that must be overcomed by the reactant particles.

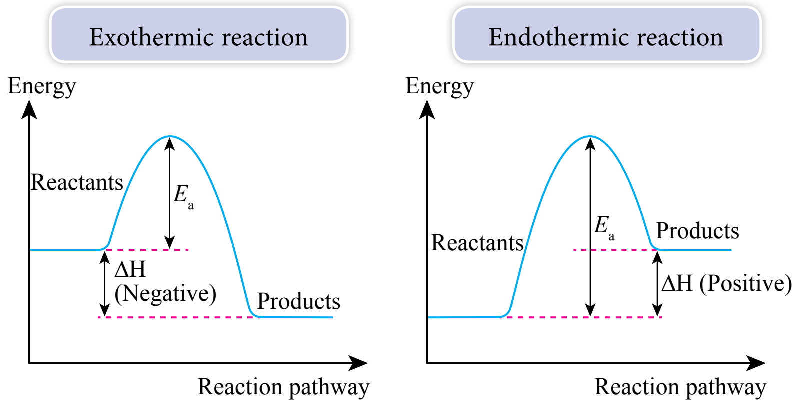


Figure 7.27 Energy profile diagram for exothermic reaction and endothermic reaction

Literacy Tips

You will learn more about exothermic and endothermic reactions in the topic of thermochemistry in Form 5.

The change in energy content that occurs when reactants are changed into products is known as the heat of reaction and is represented by the symbol ΔH.

Test Yourself 7.4

1. The Kinetic Theory of Matter states that the particles in matter are constantly moving. Mark (✓) for true statements and (✗) for false statements.
   (a) At constant temperature, all particles move with the same velocity. ☐
   (b) Particles in solids are moving freely. ☐
   (c) Collisions between particles are random. ☐
   (d) The kinetic energy of particles increases with increasing temperature. ☐
2. Scientists use the collision theory to explain how chemical reactions occur. State two important conditions for effective collisions.
3. Catalysts can help to speed up chemical reactions. How does a catalyst speed up a chemical reaction?
4. All reactions including exothermic reactions and endothermic reactions have activation energy that must be overcome by reactant particles.
   (a) What do you understand by the term activation energy?
   (b) Mark and label the activation energy in Figure 7.28.
   (c) Complete the following statements:
      (i) Exothermic reactions ___________ heat to ___________.
      (ii) Endothermic reactions ___________ heat from ___________.

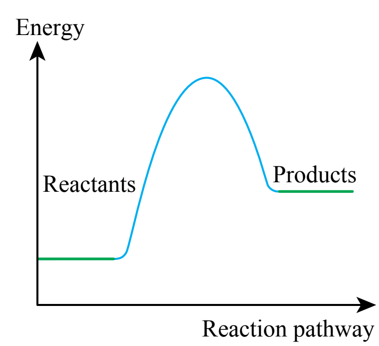


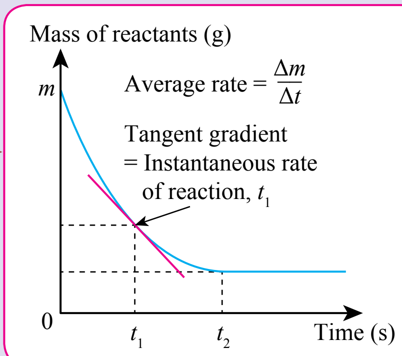
Figure 7.28

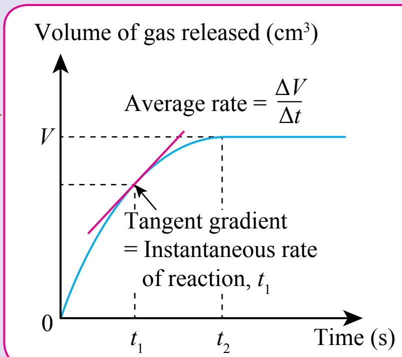
Chain Concept

Rate of Reaction

definition

$$\frac{\text{Change in the quantity of reactants or products}}{\text{Time taken}}$$





Quick Quiz

http://bit.ly/33X1ksG

explained by

Collision Theory

- Reactant particles must collide with one another
- Frequency of effective collisions between particles increases, the rate of reaction increases

affected by

Concentration
- Concentration of reactant ⬆, rate of reaction ⬆
- Number of particles per unit volume ⬆

Size of reactant
- Size of reactant ⬇, rate of reaction ⬆
- Total surface area exposed to collision ⬆

Temperature
- Temperature ⬆, rate of reaction ⬆
- Temperature ⬆, kinetic energy of particles ⬆

Presence of catalyst
- Presence of catalyst, rate of reaction ⬆
- Alternative pathway with lower activation energy, E_a'.

SELF Reflection

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

https://bit.ly/32lEzyv

Achievement Test 7

1. Rate of reaction measures the change in the quantity of reactants or products per unit time.
   (a) State three units for measuring the quantity of substances.
   (b) For each unit of measurement for the quantity of substances in 1(a), state the corresponding unit for the rate of reaction.

2. There are chemical reactions that are fast or slow in daily life. Some examples are given below. Arrange the reactions in the descending order of the speed of reaction.
   (a) Banana decaying
   (b) Baking a cake
   (c) Boiling eggs
   (d) Combustion of domestic gas
   (e) Rusting of iron nails

3. A protein-digesting enzyme is used to study the effect of temperature on the rate of protein digestion in milk. The set-up of the apparatus is shown in Figure 1. The time measured is the time taken for the enzyme to digest all the protein and the milk becomes clear, that is until the '×' mark is visible. Table 1 shows the results of the experiment.

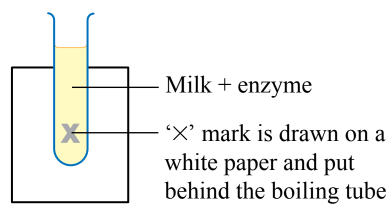


Figure 1

Table 1

Temperature (°C)	15.0	25.0	35.0	45.0	55.0	65.0
Time taken for the '×' mark to be visible (minute)	12.0	7.0	2.5	4.0	7.0	19.0
$\frac{1}{\text{time}}$ (minute^{-1})						

   (a) State the changes that are observed and measured.
   (b) State the manipulated variable and the fixed variables.
   (c) The time of reaction is determined by measuring the time taken for the milk solution to turn clear.
      (i) What is the relationship between the rate of reaction and time?
      (ii) Complete Table 1 by calculating the value of $\frac{1}{\text{time}}$.
      (iii) Plot a graph of $\frac{1}{\text{time}}$ against temperature.
      (iv) What conclusion can be formulated based on the graph in (c)(iii)? Explain your answer.

4. The collision theory explains how reactant particles interact for reaction to occur and products formed.
   (a) What are the **two** main principles of the collision theory?
   (b) Dinitrogen monoxide, N_2O, known as laughing gas, is produced from the following reaction:

$$NH_4NO_3(aq) \rightarrow N_2O(g) + H_2O(l) + \text{Heat}$$

   (i) Balance the above equation.
   (ii) Draw the fully labelled energy profile diagram, including the activation energy, for the reaction.

   (c) Dinitrogen monoxide, N_2O reacts with nitrogen monoxide, NO to produce nitrogen, N_2 and nitrogen dioxide, NO_2.

$$N_2O(g) + NO(g) \rightarrow N_2(g) + NO_2(g)$$

   The reactants, dinitrogen monoxide, N_2O and nitrogen monoxide, NO have to collide in the correct orientation to produce effective collisions and for the reaction to occur. Figure 2 shows the atomic arrangement of the reactants and products.

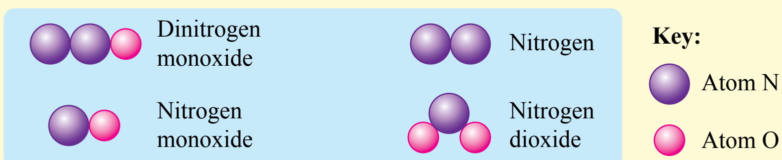


Figure 2

   Draw the orientation of the reactant particles, dinitrogen monoxide, N_2O and nitrogen monoxide, NO that results in effective collisions.

Enrichment Corner

1. 1.0 g marble powder, $CaCO_3$ is added simultaneously to 50 cm^3 of hydrochloric acid, HCl of concentrations 0.5 mol dm^{-3} and 1.0 mol dm^{-3}. Excess acid is used in each beaker. Which reaction proceeds fastest? Explain your answer using the collision theory.

2. Acids reacts with metals to produce salt and hydrogen gas. One example of the reaction is shown below:

   Tin + Hydrochloric acid → Tin(II) chloride + Hydrogen

   The time of reaction can be obtained by recording the volume of gas released at fixed time intervals. Plan an experiment to determine the effect of particle size on the rate of reaction. In your answer, include the followings:
   (a) Sketch the set-up of the apparatus
   (b) Volume and concentration of the acid used
   (c) Mass and the physical state of tin used
   (d) Temperature of the reaction
   (e) Procedure of the experiment
   (f) Appropriate graphs
   (g) Explanation on the conclusion obtained

Check Answers
https://bit.ly/35RsfIt

CHAPTER

8

Manufactured Substances in Industry

Keywords

- Alloy
- Pure metal
- Superconductor
- Glass
- Ceramic
- Composite material

What will you learn?

8.1 Alloy and Its Importance
8.2 Composition of Glass and Its Uses
8.3 Composition of Ceramics and Its Uses
8.4 Composite Materials and Its Importance

Bulletin

Developments in the automobile industry from time to time has brought about many astounding changes.

Try to visualise yourself in the cockpit of the most advanced car in the future. With the help of Artificial Intelligence (AI), the car can automatically move according to the driver's instructions. Besides traditional synthetic materials, the usage of advanced materials such as nano materials can lead to the invention of high capability systems to execute AI programs in the vehicle.

The University of Kuala Lumpur Malaysian Spanish Institute, UniKL MSI has successfully found a way to produce nanoparticles at a low cost. This ideal innovation indirectly leads to the invention of the most advanced car.

Why is pure aluminium not used to make the body of aeroplanes?

What are the two main elements found in all types of glass?

What is the property of ceramic that makes it suitable to be used in the construction of houses?

8.1 Alloy and Its Importance

Photograph 8.1
The National Monument

The National Monument was built in 1966 using alloys. What is an alloy?

An **alloy** is a mixture of two or more elements where the main element is a metal. Did you know that many objects around you are made from alloys? Look at several examples of alloys as shown in Figure 8.1.

Learning Standard

At the end of the lesson, pupils are able to:
- 8.1.1 Describe briefly alloy with examples
- 8.1.2 Compare the properties of an alloy with its pure metal through experiment
- 8.1.3 Justify the usage of alloys based on their composition and properties

MY MALAYSIA is Great

The National Monument of Malaysia was built using bronze.

Figure 8.1 *Examples of alloys and their importance*

Comparison of Properties of Alloys and Pure Metals

The strength and hardness of alloys are based on the arrangement of particles. Are alloys stronger and harder compared to pure metals or vice versa?

Experiment 8.1

Aim: To investigate the comparison between the properties of alloys and pure metals.

Problem statement: Is an alloy more resistant to corrosion and harder than a pure metal?

Materials: Stainless steel plate, iron plate, distilled water, bronze block and copper block

Apparatus: 100 cm^3 beaker, 100 cm^3 measuring cylinder, sandpaper, steel ball bearing, 1 kg weight, retort stand with clamp, meter ruler and cellophane tape

A Resistance to corrosion

Hypothesis: Stainless steel is more resistant to corrosion than iron.

Variables:

(a) Manipulated : Type of plate
(b) Responding : Corrosion of plate
(c) Fixed : Size of plate and volume of distilled water

Procedure:

1. Clean the surfaces of stainless steel and iron plates by using a sandpaper. Observe the surfaces of both plates. Record your observations.
2. Immerse both plates in a beaker containing 80 cm^3 of distilled water as shown in Figure 8.2.

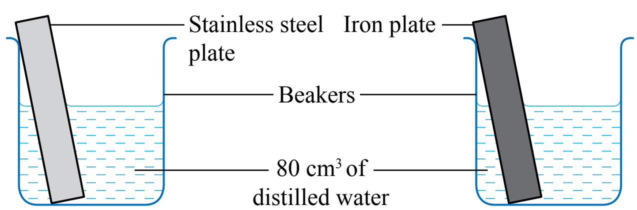


Figure 8.2

3. Leave both beakers aside for one week.
4. After one week, remove both plates and observe the conditions of their surfaces. Record your observations in Table 8.1.

Results:

Table 8.1

Type of plate	Condition of plate's surface	
	After cleaning with sandpaper	After immersing in distilled water for one week
Stainless steel		
Iron		

B Hardness of substances

Hypothesis: Construct a suitable hypothesis for this experiment.

Variables: State the variables involved in this experiment.

Procedure:

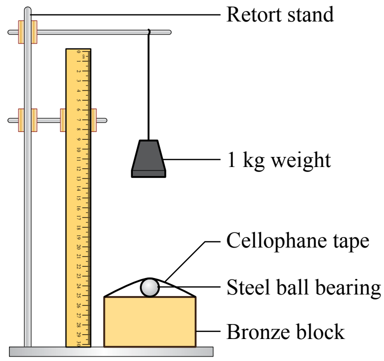


Figure 8.3

1. Fix a steel ball bearing on the surface of the bronze block using a cellophane tape.
2. Hang a 1 kg weight on the retort stand at 50 cm above the surface of the bronze block, as shown in Figure 8.3.
3. Release the weight onto the steel ball bearing.
4. Measure the diameter of the dent formed on the surface of the bronze block.
5. Repeat steps 1 to 4 three times but on different surfaces of the bronze block to obtain an average diameter of the dent formed. Record the reading in Table 8.2.
6. Repeat steps 1 to 5 by replacing the bronze block with a copper block.

Results:

Table 8.2

Type of block	Diameter of dent (cm)				
	1	2	3	4	Average
Bronze					
Copper					

Conclusion:

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

Discussion:

1. Why must the stainless steel plate and iron plate be cleaned with a sandpaper?
2. Compare the rate of corrosion of the stainless steel and iron plates.
3. Which block formed a dent with a larger diameter?
4. State the relationship between the diameter of the dent and the hardness of the substance.

Prepare a complete report after carrying out this experiment.

Figure 8.4 shows the comparison between the properties of an alloy and a pure metal. The alloying process helps to prevent the corrosion of metal and alter the properties of a pure metal to make it harder and stronger. How did these changes happen?

Alloy		Pure metal
Shiny	Surface	Dull
Resistant to corrosion	Resistance to corrosion	Easily corroded
Hard	Hardness	Less hard

Figure 8.4 *Comparison between the properties of an alloy and a pure metal*

A pure metal is made up of one type of atom that is of the same size and **arranged in an orderly arrangement**. When force is applied, the layers of atoms in the metal easily slide over each other. This causes pure metals to be ductile and easily pulled into fine wires.

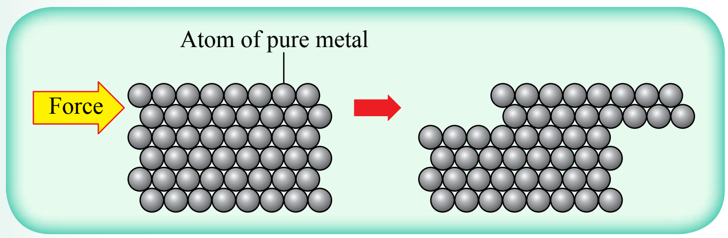


Figure 8.5 *Pure metals are ductile*

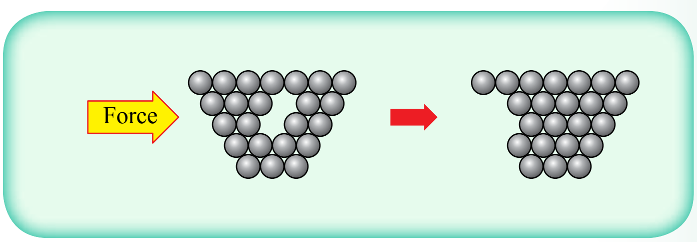


Figure 8.6 *Pure metals are malleable*

Pure metals are also malleable and its shape can be easily changed. There are empty spaces between the atoms in a pure metal. When force is applied, the layer of atoms in a metal will slide to **fill the empty spaces** and form a new structure.

An alloy is formed when foreign atoms are mixed with the pure metal. These foreign atoms are different in size compared to the atoms in the pure metal. Hence, **the orderly arrangement of atoms in a pure metal is disrupted**. This makes it difficult for the layers of atoms in an alloy to slide over each other when force is applied.

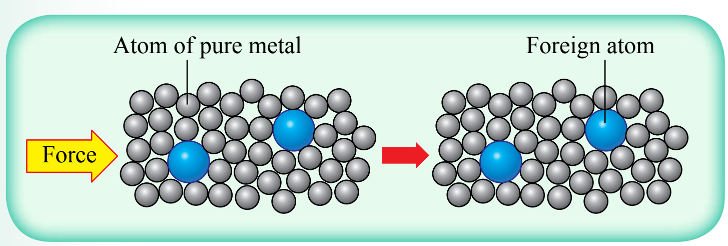


Figure 8.7 *Arrangement of atoms in an alloy*

Activity 8.1

Competition to build a model of particle arrangement in an alloy

21st Century Skills CT

1. Carry out this activity in pairs.
2. Discuss with your partner and build a model to illustrate the arrangement of particles in an alloy using balls or spheres.
3. Present your group work by explaining how the model can form an alloy with sturdy arrangement of particles.

Justify the Uses of Alloys based on Their Composition and Properties

The uses of alloys is based on the composition and properties of the alloy produced. Alloys are made for specific purposes. Scientists change the elemental composition to produce alloys with different properties. For example, steel and stainless steel originate from the same pure metal, which is iron. However, both alloys have different properties and are used for different purposes.

Table 8.3 *Composition, properties and the uses of alloys*

Alloy	Composition	Properties	Uses
Duralumin	• 93% Aluminium • 3% Copper • 3% Magnesium • 1% Manganese	• Stronger than pure aluminium • Low density • Does not rust	• Body of aeroplanes • Electric cables • Racing bicycles
Bronze	• 90% Copper • 10% Tin	• Stronger than pure copper • Does not rust • Shiny	• Medals • Monuments • Trophies
Brass	• 70% Copper • 30% Zinc	• Stronger than pure copper • Does not rust • Shiny	• Musical instruments • Doorknobs • Keys
Steel	• 98% Iron • 0.2 – 2% Carbon	• Also known as carbon steel • Stronger and harder • Malleable • There are three types of steel, which are low-carbon steel, average-carbon steel and high-carbon steel	• Structure of buildings • Railway tracks • Body of cars
Stainless steel	• 73% Iron • 18% Chromium • 8% Nickel • 1% Carbon	• Stronger than pure iron • Resistant to corrosion	• Cutlery • Sinks • Surgical instruments
Pewter	• 95% Tin • 3.5% Antimony • 1.5% Copper	• Stronger than pure tin • Does not rust • Shiny	• Decorative ornaments • Trophies • Souvenirs

* The composition percentage of metals in each alloy may vary

Photograph 8.2 Maglev train

A superconductor is an example of an alloy used in electrical transportation such as the Maglev train. Superconductors do not have electrical resistance at very low temperatures. This alloy is used to make a magnet that can levitate the train and move it at a very high speed.

AR

HISTORY INTEGRATION

Superconductors were discovered in 1911 when mercury that was cooled at 4 K by Heike Kamerlingh Onnes did not have any electrical resistance.

Activity 8.2

21st Century Skills CT

Making a poster to relate the properties and suitability of alloys in daily life

1. Carry out the Gallery Walk activity.
2. Obtain information from various reading sources and the Internet regarding the characteristics and properties of the following alloys and their uses in daily life.

Brass | Stainless steel | Pewter

3. Discuss with your group members and design an interesting poster.
4. Display your group work in the class. Move with your group to see the work of other groups.
5. Write comments on other groups' work on sticky notes and paste them.

TestYourself 8.1

1. Atoms in pure iron are arranged in an orderly manner and in layers.
   (a) What is the effect of atom arrangement in pure iron on the ductility and malleability of the metal?
   (b) Iron alloy can be made by mixing some carbon into molten iron. How does the arrangement of atoms in the iron alloy affect the hardness of the alloy?
2. The purity of gold is measured in carats (K). 24 carat gold is pure gold without the addition of any other metal whereas 18 K gold is a mixture comprising of 18 units by mass of gold with 6 units by mass of other metal such as copper.
   (a) What is the role of copper in 18 K gold?
   (b) Calculate the composition percentage by mass in 24 g of 18 K gold.
3. Justify the following statements:
   (a) Stainless steel is used to make washing machines
   (b) High voltage electric cables are made from aluminium alloy
   (c) 18 K gold is used to make rings

8.2 Composition of Glass and Its Uses

Rainbow Skywalk in Georgetown, Penang is a bridge made of glass. Do you know of any other structures that are made from glass? What about the method to make glass?

Learning Standard

At the end of the lesson, pupils are able to:
8.2.1 Describe briefly with examples the type of glass, their composition, properties and uses

Photograph 8.3 *Rainbow Skywalk*

When silica is heated together with other chemicals, various types of **glass** with different properties are obtained. However, all types of glass have the same basic properties.

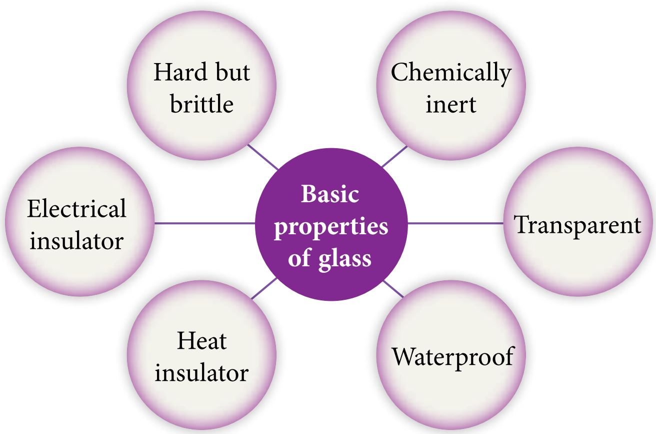


Figure 8.8 *Basic properties of glass*

Types of Glass

In this chapter, you will learn about four types of glass, which are fused silica glass, soda-lime glass, borosilicate glass and lead crystal glass.

Fused silica glass is made from silica (silicon dioxide, SiO_2) without adding any other chemical.

Silica, SiO_2 requires high temperature around 1800 °C to melt. Hence, fused silica glass has a high melting point. This glass does not expand nor contract much when there is a large change in temperature. Fused silica glass is suitable to be used in making telescope lens.

Photograph 8.4 *Telescope*

Photograph 8.5 Glass containers

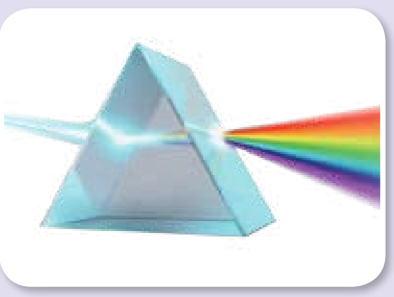
Soda-lime glass is made from silica, SiO_2, soda (sodium carbonate, Na_2CO_3) and limestone (calcium carbonate, $CaCO_3$).

Soda, Na_2CO_3 lowers the melting point of silica, SiO_2. Hence, soda glass has a low melting point, around 1000 °C. This glass is easily moulded and used to make glass containers such as bottles and jugs. However, this glass cannot withstand high temperatures and can easily crack when subjected to sudden temperature change.

Borosilicate glass is made from silica, SiO_2, soda, Na_2CO_3, limestone, $CaCO_3$, boron oxide, B_2O_3 and aluminium oxide, Al_2O_3.

Many laboratory glassware such as beakers and flasks are made from borosilicate glass because of its resistance to heat. These glassware do not crack easily when subjected to thermal stress because of its low expansion coefficient. Borosilicate glass can be removed from the refrigerator and heated immediately without cracking.

Photograph 8.6 Laboratory glassware



Photograph 8.7 Prism

Lead crystal glass is made from silica, SiO_2, soda, Na_2CO_3 and lead(II) oxide, PbO.

Lead, Pb replaces calcium, Ca to produce glass that is softer and denser. Lead glass is heavier and has a high refractive index. This glass is suitable to be used in making prisms.

Activity 8.3

Making a multimedia presentation about types of glass, composition, properties and uses

CT

1. Carry out this activity in groups.
2. Gather information from various reading sources or the Internet about types of glass.
3. Interpret the data regarding the composition, properties and uses of glass.
4. Present the information obtained to the class in the multimedia presentation.

Test Yourself 8.2

1. Silica is used to make all types of glass.
   (a) State the type of glass that is made up of only silica.
   (b) Soda-lime glass contains alkali metal ions. Name the ion.
2. A sample of borosilicate glass has composition of 80% silica, SiO_2,15% boron oxide, B_2O_3 and 5% alumina, Al_2O_3. Calculate the mass of each component in the borosilicate glass sample with mass of 1 kg.
3. Aini's mother : Aini, do not store food in lead crystal glass containers.
   Aini : Why not, mother?

   Based on the conversation above, explain the advantages and disadvantages of using containers made from lead crystal glass.

8.3 Composition of Ceramics and Its Uses

The Great Pyramid of Giza in Egypt is believed to be made from ceramic. What is ceramic? Is ceramic a type of element or compound?

Photograph 8.8 *The Great Pyramid of Giza*

Learning Standard

At the end of the lesson, pupils are able to:
8.3.1 Describe briefly with examples of ceramics, their composition, properties and uses
8.3.2 Expain the uses of ceramics in daily life

A **ceramic** is a solid made up of inorganic and non-metallic substances. Ceramic is produced through the process of shaping and hardening by using heating technique at a high temperature. Most ceramics are made up of metal compounds, non-metal compounds or metalloid compounds. Photograph 8.9 shows examples of ceramic products.

Photograph 8.9 *Examples of ceramic products*

All ceramics have the same basic properties. Do ceramics have the same properties as alloys and glass or vice versa?

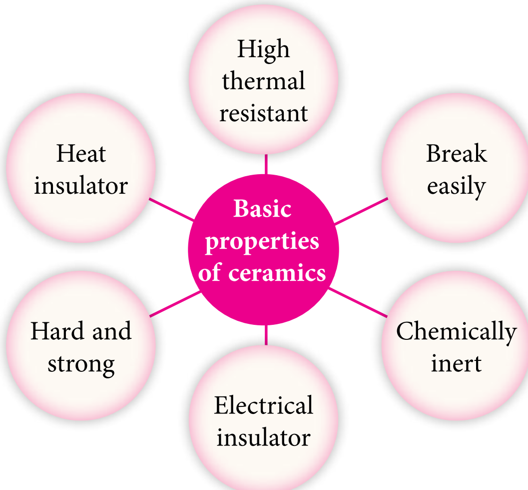


***Figure 8.9** Basic properties of ceramics*

The atoms in ceramics are bonded by strong covalent bonds and ionic bonds. Hence, ceramics only melt at very high temperatures, are hard and resistant to compression. When force is applied, the atoms in ceramics cannot slide over each other because these atoms are strongly bonded in indefinite arrangement. The energy from the force will be used to break the bonds between the atoms. Hence, ceramics are brittle and weak towards stretching. The electrons in ceramics cannot move freely to conduct electricity or heat.

Types of Ceramics

Did you know that ceramics can be classified into two groups, that is traditional ceramics and advanced ceramics?

Activity 8.4

Classifying ceramics into traditional ceramics and advanced ceramics 21st Century Skills CT

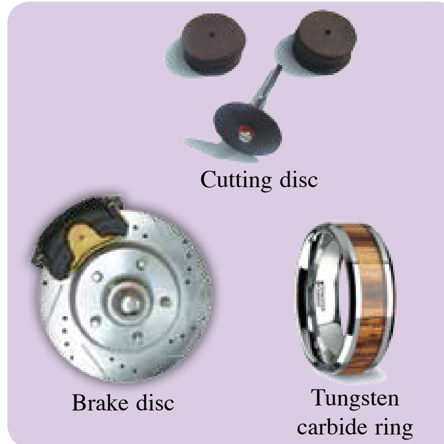
1. Carry out this activity in groups.
2. Obtain information from various reading sources or the Internet about several examples of ceramics and the classification of ceramics into traditional ceramics or advanced ceramics.
3. Based on the information obtained, discuss with your group members and produce a mind map.
4. Present your group work to the class.

Traditional ceramics are made from clay such as kaolin, $Al_2O_3.2SiO_2.2H_2O$. Clay is mixed with water to produce a soft, mouldable mixture. The mixture is then heated at a very high temperature. Generally, traditional ceramics are used to make bricks, pottery and crockery.

***Photograph 8.10** Examples of traditional ceramic use*

Advanced ceramics are made from inorganic compounds such as oxides, carbides and nitrides. Advanced ceramics have higher resistance to heat and abrasion, more chemically inert and have superconductivity properties.

Advanced ceramics such as silicon carbide are used to make cutting discs due to its hard and strong properties. Silicon carbide is also used to make brake discs because it can withstand thermal shocks and has high resistance to heat. Advanced ceramics are also used to make tungsten carbide rings because it is hard and resistant to abrasion. What other properties and use of traditional ceramics and advanced ceramics that you know?



Photograph 8.11 *Examples of advanced ceramic use*

Activity 8.5

Making a multimedia presentation about the classification, properties and uses of ceramics CT

1. Carry out this activity in groups.
2. Gather information from various reading sources or the Internet about the classification, properties and uses of ceramics.
3. Use Table 8.4 to organise the information that you have obtained.

Table 8.4

Ceramic	Classification of ceramic		Properties	Uses
	Traditional	Advanced		
...	✓		...	...

4. Present the information obtained in an interesting multimedia presentation to the class.

Ceramic Uses Application

Table 8.5 *Ceramic uses*

Examples of ceramic uses	Medicine	• Zirconia ceramic is used in dental implants. • Alumina ceramic is used to make knee bone. • Ceramic is used in Magnetic Resonance Imaging (MRI) machines because it has superconductivity properties.
	Transportation	• Engine components in jet planes are made from ceramics.
	Energy production	• Ceramic is used to make electrical insulators in high voltage areas such as power stations.

Activity 8.6

21st Century Skills CT

Explaining the use of ceramics in house construction based on the properties of ceramics

1. Carry out the Three Stray One Stay activity.
2. Watch a video clip about house construction from the Internet.
3. Based on what you have watched:
   (a) List ceramic materials used in the construction of houses
   (b) Discuss the properties of ceramics involved
4. Present your discussion using a suitable mind map.
5. Select a representative to explain the use of ceramic in the construction of houses based on their properties. The other members move to observe and obtain information from the work of other groups.

Test Yourself 8.3

1. Fill in the blanks:
   (a) Ceramic is a non ________ solid element and non ________ compound.
   (b) Give three examples of substances that make up ceramics.
2. Silicon carbide is an example of advanced ceramic that has a hard structure and diamond-like properties. Can silicon carbide be used to make drinking glass? Explain.
3. Kaolin is a white clay used to make white pottery. What substance must be added to produce green coloured pottery? Explain.

8.4 Composite Materials and Its Importance

Photograph 8.12
Traditional house

Most traditional houses in Malaysia are built using wood. Wood is a natural **composite material** that is strong and sturdy. What is the meaning of composite material? Why is wood classified as a composite material?

Learning Standard

At the end of the lesson, pupils are able to:
8.4.1 State the meaning and properties of composite materials
8.4.2 Describe with examples the uses of composite materials
8.4.3 Compare and contrast the properties of a composite material with its constituent materials

A composite material is a material made from combining two or more non-homogeneous substances, that is matrix substance and strengthening substance. The matrix substance surrounds and binds the strengthening substance together.

Chemistry & Us

Teeth is a composite material made up of hydroxyapatite and collagen.

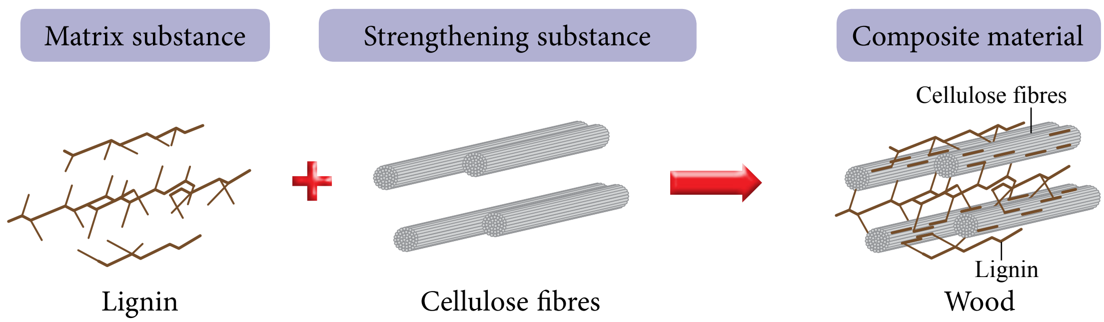


Figure 8.10 Example of matrix substance, strengthening substance and composite material

Both components of a composite material have different physical and chemical properties. When combined, the composite material formed has better properties than the original components.

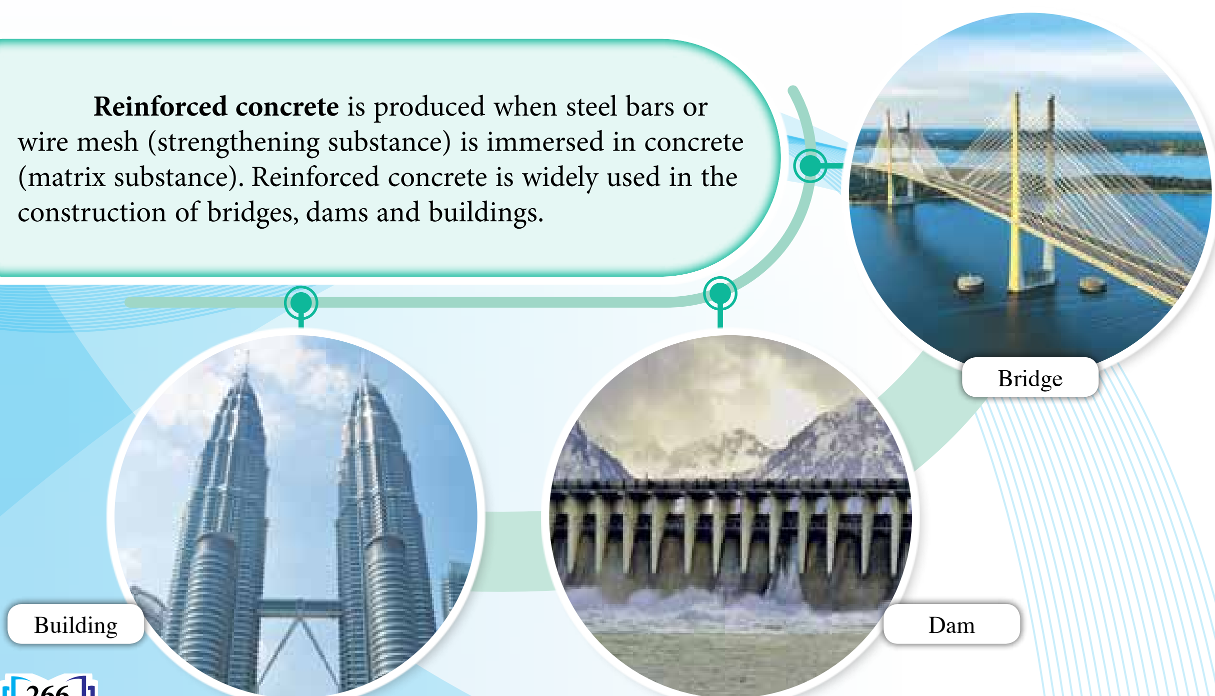
Career Kiosk

A materials scientist studies the structure and chemical properties of natural and synthetic substances to develop new, enhanced materials.

Composite Materials and Their Uses

Composite materials are widely used in the development and advancement of technology nowadays.

Reinforced concrete is produced when steel bars or wire mesh (strengthening substance) is immersed in concrete (matrix substance). Reinforced concrete is widely used in the construction of bridges, dams and buildings.



Fibre glass is produced when plastic (matrix substance) is strengthened with glass fibres (strengthening substance). This composite material is used to make helmets, car bumpers and printed circuit boards.

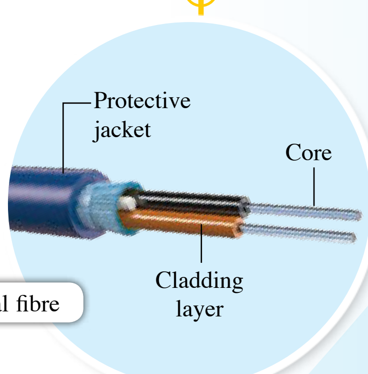
Helmet

Car bumper

Printed circuit board

Optical fibre consists of three layers. The innermost layer is the core that is made up of silica glass fibres (strengthening substance). The core is encased in a second layer or cladding that is made up of glass or plastic (matrix substance). The outermost layer is made of plastic that acts as a protective jacket (matrix substance). Optical fibres are used to transmit information and data in the form of light. Light moves through the optical fibre (core section) in a series of total internal reflection. The core and cladding have different refractive indexes to enable them to carry data in large capacity and to not be influenced by electromagnetic disturbances. This composite material has replaced copper wires in video cameras and connects computers in Local Area Network (LAN).

Video camera



Optical fibre

Cables in computer network

Photochromic glass is formed when glass (matrix substance) is combined with silver chloride, AgCl and copper(I) chloride, CuCl (strengthening substance). When exposed to sunlight, photochromic glass darkens. This is due to the formation of silver atoms, Ag that prevents the passage of light. In dim light, copper(I) chloride, CuCl in photochromic glass catalyses the reverse process so that glass becomes transparent again. Photochromic glass protects the user from UV rays and is suitable for use in car windows, building windows and camera lenses.

Photochromic glass
http://bit.ly/33wWTEO

Car window

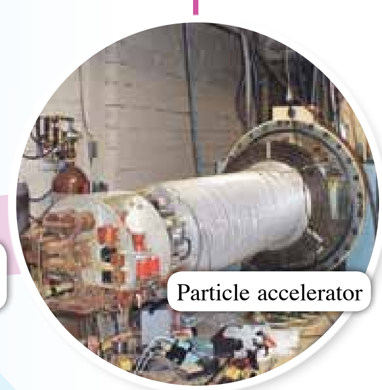
Camera lens

Building window

Superconductors such as yttrium barium copper oxide, YBCO ceramic is a composite material that has superconductivity properties other than alloys. This superconductor is used to make electromagnets, that are superconductor magnets or supermagnets. Superconductor magnets are light and have strong magnetic force. Superconductor magnets are used in particle accelerators and involved in Nuclear Magnetic Resonance (NMR) machines and Magnetic Resonance Imaging (MRI) machines.

Magnetic Resonance Imaging (MRI)

Nuclear Magnetic Resonance (NMR)



Particle accelerator

Comparison and Difference in Properties of Composite Materials and Their Original Components

Composite materials have different properties compared to their original components. What is the difference in the properties of a composite material and its original components?

Concrete can withstand high compression forces but will break if subjected to high stretching forces. Combination of concrete and steel bars or wire mesh can increase the ability of the concrete to withstand compression forces.

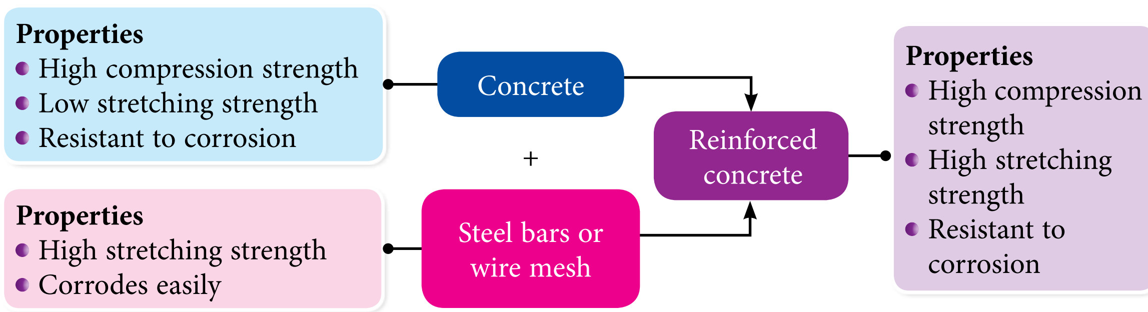


Figure 8.11 *Comparison in properties of reinforced concrete with its original components*

Plastic matrix consists of plastic that is weak, soft and easily burned. The properties of plastic are reinforced by adding glass fibres.

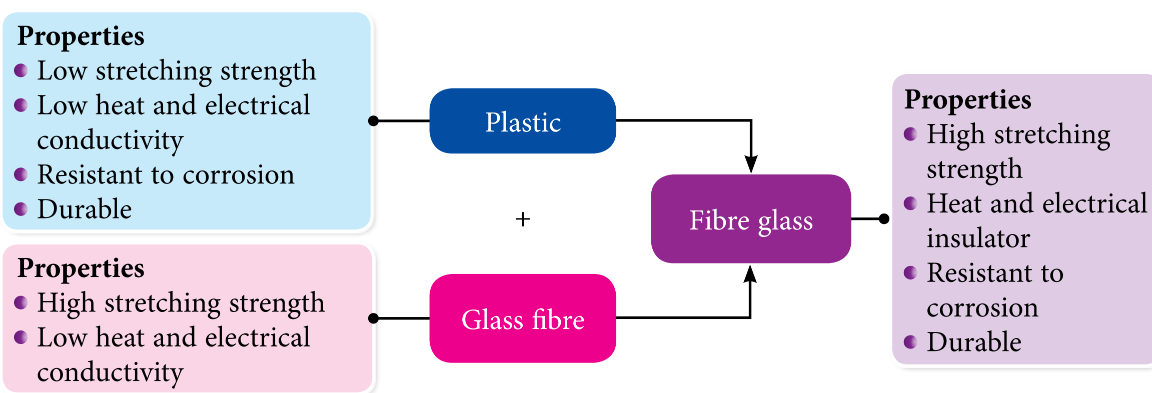


Figure 8.12 *Comparison in properties of fibre glass with its original components*

Optical fibre has high compression strength although the original component that is glass fibre, is brittle.

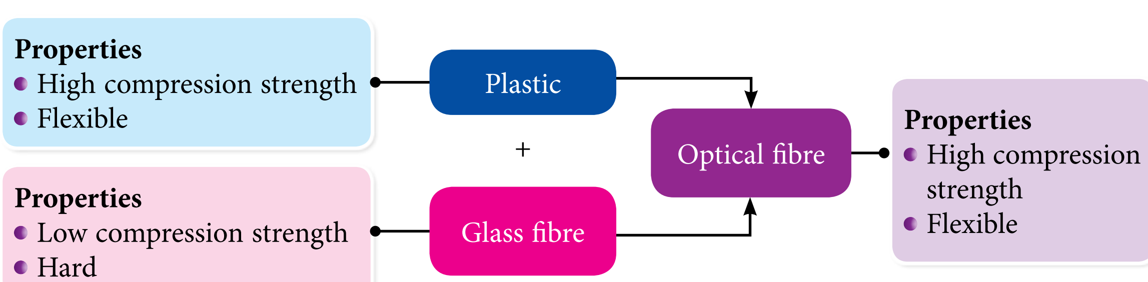


Figure 8.13 *Comparison in properties of optical fibre with its original components*

Glass is transparent and does not absorb UV rays. Silver halide salt crystals such as silver chloride, AgCl is transparent to visible light and absorbs UV rays at the same time.

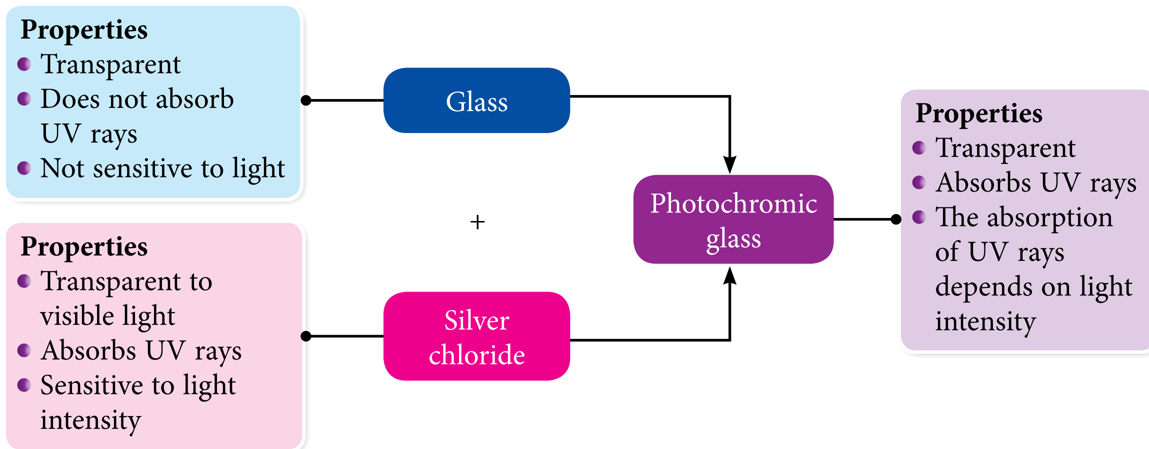


Figure 8.14 *Comparison in properties of photochromic glass with its original components*

Superconductors can conduct electrical current without any resistance at very low temperature whereas its original components cannot.

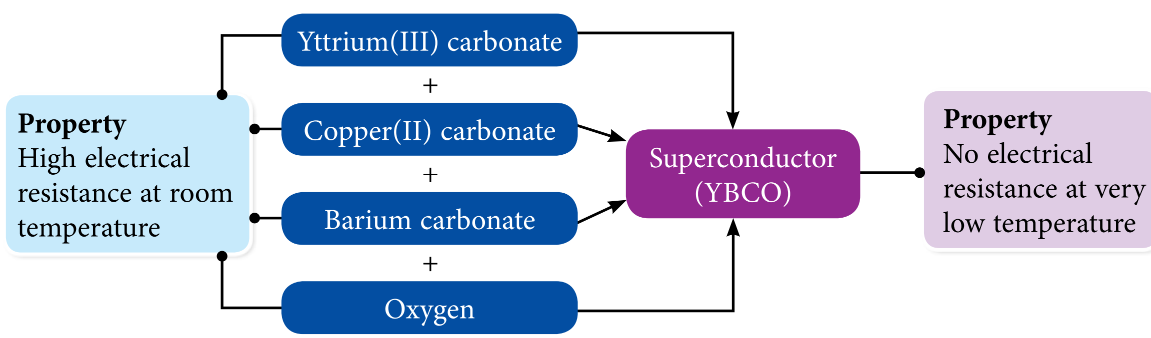


Figure 8.15 *Comparison in properties of superconductor with its original components*

Activity 8.7

CT

Making a multimedia presentation about the properties, examples and comparison between composite materials and their original components

1. Carry out this activity in groups.
2. Gather information from various reading sources or the Internet about composite materials in terms of:
   (a) Properties
   (b) Examples
   (c) Comparison of properties with the original components
3. Present your group work to the class in the form of multimedia presentation.

Activity 8.8

STEM CT

Building a composite material

1. Carry out this activity in groups.
2. Read and understand the following passage:

> The recycling of old newspapers has saved the environment. When 1 tonne of paper is recycled each year, 7000 gallons of water, 4200 kilowatt-hour of energy and 17 trees are saved. Old newspapers can also be reused in the production of products such as baskets, bag handles and paper maché. Starting from this simple effort, you have played a role in building a safe, healthy and beautiful world.

3. Discuss with your group members and draw a composite material. This drawing must combine at least two of the following substances:

   Alloy | Glass | Ceramic | Composite material

4. Write the procedure and build the creation.
5. Present the group work in class. The other group members can obtain information about other groups' work to improve on the creation.

Test Yourself 8.4

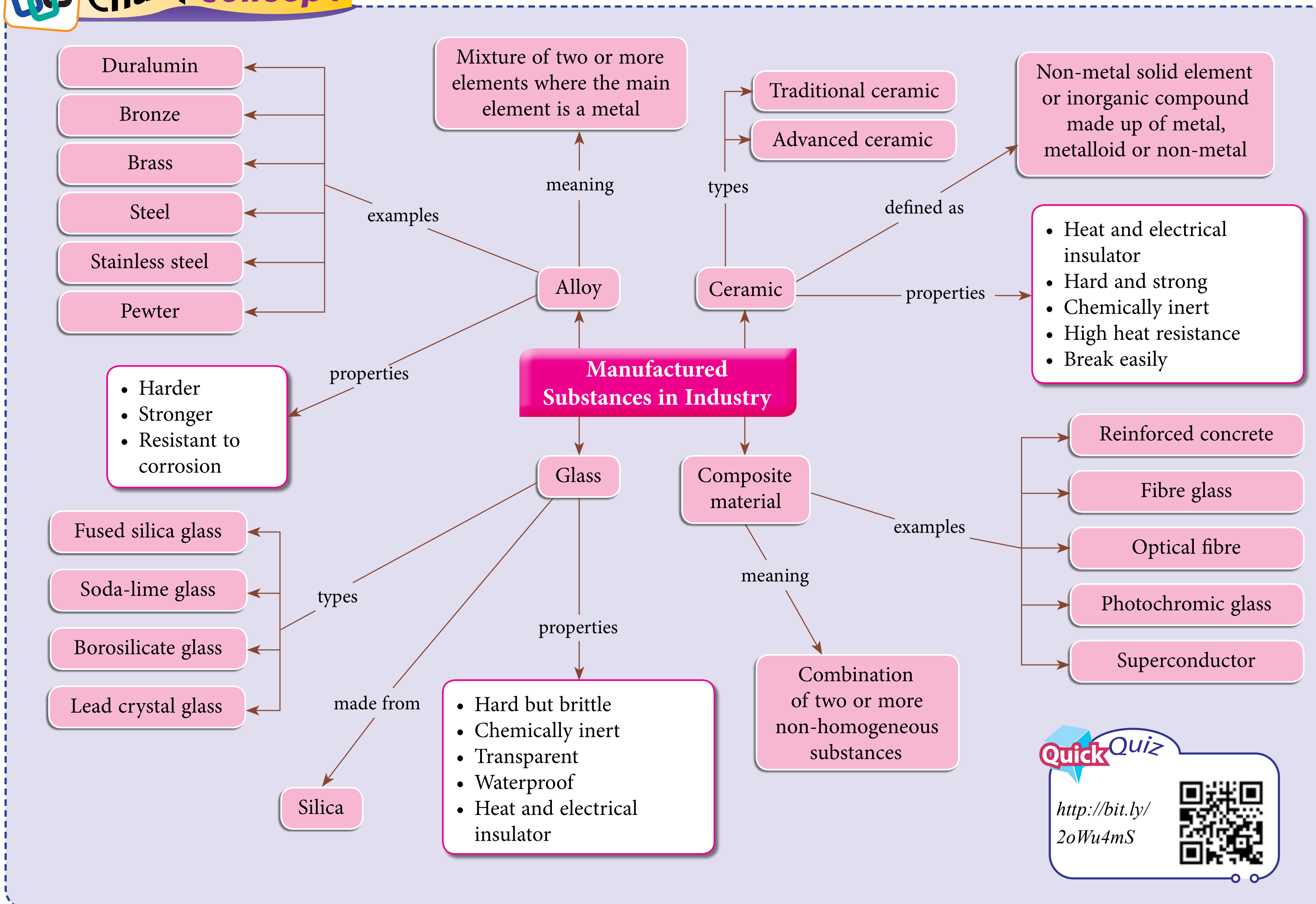
1. Concrete is an example of composite material that has been used since ancient times.
   (a) What is the meaning of composite material?
   (b) Is concrete suitable to be used to build the pillars of buildings? Explain.
   (c) Explain how concrete may be reinforced.
   (d) State two uses of reinforced concrete.

2. Fibre glass is made by immersing glass fibre in molten plastic.
   (a) Name the matrix substance and strengthening substance used to make fibre glass.
   (b) Explain why fibre glass is suitable to be used to make water storage tanks.

3. Optical fibre has replaced copper wire in the transmission of information and data.
   (a) Name three structures that make up an optical fibre.
   (b) How does optical fibres transmit information and data?
   (c) Compare the usage of optical fibres and copper wires in high definition cable TV network.

4. Photochromic glass is a composite material which is always used to make car windows.
   (a) State the main component in photochromic glass.
   (b) Which component in 4(a) is sensitive to UV light?
   (c) State two other uses of photochromic glass.

Chain Concept



SELF Reflection

1. What new knowledge have you learned in **Manufactured Substances in Industry**?
2. Which is the most interesting subtopic in **Manufactured Substances in Industry**? Why?
3. Give several examples of application of **Manufactured Substances in Industry** in daily life.
4. Rate your performance in **Manufactured Substances in Industry** 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 **Manufactured Substances in Industry**?

https://bit.ly/2BiDzPy

Achievement Test 8

1. The addition of coke (carbon) in the extraction process of iron is to remove oxygen from iron ore. The iron and carbon mixture will form steel. Table 1 shows two types of steel with different percentage of carbon.

Table 1

Steel	Carbon %
Cast iron	4.0
High-carbon steel	0.8

   (a) Cast iron is brittle whereas high-carbon steel is hard and strong. Based on Table 1, calculate the percentage of carbon that must be removed from cast iron to produce high-carbon steel.

   (b) Stainless steel is produced from a mixture of chromium, nickel and carbon.
      (i) State the percentage of chromium, nickel and carbon in stainless steel.
      (ii) Stainless steel is suitable to be used to make high quality knife blades. Explain.

2. Lead crystal glass can be used to make spectacle lenses.
   (a) What is the composition of lead crystal glass?
   (b) Explain the advantages and disadvantages of using lead crystal glass to make spectacle lenses.
   (c) Nowadays, spectacle lenses are made from polycarbonate polymer. The properties of polycarbonate are as follows:

      - Low density and easily moulded
      - Absorbs UV rays and is very transparent
      - High impact resistance

   You need a pair of new spectacles. Will you choose lenses made from lead crystal glass or polycarbonate? Explain your answer.

3. Traditional ceramics are made from clay such as kaolin.
   (a) Name two oxide compounds found in kaolin.
   (b) Give the formula of the ion that produces brown colour in clay.
   (c) State two uses of traditional ceramics.

4. The various unique properties of ceramics are modified in its use in various fields. State the property of ceramic involved in the manufacture of the following objects:
   (a) Car engine
   (b) Spark plug

5. Metals can conduct electricity. Ceramic materials can also be processed to conduct electricity and be made superconductors. Figure 1 shows the change in the electrical resistance value of two conductors against the temperature.

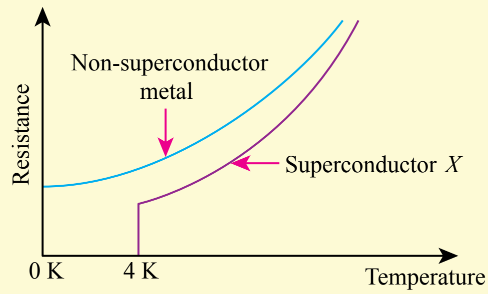


Figure 1

   (a) Give an example of a ceramic that shows superconductivity properties.
   (b) Explain the difference in the electrical conductivity properties of the two conductors in Figure 1.
   (c) How do scientists create a very cold condition to investigate the superconductivity phenomena?

Enrichment Corner

1. Silicon carbide, SiC is a hard and strong substance that melts at 2700 °C. Silicon carbide, SiC is suitable to be used as an abrasive. Explain why this substance is hard and has high melting point.

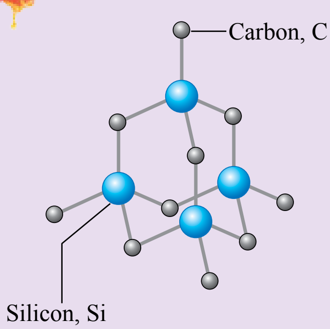


Figure 1

Check Answers

https://bit.ly/367eOnU

THE PERIODIC TABLE OF ELEMENTS

Group →

Period ↓

Symbol of the element → H
Proton number → 1
Name of the element → Hydrogen
Relative atomic mass → 1

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** Hydrogen 1																	2 **He** Helium 4
2	3 **Li** Lithium 7	4 **Be** Beryllium 9											5 **B** Boron 11	6 **C** Carbon 12	7 **N** Nitrogen 14	8 **O** Oxygen 16	9 **F** Fluorine 19	10 **Ne** Neon 20
3	11 **Na** Sodium 23	12 **Mg** Magnesium 24											13 **Al** Aluminium 27	14 **Si** Silicon 28	15 **P** Phosphorus 31	16 **S** Sulphur 32	17 **Cl** Chlorine 35.5	18 **Ar** Argon 40
4	19 **K** Potassium 39	20 **Ca** Calcium 40	21 **Sc** Scandium 45	22 **Ti** Titanium 48	23 **V** Vanadium 51	24 **Cr** Chromium 52	25 **Mn** Manganese 55	26 **Fe** Iron 56	27 **Co** Cobalt 59	28 **Ni** Nickel 59	29 **Cu** Copper 64	30 **Zn** Zinc 65	31 **Ga** Gallium 70	32 **Ge** Germanium 73	33 **As** Arsenic 75	34 **Se** Selenium 79	35 **Br** Bromine 80	36 **Kr** Krypton 84
5	37 **Rb** Rubidium 85.5	38 **Sr** Strontium 88	39 **Y** Yttrium 89	40 **Zr** Zirconium 91	41 **Nb** Niobium 93	42 **Mo** Molybdenum 96	43 **Tc** Technetium	44 **Ru** Ruthenium 101	45 **Rh** Rhodium 103	46 **Pd** Palladium 106	47 **Ag** Silver 108	48 **Cd** Cadmium 112	49 **In** Indium 115	50 **Sn** Tin 119	51 **Sb** Antimony 122	52 **Te** Tellurium 128	53 **I** Iodine 127	54 **Xe** Xenon 131
6	55 **Cs** Caesium 133	56 **Ba** Barium 137	57 – 71 Lanthanides	72 **Hf** Hafnium 178.5	73 **Ta** Tantalum 181	74 **W** Tungsten 184	75 **Re** Rhenium 186	76 **Os** Osmium 190	77 **Ir** Iridium 192	78 **Pt** Platinum 195	79 **Au** Gold 197	80 **Hg** Mercury 201	81 **Tl** Thallium 204	82 **Pb** Lead 207	83 **Bi** Bismuth 209	84 **Po** Polonium	85 **At** Astatine	86 **Rn** Radon
7	87 **Fr** Francium	88 **Ra** Radium	89 – 103 Actinides	104 **Rf** Rutherfordium	105 **Db** Dubnium	106 **Sg** Seaborgium	107 **Bh** Bohrium	108 **Hs** Hassium	109 **Mt** Meitnerium	110 **Ds** Darmstadtium	111 **Rg** Roentgenium	112 **Cn** Copernicium	113 **Nh** Nihonium	114 **Fl** Flerovium	115 **Mc** Moscovium	116 **Lv** Livermorium	117 **Ts** Tennessine	118 **Og** Oganesson

Lanthanides series	57 **La** Lanthanum 139	58 **Ce** Cerium 140	59 **Pr** Praseodymium 141	60 **Nd** Neodymium 144	61 **Pm** Promethium	62 **Sm** Samarium 150	63 **Eu** Europium 152	64 **Gd** Gadolinium 157	65 **Tb** Terbium 159	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 165	68 **Er** Erbium 167	69 **Tm** Thulium 169	70 **Yb** Ytterbium 173	71 **Lu** Lutetium 175
Actinides series	89 **Ac** Actinium	90 **Th** Thorium 232	91 **Pa** Protactinium 231	92 **U** Uranium 238	93 **Np** Neptunium	94 **Pu** Plutonium	95 **Am** Americium	96 **Cm** Curium	97 **Bk** Berkelium	98 **Cf** Californium	99 **Es** Einsteinium	100 **Fm** Fermium	101 **Md** Mendelevium	102 **No** Nobelium	103 **Lr** Lawrencium

Key: Metal | Semi-metal | Non-metal

(Source: International Union of Pure and Applied Chemistry, IUPAC)

THE DATA TABLE OF ELEMENTS

Element	Symbol	Proton number	Relative atomic mass	Melting point (°C)	Boiling point (°C)	Density (g cm^{-3})
Aluminium	Al	13	27	660	2350	2.70200
Silver	Ag	47	108	962	2160	10.50000
Argon	Ar	18	40	-189	-186	0.00170
Barium	Ba	56	137	710	1640	3.59000
Beryllium	Be	4	9	1285	2470	1.84800
Boron	B	5	11	2030	3700	2.47000
Bromine	Br	35	80	-7	59	3.11900
Iron	Fe	26	56	1540	2760	7.89400
Fluorine	F	9	19	-220	-188	0.00160
Phosphorus	P	15	31	44	280	1.82000
Helium	He	2	4	-270	-269	0.00017
Hydrogen	H	1	1	-259	-252	0.00008
Iodine	I	53	127	114	184	4.95000
Potassium	K	19	39	63	777	0.86200
Calcium	Ca	20	40	839	1490	1.55000
Carbon	C	6	12	3500	4827	2.26000
Chlorine	Cl	17	35.5	-101	-34	0.00300
Cobalt	Co	27	59	1495	2870	8.90000
Crypton	Kr	36	84	-156	-152	0.00350
Chromium	Cr	24	52	1860	2600	7.19000
Copper	Cu	29	64	1084	2580	8.93000
Lithium	Li	3	7	180	1360	0.53400
Magnesium	Mg	12	24	650	1100	1.73800
Manganese	Mn	25	55	1250	2120	7.47000
Sodium	Na	11	23	98	900	0.97100
Neon	Ne	10	20	-248	-246	0.00080
Nickel	Ni	28	59	1455	2150	8.90000
Nitrogen	N	7	14	-210	-196	0.00120
Oxygen	O	8	16	-219	-183	0.00130
Lead	Pb	82	207	327	1760	11.35000
Rubidium	Rb	37	85.5	39	705	1.53000
Caesium	Cs	55	133	29	670	1.87300
Silicon	Si	14	28	1410	2620	2.33000
Scandium	Sc	21	45	1540	2800	2.99000
Tin	Sn	50	119	232	2270	7.28000
Sulphur	S	16	32	115	445	1.96000
Titanium	Ti	22	48	1670	3300	4.51000
Vanadium	V	23	51	1920	3400	6.09000
Xenon	Xe	54	131	-122	-108	0.00550
Zinc	Zn	30	65	420	913	7.14000

GLOSSARY

Abrasion	Resistance towards surface friction that occurs in a structure.
Acidic oxide	Oxide compound formed from the reaction between non-metals and oxygen.
Antiseptic	Chemical substance used to kill or prevent the growth of bacteria.
Aqueous solution	A solution which solvent is water.
Atom	The smallest particle in an element that takes part in a reaction.
Basic oxide	Oxide compound that is formed from the reaction between metals and oxygen.
Boiling point	Constant temperature at which a substance changes from liquid to gas at a particular pressure.
Chemical equation	A way of writing that describes a chemical reaction in the form of words or chemical formula.
Chemotherapy	Treatment that involves the use of certain chemicals to treat and control certain diseases, especially cancer.
Coefficient	The number in front of a chemical formula in a chemical equation.
Colouring agent	Natural of synthetic colouring substance that is added to enhance the final colour of processed food.
Crystallisation	The process or forming crystals from a saturated solution.
Degree of dissociation	Mole ratio of reactants that has dissociated to products in 1 litre of solution.
Delocalised electron	Electron that moves freely and is not owned by any atoms or ions.
Disinfectant	Germ-killing agent used to sterilise objects such as laboratory equipment.
Duplet electron arrangement	Stable arrangement of two electrons in the valence shell.
Electron	Negatively charged subatomic particle that orbits the nucleus of an atom.
Electronegativity	The tendency of an atom to pull shared electrons towards itself in a covalent bond.
Expansion coefficient	The change in particle size to temperature changes ratio.

Fungicide	Chemical substance to retard or destroy fungi.
Herbicide	Chemical substance to retard or destroy weeds.
Lewis structure	Diagram that shows the bonds between atoms in a molecule and the electron lone pairs in a molecule.
Maglev	Train transportation system that uses magnets to levitate and propel trains.
Metalloid	Element with metal and non-metal properties.
Neutron	Neutral subatomic particle in the nucleus of an atom.
Octet electron arrangement	Stable arrangement of eight electrons in the valence shell.
Pesticide	Poison that is used to kill pests.
Pharmaceutical	Field related to medicine.
Precipitate	Solid that does not dissolve in a solvent and deposited at the bottom.
Preservative	Food additive that delays or prevents the growth and reproduction processes of microorganisms that spoil food.
Proton	Positively charged subatomic particle in the nucleus of an atom.
Reactant	Starting material in a chemical reaction.
Reaction pathway	Refers to a reaction coordinate diagram that shows the change of energy when a reaction occurs.
Refractive index	The ratio of the speed of light in vacuum to the speed of light in a particular medium.
Saturated solution	Solution that contains maximum amount of solute and cannot dissolve any more solute at a particular temperature.
Semiconductor	Substance that has electrical insulator and conductor properties.
Solute	Substance that dissolves in a solvent.
Stoichiometry	Study that is related to the quantity of substance involved in a chemical reaction.
STP	Abbreviation for standard temperature and pressure, which is 0 °C and 1 atm respectively.
Volatility	The property of a liquid that rapidly changes to vapour.

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