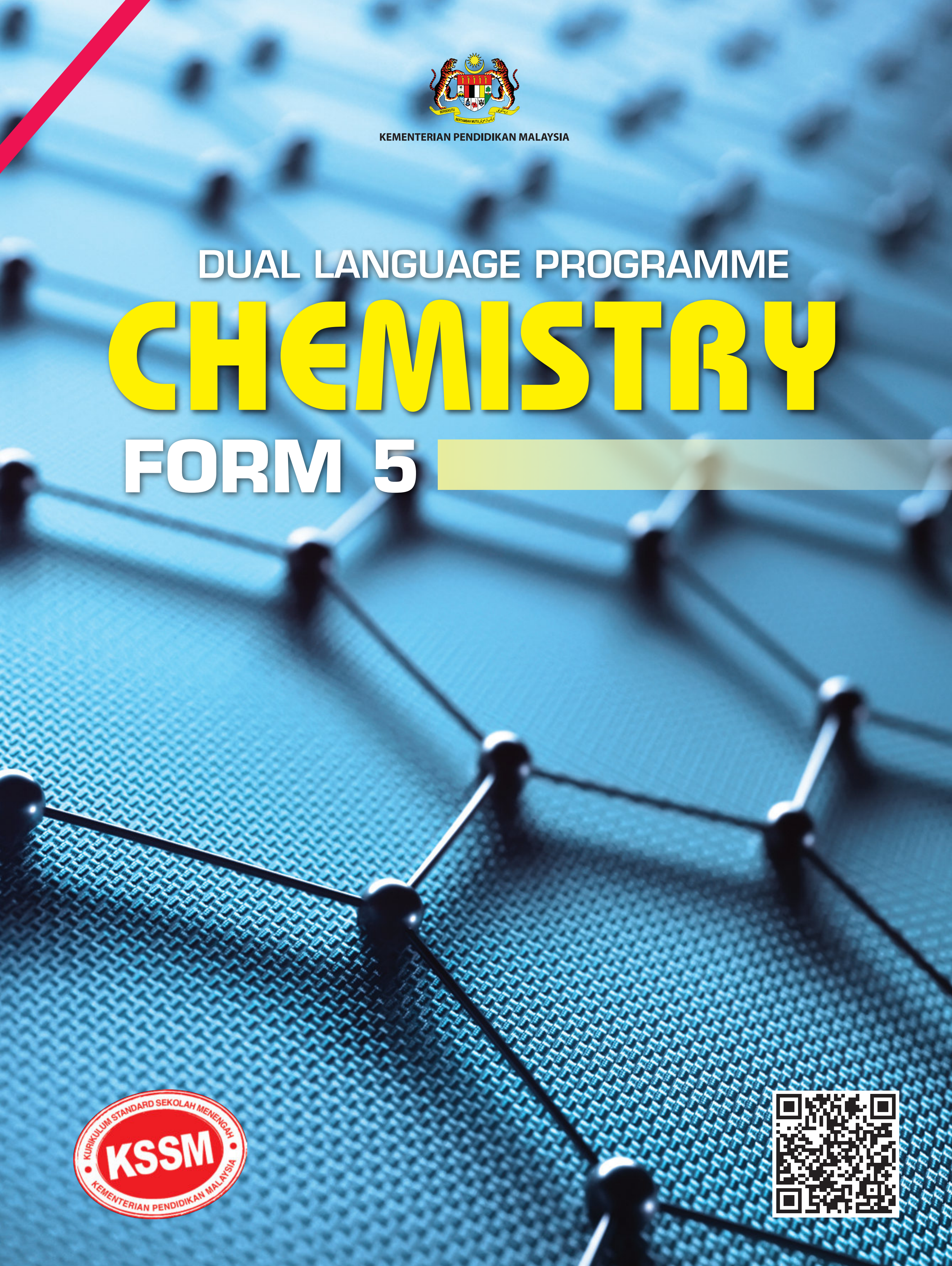


KEMENTERIAN PENDIDIKAN MALAYSIA

DUAL LANGUAGE PROGRAMME

CHEMISTRY

FORM 5

KURIKULUM STANDARD SEKOLAH MENENGAH

KSSM

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;

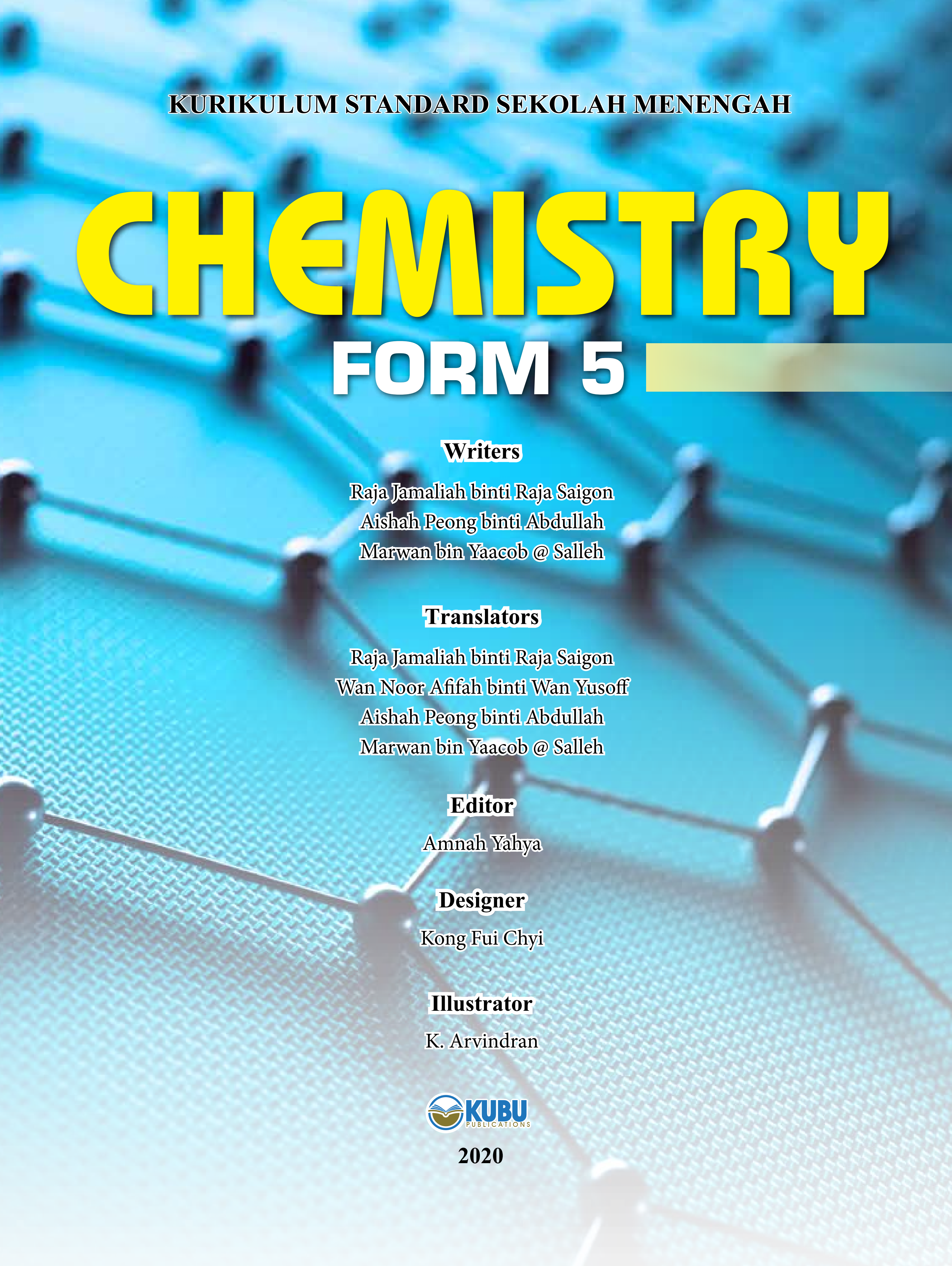
Menjamin satu cara yang liberal terhadap
tradisi-tradisi kebudayaannya yang kaya dan pelbagai corak;

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 5

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Heat

Theme 4

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Introduction

This *Kurikulum Standard Sekolah Menengah* (KSSM) Form 5 Chemistry textbook is written in line with *Dokumen Standard Kurikulum dan Pentaksiran* (DSKP) published by Curriculum Development Division, Ministry of Education Malaysia. For a successful implementation and to fulfil the requirements of DSKP, this book is written based on three domains which are knowledge, skills and values. There are four themes discussed which are Chemical Process, Organic Chemistry, Heat and Technology in Chemistry.

This textbook is also equipped with special features, namely High Order Thinking Skills (HOTS), 21st Century Learning Skills, Science, Technology, Engineering and Mathematics (STEM). Digital components such as QR code (Quick Response Code) and Augmented Reality (AR) are also incorporated as added value in fostering pupils' interests in acquiring knowledge and to put into practice in daily life.

Special features in this book and their functions

Stimulus page:
Contains captivating photos and stimulating texts for pupils to continue to explore the chapter.

Key words
Important terms or concepts that need to be mastered by pupils.

What will you learn?
Summary on content of the chapter that highlights preliminary information about the topic.

Bulletin
Highlights news related to the chapter to stimulate pupils' inquisitive nature and to ignite intellectual curiosity.

Mind booster
Questions to promote critical thinking.

The activities covered in the book:

Activity

Activities provided that require pupils to carry out:
- inquiry
- discussion
- problem solving
- use of technology
- projects
- field trip

Laboratory Activity Inquiry or guided activities to be carried out in the laboratory.

Experiment Experiments that involve Science Process Skills (SPS), Manipulative Skills and Noble Values.

PAK21 **STEM**

21st Century Learning Activities:
- Thinking Skills and Problem Solving.
- Interpersonal and Intrapersonal Skills.
- Information and Communication Skills.
- STEM Approach.

High Order Thinking Skills (HOTS) questions that cover application, analysis, evaluation and creation.

Mind Challenge Questions that challenge pupils to think critically and creatively.

Self Assess Questions to assess pupils' understanding at the end of each subtopic.

Icons in this book:

Learning Standards

Prepared based on *Dokumen Standard Kurikulum dan Pentaksiran* (DSKP) Form 5 Chemistry.

Topic Link

Related topics learnt or will be learnt.

Do you know?

Brief statements about facts or chemistry terminologies.

INFO

Gives brief information about the topic learnt.

Noble Value

Instilling scientific and noble values through activities that require pupils' cooperation, tolerance, trustworthiness, flexibility, open-mindedness (broad-mindedness), diligence, resilience, systematic approach, confidence and adherence to the code of ethics.

CAUTION

A reminder to pupils about hazards while conducting experiments or laboratory activities.

Precautionary steps

Note of reminder while conducting experiments or activities.

Cross-Curriculum History **Cross-Curriculum Physics** **Cross-Curriculum Language** **Cross-Curriculum Mathematics** **Cross-Curriculum Entrepreneurship**

Information on cross-curricular elements related to the topics.

Malaysian Excellence

Elements of patriotism and achievements of scientists on the development of science and technology in Malaysia.

Chemistry Portal

Scan this QR code with your smart mobile devices to access videos and additional information uploaded to the server.

- ❗ Activities, additional information and notes on the topics learnt.
- ▶ Videos related to the chapter or subtopic.

Components at the end of the chapter:

Concept Map

Summary of the chapter in graphic for easy recall.

SELF Reflection

To evaluate pupils' mastery of the topic learnt in the chapter.

ACHIEVEMENT TEST

Questions that assess pupils' understanding at the end of the chapter.

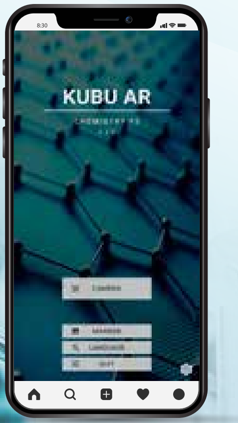
Enrichment Corner

Enrichment exercises with level 5 (evaluating) and level 6 (creating) HOTS questions.

Steps to scan three-dimensional animations:

Download Form 5 Chemistry AR application to scan the QR codes to watch three-dimensional animations.

AR code



DOWNLOAD ON THE App Store

GET IT ON Google play

T&L support materials

https://bit.ly/kpkt5pdpc

Suggested answers

Access the following website to refer to the suggested answers: https://bit.ly/kpkt5ans

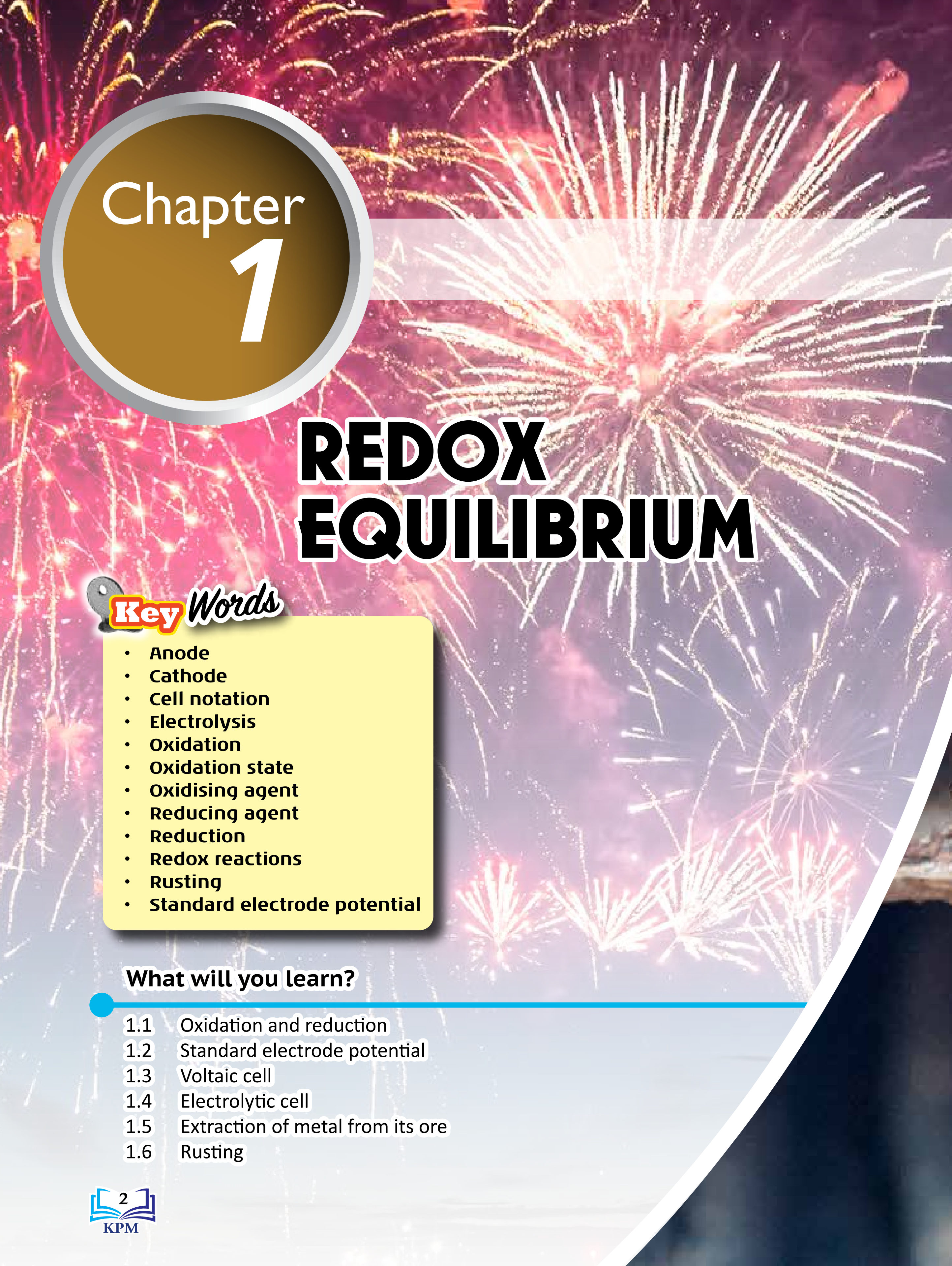
Virtual Explorations

https://bit.ly/kpkt5ve

THEME 1

CHEMICAL PROCESS

This theme gives opportunity for pupils to understand and apply the concept of oxidation and reduction in redox reaction. Standard electrode potential is introduced as a measure of the strength of oxidising and reducing agents. Redox reactions in voltaic cell and electrolytic cell are discussed too. The applications of redox reactions in industry such as electroplating, purification of metal and extraction of metal and its effect to the environment are explored. Pupils will discover the mechanism and methods of preventing rusting.



Chapter 1

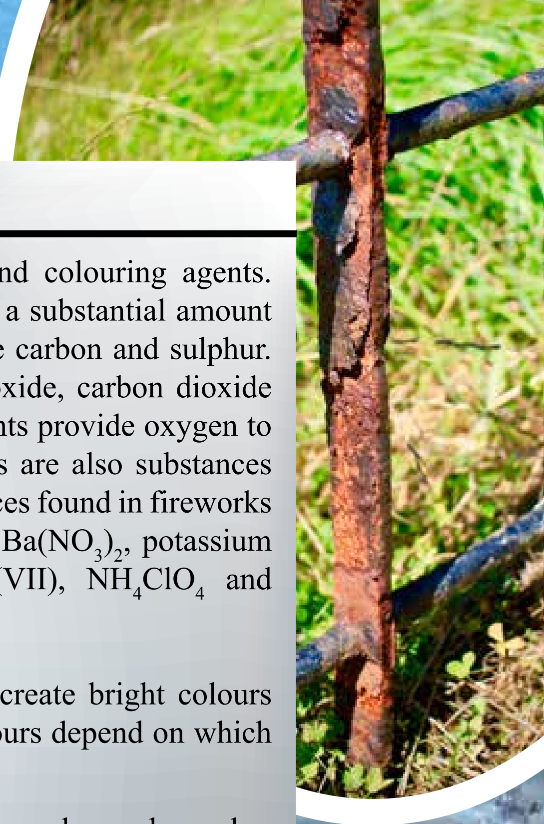
REDOX EQUILIBRIUM

Key Words

- **Anode**
- **Cathode**
- **Cell notation**
- **Electrolysis**
- **Oxidation**
- **Oxidation state**
- **Oxidising agent**
- **Reducing agent**
- **Reduction**
- **Redox reactions**
- **Rusting**
- **Standard electrode potential**

What will you learn?

1.1 Oxidation and reduction
1.2 Standard electrode potential
1.3 Voltaic cell
1.4 Electrolytic cell
1.5 Extraction of metal from its ore
1.6 Rusting



Bulletin

Fireworks contain fuels, oxidising agents and colouring agents. Fuels burn and undergo oxidation to produce a substantial amount of gas. The fuels that are commonly used are carbon and sulphur. These substances burn to form carbon monoxide, carbon dioxide and sulphur dioxide gases. The oxidising agents provide oxygen to help the fuels burn quicker. Oxidising agents are also substances that contain a lot of oxygen. Common substances found in fireworks are potassium nitrate, KNO_3, barium nitrate, $Ba(NO_3)_2$, potassium chlorate(VII), $KClO_4$, ammonium chlorate(VII), NH_4ClO_4 and barium peroxide, BaO_2.

Additionally, colouring agents are added to create bright colours that form exciting fireworks display. The colours depend on which metal ions are present, such as the following:

Colouring agent	Colour
Strontium carbonate	Red
Barium nitrate	Green
Sodium chloride	Yellow
Copper(II) chloride	Blue

When fireworks are burned, a redox reaction happens. Fuels like sulphur or oxidised carbon, and oxidising agents like potassium nitrate are reduced. Fireworks powder is a mixture of potassium nitrate (75%), oxidised carbon (15%) and sulphur (10%).

What is meant by redox reaction?

How is the electrolysis process applied in daily life?

How can the oxidising agents and reducing agents be determined based on the standard electrode potential value, E^0?

What are the steps that need to be taken to prevent rusting?

1.1 OXIDATION AND REDUCTION

- A rocket requires an immense thrust force to launch into space. The thrust force is produced through a combustion reaction between fuel and oxygen.
- The combustion reaction is an example of a redox reaction. What is meant by a redox reaction?

A redox reaction is a chemical reaction where oxidation and reduction occur simultaneously.

- Initially, a redox reaction refers to a reaction involving oxygen. However, there are various types of redox reactions that can be defined differently as shown in Figure 1.1.

Learning Standards

Pupils are able to:

1.1.1 describe redox reactions through activities.
1.1.2 explain redox reaction based on the change in oxidation number through activities.
1.1.3 investigate displacement reaction as a redox reaction through activities.

Cross-Curriculum Language

The term redox is derived from two words:

REDOX

Reduction Oxidation

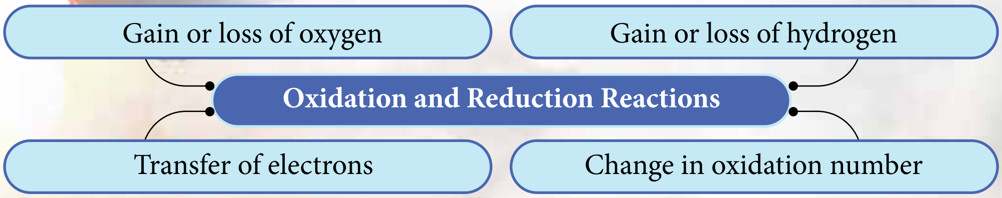


Figure 1.1 Redox reactions

Oxidation and Reduction in Terms of Gain and Loss of Oxygen

- The redox reaction that takes place between magnesium, Mg and carbon dioxide, CO_2 in Photograph 1.1 produces magnesium oxide, MgO and carbon, C. Can you write a balanced chemical equation for the reaction between magnesium, Mg and carbon dioxide, CO_2?
- The definitions of oxidation and reduction reactions can be explained in terms of gain and loss of oxygen.

Oxidation reaction takes place when a reactant **gains oxygen**.
Reduction reaction takes place when a reactant **loses oxygen**.

Photograph 1.1 Combustion of magnesium ribbon, Mg in dry ice

$$\overbrace{2Mg(s) + CO_2(g) \rightarrow 2MgO(s)}^{\text{Oxidation (gain of oxygen)}} + C(s)$$

$$2Mg(s) + \underbrace{CO_2(g) \rightarrow 2MgO(s) + C(s)}_{\text{Reduction (loss of oxygen)}}$$

Oxidised substance: Magnesium, Mg	Magnesium, Mg gains oxygen.
Reduced substance: Carbon dioxide, CO_2	Carbon dioxide, CO_2 loses oxygen.
Oxidising agent: Carbon dioxide, CO_2	Carbon dioxide, CO_2 oxidises magnesium, Mg.
Reducing agent: Magnesium, Mg	Magnesium, Mg reduces carbon dioxide, CO_2.

ACTIVITY 1A

PAK21

Carry out a discussion to answer the following questions in a brainstorming activity.

1. The reaction between copper(II) oxide, CuO and carbon, C is an example of a redox reaction.
  - (a) Write a balanced chemical equation for the reaction that takes place.
  - (b) State the names of the reactions that take place for:
    - (i) Copper(II) oxide, CuO.
    - (ii) Carbon, C.
  - (c) Identify:
    - (i) Oxidised substance.
    - (ii) Reduced substance.
    - (iii) Oxidising agent.
    - (iv) Reducing agent.

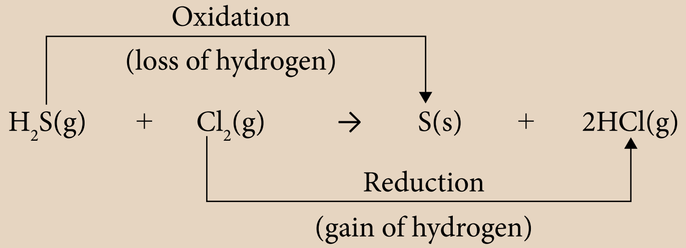
Record the outcome of your group's discussion in your notebook.

Oxidation and Reduction in Terms of Gain and Loss of Hydrogen

- How can we identify the reaction that does not involve oxygen whether it is oxidation or reduction?
- Chemists extend the definition of oxidation and reduction to the compounds reacting with hydrogen or to reactants containing hydrogen.
- The definitions of oxidation and reduction reactions can be explained in terms of gain and loss of hydrogen.

Oxidation reaction takes place when a reactant **loses hydrogen**.
Reduction reaction takes place when a reactant **gains hydrogen**.

- An example of a reaction that does not involve oxygen is a reaction between hydrogen sulphide, H_2S, and chlorine, Cl_2.



$$H_2S(g) + Cl_2(g) \rightarrow S(s) + 2HCl(g)$$

Oxidised substance: Hydrogen sulphide, H_2S	Hydrogen sulphide, H_2S loses hydrogen.
Reduced substance: Chlorine, Cl_2	Chlorine, Cl_2 gains hydrogen.
Oxidising agent: Chlorine, Cl_2	Chlorine, Cl_2 oxidises hydrogen sulphide, H_2S.
Reducing agent: Hydrogen sulphide, H_2S	Hydrogen sulphide, H_2S reduces chlorine, Cl_2.

ACTIVITY 1B

PAK21

Carry out this activity in pairs.
The following reaction is a redox reaction:

$$2NH_3(g) + 3CuO(s) \rightarrow N_2(g) + 3Cu(s) + 3H_2O(l)$$

(a) Identify:
- (i) Oxidised substance.
- (ii) Reduced substance.
- (iii) Oxidising agent.
- (iv) Reducing agent.

(b) Explain your answers to your classmates.

Oxidation and Reduction in Terms of Electron Transfer

Photograph 1.2 Combustion of magnesium ribbon, Mg in oxygen, O_2

- Combustion of magnesium, Mg in oxygen, O_2 produces magnesium oxide, MgO. Magnesium oxide, MgO is an ionic compound formed when electrons are transferred from a metal to a non-metal.

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

Electron transfer

- The definitions of oxidation and reduction reactions can be explained in terms of electron transfer.

Chemistry Portal

Redox in Terms of Electron Transfer
https://bit.ly/kpkt5v1

Oxidation reaction takes place when a reactant **loses electron**.
Reduction reaction takes place when a reactant **gains electron**.

- Not all redox reactions can be explained in terms of loss and gain of oxygen or hydrogen.
- Since the discovery of electrons by J.J Thomson in 1897, chemists have started to use the concept of electron transfer in explaining redox reactions.
- Primarily, redox reactions can be explained through the concept of electron transfer.
- Transfer of electrons in a redox reaction can be elaborated in the following half equations:

Half equation of oxidation reaction:	$Mg \longrightarrow Mg^{2+} + 2e^-$
Half equation of reduction reaction:	$O_2 + 4e^- \longrightarrow 2O^{2-}$

Oxidised substance: Magnesium, Mg	Magnesium atom, Mg loses electrons.
Reduced substance: Oxygen, O_2	Oxygen molecule, O_2 gains electrons.
Oxidising agent: Oxygen, O_2	Oxygen, O_2 is the electron acceptor.
Reducing agent: Magnesium, Mg	Magnesium, Mg is an electron donor.

- Let us investigate oxidation and reduction reactions that involve the transfer of electrons at a distance.

Laboratory Activity 1A Transfer of Electrons at a Distance

PAK 21 Learning Science Through Inquiry

Aim: To investigate oxidation and reduction reactions in terms of electron transfer at a distance.

Materials: 1.0 mol dm^{-3} of sulphuric acid, H_2SO_4, 0.5 mol dm^{-3} of potassium iodide, KI solution, 0.1 mol dm^{-3} of acidified potassium manganate(VII), $KMnO_4$ solution and starch solution.

Apparatus: U-tube, connecting wires with crocodile clips, galvanometer, retort stand, carbon electrodes, dropper and test tube.

Procedure:

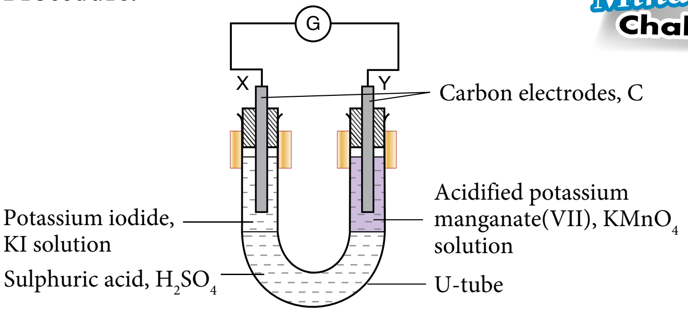


Figure 1.2

Mind Challenge

The carbon electrodes must not touch the layer of sulphuric acid, H_2SO_4. Why?

INFO

The negative terminal is the electrode where electrons are released.

The positive terminal is the electrode where electrons are accepted.

1. Pour 1.0 mol dm^{-3} of sulphuric acid, H_2SO_4 into the U-tube until half full and clamp it vertically.
2. Carefully, pour 0.5 mol dm^{-3} of potassium iodide, KI solution into arm X of the U-tube using a dropper until the solution reaches the height of 3 cm.
3. Carefully, pour 0.1 mol dm^{-3} of acidified potassium manganate(VII), $KMnO_4$ solution into arm Y of the U-tube using a dropper until the solution reaches the height of 3 cm.

4. Connect the carbon electrodes to the galvanometer using the connecting wires.
5. Dip one of the carbon electrodes into the potassium iodide, KI solution while the other carbon electrode into the acidified potassium manganate(VII), $KMnO_4$ solution to complete the circuit as shown in Figure 1.2.
6. Observe the direction of the deflection of the galvanometer needle and determine the positive and negative terminals for each electrode.
7. Leave the apparatus set-up for 30 minutes.
8. Observe the colour change of the potassium iodide, KI solution and the acidified potassium manganate(VII), $KMnO_4$ solution.
9. Record your observation in the table below.
10. After 30 minutes, draw out a little of the solution in arm X of the U-tube using a dropper and pour it into a test tube.
11. Add starch solution into the test tube to verify the product formed.

Data and observation:

Solution	Observation	Inference
Potassium iodide, KI		
Acidified potassium manganate(VII), $KMnO_4$		

Discussion:

1. Based on your observation, write the half equations for electrode X and electrode Y.
2. What are the types of reactions that take place at electrode X and electrode Y?
3. Write the overall ionic equation for the reaction that takes place.
4. Identify the oxidised substance, reduced substance, oxidising agent and reducing agent. Give reasons for your answers.
5. State the direction of the electron flow in the experiment.
6. State the positive terminal and negative terminal of the experiment.
7. What is the function of sulphuric acid, H_2SO_4?
8. Other than using the U-tube, draw a labelled set-up of apparatus that can be used for the experiment to investigate the transfer of electrons at a distance between iron(II) sulphate, $FeSO_4$ solution and chlorine water, Cl_2.

Prepare a complete report after carrying out this laboratory activity.

In this laboratory activity, it is found that:

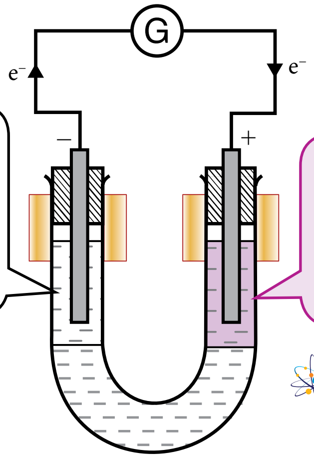
- The deflection of the galvanometer needle shows that there is a transfer of electrons through the connecting wires from the reducing agent (negative terminal) to the oxidising agent (positive terminal).
- The colour change of the solutions also shows that the oxidation and reduction reactions have taken place.
- Potassium iodide, KI solution and acidified potassium manganate(VII), $KMnO_4$ solution are separated by an electrolyte which is sulphuric acid, H_2SO_4.
- Electrons move from the electrode in potassium iodide, KI solution to the electrode in acidified potassium manganate(VII), $KMnO_4$ solution through the connecting wires.

Potassium iodide, KI solution
(Reducing agent)

Iodide ions, I^- release electrons to form iodine, I_2

$2I^- \rightarrow I_2 + 2e^-$

(colourless solution) (brown solution)



Acidified potassium manganate(VII), $KMnO_4$ solution
(Oxidising agent)

Manganate(VII) ion, MnO_4^- receives electrons to form manganese(II) ion, Mn^{2+}

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

(purple solution) (colourless solution)

Topic Link **Redox:** Voltaic cell on page 27.

Figure 1.3 The set-up of apparatus to investigate the transfer of electrons at a distance

- Do you know how to write the half equation for potassium iodide, KI solution and the half equation for acidified potassium manganate(VII), $KMnO_4$ solution as shown in Figure 1.3?

Writing half equation for oxidation:

Colourless solution of potassium iodide, KI changes to brown

1 Write the reactant and product	$2I^-(aq) \rightarrow I_2(aq)$ (colourless) (brown)
2 Add the electron to the side that does not have charges to balance the charges	$2I^-(aq) \rightarrow I_2(aq) + 2e^-$ Charge = -2 Charge = 0 Charge = -2 Total charge = -2 Total charge = 0 + (-2) = -2

Writing half equation for reduction:

The purple colour of acidified potassium manganate(VII), $KMnO_4$ solution changes to colourless

1 Write the reactants and product	$MnO_4^-(aq) + H^+(aq) \rightarrow Mn^{2+}(aq) + H_2O(l)$ (purple) (acidic condition) (colourless)

In acidic condition, the reaction produces water

2 Balance the number of atoms for each element	$MnO_4^-(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l)$
3 Sum up the total charges of reactants and products	$MnO_4^-(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l)$ Charge = -1 Charge = +8 Charge = +2 Charge = 0 Total charge = (-1) + (+8) = +7 Total charge = (+2) + 0 = +2
4 Add electrons to the side that has more positive charges to balance the charges	$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$ Charge = -5 Total charge = (-1) + (+8) + (-5) = +2 Total charge = (+2) + 0 = +2

- Based on the half equation of oxidation and the half equation of reduction, what is the overall ionic equation for the redox reaction in Laboratory Activity 1A?

Chemistry Portal

Writing Ionic Equation
https://bit.ly/kpkt5v2

Oxidising Agent and Reducing Agent
https://bit.ly/kpkt5v3

Half equations:

$2I^- \longrightarrow I_2 + 2e^-$ … ①
$MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$ … ②
Number of electrons in equations ① and ② must be the same

$10I^- \longrightarrow 5I_2 + 10e^-$ … ① × 5
$2MnO_4^- + 16H^+ + 10e^- \longrightarrow 2Mn^{2+} + 8H_2O$ … ② × 2
Sum up equations ① and ②

$10I^- + 2MnO_4^- + 16H^+ + \cancel{10e^-} \longrightarrow 5I_2 + \cancel{10e^-} + 2Mn^{2+} + 8H_2O$

Ionic equation:

$10I^- + 2MnO_4^- + 16H^+ \longrightarrow 5I_2 + 2Mn^{2+} + 8H_2O$

- Table 1.1 shows examples of commonly used oxidising agents, whereas Table 1.2 shows examples of commonly used reducing agents.

Cross-Curriculum Mathematics

Table 1.1 Examples of oxidising agents

Oxidising agent	Half equation
Acidified potassium manganate(VII), $KMnO_4$	$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$
Acidified potassium dichromate(VI), $K_2Cr_2O_7$	$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$
Chlorine water, Cl_2	$Cl_2(aq) + 2e^- \rightarrow 2Cl^-(aq)$
Bromine water, Br_2	$Br_2(aq) + 2e^- \rightarrow 2Br^-(aq)$
Iron(III) chloride, $FeCl_3$	$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$
Acidified hydrogen peroxide, H_2O_2	$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightarrow 2H_2O(l)$

Table 1.2 Examples of reducing agents

Reducing agent	Half equation
Potassium iodide, KI	$2I^-(aq) \rightarrow I_2(aq) + 2e^-$
Potassium bromide, KBr	$2Br^-(aq) \rightarrow Br_2(aq) + 2e^-$
Iron(II) sulphate, $FeSO_4$	$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$
Reactive metals (e.g. zinc, Zn)	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
Sulphur dioxide, SO_2	$SO_2(g) + 2H_2O(l) \rightarrow SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$

Oxidation Number

What is oxidation number?

- The oxidation number or oxidation state is the charge of the elements in a compound if the transfer of electrons occurs in an atom to form chemical bonds with other atoms.
- The oxidation number of an element in an ion or a compound can be determined based on the following guidelines:

Chemistry Portal

Redox in Terms of Oxidation Number
https://bit.ly/kpkt5v4

1 The oxidation number for all elements is zero.

Element	Oxidation number
Sodium, Na	0
Carbon, C	0
Helium, He	0
Oxygen, O_2	0
Chlorine, Cl_2	0

2 The oxidation number for a monoatomic ion is equal to the charge of the ion.

Monoatomic ion	Oxidation number
Copper(II) ion, Cu^{2+}	+2
Potassium ion, K^+	+1
Bromide ion, Br^-	-1
Oxide ion, O^{2-}	-2
Aluminium ion, Al^{3+}	+3

3 The oxidation number of the element in its compound for Group 1, Group 2 and Group 13 in the Periodic Table are +1, +2 and +3, respectively.

Compound	Oxidation number	Compound	Oxidation number
Lithium chloride, $\underline{Li}Cl$	+1	Magnesium oxide, $\underline{Mg}O$	+2
Sodium oxide, $\underline{Na}_2O$	+1	Aluminium chloride, $\underline{Al}Cl_3$	+3

4 The sum of oxidation numbers of the element in a compound is zero.

Example:
The sum of oxidation numbers for sodium chloride, NaCl.
The oxidation number of Na + oxidation number of Cl
= (+1) + (-1) = 0

Determine the oxidation number of sulphur in sulphur trioxide, $\underline{S}O_3$.
$x + 3(-2) = 0$
$x = +6$
The oxidation number of S = +6

5 The sum of oxidation numbers of the element in a polyatomic ion is equal to the charge of the ion.

Example:
The sum of oxidation numbers for ammonium ion, NH_4^+.
The oxidation number N + Oxidation number 4H
= (−3) + 4(+1) = +1

Determine the oxidation number of carbon in carbonate ion, $\underline{C}O_3^{2-}$.
$x + 3(-2) = -2$
$x = +4$
The oxidation number of C = +4

6 The oxidation number of hydrogen in a compound is normally +1 except in metal hydrides which is -1.

The oxidation number of hydrogen in hydrogen chloride, $\underline{H}Cl$.

$x + (-1) = 0$

$x = +1$

The oxidation number of H = +1

Determine the oxidation number of hydrogen in sodium hydride, $Na\underline{H}$.

$+1 + x = 0$

$x = -1$

The oxidation number of H = -1

7 The oxidation number of oxygen in a compound is normally -2, except in peroxides which is -1.

The oxidation number of oxygen in magnesium oxide, $Mg\underline{O}$.

$(+2) + x = 0$

$x = -2$

The oxidation number of O = -2

Determine the oxidation number of oxygen in hydrogen peroxide, $H_2\underline{O}_2$.

$2(+1) + 2x = 0$

$2x = -2$

$x = -1$

The oxidation number of O = -1

8 The oxidation number of the elements in Group 17 in a compound is normally -1.

- The oxidation number of fluorine is always -1.
- The oxidation number of chlorine, bromine and iodine is usually -1, except when they are bound to a more electronegative element, such as oxygen. Thus, their oxidation number will have a positive value.

The oxidation number of fluorine in hydrogen fluoride, $H\underline{F}$.

$(+1) + x = 0$

$x = -1$

The oxidation number of F = -1

The oxidation number of chlorine in potassium chlorate(I), $K\underline{Cl}O$.

$(+1) + x + (-2) = 0$

$x = +1$

The oxidation number of Cl = +1

The oxidation number of bromine in bromate(V) ion, $\underline{Br}O_3^-$.

$x + 3(-2) = -1$

$x = +5$

The oxidation number of Br = +5

Chemistry Portal

Determining the Oxidation Number
https://bit.ly/kpkt5v5

Reinforcement Exercises in Determining the Oxidation Number
https://bit.ly/kpkt5n1

ACTIVITY 1C

Determine the oxidation number for the underlined elements. Show all workings, if any.

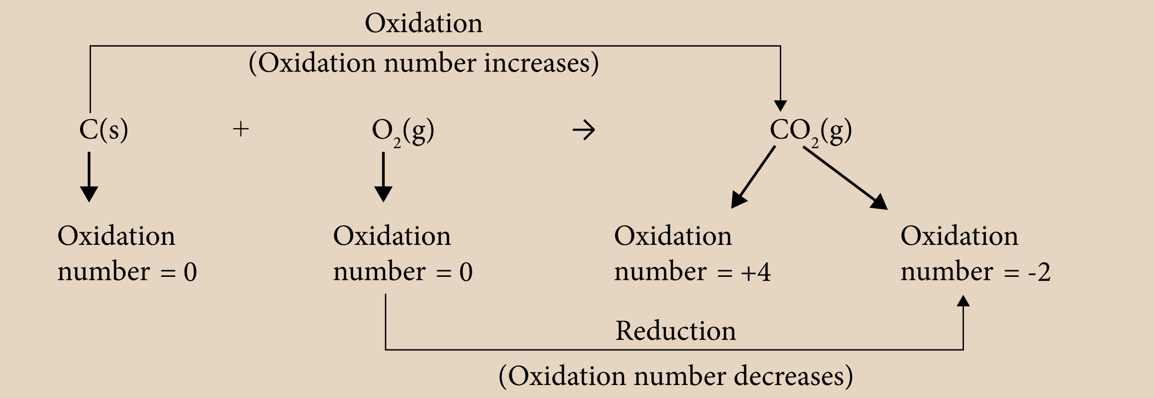
1.	$\underline{Mn}O_4^-$	**3.**	$Al\underline{H}_3$	**5.**	$\underline{Cu}_2O$	**7.**	$\underline{V}O^{2+}$
2.	$\underline{Ba}(OH)_2$	**4.**	$HO\underline{Br}$	**6.**	$\underline{C}_2O_4^{2-}$	**8.**	$\underline{S}_8$

Oxidation and Reduction in Terms of Change in Oxidation Number

- Chemists found that the concept of electron transfer in explaining redox reactions is limited to the reactions associated with the ionic compounds. Hence, the definitions of oxidation and reduction are extended by using the concept of oxidation numbers in describing redox reactions to cover all reactions.

> Oxidation reaction takes place when the **oxidation number** of an element **increases**.
> Reduction reaction takes place when the **oxidation number** of an element **decreases**.

- An example of the reaction is between carbon, C and oxygen, O_2 to produce carbon dioxide, CO_2.



Oxidised substance: Carbon, C	Oxidation number of carbon, C increases
Reduced substance: Oxygen, O_2	Oxidation number of oxygen, O decreases
Oxidising agent: Oxygen, O_2	Oxygen, O_2 oxidises carbon, C
Reducing agent: Carbon, C	Carbon, C reduces oxygen, O_2

- Conclusion:
  - (a) An oxidising agent is a substance that oxidises other substances and is reduced in a redox reaction.
  - (b) A reducing agent is a substance that reduces other substances and is oxidised in a redox reaction.

ACTIVITY 1D

PAK21

Carry out this activity in groups.

Table 1.3 shows the chemical equations for two examples of redox reactions.

(a) Discuss why the reactions in Table 1.3 can be classified as redox reactions.

(b) For each reaction, identify the following:
  - (i) Oxidised and reduced substances.
  - (ii) Oxidising and reducing agents.

Table 1.3

Chemical equation
$CuO(s) + H_2(g) \rightarrow Cu(s) + H_2O(l)$
$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Present the outcome of your group discussion in your class in a Gallery Walk activity.

The Oxidation Number and Naming of Compounds According to the IUPAC Nomenclature

- Transition elements are metals that normally exhibit more than one oxidation number in their compounds.
- According to the IUPAC nomenclature, Roman numerals are used to indicate the oxidation number of the metals in their compounds.
- For example, Figure 1.4 shows iron that forms two types of nitrates.

INFO

According to the IUPAC nomenclature, metals that have only one oxidation number in their compounds do not need Roman numerals in the naming. For example, $Mg(NO_3)_2$ is named as magnesium nitrate.

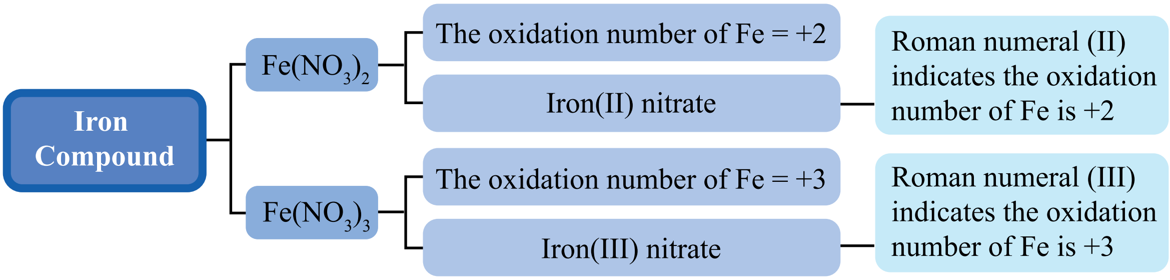


Figure 1.4 Naming according to the IUPAC system for iron compound

- Table 1.4 shows the naming of compounds containing metals that have more than one oxidation number according to the IUPAC nomenclature.

Table 1.4 Compound names according to the IUPAC nomenclature

Compound formula	Oxidation number	IUPAC name
MnO_2	The oxidation number of manganese is +4	Manganese(IV) oxide
$KMnO_4$	The oxidation number of manganese is +7	Potassium manganate(VII)
$CrCl_3$	The oxidation number of chromium is +3	Chromium(III) chloride
$K_2Cr_2O_7$	The oxidation number of chromium is +6	Potassium dichromate(VI)

ACTIVITY 1E

PAK21

Carry out this activity in pairs.

1. State the name of the following compounds according to the IUPAC nomenclature.
   (a) Cu_2O (b) CuO (c) Hg_2Cl_2 (d) $HgCl_2$ (e) K_2CrO_4
2. Write the formula for the following compounds.
   (a) Vanadium(V) oxide (b) Sodium oxide (c) Lead(II) carbonate
3. State the name of the following two compounds according to the IUPAC nomenclature and explain the reason for the difference of those names.
   Fe_2O_3 Al_2O_3

Record the findings in your notebook.

Conversion of Iron(II) Ion, Fe^{2+} to Iron(III) Ion, Fe^{3+} and Vice Versa

Photograph 1.3
Iron pills iron(II) gluconate, $Fe(C_6H_{11}O_7)_2$

- Compound of iron(II) ion, Fe^{2+} and compound of iron(III) ion, Fe^{3+} are widely used in our lives. Photograph 1.3 shows iron pills, which contain iron(II) gluconate, $Fe(C_6H_{11}O_7)_2$, that are prescribed to anaemic patients and pregnant women.
- The presence of iron(II) ion, Fe^{2+} and iron(III) ion, Fe^{3+} can be verified by using sodium hydroxide, NaOH solution, aqueous ammonia, NH_3, potassium hexacyanoferrate(II), $K_4[Fe(CN)_6]$ solution, potassium hexacyanoferrate(III), $K_3[Fe(CN)_6]$ solution or potassium thiocyanate, KSCN solution.

Laboratory Activity 1B

Conversion of Iron(II) Ion, Fe^{2+} to Iron(III) Ion, Fe^{3+} and Vice Versa

PAK 21 Learning Science Through Inquiry

Aim: To study the conversion of iron(II) ion, Fe^{2+} to iron(III) ion, Fe^{3+} and vice versa.

Materials: 0.5 mol dm^{-3} of iron(II) sulphate, $FeSO_4$ solution (freshly prepared), 0.5 mol dm^{-3} of iron(III) chloride, $FeCl_3$ solution, bromine water, Br_2, zinc powder, Zn and 2.0 mol dm^{-3} of sodium hydroxide, NaOH solution.

Apparatus: Boiling tube, test tube, boiling tube holder, dropper, spatula, filter funnel, filter paper, Bunsen burner and test tube rack.

Procedure:

A. Conversion of iron(II) ion, Fe^{2+} to iron(III) ion, Fe^{3+}

1. Pour 2 cm^3 of 0.5 mol dm^{-3} of iron(II) sulphate, $FeSO_4$ solution (freshly prepared) into a boiling tube held by a boiling tube holder as shown in Figure 1.5.
2. Using the dropper, add bromine water, Br_2 while shaking the boiling tube until no further colour change can be observed.
3. Gently heat the mixture in the boiling tube.
4. Add sodium hydroxide, NaOH solution into the mixture to confirm the presence of iron(III) ion, Fe^{3+}.
5. Record all observations.

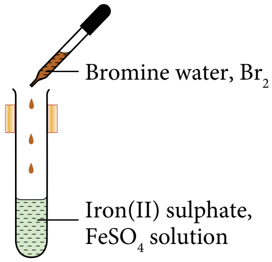


Figure 1.5

B. Conversion of iron(III) ion, Fe^{3+} to iron(II) ion, Fe^{2+}

1. Pour 2 cm^3 of 0.5 mol dm^{-3} of iron(III) chloride, $FeCl_3$ solution into a boiling tube as shown in Figure 1.6.
2. Add half a spatula of zinc powder, Zn into the solution.
3. Gently heat the mixture.
4. Filter the mixture into a test tube.
5. Add sodium hydroxide, NaOH solution into the filtrate to confirm the presence of iron(II) ion, Fe^{2+}.
6. Record all observations.

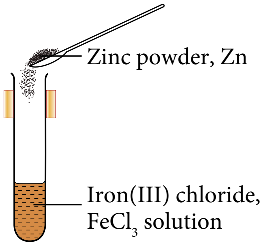


Figure 1.6

Data and observation:

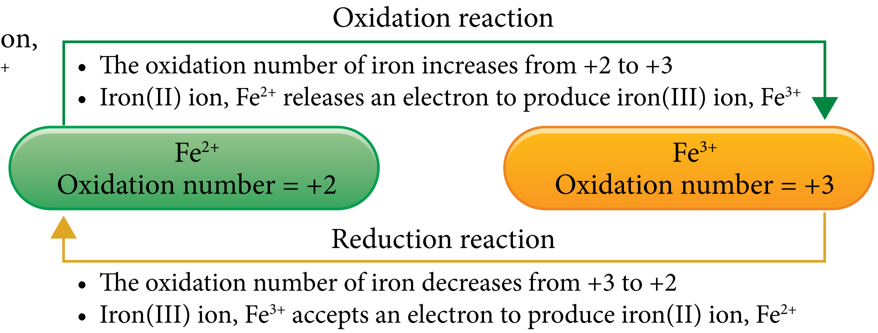
Construct a suitable table to record all observations in section A and section B.

Discussion:

1. For each conversion in sections A and B, identify the substances that are oxidised or reduced. Give reasons for your answers in terms of:
   (a) change in the oxidation number. (b) transfer of electron.
2. What is the role of bromine water, Br_2 in section A and zinc powder, Zn in section B? Give your reasons.
3. Why is freshly prepared iron(II) sulphate, $FeSO_4$ solution used for the experiment in section A?
4. Name a reagent that can be used to verify the presence of iron(III) ion, Fe^{3+} in section A and iron(II) ion, Fe^{2+} in section B.
5. Suggest another substance that can replace bromine water, Br_2 in section A and zinc powder, Zn in section B.

Prepare a complete report after carrying out this laboratory activity.

- Conversion of iron(II) ion, Fe^{2+} to iron(III) ion, Fe^{3+} and vice versa in Figure 1.7 shows that the change in the oxidation number in the redox reaction is associated with the transfer of an electron.



- The oxidation number of iron increases from +2 to +3
- Iron(II) ion, Fe^{2+} releases an electron to produce iron(III) ion, Fe^{3+}

- The oxidation number of iron decreases from +3 to +2
- Iron(III) ion, Fe^{3+} accepts an electron to produce iron(II) ion, Fe^{2+}

Figure 1.7 Conversion of iron (II) ion, Fe^{2+} to iron(III) ion, Fe^{3+} and vice versa

Displacement Reaction of Metal from Its Salt Solution

- Displacement of metal is carried out by adding a metal into a salt solution of another metal. A more electropositive metal is able to displace a less electropositive metal from its salt solution.
- Figure 1.8 shows a piece of zinc plate, Zn is added into a test tube containing copper(II) nitrate, $Cu(NO_3)_2$ solution. The observation and inference for the reaction are as follows:

Observation	Inference
The blue colour of copper(II) nitrate, $Cu(NO_3)_2$ solution becomes paler.	• The concentration of copper(II) ions, Cu^{2+} decreases.
Brown solid is deposited.	• Solid copper, Cu is formed. • Copper(II) ion, Cu^{2+} receives two electrons and forms copper atom, Cu. • Copper(II) ion, Cu^{2+} is reduced.
The zinc plate, Zn becomes thinner.	• Zinc atom, Zn ionises to form zinc ion, Zn^{2+}. • Zinc atom, Zn releases two electrons to form zinc ion, Zn^{2+}. • Zinc, Zn is oxidised.

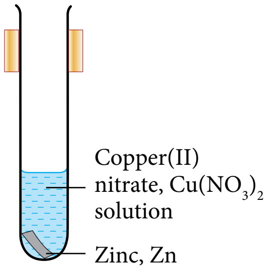


Figure 1.8

- Half equation, ionic equation and chemical equation for the reaction can be constructed by referring to the observations of and inferences from the reaction that takes place.

Oxidation half equation: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ (zinc atom, Zn releases electrons)

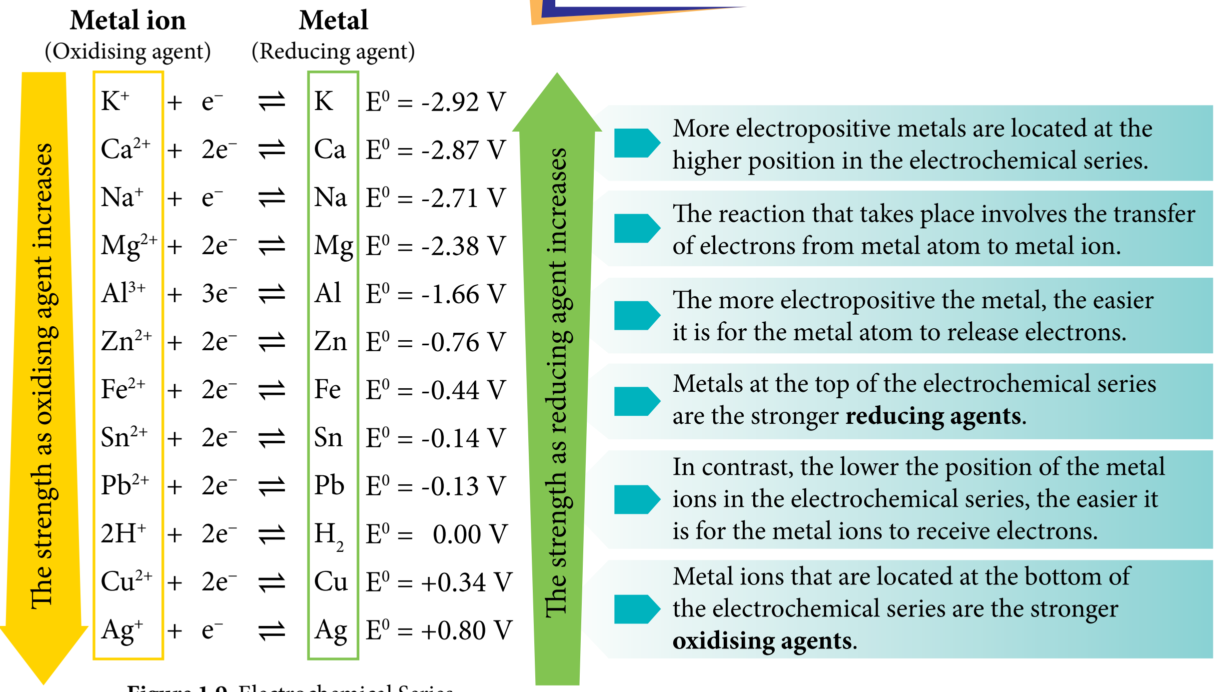
Reduction half equation: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ (copper(II) ion, Cu^{2+} receives electrons)

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

Chemical equation: $Zn(s) + Cu(NO_3)_2(aq) \rightarrow Zn(NO_3)_2(aq) + Cu(s)$

- Electropositivity is the tendency of atoms to release electrons to form cations.
- Electrochemical series is a series of metals that are arranged according to the standard electrode potential, E^0 in the order of most negative to most positive. More electropositive metals are stronger reducing agents because the E^0 value is more negative; so, atoms are easier to lose electrons. Figure 1.9 shows the Electrochemical Series that is part of the standard electrode potential.

Topic Link
Redox: Standard electrode potential on page 23.
Redox: Corrosion of metal on page 52.
Thermochemistry: Heat of displacement on page 125.



Metal ion (Oxidising agent)				Metal (Reducing agent)	
K^+	+	e^-	$\rightleftharpoons$	K	$E^0 = -2.92$ V
Ca^{2+}	+	$2e^-$	$\rightleftharpoons$	Ca	$E^0 = -2.87$ V
Na^+	+	e^-	$\rightleftharpoons$	Na	$E^0 = -2.71$ V
Mg^{2+}	+	$2e^-$	$\rightleftharpoons$	Mg	$E^0 = -2.38$ V
Al^{3+}	+	$3e^-$	$\rightleftharpoons$	Al	$E^0 = -1.66$ V
Zn^{2+}	+	$2e^-$	$\rightleftharpoons$	Zn	$E^0 = -0.76$ V
Fe^{2+}	+	$2e^-$	$\rightleftharpoons$	Fe	$E^0 = -0.44$ V
Sn^{2+}	+	$2e^-$	$\rightleftharpoons$	Sn	$E^0 = -0.14$ V
Pb^{2+}	+	$2e^-$	$\rightleftharpoons$	Pb	$E^0 = -0.13$ V
$2H^+$	+	$2e^-$	$\rightleftharpoons$	H_2	$E^0 = 0.00$ V
Cu^{2+}	+	$2e^-$	$\rightleftharpoons$	Cu	$E^0 = +0.34$ V
Ag^+	+	e^-	$\rightleftharpoons$	Ag	$E^0 = +0.80$ V

- More electropositive metals are located at the higher position in the electrochemical series.
- The reaction that takes place involves the transfer of electrons from metal atom to metal ion.
- The more electropositive the metal, the easier it is for the metal atom to release electrons.
- Metals at the top of the electrochemical series are the stronger **reducing agents**.
- In contrast, the lower the position of the metal ions in the electrochemical series, the easier it is for the metal ions to receive electrons.
- Metal ions that are located at the bottom of the electrochemical series are the stronger **oxidising agents**.

Figure 1.9 Electrochemical Series

- By using a suitable metal, can you explain the redox reaction that takes place in the displacement of silver, Ag from its salt solution?

Mind Challenge

What can you observe when a piece of copper, Cu is added into a test tube containing magnesium sulphate, $MgSO_4$ solution? Does displacement reaction take place? Explain your answer.

Laboratory Activity 1C Displacement of Metal from Its Salt Solution

PAK21 Learning Science Through Inquiry

Aim: To investigate a redox reaction in the displacement of metal from its salt solution.

Materials: Magnesium ribbon, Mg, lead plate, Pb, copper plate, Cu, 0.5 mol dm^{-3} of lead(II) nitrate, $Pb(NO_3)_2$ solution, 0.5 mol dm^{-3} of magnesium nitrate, $Mg(NO_3)_2$ solution and 0.5 mol dm^{-3} of copper(II) nitrate, $Cu(NO_3)_2$ solution.

Apparatus: Test tube, test tube rack and sandpaper.

Procedure:

1. Using the metal plates and salt solutions provided, plan an experiment to investigate a redox reaction in the displacement of metal from its salt solution.
2. Write clear steps of the investigation.
3. Record all observations.

Results:

Construct a suitable table to record all observations and inferences.

Discussion:

1. For each set of experiment:
   (a) Write the oxidation half equation, reduction half equation and overall ionic equation.
   (b) Identify:
      (i) Oxidised substance.
      (ii) Reduced substance.
      (iii) Oxidising agent.
      (iv) Reducing agent.
   (c) Give reasons for your answers in (b)(i), (ii), (iii) and (iv).

Prepare a complete report after carrying out this laboratory activity.

Displacement Reaction of Halogen from Its Halide Solution

- The atom of halogen elements has the tendency to receive electrons to form halide ions. Therefore, halogens undergo reduction reactions and act as oxidising agents.

The reactivity of halogen decreases down Group 17

- Halogens become more difficult to receive electrons. Therefore, the strength of these halogens as oxidising agents decreases.
- Conversely, it is easier for the halide ions to release their electrons, and the strength of halide ions as reducing agents increases.

- The displacement of a halogen is carried out by adding a halogen into a solution of another halide. The halogen at the top of Group 17 (more reactive) can displace the halogen at the bottom (less reactive) from its halide solution.

- Figure 1.10 shows chlorine water, Cl_2 is added into a test tube containing potassium bromide, KBr. The observations of and inferences from the reaction are as follows.

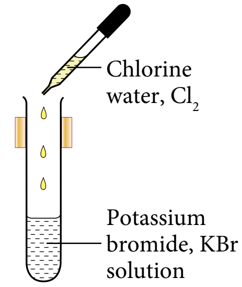


Figure 1.10

Observation	Inference
The colour of potassium bromide, KBr changes from colourless to brown.	• Bromine, Br_2 is formed. • Bromide ion, Br^- releases electrons to form bromine molecule, Br_2. • Bromide ion, Br^- is oxidised .
The colour of chlorine water, Cl_2 changes from greenish yellow to colourless.	• Chlorine molecule, Cl_2 accepts electrons to form chloride ion, Cl^-. • Chlorine, Cl_2 is reduced.

- The half equation, ionic equation and chemical equation for the reaction can be constructed by referring to the observations of and inferences from the reaction that takes place.

Oxidation half equation: $2Br^-(aq) \rightarrow Br_2(aq) + 2e^-$ (bromide ion, Br^- releases electrons)

Reduction half equation: $Cl_2(aq) + 2e^- \rightarrow 2Cl^-(aq)$ (chlorine molecule, Cl_2 accepts electrons)

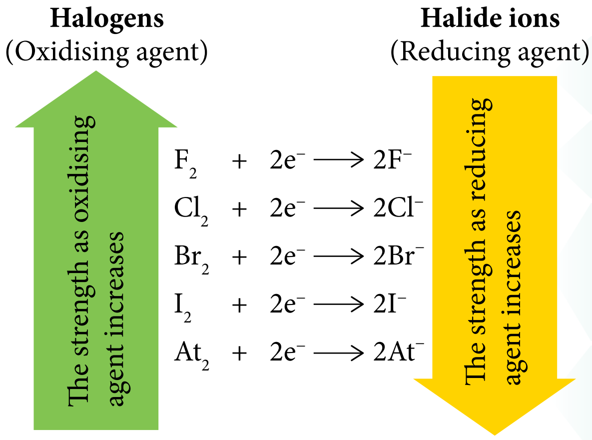
Ionic equation:

$$\underset{\text{Reducing agent}}{2Br^-(aq)} + \underset{\text{Oxidising agent}}{Cl_2(aq)} \rightarrow Br_2(aq) + 2Cl^-(aq)$$

Electron transfer

Chemical equation:

$$\underset{\text{Colourless solution}}{2KBr(aq)} + \underset{\text{Greenish yellow}}{Cl_2(aq)} \rightarrow \underset{\text{Brown}}{Br_2(aq)} + \underset{\text{Colourless solution}}{2KCl(aq)}$$



- The more reactive the halogen, the easier it is for the halogen to accept an electron.
- Halogens that are located at the top of Group 17 are stronger **oxidising agents**.
- In contrast, the lower the position of the halide ions of halogens in Group 17, the easier it is for the halide ions to release an electron.
- Halide ions of halogens that are located at the bottom of Group 17 are stronger **reducing agents**.

Figure 1.11 Group 17 elements

- Using a suitable halogen, can you explain the redox reaction that takes place in the displacement of iodine, I_2 from its halide solution?

Mind Challenge

What can be observed when iodine, I_2 solution is added into a test tube containing potassium bromide, KBr? Does a displacement reaction take place? Explain your answer.

Laboratory Activity 1D Displacement of a Halogen from Its Halide Solution

PAK 21 Learning Science Through Inquiry

Aim: To investigate the redox reaction in the displacement of a halogen from its halide solution.

Materials: Chlorine water, Cl_2, bromine water, Br_2, iodine, I_2 solution, 0.5 mol dm^{-3} of potassium chloride, KCl solution, 0.5 mol dm^{-3} of potassium bromide, KBr solution, 0.5 mol dm^{-3} of potassium iodide, KI solution and organic solvent 1,1,1-trichloroethane, CH_3CCl_3.

Precautionary steps

Chlorine, bromine and iodine are poisonous. Use chlorine water, bromine water and iodine solution with extreme care.

Apparatus: Test tubes, measuring cylinder and test tube rack.

Procedure:

A. The colour of a halogen in the aqueous solution and organic solvent 1,1,1-trichloroethane, CH_3CCl_3

1. Pour 2 cm^3 of chlorine water, Cl_2 into a test tube.
2. Add 2 cm^3 of the organic solvent 1,1,1-trichloroethane, CH_3CCl_3 into the test tube as shown in Figure 1.12.
3. Shake the mixture vigorously and leave the test tube for 30 seconds at the test tube rack.
4. Observe and record the colour of the aqueous layer and the layer of 1,1,1-trichloroethane, CH_3CCl_3.
5. Repeat steps 1 to 4 using bromine water, Br_2 and iodine, I_2 solution.

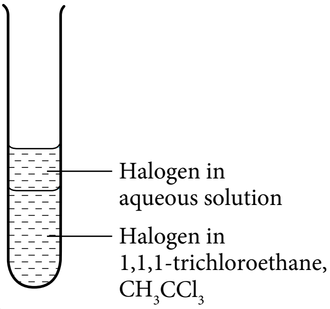


Figure 1.12

B. The displacement reaction of a halogen from its halide solution

1. Pour 2 cm^3 of potassium chloride, KCl solution into a test tube.
2. Add 2 cm^3 of bromine water, Br_2 into the test tube.
3. Shake the mixture and observe any colour change.
4. Add 2 cm^3 of 1,1,1-trichloroethane, CH_3CCl_3, into the test tube.
5. Shake the mixture vigorously and leave the test tube for 30 seconds.
6. Observe and record the colour of the aqueous layer and the layer of 1,1,1-trichloroethane, CH_3CCl_3.
7. Repeat steps 1 to 6 by using halide solutions and halogens as shown in the following table:

Halide solution	Halogen
Potassium chloride, KCl	Bromine water, Br_2
	Iodine, I_2 solution
Potassium bromide, KBr	Chlorine water, Cl_2
	Iodine, I_2 solution
Potassium iodide, KI	Chlorine water, Cl_2
	Bromine water, Br_2

Result:

Construct a suitable table to record all observations in section A and section B.

Discussion:

1. What is the function of 1,1,1-trichloroethane, CH_3CCl_3 in this experiment?
2. State the halogen that can:
   (a) displace chlorine, Cl_2 from potassium chloride, KCl solution.
   (b) displace bromine, Br_2 from potassium bromide, KBr solution.
   (c) displace iodine, I_2 from potassium iodide, KI solution.
3. For each halogen displacement reaction that occurred:
   (a) write the half-equations for the oxidation reaction and reduction reaction.
   (b) write the overall ionic equation for the redox reaction.
   (c) identify the oxidised substances, reduced substances, oxidising agents and reducing agents. Give reasons for your answers.
4. Based on the observation from this laboratory activity:
   (a) arrange chlorine, Cl_2, bromine, Br_2 and iodine, I_2 in an ascending order of strength as oxidising agents.
   (b) deduce the relationship between the strength of a halogen as an oxidising agent and its position in Group 17.
   (c) arrange chloride ion, Cl^-, bromide ion, Br^- and iodide ion, I^- in an ascending order of strength as reducing agents.

Prepare a complete report after carrying out this laboratory activity.

Chemistry Portal

Displacement of Metal Reaction
https://bit.ly/kpkt5v6

Displacement of Halogen Reaction
https://bit.ly/kpkt5v7

Self Assess 1.1

1. What is the meaning of a redox reaction?
2. Table 1.5 shows the equations for several redox reactions.

Table 1.5

Reaction	Chemical equation
I	$Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$
II	$2Pb(s) + O_2(g) \rightarrow 2PbO(s)$
III	$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$
IV	$Br_2(aq) + 2I^-(aq) \rightarrow 2Br^-(aq) + I_2(aq)$

For each of the above redox reaction:
(a) write the half equations for oxidation and reduction.
(b) identify the oxidised substance, reduced substance, oxidising agent and reducing agent. Explain your answer in terms of the transfer of electrons.

1.2 STANDARD ELECTRODE POTENTIAL

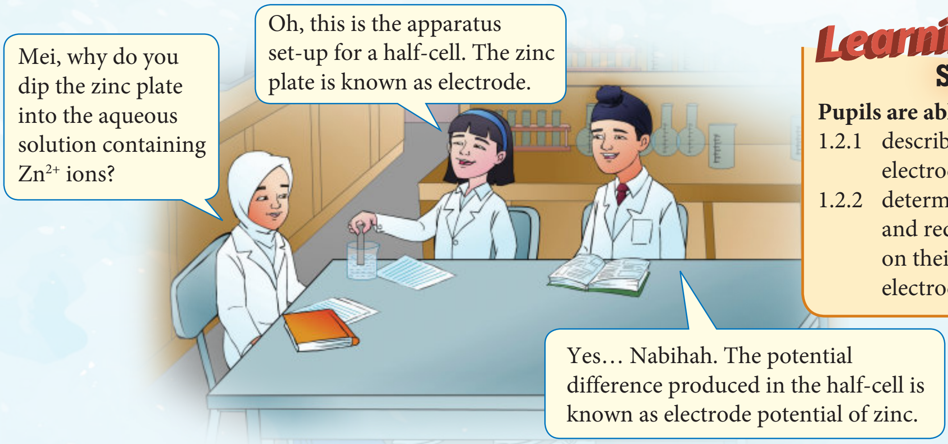


Figure 1.13 Understanding electrode potential

Learning Standards

Pupils are able to:

1.2.1 describe the standard electrode potential.

1.2.2 determine oxidising agent and reducing agent based on their value of standard electrode potentials.

- Based on the conversation among the pupils in Figure 1.13, what do you understand about electrode potential? How can we determine the standard electrode potential?

Electrode potential is the potential difference produced when an equilibrium is established between metal M and the aqueous solution containing metal M^{n+} ions in a half-cell.

- The electrode potential of a cell cannot be measured directly. Therefore, the electrode potential value of an electrode system is determined based on the difference of electrode potential between two half-cells.
- The electrode potential of an electrode system can be measured by pairing up the electrode to the standard reference electrode system. The international consensus is that the standard hydrogen electrode is selected as reference electrode to measure the value of standard electrode potential.

- The standard electrode potential, E^0 of the cell is measured at standard conditions, namely:
  (i) concentration of ions in aqueous solutions is 1.0 mol dm^{-3}.
  (ii) gas pressure of 1 atm or 101 kPa.
  (iii) temperature at 25 °C or 298K.
  (iv) platinum is used as an inert electrode when a half-cell is not a metal electrode.

Standard Hydrogen Electrode

- The diagram of standard hydrogen electrode half-cell is shown in Figure 1.14.

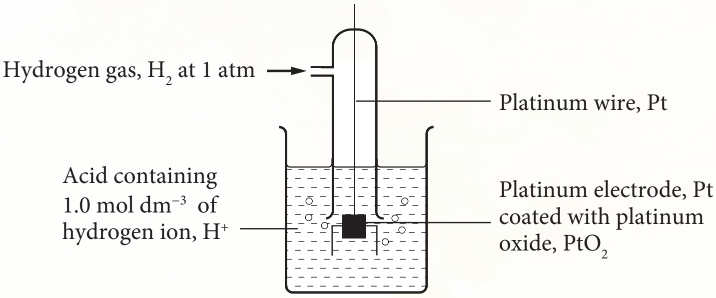


Figure 1.14 Standard hydrogen electrode

INFO

The function of platinum(IV) oxide, PtO_2 is to increase the surface area of platinum, Pt to adsorb hydrogen gas, H_2; so that hydrogen molecules are in closer contact with hydrogen ions, H^+ in the solution.

- The standard hydrogen electrode consists of a platinum electrode, Pt dipped into an acid containing 1.0 mol dm^{-3} of hydrogen ions, H^+ and hydrogen gas, H_2 at a pressure of 1 atm channelled into the acid.
- Half equation of the hydrogen half-cell:

$$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$$

- The standard hydrogen electrode potential, E^0 is given the value of 0.00 V:

$$H^+(aq) + e^- \rightleftharpoons \frac{1}{2}H_2(g) \quad E^0 = 0.00\ V$$

Chemistry Portal

Standard Hydrogen Electrode
https://bit.ly/kpkt5v9

Standard Electrode Potential Value, E^0

How is the standard electrode potential value, E^0 of zinc determined?

- Figure 1.15 shows the standard electrode potential, E^0 zinc is obtained when a half-cell consisting of a zinc electrode, Zn is dipped into a solution containing 1.0 mol dm^{-3} of zinc ions, Zn^{2+} while connected to a standard hydrogen electrode and a salt bridge.

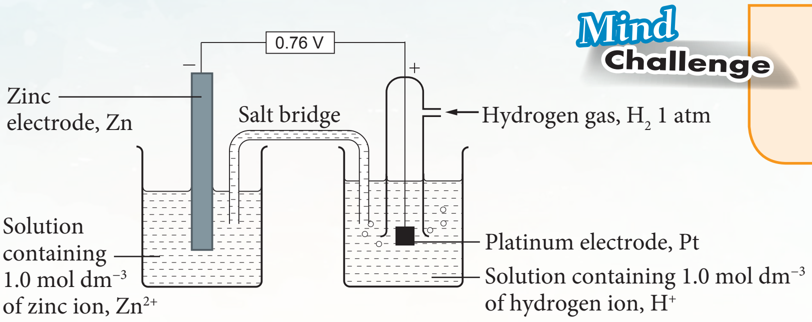


Figure 1.15 Apparatus set-up to determine standard electrode potential, E^0 of zinc

Mind Challenge

The salt bridge contains a saturated solution of potassium nitrate. What is the function of a salt bridge?

Chemistry Portal

Standard Electrode Potential
https://bit.ly/kpkt5v8

- Since the standard hydrogen potential is 0.00 V, the voltmeter reading of 0.76 V shows the electrode potential of zinc. Zinc, Zn has a greater tendency to release electrons compared to hydrogen. Hence, zinc, Zn becomes the negative terminal. Electrons move from zinc electrode, Zn (negative terminal) to platinum electrode, Pt (positive terminal) through the connecting wires.

- Half equation at the negative terminal (oxidation reaction)

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

- Half equation at the positive terminal (reduction reaction)

$$2H^+(aq) + 2e^- \rightarrow H_2(g)$$

- A standard electrode potential for zinc half-cell is written as reduction.

$$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s) \quad E^0 = -0.76\ V$$

- The negative symbol shows that zinc electrode is the negative terminal when connected to the standard hydrogen electrode.

Oxidising Agents and Reducing Agents Based on the Value of Standard Electrode Potential

- Table 1.6 shows a part of the standard electrode potential series of half-cells that are arranged in an ascending order of the standard electrode potential value from the most negative to the most positive.
- The standard electrode potential, E^0 is also known as the standard reduction potential. All half-cell equations are written as reduction.
- E^0 value is a measure of the tendency of a substance to accept or donate electrons.

$$\text{Oxidising agent} + \text{electron} \rightleftharpoons \text{Reducing agent}$$

Table 1.6 Standard electrode potential series

Strength as oxidising agents increase

Strength as reducing agents increase

Half-cell equations	E^0 / V (298 K)
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	-3.04
$K^+(aq) + e^- \rightleftharpoons K(s)$	-2.92
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	-2.87
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	-2.71
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	-2.38
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	-1.66
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	-0.76
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	-0.44
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	-0.25
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	-0.14
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	-0.13
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.07
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.52
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$S_2O_8^{2-}(aq) + 2e^- \rightleftharpoons 2SO_4^{2-}(aq)$	+2.01
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87

- Based on Table 1.6, a comparison of standard electrode potential, E^0 value is used to determine whether silver, Ag or magnesium, Mg is an oxidising agent or reducing agent.

E^0 value of Ag^+ ion is more positive,
- Silver ion, Ag^+ on the left side is a stronger oxidising agent.
- It is easier for Ag^+ ion to receive electrons and undergo reduction.
- Conversely, silver atom, Ag on the right side is difficult to release electrons.

E^0 value of Mg is more negative,
- Magnesium atom, Mg on the right side is a stronger reducing agent.
- It is easier for magnesium atom, Mg to release electrons and undergo oxidation.
- Conversely, magnesium ion, Mg^{2+} on the left side is difficult to accept electrons.

- To summarise, the value of E^0 can be used to determine the substance that will undergo oxidation or reduction, along with the strength of the oxidising agents or reducing agents as shown in Figure 1.16.

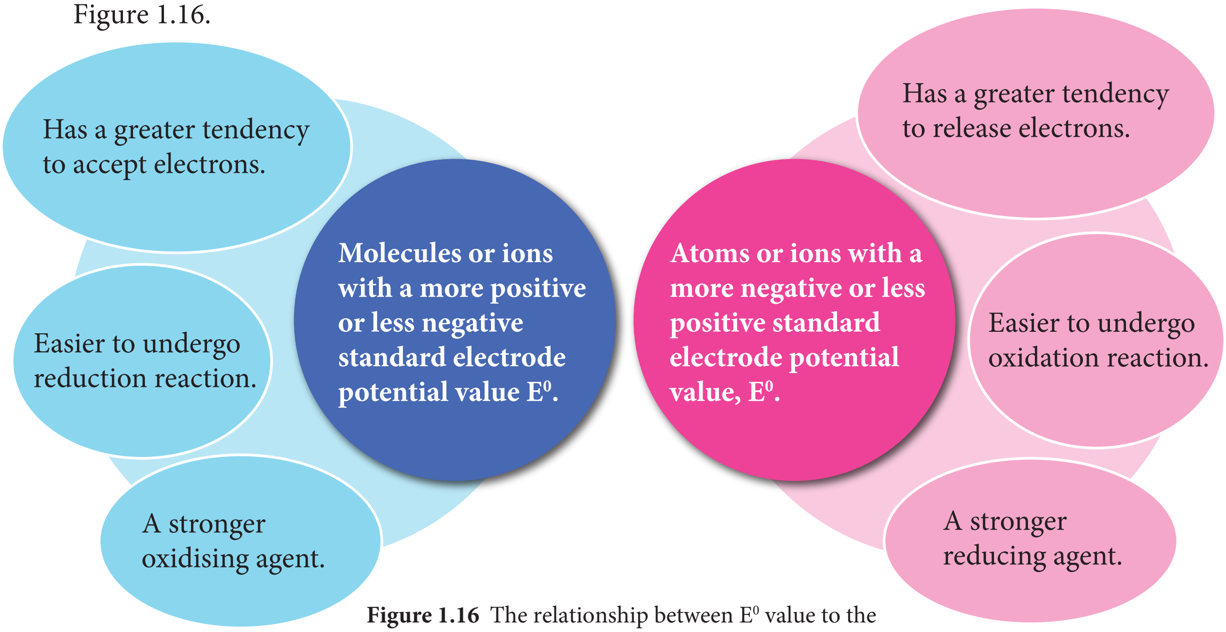


Figure 1.16 The relationship between E^0 value to the strength of a substance as an oxidizing agent and a reducing agent

- By referring to the standard electrode potential value in Table 1.6, how do you identify the oxidising agent and reducing agent in Photographs 1.4 (a) and 1.4 (b)?

Copper wire, Cu in silver nitrate, $AgNO_3$ solution

Photograph 1.4(a)
(**Source:** Quora.com, 2018)

Does a reaction occur between copper, Cu and silver nitrate, $AgNO_3$?

(i) The standard electrode potential value, E^0 is arranged from the most negative to the most positive.

$Cu^{2+} + 2e^- \rightleftharpoons Cu \qquad E^0 = +0.34\ V$

$Ag^+ + e^- \rightleftharpoons Ag \qquad E^0 = +0.80\ V$

(ii) **E^0 value of Cu is more negative or less positive** than E^0 of Ag:
  - Copper, Cu is a stronger reducing agent compared to silver, Ag.
  - Therefore, copper atom, Cu has a greater tendency to release electrons to form copper(II) ions, Cu^{2+}.
  - Copper, Cu undergoes oxidation reaction.

(iii) **The E^0 value of Ag^+ ion is more positive** than E^0 of Cu^{2+} ion:
  - The silver ion, Ag^+ is a stronger oxidising agent than copper(II) ions, Cu^{2+}.
  - Therefore, silver ion, Ag^+ has a greater tendency to receive electrons to form silver atom, Ag.
  - Silver ion, Ag^+ undergoes reduction.

Copper, Cu can displace silver, Ag from silver nitrate, $AgNO_3$ solution because copper, Cu is a stronger reducing agent compared to silver, Ag.
Displacement reaction equation:

$$Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

Copper wire, Cu in magnesium nitrate, $Mg(NO_3)_2$ solution

Photograph 1.4(b)
(**Source:** Quora.com, 2018)

Does a reaction between copper, Cu and magnesium nitrate, $Mg(NO_3)_2$ take place?

(i) The standard electrode potential value, E^0 is arranged from the most negative to the most positive.

$Mg^{2+} + 2e^- \rightleftharpoons Mg \quad E^0 = -2.38\ V$

$Cu^{2+} + 2e^- \rightleftharpoons Cu \quad E^0 = +0.34\ V$

(ii) **The E^0 value of Cu is more positive** than E^0 of Mg:
- Copper, Cu is a weaker reducing agent than magnesium, Mg.
- Therefore, copper atom, Cu has a lower tendency to release electrons to form copper(II) ion, Cu^{2+}.
- Copper, Cu does not undergo oxidation.

(iii) **The E^0 value of Mg^{2+} ion is more negative** than E^0 of Cu^{2+} ion:
- Magnesium ion, Mg^{2+} is a weaker oxidising agent than copper(II) ions, Cu^{2+}.
- Therefore, magnesium ions, Mg^{2+} are difficult to receive electrons to form magnesium atom, Mg.
- Magnesium ion, Mg^{2+} does not undergo reduction.

Copper, Cu cannot displace magnesium, Mg from magnesium nitrate, $Mg(NO_3)_2$ solution because copper, Cu is a weaker reducing agent compared to magnesium, Mg.

The displacement reaction does not occur.

ACTIVITY 1F

PAK21

Carry out a Think-Pair-Share activity.

1. Refer to page 24 for the standard electrode potential cell value, E^0.
2. Discuss with your friends whether the following reactions occur:
   (a) $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6Cl^-(aq) \rightarrow 2Cr^{3+}(aq) + 3Cl_2(g) + 7H_2O(l)$
   (b) $H_2O_2(aq) + 2Br^-(aq) + 2H^+(aq) \rightarrow Br_2(aq) + 2H_2O(l)$
3. Present the results of your discussion in class.

Self Assess 1.2

1. Table 1.7 shows the standard electrode potential values of half-cells for some metals.

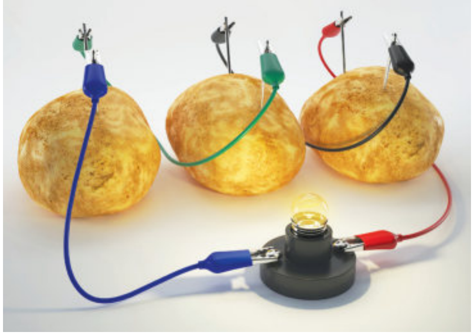
Table 1.7

$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	$E^0 = +0.34\ V$
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	$E^0 = -2.38\ V$
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	$E^0 = +0.80\ V$
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	$E^0 = -0.76\ V$

(a) Arrange the atoms or ions in Table 1.7 in an ascending order of the strength of oxidising agents and reducing agents.

(b) Based on your answer in (a), explain if the reaction will occur for the following reactants:
   (i) $Mg(s) + Cu^{2+}(aq)$.
   (ii) $Mg(s) + Zn^{2+}(aq)$.
   (iii) $Cu(s) + Zn^{2+}(aq)$.

1.3 VOLTAIC CELL



Photograph 1.5 Voltaic cell from potatoes as a source of electricity

- Do you know that when two different pieces of metals are inserted into potatoes, an electrical energy is generated?

Learning Standards

Pupils are able to:

1.3.1 explain redox reaction in voltaic cell through experiment.

Topic Link

Redox: Electrolyte and non-electrolyte on page 31.

What is a simple chemical cell?

- Two different metal plates are dipped into an electrolyte and connected with connecting wires.
- Also known as voltaic cell or galvanic cell.
- Converts chemical energy to electrical energy.
- A redox reaction occurs in the cell that causes the flow of electrons. The potential difference detected by the voltmeter indicates the presence of electrical current.

Redox Reaction in a Voltaic Cell

- Figure 1.17 shows an example of a simple chemical cell for a pair of Mg/Cu metals.
- The E^0 value of magnesium is more negative, therefore, magnesium becomes the negative terminal.
- The reaction that occurs at the negative terminal is oxidation.
- The E^0 value of copper, Cu is more positive; therefore, copper, Cu becomes the positive terminal.
- The reaction at the positive terminal is reduction reaction.

Negative terminal: $Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$

Positive terminal: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

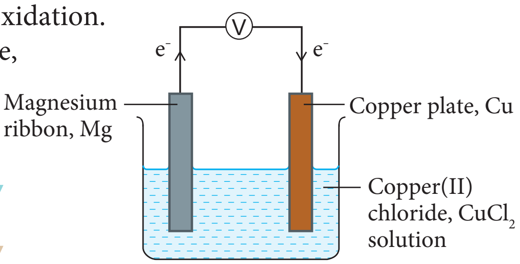
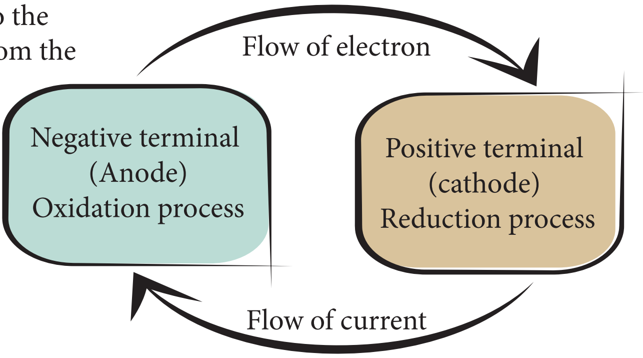


Figure 1.17 Example of a simple chemical cell

- Electrons flow from the negative terminal to the positive terminal; while the current flows from the positive terminal to the negative terminal.
- Anode are electrodes where oxidation occurs. In a voltaic cell, the negative terminal is also known as anode.
- Cathodes are electrodes where reduction occurs. In a voltaic cell, the positive terminal is also known as cathode.



- A chemical cell can also be constructed by combining two half-cells with different E^0 values.
- A Daniell cell is an example of a voltaic cell where zinc, Zn metal and copper, Cu metal are used as electrodes, which are then dipped into their respective ionic salt solutions.
- Both salt solutions are connected by a salt bridge or separated by a porous pot. What is the function of the salt bridge or the porous pot?
- Figure 1.18 (a) shows a Daniell cell that uses a salt bridge and Figure 1.18 (b) shows a Daniell cell that uses a porous pot.

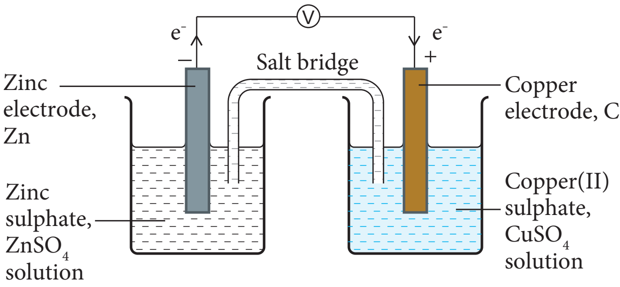


Figure 1.18(a) A Daniell cell that uses a salt bridge

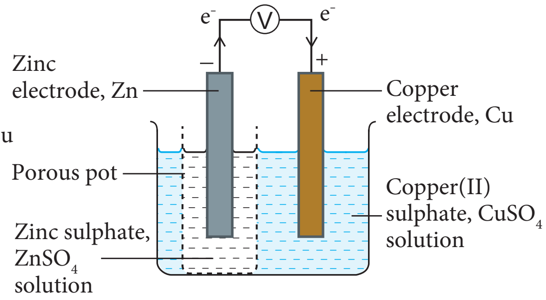


Figure 1.18(b) A Daniell cell that uses a porous pot

It is found that in a Daniell cell:

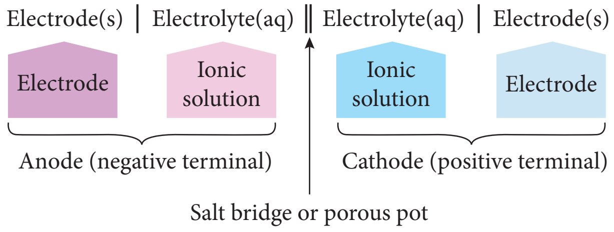
- the E^0 for two half-cells are:

$$\begin{array}{lll} Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s) & & E^0 = -\,0.76\ V \\ Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) & & E^0 = +\,0.34\ V \end{array}$$

- zinc, Zn with a more negative E^0 value is the negative terminal (anode). Copper, Cu with a more positive E^0 value is the positive terminal (cathode).
- the reactions that take place are:

Zinc electrode (anode)	:	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ (Oxidation reaction)
Copper electrode (cathode)	:	$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ (Reduction reaction)
Overall ionic equation	:	$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

- electrons flow from zinc electrode, Zn to copper electrode, Cu through a connecting wire.
- the voltaic cell can be written in the form of cell notation. Anode is written on the left side of the cell notation and cathode on the right side.



Chemistry Portal

Cell Notation
https://bit.ly/kpkt5v10

- Cell notation for a Daniell cell:

$$\underbrace{\text{Zn(s)} \mid \text{Zn}^{2+}\text{(aq, 1.0 mol dm}^{-3})}_{\text{Anode (negative terminal)}} \parallel \underbrace{\text{Cu}^{2+}\text{(aq, 1.0 mol dm}^{-3}) \mid \text{Cu(s)}}_{\text{Cathode (positive terminal)}}$$

- The voltage reading, E^0_{cell} for the Daniell cell:

$$E^0_{cell} = E^0_{(cathode)} - E^0_{(anode)}$$

$$E^0_{cell} = (+0.34) - (-0.76) = +1.10 \text{ V}$$

The cell voltage, E^0_{cell} can be determined by using the following formula:

$$E^0_{cell} = E^0_{(positive\ terminal)} - E^0_{(negative\ terminal)}$$

$$E^0_{cell} = E^0_{(cathode)} - E^0_{(anode)}$$

Experiment 1A Determining the Voltage of a Voltaic Cell

PAK21 Learning Science Through Inquiry

Aim: To determine the voltage of a voltaic cell by using different pairs of metals.

Problem statement: How can different pairs of metals dipped into electrolytes affect the voltage of the voltaic cell?

Hypothesis: The pairs of metals with greater difference of standard electrode potential value will produce greater voltage readings.

Variables:

(a) Manipulated variables : Different pairs of metals.
(b) Responding variables : The voltage reading of the cell.
(c) Fixed variables : Volume and concentration of electrolytes.

Operational definition – Chemical cell: Voltmeter readings show electric current is produced when different types of pairs of metals are dipped into electrolytes.

Materials: State a list of different metal plates and suitable salt solutions with a concentration of 1.0 mol dm^{-3}.

Apparatus: Sandpaper, voltmeter and connecting wire with crocodile clips and state a suitable apparatus to construct a chemical cell.

Procedure:

1. Using the provided metal plates and salt solutions, plan an experiment to construct a simple chemical cell or a chemical cell that combines two half-cells.
2. Draw a labelled diagram of a simple chemical cell or a chemical cell that combines two half-cells to carry out this experiment.
3. Write the investigation steps clearly.
4. Record all observations.

Results:

Record all observations in the following table.

Pair of metals	Voltage (V)	Negative terminal(anode)	Positive terminal (cathode)

Discussion:

For each set of the experiment:

1. write the half equation for oxidation reaction, half equation for reduction reaction and the overall ionic equation.
2. write the cell notations for the voltaic cells.
3. calculate the theoretical voltage of the cells using the standard electrode potential value of the half-cells.
4. deduce the relationship between the pair of metals and the voltage of the cells.

Prepare a complete report after carrying out this experiment.

ACTIVITY 1G

PAK 21

Carry out this activity collaboratively in groups.

1. Figure 1.19 shows an apparatus set-up for a voltaic cell.

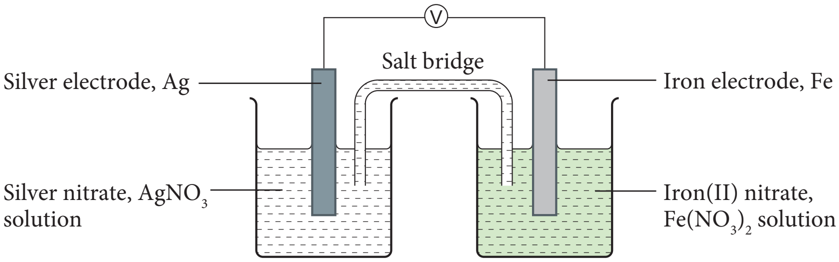


Figure 1.19

(a) Based on Figure 1.19, and referring to the standard electrode potential of a half-cell:
    (i) identify the negative and positive terminals.
    (ii) write the cell notation for the voltaic cell.
    (iii) write the half equations for oxidation reaction, reduction reaction and the overall ionic equation.
    (iv) calculate the voltage of the cell.

Present your group's results to your friends.

SelfAssess 1.3

1. Write the cell notation for the following voltaic cells:
    (a) Sn^{2+} / Sn and Mg^{2+}/Mg.
    (b) Cl_2 / Cl^- and MnO_4^-/Mn^{2+}.
2. Calculate the voltage for the following cells:
    (a) $Ni(s) \mid Ni^{2+}(aq) \parallel Pb^{2+}(aq) \mid Pb(s)$.
    (b) $Pt(s) \mid I^-(aq), I_2(aq) \parallel Ag^+(aq) \mid Ag(s)$.
    (c) $Pt(s) \mid Fe^{2+}(aq), Fe^{3+}(aq) \parallel Ag^+(aq) \mid Ag(s)$.
    (d) $Pt(s) \mid Br^-(aq), Br_2(aq) \parallel Cl_2(aq), Cl^-(aq) \mid Pt(s)$.

1.4 ELECTROLYTIC CELL

Learning Standards

Pupils are able to:

1.4.1 describe electrolysis
1.4.2 describe electrolysis of molten compound through activities.
1.4.3 explain factors that affect electrolysis of aqueous solution through experiment.
1.4.4 compare voltaic cell and electrolytic cell.
1.4.5 describe electroplating and purification of metal by electrolysis through activities.

Electrolysis

Electrolyte and Non-Electrolyte

Photograph 1.6
Michael Faraday

- In 1834, Michael Faraday, an English scientist presented the Faraday Law. He named the chemical substances that can conduct electricity as electrolytes and the ones that cannot conduct electricity as non-electrolytes.

Topic Link **Form 4 Chemistry:** Ionic and covalent compounds.

Electrolytes are substances that can conduct electricity in either the molten state or aqueous solution and undergo chemical changes.

Non-electrolytes are substances that cannot conduct electricity in all states.

- Figure 1.20 shows a tree map classification of substances into electrolytes and non-electrolytes.

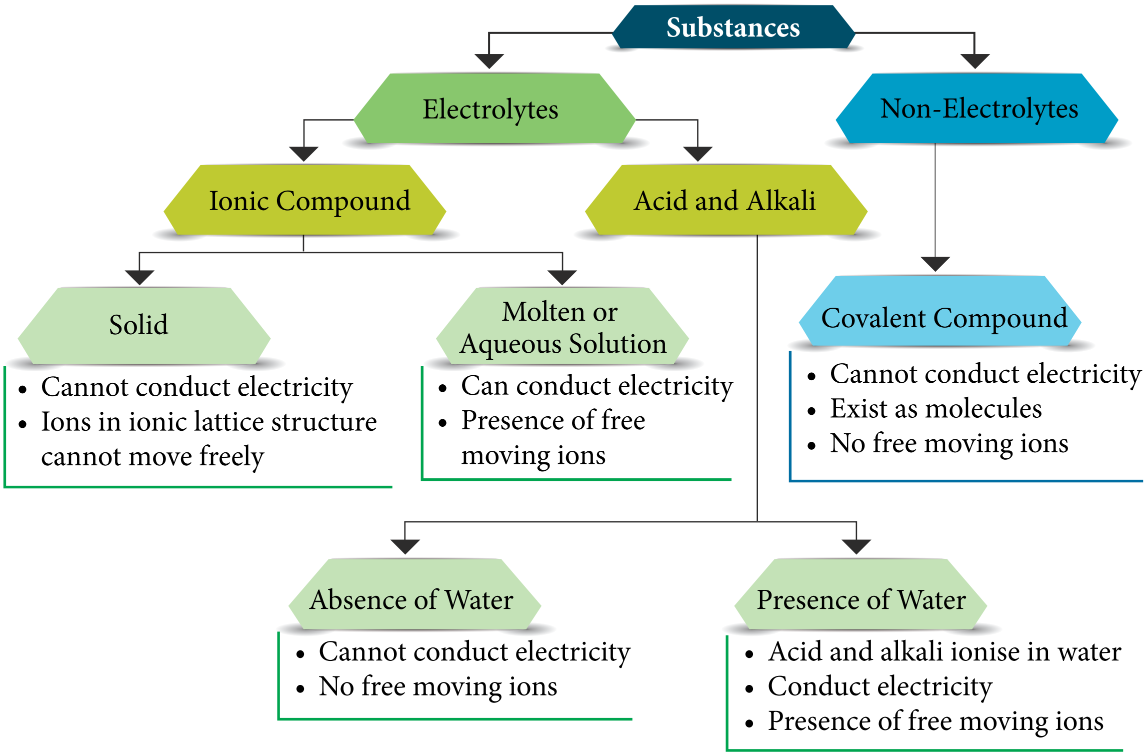


Figure 1.20 The relationship between electrical conductivity and presence of free moving ions

- Can you identify the electrolyte substance and the non-electrolyte substance? Try to recall the electrical conductivity of ionic compound and covalent compound learned in form four.
- Lead(II) bromide, $PbBr_2$ and sodium chloride, NaCl are examples of electrolytes and are ionic compounds while acetamide, CH_3CONH_2 and glucose, $C_6H_{12}O_6$ are examples of non-electrolytes and are covalent compounds.
- Molten lead(II) bromide, $PbBr_2$ and sodium chloride, NaCl solution can conduct electricity because there are ions that move freely. These ions carry charges. Figure 1.21 shows the electrolytes in the molten state and an aqueous solution containing ions that move freely.
- Acetamide, CH_3CONH_2 and glucose, $C_6H_{12}O_6$ cannot conduct electricity in the molten state or aqueous solution because they exist as molecules and there are no free moving ions. Therefore, there are no ions to carry any charges.

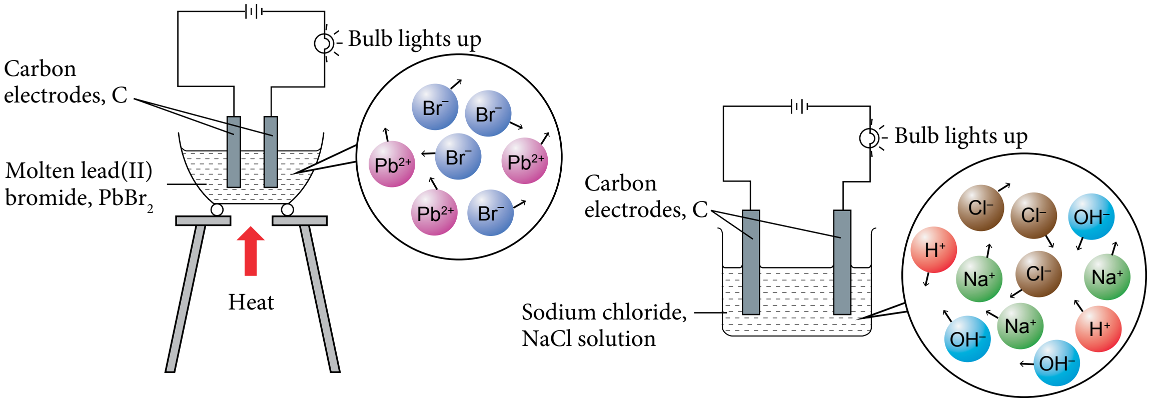


Figure 1.21 Electrolytes can conduct electricity due to the presence of ions that move freely

Topic Link

Form 4 Chemistry:
Metallic bond.

Comparison Between Conductors and Electrolytes

- Table 1.8 shows the differences between conductors and electrolytes.

Table 1.8 Differences between conductors and electrolytes

Conductor	Electrolyte
Substances that conduct electricity in solid or molten state, but do not undergo chemical changes.	Substances that conduct electricity in molten state or aqueous solution, and undergo chemical changes.
Substances that conduct electricity without undergoing decomposition.	Substances that conduct electricity and undergo decomposition into their constituent elements.
Can conduct electricity due to the presence of electrons that move freely.	Can conduct electricity due to the presence of ions that move freely.
Electrical conductivity decreases as temperature increases.	Electrical conductivity increases as temperature increases.
Examples of conductors are metals and graphite.	Examples of electrolytes are ionic compounds, acids and alkalis.

Topic Link **Form 4 Chemistry:**
Ionic compound and covalent compound.

Chemistry Portal

Comparison Between Conductors and Electrolytes
https://bit.ly/kpkt5v12

ACTIVITY 1H

PAK 21 Learning Science Through Inquiry

Compounds can be classified into electrolytes and non-electrolytes.

How do you prove a substance is an electrolyte or non-electrolyte?

1. Carry out this activity in pairs.
2. Each group will choose one substance X to be investigated. Substance X provided are as follows:
   (a) Solid copper(II) chloride, $CuCl_2$
   (b) Solid glucose, $C_6H_{12}O_6$
   (c) Solid oxalic acid, $C_2H_2O_4$
   (d) Aqueous ammonia, NH_3
   (e) Liquid hexane, C_6H_{14}
   (f) Liquid ethanol, C_2H_5OH
3. By taking into consideration the safety factors and properties of substance X, you can use the set-up of apparatus in Figure 1.22 or Figure 1.23 to determine the electrical conductivity of substance X.

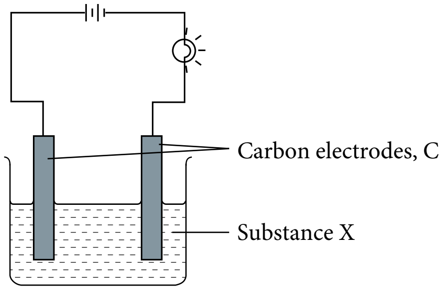


Figure 1.22

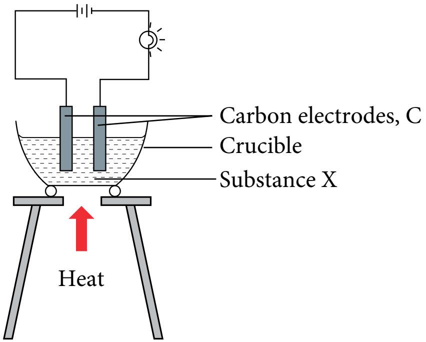


Figure 1.23

4. Get your teacher's consent to carry out the activity. The chosen set-up of apparatus must be suitable for substance X to be investigated.
5. Prepare a brief presentation on the activity that you have carried out by including the following information:
   (a) Observations on whether the bulb lights up or not.
   (b) Inference from your observation.
   (c) Conclusion on the chosen substance whether it is an electrolyte or non-electrolyte.
6. Present your findings to your classmates.

Electrolysis of Molten Compounds

Electrolysis is a process whereby compounds in the molten state or an aqueous solution decompose into their constituent elements by passing electricity through them.

- When an electric current is passed through an electrolyte, the ions move freely. Anions (negative ions) move to the anode, and the cations (positive ions) move to the cathode. What is meant by anode and cathode? During the electrolysis process, redox reactions occur at the anode and cathode.

Laboratory Activity IE Electrolysis of Molten Lead(II) Bromide, $PbBr_2$

PAK21 Learning Science Through Inquiry

Aim: To study the electrolysis of molten lead(II) bromide, $PbBr_2$.

Material: Lead(II) bromide powder, $PbBr_2$.

Apparatus: Beaker, crucible, light bulb, battery, carbon electrodes, connecting wire with crocodile clip, switch, tripod stand, pipe clay triangle and Bunsen burner.

Procedure:

1. Fill a crucible with lead(II) bromide powder, $PbBr_2$ until half full.
2. Place the crucible on top of the pipe clay triangle at the tripod stand.
3. Connect the carbon electrodes to the battery, light bulb and switch using the connecting wires as shown in Figure 1.24.
4. Heat the lead(II) bromide powder, $PbBr_2$ until it melts.
5. Dip the carbon electrodes, C into the molten lead(II) bromide, $PbBr_2$ and turn on the switch to complete the circuit.
6. Observe and record any changes that occur at the anode.
7. After 5 minutes, turn off the switch and carefully pour the molten lead(II) bromide, $PbBr_2$ into a beaker.
8. Observe the substances that are formed at the cathode and anode and record your observation.

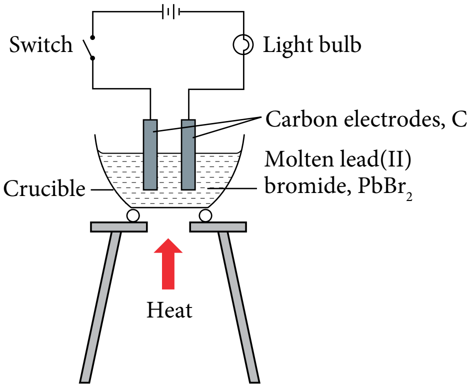


Figure 1.24

CAUTION

The brown gas released is bromine gas and is poisonous.

Results:

Record all observations in the following table.

Electrode	Observation	Inference
Anode		
Cathode		

Discussion:

1. State the name of the ions that move to the cathode and anode during electrolysis.

2. Write the half equations for the reactions at the:
    (a) cathode.
    (b) anode.
3. Identify the products formed at the cathode and anode.
4. Explain how the products at the cathode and anode are formed.
5. Write the overall ionic equation that represents the electrolysis of molten lead(II) bromide, $PbBr_2$.

Prepare a complete report after carrying out this laboratory activity.

Do you know

Carbon and platinum electrodes are inert electrodes.

Chemistry Portal

Electrolysis of Lead(II) Bromide
https://bit.ly/kpkt5v11

- During electrolysis, why does the bulb light up when lead(II) bromide, $PbBr_2$ has melted? Lead(II) bromide, $PbBr_2$ is an ionic compound consisting of lead(II) ions, Pb^{2+} and bromide ions, Br^-.
- Solid lead(II) bromide, $PbBr_2$ cannot conduct electricity because the lead(II) ions, Pb^{2+} and bromide ions, Br^- are fixed in lattice ion structure and cannot move freely.
- When lead(II) bromide, $PbBr_2$ melts, lead(II) ions, Pb^{2+} and bromide ions, Br^- can move freely as shown in Figure 1.25.
- The observations of and inferences from the electrolysis of molten lead(II) bromide, $PbBr_2$ in Table 1.9 can be explained by using a flow chart in Figure 1.26.

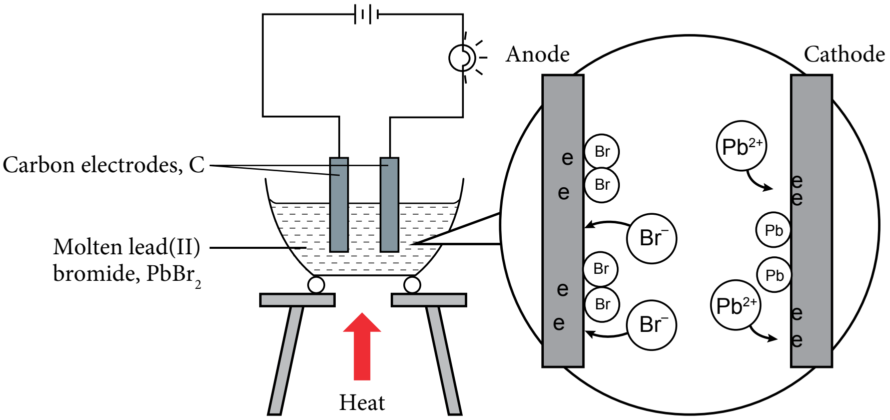


Figure 1.25 Lead(II) ions, Pb^{2+} move to the cathode and bromide ions, Br^- move to the anode

Table 1.9

Observation	Inference
• Brown gas is released at the anode • Grey solid is formed at the cathode	• Bromine gas is produced • Lead metal, Pb is formed

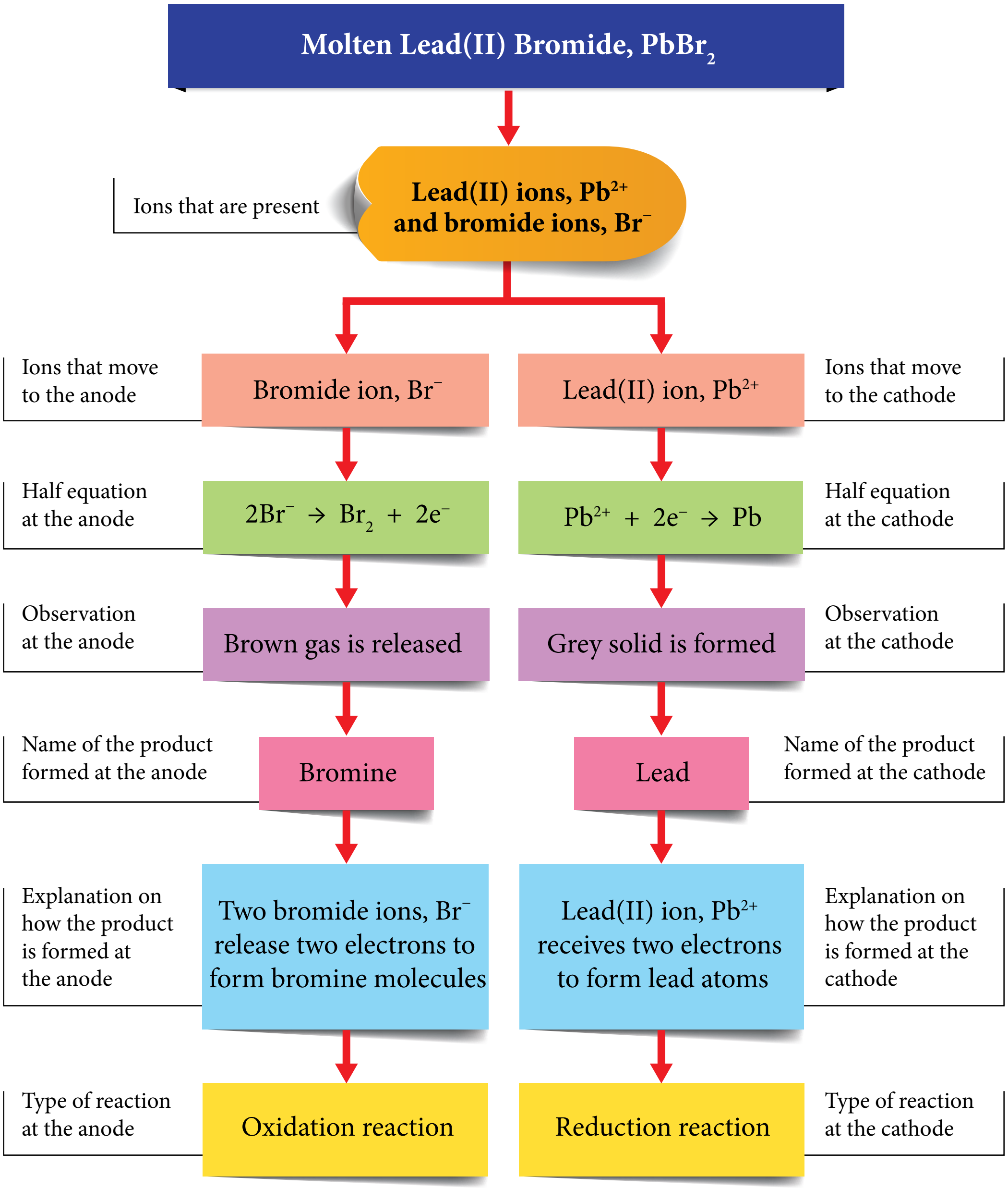


Figure 1.26 Flow chart for the electrolysis of molten lead(II) bromide, $PbBr_2$

ACTIVITY 1I

PAK21

1. Using a suitable thinking map, predict the observation and explain how the products of electrolysis are formed at the anode and cathode for:
   (a) molten zinc oxide, ZnO.
   (b) molten magnesium chloride, $MgCl_2$.
2. Present your answers by carrying out a Gallery Walk activity.

Factors that Affect the Electrolysis of an Aqueous Solution

- Electrolysis also occurs when an electric current flows through an aqueous solution. In the aqueous solution, apart from the ions of the solute, the hydrogen ions, H^+ and hydroxide ions, OH^- from the partial dissociation of water are also present. How do we determine the formation of products at the anode and at the cathode?
- There are three factors that affect the formation of products at the electrodes for the electrolysis of an aqueous solution, which are:

E^0 Value

Concentration of solution

Type of electrode used

Factors that affect the formation of products in electrolysis	Electrode	Ion chosen to be discharged
E^0 Value	Anode	Anions with a more negative or less positive E^0 value in the standard electrode potential series will be easier to be discharged and oxidised.
	Cathode	Cations with a more positive or less negative E^0 value in the standard electrode potential series will be easier to be discharged and reduced.
Concentration of solution	Anode	(i) This factor is only considered for the selection of ions at the anode if the aqueous solution contains halide ions. (ii) Halide ions with a higher concentration in the electrolytes will be discharged and oxidised at the anode, even though the E^0 value of the halide ions are more positive.
	Cathode	Cations with a more positive or less negative E^0 value in the standard electrode potential series will be easier to be discharged and reduced.
Type of electrode	Anode	(i) This factor is only considered for active electrodes (e.g. copper or silver). (ii) No anions are discharged. (iii) Metal atoms at the anode release electrons to form metal ions.
	Cathode	Cations with a more positive or less negative E^0 value in the standard electrode potential series will be easier to be discharged and reduced.

- For electrolysis of an aqueous solution, water also takes part in the electrolysis process.
- The equation for water dissociation is as follows:

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

- During electrolysis, cations and hydrogen ions, H^+ move to the cathode, while anions and hydroxide ions, OH^- move to the anode.

INFO

- Since the concentration of H^+ ions and OH^- ions from water dissociation is very low, water molecules, H_2O are oxidised or reduced. At the anode, water molecules, H_2O are oxidised and oxygen gas, O_2 is released, while at the cathode, water molecules, H_2O are also reduced and hydrogen gas, H_2 is released.
- Further explanation about oxidation and reduction involving water molecules, H_2O will be learnt at higher level (postsecondary).

Laboratory Activity 1F Electrolysis of an Aqueous Solution Using Carbon Electrodes

PAK21 Learning Science Through Inquiry

Aim: To study the electrolysis of the aqueous solution of copper(II) sulphate, $CuSO_4$ and dilute sulphuric acid, H_2SO_4 with carbon electrodes.

Materials: 0.1 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution and 0.1 mol dm^{-3} of sulphuric acid, H_2SO_4

Apparatus: Electrolytic cell, battery, carbon electrodes, connecting wire with crocodile clip, switch, ammeter, test tubes and wooden splinter.

Procedure:

1. Pour the 0.1 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution into the electrolytic cell until half full.
2. Fill two test tubes with 0.1 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution until full and invert them on top of the carbon electrodes in the electrolytic cell.
3. Connect the carbon electrodes to the switch, ammeter and battery with the connecting wires to complete the circuit as shown in Figure 1.27.
4. Turn the switch on for a few minutes.
5. Observe and record any changes at the anode and cathode.
6. Carry out the confirmatory tests on the collected gases.
   (a) Insert a glowing wooden splinter into the test tube at the anode.
   (b) Place a burning wooden splinter into the test tube at the cathode.
7. Repeat steps 1 to 6 using 0.1 mol dm^{-3} of sulphuric acid, H_2SO_4.
8. Record your observations.

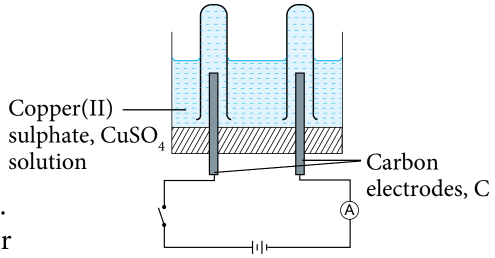


Figure 1.27

Results:

Construct a table to record your observations.

Discussion:

1. State the ions present in the aqueous solution of:
   (a) Copper(II) sulphate, $CuSO_4$ solution. (b) Sulphuric acid, H_2SO_4.
2. For each of the copper(II) sulphate, $CuSO_4$ solution and sulphuric acid, H_2SO_4:
   (a) name the ions that move to the cathode and anode during electrolysis.
   (b) identify the ions discharged at the cathode and anode. Give a reason for your answer.
   (c) name the products formed at the cathode and anode.
   (d) write the half equations of the reactions that take place at the cathode and anode.
   (e) explain how the products at the cathode and anode are formed.
   (f) write the overall ionic equation that represents electrolysis.

Prepare a complete report after carrying out this laboratory activity.

- Figure 1.28 shows the anions that move to the anode and the cations that move to the cathode during the electrolysis of copper(II) sulphate, $CuSO_4$ solution using carbon electrodes.

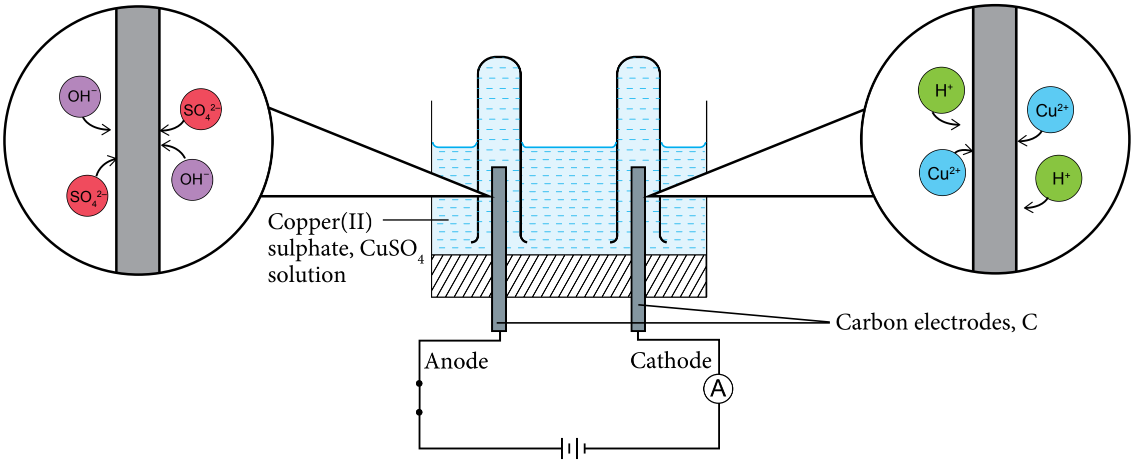


Figure 1.28 Hydroxide ion, OH^- and sulphate ion, SO_4^{2-} move to the anode and coppper(II) ion, Cu^{2+} and hydrogen ion, H^+ move to the cathode

- Table 1.10 shows the observation and inference, a few minutes after the electrolysis of copper(II) sulphate, $CuSO_4$ solution.

Table 1.10

Observation	Inference
• Colourless gas bubbles are released at the anode • Brown solid is deposited at the cathode	• Oxygen gas, O_2 is produced • Copper metal, Cu is formed

- The standard electrode potential value, E^0 of an anion and cation will determine the reactions that take place at the electrodes.

Anode

Half-cell standard electrode potential	E^0 (V)
$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01

- The value of E^0 for OH^- ions is less positive than E^0 for SO_4^{2-} ions. Thus OH^- ions will be discharged and oxidised at the anode.

Cathode

Half-cell standard electrode potential	E^0 (V)
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34

- The value of E^0 for Cu^{2+} ion is more positive than E^0 for H^+ ions. Thus the Cu^{2+} ions will be discharged and reduced at the cathode.

- How do we use the standard electrode potential value, E^0 to determine the results at the anode and cathode?

Chemistry Portal

Electrolysis of Aqueous Solution
https://bit.ly/kpkt5v13

Half Equation at the Anode and Cathode
https://bit.ly/kpkt5v14

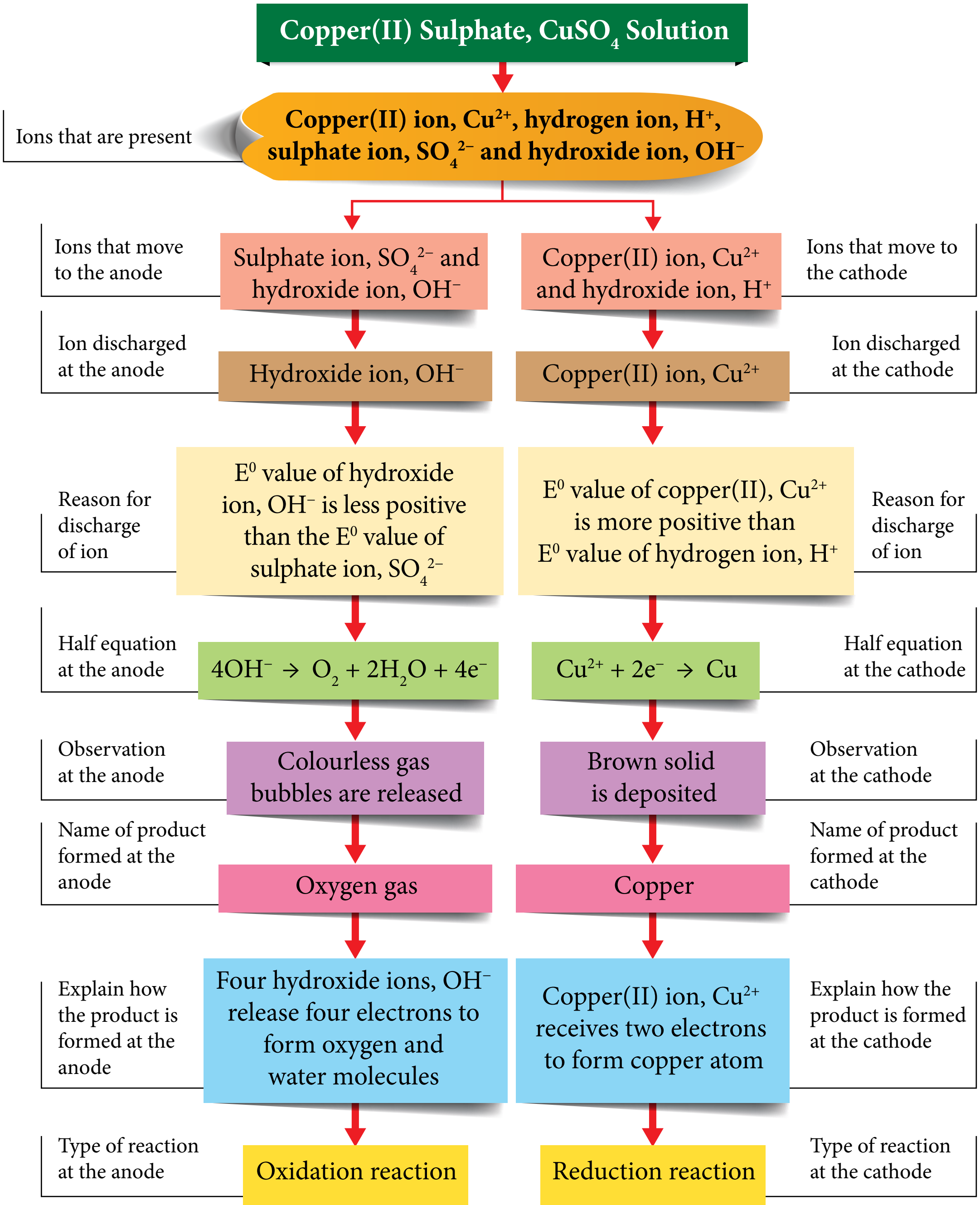


Figure 1.29 Flow chart of the electrolysis of copper(II) sulphate, $CuSO_4$ solution

- In the electrolysis of aqueous solution of copper(II) sulphate, $CuSO_4$:
  (i) copper(II) ions, Cu^{2+} are selected to be discharged and reduced at the cathode because the E^0 value of copper(II) ions, Cu^{2+} is more positive than the E^0 of hydrogen ion, H^+.
  (ii) hydroxide ions, OH^- are selected to be discharged and oxidised at the anode because the E^0 value of hydroxide ion, OH^- is less positive than the E^0 of sulphate ion, SO_4^{2-}.
- Explain the formation of products at the cathode and anode for the electrolysis of sulphuric acid, H_2SO_4 based on the results of the experiment in Laboratory Activity 1F using a flow chart as shown in Figure 1.29.

- Do the ions selected to be discharged in the electrolysis of dilute hydrochloric acid, HCl depend on the value of E^0? Do the types of electrodes affect the products of electrolysis?

Experiment 1B The Effects of Concentrations of Ions in Solutions on the Selective Discharge of Ions

PAK21 Learning Science Through Inquiry

Aim: To study the effects of the concentrations of ions in hydrochloric acid, HCl on the selective discharge of ions at the electrodes.

Problem statement: Does the concentration of hydrochloric acid, HCl affect the selection of ions to be discharged at the anode?

Hypothesis: When 1.0 mol dm^{-3} of hydrochloric acid, HCl is used, chloride ions, Cl^- are discharged at the anode; when 0.0001 mol dm^{-3} of hydrochloric acid, HCl is used, hydroxide ions, OH^- are discharged at the anode.

Variables:

(a) Manipulated variable : Concentration of hydrochloric acid, HCl.
(b) Responding variable : Ions discharged at the anode.
(c) Fixed variable : Hydrochloric acid, HCl and carbon electrodes.

Materials: 1.0 mol dm^{-3} of hydrochloric acid, HCl and 0.0001 mol dm^{-3} of hydrochloric acid, HCl.

Apparatus: Electrolytic cell, battery, carbon electrode, connecting wires with crocodile clips, switch, ammeter, test tube, wooden splinter and blue litmus paper.

Procedure:

1. Pour 1.0 mol dm^{-3} of hydrochloric acid, HCl into the electrolytic cell until half full.
2. Fill two test tubes with 1.0 mol dm^{-3} of hydrochloric acid, HCl until full and invert the test tubes onto the carbon electrodes in the electrolytic cell.
3. Connect the electrodes to the switch, ammeter and battery with connecting wires as shown in Figure 1.30.
4. Turn on the switch to complete the circuit and leave aside for a few minutes.
5. Observe and record any changes that occur at the anode and cathode.
6. Collect the gas produced at the anode.
7. Carry out a confirmatory test on the gas collected. Insert a damp blue litmus paper into the test tube at the anode.
8. Repeat steps 1 to 6 using 0.0001 mol dm^{-3} of hydrochloric acid, HCl.
9. Carry out a confirmatory test for the gas collected. Insert a glowing wooden splinter inside the test tube at the anode.
10. Record your observations.

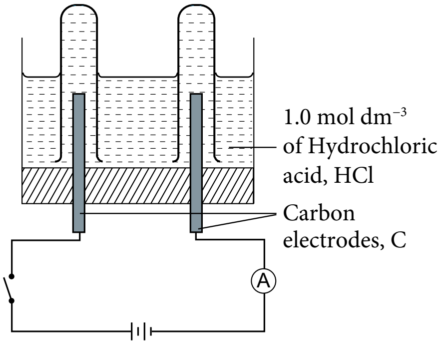


Figure 1.30

Results:

Record all observations in the table below.

Solution	Observation at the anode
1.0 mol dm^{-3} of hydrochloric acid, HCl	
0.0001 mol dm^{-3} of hydrochloric acid, HCl	

Discussion:

1. For each 1.0 mol dm^{-3} and 0.0001 mol dm^{-3} of hydrochloric acid, HCl:
   (a) name the products formed at the anode during electrolysis. Explain your answer.
   (b) write the half equations to show the formation of the products at the anode during electrolysis.
2. State the operational definition of electrolysis in this experiment.
3. After electrolysis of 1.0 mol dm^{-3} of hydrochloric acid, HCl is carried out for 1 hour, state the observation at the anode. Explain why.

Prepare a complete report after carrying out this experiment.

Experiment 1C The Effects of Type of Electrode on the Selection of Ions to be Discharged

PAK21 Learning Science Through Inquiry

Aim: To study the effects of the type of electrode used on the selective discharge of ions at the electrodes.

Problem statement: Does the type of electrode used affect the selective discharge of ions at the electrodes?

Hypothesis: Construct a hypothesis that relate the type of electrode used with the products formed at the anode.

Variables: State all variables.

Material: 0.5 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution.

Apparatus: Beaker, battery, carbon electrode, copper electrode, connecting wires with crocodile clips, switch, ammeter, test tube, wooden splinter, electronic scale and sandpaper.

Procedure:

Using the apparatus and material provided, plan an experiment to investigate the effects of the type of electrode used on the products formed at the anode.

Results:

Record all observations in a table.

Discussion:

1. Name the products formed during the electrolysis of copper(II) sulphate, $CuSO_4$ using electrode:
   (a) carbon. (b) copper.
2. Write the half equations to show the formations of products at the anode for the electrolysis of copper(II) sulphate, $CuSO_4$ solution using electrode:
   (a) carbon. (b) copper.
3. What can be observed of the colour of copper(II) sulphate, $CuSO_4$ solution when electrolysis is carried out using electrode:
   (a) carbon. (b) copper.

Explain your answer.

Prepare a complete report after carrying out this experiment.

ACTIVITY 1J

PAK21

Carry out the activity in groups.

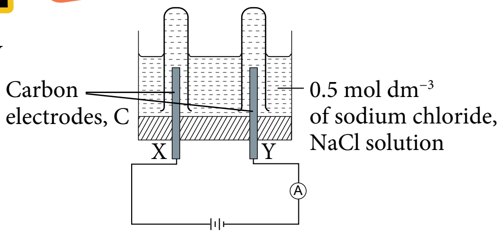


Figure 1.31(a)

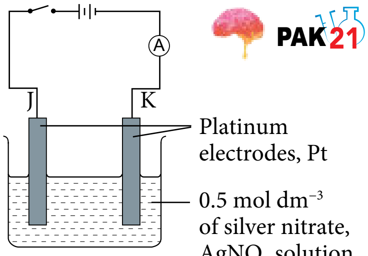


Figure 1.31(b)

1. Carefully study the electrolytic cell in Figure 1.31 (a) and Figure 1.31 (b).
2. Based on Figures 1.31 (a) and 1.31 (b), discuss:
   - (a) the products formed on each electrode.
   - (b) half equations for each electrode.
   - (c) changes in the products if the concentrations of the electrolyte is changed to 0.0001 mol dm^{-3}.
3. Present your findings to the class by using suitable i-Think maps.

Comparison Between Voltaic Cell and Electrolytic Cell

- Figure 1.32 shows a double bubble map comparing chemical cells with electrolytic cells.

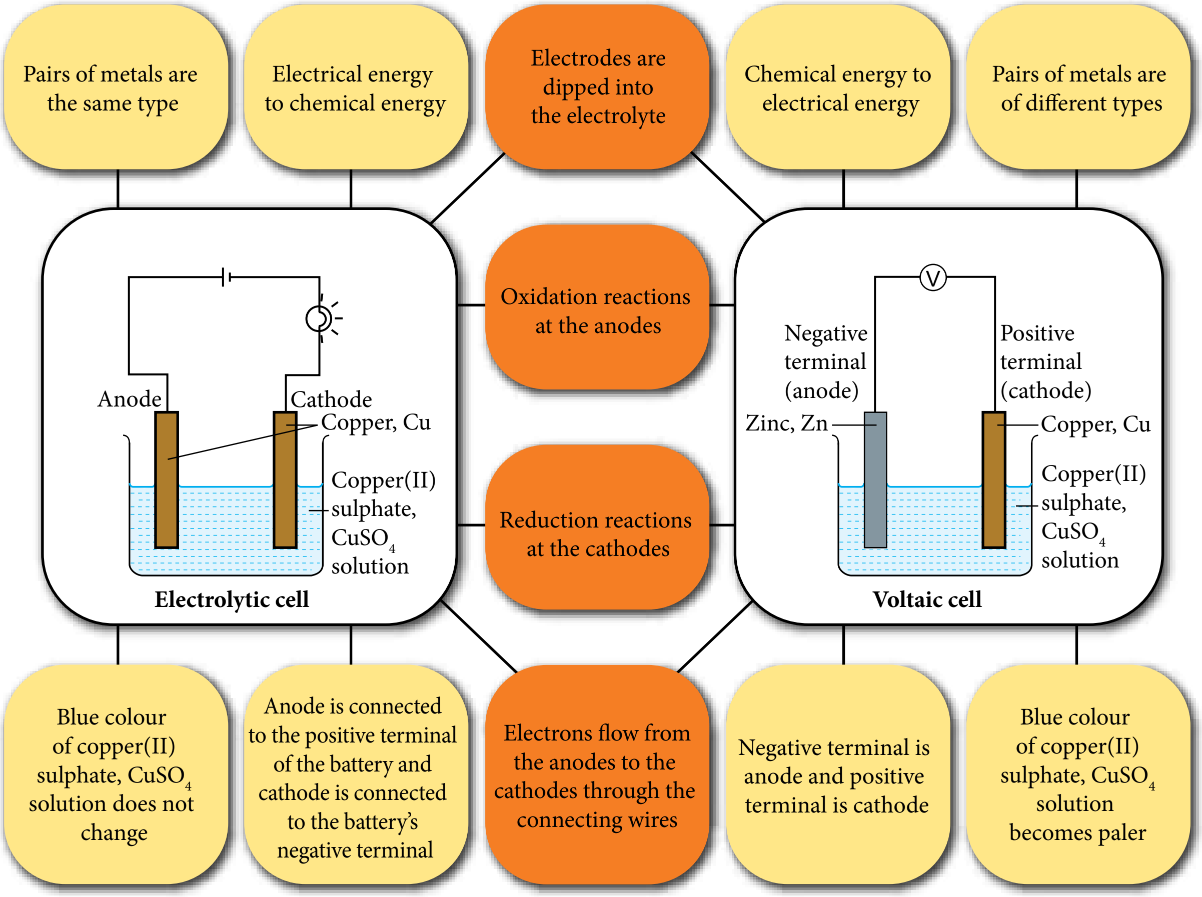


Figure 1.32 Similarities and differences between voltaic and electrolytic cells

ACTIVITY 1K

PAK 21

Carry out this activity collaboratively in groups.

1. Based on Figure 1.32, write the half equations for the reactions at the electrodes and explain the differences in observations of both cells.
2. Share your group's findings with other groups using multimedia presentations.

Electroplating and Purification of Metals

Photograph 1.7 Items electroplated with 18K gold

- Do you know that metal plating is done to make metals look more attractive and resistant to corrosion?
- The main applications of electrolysis in industries are extraction of metals, plating of metals and purification of metals.
- Purification of metals through electrolysis is intended to extract pure metals from the impure metals.

Electroplating of Metals

- Electroplating of metals through electrolysis is done by making the object being electroplated as the cathode, the electroplating metal as the anode, and an aqueous solution containing the ions of the electroplating metal as the electrolyte.
- For example, to electroplate an iron ring with copper, Cu, the copper anode ionises to become copper(II) ions, Cu^{2+}.

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

- Copper(II) ions, Cu^{2+} move to the cathode, are discharged and deposited as a thin layer of copper, Cu on the iron ring.

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

- The blue colour of copper(II) sulphate, $CuSO_4$ solution does not change because the concentration of copper(II) ions, Cu^{2+} remains the same. The rate of ionisation of copper, Cu at the anode is the same as the rate of discharged copper(II) ions, Cu^{2+} at the cathode. Can you explain the redox reactions that occur in the electroplating of metals?

Do you know

Do you know that electroplating can also be conducted on non metal objects?

(**Source:** Sirim, 2016)

Chemistry Portal

SIRIM Metal Plating Technology for Manufacturing Handicrafts
https://bit.ly/kpkt5v15

Laboratory Activity 1G Electroplating of Metals by Electrolysis

PAK 21 Learning Science Through Inquiry

Aim: To study the electroplating of an iron spoon with copper.

Materials: 1.0 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution, iron spoon, copper plate and sandpaper.

Apparatus: Beaker, battery, connecting wires with crocodile clips, ammeter, switch and rheostat.

Procedure:

1. Clean the copper plate and iron spoon with sandpaper.
2. Pour 1.0 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution into a beaker until half full.
3. Connect the iron spoon to the negative terminal of the battery and the copper plate to the positive terminal of the battery using the connecting wires.
4. Dip the iron spoon and copper plate into the 1.0 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution as shown in Figure 1.33.
5. Turn on the switch and adjust the current flow to 0.2 A using the rheostat.
6. Turn off the switch after 30 minutes.
7. Take out the iron spoon from the electrolyte and leave to dry.
8. Record your observation and complete the table below.

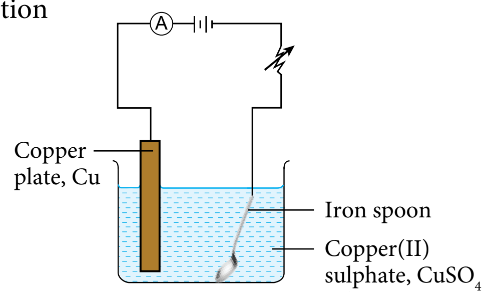


Figure 1.33

Results:

Record all observations in the following table.

Electrode	Observation	Inference	Half equation
Anode (Copper metal)			
Cathode (Iron spoon)			

Discussion:

1. Based on the half equations that you wrote for the reactions at the anode and cathode:
   (a) is electroplating a redox reaction?
   (b) explain your answer in 1(a) in terms of electron transfer.
2. Is there any colour change to the copper(II) sulphate, $CuSO_4$ solution? Explain your answer.
3. A good electroplating occurs if the layer of the plating on the metal is uniform and long lasting. Suggest two ways to achieve good electroplating.
4. Draw a labelled diagram of the set-up of apparatus for an experiment to electroplate an iron ring with nickel metal.

Chemistry Portal

Electroplating Process
https://bit.ly/kpkt5v16

Prepare a complete report after carrying out this laboratory activity.

Purification of Metal

- Copper is an important mineral and element in our daily life. It is an important industrial metal due to its ductility, malleability, electrical conductivity and resistance towards corrosion.
- Copper used in electrical wiring must have a 99.99% purity. The purity of copper extracted by the process of melting is about 99.5%. Even a slight difference in copper purity will negatively impact its conductivity. To determine whether a copper metal is pure, one must conduct the purification of metals through electrolysis.
- The purification of copper by electrolysis is carried out with a piece of pure, thin copper as the cathode; impure copper as the anode; and an aqueous salt solution of copper, such as copper(II) nitrate, $Cu(NO_3)_2$ as electrolyte.
- Impure copper anode ionises to form copper(II) ions, Cu^{2+}. Copper dissolves to become copper(II) ions, Cu^{2+} and impurities accumulate below the impure copper anode. The anode becomes thinner.

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

- At the pure copper cathode, copper(II) ions, Cu^{2+} are discharged to form copper atoms, Cu. Solid copper is deposited and the copper cathode becomes thicker.

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

Photograph 1.8 Industrial purification of copper

Photograph 1.9
Copper connecting wires

Chemistry Portal

Purification of Copper Metal
https://bit.ly/kpkt5v17

Laboratory Activity 1H Purification of Metals by Electrolysis

PAK21 Learning Science Through Inquiry

Aim: To study the purification of copper by electrolysis.

Materials: 1.0 mol dm^{-3} of copper(II) nitrate, $Cu(NO_3)_2$ solution, impure copper plate and pure copper plate.

Apparatus: Beaker, battery, connecting wires with crocodile clips, ammeter and switch.

Procedure:

1. Pour 1.0 mol dm^{-3} of copper(II) nitrate, $Cu(NO_3)_2$ solution into a beaker until half full.
2. Connect the pure copper plate to the negative terminal of the battery and the impure copper plate to the positive terminal of the battery as shown in Figure 1.34.
3. Turn on the switch and let the electricity flow for 30 minutes.
4. Record the changes at the anode and cathode in the following table and complete the table.

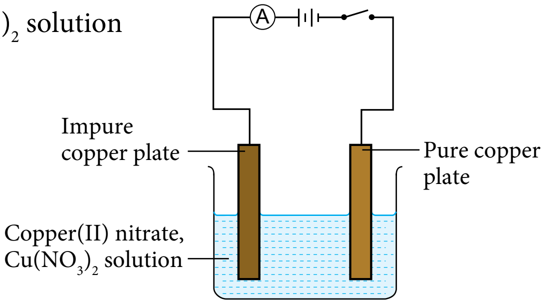


Figure 1.34

Results:

Electrode	Observation	Inference	Half equation
Anode (Impure copper)			
Cathode (Pure copper)			

Discussion:
1. Is purification process of copper a redox reaction? Explain your answer.
2. Is there any colour change to the copper(II) nitrate, $Cu(NO_3)_2$ solution? Explain your answer.
3. Impurities only form under the anode and not under the cathode. Give a reason.
4. Write the conclusion for this experiment.

Prepare a complete report after carrying out this laboratory activity.

SelfAssess 1.4

1. Table 1.11 shows electrodes, electrolytes and observations at the anode for three electrolytic cells.

Table 1.11

Electrolytic cell	Electrolyte	Electrode	Observation at the anode
I	0.0001 mol dm^{-3} of copper(II) chloride, $CuCl_2$ solution	Carbon	Colourless gas bubbles are released
II	1.0 mol dm^{-3} of copper(II) chloride, $CuCl_2$ solution	Carbon	Greenish yellow gas bubbles are released
III	0.0001 mol dm^{-3} of copper(II) chloride, $CuCl_2$ solution	Copper	Anode becomes thinner

   (a) Name the anions present in copper(II) chloride, $CuCl_2$ solution.
   (b) State the name of the gases released at the anode in electrolytic cells I and II. Explain your answers.
   (c) (i) Write the half equation for the reaction that occurs at the anode of electrolytic cell III.
       (ii) Explain how the product at the anode in electrolytic cell III is formed.
   (d) State the type of reaction that occurs at the anode.
   (e) If the experiment of electrolytic cell I is repeated using molten copper(II) chloride, $CuCl_2$, predict the observation at the anode.

2. Salim uses the apparatus shown in Figure 1.35 to electroplate an iron key with silver, Ag metal.
   (a) What is the purpose of electroplating the iron key with silver, Ag?
   (b) After 30 minutes Salim found out that the iron key has not been electroplated with silver, Ag.
       (i) Suggest a suitable electrolyte X.
       (ii) What should Salim do with the silver plate, Ag and iron key so that it can be electroplated with silver, Ag?

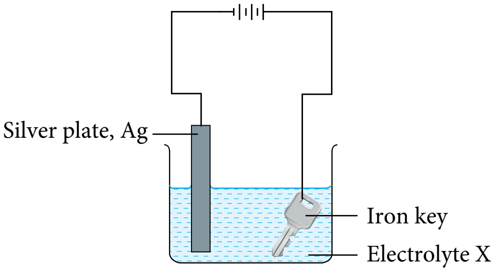


Figure 1.35

3. You are required to conduct an experiment to purify nickel, Ni by electrolysis.
   (a) Draw a labelled set-up of apparatus to be used in this experiment.
   (b) State the observations at the anode and cathode.
   (c) Write the half equation for the reaction that occurs at the anode.

1.5 EXTRACTION OF METAL FROM ITS ORE

Extraction of Metals

Learning Standards

Pupils are able to:

1.5.1 explain extraction of metal from its ore through electrolysis process.

1.5.2 explain metal extraction from its ore through reduction process by carbon.

- Metals usually exist as compounds or mixed with other substances, such as rocks and dirt. Compounds containing metals are also known as ore or mineral and exist as metal oxides, metal sulphides or metal carbonate. Figure 1.36 shows the examples of naturally occuring metal and ore.
- Non reactive metals such as gold and silver do not need to be extracted because they exist as metal elements. Reactive metals like iron and aluminium require a particular way to be extracted from their respective ores.
- The methods for extracting reactive metals are based on the position of the metal in the reactivity series of metal. Two of the most common ways to extract metals from their respective ores are:

Electrolysis	For metals that are more reactive than carbon
Reduction by carbon	For metals that are less reactive than carbon

Gold

Iron ore (Hematite)

Aluminium ore (Bauxite)

Figure 1.36 Naturally occurring metal and ore

Extraction of Metal from Its Ore Through the Process of Electrolysis

- Reactive metals like aluminium, Al can be extracted from its ore using electrolysis.
- In the extraction of aluminium, Al, aluminium ore or bauxite is firstly purified to obtain aluminium oxide, Al_2O_3, which is then melted down to enable the process of molten electrolysis to be conducted.
- The melting process uses an extremely high energy since the melting point of aluminium oxide, Al_2O_3 is 2000 °C. To overcome this problem, cryolite, Na_3AlF_6 is melted together with aluminium oxide, Al_2O_3 to lower its melting point.
- Let us study Figure 1.37 to understand the process of aluminium, Al extraction by electrolysis.

Topic Link

Form 3 Science: Mineral.

INFO

Aluminium is a common mineral found in the Earth's crust. However recycling aluminium is 95% more efficient compared to extracting aluminium from bauxite.

Do you know?

Aluminium oxide is also known as alumina.

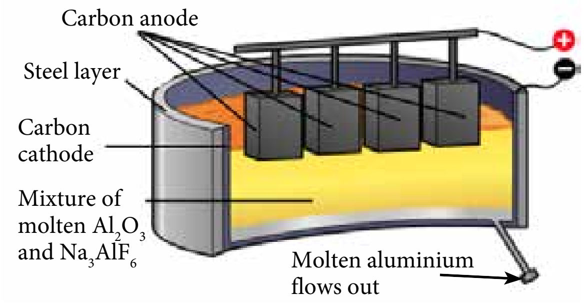


Figure 1.37 Extraction of aluminium from molten aluminium oxide, Al_2O_3 by electrolysis

Mind Challenge

Carbon dioxide gas is also released during the extraction process. How is carbon dioxide gas produced?

Topic Link

Redox: Electrolysis of molten compound on page 34.

- The extraction of aluminium using electrolysis is a redox reaction. But, what happens during the extraction?

Electrode	Anode	Cathode
Reaction involved	Oxide ion, O^{2-} donates electrons and undergoes the oxidation reaction, and forms oxygen molecule, O_2.	Aluminium ion, Al^{3+} is reduced to aluminium atom, Al by receiving electrons and forms molten aluminium.
Half equation	$2O^{2-}(l) \rightarrow O_2(g) + 4e^-$	$Al^{3+}(l) + 3e^- \rightarrow Al(l)$

- Molten aluminium sinks to the bottom of the layer because its density is higher, and then is drained out through a designated channel.
- The entire process of aluminium extraction consumes a huge amount of electricity. During the process of electrolysis for molten aluminium oxide, Al_2O_3, carbon dioxide, CO_2 is also formed, which negatively affects the environment.
- Apart from that, the purification process of bauxite also creates a residue in a form of red sludge that is toxic.
- Therefore, as consumers, we must recycle aluminium to reduce pollution on the environment. As a pupil, what is the role that you can play in this issue?

Photograph 1.10 Red toxic sludge pollution from bauxite waste due to a burst reservoir in Hungary in 2010
(**Source:** theguardian.com, 2014)

Noble Value

Preserve and conserve the environment.

ACTIVITY 1L Discussion

PAK 21

Carry out this activity in groups.

1. Scan the QR code to watch a video on aluminium extraction by electrolysis.
2. Based on the information in the video, discuss:
   (a) the ionic equation for the reaction.
   (b) the overall chemical equation involved.
   (c) whether the extraction of aluminium is a redox reaction?

Write your discussion in your notebook.

Chemistry Portal

Extraction of Aluminium Metal
https://bit.ly/kpkt5v18

Extraction of Metal from Its Ore Through the Process of Carbon Reduction

- Iron metal, which is less reactive than carbon, C can be extracted by carbon, C reduction process. This process is carried out in a blast furnace by heating up iron ore or hematite (Fe_2O_3) with coke, C and limestone, $CaCO_3$.
- There are several important reactions involved in this extraction process. Let us study Figure 1.38.

Topic Link

Form 3 Science:
Extraction of metal.

Do you know

Other than hematite, iron ore also consists of magnetite (Fe_3O_4), iron pyrite (FeS_2) and siderite ($FeCO_3$).

Mind Challenge

Can you name the waste gas formed from this process?

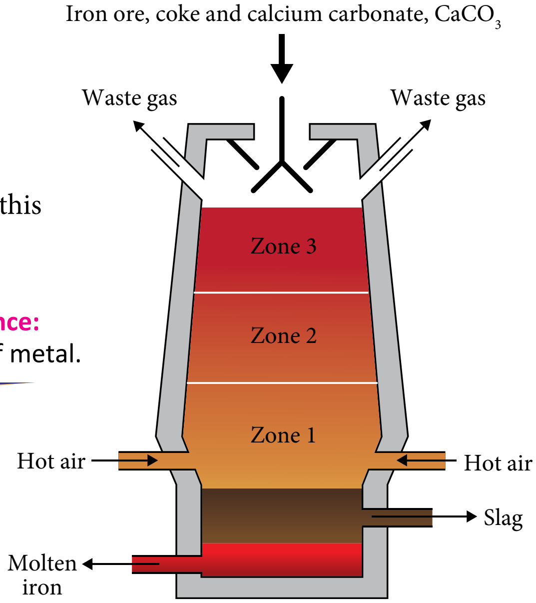


Figure 1.38 Blast furnace

Reaction	Explanation
Zone 1 Coke, C reacts with oxygen, O_2 from the hot air to form carbon dioxide, CO_2. $C(s) + O_2(g) \rightarrow CO_2(g)$	This is a redox exothermic reaction that makes the temperature of the blast furnace reach 1600 °C.
Zone 2 The produced carbon dioxide, CO_2 reacts with the remaining coal. $C(s) + CO_2(g) \rightarrow 2CO(g)$	Carbon monoxide, CO is the reducing agent for the subsequent reaction. This is an endothermic reaction that lowers the temperature in Zone 2.
Zone 3 Coke, C and carbon monoxide, CO function as reducing agents and reduce iron(III) oxide, Fe_2O_3 or iron ore to molten iron. $2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(l) + 3CO_2(g)$ $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)$	Iron(III) oxide, Fe_2O_3 is reduced by carbon monoxide, CO. Iron deposits are formed at the bottom of the blast furnace.
At high temperature, calcium carbonate, $CaCO_3$ decomposes to form calcium oxide, CaO (quicklime) and carbon dioxide, CO_2. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ Impurities in the iron ore like silicon(IV) oxide, SiO_2 react with calcium oxide to form slag or calcium silicate, $CaSiO_3$. $CaO(s) + SiO_2(s) \rightarrow CaSiO_3(l)$	Calcium oxide, CaO is a base and can neutralise the acidic silicone(IV) oxide, SiO_2. This reaction is important to separate the impurities from molten iron. The difference in density causes the slag to be at the top layer of the molten iron, which makes the separation process easier.

Extraction Using a More Reactive Metal

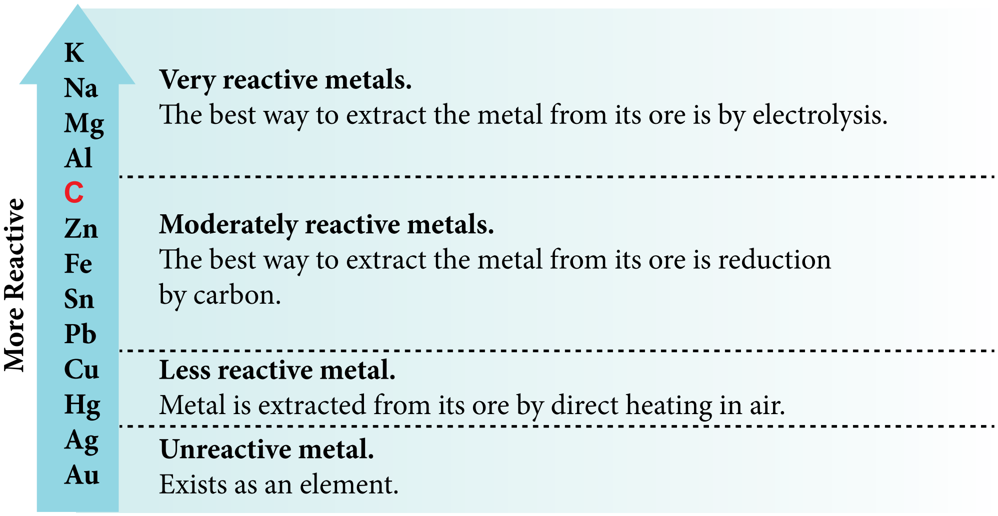
Chemistry Portal

Thermite Reaction
https://bit.ly/kpkt5v19

- When metals are heated together, the more reactive metal can extract the less reactive metal from its metal oxide. This reaction releases large amounts of heat that produce metal in molten state.
- For example, in a thermite reaction, aluminium powder, Al is heated together with iron(III) oxide powder, Fe_2O_3. The more reactive aluminium, Al reduces iron(III) oxide, Fe_2O_3 to produce molten iron, Fe. This is a very useful reaction in producing small quantities of molten iron for welding railway tracks.
- The following is the equation for the thermite reaction:

$$Fe_2O_3(s) + 2Al(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

- Some other metals like chromium, Cr and titanium, Ti can be extracted from their respective metal oxides using reduction by more reactive metals.
- Metal extraction methods are different, depending on the reactivity of the metals to be extracted. Figure 1.39 shows how the reactivity series of metals that can help us in determining the best way to extract the metal from its ore.



Very reactive metals.
The best way to extract the metal from its ore is by electrolysis.

Moderately reactive metals.
The best way to extract the metal from its ore is reduction by carbon.

Less reactive metal.
Metal is extracted from its ore by direct heating in air.

Unreactive metal.
Exists as an element.

Figure 1.39 Reactivity series of metal

Self Assess 1.5

1. Name a metal that exists as an element.
2. Explain why aluminium cannot be extracted through reduction reaction by carbon.
3. Iron is extracted by using a blast furnace:
   (a) Write the chemical equation for a redox reaction that produces molten iron.
   (b) What is the function of calcium carbonate in the process of iron extraction?
4. Name the metal that can be used to extract copper from copper(II) oxide.
   Explain your answer.

1.6 RUSTING

Photograph 1.11 A rusting ship

Learning Standards

Pupils are able to:

1.6.1 describe metal corrosion process as redox reaction through activities.

1.6.2 experiment to prevent rusting.

- Rusting of iron is a chemical process that occurs when iron is exposed to oxygen and water, and undergoes a redox reaction.
- Rusting of iron is a metal corrosion that occurs to iron. When iron metal rusts, a layer of reddish-brown iron oxide is formed on the iron surface that is easily cracked and permeable. Thus, rusting occurs continuously and damage the structure of the iron.
- Apart from the rusting of iron, corrosion can also occur on other metals. For example, on items made from silver (argentum) and bronze, which is copper alloy.
- What does metal corrosion mean?

> Corrosion of metal is a redox reaction where the metal is oxidised spontaneously when the metal atoms release electrons to form metal ions.

$$M \rightarrow M^{n+} + ne^-$$

- In general, the more electropositive the metal is, the easier it is for the metal to corrode. For example, corrosion of iron, Fe is faster than copper, Cu.

Experiment 1D Corrosion of Metal that Occurs on Copper and Iron

PAK21 Learning Science Through Inquiry

Aim: To study the corrosion of copper and iron.

Problem statement: Do copper and iron undergo corrosion?

Hypothesis: Copper metal corrodes to produce blue precipitate and iron metal corrodes to produce brown precipitate.

Variables:

(a) Manipulated variable : Copper and iron.

(b) Responding variable : Presence of blue and brown precipitate.

(c) Fixed variable : Salt solution.

Materials: 20 cm of copper wire, 20 cm of iron wire, 0.5 mol dm^{-3} of sodium chloride, NaCl solution, 0.05 mol dm^{-3} of potassium chloride, KCl solution and 0.5 mol dm^{-3} of sodium hydroxide, NaOH solution.

Apparatus: Test tubes, test tube rack, sandpaper, beaker, tripod stand, wire gauze and Bunsen burner.

Procedure:

1. Clean the copper wire and iron wire using sandpaper.
2. Coil the copper wire and iron wire before putting them into two separate test tubes.
3. Add 12 cm^3 of 0.5 mol dm^{-3} of sodium chloride, NaCl solution, 6 cm^3 of 0.05 mol dm^{-3} of potassium chloride, KCl solution and 2 cm^3 of 0.5 mol dm^{-3} of sodium hydroxide, NaOH solution into a beaker. Heat the mixture.
4. Pour the mixture into the test tubes until it covers the metals as shown in Figure 1.40.
5. Place both test tubes on the test tube rack and keep them aside for 3 days.
6. Record all observations.

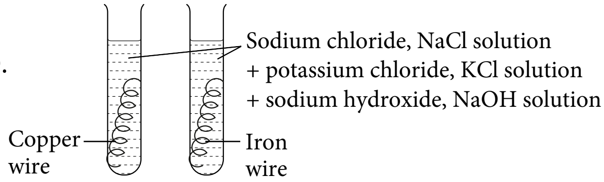


Figure 1.40

Results:

Record your observations and inferences in a suitable table.

Discussion:

1. What is the purpose of using sodium hydroxide, NaOH in this experiment?
2. Based on the observations in this experiment, write the half equations for the reactions that occur.
3. What is the conclusion of this experiment?

Prepare a complete report after carrying out this experiment.

Iron Rusting as a Redox Reaction

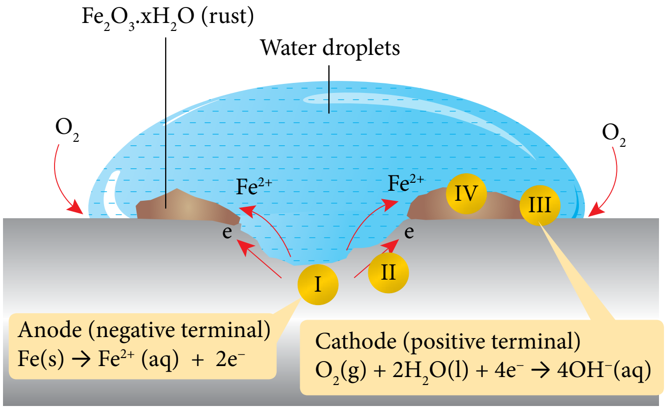


Figure 1.41 Mechanism of rusting

- Rusting of iron occurs with the presence of water and oxygen.
- Rusting of iron is a redox reaction where oxygen acts as an oxidising agent, while iron acts as a reducing agent.
- Figure 1.41 shows a mechanism of rusting of iron.
- Based on Figure 1.41, when iron comes into contact with water and is exposed to oxygen, a simple chemical cell is formed.

I. The surface of the iron in the middle of the water droplet where the concentration of oxygen is low serves as the anode (negative terminal). Iron atom, Fe loses electrons and undergoes oxidation to form iron(II) ions, Fe^{2+}.

Half equation of oxidation at the anode: $\boxed{Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-}$

II. Electrons flow through the iron, Fe to the end of the water droplet where the concentration of oxygen is higher. The iron, Fe surface at that part becomes the cathode (positive terminal), where reduction occurs.

III. Oxygen, O_2 that dissolves in water accepts electrons and undergoes reduction to form hydroxide ion, OH^-.
Half equation of reduction at the cathode: $\boxed{O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)}$

IV. The iron(II) ion, Fe^{2+} produced reacts with hydroxide ion, OH^- to form iron(II) hydroxide, $Fe(OH)_2$.

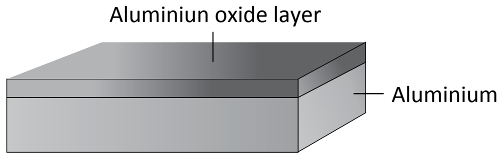
$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$$

Iron(II) ion, Fe^{2+} is green but rust is brown because iron(II) hydroxide, $Fe(OH)_2$ undergoes continuous oxidation with oxygen to form hydrated iron(III) oxide $Fe_2O_3.xH_2O$ (rust). x is an integer that has various values.

- Iron(III) oxide, Fe_2O_3 or rust is brittle, permeable and does not stick strongly. Thus, water and oxygen can permeate into the iron metal underneath. Iron will continuously rust.
- Rusting of iron occurs faster in the presence of acid or salt because when these substances dissolve in water, the solution becomes a better electrolyte. Electrolytes increase the electrical conductivity of water.
- Iron in steel form is widely used in building materials. For example, it is used in the manufacturing of vehicles, building construction materials, bridges and railway tracks. However, rusting would cause the structure of iron to become weaker.
- Every year, a huge financial provision is required to overcome the problem of rusting of iron.
- What steps should be taken to prevent rusting of iron?

INFO

- A layer of aluminium oxide is hard and non porous, protecting the aluminium underneath from corroding.
- Other metals with the same characteristics are zinc, lead, nickel and chromium.



Experiment 1E Effects of Other Metals on Rusting

PAK21 Learning Science Through Inquiry

Aim: To study the effects of other metals on rusting.

Problem statement: How do different metals in contact with iron affect rusting?

Hypothesis: When a more electropositive metal comes into contact with an iron nail, the iron does not rust; when a less electropositive metal comes into contact with an iron nail, the iron nail rusts.

CAUTION

Potassium hexacyanoferrate(III) solution is poisonous.

Variable:

(a) Manipulated variable : Different metals coiled around the iron nail.
(b) Responding variable : Rusting of iron.
(c) Fixed variable : Iron nail.

Materials: Agar solution, phenolphthalein, potassium hexacyanoferrate(III), $K_3Fe(CN)_6$ solution, iron nails, magnesium ribbon, Mg, tin strip, Sn, zinc strip, Zn and copper strip, Cu.

Apparatus: Test tubes, test tube rack and sandpaper.

Procedure:

1. Label five test tubes P, Q, R, S and T.
2. Using sandpaper, clean five iron nails, magnesium ribbon, tin strip, zinc strip and copper strip.
3. Coil each nail with magnesium ribbon, zinc strip, tin strip and copper strip respectively.
4. Put each nail coiled with metal into test tubes P, Q, R and S respectively as in Figure 1.42. The nail with no metal coil is placed into test tube T.
5. Pour hot agar mixture containing potassium hexacyanoferrate(III), $K_3Fe(CN)_6$ solution and phenolphthalein into each test tube until the nails are completely immersed.
6. Place all test tubes on the test tube rack and leave aside for one day.
7. Record your observations.

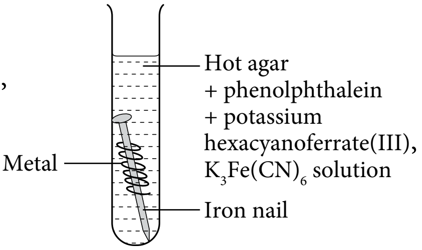


Figure 1.42

Results:

Construct a table to record your observations.

Discussion:

1. What is the function of potassium hexacyanoferrate(III), $K_3Fe(CN)_6$ and phenolphthalein in this experiment?
2. Explain why hot agar solution is used in this experiment instead of water.
3. State the relationship between the intensity of the blue colour with the rate of rusting that takes place.
4. State the function of test tube T.
5. Based on the result of this experiment, classify the metals into metals that prevent rusting and metals that accelerate rusting.
6. What is the relationship between the electropositivity of a metal that comes into contact with iron and rusting of iron?
7. Can the hypothesis be accepted? Write a conclusion for this experiment.

Prepare a complete report after carrying out this experiment.

- When iron comes into contact with a more electropositive metal such as zinc, Zn, rusting of iron slows down. Zinc atoms, Zn release electrons more easily than iron, Fe. Zinc, Zn corrodes and undergoes oxidation.

Topic Link **Redox:** Electrochemical series on page 17.

Half equation of oxidation $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

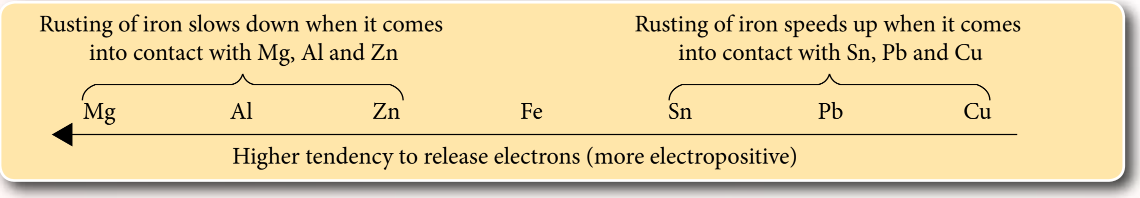
- The released electrons flow through iron to the metal surface where there is water and oxygen.

Half equation of reduction $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

- When iron comes into contact with less electropositive metals, such as lead, the rusting of iron becomes faster. Iron atoms, Fe lose electrons, forming iron(II) ions, Fe^{2+}. Thus, iron rusts and is oxidised.

Half equation of oxidation $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

- Effects of other metals on rusting of iron are as follows:



Ways to Prevent Rusting

A Use of Protective Surface

This method prevents iron from coming into contact with water and oxygen.

Paint, grease and plastic wrappings

- Paint for fences, cars and bridges.
- Oil or grease on car engines.
- Plastic coatings on wire fences.

Fence wire wrapped with plastics

Using other metals

- Galvanisation
    - Iron or steel is galvanised with a thin layer of zinc.
    - Zinc forms a protective layer of zinc oxide that is hard, strong, non porous and protects the iron.
- Tin plating (stanum)
    - Steel plates are plated with an extremely thin layer of tin.
    - Tin forms a layer of oxide protection.
- Chrome plating
    - Used on car bumpers, bicycles, decorative items and others.

Food cans plated with tin

Galvanised iron roof

Mind Challenge

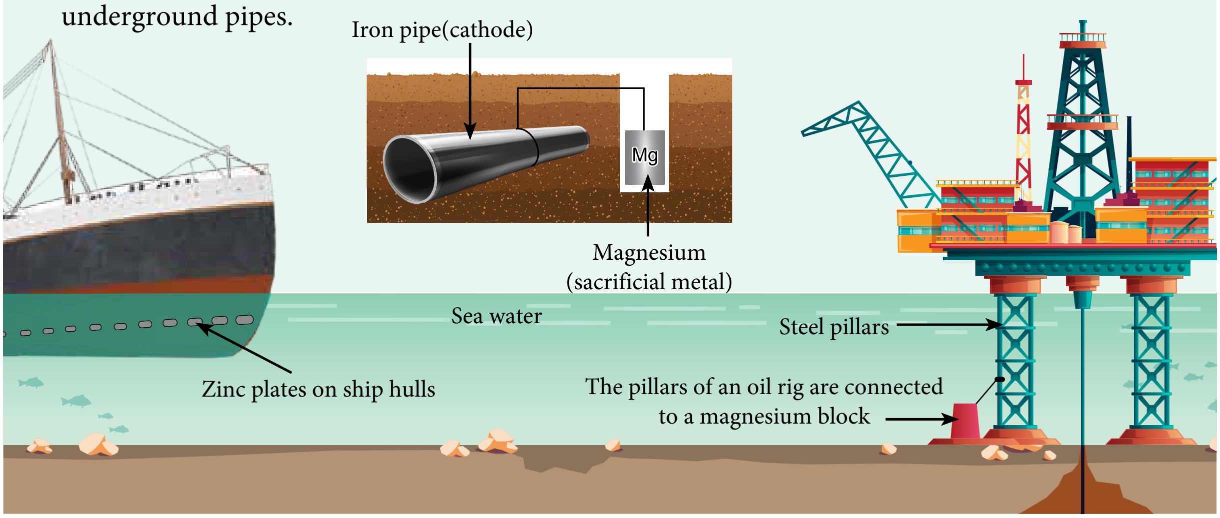
STEM

Ali would not buy dented canned food. Explain why.

B Sacrificial Protection

Iron is attached to a more electropositive metal, such as magnesium and zinc.

- When iron is attached to a more electropositive metal, the more electropositive metal corrodes and rusting can be prevented. The more electropositive metal becomes a sacrificial metal.
- This sacrificial metal must be replaced from time to time.
- Sacrificial protection is used for corrosion protection for bridge pillars, ship hulls and underground pipes.



C Alloying

In stainless steel, iron is alloyed with carbon, chromium and nickel.

Stainless steel cutlery set

- Chromium and nickel create a shiny, protective and corrosion proof oxide layer.
- The oxide layer formed protects the iron from being exposed to water and oxygen to prevent rusting.
- Stainless steel is widely used in surgical instruments and kitchen utensils.

Noble Value Appreciate the contributions of science and technology.

ACTIVITY 1M

PAK21

Conduct this activity in groups.

1. Discuss and explain the following situation:
   (a) What is the difference between rusting of iron and metal corrosion?
   (b) Describe the mechanisms for rusting from the aspects of oxidation and reduction.
   (c) How can metals that are more electropositive than iron prevent rusting of iron? State examples of application in daily life for each situation.
2. Present your discussion with the group members in a Gallery Walk activity.

Self Assess 1.6

1. Figure 1.43 shows the observation of two experiments to study the effects of metals P and Q on rusting of iron.

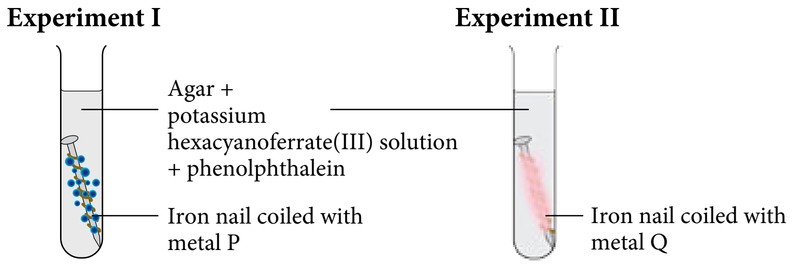
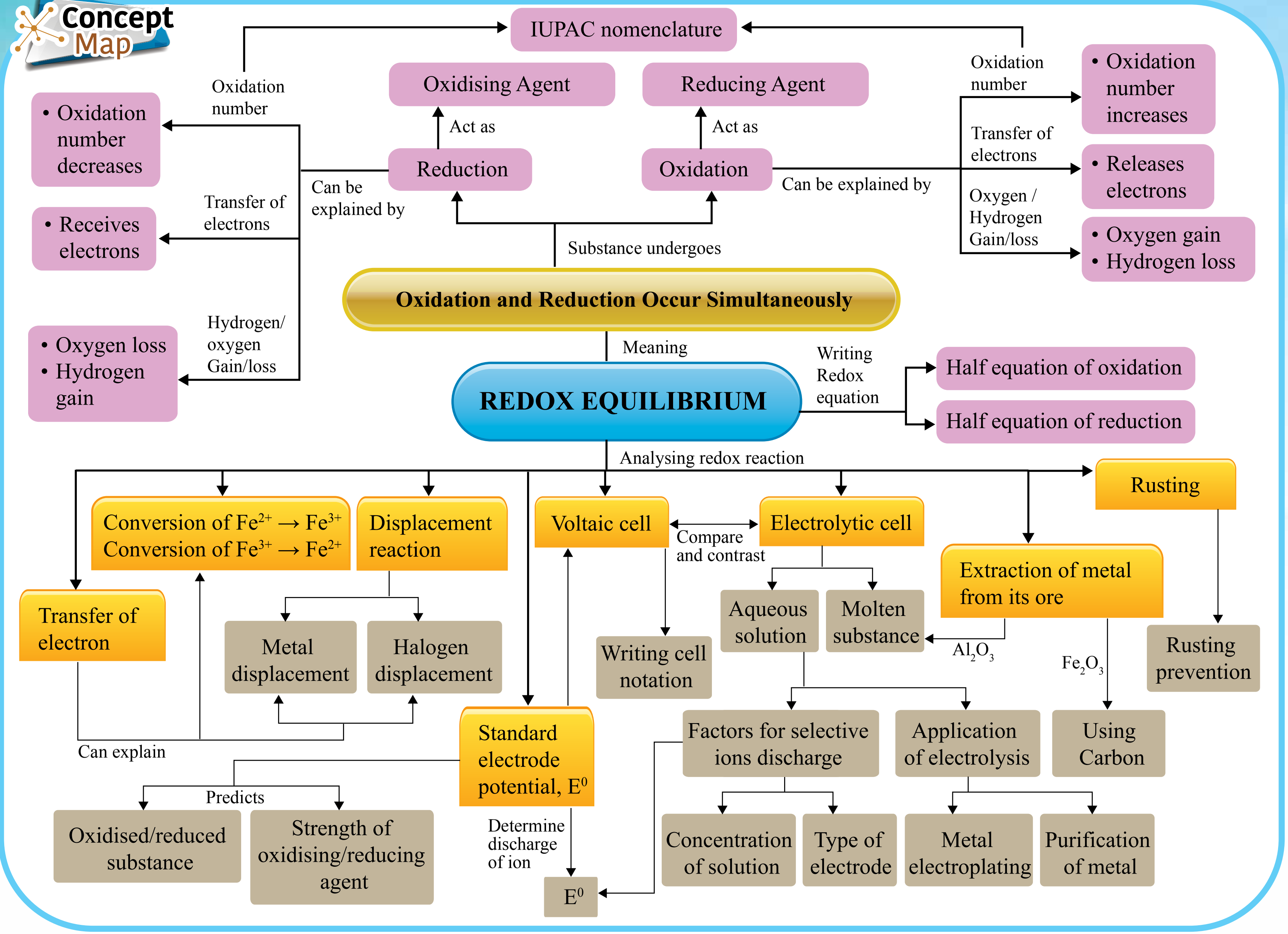


Figure 1.43

   (a) Suggest metals P and Q.
   (b) Explain and include the half equations for the reactions in experiment I and experiment II.
   (c) Arrange iron, metal P and metal Q in an ascending order of electropositivity.
2. In the food manufacturing industry, steel plates are plated with tin before being used to make food cans. Explain how tin prevents steel from rusting.

Concept Map



REDOX EQUILIBRIUM

Meaning

Oxidation and Reduction Occur Simultaneously

Substance undergoes

Reduction

Act as

Oxidising Agent

Can be explained by

Oxidation number

- Oxidation number decreases

Transfer of electrons

- Receives electrons

Hydrogen/ oxygen Gain/loss

- Oxygen loss
- Hydrogen gain

Oxidation

Act as

Reducing Agent

Can be explained by

Oxidation number

- Oxidation number increases

Transfer of electrons

- Releases electrons

Oxygen / Hydrogen Gain/loss

- Oxygen gain
- Hydrogen loss

IUPAC nomenclature

Writing Redox equation

Half equation of oxidation

Half equation of reduction

Analysing redox reaction

Transfer of electron

Conversion of $Fe^{2+} \longrightarrow Fe^{3+}$
Conversion of $Fe^{3+} \longrightarrow Fe^{2+}$

Displacement reaction

Metal displacement

Halogen displacement

Can explain

Standard electrode potential, E^0

Predicts

Oxidised/reduced substance

Strength of oxidising/reducing agent

Determine discharge of ion

E^0

Voltaic cell

Compare and contrast

Electrolytic cell

Writing cell notation

Aqueous solution

Molten substance

Factors for selective ions discharge

Concentration of solution

Type of electrode

Application of electrolysis

Metal electroplating

Purification of metal

Extraction of metal from its ore

Al_2O_3

Fe_2O_3

Using Carbon

Rusting

Rusting prevention

SELF Reflection

1. Have you mastered the topic of **Redox Equilibrium**?
2. What is the content in the topic of **Redox Equilibrium** that you want to have a more in-depth understanding of? Why?
3. How does the topic of **Redox Equilibrium** benefit you in daily life?
4. How would you assess your ability to describe the content in the topic of **Redox Equilibrium** to your friends?
5. What can you do to improve your understanding of the topic of **Redox Equilibrium**?

ACHIEVEMENT TEST

1. Identify whether a redox reaction occurs for each reaction below.

   Reaction I : $FeSO_4(aq) + Mg(s) \rightarrow Fe(s) + MgSO_4(aq)$
   Reaction II : $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

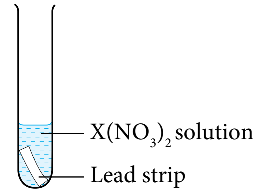
   Explain your answer based on the change in oxidation number.

2. The overall ionic equation below shows the reaction between iodine, I_2 and sulphur dioxide, SO_2.

$$I_2(aq) + SO_2(g) + 2H_2O(l) \rightarrow 2I^-(aq) + SO_4^{2-}(aq) + 4H^+(aq)$$

   Based on the equation above:
   (a) state the change in oxidation number for iodine and sulphur.
   (b) name the oxidising agent and reducing agent in this reaction.
   (c) write the reduction half equation.

3. Figure 1 shows the set-up of apparatus and observation for the experiment to study displacement of a metal from its salt solution.

Set-up of apparatus	Observation
 **Figure 1**	• Blue colour $X(NO_3)_2$ solution becomes pale blue. • Lead strip becomes thinner. • Brown solid is deposited at the bottom of the test tube.

   (a) Suggest a suitable $X(NO_3)_2$ solution and name the brown solid at the bottom of the test tube.
   (b) Write the half equations for oxidation and reduction.
   (c) Write the ionic equation for the redox reaction that takes place.
   (d) State the change in oxidation number of X in this experiment.

4. Table 1 shows the results of an experiment to study the displacement of halogen from its halide solution.

Table 1

Experiment	Observation
A brown halogen gas is passed into a test tube containing a mixture of sodium iodide, NaI solution and dichloromethane, CH_2Cl_2.	• A colourless layer of aqueous solution. • A purple layer of dichloromethane.

(a) Name the halogen gas that is passed into the test tube in this experiment.
(b) Name the product of the reaction that can be detected with dichloromethane, CH_2Cl_2.
(c) Write the half equations for oxidation, reduction and ionic equation for the redox reaction.

5. Based on the E^0 value, arrange the following atom or ion in an ascending order of the strength of oxidising agent and reducing agent.

$P \rightleftharpoons P^{2+}(aq) + 2e$ $E^0 = -0.85$ V
$Q \rightleftharpoons Q^{3+}(aq) + 3e^-$ $E^0 = +1.66$ V
$R \rightleftharpoons R^{2+}(aq) + 2e^-$ $E^0 = +2.87$ V

6. Figure 2 shows a set-up of apparatus for a voltaic cell. With reference to the half-cell standard electrode potential, E^0:
(a) identify the negative and positive terminals.
(b) write the cell notation for the chemical cell.
(c) write the equations for reduction, oxidation and the overall ionic equation.
(d) calculate the voltage of the cell.

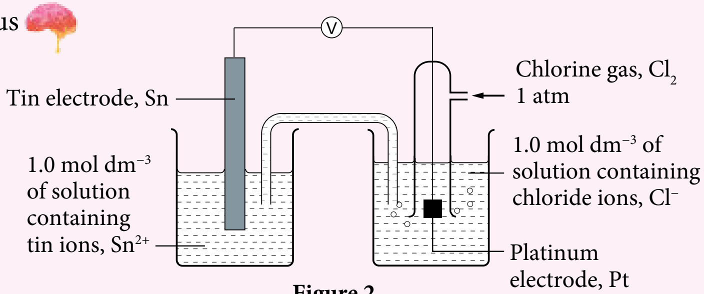


Figure 2

7. Figure 3 shows two sets of apparatus used to study the electrolysis of copper(II) nitrate solution.
(a) Name the product formed at the anode in set I.
Explain your answer.
(b) Describe, in brief, the chemical test to verify the product at the anode in set I.
(c) Compare the colour of copper(II) nitrate solution in Set I and Set II after the electrolysis is conducted for one hour. Explain your answers.

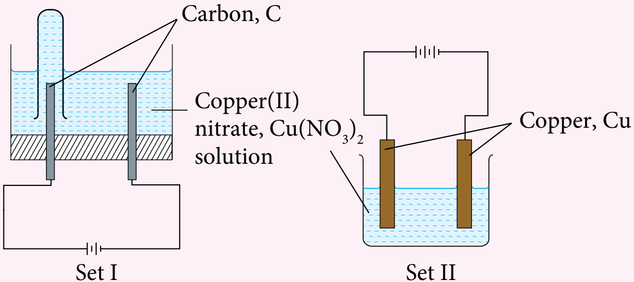


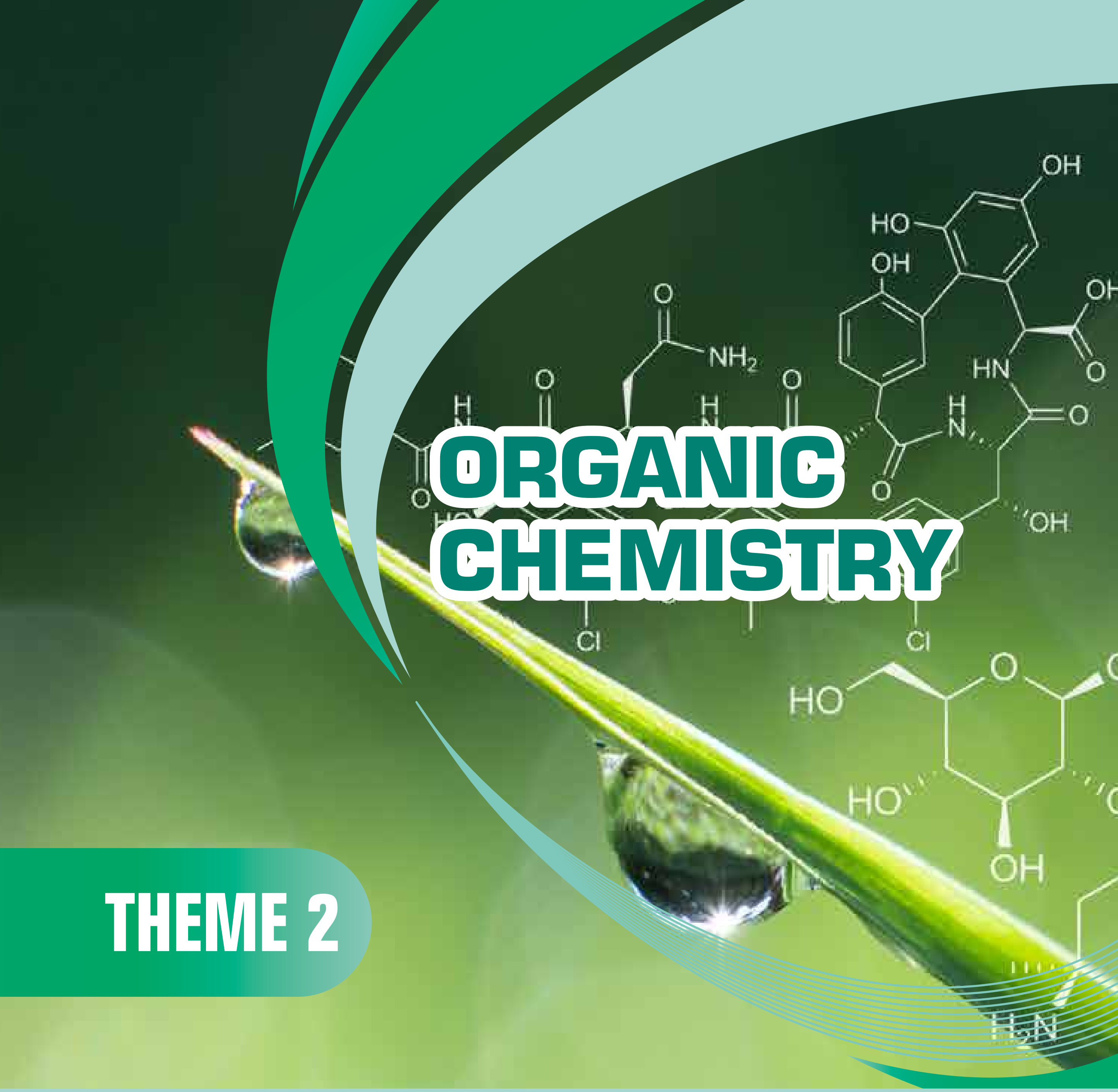
Figure 3

Enrichment Corner

An old oil painting that used lead-based paints, forms black lead sulphide, PbS.

Repainting it by using hydrogen peroxide, H_2O_2 can help restore the original colour.
Chemical equation: $PbS(s) + 4H_2O_2(aq) \rightarrow PbSO_4(s) + 4H_2O(l)$

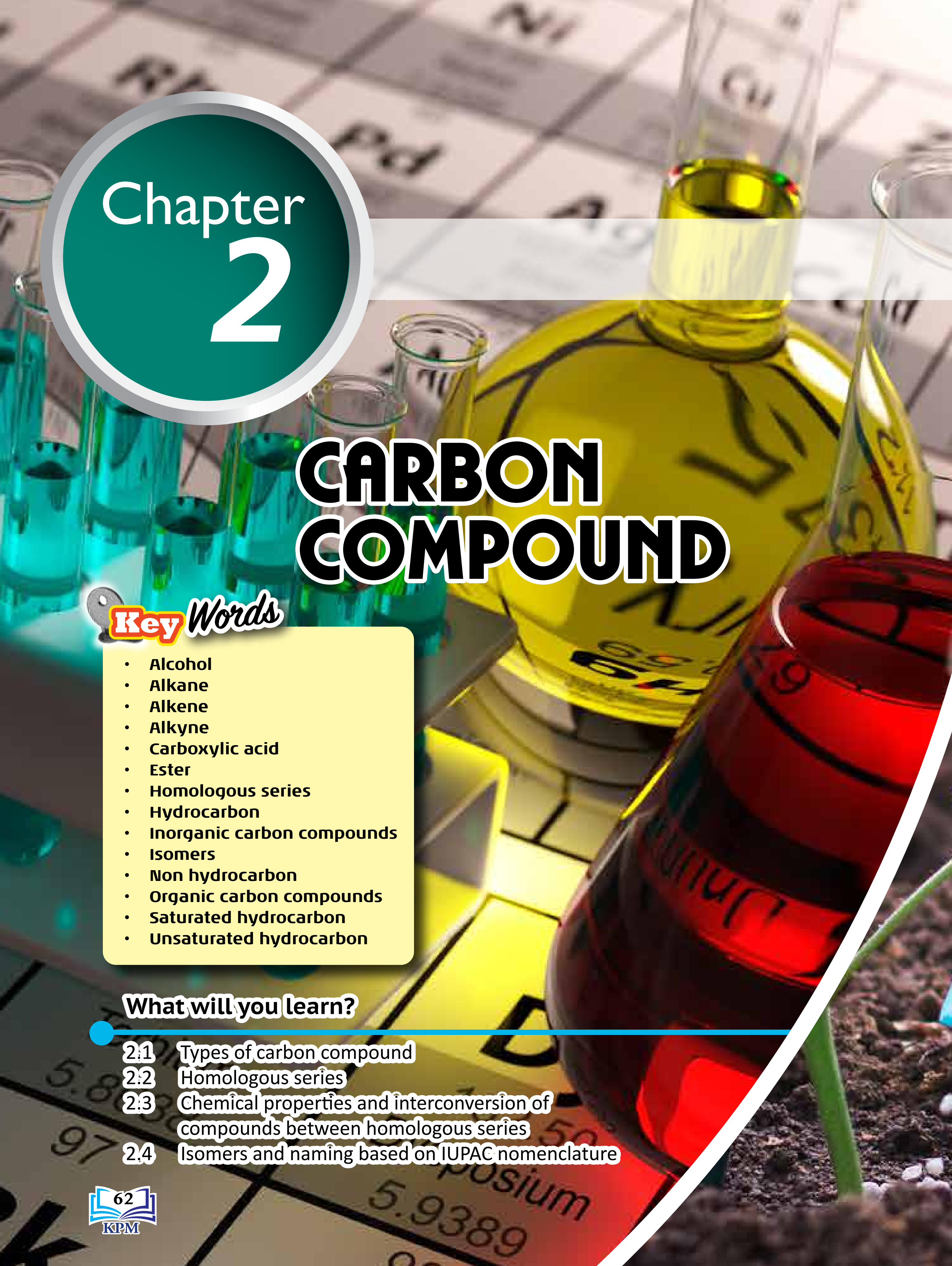
Based on the equation above, identify the oxidised substance and the reduced substance. Explain the redox reaction that occurs in terms of change in oxidation number.



ORGANIC CHEMISTRY

THEME 2

This theme discusses basic organic substances around us, classification of hydrocarbon compounds based on homologous series, physical properties, and chemical properties. Knowledge on preparation methods and chemical properties of substances are important in the application of processing and production of commercial and industrial substances.



Chapter 2

CARBON COMPOUND

Key Words

- Alcohol
- Alkane
- Alkene
- Alkyne
- Carboxylic acid
- Ester
- Homologous series
- Hydrocarbon
- Inorganic carbon compounds
- Isomers
- Non hydrocarbon
- Organic carbon compounds
- Saturated hydrocarbon
- Unsaturated hydrocarbon

What will you learn?

2.1 Types of carbon compound
2.2 Homologous series
2.3 Chemical properties and interconversion of compounds between homologous series
2.4 Isomers and naming based on IUPAC nomenclature

Bulletin

Source: (https://loanstreet.com.my/ms/pusat-pembelajaran/pesta-kaamatan-hari-gawai)

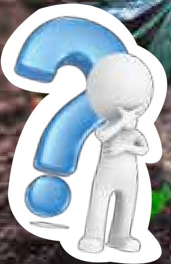
One of the unique things that is part of the lives of the ethnic groups in Sabah and Sarawak is a drink called *tuak*. Do you know that *tuak* is a drink that is made by fermenting certain foods such as tapioca, rice or glutinous rice with yeast? *Tuak* is an important element during local rituals and special events like the annual ceremonies of the Ibans, Melanaus, Dayaks and other ethnic sub-groups. Normally, *tuak* is served to guests as a welcome drink during the *Kaamatan* and *Gawai* Festivals that are celebrated after the harvest season every year.

In science, what is the chemical reaction involved in the production of *tuak*? The answer is quite easy. *Tuak* is a type of drink that is prepared through a process called fermentation. Fermentation involves the use of yeast to break down large molecules of carbohydrates, such as sucrose or glucose, into smaller molecules like ethanol, C_2H_5OH. The yeast secretes the enzyme called zymase that transforms glucose into ethanol, C_2H_5OH and carbon dioxide, CO_2.

$$\underset{\text{Glucose}}{C_6H_{12}O_6(aq)} \xrightarrow{\text{Zymase}} \underset{\text{Ethanol(14-15\%)}}{2C_2H_5OH(l)} + \underset{\text{Carbon dioxide}}{2CO_2(g)}$$

It is important to note that *tuak* can be harmful because it can cause intoxication, hallucinations and induce vomiting if it is consumed in large quantities.

What is the source of raw materials for the petrochemical industry?



What is the chemical that forms the major composition in liquid disinfectant?

What are the chemicals that induce the smell of fruits and perfumes?

2.1 TYPES OF CARBON COMPOUNDS

- Carbon transfers from the atmosphere to living organisms on earth and back to the atmosphere. Based on Figure 2.1, can you explain what process has taken place?

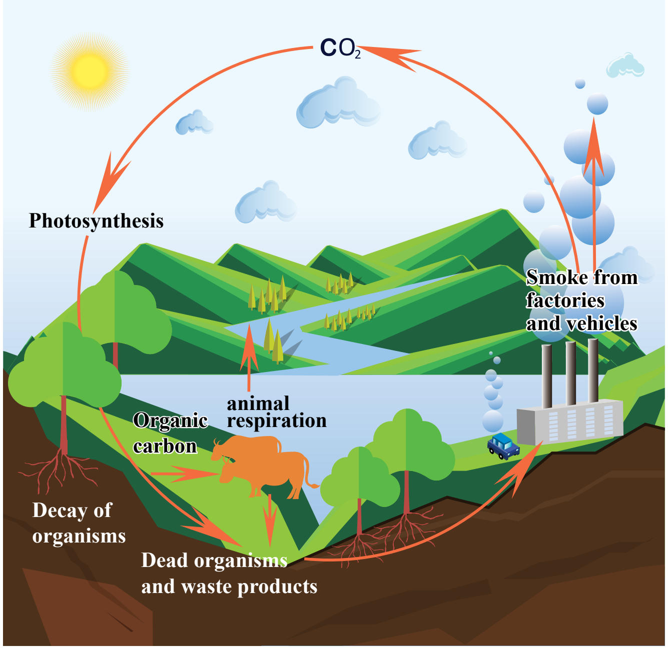


Figure 2.1 Carbon cycle

Learning Standards

Pupils are able to:

2.1.1 understand carbon compounds.
2.1.2 explain sources of hydrocarbon.

Topic Link

Form 2 Science: Carbon Cycle.

INFO

- Early chemists defined organic carbon compounds as compounds originating from animals or plants (living things), such as petroleum, carbohydrate, protein, fat and urea.
- Nowadays, organic compounds also include compounds of natural ingredients that are synthesised in the laboratory. Examples include plastics, perfumes, detergents and medicines.

What are carbon compounds?

- Carbon compounds are compounds that contain **carbon** as their constituent element.
- There are two types of carbon compounds:
  (i) Organic compounds
  (ii) Inorganic compounds

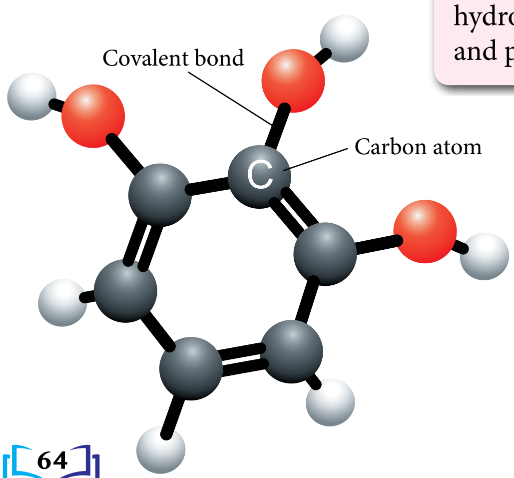
Carbon Compounds

Organic compounds

Compounds originating from living things that contain the carbon element bonded covalently with other elements such as hydrogen, nitrogen, sulphur and phosphorus.

Inorganic compounds

Compounds originating from non-living materials such as oxides of carbon, carbonate compounds and cyanide compounds.



Do you know?

- In our daily lives, the word organic carries different meanings.
- Organic food is grown without using pesticides, synthetic fertilisers and without genetic modification (GMO).
- Organic beef, poultry, eggs and dairy products are made from animals that are free from antibiotics or growth hormones.

Hydrocarbon and Non Hydrocarbon

- Organic compounds are divided into hydrocarbons and non hydrocarbons.

Hydrocarbon	Organic compounds containing only hydrogen and carbon.
Non Hydrocarbon	Organic compounds containing carbon and hydrogen and other elements, such as oxygen, nitrogen, phosphorus or halogens.

- Table 2.1 shows examples of hydrocarbons and non hydrocarbons.

Table 2.1 Examples of hydrocarbons and non hydrocarbons

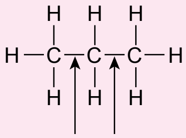
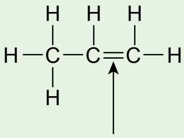
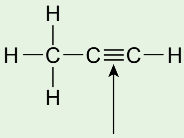
Organic compounds	Composition	Type
Protein	Carbon, hydrogen, nitrogen, oxygen	Non hydrocarbon
Petrol	Carbon, hydrogen	Hydrocarbon
Starch	Carbon, hydrogen, oxygen	Non hydrocarbon
Fat	Carbon, hydrogen, oxygen	Non hydrocarbon
Natural gas	Carbon, hydrogen	Hydrocarbon
Alcohol	Carbon, hydrogen, oxygen	Non hydrocarbon

- Hydrocarbons are classified into saturated and unsaturated hydrocarbons based on the types of their covalent bonds.

Saturated Hydrocarbon	Hydrocarbons containing only single bonds between carbon atoms.
Unsaturated Hydrocarbon	Hydrocarbons containing at least one double bond or triple bond between carbon atoms.

- Table 2.2 shows examples of structural formulae of saturated and unsaturated hydrocarbons.

Table 2.2 Examples of structural formulae of saturated and unsaturated hydrocarbons

Saturated hydrocarbon	Unsaturated hydrocarbon	
 Single bonds between carbon atoms	 Double bond between carbon atoms	 Triple bond between carbon atoms

Topic Link **Carbon Compound:** Homologous series on page 72.

Chemistry Portal

Revision on Covalent Bonds of Saturated Hydrocarbons and Unsaturated Hydrocarbons
https://bit.ly/kpkt5n3

ACTIVITY 2A

Carry out the activity in pairs.

1. Classify the following substances into organic or inorganic compounds:
   - (a) Propanol, C_3H_7OH
   - (b) Carbon dioxide, CO_2
   - (c) Lead(II) carbonate, $PbCO_3$
   - (d) Glucose, $C_6H_{12}O_6$
   - (e) Ethanoic acid, CH_3COOH

2. State the term for each of the following statements:
   - (a) Compounds containing the carbon element.
   - (b) Hydrocarbons possessing only single bonds.
   - (c) Organic compounds containing only carbon and hydrogen.
   - (d) Carbon compounds derived from living things.
   - (e) Hydrocarbons possessing double or triple bonds between carbon atoms.

Sources of Hydrocarbons

- The main source of hydrocarbons is petroleum or crude oil.
- Petroleum is formed from the remains of plants and animals that perished at the bottom of the ocean, millions of years ago.
- Petroleum is a mixture of simple or long-chain hydrocarbons.
- Petroleum cannot be used before processing. It needs to be refined into its constituents through a distillation process.
- The two stages of oil refining are fractional distillation and cracking.

Do you know

- The van der Waals force between molecules gets stronger as the molecule size increases.
- The boiling point of hydrocarbons increases as the molecule size increases because more energy is needed to overcome the force.

Fractional Distillation	The fractions of hydrocarbons in petroleum are separated at different temperatures according to the size of the hydrocarbons.
Cracking	Long chain hydrocarbons are cracked into smaller molecules at a high temperature using a catalyst.

Fractional Distillation

Photograph 2.1 Petroleum fractional distillation process at an oil refinery

- During the fractional distillation process, petroleum is heated and streamed into a distillation tower as shown in Figure 2.2.
- The fractions in petroleum can be separated because each fraction of the hydrocarbons has its own boiling point.
- Hydrocarbons with a lower boiling point will vaporise first, and then rise to the top of the tower before condensing and separating.
- Hydrocarbons with a higher boiling point are collected at the bottom of the tower and will condense into liquid.
- There are two main uses of hydrocarbon compounds derived from fractional distillation:
   - (a) As fuels.
   - (b) As raw materials for the petrochemical industry.

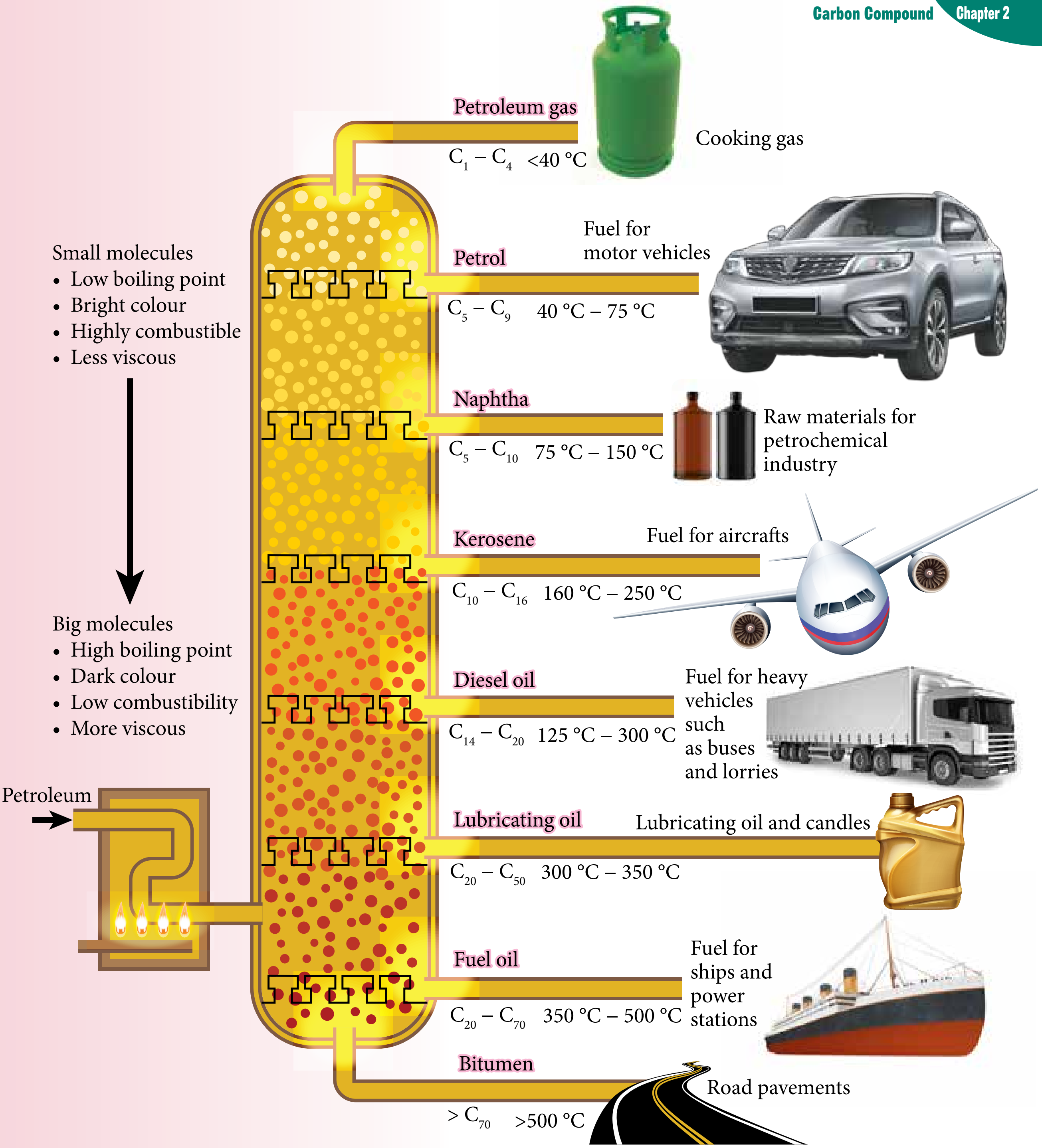


Figure 2.2 The process of fractional distillation of petroleum and how the products are used in daily life

Chemistry Portal

Sources of Hydrocarbons
https://bit.ly/kpkt5v20

Fractional Distillation of Petroleum
https://bit.ly/kpkt5v21

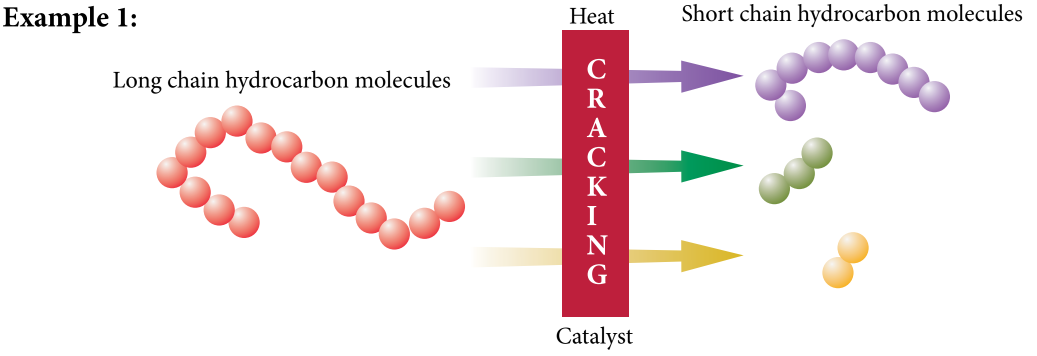
Topic Link **Thermochemistry:** Calculating the Fuel Value on page 137.

Cracking

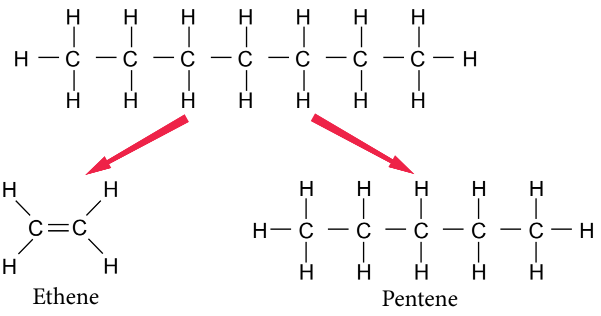
- Cracking is the process of breaking long chain hydrocarbons into smaller hydrocarbons.
- In the cracking process, compounds of large hydrocarbon molecules are heated at a high temperature and pressure.
- A catalyst such as a mixture of aluminium oxide, Al_2O_3 and silicon(IV) oxide, SiO_2 are usually used to increase the rate of reaction.
- Cracking process produces:
  (i) smaller hydrocarbons such as petrol that is used as fuel.
  (ii) alkane and alkene hydrocarbons with shorter chains, to be used as raw materials in the manufacturing of polymers, medicines, detergents, solvents, fertilizers and many more useful products.
- The demand for smaller-sized hydrocarbons is higher because it combusts easily, and is used as fuel.
- The separation of petroleum compounds through fractional distillation cannot meet the high demands of smaller sized hydrocarbons. Figure 2.3 shows the examples of a long-chain hydrocarbon cracking reaction.

Topic Link **Carbon Compound:** Alkanes and alkenes on page 73.

Example 1:



Example 2: Long chain hydrocarbon molecules



Chemical equation: $C_7H_{16} \rightarrow C_2H_4 + C_5H_{12}$

Example 3:

$C_{10}H_{22}$	$\rightarrow$	$2C_5H_{10}$	$+$	H_2
Decane		Pentene		Hydrogen

Chemistry Portal

Cracking Reaction
https://bit.ly/kpkt5v22

Figure 2.3 Examples of cracking reaction on long-chain hydrocarbons into smaller hydrocarbon molecules and hydrogen gas

Laboratory Activity 2A Fractional Distillation of Petroleum

PAK21 Learning Science Through Inquiry

Aim: To study the fractional distillation of petroleum

Materials: Petroleum and cotton

Apparatus: Filter paper, retort stand, thermometer (0 °C – 360 °C), round bottom flask, conical flask, test tube, Liebig condenser, wire gauze, tripod stand, test tubes, evaporating dish, porcelain chips, wooden block and Bunsen burner.

CAUTION

The emitted gases are flammable.

Procedure:

1. Measure 50 cm^3 of petroleum and pour into a round bottom flask.
2. Add one spatula of porcelain chips into the round bottom flask.
3. Set up the apparatus as shown in Figure 2.4.
4. Gently heat the petroleum and collect four fractions of petroleum into four separate test tubes at a temperature range of 30 °C – 80 °C, 80 °C – 120 °C, 120 °C – 160 °C and 160 °C – 200 °C.
5. Observe each fraction of petroleum collected at different temperatures and record the colour and their viscosity.
6. Place some cotton into an evaporating dish.
7. Put a few drops of the petroleum fraction collected in the test tube onto the cotton in the evaporating dish.
8. Ignite the cotton and observe the colour of the flame and the quantity of soot by placing filter paper above the flame.
9. Repeat steps 6 to 8 for petroleum fractions collected in test tubes 2, 3 and 4.
10. Record your observations in the table below.

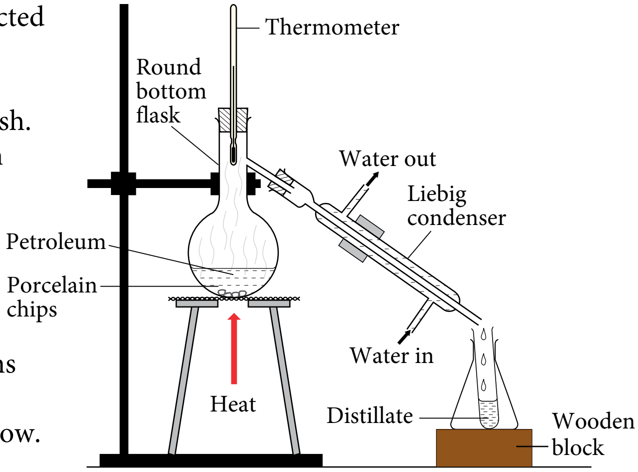


Figure 2.4

Result:

Test tube	Boiling point/°C	Colour	Viscosity	Sootiness
1	30 – 80			
2	80 – 120			
3	120 – 160			
4	160 – 200			

Discussion:

1. Why are porcelain chips added into the round bottom flask?
2. Why is a normal thermometer not used in this activity?
3. State the relation between the boiling point of the fraction of petroleum and the following:
   (a) its colour,
   (b) its viscosity, and
   (c) quantity of soot formed after burning.
4. Which fraction of petroleum is most flammable?

Prepare a complete report after carrying out this laboratory activity.

What are the alternative sources of hydrocarbons?

Chemistry Portal

Bioethanol, Biodiesel and Biogas
https://bit.ly/kpkt5v23

- Based on our current rate of usage, scientists predict that most of the petroleum reserves on earth will be exhausted within 100 years. Therefore, there is a need for proactive and effective steps to produce alternative resources to replace petroleum.
- Alternatives to hydrocarbon refer to alternative energy sources other than nonrenewable fossil fuels.
- Biomass is organic matter of plants and animals. It contains latent energy derived from the sun.
- These alternative resources are renewable. Alternative energy sources can be derived from many chemical processes derived from biomass.
- Figure 2.5 shows examples of alternative energy sources.

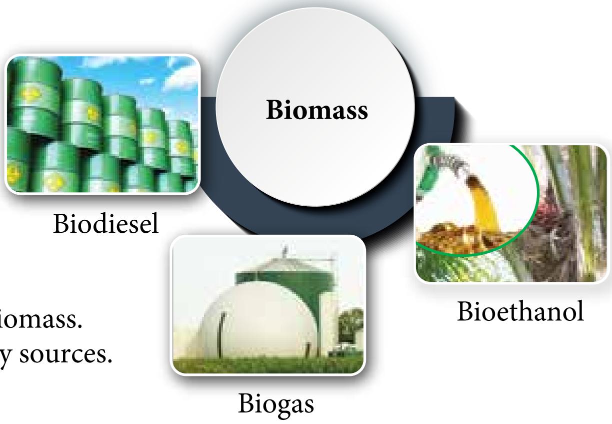


Figure 2.5 Examples of alternative energy sources

ACTIVITY 2B

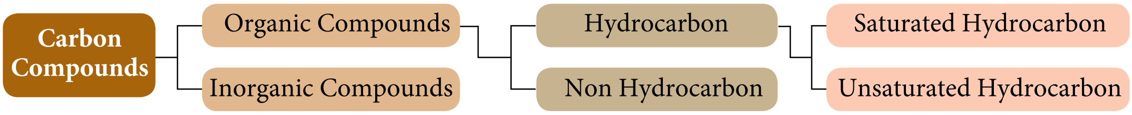
PAK21

Conducting project-based learning to produce bioethanol as an alternative energy source of hydrocarbon from organic wastes.

Produce bioethanol by using food wastes found in your surroundings. Discuss with your teacher in order to conduct the activity in the school laboratory.

Self Assess 2.1

1. The following figure shows classifications of carbon compounds.



Based on the figure above, state the definitions of:
(a) Organic compounds.
(b) Hydrocarbon and non hydrocarbon.
(c) Saturated and unsaturated hydrocarbons.

2. (a) What is meant by cracking?
(b) Copy and complete the following reactions:
(i) $C_{10}H_{22} \rightarrow C_6H_{14} +$ …………..
(ii) ………….. $\rightarrow C_4H_8 + C_3H_6 + C_4H_{12}$
(c) Discuss the importance of the cracking process.

2.2 HOMOLOGOUS SERIES

What is homologous series?

- There are millions of organic compounds known so far.
- In order to study the physical properties and chemical reactions of organic compounds, they are classified into groups of compounds called the homologous series.
- The homologous series has the following characteristics:

i	The same general formula.
ii	The same functional group.
iii	The same chemical properties.
iv	Consecutive members differ by one carbon atom and two hydrogen atoms (CH_2 or relative molecular mass = 14).
v	Physical properties that gradually change from one member to the next.

- The homologous series that we will learn in this chapter are alkane, alkene, alkyne, alcohol, carboxylic acid and ester as shown in Table 2.3.

Learning Standards

Pupils are able to:

2.2.1 explain homologous series.

2.2.2 construct molecular formulae and structural formulae, and name the members of the homologous series.

2.2.3 describe physical properties of the compounds in a homologous series.

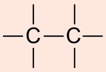
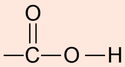
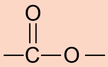
INFO

- A functional group is a group of atoms bonded to an organic molecular compound.
- The functional group determines the chemical properties of the homologous series.
- Chemical reactions occur at the functional group.

Do you know

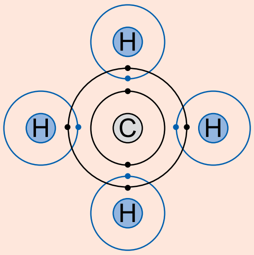
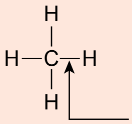
Each homologous series consists of members according to the number of carbon atoms, n.

Table 2.3 The homologous series that will be learned in this topic

Homologous series	General formula	Functional group	Name of functional group	Type of organic compound
Alkane	C_nH_{2n+2} , n = 1, 2, 3, …	 $-\overset{\vert}{\underset{\vert}{C}}-\overset{\vert}{\underset{\vert}{C}}-$	Single bond between carbon atoms	Saturated hydrocarbon
Alkene	C_nH_{2n} , n = 2, 3, ……	$>C=C<$	Double bond between carbon atoms	Unsaturated hydrocarbon
Alkyne	C_nH_{2n-2} , n = 2, 3, ……	$-C\equiv C-$	Triple bond between carbon atoms	Unsaturated hydrocarbon
Alcohol	$C_nH_{2n+1}OH$, n = 1, 2, …	$-OH$	Hydroxyl	Non hydrocarbon
Carboxylic acid	$C_nH_{2n+1}COOH$, n = 0, 1, 2..	 $-\overset{O}{\overset{\Vert}{C}}-O-H$	Carboxyl	Non hydrocarbon
Ester	$C_mH_{2m+1}COOC_nH_{2n+1}$ n = 0,1, 2, ...n = 1,2,3…	 $-\overset{O}{\overset{\Vert}{C}}-O-$	Carboxylate	Non hydrocarbon

Molecular Formula, Structural Formula, and the Nomenclature of Homologous Series Members

- The molecular formula is a chemical formula that shows the type and actual number of atoms of each element in a molecule.
- The structural formula shows the type of bond and how the atoms in a molecule are bonded to each other. Example:

Molecular formula of methane	Electron arrangement in methane	Structural formula of methane
CH_4		 Represents one pair of electrons shared to form a single covalent bond

- The names of the members of each homologous series in a straight chain, according to the IUPAC nomenclature, consist of two components which are:

Root name
Represents the number of carbon atoms in the longest chain

Suffix
Represents the homologous series

- Table 2.4 shows the root name of the members of homologous series according to the number of carbon atoms in the longest carbon chain.

Table 2.4 The root name of the members of homologous series

Number of carbon atom	1	2	3	4	5	6	7	8	9	10
Root name	Meth	Eth	Prop	But	Pent	Hex	Hept	Oct	Non	Dec

- Table 2.5 shows the suffix of homologous series members.

Table 2.5 Suffix of homologous series members

Homologous series	Alkane	Alkene	Alkyne	Alcohol	Carboxylic acid	Ester
Suffix	“ane”	“ene”	“yne”	“ol”	“oic”	“oate”

Example:
Write the molecular formula and the name of an alkane with three carbon atoms.
When n = 3
Molecular formula for $C_nH_{2n+2} = C_3H_{2(3)+2} = C_3H_8$

Root name : Prop Suffix: -ane

The name of the alkane with three carbon atoms is propane.

Do you know

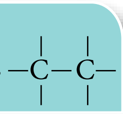
The nomenclature of organic compounds is based on the regulations set by the International Union of Pure and Applied Chemistry (IUPAC).

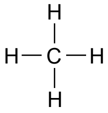
Alkane

- Photographs 2.2 and 2.3 show the use of members of the alkane homologous series in their natural existence and for cooking, respectively.

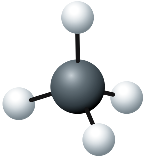
Photograph 2.2 The thin waxy layer on fruits is an alkane

Photograph 2.3 Butane gas, C_4H_{10} used for cooking is an alkane

Saturated Hydrocarbon	The presence of a single covalent bond between carbon atoms.
Functional Group	A single covalent bond between carbon atoms,  $-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}}-$
General Formula	C_nH_{2n+2} , n = 1,2,3...



Structural formula of CH_4



Model of CH_4 molecule

INFO

Each carbon atom is bonded to four other atoms by a single covalent bond of C—C or C—H.

Example:
First member, n = 1
Molecular formula: $C_1 H_{2(1)+2} = CH_4$
Name of member: Methane (Refer to Tables 2.4 and 2.5)

Chemistry Portal

Constructing Models of Alkane Molecules
https://bit.ly/kpkt5v50

ACTIVITY 2C Constructing a Model of an Alkane Molecule

PAK21

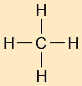
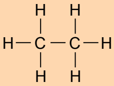
Conduct this activity in groups.

Materials: Model of carbon and hydrogen atoms

Procedure:

1. Construct a molecular model for the first ten members of the straight chain alkane using the provided model.
2. Referring to the model built for the first ten members of straight chain alkane:
   (a) write the molecular formula.
   (b) draw the structural formula.
   (c) name them according to the IUPAC nomenclature.
3. Present your work by using Table 2.6 as your reference.

Table 2.6 The first ten members of alkanes

Number of carbon atom	Name of alkane	Molecular formula C_nH_{2n+2}	Structural formula
1	Methane	CH_4	
2	Ethane	C_2H_6	

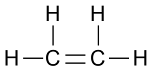
Chemistry Portal

The First Ten Members of Alkanes
https://bit.ly/kpkt5n33

Alkene

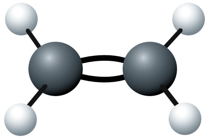
- Did you know that fruits produce ethene gas, C_2H_4 naturally, causing them to ripen. Ethene gas, C_2H_4 is a member of the alkene homologous series.

Photograph 2.4 Ripening bananas



$$H-\overset{H}{\overset{|}{C}}=\overset{H}{\overset{|}{C}}-H$$

Structural formula of C_2H_4



Model of C_2H_4 molecule

Unsaturated Hydrocarbon	The presence of double covalent bonds between carbon atoms.
Functional Group	Double bond between carbon atoms, $>C=C<$
General Formula	C_nH_{2n} , n = 2,3...

Example:
First member, n = 2
Molecular formula: $C_2H_{2(2)} = C_2H_4$

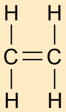
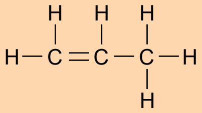
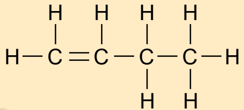
- Root name: Obtained from the longest carbon chain.
- Add the suffix "ene" to the root name because "ene" is a member of the alkene homologous series.

Name of member: Ethene

ACTIVITY 2D

Copy and complete Table 2.7 for the first nine members of alkenes.

Table 2.7 The first nine members of alkenes

Number of carbon atom	Name	Molecular formula	Structural formula
2	Ethene	C_2H_4	
3	Propene	C_3H_6	
4	But-1-ene	C_4H_8	

Chemistry Portal

The First Nine Members of Alkenes
https://bit.ly/kpkt5n34

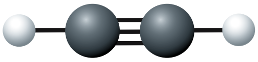
Alkyne

- Photograph 2.5 shows ethyne gas, C_2H_2 that is used for cutting metal. Ethyne, C_2H_2 is a member of the alkyne homologous series.

Photograph 2.5 Ethyne gas that is used for metal cutting

H—C≡C—H

Structural formula of C_2H_2



Model of C_2H_2 molecule

Unsaturated Hydrocarbon	The presence of triple covalent bonds between carbon atoms.
Functional Group	Triple bond between carbon atoms, $-C\equiv C-$
General Formula	C_nH_{2n-2} , n = 2,3...

Example:
First member, n = 2
Molecular formula: $C_2H_{2(2)-2} = C_2H_2$

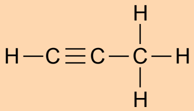
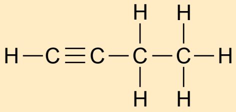
- Root name: Obtained from the longest carbon chain.
- Add the suffix "yne" to the root name because "yne" is a member of the alkyne homologous series.

Name of member: Ethyne

Activity 2E

Copy and complete Table 2.8 for the first six members of alkynes.

Table 2.8 The first six members of alkynes

Number of carbon atom	Name	Molecular formula	Structural formula
2	Ethyne	C_2H_4	H—C≡C—H
3	Propyne	C_3H_6	 $H-C\equiv C-\underset{H}{\overset{H}{\mid}}{C}-H$
4	But-1-yne	C_4H_6	 $H-C\equiv C-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$

Chemistry Portal

The First Six Members of Alkynes
https://bit.ly/kpkt5n35

Alcohol

- Photograph 2.6 shows examples of various items produced from members of alcohol homologous series.

Antiseptic Perfume

Solvent Fuel

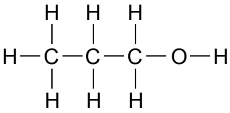
Photograph 2.6 Examples of items that are produced from alcohols

Non Hydrocarbon	Contains carbon, hydrogen and oxygen atoms.
Functional Group	Hydroxyl group, —OH
General Formula	$C_nH_{2n+1}OH$, n = 1,2,3...

Do you know

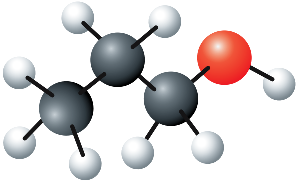
The hydroxyl group —OH is different from the hydroxide ion OH^- in alkali. There are no hydroxide ions OH^- in alcohol.

Example:
Third member, n = 3
Molecular formula: $C_3H_{2(3)+1}OH = C_3H_7OH$



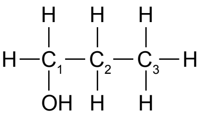
$$\begin{matrix} & H & & H & & H & & & \\ & | & & | & & | & & & \\ H- & C & - & C & - & C & - & O & -H \\ & | & & | & & | & & & \\ & H & & H & & H & & & \end{matrix}$$

Structural formula of C_3H_7OH



Model of C_3H_7OH molecule

- Naming of straight chain alcohols according to the IUPAC nomenclature:
  - (i) Determine the number of carbon atoms in the longest carbon chain containing the hydroxyl group —OH to derive the name of the alkane containing the same number of carbon atoms as alcohol.
  - (ii) Replace the "e" ending from the alkane name with "ol".
    Example:



$$\begin{matrix} & H & & H & & H & \\ & | & & | & & | & \\ H- & C_1 & - & C_2 & - & C_3 & -H \\ & | & & | & & | & \\ & OH & & H & & H & \end{matrix}$$

Corresponding alkane name: Propane

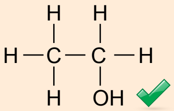
Alcohol name: Propanol

Hydroxyl position is at the first carbon

IUPAC name: Propan-1-ol

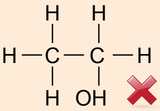
Mind Challenge

Structural formula A



$$\begin{matrix} & H & & H & \\ & | & & | & \\ H- & C & - & C & -H \\ & | & & | & \\ & H & & OH & \end{matrix}$$ ✓

Structural formula B



$$\begin{matrix} & H & & H & \\ & | & & | & \\ H- & C & - & C & -H \\ & | & & | & \\ & H & & OH & \end{matrix}$$ ✗

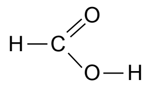
Discuss why structural formula A is correctly drawn while structural formula B is incorrect.

Carboxylic Acid

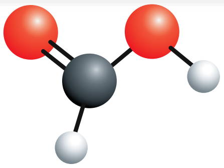
- Ant bites that cause pain contain methanoic acid, HCOOH or formic acid. Vinegar contains ethanoic acid, CH_3COOH, which is also known as acetic acid. Do you know that ethanoic acid and methanoic acid are members of carboxylic acid homologous series?

Photograph 2.7 Ant bites and vinegar

Non Hydrocarbon	Contains carbon, hydrogen and oxygen atoms.
Functional Group	Carboxyl group, —COOH
General Formula	$C_nH_{2n+1}COOH$, n = 0,1,2,3...



Structural formula HCOOH



Model of HCOOH molecule

- Naming of carboxylic acids according to the IUPAC nomenclature:
  - (i) Determine the number of carbon atoms, and state the corresponding alkane name.

Example:
First member, n = 0
Molecular formula: $C_0\,H_{2(0)+1}$ COOH = HCOOH

  - (ii) Replace the "e" ending from the alkane name with "oic acid".
    Example:

(a) Molecular formula: HCOOH
The number of carbon atom is 1
The corresponding alkane name is methane.
The name for HCOOH is methanoic acid.

(b) Molecular formula: CH_3COOH
The number of carbon atoms is 2
The corresponding alkane name is ethane.
The name for CH_3COOH is ethanoic acid.

ACTIVITY 2F

1. Copy and complete Table 2.9 to show the molecular formula, structural formula and the names for the first six straight chain members of alcohols and carboxylic acids.

Table 2.9 The first six members of alcohols and carboxylic acids

n	Molecular formula	Number of carbon atom	Structural formula	Name

2. Explain why the first value of n is 0 for the general formula of the carboxylic acid homologous series.
3. Explain why the carboxyl functional group —COOH always occur at the first carbon.

Chemistry Portal

Worksheet for the First Six Members of Alcohols and Carboxylic Acids
https://bit.ly/kpkt5n4

Describing the Physical Properties of Compounds in a Homologous Series

Physical Properties of Alkanes, Alkenes and Alkynes

- Members of the homologous series of alkanes, alkenes and alkynes consist of neutral molecules.
- Alkanes, alkenes and alkynes have physical properties of covalent compounds as shown in Figure 2.6.

Physical Properties of Alkanes, Alkenes and Alkynes

Solubility	Electrical Conductivity	Melting and Boiling Points	Density
• Soluble in organic solvent. • Insoluble in water.	• Cannot conduct electricity in all states.	• Low melting and boiling points that increase as the molecule size increases.	• Less dense than water.

Figure 2.6 Physical properties of alkanes, alkenes and alkynes

ACTIVITY 2G

PAK21

You are required to conduct this activity in groups.
Table 2.10 shows the physical properties of the first seven members of alkanes and Table 2.11 shows the physical properties of the first six members of alkenes.

Table 2.10 Physical properties of the first seven members of alkanes

Molecular formula	Melting point/°C	Boiling point/°C	Physical state at room temperature
CH_4	-182	-162	…
C_2H_6	-183	-89	…
C_3H_8	-188	-42	…
C_4H_{10}	-138	-0.5	…
C_5H_{12}	-130	36	…
C_6H_{14}	-95	69	…
C_7H_{16}	-91	98	…

Table 2.11 Physical properties of the first six members of alkenes

Molecular formula	Melting point/°C	Boiling point/°C	Physical state at room temperature
C_2H_4	-169	-104	…
C_3H_6	-185	-47	…
C_4H_8	-185	-6	…
C_5H_{10}	-165	30	…
C_6H_{12}	-140	63	…
C_7H_{14}	-119	93	…

1. Complete Tables 2.10 and 2.11.
2. Based on the data in Tables 2.10 and 2.11, state and explain the three characteristics of the homologous series shown by alkanes and alkenes.

Present your answer in a Gallery Walk activity.

- From Activity 2G, you are able to identify the changes in the physical properties for the first seven members of alkanes and the first six members of alkenes.
- Therefore, it can be concluded that as the number of carbon atoms in each molecule increases, the molecular size increases, the van der Waals force or the attraction between molecules also becomes stronger. More heat energy is needed to overcome this force, and therefore the melting point and boiling point also increase.

Physical Properties of Alcohols and Carboxylic Acids

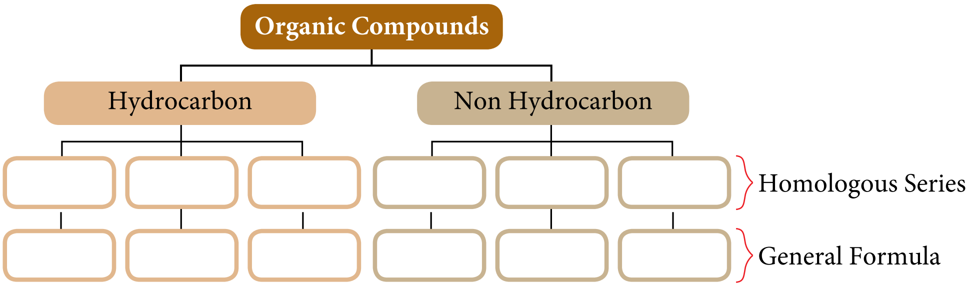
- Alcohols and carboxylic acids are non hydrocarbon organic compounds containing carbon, hydrogen and oxygen.
- The boiling points of alcohols and carboxylic acids are relatively higher than their corresponding alkenes.
- Their solubility in water decreases as the molecule size increases.
- Table 2.12 shows the physical properties of alcohols and carboxylic acids.

Table 2.12 Physical properties of alcohols and carboxylic acids

Homologous series	Alcohol	Carboxylic acid
Boiling point	• Low boiling point that increases with the increasing number of carbon atoms per molecule.	• Low boiling point that increases with the increasing number of carbon atoms per molecule.
Physical state at room temperature	• The first eleven members of alcohols exist as liquids.	• The first nine members of carboxylic acids exist as liquids.
Solubility in water	• Methanol, ethanol and propanol are miscible in water in all proportions. • As the molecular size increases, the solubility decreases.	• Methanoic acid, ethanoic acid and propanoic acid are very soluble in water. • As the molecular size increases, the solubility decreases.

Self Assess 2.2

1. Complete the following tree map with respective homologous series and general formula.



2. Table 2.13 shows the molecular formula of organic compounds P, Q, R, S and T from different homologous series.

Table 2.13

P	Q	R	S	T
C_3H_7COOH	C_4H_8	C_3H_7OH	C_7H_{16}	C_5H_8

(a) For all compounds in the table above:
   (i) state their homologous series,
   (ii) draw the structural formula,
   (iii) write their IUPAC names.

(b) List all compounds that exist in the form of:
   (i) gas at room temperature.
   (ii) liquid at room temperature.

(c) List all compounds that:
   (i) dissolve in water.
   (ii) do not dissolve in water.

(d) Compare the boiling points of compounds Q and S. Explain your answer.

2.3

CHEMICAL PROPERTIES AND INTERCONVERSION OF COMPOUNDS BETWEEN HOMOLOGOUS SERIES

Learning Standards

Pupils are able to:

2.3.1 describe the chemical properties of each homologous series through activities.

2.3.2 understand ester through activity.

Chemical Properties of Alkanes

- Each homologous series has a functional group that is different from other homologous series. The functional group determines the chemical properties of a homologous series.
- Alkanes are saturated hydrocarbons that only have a single covalent bond C—C and C—H.
- Alkanes are unreactive because the strong C—C and C—H bonds can only be broken by a large amount of energy.
- Even though alkanes do not react with most chemical substances, they undergo two types of reactions:

  I. Combustion
  II. Substitution

I. Combustion Reaction

- Alkanes burn completely in excess oxygen, O_2, releasing carbon dioxide, CO_2 and water, H_2O. For example, a complete combustion of methane, CH_4 in excess oxygen, O_2 occurs as follows:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

- Alkanes undergo incomplete combustion when there is not enough or limited supply of oxygen, O_2. Incomplete combustion of alkanes produces carbon particles, C (in the form of soot), carbon monoxide gas, CO which is poisonous, and water, H_2O. An example of an incomplete combustion of methane, CH_4 occurs as follows:

$$2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(l)$$

$$CH_4(g) + O_2(g) \rightarrow C(s) + 2H_2O(l)$$

- The combustion of alkanes release large amounts of heat. Therefore, it is very suitable to be used as fuel.
- The combustion of alkanes with more number of carbon atoms, C will produce more soot.

INFO

Balancing the equation for combustion:
Step 1: Balance C.
Step 2: Balance H.
Step 3: Balance O and you can use fractions.

Do you know?

- The main component of natural gas is methane, CH_4.
- Methane gas, CH_4 is also produced when organic waste decomposes in the absence of oxygen, O_2. Due to its flammability, methane, CH_4 can cause fires at landfills and peatlands.

Mind Challenge

Small hydrocarbon molecules such as natural gas for vehicles (NGV) and petrol are denser than air. Therefore, at petrol stations, the use of mobile phones or smoking while refuelling is prohibited as shown in Figure 2.7. Explain the rationale for this prohibition by relating to the physical and chemical properties of these hydrocarbons.

Figure 2.7 Prohibition on smoking and using mobile phones

II. Substitution Reaction

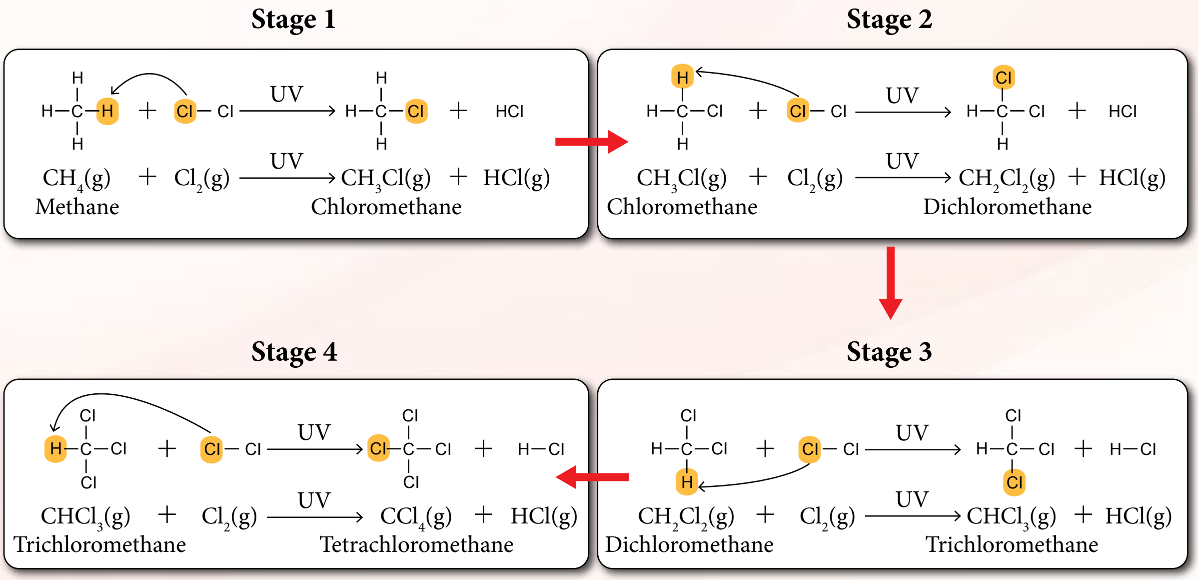
- Alkanes undergo substitution reaction with halogens such as chlorine, Cl_2 and bromine, Br_2 under sunlight or ultraviolet (UV) rays.

Substitution reaction occurs when each hydrogen atom, H in an alkane molecule is substituted one by one with halogen atoms, until all the hydrogen atoms, H have been substituted.

- Sunlight or UV rays are needed to break the covalent bonds in the halogen molecules, such as chlorine, Cl_2 to produce chlorine atoms, Cl.

Example:

- When methane gas, CH_4 reacts with chlorine gas, Cl_2 under sunlight, various molecules are formed due to the substitution reaction.
- The following chemical equations show how the chlorine atoms, Cl from the chlorine molecule, Cl_2 replaces, stage by stage, the hydrogen atoms, H from the methane molecule, CH_4 until tetrachloromethane molecule, CCl_4 is formed.



Stage 1

$$CH_4(g) + Cl_2(g) \xrightarrow{UV} CH_3Cl(g) + HCl(g)$$

Methane → Chloromethane

Stage 2

$$CH_3Cl(g) + Cl_2(g) \xrightarrow{UV} CH_2Cl_2(g) + HCl(g)$$

Chloromethane → Dichloromethane

Stage 3

$$CH_2Cl_2(g) + Cl_2(g) \xrightarrow{UV} CHCl_3(g) + HCl(g)$$

Dichloromethane → Trichloromethane

Stage 4

$$CHCl_3(g) + Cl_2(g) \xrightarrow{UV} CCl_4(g) + HCl(g)$$

Trichloromethane → Tetrachloromethane

ACTIVITY 2H

PAK21

Conduct this activity in groups.

1. Write the balance equation for the combustion of the following alkane:
   (a) Ethane, C_2H_6 (b) Propane, C_3H_8 (c) Hexane, C_6H_{14} (d) Octane, C_8H_{18}
2. Based on your knowledge on the reaction between alkane and halogen, discuss how ethane, C_2H_6 and bromine, Br_2 react with the presence of sunlight:
   (a) Write the equation for each stage of the substitution reaction that occurs.
   (b) Name each of the compounds formed.

   Share your answers in a Gallery Walk activity.

Chemical Properties of Alkenes

- Alkenes are chemically more reactive than alkanes due to the existence of a double covalent bond between two carbon atoms, C. Almost all chemical reactions in alkenes occur at the double bond.
- Chemical reactions of alkenes are as follows:
  I. Combustion.
  II. Addition.
  III. Addition polymerisation.

I. Combustion Reaction

- Alkenes burn completely in excess oxygen, O_2 to produce carbon dioxide, CO_2 and water, H_2O. The combustion of ethene, C_2H_4 is as follows:

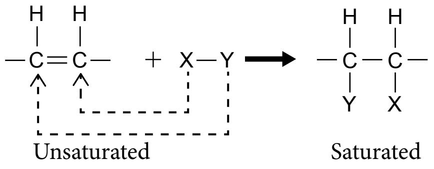
$$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$$

- Alkenes undergo incomplete combustion in insufficient oxygen, O_2 supply to form carbon particles (in the form of soot), carbon monoxide gas, CO that is poisonous and water, H_2O.
- The combustion of alkenes can produce a flame with more soot compared to their corresponding alkanes. This is because alkenes have a higher percentage of carbon by mass compared to alkanes.

II. Addition Reaction

- As alkenes are unsaturated hydrocarbons, they undergo addition reactions.

Addition reaction occurs when another atom is added to each carbon atom, C at the double bond $-C{=}C-$ to form a single covalent bond $-C-C-$.



- Five addition reactions that occur on alkenes:

1. Addition of hydrogen (Hydrogenation).
2. Addition of halogen (Halogenation).
3. Addition of halogen halide.
4. Addition of water (Hydration).
5. Oxidation with acidified potassium manganate(VII), $KMnO_4$ solution.

1. Addition of Hydrogen (Hydrogenation)

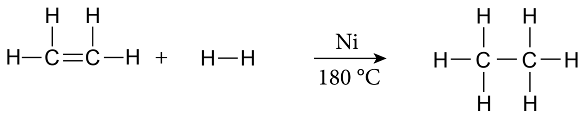
- Alkenes react with hydrogen at a temperature of 180 °C in the presence of nickel /platinum as a catalyst to produce the corresponding alkanes.

$$\underset{\text{Alkene}}{C_nH_{2n}} + H_2 \xrightarrow[180\text{ °C}]{Ni} \underset{\text{Alkane}}{C_nH_{2n+2}}$$

Chemistry Portal

Hydrogenation of Ethene
https://bit.ly/kpkt5v24

Example:
Ethene gas, C_2H_4 reacts with hydrogen gas, H_2 in the presence of nickel as a catalyst at 180 °C to produce ethane gas, C_2H_6.



$$H{-}\overset{\overset{H}{|}}{C}{=}\overset{\overset{H}{|}}{C}{-}H \;+\; H{-}H \xrightarrow[180\text{ °C}]{Ni} H{-}\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}{-}\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}{-}H$$

Ethene Hydrogen Ethane

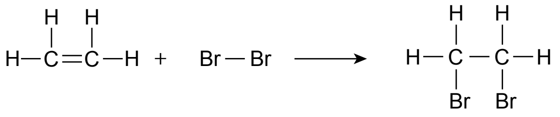
$$C_2H_4(g) + H_2(g) \xrightarrow[180\text{ °C}]{Ni} C_2H_6(g)$$

Do you know?

Catalytic hydrogenation is a method used to convert vegetable oils to solid fats in the margarine manufacturing industry.

2. Addition of Halogen (Halogenation)

- Alkenes react with halogens such as chlorine, Cl_2 and bromine, Br_2 at room conditions. For example, when ethene gas, C_2H_4 is bubbled through bromine water, Br_2, the brown colour of bromine water, Br_2 is decolourised.



$$H{-}\overset{\overset{H}{|}}{C}{=}\overset{\overset{H}{|}}{C}{-}H \;+\; Br{-}Br \longrightarrow H{-}\underset{\underset{Br}{|}}{\overset{\overset{H}{|}}{C}}{-}\underset{\underset{Br}{|}}{\overset{\overset{H}{|}}{C}}{-}H$$

Ethene Bromine 1,2-dibromoethane

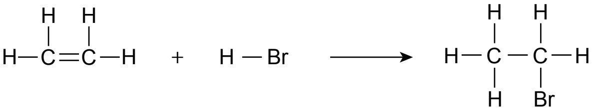
$$C_2H_4(g) + Br_2(l) \longrightarrow C_2H_4Br_2(l)$$

Mind Challenge

Predict the products of the reaction between ethene, C_2H_4 and chlorine, Cl_2.

3. Addition of Hydrogen Halide

- Alkenes react with hydrogen halides, such as hydrogen chloride, HCl or hydrogen bromide, HBr at room temperature to form haloalkane.
- For example, when dry hydrogen bromide gas, HBr is passed through ethene gas, C_2H_4, bromoethane is produced.



Ethene Hydrogen Bromide Bromoethane

$$C_2H_4(g) + HBr(g) \longrightarrow C_2H_5Br(l)$$

4. Addition of Water (Hydration)

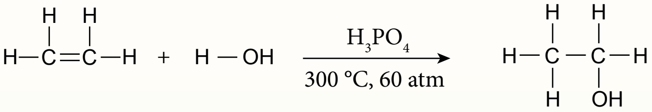
- Alkenes react with water (in the form of steam) at high temperature and pressure, in the presence of phosphoric acid, H_3PO_4 as a catalyst to produce alcohol.

$$C_nH_{2n} + H_2O \xrightarrow[300\ °C,\ 60\ atm]{H_3PO_4} C_nH_{2n+1}OH$$

- For example, ethene gas, C_2H_4 undergoes an addition reaction with steam at the temperature of 300 °C, pressure of 60 atm and catalysed by phosphoric acid, H_3PO_4 to produce ethanol, C_2H_5OH.

Do you know

Hydration of alkenes is a method of alcohol preparation in the alcohol production industry.

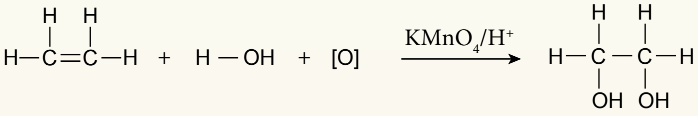


Ethene Steam Ethanol

$$C_2H_4(g) + H_2O(g) \longrightarrow C_2H_5OH(l)$$

5. Oxidation with Acidified Potassium Manganate(VII), $KMnO_4$ Solution

- Alkenes react with acidified potassium manganate(VII), $KMnO_4$ solution.
- In this reaction, two hydroxyl groups —OH are added to the double bond.
- Alkenes decolourise the purple colour of acidified potassium manganate(VII), $KMnO_4$ solution. For example:



Ethene Ethan-1,2-diol

$$C_2H_4(g) + H_2O(l) + [O] \xrightarrow{KMnO_4/H^+} C_2H_4(OH)_2$$

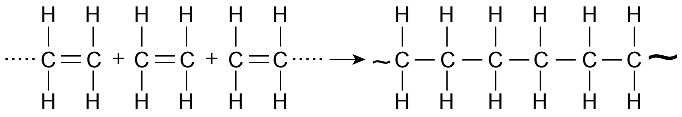
III. Addition Polymerisation Reaction

- Small alkene molecules undergo addition reaction with one another to form long chain molecules.
- Alkene molecules link together to form a long chain of molecules called polymer, while the smaller alkene molecules are the basic units called monomers.
- The reaction of alkene monomers to form polymers is called addition polymerisation.
  Example:

Topic Link **Polymer:** Addition polymerisation on page 147.

Ethene, C_2H_4 undergoes addition polymerisation at 200 °C and pressure of 1200 atm to produce polythene.

- This reaction is simplified in Figure 2.8.

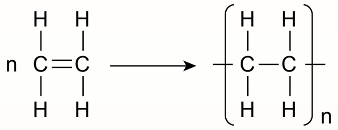


Monomer: Ethene

Polymer: Polytene

Figure 2.8 Polymerisation of ethene, C_2H_4

- In general, the polymerisation equation is as follows:



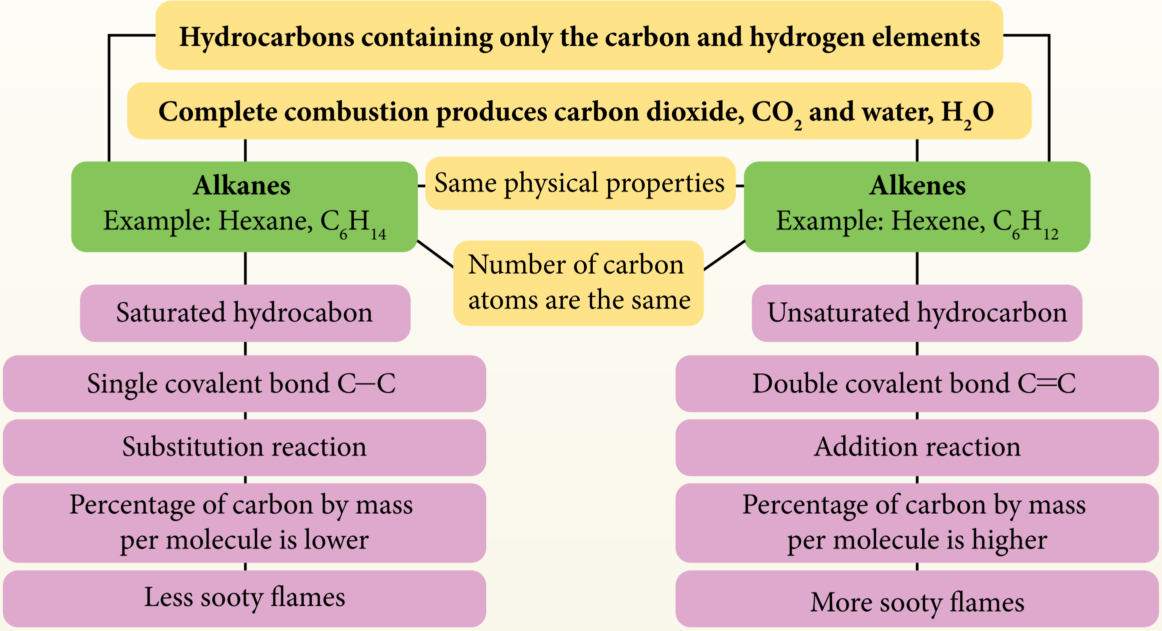
$$n\,H_2C{=}CH_2 \longrightarrow \left[\!-CH_2-CH_2-\!\right]_n$$

n is any sizeable integer value.

Mind Challenge

Compare and contrast ethene and polythene with reference to their structural formulae.

Comparison Between Alkanes and Alkenes



Hydrocarbons containing only the carbon and hydrogen elements

Complete combustion produces carbon dioxide, CO_2 and water, H_2O

Alkanes
Example: Hexane, C_6H_{14}

Same physical properties

Number of carbon atoms are the same

Alkenes
Example: Hexene, C_6H_{12}

Alkanes	Alkenes
Saturated hydrocabon	Unsaturated hydrocarbon
Single covalent bond C—C	Double covalent bond C=C
Substitution reaction	Addition reaction
Percentage of carbon by mass per molecule is lower	Percentage of carbon by mass per molecule is higher
Less sooty flames	More sooty flames

Experiment 2A Comparing Alkanes and Alkenes

PAK21 Learning Science Through Inquiry

A. Sootiness of Flame

Aim: To compare hexane, C_6H_{14} and hexene, C_6H_{12} for sootiness of flames during combustion.

Problem statement: Do alkanes and alkenes burn with the same quantity of soot?

Hypothesis: Hexene, C_6H_{12} burns with a more sooty flame compared to hexane, C_6H_{14}.

Variable:
(a) Manipulated variable : Hexane, C_6H_{14} and hexene, C_6H_{12}.
(b) Responding variable : Sootiness of flames.
(c) Constant variable : Volume of hexane, C_6H_{14} and hexene, C_6H_{12}.

Materials: Hexane, C_6H_{14}, hexene, C_6H_{12}, wooden splinter, matches and filter paper.

Apparatus: Evaporating dish and measuring cylinder.

Procedure:
1. Pour 2 cm^3 of hexane, C_6H_{14} into an evaporating dish.
2. Use a lighted wooden splinter to ignite hexane, C_6H_{14}.
3. When hexane, C_6H_{14} starts to burn, place a piece of filter paper above the flame as shown in Figure 2.9.
4. Repeat steps 1 to 3 using hexene, C_6H_{12} to replace hexane, C_6H_{14}.
5. Record the observation of the sootiness of the flame and the quantity of soot formed on the filter paper.

CAUTION
Use safety goggles when conducting this experiment.

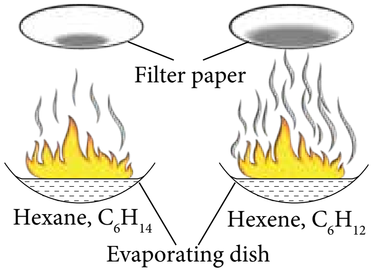


Figure 2.9

B. Reaction with Bromine Water, Br_2

Aim: To compare hexane, C_6H_{14} and hexene, C_6H_{12} using bromine water, Br_2.

Hypothesis: Hexene, C_6H_{12} decolourises the brown colour of bromine water, Br_2 while hexane, C_6H_{14} does not decolourise the brown colour of bromine water, Br_2.

Variable:
(a) Manipulated variable : Hexane, C_6H_{14} and hexene, C_6H_{12}.
(b) Responding variable : Colour change of bromine water, Br_2.
(c) Constant variable : Volume of hexane, C_6H_{14} and hexene, C_6H_{12}.

Materials: Hexane, C_6H_{14}, hexene, C_6H_{12} and bromine water, Br_2 in 1,1,1-trichloroethane, CH_3CCl_3.

Apparatus: Test tube, measuring cylinder and dropper.

Procedure:
1. Pour 2 cm^3 of hexane, C_6H_{14} into a test tube.
2. Add 2 - 3 drops of bromine water, Br_2 in 1,1,1-trichloroethane, CH_3CCl_3 to hexane, C_6H_{14} as shown in Figure 2.10.
3. Shake the mixture.
4. Record all observations.
5. Repeat steps 1 to 4 using hexene, C_6H_{12} to replace hexane, C_6H_{14}.

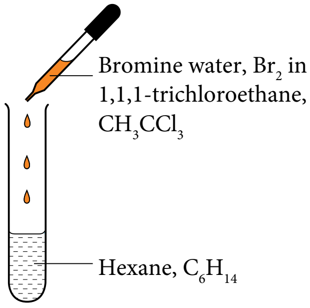


Figure 2.10

C. Reaction with Acidified Potassium Manganate(VII), $KMnO_4$ Solution

Aim: To compare hexane, C_6H_{14} and hexene, C_6H_{12} using acidified potassium manganate(VII), $KMnO_4$ solution.

Hypothesis: Hexene, C_6H_{12} decolourises the purple colour of acidified potassium manganate(VII), $KMnO_4$ solution while hexane, C_6H_{14} does not decolourise acidified potassium manganate(VII), $KMnO_4$ solution.

Variable:

(a) Manipulated variable : Hexane, C_6H_{14} and hexene, C_6H_{12}.
(b) Responding variable : Colour change of acidified potassium manganate(VII), $KMnO_4$ solution.
(c) Constant variable : Volume of hexane, C_6H_{14} and hexene, C_6H_{12}.

Materials: Hexane, C_6H_{14}, hexene, C_6H_{12} and acidified potassium manganate(VII), $KMnO_4$ solution.

Apparatus: Test tube, measuring cylinder and dropper.

Procedure:

1. Pour 2 cm^3 of hexane, C_6H_{14} into a test tube.
2. Add 2 – 3 drops of acidified potassium manganate(VII), $KMnO_4$ solution to hexane, C_6H_{14}, as shown in Figure 2.11.
3. Shake the mixture.
4. Record all the observations.
5. Repeat steps 1 to 4 using hexene, C_6H_{12} to replace hexane, C_6H_{14}.

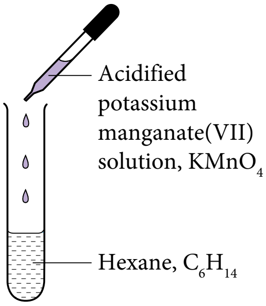


Figure 2.11

Observation:

Construct a table to record your observations.

Discussion:

1. (a) Based on your observations, compare the sootiness of flames of hexane, C_6H_{14} and hexene, C_6H_{12}.
   (b) Calculate the percentage of carbon by mass per molecule in hexane, C_6H_{14} and hexene, C_6H_{12}.
   (c) State the relationship between the percentage of carbon by mass per molecule in hexane, C_6H_{14} and hexene, C_6H_{12}, and the sootiness of the flames.
2. (a) Suggest two reagents that can be used to distinguish between hexane, C_6H_{14} and hexene, C_6H_{12}. Explain your answer.
   (b) Explain the difference in reactivity of hexane, C_6H_{14} and hexene, C_6H_{12} in terms of chemical bonds in their molecules.
3. What is the operational definition of unsaturated hydrocarbons in this experiment?

Prepare a complete report after carrying out this experiment.

- The combustion of alkenes produces more soot compared to alkanes. This is because the percentage of carbon by mass per molecule is higher in alkenes than alkanes.
  Example:

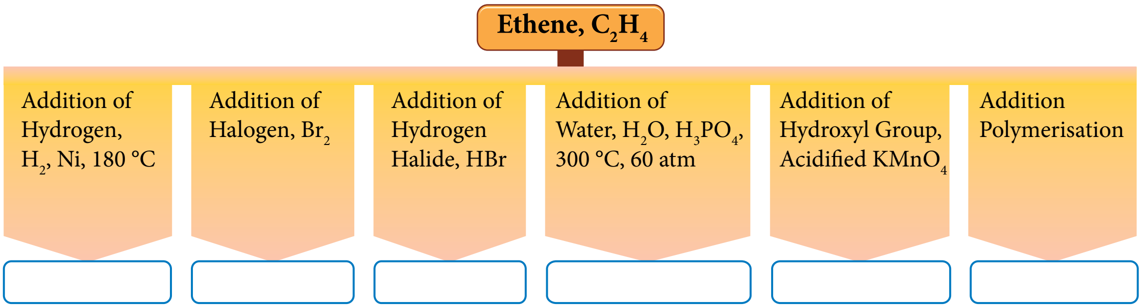
Corresponding hydrocarbon	Propane, C_3H_8	Propene, C_3H_6
Percentage of carbon by mass per molecule	$\%C = \frac{3(12)}{3(12) + 8(1)} \times 100\%$ $= 81.82\%$	$\%C = \frac{3(12)}{3(12) + 6(1)} \times 100\%$ $= 85.71\%$

- Propene, C_3H_6 burns with a sootier flame compared to propane, C_3H_8 because the percentage of carbon by mass per molecule in propene, C_3H_6 is higher than propane, C_3H_8.
- The soot formed is carbon. The greater the number of carbon atoms per molecule, the higher the percentage of carbon by mass per molecule and the more soot is produced by the flame.
- Alkenes react with bromine water, Br_2 and acidified potassium manganate(VII), $KMnO_4$ solution, while alkanes do not show any changes with these two reagents.
- Alkenes are more reactive than alkanes due to the presence of double bonds in alkene molecules. Addition reaction occurs in alkenes but does not occur in alkanes.

ACTIVITY 21

PAK21

1. Copy and complete the tree map by writing the chemical equation for each addition reaction that occurs on ethene, C_2H_4.



2. Hexane, C_6H_{14} and hexene, C_6H_{12} are colourless liquids.
   (a) State the difference in observations when both liquids are burnt in excess oxygen. Explain why the differences occur.
   (b) Other than combustion, describe a chemical test that can be used to distinguish these two liquids.

Preparation of Alcohols

- Ethanol, C_2H_5OH is the most important alcohol and has many uses.
- Two methods of ethanol preparation:
  (a) Fermentation of glucose or starch with the presence of yeast.
  (b) Hydration of ethene, C_2H_4 with the presence of a catalyst.

Fermentation of Glucose

- Fermentation is the process in which yeast acts on carbohydrates (sugar or starch) to produce ethanol, C_2H_5OH and carbon dioxide, CO_2 in the absence of oxygen, O_2.
- Yeast contains the enzyme zymase that acts as a catalyst, which breaks down sugar or starch into glucose. Fermentation of glucose will produce ethanol, C_2H_5OH and carbon dioxide, CO_2.

Chemical equation for fermentation:

$$\underset{\text{Glucose}}{C_6H_{12}O_6(aq)} \xrightarrow{\text{Zymase enzyme}} \underset{\text{Ethanol}}{2C_2H_5OH(l)} + \underset{\text{Carbon dioxide}}{2CO_2(g)}$$

- The ethanol, C_2H_5OH produced is purified by fractional distillation.

Hydration of Ethene

- Ethene, C_2H_4 reacts with steam (H_2O) at 300 °C and pressure of 60 atm, with the presence of phosphoric acid, H_3PO_4 as a catalyst

$$\underset{\text{Ethene}}{C_2H_4(g)} + \underset{\text{Steam}}{H_2O(g)} \xrightarrow[\text{300 °C, 60 atm}]{H_3PO_4} \underset{\text{Ethanol}}{C_2H_5OH(l)}$$

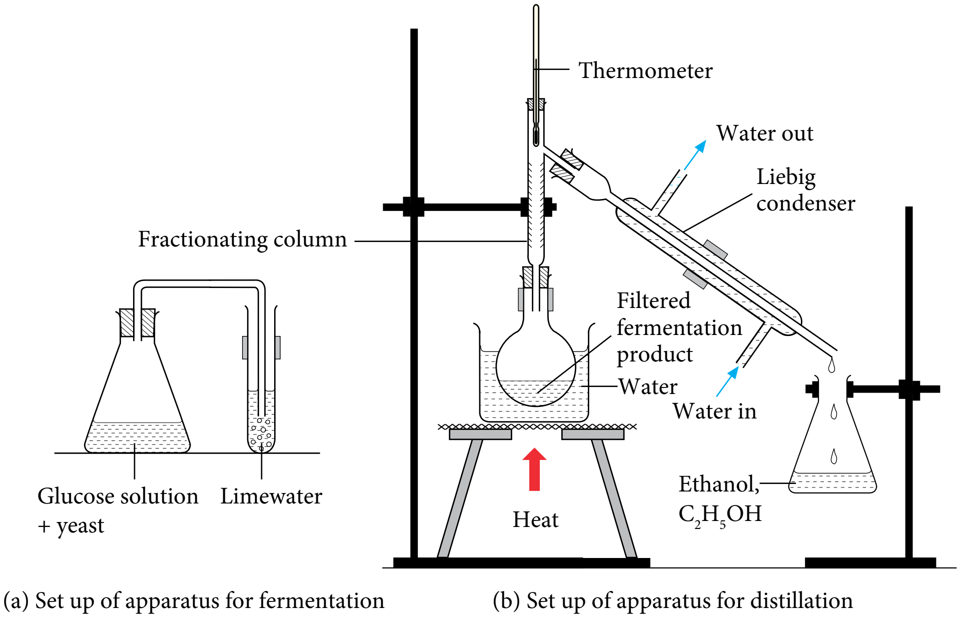
Laboratory Activity 2B Preparation of Ethanol, C_2H_5OH Through Fermentation of Glucose

PAK21 Learning Science Through Inquiry

Aim: To prepare ethanol, C_2H_5OH through fermentation of glucose.

Materials: Glucose, $C_6H_{12}O_6$, yeast, limewater, distilled water and filter paper.

Apparatus: Conical flask, beaker, measuring cylinder, round-bottom flask, delivery tube, stopper, test tube, thermometer, fractionating column, Liebig condenser, retort stand, wire gauze, Bunsen burner, tripod stand, rubber tubing, filter funnel and glass rod.



(a) Set up of apparatus for fermentation (b) Set up of apparatus for distillation

Figure 2.12 Preparation of ethanol through glucose fermentation

Procedure:

1. Put 20 g of glucose, $C_6H_{12}O_6$ into 200 cm^3 of distilled water into a conical flask.
2. Add 10 g of yeast into the conical flask and stir with a glass rod until the mixture is even.
3. Close the conical flask with a stopper connected to the delivery tube.

4. Insert the end of the delivery tube into the test tube as shown in Figure 2.12. Make sure the end of the delivery tube is dipped into the limewater.
5. Place the apparatus at room temperature (30 °C) for three days.
6. After three days, filter the mixture from the conical flask.
7. The filtrate is poured into a round-bottom flask. The apparatus for distillation is set up as shown in Figure 2.12.
8. Heat the filtrate in the water bath and collect the distillate at 78 °C.
9. Record the colour and smell of the distillate.

Observation:

Construct a table to record your observations.

Discussion:

1. What is the function of yeast in the fermentation of glucose, $C_6H_{12}O_6$?
2. Why must the end of the delivery tube be immersed in limewater?
3. Name the gas released in the fermentation of glucose, $C_6H_{12}O_6$.
4. Name the product collected in fractional distillation at 78 °C.
5. Explain why ethanol, C_2H_5OH from the filtrate can be separated at 78 °C.
6. Write the chemical equation for the fermentation of glucose, $C_6H_{12}O_6$.
7. Fermentation to produce ethanol, C_2H_5OH can also be carried out using fruits. Explain why.

Results:

1. Ethanol, C_2H_5OH can be prepared through the fermentation of glucose, $C_6H_{12}O_6$.
2. Ethanol, C_2H_5OH is a colourless and volatile liquid at room temperature.

Prepare a complete report after carrying out this laboratory activity.

Chemical Properties of Alcohols

- All alcohols have the same chemical properties due to the presence of hydroxyl group, —OH as a functional group. The important chemical reactions involving alcohols are:
  I. Combustion II. Oxidation III. Dehydration

Combustion of Alcohols

- Alcohols burn in excess oxygen, O_2 to produce carbon dioxide, CO_2 and water, H_2O.
- Alcohols are flammable and burn with a blue flame without soot.
  For example:

$$\underset{\text{Ethanol}}{C_2H_5OH(l)} + \underset{\text{Oxygen}}{3O_2(g)} \longrightarrow \underset{\text{Carbon dioxide}}{2CO_2(g)} + \underset{\text{Water}}{3H_2O(l)}$$

- The combustion of ethanol, C_2H_5OH releases large quantities of heat.
- Ethanol, C_2H_5OH can be used as fuel for rockets.

INFO

- Alkanes, alkenes and alcohols burn completely in oxygen, producing carbon dioxide gas and water.
- Perform the same steps as alkanes and alkenes to balance the equation for the combustion of alcohols.

Oxidation of Alcohols

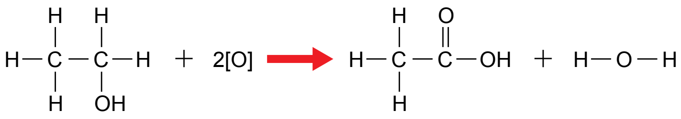
Topic Link

Redox: Redox in terms of transfer of oxygen or hydrogen on page 4.

- Alcohols can be oxidised to form carboxylic acids, a homologous series with functional group —COOH in the presence of a suitable oxidising agent.

$$\underset{\substack{n = 1,2,3\ldots \\ \text{Alcohol}}}{C_nH_{2n+1}OH} + 2[O] \rightarrow \underset{\substack{m = 0,1,2,3\ldots. \\ \text{Carboxylic acid}}}{C_mH_{2m+1}COOH} + H_2O$$

- Common oxidising agents include acidified potassium manganate(VII), $KMnO_4$ solution and acidified potassium dichromate(VI), $K_2Cr_2O_7$ solution.
  Example:
  (a) Oxidation of ethanol, C_2H_5OH by acidified potassium manganate(VII), $KMnO_4$ solution.



$$CH_3CH_2OH + 2[O] \rightarrow CH_3COOH + H_2O$$

Chemical equation:

$$\underset{\text{Ethanol}}{C_2H_5OH(l)} + 2[O] \longrightarrow \underset{\text{Ethanoic acid}}{CH_3COOH(aq)} + H_2O(l)$$

The purple colour of acidified potassium manganate(VII), $KMnO_4$ solution is decolourised in this reaction. The orange colour of acidified potassium dichromate(VI), $K_2Cr_2O_7$ solution turns green when it reacts with ethanol. In this reaction, ethanol is also oxidised into ethanoic acid.

(b) Oxidation of propanol, C_3H_7OH.

$$\underset{\text{Propanol}}{C_3H_7OH(l)} + 2[O] \longrightarrow \underset{\text{Propanoic acid}}{C_2H_5COOH(aq)} + H_2O(l)$$

Dehydration of Alcohols

- Dehydration of alcohols involves the removal of a water molecule from each alcohol molecule to produce a corresponding alkene.

$$\underset{n = 1,2,3\ldots}{C_nH_{2n+1}OH} \xrightarrow[\Delta]{\text{porcelain chips}} \underset{n = 2,3,4\ldots}{C_nH_{2n}} + H_2O$$

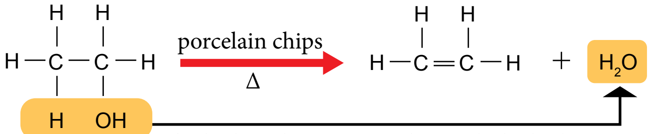
- Water molecules are removed from alcohols when alcohol vapour is flowed over a strongly heated catalyst, such as porcelain chips, aluminum oxide, alumina or concentrated sulphuric acid.

Mind Challenge

Methanol cannot undergo dehydration reaction. Explain why.

Example:

(a) Dehydration of ethanol, C_2H_5OH.



The hydroxyl group, together with the hydrogen atom, is removed from the adjacent carbon atoms to form water, H_2O.

Chemical equation:

$$\underset{\text{Ethanol}}{C_2H_5OH(l)} \xrightarrow[\Delta]{\text{porcelain chips}} \underset{\text{Ethene}}{C_2H_4(g)} + \underset{\text{Water}}{H_2O(l)}$$

(b) Dehydration of propanol, C_3H_7OH.

$$\underset{\text{Propanol}}{C_3H_7OH(l)} \xrightarrow[\Delta]{\text{porcelain chips}} \underset{\text{Propene}}{C_3H_6(g)} + \underset{\text{Water}}{H_2O(l)}$$

- Alkenes, produced from the dehydration of alcohols have the following characteristics:
  (i) burn with yellow sooty flame,
  (ii) decolourise the brown colour of bromine water, Br_2 to colourless,
  (iii) decolourise the purple colour of potassium manganate(VII), $KMnO_4$ solution to colourless.

Laboratory Activity 2C Chemical Properties of Ethanol

PAK21 Learning Science Through Inquiry

Aim: To study the chemical properties of ethanol, C_2H_5OH.

Materials: Ethanol, C_2H_5OH, porcelain chips, glass wool, potassium dichromate(VI), $K_2Cr_2O_7$ solution, potassium manganate(VII), $KMnO_4$ solution, concentrated sulphuric acid, H_2SO_4, blue litmus paper, bromine water, Br_2.

Apparatus: Test tube, boiling tube, boiling tube stopper with delivery tube, retort stand, test tube holder, Bunsen burner, measuring cylinder, dropper and beaker.

A. Oxidation of Ethanol, C_2H_5OH

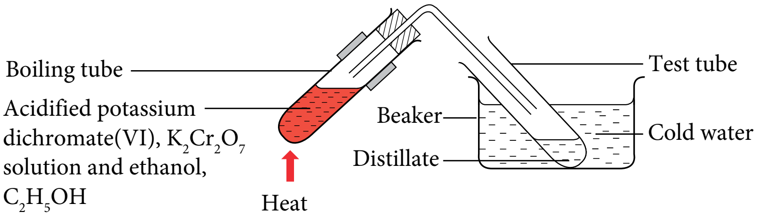


Figure 2.13

CAUTION

Concentrated sulphuric acid is corrosive. Handle with care.

Procedure:

1. Pour 5 cm^3 of potassium dichromate(VI), $K_2Cr_2O_7$ solution into a boiling tube.
2. Add 10 drops of concentrated sulphuric acid, H_2SO_4.
3. Gently heat the solution.
4. Add 3 cm^3 of ethanol, C_2H_5OH drop by drop into the boiling tube.
5. Connect the delivery tube to the boiling tube as shown in Figure 2.13. Heat the mixture with a gentle flame until the mixture boils.

6. Collect the distillate in a test tube and test it with the blue litmus paper.
7. Repeat steps 1 to 6 by replacing potassium dichromate(VI), $K_2Cr_2O_7$ solution with potassium manganate(VII), $KMnO_4$ solution.

Observation:

Test on Distillate	Observation
Colour change of potassium dichromate(VI), $K_2Cr_2O_7$ solution	
Colour change of potassium manganate(VII), $KMnO_4$ solution	
Colour of distillate	
Smell of distillate	
Effect on blue litmus paper	

Discussion:

1. What is the product formed by the oxidation reaction of ethanol, C_2H_5OH?
2. Name the oxidising agent used in this experiment.
3. Write the chemical equation of the reaction that occurs.
4. What is the property of the product of alcohol oxidation?

Conclusion:

The oxidation of ethanol, C_2H_5OH produces ethanoic acid, CH_3COOH.

B. Dehydration of Ethanol, C_2H_5OH

Procedure:

1. Place the glass wool in a boiling tube.
2. Pour 2 cm^3 of ethanol, C_2H_5OH into the boiling tube to wet the glass wool.
3. Place the porcelain chips in the middle of the boiling tube as shown in Figure 2.14.
4. Heat the porcelain chips with a strong flame. Heat the glass wool with a gentle flame to vaporise the ethanol, C_2H_5OH and the vapour is flowed through the heated porcelain chips.
5. Collect two test tubes of the gas released, as shown in Figure 2.14.
6. (i) Add a few drops of bromine water, Br_2 into the first test tube and shake.
   (ii) Add a few drops of acidified potassium manganate(VII), $KMnO_4$ solution into the second test tube and shake.

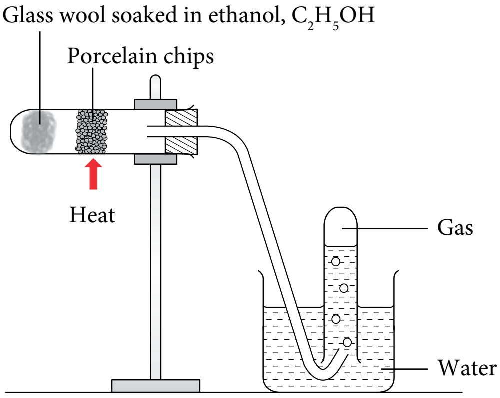


Figure 2.14

Observation:

Reagent	Observation
Bromine water, Br_2	
Acidified potassium manganate(VII), $KMnO_4$ solution	

Discussion:

1. Name the gas released when ethanol, C_2H_5OH undergoes dehydration.
2. State the function of porcelain chips.
3. Write the chemical equation for the dehydration of alcohol, C_2H_5OH.

Conclusion:

Dehydration of ethanol, C_2H_5OH produces ethene, C_2H_4.

Prepare a complete report after carrying out this laboratory activity.

Chemical Properties of other Members of the Alcohol Homologous Series

- All members of the alcohol homologous series have the functional group hydroxyl —OH, which is similar to ethanol, C_2H_5OH.
- Thus, other members of the homologous series also undergo combustion, oxidation and dehydration.

ACTIVITY 2J

Write the complete equation for each of the following alcohol reaction.

1. Complete combustion in excess oxygen:
   (a) Methanol. (b) Propanol.

2. Oxidation by acidified potassium manganate(VII), $KMnO_4$ oxidising agent:
   (a) Butanol. (b) Pentanol.

3. Dehydration by porcelain chips as the catalyst:
   (a) Butanol. (b) Pentanol.

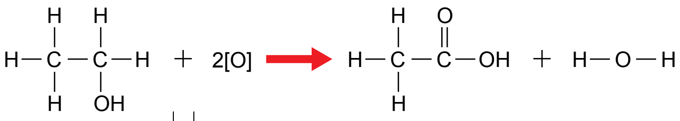
Chemical Properties of Carboxylic Acids

- Carboxylic acids can be produced from the oxidation of alcohol.
- Ethanoic acid, CH_3COOH is produced when ethanol, C_2H_5OH is oxidised by oxidising agents, such as acidified potassium manganate(VII), $KMnO_4$ solution or acidified potassium dichromate(VI), $K_2Cr_2O_7$ solution through the reflux method as shown in Figure 2.15.

Topic Link Carbon Compound: Oxidation of alcohol on page 91.

Do you know

- Reflux method is to ensure that ethanol reacts completely with the oxidising agent.
- A Liebig condenser that is fitted upright into a round-bottom flask will condense ethanol vapour to liquid ethanol. Liquid ethanol flows back into the round-bottom flask to react completely with the oxidising agent.



$$\mathrm{H{-}\underset{H}{\overset{H}{C}}{-}\underset{OH}{\overset{H}{C}}{-}H} + 2[\mathrm{O}] \rightarrow \mathrm{H{-}\underset{H}{\overset{H}{C}}{-}\overset{O}{\overset{\|}{C}}{-}OH} + \mathrm{H{-}O{-}H}$$

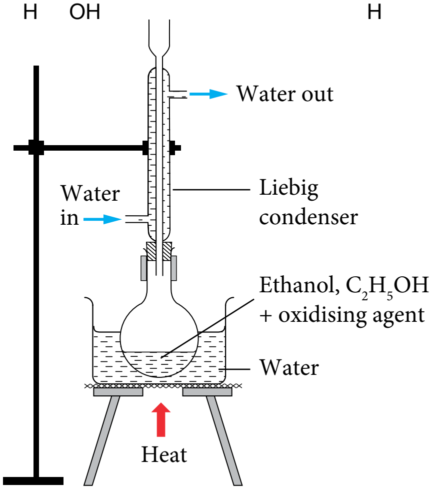


Figure 2.15 Ethanol oxidation reaction by oxidising agent through reflux

- The chemical properties of carboxylic acids are studied through the chemical reactions of ethanoic acid, CH_3COOH.
- The chemical properties of carboxylic acids are determined by the carboxyl, —COOH functional group.
- Two important chemical reactions of carboxylic acids:
  (i) Reaction as an acid.
  (ii) Reaction with alcohol.

Topic Link Form 4 Chemistry: Chemical properties of acids

I. Chemical Reactions of Ethanoic Acid, CH_3COOH

(a) **Carboxylic acid + Base → Carboxylate salt + Water**
For example, the reaction between ethanoic acid, CH_3COOH and copper(II) oxide, CuO produces copper ethanoate, $(CH_3COO)_2Cu$ and water, H_2O.

$$2CH_3COOH(aq) + CuO(s) \rightarrow (CH_3COO)_2Cu(aq) + H_2O(l)$$

(b) **Carboxylic acid + Metal carbonate → Carboxylate salt + Water + Carbon dioxide**
For example, the reaction between ethanoic acid, CH_3COOH and sodium carbonate, Na_2CO_3 produces sodium ethanoate, CH_3COONa, carbon dioxide, CO_2 and water, H_2O.

$$2CH_3COOH(aq) + Na_2CO_3(s) \rightarrow 2CH_3COONa(aq) + H_2O(l) + CO_2(g)$$

(c) **Carboxylic acid + Metal → Carboxylate salt + Hydrogen**
For example, the reaction between ethanoic acid, CH_3COOH and magnesium metal, Mg produces magnesium ethanoate, $(CH_3COO)_2Mg$ and hydogen, H_2.

$$2CH_3COOH(aq) + Mg(s) \rightarrow (CH_3COO)_2Mg(aq) + H_2(g)$$

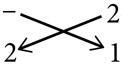
Do you know

- Ethanoic acid is a weak acid that partially ionises in water, producing low concentration of hydrogen ions.

$$\underset{\text{Ethanoic acid}}{CH_3COOH(aq)} \rightleftharpoons \underset{\text{Ethanoate ion}}{CH_3COO^-(aq)} + \underset{\text{Hydrogen ion}}{H^+(aq)}$$

- Constructing the formula of copper(II) ethanoate:

CH_3COO^- Cu^{2+}



: Charge of the ion
: Cross-change the coefficient of the charge

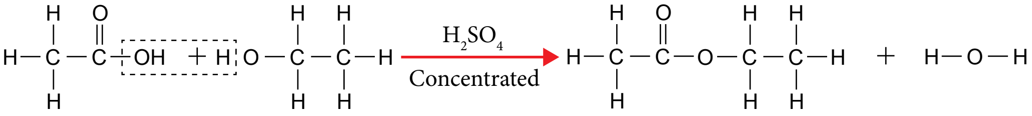
$(CH_3COO)_2Cu$

II. Reaction with Alcohols

- Carboxylic acids react with alcohols to produce esters and water.

$$\underset{C_mH_{2m+1}COOH}{\textbf{Carboxylic acid}} + \underset{C_nH_{2n+1}OH}{\textbf{Alcohol}} \xrightarrow[\text{Concentrated}]{H_2SO_4} \underset{C_mH_{2m+1}COOC_nH_{2n+1}}{\textbf{Ester}} + \underset{H_2O}{\textbf{Water}}$$

- This reaction is called esterification, with the presence of concentrated sulphuric acid, H_2SO_4 as a catalyst.
  Example:
  When a mixture of glacial ethanoic acid, CH_3COOH and ethanol, C_2H_5OH, with a few drops of concentrated sulphuric acid, H_2SO_4, is heated, an ester called ethyl ethanoate, $CH_3COOC_2H_5$ is formed.



$$\underset{\text{Ethanoic acid}}{CH_3COOH} + \underset{\text{Ethanol}}{C_2H_5OH} \rightarrow \underset{\text{Ethyl ethanoate}}{CH_3COOC_2H_5} + \underset{\text{Water}}{H_2O}$$

- Ethyl ethanoate, $CH_3COOC_2H_5$ is a colourless liquid that has the sweet fruity smell and insoluble in water. Ethyl ethanoate, $CH_3COOC_2H_5$ floats, forming a layer on the surface of the water.
- Concentrated sulphuric acid, H_2SO_4 is a catalyst in the esterification reaction.

Topic Link **Carbon Compound:** Ester on page 97.

Do you know

- Water removal occurs at the carboxyl functional group, —COOH in carboxylic acids and hydroxyl, —OH in alcohols.
- Water molecules (H—O—H) are formed from the —OH that is removed from carboxylic acids and the —H that is removed from alcohols.

Chemical Properties of Other Homologous Series of Carboxylic Acids

- All members of the carboxylic acid homologous series have the same functional group as ethanoic acid, CH_3COOH which is carboxyl, —COOH.
- Thus, other carboxylic acids also show similar chemical properties with ethanoic acid, CH_3COOH.

Laboratory Activity 2D Chemical Properties of Ethanoic Acid, CH_3COOH

PAK 21 Learning Science Through Inquiry

Aim: To study the chemical properties of ethanoic acid, CH_3COOH.

Problem statement: Can ethanoic acid, CH_3COOH react with metal, metal oxide and metal carbonate?

Materials: 1 mol dm^{-3} of ethanoic acid, CH_3COOH, magnesium ribbon, Mg, sodium carbonate powder, Na_2CO_3, copper(II) oxide powder, CuO and limewater.

Apparatus: Test tube rack, stopper with delivery tube, Bunsen burner, test tube holder, boiling tube, wooden splinter and glass rod.

Procedure: Using the apparatus and materials provided, plan an experiment to investigate the reaction of ethanoic acid, CH_3COOH with metal, metal carbonate and metal oxide.

Results: Record all observations in one table.

Topic Link **Form 4 Chemistry:** Chemical properties of acids

Discussion:

1. Name the gases released when ethanoic acid, CH_3COOH reacts with sodium carbonate, Na_2CO_3 and magnesium, Mg.
2. Name the salts produced when ethanoic acid, CH_3COOH reacts with:
   (a) Magnesium, Mg (b) Sodium carbonate, Na_2CO_3 (c) Copper(II) oxide, CuO
3. Write the reaction equations between ethanoic acid and:
   (a) Magnesium, Mg (b) Sodium carbonate, Na_2CO_3 (c) Copper(II) oxide, CuO

Conclusion: State the conclusion of the experiment you have conducted.

Prepare a complete report after carrying out this laboratory activity.

Esters

- Based on Figure 2.16, what do you understand about esters?

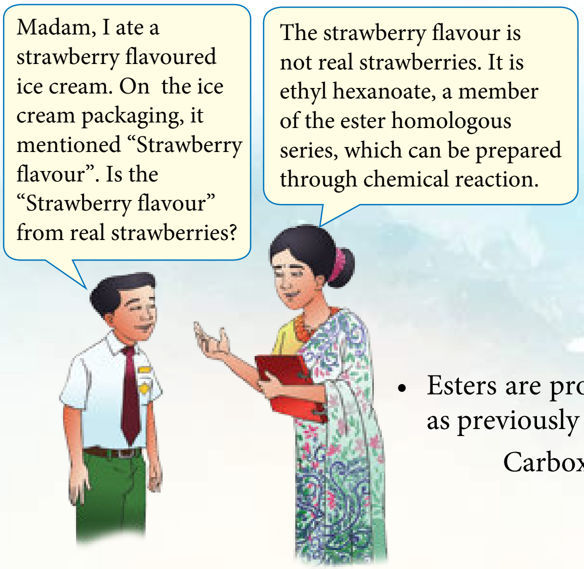


Figure 2.16 Understanding Ester

Non Hydrocarbon	Contains carbon, hydrogen and oxygen atoms.
Functional Group	Carboxylate, $-\overset{O}{\overset{\|}{C}}-O-$
General Formula	$C_mH_{2m+1}COOC_nH_{2n+1}$ m = 0,1,2,3.... n = 1,2,3...

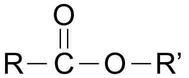
- Esters are produced when carboxylic acids react with alcohols as previously studied in chemical properties of alcohols.

Carboxylic acid + Alcohol → Ester + Water

- The general formula of esters can be derived by combining parts of the alcohol molecular formula and parts of the carboxylic acid molecular formula, with the removal of one water molecule.

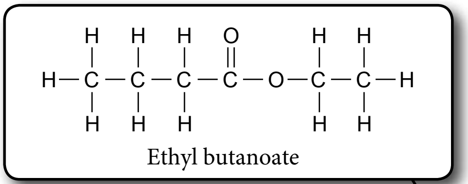
Carboxylic acid	+	Alcohol	→	Ester	+	Water
$C_mH_{2m+1}COOH$		$C_nH_{2n+1}OH$		$C_mH_{2m+1}COOC_nH_{2n+1}$		H_2O
m = 0,1,2,3....		n = 1,2,3...				

- The general formula for esters can also be written as:

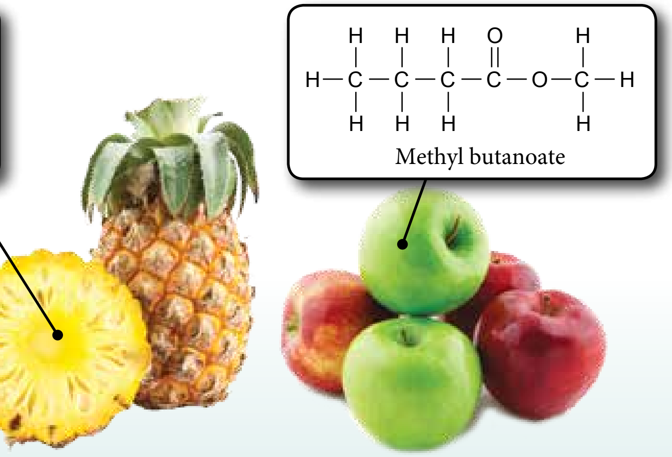


$$R-\overset{O}{\overset{\|}{C}}-O-R'$$

R is C_mH_{2m+1} from carboxylic acid
R' is C_nH_{2n+1} from alcohol



Ethyl butanoate



Methyl butanoate

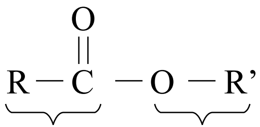
Photograph 2.8 Examples of the structural formulae for esters found in fruits

Do you know

The fragrant smell of flowers and fruits are mostly due to esters.

Naming of Esters

- The naming of esters comes from parts of alcohol and parts of carboxylic acid.



$$\underbrace{R-\overset{\overset{\displaystyle O}{||}}{C}}\ -\underbrace{O-R'}$$

Part two:
Derived from carboxylic acid, the name ends with "oate".

Part one:
Derived from alcohol, the name ends with "yl".

First part } From the alcohol where "ol" is replaced with "yl".

Second part } From carboxylic acid where "oic acid" is replaced with "oate".

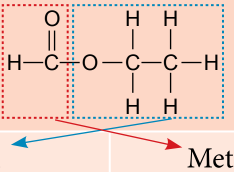
Example:

Naming of the first part	Naming of the second part	Name of ester
Methanol ⇒ Methyl	Methanoic acid ⇒ Methanoate	Methyl methanoate
Ethanol ⇒ Ethyl	Ethanoic acid ⇒ Ethanoate	Ethyl ethanoate
Propanol ⇒ Propyl	Propanoic acid ⇒ Propanoate	Propyl propanoate

- Table 2.14 shows the steps to determine the name of esters and written equation for esterification reaction.

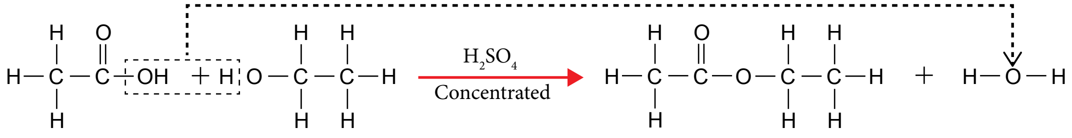
Example 1:

Table 2.14 The steps to determine the name of ethyl methanoate ester and the balanced equation for esterification reaction

Molecular formula	$HCOOC_2H_5$	
Structural formula		
Name of ester	Ethyl	Methanoate
	From ethanol	From methanoic acid
Ester produced from	$HCOOH$ Methanoic acid	C_2H_5OH Ethanol
Esterification equation	$HCOOH + C_2H_5OH \rightarrow HCOOC_2H_5 + H_2O$	

- Eliminate hydroxyl group —OH from carboxylic acid , HCOOH.
- Remove H atom from the hydroxyl group of alcohol, C_2H_5OH.
- Combine the two remaining parts by forming an ester link —COO—.

Example 2:
The esterification reaction between ethanoic acid, CH_3COOH and ethanol, C_2H_5OH forms ethyl ethanoate, $CH_3COOC_2H_5$ with the presence of concentrated sulphuric acid, H_2SO_4 as a catalyst.



CH_3COOH + C_2H_5OH → $CH_3COOC_2H_5$ + H_2O

Ethanoic acid, Ethanol, Ethyl ethanoate, Water

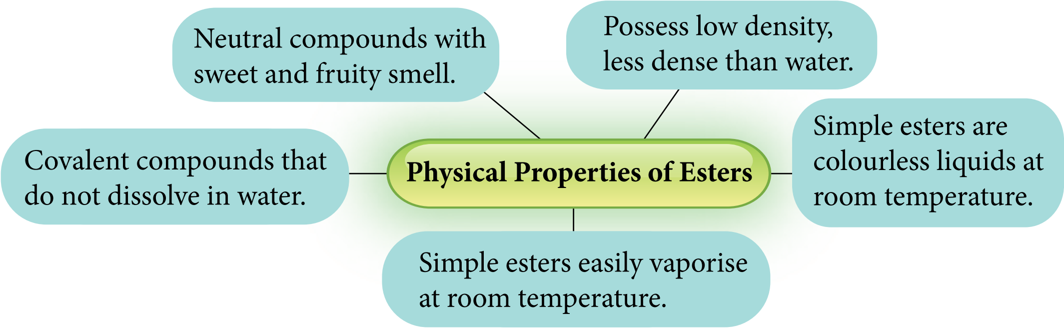
ACTIVITY 2K

Write the molecular and structural formulae of alcohol and carboxylic acid components for the following esters. Next, draw the structural formula of each of these esters.

(i) Methyl methanoate (ii) Ethyl propanoate (iii) Propyl ethanoate

Physical Properties of Esters

- Figure 2.17 shows a bubble map of physical properties of ester.



Physical Properties of Esters

Neutral compounds with sweet and fruity smell.

Possess low density, less dense than water.

Covalent compounds that do not dissolve in water.

Simple esters are colourless liquids at room temperature.

Simple esters easily vaporise at room temperature.

Figure 2.17 Physical properties of ester

Laboratory Activity 2E Reaction of Ethanoic Acid with Ethanol

PAK 21 Learning Science Through Inquiry

Aim: To study the reaction of ethanoic acid, CH_3COOH with ethanol, C_2H_5OH.

Materials: Glacial ethanoic acid, CH_3COOH, absolute ethanol, C_2H_5OH and concentrated sulphuric acid, H_2SO_4.

Apparatus: Beaker, Bunsen burner, test tube holder, boiling tube, dropper, glass rod and measuring cylinder.

CAUTION

- Concentrated acid is corrosive.
- Do not overheat the mixture as ethanol is highly flammable.

Procedure:

1. Add 2 cm^3 of glacial ethanoic acid, CH_3COOH in a boiling tube.
2. Add 4 cm^3 of absolute ethanol, C_2H_5OH to the glacial ethanoic acid, CH_3COOH.
3. Add five drops of concentrated sulphuric acid, H_2SO_4 into the mixture with a dropper and shake the boiling tube as shown in Figure 2.18.
4. Heat the mixture gently with a small flame to bring it to a boil for two to three minutes.
5. Pour the content of the boiling tube into a beaker half filled with water.
6. Record the smell, colour and solubility of the product.

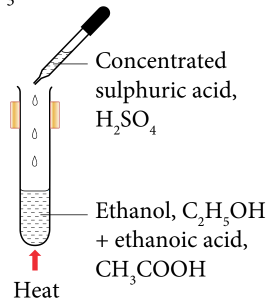


Figure 2.18

Observation:

Test	Observation
Colour	
Smell	
Solubility	

Discussion:

1. Name the reaction that occurs between glacial ethanoic acid, CH_3COOH and ethanol, C_2H_5OH.
2. Name the product formed from the reaction.
3. Compare the density of the product formed with water.
4. What is the function of concentrated sulphuric acid, H_2SO_4?
5. Write the equation for the reaction between ethanoic acid, CH_3COOH and ethanol, C_2H_5OH.

Conclusion:

Ethanoic acid, CH_3COOH reacts with ethanol, C_2H_5OH to produce ester and water.

Prepare a complete report after carrying out this laboratory activity.

Self Assess 2.3

1. Table 2.15 shows carbon compounds and their respective molecular formulae.

Table 2.15

Compound	P	Q	R	T
Molecular formula	C_3H_8	C_3H_6	C_2H_5OH	CH_3COOH

(a) (i) Compare and contrast the sootiness of flames of compound P and compound Q when burnt in excess oxygen. Explain your answer.
[Relative atomic mass: C = 12, H = 1].

(ii) Table 2.16 shows the result of an experiment where compound P and compound Q were separately shaken in bromine water in test tubes.

Table 2.16

Compound	**Observation**
P	The brown colour of bromine water does not change.
Q	The brown colour of bromine water decolourises.

Based on Table 2.16, explain the differences in these observations.

(b) 2.3 g of compound R burns completely in excess oxygen to produce carbon dioxide gas and water. Write the chemical equation for the reaction and determine the volume of carbon dioxide gas produced. [Molar mass R = 46 g mol^{-1}, molar volume of the gas at room condition = 24 dm^3 mol^{-1}].

(c) State two compounds from Table 2.16 that react to produce ester.
Name and draw the structural formula for the ester formed.

(d) Acid X is used as a catalyst during the esterification reaction. When the concentrated acid X is spilt on the marble floor, gas bubbles are formed. Name acid X and write the chemical equation for the reaction.

2.4 ISOMERS AND NAMING BASED ON IUPAC NOMENCLATURE

What is meant by structural isomerism?

- Structural isomerism is a phenomenon where a compound has the same molecular formula but with two or more different structural formulae.

Isomers are molecules that have the same molecular formula but different structural formulae.

- Structural isomerism can occur in several ways:
  - (i) **Chain isomerism**
    The isomers have different arrangements of carbon chains; either straight chain or branched chain.
  - (ii) **Position isomerism**
    The isomers have different positions of functional group on the same carbon chain.
- Figure 2.19 shows an example of structural isomerism in butane, C_4H_{10} and butene, C_4H_8.

Learning Standards

Pupils are able to:

2.4.1 describe structural isomerism.
2.4.2 construct structure of isomers.
2.4.3 explain with examples the uses of each homologous series in daily life.

Do you know

Functional group isomerism is also a type of structural isomerism. This type of isomerism will be studied at a higher level.

AR code

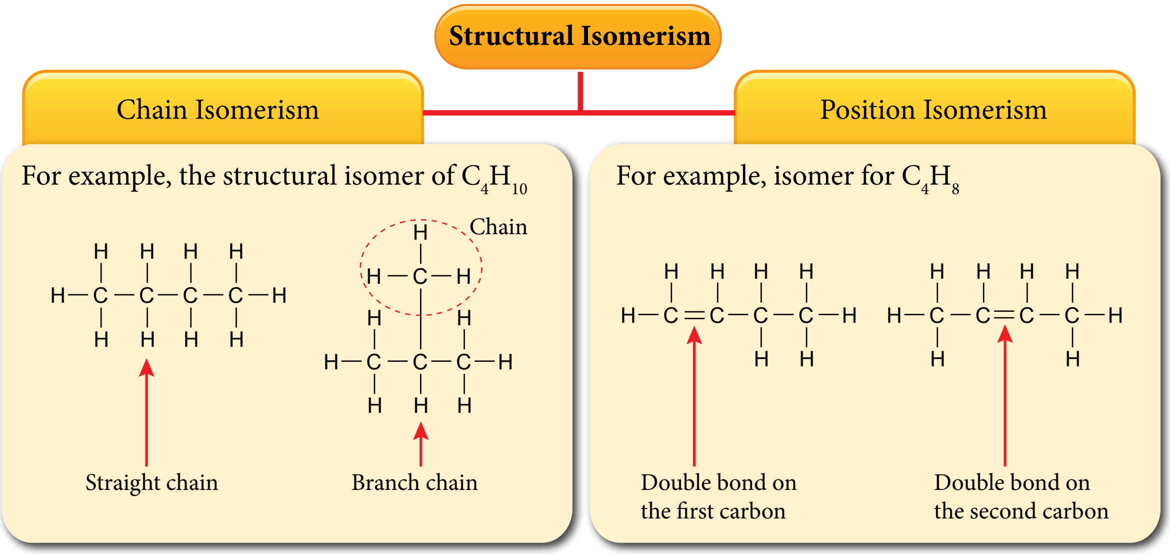


Figure 2.19 Example of structural isomer

- The isomers show:
  - (i) the same chemical properties because each isomer has the same functional group.
  - (ii) the physical properties, such as melting point and boiling point, are different. The more branches there are, the lower the melting point and boiling point are.
- Generally, the number of isomers of a molecule increases with the increase of the number of carbon atoms in the molecule.

INFO

- The isomers of alkanes are formed by chain isomers only.
- Isomers of alkenes, alkynes and alcohols are formed from chain isomers and position isomers.

Steps in Drawing Isomers

1. To draw isomers for alkanes, start by connecting the carbon atoms in a straight chain followed by a branched chain.
2. To draw isomers for alkenes and alkynes:
   - (i) Start with a straight chain formula and change the position of the double bond or triple bond to a different carbon position.
   - (ii) Next, draw a structural formula with a branched chain from each straight chain that has different positions of double or triple bonds.

ACTIVITY 2L

PAK21

1. Conduct this activity in groups.
2. Scan the QR code to conduct an activity on constructing isomers for alkanes, alkenes and alkynes.

Constructing Isomers
https://bit.ly/kpkt5n6

Chemistry Portal

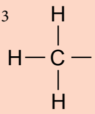
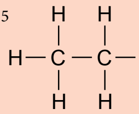
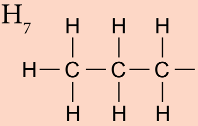
Structural Isomers and the Naming of Alkanes According to the IUPAC Nomenclature
https://bit.ly/kpkt5v25

Structural Isomers and the Naming of Alkenes According to the IUPAC Nomenclature
https://bit.ly/kpkt5v26

Naming of Isomers According to the IUPAC Nomenclature

- There are three parts in the naming of isomers:
  - (a) The prefix indicates the branch group, which is the alkyl group, with the general formula C_nH_{2n+1} that is attached to the longest carbon chain.

    Example:

Molecular formula and structural formula of alkyl group	$-CH_3$ 	$-C_2H_5$ 	$-C_3H_7$ 
Name of alkyl group	Methyl	Ethyl	Propyl

  - (b) The root name shows the number of carbon atoms in the longest carbon chain.
  - (c) The suffix shows the homologous series.

    Example:

Homologous series	Alkane	Alkene	Alkyne	Alcohol
Suffix	'ane'	'ene'	'yne'	'ol'

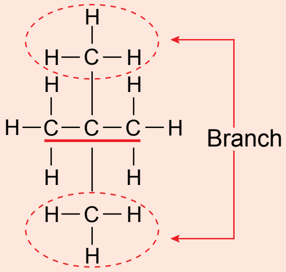
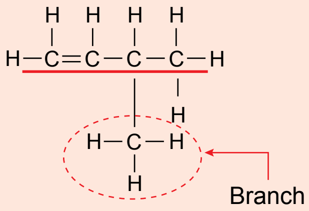
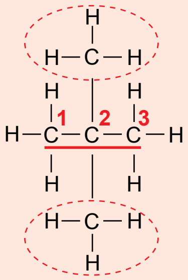
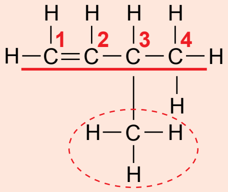
Mind Challenge

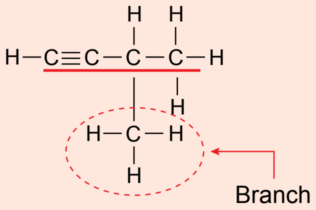
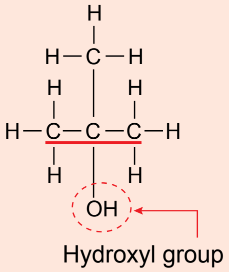
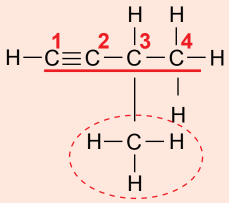
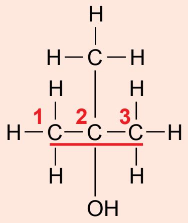
What are the advantages of adhering to the same system in the naming of organic compounds?

- **Steps for writing** the name of a branched chain isomer are as follows:

Name writing sequence	Prefix →	Root name →	Suffix
How to write	• Prefix and root names are "written close together" • Number and name, write "–" • Number and number, write " , "		

Steps in Naming of Isomers According to the IUPAC Nomenclature

Step	Example of alkane isomer	Example of alkene isomer
1. Identify and name the longest carbon chain, or the longest carbon chain containing the functional group for alkene.		
⇒ Root name is obtained	Longest carbon chain: 3 carbons Root name: Propane	Longest carbon chain: 4 carbons Root name: Butene
2. Identify branch and functional group.		
3. Number the carbon atoms in the longest chain from one end so that: • the branch gets the lowest number for alkane. • the functional group gets the lowest number for alkene.		
4. State the position and name of the branch, together with the functional group.	The branches are: • Two methyl groups. • Both methyl groups are on carbon number 2.	The branch is: • A methyl group on carbon number 3.
⇒ Prefix is obtained from the name and position of the branch.	**Prefix:** 2,2-dimethyl	**Prefix:** 3-methyl
⇒ Suffix is obtained from the homologous series.	Homologous series is alkane. **Suffix:** “ane”	Homologous series is alkene. **Suffix:** -1-ene (Double bond is on the first carbon).
Name the isomer according to the writing steps.	2,2-dimethylpropane	3-methylbut-1-ene

Step	Example of alkyne isomer	Example of alcohol isomer
1. Identify and name the longest carbon chain containing a functional group.		
⇒ Root name obtained	Longest carbon chain: 4 carbons Root name: Butyne	Longest carbon chain: 3 carbons Root name: Propanol
2. Identify branch and functional group.		
3. Number the carbon atoms in the longest chain from one end, so that the functional group gets the lowest number.		
4. State the position and name of the branch, and functional group.	The branch is: • One methyl on carbon number 3.	The branch is: • One methyl group on carbon number 2.
⇒ Prefix is obtained from the name and position of the branch.	**Prefix:** 3-methyl	**Prefix:** 2-methyl
⇒ Suffix is obtained from the homologous series.	Homologous series is alkyne **Suffix:** -1-yne (Triple bond is on the first carbon)	Homologous series is alcohol **Suffix:** -2-ol (Hydroxyl group is on the second carbon)
Name the isomer according to the writing steps.	3-methylbut-1-yne	2-methylpropan-2-ol

Isomers for Alkanes, Alkenes and Alkynes

- Figure 2.20 shows the molecular model for butane isomer, C_4H_{10}.
- Let us conduct Activity 2M to improve your skills in drawing and naming of isomers according to the IUPAC nomenclature.

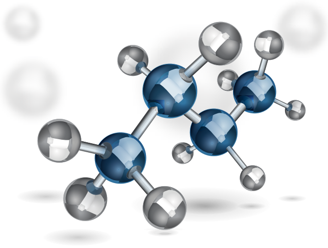
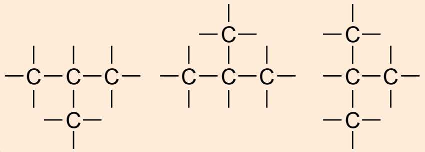


Figure 2.20 The molecular model for butane isomer, C_4H_{10}

Mind Challenge

Molecules can be rotated. Are these three structures different?



ACTIVITY 2M

PAK21

Carry out this activity in groups.

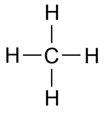
1. Draw the isomers and name them according to the IUPAC nomenclature for homologous series of alkanes, alkenes and alkynes containing 4 and 5 carbon atoms.
2. Share the findings in a Gallery Walk activity.

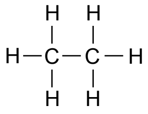
Chemistry Portal

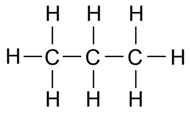
Isomers of Alkanes, Alkenes and Alkynes
https://bit.ly/kpkt5n7

INFO

- Methane, CH_4, ethane, C_2H_6 and propane, C_3H_8 have no isomer because there is only one way for the structural formulae of these molecules to be constructed.
- Isomerism in alkanes begins with butane, C_4H_{10}.


CH_4

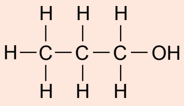
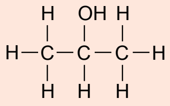
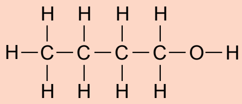
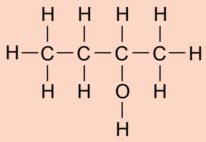
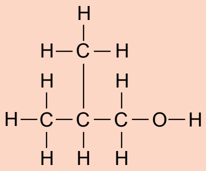
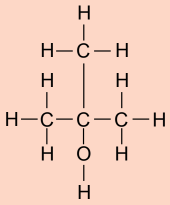

C_2H_6


C_3H_8

Isomers for Alcohols

- Isomerism in alcohol homologous series starts with a molecule that has three carbon atoms.
- Similar to alkenes and alkynes, isomerism in alcohols consists of chain isomers as well as position isomers (different position of hydroxyl functional groups, —OH).
- Table 2.17 shows the isomers of propanol, C_3H_7OH and butanol, C_4H_9OH.

Table 2.17 Propanol and butanol isomers

Alcohol	Isomer	Number of isomer
Propanol, C_3H_7OH	 Propan-1-ol  Propan-2-ol	2
Butanol, C_4H_9OH	 Butan-1-ol  Butan-2-ol  2-methylpropan-1-ol  2-methylpropan-2-ol	4

ACTIVITY 2N

PAK21

Carry out this activity in groups.

1. Write the molecular formula of an alcohol with 5 carbon atoms.
2. Draw and name all possible isomers of the molecular formula in question 1. Share all findings by carrying out the Stay-Stray activity.

Uses of Homologous Series in Daily Life

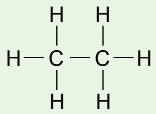
Uses of Alkanes and Alkenes

- Alkanes have high heat of combustion. Thus, the main usages of alkanes are for fuel and raw materials in the petrochemical industry.
- Alkenes are also used as raw materials in the petrochemical industry.
- Figure 2.21 shows examples of the uses of members of the homologous series of alkanes and alkenes.

Malaysian Excellence

Petronas' Success in Supplying LNG to the World's Largest LNG Vessel.
https://bit.ly/kpkt5n36

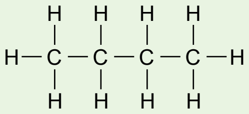
Ethane



$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$

- Production of ethene from ethane to make detergents and plastics.
- Liquefied natural gas LNG that contains ethane is used as fuel for power stations.

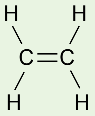
Butane



$H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$

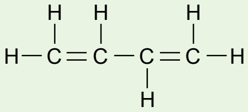
- Production of fuel for lighters and portable stoves.
- LPG cooking gas when mixed with propane.

Ethene



- Production of alcohol, such as ethanol.
- Production of polythene, polyvinyl chloride (PVC) and polystyrene.

But-1,3-diene



$H-\overset{H}{C}=\overset{H}{C}-\underset{H}{C}=\overset{H}{C}-H$

- Production of synthetic rubber to manufacture tyres and hot water bags.

Figure 2.21 Examples of uses of alkanes and alkenes

Uses of Alcohols

- Photograph 2.9 shows the use of a hand sanitiser containing more than 70% alcohol to prevent COVID-19 infection. Why is alcohol used as a sanitiser?
- The physical properties of alcohols are suitable for the production of materials for everyday use. Ethanol is a type of alcohol that is widely used. Figure 2.22 shows the various uses of alcohols.

Photograph 2.9 Using hand sanitiser

Fuel

As fuel in clean fuel, bio fuel and gasohol.

Properties of alcohols
- Highly flammable, and combustion releases a lot of heat without soot.

Solvent

As a solvent in
- Paint, lacquer, dyes and printing ink.
- Cosmetics such as perfume, nail varnish, cream and lotion.

Properties of alcohols
- Colourless, good organic solvent, miscible in water and volatile.

Manufacturing sector

Raw materials in the production of vinegar, explosives, polymer perspex and fibre.

Properties of alcohols
- Chemically reactive.

Pharmaceutical products

In the medical field
- Antiseptics for injections, surgeries and general hygiene.
- Solvent for medicines such as cough medicine.

Properties of alcohols
- Antiseptic, good organic solvent and volatile.

Figure 2.22 Various usages of alcohol

Chemistry Portal

Production and Uses of Ethanol
https://bit.ly/kpkt5v27

INFO

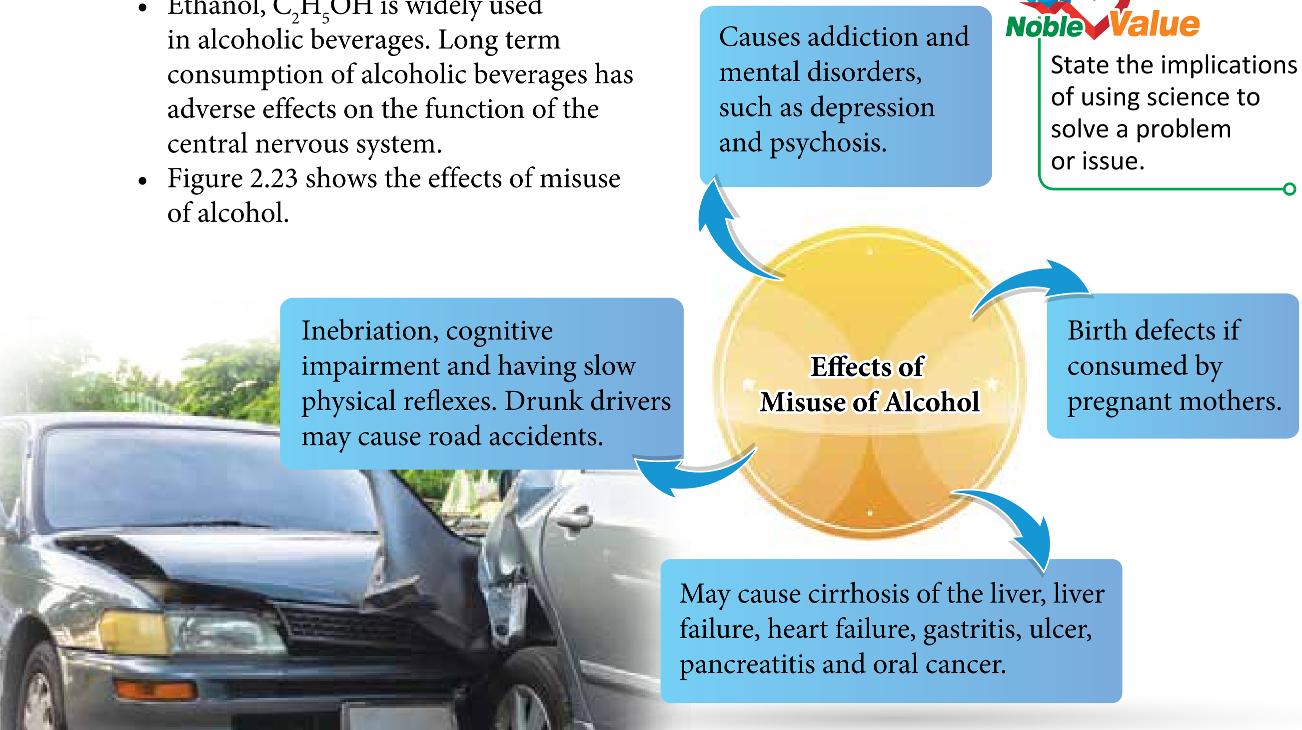
In Brazil, ethanol produced from the fermentation of sugar cane is mixed with petrol as "gasohol" fuel.

Effects of Misuse of Alcohol

- Ethanol, C_2H_5OH is widely used in alcoholic beverages. Long term consumption of alcoholic beverages has adverse effects on the function of the central nervous system.
- Figure 2.23 shows the effects of misuse of alcohol.

Noble Value

State the implications of using science to solve a problem or issue.



Effects of Misuse of Alcohol

Causes addiction and mental disorders, such as depression and psychosis.

Birth defects if consumed by pregnant mothers.

May cause cirrhosis of the liver, liver failure, heart failure, gastritis, ulcer, pancreatitis and oral cancer.

Inebriation, cognitive impairment and having slow physical reflexes. Drunk drivers may cause road accidents.

Figure 2.23 Effects of misuse of alcohol
(**Source:** MyHEALTH official portal. Ministry of Health Malaysia)

Uses of Carboxylic Acids

- The most important carboxylic acid is ethanoic acid, CH_3COOH that is widely used as:
  - (i) food preservatives in chilli sauce, ketchup and other food flavourings.
  - (ii) raw materials with other chemicals to produce dyes, paints, pesticides and plastics.
- Methanoic acid, HCOOH is used in the rubber industry for coagulation of latex.
- Fatty acids are long-chain carboxylic acids used to make soap.
- Carboxylic acids are also used to manufacture polymers, namely polyester such as terylene and polyamide such as nylon.

Topic Link

Polymer: Condensation polymerisation on page 147.

Pesticides

Plastics

T-shirt

Chilli sauce

Usage of Esters

- Esters with small molecules easily evaporate and are fragrant, making them suitable for use in the manufacturing of cosmetics and perfumes. Esters are also used as food flavourings. Table 2.18 shows examples of esters as food flavourings.

Table 2.18 Examples of esters as food flavourings

Ester	Flavour
Methyl butanoate, $C_3H_7COOCH_3$	Apple
Penthyl ethanoate, $CH_3COOC_5H_{11}$	Banana
Ethyl butanoate, $C_3H_7COOC_2H_5$	Pineapple

- Ethyl ethanoate, $CH_3COOC_2H_5$ is an ester, used as a solvent for organic compounds in lotions, nail varnishes, lacquers and glue.
- Oils and fats are esters, formed between fatty acids and glycerol that are used in the production of soap.
- Polyester is a polymer for the production of synthetic fabrics.

Topic Link

Consumer and industrial chemistry:
Oils and fats, cleaning agents and food additives on page 166.


Polyester fabric

Food flavouring

Glue


Soap

ACTIVITY 20 Discussion

PAK 21

1. Carry out this activity in groups.
2. The petrochemical industry is thriving and contributes to the country's economic growth. Plan a forum to discuss the justification for the use of chemicals from the following homologous series:
   (a) Alkane (b) Alkene (c) Alcohol (d) Carboxylic acid (e) Ester

Each group should send a representative as a forum panel. Conduct your forum by inviting representatives from other classes as spectators.

Self Assess 2.4

1. Draw the structural formula for each of the following compounds:
   (a) 2,3-dimethylbutane (b) 3,4-dimethylpent-1-ene (c) 3,4-dimethylheptane
   (d) 4-methylhex-1-yne (e) 3-methylpentan-2-ol (f) 1,2-dibromohexane
2. Figure 2.24 shows the structural formulae of three hydrocarbons, X, Y and Z.
   (a) Name the hydrocarbons labeled X, Y and Z.
   (b) Determine whether X, Y and Z are isomers. Give your reasons.

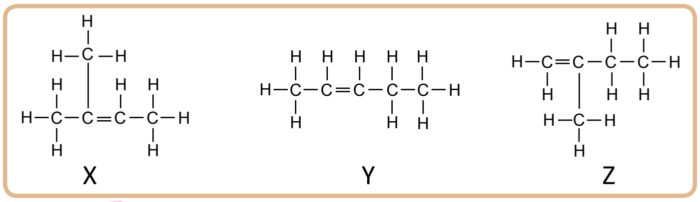
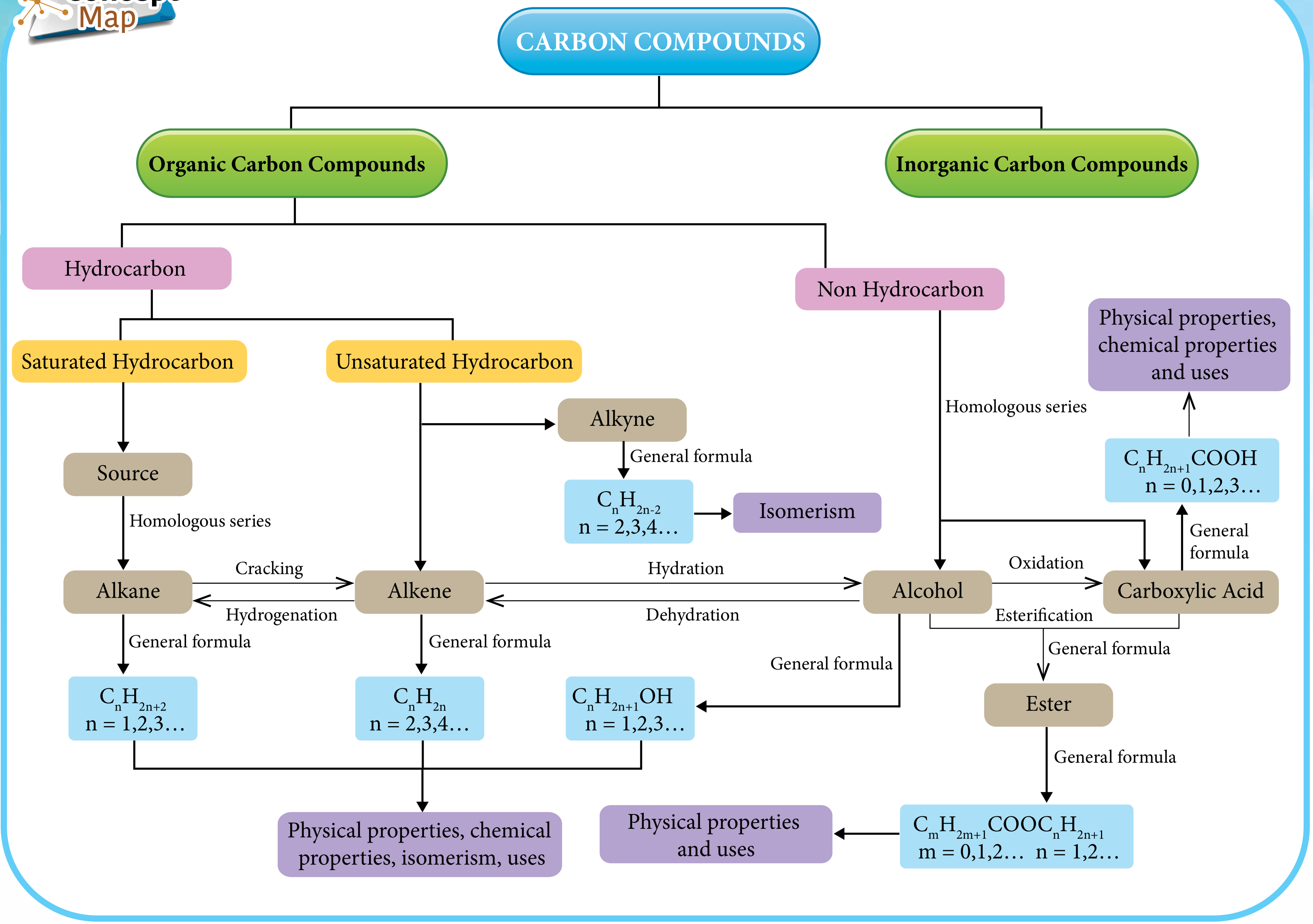


Figure 2.24

Concept Map



CARBON COMPOUNDS

Organic Carbon Compounds

Inorganic Carbon Compounds

Hydrocarbon

Non Hydrocarbon

Saturated Hydrocarbon

Unsaturated Hydrocarbon

Source

Homologous series

Alkane

Cracking

Hydrogenation

Alkene

Alkyne

General formula

C_nH_{2n-2}
n = 2,3,4…

Isomerism

Hydration

Dehydration

Homologous series

Alcohol

Oxidation

Esterification

Carboxylic Acid

General formula

$C_nH_{2n+1}COOH$
n = 0,1,2,3…

Physical properties, chemical properties and uses

General formula

C_nH_{2n+2}
n = 1,2,3…

General formula

C_nH_{2n}
n = 2,3,4…

General formula

$C_nH_{2n+1}OH$
n = 1,2,3…

General formula

Ester

General formula

$C_mH_{2m+1}COOC_nH_{2n+1}$
m = 0,1,2… n = 1,2…

Physical properties, chemical properties, isomerism, uses

Physical properties and uses

SELF Reflection

1. Have you mastered the topic of **Carbon Compound**?
2. What is the content in the topic of **Carbon Compound** that you want to have a more in-depth understanding of? Why?
3. How does the topic of **Carbon Compound** benefit you in daily life?
4. How would you assess your ability to describe the content in the topic of **Carbon Compound** to your friends?
5. What can you do to improve your understanding of the topic of **Carbon Compound**?

ACHIEVEMENT TEST

1. Figure 1 shows the products of petroleum fractional distillation at the oil refinery.
   (a) Why can petroleum be separated into its components by fractional distillation ?
   (b) Which of the following is A, B, C, D or E?
      (i) A fraction of kerosene.
      (ii) Used as fuel for heavy vehicles such as buses and lorries.
      (iii) Used to pave roads.
   (c) Process X converts fuel oil to ethene, butene and petrol.
      (i) What is process X and the catalyst used?
      (ii) What is the importance of process X?

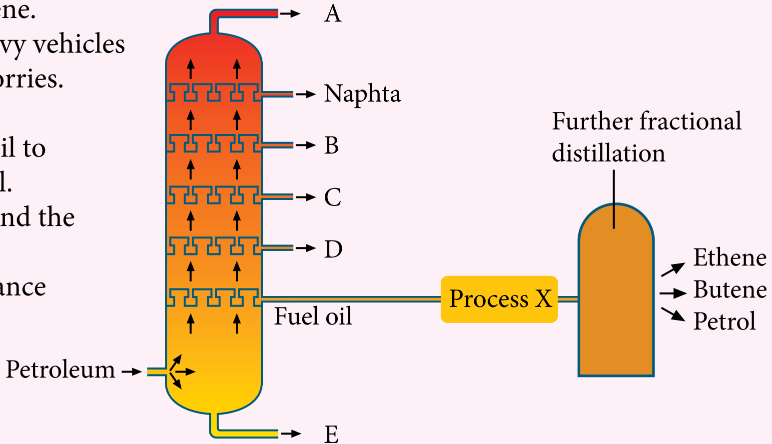
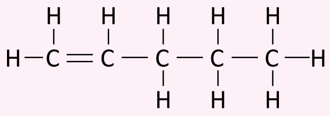


Figure 1

2. Figure 2 shows the structural formula of compound X.
   (a) Compound X is an unsaturated hydrocarbon.
      (i) What is meant by unsaturated hydrocarbon?
      (ii) State the homologous series of compound X.
      (iii) Compound X forms an isomer.
      Draw the structural formulae of all isomers for compound X and name each isomer according to the IUPAC nomenclature.
   (b) At a temperature of 180 °C and with the presence of nickel as a catalyst, compound X can be converted into saturated hydrocarbons.
      (i) Name the reaction that takes place.
      (ii) Draw the structural formula for the compound formed.



$$\mathrm{H-C=C-C-C-C-H}$$

Figure 2

(c) Compound X burns completely in excess oxygen.
  (i) Write a balanced chemical equation for a complete combustion of compound X.
  (ii) 14 g of compound X undergoes complete combustion at room temperature. Calculate the volume of carbon dioxide gas released.
  [1 mole of gas occupies a volume of 24 dm^3 at room temperature.
  Relative atomic mass: H = 1; C = 12].

3. Figure 3 shows a series of reactions involving compound Q, C_2H_6O.

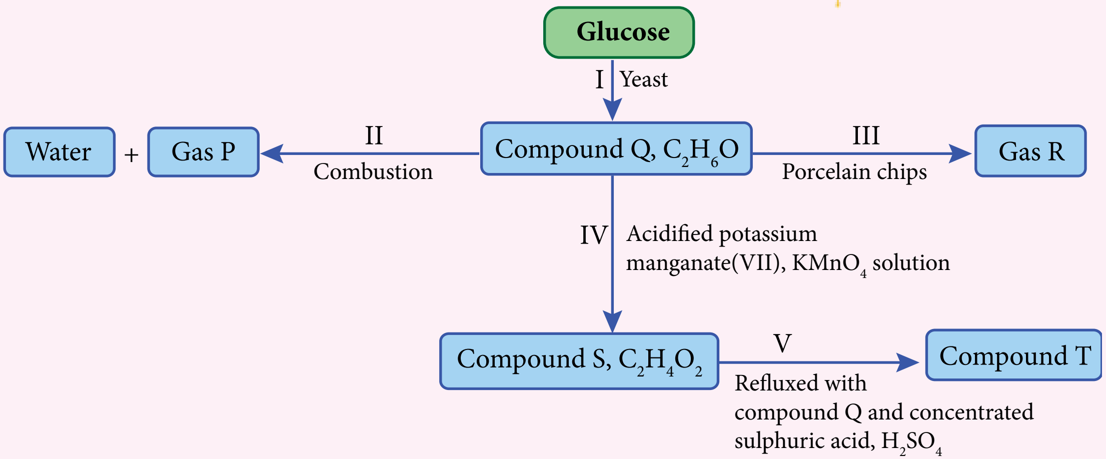


Figure 3

(a) (i) Name reaction I.
  (ii) State the name of compound Q.
  (iii) Draw the structural formula of compound Q.
(b) Write the chemical equation for the complete combustion of compound Q.
(c) (i) State the name of gas R released in reaction III.
  (ii) Draw the apparatus set-up to carry out the experiment for reaction III in the laboratory.
(d) State the colour change of acidified potassium manganate(VII), $KMnO_4$ solution in reaction IV.
(e) (i) State the name of reaction V.
  (ii) State the name of compound T.

Enrichment Corner

Fruits and flowers contain a variety of esters with various flavours and smells. Natural esters are difficult to extract from natural resources. These esters can be produced in the laboratories when alcohol reacts with carboxylic acid. Table 1 shows the esters and their smells.

Table 1

Ester	Smell
Pentyl ethanoate	Banana
Pentyl butanoate	Apricot

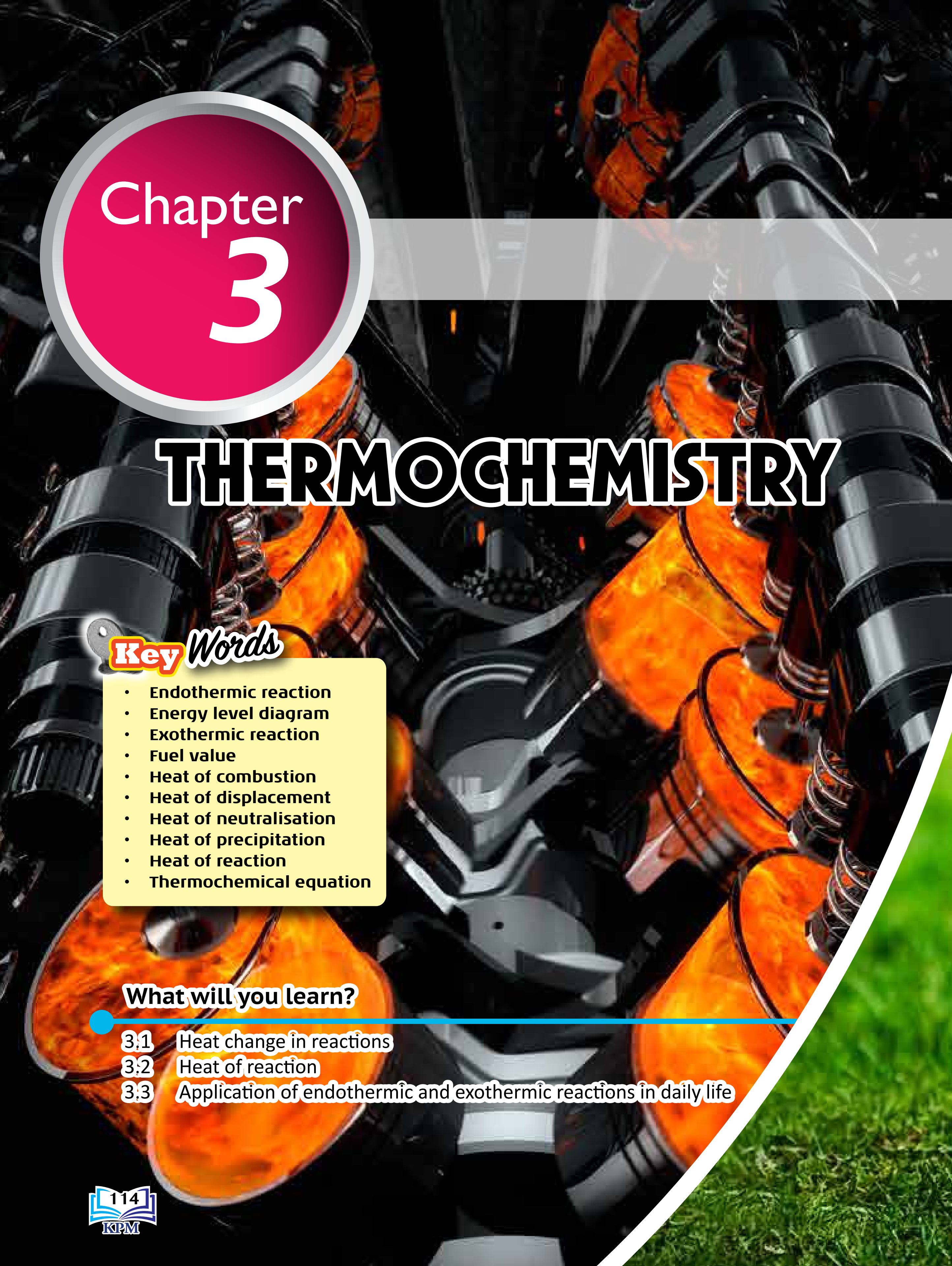
Referring to the information in Table 1, plan a laboratory experiment to prepare two different esters using the same alcohol and different carboxylic acids, and identify the smells. In your answer, include the following information:

(a) Hypothesis for this experiment.
(b) All variables involved.
(c) Materials and apparatus used.
(d) Procedures for conducting the experiment.
(e) Observation.
(f) Chemical equations.

THEME 3

HEAT

This theme analyses heat change in chemical reactions. The study of heat of reaction includes heat of precipitation, heat of displacement, heat of neutralisation and heat of combustion. Applications of exothermic and endothermic reactions in daily life is discussed. Knowledge on fuel value is used in choosing the most suitable daily fuel. Pupils' creativity and innovativeness are fostered through product designing activities which involve knowledge applications on exothermic and endothermic reactions.



Chapter 3

THERMOCHEMISTRY

Key Words

- Endothermic reaction
- Energy level diagram
- Exothermic reaction
- Fuel value
- Heat of combustion
- Heat of displacement
- Heat of neutralisation
- Heat of precipitation
- Heat of reaction
- Thermochemical equation

What will you learn?

3.1 Heat change in reactions
3.2 Heat of reaction
3.3 Application of endothermic and exothermic reactions in daily life

Bulletin

“Affordable, ready to drink and on the go”. These are the important concepts that Datuk Kenneth Warren Kolb had in mind when he invented Hot Can, a smart self-heating can that contains beverages and soups.

These self-heating cans allow users to enjoy hot food or drinks without heating. The can works through an exothermic reaction between two chemicals.

There are two chambers surrounding each other. The outer chamber stores food or drinks while the interior chamber stores the chemicals that react when mixed.

Common chemicals used are aluminium and silica, calcium oxide and water, and copper sulphate and zinc.

When both materials combine, a chemical reaction generates enough heat to raise the temperature of the can.

How do you calculate heat change?

Do all chemical reactions release heat?

Which is the most suitable fuel for daily usage?

3.1 HEAT CHANGE IN REACTIONS

Exothermic and Endothermic Reactions

Learning Standards

Pupils are able to:

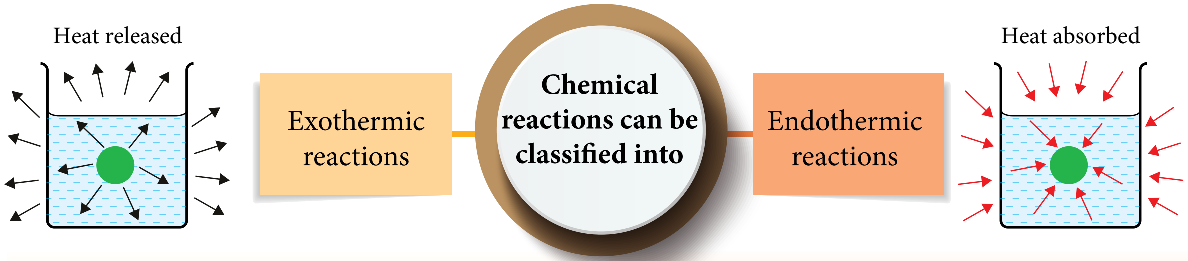
3.1.1 deduce exothermic and endothermic reactions through activities.

3.1.2 interpret energy level diagram.

Photograph 3.1
Frying an egg

- Have you ever fried an egg? While frying eggs, heat from the pan is absorbed and causes the egg in liquid form to turn solid. Is the change in the egg caused by an exothermic or endothermic reaction?
- There is a change of energy when a chemical reaction occurs, and usually involves heat energy. Heat energy is either released or absorbed during a chemical reaction.

Topic Link **Form 3 Science:** Thermochemistry



Exothermic reactions

Chemical reactions can be classified into

Endothermic reactions

- Chemical reactions that release heat to the surroundings.
- Heat released to the surroundings causes the surrounding temperature to rise.
- The container becomes hot.
- Examples: respiration, oxidation of metals, neutralisation reaction, combustion of fuel, production of ammonia, and dissolving sodium hydroxide in water.

- Chemical reactions that absorb heat from the surroundings.
- Heat absorbed from the surroundings causes the temperature to drop.
- The container becomes cold.
- Examples: photosynthesis, decomposition of metal carbonate when heated, decomposition of metal nitrates when heated and dissolving ammonium salts in water.

Photograph 3.2 shows the hand feeling cold when using the hand sanitiser containing alcohol that evaporates during hand sanitisation. What is this type of reaction?

Photograph 3.2 Hand sanitiser on the hands

Photograph 3.3 shows the hand feeling warm when detergent powder in the palm of the hand comes into contact with water. What is this type or reaction?

Photograph 3.3
Detergent on the hands

- Let us conduct the following laboratory activity to identify the exothermic and endothermic reactions when chemicals are dissolved in water.

Laboratory Activity 3A

Determining Exothermic and Endothermic Reactions

PAK 21 Learning Science Through Inquiry

Aim: To study the types of reactions based on heat change and the changes in thermometer readings when substances dissolve in water.

CAUTION

Sodium hydroxide corrodes.
Handle with care.

Materials: Solid sodium hydroxide, NaOH, solid anhydrous calcium chloride, $CaCl_2$, solid ammonium nitrate, NH_4NO_3, solid sodium thiosulphate, $Na_2S_2O_3$ and distilled water.

Apparatus: Polystyrene cups with lids, spatula, measuring cylinder and thermometer.

Procedure:

1. Measure 20 cm^3 of distilled water and pour it into a polystyrene cup.
2. Put a thermometer in the polystyrene cup and leave it for two minutes. Record the initial temperature of the distilled water.
3. Add one spatula of solid sodium hydroxide, NaOH into the polystyrene cup.
4. Stir the mixture carefully with the thermometer.
5. Record the highest or the lowest temperature of the mixture.
6. Repeat steps 1 to 5 by replacing solid sodium hydroxide, NaOH with solid ammonium nitrate, NH_4NO_3, solid sodium thiosulphate, $Na_2S_2O_3$ and solid anhydrous calcium chloride, $CaCl_2$.

Results:

Construct a table to record your observations.

Discussion:

1. Based on your results, determine:
   (a) which reaction absorbs heat.
   (b) which reaction releases heat.
2. With reference to 1(a) and 1(b), classify the reactions as endothermic or exothermic reactions.

Chemistry Portal

Endothermic Reaction
https://bit.ly/kpkt5v28

Prepare a complete report after carrying out this laboratory activity.

Energy Level Diagram

- During a chemical reaction, heat is absorbed or released. This heat is called heat of reaction, and is given the symbol ΔH. The unit for heat of reaction is kJ mol^{-1}.
- In a chemical reaction, when heat is released to the surroundings, ΔH is given a negative sign. When heat is absorbed from the surroundings, ΔH is given a positive sign.
- The energy change in a chemical reaction can be represented using an energy level diagram. The energy level diagram shows the difference in the heat energy content between the reactants and the products.

$$\Delta H = H_{\text{products}} - H_{\text{reactants}}$$

Do you know

The symbol Δ, delta is the fourth letter in the Greek alphabet that denotes difference or change.

Heat of reaction, ΔH is the heat change of one mole of reactant that reacts or one mole of product that is formed.

- The following thermochemical equation shows an exothermic reaction, while Figure 3.1 shows the energy level diagram for the reaction.

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g) \qquad \Delta H = -467\ \text{kJ mol}^{-1}$$

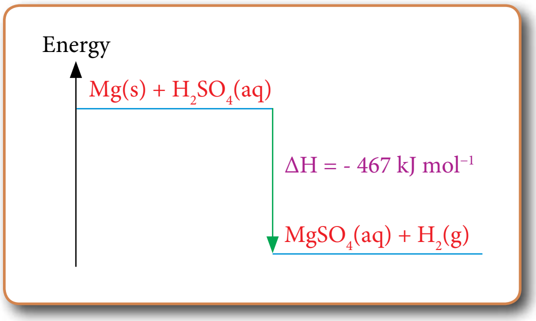


Figure 3.1 Energy level diagram for an exothermic reaction

- The reaction between magnesium, Mg and sulphuric acid, H_2SO_4 forming magnesium sulphate, $MgSO_4$ and hydrogen gas, H_2 is an exothermic reaction.
- When 1 mole of Mg reacts with 1 mole of H_2SO_4 to form 1 mole of $MgSO_4$ and 1 mole of H_2 gas, 467 kJ of heat is released to the surroundings.
- During the reaction, the temperature of the mixture increases.
- The total energy content of the products ($MgSO_4$ and H_2) is lower than the total energy content of the reactants (Mg and H_2SO_4). Therefore, ΔH is negative.

- The following thermochemical equation shows an example of an endothermic reaction, while, Figure 3.2 shows the energy level diagram for the reaction.

$$N_2(g) + O_2(g) \rightarrow 2NO(g) \qquad \Delta H = +180\ \text{kJ mol}^{-1}$$

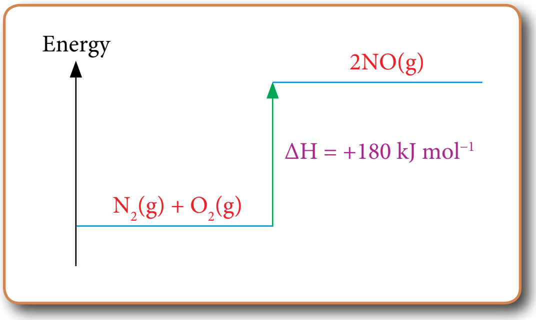
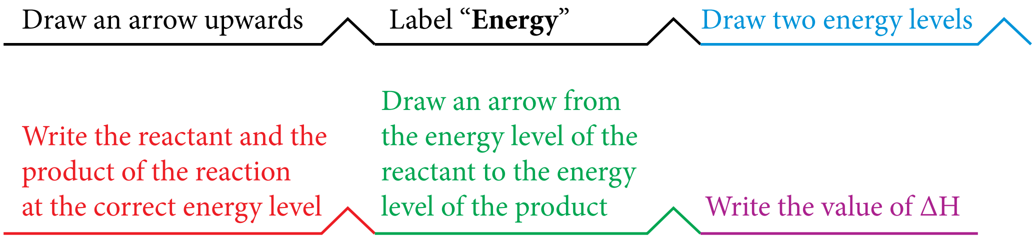


Figure 3.2 Energy level diagram for an endothermic reaction

- The reaction between nitrogen gas, N_2 and oxygen gas, O_2 forming nitrogen monoxide gas, NO is an endothermic reaction.
- When 1 mole of N_2 gas reacts with 1 mole of O_2 gas to form 2 moles of NO gas, 180 kJ heat energy is absorbed from the surroundings.
- During the reaction, the temperature of the mixture decreases.
- The total energy content of the product (NO) is higher than the total energy content of the reactants (N_2 and O_2). Therefore, ΔH is positive.

- The following bridge map shows how the energy level diagram is constructed.



Energy Change During Breaking and Formation of Bonds

- During a chemical reaction, the chemical bonds in the reactants are broken, and new bonds are formed in the products. Based on Table 3.1, the change in energy for the reaction between hydrogen, H_2 and chlorine, Cl_2 to produce hydrogen chloride, HCl is shown in Figure 3.3.

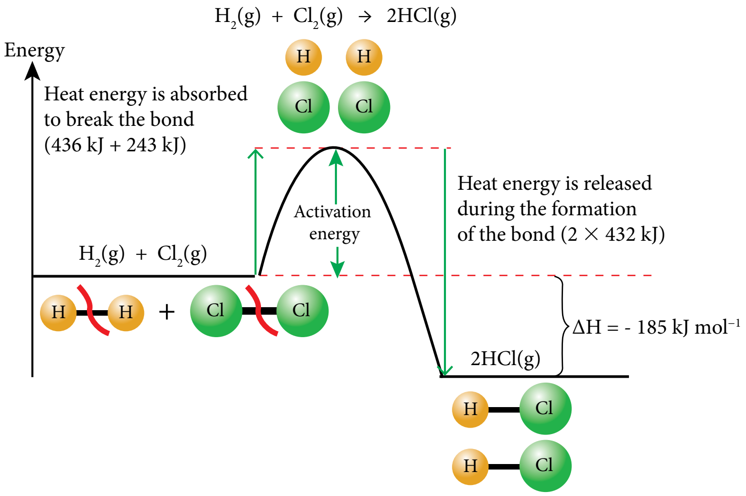


Figure 3.3 The energy profile shows the relationship between the breaking and formation of bonds in an exothermic reaction

Chemistry Portal

Breaking and Formation of Bonds
https://bit.ly/kpkt5v29

Table 3.1 Chemical bond energy

Bond	Bond Energy (kJ mol^{-1})
H-H	436
Cl-Cl	243
H-Cl	432

- In an exothermic reaction, the heat energy released during the formation of the bonds in the products is greater than the heat energy absorbed to break the bonds in the reactants.
- In an endothermic reaction, the heat energy absorbed to break the bonds in the reactants is greater than the heat energy released during the formation of the bonds in the products.

Self Assess 3.1

1. The thermochemical equation for the decomposition reaction of calcium carbonate, $CaCO_3$ is as follows:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g) \quad \Delta H = +540 \text{ kJ mol}^{-1}$$

   (a) Draw the energy level diagram for the reaction.
   (b) Write three statements that can be obtained from the energy level diagram in (a).

2. The thermochemical equation below shows the formation of lead(II) sulphate, $PbSO_4$.

$$Pb(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow PbSO_4(s) + 2NaNO_3(aq) \quad \Delta H = -50 \text{ kJ mol}^{-1}$$

   (a) State whether the reaction above is an exothermic or endothermic reaction.
   (b) Determine which bond is broken and which bond is formed.
   (c) Explain the energy change involved in bond breaking and bond formation.
   (c) Draw the energy level diagram for the reaction.

3.2 HEAT OF REACTION

- The heat of reaction is normally named according to the types of reactions that occur. Figure 3.4 shows the types of heat of reaction.

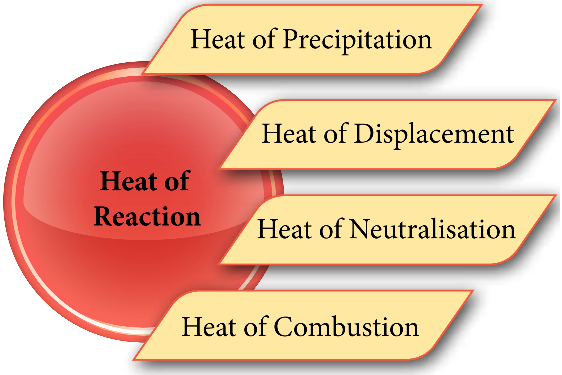


Figure 3.4 Types of heat of reactions

- The heat of reaction can be determined through experiments by establishing the temperature change when the reaction occurs. The value of temperature change obtained is used to calculate heat of reaction.
- Figure 3.5 shows a flow chart of the steps to calculate heat of reaction.

Learning Standards

Pupils are able to:

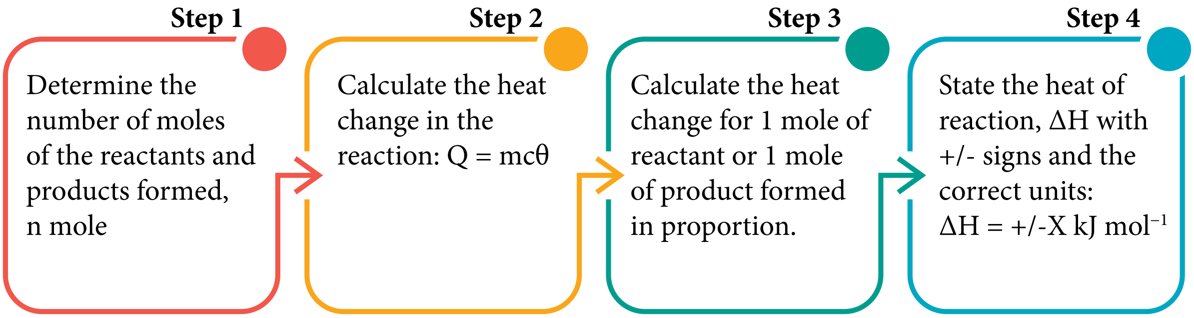
3.2.1 determine heat of precipitation through activity.
3.2.2 determine heat of displacement through activity.
3.2.3 compare heat of neutralisation through experiments for reactions between item:
  (a) strong acid and strong alkali,
  (b) weak acid and strong alkali,
  (c) strong acid and weak alkali,
  (d) weak acid and weak alkali.
3.2.4 compare heat of combustion for various types of alcohol through experiment.

Cross-Curriculum History

The Joule symbol J is the SI issued unit for energy, work and heat that is used in honour of James Prescott Joule (1818-1889).

Cross-Curriculum Physics

Physics Link: $Q = mc\theta$



Step 1
Determine the number of moles of the reactants and products formed, n mole

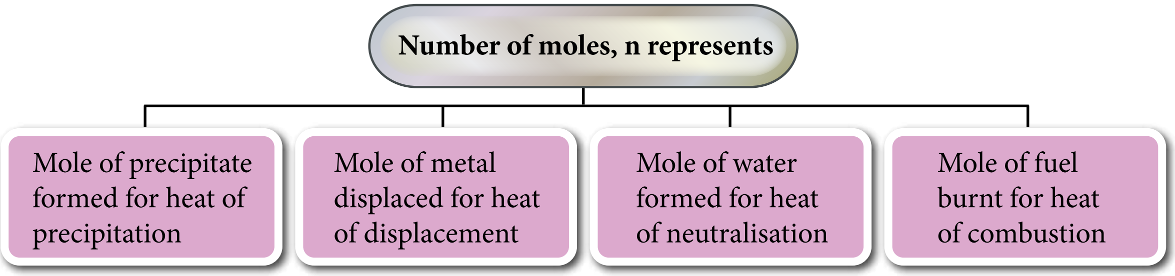
Step 2
Calculate the heat change in the reaction: $Q = mc\theta$

Step 3
Calculate the heat change for 1 mole of reactant or 1 mole of product formed in proportion.

Step 4
State the heat of reaction, ΔH with +/- signs and the correct units: $\Delta H = +/-X \text{ kJ mol}^{-1}$

Figure 3.5 General steps to calculate heat of reactions

- The number of moles, n is according to the types of heat of reactions as follows:



Number of moles, n represents

Mole of precipitate formed for heat of precipitation

Mole of metal displaced for heat of displacement

Mole of water formed for heat of neutralisation

Mole of fuel burnt for heat of combustion

- Most chemical reactions carried out to determine the heat of reaction involve aqueous solutions. Some assumptions are made during calculations:

  - The density of any aqueous solution is equal to the density of water, 1 g cm^{-3}.
  - The specific heat capacity of any aqueous solution is equal to the specific heat capacity of water, which is 4.2 J g^{-1} °C^{-1}.
  - No heat is lost to the surroundings.
  - No heat is absorbed by the apparatus of the experiment.

Heat of Precipitation

Figure 3.6 Usage of barium sulphate in medicine

- Based on the conversation above, do you know that barium sulphate, $BaSO_4$ is an insoluble salt that is used in the fields of medicine? Try to reflect on the insoluble salts learned in form 4. All insoluble salts are precipitates.

Topic Link **Form 4 Chemistry:** Preparation of insoluble salts.

- Insoluble salts are formed by a double decomposition reaction that involves heat change, which is known as heat of precipitation. What is meant by heat of precipitation?

Heat of precipitation is the heat change when **1 mole of precipitate** is formed from their ions in an aqueous solution.

- The thermochemical equation for the formation of barium sulphate, $BaSO_4$ precipitate is:

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) \quad \Delta H = -42 \text{ kJ mol}^{-1}$$

- Based on the thermochemical equation, 42 kJ of heat is released when 1 mole of barium sulphate, $BaSO_4$ precipitate is formed. Therefore, the heat of precipitation of barium sulphate, $BaSO_4$ is -42 kJ mol^{-1}.

Photograph 3.4 White precipitate of barium sulphate, $BaSO_4$

Example:

100 cm^3 of 1.0 mol dm^{-3} of lead(II) nitrate, $Pb(NO_3)_2$ solution is added to 100 cm^3 of 1.0 mol dm^{-3} of sodium sulphate, Na_2SO_4 solution. The temperature of the mixture rises from 30.0 °C to 33.0 °C. Calculate the heat of precipitation of lead(II) sulphate, $PbSO_4$.
[Specific heat capacity of solution, $c = 4.2 \text{ J g}^{-1} \text{°C}^{-1}$; density of solution = 1 g cm^{-3}]

Solution:

Step 1: Calculate the number of moles of lead(II) sulphate, $PbSO_4$ precipitate formed.

Number of moles of lead(II) ions, Pb^{2+} = Number of moles of lead(II) nitrate, $Pb(NO_3)_2$

$$= 1.0 \text{ mol dm}^{-3} \times \frac{100}{1000} \text{ dm}^3 = 0.1 \text{ mol}$$

Number of moles of sulphate ions, SO_4^{2-}
= Number of moles of sodium sulphate, Na_2SO_4

$$= 1.0 \text{ mol dm}^{-3} \times \frac{100}{1000} \text{ dm}^3 = 0.1 \text{ mol}$$

Use the formula, $n = \frac{MV}{1000}$
n = number of mole
M = molarity of the solution
V = volume of the solution in cm^3

$$\begin{array}{lllll} Pb^{2+}(aq) & + & SO_4^{2-}(aq) & \rightarrow & PbSO_4(s) \\ 1 \text{ mol} & & 1 \text{ mol} & & 1 \text{ mol} \end{array}$$

Write the ionic equation for the reaction

Compare the stoichiometry of the ionic equation

From the ionic equation, 1 mole of lead(II) ions, Pb^{2+} reacts with 1 mole of sulphate ions, SO_4^{2-} to produce 1 mole of lead(II) sulphate, $PbSO_4$.

Therefore, 0.1 mole of lead(II) ions, Pb^{2+} reacts with 0.1 mole of sulphate ions, SO_4^{2-} to produce 0.1 mole of lead(II) sulphate, $PbSO_4$.

Step 2: Calculate the heat change.

Mass of solution, m = Total volume of mixture × density of solution
= $(100 + 100) \text{ cm}^3 \times 1 \text{ g cm}^{-3}$
= 200 g

Temperature change of the solution, θ = Highest temperature − initial temperature
= 33.0 °C − 30.0 °C = 3.0 °C

Heat released in the reaction, $Q = mc\theta$
$= 200 \text{ g} \times 4.2 \text{ J g}^{-1} \text{°C}^{-1} \times 3.0 \text{ °C}$
= 2520 J
= 2.52 kJ

Step 3 : Calculate the heat change for the formation of 1 mole of precipitate.

Precipitation of 0.1 mole of lead(II) sulphate, $PbSO_4$ releases 2.52 kJ of heat.

Therefore, the precipitation of 1 mole of lead(II) sulphate, $PbSO_4$ releases $\frac{2.52 \text{ kJ}}{0.1 \text{ mol}}$ of heat, which is 25.2 kJ mol^{-1}

Step 4: Write the heat of reaction, ΔH.

Heat of precipitation of lead(II) sulphate, $PbSO_4$ $\Delta H = -25.2 \text{ kJ mol}^{-1}$

Negative sign (-) shows that this is an exothermic reaction.

Laboratory Activity 3B Determining Heat of Precipitation

PAK 21 Learning Science Through Inquiry

Aim: To determine the heat of precipitation of silver chloride, AgCl and magnesium carbonate, $MgCO_3$.

Materials: 0.5 mol dm^{-3} of silver nitrate, $AgNO_3$ solution, 0.5 mol dm^{-3} of sodium chloride, NaCl solution, 0.5 mol dm^{-3} of magnesium nitrate, $Mg(NO_3)_2$ solution and 0.5 mol dm^{-3} of sodium carbonate, Na_2CO_3 solution.

Apparatus: Two polystyrene cups with lids, measuring cylinder and thermometer.

Operational definition - Heat of Precipitation: when sodium chloride, NaCl solution is added to silver nitrate, $AgNO_3$ solution to produce 1 mole of silver chloride, AgCl precipitate, the thermometer reading increases.

Procedure:

1. Measure 25 cm^3 of 0.5 mol dm^{-3} of silver nitrate, $AgNO_3$ solution and pour it into a polystyrene cup.
2. Put a thermometer into the solution and leave aside for two minutes.
3. Record the temperature of the solution.
4. Measure 25 cm^3 of 0.5 mol dm^{-3} of sodium chloride, NaCl solution, and pour it into another polystyrene cup.
5. Put a thermometer into the solution and leave it aside for two minutes. Record the temperature of the solution.
6. Pour the sodium chloride, NaCl solution quickly and carefully into the polystyrene cup containing the silver nitrate, $AgNO_3$ solution.

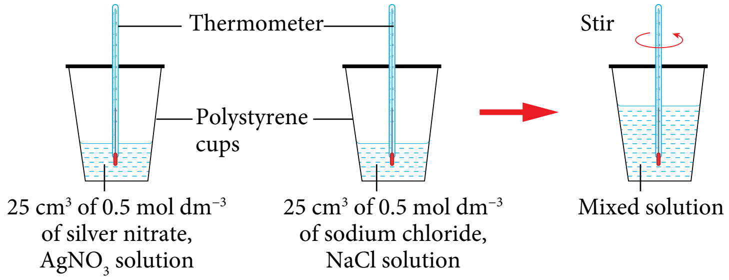


Figure 3.7

CAUTION

Silver nitrate solution may cause dark stains on your skin and clothes.

7. Cover the polystyrene cup and stir the mixture using the thermometer as shown in Figure 3.7.
8. Record the highest temperature of the mixture.
9. Repeat steps 1 to 8 by replacing silver nitrate, $AgNO_3$ solution with magnesium nitrate, $Mg(NO_3)_2$ solution, and sodium chloride, NaCl solution with sodium carbonate, Na_2CO_3 solution.

Results:

Construct a suitable table to record your results and observations.

Discussion:

1. State the type of reaction that occurred.
2. Calculate the heat of precipitation of silver chloride, AgCl and magnesium carbonate, $MgCO_3$
   [Use the heat change formula, $Q = mc\theta$]
   [Given: Specific heat capacity of solution, $c = 4.2\ J\ g^{-1}\ °C^{-1}$; density of solution = $1\ g\ cm^{-3}$]

3. Write the thermochemical equation for the precipitation of silver chloride, AgCl and magnesium carbonate, $MgCO_3$.
4. Construct the energy level diagram for the precipitation of silver chloride, AgCl and magnesium carbonate, $MgCO_3$.
5. The theoretical value for the heat of precipitation of silver chloride, AgCl is -65.5 kJ mol^{-1}. Is this value the same as the value obtained in this experiment? Explain your answer.

Conclusion:

What is the conclusion that can be drawn from this experiment?

Prepare a complete report after carrying out this laboratory activity.

Example:

The following equation shows the precipitation of silver chloride, AgCl.

$$AgNO_3(aq) + KCl(aq) \rightarrow AgCl(s) + KNO_3(aq) \qquad \Delta H = -65.5 \text{ kJ mol}^{-1}$$

If 20 cm^3 of 0.5 mol dm^{-3} of silver nitrate, $AgNO_3$ solution is added into 20 cm^3 of 0.5 mol dm^{-3} of potassium chloride, KCl solution, calculate the rise in temperature of the mixture.
[Given: Specific heat capacity of solution, c = 4.2 J g^{-1} °C^{-1}; density of solution = 1 g cm^{-3}]

Solution:

Step 1: Calculate the number of moles of silver chloride, AgCl formed.

Number of moles of potassium chloride, KCl $= \dfrac{0.5 \times 20}{1000} = 0.01$ mol

Number of moles of silver nitrate, $AgNO_3 = \dfrac{0.5 \times 20}{1000} = 0.01$ mol

From the equation, 1 mole of potassium chloride, KCl reacts with 1 mole of silver nitrate, $AgNO_3$ to produce 1 mole of silver chloride, AgCl.

Therefore, 0.01 mole of potassium chloride, KCl reacts with 0.01 mole of silver nitrate, $AgNO_3$ to produce 0.01 mole of silver chloride, AgCl.

Step 2: Calculate the heat change.

Given $\Delta H = -65.5 \text{ kJ mol}^{-1}$

When 1 mole of silver chloride, AgCl is formed, 65.5 kJ of heat is released.

Therefore, 0.01 mole of silver chloride, AgCl is formed, $\dfrac{0.01 \text{ mol} \times 65.5 \text{ kJ}}{1 \text{ mol}} = 0.655$ kJ heat is released.

Step 3: Calculate the rise in temperature.

Mass of solution = $(20 + 20) \text{ cm}^3 \times 1 \text{ g cm}^{-3} = 40 \text{ g}$

Heat released, Q = 655 J

$40 \text{ g} \times 4.2 \text{ J g}^{-1}\,°\text{C}^{-1} \times \theta = 655 \text{ J}$

Rise in temperature, $\theta = \dfrac{655 \text{ J}}{40 \text{ g} \times 4.2 \text{ J g}^{-1}\,°\text{C}^{-1}} = 3.9\,°\text{C}$

Heat of Displacement

- An experiment was carried out by putting an iron nail into copper(II) sulphate, $CuSO_4$ solution. Figure 3.8 shows the result of the experiment.

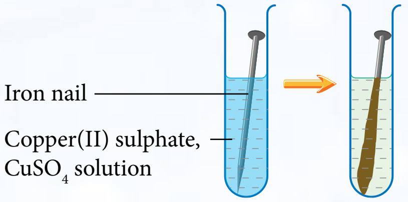


Figure 3.8 An iron nail is placed into the copper(II) sulphate, $CuSO_4$ solution

Why has a brown deposit formed on the iron nail?
Why does the blue colour solution become pale?

Topic Link

Redox:
Displacement of metal from its salt solution on page 16.

- Recall what you have learned from displacement reaction. Can you answer the questions above?
- The brown deposit, which is copper, Cu shows that iron, Fe has displaced copper, Cu from its salt solution.
- Displacement reactions also involve heat change. What is meant by heat of displacement?

> **Heat of displacement** is the heat change when **one mole of a metal is displaced** from its salt solution by **a more electropositive metal**.

- The following thermochemical equation represents a displacement reaction.

$$Fe(s) + CuSO_4(aq) \rightarrow FeSO_4(aq) + Cu(s) \quad \Delta H = -250 \text{ kJ mol}^{-1}$$

or

$$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s) \quad \Delta H = -250 \text{ kJ mol}^{-1}$$

- Based on the thermochemical equation, 250 kJ of heat is released when one mole of copper, Cu is displaced from copper(II) sulphate, $CuSO_4$ solution by iron, Fe.
- Therefore, the heat of displacement of copper from copper(II) sulphate, $CuSO_4$ solution by iron, Fe is -250 kJ mol^{-1}.

Example:

An excess of magnesium powder, Mg is added into 50 cm^3 of 0.25 mol dm^{-3} of iron(II) sulphate, $FeSO_4$ solution. The temperature of the mixture increases by 4.0 °C. Calculate the heat of displacement of iron, Fe from its salt solution.

[Given: Specific heat capacity of solution, $c = 4.2 \text{ J g}^{-1} \text{ °C}^{-1}$, density of solution = 1 g cm^{-3}]

Solution:

Step 1: Write the chemical equation.

$Mg(s) + FeSO_4(aq) \rightarrow Fe(s) + MgSO_4(aq)$

Step 2: Calculate the number of moles of iron, Fe displaced from iron(II) sulphate, $FeSO_4$ solution.

The number of moles of iron(II) sulphate, $FeSO_4$ solution = $\frac{0.25 \times 50}{1000}$ = 0.0125 mol.

From the equation, 1 mole of iron, Fe is displaced from 1 mole of iron(II) sulphate, $FeSO_4$ solution. Therefore, 0.0125 mole of iron, Fe is displaced from 0.0125 mole of iron(II) sulphate, $FeSO_4$ solution.

Step 3: Calculate the heat change.

Mass of solution, m $= 50\ \text{cm}^3 \times 1\ \text{g cm}^{-3}$
$= 50\ \text{g}$

Heat change, Q $= 50\ \text{g} \times 4.2\ \text{J g}^{-1}\ °\text{C}^{-1} \times 4.0\ °\text{C}$
$= 840\ \text{J}$
$= 0.84\ \text{kJ}$

Step 4: Calculate the heat change for 1 mole of iron, Fe displaced.

Displacement of 0.0125 mole of iron, Fe releases 0.840 kJ of heat.

Therefore, the displacement of 1 mole of iron, Fe can release $\frac{0.840\ \text{kJ}}{0.0125} = 67.2$ kJ of heat.

Step 5: Write the heat of displacement, ΔH.

Heat of displacement of iron, Fe by magnesium, Mg $\Delta H = -\,67.2\ \text{kJ mol}^{-1}$

The negative sign (-) shows that this is an exothermic reaction.

Laboratory Activity 3C Determining Heat of Displacement

PAK21 Learning Science Through Inquiry

Aim: To determine and compare the heat of displacement of copper from copper(II) sulphate, $CuSO_4$ solution with zinc metal, Zn and magnesium metal, Mg.

Materials: 0.5 mol dm^{-3} of copper(II) sulphate, $CuSO_4$ solution, magnesium powder, Mg and zinc powder, Zn.

Apparatus: Polystyrene cups with lids, thermometer, measuring cylinder and spatula.

Procedure:

1. Based on Figure 3.9, list down the suggested apparatus and materials, plan the procedure for the experiment and consider any precautionary steps that need to be taken to calculate the heat of displacement of copper, Cu.
2. Discuss the planned procedures with your teacher before you proceed.

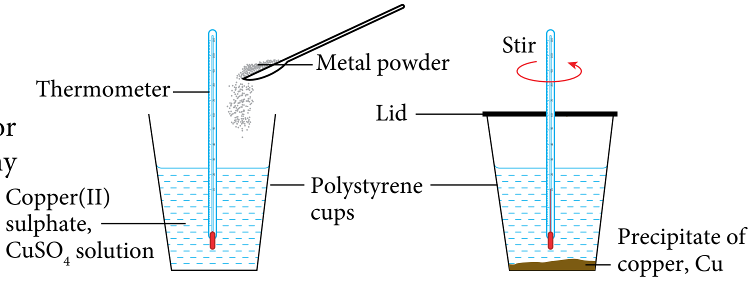


Figure 3.9 Determining the heat of displacement of copper

Results:

Construct a suitable table to record your readings.

Discussion:

1. Based on the experiment:
   (a) write the chemical and the ionic equations for both reactions.
   (b) calculate the heat of displacement, ΔH of copper, Cu by magnesium, Mg and zinc, Zn.
   [Given: Specific heat capacity of solution: $c = 4.2\ \text{J g}^{-1}\ °\text{C}^{-1}$; density of solution $= 1\ \text{g cm}^{-3}$]
   (c) explain why the value of heat of displacement of copper, Cu by magnesium metal, Mg and zinc metal, Zn is different.
   (d) draw the energy level diagram for both reactions.
2. Why are both metals used in excess in this experiment?
3. Apart from the change in temperature, state other observations that can be found during the experiment.

4. What is the operational definition of the heat of displacement in this experiment?
5. Will the heat of displacement, ΔH of copper, Cu be the same if copper(II) sulphate, $CuSO_4$ solution is replaced with copper(II) nitrate, $Cu(NO_3)_2$ solution? Explain your answer.

Conclusion:

Write the conclusion for this experiment.

Prepare a complete report after carrying out this laboratory activity.

ACTIVITY 3A

PAK 21

A student carried out an experiment to determine the heat of displacement for the reaction between copper, Cu and silver nitrate, $AgNO_3$ solution. In this experiment, excess copper powder, Cu is added into 100 cm^3 of 0.5 mol dm^{-3} of silver nitrate, $AgNO_3$ solution.
The heat of displacement in this experiment is -105 kJ mol^{-1}.
[Specific heat capacity of solution, $c = 4.2$ J g^{-1} °C^{-1}; density of solution = 1 g cm^{-3}]

(a) Write the thermochemical equation for this reaction.
(b) Calculate the heat released in this experiment.
(c) Calculate the change in temperature.
(d) Draw the energy level diagram for this reaction.
(e) The experiment is repeated using 100 cm^3 of 1.0 mol dm^{-3} of silver nitrate, $AgNO_3$ solution and excess copper powder, Cu. Calculate the change in temperature in this experiment. Explain why the change in temperature is different from the calculated value in (c).

Heat of Neutralisation

Figure 3.10 Experiment of neutralisation

Topic Link
Form 4 Chemistry:
Neutralisation

- Neutralisation is a reaction between an acid and an alkali to produce only salt and water.
- Neutralisation reaction is an exothermic reaction.
- Hydrogen ions, H^+ from acid reacts with hydroxide ions, OH^- from alkali to form water, H_2O molecules. The ionic equation is as follows:

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

The heat of neutralisation is the heat change when **one mole of water** is formed from the reaction between **an acid and an alkali**.

- The themochemical equation for neutralisation reaction between hydrochloric acid, HCl and sodium hydroxide, NaOH solution is:

$$\mathrm{NaOH(aq)} + \mathrm{HCl(aq)} \rightarrow \mathrm{NaCl(aq)} + \mathrm{H_2O(l)} \quad \Delta H = -57\ \mathrm{kJ\ mol^{-1}}$$

- The thermochemical equation shows 57 kJ heat is released when one mole of water, H_2O is formed from the neutralisation reaction between 1 mole of hydrochloric acid, HCl (1 mole of hydrogen ions, H^+) and 1 mole of sodium hydroxide, NaOH (1 mole of hydroxide ions, OH^-).
- Neutralisation reactions can occur between acids and alkalis of different strengths as follows:
  (a) strong acid and strong alkali
  (b) weak acid and strong alkali
  (c) strong acid and weak alkali
  (d) weak acid and weak alkali
- What is the effect of using different acids and alkalis on the heat of neutralisation? Conduct Experiment 3A to find out.

Experiment 3A Comparing Heat of Neutralisation

PAK21 Learning Science Through Inquiry

Aim: To determine and compare heat of neutralisation between acids and alkalis of different strengths.

A. Reactions of a strong acid with a strong alkali and a weak acid with a strong alkali.

Problem statement: Does the reaction between a strong acid and a strong alkali produce a higher heat of neutralisation when compared to the reaction between a weak acid and a strong alkali?

Hypothesis: The reaction between a strong acid and a strong alkali produces a higher heat of neutralisation than the reaction between a weak acid and a strong alkali.

Variables:

(a) Manipulated variable : Hydrochloric acid, HCl and ethanoic acid, CH_3COOH
(b) Responding variable : Heat of neutralisation
(c) Fixed variable : Volume and concentration of sodium hydroxide, NaOH solution

Materials: 1.0 mol dm^{-3} of hydrochloric acid, HCl, 1.0 mol dm^{-3} of ethanoic acid, CH_3COOH and 1.0 mol dm^{-3} of sodium hydroxide, NaOH solution.

Apparatus: Polystyrene cups with lids, thermometer and measuring cylinder.

Procedure:

1. Measure and pour 50 cm^3 of 1.0 mol dm^{-3} of hydrochloric acid, HCl into a polystyrene cup.
2. Measure and pour 50 cm^3 of 1.0 mol dm^{-3} of sodium hydroxide, NaOH solution into another polystyrene cup.
3. Put a thermometer into each solution and record the initial temperature of each solution.
4. Pour 1.0 mol dm^{-3} of hydrochloric acid, HCl quickly and carefully into the 1.0 mol dm^{-3} of sodium hydroxide, NaOH solution.
5. Stir the mixture using the thermometer.
6. Record the highest temperature.
7. Repeat steps 1 to 6 by replacing hydrochloric acid, HCl with ethanoic acid, CH_3COOH.

Noble Value

Systematic, confident and ethical.

B. Reactions of a strong acid with a weak alkali and a weak acid with a weak alkali

Problem statement: Does the reaction between a strong acid and a weak alkali produce a higher heat of neutralisation compared to the reaction between a weak acid and a weak alkali?

Hypothesis: Construct a hypothesis that involves the reactions of a strong acid, a weak acid with a weak alkali and the heat of neutralisation.

Variables: State all variables.

Materials: 1.0 mol dm^{-3} of hydrochloric acid, HCl, 1.0 mol dm^{-3} of ethanoic acid, CH_3COOH and 1.0 mol dm^{-3} of ammonia, NH_3 solution.

Apparatus: Polystyrene cups with lids, thermometer and measuring cylinder.

Procedure:

Using the materials and apparatus provided, plan and carry out an experiment to investigate the effects of strengths of acids on the heat of neutralisation with weak alkalis.

Results:

Copy and complete Table 3.2 to record the initial temperature of the acids and alkalis, average temperature of acids and alkalis, highest temperature and increase in temperature.

Table 3.2

Reacting mixture	Hydrochloric acid, HCl and sodium hydroxide, NaOH solution	Ethanoic acid, CH_3COOH and sodium hydroxide, NaOH solution	Hydrochloric acid, HCl and ammonia, NH_3 solution	Ethanoic acid, CH_3COOH and ammonia, NH_3 solution
Initial temperature of acid (°C)				
Initial temperature of alkali (°C)				
Average temperature of acid and alkali (°C)				
Highest temperature of mixture (°C)				
Temperature rise (°C)				

Discussion:

1. Write the chemical equation for each neutralisation reaction that takes place.
2. Calculate the heat of neutralisation, ΔH for each reaction.
   [Given: Specific heat capacity of solution: $c = 4.2\ J\ g^{-1}\ °C^{-1}$; density of solution = $1\ g\ cm^{-3}$]
3. Construct the energy level diagram for each neutralisation reaction.
4. Compare the value of the heat of neutralisation for each neutralisation reaction in this experiment.
5. Explain the reason for the difference in the value of the heat of neutralisation.
6. The theoretical value of the heat of neutralisation between a strong acid and a strong alkali is -57 kJ mol^{-1}. Compare this value with the heat of neutralisation obtained from this experiment. Suggest a reason for this difference.

Conclusion:

Can the hypothesis be accepted? What is the conclusion of this experiment?

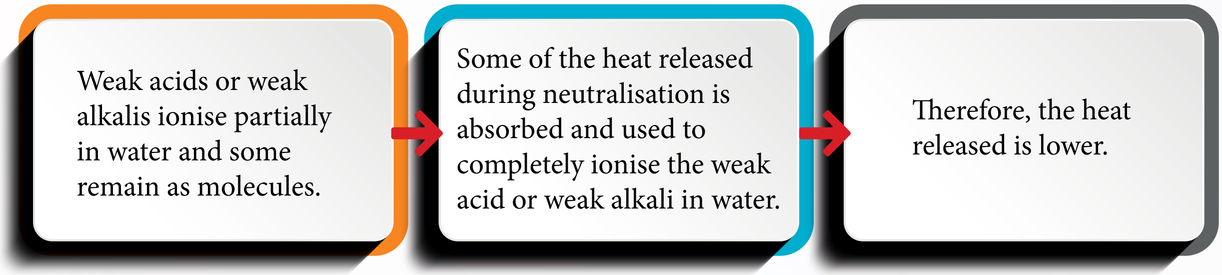
Prepare a complete report after carrying out this experiment.

- The theoretical value of the heat of neutralisation between a strong acid and a strong alkali is -57 kJ mol^{-1}.
- Table 3.3 shows the heat of neutralisation of various neutralisation reactions.

Table 3.3 Heat of neutralisaton of various neutralisation reactions

Example	Heat of neutralisation, ΔH (kJ mol^{-1})
Strong acid + Strong Alkali → Salt + Water	-57
Weak acid + Strong Alkali → Salt + Water	-55
Strong acid + Weak alkali → Salt + Water	-52
Weak acid + Weak alkali → Salt + Water	-50

- Note that there is an influence of acid and alkali strengths over the heat of neutralisation. The value of the heat of neutralisation is lower when weak acids or weak alkalis are used. This is explained in the flow chart of Figure 3.11.



Weak acids or weak alkalis ionise partially in water and some remain as molecules.

Some of the heat released during neutralisation is absorbed and used to completely ionise the weak acid or weak alkali in water.

Therefore, the heat released is lower.

Figure 3.11 Explanation related to heat of neutralisation that involves weak acids or weak alkalis

- The heat of neutralisation between weak acids and weak alkalis is the lowest:
  (a) More heat energy is needed to completely ionise both weak acids and weak alkalis.
  (b) Therefore, hydrogen ions, H^+ and hydroxide ions, OH^- produced can completely react to form 1 mole of water.

How about the neutralisation reaction between sulphuric acid, H_2SO_4, a diprotic acid, and sodium hydroxide, NaOH solution?

Topic Link

Form 4 Chemistry:
1. Strength of acids and alkalis
2. Basicity of acids

- Hydrochloric acid, HCl is a monoprotic acid while sulphuric acid, H_2SO_4 is a diprotic acid.
- Complete neutralisation between a strong diprotic acid and a strong alkali produces twice the quantity of heat compared to a strong monoprotic acid.

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \qquad \Delta H = -57 \text{ kJ mol}^{-1}$$

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) \qquad \Delta H = -114 \text{ kJ}$$

- One mole of a strong diprotic acid such as sulphuric acid, H_2SO_4 ionises in water to produce two moles of hydrogen ions, H^+:

$$H_2SO_4(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$$

- Two moles of hydrogen ions, H^+ will produce two moles of water, H_2O when they react with two moles of hydroxide ions, OH^-. 114 kJ heat is released because two moles of water are formed.

$$2H^+(aq) + 2OH^-(aq) \rightarrow 2H_2O(l) \quad \Delta H = -114 \text{ kJ}$$

- The heat of neutralisation of sulphuric acid, H_2SO_4 with sodium hydroxide, NaOH solution is still the same, which is -57 kJ, because the meaning of the heat of neutralisation is the heat released for the formation of one mole of water.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l) \quad \Delta H = -57 \text{ kJ mol}^{-1}$$

- Using monoprotic acids such as hydrochloric acid, HCl or nitric acid, HNO_3 with a strong alkali, such as sodium hydroxide, NaOH or potassium hydroxide, KOH, will produce one mole of water.

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \quad \Delta H = -57 \text{ kJ mol}^{-1}$$

$$HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l) \quad \Delta H = -57 \text{ kJ mol}^{-1}$$

Example:

60 cm^3 of 2.0 mol dm^{-3} of sodium hydroxide, NaOH solution is added into 60 cm^3 of 2.0 mol dm^{-3} of ethanoic acid, CH_3COOH. The highest temperature of the mixture is 40.5 °C. The initial temperature of sodium hydroxide, NaOH solution is 28.0 °C, and ethanoic acid, CH_3COOH solution is 28.0 °C. Calculate the heat of neutralisaton.

[Specific heat capacity of solution: $c = 4.2 \text{ J g}^{-1}\,°\text{C}^{-1}$; density of solution = 1 g cm^{-3}]

Solution:

Step 1: Calculate the number of moles of water, H_2O produced.

$$\text{Number of mole of sodium hydroxide, NaOH} = \frac{2.0 \times 60}{1000} = 0.12 \text{ mol}$$

$$\text{Number of mole of ethanoic acid, } CH_3COOH = \frac{2.0 \times 60}{1000} = 0.12 \text{ mol}$$

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

From the equation, 1 mole of sodium hydroxide, NaOH reacts with 1 mole of ethanoic acid, CH_3COOH to produce 1 mole of water, H_2O.

Therefore, 0.12 mole of sodium hydroxide, NaOH reacts with 0.12 mole of ethanoic acid, CH_3COOH to produce 0.12 mole of water, H_2O.

Step 2: Calculate the heat change.

Heat released in the reaction, $Q = mc\theta$

$$= (60 + 60)\ \text{g} \times 4.2\ \text{J g}^{-1}\ ^\circ\text{C}^{-1} \times (40.5 - 28.0)\ ^\circ\text{C}$$

$$= 6300\ \text{J}$$

$$= 6.3\ \text{kJ}$$

Step 3: Calculate the heat change for the formation of 1 mole of water.

Formation of 0.12 mole of water, H_2O releases 6.3 kJ of heat.

Therefore, the formation of 0.12 mole of water, H_2O releases $\dfrac{6.3\ \text{kJ}}{0.12\ \text{mol}}$ of heat, which is 52.5 kJ mol^{-1}.

Step 4: Write the heat of neutralisation, ΔH.

Heat of neutralisation, $\Delta H = -52.5\ \text{kJ mol}^{-1}$

ACTIVITY 3B

PAK21

When 100 cm^3 of 2.0 mol dm^{-3} of dilute hydrochloric acid, HCl is added to 100 cm^3 of 2.0 mol dm^{-3} of sodium hydroxide, NaOH solution, the temperature of the reaction increases from 30.0 °C to 43.5 °C.
[Specific heat capacity of solution, $c = 4.2\ \text{J g}^{-1}\ ^\circ\text{C}^{-1}$; density of solution = $1\ \text{g cm}^{-3}$]

(a) Calculate the heat of neutralisation.
(b) Write the thermochemical equation.
(c) Construct an energy level diagram for this reaction.
(d) Predict the temperature change if the hydrochloric acid, HCl is replaced with nitric acid, HNO_3 with the same volume and concentration. Explain your answer.

Heat of Combustion

- Based on the conversation in Figure 3.12, burning of different fuels will produce different energy value. Combustion of fuel is an exothermic reaction.

Figure 3.12 Cooking using wood

- Consider the complete combustion of methane, CH_4 in oxygen, O_2.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \quad \Delta H = -394 \text{ kJ mol}^{-1}$$

- The thermochemical equation shows that when one mole of methane, CH_4 is completely burnt in oxygen, O_2, heat released is 394 kJ.
- The heat released is known as heat of combustion.

The heat of combustion is the heat released when **1 mole of a substance is completely** burnt in excess oxygen, O_2.

Experiment 3B Determining the Heat of Combustion of Various Alcohols.

PAK21 Learning Science Through Inquiry

Aim: To determine the heat of combustion of various alcohols.

Problem statement: Does the number of carbon atoms per molecule in alcohol affect the heat of combustion?

Hypothesis: The higher the number of carbon atoms per molecule of alcohol, the higher the heat of combustion.

Topic Link Carbon compound: Combustion of alcohol on page 86.

Variables:
(a) Manipulated variable : Types of alcohol
(b) Responding variable : Heat of combustion
(c) Fixed variable : Volume of water

Materials: Methanol, CH_3OH, ethanol, C_2H_5OH, propanol, C_3H_7OH, butanol, C_4H_9OH and water, H_2O.

Apparatus: Copper can, tripod stand, pipeclay triangle, thermometer (0 °C – 100 °C), measuring cylinder, spirit lamp, electronic weighing balance, wind shield and wooden block.

Procedure:

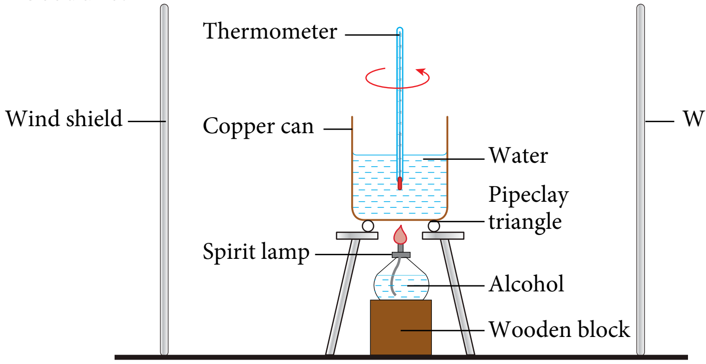


Figure 3.13 Apparatus to determine the heat of combustion

Precautionary steps
Make sure the flame from the spirit lamp touches the bottom of the copper can.

CAUTION
Be cautious when handling alcohols. They are very volatile and highly flammable.

1. Using a measuring cylinder, measure 200 cm^3 of water and pour it into a copper can.
2. Place the copper can on a tripod stand as shown in Figure 3.13.
3. Measure and record the initial temperature of the water.
4. Fill the spirit lamp with methanol, CH_3OH until about three quarter full.
5. Weigh and record the mass of the lamp with its lid and its content.
6. Place the lamp under the copper can and light up the wick of the lamp.

7. Adjust the position of the lamp with a block of wood so that the light of the lamp touches the part under the copper can.
8. Stir the water in the copper can continuously throughout the experiment with the thermometer.
9. Turn off the flame when the water temperature rises by 30 °C. Record the highest temperature of the water.
10. Weigh and record the mass of the lamp with its lid and content immediately after combustion.
11. Repeat steps 1 to 10 using ethanol, C_2H_5OH, propanol, C_3H_7OH and butanol, C_4H_9OH to replace methanol, CH_3OH,

Results:

Construct a suitable table to record your readings.

Noble Value

Honest and accurate in recording and validating data.

Discussion:

1. For all alcohols used in this experiment:
   (a) determine the heat of combustion, ΔH.
   [Given: Specific heat capacity of solution: $c = 4.2\ \text{J g}^{-1}\ °\text{C}^{-1}$; density of solution $= 1\ \text{g cm}^{-3}$]
   (b) write the thermochemical equation for the combustion of alcohols.
   (c) construct an energy level diagram for the combustion of alcohols.
2. What is the relationship between the number of carbon atoms per molecule in the alcohols with the value of heat of combustion?
3. State the operational definition for the heat of combustion of alcohols.
4. Why is a copper can used in this experiment?
5. Observe the outer surface of the bottom of the copper can. What do you observe? Name the substance that is formed and give a reason for the formation of the substance.
6. List out the precautionary steps to be taken to obtain a more accurate result in this experiment.

Conclusion:

Can the hypothesis be accepted? What is the conclusion of this experiment?

Prepare a complete report after carrying out this experiment.

- Alcohol molecules consist of carbon atom, C, hydrogen atom, H and oxygen atom, O. Complete combustion of alcohols produces carbon dioxide, CO_2 and water, H_2O. Combustion of alcohol also releases energy, which is an exothermic reaction. Figure 3.14 shows the graph of heat of combustion of alcohols against the number of carbon atoms per molecule of alcohols.

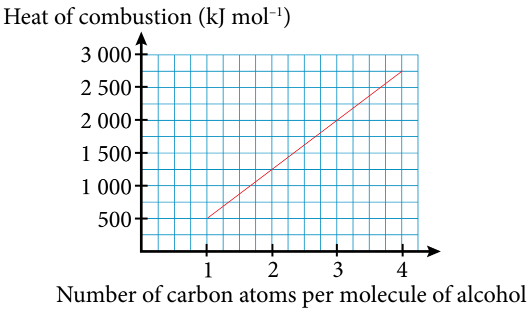


Figure 3.14 Graph of heat of combustion of alcohol against the number of carbon atoms per molecule of alcohol

- As the number of carbon atoms per alcohol molecule increases, the combustion of alcohol produces more carbon dioxide and water molecules. Therefore, more heat is released.
- The increment in the heat of combustion between successive members of alcohols is almost the same. This is because each member differs from the following member with one CH_2 group.

Example:

The thermochemical equation for the complete combustion of ethanol, C_2H_5OH is shown below.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l) \quad \Delta H = -1376 \text{ kJ mol}^{-1}$$

Calculate the mass of ethanol, C_2H_5OH needed to burn completely in excess oxygen, O_2 in order to raise the temperature of 200 cm^3 of water, H_2O by 50.0 °C. (Assume that no heat is lost to the surroundings) [Specific heat capacity of solution, $c = 4.2 \text{ J g}^{-1} \text{°C}^{-1}$; density of solution = 1 g cm^{-3}; molar mass of ethanol = 46 g mol^{-1}]

Solution:

Step 1: Calculate the heat released from the combustion of ethanol, C_2H_5OH.

$$\begin{aligned} \text{Heat released, } Q &= mc\theta \\ &= 200 \text{ g} \times 4.2 \text{ J g}^{-1} \text{°C}^{-1} \times 50.0 \text{ °C} \\ &= 42000 \text{ J} \\ &= 42 \text{ kJ} \end{aligned}$$

Step 2: Calculate the mass of ethanol, C_2H_5OH.

From the thermochemical equation, 1376 kJ of heat is released from the combustion of 1 mole of ethanol, C_2H_5OH.

Therefore, 42 kJ of heat is released from $\dfrac{(42 \times 1) \text{ mol}}{1376}$ of ethanol, C_2H_5OH, which is 0.03 mole of ethanol, C_2H_5OH.

$$\begin{aligned} \text{Mass of ethanol, } C_2H_5OH &= 0.03 \text{ mol} \times 46 \text{ g mol}^{-1} \\ &= 1.38 \text{ g} \end{aligned}$$

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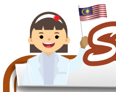
Calculation Activity for the Heat of Combustion

https://bit.ly/kpkt5n38



Self Assess 3.2

Solve the following problems:

Use specific heat capacity of solution, $c = 4.2 \text{ J g}^{-1} \text{°C}^{-1}$; density of solution = 1 g cm^{-3}

1. 50 cm^3 of 2.0 mol dm^{-3} of calcium chloride, $CaCl_2$ solution is added into 50 cm^3 of 2.0 mol dm^{-3} of sodium carbonate, Na_2CO_3 solution. The temperature of the mixture decreases from 27.0 °C to 23.0 °C. Calculate the heat of precipitation of calcium carbonate, $CaCO_3$.

2. In an experiment, excess magnesium powder, Mg is added into 50 cm^3 of 0.25 mol dm^{-3} of iron(II) sulphate, $FeSO_4$ solution at 29.0 °C. The thermochemical equation is as follows:

   $$Mg(s) + Fe^{2+}(aq) \rightarrow Mg^{2+}(aq) + Fe(s) \qquad \Delta H = -80.6 \text{ kJ mol}^{-1}$$

   Calculate the highest temperature reached in this experiment.

3. Table 3.4 shows the value of the heat of neutralisation, ΔH for the reaction between sodium hydroxide, NaOH solution and two different acids.

   Table 3.4

Reactants	ΔH (kJ mol^{-1})
Sodium hydroxide solution and ethanoic acid	-55
Sodium hydroxide solution and hydrochloric acid	-57

   Explain the reason for the difference in the value of heat of neutralisation, ΔH.

3.3 APPLICATION OF EXOTHERMIC AND ENDOTHERMIC REACTIONS IN DAILY LIFE

- The discovery of how to light a fire is considered as one of the most important discoveries in human civilisations.
- Energy generated through combustion allows humans to chase away wild animals, cook food and control their own light sources and heat.
- Knowledge of exothermic and endothermic reactions enables human life to be more comfortable.
- Examples of applications you have learned in Form Three are the use of cold packs and hot packs.

Learning Standards

Pupils are able to:

3.3.1 state a few examples of application of exothermic and endothermic reactions in daily life.

3.3.2 analyse fuel value.

Examples of Applications of Exothermic Reactions in Everyday Life

Hot Can

Hot food or beverages prepared without external heat.

Termite reaction

Welding of railway tracks.

Combustion of fuel

Used for cooking food.

Examples of Applications of Endothermic Reactions in Everyday Life

Gel pads

Relieves fever.

Self cooling beverages

Beverages in cold cans without storing in refrigerators or using ice.

Sorbet

The tongue feels cold when the sorbet is put in the mouth.

Chemistry Portal

Air Bags

https://bit.ly/kpkt5v31

Mind Challenge

Sweating causes the body to feel cold. Is sweating an exothermic or endothermic reaction? Explain the reason for your answer.

ACTIVITY 3C

STEM PAK21

Alex loves camping and he loves his drinks to be cold. How can you help Alex enjoy having his drinks cold while camping? Based on information from reading sources or websites about exothermic reaction and endothermic reaction, how can you help Alex?

You are required to solve this problem by designing a cold pack so that Alex can enjoy cold orange juice. Prepare a complete report by including the materials and apparatus used, cold pack preparation procedure, data obtained, a sketch of the diagram of the cold pack and the advantages of the cold pack produced. You are required to creatively present the results of the cold pack design.

What is fuel value?

- Fuels are substances that burn in the air to produce heat energy.
- Each fuel has different heat of combustion

The fuel value of a fuel is the amount of heat energy released when one gram of fuel is completely burnt in excess oxygen.

- The unit for fuel value is kJ g^{-1}.
- The fuel value can also be determined with the heat of combustion of substances.

$$\text{Fuel value (kJ g}^{-1}\text{)} = \frac{\text{heat combustion of substance (kJ mol}^{-1}\text{)}}{\text{molar mass of substance (g mol}^{-1}\text{)}}$$

- **Example of calculation:**
  The heat of combustion of octane, C_8H_{18} is -5 500 kJ mol^{-1}.
  Calculate the fuel value of octane, C_8H_{18}.
  [Given: Relative atomic mass: H = 1, C = 12]

  Solution:
  Molar mass of octane, C_8H_{18} $= 8(12) + 18(1)$
  $= 114$ g mol^{-1}

  Complete combustion of 114 g of octane, C_8H_{18} releases 5 500 kJ of heat.
  Therefore, combustion of 1 g of octane, C_8H_{18}
  $= \dfrac{5\ 500 \text{ kJ mol}^{-1}}{114 \text{ g mol}^{-1}}$
  $= 48.2$ kJ g^{-1}
  Therefore, the fuel value of octane, C_8H_{18} is 48.2 kJ g^{-1}

Malaysian Excellence

Sarawak Invented the World's First Starch Biogas
https://bit.ly/kpkt5n28

INFO

Fuel for vehicles are known as RON 95 or RON 97. RON refers to Research Octane Number. Fuel with a higher RON is more difficult to burn. Fuel with a lower RON will burn easily.

- Octane has a higher fuel value than methane as shown in Table 3.5, but its combustion will produce more soot. Given a choice, which fuel would you choose to cook with?
- The justification for the selection of suitable fuels for various usage depends on several factors as listed in Figure 3.15.

Table 3.5 Fuel values

Fuel	Fuel value (kJ g^{-1})
Wood	20
Methane	27
Charcoal	30
Ethanol	30
Petrol	34
Kerosene	37
Natural Gas	50
Hydrogen	143

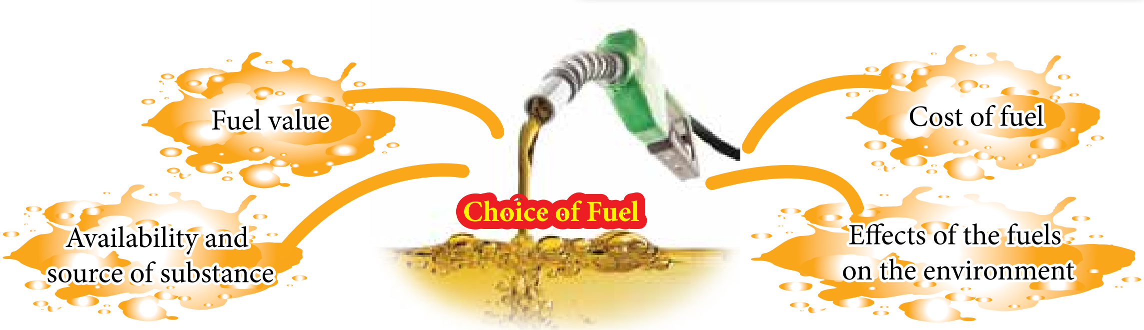


Figure 3.15 Factors in the selection of fuels

- Let us carry out Activity 3D to further discuss the justification of selection of fuel.

ACTIVITY 3D

STEM PAK21

1. Carry out a discussion activity in groups.
2. Using the knowledge of fuel values you have learned, choose suitable fuels used for daily activities such as frying eggs or making popcorns.
3. Justify your group's fuel selection and present the results of the discussion in class.

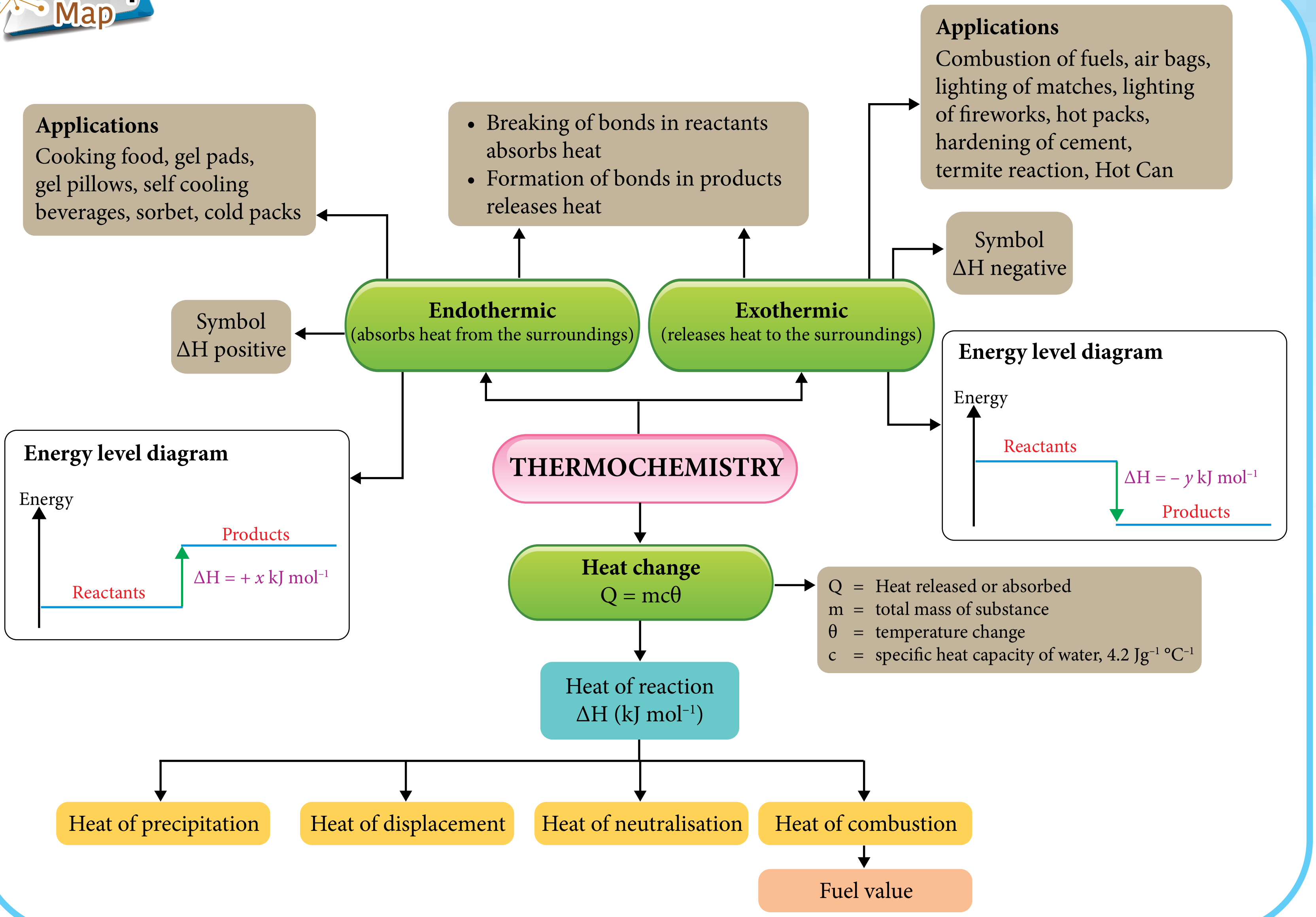
Self Assess 3.3

1. State the meaning of fuel value.
2. Table 3.6 shows the fuel value of a few types of fuels:
   (a) Based on Table 3.6, choose the most suitable fuel to replace petrol in vehicles.
   (b) Compare your choice of fuel with petrol in terms of its effects on the environment.

Table 3.6

Fuel	Fuel value (kJ g^{-1})
Ethanol	30
Petrol	34
Natural gas	50
Hydrogen gas	143

Concept Map



THERMOCHEMISTRY

Endothermic
(absorbs heat from the surroundings)

Applications
Cooking food, gel pads, gel pillows, self cooling beverages, sorbet, cold packs

Symbol
ΔH positive

Energy level diagram

- Breaking of bonds in reactants absorbs heat
- Formation of bonds in products releases heat

Exothermic
(releases heat to the surroundings)

Applications
Combustion of fuels, air bags, lighting of matches, lighting of fireworks, hot packs, hardening of cement, termite reaction, Hot Can

Symbol
ΔH negative

Energy level diagram

Heat change
$Q = mc\theta$

Q = Heat released or absorbed
m = total mass of substance
θ = temperature change
c = specific heat capacity of water, 4.2 $Jg^{-1}\,°C^{-1}$

Heat of reaction
ΔH ($kJ\ mol^{-1}$)

Heat of precipitation

Heat of displacement

Heat of neutralisation

Heat of combustion

Fuel value

SELF Reflection

1. Have you mastered the topic of **Thermochemistry**?
2. What is the content in the topic of **Thermochemistry** that you want to have a more in-depth understanding of? Why?
3. How does the topic of **Thermochemistry** benefit you in daily life?
4. How would you assess your ability to describe the content in the topic of **Thermochemistry** to your friends?
5. What can you do to improve your understanding of the topic of **Thermochemistry**?

ACHIEVEMENT TEST

Use the information:

[Specific heat capacity of solution, c = 4.2 J g^{-1} $°C^{-1}$; density of solution = 1 g cm^{-3}]

1. In an experiment, 100 cm^3 of dilute hydrochloric acid, HCl is mixed with 100 cm^3 of sodium hydroxide, NaOH solution in a polystyrene cup. The concentrations of the acid and alkali are the same. The temperature of the mixture increases by 7.0 °C.
   Calculate the heat released in the experiment.

2. The article below refers to the first tram in the world using hydrogen fuel.

HYDROGEN POWERED TRAMS DEVELOPED IN CHINA

In order to reduce the abundant emissions of dangerous greenhouse gases in China, a Chinese company SIFANG has invented the first hydrogen-powered tram in the world. The trams will be operated entirely by hydrogen fuel cells. When 1 mole of hydrogen is burnt, the heat released is 282 kJ. The highest speed is only 70 kilometers per hour and it will operate in urban areas only. Each tram is designed to carry 380 passengers.

(**Source:** http://www.altemative-energy-news.info/hydrogen-powered-tram)

Based on the article above:

(a) (i) is the reaction endothermic or exothermic? Explain your answer.
    (ii) write the thermochemical equation for the combustion of hydrogen.
    (iii) construct an energy level diagram for the combustion of hydrogen.

(b) In an experiment, 50 g of hydrogen liquid is burnt in excess oxygen.
    [Relative atomic mass: H = 1]
    Calculate:
    (i) the number of moles of hydrogen used.
    (ii) the total energy released when 50 g of hydrogen is burnt.

(c) Justify the use of hydrogen as a fossil fuel.

Chemistry Portal

Additional Exercises
https://bit.ly/kpkt5n11

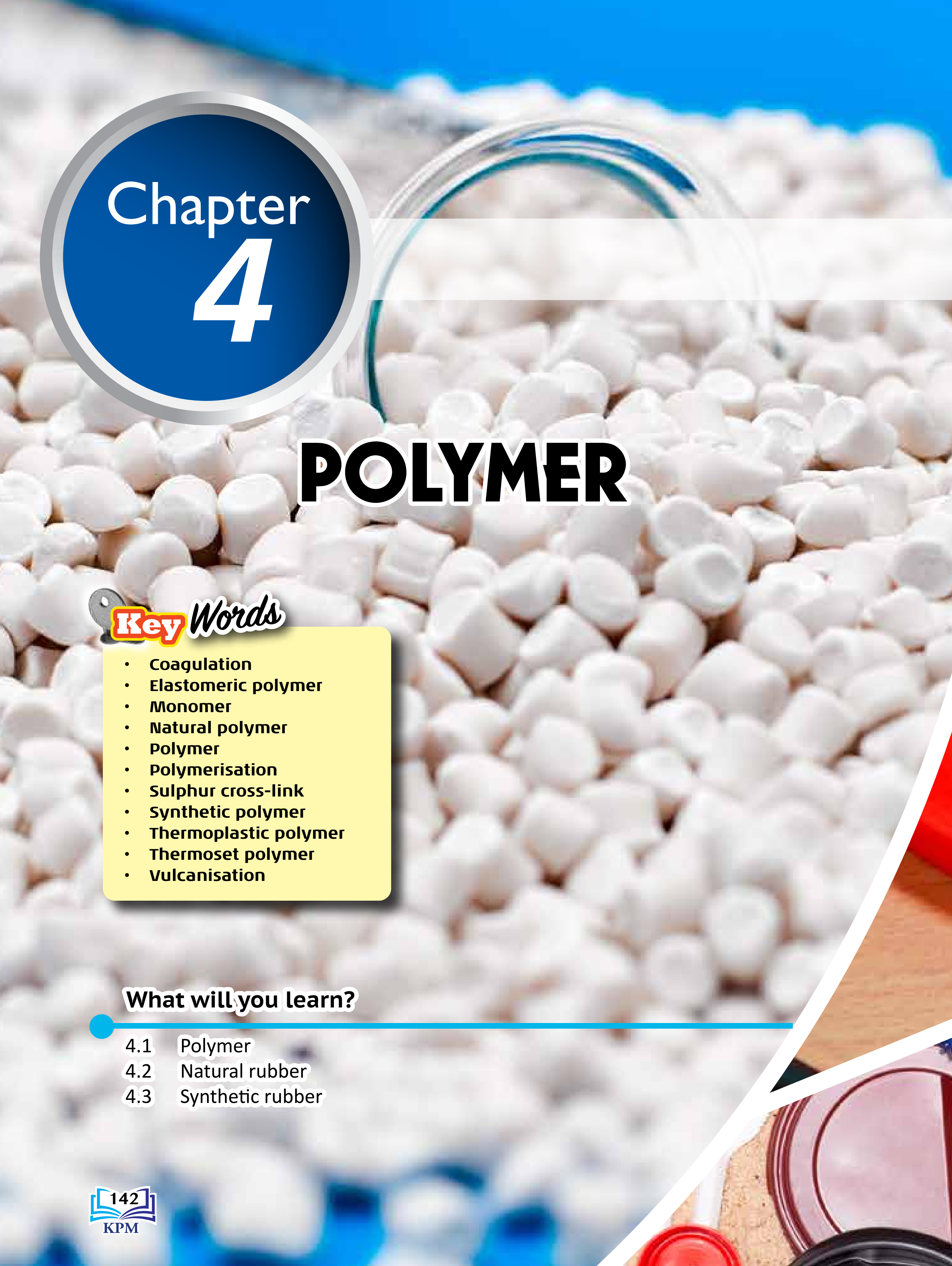
Enrichment Corner

The chemical substance used in hot packs are exothermic when it reacts with water. The reaction of sodium metal with water is also exothermic. In your opinion, can sodium metal be used in the preparation of hot packs? Give reasons for your answer.

THEME 4

TECHNOLOGY IN CHEMISTRY

This theme creates awareness and understanding on the importance of chemistry application in daily life and industries in line with the current technology for the benefit of the society. The scope of the study of Polymer Chemistry covers its definitions, classifications, uses and its effects on the environment. An introduction to the food industry and consumer materials encourages the engagement of pupils in entrepreneurship. The application of knowledge on nanotechnology and green technology is aimed at raising pupils' awareness of their responsibilities towards environmental sustainability.



Chapter 4

POLYMER

Key Words

- Coagulation
- Elastomeric polymer
- Monomer
- Natural polymer
- Polymer
- Polymerisation
- Sulphur cross-link
- Synthetic polymer
- Thermoplastic polymer
- Thermoset polymer
- Vulcanisation

What will you learn?

Bulletin

Polymer was invented at the end of the 19th century in the effort to substitute ivory that was used as billiard balls. Bakelite was later invented by Leo Baekeland in 1907. Polymer science continues to grow until the present day with the manufacturing of various new polymers to meet the needs of technology and modern life.

(**Source:** https://www.sciencehistory.org/the-history-and-future-of-plastics)

What are the characteristics of vulcanised rubber?

What can be manufactured by using polymers?

How can the coagulation of latex be prevented?

4.1 POLYMER

Photograph 4.1 Various products that can be manufactured from polymers

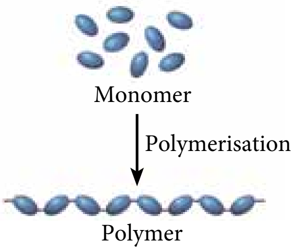


Figure 4.1 The production of a polymer from monomers

Learning Standards

Pupils are able to:

4.1.1 explain polymer.
4.1.2 explain polymerisation reaction through activities.
4.1.3 justify the use of polymers in daily life.

Do you know

The English prefix “poly-”, means ‘many’.

Chemistry Portal

Polymerisation
https://bit.ly/kpkt5v33

What is polymer?

- There are various products around us that are made from polymers, such as protein, starch, polyethene and nylon. What is meant by polymer?

> A polymer is a long chain molecule that is made from a combination of many repeating basic units.

- The basic unit of a polymer is known as **monomer**.
- The monomer combination reaction to produce a polymer is called **polymerisation reaction** as shown in Figure 4.1.
- Polymers can be classified into several groups based on the source of the polymer, how the polymer is produced and the characteristics of the polymer produced.

Source of Polymer

- Polymers can either be natural polymers or synthetic polymers.
- Natural polymers are polymers that are naturally available and can be obtained from our surroundings.
- Examples of natural polymers are starch, protein and cotton.
- Synthetic polymers, on the other hand, are man-made through chemical reactions in laboratories or factories.
- Nylon, polyethene, polystyrene and polyvinyl chloride (PVC) are examples of synthetic polymers that are manufactured in the industrial sector.

Starch is a natural polymer that originates from glucose.

Do you know

The term "plastic" is a general name referring to a synthetic polymer. The advancement of technology allows plastics with distinguished characteristics to be manufactured.

Nylon can be used to manufacture various products, such as ropes and clothes.

Meat is a source of protein. Protein is made up of amino acids that are a type of monomer.

Table 4.1 Examples of the names of polymers and monomers

Source of polymer	Polymer	Monomer
Natural	Starch	Glucose
Natural	Cellulose	Glucose
Natural	Protein	Amino acid
Natural	Natural rubber	Isoprene
Synthetic	Polystyrene	Styrene
Synthetic	Polypropene	Propene
Synthetic	Polyvinyl chloride	Vinyl chloride

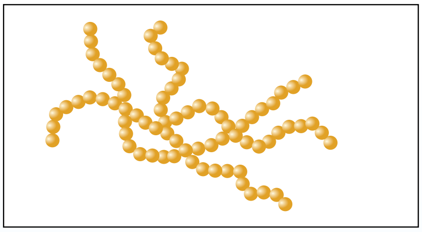
INFO

Polymers are often considered as products manufactured by industries that can cause pollution. There are various types of natural polymers that exist around us.

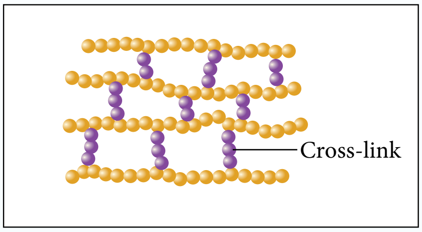
Chemistry Portal

Polymer
https://bit.ly/kpkt5v34

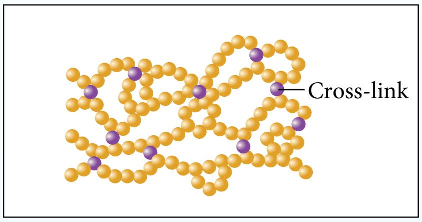
Types of Polymers



- **Thermoplastic polymers** are polymers that can be repeatedly remoulded upon heating and can be recycled.
- When heated, the thermoplastic polymers melt and solidify when they are cooled.
- Examples: polyethene, polyvinyl chloride (PVC) and nylon.



- **Thermosetting polymers** cannot be remoulded after heating.
- Thermosetting polymers normally disintegrate or burn upon heating and cannot be recycled.
- Examples: melamine and bakelite.



- **Elastomer polymers** can be stretched and can return to their original shape when released.
- Possess high elasticity properties.
- Examples: polyurethane and styrene-butadiene rubber (SBR).

ACTIVITY 4A

PAK 21

1. Carry out the activity in groups.
2. Find the following information by surfing the Internet or by using additional reference books from the library.
   (a) The differences between natural and synthetic polymers.
   (b) Examples of natural and synthetic polymers.
3. Create an interesting infographic poster using the double bubble map approach.
4. Present the findings of each group to the class in a Gallery Walk activity.

Polymerisation Reaction

- Polymerisation reactions can be divided into two types: **addition polymerisation** and **condensation polymerisation**. Let us learn about these two types of polymerisation reactions in more detail.

Addition Polymerisation

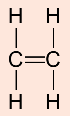
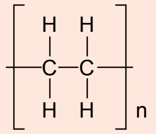
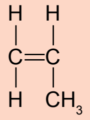
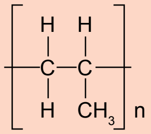
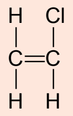
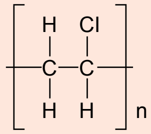
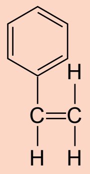
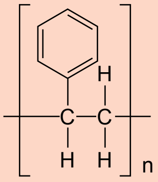
- Addition polymerisation occurs when monomers that have double covalent bonds between two carbon atoms, C=C react with one another.
- Examples of polymers that are produced through addition polymerisations are shown in Table 4.2 with their respective monomers.

Topic Link **Organic Chemistry:** Addition polymerisation reaction on page 85.

Mind Challenge

Can saturated hydrocarbon undergo addition polymerisation reaction? Why?

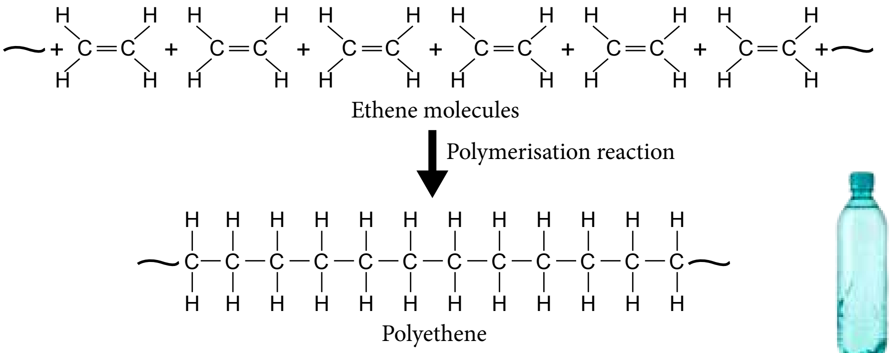
Table 4.2 List of polymers produced through addition polymerisation and the monomers involved

Monomer	Polymer	Characteristic	Use
 Ethene	 Polyethene	Durable and strong.	Plastic bags, plastic bottles and plastic packaging.
 Propene	 Polypropene	Durable.	Toys and textile.
 Chloroethene (Vinyl chloride)	 Polychloroethene (Polyvinyl chloride, PVC)	Strong and hard.	Water pipes and electrical insulators.
 Styrene	 Polystyrene	Light and heat insulator.	Heat insulators and food packaging.

- During the reaction, the double bond is "opened" and monomers are "added" to the molecule chain to produce a polymer.
- An example of the reaction that occurs is shown in Figure 4.2.

Do you know

Polyethene is also known as polythene or polyethylene.



Summary,

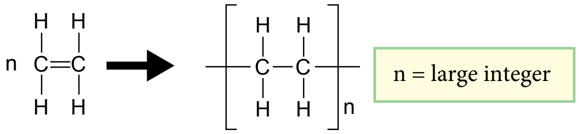


Figure 4.2 Addition polymersation reaction to produce polyethene

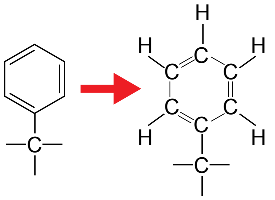
Photograph 4.2 Products from polyethene

Chemistry Portal

Polymerisation of Ethene
https://bit.ly/kpkt5v35

INFO

The phenyl group is a cyclic hydrocarbon with the formula -C_6H_5 and can be drawn as shown.



Condensation Polymerisation

- Condensation polymerisation involves at least two different monomers.
- The monomers involved consist of two functional groups that will take part in the polymerisation reaction.
- The product of condensation polymerisation is a polymer and another by-product such as water molecule, H_2O or hydrogen chloride molecule, HCl .
- Condensation polymerisation reaction to produce terylene, a type of polyester, and nylon, a type of polyamide, is shown in Figure 4.3 and 4.4.

Chemistry Portal

Condensation Polymerisation
https://bit.ly/kpkt5v36

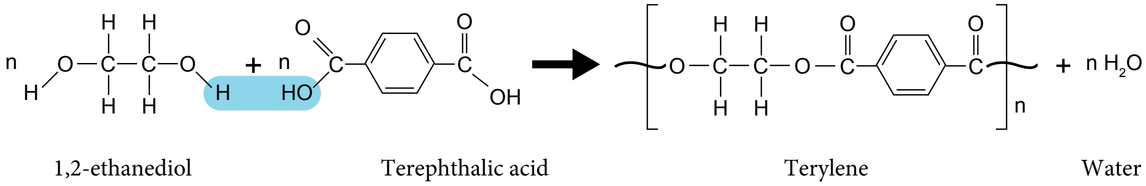


Figure 4.3 Condensation polymerisation reaction to produce terylene

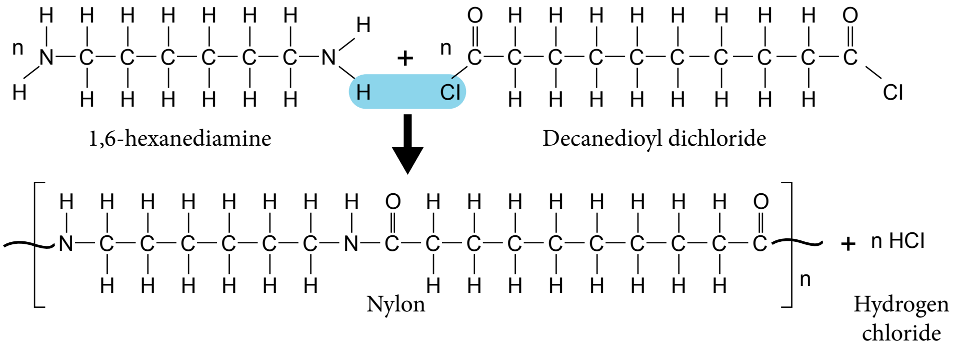


Figure 4.4 Condensation polymerisation reaction to produce nylon

Chemistry Portal

Synthesis of nylon in the laboratory

https://bit.ly/kpkt5v30

Laboratory Activity 4A Synthesis of Nylon

PAK 21 Learning Science Through Inquiry

Aim: To synthesise nylon and study the properties of nylon produced.

Materials: 1,6-diaminohexane, $C_6H_{16}N_2$, decanedioyl dichloride, $C_{10}H_{16}Cl_2O_2$, cyclohexane, C_6H_{14}, sodium hydroxide powder, NaOH and distilled water.

Apparatus: Glass rod, beaker, tweezer and measuring cylinder.

Procedure:

1. Dissolve 2 cm^3 of decanedioyl dichloride, $C_{10}H_{16}Cl_2O_2$ in 50 cm^3 hexane, C_6H_{14} and label it as Solution A.
2. Dissolve 3 cm^3 of 1,6-diaminohexane, $C_6H_{16}N_2$ and 1 g of sodium hydroxide powder, NaOH in 50 cm^3 of distilled water; label it as Solution B.
3. Using a glass rod, pour Solution B slowly into Solution A to avoid mixing.
4. Pull the layer formed between the two solutions using a tweezer and coil it around the glass rod as shown in Figure 4.5.
5. Wind the glass rod slowly to pull out the nylon until no more nylon is produced.
6. Wash the nylon produced on the glass rod with distilled water and dry.

Precautionary steps

- Make sure rubber gloves are worn while carrying out this activity.
- The activity needs to be carried out inside a fume chamber.
- Stir and mix the remaining Solutions A and B completely before discarding.

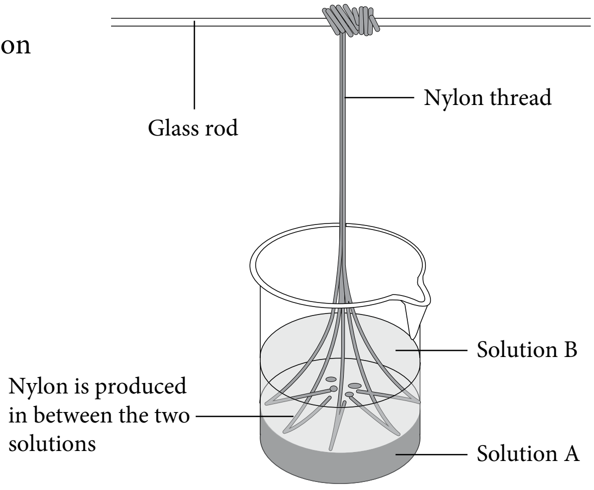


Figure 4.5

Discussion:

1. Using the nylon thread produced, discuss:
   (a) the strength of the nylon
   (b) the elasticity of the nylon
   (c) the resistance towards heat
2. State the uses of nylon.

Prepare a complete report after carrying out this laboratory activity.

ACTIVITY 4B

PAK21

1. Carry out the activity in groups.
2. Each group member needs to find the information on one of the following aspects:
   (a) Condensation polymerisation
   (b) Addition polymerisation
   (c) Properties and use of nylon
3. Share the findings by carrying out the Stay-Stray activity.

The Use of Polymer in Daily Life

- Synthetic polymers are used in various aspects of life as they possess properties that cannot be found in natural polymers, such as:

Characteristics of synthetic polymers

- Good insulator of heat
- Inert and unreactive
- Lightweight, strong and hard
- Resistant to high heat

Uses of Synthetic Polymers

Various medical and laboratory apparatus are made of polypropene.

Polyethene is widely used as plastic bags.

Nylon produces threads that are important for the textile industry.

Layering of acrylic polymer for roof waterproofing.

Polymers and the Environment

- Diverse properties that can be found in polymers increase their demands and uses over the years.
- Some polymers are durable and take a very long time to disintegrate that cause serious pollution problems.
- Marine pollution causes many creatures to die and microplastics to enter the food chain.
- Landfills, on the other hand, are filled with non-biodegradable plastic bags that affect the environment.
- What can you do to overcome these problems?

Photograph 4.3 Effects of plastic pollution to the environment

INFO

Plastic bags are polymer materials that are most disposed of in Malaysia. Did you know that Malaysia has launched the Roadmap Towards Zero Single-Use Plastics 2018-2030 to overcome this problem?

Chemistry Portal

Malaysia's Roadmap Towards Zero Single-Use Plastics
https://bit.ly/kpkt5n12

- In line with the advancement of science and Green Technology, various methods have been introduced to ensure more sustainable use of polymers.
- Recycling is the easiest way for consumers to ensure that synthetic polymers do not end up in landfills.
- The introduction of degradable polymers, particularly for plastic products, enables pollution to be reduced.
- Additives are added to enable plastics to decompose naturally by bacteria (biodegradable) or decompose by light (photodegradable).
- Plastic products will decompose faster and this will reduce the plastic dumping issue in landfills that will essentially be safer for the wildlife.

Chemistry Portal

Plastics Identification Codes
https://bit.ly/kpkt5n13

Do you know

Plastic bottles take up to 450 years to completely decompose. What about wastes from other polymers?


First day — After 30 days — After 55 days

Photograph 4.4 Photodegradable plastics
(**Source:** https://www.atl-dunbar.co.uk/polythene-alternatives-for-packaging, 2018)

Photograph 4.5
Biodegradable plastic cup

Chemistry Portal

Decomposition of Solid Wastes
https://bit.ly/kpkt5v37

ACTIVITY 4C

PAK21

1. Carry out this activity in groups.
2. Find information about pollutions involving polymers and how to overcome them.
3. Produce a simple brochure that consists of information about your findings as an awareness campaign about the sustainable use of polymers.
4. Distribute the brochures to each class in your school.

Self Assess 4.1

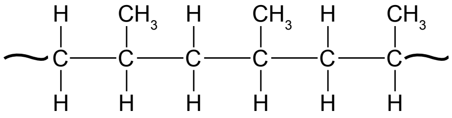


Figure 4.6

1. Figure 4.6 shows the structure of a polymer.
   (a) How many types of monomers are needed to produce this polymer?
   (b) Draw and name the monomers involved.
2. Synthetic polymers are stronger and more durable compared to natural polymers. Justify the use of synthetic polymers in our daily lives.

4.2 NATURAL RUBBER

Learning Standards

Pupils are able to:

4.2.1 explain on natural rubber in terms of naming, structural formula and its properties.
4.2.2 experiment on latex coagulation.
4.2.3 explain the vulcanisation process using sulphur through an activity.
4.2.4 study the elasticity of vulcanised rubber and unvulcanised rubber through experiments.

Rubber and History

- Rubber trees or the scientific name *Hevea brasiliensis* were brought to Malaysia in 1877 and have continued to be developed as an important commodity in our country until the present day. Among Malaysia's major exports are rubber gloves, condoms and catheters.

Cross-Curriculum History

Mind Challenge

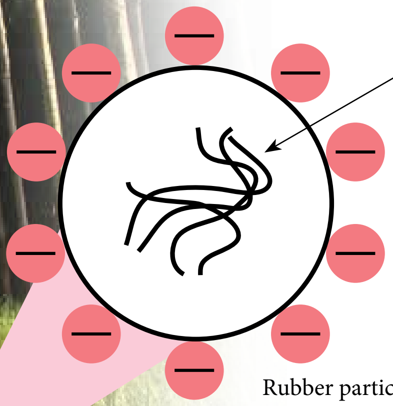
Can you identify the homologous series for the monomers of natural rubber?

Do you know?

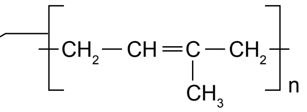
Latex is a colloid and not a solution. Rubber particles do not dissolve in water but disperse separately in water.

- Latex is a white fluid obtained from rubber trees when the tree bark is tapped.
- Natural rubber that is found in latex is a natural polymer known as polyisoprene.

Latex is produced by tapping the rubber tree barks



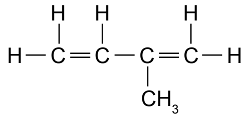
Rubber particle cross section



$$\left[CH_2 - CH = \underset{\substack{|\\ CH_3}}{C} - CH_2 \right]_n$$

Polyisoprene

Structural formula of rubber monomer



$$H - \overset{H}{\overset{|}{C}} = \overset{H}{\overset{|}{C}} - \underset{\substack{|\\ CH_3}}{C} = \overset{H}{\overset{|}{C}} - H$$

Isoprene

- Monomer for polyisoprene is isoprene or with the IUPAC name 2-methylbut-1,3-diene.
- The protein membrane of rubber particles is negatively charged on the outer surface.
- This causes rubber particles to repel each other, preventing coagulation.

Characteristics of Natural Rubber

- The characteristics of natural rubber depend on rubber polymers that are natural elastomeric polymers.
- The presence of double bond C=C in the rubber polymer structure affects the resistance of natural rubber towards oxidation by air.
- The characteristics of natural rubber are shown in Figure 4.3.

INFO

Malaysia is among the top rubber producers in the world.

Table 4.3 Characteristics of natural rubber

Characteristics	Remarks
Soft	Soft white solid at room temperature.
Elastic	Natural rubber can be stretched and can return to its original shape when released.
Low heat resistance	At high temperature, natural rubber will become soft and sticky.
Electrical insulator	Natural rubber cannot conduct electricity and is a good electrical insulator.
Easily oxidised	Oxygen in the air can react with the double bond between carbons and cause natural rubber to be oxidised.
Reactive to chemicals	Reacts easily with acids, alkalis and organic solvents.
Waterproof	Natural rubber is water impermeable.

- Various products can be manufactured using natural rubber as shown in Figure 4.7.
- The limitations found in natural rubber can be overcome by adding certain additives to obtain the desired characteristics.

Malaysian Excellence

Dr Lee Jiang Jun from the Malaysian Rubber Board has successfully invented an earthquake isolator from rubber that is used all over the world.

(**Source:** thestar.com.my, 2020)

Figure 4.7 Uses of natural rubber

INFO

The Malaysian Rubber Board is an agency responsible for the rubber industry in Malaysia that includes conducting studies on the latest technology involving natural rubber.

ACTIVITY 4D

PAK 21

Discuss the following questions in pairs and write down the answers in your notebook.

(i) What is the IUPAC name for the monomer of natural rubber?

(ii) Explain the characteristics of rubber particles that prevent rubber from coagulating.

(iii) Rubber gloves are among the products made from natural rubber. Explain the characteristics of natural rubber that enable rubber gloves to be produced.

Coagulation of Latex

Photograph 4.6 Latex coagulates when exposed to the air

- Latex is collected in liquid form for processing or it can be left to coagulate and to be collected a day after it was tapped.
- The collection of latex in liquid form should be done quickly because once exposed to the air for a few hours, the latex will start to coagulate and turn solid.
- What causes latex to coagulate, and in what way can latex be prevented from coagulating?

Experiment 4A Coagulation of Latex

Aim: To study the coagulation process in latex and how to prevent coagulation.

Problem statement: Does acid cause latex to coagulate and alkali prevent latex from coagulating?

Hypothesis: The presence of acid in latex causes latex to coagulate, while the presence of alkali prevents the coagulation of latex.

Variables:

(a) Manipulated variable : Ethanoic acid, CH_3COOH and ammonia, NH_3 solution.

(b) Responding variable : Coagulation of latex.

(c) Fixed variable : Volume of latex.

Materials: Latex, 1.0 mol dm^{-3} of ethanoic acid, CH_3COOH and 1.0 mol dm^{-3} of ammonia, NH_3 solution.

Apparatus: Beaker, measuring cylinder, glass rod and dropper.

Precautionary steps

Make sure gloves are worn while carrying out the experiment.

Procedure:

1. Label the beakers A, B and C, respectively.
2. Measure 20 cm^3 of latex using a measuring cylinder and pour it into each beaker.
3. Measure 2 cm^3 of ethanoic acid, CH_3COOH using a measuring cylinder and pour the acid into beaker A while stirring continuously with a glass rod.
4. Step 3 is repeated by replacing ethanoic acid, CH_3COOH with ammonia, NH_3 solution for beaker B, while beaker C acts as a control.
5. The observation is recorded.

Observation: Construct a suitable table to record your observation.

Discussion:

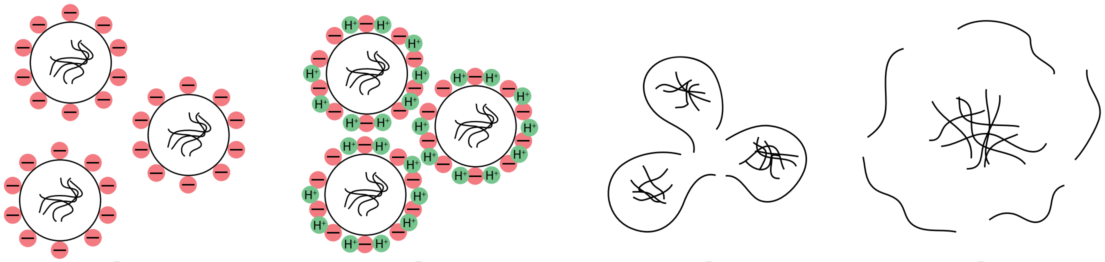
1. Which substance causes latex to coagulate and which substance prevents latex from coagulating?
2. Explain your observation of beaker C.
3. What substance can be used to replace ethanoic acid, CH_3COOH and ammonia, NH_3 solution?

Conclusion:

Can the hypothesis be accepted? What is the conclusion of this experiment?

Prepare a complete report after carrying out this experiment.

Coagulation Process of Latex



① The negatively charged protein membrane causes rubber particles to repel each other.

② Hydrogen ions, H^+ from acid neutralise the negatively charged protein membrane.

③ Rubber particles collide with one another that cause the protein membrane to break.

④ Rubber polymers combine with one another that cause latex to coagulate.

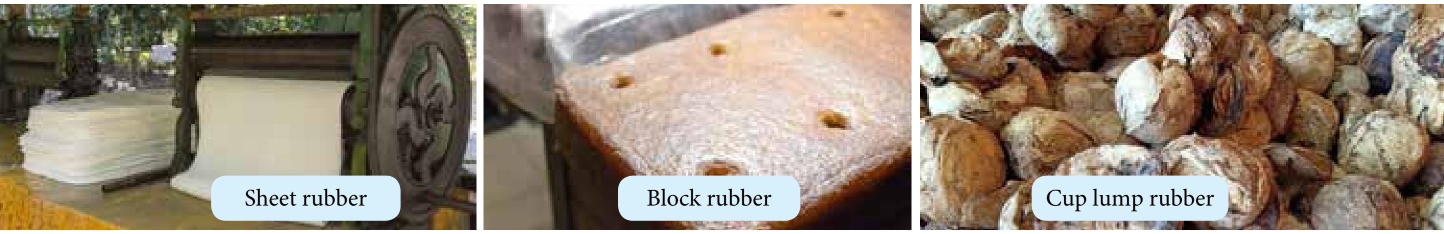
- Acid can coagulate the latex by neutralising the negatively charged protein membrane.
- Coagulation can take place by adding a weak acid into the latex, or it can occur naturally by leaving the latex exposed to the air.
- Bacteria in the air enter the latex and secrete lactic acid, which eventually causes the latex to coagulate.

Chemistry Portal

Coagulation of Latex
https://bit.ly/kpkt5v38

Mind Challenge

Compared to strong acids, weak acids are normally used to coagulate latex. Do you know why?


Sheet rubber
Block rubber
Cup lump rubber

Photograph 4.7 Various ways latex is processed before taken to the factory for further processing

Latex Coagulation Prevention

- Latex is also needed in liquid form to produce specific products, such as gloves and rubber tubes. Alkaline solutions such as ammonia, NH_3 is added into the latex to ensure that coagulation does not take place.
- Alkaline solutions consist of hydroxide ions, OH^- that can neutralise the acid produced by the bacteria. The protein membrane of rubber particles remains negatively charged and rubber particles will continue to repel when they draw near one another.

Laboratory Activity 4B Producing a Product from Latex

PAK 21 Learning Science Through Inquiry

Aim: To produce a product from latex.

Materials: Latex and ethanoic acid, CH_3COOH.

Apparatus: Beaker, glass rod and measuring cylinder.

Precautionary steps

The product needs to be washed and dried beforehand to eliminate any excess ethanoic acid on the product.

Procedure:

1. Measure 200 cm^3 of latex using a measuring cylinder and pour into a beaker.
2. Measure 5 cm^3 of ethanoic acid, CH_3COOH using a measuring cylinder and pour it into the latex.
3. Stir the latex using a glass rod.
4. Leave the glass rod in the latex for a while to allow a layer of latex to form on the glass rod.
5. Take out the glass rod from the latex and allow it to dry.
6. Dip the glass rod in the latex again to allow a thicker layer of latex to form.
7. Repeat steps 5 and 6 until the desired thickness is obtained.
8. Remove the glass rod from the latex and let it dry for a few days.
9. Strip the layer of dry latex from the glass rod to get a rubber tube.

Discussion:

1. Name another product that can be produced using this method.
2. Can the tube produced be stored for a very long time? Explain.
3. State the characteristics of the product produced in terms of:
   (a) elasticity (b) hardness (c) resistance towards heat

Prepare a complete report after carrying out this laboratory activity.

Activity 4E

PAK 21

1. Carry out the activity as a group discussion.
2. Present the answers for the following questions using an i-Think map.
   (a) Classify the following substances into coagulant and anti-coagulant for latex.

   Formic acid **Ammonia solution** **Barium hydroxide solution** **Formaldehyde** **Vinegar**

   (b) Explain why latex that coagulates naturally takes a longer time compared to when a coagulant is added.

   (c) Using a diagram, describe the mechanisms that prevent latex from coagulating.

Vulcanisation of Rubber

- Natural rubber is soft and easily oxidised when exposed to the air for a long period of time. This condition renders natural rubber unsuitable to be used for certain conditions or applications.
- The characteristics of natural rubber can be improved by undergoing the vulcanisation process.

> Vulcanisation is a process of producing rubber that is more elastic and with better quality through the production of cross-links between polymer chains.

- During a vulcanisation process, the double bond between carbons found in rubber molecules will react with sulphur or other substances to produce sulphur cross-links as shown in Figure 4.8.
- The sulphur cross-links make vulcanised rubber stronger.

Do you know

Charles Goodyear (1800-1860) is recorded as the individual who discovered and patented the vulcanisation process in 1844.
https://bit.ly/kpkt5v39

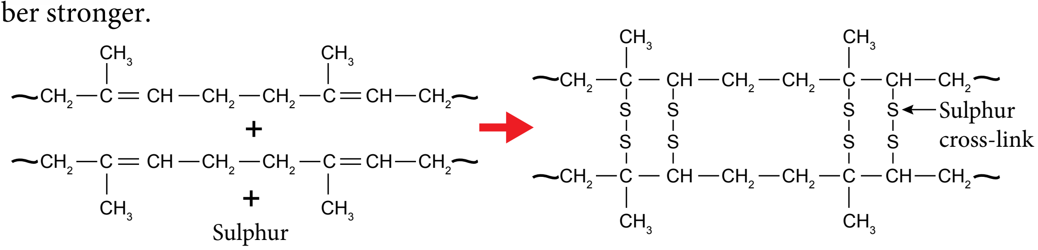


Figure 4.8 Vulcanisation of rubber to form sulphur cross-link.

Laboratory Activity 4C Vulcanisation of Rubber

PAK21 Learning Science Through Inquiry

Aim: To produce vulcanised rubber.

Materials: Latex, ethanoic acid, CH_3COOH and solution of disulphur dichloride, S_2Cl_2 in methylbenzene, C_7H_8 solution.

Apparatus: Beaker, dropper, retort stand, white tile, clip, knife and measuring cylinder.

Precautionary steps

The activity needs to be carried out inside a fume chamber.

Procedure:

1. Measure 25 cm^3 of latex using a measuring cylinder and pour it into a beaker.
2. Drop 3-5 drops of ethanoic acid, CH_3COOH using a dropper into the latex and stir using a glass rod.
3. Pour the latex onto the white tile and spread it over using the glass rod as shown in Figure 4.9.
4. The rubber on the white tile is left to dry for a few days.
5. Cut the dried rubber on the tile into smaller pieces using a knife.
6. Dip the rubber pieces into a disulphur dichloride, S_2Cl_2 solution.
7. Dry the rubber pieces by hanging them on the retort stand.

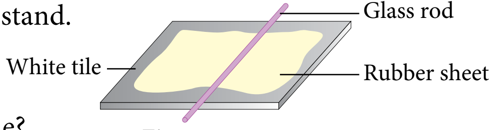


Figure 4.9

Discussion:

1. What is the function of ethanoic acid, CH_3COOH?
2. Why does latex need to be spread out on the white tile?
3. How do you know vulcanised rubber is successfully produced?

Prepare a complete report after carrying out this laboratory activity.

Alternative Vulcanisation Methods

- Vulcanisation by using sulphur is the main method used to produce vulcanised rubber from natural rubber.
- Nonetheless, this vulcanisation method cannot be used for certain types of rubber, particularly synthetic rubber which does not contain C=C.
- There are a few alternative vulcanisation methods that can be utilised to produce vulcanised rubber without using sulphur as shown in Figure 4.10.
- Vulcanised rubber produced is free from sulphur and more environmentally friendly.

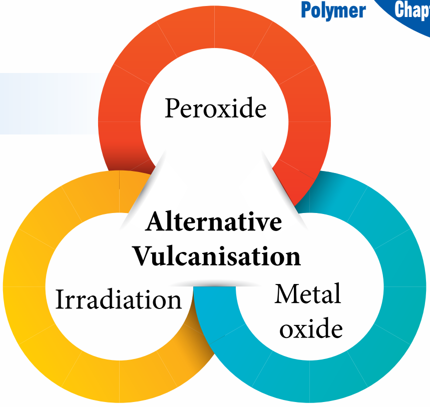


Figure 4.10 Alternative vulcanisation methods

Chemistry Portal

Alternative Vulcanisation Methods
https://bit.ly/kpkt5n15

Experiment 4B Elasticity of Vulcanised Rubber and Unvulcanised Rubber

PAK 21 Learning Science Through Inquiry

Aim: To investigate the elasticity of vulcanised and unvulcanised rubber.

Problem statement: Is vulcanised rubber more elastic than unvulcanised rubber?

Hypothesis: Vulcanised rubber is more elastic than unvulcanised rubber.

Variables:
(a) Manipulated variable : Vulcanised and unvulcanised rubber strips.
(b) Responding variable : The elongation of rubber strips when the weight is removed.
(c) Fixed variable : Size of rubber strip and the mass of weight used.

Materials: Vulcanised and unvulcanised rubber strips.

Apparatus: Retort stand, bulldog clip, 50 g weight and metre ruler.

Procedure:
1. Hang the two rubber strips on the retort stand using bulldog clips as shown in Figure 4.11.
2. Measure and record the initial length, L_1 of both rubber strips to be used in this experiment.
3. Hang a 50 g weight on each rubber strip and record each final length, L_2.
4. Remove the weights, and once again, record the length, L_3 of each rubber strip.

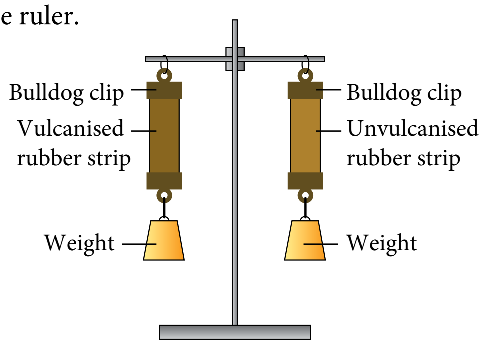


Figure 4.11

Results:
Create a suitable table to record all readings.

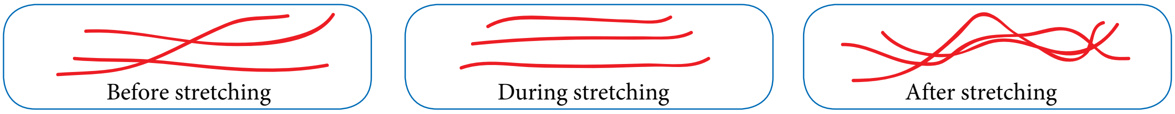
Discussion:
1. Which rubber strip shows the highest elongation?
2. Which strip is more elastic? Explain your answer based on the results obtained.
3. Predict which rubber strip will snap first if the mass of the weight continues to increase.
4. What can be concluded from this experiment?

Prepare a complete report after carrying out this experiment.

Properties of Vulcanised Rubber

- Vulcanised rubber has different characteristics from unvulcanised rubber due to the formation of cross-links during the vulcanisation process as shown in Figure 4.12.
- The formation of sulphur cross-links reduces the double bonds between two carbon atoms in vulcanised rubber that makes it harder to be oxidised.
- Strong sulphur cross-links prevents the rubber polymer from sliding when it is stretched and can return to its original shape when released. High heat energy is needed to break the linkage.

Unvulcanised Rubber



Vulcanised Rubber

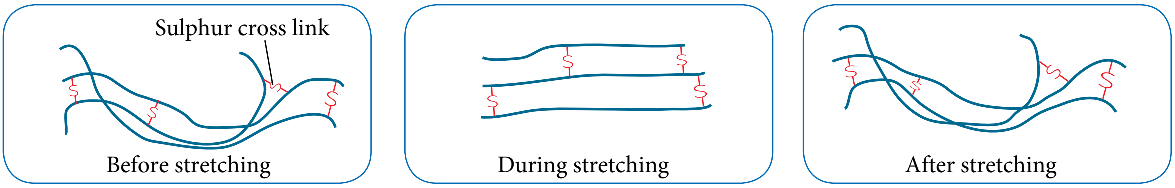


Figure 4.12 Illustration on the elasticity of vulcanised and unvulcanised rubber

- This condition makes vulcanised rubber more elastic and has high heat resistance.
- These unique characteristics of vulcanised rubber allow various items to be produced compared to unvulcanised rubber.
- How do the characteristics of vulcanised rubber differ from unvulcanised rubber?

Table 4.4 The differences between vulcanised and unvulcanised rubber

Characteristics	Vulcanised Rubber	Unvulcanised Rubber
Elasticity	More elastic	Less elastic
Hardness	Hard	Soft
Strength	High	Low
Resistance towards heat	Resistant to high heat	Less resistant to high heat
Resistance towards oxidation	More resistant towards oxidation	Easier to be oxidised

Self Assess 4.2

1. Name the polymer for natural rubber.
2. The presence of acid in latex causes latex to coagulate.
   (a) State the function of acid in the coagulation process of latex.
   (b) Describe the coagulation process of latex.
3. What is the advantage of the irradiation vulcanisation process over sulphur vulcanisation process?
4. Compare and contrast vulcanised and unvulcanised rubber.

4.3 SYNTHETIC RUBBER

Photograph 4.8 Everyday objects with high elasticity

Learning Standards

Pupils are able to:

4.3.1 explain synthetic rubber.
4.3.2 justify the use of natural rubber and synthetic rubber.

Synthetic Rubber

- Refer to Photograph 4.8. Can you guess the material used to produce the above items?
- Even though the items have natural rubber characteristics, such as high elasticity, they are not produced by using natural rubber. Instead, synthetic rubber is used. Other synthetic rubber characteristics are shown in Figure 4.13.

Synthetic rubber is a synthetic polymer that is elastic in nature or elastomer polymer.

- Most synthetic rubber is produced as by-products of petroleum.
- Examples of synthetic rubber is neoprene, styrene-butadiene rubber (SBR) and silicone rubber.

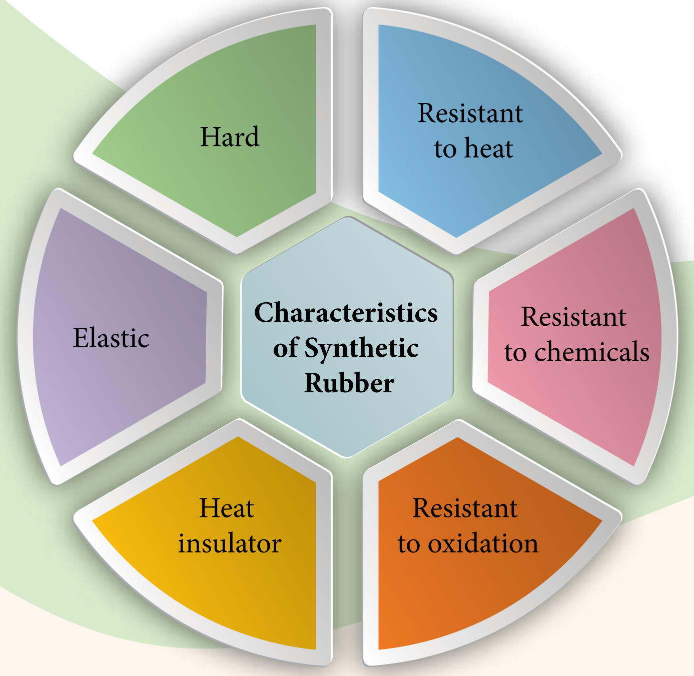


Figure 4.13 Characteristics of Synthetic Rubber

INFO

Synthetic rubber was invented in the early 20th century to replace natural rubber.

Mind Challenge

More than 60% of rubber products are manufactured using synthetic rubber. What factors have contributed to this situation?

Chemistry Portal

Production of Synthetic Rubber
https://bit.ly/kpkt5v40

Uses of Synthetic Rubber

- With the unique characteristics found in synthetic rubber, various items can be manufactured.
- Having the advantage of mass production capacity, while not being reliant on the weather or diseases like rubber trees are, makes synthetic rubber the main choice for manufacturing industries.
- How is the use of natural rubber different from synthetic rubber?

Malaysian Excellence

Ekoprena and Pureprena are two types of advanced rubber developed by the Malaysian Rubber Board. They have distinctive characteristics and are sourced from environmentally friendly materials.

ACTIVITY 4F Discussion

PAK 21

1. Carry out the activity in groups.
2. Discuss the differences between the uses of natural rubber and synthetic rubber based on the characteristics of both materials.
3. Present the outcomes of the discussion in the form of a mind map or concept map to be shared with the rest of the class in a Gallery Walk activity.

Table 4.5 Examples of synthetic rubber and their uses

Synthetic rubber	Characteristics	Uses
Neoprene (polychloroprene)	High heat resistance, oxidation resistance and flame resistance.	Conveyor belts, petrol rubber hoses and gloves.
Styrene-butadiene rubber (SBR)	Abrasion resistance and high heat resistance.	Tyres and shoe soles.
Silicone rubber	High temperature resistance and inert.	Medical implants, cooking utensils, automotive components and sealants.
Thiokol	Oil and solvent resistance.	Sealants.
Nitrile rubber	Oil and solvent resistance.	Gloves.

Use of Rubber and the Environment

- Unsustainable use of rubber materials will lead to environmental pollution.
- Synthetic rubber, particularly, takes a very long time to decompose and makes disposal difficult.
- Vehicle tyres are among the products of synthetic rubber that need to be disposed of in large quantities.

Photograph 4.9 Stacks of discarded tyres

- Natural rubber, on the other hand, takes a short time to decompose biologically.
- Nevertheless, the use of natural rubber is limited due to the natural properties of natural rubber that are less resistant to heat and chemical solvents.
- How can we overcome the issue of reducing the disposal of rubber material waste?

Do you know

Several countries, including the United States of America, recycle discarded tyres into fuel to generate electricity.

Photograph 4.10 Ways for rubber materials to be recycled or reused to reduce rubber material waste

ACTIVITY 4G Discussion

STEM PAK 21

1. Carry out the activity in groups.
2. Plan a forum to have a discussion on the use of synthetic rubber and the effects on the environment.
3. Each group needs to send a representative as a forum panel.
4. Stage the forum by inviting representatives from other classes as your audience.

ACTIVITY 4H Field Trip

PAK 21

1. Scan the QR code to visit the Malaysian Rubber Board website.
2. Find information about the latest research on rubber.
3. Plan a field trip with your teacher to a nearby rubber plantation to see how rubber is processed.

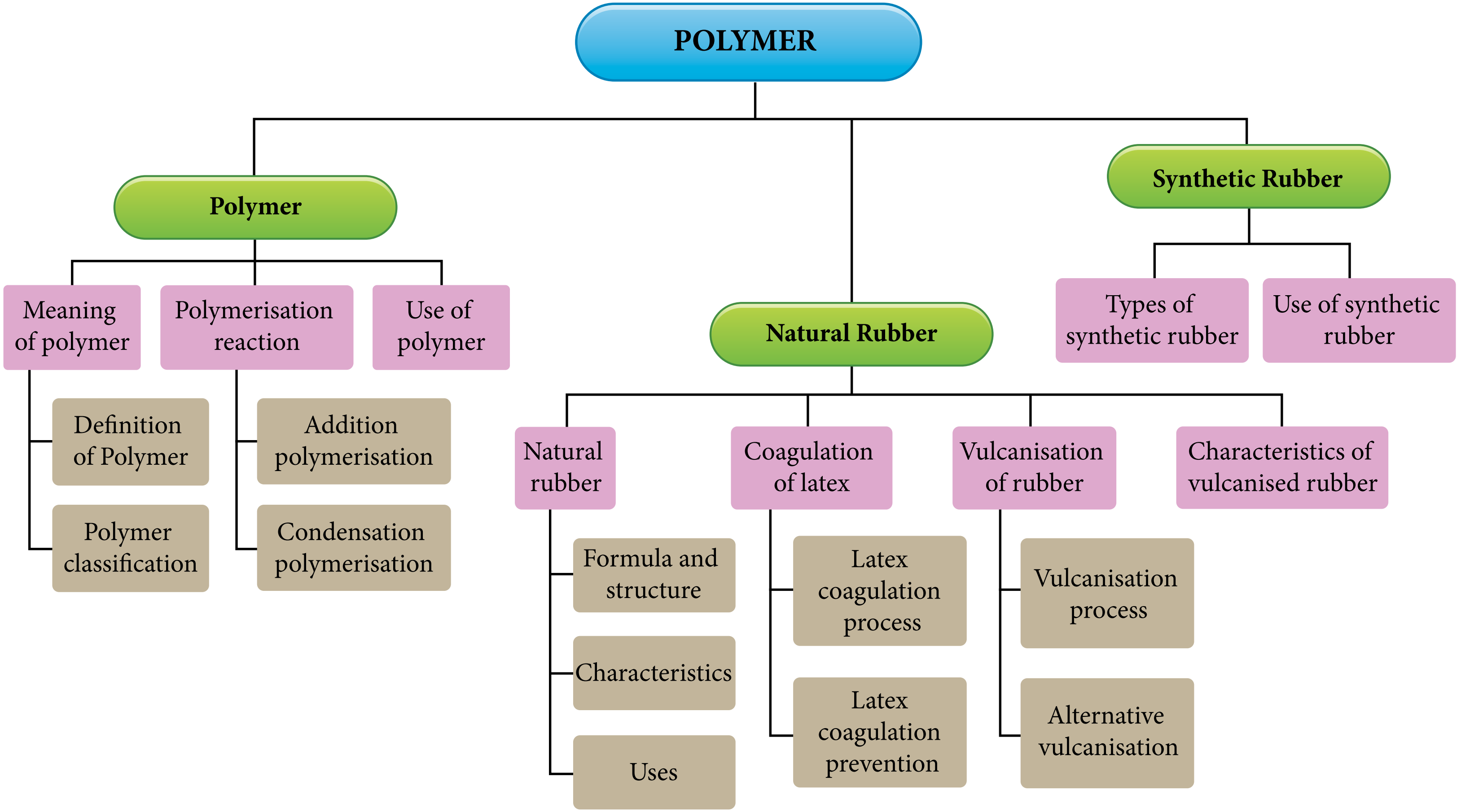
Chemistry Portal

Malaysian Rubber Board
https://bit.ly/kpkt5n16

SelfAssess 4.3

1. What is meant by synthetic rubber?
2. Surgical gloves can be manufactured by using natural rubber or synthetic rubber.
   (a) Name a synthetic rubber that can be used to manufacture surgical gloves.
   (b) How are the characteristics of natural rubber surgical gloves different from those produced by using synthetic rubber?
3. “Synthetic rubber lasts longer and is difficult to decompose naturally”.
   Justify the use of synthetic rubber in manufacturing various items.

Concept Map



- **POLYMER**
  - **Polymer**
    - Meaning of polymer
      - Definition of Polymer
      - Polymer classification
    - Polymerisation reaction
      - Addition polymerisation
      - Condensation polymerisation
    - Use of polymer
  - **Natural Rubber**
    - Natural rubber
      - Formula and structure
      - Characteristics
      - Uses
    - Coagulation of latex
      - Latex coagulation process
      - Latex coagulation prevention
    - Vulcanisation of rubber
      - Vulcanisation process
      - Alternative vulcanisation
    - Characteristics of vulcanised rubber
  - **Synthetic Rubber**
    - Types of synthetic rubber
    - Use of synthetic rubber

SELF Reflection

1. Have you mastered the topic of **Polymer**?
2. What is the content in the topic of **Polymer** that you want to have a more in-depth understanding of? Why?
3. How does the topic of **Polymer** benefit you in daily life?
4. How would you assess your ability to describe the contents in the topic of **Polymer** to your friends?
5. What can you do to improve your understanding of the topic of **Polymer**?

ACHIEVEMENT TEST

1. Polymerisation is a process of producing long chain molecules from monomers.
   (a) Draw the monomers for polyvinyl chloride (PVC).
   (b) What is the type of polymerisation involved in the production of PVC?
   (c) The table below shows the information about polyethene and its monomer.

Substance	Ethene	Polyethene
Physical state at room temperature	Gas	Solid

   (i) State the use of polyethene.
   (ii) Explain the difference between the physical state of ethene and polyethene.

2. Polymers can be classified into natural polymers and synthetic polymers.
   (a) Give an example of each type of polymer.
   (b) Explain the difference between natural polymers and synthetic polymers.
   (c) Melamine is a thermosetting synthetic polymer.
      (i) What is the meaning of thermosetting polymer?
      (ii) State the disadvantages of using thermosetting polymers.

3. A student carried out an experiment to investigate the elasticity of natural rubber and vulcanised rubber by using the same sized rubber strips. Figure 1 shows the observation obtained from the experiment.
   (a) Based on the observation, which strip is a natural rubber strip? Explain your answer.
   (b) Which strip will snap first if the mass of the weight continues to increase?

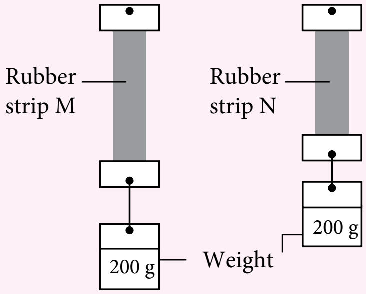


Figure 1

Enrichment Corner

Plants synthesise glucose through photosynthesis and glucose is a simple sugar with the formula $C_6H_{12}O_6$. The structural formula for glucose is shown in Figure 2.

Glucose is a monomer for starch that is useful as an energy source. Based on the structure of glucose, explain the polymerisation process that takes place among glucose molecules to produce starch.

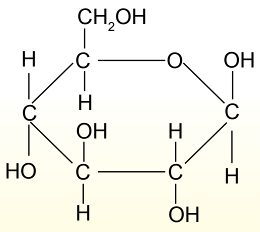
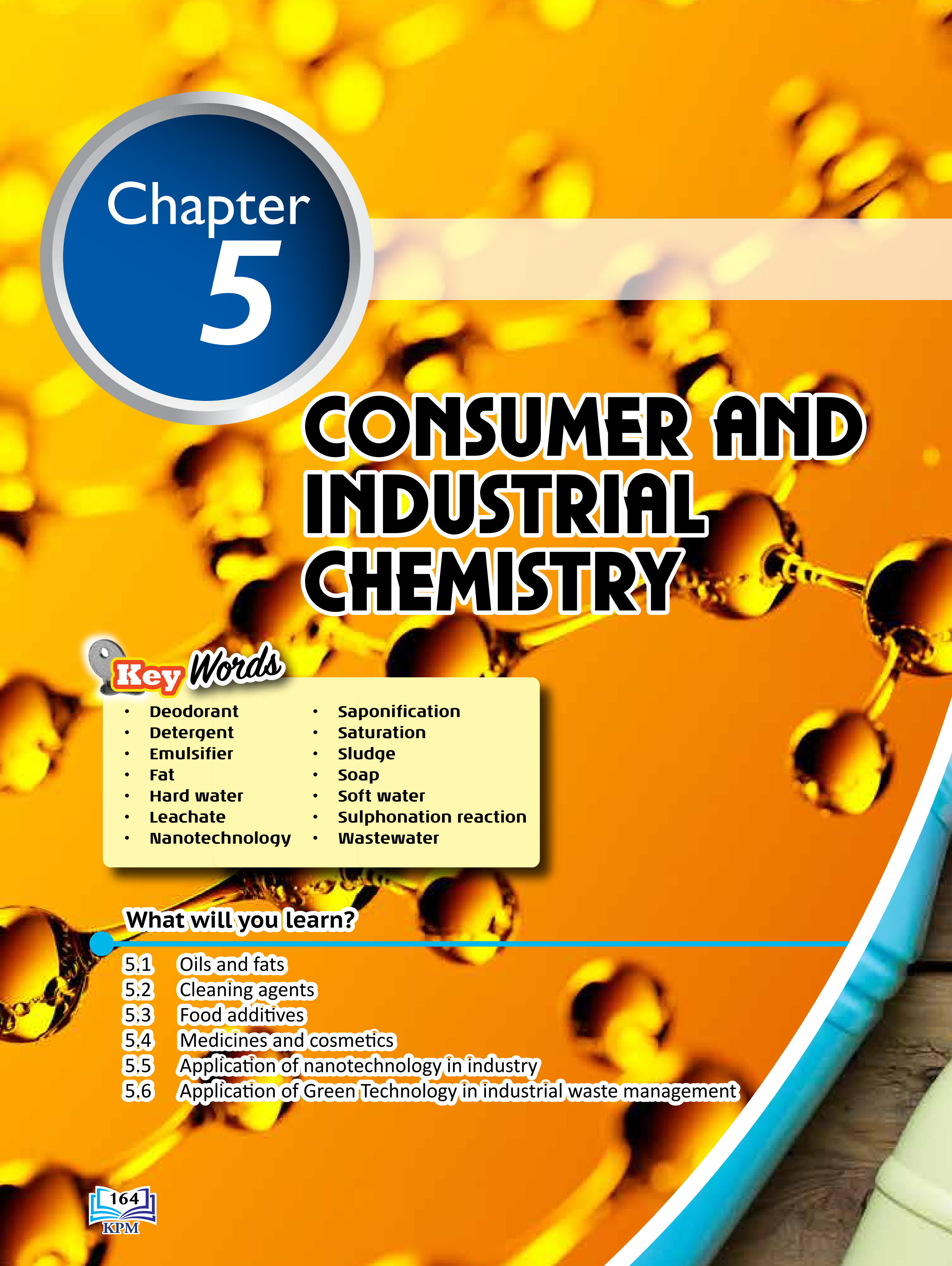


Figure 2



Chapter 5

CONSUMER AND INDUSTRIAL CHEMISTRY

Key Words

- Deodorant
- Detergent
- Emulsifier
- Fat
- Hard water
- Leachate
- Nanotechnology
- Saponification
- Saturation
- Sludge
- Soap
- Soft water
- Sulphonation reaction
- Wastewater

What will you learn?

5.1 Oils and fats
5.2 Cleaning agents
5.3 Food additives
5.4 Medicines and cosmetics
5.5 Application of nanotechnology in industry
5.6 Application of Green Technology in industrial waste management

Bulletin

Consumer chemistry is a very important branch in manufacturing consumer essential products. This branch expands exponentially with the steady increase in consumer demands. Consumer chemistry covers food, energy, cleaning agents, medicines, cosmetics and many other areas.

The advancement in consumer chemistry has not only produced various products that satisfy consumer needs, but the technology developed is integrated with the latest technology, such as nanotechnology and Green Technology. This means the manufacturing of products is able to use energy more efficiently, effectively and environmentally friendly.

What is the function of an emulsifier?

What is the difference between oils and fats?

How does soap get rid of dirt from clothes?

5.1 OILS AND FATS

The Difference Between Oils and Fats

- Oils and fats are parts of the dietary requirements for humans that are responsible for supplying energy, providing body temperature insulation and helping with the absorption of important vitamins.
- At room temperature, fats normally exist in a solid form. Fats in liquid form are known as oils.
- Fats are usually found in meat and butter, while various types of oils can be obtained from plants, such as palm oil, soybean oil and coconut oil. Thus, what is meant by oils and fats?

> Oils and fats are esters produced through the reaction between fatty acids and glycerol (propan-1,2,3-triol).

- Fatty acids have very long carbon chains. The characteristics of oils or fats rely on the types of fatty acids involved in the esterification reactions with glycerol.
- Examples of fatty acids are palmitic acid, stearic acid and linoleic acid.
- An example of an esterification reaction between fatty acids with glycerol to form fat is shown in Figure 5.1

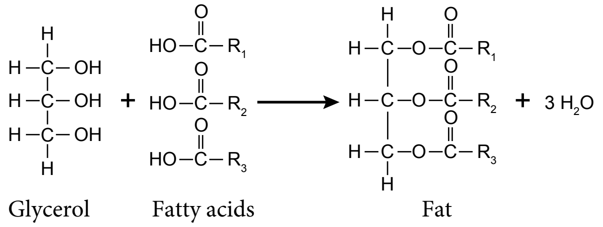


Figure 5.1 Esterification reaction

Learning Standards

Pupils are able to:

5.1.1 compare and contrast oils and fats.
5.1.2 explain the conversion process of unsaturated fats to saturated fats.
5.1.3 justify the use of oils and fats in daily life.

Photograph 5.1 Examples of oils and fats. Palm oil is an oil, while butter is a fat

Mind Challenge

Can you identify the functional group found in fatty acids and glycerol? What is the homologous series for fatty acids and glycerol?

- The reaction between one glycerol molecule and three fatty acid molecules forms one fat molecule. R_1, R_2 and R_3 represent the parts of hydrocarbon chains in fatty acids and fats. R_1, R_2 and R_3 can either be identical or different.
- Although oils and fats are grouped into the same homologous series, there are characteristics that can differentiate oils and fats. Table 5.1 shows the differences between oils and fats.

Table 5.1 Differences between oils and fats

Aspect	Oils	Fats
Source	Plants	Animals
Physical state at room temperature	Liquid	Solid
Melting point	Low	High
Content of fatty acids	High percentage of unsaturated fatty acids	High percentage of saturated fatty acids
Example	Palm oil	Butter

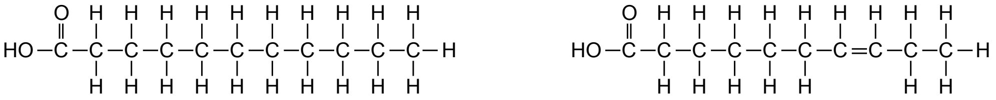
ACTIVITY 5A

PAK21

1. Carry out the activity in groups.
2. Find the following information by visiting nearby grocery shops or shopping malls to read the labels on oil packagings.
   (a) Percentage of saturated fat and unsaturated fat
   (b) Physical state at room temperature
   (c) Colour
   (d) Source
3. Present your findings in class.

Saturated Fats and Unsaturated Fats

- Saturated fats contain saturated fatty acids, and unsaturated fats contain unsaturated fatty acids.
- Examples of saturated fatty acids are palmitic acid, lauric acid and stearic acid; while examples of unsaturated fatty acids are oleic acid, linoleic acid and linolenic acid.
- Unsaturated fatty acids have at least one double bond in the carbon chain; whereas saturated fatty acids only have a single covalent bond in the carbon chain as shown in the examples in Figure 5.2.
- The presence of double bonds causes unsaturated fats to have low melting points and exist as liquids.


Saturated fatty acid

Unsaturated fatty acid

Figure 5.2 Difference between saturated fatty acid and unsaturated fatty acid

Conversion of Unsaturated Fats to Saturated Fats

- Oils consist of a high percentage of unsaturated fats. Unsaturated fats are converted into saturated fats through hydrogenation reaction.
- During a hydrogenation reaction, hydrogen gas, H_2 is passed into hot oil with the presence of nickel, Ni as the catalyst. The double bond in the carbon chain is "opened" and the hydrogen atoms, H are added to the carbon chain. Figure 5.3 shows the example of a hydrogenation reaction.
- The addition of hydrogen atoms to the carbon chain causes the molecular mass to increase that leads to the increase in the melting point and boiling point. This situation explains why margarine exists in a solid form at room temperature, even though it is produced from oil.

Mind Challenge

Between oils and fats, which one can last longer and can stand from turning rancid? Why?

Chemistry Portal

Hydrogenation
https://bit.ly/kpkt5v41

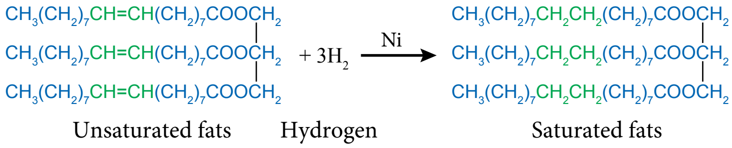


Figure 5.3 Hydrogenation reaction of unsaturated fat to saturated fat

ACTIVITY 5B Field Trip

PAK21

1. Carry out the activity together with your teacher.
2. Plan a field trip to a margarine processing factory.
3. Find information about margarine processing, including sources used and waste disposal management.
4. Write a report together with an infographic poster to be shared with the pupils at your school.

Uses of Oils and Fats in Life

- Oils and fats are widely used in our daily life. Among the use of oils and fats are as follows:

Biofuel
Oils and fats can be used to produce biofuels, such as biodiesel to be used by vehicles with diesel engines.

Nutritional Source
Oils and fats supply energy and help the body to absorb important vitamins, such as vitamins A, D, E, and K.

Soap and Personal Care
Oils and fats are the main ingredients for soap making. Personal care items, like skin moisturisers, also utilise oils in their productions.

Animal Feeds
Oils and fats are also used to manufacture feeds for cattle to fulfil their nutritional needs.

- Although oils and fats are rich with benefits, excessive intake in our diet can contribute to heart related problems, and not to mention body weight issues or obesity.
- The risk for arteriosclerosis or hardening of the arteries is higher if excessive fat intakes are sourced from animals or saturated fats.

ACTIVITY 5C

PAK21

1. Carry out the activity in groups.
2. Find information about the usage of saturated fats and unsaturated fats in processing food products, and their importance in maintaining a healthy lifestyle.
3. Produce a creative presentation to be showcased to your class.

SelfAssess 5.1

1. What is the meaning of unsaturated fats?
2. State the homologous series of saturated fats.
3. Compare and contrast oils and fats.
4. List the uses of oils and fats.

5.2 CLEANING AGENTS

Photograph 5.2 Various cleaning products

Learning Standards

Pupils are able to:

5.2.1 describe soap and detergent.

5.2.2 describe soap preparation process through an activity.

5.2.3 compare the cleansing action of soap and detergent through experiments.

- The use of cleaning agents for washing and personal hygiene is part of the daily routine of everyday life. Generally, cleaning agents refer to soaps and detergents.

What is soap?

- Soaps are sodium or potassium fatty acid salts.
- Soaps are produced from the neutralisation reaction between fatty acids and alkalis.
- Fatty acids are long-chain carboxylic acids.
- Sources of fatty acids can be obtained from natural esters in animal fats or vegetable oils.
- The general formula for soap is $RCOO^-Na^+$ or $RCOO^-K^+$.
- R is an alkyl group containing at least 8 carbon atoms. However, this alkyl group usually contains 12 to 20 carbon atoms.
- R consists of saturated or unsaturated hydrocarbons.
- Table 5.2 shows examples of soaps:

Table 5.2 Examples of soaps

Soap	Chemical formula	Fatty acid	Source
Sodium laurate	$CH_3(CH_2)_{10}COONa$	$CH_3(CH_2)_{10}COOH$ Lauric acid	Coconut oil
Sodium palmitate	$CH_3(CH_2)_{14}COONa$	$CH_3(CH_2)_{14}COOH$ Palmitic acid	Palm oil

- Figure 5.4 shows an example of the structural formula of soap that is sodium palmitate, $CH_3(CH_2)_{14}COONa$.

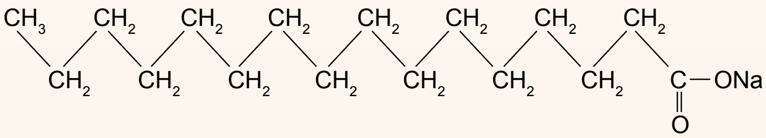


Figure 5.4 Structural formula of sodium palmitate, $CH_3(CH_2)_{14}COONa$

Cross-Curriculum History

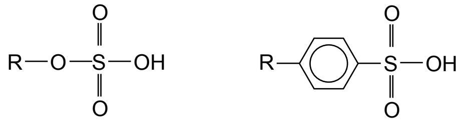
History of Soap Making

https://bit.ly/kpkt5n18

What is detergent?

- The production of detergents began during the second world war owing to the lack of animal fats and vegetable oils.
- Detergents are non-soap cleaning agents.
- Detergents are sodium salts of sulphonic acids.
- Two types of sulphonic acids used to make detergents are alkyl sulphonic acid and alkylbenzene sulphonic acid as shown in Figure 5.5.

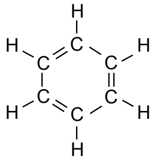

Photograph 5.3 Examples of detergents in powder and liquid forms

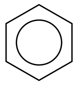

Alkyl sulphonic acid

Alkylbenzene sulphonic acid

Figure 5.5 Structural formula of alkyl sulphonic acid and alkylbenzene sulphonic acid

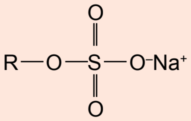
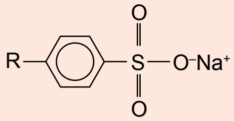
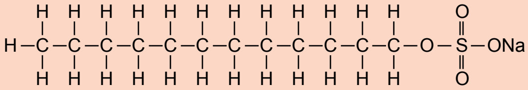
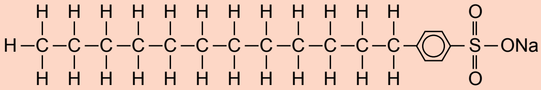
INFO


Structural formula of benzene


Simplified structural formula of benzene

- Detergents are usually made from petroleum fractions.
- Table 5.3 shows two general groups of detergents.

Table 5.3 Two general groups of detergents with examples of structural formulae

Sodium alkyl sulphate	Sodium alkylbenzene sulphonate
 $R-O-\underset{\underset{O}{\Vert}}{\overset{\overset{O}{\Vert}}{S}}-O^{-}Na^{+}$	
Example of structural formula:  $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-O-\underset{\underset{O}{\Vert}}{\overset{\overset{O}{\Vert}}{S}}-ONa$	Example of structural formula: 

Preparation of Soap

- Soaps can be prepared from natural sources through hydrolysis of oils or fats in sodium hydroxide, NaOH or potassium hydroxide, KOH solutions.
- This reaction is called saponification, which is the process of hydrolysis of oils or fats by alkalis.
- Oils or fats react with concentrated alkalis to produce glycerol and fatty acid salts, which is soap.

General equation of saponification reaction

Oil/Fat + Concentrated alkali → Soap + Glycerol

- Oils and fats are natural esters known as triglycerides.
- Alkaline hydrolysis on triglicerides will produce glycerol and soap (salts of fatty acids) as shown in Figure 5.6.

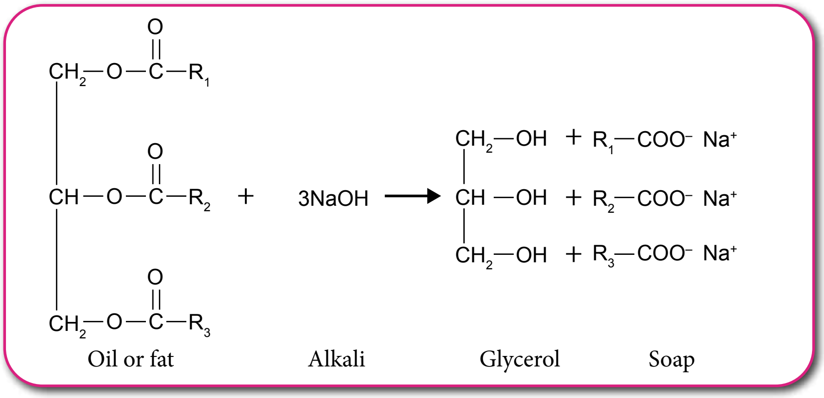


Figure 5.6 Saponication reaction to produce glycerol and soap (fatty acid salts)

Do you know

Do you know that sodium hydroxide is also known as lye?

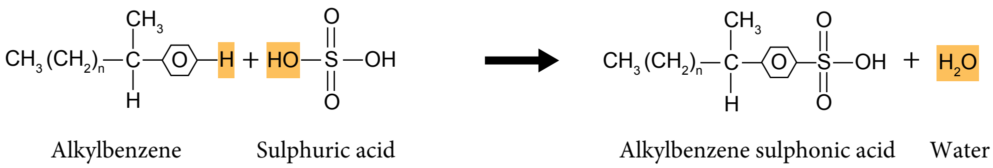
- R_1, R_2 and R_3 are long chain hydrocarbons. R_1, R_2 and R_3 may be the same or different.

Preparation of Detergents

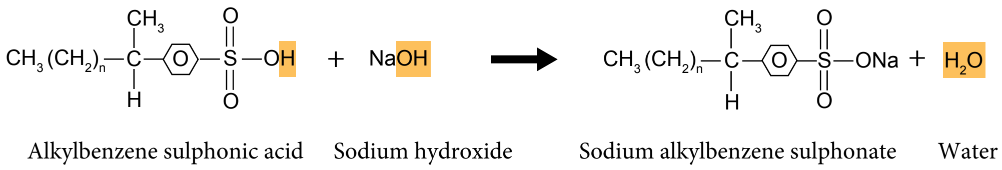
- Detergents are usually made from petroleum fractions and sulphuric acid, H_2SO_4.
- They are produced through two processes which are:
  (a) Sulphonation or sulphation
  (b) Neutralisation

(a) Preparation of Sodium Alkylbenzene Sulphonate

(i) **Sulphonation of alkylbenzene:** Alkylbenzene reacts with concentrated sulphuric acid, H_2SO_4 to form alkylbenzene sulphonic acid.

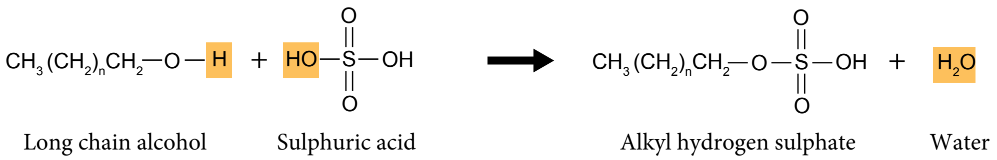


(ii) **Neutralisation:** Alkylbenzene sulphonic acid will be neutralised by sodium hydroxide, NaOH solution to produce alkylbenzene sulphonate salt, which is detergent.



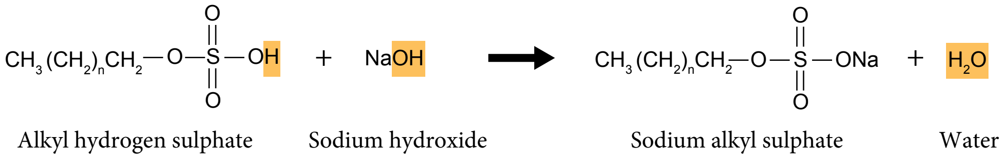
(b) Preparation of Sodium Alkyl Sulphate

(i) **Sulphation of alkol:** Long chain alcohol reacts with concentrated sulphuric acid, H_2SO_4 to form alkyl hydrogen sulphate.



$$CH_3(CH_2)_nCH_2-O-H + HO-\overset{O}{\underset{O}{S}}-OH \longrightarrow CH_3(CH_2)_nCH_2-O-\overset{O}{\underset{O}{S}}-OH + H_2O$$

(ii) **Neutralisation**: Alkyl hydrogen sulphate will be neutralised by sodium hydroxide, NaOH solution to produce sodium alkyl sulphate, which is detergent.


$$CH_3(CH_2)_nCH_2-O-\overset{\overset{O}{||}}{\underset{\underset{O}{||}}{S}}-OH + NaOH \rightarrow CH_3(CH_2)_nCH_2-O-\overset{\overset{O}{||}}{\underset{\underset{O}{||}}{S}}-ONa + H_2O$$

ACTIVITY 5D

Cross-Curriculum Entrepreneurship

STEM PAK21

To Create a Creative Commercial Soap

Photograph 5.4 shows examples of handmade soaps. The addition of colour and fragrance will produce soaps that are attractive enough to be commercialised.


Photograph 5.4 Examples of handmade soaps

Chemistry Portal

Chemistry Portal
Easy Methods to Make Soap
https://bit.ly/kpkt5v42

Making Soap from Used Cooking Oil
https://bit.ly/kpkt5v43

Using a suitable cooking oil and solid sodium hydroxide, NaOH, you are required to produce soaps that can be commercialised.

1. Carry out this activity in groups.
2. Discuss in your respective groups, the qualities that the soap should have. Figure 5.7 can help generate some ideas.
3. Make a plan to produce your group's soap.
4. Show your plan to your chemistry teacher to get your teacher's approval.
5. Produce your group's soap.
6. Prepare a brochure containing information about the advantages of the soap produced.
7. Display each group's soap product in a Gallery Walk activity.

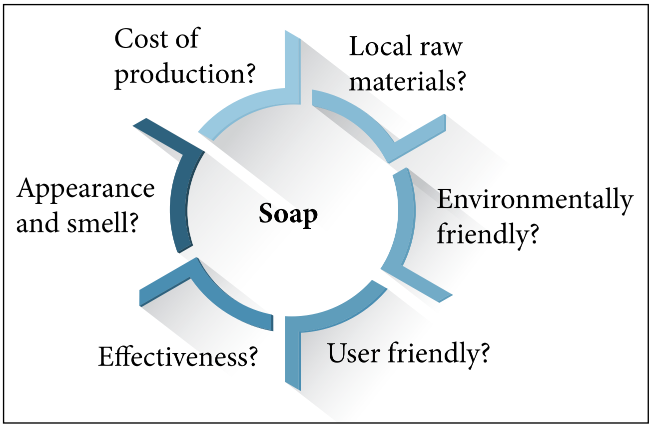


Figure 5.7 Growth of ideas to produce handmade soap

Cleansing Action of Soap and Detergent

- Basically, the cleansing action of soap and detergent is the same.
- Soaps and detergents act as emulsifying agents because soap and detergent molecules are soluble in oil or grease and water.
- When soap or detergent is dissolved in water, soap or detergent molecules dissolve to form:
  (i) sodium ion, Na^+ or potassium ion, K^+.
  (ii) soap anion or detergent anion.
- Examples of equations for ionisation of soap and detergent:

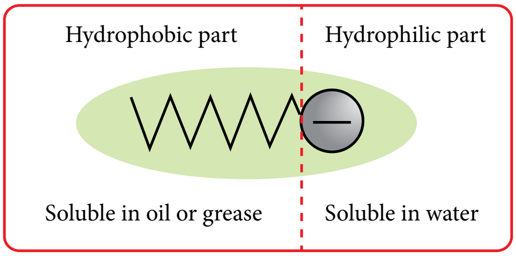
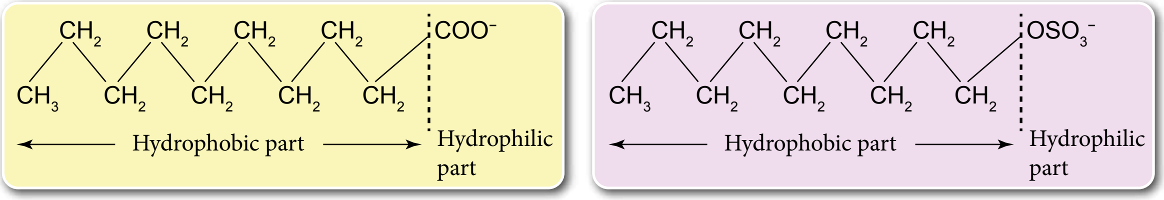


Figure 5.8 Simple structure of soap anion or detergent anion

$$\text{Soap} \xrightarrow{\text{Water}} \text{Soap anion + Sodium ion}$$

$$\text{Detergent} \xrightarrow{\text{Water}} \text{Detergent anion + Sodium ion}$$



Soap anion structural formula

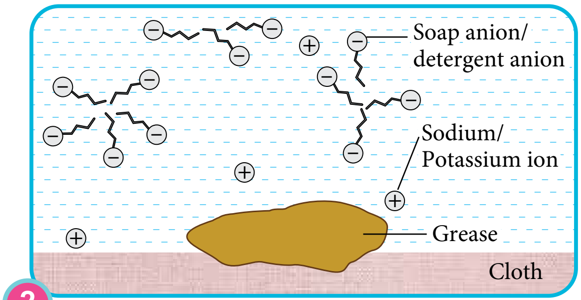
Detergent anion structural formula

Figure 5.9 Examples of soap and detergent anions

- Referring to Figures 5.8 and 5.9, the structures of soap anion and detergent anion consist of two parts, namely:
  (i) hydrophilic part that is soluble in water.
  (ii) hydrophobic part that is soluble in oil or grease.
- Both of these properties make soap and detergent effective cleaning agents. Figure 5.10 describes the cleansing action of soap and detergent.

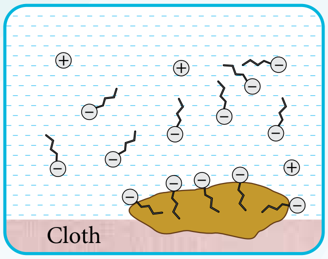
1

- Adding soap or detergent into water will reduce the surface tension of water.
- This increases the water's ability to wet the surface of the cloth.

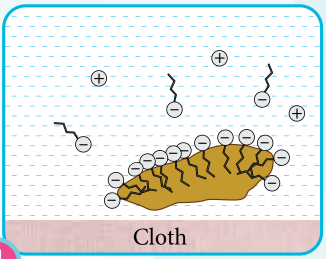


2

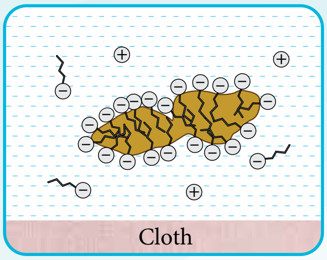
- Soap or detergent will ionise in water to produce free moving soap anions or detergent anions.



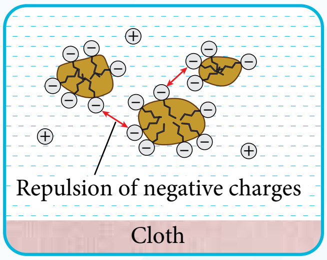
3
- The hydrophilic parts of soap anions or detergent anions dissolve in water.
- The hydrophobic parts dissolve in grease.



4
- Movement of water during scrubbing and agitation causes grease to pull away from the surface of the cloth.



5
- The hydrophilic parts of soap anions or detergent anions surround the grease.
- Grease floats to the surface of the water.



6
- Grease will break into small droplets.
- The small droplets will not reattach to the surface of the cloth due to the repulsion of negative charges of the hydrophilic parts on the surface of the grease.
- The droplets are suspended in water, forming an emulsion.
- Rinsing with water causes the surface of the cloth to become clean because the grease droplets are left in the water.

Figure 5.10 The cleansing action of soap and detergent

INFO

Dry Cleaning

Dry cleaning does not use water, but use other solvents instead, such as 1,1,1-trichloroethane.

https://bit.ly/kpkt5n19

Chemistry Portal

Cleansing Action of Soaps and Detergents

https://bit.ly/kpkt5v44

Comparison of Cleansing Action of Soap and Detergent

- Water containing calcium ions, Ca^{2+} and magnesium ions, Mg^{2+} is called hard water.
- Soap anions combine with the cations to form insoluble salts called scum.

$$\underbrace{2CH_3(CH_2)_{16}COO^-(aq)}_{\text{Stearate ion}} + \underbrace{Ca^{2+}(aq)}_{\text{Calcium ion}} \rightarrow \underbrace{[CH_3(CH_2)_{16}COO]_2Ca(s)}_{\text{Calcium stearate (scum)}}$$

$$\underbrace{2CH_3(CH_2)_{16}COO^-(aq)}_{\text{Stearate ion}} + \underbrace{Mg^{2+}(aq)}_{\text{Magnesium ion}} \rightarrow \underbrace{[CH_3(CH_2)_{16}COO]_2Mg(s)}_{\text{Magnesium stearate (scum)}}$$

- The formation of scum causes wastage of soap because more soap will be needed for the cleansing action.

Photograph 5.5
Formation of scum in the river

- Detergent anions also combine with the cations to form soluble salts in water. Therefore, the effectiveness of the detergent's cleansing action is not affected by hard water.

$$\underset{\text{Detergent anion}}{2ROSO_3^-(aq)} + \underset{\text{Calcium ion}}{Ca^{2+}(aq)} \longrightarrow \underset{\text{Calcium salt}}{(ROSO_3)_2Ca(aq)}$$

$$\underset{\text{Detergent anion}}{2ROSO_3^-(aq)} + \underset{\text{Magnesium ion}}{Mg^{2+}(aq)} \longrightarrow \underset{\text{Magnesium salt}}{(ROSO_3)_2Mg(aq)}$$

Experiment 5A Effectiveness of Cleansing Action of Soap and Detergent

PAK21 Learning Science Through Inquiry

Aim: To compare the effectiveness of the cleansing actions of soap and detergent in hard water.

Problem statement: Is soap more effective than detergent in hard water?

Hypothesis: Suggest a hypothesis for this experiment.

Variables: Determine all the variables in this experiment.

Materials: Hard water, soap, detergent and cloth with greasy stain.

Apparatus: Beaker, measuring cylinder, spatula, glass rod and electronic scales.

Procedure:
Using the apparatus and materials supplied, plan an experiment to compare the effectiveness of the cleansing actions of soaps and detergents in hard water.

Results:
Record all observations in a table.

Conclusion:
Can the hypothesis be accepted? Write a conclusion for this experiment.

Prepare a complete report after carrying out this experiment.

- Table 5.4 shows the comparison of effectiveness of cleansing action of soap and detergent.

Table 5.4 Comparison of effectiveness of cleansing action of soap and detergent

Aspect	Soap	Detergent
Effectiveness in soft water	Effective as cleaning agent.	Effective as cleaning agent.
Effectiveness in hard water	Less effective due to the formation of scum.	More effective because no scum is formed.
Effectiveness in acidic water	Not effective due to the formation of insoluble organic acid.	Effective because the organic acid formed is soluble.

Additives in Detergent

- Do you know that most cleansing agents today are detergents? There are various types of detergents available on the market with slightly different cleansing qualities. These differences are due to the additives in the detergents. The additives give special properties to the detergent. Table 5.5 lists several types of additives found in detergents, along with their functions and examples.

Table 5.5 Additives in detergents

Additives	Function	Example
Biological enzyme	To remove protein stains, such as blood, milk and sugar.	Amylase, protease, cellulase and lipase.
Whitening agent	To change dirt to colourless substance.	Sodium perborate and Sodium hypochlorite.
Optical whitener	To make clothes become whiter and brighter.	Fluorescent dyes.
Water softener and builder	To enhance the effectiveness of the detergent by softening the water.	Sodium tripolyphosphate.
Foam control agent	To control the foam formed by the detergent.	Alkyl monoethanolamide.
Anti suspension agent	To prevent the removed dirt from redepositing to the clothes.	Sodium carboxylmethylcellulose.
Fragrances	To enhance the fragrance of the detergent and fabric.	Jasmine and lavender.
Drying agent	To ensure that the detergent powder is always dry in its container.	Sodium sulphate and sodium silicate.

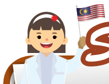
ACTIVITY 5E

PAK21

To study the ratio of the additives and their functions in a detergent.

1. When choosing a detergent, the following criteria may be considered:
   (a) What
   - is the use of the detergent,
   - is its physical condition,
   - are the additives found in the detergent, and
   - are the side effects if the detergent is used?

   (b) Is the detergent
   - suitable for household/domestic water, and
   - eco-friendly?
2. Conduct this activity in groups in a Round Robin activity.
3. Get an example of a detergent and conduct a study on the ratio of additives, together with their functions in the detergent by focusing on the above criteria.
4. Present the findings of your group in class using a multimedia presentation.



SelfAssess 5.2

1. What is soap?
2. What is detergent?
3. Name the process of soap preparation.
4. Give a balanced chemical equation for the reaction between stearic acid and sodium hydroxide to prepare soap.
5. State the two stages in the process of preparing detergents.
6. One of the properties of soap or detergent is to form foam. What is the function of the foam?

5.3 FOOD ADDITIVES

- Do you know that in the food preparation industry, ingredients such as dyes, flavours and preservatives have been added for the purpose of making the food look more attractive, tasty and even last longer? These ingredients are known as food additives.

Learning Standards

Pupils are able to:

5.3.1 describe with examples the type of food additives and their functions.
5.3.2 justify the usage of food additives.

What are food additives?

- Food additives are natural or synthetic ingredients added to food to prevent damage or to improve the appearance, taste or texture.
- As a result of the emergence of processed foods in the food industry nowadays, more food additives have been introduced whether from natural or synthetic sources.
- For the awareness and interests of the consumers, the Ministry of Health simultaneously enforces the Food Act 1983 and the Food Regulations 1985.

Both these acts and regulations are aimed at ensuring that the food sold to the public is safe to eat, and the labels are not misleading the consumers. Focus is given on food standards and its contents, guarantees for certain foods, marked dates for foods, nutritional supplements, and packaging aspects.

Types of Food Additives

- Figure 5.11 lists the types of food additives, and Table 5.6 describes their functions and examples.

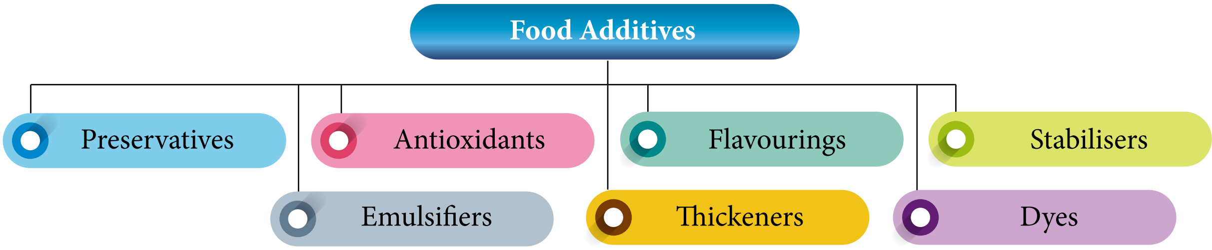


Figure 5.11 Types of food additives

Table 5.6 Food additives

Food additives and their functions	Examples
Preservatives • Prevent or delay the growth of bacteria or fungi to make the food last longer.	• Common salt in dried fish. • Sugar in jams. • Vinegar in pickles. • Benzoic acid in chilli sauces. • Sodium benzoate in bread. • Sodium nitrite or sodium nitrate in sausages. • Sulphur dioxide in dried fruits.

Antioxidants • Slow down the oxidation of fats in food. • Prevent oily or greasy food from becoming rancid.	• Ascorbic acid (Vitamin C) in sweets. • Citric acid in oily food such as cakes and biscuits. • Tocopherol (Vitamin E) in margarine.
Flavourings • Replace the loss of original flavours during food processing. • Add flavour or fragrant smell to make food tastier. • Replace food seasonings that are expensive or seasonal, such as those found in certain fruits.	• Monosodium glutamate (MSG) in instant noodles. • Aspartame, sorbitol, stevia (sweetener). • Esters such as propyl ethanoate (pear flavour). ethyl ethanoate (pineapple flavour).
Stabilisers • Give uniformed and smooth texture.	• Pectin to thicken jams. • Agar from seaweed to make jellies.
Emulsifiers • Emulsify two immiscible liquids.	• Monoglycerides or triglycerides in peanut butter. • Lecithin in chocolates.
Thickeners • Thicken liquids.	• Starch, gelatine, acacia gum and xanthan gum are used to thicken soups and sauces.
Dyes • Add or restore colour to make the food look attractive and delicious.	• Azo compounds to give yellow, red, brown or black colours. • Triphenyl compounds to give green, blue or purple colours. • Caramel to give the brown colour.

Mind Challenge

How does the common salt or sugar act as a preservative?

INFO

Photograph 5.7
Stevia plant

Stevia is a species of herbs from the sunflower family. It tastes 300 times sweeter than sugar.

Chemistry Portal

Durian Seeds as Stabilisers
https://bit.ly/kpkt5n20

ACTIVITY 5F

PAK 21

To perform chromatography on food dyes.

1. Carry out this activity in groups.
2. Watch the video on page 179 to recall what you have learned in form one on how to carry out chromatography.

3. Determine the type of food dyes whether they are:
   (a) synthetic dyes, or
   (b) natural dyes.
4. Carry out the chromatography.
5. Present your findings in your class.

Chemistry Portal

Chromatography
https://bit.ly/kpkt5v46

Do you know

E number refers to the code used in European countries to label food additives as shown in Photograph 5.8.

Ingredients: Sugar, Milk Solids, Cocoa Butter, Cocoa Mass, Non Hydrogenated Vegetable Fat (Palm, Illipe, Shea), Emulsifiers (Soya Lecithin, E476) and Flavour. All additives are of plant and synthetic origin.

Photograph 5.8 Example of food label

ACTIVITY 5G

PAK21

Organise a jelly making contest.

1. Jelly is a favourite dessert of those who love sweet food. The use of food additives such as dyes and flavours will make the jellies look more attractive and appetising.
2. Organise a jelly making contest in your school. Among the necessary things that need to be planned and implemented include:
   - Rules of the contest
   - Panel of judges
   - Sponsors for the prizes
   - Criteria for choosing the best jelly
   - Contest promotion
3. Write a news report for this competition for your school magazine or website.

Justification for Using Food Additives

- There is no denying that some food additives can affect our health. However, food additives can be used in our food.
- Food producers must comply with the regulated amount of food additives so that the health of consumers is not affected. Figure 5.12 shows the justification for the use of food additives, as well as adverse effects if taken in excess.

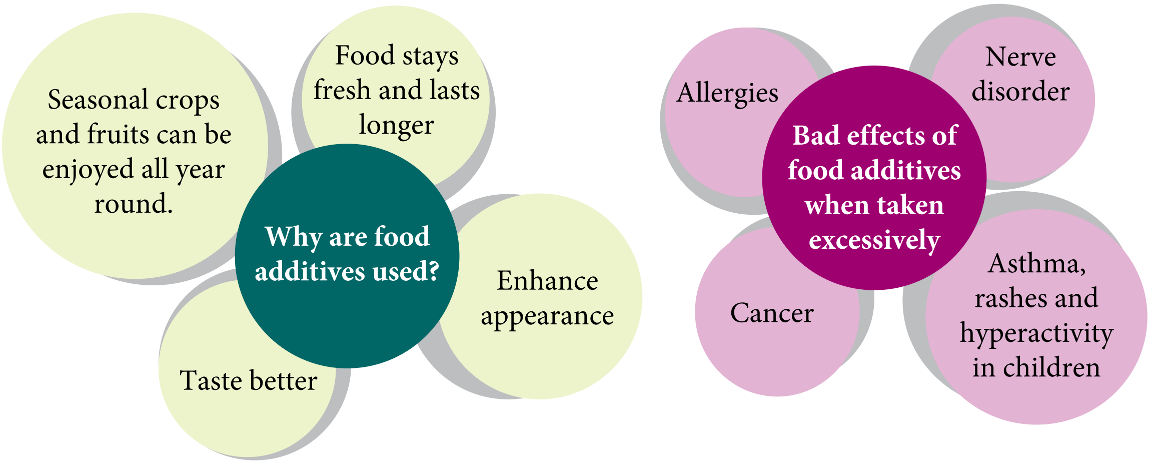


Figure 5.12 Justification for the usage of food additives and harmful effects if taken excessively
(**Source:** http://www.myhealth.gov.my/aditif-makanan-apa-yang-perlu-anda-tahu)

ACTIVITY 5H

PAK 21

Justification for consumption of food additives.

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

> A variety of processed food contain additives that are meant to make the food more appetising, delicious and long lasting. Consumption of food additives over a long period of time can cause adverse effects such as allergies and other health problems. Among the examples of additives are as follows:
> (a) sulphur dioxide,
> (b) sodium nitrite and sodium benzoate,
> (c) monosodium glutamate (MSG), and
> (d) dyes.

3. Gather information on the food additives mentioned above.
4. Justify the use of these food additives.
5. Prepare an interesting multimedia presentation of your group's findings.
6. Present your group work in class.

ACTIVITY 5I

PAK 21

Impact of food additives on nutritional values and food functions.

1. Carry out this activity collaboratively in groups.
2. Collect and analyse data from the Ministry of Health Malaysia (MOH) or from other countries on the impact of food additives on nutritional values and food functions.

Chemistry Portal

Food Division, Ministry of Health, Malaysia
https://bit.ly/kpkt5n21

MyHealth Portal Ministry of Health, Malaysia
https://bit.ly/kpkt5n22

3. Discuss the information that you have analysed.
4. Present your group's findings in class in the form of a multimedia presentation.

Self Assess 5.3

1. State the seven types of food additives.
2. The diagram below shows the food content label on *Marjerin Lazat* food packaging.

Marjerin Lazat
Ingredients: Vegetable oil, salt, solid milk, emulsifier, ascorbic acid, flavouring and permitted food dyes.

   (a) What type of food additive is ascorbic acid?
   (b) State the function of ascorbic acid in the margarine.
   (c) Identify two other food additives in the margarine.

5.4 MEDICINES AND COSMETICS

What are medicines?

- Medicines are chemicals used to help with the treatment or prevention of diseases.
- Medicines can be classified into traditional medicines and modern medicines.
- Medicines are safe if taken properly.
- Generally, medicines are for health use, but misuse or abuse of them can be harmful.

Learning Standards

Pupils are able to:

5.4.1 explain with examples types of medicine, their function and side effects.
5.4.2 justify the usage of medicines.
5.4.3 explain cosmetics with examples.
5.4.4 justify the usage of cosmetics.

Traditional Medicines

- Obtained from herbal plants or animals and are not chemically processed.
- Usually prepared by crushing certain parts of the plants using pestle and mortar and rubbing on sore limbs.
- There are also certain parts of the plants or animals that are boiled to get the essence and to be consumed orally.
- Nowadays, traditional medicines have evolved through processing, and marketed in the form of pills or capsules. Figure 5.13 shows examples of some plants commonly used as traditional medicines in Malaysia along with their uses.

Ginger
(*Zingiber officinale*):
- Remove wind (gas) from the body.
- Prevent colds.
- Help to warm the body.

Aloe vera
(*Aloe barbadensis miller*):
- Treat skin diseases.
- Treat wounds caused by burns.

Ginseng
(*Panax ginseng*):
- Build immunity against infections.
- Lower blood pressure and cholesterol level.

Tamarind
(*Tamarindus indica*):
- Juice of the fruit relieves coughs.
- Brighten the skin.

Figure 5.13 Examples of plants usually used as traditional medicines in Malaysia

Mind Challenge

Ketum leaves are traditionally used to relieve back pain and regain energy, but sales of the products processed from ketum leaves are illegal. Do you know why?

Photograph 5.9
Ketum leaves

Chemistry Portal

Traditional Medicines
https://bit.ly/kpkt5n23

Modern Medicines

- Rapid developments in the field of medicine through new technologies, such as biotechnology, nanotechnology and genetic engineering, have boost the production of modern medicine in the pharmaceutical industry.
- Do you know that most modern medicines produced today come from plants, microorganisms or synthetic chemicals? Modern medicines are available in various forms, such as pills, capsules, powders and liquids.
- Figure 5.14 lists the types of modern medicines; while Table 5.7 explains their functions, uses and side effects, along with examples.

Cross-Curriculum History

Ibnu Sina (Avicenna)
Father of Modern Medicine
https://bit.ly/kpkt5n31

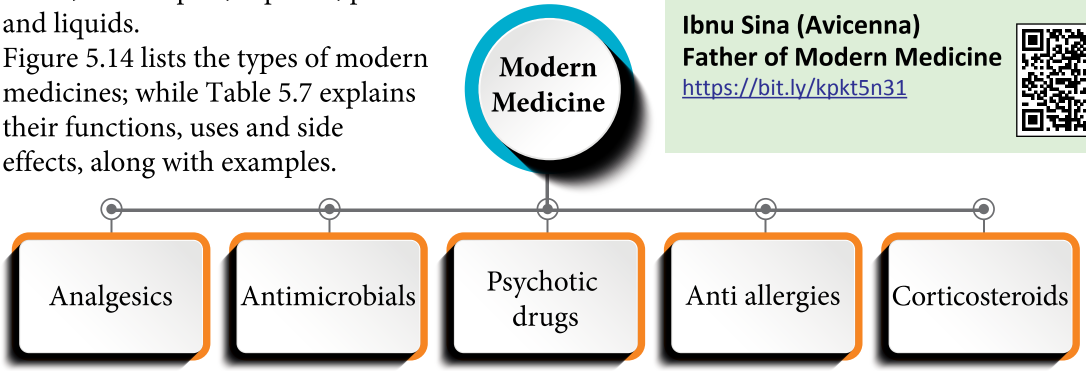


Figure 5.14 Types of modern medicines

Table 5.7 Types of modern medicines, functions, uses, side effects and examples

Type and example	Function	Use and side effects
Analgesics Example: • Aspirin • Paracetamol • Codeine 	• Aspirin and paracetamol relieve pain in conscious state. • Codeine relieves pain, alleviates coughs and treats diarrhoea.	• Should be taken according to doctor's prescription. • Aspirin is acidic and not suitable for gastric patients or children because it causes stomach ulcers. • Paracetamol overdose can cause liver damage. • Codeine causes drowsiness.
Antimicrobials Example: • Antibiotics, such as penicillin and streptomycin. • Antiseptics, such as hydrogen peroxide, iodine and boric acid. • Disinfectants, such as alcohol and formaldehyde.	• Antibiotics kill or retard bacterial growth. • Antiseptics are applied externally on the skin. • Disinfectants destroy pathogens found on non-living objects such as the floor and drainage system.	• Antibiotics need to be fully consumed so that all bacteria are killed. Otherwise, the bacteria will become immune to the antibiotics and the disease will recur. • Antiseptics are only to be applied externally and not to be digested. • Allergies can be fatal. Those with penicillin allergy are usually given an Allergy Alert Card to alert others of their condition.

Psychotic Drugs Example: • Haloperidol • Chlorpromazine • Clozapine	• Treatment for psychosis, a symptom of mental illness that causes patients to see, hear and believe something that is not real.	• Taken with a doctor's prescription. • Can cause abnormal involuntary facial and body movements. • Can cause stiffness and shakes.
Anti allergies Example: • Antihistamines	• To relieve runny nose and itchiness.  	• Can only be taken as prescribed by a doctor. • Causes drowsiness. • Antihistamines can also cause dry mouth (xerostomia), blurred vision and constipation if taken in high dosage.
Corticosteroids Example: • Betamethasone valerate or prednisolone  	• Provide relief to the inflamed area. • Reduce swelling, redness, itchiness, allergic reactions, asthma and arthritis.	• Can only be taken with doctor's prescription. • Long-term intake can cause moon face (facial swelling), high blood pressure and increase blood sugar level.

Effectiveness and Abuse or Misuse of Medicines

- Modern and traditional medicines can both treat many of the same illnesses, although the efficacy level may differ.
- Modern medicines have undergone various clinical trials before they are ready for usage. However, some traditional medicines do not have any data to authenticate their effectiveness. In fact, the lack of observational data makes it hard to determine the correct dosage.
- The wrong dosage can cause undesirable effects and can lead to drug abuse. Drug abuse does not only concern modern medicines, but traditional medicines too.

Antibiotics
Resistance to antibiotics

Herbal based traditional medicine
Liver and kidney failure

Codeine
Addiction

Photograph 5.10 Examples of medicines and effects of abuse

- To harmonise the field of traditional treatment in the modern era, the Traditional Medicine and Complementary Act 2016 was introduced to ensure that traditional treatments administered meet the criteria set by the government.
- The National Traditional and Complementary Medicine Policy is also introduced to ensure that traditional medicines and treatments are safe and possess quality.
- The National Pharmaceutical Regulatory Agency (NPRA) is a body responsible for the supervision of drug safety and quality control of cosmetics in Malaysia.

Chemistry Portal

Medicine: What you need to know?
https://bit.ly/kpkt5n24

Do you know

Placebo does not have any therapeutic value even though they resemble real medicines.

ACTIVITY 5J

STEM PAK 21

In China there are hospitals that provide treatments using herbs and traditional medicines. During the COVID-19 pandemic, COVID-19 patients in Wuhan, China were given traditional and modern medical treatments.

Based on the statement above, gather information from reading sources or websites to produce a folio or scrapbook about the use of traditional medicines and modern medicines in life. Creatively present your folio or scrapbook with the title "Harmonising traditional and modern medicines".

Cosmetics

- Cosmetics have been used for a long time to highlight personal appearances, in addition to maintaining hygiene. What is meant by cosmetics?

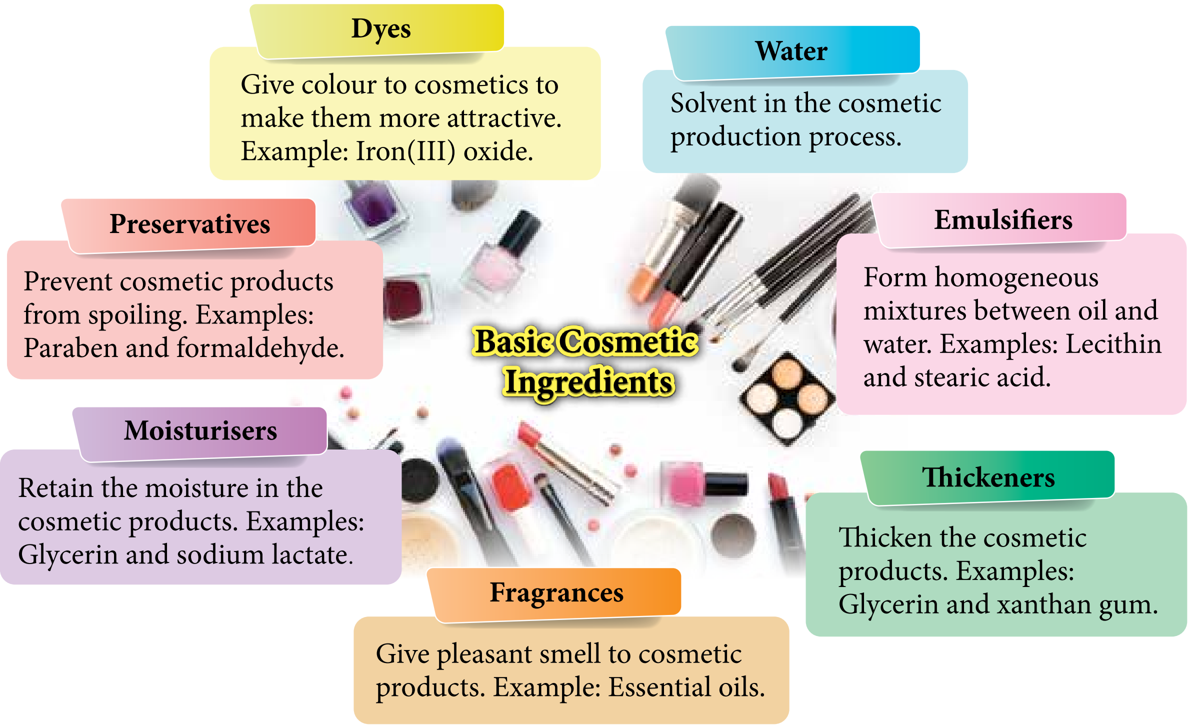
Cosmetics are materials or products that are used externally to cleanse, protect or enhance one's appearances.

- Various types of ingredients are used in the production of cosmetics so that the desired effects are obtained. Nonetheless, basic ingredients for cosmetics are normally derived from a combination of substances such as water, emulsifiers, thickeners, dyes, moisturisers and preservatives.
- Further information about basic cosmetic ingredients is shown in Figure 5.15.

Chemistry Portal

Knowing Your Cosmetics
https://bit.ly/kpkt5n2

Verification method for Medicines and Cosmetics that are Registered with the Ministry of Health
https://bit.ly/kpkt5v47



Dyes
Give colour to cosmetics to make them more attractive. Example: Iron(III) oxide.

Water
Solvent in the cosmetic production process.

Preservatives
Prevent cosmetic products from spoiling. Examples: Paraben and formaldehyde.

Emulsifiers
Form homogeneous mixtures between oil and water. Examples: Lecithin and stearic acid.

Moisturisers
Retain the moisture in the cosmetic products. Examples: Glycerin and sodium lactate.

Thickeners
Thicken the cosmetic products. Examples: Glycerin and xanthan gum.

Fragrances
Give pleasant smell to cosmetic products. Example: Essential oils.

Figure 5.15 Basic cosmetic ingredients

- Sales and production of cosmetics in Malaysia are subjected to the Control of Drugs and Cosmetics Regulations 1984 to ensure the safety of all users. There are various types of cosmetics found on the market that can be classified into three main groups as shown in Figure 5.16.

Types of Cosmetics

Makeup cosmetics	To beautify the face: facial powders, lipsticks, eyeshadows, eyeliners and mascara.
Treatment cosmetics	To treat the body: creams, skin moisturisers and facial masks.
Fragrances	To provide fragrances: deodorants and perfumes.

Figure 5.16 Types of cosmetics

Usage of Cosmetics in Everyday Life

- Cosmetics can be produced organically using materials available around us, or commercially available on the market.
- There are various advantages of using cosmetics, depending on their types. Regular use of safe and high quality materials and sources is able to deliver the desired effects. Figure 5.17 shows the advantages of homemade cosmetics and disadvantages of commercial cosmetics.

Advantages of homemade cosmetics

- Easy to produce using natural ingredients.
- Safe and free from harmful chemicals.
- Low cost.

Disadvantages of commercial cosmetics

- Harmful side effects
- Harmful chemicals that are illegally added.
- Excessive claims and misleading advertisements.

Figure 5.17 Advantages of homemade cosmetics and disadvantages of commercial cosmetics
(**Source:** http://www.myhealth.gov.my/category/ubat-dan-anda/ubat-kosmetik)

- Examples of harmful chemicals and side effects of their usage are shown in Table 5.8.

Table 5.8 Side effects of harmful chemicals in cosmetic products

Harmful chemical	Side effect	Remark
Mercury	Skin irritation and damage to the kidney and nervous system if absorbed into the bloodstream.	Usually added illegally into whitening creams and other cosmetic products.
Hydroquinone	Hypersensitive skin and exposure to harmful UV rays caused by reduced pigmentation.	
Betamethasone valerate	Skin irritation and changes to skin pigmentation.	
Tretinoin	Redness and peeling skin.	Acne cream.

(**Source:** https://www.moh.gov.my/index.php/database_stores/attach_download/337/1501)

- As consumers, we should be alert to the ingredients of cosmetic products and verify that the cosmetic products to be used are registered with the National Pharmaceutical Regulatory Agency.

ACTIVITY 5K

Cross-Curriculum Entrepreneurship STEM PAK 21

Rapid developments in the world of entrepreneurship have resulted in a plethora of beauty products in the market. You are required to carry out an innovative research and produce a marketable cosmetic product derived from organic sources. Explain the benefits of the produced cosmetic product.

SelfAssess 5.4

1. Give three examples of traditional medicines and their uses.
2. State five types of modern medicines.
3. Aida has a headache. What type of medication is appropriate to relieve the pain?
4. Give three types of cosmetics.

5.5 APPLICATION OF NANOTECHNOLOGY IN INDUSTRY

Nanoscience and Nanotechnology

- The desire to see something extremely small has always been a major drive in scientific research.
- Understanding a certain structure at a tiny scale with the advancement in current scientific researches has enabled us to manipulate the properties of substances to produce materials with the desired properties.
- Among the studies on these tiny structures, there are those that relate to nanoparticles, namely graphene sheets and gold nanoparticles that have contributed to the rapid development of nanoscience and nanotechnology.
- What do you understand about nanoscience and nanotechnology?

Nanoscience is a study on processing of substances at nanoscale that are between 1 nanometre to 100 nanometres.

Nanotechnology is a development of substances or gadgets using the properties of nanoparticles.

Learning Standards

Pupils are able to:

5.5.1 explain the meaning of nanotechnology.

5.5.2 describe nanotechnology with examples and its application in daily life.

Cross-Curriculum History

The term 'nanotechnology' was first coined by Professor Norio Taniguchi in 1974.

- To see the connection between nanoscale and the materials around us, let us study Figure 5.18. Can you add a few more materials?

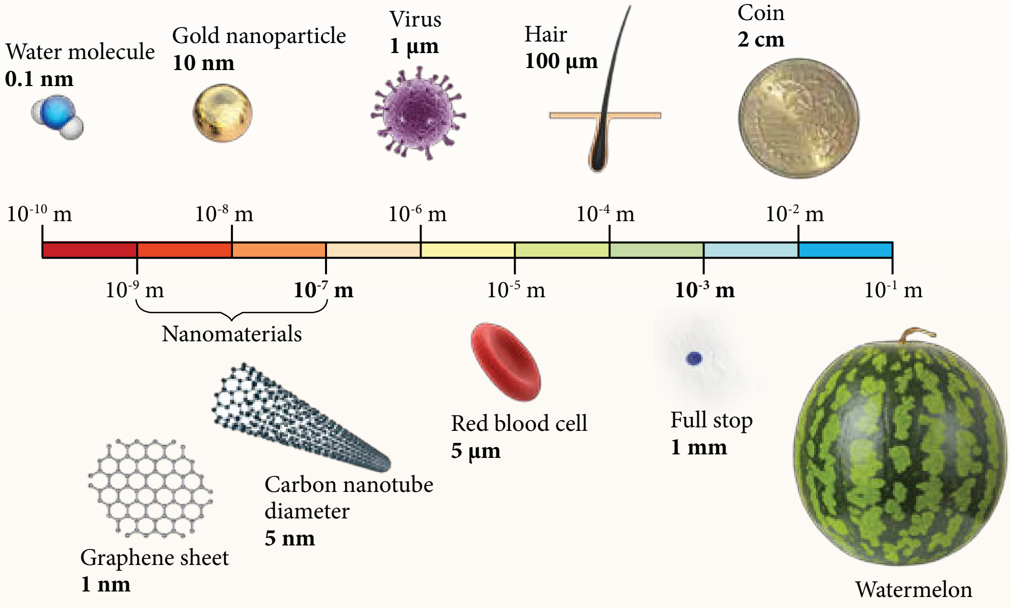


Figure 5.18 Size comparison between different materials

ACTIVITY 5L

Chemistry Portal

PAK21

Nanotechnology
https://bit.ly/kpkt5v48

1. Carry out the activity in groups.
2. Scan the QR code to watch the video about nanotechnology.
3. Produce a creative poster to explain the meaning of nanotechnology.
4. Showcase the poster in your class.

Application of Nanotechnology in Daily Life

- Nanoparticle sizes, ranging from 1 to 100 nanometres, enable various applications to be invented due to its extremely small size.
- In the cosmetics field, for example, the usage of nanoparticles is able to provide more satisfying outcomes as these extremely small particles have the ability to easily penetrate the skin even more.
- Nanoparticles are also able to coat the surface more evenly, which makes them the best coating agent. Various other applications of nanotechnology can be seen in Figure 5.19.

INFO

NANOMALAYSIA

NanoMalaysia is a company incorporated under the Ministry of Science, Technology and Innovation for the development in the field of nanotechnology.

Semiconductors and electronics	• Smaller and more efficient semiconductors. • High conductivity wiring system.
Energy and electricity	• Smaller and more efficient solar cells. • Long-lasting batteries.
Textile	• Water, fire and dirt resistant fabrics. • Anti-wrinkle and UV protective fabrics.
Medical	• Highly sensitive testing devices. • More effective drug delivery system.
Agriculture	• More effective pesticides. • Highly efficient and thorough fertilisation.
Food	• Nanoscale food additives. • Anti-microbial food packaging.

Figure 5.19 Various applications of nanotechnology

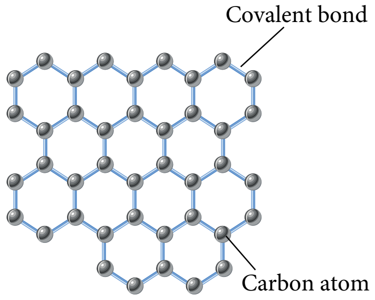
ACTIVITY 5M

PAK21

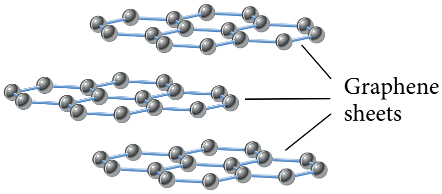
1. Carry out the activity in groups.
2. Each group will select one area of nanotechnology application.
3. Find additional information from books or electronic sources.
4. Present your findings in the form of an infographic poster.
5. Showcase the infographic poster on the classroom wall as a Gallery Walk activity.
6. Each group takes turn to read the showcased posters.

Development in the Field of Nanotechnology

- The coverage of the field of nanotechnology is very wide, crossing various disciplines, including physics, chemistry, biology, medicine and engineering. This contributes to the rapid research and development on applications of nanotechnology in various aspects of life.
- As an example, a material that has become one of the main focuses is a carbon derivative that is known as graphene.
- Graphene is one of the carbon allotropes, other than diamond and graphite, but has different characteristics from the rest. The size of graphene measures from 0.1 nm, which makes graphene among the most important materials in nanoscience and nanotechnology.
- Graphene sheets can be converted into other materials, including graphites, carbon nanotubes and fullerene balls. Figure 5.20 shows the structure of graphene.



Graphene sheet



Arrangement of graphene sheets in graphite

Figure 5.20 Graphene structure

Physical Properties of Graphene

- Graphene is an extraordinary material with various distinctive characteristics that can be attributed to its physical properties. Let us explore the physical properties of graphene found in Figure 5.21.

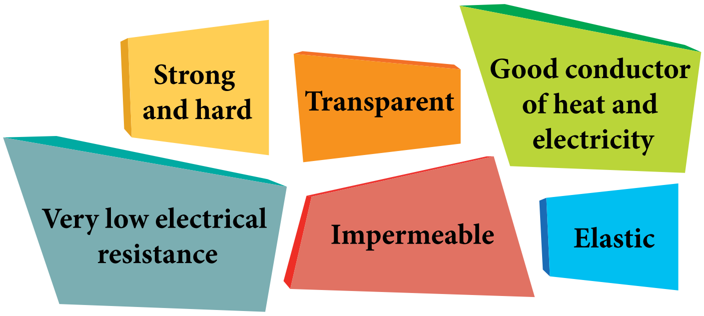


Figure 5.21 Physical properties of graphene

Cross-Curriculum
History

Graphene was successfully isolated in 2004 by two scientists, Andre Gein and Konstantin Novoselov. They were awarded the Nobel Prize in 2010 for their success.

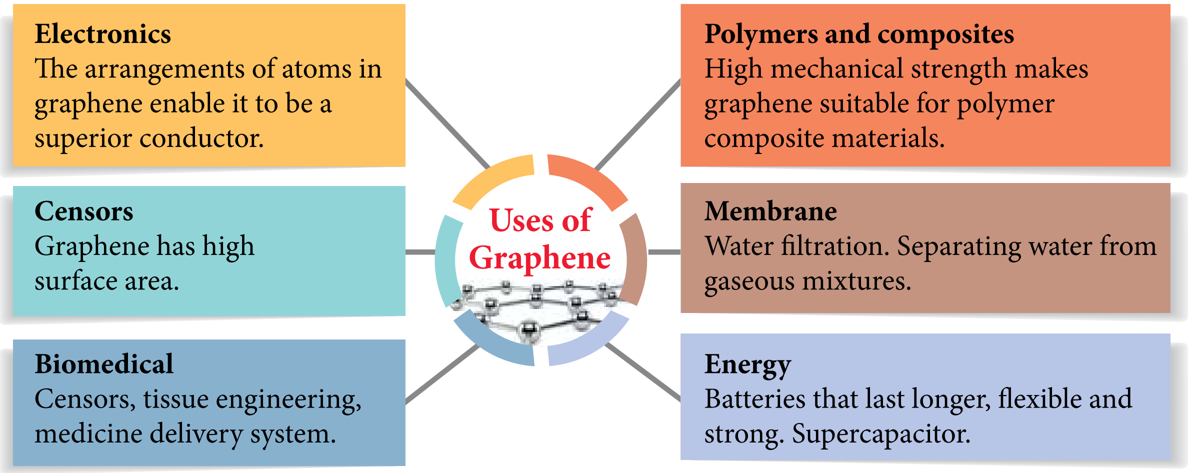
(**Source:** https://www.graphene.manchester.ac.uk/learn/discovery-of-graphene/)

Chemical Properties of Graphene

- Graphene sheets burn at a lower temperature than graphite. Graphene is the most reactive carbon allotropes.
- Researchers are still studying in detail the chemical reactions of graphene due to the relatively new discovery and isolation of graphene. Nonetheless, a few compounds have successfully been synthesised, namely, graphene oxide that is used as a catalyst.

Uses of Graphene

- The discovery of graphene has opened a new chapter in the field of nanotechnology. Numerous readily available applications can be improved or replaced with graphene that has superior and distinctive characteristics. Uses of graphene in various fields are shown in Figure 5.22.



Electronics
The arrangements of atoms in graphene enable it to be a superior conductor.

Censors
Graphene has high surface area.

Biomedical
Censors, tissue engineering, medicine delivery system.

Polymers and composites
High mechanical strength makes graphene suitable for polymer composite materials.

Membrane
Water filtration. Separating water from gaseous mixtures.

Energy
Batteries that last longer, flexible and strong. Supercapacitor.

Figure 5.22 The uses of graphene in various fields

Malaysian *Excellence*

NanoMalaysia Autonomous Vehicle – Navi by NanoMalaysia is an autonomous car that utilises nanotechnology.

(**Source:** nanomalaysia.com, 2019)

Chemistry Portal

Malaysia National Graphene Action Plan, 2020 (NGAP2020)
https://bit.ly/kpkt5n30

Noble Value

Appreciate the contributions of science and technology.

Self Assess 5.5

1. What is the difference between nanoscience and nanotechnology?
2. Explain how nanotechnology can elevate the standards of living.
3. Give examples of the applications of nanotechnology.
4. “Graphene is suitable to be used for filtering materials”. Explain the statement.

5.6 APPLICATION OF GREEN TECHNOLOGY IN INDUSTRIAL WASTE MANAGEMENT

Learning Standards

Pupils are able to:

5.6.1 explain Green Technology with examples.

5.6.2 describe application of Green Technology in the sectors of waste management and industrial waste water.

5.6.3 justify the application of Green Technology in daily life.

Development of Green Technology

- The introduction of National Green Technology Policy in 2009 has paved a way for a wider utilisation of Green Technology in various sectors in Malaysia.
- Community awareness towards environmental pollution and climate change has sped up the efforts in producing and utilising Green Technology while sustainably managing resources.

Green Technology is a technology or application developed to minimise the negative effects of harmful human activities.

- Malaysia Green Technology and Climate Change Centre, which is also known as GreenTech Malaysia, is a government agency responsible for initiating various programmes and incentives to encourage the adoption of Green Technology in various economic sectors in Malaysia.
- The usage of Green Technology is not solely limited to the industrial sector but it is very broad across various aspects of life.
- In applications involving manufacturing of products or services, the use of technology with environmentally friendly approaches is adopted starting from the utilisation and management of resources to waste management.
- Figure 5.23 shows the main Green Technology sectors in Malaysia and examples of applications within the sectors.

Chemistry Portal

Green Technology Masterplan
https://bit.ly/kpkt5n25

The National Green Technology Policy
https://bit.ly/kpkt5n5

Energy Supply
Renewable energy such as solar, hydro, geothermal and wind.

Transportation
Vehicles using alternative fuels.

Buildings
Use of environmentally friendly building materials and energy saving buildings.

Waste and Wastewater Management
Recycling and Landfill Leachate Treatment Method.

Agriculture and Forestry
Use of compost and forest preservation.

Industry
Use of energy efficient tools and technology.

Figure 5.23 Green Technology sectors and the applications involved

Green Technology in Waste and Wastewater Management

Figure 5.24 Green Technology approaches in waste and wastewater management

- Green Technology is utilised in waste and wastewater management with the aim of ensuring more efficient waste management, reduction in greenhouse gases emission and removal of cleaner wastewater.
- The carbon footprints can also be indirectly reduced and various alternative methods in managing waste and wastewater can be explored through Green Technology.
- Green Technology approaches in waste and wastewater management are shown in Figure 5.24.

Waste Management

- Rapid developments and growth in population have contributed to large quantities of generated solid waste or rubbish. If not properly managed, the quality of life and public health will be affected.
- Waste management does not only involve local authorities, but all communities also need to play a role in ensuring the effectiveness of waste management, especially solid wastes.
- Figure 5.25 shows the stages in waste management. Can you identify the stage of waste management that utilises Green Technology?

INFO

Leachate is contaminated liquid produced from water leached from solid waste.

Noble Value

Interested and curious about the environment.

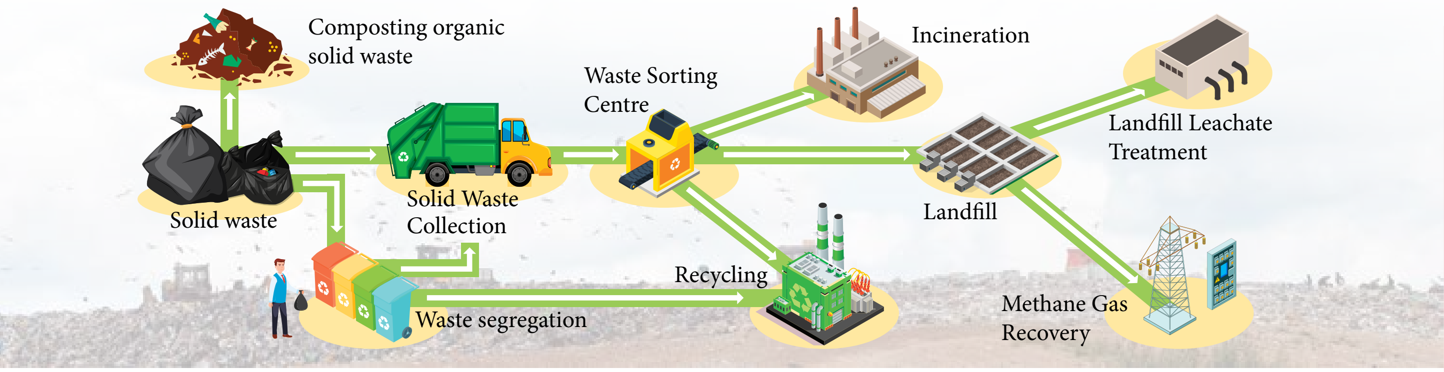


Figure 5.25 Green Technology in various stages of waste management.

Wastewater Management

- Wastewater is a liquid waste that consists of human waste, food waste, oil and chemicals. Wastewater can be divided into domestic wastewater, stormwater runoff and industrial wastewater.
- Compared to domestic wastewater and stormwater runoff, industrial wastewater may contain acrylonitrile, methylbenzene, toluene and heavy metals, such as arsenic, mercury and lead.
- These hazardous chemicals are difficult to decompose biologically and require more systematic treatments so that they will not pollute the environment nor affect human health.

ACTIVITY 5N

"How is industrial wastewater treated before being discharged?"

1. In groups, discuss the solution to the above question through a brainstorming session.
2. Scan the QR code to obtain the Chemistry Green Technology Module (pages 29 – 32) for an activity on wastewater treatment using electrolysis.
3. Conduct this activity under the supervision of your teacher.
4. Present your findings in class in a Gallery Walk activity.

Chemistry Portal

Chemistry Green Technology Module
https://bit.ly/kpkt5n8

- Landfill Leachate Treatment Method by using the electrolysis principle, which is also known as electrocoagulation process, is a Green Technology approach that can be used to treat wastewater, including industrial wastewater.
- Carbon or copper electrodes are used while wastewater is the electrolyte in the electrocoagulation process. Pollutants will form flocs and can be isolated from water and then removed as sludge.
- After proper treatment, sludge can be used as fertilisers for the agricultural sector or disposed of by appropriate methods depending on the composition of the materials contained in sludge.
- Wastewater that has been treated can be reused for crop irrigation, or discharged as effluent.
- Steps in wastewater treatment are briefly shown in Figure 5.26.

INFO

Effluent is waste in the liquid form discharged into the drainage system or water source.

Chemistry Portal

Wastewater Treatment
https://bit.ly/kpkt5v49

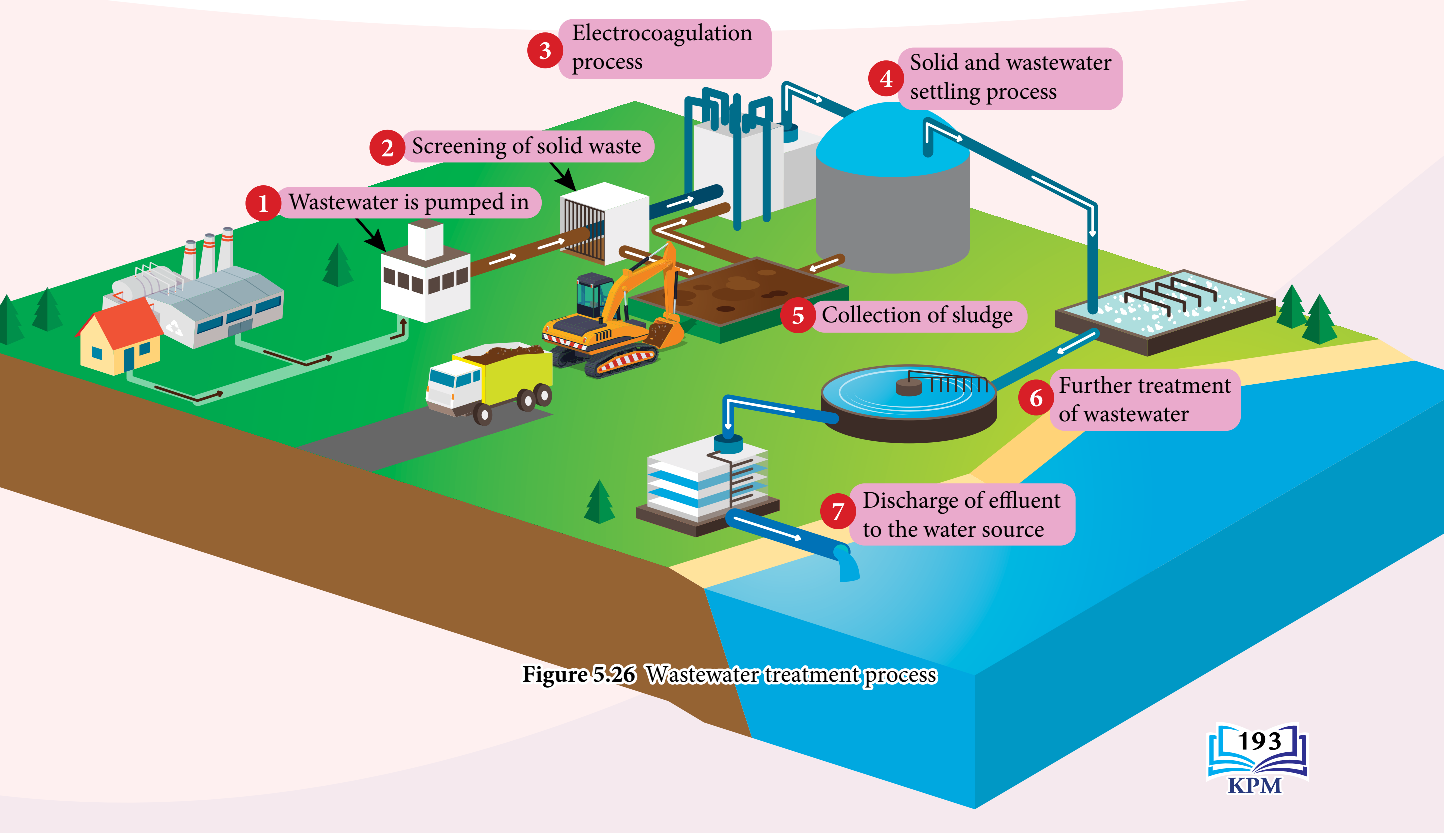


Figure 5.26 Wastewater treatment process

The Importance of Green Technology in Life

- Green Technology has trailblazed a new chapter in the field of technology with more environmentally friendly approaches without neglecting the original purpose of technology. This development contributes to the economic sector of the country through the creation of new industrial sectors and employment opportunities based on Green Technology. The importance of Green Technology in life can be seen in Figure 5.27.
- Environmental pollution can be reduced and management of resources will be more efficient and well organised. How can you as a pupil integrate Green Technology in your daily life?

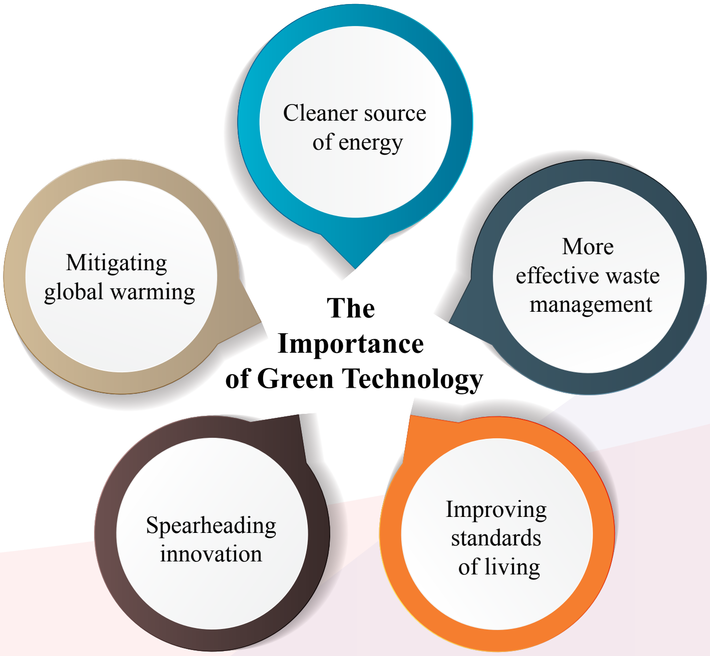


Figure 5.27 Importance of Green Technology

(**Source:** nst.com.my, 2019)

(**Source:** astroawani.com, 2019)

Photograph 5.11 The pollution of Kim Kim River in 2019 was caused by the discharge of untreated industrial wastewater into the river

ACTIVITY 50

STEM PAK 21

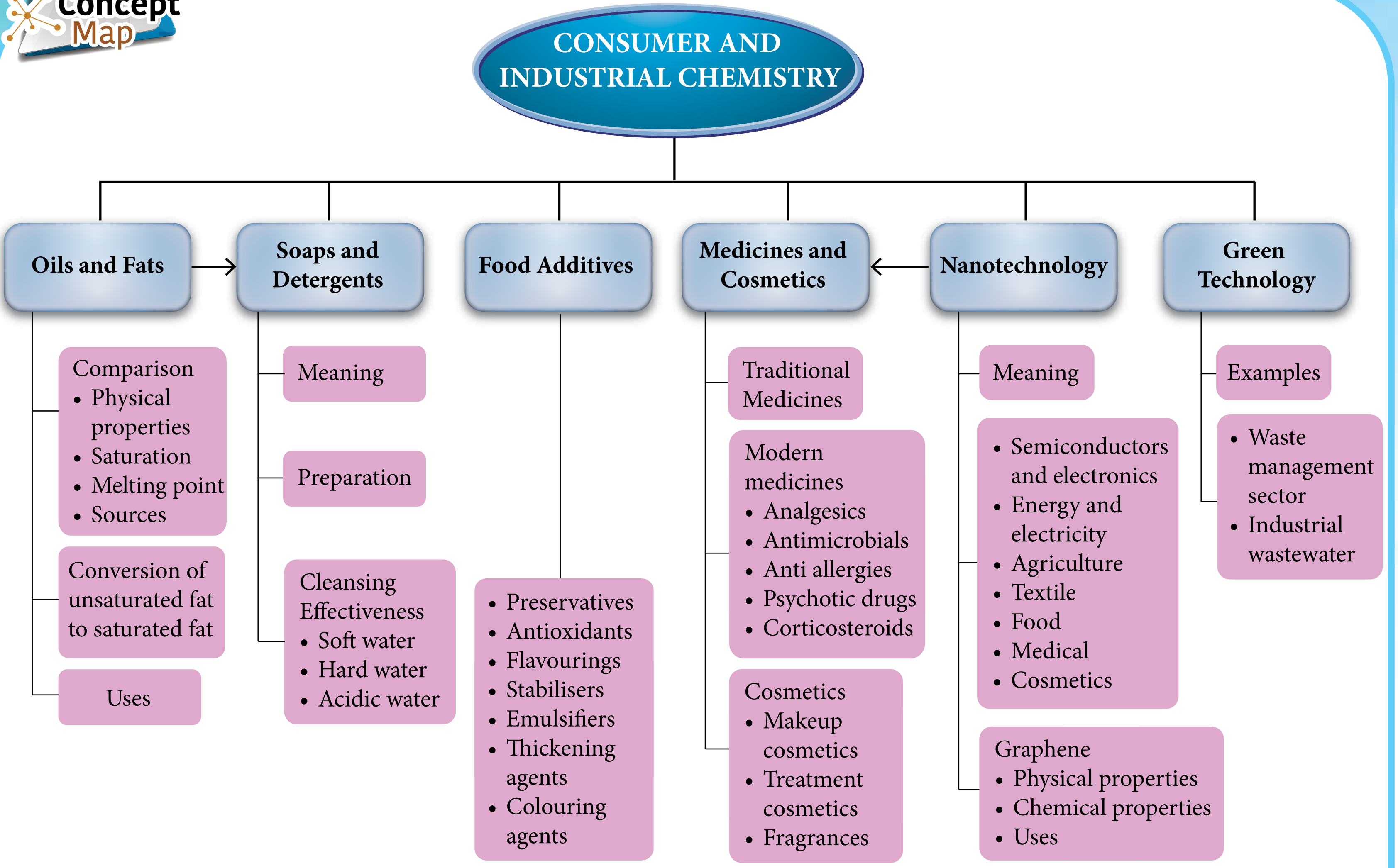
There are various wastes in your school that include food wastes and plastic bottles. Electricity consumption is also high due to the lengthy use of fans and lights.

1. Plan a competition in class.
2. Each group is required to submit a product or proposal to address the above issues using the Green Technology approach.
3. Invite the teachers to judge the product from each group.

SelfAssess 5.6

1. What is the meaning of Green Technology?
2. Why is there a need to treat the leachate in solid waste disposal process?
3. List the Green Technology used in wastewater management.
4. How can Green Technology mitigate the greenhouse effect?

Concept Map



CONSUMER AND INDUSTRIAL CHEMISTRY

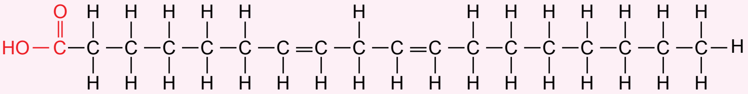
- **Oils and Fats** → Soaps and Detergents
  - Comparison
    - Physical properties
    - Saturation
    - Melting point
    - Sources
  - Conversion of unsaturated fat to saturated fat
  - Uses
- **Soaps and Detergents**
  - Meaning
  - Preparation
  - Cleansing Effectiveness
    - Soft water
    - Hard water
    - Acidic water
- **Food Additives**
  - Preservatives
  - Antioxidants
  - Flavourings
  - Stabilisers
  - Emulsifiers
  - Thickening agents
  - Colouring agents
- **Medicines and Cosmetics**
  - Traditional Medicines
  - Modern medicines
    - Analgesics
    - Antimicrobials
    - Anti allergies
    - Psychotic drugs
    - Corticosteroids
  - Cosmetics
    - Makeup cosmetics
    - Treatment cosmetics
    - Fragrances
- **Nanotechnology** → Medicines and Cosmetics
  - Meaning
  - Semiconductors and electronics
  - Energy and electricity
  - Agriculture
  - Textile
  - Food
  - Medical
  - Cosmetics
  - Graphene
    - Physical properties
    - Chemical properties
    - Uses
- **Green Technology**
  - Examples
  - Waste management sector
  - Industrial wastewater

SELF Reflection

1. Have you mastered the topic of **Consumer and Industrial Chemistry**?
2. What is the content in the topic of **Consumer and Industrial Chemistry** that you want to have a more in-depth understanding of? Why?
3. How does the topic of **Consumer and Industrial Chemistry** benefit you in daily life?
4. How would you assess your ability to describe the contents in the topic of **Consumer and Industrial Chemistry** to your friends?
5. What can you do to improve your understanding of the topic of **Consumer and Industrial Chemistry**?

ACHIEVEMENT TEST

1. Oils and fats are the products of reactions between fatty acids and glycerol. Figure 1 shows the structure of fatty acid P.



$$\mathrm{HO-\overset{O}{\overset{\|}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{H}{C}=\underset{H}{C}-\overset{H}{\underset{H}{C}}-\underset{H}{C}=\underset{H}{C}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H}$$

Figure 1

(a) State the type of fat produced when fatty acid P reacts with glycerol.
(b) Oils or fats that consist of fatty acid P easily oxidise and turn rancid when exposed to the air. Explain why.

2. (a) The equation below shows the reaction for the preparation of soap in a laboratory.

Palm oil + concentrated sodium hydroxide → sodium palmitate (soap) + glycerol

(i) What is the name of the reaction?
(ii) What is the homologous series for palm oil?

(b) A pupil wants to prepare potassium palmitate soap.
What alkali should the pupil use?

3. Figure 2 shows the cleansing results for clothes with greasy stains by using two different cleaning agents, A and B.

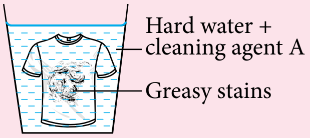
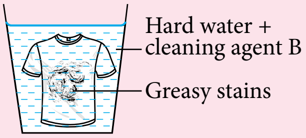
Cleaning agent	**A**	**B**
Anion formula	$CH_3(CH_2)_{11}OSO_3^-$	$CH_3(CH_2)_{16}COO^-$
Cleaning in hard water		
Result	Greasy stains are cleaned	Some greasy stains remain

Figure 2

(a) State types of cleaning agents A and B.
(b) Based on Figure 2, compare and contrast the cleansing actions for both cleaning agents in hard water. Explain your answer.

4. Table 1 shows the information found on labels of three types of food. P, Q and R are food additives.

Table 1

Pineapple in syrup	Tomato sauce	Vanilla Ice Cream
Sweet and manufactured naturally from natural sources.	Tasty and lasts long.	Flavourful and soft
Ingredients: Fresh pineapple cuts, food additive P	Ingredients: Tomato, sugar, salt, corn flour, artificial colouring, food additive Q	Ingredients: Milk, vanilla, sugar, artificial colouring, food additive R

Based on the labels found on food containers in Table 1:
(a) State the names of food additives P, Q and R.
(b) Identify the type of food additives and their corresponding functions.

5. Table 2 shows the information about two types of antimicrobial medicines X and Y.

Table 2

Medicine	Remarks
X	• Applied to wounds or injuries • Cannot be consumed
Y	• Used for tuberculosis and pneumonia

(a) Name the types of medicines X and Y.
(b) What action should be taken to ensure that the intake of medicine Y is effective? Give your reason.

6. Photograph 1 shows a sunblock lotion that utilises nanotechnology.
(a) What is the meaning of nanotechnology?
(b) Explain the advantage of nanotechnology application in sunblock lotions.
(c) State two other uses of nanotechnology.

Photograph 1

7. Water pollution could possibly be sourced from the leachate of untreated wastewater disposal.
(a) Explain the steps to overcome this issue using Green Technology.
(b) Describe the advantages of using Green Technology in wastewater treatment process.
(c) Sludge is the substance produced from the wastewater treatment process. How can sludge benefit mankind?

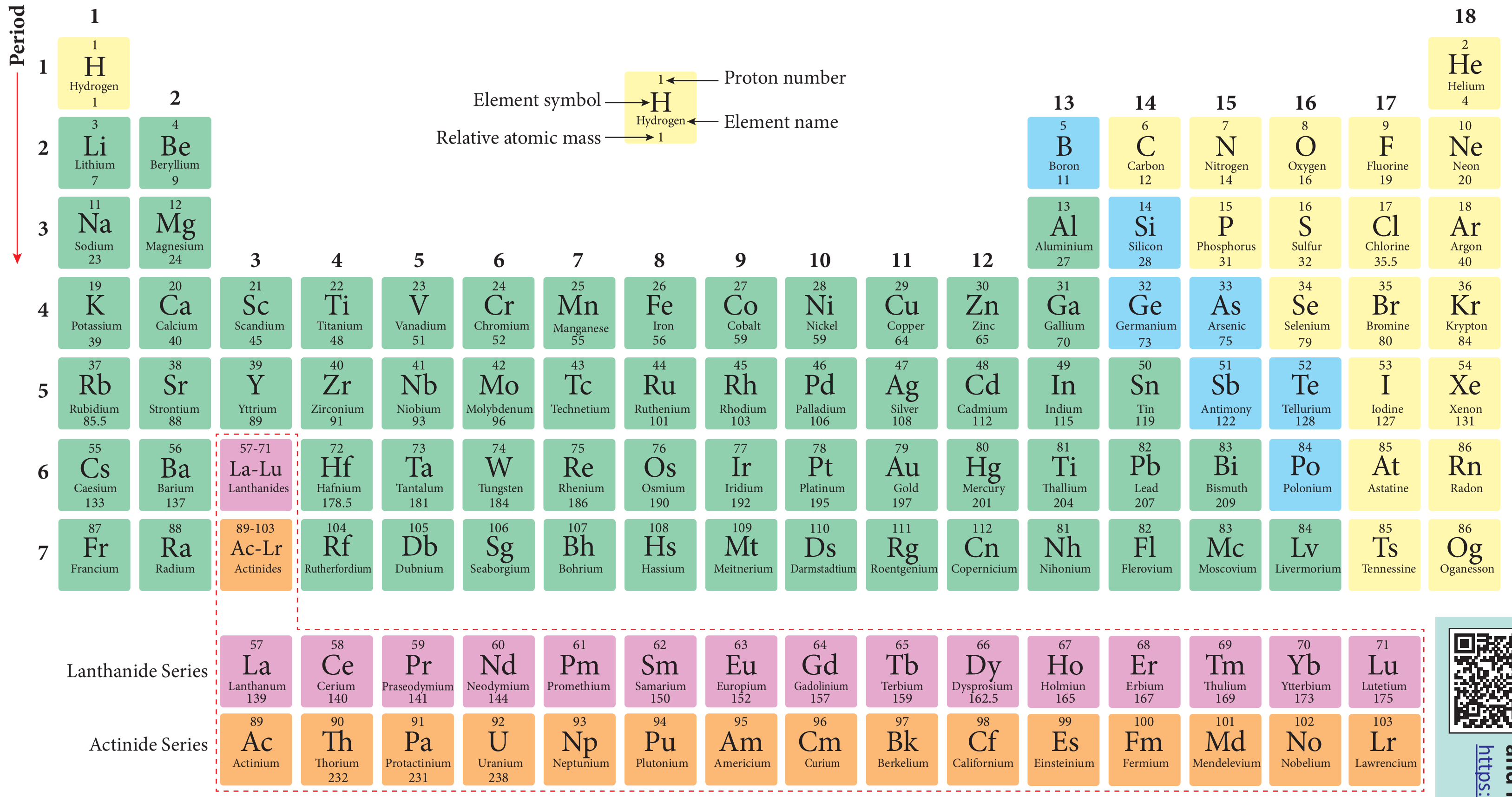
Chemistry Portal

Additional Exercises
https://bit.ly/kpkt5n26

Enrichment Corner

Virgin coconut oil has various benefits and consists of low percentage of unsaturated fatty acids, which is around 8%, while palm oil can consist up to 50% of unsaturated fatty acids. In your opinion, which oil will last longer and cannot be easily oxidised? Explain your answer.

Periodic Table of Elements



1 ← Proton number
Element symbol → H
Hydrogen ← Element name
Relative atomic mass → 1

Group →

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 Sulfur 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 La-Lu 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 Ti 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 Ac-Lr 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	81 Nh Nihonium	82 Fl Flerovium	83 Mc Moscovium	84 Lv Livermorium	85 Ts Tennessine	86 Og Oganesson
Lanthanide 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	
Actinide 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	

Legend: 🟩 Metal 🟦 Semi metal 🟨 Non-metal

Chemistry Portal

Chemical Data and Formula
https://bit.ly/kpkt5for

Glossary

Addition reaction – A chemical reaction that occurs when another atom is added to each carbon atom at the double bond —C=C— to form a single covalent bond —C—C—.

Anode – The electrode where the oxidation reaction takes place.

Cathode – The electrode where the reduction reaction takes place.

Cell notation – Shorthand representation of a chemical cell with the anode on the left and the cathode on the right is separated by two vertical lines representing a salt bridge or porous pot.

Cracking –The process whereby long chain hydrocarbons are broken down into smaller molecules at high temperatures in the presence of a catalyst.

Daniell cell – Chemical cell consists of zinc, Zn metal electrodes and copper, Cu metal electrodes dipped into their respective ionic salt solutions.

Electrochemical Series – A series of metal arrangement in the order of standard electrode capacity, E^0 from the most negative to the most positive.

Electrolysis – A process of decomposition of a compound in a molten state or an aqueous solution to its constituent elements when electric current is passed through it.

Electrolyte – A substance in a molten state or an aqueous solution that can conduct electric currents and undergo chemical changes.

Electroplating – The electrolysis process of coating the surface of a metal with thin and even layer of another metal.

Endothermic reaction – A chemical reaction that absorbs heat from the surroundings.

Exothermic reaction – A chemical reaction that releases heat to the surroundings.

Esterification – The reaction of alcohol with carboxylic acid to produce ester and water.

Fatty acid – Long chain carboxylic acid.

Functional group – A group of atoms bonded to a molecule of an organic compound that determines the chemical properties of homologous series.

Galvanisation – The process of coating of iron with a layer of zinc so that it is resistant to corrosion.

General formula – The formula that shows the general form of the molecular formula of a homologous series.

Glycerol – An alcohol that consists of three carbon atoms and three hydroxyl groups.

Graphene – One of the carbon allotropes, other than diamond and graphite.

Green Technology – A technology or application developed to minimise the negative effects of human activities.

Hard water – Water that contains calcium, ions, Ca^{2+} or magnesium ions, Mg^{2+} that dissolve in it.

Homologous series – A group of organic compounds which has the same functional group and is represented by a general formula.

Isomer – Molecules that have the same molecular formula but different structural formulae.

Metal corrosion – A redox reaction in which metal is oxidised spontaneously when a metal atom releases an electron to form a metal ion.

Molecular formula – The formula that shows the type and actual number of atoms of each element in a molecule.

Nanoscience – The study on processing of substances at nano scale which is in between 1 nanometre to 100 nanometres.

Nanotechnology – The development of substances or gadgets using the properties of nanoparticles.

Oxidation number or oxidation state – Charge of an element in a compound if electron transfer occurs in an atom to form a chemical bond with another atom.

Oxidising agent – Substance that oxidise other substances and is reduced in a redox reaction.

Polymerisation – The monomer combination reaction to produce a polymer.

Reactivity series of metal – A series of metal arrangement in an ascending order of metal reactivity towards oxygen.

Redox reactions – Chemical reactions that involve oxidation and reduction that occur simultaneously.

Reducing agent – A substance that reduce other substances and is oxidised in a redox reaction.

Rusting – A redox reaction in which there is an oxidation process of iron to hydrated iron(III) oxide, $Fe_2O_3.xH_2O$ or rust.

Saponification – Hydrolysis process of fats or oils by an alkali.

Soft water – Water that does not contain calcium ions, Ca^{2+} or magnesium ions, Mg^{2+} that dissolve in it.

Standard electrode potentials, E^0 – Potential difference produced in half cells under standard conditions with a concentration of ion in an aqueous solution is 1.0 mol dm^{-3} at 25 °C and pressure of 1 atm or 101 kPa and is coupled with standard hydrogen electrode.

Structural formula – The formula shows type of bond and how the atoms in a molecule are bonded to each other.

Substitution reaction – A chemical reaction that occurs when each hydrogen atom in an alkane molecule is substituted one by one with halogen atoms, until all the hydrogen atoms are substituted.

Vulcanisation – A process of producing rubber that is more elastic and with better quality through the production of cross-link between polymer chains.

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Dengan ini **SAYA BERJANJI** akan menjaga buku ini dengan baiknya dan bertanggungjawab atas kehilangannya serta mengembalikannya kepada pihak sekolah pada tarikh yang ditetapkan.

Skim Pinjaman Buku Teks

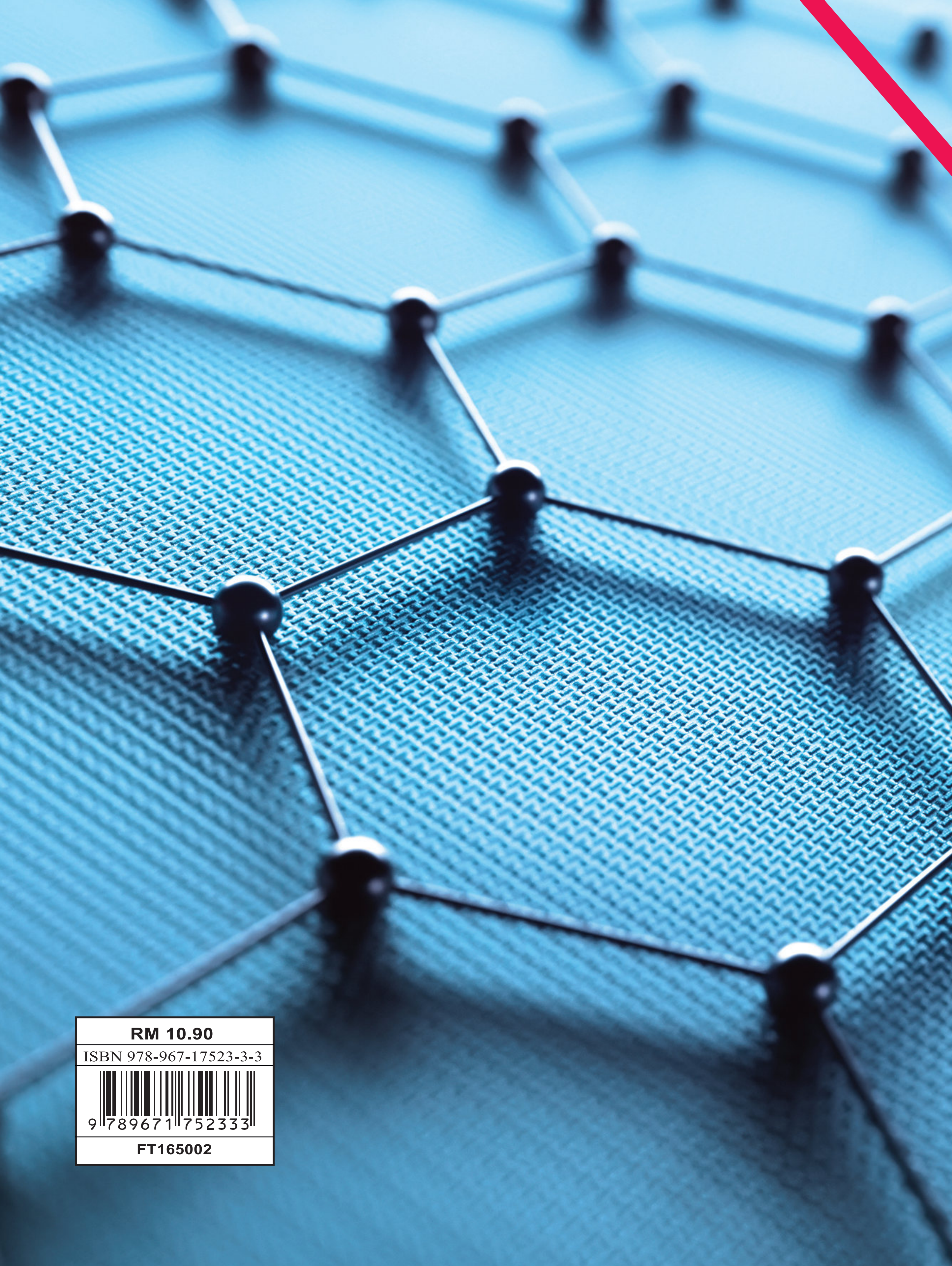
Sekolah ______________________________

Tahun	Tingkatan	Nama Penerima	Tarikh Terima

Nombor Perolehan: ______________________________

Tarikh Penerimaan: ______________________________

BUKU INI TIDAK BOLEH DIJUAL



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