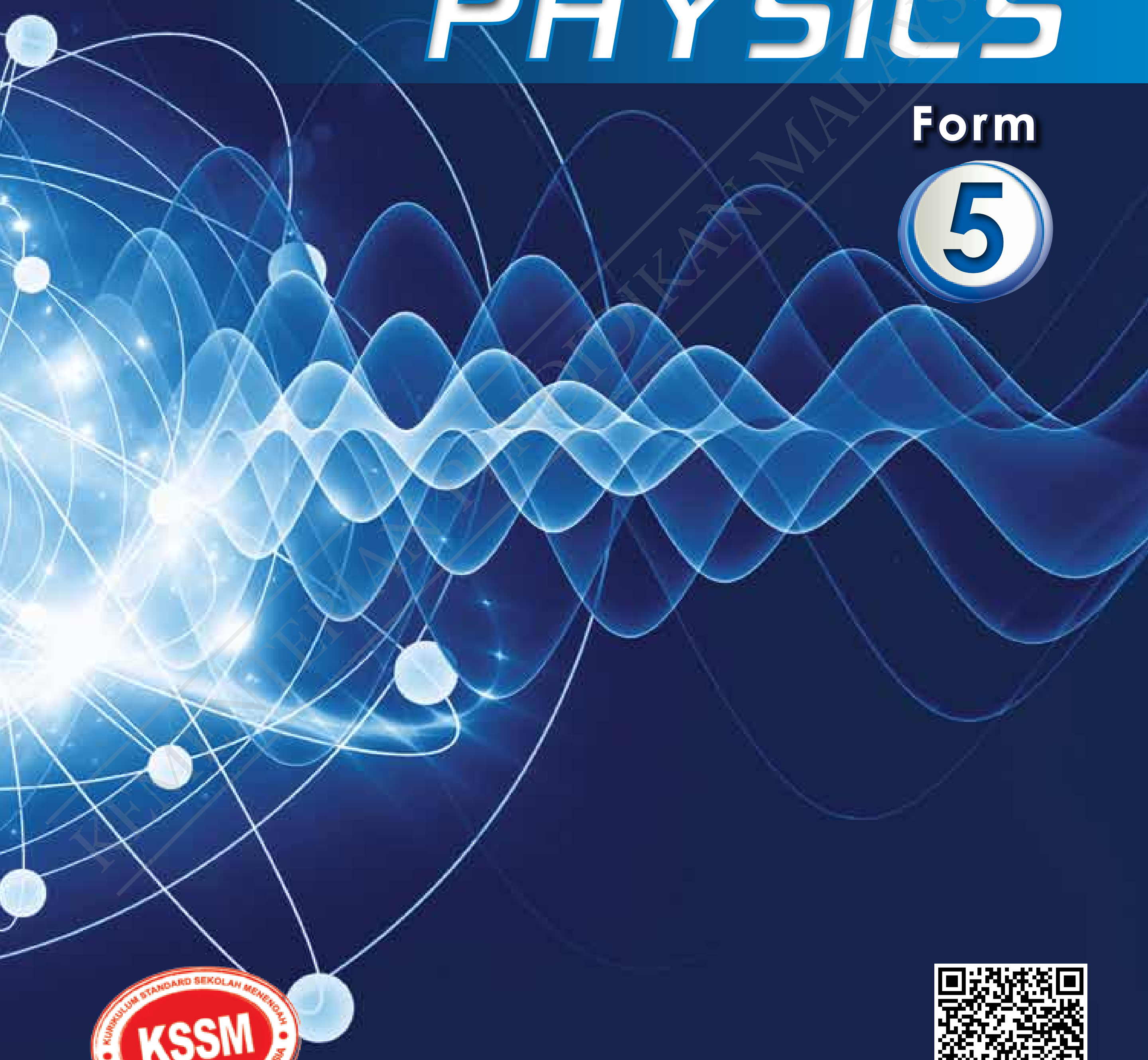
KEMENTERIAN PENDIDIKAN MALAYSIA

DUAL LANGUAGE PROGRAMME

PHYSICS

Form 5



KURIKULUM STANDARD SEKOLAH MENENGAH
KSSM
KEMENTERIAN PENDIDIKAN MALAYSIA

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

DUAL LANGUAGE PROGRAMME

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Form 5

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2020

KEMENTERIAN PENDIDIKAN MALAYSIA

BOOK SERIAL NO: 0130

KPM 2020 ISBN 978-983-092-447-2
First Published 2020

Published for the Ministry of Education Malaysia by:
Penerbit Bestari Sdn. Bhd.
199301003520 (258257-P)
No. 22-01, Jalan Molek 1/10,
Taman Molek, 81100 Johor Bahru,
Johor Darul Takzim.
Tel: 07-3612868 Fax: 07-3526292
Website: www.pbestarisb.com

Layout and typesetting by:
Penerbit Bestari Sdn. Bhd.
199301003520 (258257-P)

Font style: Minion Pro
Font size: 11 point

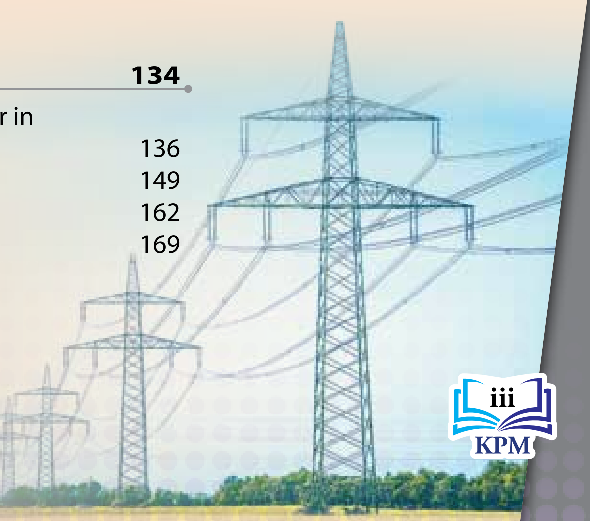
Printed by:
Dolphin Press International Sdn. Bhd.
(803493-W)
No. 1, Jalan 13/118B,
Desa Tun Razak, Cheras,
56000, Kuala Lumpur

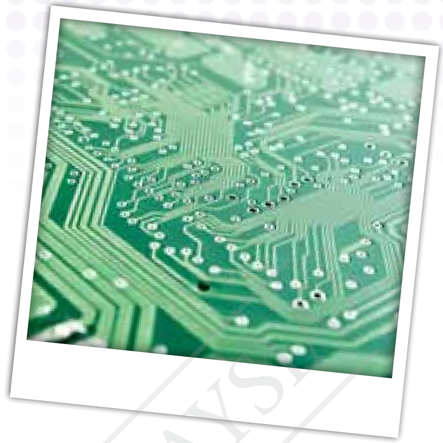
Acknowledgements

The publishing of this textbook involves the cooperation of various organisations and individuals. The publisher and authors would like to express appreciation and thanks to the following.

- Committee members of *Penambahbaikan Pruf Muka Surat*, Educational Resources and Technology Division, Ministry of Education Malaysia.
- Committee members of *Penyemakan Naskhah Sedia Kamera*, Educational Resources and Technology Division, Ministry of Education Malaysia.
- Committee members of *Penyemakan Naskhah Sedia Kamera* DLP, Educational Resources and Technology Division, Ministry of Education Malaysia.
- Committee members of *Penyemakan Pembetulan Naskhah Sedia Kamera* DLP, Educational Resources and Technology Division, Ministry of Education Malaysia.
- Officers of the Educational Resources and Technology Division and the Curriculum Development Division, Ministry of Education Malaysia.
- Officers of the English Language Teaching Centre, Ministry of Education Malaysia.
- National Academy of Arts Culture and Heritage (ASWARA).
- Sekolah Tun Fatimah, Johor Bahru.

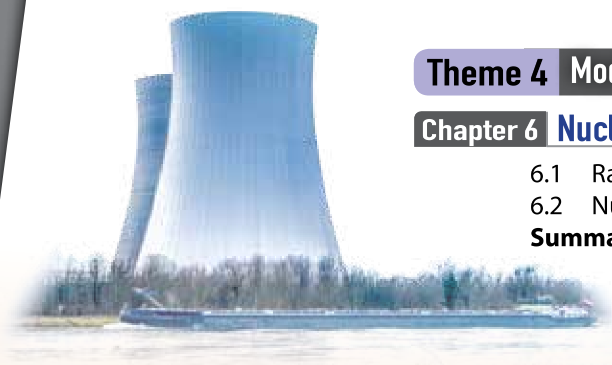
CONTENTS





Theme 3 Applied Physics

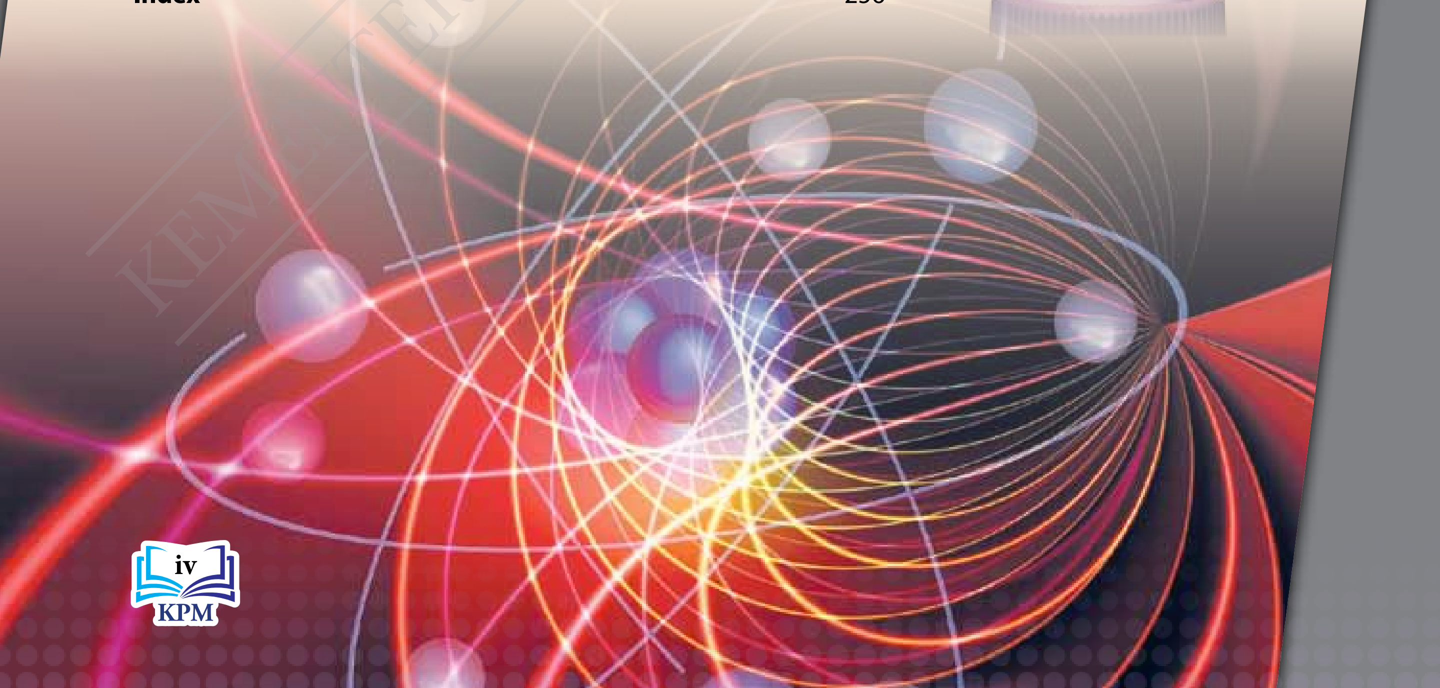
Chapter 5 Electronics



Theme 4 Modern Physics

Chapter 6 Nuclear Physics

Chapter 7 Quantum Physics



Introduction

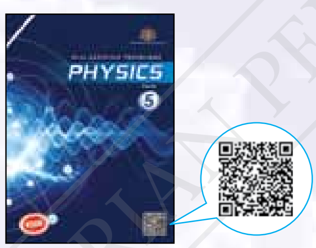
The **Form 5 Physics** *Kurikulum Standard Sekolah Menengah* (KSSM) textbook is written based on the *Dokumen Standard Kurikulum dan Pentaksiran* (DSKP) for Form 5 prepared by the Ministry of Education Malaysia. For successful implementation of KSSM and to cater to the needs of DSKP, this book is written based on three domains, which are knowledge, skills and values. This book incorporates special features with more emphasis on Science, Technology, Engineering and Mathematics (STEM), thinking skills, scientific skills and computational thinking (CT) so that pupils are equipped with 21st century skills and become scientifically-thoughtful individuals.

This book incorporates the special features as follows:

QR Code

QR code on the cover of the book to obtain:

(a) Description of themes in the book
(b) Biodata of authors
(c) Updated information and facts (if available)



Science, Technology, Engineering and Mathematics

STEM

Activities that incorporate project-based learning through the STEM (Science, Technology, Engineering and Mathematics) approach. The STEM approach is a teaching and learning method which applies integrated knowledge, skills and values of STEM.

21st Century Learning Activities

Various activities that focus on student-centred learning and have elements of Higher Order Thinking Skills (HOTS).

21st Century Skills

Activities that involve the following:

- Critical thinking and problem-solving skills **CPS**
- Interpersonal and self-reliance skills **ISS**
- Information and communication skills **ICS**

Computational Thinking

Activities that involve the following:

- Decomposition
- Pattern Recognition
- Abstraction
- Algorithms
- Logical Reasoning
- Evaluation

Thinking Tools

The use of various thinking tools such as graphic organisers and mind maps to help pupils master thinking skills.

LS 1.1.1
Learning Standard on every page

EAC
Elements across curriculum related to the topic are applied

Let's Try
Simple activities that can be carried out by pupils

HOTS questions to test pupils' ability to apply knowledge, skills and values in reasoning and reflection in order to solve problems, make decisions, innovate and create

Safety Precaution
Steps needed to be taken by pupils to obtain accurate results and to prevent any accidents during scientific research

Concept Chain
A short summary in the form of a concept chain at the end of each chapter

Info GALLERY
Interesting additional information related to a topic

BRIGHT Info
Simple and easy notes for pupils to memorise

SCIENCE, TECHNOLOGY and SOCIETY Gateway
Information on the applications of science and technology

Brain-Teaser
Questions that challenge pupils' thinking

LET'S RECALL
Information from the topic pupils' have learned

Note
A brief description to explain or elaborate something related to the topic

Self-Reflection
Self-reflection to evaluate pupils' mastery of the chapter

My Glorious Malaysia
Information on patriotic elements, cultures and achievements of Malaysians

Career Booth
Information on careers related to the field of physics

LET'S ANSWER
Examples of questions and solutions to evaluate pupils' understanding

SCAN ME
Links to websites are provided for extra information

Interactive Games
Crossword puzzles related to the topics

QUIZ
A QR code for a short interactive quiz at the end of each chapter

21st Century Challenge
Enrichment exercises with level 5 (Evaluating) and level 6 (Creating) HOTS questions

Formative Practice
Questions to test pupils' understanding at the end of each subtopic

Summative Practice
LOTS and HOTS questions of various levels to test pupils' understanding at the end of each chapter

Activities in this book consist of:

Guide to Scanning AR (Augmented Reality) for Interactive Three-Dimensional Animations

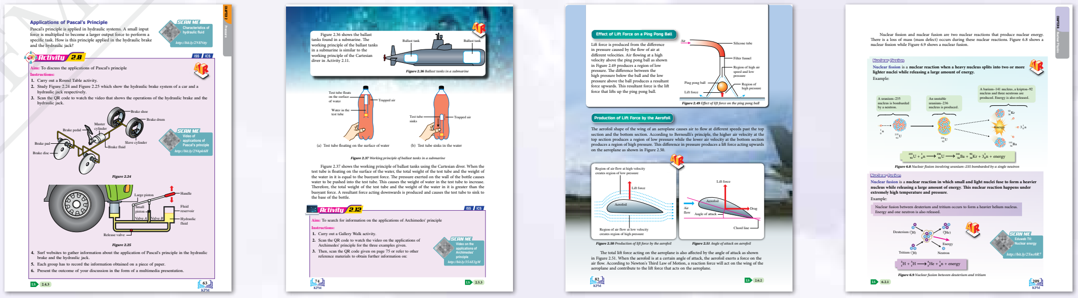
Scan the QR code on the right to download the application.

Download at Google Play

Download at App Store

Use the application to scan the QR code on the right to download the Textbook AR.

Next, use the application to scan pages with the AR icon (pages 63, 74, 82, 152 and 209).



CHAPTER 1

Force and Motion II

How is a resultant force determined?

Why do we resolve a single force into two components?

How are forces in equilibrium represented by a vector diagram?

What are the factors that affect the spring constant?

You will learn:

- 1.1 Resultant Force
- 1.2 Resolution of Forces
- 1.3 Forces in Equilibrium
- 1.4 Elasticity

Learning Standards and List of Formulae in Chapter 1

Information Portal

The Langkawi Skybridge is located at the peak of Gunung Mat Cincang, Pulau Langkawi, Kedah. It is the longest curved pedestrian bridge in the world.

The span of the bridge which is 125 metres in length is suspended by eight cables from a single pylon. Although the 81.5-metre high pylon is inclined and the bridge is curved, the Langkawi Skybridge is always in a stable condition. The design of the bridge has taken into account the actions of external forces such as the wind, the movement of tourists and the distribution of load. All these forces acting on the bridge have to be in equilibrium to ensure the integrity of the structure of the bridge and the safety of its users.

http://bit.ly/2t0aOXv

Importance of the Chapter

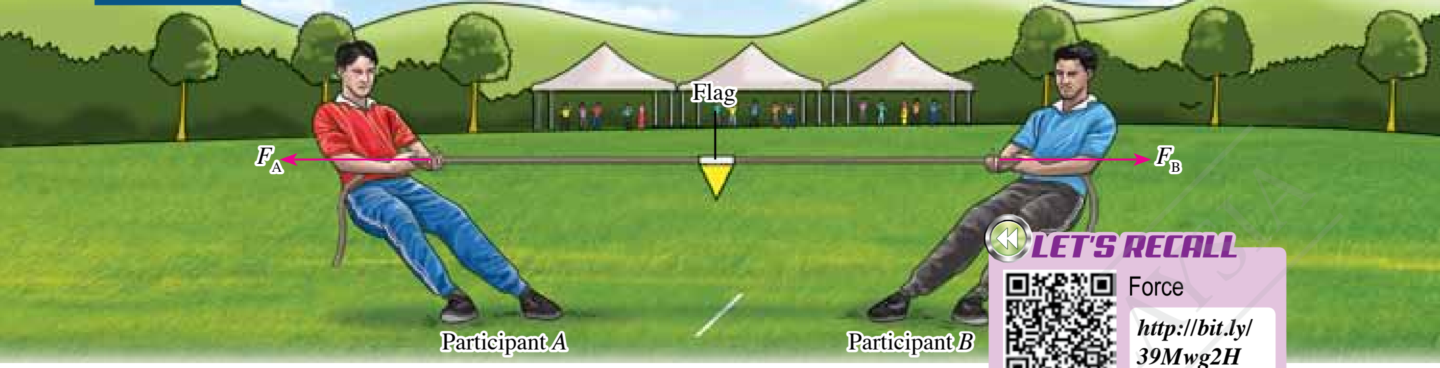
Engineers and designers of structures need to understand and apply the fundamental concepts of physics such as resultant force, resolution of forces and forces in equilibrium when designing a unique structure. These aspects are important to guarantee the integrity of the building structure.

Futuristic Lens

Futuristic architecture combines the knowledge and skills in physics, engineering, materials science and creative thinking to create building structures beyond the human imagination. Therefore, the concepts and principles of physics are still fundamental for futuristic architecture.

http://bit.ly/2R2cZSi

1.1 Resultant Force



LET'S RECALL
Force
http://bit.ly/39Mwg2H

Figure 1.1 *Tug-of-war*

Figure 1.1 shows two participants who are competing in a tug-of-war competition. Participant *A* and participant *B* exert forces F_A and F_B respectively on the rope. What determines whether the flag tied to the rope is at rest, moves to the left or moves to the right?

Activity 1.1

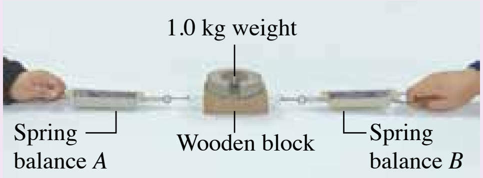
Aim: To generate the idea of resultant force and to determine its direction

Apparatus: Two spring balances and a 1.0 kg weight

Material: A wooden block with a hook at both ends

Instructions:

1. Set up the apparatus as shown in Photograph 1.1.
2. Pull the wooden block using spring balance *A* and spring balance *B* in opposite directions, so that the wooden block does not move.
3. Record the readings of the spring balances in Table 1.1.
4. Repeat steps 2 and 3 so that the wooden block moves:
   (a) to the right (b) to the left.



Photograph 1.1

Results:

Table 1.1

Condition of the wooden block	Reading of spring balance *A* / N	Reading of spring balance *B* / N
Stationary		
Moves to the right		
Moves to the left		

Discussion:

1. Compare the readings of the two spring balances when the wooden block is:
   (a) at rest (b) moving to the right (c) moving to the left
2. State the relationship between the direction of motion of the wooden block and the direction of the force acting on the wooden block.

When two forces of the same magnitude acting in opposite directions are applied on a stationary object, the object remains at rest. Assuming the two opposing forces have different magnitudes, the object will move in the direction of the larger force. **The resultant force** is **the single force that represents the vector sum of two or more forces acting on an object**.

Figure 1.2 shows three situations that can be observed in the tug-of-war competition between participant *A* and participant *B*. Observe also the magnitude of forces F_A and F_B which are represented by the lengths of the arrows as well as the motion produced.

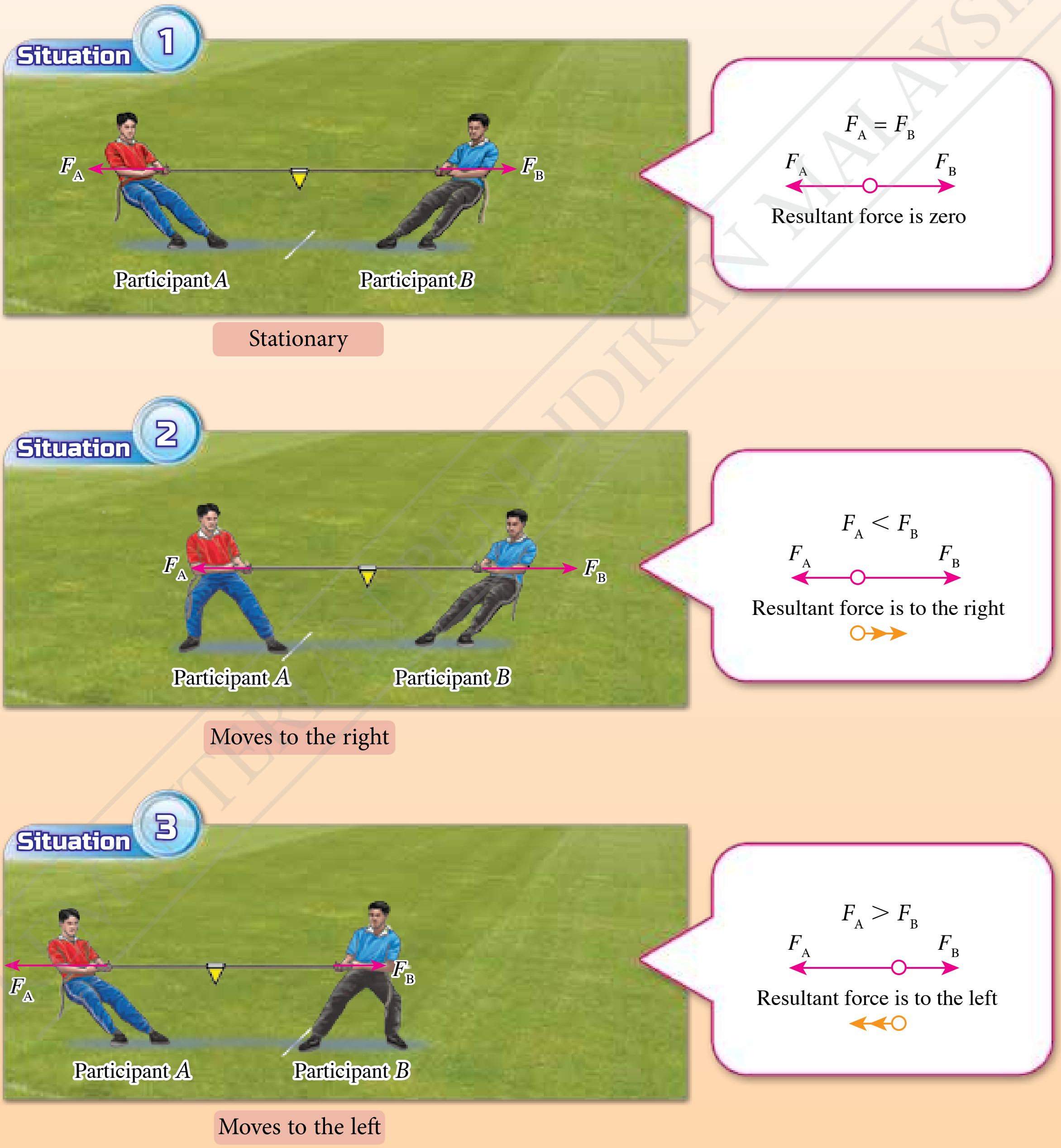


***Figure 1.2** Three situations in a tug-of-war competition between participant A and participant B*

Determining a Resultant Force

A resultant force is the vector sum of the forces acting on a point. How do we determine the resultant force of two forces acting on a point?

Activity 1.2 Pattern Recognition

Aim: To determine the resultant force produced when two forces are acting on an object on a plane

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Observe the four situations that involve two forces acting on a point.
3. Examine the suggested method and the sample calculation.
4. Scan the QR code and print the worksheet. Calculate the resultant force for each situation.

SCAN ME
Worksheet Activity 1.2
https://bit.ly/32ijdmS

Situation 1: Two forces acting on an object in the same direction

Method and sample calculation

(i) The magnitude of the resultant force is equal to the sum of the two forces.
(ii) The direction of the resultant force is the same as the direction of the two forces.
(iii) The resultant force is stated by its magnitude and direction.

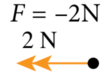
Assume that the force to the right is positive:
(i) Magnitude of the resultant force,
$F = 6 + 8$
$= 14$ N
(ii) Direction of the resultant force is to the right
(iii) Resultant force,
$F = 14$ N to the right

Situation 2: Two forces acting on an object in the opposite directions

Method and sample calculation

(i) The magnitude of the resultant force is obtained from the vector sum of the two forces.
(ii) The direction of the resultant force is in the direction of the force with the larger magnitude.
(iii) The resultant force is stated by its magnitude and direction.

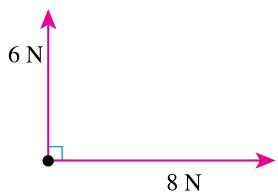
(i) Assume that the force to the right is positive:
Resultant force,
$F = -8 + 6$
$= -2$ N
Magnitude of the resultant force = 2 N
(ii) Direction of the resultant force is to the left
(iii) Resultant force,
$F = 2$ N to the left or
$F = -2$N



Situation 3: Two forces acting on an object perpendicular to each other

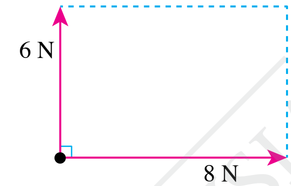
Method and sample calculation

Consider the two forces as the sides of a rectangle.

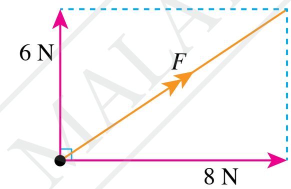


(i) Complete the diagram with the sides representing the two forces that are perpendicular to each other.
(ii) Draw the diagonal of the rectangle that represents the resultant force, F of the two forces.
(iii) Calculate the length of the diagonal using Pythagoras' Theorem.
(iv) Calculate the angle between the diagonal and one of the sides of the rectangle.

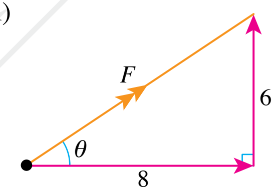
(i)



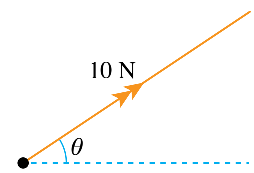
(ii)



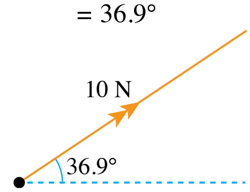
(iii)



$F = \sqrt{6^2 + 8^2}$
$F = 10$ N



(iv) $\tan \theta = \frac{6}{8}$
$= 0.75$
$\theta = \tan^{-1}(0.75)$
$= 36.9°$

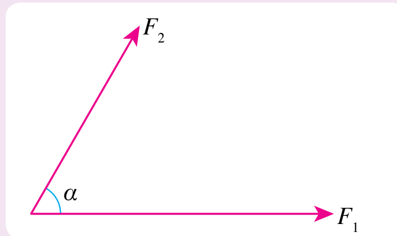


Info GALLERY

The resultant force can also be determined by drawing a scaled diagram.

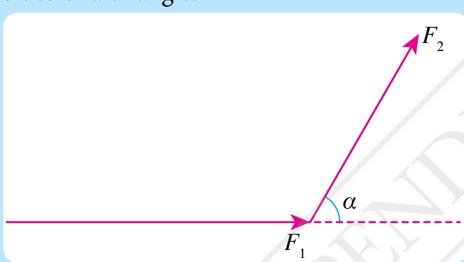
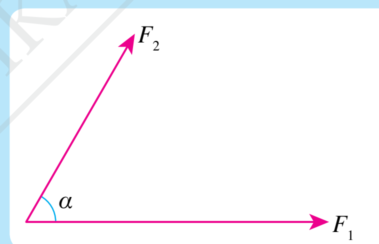
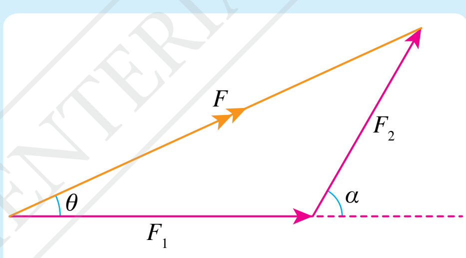
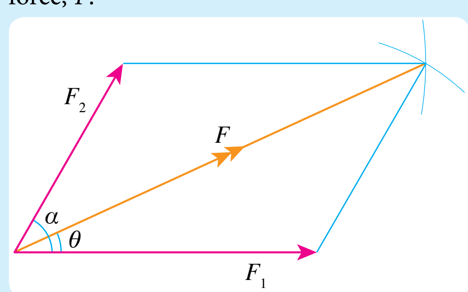
Situation 4: Two forces acting on an object in directions that are not perpendicular to each other

Method and sample of scaled drawing



SCAN ME
Video of triangle of forces method
http://bit.ly/2T2joj0

Table 1.2

Triangle of forces method	Parallelogram of forces method
(i) Choose a suitable scale to draw lines that represent the magnitude of the forces.	(i) Choose a suitable scale to draw lines that represent the magnitude of the forces.
(ii) By using a ruler and a protractor, draw the force F_1 followed by force F_2 to form two sides of a triangle.  	(ii) By using a ruler and a protractor, draw the force F_1 and force F_2 from a point to form two adjacent sides of a parallelogram. 
(iii) Complete the triangle. The third side represents the resultant force, F.  	(iii) With the aid of a pair of compasses, complete the parallelogram. Draw the diagonal from the point of action of the forces. The diagonal represents the resultant force, F. 
(iv) Measure the length of side F and calculate the magnitude of the resultant force using the scale you have chosen.	(iv) Measure the length of the diagonal and calculate the magnitude of the resultant force using the scale you have chosen.
(v) Measure the angle, θ.	(v) Measure the angle, θ.

The magnitude and direction of two forces that are at an angle with each other can be determined by practical means using a Vector Force Table Kit.

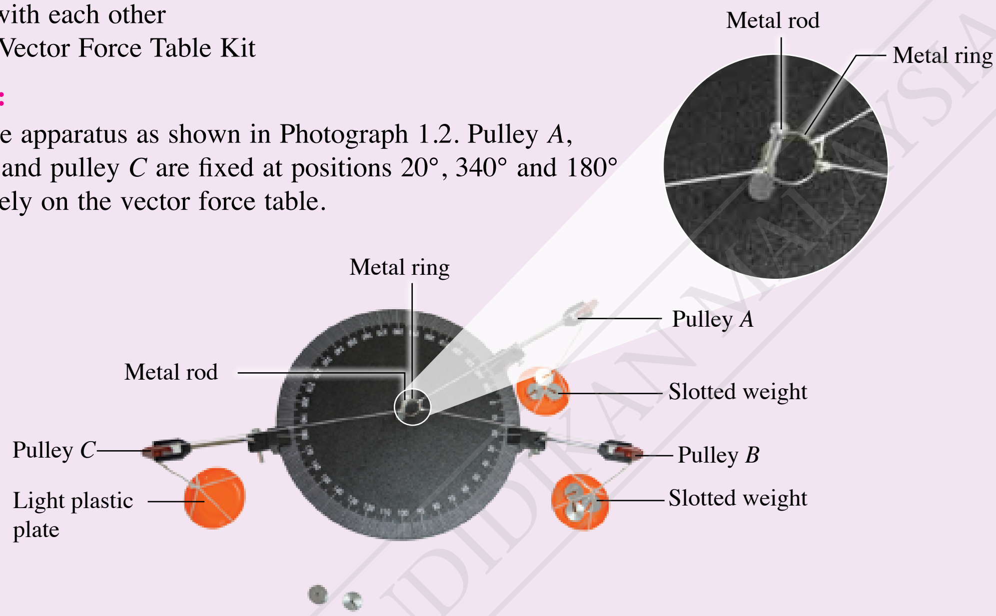
Activity 1.3

Aim: To determine the magnitude and direction of the resultant force of two forces that make an angle with each other

Apparatus: Vector Force Table Kit

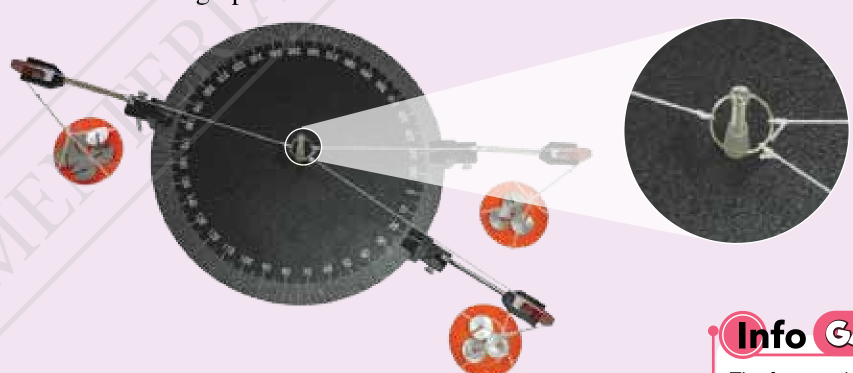
Instructions:

1. Set up the apparatus as shown in Photograph 1.2. Pulley *A*, pulley *B* and pulley *C* are fixed at positions 20°, 340° and 180° respectively on the vector force table.



Photograph 1.2

2. Place slotted weights of mass 150 g on the plastic plate below pulley *A* and slotted weights of mass 150 g on the plastic plate below pulley *B*. The metal ring will be displaced and will touch the metal rod at the centre of the vector force table.
3. Add slotted weights on the plate below pulley *C* until the metal ring no longer touches the metal rod as shown in Photograph 1.3.



Photograph 1.3

4. Record the total mass on the plate below pulley *C* in Table 1.3.
5. Repeat steps 1 to 4 with:
   (i) pulley *A* at the 40° position and pulley *B* at the 320° position
   (ii) pulley *A* at the 60° position and pulley *B* at the 300° position

Info GALLERY

The force acting on the metal ring through pulley *C* balances the resultant force acting on the metal ring through pulley *A* and pulley *B*.

LS 1.1.2

Results:

Table 1.3

Pulley *A*			Pulley *B*			Pulley *C*	
Position	Mass / g	Force applied / N	Position	Mass / g	Force applied / N	Mass / g	Force applied / N
20°	150	1.5	340°	150	1.5		
40°	150	1.5	320°	150	1.5		
60°	150	1.5	300°	150	1.5		

Discussion:

1. What is the direction of the resultant force of the two forces that act on the metal ring through pulley *A* and pulley *B*?
2. Why is the magnitude of the force acting on the metal ring through pulley *C* equal to the magnitude of the resultant force?
3. How does the magnitude of the resultant force change when the angle between the two forces increases?

Resultant Force on an Object in Various States of Motion

A free body diagram of an object is a **diagram that shows all the forces acting on that object only**. Figure 1.3 shows the free body diagram of a book on a table. The forces labelled are the forces acting on the book while the force acting on the table is not shown. Figure 1.4 shows the free body diagram of a bag on an inclined plane.

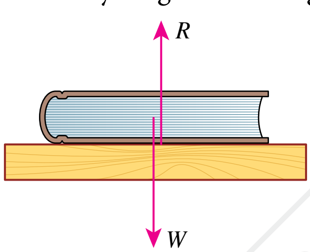


Figure 1.3 *Free body diagram of a book on a table*

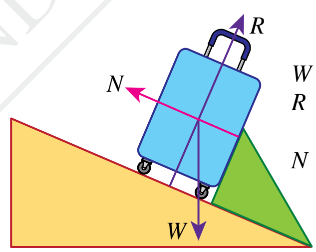


Figure 1.4 *Free body diagram of a bag on an inclined plane*

When considering the effect of the resultant force on an object, you only need to draw the free body diagram of the object. Figure 1.5 shows two examples of free body diagram of a moving trailer and a moving rocket.

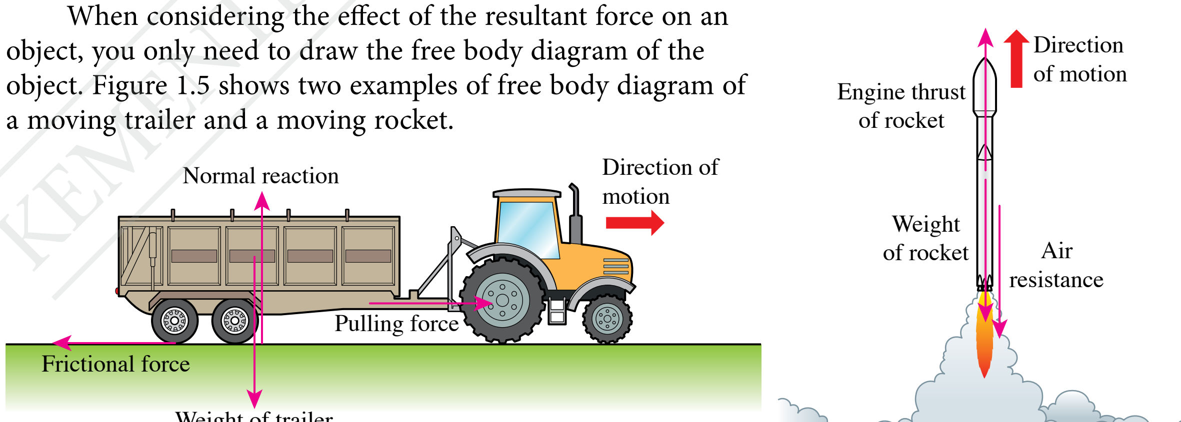
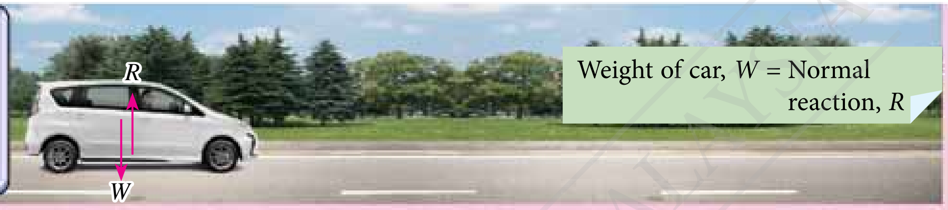


Figure 1.5 *Free body diagram of a moving trailer and a moving rocket*

Newton's Second Law of Motion can be expressed as $F = ma$. If a number of forces act on an object at the same time, F represents the resultant force on the object. Figure 1.6 shows the information on the magnitude of the resultant force on an object in different states of motion.

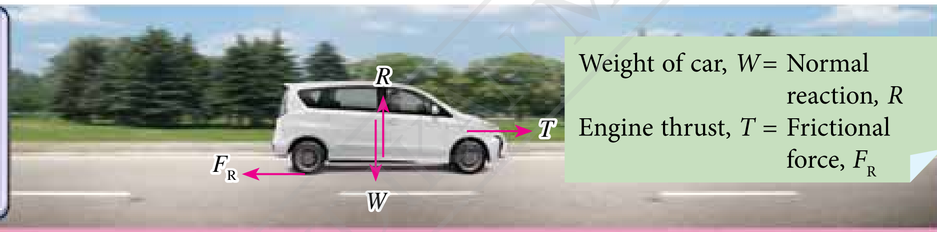
Object in a stationary state

- Velocity, $v = 0$
- Acceleration, $a = 0$
- Resultant force, $F = 0$ N



Object moving with a uniform velocity

- Velocity is constant or not changing
- Acceleration, $a = 0$
- Resultant force, $F = 0$ N



Object moving with a uniform acceleration

- Velocity is increasing
- Acceleration, $a \neq 0$
- Resultant force, $F \neq 0$ N

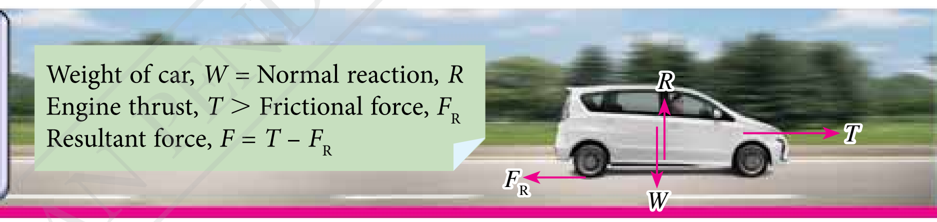


Figure 1.6 *Forces acting on an object in different states of motion*

Activity 1.4

Evaluation

Aim: To discuss the resultant force that acts on an object with the aid of free body diagrams

Instructions:

1. Carry out this activity in pairs.
2. You are given an object in a certain state of motion in Table 1.4. For each situation:
   (a) sketch a free body diagram and label all the forces acting on the object
   (b) state the value of the acceleration, either zero or not zero
   (c) state the magnitude of the resultant force, F either zero or not zero
   (d) compare the forces acting on the object

Table 1.4

State of motion	Stationary on the ground (engine is switched off)	Moves upwards with acceleration	Moves upwards with constant velocity
Free body diagram			
Acceleration, a			
Resultant force, F			
Comparison between forces			

3. Scan the QR code and print Table 1.4.

SCAN ME
Worksheet (Table 1.4)
http://bit.ly/2SXwcqO

Discussion:
Based on the example in this activity, summarise the relationship between the resultant force and the state of motion of an object in the form of a suitable thinking map.

Solving Problems Involving Resultant Force, Mass and Acceleration of an Object

Example 1

Figure 1.7 shows a coconut of mass 2.0 kg falling with an acceleration of 9.0 m s^{-2}.

(a) Sketch the free body diagram of the coconut.
(b) Calculate the resultant force acting on the coconut.
(c) State the direction of resultant force.
(d) What is the magnitude of the air resistance acting on the coconut?
[Gravitational acceleration, g = 9.81 m s^{-2}]

Figure 1.7

LET'S ANSWER
http://bit.ly/2ZW39FA

Solution

(a) The forces acting on the coconut are its weight and air resistance (Figure 1.8).

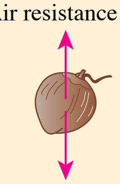


Figure 1.8

(b) **Step 1:** Identify the problem → **Step 2:** Identify the information given → **Step 3:** Identify the formula that can be used → **Step 4:** Solve the problem numerically

1. Resultant force acting on the coconut, F
2. Mass of coconut, $m = 2.0$ kg
   Acceleration of coconut, $a = 9.0 \text{ m s}^{-2}$
3. $F = ma$
4. $F = 2.0 \times 9.0$
   $= 18.0$ N

(c) The coconut accelerates downwards. Therefore, the resultant force is downwards.

(d) Mass of coconut, $m = 2.0$ kg
Gravitational acceleration, $g = 9.81 \text{ m s}^{-2}$
Weight of coconut, $W = mg$
$= 2.0 \times 9.81$
$= 19.62$ N

$F = W - R$
$18.0 = 19.62 - R$
$R = 19.62 - 18.0$
$= 1.62$ N

Example 2

A passenger of mass 60 kg is in a lift.

(a) Sketch the free body diagram using the symbol W to represent the weight of the passenger and symbol R for the normal reaction from the floor of the lift.

(b) Calculate the magnitude of the normal reaction, R when the lift is:
  (i) stationary
  (ii) moving upwards with an acceleration of 1.2 m s^{-2}
  (iii) moving with a uniform velocity of 8.0 m s^{-1}
  [Gravitational acceleration, $g = 9.81 \text{ m s}^{-2}$]

Solution

(a) Figure 1.9 shows the free body diagram of the passenger in the lift.

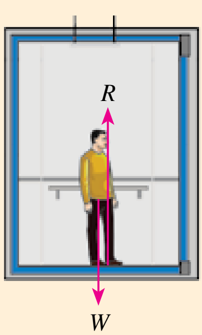


Figure 1.9

(b) (i) Resultant force, $F = 0$
$R = W$
$R = mg$
$= 60 \times 9.81$
$= 588.6$ N

(ii) The resultant force acts upwards
$F = ma$
$R - W = ma$
$R - 588.6 = 60 \times 1.2$
$R = 72 + 588.6$
$= 660.6$ N

(iii) Resultant force, $F = 0$
$R = W$
$R = 588.6$ N

Example 3

Figure 1.10 shows a trolley of mass 1.2 kg being pulled on a table by a load through a pulley. The trolley moves with an acceleration of 4.0 m s^{-2} against a friction of 6.0 N.

(a) Sketch the free body diagram of the trolley and the load. Use W = the weight of the trolley, R = normal reaction on the trolley, F_R = friction, T = tension of the string and B = the weight of the load.

(b) Compare the weight of the trolley, W with the normal reaction, R.

(c) Calculate the resultant force acting on the trolley, F.

(d) Calculate the tension in the string pulling the trolley, T.

(e) What is the mass of the load, m?
[Gravitational acceleration, g = 9.81 m s^{-2}]

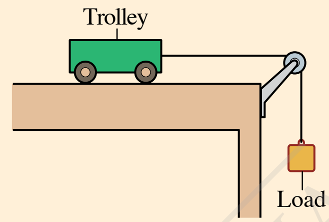


Figure 1.10

Note

Based on Figure 1.11, the two forces, T (the action and the reaction) are acting along the string between the trolley and the load. Since the trolley and the load are connected by a string, both will move with the same acceleration.

Solution

(a) Figure 1.11 shows the free body diagram of the trolley and the load.

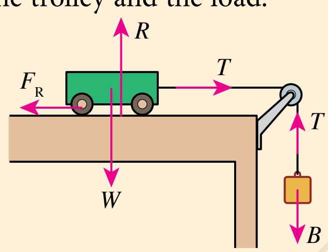


Figure 1.11

(b) Weight of trolley, W = normal reaction, R

(c) Mass of trolley, m = 1.2 kg
Acceleration of the trolley, a = 4.0 m s^{-2}

$F = ma$
$= 1.2 \times 4.0$
$= 4.8$ N

(d) Resultant force, F = 4.8 N
Friction, F_R = 6.0 N

$F = T - F_R$, thus $T = F + F_R$
$T = 4.8 + 6.0$
$= 10.8$ N

(e) Acceleration of the load, a = 4.0 m s^{-2}
Gravitational acceleration, g = 9.81 m s^{-2}

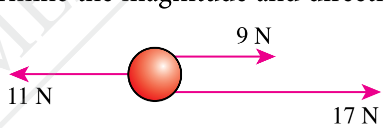
$F = ma$
$= m \times 4.0$
$= 4m$
$B = mg$
$= m \times 9.81$
$= 9.81m$

$F = B - T$
$4m = 9.81m - 10.8$
$5.81m = 10.8$
$m = \dfrac{10.8}{5.81}$
$= 1.86$ kg

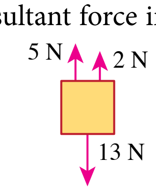
Formative Practice 1.1

1. Determine the magnitude and direction of the resultant force in the following situations.

(a)



(b)



2. Figure 1.12 shows the forces acting on a ball that is kicked simultaneously by two players.

(a) Sketch a diagram that shows the 240 N force, the 180 N force and the resultant force.

(b) Calculate the magnitude of the resultant force on the ball.

(c) State the direction of motion of the ball.

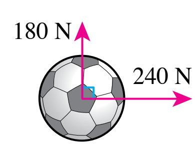


Figure 1.12

1.2 Resolution of Forces

Figure 1.13 *Tarik upih game*

Figure 1.13 shows a boy pulling his friend during a *tarik upih* game at the school sports carnival. Why is the motion of the friend to the right while the direction of the applied pulling force is inclined upwards? This is due to the pulling force having a horizontal component and a vertical component. **Resolution of forces** is **the process of resolving a force into two components**.

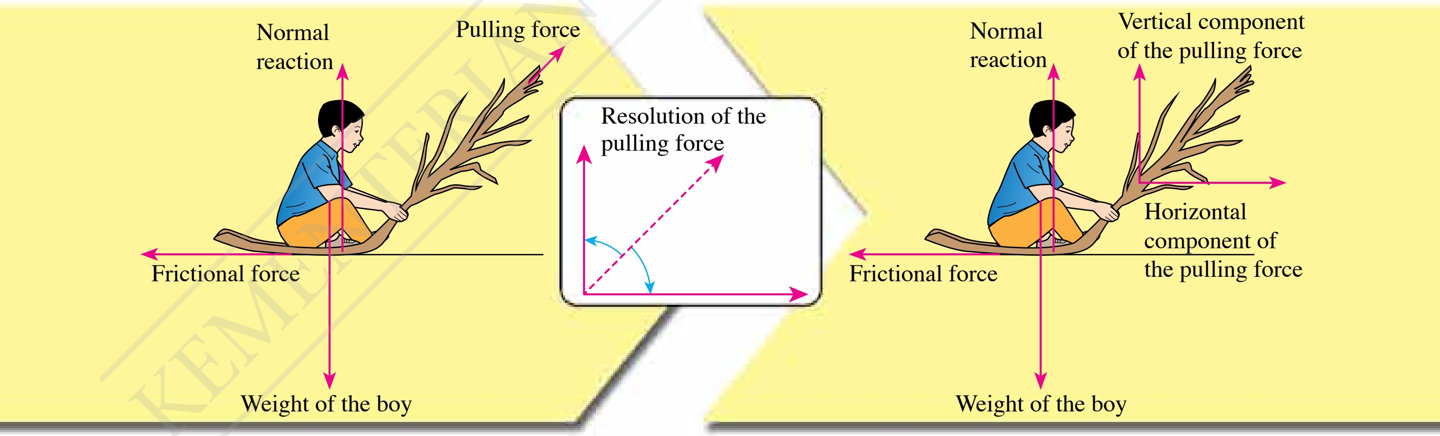


Figure 1.14 *Resolution of the pulling force when the boy is being pulled*

The pulling force acting on the boy can be resolved into two perpendicular components as shown in Figure 1.14. The vertical component is to balance the weight of the boy while the horizontal component overcomes friction and moves the boy to the right. How do we determine the magnitudes of the two components?

LS 1.2.1

Figure 1.15 shows a force, F acting on a small block at an angle, θ above the horizontal. The resolution of force, F into two components and the magnitudes of the two components can be determined by following the steps (Figure 1.16).

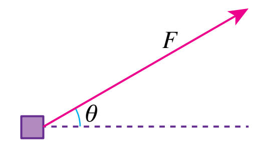
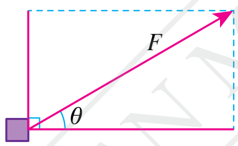


***Figure 1.15** Force, F acting on a block*

1

Draw the horizontal component, F_x and the vertical component, F_y to form a rectangle as shown in the diagram.



2

Calculate the magnitude of the components.

$F_x = F \cos \theta$

$F_y = F \sin \theta$

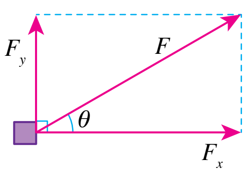


***Figure 1.16** Steps in determining the resolution of forces*

BRIGHT Info

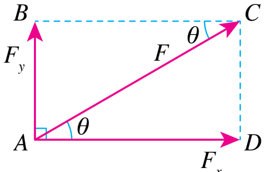
Explanation with trigonometry:

Triangle ACD: $\cos \theta = \dfrac{F_x}{F}$

$F_x = F \cos \theta$

Triangle ABC: $\sin \theta = \dfrac{F_y}{F}$

$F_y = F \sin \theta$



Activity 1.5

Decomposition

Aim: To resolve a force into two components for an object moving in a direction not parallel to the direction of the force

Instructions:

1. Carry out this activity in pairs.
2. Study Figure 1.17 and determine the magnitudes of:
   (a) the horizontal component of the pushing force.
   (b) the vertical component of the pushing force.
3. Study Figure 1.18 and determine the magnitudes of:
   (a) the component of the weight of the boy in the direction parallel to the inclined plane.
   (b) the component of the weight of the boy in the direction perpendicular to the inclined plane.

Figure 1.17 *Mopping the floor*

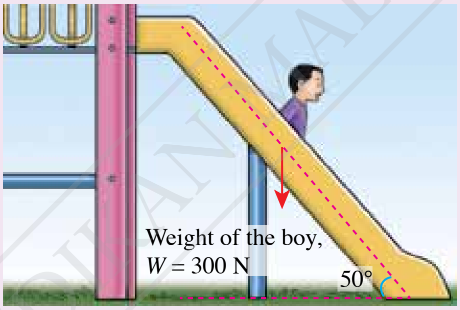


Figure 1.18 *Going down the slide*

Discussion:

1. What is the purpose of resolving a force into two perpendicular components?
2. Discuss the suitability of resolving a force into two components that are not perpendicular.

Solving Problems Involving Resultant Force and Resolution of Forces

LET'S ANSWER

http://bit.ly/36yhJWl

Example 1

Figure 1.19 shows a wooden block being pulled by force, T that inclines at an angle of 30° above the horizontal surface. Table 1.5 shows the magnitudes of the forces acting on the block.

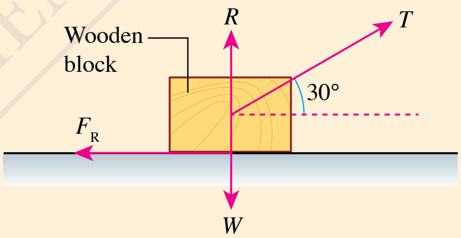


Figure 1.19

Table 1.5

Force	Magnitude
Pull, T	36 N
Weight, W	24 N
Normal reaction, R	6 N
Frictional force, F_R	20 N

(a) Calculate the magnitudes of the horizontal component and vertical component of the pull, T.
(b) Determine the magnitude and direction of the resultant force acting on the block.
(c) What is the acceleration of the block if its mass is 2.4 kg?

LS 1.2.1 1.2.2

Solution

(a) **Step 1:** Identify the problem → **Step 2:** Identify the information given → **Step 3:** Identify the formula that can be used → **Step 4:** Solve the problem numerically

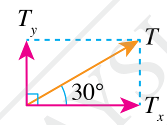
1. Magnitude of the horizontal component, T_x and vertical component, T_y of the pull, T

2. Angle above the horizontal surface = 30°
   Magnitude of the pulling force, T = 36 N

3. $T_x = T \cos 30°$
   $T_y = T \sin 30°$

4. $T_x = 36 \cos 30°$
   $= 31.18$ N (to the right)

   $T_y = 36 \sin 30°$
   $= 18.00$ N (upwards)



(b) Horizontal component to the right,
$T_x = 31.18$ N
Frictional force, $F_R = 20$ N

Resultant of horizontal components
$= T_x + F_y$
$= 31.18 + (–20)$
$= 11.18$ N

Vertical component upwards, $T_y = 18.00$ N
Normal reaction, $R = 6$ N
Weight, $W = 24$ N
Resultant of vertical components
$= T_y + R + W$
$= 18 + 6 + (–24)$
$= 0$ N

Resultant force on the block, F is 11.18 N to the right.

(c) Resultant force, $F = 11.18$ N
Mass of block, $m = 2.4$ kg
$F = ma$

Acceleration of the block, $a = \dfrac{F}{m}$
$= \dfrac{11.18}{2.4}$
$= 4.66 \text{ m s}^{-2}$

Example 2

Figure 1.20 shows the free body diagram of a block sliding down a smooth inclined plane.

(a) Sketch the component of the weight of the block parallel to the inclined plane and the component of the weight of the block perpendicular to the inclined plane.

(b) Determine the resultant force acting on the block.

(c) Calculate the acceleration of the block if its mass is 2.4 kg.

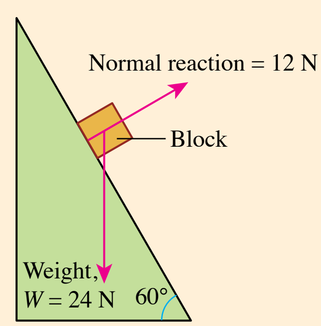


Figure 1.20

LS 1.2.2

Solution

(a) Figure 1.21 shows a sketch of the component of the weight of the block parallel to the inclined plane, W_x and the component of the weight of the block perpendicular to the inclined plane, W_y.

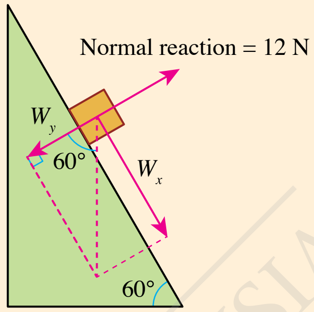


Figure 1.21

(b) $W_x = 24 \sin 60°$
$= 20.78$ N
$W_y = 24 \cos 60°$
$= 12$ N
Resultant of the forces perpendicular to the inclined plane = 12 + (–12)
= 0 N
Resultant force on the block = 20.78 N

(c) Resultant force, F = 20.78 N
Mass of block, m = 2.4 kg
$F = ma$

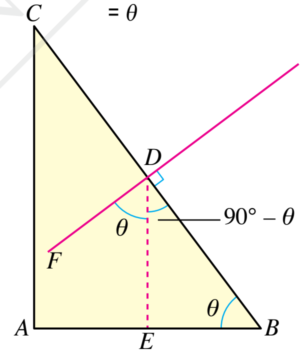
Acceleration of block, $a = \dfrac{F}{m}$

$= \dfrac{20.78}{2.4}$

$= 8.66 \text{ m s}^{-2}$

BRIGHT Info

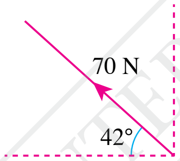
Resolution of forces for object on inclined plane
Given $\angle ABC = \theta$
Thus, $\angle BDE = 90° - \theta$
and $\angle EDF = 90° - (90° - \theta)$
$= \theta$



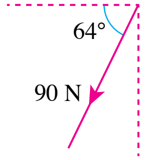
Formative Practice 1.2

1. Resolve the following forces into horizontal component and vertical component.

(a)



(b)



2. Figure 1.22 shows a man pushing a lawn mower with a force of 90 N.

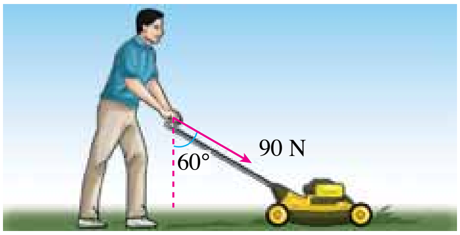


Figure 1.22

(a) Resolve the pushing force into its horizontal component and vertical component.
(b) State the function of the horizontal component and vertical component of the pushing force when the lawn mower is being pushed.

1.3 Forces in Equilibrium

Photograph 1.4 shows a *Ngajat* dancer standing still for a while during the dance. What is the relationship between the forces acting on the dancer? Since the acceleration of the dancer is zero, there is no resultant force acting on him. Therefore, the forces are said to be in equilibrium.

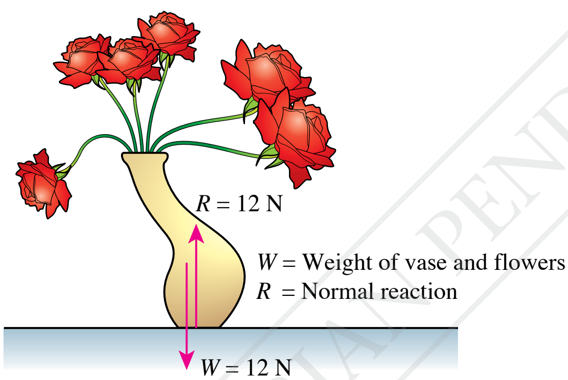
An object is said to be in equilibrium of forces when the forces acting on it produce a zero resultant force. Observe the free body diagrams for two examples of forces in equilibrium as shown in Figure 1.23.

Photograph 1.4 *Ngajat Dance*

BRIGHT Info

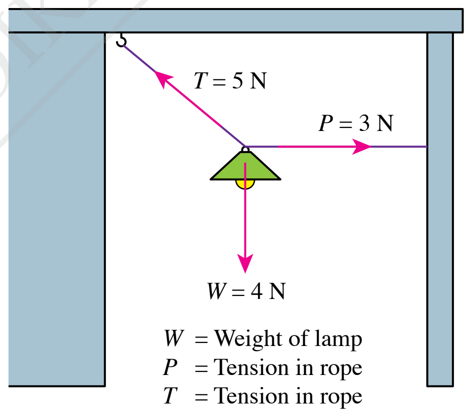
$F = ma$

$a = 0,\ F = 0$



Resultant force of W and $R = 0$

(a) Vase of flowers on a table



Resultant force of W, P and $T = 0$

(b) Lamp hung from two strings

Figure 1.23 *Examples of forces in equilibrium*

In Figure 1.23(a), the vase is in equilibrium of forces. The resultant force of W and R is zero. In Figure 1.23(b), the lamp also in equilibrium of forces. However, there are three forces acting on the lamp. This can be represented by a **triangle of forces**.

A triangle of forces can be drawn to show the equilibrium of three forces acting on an object. The magnitudes of the three forces are represented by the lengths of the sides of a triangle and they are drawn in sequence according to the directions of the forces.

The three forces W, P and T in Figure 1.24 are in equilibrium. Therefore, the three forces drawn in sequence will form a triangle.

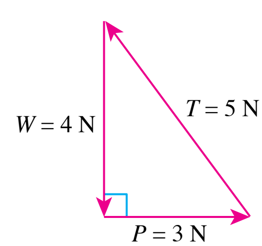


Figure 1.24 *Triangle of forces*

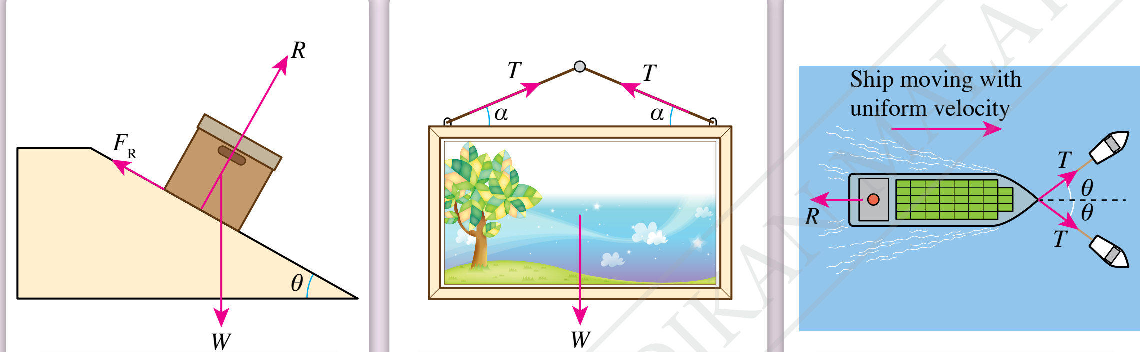
Activity 1.6

Aim: To draw the triangle of forces

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code for the guide to draw the triangle of forces.
3. By referring to Figure 1.25, sketch the triangle of forces for the following situations:

SCAN ME
Method to draw triangle of forces
http://bit.ly/2QU7vZW



W = Weight of box
R = Normal reaction
F_R = Frictional force

W = Weight of photo and frame
T = Tension in the string

T = Tension in the cable
R = Water resistance

(a) A box stationary on an inclined plane

(b) Photo and frame hung by a string

(c) A container ship being pulled by two tug boats with a uniform velocity

Figure 1.25

4. Put up your sketch at the Physics Corner of the notice board in your class.

Discussion:

1. Discuss two more examples of three forces in equilibrium.
2. Sketch the triangle of forces for the two examples that you have suggested.

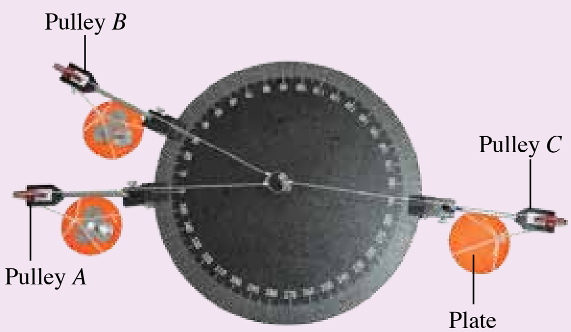
Activity 1.7

Aim: To use a Vector Force Table Kit to demonstrate forces in equilibrium

Apparatus: Vector Force Table Kit and slotted weights of various masses

Instructions:

1. Set up the apparatus as shown in Photograph 1.5. Pulley *A* and pulley *B* are fixed at positions 0° and 30° respectively at the vector force table.



Photograph 1.5

Photograph 1.6

2. Place slotted weights of mass 200 g on the plate below pulley *A* and slotted weights of mass 150 g on the plate below pulley *B*. The metal ring will be displaced and will touch the metal rod at the centre of the vector force table.
3. Add slotted weights on the plate below pulley *C* until the metal ring no longer touches the metal rod, as shown in Photograph 1.6. Record the mass of the slotted weights and determine the position of pulley *C*.
4. Repeat steps 1 to 3 with pulley *B* at positions 90° and 150°.
5. Record your results in Table 1.6.

SCAN ME
Video of method to achieve forces in equilibrium
http://bit.ly/36wG4vP

Results:

Table 1.6

Pulley *A*			Pulley *B*			Pulley *C*		
Position	Mass / g	Force applied / N	Position	Mass / g	Force applied / N	Mass / g	Position	Force applied / N
0°	200	2.0	30°	150	1.5			
0°	200	2.0	90°	150	1.5			
0°	200	2.0	150°	150	1.5			

Discussion:

Based on the results of this activity, predict the angles between the three forces in equilibrium when the three forces have the same magnitude.

Solving Problems Involving Forces in Equilibrium

Example 1

Figure 1.26 shows a stationary lamp hanging from two strings. The tension, T is 8 N and the string is inclined at an angle of 60° above the horizontal as shown in the diagram.
Calculate the magnitude of the:
(a) tension, P
(b) weight of the lamp, W.

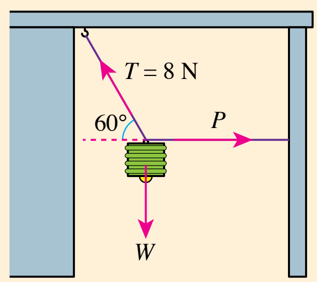


Figure 1.26

LET'S ANSWER
http://bit.ly/35xp8UG

Solution

Method 1: Resolution of Forces

The tension, T can be resolved into a horizontal component, T_x and a vertical component, T_y as shown in Figure 1.27.
The lamp is in equilibrium, thus resultant force on the lamp = 0.

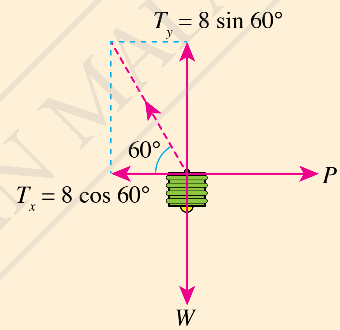


Figure 1.27

(a) The resultant of the horizontal forces = 0, that is, the horizontal forces are balanced.
Tension in the string, $P = T_x$
$= 8 \cos 60°$
$= 4$ N

(b) The resultant of the vertical forces = 0, that is, the vertical forces are balanced.
Weight of the lamp, $W = T_y$
$= 8 \sin 60°$
$= 6.93$ N

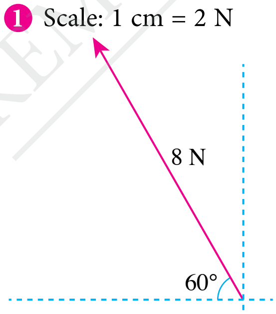
Method 2: Scaled drawing of the triangle of forces

Step 1:
Choose a scale. Draw the force, T with known magnitude and direction.

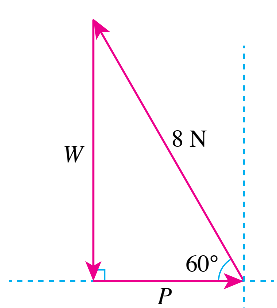
Step 2:
Draw a vertical line downwards representing W and a horizontal line to the right representing P to form a triangle.

Step 3:
Measure the length of the sides of the triangle. Use the scale you have chosen to calculate the magnitude of the force.

1 Scale: 1 cm = 2 N



2



3
(a) P = 2.0 cm
= 2.0 × 2 N
= 4.0 N

(b) W = 3.5 cm
= 3.5 × 2 N
= 7.0 N

LS 1.3.3

Example 2

Figure 1.28 shows a box of weight 50 N stationary on an inclined plane.

(a) Draw a free body diagram of the box showing the weight of the box, W, normal reaction, R and the frictional force, F_R.

(b) By drawing a scaled triangle of forces diagram, determine the magnitudes of the normal reaction, R and the frictional force, F_R.

(c) By resolving the weight of the box, W into a component parallel to the inclined plane and a component perpendicular to the inclined plane, determine the magnitudes of the normal reaction, R and the frictional force, F_R.

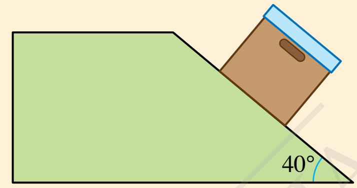


Figure 1.28

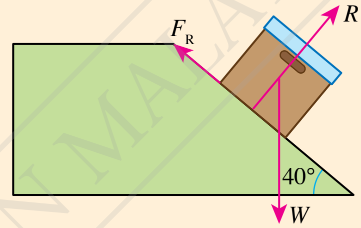


Figure 1.29

Solution

(a) Figure 1.29 shows the free body diagram of the box.

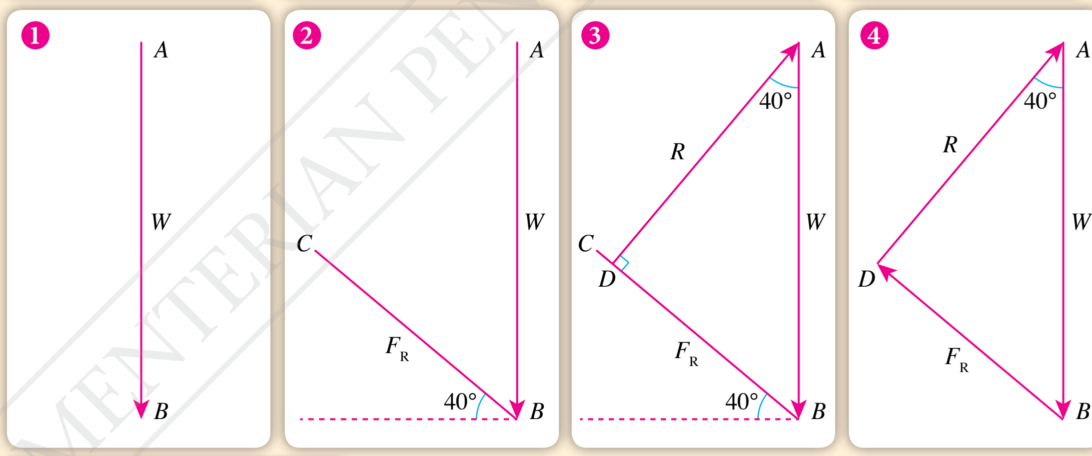
(b) Scale: 1 cm = 10 N

Step 1: Draw the line AB of length 5.0 cm to represent the weight, W.

Step 2: Mark the angle 40° and draw the line BC to show the direction of force, F_R.

Step 3: Mark the angle 40° and draw the line AD to represent the force, R.

Step 4: Complete the triangle ABD with direction of forces.



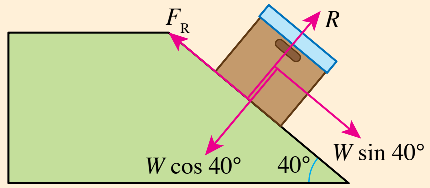
Step 5: Measure the length of the side BD, which represents the force, F_R.

$BD = 3.2$ cm
$F_R = 3.2 \times 10$
$= 32$ N

Step 6: Measure the length of the side AD, which represents the force, R.

$AD = 3.8$ cm
$R = 3.8 \times 10$
$= 38$ N

(c)



Info GALLERY

The method of calculation will give a more accurate answer compared to the answer obtained by the method of scaled drawing.

The box is in equilibrium.
Resultant force = 0 N
Forces parallel to the inclined plane are balanced.
Forces perpendicular to the inclined plane are balanced.

$$F_R = W \sin 40° = 50 \sin 40° = 32.14 \text{ N}$$

$$R = W \cos 40° = 50 \cos 40° = 38.30 \text{ N}$$

Example 3

Figure 1.30 shows a poster hanging on the wall of the laboratory with a string and a nail. The weight of the poster is 12.0 N.

(a) Draw the triangle of forces for the weight of the poster and the tensions in the string.
(b) Calculate the value of *T*.

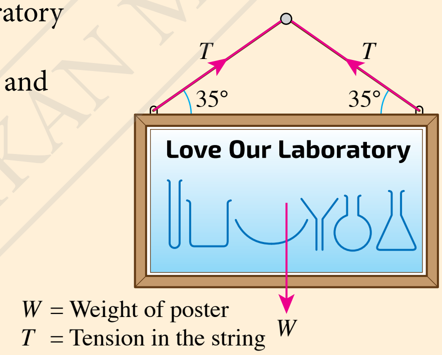
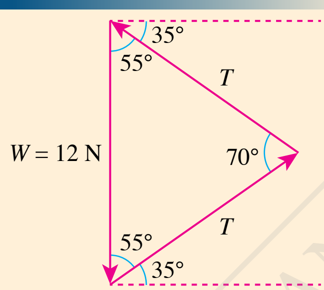


Figure 1.30

Solution

(a)



(b) Using the sine rule:

$$\frac{T}{\sin 55°} = \frac{12}{\sin 70°}$$

$$T = \frac{12 \times \sin 55°}{\sin 70°}$$

$$= 10.46 \text{ N}$$

Using the cosine rule:

$$W^2 = T^2 + T^2 - 2(T \times T \times \cos 70°)$$

$$12^2 = T^2 + T^2 - 2(T \times T \times \cos 70°)$$

$$144 = T^2 (1 + 1 - 2 \cos 70°)$$

$$T^2 = \frac{144}{(1 + 1 - 2 \cos 70°)}$$

$$T = 10.46 \text{ N}$$

Formative Practice 1.3

1. State the meaning of forces in equilibrium.
2. Figure 1.31 shows a block that is stationary on an inclined plane when a stopping force, *P* is applied horizontally.
   (a) Sketch and label the weight of the block, *W* and the normal reaction from the surface of the plane, *R*.
   (b) Sketch the triangle of forces for *P*, *W* and *R*.

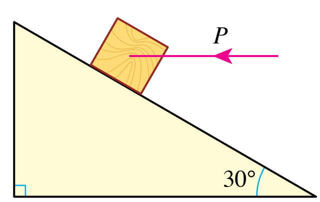


Figure 1.31

1.4 Elasticity

A man pulls an elastic cord during an exercise routine as shown in Photograph 1.7. After his exercise, the cord returns to its original length. What property is shown by the elastic cord?

(a) *During exercise* (b) *After exercise*

Photograph 1.7 *Stretching exercise with an elastic cord*

Activity 1.8

Aim: To generate ideas on elasticity

Apparatus: Half-metre rule

Materials: Spring, sponge, plasticine and white A4 paper

A Spring

Instructions:

1. Measure the length of a spring.
2. Apply small forces on the spring to change its shape and size in a few different ways by pulling, bending and other ways that you can think of as shown in Photograph 1.8.
3. Observe whether the spring can return to its original shape and size after the external force is removed by measuring it again.

Photograph 1.8

B Sponge

Instructions:

1. Hold the sponge in your hand as shown in Photograph 1.9 and observe its shape and size.
2. Apply forces on the sponge to change its shape and size in a few different ways by pressing, squeezing, twisting and other ways that you can think of.
3. Observe whether the sponge can return to its original shape and size.

Photograph 1.9

C Plasticine

Instructions:

1. Place a piece of plasticine on a piece of white paper. Observe the size and shape of the plasticine.
2. Press the plasticine with your thumb to change its shape as shown in Photograph 1.10.
3. Remove your thumb from the plasticine. Observe the size and shape of the plasticine.

Photograph 1.10

Discussion:

1. Discuss the change in the shape and size of the spring and sponge when a force is applied and removed.
2. Discuss whether the plasticine can return to its original size and shape when the force applied on it is removed.

The force applied on an object can change its shape and size. **Elasticity** is **the property of material that enables an object to return to its original shape and size after the force applied on it is removed**.

SCAN ME
Video of elasticity demonstration
http://bit.ly/2ZWutU8

Relationship Between Force and Extension of a Spring

A spring extends when a pulling force is applied on it. What is the relationship between the applied force and the extension of the spring?

Experiment 1.1

Inference: The force applied on a spring affects the extension of the spring

Hypothesis: The larger the force applied on a spring, the larger the extension of the spring

Aim: To determine the relationship between the force and extension of a spring

Variables:

(a) Manipulated: Force, F
(b) Responding: Extension of the spring, x
(c) Constant: Stiffness of the spring

Apparatus: Spring with length not less than 10 cm, five pieces of 10 g slotted weights, five pieces of 20 g slotted weights, five pieces of 50 g slotted weights, half-metre rule and two retort stands with clamps

Materials: Pin, plasticine and thread

Procedure:

1. Set up the apparatus as shown in Figure 1.32. Ensure that the zero mark of the half-metre rule is at the same level as the upper end of the spring.

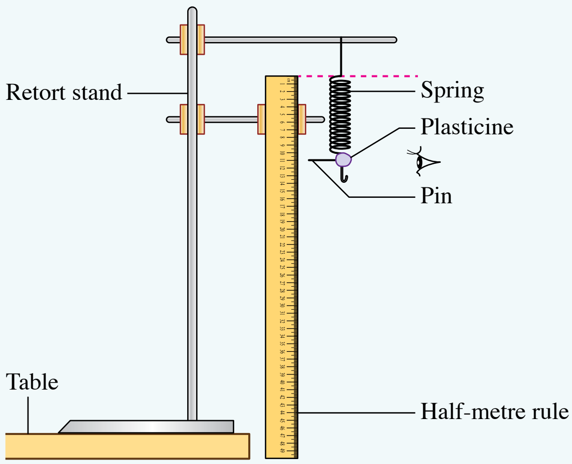
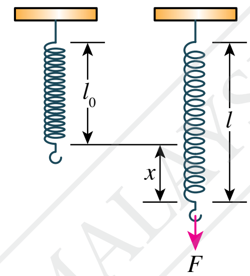


Figure 1.32

2. Determine the original position of the pin, that is, the original length of the spring, l_0.
3. Plan steps to:
   (a) increase the force applied on the spring using the slotted weights supplied.
   (b) measure the extension of the spring.
4. Carry out the experiment according to the steps you have planned.

Info GALLERY

The extension of a spring is the increase in length of the spring when a stretching force is applied on it.



The extension of a spring is the difference between the extended length, l and the original length, l_0.

$x = l - l_0$

Note

Ensure that the extension of the spring does not exceed half of the original length so that the spring is not overstretched and able to return to its original length.

Results:

Prepare a table to record:

(a) the mass of the slotted weights used to stretch the spring
(b) the force applied on the spring
(c) the extended length of the spring
(d) the extension of the spring

Data analysis:

Identify and plot a graph that will help you to test your hypothesis.

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. What are the precautions needed to be taken so that the spring is not overextended?
2. Do the points plotted on the graph form a perfect straight line? Discuss the reasons.

The results of Experiment 1.1 produces a graph with a straight line passing through the origin as shown in Figure 1.33. This shows that the extension of the spring is directly proportional to the force applied on the spring.

SCAN ME
Elastic limit
http://bit.ly/39K9MPS

Hooke's law states that the extension of a spring is directly proportional to the force applied on the spring provided the elastic limit of the spring is not exceeded.

This relationship can be written as:

$$x \propto F$$
$$F \propto x$$
$$F = kx$$

where F = applied force
x = extension of the spring
k = spring constant

$F = kx$ is the formula for Hooke's law

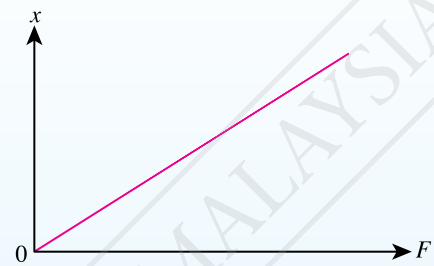


***Figure 1.33** Graph of x against F*

Analysis of the Graph of Force Against the Extension of a Spring

Figure 1.34 shows the graph of force against the extension of a spring.

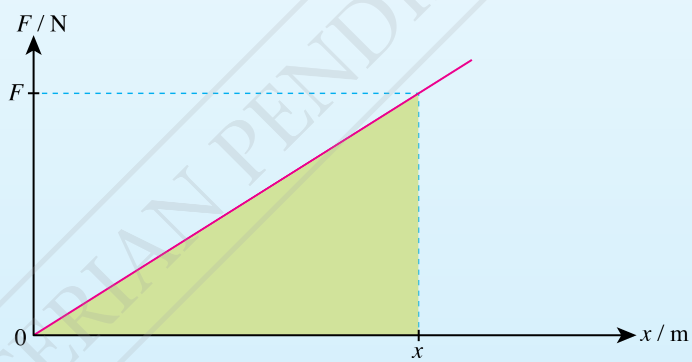


***Figure 1.34** Graph of F against x*

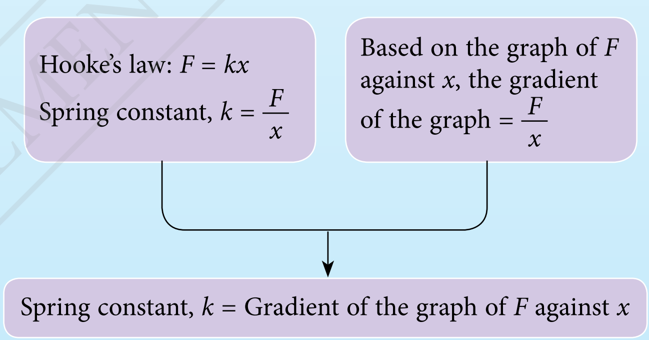


***Figure 1.35** Relationship between spring constant and gradient of the graph*

SCAN ME
Spring constant
http://bit.ly/2s1GhrL

Figure 1.36 shows the method to obtain elastic potential energy formula from the area under the graph of force against extension of the spring.

Elastic potential energy, E_p
$= $ work done to stretch the spring
$= $ (average force) × extension of the spring
$$= \frac{(0 + F)}{2} \times x$$
$$= \frac{1}{2}Fx$$

Based on the graph of F against x:
Area under the graph = area of the right-angled triangle
$$= \frac{1}{2} \times F \times x$$
$$= \frac{1}{2}Fx$$

Elastic potential energy = area under the graph of F against x
$$E_p = \frac{1}{2}Fx$$
Substitute $F = kx$, $$E_p = \frac{1}{2}(kx) \times x$$
$$E_p = \frac{1}{2}kx^2$$

***Figure 1.36** The elastic potential energy formula*

Activity 1.9

Evaluation

Aim: To analyse graphs of F against x to determine the values of:
- Spring constant, k
- Elastic potential energy, E_p

Instructions:

1. Carry out this activity in pairs.

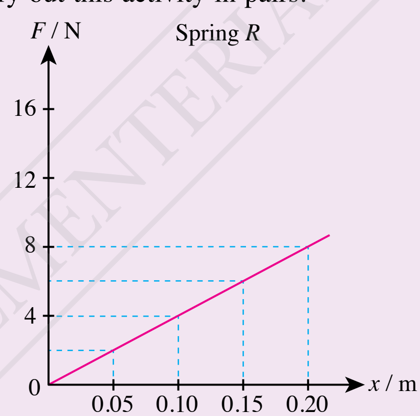


***Figure 1.37** Graph of F against x for spring R*

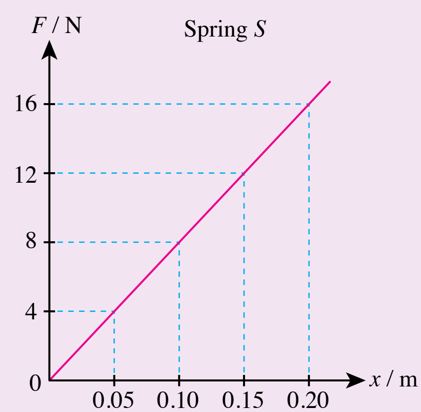


***Figure 1.38** Graph of F against x for spring S*

2. From the graph of F against x for spring R in Figure 1.37:
   (a) determine the value of the spring constant, k by calculating the gradient of the graph
   (b) determine the elastic potential energy, E_p when the spring is stretched to an extension, $x = 0.20$ m by calculating the area under the graph.

3. From the graph of F against x for spring S in Figure 1.38:
   (a) determine the value of the spring constant, k by calculating the gradient of the graph.
   (b) determine the elastic potential energy, E_p when the spring is stretched to an extension, $x = 0.20$ m by calculating the area under the graph.

Discussion:
Based on your answers in steps 2 and 3, compare spring R and spring S from the aspects of:
(a) the stiffness of the spring.
(b) the elastic potential energy that can be stored in the spring.

There are various types of springs and each spring has its own spring constant. What are the factors that affect the value of the spring constant?

Activity 1.10

Aim: To discuss the factors that affect the value of the spring constant
Apparatus: Two pieces of 50 g slotted weights, half-metre rule and retort stand
Materials: Four pairs of springs with different characteristics (Figure 1.39)

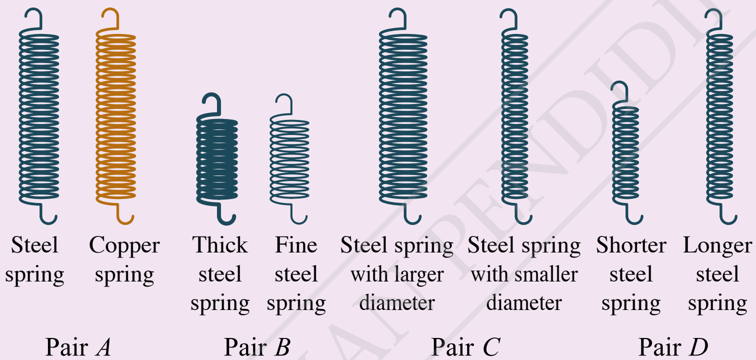


Figure 1.39

Note
The pairs of springs B, C and D are made of the same material.

Instructions:
1. Hang the two springs from pair A on the retort stand as shown in Figure 1.40.
2. Stretch the two springs by hanging the 50 g slotted weights at the ends of the springs.
3. Observe the extension of the two springs. Compare the spring constants of the two springs.
4. Record your observations.
5. Repeat steps 1 to 4 for the pairs of springs B, C and D.

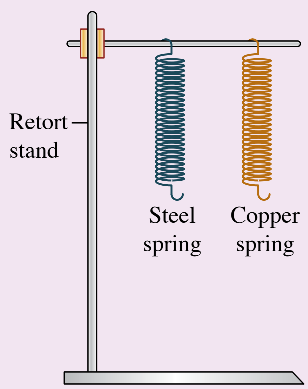


Figure 1.40

Discussion:
1. Identify four factors that affect the value of the spring constant.
2. How do the four factors affect the value of the spring constant? Explain your observations using a suitable thinking map.

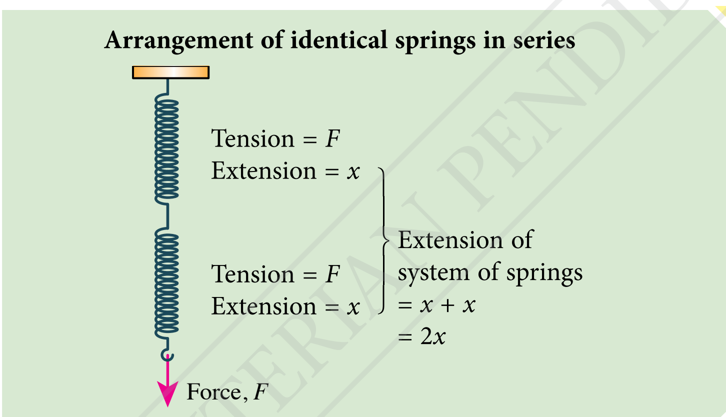
The value of the spring constant is affected by the material of the spring, the length of the spring, the diameter of the spring and the thickness of the spring wire. Table 1.7 shows a summary of the four factors that affect the value of the spring constant.

Table 1.7 *Four factors that affect the value of the spring constant*

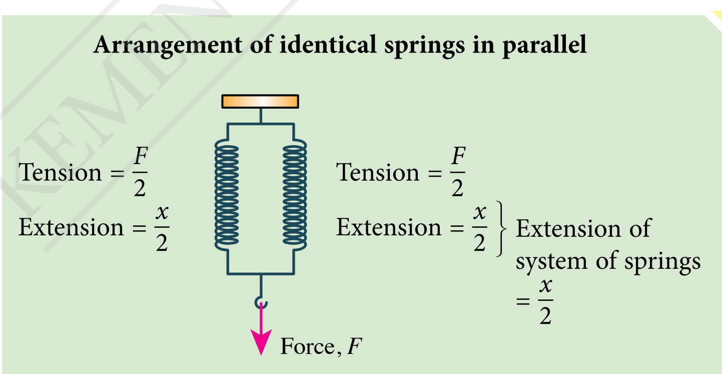
Factor	Change in the factor	Effect on the value of the spring constant
Material of the spring	Different material	Changes according to the type of material
Length of spring	Shorter	Higher
	Longer	Lower
Diameter of spring	Smaller diameter	Higher
	Larger diameter	Lower
Thickness of spring wire	Wire with smaller diameter	Lower
	Wire with larger diameter	Higher

Solving Problems Involving Force and Extension of a Spring

In a system made up of two or more identical springs, the springs can be arranged in series or in parallel. Figure 1.41 shows two identical springs arranged in series and in parallel.



The stretching force applied on the springs acts on each spring in the series arrangement.



The stretching force applied on the springs is divided equally among the springs.

Figure 1.41 *Arrangement of springs in series and in parallel*

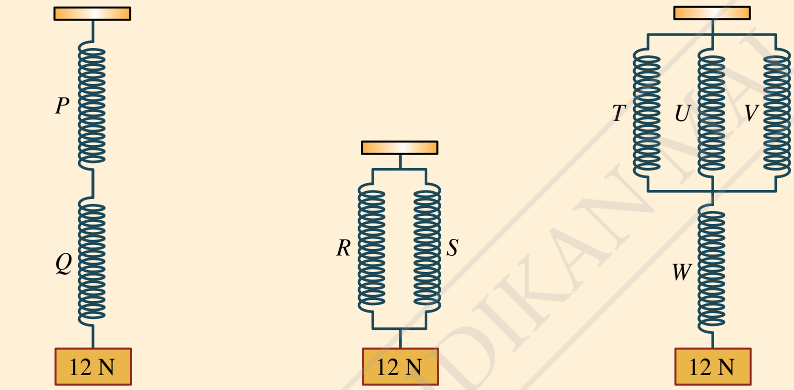
Example 1

(a) A spring with original length 50 mm extends by 6 mm when stretched by a force of 12 N. Calculate the spring constant of the spring.

(b) Figure 1.42 shows three arrangements of springs consisting of springs identical to the one mentioned in (a). For each arrangement, determine:

(i) the tension in each spring
(ii) the extension of each spring
(iii) the total extension of the system of springs
(iv) the total length of the arrangement of springs

LET'S ANSWER
http://bit.ly/2FEgv09



Arrangement *A* | Arrangement *B* | Arrangement *C*

Figure 1.42

Solution

(a)

Step 1: Identify the problem → **Step 2:** Identify the information given → **Step 3:** Identify the formula that can be used → **Step 4:** Solve the problem numerically

① Spring constant, k

② Force, $F = 12$ N
Extension of spring, $x = 6$ mm

③ $F = kx$

$k = \dfrac{F}{x}$

④ $k = \dfrac{12}{6}$

$= 2 \text{ N mm}^{-1}$

(b)

Arrangement of springs	Arrangement *A*: Two springs in series		Arrangement *B*: Two springs in parallel		Arrangement *C*: Three springs *T*, *U* and *V* in parallel which are in series with spring *W*			
	P	*Q*	*R*	*S*	*T*	*U*	*V*	*W*
(i) Tension / *N*	12	12	$\frac{12}{2} = 6$	$\frac{12}{2} = 6$	$\frac{12}{3} = 4$	$\frac{12}{3} = 4$	$\frac{12}{3} = 4$	12
(ii) Extension / mm	6	6	3	3	2	2	2	6
						2		
(iii) Extension of the system of springs / mm	6 + 6 = 12		3		2 + 6 = 8			
(iv) Total length of the arrangement of springs / mm	50 + 50 + 12 = 112		50 + 3 = 53		50 + 50 + 8 = 108			

Formative Practice 1.4

1. What is the meaning of elasticity?

2. Figure 1.43 shows the graph of force, *F* against extension, *x* for a spring.
   (a) State Hooke's law.
   (b) Does the spring obey Hooke's law?
   (c) Calculate the spring constant.
   (d) What is the elastic potential energy in the spring when stretched to an extension of 0.04 m?

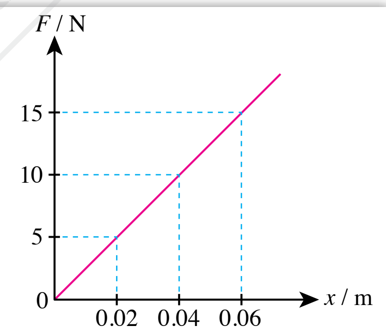


Figure 1.43

3. Figure 1.44 shows an arrangement consisting of three identical springs *P*, *Q* and *R*. The spring constant is 4 N cm^{-1}. The arrangement is compressed by an 8 N force. Determine:
   (a) the force experienced by each spring
   (b) the compression of each spring
   (c) the compression of the system of springs

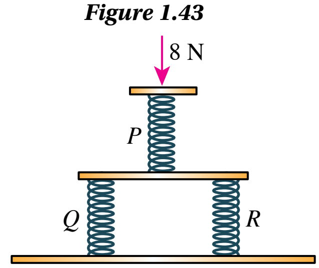


Figure 1.44

4. Figure 1.45 shows the graph of *F* against *x* for a spring. The shaded area in the graph has a value of 0.4 J.
   (a) What is the force that produces the extension of 5 cm in the spring?
   (b) Calculate the spring constant.

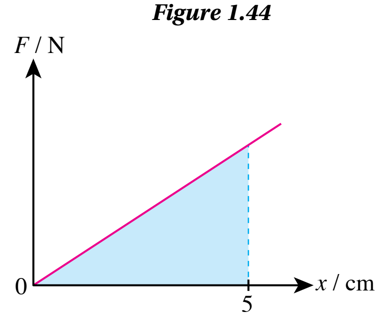


Figure 1.45

Concept Chain

Interactive Games
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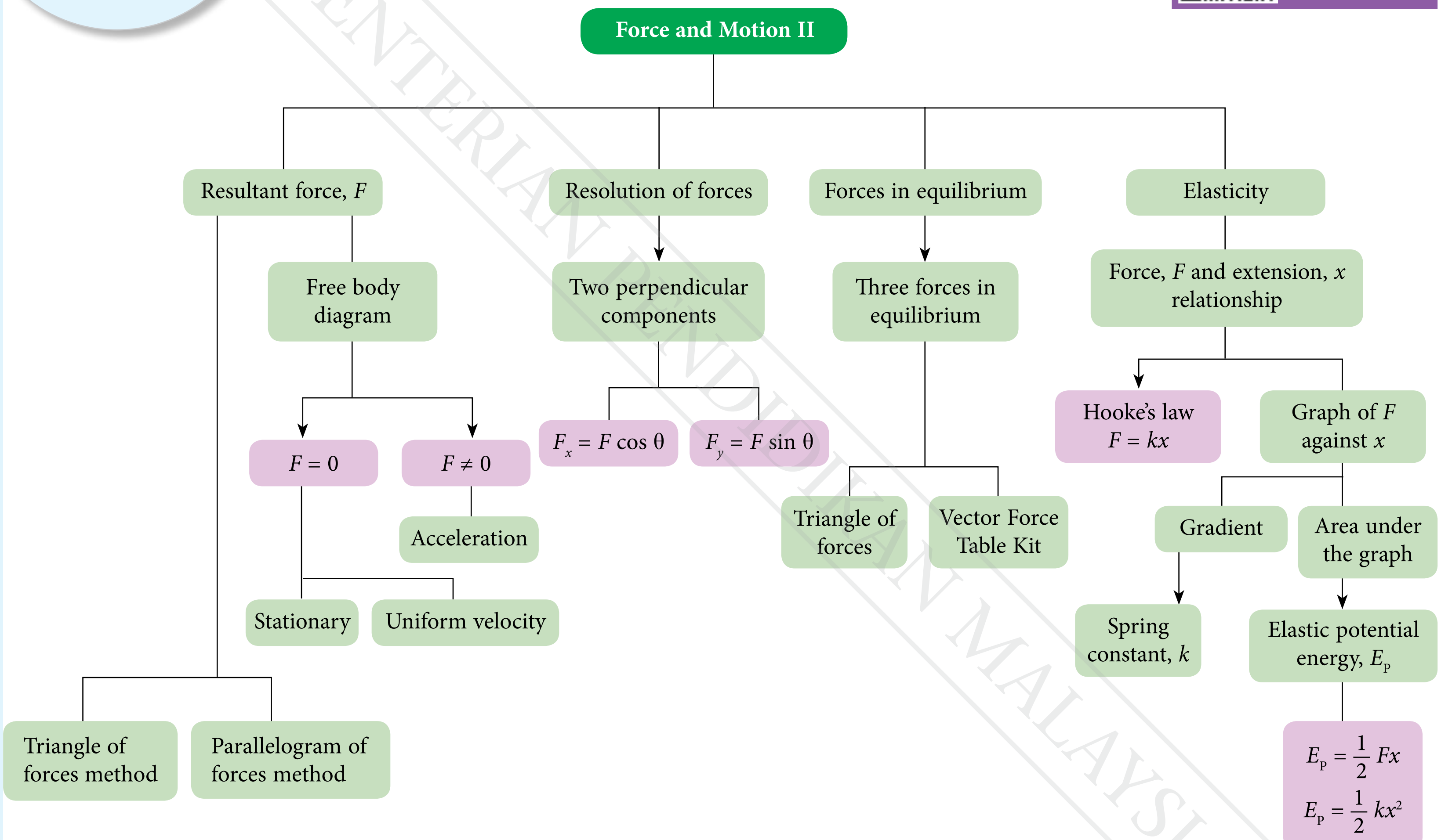


Self-Reflection

1. New things I have learnt in the chapter on 'Force and Motion II' are ____________.

2. The most interesting thing I have learnt in this chapter is ____________.

3. The things I still do not fully understand are ____________.

4. My performance in this chapter.

Poor 1 2 3 4 5 Very good

5. I need to ____________ to improve my performance in this chapter.

SCAN ME
Download and print Self-Reflection
http://bit.ly/2ZV2R1U

QUIZ PORTAL
http://bit.ly/2FukrQI

Summative Practice

1. Figure 1 shows the top view of a worker, *X* who is applying a pulling force of 70 N on a sack of flour on a track. Another worker, *Y* is able to apply a pulling force of 60 N on the sack. Determine the direction of the pulling force that must be applied by worker *Y* on the sack so that the sack moves along the line *PQ*.
[Ignore the friction between the sack and the surface of the track]

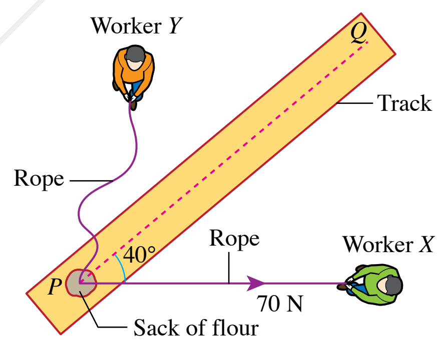


Figure 1

2. Figure 2 shows the top view of a pulling force applied by two persons, *P* and *Q* in an attempt to pull down a tree.
   (a) By using the method of parallelogram of forces, determine the magnitude and direction of the resultant force on the tree.
   (b) Discuss the advantage and disadvantage of having a large angle between the directions of the two forces.
   (c) Which person has to be more careful when the tree begins to topple?

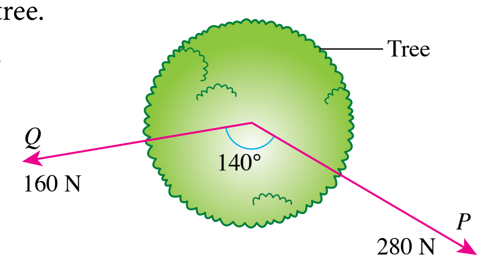


Figure 2

3. Figure 3 shows a children's playground equipment. The spring in the equipment experiences a compression of 5.0 cm when a child of mass 28 kg sits on it. What is the spring constant of the spring in N m^{-1}?
[Gravitational acceleration, g = 9.81 m s^{-2}]

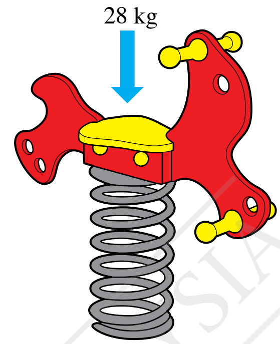


Figure 3

4. Justify the following statement.

> When two forces of 17 N and 13 N act on a point, the resultant force produced cannot be smaller than 4 N or larger than 30 N.

5. The motion of a motorcycle of mass 180 kg is as follows.

> Stage I: Stationary at a junction
> Stage II: Moves towards the East with velocity that increases from zero to 20 m s^{-1} in a time of 8 s.
> Stage III: Continues to move with a uniform velocity of 20 m s^{-1}.

For each stage, state the magnitude and direction of the resultant force on the motorcycle.

6. Figure 4 shows a chef exerting a force of 12 N to cut an onion.
   (a) Calculate the horizontal component and vertical component of the 12 N force.
   (b) What is the function of the horizontal component and vertical component in the action of cutting the onion?

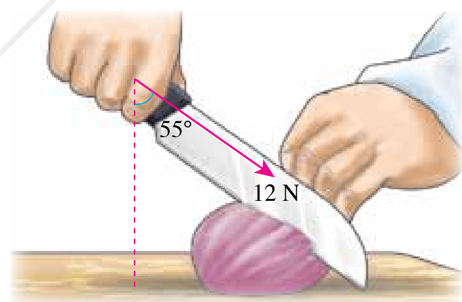


Figure 4

7. Figure 5 shows three forces acting on an object. The object is at rest. Calculate the magnitude of forces S and T.

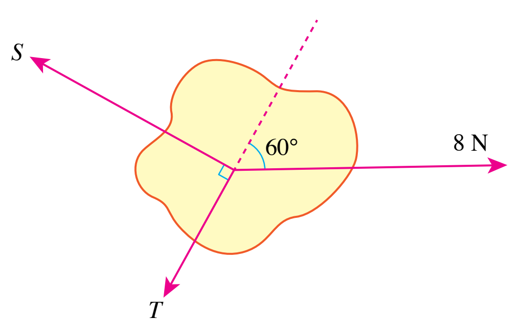
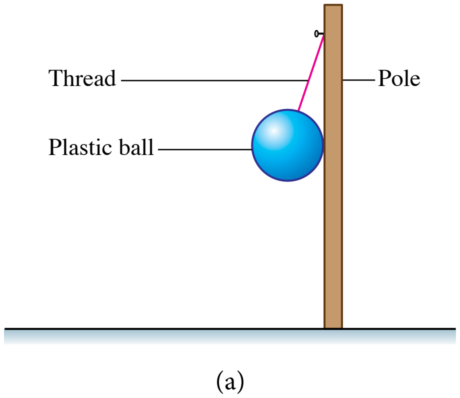


Figure 5

8. Figure 6(a) shows a plastic ball hanging from a pole. Figure 6(b) is the triangle of forces for forces *X*, *Y* and *Z* acting on the ball.
On Figure 6(a), sketch a free body diagram of the plastic ball.



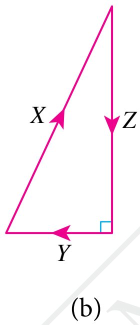


Figure 6

9. Three coplanar forces, 10 N, 24 N and 26 N act on an object. Draw a triangle of forces for the three forces if the object is in equilibrium.

10. Figure 7 shows the graph of force against extension for steel spring *M* and steel spring *N*.

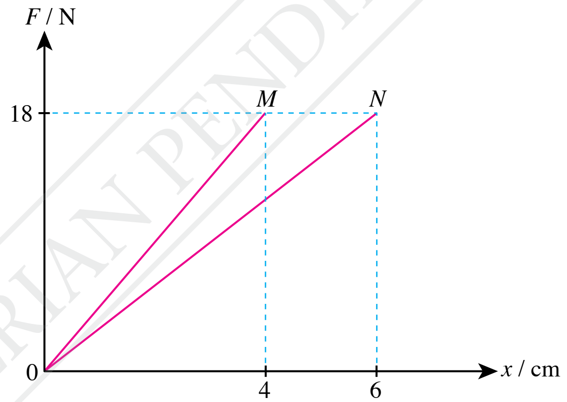


Figure 7

(a) Calculate the spring constant for steel spring *M*.

(b) What is the elastic potential energy stored in steel spring *N* when it is stretched to an extension of 6 cm?

(c) Compare and contrast steel spring *M* with steel spring *N*.

11. A spring stores elastic potential energy of 18 J when the extension of the spring is 4.0 cm. What is the force required to stretch the spring to an extension of 3.0 cm?

12. A technician was assigned to study the use of three types of springs, *X*, *Y* and *Z* with spring constants given in Table 1.

Table 1

Types of spring	Spring constant / N cm^{-1}
X	200
Y	300
Z	600

(a) Table 2 shows four arrangements of springs considered by the technician.

Table 2

Arrangement	Force applied / N	Extension of system of springs / cm
Two springs of type *X* in series	400	
Two springs of type *X* in parallel	600	
Two springs of type *Y* in series	300	
Two springs of type *Z* in parallel	600	

For each arrangement of springs, determine the extension and complete Table 2.

(b) What is the assumption that you have made based on your calculation in 12(a)?

21st Century Challenge

13. Figure 8 shows an iron plate on the floor of a warehouse. The iron plate is to be supported by a system of springs below it. The system of springs is capable of supporting a maximum load of 3 600 kg with a compression of 5.0 cm.

Figure 9 shows two types of springs that can be used.

You are given the task of suggesting a suitable design for the system of springs to support the iron plate.

Your suggestion should consider the following aspects:

(a) the type of spring used
(b) the number of springs used
(c) the position of each spring

Justify the design that you have suggested.

[Gravitational acceleration, $g = 9.81$ m s^{-2}]

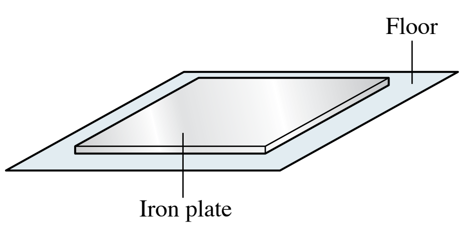


Figure 8

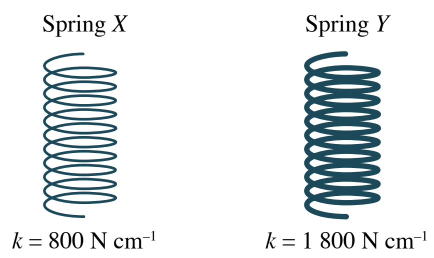


Figure 9

CHAPTER 2

Pressure

What are liquid pressure, atmospheric pressure and gas pressure?

What is the effect of the changes in pressure in the sea and atmospheric pressure on human beings?

How is Pascal's principle applied in daily life?

How is Archimedes' principle used in the buoyancy of ships?

How is Bernoulli's principle used in the field of aviation?

You will learn:

Learning Standards and List of Formulae in Chapter 2

Information Portal

A high spirit of inquiry has driven human beings to explore deep into the ocean. A deep sea vehicle is a sea vehicle that can carry people to explore the bottom of the ocean.

Limiting Factor is the name of one such deep sea vehicle. It can carry two explorers and can dive to a depth of 11 000 metres below sea level. At this level of depth, the pressure on the deep sea vehicle is more than one thousand times the pressure at sea level. The body of this vehicle has a structure that can withstand this extreme pressure. The pressure in the cabin is always controlled so that the cabin can accommodate the explorers.

http://bit.ly/2FyV2Wc

Importance of the Chapter

The motion of a deep sea vehicle involves the concept of buoyant force. Atmospheric pressure as well as water pressure at extreme depth is taken into consideration in the design and construction of deep sea vehicles. Understanding of the effect of water pressure at extreme depths enables the preparation for expeditions to the bottom of the sea, the construction of the equipment used, as well as precautions to be taken when working in high pressure environment.

Futuristic Lens

Remotely controlled deep sea vehicles have the potential to be used in the maintenance of undersea cables and the mining of minerals at the seabed. The engineering technology used in the development of deep sea vehicles has the potential to inspire the construction of cities under the sea in the future.

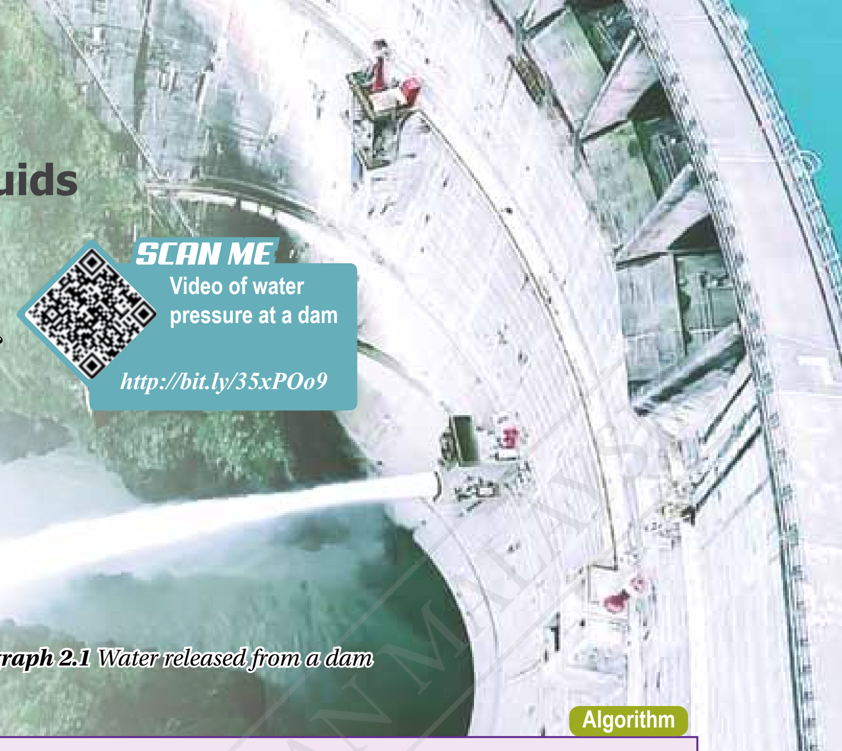
http://bit.ly/2FxZKU6

2.1 Pressure in Liquids

Photograph 2.1 shows water being released from a dam. The outlet of the dam is near the base of the dam. Why does the water shoot out at high speed? Why is the outlet constructed near the base of the dam? What are the factors that affect water pressure?

SCAN ME
Video of water pressure at a dam
http://bit.ly/35xPOo9

LET'S RECALL
Pressure
http://bit.ly/2Nbf9xT



***Photograph 2.1** Water released from a dam*

Activity 2.1

Algorithm

Aim: To derive the formula $P = h\rho g$ from the formulae $P = \frac{F}{A}$ and $\rho = \frac{m}{V}$

Instructions:

1. Carry out this activity in pairs.
2. Consider a liquid column with height, h and base area, A in a container filled with the liquid as shown in Figure 2.1.
3. Fill in the blanks to derive the formula for liquid pressure.

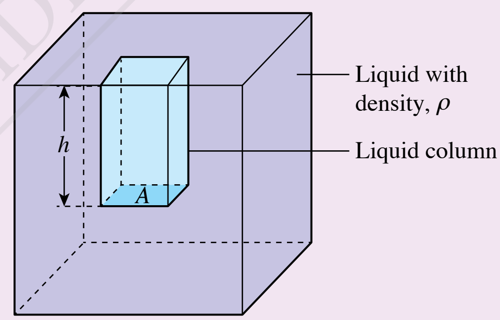


Figure 2.1

Volume of liquid column, V = ______ [Volume = base area × height]

Mass of liquid column, m = ______ [Mass = volume × density]

Weight of liquid column, W = ______ [Weight = mass × gravitational acceleration]

Pressure at the base of liquid column, P = ______ [Pressure = $\frac{\text{Weight of column}}{\text{Surface area}}$]

P = ______

Discussion:

State three factors that affect liquid pressure.

Note
The pressure at the base of a liquid column is caused by the weight of the liquid column.

LS 2.1.1

Liquid pressure is calculated using the following formula.

$$P = h\rho g$$

where P = liquid pressure
h = depth of liquid
ρ = density of liquid
g = gravitational acceleration

The S.I. unit for pressure, P is pascal (Pa)
1 Pa = 1 N m^{-2} or 1 kg m^{-1} s^{-2}

Info GALLERY

Liquid pressure does not depend on its mass, volume, and surface area.

Factors Affecting Liquid Pressure

Experiment 2.1

Inference: Pressure in a liquid depends on the depth of the liquid

Hypothesis: The greater the depth of the liquid, the higher the pressure in the liquid

Aim: To study the relationship between the depth of the liquid and the pressure in the liquid

Variables:

(a) Manipulated: Depth of the liquid, h
(b) Responding: Pressure in the liquid, represented by the difference in height of the water columns, D between the two water levels in the U-tube
(c) Constant: Density of the liquid

Apparatus: 500 ml measuring cylinder, silicone tube, thistle funnel with its mouth closed by a thin sheet of rubber, U-tube, two half-metre rule and retort stand

Materials: Water and food colouring

Procedure:

1. Set up the apparatus as shown in Figure 2.2. Initially, the thistle funnel is outside the measuring cylinder and the levels of water in both arms of the U-tube is the same.
2. Immerse the thistle funnel into the measuring cylinder until the depth, h = 4.0 cm.
3. Determine the difference in height of water columns, D between the two water levels in the U-tube.
4. Repeat steps 2 and 3 for depths, h = 8.0 cm, 12.0 cm, 16.0 cm and 20.0 cm.
5. Record the difference in height of the water columns, D in Table 2.1.

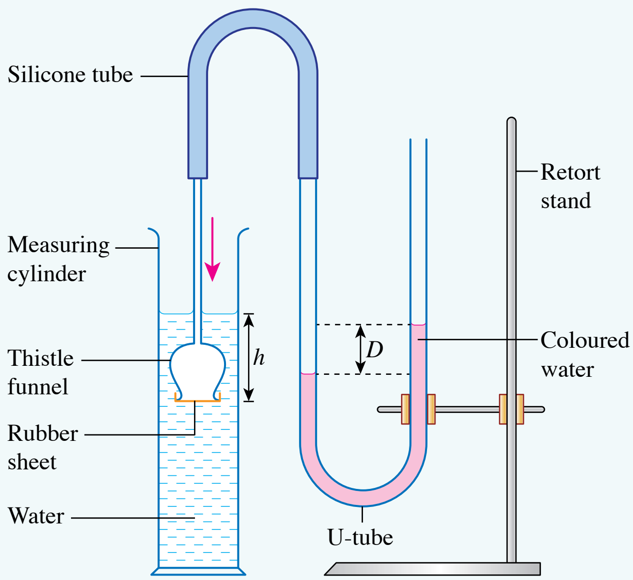


Figure 2.2

Results:

Table 2.1

Depth of water, *h* / cm	Difference in height of water columns, *D* / cm
4.0	
8.0	
12.0	
16.0	
20.0	

Data analysis:
Plot the graph of *D* against *h*.

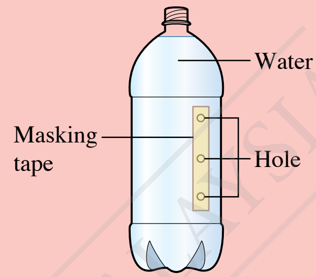
Conclusion:
What conclusion can be drawn from this experiment?

Prepare a complete report for this experiment.

Discussion:
1. What is the relationship between water pressure and depth of the water?
2. State one precaution for this experiment.

Let's Try

The effect of depth on water pressure can be studied by using a plastic bottle.



After the bottle has been filled with water, the masking tape is removed. The spurt distance of water from the three holes will show the relationship between water pressure and depth.

Experiment 2.2

Inference: The pressure in a liquid depends on the density of the liquid

Hypothesis: The higher the density of the liquid, the higher the pressure in the liquid

Aim: To study the relationship between density of the liquid and the pressure in the liquid

Variables:
(a) Manipulated: Density of the liquid, ρ
(b) Responding: Pressure in the liquid, represented by the difference in height of the water columns, *D* between the two water levels in the U-tube.
(c) Constant: Depth of the liquid

Apparatus: Half-metre rule, three 600 ml beakers, U-tube, silicone tube, thistle funnel with its mouth covered by a thin sheet of rubber, and retort stand

Materials: Masking tape, water, alcohol and glycerine

Procedure:
1. Mark all the beakers 2 cm from the base with masking tape.
2. Set up the apparatus as shown in Figure 2.3.

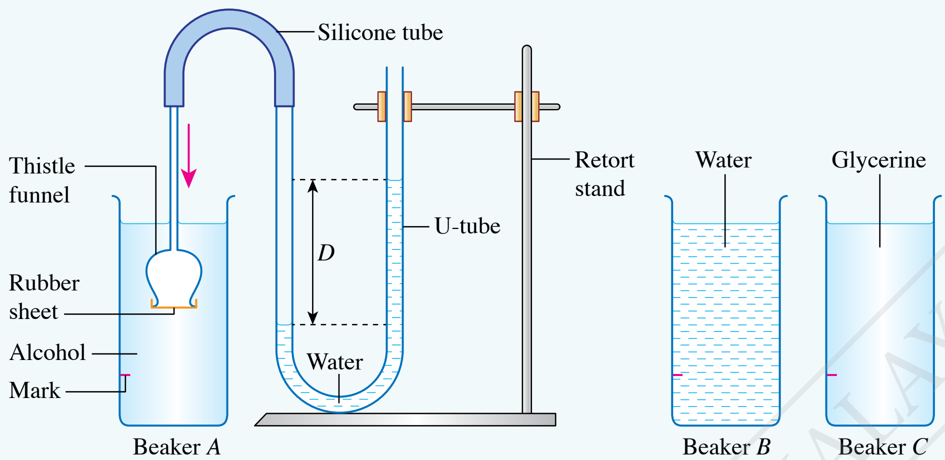


Figure 2.3

3. Bring the mouth of the thistle funnel near to the surface of the alcohol in beaker *A*. Slowly immerse the thistle funnel vertically into the alcohol until the mouth of the thistle funnel is at the same level as the mark.
4. Determine the difference in height of the water columns, *D* between the two water levels in the U-tube. Then, remove the thistle funnel and dry it.
5. Repeat steps 3 and 4 for beaker *B* and beaker *C*.
6. Record the difference in height of the water columns, *D* in Table 2.2.

Results:

Table 2.2

Beaker	Type of liquid	Density of liquid, ρ / kg m^{-3}	Difference in height of water columns, *D* / cm
A	Alcohol	790	
B	Water	1 000	
C	Glycerine	1 300	

Data analysis:

Relate the difference in height of the water columns in the U-tube to the density of the liquid.

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. Why is the method in Let's Try in page 42 not suitable to study the relationship between density and pressure in a liquid?
2. Why is mercury not suitable as the liquid in the U-tube?

Activity 2.2

Aim: To show that cross-sectional area and the shape of a column do not affect pressure in liquids

Apparatus: Liquid level apparatus (any shape)

Materials: Water and food colouring

Instructions:

1. Place an empty liquid level apparatus on the horizontal surface of a table as shown in Figure 2.4.
2. Pour coloured water into the apparatus until almost full.
3. Observe the height of the water level in each column.

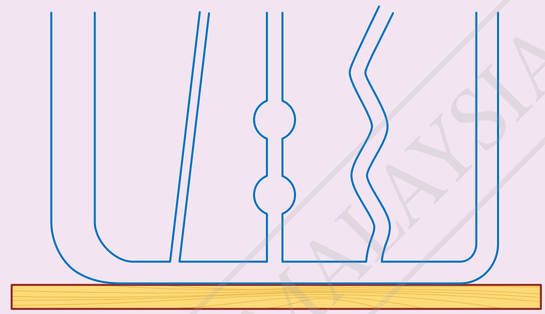


Figure 2.4

Discussion:

1. Compare the height of the water level in each column.
2. Discuss whether the pressure in a liquid is affected by the cross-sectional area and the shape of the columns.

Based on the observation in Activity 2.2, the height of water levels in the different columns are the same. This means that cross-sectional area and the shapes of the column do not affect pressure in liquids.

SCAN ME
Video of water spurting out of a bottle
http://bit.ly/3023kiV

Figure 2.5, shows water spurting out of all three holes at the same level of the plastic bottle has the same horizontal spurt distance.

This observation shows that pressure at a point in a liquid acts in all directions. Points at the same level have the same pressure.

***Figure 2.5** Water spurting out of a bottle*

BRIGHT Info

Points at the same level in a static liquid have the same pressure.

Figure 2.6 shows a U-tube filled with liquid *X*. Then it is added with liquid *Y* which does not mix with liquid *X*. This apparatus can be used to compare the densities of two immiscible liquids.

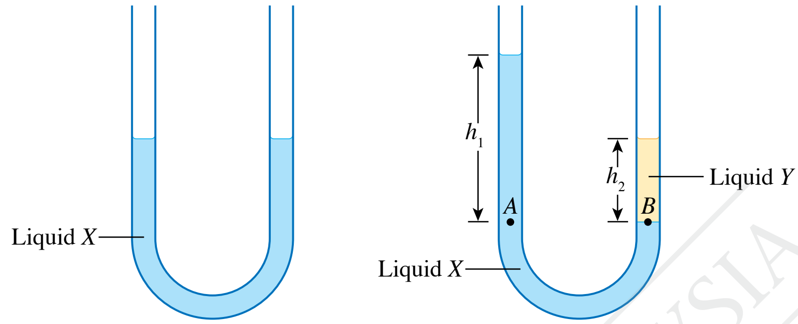


Figure 2.6 *A U-tube filled with liquid X and liquid Y*

Liquid pressure at point *A*, $P_1 = h_1 \rho_1 g$, where ρ_1 = density of liquid *X*
Liquid pressure at point *B*, $P_2 = h_2 \rho_2 g$, where ρ_2 = density of liquid *Y*

Since points *A* and *B* are at the same level and both liquids are static,

pressure at point *A* = pressure at point *B*

$$P_1 = P_2$$
$$h_1 \rho_1 g = h_2 \rho_2 g$$
$$\text{Therefore, } h_1 \rho_1 = h_2 \rho_2$$

The values of h_1 and h_2 can be measured with a metre rule. If the density of liquid *X*, ρ_1 is known, the density of liquid *Y*, ρ_2 can be calculated and vice versa.

Solving Problems Involving Pressure in Liquids

The formula $P = h\rho g$ is used to calculate the pressure at a depth in a liquid. The surface of the liquid also experiences pressure. Therefore, the actual pressure experienced by an object in a liquid is calculated with the following formula.

Actual pressure = $h\rho g + P_{atm}$, where P_{atm} = atmospheric pressure

BRIGHT Info

At sea level, atmospheric pressure has a value of about 100 000 Pa, or 100 kPa.

LET'S ANSWER

http://bit.ly/2QFcNcV

Example 1

Figure 2.7 shows a fish is at a depth of 1.5 m in an aquarium. The density of water in the aquarium is 1 050 kg m^{-3} and atmospheric pressure is 100 kPa. [Gravitational acceleration, g = 9.81 m s^{-2}]

(a) What is the pressure experienced by the fish caused by the water around it?

(b) Calculate the actual pressure acting on the fish.

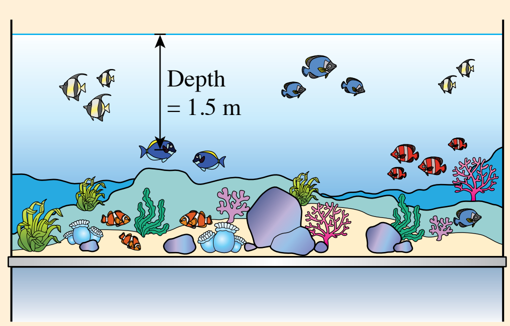


Figure 2.7

Solution

(a)

Step 1: Identify the problem	Step 2: Identify the information given	Step 3: Identify the formula that can be used	Step 4: Solve the problem numerically

1. Pressure on the fish, P
2. Depth of the fish, h = 1.5 m
   Density of aquarium water, ρ = 1 050 kg m^{-3}
   Gravitational acceleration, g = 9.81 m s^{-2}
3. $P = h\rho g$
4. $P = h\rho g$
   $= 1.5 \times 1\,050 \times 9.81$
   $= 15\,450.8$ Pa
   $= 15.5$ kPa

(b) Atmospheric pressure, P_{atm} = 100 kPa

Actual pressure $= h\rho g + P_{atm}$
$= 15.5 + 100$
$= 115.5$ kPa

Example 2

Figure 2.8 shows a U-tube filled with water and olive oil. The density of water is 1 000 kg m^{-3}. Calculate the density of olive oil.

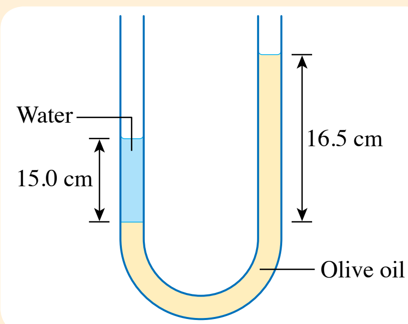


Figure 2.8

Solution

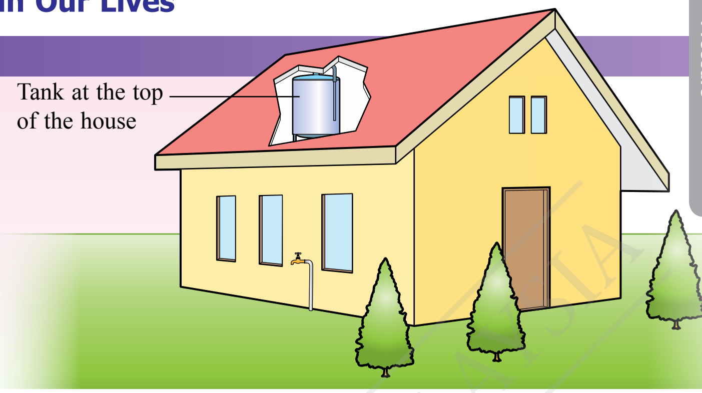
Density of olive oil, ρ_2
Height of water column, h_1 = 15.0 cm
Density of water, ρ_1 = 1 000 kg m^{-3}
Height of olive oil column, h_2 = 16.5 cm

$$h_1\rho_1 g = h_2\rho_2 g$$
$$h_1\rho_1 = h_2\rho_2$$
$$15.0 \times 1\,000 = 16.5 \times \rho_2$$
$$\rho_2 = \frac{15.0 \times 1\,000}{16.5}$$
$$= 909.1 \text{ kg m}^{-3}$$

Applications of Pressure in Liquids in Our Lives

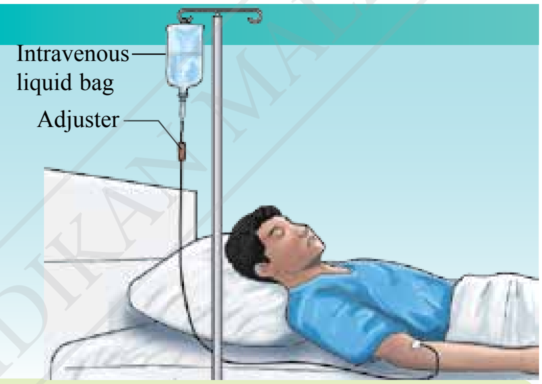
Position of water tank in the house

- A water tank is usually placed in the space between the ceiling and the roof.
- The difference in height between the water level in the tank and the water tap produces a high water pressure at the tap.
- Water flows at high speed when the tap is turned on.

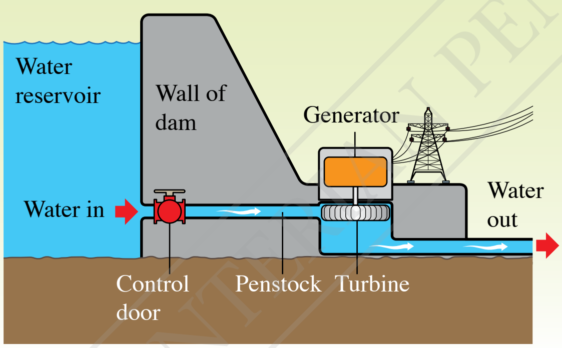


Position of intravenous liquid

- A bag of intravenous liquid is placed at a position higher than the body of a patient.
- The pressure due to the difference in height of the liquid columns will push the intravenous liquid into the body of the patient.
- The rate of flow of intravenous liquid into the patient's body depends on the height of the bag and can be controlled by the adjuster.

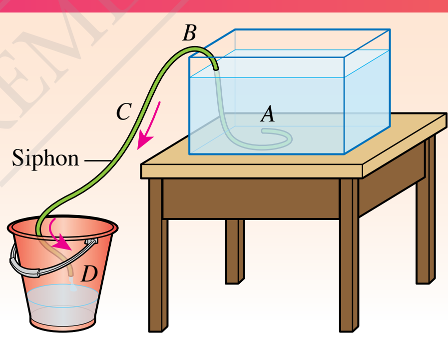


Construction of a dam



- The wall of a dam is built thicker at the base of the dam because water pressure increases with depth.
- The thicker section of the dam is able to withstand the high water pressure.
- The penstock is at the lower section so that the high water pressure will produce a fast flow of water to drive the turbines.

Use of the siphon



- A siphon is used to transfer water from a higher region to a lower region.
- One end of the tube that is filled with water is placed in the tank of water at a higher position while the other end is placed at a lower position.
- The flow of water from end *D* produces a region of lower pressure at point *B*. Atmospheric pressure pushes water into the tube at *A*.

Figure 2.9 *Applications of pressure in liquids in daily life*

A simple siphon consists of a flexible tube. Liquid can be transferred out continuously from a reservoir for a period of time without the use of electrical power. What are the factors that affect the rate of transfer of liquid using a siphon?

Activity 2.3

STEM / ISS / ICS

Aim: To conduct a study to determine the highest rate of transfer of liquid using a siphon

Instructions:

1. Carry out this activity in small groups.
2. Gather information on the siphon through reading materials or websites for the following aspects:
   (a) characteristics of a siphon
   (b) factors that affect the rate of transfer of liquid
   (c) the method in determining the rate of transfer of liquid by a siphon
3. Discuss the information required and complete the K-W-L Data Strategy Form.
4. Plan and carry out an experiment to study how the factors identified in 2(b) affect the rate of transfer of liquid.
5. Suggest a design for the siphon and the method of using the siphon that will transfer water at the highest rate of transfer.
6. Construct the siphon following the suggested design and test out the siphon.
7. Suggest improvements that can be made.
8. Present the design of your siphon.

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

BRIGHT Info

The rate of transfer of liquid can be defined as the volume of liquid transferred in one second.

Rate of transfer of liquid = $\frac{V}{t}$ in units ml s^{-1}.

V is the volume of liquid transferred in time, t.

Formative Practice 2.1

1. State three factors that affect the pressure in a liquid.
2. What is the water pressure at a depth of 24 m in a lake?
   [Density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]
3. A diver dives to a depth of 35 m in the sea. What is the actual pressure acting on his body?
   [Density of sea water, ρ = 1 060 kg m^{-3}, gravitational acceleration, g = 9.81 m s^{-2} and atmospheric pressure = 100 kPa]

2.2 Atmospheric Pressure

Photograph 2.2 shows a glass sheet lifted using large rubber suckers. How is atmospheric pressure applied in the use of the rubber suckers?

Atmospheric pressure is the **pressure due to the weight of the layer of air acting on the surface of the earth**. The earth is surrounded by a thick layer of air consisting of various types of gases. This layer of air has weight and exerts a pressure on the surface of the earth as well as all objects on it. Therefore, all objects on the surface of the earth experience atmospheric pressure.

***Photograph 2.2** Glass sheet lifted using large rubber suckers*

Activity 2.4

Aim: To discuss atmospheric pressure from the aspect of the weight of the air acting on objects at the surface of the earth

Instructions:

1. Carry out this activity in pairs.
2. Study situations 1 and 2.

Situation 1:	Situation 2:
A diver in the sea experiences water pressure. This water pressure is caused by the weight of the water column acting on him.	Human beings living on land are surrounded by air.

3. Based on situation 1, explain the existence of atmospheric pressure on human beings in situation 2 from the aspect of the weight of the air acting on him.

SCAN ME
Video on the effects of atmospheric pressure
http://bit.ly/2FyJcLM

Discussion:

1. Discuss the similarities and differences between atmospheric pressure and water pressure.
2. Estimate the atmospheric pressure at the surface of the earth. It is given that the thickness of the atmosphere, h = 120 km, the average density of air, $\rho = 8.5 \times 10^{-2}$ kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}.

The Value of Atmospheric Pressure

The value of atmospheric pressure can be measured by using a mercury barometer. A mercury barometer consists of a 1 metre long glass tube containing mercury. Initially, the glass tube filled with mercury and is covered with a lid as shown in Figure 2.10(a). The glass tube is then inverted and the covered end is immersed into a bowl of mercury as shown in Figure 2.10(b).

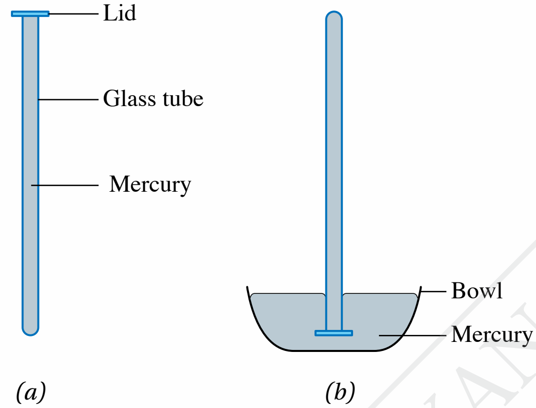


Figure 2.10 *Preparation of a mercury barometer*

When the lid is removed, the mercury column in the glass tube will fall until a certain height and remain at that height as shown in Figure 2.11.

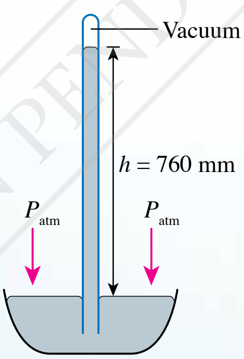


Figure 2.11 *Mercury barometer*

EAL History

Evangelista Torricelli conducted an experiment with a mercury barometer in the year 1643. He concluded that the mercury column in the glass tube is supported by atmospheric pressure.

The atmospheric pressure acting on the surface of the mercury in the bowl supports the mercury column. The height of the mercury column depends on the magnitude of the atmospheric pressure. The value of the atmospheric pressure is stated in terms of the height of the mercury column. If the height of the mercury column, h = 760 mm, then the atmospheric pressure, P_{atm} = 760 mm Hg.

The formula $P = h\rho g$ is used to obtain the value of atmospheric pressure in pascal (Pa).

P_{atm} = 760 mm Hg, where h = 760 mm = 0.76 m

Density of mercury, $\rho = 1.36 \times 10^4$ kg m^{-3}

Atmospheric pressure, $P_{atm} = h\rho g$

$= 0.76 \times 1.36 \times 10^4 \times 9.81$

$= 101\ 396.16$ Pa

$= 101\ 396$ Pa

The value of atmospheric pressure can change with weather. In addition, the thin air at high altitudes causes the atmospheric pressure to be lower.

Fortin Barometer and Aneroid Barometer

The Fortin barometer as shown in Figure 2.12 is a mercury barometer that measures atmospheric pressure to a high degree of accuracy. The Fortin barometer has a height of almost one metre. This instrument is usually used to measure atmospheric pressure at meteorological centres.

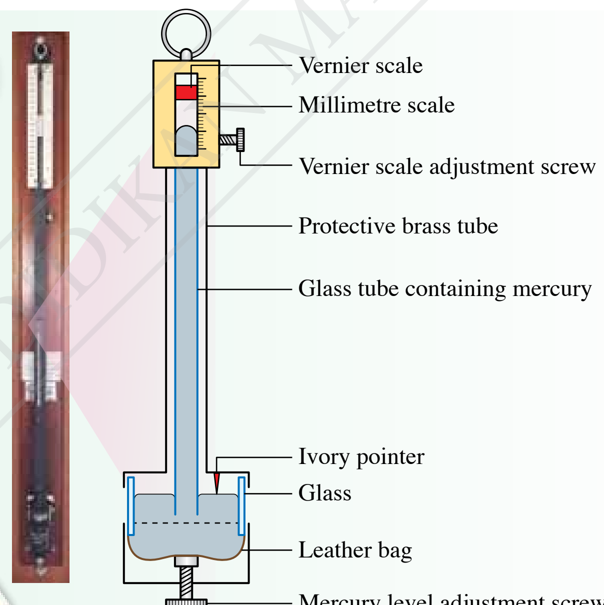


Figure 2.12 *Fortin barometer*

Brain-Teaser

What is the height of a water barometer?

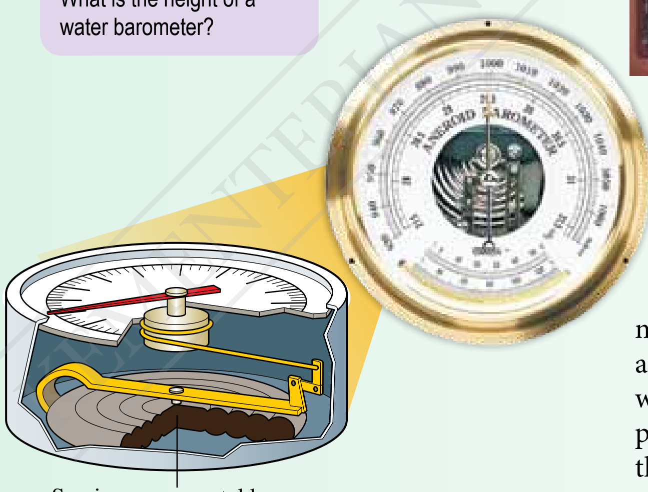


Figure 2.13 *Aneroid barometer*

The Aneroid barometer functions mechanically. The partial-vacuum metal box as shown in Figure 2.13 can change its size when there are changes in the atmospheric pressure. This small change in the volume of the box is amplified by a mechanical system to move the pointer of the barometer. Aneroid barometers are suitable to be used in homes, ships and aeroplanes to obtain a quick reading of the atmospheric pressure.

Table 2.3 shows the differences between the Fortin barometer and Aneroid barometer.

***Table 2.3** Differences between Fortin barometer and Aneroid barometer*

Fortin barometer	Aneroid barometer
The value of the atmospheric pressure is determined by the changes in the height of the mercury column	The value of the atmospheric pressure is determined by the changes in the volume of the partial-vacuum metal box
Larger size and not portable	Smaller size and portable
Takes a longer time to give a reading for atmospheric pressure	Gives a direct reading for atmospheric pressure
Higher accuracy, up to ±0.1 mm Hg	Lower accuracy, up to ±1 mm Hg

Solving Problems in Daily Life Involving Various Units of Pressure

The S.I. unit of pressure is pascal (Pa). However, a few other units of pressure are still commonly used in various fields. Study Figure 2.14 that shows the use of various units of pressure.

UNIT PRESSURE

pascal (Pa)

- S.I. unit of pressure
- Used in the field of science
- Values of pressure need to be converted to the unit Pa before substitution in physics formulae
- Atmospheric pressure at the peak of Mount Kinabalu is about 60 000 Pa

mm Hg

- Manometric unit of pressure
- Used in the fields of medicine, meteorology, aviation and science
- Blood pressure of 120/80 recorded by a doctor is in mm Hg

m H_2O

- A metric unit
- Used for pressures of water in the sea, water reservoirs and dams
- Water pressure in the Bakun Dam is 150 m H_2O

millibar (mbar)

- A smaller metric unit
- Used in the field of meteorology
- Equivalent to the unit hectopascal (hPa)
  1 millibar = 1 hPa
- Atmospheric pressure is 1 013 mbar

***Figure 2.14** Examples of units of pressure used in daily life*

Example 1

The blood pressure reading of a patient is 160/100. What is the pressure 160 mm Hg in Pa?
[Density of Hg, ρ = 1.36 × 10^4 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

LET'S ANSWER
http://bit.ly/37T3Y4Z

Solution

Step 1: Identify the problem

Step 2: Identify the information given

Step 3: Identify the formula that can be used

Step 4: Solve the problem numerically

1. Pressure 160 mm Hg in Pa

2. Height of liquid column, h = 160 mm
   = 0.16 m
   Gravitational acceleration, g = 9.81 m s^{-2}
   Density of Hg, ρ = 1.36 × 10^4 kg m^{-3}

3. $P = h\rho g$

4. P = 0.16 × 1.36 × 10^4 × 9.81
   = 2.13 × 10^4 Pa

Example 2

The maximum pressure that a wall at the seaside can withstand is 3.6 × 10^5 Pa. What is this maximum pressure in m H_2O?
[Density of H_2O, ρ = 1.00 × 10^3 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

Solution

Maximum pressure, P = 3.6 × 10^5 Pa
Density of H_2O, ρ = 1.00 × 10^3 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}

$$P = h\rho g$$

$$h = \frac{P}{\rho g}$$

$$= \frac{3.6 \times 10^5}{1.00 \times 10^3 \times 9.81}$$

$$= 36.7 \text{ m}$$

Maximum pressure = 36.7 m H_2O

Effects of Atmospheric Pressure at High Altitude and Effects of Pressure at Extreme Depth under the Surface of the Sea

Figure 2.15 shows the effects of atmospheric pressure at high altitude. Figure 2.16 shows the effects of pressure at extreme depth under the surface of the sea.

Atmospheric Pressure at High Altitude

At higher altitude:
- Thin of air causes the atmospheric pressure to become lower
- The percentage of oxygen in the air reduces

Effects on human beings at high altitude:
- Increase in the rate of breathing
- Lower absorption of oxygen in the lungs
- Increase in the metabolic rate
- Loss of appetite
- Dehydration
- Inability to think clearly

Adaptations and actions to be taken

Mountain climbers
- Prepare and train before climbing
- Prepare equipment such as smartwatch that can measure altitude, blood pressure and body temperature
- Climb at a slow rate to allow the body to adjust to the changes in pressure
- Drink water even when not thirsty to prevent dehydration

Aircraft
- Increase the pressure in the aircraft cabin to match the sea level pressure
- Recycle the air in the cabin so that it is fresh and contains adequate oxygen level
- Remind the passengers to drink enough water to prevent dehydration during long distance flights

Figure 2.15 Effects of atmospheric pressure at high altitude

Info GALLERY

- At the summit of Mount Kinabalu, the atmospheric pressure is about 60 percent of the atmospheric pressure at sea level.
- At the level of commercial aircraft flight, atmospheric pressure is only a quarter of the atmospheric pressure at sea level.

Info GALLERY

Outer space is the space outside the earth's atmosphere. The pressure in outer space is almost zero. The spacecraft that carries astronauts needs:
- Pressurisation of the spacecraft cabin to match the atmospheric pressure on the earth so that astronauts do not need to wear a pressure suit while in the spacecraft cabin
- Installation of an oxygen generator to supply oxygen to astronauts
- A supply of pressure suits to be worn by astronauts when exiting the spacecraft in order to balance the pressure in the body

Pressure at an Extreme Depth under the Surface of the Sea

At an extreme depth under the surface of the sea:
- Water pressure increases with its depth
- An increase in depth of 10 m causes an increase in water pressure by 1 atmosphere
- Water pressure and atmospheric pressure are experienced

Effects on human beings at extreme depth under the surface of the sea
- Body tissues absorb excess nitrogen gas
- Nitrogen gas dissolves into the blood
- Inability to think clearly
- Formation of nitrogen bubbles in the tissues or blood vessels if pressure is reduced too rapidly

Adaptations and actions to be taken

Divers
- Do physical exercises to enable the body to adapt to a high pressure environment before diving
- Wear a diving suit to slow down heat loss from the body
- Slowly ascend to sea level so that nitrogen bubbles do not form in the tissues and blood vessels

Submarines
- Submarine is made of steel or titanium with a circular cross section to withstand the high pressure of surroundings
- Pressure in the cabin of the submarine is controlled to almost the same level as sea level for the comfort of the crew
- Oxygen tanks or electrolytic oxygen generators are provided so that the oxygen supply is adequate

Figure 2.16 Effects of extreme depth under the surface of the sea

Info GALLERY

- A diver who dives to a depth of 30 m in search of pearl oysters will experience a pressure 4 times the normal atmospheric pressure.
- Submarines moving to a depth of 240 m experience a very high pressure, which is 25 times the pressure at sea level.

SCAN ME

Video of formation of nitrogen bubbles in the tissues or blood vessels

https://bit.ly/VidNitro

Career Booth

Professional divers can serve in the navy, work as commercial divers or serve as recreational trainers at sea. In addition to theoretical knowledge and skills, professional divers need to undergo a series of intensive training in order for the diver's body to adapt to extreme pressure.

Formative Practice 2.2

1. Explain the existence of atmospheric pressure.

2. The height of the mercury column in a barometer is 756 mm Hg on a cloudy day. Calculate the atmospheric pressure at that time in pascal.
[Density of mercury, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

3. What is the actual pressure at a depth of 125 m in a dam? State your answer in m H_2O and pascal.
[Atmospheric pressure = 10.3 m H_2O, density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

2.3 Gas Pressure

Manometer

Photograph 2.3 shows a manometer which consists of a glass U-tube containing coloured water. This apparatus is used to measure gas pressure. Figure 2.17 shows a manometer before and after it is connected to a gas supply.

Photograph 2.3 *Manometer*

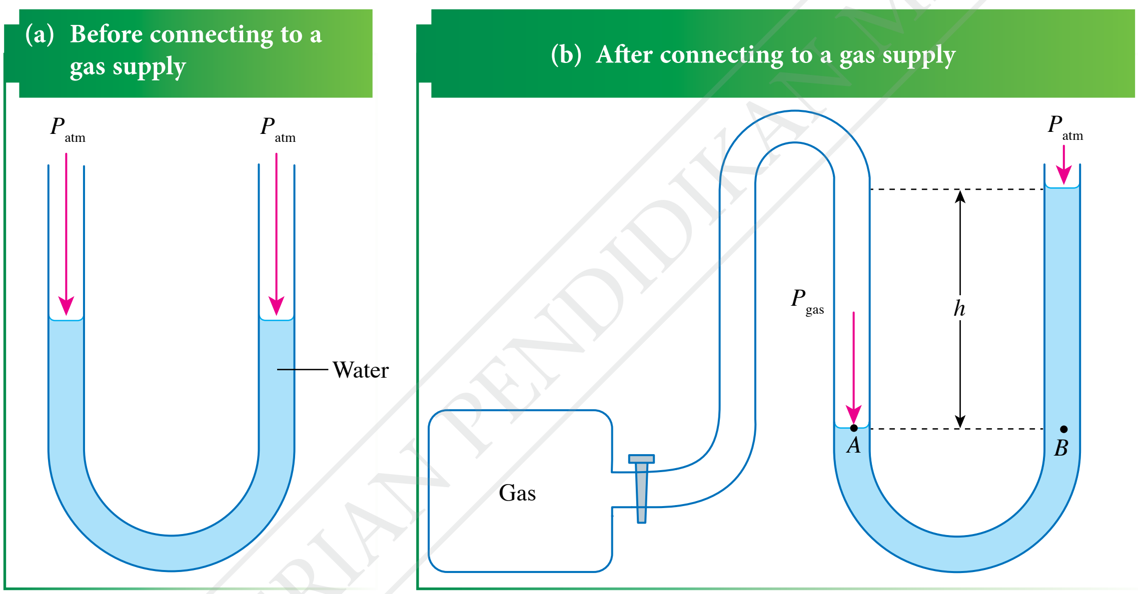


Figure 2.17 *Water manometer before and after connecting to a gas supply*

Pressure at A = gas pressure, P_{gas}

Pressure at B = pressure due to water column h + atmospheric pressure

= h cm H_2O + P_{atm}

Point A and point B are at the same level, therefore

Pressure at A = pressure at B

$$P_{gas} = h \text{ cm } H_2O + P_{atm}$$

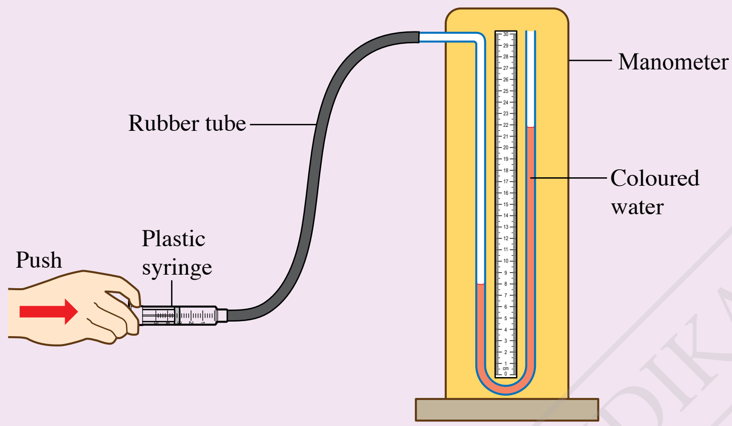
The height, h of the water column represents the difference between the gas pressure and atmospheric pressure. Let us carry out Activity 2.5 to understand more about gas pressure in a container by using a water manometer.

Activity 2.5

Aim: To determine the pressure of a gas using a water manometer
Apparatus: Manometer, rubber tube, half-metre rule, 10 ml plastic syringe
Materials: Water and red colouring

Instructions:

1. Set up the apparatus as shown in Figure 2.18. Make sure that the volume of air in the syringe is 10 ml and the water levels in both arms of the U-tube are the same.



SCAN ME
Video of demonstration of a simple manometer
http://bit.ly/DemoMano

Figure 2.18

2. Push the piston slightly into the syringe until a reading of 8 ml is shown on the syringe so that the water levels in both arms of the glass tube are no longer at the same level.
3. Determine the height, *h* between the water levels in both arms of the U-tube.
4. Repeat steps 2 and 3 with readings of 6 ml and 4 ml on the syringe.
5. Record your results in Table 2.4.
6. Calculate the air pressure in the syringe in m H_2O.
   [Use the value P_{atm} = 10 m H_2O]

Results:

Table 2.4

Reading on the syringe, *V* / ml	Height, *h* / m	Air pressure, *P* / m H_2O
8		
6		
4		

Discussion:

1. How can the value of air pressure from this activity be stated in Pa?
2. Suggest a suitable liquid to be used in the manometer for measuring higher gas pressures.

Solving Problems in Daily Life Involving Gas Pressure

Example 1

Figure 2.19 shows a mercury manometer connected to a flask with compressed gas.
[Atmospheric pressure, P_{atm} = 76 cm Hg, density of Hg, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

(a) What is the pressure of the compressed gas in cm Hg?
(b) Calculate the gas pressure in Pa.
(c) Will your answers in (a) and (b) change if the glass tube of the manometer has a larger diameter?

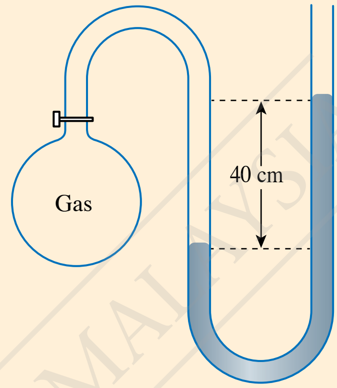


Figure 2.19

Solution

(a)

Step 1:	Step 2:	Step 3:	Step 4:
Identify the problem	Identify the information given	Identify the formula that can be used	Solve the problem numerically

1. Pressure of compressed gas, P in the unit cm Hg
2. Height of column, h = 40 cm
   Atmospheric pressure,
   P_{atm} = 76 cm Hg
3. $P = h + P_{atm}$
4. $P = 40 + 76$
   $= 116$ cm Hg

(b) Pressure of compressed gas, P in Pa
To convert cm Hg to Pa
Height, h = 116 cm = 1.16 m
Density of Hg, ρ = 13 600 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}
Gas pressure, $P = h\rho g$
$= 1.16 \times 13\,600 \times 9.81$
$= 1.55 \times 10^5$ Pa

(c) The answers obtained in (a) and (b) will not change because pressure in liquids does not depend on the surface area.

Info GALLERY

Nowadays, mercury manometers are seldom used because mercury is a very toxic liquid. Digital manometers that use pressure transducer are more common because they are portable and give a more accurate reading.

LET'S ANSWER

http://bit.ly/39QwLJ7

Example 2

Figure 2.20 shows a mercury manometer used to measure the pressure in an air flow pipe.

(a) What is the difference between the air pressure in the pipe and the atmospheric pressure in cm Hg?

(b) If the atmospheric pressure is 75 cm Hg, what is the air pressure in the pipe in Pa?
[Density of Hg, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

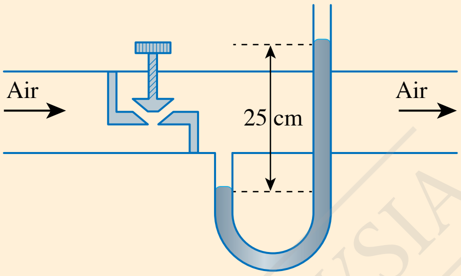


Figure 2.20

Solution

(a) Difference in pressure = height of mercury column
= 25 cm Hg

(b) Density of Hg, ρ = 13 600 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}
Atmospheric pressure, P_{atm} = 75 cm Hg
Air pressure in the pipe, $P = h + P_{atm}$

Air pressure in the pipe, P = 25 + 75
= 100 cm Hg

To convert cm Hg to Pa:
$P = h\rho g$
$= (100 \times 10^{-2}) \times 13\,600 \times 9.81$
$= 1.33 \times 10^{5}$ Pa

Formative Practice 2.3

1. Figure 2.21 shows a water manometer connected to a flask containing gas.
   (a) Compare the gas pressure in the flask with the atmospheric pressure.
   (b) State the difference between the gas pressure and the atmospheric pressure in m H_2O.
   (c) Calculate the gas pressure in pascal.
   [Density of water, ρ = 1 000 kg m^{-3} gravitational acceleration, g = 9.81 m s^{-2} and atmospheric pressure = 10.3 m H_2O]

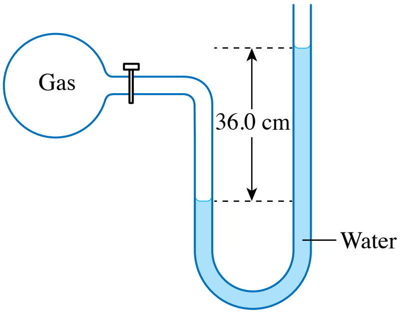


Figure 2.21

2. What are the advantages of using a mercury manometer compared to a water manometer?

3. A mercury manometer is connected to a steel cylinder containing compressed gas. The pressure of the compressed gas and the atmospheric pressure are 180 kPa and 101 kPa respectively. Calculate the difference in height between the two mercury columns in the manometer.
[Density of Hg, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

LS 2.3.2

2.4 Pascal's Principle

Photograph 2.4 shows a coconut milk extractor that functions by applying the principle of transmission of pressure in a closed fluid. How can a large force be produced to press the grated coconut?

Let's Try

Video of Pascal's piston

http://bit.ly/2QX2v6I

Photograph 2.4 *Coconut milk extractor*

Activity 2.6

Aim: To generate ideas about the transmission of pressure in liquids

Apparatus: Pascal's piston and plastic basin

Material: Water

Instructions:

1. Fill the plastic basin with tap water until almost full.
2. Immerse the Pascal's piston into the water and pull the piston so that water enters it.
3. Hold the Pascal's piston above the basin and push the piston inwards as shown in Figure 2.22.
4. Observe the flow of water out of the Pascal's piston.

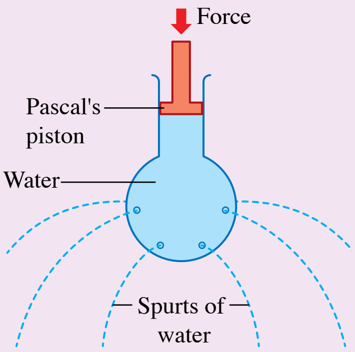


Figure 2.22

Discussion:

What is your observation on the flow of water out of the holes when the Pascal's piston is pushed inwards? Explain your answer.

When the piston is pushed, a force is exerted on the surface of the water and pressure is produced. This pressure is transmitted uniformly throughout the water in all directions. This causes the water to spurt out from every hole. **Pascal's principle states that the pressure applied on an enclosed fluid is transmitted uniformly in all directions in the fluid.**

Hydraulic System as a Force Multiplier

According to Pascal's principle, pressure applied on the surface of a liquid is transmitted uniformly throughout the liquid. If this pressure is transmitted to a larger surface area, what is the effect on the force produced on that surface?

BRIGHT Info

$$\text{Pressure} = \frac{\text{Force}}{\text{Surface area}}$$

Force = pressure × surface area

Activity 2.7

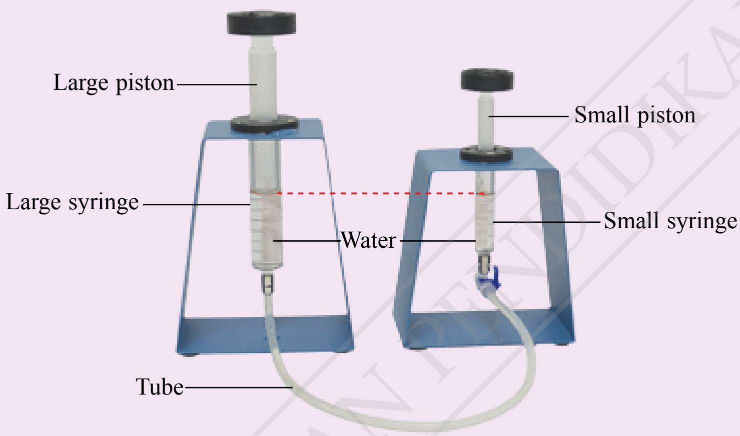
Aim: To study a simple hydraulic system as a force multiplier

Apparatus: Model of a simple hydraulic system, 3 pieces of 100 g slotted weights, 5 pieces of 50 g slotted weights, 5 pieces of 20 g slotted weights and 5 pieces of 10 g slotted weights

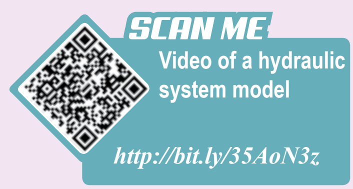
Material: Water

Instructions:

1. Set up a simple hydraulic system model as shown in Photograph 2.5.
2. Ensure that water levels in both syringes are the same.



Photograph 2.5



3. Place a 50 g slotted weight on the small piston.
4. Add slotted weights (10 g, 20 g, 50 g or 100 g) on the large piston until the water levels in both syringes are the same again.
5. Record the total mass of the slotted weights on the large piston.
6. Repeat steps 3 to 5 with 80 g and 100 g slotted weights on the small piston.

Results:

Table 2.5

Mass on the small piston / g	Total mass on the large piston / g
50	
80	
100	

Discussion:

1. Compare the pressure on the surface of the water in small syringe and large syringe.
2. Compare the force acting on the small piston with the force acting on the large piston.

A hydraulic system is a system that uses a liquid to transmit pressure. The hydraulic system in Activity 2.7 shows that a force acting on the small piston can produce a larger force on the large piston. This shows that a hydraulic system not only transmits pressure, but also multiplies force. Figure 2.23 shows a hydraulic system that functions as a force multiplier.

Brain-Teaser

What are the advantages of a hydraulic system?

Brain-Teaser

Why is water not used in a hydraulic system?

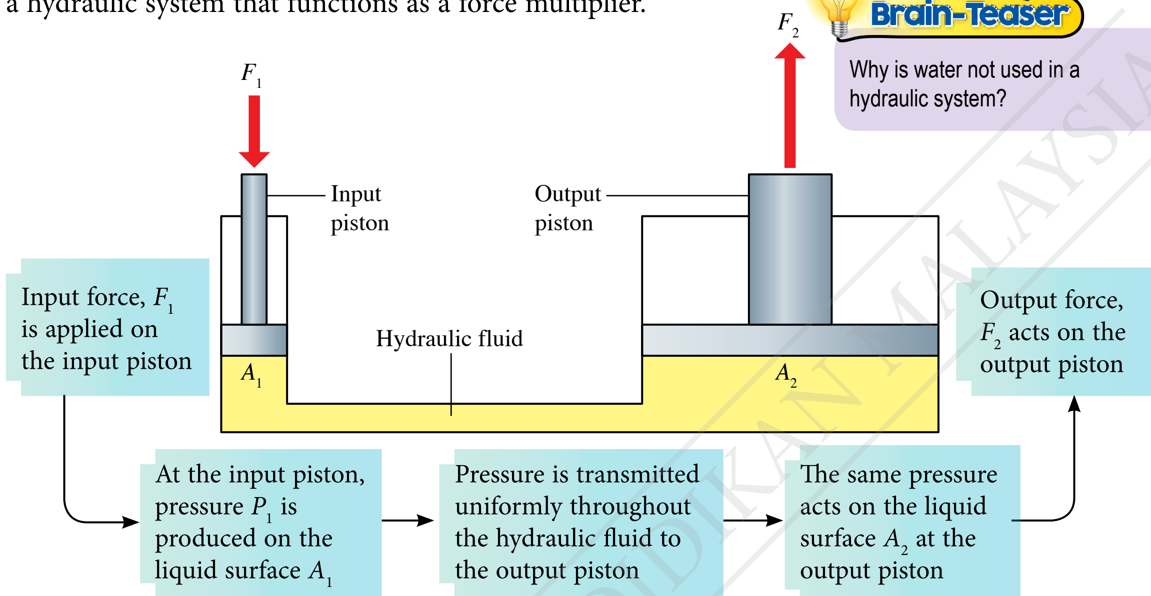


Figure 2.23 *A hydraulic system*

Based on Figure 2.23, the formula for force multiplier can be derived from Pascal's principle as follows:

Pressure on the liquid surface below the input piston, $P_1 = \dfrac{F_1}{A_1}$

Pressure on the output piston, $P_2 = \dfrac{F_2}{A_2}$

Pressure on the output piston is the pressure transmitted from the input piston.

Therefore, $P_2 = P_1$

$$\frac{F_2}{A_2} = \frac{F_1}{A_1}$$ ➔ Formula for Pascal's principle

SCAN ME

Simulation of a simple hydraulic system

http://bit.ly/2QFvKMB

A hydraulic system is a force multiplier system. When the value of the surface area A_2 is greater than the surface area A_1, the force on the output piston, F_2 is greater than the force on the input piston, F_1. This is determined by:

$$F_2 = \frac{A_2}{A_1} \times F_1$$

The value of the multiplying factor is $\dfrac{A_2}{A_1}$

Applications of Pascal's Principle

Pascal's principle is applied in hydraulic systems. A small input force is multiplied to become a larger output force to perform a specific task. How is this principle applied in the hydraulic brake and the hydraulic jack?

SCAN ME
Characteristics of hydraulic fluid
http://bit.ly/2N8Ntty

Activity 2.8

ISS ICS

AR

Aim: To discuss the applications of Pascal's principle

Instructions:

1. Carry out a Round Table activity.
2. Study Figure 2.24 and Figure 2.25 which show the hydraulic brake system of a car and a hydraulic jack respectively.
3. Scan the QR code to watch the video that shows the operations of the hydraulic brake and the hydraulic jack.

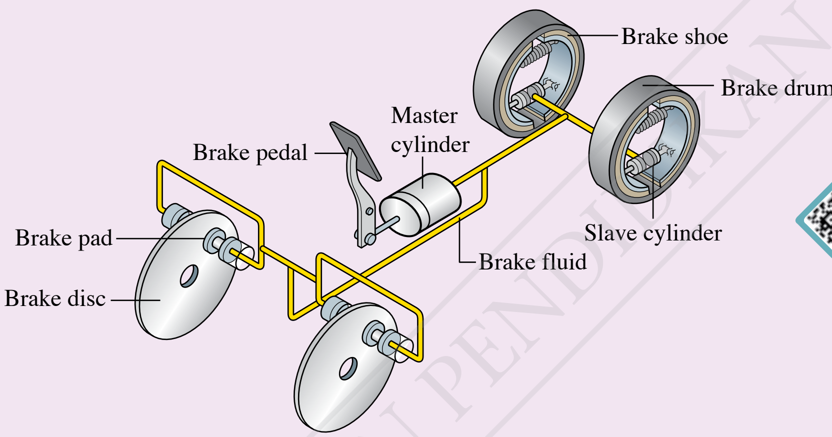


Figure 2.24

SCAN ME
Video of applications of Pascal's principle
http://bit.ly/2N6pk6H

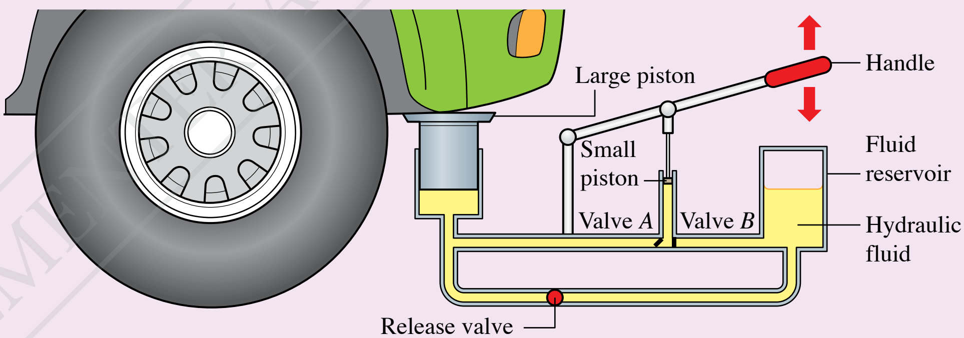


Figure 2.25

4. Surf websites to gather information about the application of Pascal's principle in the hydraulic brake and the hydraulic jack.
5. Each group has to record the information obtained on a piece of paper.
6. Present the outcome of your discussion in the form of a multimedia presentation.

LS 2.4.3

Solving Problems in Daily Life Involving Pascal's Principle

Example 1

Figure 2.26 shows a hydraulic system. Calculate:

(a) the multiplying factor

(b) the output force, F_2

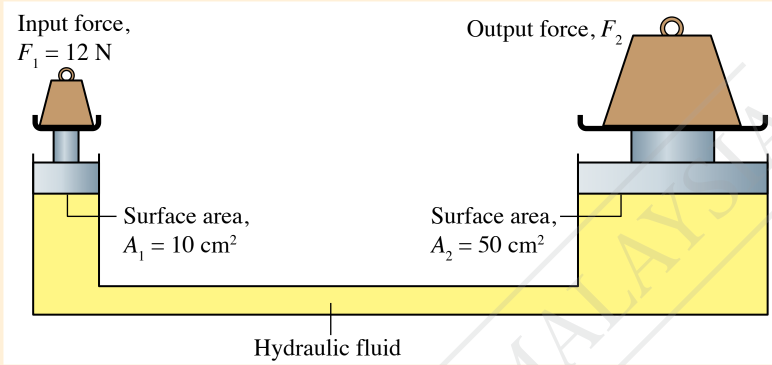


Figure 2.26

Solution

(a)

Step 1: Identify the problem → **Step 2:** Identify the information given → **Step 3:** Identify the formula that can be used → **Step 4:** Solve the problem numerically

1. Multiplying factor of the hydraulic system
2. Surface area, $A_1 = 10 \text{ cm}^2$
   Surface area, $A_2 = 50 \text{ cm}^2$
3. Multiplying factor $= \dfrac{A_2}{A_1}$
4. Multiplying factor $= \dfrac{50}{10}$
   $= 5$

(b) Output force, F_2

Multiplying factor = 5

Input force, F_1 = 12 N

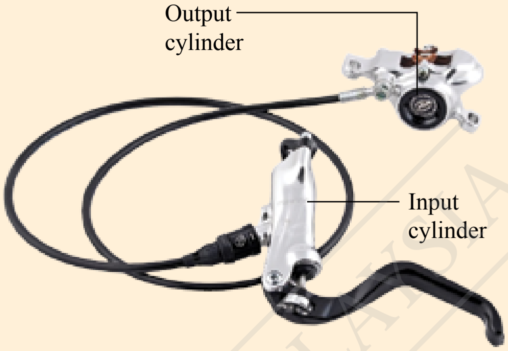
$$\text{Output force, } F_2 = \frac{A_2}{A_1} \times F_1$$
$$= 5 \times 12$$
$$= 60 \text{ N}$$

LET'S ANSWER

http://bit.ly/307ltvD

Example 2

A technician intends to design a hydraulic brake system for his bicycle as shown in Photograph 2.6. The input force that a cyclist is able to exert is 60 N at the input cylinder which has a cross-sectional area of 0.80 cm². What is the cross-sectional area of the output cylinder that will produce a braking force of 840 N?



Photograph 2.6

Solution

Input force, $F_1 = 60$ N

Cross-sectional area of input cylinder, $A_1 = 0.80$ cm²

Output force (braking force), $F_2 = 840$ N

Cross-sectional area of output cylinder = A_2

Formula for Pascal's principle, $\frac{F_2}{A_2} = \frac{F_1}{A_1}$

$$\frac{840}{A_2} = \frac{60}{0.80}$$

$$A_2 = \frac{840 \times 0.80}{60}$$

$$= 11.2 \text{ cm}^2$$

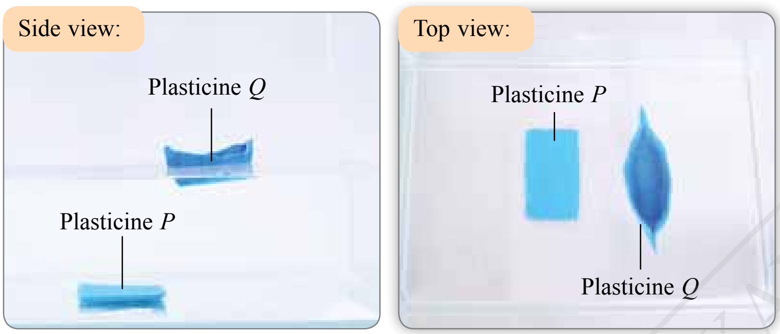
Formative Practice 2.4

1. State Pascal's principle.
2. Describe how a hydraulic machine can achieve force multiplication by applying Pascal's principle.
3. In a hydraulic system, an input force of 4.0 N acts on a piston with surface area 0.50 cm². Calculate the output force produced on a piston with surface area 6.4 cm².
4. A pupil has a small syringe with a piston of diameter 1.5 cm. The pupil intends to construct a hydraulic system that can multiply force from 6 N to 72 N. What is the diameter of a large syringe that is required for this hydraulic system?

2.5 Archimedes' Principle

Buoyant Force

Photograph 2.7 shows two pieces of plasticine, *P* and *Q* with the same mass. When the two pieces of plasticine are placed in a container with water, plasticine *P* sinks while plasticine *Q* floats on the surface of the water. How does this situation occur?



***Photograph 2.7** Plasticine in a container of water*

My Glorious Malaysia

Tengku Tengah Zaharah Mosque at Teluk Ibai, Terengganu is the first floating mosque in Malaysia. This mosque is built on a floating platform at the estuary of a river and can accommodate up to 2 000 worshippers. The buoyant force produced by the water around the platform supports the weight of the mosque.

Activity 2.9

Aim: To discuss the buoyant force on an object immersed in a liquid

Instructions:

1. Carry out this activity in pairs.
2. Study Figure 2.27 that shows a cylinder submerged in a liquid.
3. Compare the depth of the top surface and the depth of the bottom surface of the cylinder.
4. Compare the liquid pressure on the top surface with the liquid pressure on the bottom surface of the cylinder.
5. Compare the magnitude on the force on the top surface with the magnitude of the force on the bottom surface on the cylinder caused by the liquid pressure.
6. What is the direction of the resultant force acting on the cylinder as a result of the difference in liquid pressure?

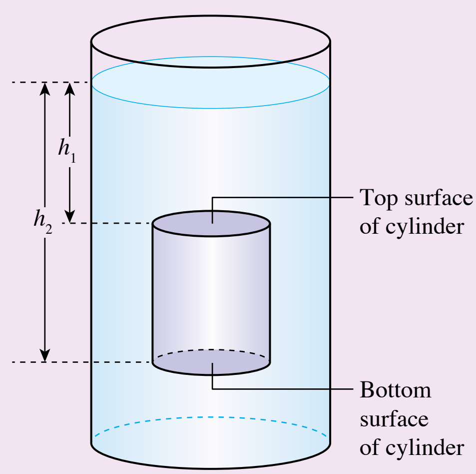


Figure 2.27

Buoyant force is the **force acting upwards on an object immersed in a liquid when there is pressure difference between the lower surface and upper surface of the object.** The formula for buoyant force can be derived as follows:

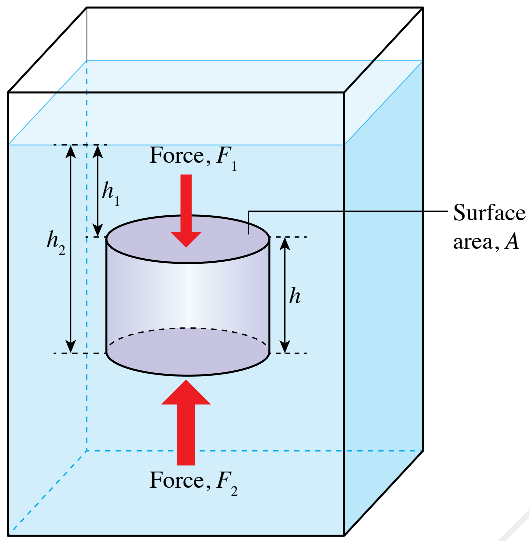


***Figure 2.28** Cylinder fully submerged in a liquid*

Info GALLERY

Fluids consist of liquids and gases. Archimedes' principle is usually applied to liquids because liquids have a higher density than gases. However, Archimedes' principle should be applied to gases in conditions where the magnitude of the buoyant force cannot be neglected compared to the weight of the object. An example of this is the motion of hot air balloons.

Pressure on the top surface, $P_1 = h_1 \rho g$

Force acting on the top surface, $F_1 = P_1 A$
$= h_1 \rho g A$

Pressure on the bottom surface, $P_2 = h_2 \rho g$

Force acting on the bottom surface, $F_2 = P_2 A$
$= h_2 \rho g A$

Resultant force, F (upwards) $= F_2 - F_1$
$= h_2 \rho g A - h_1 \rho g A$
$= \rho A (h_2 - h_1) g$
$= \rho A h g$
$= \rho V g$

This resultant force is the buoyant force, F_B.

BRIGHT Info

Height of cylinder, $h = (h_2 - h_1)$
Volume of cylinder, $V = Ah$
$V = A(h_2 - h_1)$,
The volume of cylinder is the same as the volume of water displaced.

BRIGHT Info

Since $\rho = \frac{m}{V}$, the mass of water displaced is $m = \rho V$.

Weight of water displaced,
$W = mg$
$W = \rho V g$

Archimedes' principle **states that an object which is partially or fully immersed in a fluid will experience a buoyant force equal to the weight of fluid displaced.**

Buoyant force = Weight of fluid displaced
$F_B = \rho V g$

SCAN ME
EduwebTV: Archimedes' principle
http://bit.ly/2t4fBXY

Experiment 2.3

Inference: Buoyant force depends on weight of liquid displaced

Hypothesis: The greater the weight of liquid displaced, the greater the buoyant force

Aim: To determine the relationship between the buoyant force and the weight of liquid displaced

Variables:

(a) Manipulated: Weight of water displaced
(b) Responding: Buoyant force
(c) Constant: Density of water

Apparatus: Slotted weights, Eureka can, beaker, spring balance, electronic balance, retort stand and wooden block

Material: Water

Procedure:

1. Set up the apparatus as shown in Figure 2.29.

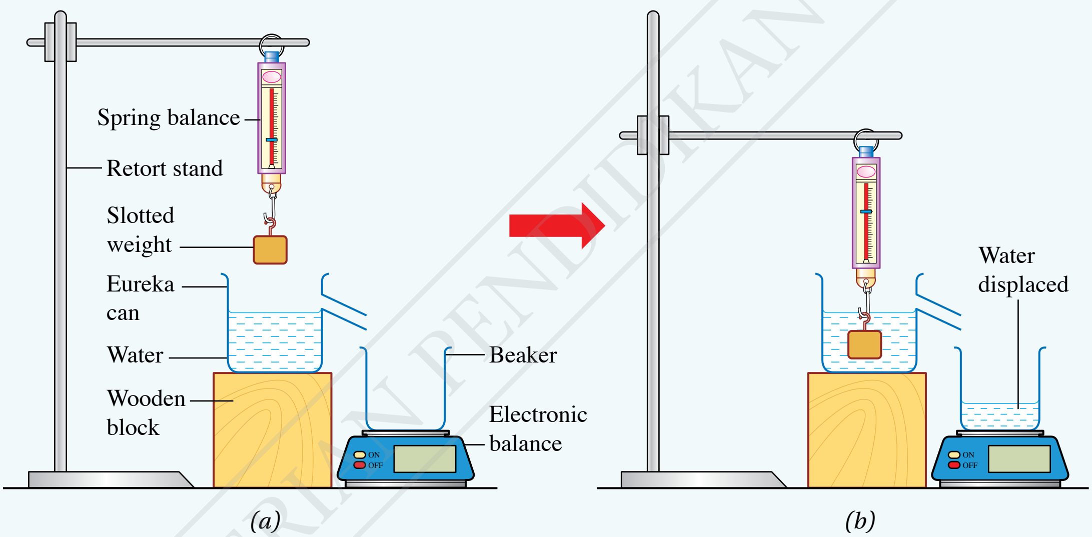


Figure 2.29

2. Hang a 100 g slotted weight on the spring balance. Record the weight of the slotted weight in the air, W_A in Table 2.6.
3. Place the beaker on the electronic balance. Reset the reading of the electronic balance to zero.
4. Immerse the slotted weight fully into the water. Record the weight of the slotted weight in water, W_W.
5. Calculate the buoyant force, $F_B = W_A - W_W$.
6. From the reading of the electronic balance, calculate the weight of water displaced, W_D. [Assume 1 kg = 10 N]
7. Repeat steps 2 to 5 using slotted weights of mass 200 g, 300 g, 400 g and 500 g.
8. Record all your results in Table 2.6.

Results:

Table 2.6

Weight in the air, W_A / N	Weight in water, W_W / N	Weight of water displaced, W_D / N	Buoyant force, F_B / N

Data analysis:

1. Plot the graph of W_D against F_B.
2. Calculate the gradient of the graph.

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. What is the value of the gradient of the graph?
2. State the relationship between the buoyant force and the weight of water displaced based on the results of the experiment.

Figure 2.30 shows the flow and relationship between the concepts involved in Experiment 2.3.

Object in the air	Object submerged in liquid	Object displaces liquid	Object experiences apparent loss in weight	Buoyant force acts on object
Weight of object in air is the actual weight of object	Weight of object in liquid is the apparent weight of object	Volume of liquid displaced = volume of the submerged part of the object	Apparent loss in weight of an object = weight of an object in the air – weight of an object in liquid	Buoyant force = weight of liquid displaced

***Figure 2.30** Relationship between concepts that explain buoyant force and the weight of liquid displaced*

Buoyant force = Weight of liquid displaced
= Apparent loss in weight

Relationship between the Equilibrium of Forces and the State of Floatation of an Object in a Fluid

When an object is submerged in a fluid, the object experiences two forces: the weight of the object, W due to gravity and the buoyant force, F_B due to the fluid displaced. The state of floatation of the object is determined by the relative magnitudes of the two forces.
Figure 2.31 summarises the state of floatation of an object in a fluid.

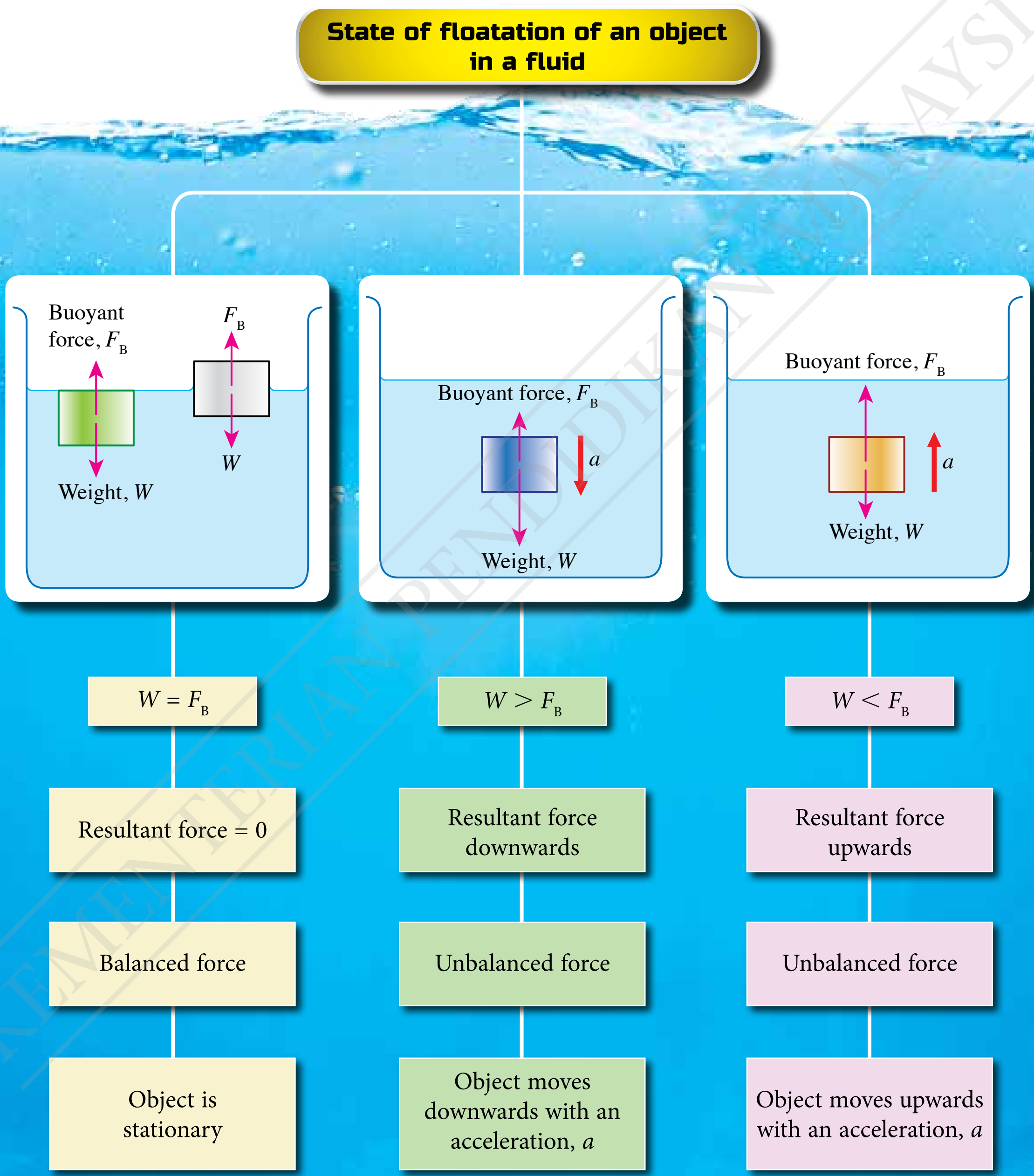


***Figure 2.31** State of floatation of an object in a fluid*

Figure 2.32 shows the forces acting on a ship floating on the surface of the sea.

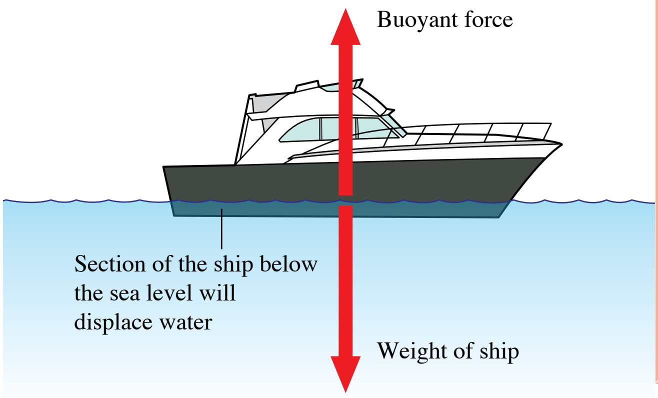


Figure 2.32 *Ship floating on the sea*

Forces acting on the ship are in equilibrium. The resultant force on the ship is zero.
Hence, weight of ship = buoyant force

Based on Archimedes' principle,
Buoyant force = weight of water displaced

Therefore,
Weight of ship = weight of water displaced

Volume of sea water displaced = volume of the section of the ship immersed in sea water

This shows that an object floating on the surface of water needs to displace an amount of water which has the same weight as the weight of the object.

Info GALLERY

A ship can float on the vast sea or a narrow canal if there is enough water to displace until the weight of water displaced is equal to the weight of the ship.

Applications of Archimedes' Principle in Daily Life

A hydrometer is a measuring instrument that applies Archimedes' principle to measure the density of liquids. The hydrometer will float at different levels of depth in liquids with different densities as shown in Figure 2.33. When the hydrometer is stationary in a liquid, the weight of liquid displaced is equal to the weight of the hydrometer. In a less dense liquid, a larger section of the hydrometer is immersed in the liquid to displace a larger volume of liquid, and vice versa. Figure 2.34 shows a milk hydrometer that is commonly used at milk manufacturing factories to test the dilution of milk.

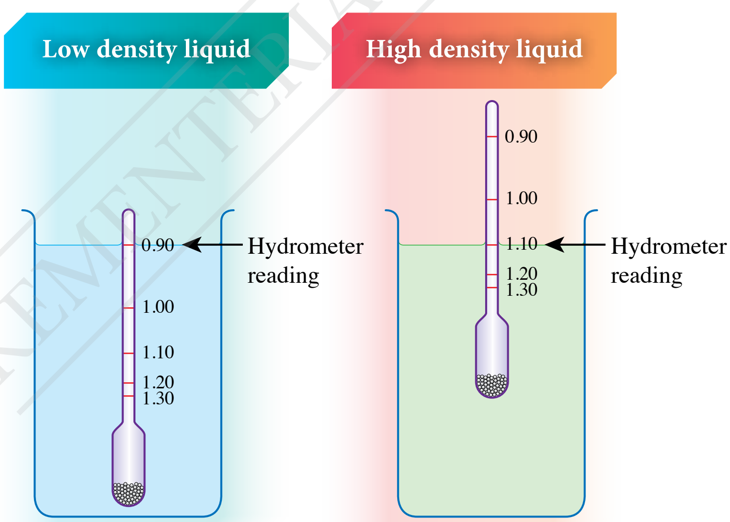
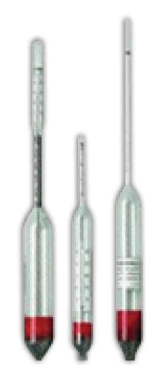


Figure 2.33 *Measuring the density of liquid using a hydrometer*



- Used in milk manufacturing factories
- To test the dilution of milk
- Range: 1.000 – 1.240 g cm^{-3}

Figure 2.34 *Milk hydrometer*

LS 2.5.2 2.5.3

Activity 2.10

Aim: To use a hydrometer to determine the density of various liquids

Apparatus: Hydrometer and three 100 ml measuring cylinders

Materials: Distilled water, olive oil and glycerine

Instructions:

1. Fill three measuring cylinders with distilled water, olive oil and glycerine respectively.
2. Immerse the hydrometer slowly into the distilled water. Record the reading of the hydrometer when it is stationary.
3. Remove the hydrometer. Clean and dry the hydrometer.
4. Repeat steps 2 and 3 for olive oil and glycerine.
5. Record all your readings in Table 2.7.

Info GALLERY

A hydrometer measures specific gravity, that is the density of a liquid relative to the density of water. The hydrometer reading is the density of the liquid if the density of water is 1.00 g cm^{-3}.

Results:

Table 2.7

Type of liquid	Density / g cm^{-3}
Distilled water	
Olive oil	
Glycerine	

Discussion:

1. Why does the scale of the hydrometer not start from zero?
2. Why is the smaller scale reading of the hydrometer at the top end of the tube?
3. State one precaution while carrying out this activity.

How does a submarine submerge and emerge in the sea? Carry out Activity 2.11 to show the working principle of ballast tanks in submarines.

Activity 2.11

STEM ISS

Aim: To construct a Cartesian diver to show the working principle of ballast tanks in a submarine

Apparatus: 1.5 litre plastic bottle and a test tube that can be inserted into the plastic bottle

Materials: Masking tape, water and food colouring

Instructions:

1. Prepare the apparatus as shown in Figure 2.35(a).
2. Fill the test tube with water until it is three quarter full. Invert the test tube and quickly put it inside the plastic bottle. The test tube should float on the surface of the water as shown in Figure 2.35(b).

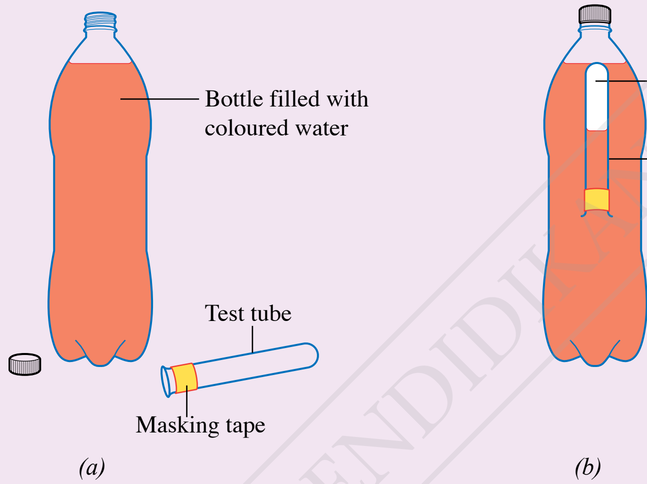


Figure 2.35

3. Observe the level of water in the test tube.
4. Squeeze the lower part of the bottle so that the test tube sinks slowly to the base of the bottle. Observe the level of water in the test tube.
5. Slowly release the pressure on the bottle so that the test tube moves up again to the surface of the water. Observe the change in the level of water in the test tube.

Discussion:

1. (a) Compare the level of water in the test tube when the test tube is floating on the surface and when it sinks to the base of the bottle.
   (b) Compare the volume of water in the test tube when it is floating on the surface and when it sinks to the base of the bottle.
2. How does the volume of air in the test tube change when the test tube moves up from the base of the bottle to the surface of the water?
3. Explain the movement of the test tube by applying Archimedes' principle.

SCAN ME
Video of a Cartesian diver
http://bit.ly/2uwbnbS

Figure 2.36 shows the ballast tanks found in a submarine. The working principle of the ballast tanks in a submarine is similar to the working principle of the Cartesian diver in Activity 2.11.

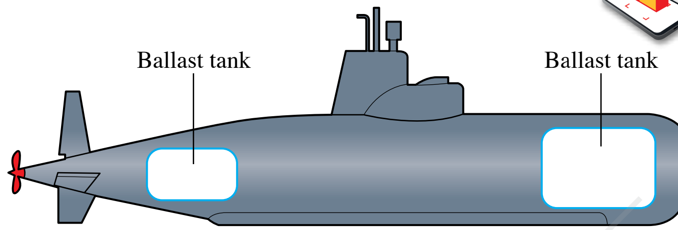
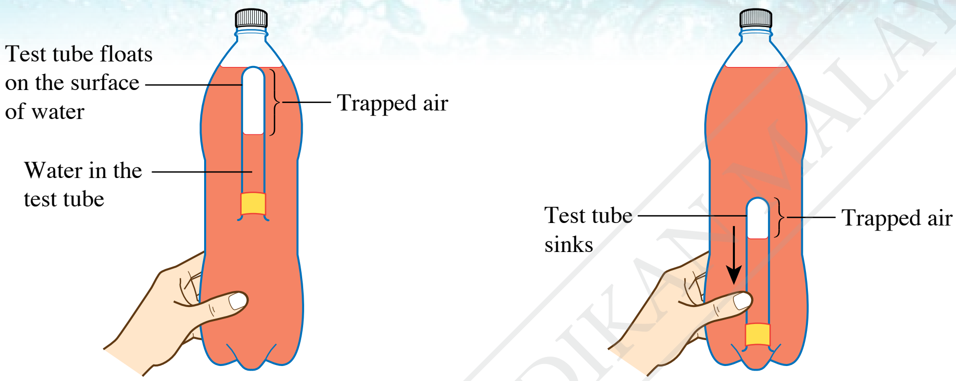


Figure 2.36 *Ballast tanks in a submarine*



(a) Test tube floating on the surface of water

(b) Test tube sinks in the water

Figure 2.37 *Working principle of ballast tanks in a submarine*

Figure 2.37 shows the working principle of ballast tanks using the Cartesian diver. When the test tube is floating on the surface of the water, the total weight of the test tube and the weight of the water in it is equal to the buoyant force. The pressure exerted on the wall of the bottle causes water to be pushed into the test tube. This causes the weight of water in the test tube to increase. Therefore, the total weight of the test tube and the weight of the water in it is greater than the buoyant force. A resultant force acting downwards is produced and causes the test tube to sink to the base of the bottle.

Activity 2.12

ISS / ICS

Aim: To search for information on the applications of Archimedes' principle

Instructions:

1. Carry out a Gallery Walk activity.
2. Scan the QR code to watch the video on the applications of Archimedes' principle for the three examples given.
3. Then, scan the QR code given on page 75 or refer to other reference materials to obtain further information on:

SCAN ME
Video on the applications of Archimedes' principle
http://bit.ly/35AE3gM

LS 2.5.3

(a) Ship and Plimsoll line

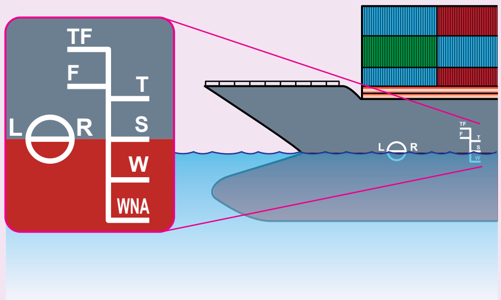


Figure 2.38

SCAN ME
Ship and Plimsoll line
https://bit.ly/2XVxLGv

(b) Submarine

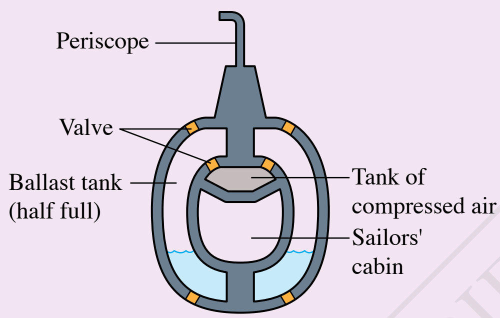


Figure 2.39

SCAN ME
Submarine
http://bit.ly/2DLLcPI

(c) Hot air balloon

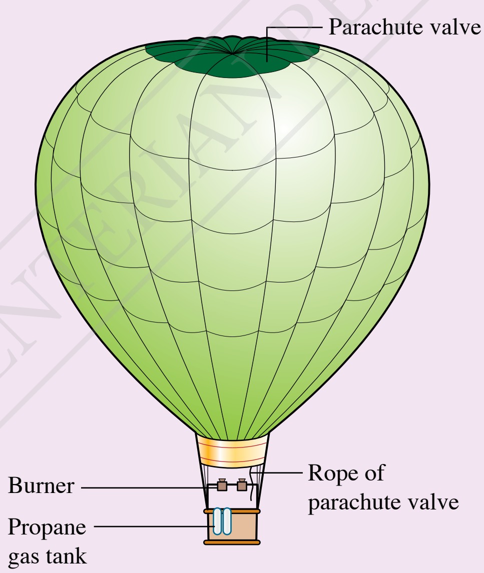


Figure 2.40

BRIGHT Info

Balloon goes up when:
- parachute valve is closed
- burner is ignited
- air is heated up
- weight of balloon $<$ buoyant force

Balloon comes down when:
- parachute valve is opened
- hot air is released
- burner is turned off
- weight of balloon $>$ buoyant force

SCAN ME
Hot air balloon
http://bit.ly/2PeeL1Y

4. Present your findings in the form of a multimedia presentation entitled ‘Applications of Archimedes' Principle in Daily Life’.

Solving Problems Involving Archimedes' Principle and Buoyancy

When an object is in a fluid:

Buoyant force = weight of fluid displaced

$$F_B = \rho V g$$

When an object is floating in a fluid:

Buoyant force = weight of object
= weight of fluid displaced

LET'S ANSWER

http://bit.ly/35JwZyh

Example 1

Figure 2.41 shows a line L on a boat. The volume of the boat below the line L is 2.8 m^3. The mass of the boat is 600 kg. What is the weight of the maximum load that can be carried by the boat?
[Density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

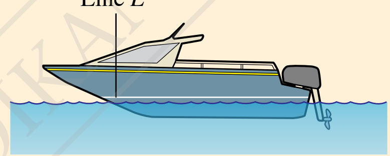


Figure 2.41

Solution

Step 1:	Step 2:	Step 3:	Step 4:
Identify the problem	Identify the information given	Identify the formula that can be used	Solve the problem numerically

1. Let the weight of maximum load that can be carried = B

2. Volume of boat below line L = 2.8 m^3
When the boat floats with a depth of immersion at line L, volume of water displaced, V = 2.8 m^3
Density of water, ρ = 1 000 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}
Mass of boat, m = 600 kg

3. Weight of boat, $W = mg$
$W + B$ = buoyant force
= weight of water displaced
$= \rho V g$

4. $W = 600 \times 9.81$
$= 5\ 886$ N
$5\ 886 + B = 1\ 000 \times 2.8 \times 9.81$
$B = 27\ 468 - 5\ 886$
$= 21\ 582$ N

Example 2

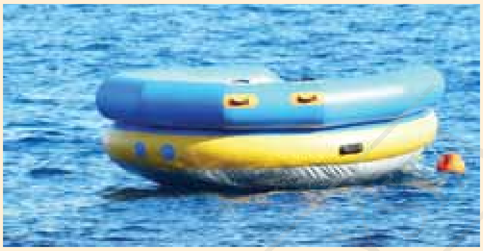
Photograph 2.8 shows a raft floating in the sea. The mass of the raft is 54 kg and the density of sea water is 1 080 kg m^{-3}.

[Gravitational acceleration, g = 9.81 m s^{-2}]

(a) What is the weight of the raft?

(b) Compare the weight of the raft with the weight of sea water displaced.

(c) Calculate the volume of water displaced by the raft.



***Photograph 2.8** Raft*

Solution

(a) Weight of raft, W

Mass of raft, m = 54 kg

Gravitational acceleration, g = 9.81 m s^{-2}

$$W = mg$$
$$= 54 \times 9.81$$
$$= 529.74 \text{ N}$$

(b) The raft is in equilibrium

Weight of raft = buoyant force

According to Archimedes' principle,

buoyant force = weight of water displaced

Therefore,

weight of raft = weight of sea water displaced

(c) Volume of water displaced, V

Weight of raft, W = 529.74 N

Density of sea water, ρ = 1 080 kg m^{-3}

Weight of raft = weight of sea water displaced

$$W = \rho V g$$
$$529.74 = 1\,080 \times V \times 9.81$$
$$V = \frac{529.74}{1\,080 \times 9.81}$$
$$= 0.05 \text{ m}^3$$

Formative Practice 2.5

1. State Archimedes' principle.

2. A small boat displaces 3.8×10^{-2} m^3 of sea water. Calculate the buoyant force acting on the boat.
[Density of sea water, ρ = 1 050 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

3. Figure 2.42 shows a block of mass 0.48 kg and volume 5.0×10^{-4} m^3 being held in water. The density of water is 1 000 kg m^{-3}. Determine the movement of the block when it is released.
[Density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

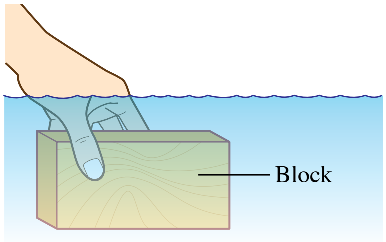


Figure 2.42

2.6 Bernoulli's Principle

Figure 2.43 shows a pupil trying to lift a folded piece of paper by blowing air below the paper. When he blew hard below the paper, the paper was pressed close to the surface of the table. It is due to the difference in velocity of air and pressure.

SCAN ME
Video on the effect of blowing air on a piece of paper
http://bit.ly/2QGxvce

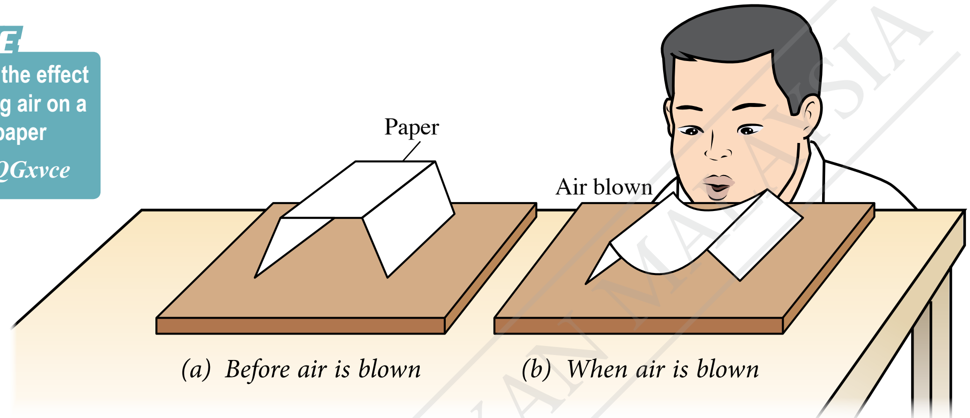


Figure 2.43 *Effect of blowing air below a folded piece of paper*

Activity 2.13

Aim: To generate the idea that high velocity of fluids creates a region of low pressure

Apparatus: Retort stand and Venturi tube

Materials: A4 paper, two balloons, thread, water and drinking straw

Instructions:

A Paper

1. Hold a piece of A4 paper with both hands and blow across the top surface of the paper as shown in Photograph 2.9.
2. Observe the movement of the paper.

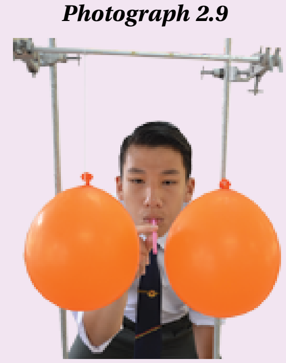
Photograph 2.9

Discussion:

1. Compare the velocity of air above and below the paper.
2. Describe the movement of the paper when air is blown above it.

B Balloons

1. Hang two inflated balloons near each other as shown in Photograph 2.10.
2. Use a drinking straw to blow air into the space between the two balloons.
3. Observe the movement of the balloons.



Photograph 2.10

Discussion:

1. Compare the velocity of air in between the two balloons with the velocity of air around them.
2. Describe the movement of the two balloons.

C Venturi tube

1. Set up the Venturi tube as shown in Figure 2.44.

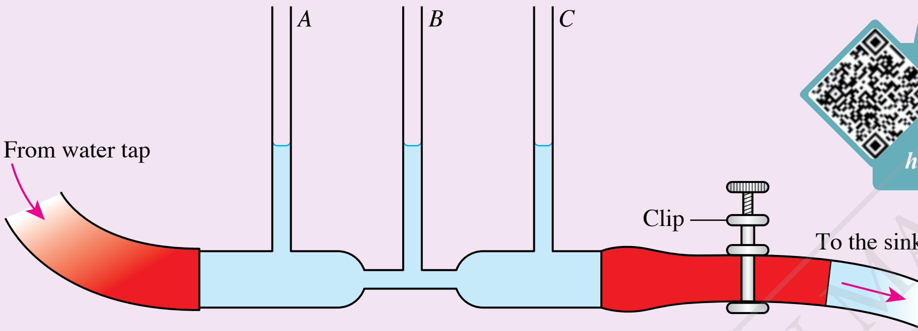


Figure 2.44

2. Turn on the water tap and let water flow into the Venturi tube until the water levels in the vertical tubes *A*, *B* and *C* are half the heights of the tubes.
3. Open the clip to allow the water to flow out into the sink. Adjust the water tap and the clip to control the water flow until the water levels in the vertical tubes are stable. Observe the heights of the water columns in the tubes.

Discussion:

1. What is the relationship between the height of the water column in the three tubes with the water pressure?
2. Compare the heights of the water columns in tubes *A*, *B* and *C*.

The observations in Activity 2.13 are caused by the effect of fluid velocity on the pressure in the fluid. The flow of air at high velocity produces a region of low pressure compared to the pressure of the surroundings. The pressure difference produces a force that acts from the region of higher pressure towards the region of lower pressure. The effect of the action of this force can be seen in the movement of the paper and balloons as shown in Figure 2.45 and Figure 2.46.

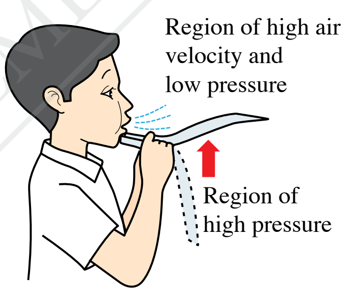


Figure 2.45 *Paper pushed upwards*

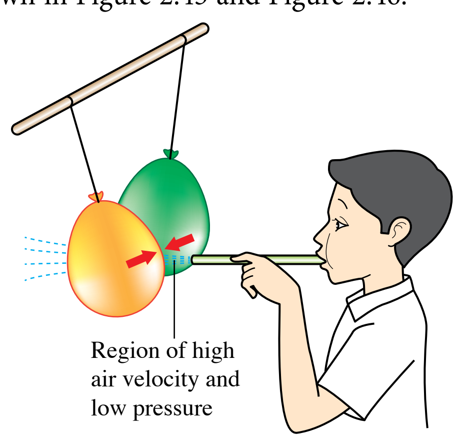


Figure 2.46 *Balloons move closer to each other*

In a Venturi tube, the heights of the water columns in tubes *A*, *B* and *C* show the pressure at *X*, *Y* and *Z* respectively as shown in Figure 2.47.

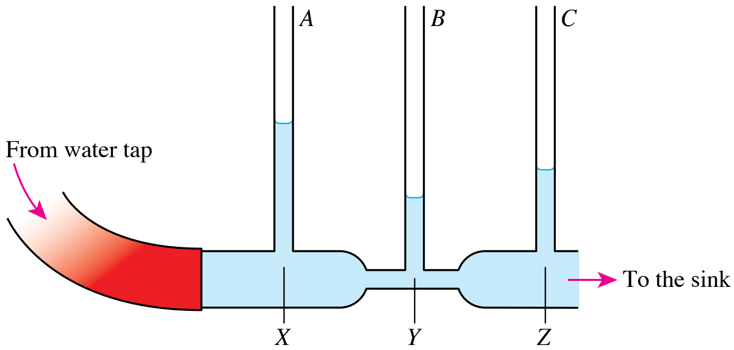


***Figure 2.47** Venturi tube*

The pressure at *X* is higher than the pressure at *Z* because water flows from *X* to *Z*. Therefore, the height of the water column in tube *A* is higher than the height of the water column in tube *C*.

The velocity of water depends on the cross-sectional area of the tube. The smaller the cross-sectional area, the higher the velocity of the water. From *X* to *Y*, the velocity of the water increases and the water pressure decreases. From *Y* to *Z*, the velocity of the water decreases and the water pressure increases.

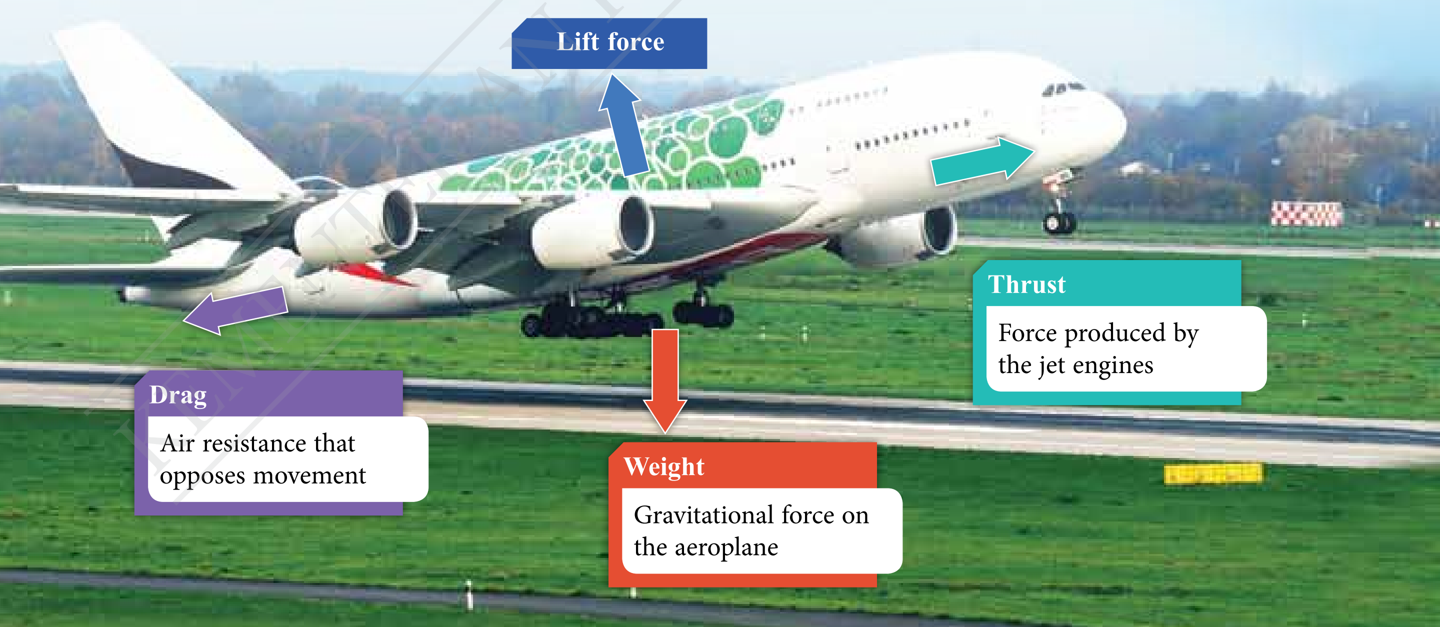
Bernoulli's principle states that when the velocity of a fluid increases, the pressure in the fluid decreases and vice versa.

SCAN ME
EduwebTV: Bernoulli's Principle
http://bit.ly/35IDnG6

Info GALLERY
When a fluid flows continuously in a pipe, the smaller the diameter of the pipe, the higher the velocity of fluid.

Lift Force

Photograph 2.24 shows an aeroplane taking off at the airport. How is the lift force produced to lift the aeroplane up into the air?



Photograph 2.11 Aeroplane taking off at the airport

LS 2.6.1 2.6.2

Activity 2.14

Aim: To observe the effect of lift force

Apparatus: Filter funnel, silicone tube, aerofoil kit and retort stand

Material: Ping pong ball

Instructions:

A Filter funnel with a ping pong ball

1. Set up the apparatus as shown in Figure 2.48. Place the ping pong ball in the inverted filter funnel.
2. Hold the filter funnel and blow hard through the silicone tube connected to the filter funnel. Observe the movement of the ping pong ball.

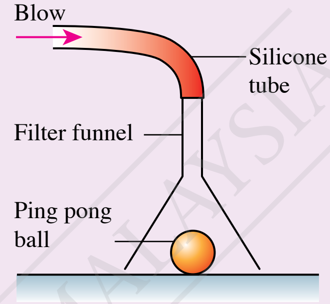


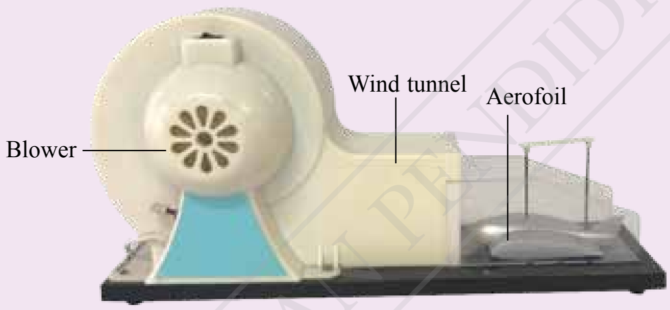
Figure 2.48

Discussion:

1. Identify the region where air flows with high velocity.
2. What happens to the ping pong ball? Explain your answer.

B Aerofoil kit

1. Set up the aerofoil kit as shown in Photograph 2.12.



Photograph 2.12

Let's Try

Paper aeroplane

http://bit.ly/306FSks

2. Switch on the blower so that a stream of air blows past the aerofoil. Observe the motion of the aerofoil.
3. Switch off the blower. Observe the motion of the aerofoil.

Discussion:

1. What happens to the aerofoil when air is blown?
2. What is the direction of the resultant force on the aerofoil?
3. Compare the pressure in the air that flows over the top surface and the bottom surface of the aerofoil.
4. Identify the regions of air flow with high velocity and low velocity around the aerofoil.

SCAN ME

Video of aerofoil kit

http://bit.ly/2FAA35c

Effect of Lift Force on a Ping Pong Ball

Lift force is produced from the difference in pressure caused by the flow of air at different velocities. Air flowing at a high velocity above the ping pong ball as shown in Figure 2.49 produces a region of low pressure. The difference between the high pressure below the ball and the low pressure above the ball produces a resultant force upwards. This resultant force is the lift force that lifts up the ping pong ball.

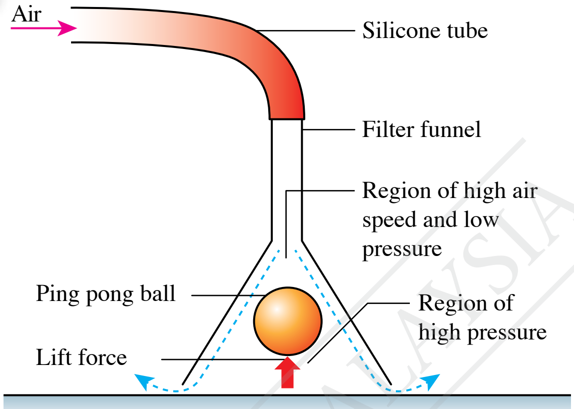


Figure 2.49 *Effect of lift force on the ping pong ball*

Production of Lift Force by the Aerofoil

The aerofoil shape of the wing of an aeroplane causes air to flow at different speeds past the top section and the bottom section. According to Bernoulli's principle, the higher air velocity at the top section produces a region of low pressure while the lower air velocity at the bottom section produces a region of high pressure. This difference in pressure produces a lift force acting upwards on the aeroplane as shown in Figure 2.50.

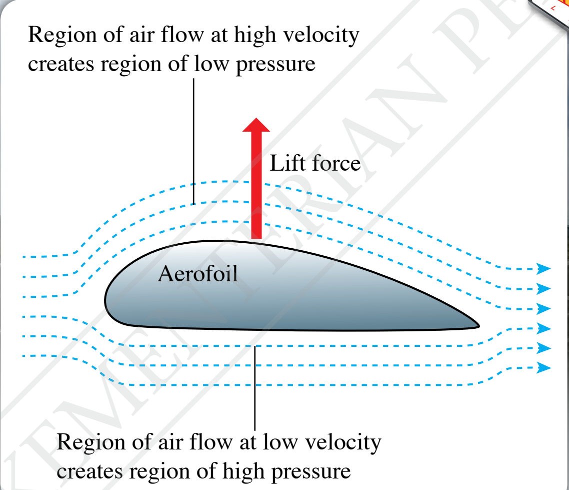


Figure 2.50 *Production of lift force by the aerofoil*

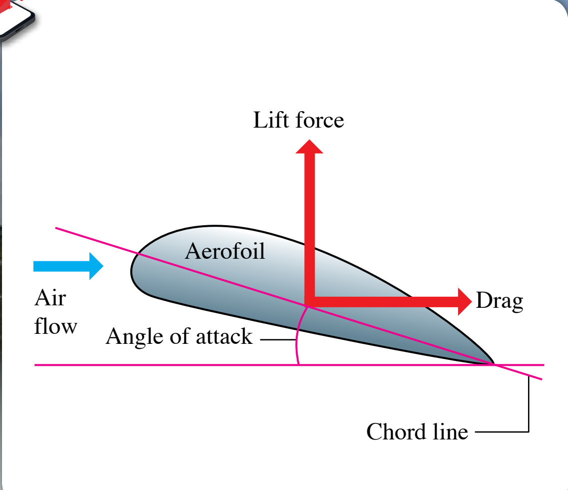


Figure 2.51 *Angle of attack on aerofoil*

The total lift force acting on the aeroplane is also affected by the angle of attack as shown in Figure 2.51. When the aerofoil is at a certain angle of attack, the aerofoil exerts a force on the air flow. According to Newton's Third Law of Motion, a reaction force will act on the wing of the aeroplane and contribute to the lift force that acts on the aeroplane.

Applications of Bernoulli's Principle in Daily Life

Bernoulli's principle is applied widely in various fields from small devices in homes to large commercial aircraft.

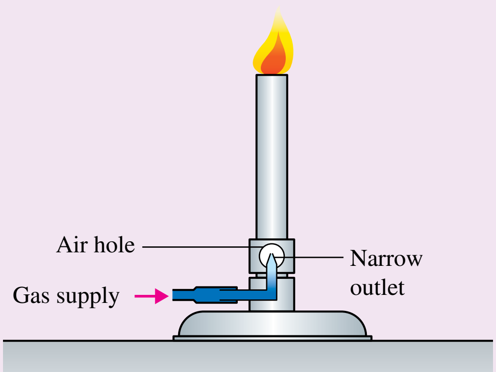
Activity 2.15

ISS / ICS

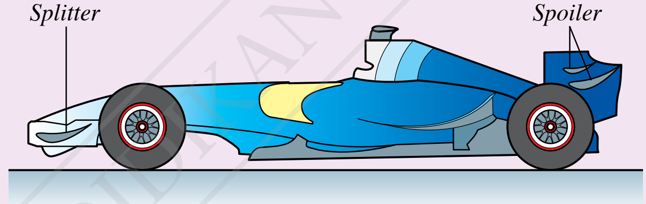
Aim: To search for information on applications of Bernoulli's principle in daily life

Instructions:

1. Carry out this activity in groups.
2. Study Figure 2.52 that shows four applications of Bernoulli's principle in daily life.

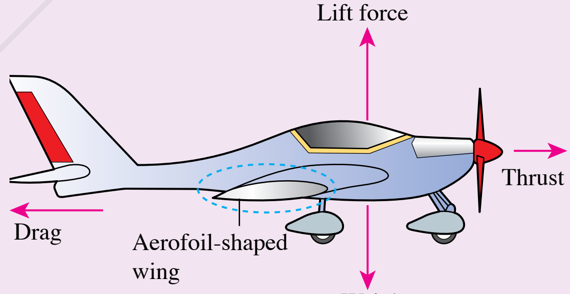


(a) Mixture of gas and air in a Bunsen burner



(b) Production of a downforce for racing cars

(c) Curved path of a football



(d) Production of lift force by the aerofoil and the angle of attack on an aeroplane

***Figure 2.52** Applications of Bernoulli's principle in daily life*

3. For each application, search for further information.
4. Prepare a multimedia report of your findings.

SCAN ME
Application of Bernoulli's principle
http://bit.ly/35ez4TI

Activity 2.16

STEM | ISS | ICS

Aim: To design a paper aeroplane based on the applications of Bernoulli's principle and Newton's Third Law of Motion

Instructions:

1. Carry out this activity in groups.
2. Gather information on paper aeroplanes from reading materials or websites covering the following:
   (a) materials required
   (b) design of a paper aeroplane that can fly far for a long time
   (c) the way to launch the paper aeroplane
   (d) direction of wind during launch
3. Use the K-W-L Data Strategy Form.
4. Sketch a diagram showing the design of the paper aeroplane.
5. Build the paper aeroplane according to the suggested design.
6. Launch the paper aeroplane and observe its flight.
7. Identify the aspects of design and the method of launching that requires improvement.
8. Discuss steps for improvement that can be carried out.
9. Build a new paper aeroplane and test its flight.
10. Present the design and the paper aeroplane.

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

SCAN ME
Guideline to design a paper aeroplane
https://go.nasa.gov/366nLNb

Note
Take into consideration Bernoulli's Principle and Newton's Third Law of Motion.

Formative Practice 2.6

1. State Bernoulli's principle.
2. Explain three ways of using a piece of A4 paper to demonstrate Bernoulli's principle.
3. Figure 2.53 shows the cross section of the wing of an aeroplane when the aeroplane is accelerating along the runway and when it begins to take off from the runway.

(a) Accelerating along the runway *(b) Taking off from the runway*

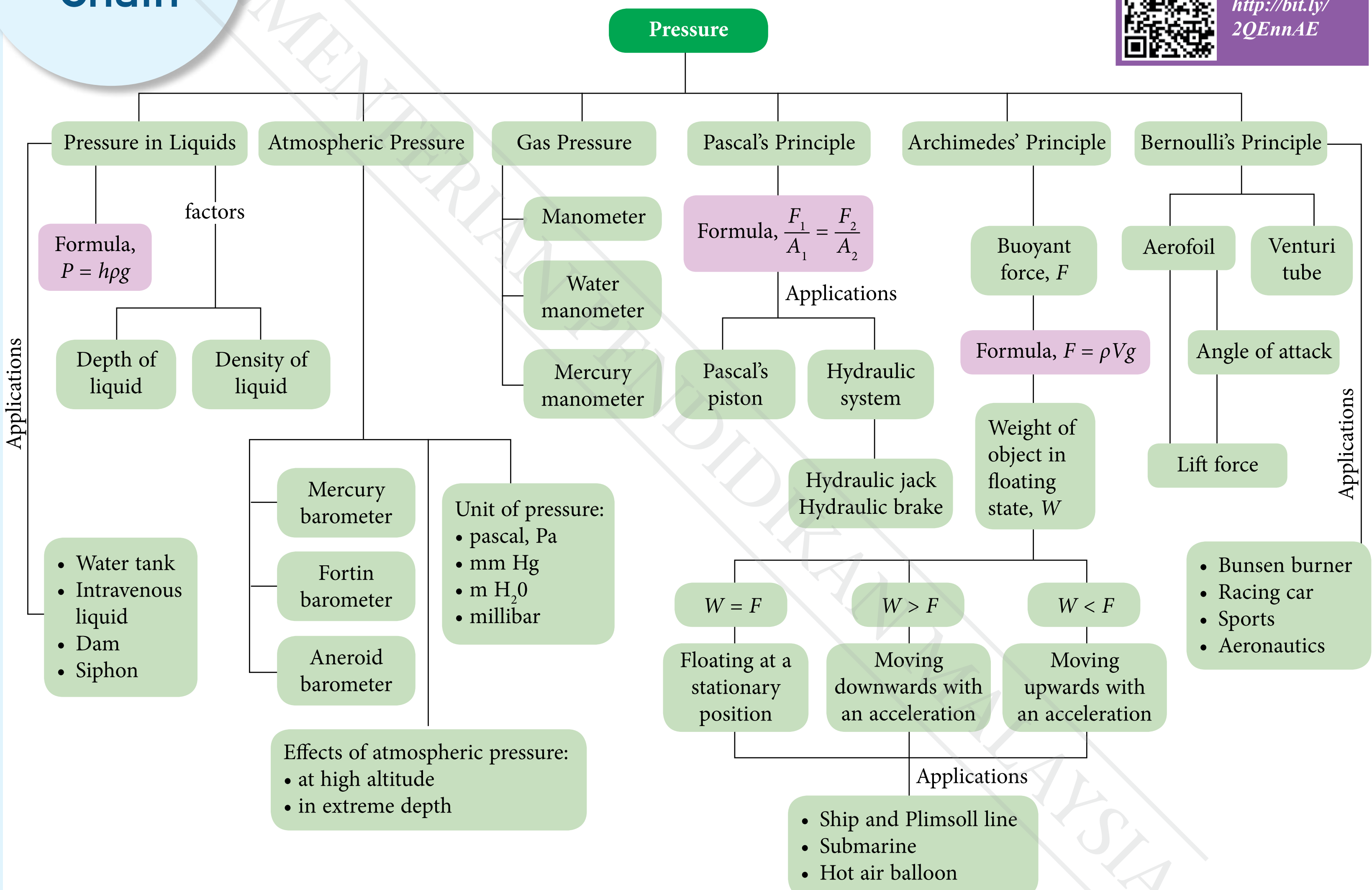
Figure 2.53

With the aid of labelled diagrams, explain how the lift force is produced when the aeroplane takes off.

LS 2.6.3

Concept Chain

Interactive Games
http://bit.ly/2QEnnAE



Self-Reflection

SCAN ME
Download and print Self-Reflection
http://bit.ly/35BhLeJ

1. New things I have learnt in the chapter on 'Pressure' are ______.
2. The most interesting thing I have learnt in this chapter is ______.
3. The things I still do not fully understand are ______.
4. My performance in this chapter.

Poor | 1 | 2 | 3 | 4 | 5 | Very good

5. I need to ______ to improve my performance in this chapter.

QUIZ PORTAL
http://bit.ly/37UiPw0

Summative Practice

1. (a) Derive the formula for pressure at depth h in a liquid with density ρ.
   (b) Calculate the pressure at depth of 24 m in a lake that contains water with a density of 1 120 kg m^{-3}.
   [Gravitational acceleration, g = 9.81 m s^{-2}]

2. Figure 1 shows the apparatus for comparing the densities of two types of liquid after some air is sucked out of the apparatus.
   (a) Explain why the pressure at point A is equal to the pressure at point B.
   (b) Calculate the density of liquid X.
   [Density of water, ρ = 1 000 kg m^{-3}]

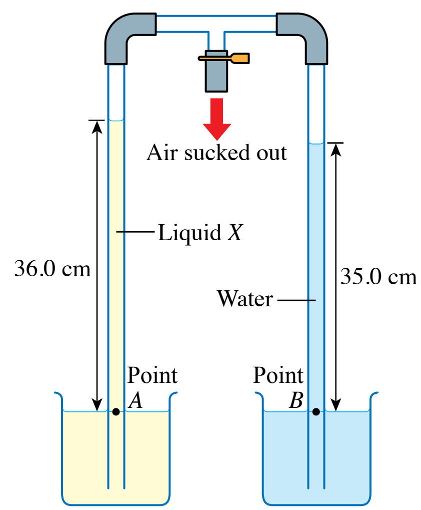


Figure 1

3. Compare and contrast the existence of pressure in the liquids and the atmospheric pressure.

4. Figure 2 shows a U-tube containing mercury.

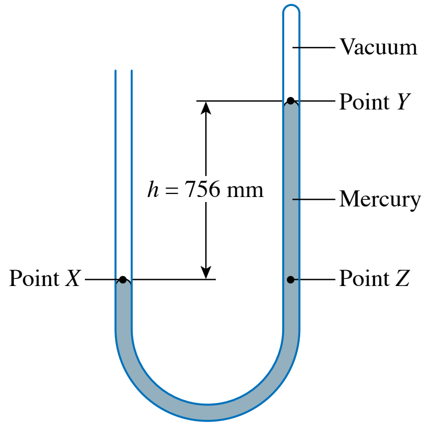


Figure 2

(a) What is the pressure acting on point X and point Y on the surface of mercury?

(b) By comparing the pressure at point X and point Z, explain why the height of the mercury column, h is a measure of atmospheric pressure.

(c) Determine the atmospheric pressure in Pa.
[Density of mercury, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

5. A mercury manometer is connected to a cylinder containing gas. The gas pressure in the cylinder and the atmospheric pressure are 180 kPa and 103 kPa respectively.
Sketch a diagram of the manometer connected to the gas cylinder. Determine the height of the mercury column in your sketch.
[Density of mercury, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

6. In a hydraulic brake system, the driver of the vehicle applies a force of 80 N on the brake pedal. This force is multiplied by the mechanical lever system to be a 400 N input force on the hydraulic liquid in the master cylinder. The diameter of the master cylinder and the diameter of the slave cylinder are 0.8 cm and 2.5 cm respectively.

(a) Calculate the pressure on the hydraulic liquid in the master cylinder.

(b) State the principle that enables pressure to be transmitted from the master cylinder to the slave cylinder.

(c) What is the braking force produced at the slave cylinder to stop the rotation of the wheel?

7. A wooden block with volume 3.24 × 10^{-3} m^3 is released in a tank of water. By doing the relevant calculations, sketch the state of buoyancy of the wooden block in the tank.
[Density of wood, ρ = 920 kg m^{-3}, density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

8. Figure 3 shows two designs of a hydraulic jack, *X* and *Y* which were suggested by a technician.

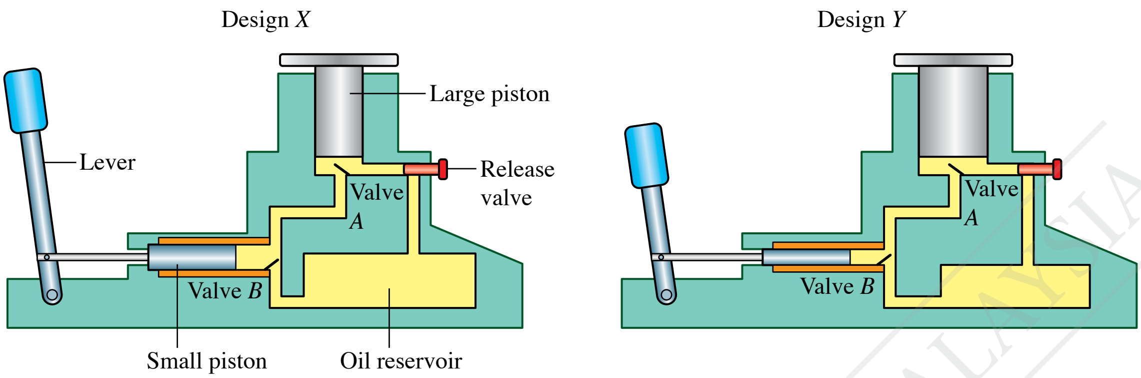


Figure 3

(a) By referring to design *X*, describe the operation of the hydraulic jack.

(b) Study design *X* and design *Y*. Compare the advantages and disadvantages of design *X* and design *Y*.

(c) Based on your answer in 8(b), suggest a design of hydraulic jack that can produce a larger output force and lift a load to a greater height.

9. A hot air balloon is in a stationary position in the air.

(a) State Archimedes' principle.

(b) Explain the relationship between the weight of the balloon and the weight of air displaced.

(c) When the flame of the burner is extinguished and the parachute valve is opened, the balloon begins to descend. Explain how this action enables the balloon to descend to the ground.

10. Figure 4 and Figure 5 show the same metal blocks of mass 0.050 kg hanging from a spring balance, immersed in water and cooking oil respectively.

(a) Compare the pressure at point *A* and point *B* in Figure 4. Explain your answer.

(b) Explain how the difference in pressure in 10(a) exerts a buoyant force on the metal block.

(c) Calculate the density of cooking oil if the density of water is 1 000 kg m^{-3}.
[Gravitational acceleration, $g = 9.81$ m s^{-2}]

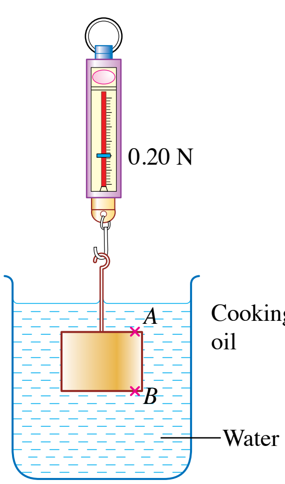


Figure 4

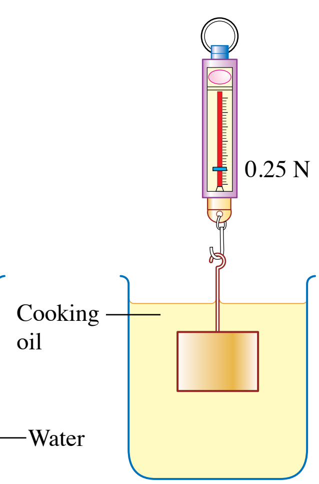


Figure 5

11. Photograph 1 shows a racing car that is stabilised by downforce while being driven at high speed.

Photograph 1

Explain the production of the downforce due to the air flowing past the:
(a) inverted aerofoil-shaped spoiler
(b) top and bottom sections of the car

21st Century Challenge

12. Figure 6 shows part of the hydraulic brake system of a car. A driver finds that the brake has to be pressed harder and further in to stop the car.

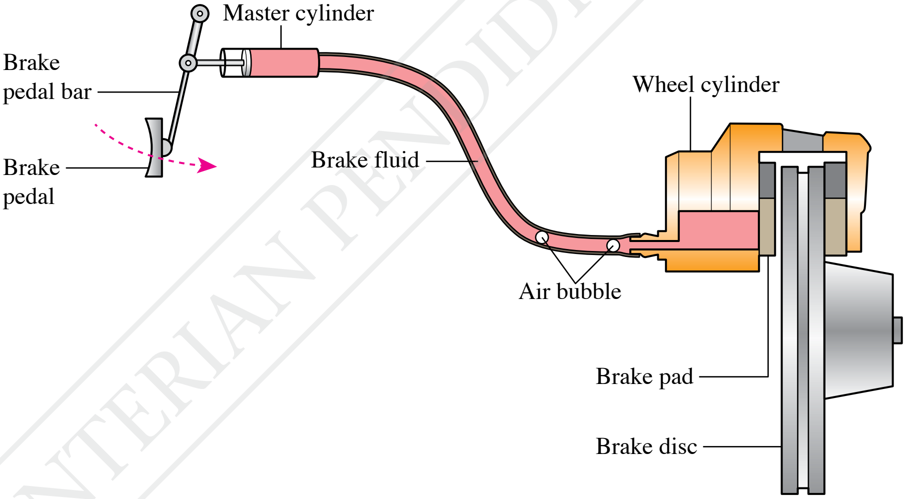


Figure 6

(a) Identify the weaknesses in the hydraulic brake system of the car.
(b) By using suitable physics concepts, suggest modifications to the brake system so that the car can be stopped more effectively. Your answer should include the following aspects:
(i) characteristics of the brake fluid
(ii) cross-sectional area of the master cylinder
(iii) cross-sectional area of the wheel cylinder
(iv) length of the brake pedal bar
(v) other suitable designs

CHAPTER 3

Electricity

How is electric field produced?

What are the factors affecting the resistance of a conducting wire?

What are the advantages of connecting dry cells in series and in parallel?

How can we reduce electrical energy consumption at home?

You will learn:

- **3.1** Current and Potential Difference
- **3.2** Resistance
- **3.3** Electromotive Force (e.m.f.) and Internal Resistance
- **3.4** Energy and Electrical Power

Learning Standards and List of Formulae in Chapter 3

Information Portal

https://bit.ly/32oAmeA

Tenaga Nasional Berhad (TNB) was expected to spend RM1.2 billion from 2018 to 2020 to install new smart meters in residential homes across the country. A smart meter is a device that allows the daily electricity usage to be recorded and converted to data that users can monitor through mobile applications. The device can collect and analyse data of electricity usage hourly. Electricity consumption data is collected and transmitted to the control centre through a radio frequency (RF). It allows users to monitor electricity consumption easily and reduces TNB's manpower in recording electricity consumption. Indirectly, this technology enhances the efficiency of electrical energy consumption in our country.

Importance of the Chapter

Careers in the Fourth Industrial Revolution (IR 4.0) require the need for software engineering skills to develope applications to meet the current market demands through two main platforms, namely Android and IOS. These platforms prioritise artificial intelligence software (AI) that makes decisions based on smart algorithms in electrical and electronic fields.

Futuristic Lens

https://bit.ly/2EtOII4

Power Line Communication (PLC) will become the digital data transmission method of the future between smart meters and the utility control center. This method allows the power consumption data and the usage profile of each home to be monitored online.

3.1 Current and Potential Difference

Observe Photograph 3.1 which shows the lightning phenomenon. How does the phenomenon occur? Recall the chapter on electricity which you studied in Form 2 Science.

Let's Recall
Electricity
https://bit.ly/2YCPNP0

***Photograph 3.1** The lightning phenomenon*

Electric Field

SCAN ME
EduwebTV: Electric field and charge flow
https://bit.ly/2Yzo2ac

When a charged comb is brought near to a fine stream of tap water, the stream of water bends towards the comb. This phenomenon indicates the existence of electric fields in our daily life. Can you list some other examples of the existence of electric fields?

(a) A fine stream of tap water is bent when a charged comb is brought near it

(b) Hair is attracted to a charged balloon

(c) Tiny pieces of paper are attracted to a charged plastic comb

(d) A charged drinking straw moves closer to an approaching finger

***Photograph 3.2** Examples of the existence of electric fields in daily life*

LS 3.1.1

Activity 3.1 Teacher's Demonstration

Aim: To study electric fields by using an electric field kit

Apparatus: Electric field kit and extra high tension (E.H.T.) power supply

Materials: Olive oil and semolina powder

Instructions:

1. Set up the apparatus as shown in Figure 3.1.

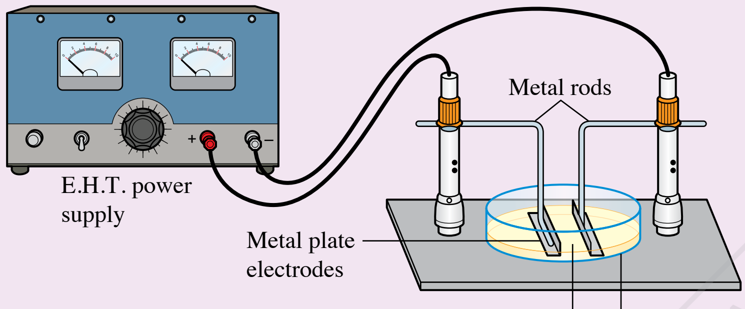


Figure 3.1

2. Scan the QR code and print Table 3.1.
3. Pour olive oil into a petri dish.
4. Sprinkle semolina powder on the surface of the olive oil.
5. Switch on the E.H.T. power supply and observe the movement of the semolina powder.
6. Record your observation in Table 3.1.
7. Repeat steps 3 to 6 with a pair of electrodes of different shapes as shown in Table 3.1.

Safety Precaution

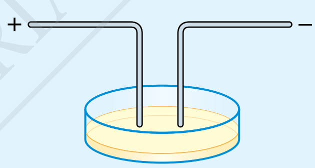
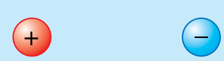
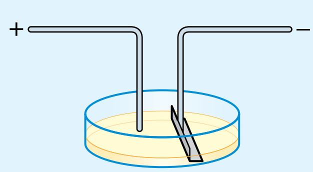
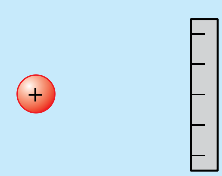
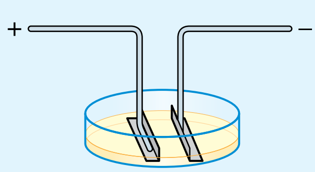
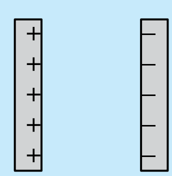
- Do not touch any metallic part while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observation is being recorded.

SCAN ME
Demonstration video of an electric field kit
https://bit.ly/2EIDqKb

SCAN ME
Worksheet (Table 3.1)
https://bit.ly/3b7dWT1

Results:

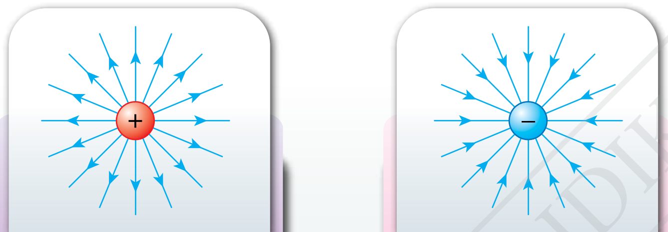
Table 3.1

Shape of electrodes	Electrodes	Electric field
Two point electrodes		
A point electrode and a plate electrode		
Two parallel plate electrodes		

Discussion:

1. Why is the E.H.T. power supply used in this activity?
2. What happens to the parallel plate electrodes when the E.H.T. power supply is switched on?
3. Why does the sprinkled semolina powder form a certain pattern when the E.H.T. power supply is switched on?
4. What is the function of olive oil in this activity?
5. Name other materials beside semolina powder that can be used in this activity.

Based on Activity 3.1, when the E.H.T. power supply is switched on, the two electrodes will be at different potentials. An electric field exists between the two electrodes. **An electric field is the region around a charged particle where any electric charge in the region will experience an electric force**. When semolina powder is placed in the electric field, it experiences an electric force. The pattern formed by the semolina powder shows the pattern of the electric field.



(a) A particle with positive charge

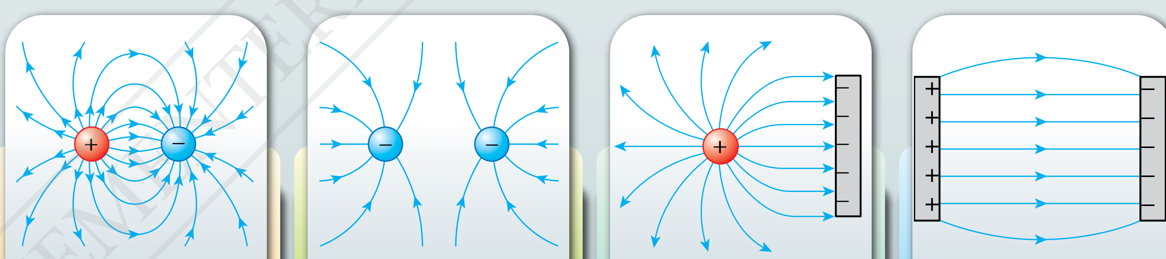
(b) A particle with negative charge

***Figure 3.2** Pattern of an electric field around a positively charged and a negatively charged particle*

Info GALLERY

An electric field line begins on a positive charge and ends on a negative charge. Electric field lines also do not cross each other.

The electric field lines around a positive charge always point outward while the electric field lines around a negative charge always point inward (Figure 3.2). Unlike charges attract each other while like charges repel each other.



(a) Two particles with unlike charges

(b) Two particles with like charges

(c) A particle and a plate with unlike charges

(d) Two parallel plates with unlike charges

***Figure 3.3** Electric field patterns*

Electric field patterns can be drawn using lines with arrows as shown in Figure 3.3. Every line represents an electric field line.

Electric Field Strength

Assume that a positive test charge, q is placed in an electric field. The test charge will experience an electric force. This force can either be a repulsive or an attractive force depending on the type of a charged particle. Figure 3.4 shows an electric force acting on a positive test charge.

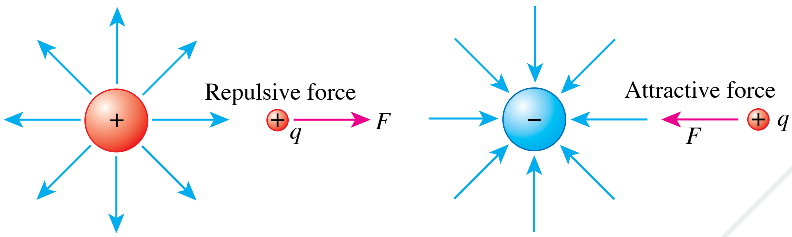


Figure 3.4 *Electric force acting on a positive test charge in an electric field*

The electric field strength, E at a given point in an electric field is defined as **the electric force acting on a unit positive charge placed at the point**.

$$E = \frac{F}{q}$$

where E = electric field strength
F = electric force
q = quantity of electric charge

The S.I. unit for E is newton per coulomb (N C^{-1})

Info GALLERY

The electric field lines follow the direction of the force on a positive test charge that is placed in the electric field.

Let's Recall

The S.I. unit for charge is coulomb (C).

Figure 3.5 shows a uniform electric field between two oppositely charged parallel plates. A uniform electric field is represented by a set of parallel electric field lines.

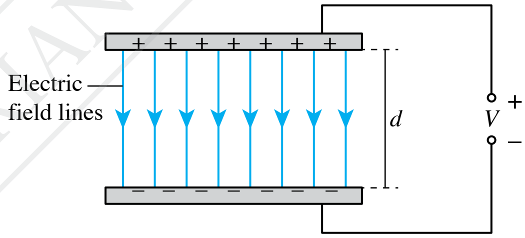


Figure 3.5 *A uniform electric field between two oppositely charged parallel plates*

The electric field strength, E produced by two parallel charged plates is

$$E = \frac{V}{d}$$

where E = electric field strength
V = potential difference between two parallel plates
d = distance between two parallel plates

The S.I. unit for E in this formula is volt per metre (V m^{-1})

BRIGHT Info

V m^{-1} is equivalent to N C^{-1}.

LS 3.1.2

Behaviour of Charged Particles in an Electric Field

In an electric field, there is electric charge which can be positive or negative. Like charges repel each other while unlike charges attract each other. What will happen to charged particles when they are placed in an electric field?

Activity 3.2 Teacher's demonstration

Aim: To show the effects of an electric field on a charged object

Apparatus: Extra high tension (E.H.T.) power supply, metal plates and retort stands

Materials: Polystyrene ball wrapped in aluminium foil, nylon string and candle

Instructions:

1. Set up the apparatus as shown in Figure 3.6.

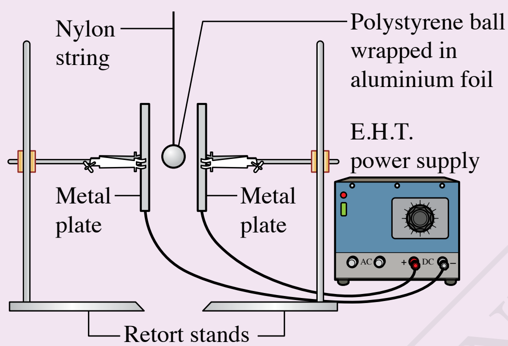


Figure 3.6

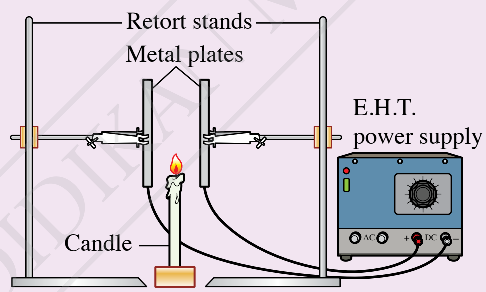


Figure 3.7

2. Switch on the E.H.T. power supply. Displace the polystyrene ball so that it touches one of the metal plates and release the ball. Record your observation.
3. Repeat step 2 by:
   (a) decreasing the distance between the two metal plates.
   (b) increasing the voltage of E.H.T. power supply.
4. Switch off the power supply and replace the polystyrene ball with a lighted candle as shown in Figure 3.7.
5. Switch on the E.H.T. power supply. Observe the effects on the candle flame. Record your observations.
6. Switch off the E.H.T. power supply. Reverse the connection at the power supply terminals and then switch on again. Observe the effects on the candle flame. Record your observations.

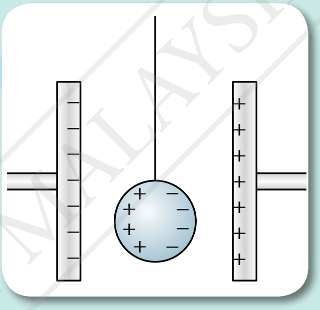
Discussion:

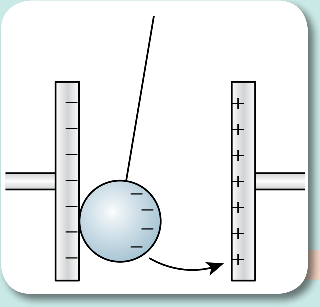
1. Why must the polystyrene ball be wrapped in aluminum foil?
2. What is the function of the nylon string?
3. What will happen to the movement of the polystyrene ball if the distance between the metal plates increases?

The effect of an electric field on a metal coated polystyrene ball

1. When a polystyrene ball is displaced to touch a positively charged metal plate and released, the polystyrene ball will swing to and fro between the two plates until the power supply is switched off.

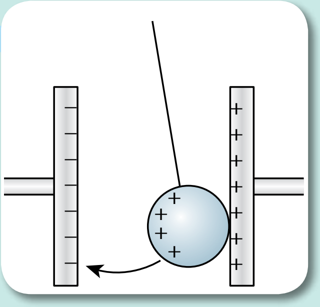
2. When the power supply is switched on, the metal coated polystyrene ball which is in between the two charged metal plates does not move. The polystyrene ball is neutral.





3. When the polystyrene ball is displaced to the negatively charged metal plate, positive charges of the ball will be discharged. The polystyrene ball will become negatively charged. Like charges on the polystyrene ball and the metal plate will produce a repulsive force which pushes the ball away. The negatively charged polystyrene ball will be attracted towards the positive metal plate.

4. At the positive metal plate, the electrons in the polystyrene ball will be transferred to the metal plate until the ball becomes positively charged. Like charges on the polystyrene ball and the metal plate produce a repulsive force which pushes the ball away. The positively charged polystyrene ball will be attracted towards the negative metal plate.



5. The process keeps repeating until the power supply is switched off.

SCAN ME
Video on the effect of an electric field on a polystyrene ball
https://bit.ly/3hzg9ZI

Figure 3.8 *The effect of an electric field on the movements of a metal coated polystyrene ball*

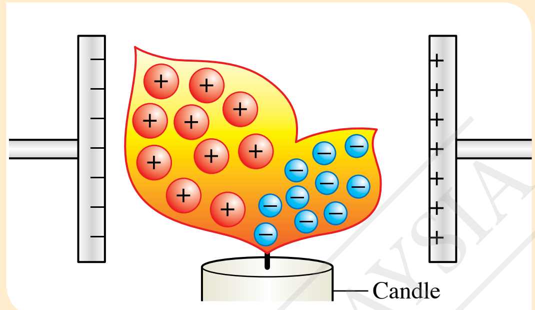
The effects of an electric field on a candle flame

1. When the power supply is switched on, the candle flame will spread out between the two metal plates. The spread of the flames towards the negatively charged metal plate is greater than towards the positively charged metal plate.

2. The heat from the candle flame causes the air to ionise to form positive ions and negative ions.

3. The negative ions will be attracted to the positively charged metal plate while the positive ions to the negatively charged metal plate.

4. Positive ions have larger mass and size compared to negative ions. Therefore, the spread of flames towards the negatively charged metal plate is greater than towards the positively charged metal plate.



SCAN ME

Video on the effects of an electric field on a candle flame

https://bit.ly/3jigi4h

Figure 3.9 *The effect of an electric field on a candle flame*

Electric Current

An electrical equipment can only function if current flows in a complete electric circuit. **Current**, I is **the rate of flow of charge, Q in a conductor**.

$$I = \frac{Q}{t} \quad \text{or} \quad Q = It$$

where I = current
Q = total charge
t = time

The S.I. unit for current, I is coulomb per second ($C\ s^{-1}$) or ampere (A).

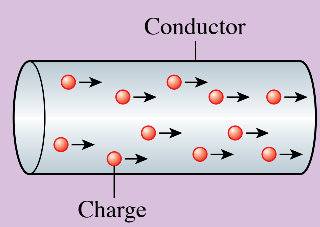


Figure 3.10 *Electric charges flowing in a conductor*

Potential Difference

You have learned that current is the rate of flow of electric charges. What makes the current flow in a circuit? This is related to the electric **potential difference**.

Brain-Teaser

In the electric field of a positively charged particle, why is the electric potential higher at a position nearer to the charge?

Current can flow from one point to another due to a potential difference between the two points in a circuit. **The potential difference**, V between two points in an electric field is **the work done, W in moving one coulomb of charge, Q from one point to another**.

$$V = \frac{W}{Q} \quad \text{or} \quad V = \frac{E}{Q}$$

where V = potential difference
W = work done
E = energy transferred
Q = the amount of charges flowing

The S.I. unit for potential difference, V is joule per coulomb ($J\ C^{-1}$) or volt (V).

The potential difference is 1 V if the work done to move 1 C of charge from one point to another is 1 J.

EAL History

Alessandro Volta was an Italian physicist who invented the voltaic pile, the first chemical battery. The unit of volt was named in his honour to recognise his contribution in the field of electricity.

BRIGHT Info

Charge of an electron,
$e = 1.6 \times 10^{-19}$ C

Therefore,

$$1\ \text{C} = \frac{1}{1.6 \times 10^{-19}}$$
$$= 6.25 \times 10^{18} \text{ electrons}$$

Formative Practice 3.1

1. Define current and potential difference.
2. What is an electric field?
3. Figure 3.11 shows an electronic advertisement board. The current flowing is 4.0×10^{-2} A. What is the number of electrons flowing in the circuit when it remains switched on for 3 hours?
4. A bulb labelled 3.0 V, 0.2 A was lit for 1 hour. Calculate:
   (a) the electric charge
   (b) the energy generated

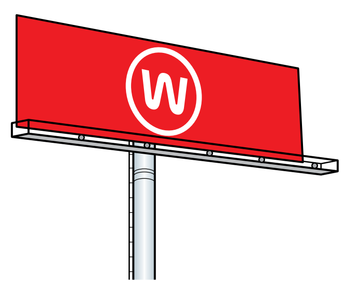


Figure 3.11

5. An electric charge of 900 C flows through a metallic conductor in 10 minutes. Calculate the current.

3.2 Resistance

Ohmic Conductor and Non-Ohmic Conductor

A conductor which obeys Ohm's Law is called an ohmic conductor whereas a conductor which does not obey Ohm's Law is called a non-ohmic conductor. Do the potential difference and the current vary according to Ohm's Law for conductors such as a constantan wire and a bulb? Carry out Experiment 3.1.

SCAN ME
Ohm's Law
https://bit.ly/31uiGir

SCAN ME
Video on Ohm's Law
https://bit.ly/2QzBPZP

Experiment 3.1

Inference: The potential difference across a conductor depends on the current flowing through it

Hypothesis: The higher the current, the higher the potential difference across the conductor

Aim: To study the relationship between the current and the potential difference of an ohmic conductor and a non-ohmic conductor

A Ohmic conductor (a constantan wire)

Variables:

(a) Manipulated: Current, I
(b) Responding: Potential difference, V
(c) Constant: Temperature, diameter and length of constantan wire

Apparatus: 1.5 V dry cell, cell holder, switch, connecting wires, ammeter, voltmeter, metre rule, rheostat, constantan wire s.w.g 24 (20 cm length)

Procedure:

1. Set up the apparatus as shown in Figure 3.12.

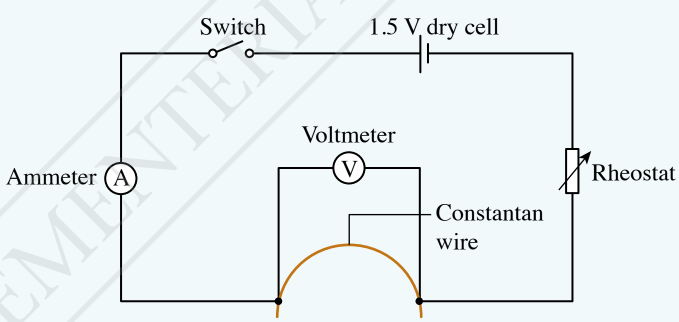


Figure 3.12

2. Close the switch and adjust the rheostat until the ammeter reads $I = 0.2$ A. Record the voltmeter reading, V in Table 3.2.
3. Repeat step 2 with values of $I = 0.3$ A, 0.4 A, 0.5 A and 0.6 A.

Info GALLERY

Standard wire gauge (s.w.g.) represents the diameter of a wire. The bigger the value of its s.w.g., the smaller the diameter.

Safety Precaution

- Ensure that the connecting wires are connected tightly.
- Avoid parallax error when taking the ammeter and voltmeter readings.
- Turn off the switch immediately after taking each reading so that the temperature of the constantan wire remains constant throughout the experiment.

Results:

Table 3.2

Current, *I* / A	Potential difference, *V* / V
0.2	
0.3	
0.4	
0.5	
0.6	

B Non-ohmic conductor (a filament bulb)

Variables:

(a) Manipulated: Current, *I*

(b) Responding: Potential difference, *V*

(c) Constant: Filament length

Apparatus: 1.5 V dry cell, cell holder, switch, connecting wires, ammeter, voltmeter, rheostat and filament bulb (2.5 V, 3 W)

Procedure:

1. Replace the constantan wire in Figure 3.12 with a filament bulb.
2. Close the switch and adjust the rheostat until the ammeter reads $I = 0.14$ A. Record the voltmeter reading, *V* in Table 3.3.
3. Repeat step 2 with values of $I = 0.16$ A, 0.18 A, 0.20 A and 0.22 A.

Results:

Table 3.3

Current, *I* / A	Potential difference, *V* / V
0.14	
0.16	
0.18	
0.20	
0.22	

Data analysis:

Plot graphs of potential difference, V against current, I for experiment A and experiment B.

Conclusion:

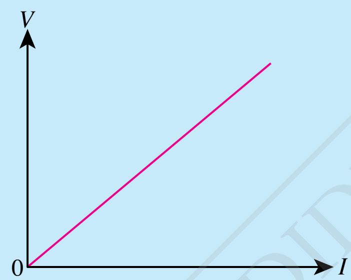
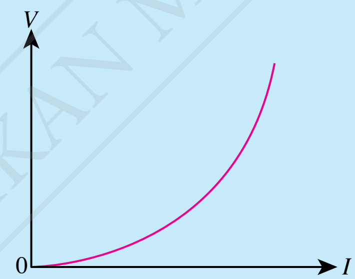
What conclusions can be drawn from both experiments?

Prepare a complete report of experiment A and experiment B.

Discussion:

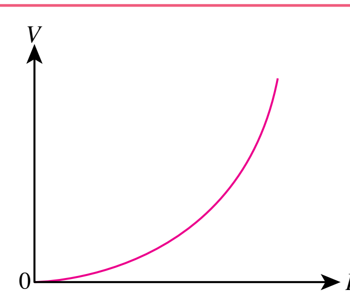
Based on the two graphs of V against I, compare the shapes and gradients of the graphs.

Table 3.4 *Comparison of graphs of V against I for an ohmic conductor and a non-ohmic conductor*

Type of conductor	Ohmic conductor	Non-ohmic conductor
Graph of V against I	A straight-line graph passing through the origin 	A curved graph passing through the origin 
Relationship between V and I	V is directly proportional to I	V increases with I
Rate of increase of voltage	Constant	Increases
Resistance	Constant	Increases

Info GALLERY

The graph on the right shows the relationship between potential difference, V and current, I for a tungsten filament bulb. The bulb filament uses a tungsten coil. The tungsten wire is actually an ohmic conductor. As the current flowing through the coil increases, the temperature of the coil increases and the bulb lights up. At the same time, the resistance of the coil also increases with the temperature. Under this condition where the temperature cannot be kept constant, the tungsten coil in the bulb exhibits a non-ohmic characteristic.

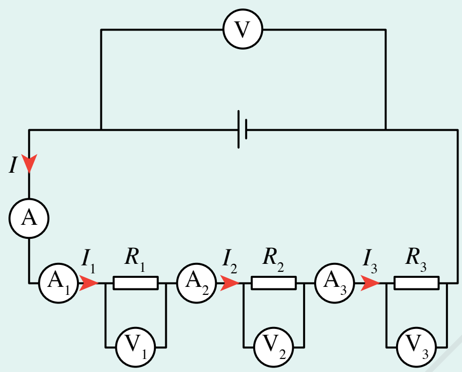
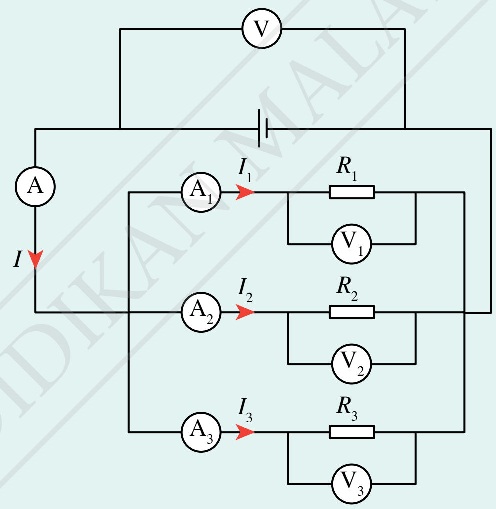


Graph of V against I

Solving Problems Involving Series and Parallel Combination Circuits

Let us recall series circuits and parallel circuits that you have studied in Form 2. The relation of current, potential difference and resistance in a series circuit are different from those in a parallel circuit. Table 3.5 summarises current, potential difference and resistance for series and parallel circuits. Based on the summary, you can determine the current, potential difference and resistance for series, parallel and combination circuits.

Table 3.5 *Summary of current, potential difference and resistance for series and parallel circuits*

Series circuit	Parallel circuit
	
The current flowing through each resistor is the same. $I = I_1 = I_2 = I_3$	The sum of current leaving a junction is equal to the sum of current entering a junction. $I = I_1 + I_2 + I_3$
The potential difference across the dry cell is equal to the sum of the potential differences across all the resistors. $V = V_1 + V_2 + V_3$	The potential difference across the dry cell is the same as the potential difference across each resistor. $V = V_1 = V_2 = V_3$
Effective resistance $R = R_1 + R_2 + R_3$	Effective resistance $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Example 1

Three resistors are arranged in series and in parallel as shown in Figure 3.13. The resistance for R_1, R_2 and R_3 are 2 Ω, 4 Ω and 12 Ω respectively.

LET'S ANSWER

https://bit.ly/32J6R7B

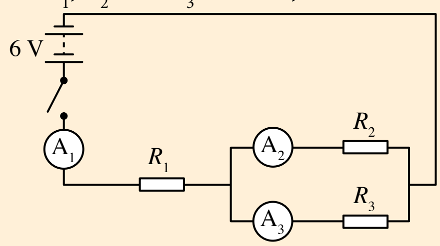


Figure 3.13

When the switch is closed, calculate:

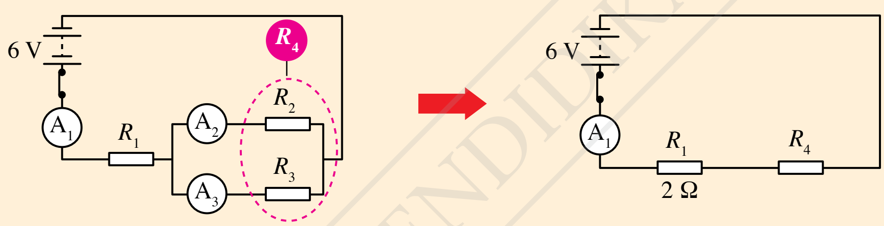
(a) the effective resistance, R

(b) the current flowing through the 2 Ω resistor and the potential difference across it

(c) the current flowing through the 4 Ω and 12 Ω resistors and the potential difference across them respectively

Solution

(a)



Total resistance in the parallel circuit,

$$\frac{1}{R_4} = \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{4} + \frac{1}{12}$$

$$= \frac{4}{12}$$

$$R_4 = \frac{12}{4}$$

$$= 3\ \Omega$$

Thus, the effective resistance in the complete circuit,

$R = R_1 + R_4$

$= 2 + 3$

$= 5\ \Omega$

(b) Total current flowing in the circuit,

$$I = \frac{V}{R}$$

$$I = \frac{6}{5}$$

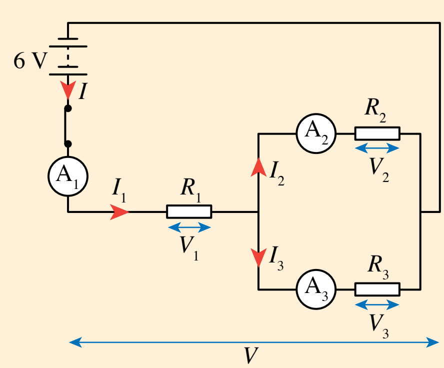
$$= 1.2\text{ A}$$

$I_1 = I$

Thus, the potential difference for $V_1 = I_1R_1$

$V_1 = 1.2\ (2)$

$= 2.4\text{ V}$



(c) For the 4 Ω and 12 Ω resistors:

Potential difference, $V = V_1 + V_2$

$V_2 = V - V_1$
$= 6 - 2.4$
$= 3.6$ V

Since R_2 is parallel with R_3,

Then, $V_3 = V_2 = 3.6$ V

So, the current flowing through the 4 Ω resistor,

$I_2 = \frac{V_2}{R_2}$
$= \frac{3.6}{4}$
$= 0.9$ A

While the current flowing through the 12 Ω resistor,

$I_3 = \frac{V_3}{R_3}$
$= \frac{3.6}{12}$
$= 0.3$ A

Example 2

Figure 3.14 shows five resistors connected in a combination circuit. Calculate:
(a) the effective resistance, *R*
(b) the current flowing through the ammeter, *I*
(c) the potential difference across points *A* and *B*, V_{AB}

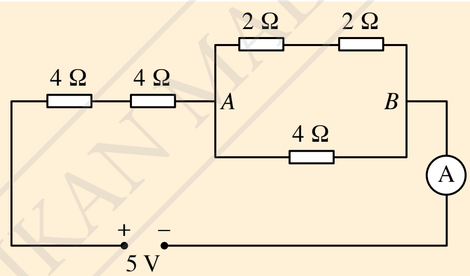
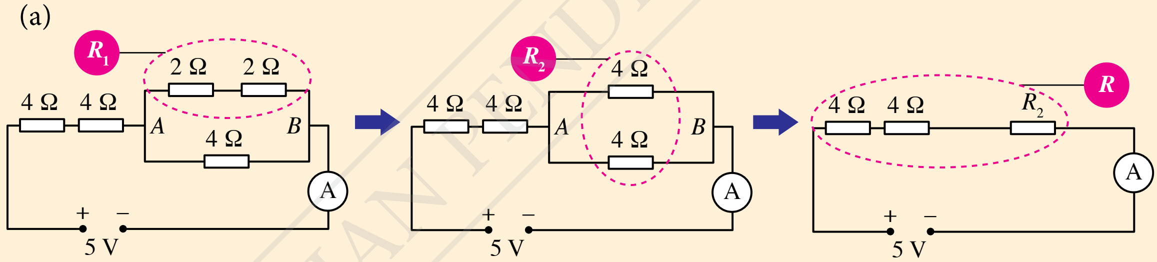


Figure 3.14

Solution

(a)



$R_1 = 2 + 2$
$= 4$ Ω

$\frac{1}{R_2} = \frac{1}{4} + \frac{1}{4}$
$= \frac{2}{4}$
$R_2 = \frac{4}{2}$
$= 2$ Ω

$R = 4 + 4 + 2$
$= 10$ Ω

(b) Potential difference, $V = 5$ V
Effective resistance, $R = 10$ Ω
Current, $I = \frac{V}{R}$
$= \frac{5}{10}$
$= 0.5$ A

(c) Resistance, $R_2 = 2$ Ω
Current, $I = 0.5$ A
Potential difference, $V_{AB} = IR_2$
$= (0.5)(2)$
$= 1.0$ V

Factors that Affect the Resistance of a Wire

Factors that affect the resistance of a wire are the length of the wire, l, cross-sectional area of the wire, A and resistivity of the wire, ρ. Conduct Experiments 3.2, 3.3 and 3.4 to study the relationship between these factors and the resistance of the wire.

Experiment 3.2

Inference: The resistance of a wire depends on the length of the wire

Hypothesis: The longer the wire, the higher the resistance of the wire

Aim: To study the relationship between the length and the resistance of a wire

Variables:

(a) Manipulated: Length of wire, l

(b) Responding: Resistance, R

(c) Constant: Diameter, resistivity and temperature of the wire

Apparatus: Two 1.5 V dry cells, cell holder, switch, connecting wires, ammeter, voltmeter, crocodile clips, rheostat and metre rule

Material: 110.0 cm of s.w.g. 24 constantan wire

Procedure:

1. Set up the apparatus as shown in Figure 3.15.

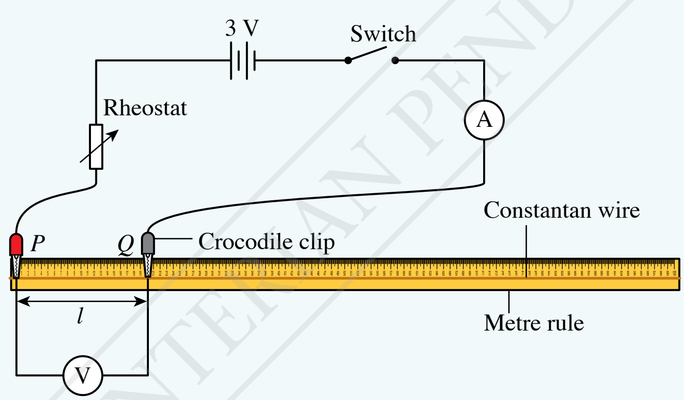


Figure 3.15

Info GALLERY

The resistivity of a wire depends on the wire material.

Note

Ensure the wire temperature is constant throughout the experiment as changes in the temperature will affect the resistance of the wire.

2. Adjust crocodile clips P and Q so that the length of the wire, l = 20.0 cm.
3. Close the switch and adjust the rheostat until the current, I flowing in the circuit is 0.5 A.
4. Record the value of potential difference across the wire in Table 3.6.
5. Repeat steps 2 to 4 for different lengths of the constantan wire, l = 40.0 cm, 60.0 cm, 80.0 cm and 100.0 cm.
6. Calculate the resistance, $R = \frac{V}{I}$.

LS 3.2.4

Results:

Table 3.6

Length of wire, *l* / cm	Current , *I* / A	Potential difference, *V* / V	Resistance, *R* / Ω
20.0			
40.0			
60.0			
80.0			
100.0			

Data analysis:

Plot a graph of resistance, *R* against the length of wire, *l*.

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:

State one precaution that needs to be taken to ensure that the wire temperature is constant throughout the experiment.

Experiment 3.3

Inference: The resistance of a wire depends on the cross-sectional area of the wire

Hypothesis: The larger the cross-sectional area of the wire, the smaller the resistance of the wire

Aim: To study the relationship between the cross-sectional area and the resistance of a wire

Variables:

(a) Manipulated: Cross-sectional area of wire, *A*
(b) Responding: Resistance, *R*
(c) Constant: Length, resistivity and temperature of the wire

Apparatus: Two 1.5 V dry cells, cell holder, switch, ammeter, voltmeter, connecting wires, crocodile clips, rheostat and metre rule

Materials: 30.0 cm constantan wires of s.w.g. 22, s.w.g. 24, s.w.g. 26, s.w.g. 28 and s.w.g. 30

Procedure:

1. Set up the apparatus as shown in Figure 3.16.

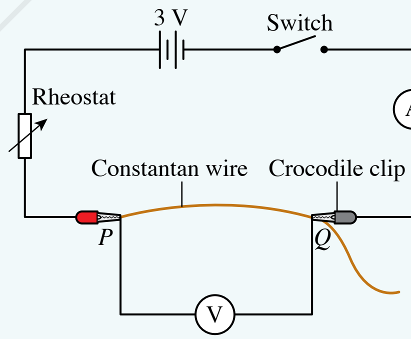


Figure 3.16

Note

Ensure that the wire temperature is constant throughout the experiment as changes in the temperature will affect the resistance of the wire.

2. Connect a 25 cm length of s.w.g. 22 constantan wire between P and Q.
3. Close the switch and adjust the rheostat until the current, I flowing in the circuit is 0.5 A.
4. Record the value of the potential difference across the wire.
5. Repeat steps 2 to 4 using the s.w.g. 24, s.w.g. 26, s.w.g. 28 and s.w.g. 30 constantan wires.
6. Based on the diameters given in Table 3.7, calculate the cross-sectional area of wire, $A = \pi r^2$ and resistance, $R = \frac{V}{I}$ for the five sets of data obtained (r = wire radius).
7. Record all the values for cross-sectional area, A, current, I, potential difference, V and resistance, R in Table 3.7.

Results:

Table 3.7

s.w.g.	Diameter, d / mm	Cross-sectional area, A / mm²	Current, I / A	Potential difference, V / V	Resistance, R / Ω
22	0.711				
24	0.559				
26	0.457				
28	0.376				
30	0.315				

Data analysis:
Plot a graph of resistance, R against cross-sectional area of wire, A.

Conclusion:
What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:
State the relationship between:
(a) the cross-sectional area and the resistance of a wire.
(b) the value of s.w.g. and the resistance of a wire.

Based on the results of Experiment 3.2, the graph in Figure 3.17 is obtained. The graph of R against l shows that as the length of the wire increases, the resistance of the wire also increases provided that the wire temperature remains constant. This shows that the resistance is directly proportional to the length of the wire.

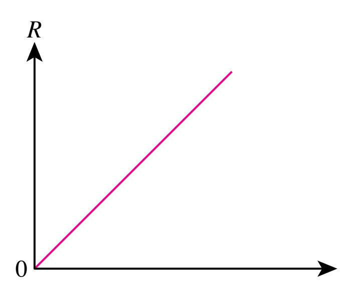


Figure 3.17 *Graph of R against l*

Based on the results of Experiment 3.3, the graph in Figure 3.18 is obtained. The graph of R against A shows that the resistance of the wire decreases as the cross-sectional area of the wire increases provided that the wire temperature remains constant. When R is plotted against $\frac{1}{A}$, a straight-line graph passing through the origin is obtained as shown in Figure 3.19. This shows that the resistance is directly proportional to $\frac{1}{A}$.

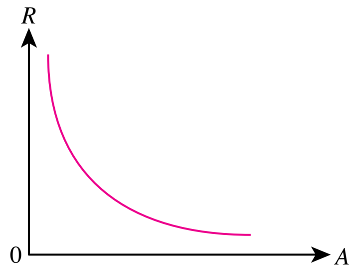


Figure 3.18 *Graph of R against A*

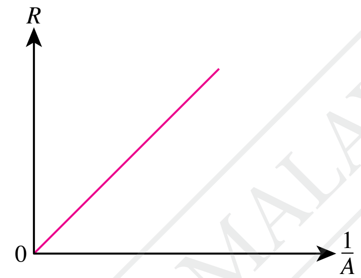


Figure 3.19 *Graph of R against* $\frac{1}{A}$

Resistivity of a Conductor

- The resistivity of a conductor, ρ is **a measure of a conductor's ability to oppose the flow of electric current**.
- The unit of resistivity is ohm-meter (Ω m).
- The value of resistivity depends on the temperature and the nature of the conductor material.

Experiment 3.4

Inference: The resistance of a wire depends on the resistivity of the wire

Hypothesis: The greater the resistivity of a conductor, the greater the resistance of the wire

Aim: To study the relationship between the resistivity and the resistance of a wire

Variables:

(a) Manipulated: Resistivity of the wire, ρ

(b) Responding: Resistance, R

(c) Constant: Length, diameter and temperature of the wire

Apparatus: Two 1.5 V dry cells, cell holder, switch, connecting wires, ammeter, voltmeter, crocodile clips, rheostat and metre rule

Materials: 35.0 cm of s.w.g. 24 constantan wire and 35.0 cm of s.w.g. 24 nichrome wire

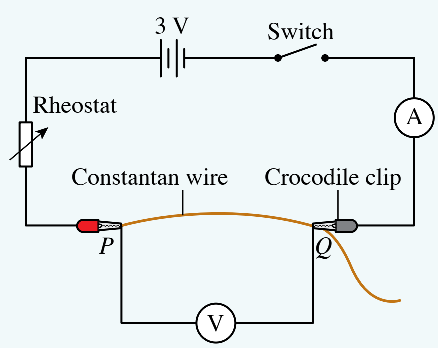


Figure 3.20

Procedure:

1. Set up the apparatus as shown in Figure 3.20.
2. Adjust the length of the constantan wire between P and Q so that its length, l = 30.0 cm.
3. Close the switch and adjust the rheostat until the current, I flowing in the circuit is 0.5 A.
4. Record the value of potential difference across the wire, V.

5. Repeat steps 2 to 4 with the nichrome wire.

6. Calculate the resistance, $R = \frac{V}{I}$ for each type of wire.

7. Record all the values of current, I, potential difference, V and resistance, R in Table 3.8.

Note

Ensure the wire temperature is constant throughout the experiment as changes in the temperature will affect the resistance of the wire.

Results:

Table 3.8

Type of wire	Current, I / A	Potential difference, V / V	Resistance, R / Ω
Constantan			
Nichrome			

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:

The resistivity of different conductors is given in Table 3.9. What can you say about the resistance of copper wire compared to the resistance of constantan and nichrome wires? Explain.

Table 3.9

Material	Resistivity of conductor, ρ / Ω m
Copper	1.68×10^{-8}
Constantan	49×10^{-8}
Nichrome	100×10^{-8}

Based on the results of Experiments 3.2, 3.3 and 3.4, the factors that affect the resistance of a wire can be summarised as shown in Figure 3.21.

$R \propto l$

$R \propto \frac{1}{A}$

$R \propto \frac{l}{A}$

$$R = \frac{\rho l}{A}$$

where ρ = the proportional constant known as the resistivity of the conductor

Figure 3.21 *Summary of the factors affecting the resistance of a wire*

Applications of Resistivity of Conductors in Daily Life

How can you apply your knowledge of resistivity in your daily life?

Activity 3.3

ISS

Aim: To study and elaborate on the applications of resistivity of conductors in daily life

Instructions:

1. Carry out this activity in groups.

2. Gather information to study the applications of resistivity of conductors on:
   (a) heating elements
   (b) electrical wiring at home (fuse and connecting wires)

3. Prepare a short report on the applications of resistivity of conductors.

Figure 3.22 describes the applications of resistivity in an electric rice cooker.

Heating Element

- The heating plate acts as a heating element.
- The conductor material has a high resistivity, melting point and is durable.

Connecting Wire

- The connecting wire consists of fine metal wires.
- Copper wire is used because copper has low resistivity which prevents the wire from heating up too quickly when current flows through it.

Figure 3.22 *Applications of resistivity in an electric rice cooker*

Different conductors have different resistivities. Likewise, non-conductors, semiconductors and superconductors have different resistivities as well.

Activity 3.4

ISS ICS

Aim: To seek information about the resistivity of conductors, non-conductors, semiconductors and superconductors

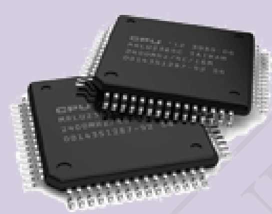
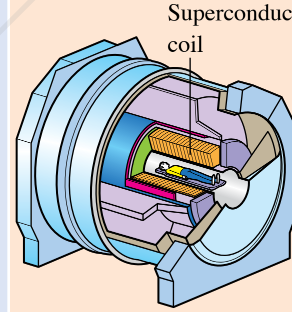
Instructions:

1. Carry out a Think-Pair-Share activity.
2. Get information from reading resources or search the websites for the resistivity of conductors, non-conductors, semiconductors and superconductors.
3. Present your findings.

SCAN ME
Examples on the resistivity of materials
https://bit.ly/3b0skwd

Table 3.10 shows the comparison between non-conductors, semiconductors, conductors and superconductors.

Table 3.10 *Comparison between non-conductors, semiconductors, conductors and superconductors*

Non-conductor	Semiconductor	Conductor	Superconductor
A material that does not conduct electricity, good insulator.	A material that conducts electricity better than an insulator but not as good as a conductor.	A material that conducts electricity.	A material that conducts electricity without any resistance.
Has the highest resistivity	Has resistivity between a non-conductor and a conductor	Has low resistivity	Has zero resistivity at critical temperature
Examples: plastic and wood.	Examples: silicone and germanium.	Examples: iron and carbon.	Example: caesium at a temperature of 1.5 K or lower
 *Plastic cover of fuse box*	 *Silicon chip*	 *Nichrome coil as a heating element*	 *Superconductor coil in MRI*

Superconductors are **materials that conduct electricity without any resistance**. Therefore, no energy is lost when the current flows through the superconductor. **Critical temperature**, T_c is **the temperature when the resistivity of a superconductor becomes zero**.

Activity 3.5

ISS / ICS

Aim: To seek information on previous studies of superconductors

Instructions:

1. Carry out this activity in groups.
2. Browse the website or scan the QR code to obtain information on previous studies of superconductors.
3. Gather information about:
   (a) the critical temperature, T_c
   (b) the graph of resistance against the thermodynamic temperature of superconductors
   (c) recent discoveries and studies of the critical temperature, T_c
4. Present your findings.

SCAN ME
Superconductors
http://bit.ly/2SqGe3v

Solving Problems Involving Wire Resistance

Example 1

The resistivity of constantan is $49 \times 10^{-8}\ \Omega$ m. Calculate the resistance of a constantan wire with a length of 50.0 cm and a diameter of 0.6 mm.

LET'S ANSWER
https://bit.ly/3jgPsJU

Solution

Step 1: Identify the problem	Step 2: Identify the information given	Step 3: Identify the formula that can be used	Step 4: Solve the problem numerically

1. Constantan wire resistance, R

2. Resistivity, $\rho = 49 \times 10^{-8}\ \Omega$ m
   Length of wire, l = 50.0 cm
   = 0.5 m
   Diameter of wire, d = 0.6 mm
   Radius of wire, $r = \dfrac{0.6 \times 10^{-3}\text{ m}}{2}$
   $= 3 \times 10^{-4}$ m

3. Cross-sectional area of wire, $A = \pi r^2$
   Resistance, $R = \dfrac{\rho l}{A}$

4. $A = \pi(3 \times 10^{-4})^2\ \text{m}^2$
   $R = \dfrac{(49 \times 10^{-8})(0.5)}{\pi(3 \times 10^{-4})^2}$
   $= 0.867\ \Omega$

Example 2

Azwan is an electrical wiring contractor in Taman Kota Puteri. He found that a coil of pure copper wire with a length of 500 m and a radius of 0.5 mm has a resistance of 10.8 Ω. What is the resistivity of copper?

Solution

Resistance of wire, $R = 10.8\ \Omega$
Length of wire, $l = 500$ m
Radius of wire, r = 0.5 mm
$= 0.5 \times 10^{-3}$ m

Resistivity of copper, $\rho = \dfrac{RA}{l}$

$= \dfrac{R\pi r^2}{l}$

$= \dfrac{(10.8)\pi(0.5 \times 10^{-3})^2}{500}$

$= 1.696 \times 10^{-8}\ \Omega$ m

Formative Practice 3.2

1. List the factors that affect the resistance of a wire.
2. Calculate the total resistance of a coil of copper wire with a length of 50.0 m and a cross-sectional area of 2.5 mm², given that the resistivity of copper at a temperature of 20°C is $1.72 \times 10^{-8}\ \Omega$ m.

3.3 Electromotive Force (e.m.f.) and Internal Resistance

Electromotive Force

There are various sources of electromotive force, e.m.f. like electric generators, dynamos, batteries and accumulators. Photograph 3.3 shows several sources of e.m.f.

The electromotive force (e.m.f.), $\mathcal{E}$ is **the energy transferred or work done by an electrical source to move one coulomb of charge in a complete circuit.**

$$\mathcal{E} = \frac{E}{Q}$$

where $\mathcal{E}$ = electromotive force
E = energy transferred / work done
Q = the amount of charge flowing
The S.I. unit for e.m.f. is volt (V) or J C^{-1}.

Lead-acid accumulator

Dry cell (Alkaline cell)

Lithium-ion battery

Photograph 3.3 *Sources of e.m.f.*

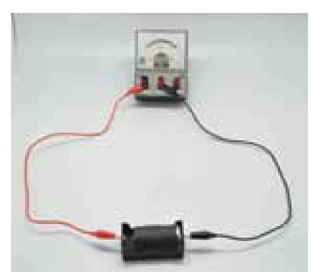
Photograph 3.4 shows a dry cell that can supply 1.5 J of electrical energy for each coulomb of charge in a complete circuit.

e.m.f. of a dry cell = 1.5 V
= 1.5 J C^{-1}

Photograph 3.4 *A dry cell*

SCAN ME
Video of Electromotive Force and Internal Resistance
https://bit.ly/2QJbAR1

Info GALLERY



A voltmeter has a high resistance. Thus, the current from a dry cell through a voltmeter can be neglected. The voltmeter reading is the e.m.f. of the dry cell.

Electromotive force and potential difference have the same S.I. units. However, electromotive force differs from potential difference under different circumstances.

Activity 3.6

Aim: To compare between e.m.f. and potential difference

Apparatus: 1.5 V dry cell, cell holder, switch, bulb, connecting wires and voltmeter

Instructions:

1. Set up the apparatus as shown in Figure 3.23 with the switch *S* open (open circuit).

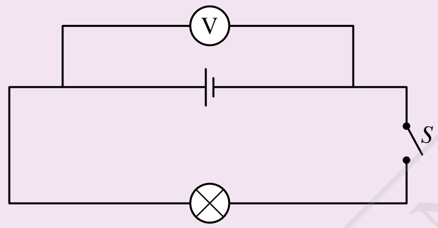


Figure 3.23

2. Observe what happens to the bulb and record the voltmeter reading in Table 3.11.
3. Close the switch *S* (closed circuit). Observe what happens to the bulb and record the voltmeter reading.

Results:

Table 3.11

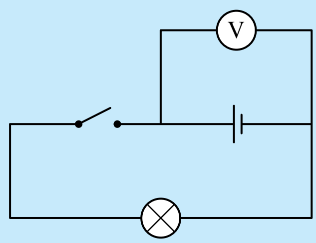
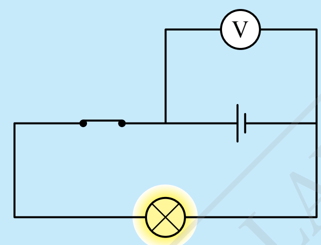
	Open circuit	Closed circuit
State of the bulb		
Voltmeter reading / V		

Discussion:

1. What is the change in energy when the bulb lights up?
2. Based on the results of this activity:
   (a) which circuit measured the potential difference across the bulb?
   (b) what is the quantity of electrical energy released by the bulb for every coulomb of charge that flows through it?
3. What is the e.m.f. of the dry cell?
4. What is the quantity of electrical energy that is supplied to every coulomb of charge flowing through the dry cell?
5. What is the difference in voltmeter readings between the open circuit and the closed circuit? Discuss why this difference occurs.

Based on Activity 3.6, a comparison between electromotive force and potential difference is shown in Table 3.12.

***Table 3.12** Comparison between electromotive force and potential difference*

Electromotive force (e.m.f.), $\mathcal{E}$	Potential difference, V
	
No current flows in the circuit	A current flows in the circuit
The voltmeter reading in an open circuit is the electromotive force, $\mathcal{E}$.	The voltmeter reading in a closed circuit is the potential difference across the bulb, V.
Work done by an electrical source to move one coulomb of charge in a complete circuit.	Work done to move one coulomb of charge between two points.

Internal Resistance

Based on Activity 3.6, the value of potential difference across the bulb, V is smaller than the e.m.f., $\mathcal{E}$ of the dry cell. This indicates that there is a **voltage drop**. What causes the voltage drop in the dry cell?

Activity 3.7

Aim: To study the effect of internal resistance on voltage drop

Apparatus: Two 1.5 V dry cells from two different brands (brands *A* and *B*), cell holder, switch, bulb with holder, connecting wires, ammeter and voltmeter

Instructions:

1. Check the dry cells you are using. Make sure both dry cells are new.
2. Set up the apparatus as shown in Figure 3.24 using the brand *A* dry cell.

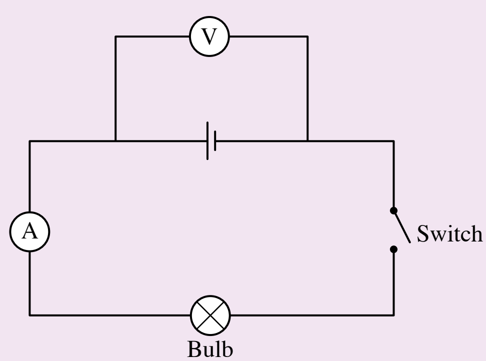


Figure 3.24

3. Record the voltmeter reading as e.m.f., $\mathcal{E}$ in Table 3.13.
4. Close the switch and record the voltmeter reading as potential difference, V.
5. Calculate the difference in voltmeter readings before and after the switch is closed to determine the voltage drop.
6. Repeat steps 2 to 5 using the brand *B* dry cell.

Results:

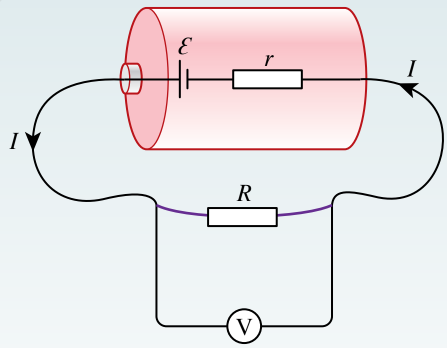
Table 3.13

	Brand *A*	Brand *B*
Voltmeter reading before switch is closed, $\mathcal{E}$ / V		
Voltmeter reading after switch is closed, V / V		
Voltage drop, $Ir = \mathcal{E} - V$		

Discussion:

1. Why should new dry cells be used in this activity?
2. Which brand of dry cell experiences greater voltage drop?
3. Why is there a difference in voltage drop between the two dry cells? Explain.

Internal resistance, r of a dry cell is **the resistance caused by electrolyte in the dry cell**. The S.I. unit for internal resistance, r is ohm (Ω). Internal resistance causes:
- loss of energy (heat) in dry cells as work has to be done to move one coulomb charge against the resistance within the dry cell
- the potential difference across the dry cell terminals to be less than the e.m.f., $\mathcal{E}$ when current flows in a complete circuit



Voltage drop, $Ir = \mathcal{E} - V$

Figure 3.25 *Internal resistance of a dry cell*

LS 3.3.2

Determining the e.m.f. and Internal Resistance of a Dry Cell

Experiment 3.5

Aim: To determine the e.m.f. and internal resistance of a dry cell

Apparatus: 1.5 V dry cell, cell holder, switch, connecting wires, ammeter, voltmeter and rheostat

Procedure:

1. Set up the apparatus as shown in Figure 3.26.
2. Plan steps to:
   - obtain an ammeter reading
   - avoid parallax errors when taking ammeter and voltmeter readings
   - reduce energy loss from the dry cell
   - repeat the experiment to obtain a set of data so that a graph of potential difference, V against current, I can be plotted

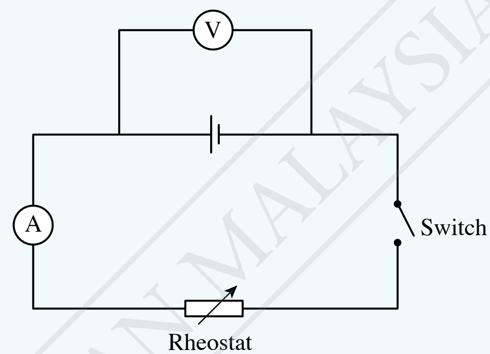


Figure 3.26

3. Carry out the experiment according to plan.
4. Record the results of the experiment and plot the graph of potential difference, V against current, I.
5. Based on the graph plotted, perform the data analysis as follows:
   (a) calculate the gradient of the graph
   (b) write a linear equation of the graph and relate it to the voltage drop, $Ir = \mathcal{E} - V$
   (c) calculate the internal resistance, r
   (d) determine the e.m.f., $\mathcal{E}$

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:

Based on the graph of this experiment, state the relationship between V and I. Explain your answer.

Voltage drop, $Ir = \mathcal{E} - V$

Then, $V = -Ir + \mathcal{E}$

where $\mathcal{E}$ = electromotive force motion (e.m.f.)
V = potential difference across variable resistor (rheostat)
I = current
r = internal resistance of dry cells
R = external resistance

$$\mathcal{E} = V + Ir$$
$$= IR + Ir$$
$$= I(R + r)$$

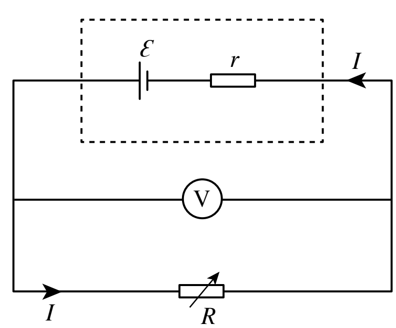


Figure 3.27

When a graph of V against I is plotted, a straight-line graph with a negative gradient is obtained as shown in Figure 3.28.

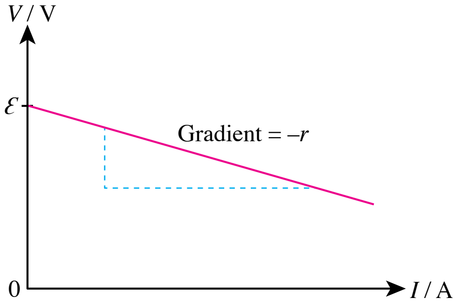


***Figure 3.28** Graph of V against I*

The equation for the linear graph is:

$$y = m\,x + c$$
$$V = -r\,I + \mathcal{E}$$

Intercept at vertical axis, $c = \mathcal{E}$
Gradient, $m = -r$

SCAN ME
A comparison of shapes of graphs of *V* against *I* in the experiment to determine the e.m.f. of a dry cell and the experiment to verify Ohm's Law
https://bit.ly/3loBfMY

Activity 3.8

Aim: To study the effects of connecting dry cell in series and parallel arrangements on:
- e.m.f., $\mathcal{E}$
- potential difference, V
- internal resistance, r
- current flows in the circuit

Apparatus: Six 1.5 V dry cells, cell holder, switch, connecting wires, ammeter, voltmeter and 10 Ω resistor

Instructions:

1. Set up the apparatus as shown in Figure 3.29 for dry cells in series and Figure 3.30 for dry cells in parallel.

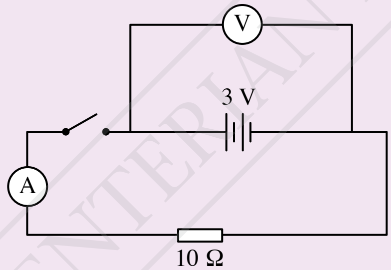


Figure 3.29

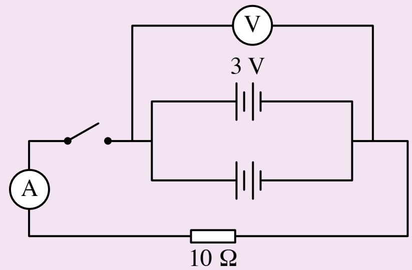


Figure 3.30

2. Record the voltmeter reading (total e.m.f. of dry cells), $\mathcal{E}$ in Table 3.14.
3. Close the switch. Record the ammeter and voltmeter readings (values of potential difference across 10 Ω resistor).
4. Using the voltage drop, $Ir = \mathcal{E} - V$, calculate the effective internal resistance, r_e for dry cells in the series and the parallel arrangements. Complete the table.

Results:

Table 3.14

	Dry cells in series	Dry cells in parallel
e.m.f., $\mathcal{E}$ / V		
Potential difference, V / V		
Current, I / A		
Effective internal resistance, r_e / Ω		

Discussion:

Which arrangement of dry cells produces smaller effective internal resistance? Explain.

Alkaline batteries that use potassium hydroxide electrolyte are twice as durable compared to zinc-carbon batteries that use ammonia chloride. Different electrolyte cause the internal resistance of the two batteries to be different. Apart from the electrolyte used, the arrangements of dry cells also affect the effective internal resistance.

Effects of Dry Cell Connected in Series and Parallel Arrangements

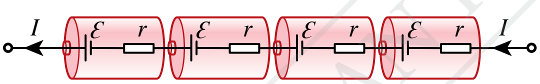
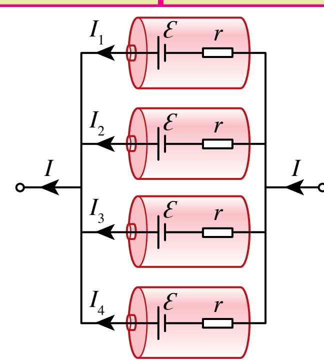
	Dry Cells in Series	Dry Cells in Parallel
Dry cell arrangement		
Effective internal resistance	$r_e = r + r + r + r$ $= 4r$	$\frac{1}{r_e} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \frac{1}{r}$ $= \frac{4}{r}$ $r_e = \frac{r}{4}$
Total e.m.f.	$4\mathcal{E}$	$\mathcal{E}$

Figure 3.31 *Effects of dry cell connected in series and parallel arrangements*

The arrangement of dry cells in series increases the effective e.m.f. while the arrangement of dry cells in parallel reduces the effective internal resistance.

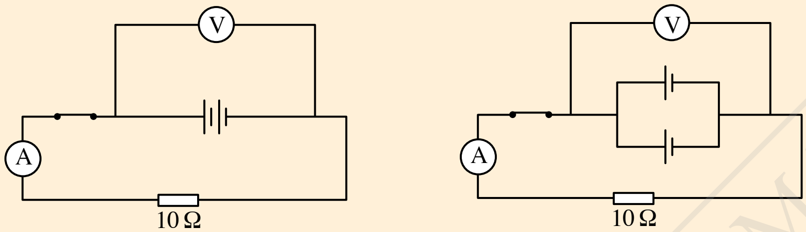
Problem Solving Involving e.m.f. and Internal Resistance of Dry Cells

There are many electrical appliances that use dry cells such as radios, flashlights and children's toys. If an electrical appliance uses more than one dry cell, how should the dry cells be arranged so that the device can function with maximum efficiency?

Example 1

Figure 3.32 shows two circuits with dry cells arranged in series and in parallel. It is given that the e.m.f., $\mathcal{E}$ of each dry cell is 1.5 V and the internal resistance, r is 0.5 Ω.

LET'S ANSWER
https://bit.ly/2YFuOv5



(a) Arrangement of two dry cells in series *(b) Arrangement of two dry cells in parallel*

Figure 3.32

(a) (i) Compare the current flow in the two circuits.
(ii) Which arrangement of dry cells gives a greater current? Explain.

(b) If the circuit in Figure 3.32(b) is replaced with three dry cells in parallel:
(i) calculate the current
(ii) compare the current in the arrangements of two dry cells in parallel and three dry cells in parallel
(iii) state the relationship between the number of dry cells arranged in parallel with the current in the circuit and explain your answer.

Solution

(a) (i) Arrangement of two dry cells in series:

$r_e = 0.5 + 0.5$
$= 1.0\ \Omega$

$\mathcal{E} = I(R + r)$

Current, $I = \dfrac{\mathcal{E}}{R + r_e}$
$= \dfrac{3}{10 + 1.0}$
$= 0.27\text{ A}$

Arrangement of two dry cells in parallel:

$\dfrac{1}{r_e} = \dfrac{1}{0.5} + \dfrac{1}{0.5}$
$r_e = 0.25\ \Omega$

Current, $I = \dfrac{\mathcal{E}}{R + r_e}$
$= \dfrac{1.5}{10 + 0.25}$
$= 0.1463\text{ A}$

(ii) The dry cell connected in series provides a higher current because of a higher effective e.m.f.

(b) (i) Arrangement of three dry cells in parallel:

$\dfrac{1}{r_e} = \dfrac{1}{0.5} + \dfrac{1}{0.5} + \dfrac{1}{0.5}$
$r_e = 0.167\ \Omega$

Current, $I = \dfrac{\mathcal{E}}{R + r_e}$
$= \dfrac{1.5}{10 + 0.167}$
$= 0.1475\text{ A}$

(ii) The current for three dry cells arranged in parallel is higher.

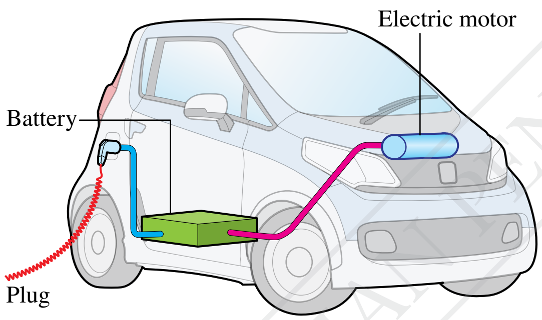
(iii) Increasing the number of dry cells that are arranged in parallel will increase the current in the circuit because the effective internal resistance decreases.

Figure 3.33 explains how two types of vehicles are powered by different electrical sources.

Types of Vehicles Using Electric Power

Electric Vehicle (E.V.)

- Electric vehicle uses 100% electric power using rechargeable batteries to supply energy to electric motors. The commonly used batteries are Li-Ion or Ni-MH batteries.
- The battery voltage range required is 300 – 800 V.



Hybrid Car

- 25 – 40% of its power is supplied by rechargeable batteries and the remainder by fossil fuels such as petrol.
- The battery voltage range used is 100 – 200 V.

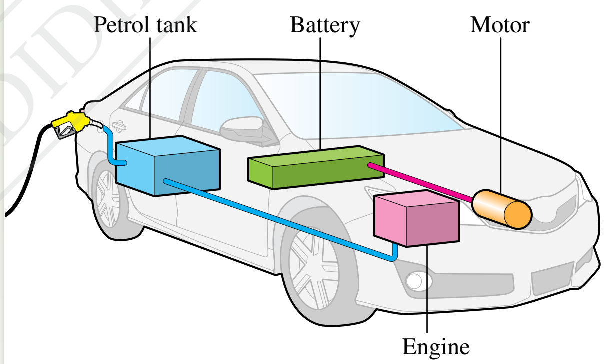


Figure 3.33 *Type of vehicles using electric power*

E.V. and hybrid cars batteries can be charged using domestic electricity supply and at E.V. charging stations or at solar cell charging power stations. Solar cells are components which can convert sunlight into electricity. Solar cells are arranged in series to form a solar panel. Arrangement of solar panels at solar cell charging power station plays a role in providing a suitable voltage and current. The use of E.V. is a good alternative in maintaining environmental sustainability.

SCIENCE, TECHNOLOGY and SOCIETY Gateway

The use of electric vehicle and hybrid cars can reduce the consumption of fossil fuel, increase the efficiency of energy usage and reduce air pollution.

Activity 3.9

CPS / ISS / ICS

Aim: Discuss the connection of solar cells and batteries in an electric vehicle to power the engine that requires high current

Instructions:

1. Carry out this activity in groups.
2. Scan the QR code given or browse the Internet to get information on how solar cells and batteries in electric vehicle are connected to generate high current.

SCAN ME
Video on solar cells and batteries connections
https://bit.ly/2EHtQYk

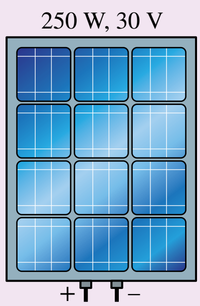
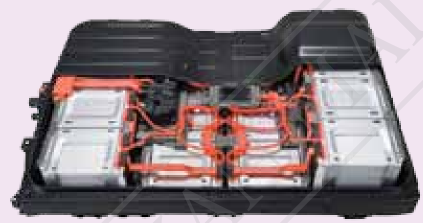


Figure 3.34 *Solar cells*



Photograph 3.5 *Battery packs in electric vehicle*

3. Discuss the connection of solar cell and batteries to start the engine of an electric car that requires high current.
4. Present the results.

Formative Practice 3.3

1. What is meant by electromotive force, e.m.f.?
2. State the difference between e.m.f. and potential difference.
3. What is the effect of internal resistance on current in a complete circuit?
4. If you are supplied with two dry cells, what type of arrangement can reduce the effective internal resistance of the dry cells?

3.4 Electrical Energy and Power

Photograph 3.6 *Various electrical appliances at home*

Photograph 3.6 shows various electrical appliances that are used at home. Electrical appliances convert electrical energy into other forms of energy. For example, lamps produce light and heat energy when supplied with electrical energy. Can you state the form of energy that is generated by the electrical appliances in Photograph 3.6?

The Relationship between Electrical Energy (E), Voltage (V), Current (I) and Time (t)

Based on the formula of potential difference, $V = \frac{E}{Q}$

where V = potential difference
E = electrical energy
Q = the amount of charge flowing

Electrical energy, $E = VQ$ and $Q = It$

Therefore, the relationship between E, V, I and t can be formulated as:

$$E = VIt$$

The S.I. unit for electrical energy, E is joule (J).

Info GALLERY

1 J is the electrical energy that is used when 1 A of current flows through an electrical device with a potential difference of 1 V across it for 1 s.

The Relationship between Power (*P*), Voltage (*V*) and Current (*I*)

Have you ever seen a label as shown in Photograph 3.7? The label displays the voltage and electrical power required to operate the electrical appliance.

Based on the label in Photograph 3.7, the electric rice cooker will use 700 J of electrical energy in one second when a voltage of 240 V is supplied. This information can be used to calculate the amount of electrical energy that is used over a period of time.

Photograph 3.7 *Power rating label on an electric rice cooker*

$$\text{Electrical power} = \frac{\text{Electrical energy used}}{\text{Time taken}}$$

$$P = \frac{E}{t}$$

and electrical energy, $E = VIt$

Therefore, the relationship between P, V and I can be derived as:

$$P = \frac{VIt}{t}$$

$$P = VI$$

From Ohm's Law, $V = IR$, two other equations for electrical power, P can be obtained as follows:

1. $P = V\left(\frac{V}{R}\right)$, then $P = \frac{V^2}{R}$
2. $P = (IR)I$, then $P = I^2R$

The S.I. unit for electrical power, P is watt (W) or J s^{-1}.

Info GALLERY

The voltage labelled on an electrical appliance is the working voltage. The working voltage is the potential difference required for an electrical appliance to operate under normal conditions. When an electrical appliance is operating at the working voltage, the electrical power used is as stated in the label.

Solving Problems Involving Electrical Energy and Power in Daily Life

Example 1

Figure 3.35 shows a circuit that is supplied with a 6 V battery to light up a lamp. If the current is 0.7 A, what is the amount of electrical energy used to light up the lamp for one minute?

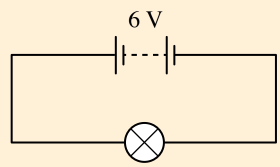


Figure 3.35

LET'S ANSWER

https://bit.ly/3jlXjWq

Solution

Step 1: Identify the problem

Step 2: Identify the information given

Step 3: Identify the formula that can be used

Step 4: Solve the problem numerically

1. Total electrical energy, E

2. Potential difference, $V = 6$ V
   Current, $I = 0.7$ A
   Time, $t = 1 \times 60$ s
   $= 60$ s

3. $E = VQ$
   $Q = It$
   Therefore, $E = VIt$

4. $E = 6 \times 0.7 \times 60$
   $= 252$ J

Example 2

A fluorescent lamp is labelled 240 V, 32 W.
Calculate:
(a) the lamp resistance
(b) the current flowing through the lamp under normal conditions
(c) the electrical energy that is supplied for three hours in kJ

BRIGHT Info

Scan the QR code for tips on how to use formulae to solve problems involving electrical energy and power.

https://bit.ly/3lxmt6G

Solution

(a) Electrical power required, $P = 32$ W
Potential difference across the lamp, $V = 240$ V
Resistance, $R = \frac{V^2}{P}$
$= \frac{240^2}{32}$
$= 1\ 800\ \Omega$

(b) Electrical power required, $P = 32$ W
Potential difference across the lamp, $V = 240$ V
Current, $I = \frac{P}{V}$
$= \frac{32}{240}$
$= 0.13$ A

(c) Electrical power required, $P = 32$ W
Time, $t = 3 \times 60 \times 60$
$= 10\ 800$ s
Electrical energy,
$E = Pt$
$= 32 \times 10\ 800$
$= 345\ 600$ J
$= 345.6$ kJ

The Power and Energy Consumption Rate for Various Electrical Devices

Nowadays, a variety of electrical appliances are available in the market. Consumers need to be wise in choosing electrical appliances that provide maximum energy saving.

For example, a 40 W Compact Fluorescent Lamp (CFL) and a 12 W Light Emitting Diode (LED) both produce the same brightness. If they are switched on for 12 hours a day, compare the costs of energy consumption for both lamps for 30 days.

Info GALLERY

The cost of electricity consumption depends on the amount of electrical energy used in a certain duration (usually 30 days). The total electrical energy used is measured in kWh.

1 kWh = 1 unit of electricity

***Table 3.15** Comparison of costs of energy consumption between CFL and LED*

CFL	LED
Energy used, $E = Pt$ $= 0.04 \text{ kW} \times 12 \text{ h}$ $= 0.48$ units Given that the cost of energy consumption is RM0.218 per unit; Cost of energy consumption = 30 days × 0.48 units × RM0.218 = RM3.139 	Energy used, $E = Pt$ $= 0.012 \text{ kW} \times 12 \text{ h}$ $= 0.144$ units Given that the cost of energy consumption is RM0.218 per unit; Cost of energy consumption = 30 days × 0.144 units × RM0.218 = RM0.942 

The energy consumption of LED is lower than CFL. This shows that LED has a higher efficiency and is more energy-saving compared to CFL.

Activity 3.10

ISS

Aim: To calculate electrical energy consumption at home

Instructions:

1. Carry out this activity individually.
2. Scan the QR code and print Table 3.16.
3. List all the electrical appliances that are found in your home such as electric rice cooker, television, lamp, electric oven, fan, air conditioner and so on in the table.
4. Collect information on the consumption of electrical energy based on the power rating of the electrical appliances. For each electrical appliances:
   (a) determine the quantity, power and hours used in a day
   (b) estimate the cost of electrical energy consumption in your home for a month

SCAN ME
Worksheet (Table 3.16)
https://bit.ly/3hxmyF3

Table 3.16

No.	Electrical appliance	Quantity (A)	Power / kW (B)	Hours used in a day / h (C)	Total energy usage / kWh (A × B × C)
1	Electric rice cooker				
2	Television				
3	Lamp				

5. Present the results of your findings.

Discussion:

1. Identify the electrical appliance in your home that consumes the highest electrical energy.

2. Suggest steps to reduce the cost of electricity consumption in your home.

Steps in Reducing Household's Electrical Energy Usage

Prudent use of electricity can help save and reduce the cost of electricity consumption at home. Can you suggest some energy saving measures that you can do at home?

Steps in Reducing Household's Electrical Energy Usage			
Close all windows and doors when using the air conditioner and ensure that the air conditioner filter is kept clean to cool the room down faster and more efficiently.	Switch off electrical appliances when they are not in use to conserve energy.	Use only full loads of laundry when using the washing machine.	Use energy saving lamps to reduce energy consumption.

Figure 3.36 *Steps in reducing household's electrical energy usage*

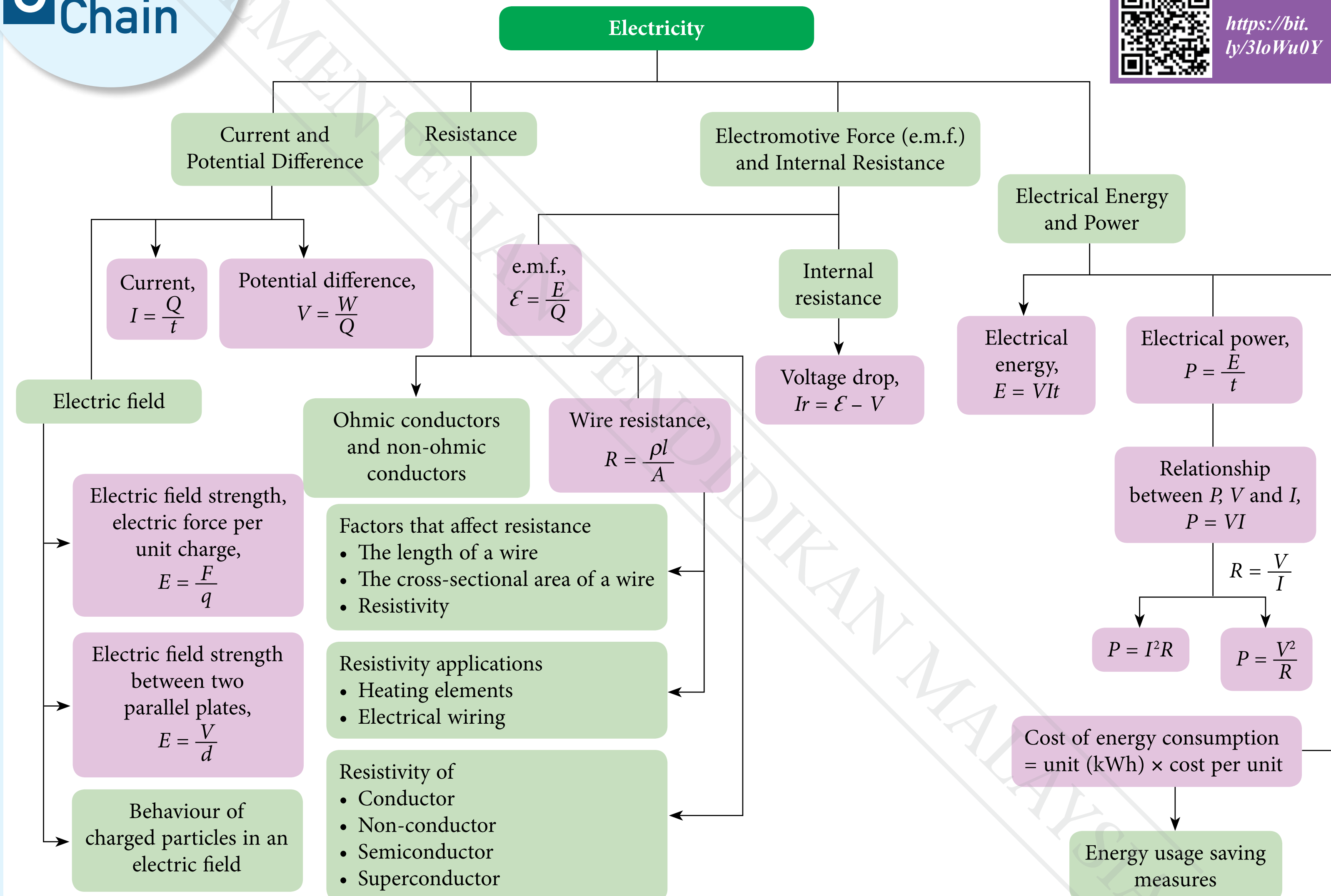
Formative Practice 3.4

1. The output power of a battery is 80 W. Determine the electrical energy that is supplied by the battery in:
(a) 10 seconds
(b) 2 hours

2. If the cost of electricity is 30 sen per unit, calculate the cost of using:
(a) 600 W LED television for 8 hours
(b) 1 kW vacuum cleaner for half an hour

Concept Chain

Interactive Games
https://bit.ly/3loWu0Y



Self-Reflection

1. New things I have learnt in the chapter on 'Electricity' are ______.

2. The most interesting thing I have learnt in this chapter is ______.

3. The things I still do not fully understand are ______.

4. My performance in this chapter.

   Poor | 1 | 2 | 3 | 4 | 5 | Very good

5. I need to ______ to improve my performance in this chapter.

Summative Practice

1. Figure 1 shows a filament lamp. Why does a coiled filament produce a brighter light?

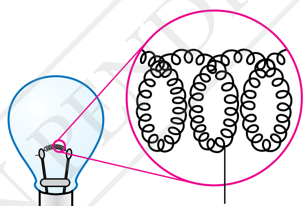


Figure 1

2. Figure 2 shows a circuit with three bulbs, *X*, *Y* and *Z* with a resistance of 3 Ω each.

   (a) If switches S_1, S_2 and S_3 are closed, calculate:
   (i) the effective resistance in the circuit
   (ii) the current indicated by the ammeter
   (iii) the potential difference across bulb *X*

   (b) Compare the brightness of light bulbs *X*, *Y* and *Z* when switches S_1, S_2 and S_3 are closed.

   (c) If only switches S_1 and S_2 are closed, calculate:
   (i) the effective resistance in the circuit
   (ii) the current indicated by the ammeter
   (iii) the potential difference across bulb *X*

   (d) Compare the brightness of light bulbs *X*, *Y* and *Z* when only switches S_1 and S_2 are closed.

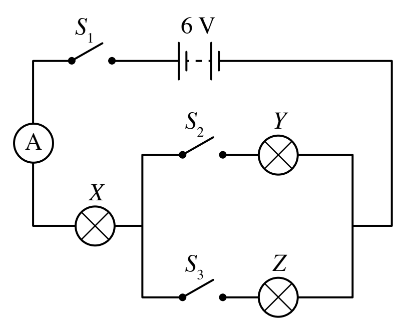


Figure 2

3. An experiment is conducted to study the relationship between electromotive force, $\mathcal{E}$ and internal resistance, r of a dry cell. The electrical circuit for the experiment is shown in Figure 3. The voltmeter readings, V and the corresponding ammeter readings, I are as shown in Table 1.

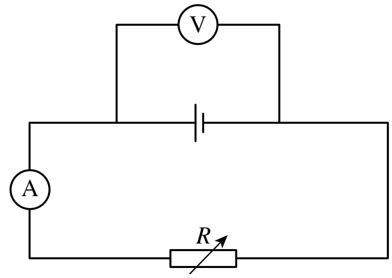


Figure 3

Table 1

V / V	I / A
1.40	0.2
1.35	0.4
1.25	0.6
1.15	0.8
1.10	1.0

(a) What is meant by electromotive force?

(b) Based on the data in Table 1, plot a graph of V against I.

(c) Based on the graph plotted, answer the following questions:
   (i) What happens to V when I increases?
   (ii) Determine the value of the potential difference, V when the current, I = 0.0 A. Show on the graph how you determine the value of V.
   (iii) Name the physical quantity that represents the value in 3(c)(ii).

(d) The internal resistance, r of the dry cell is given by $r = -m$, where m is the gradient of the graph. Calculate r.

(e) State two precautions that need to be taken in this experiment.

4. Figure 4 shows a circuit that is used to investigate the relationship between resistance, R and length of wire, l for two different wire conductors with the same diameter, that is 0.508 mm. Figure 5 shows the graph of resistance against length of wire.

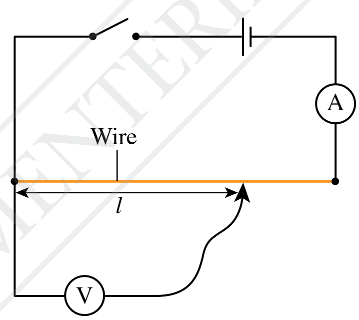


Figure 4

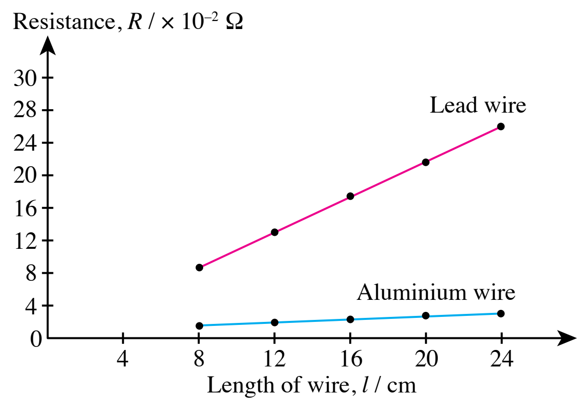


Figure 5

(a) What is meant by resistivity?

(b) Based on the graph in Figure 5, compare:
   (i) the gradients of the graph
   (ii) their resistivities.

(c) Based on your answer in 4(b), state the relationship between the gradient of the graph and the resistivity of the conductor.

5. Figure 6 shows four types of air fryers *A*, *B*, *C* and *D* with different specifications. Study the specifications of the four air fryers based on the following aspects:
- heating element
- coil turns of the heating element
- number of fan blades
- suitability of fuse

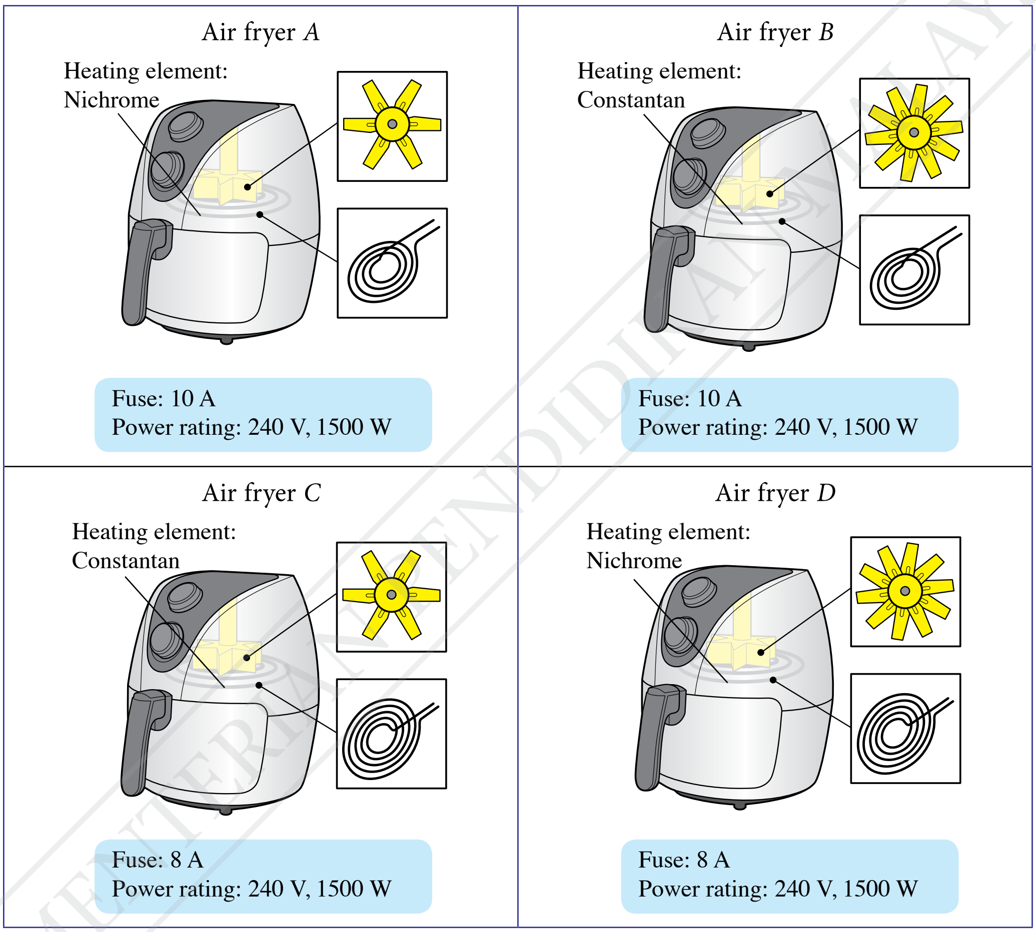


Figure 6

(a) What is the function of a fuse in an air fryer?
(b) What is meant by 240 V, 1500 W on the label of the air fryers?
(c) Discuss the specifications of the four air fryers to cook food quickly and safely.
(d) Determine the most suitable air fryer. Give your reasons.

6. Your mother has just renovated her kitchen with a modern concept. As a final touch, she asked you to buy an electric stove that can heat up food quickly and save electricity. Table 2 shows several electric stoves with its heating element features.

Table 2

Type of electric stove	Metal resistivity at 20°C, ρ / 10^{-6} Ω cm	Thermal conductivity	Melting point / °C	Oxidation rate
P	1.7	Low	1 084	High
Q	2.7	High	660	Low
R	6.9	High	1 452	Low
S	20.6	Low	327	High

(a) Discuss the suitability of the four types of electric stoves based on the features given.

(b) Determine the most suitable electric stove. Give your reasons.

21st Century Challenge

7. Figure 7 shows a heating element in an electric kettle. You are required to modify the heating element so that it is portable and can boil water faster and safer.
Explain the modifications based on the following aspects:

- number of coil turns of the heating element
- density of the heating element
- diameter of the heating wire
- type of material used as the heating element

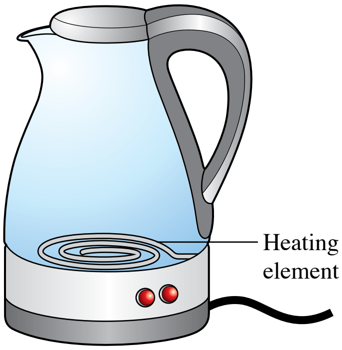


Figure 7

CHAPTER 4

Electromagnetism

How are magnetic forces used to produce rotation in an electric motor?

What is a brushless motor?

How can the concept of electromagnetic induction be applied to benefit human beings?

Why are transformers used in the transmission and distribution of electricity?

You will learn:

- **4.1** Force on a Current-carrying Conductor in a Magnetic Field
- **4.2** Electromagnetic Induction
- **4.3** Transformers

Learning Standards and List of Formulae in Chapter 4

Information Portal

The drop tower is a high technology theme park equipment based on the concept of electromagnetic induction. The passengers on the drop tower will drop from a great height and experience free fall at high speed. They are then slowed down by an arrangement of permanent magnets fixed under their seats and copper strips on the lower section of the drop tower. The motion of the permanent magnet passing the copper strips will activate electromagnetic braking. This can be explained by the concept of electromagnetic induction.

http://bit.ly/31oQxJK

Importance of the Chapter

Knowledge about electromagnetism is important because magnetic forces, electromagnetic induction and transformers have wide applications and affect various aspects of our daily life. Magnetic forces are used in various types of motors such as small electric motors in fans and modern electric motors in modern electric vehicles. The principle of electromagnetic induction is applied in electric generators and transformers for the purpose of generation and transmission of electric power from the power station to the consumer. Various new innovations that use the concept of electromagnetism are being developed by scientists and engineers.

Futuristic Lens

The concept of electromagnets is not only used to slow down motion but also to accelerate the motion of objects to very high velocities. For example, hyperloop transportation uses linear electric motors (without rotation) to accelerate vehicles moving in low pressure tubes. Transportation on land at speeds comparable to the speed of aircraft may become a reality in the near future.

http://bit.ly/2CTNa3X

4.1 Force on a Current-carrying Conductor in a Magnetic Field

Do you know that an electric train as shown in Photograph 4.1 uses a large electric motor while a smart phone uses a small motor? The function of most electric motors is based on the effect of a current-carrying conductor in a magnetic field.

Photograph 4.1 *Electric train*

SCAN ME
EduwebTV: Force on a current-carrying conductor
http://bit.ly/3glVNBT

Activity 4.1

Aim: To study the effect on a current-carrying conductor in a magnetic field

Apparatus: Low voltage direct current power supply, U-shaped steel yoke, a pair of Magnadur magnets and retort stand

Materials: Two copper rods without insulation and copper wire (s.w.g. 20 or thicker) without insulation

Instructions:

1. Set up the arrangement of apparatus as shown in Figure 4.1.

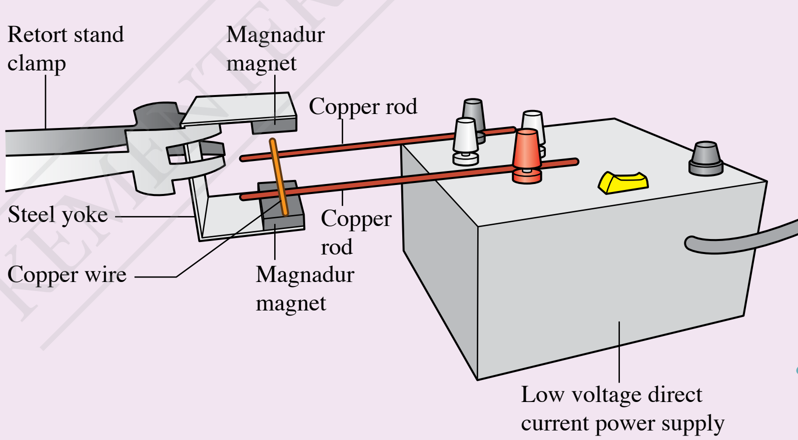


Figure 4.1

SCAN ME
Video on force
http://bit.ly/2CSkOXF

2. Turn on the power supply so that current flows into the copper wire. Observe the movement of the copper wire.
3. Turn off the power supply. Reverse the connections to the power supply so that the current in the copper wire is reversed.
4. Turn on the power supply again. Observe the movement of copper wire.
5. Turn off the power supply. Remove the steel yoke, reverse the poles of the Magnadur magnets and put back the steel yoke.
6. Turn on the power supply and observe the movement of copper wire.

Discussion:

1. Describe the motion of the copper wire when the power supply is turned on.
2. What is the effect on the copper wire when:
   (a) the direction of the current is reversed?
   (b) the poles of the magnet are reversed?
3. State two factors that affect the direction of the force acting on the current-carrying conductor.

When a current-carrying conductor is placed in a magnetic field, the conductor will experience a force. The direction of the force depends on the direction of the current and the direction of the magnetic field.

SCAN ME
Video on formation of force
http://bit.ly/3jajz5s

Pattern on Resultant Magnetic Field

Figure 4.2 shows a current-carrying conductor that is placed in a magnetic field produced by a pair of Magnadur magnets. What is the direction of the force acting on the conductor?

LET'S RECALL
Magnetic field from the electric current in a straight wire
http://bit.ly/31m7yE4

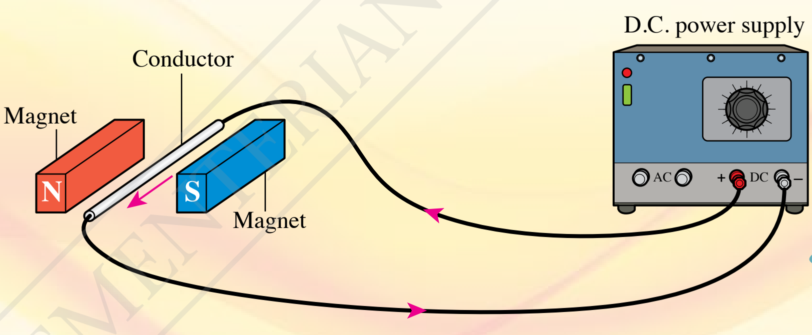


Figure 4.2 Current-carrying conductor placed between two magnets

SCAN ME
Effect on a current-carrying conductor in a magnetic field
https://bit.ly/2Qhj2T6

The force on a current-carrying conductor in a magnetic field is produced by the interaction between two magnetic fields: the magnetic field from the electric current in the conductor and the magnetic field from the permanent magnet. The two magnetic fields combine to produce a resultant magnetic field that is known as a catapult field. The pattern of the catapult field will show the direction of the force acting on the conductor.

Activity 4.2

Aim: To observe magnetic field pattern through a computer simulation

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Scan the QR code to observe the computer simulation that shows the method of drawing the pattern of the resultant magnetic field.
3. Scan the QR code and print the worksheet.
4. Based on the computer simulation that you watched, complete the worksheet to show the formation of the catapult field.
5. Label the direction of the force acting on the current-carrying conductor.

SCAN ME
Simulation of magnetic field pattern
http://bit.ly/3gou5Vf

SCAN ME
Worksheet
http://bit.ly/3gjqVC4

Figure 4.3 shows the catapult field formed when a current-carrying conductor is in a magnetic field. A **catapult field** is a **resultant magnetic field produced by the interaction between the magnetic field from a current-carrying conductor and the magnetic field from a permanent magnet**. The catapult field exerts a resultant force on the conductor.

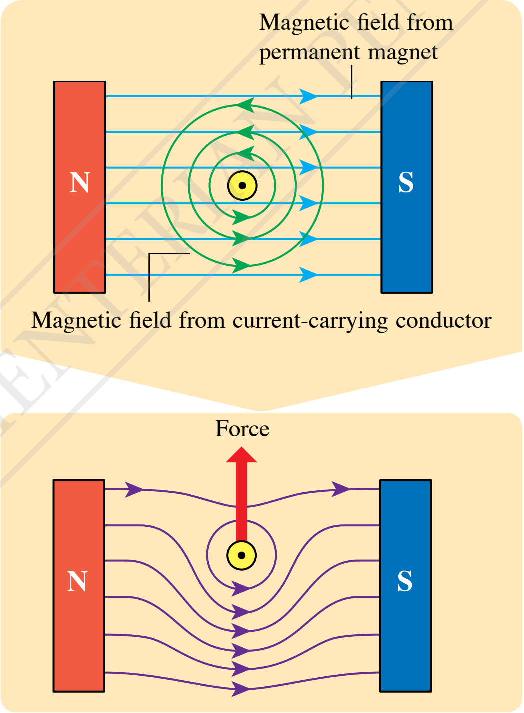
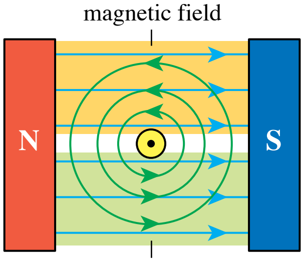


***Figure 4.3** Formation of catapult field*

BRIGHT Info

- For a straight conductor, the direction of the magnetic field is determined by the right hand grip rule.
- For a permanent magnet, the direction of the magnetic field is from north to south.
- The region of weak magnetic field and the region of strong magnetic field is determined as follows:

Opposing magnetic field lines, weak magnetic field

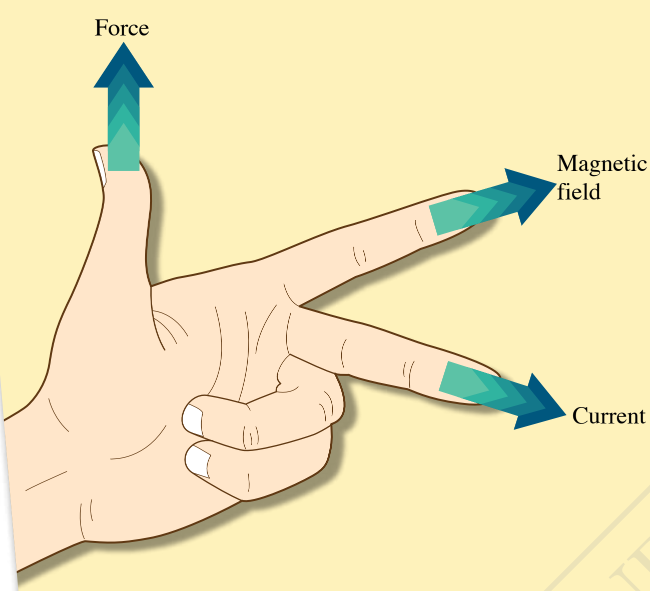


Magnetic field lines in the same direction, strong magnetic field

⊙ Direction of current out of the plane of the paper
⊗ Direction of current into the plane of the paper

The direction of the force on a current-carrying conductor can be determined by using Fleming's left-hand rule as shown in Figure 4.4.

Fleming's left-hand rule



Step 1 Index finger shows the direction of the magnetic field, that is, from north to south.

Step 2 Middle finger shows the direction of the electric current.

Step 3 The thumb will show the direction of the force acting on the conductor. The direction of motion of the conductor follows the direction of the force.

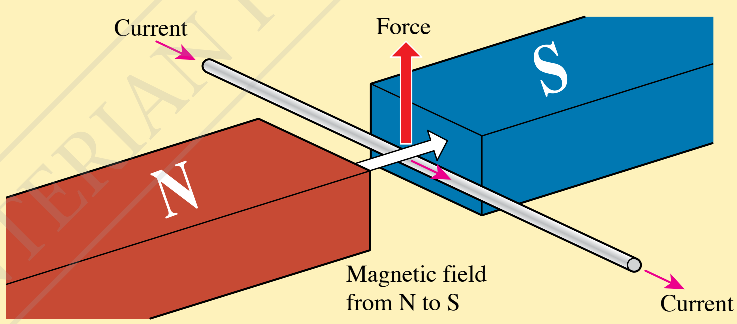


***Figure 4.4** Fleming's left-hand rule to determine the direction of the force*

Factors Affecting the Magnitude of the Force Acting on a Current-carrying Conductor in a Magnetic Field

A large force is required to drive the motor in a washing machine compared to the cooling fan in a notebook computer which requires a smaller force. What are the factors affecting the magnitude of the force acting on a current-carrying conductor in a magnetic field?

Activity 4.3

Aim: To study the factors that affect the magnitude of the force acting on a current-carrying conductor in a magnetic field

Apparatus: Direct current power supply, U-shaped steel yoke, two pairs of Magnadur magnets, electronic balance and retort stand

Materials: Copper wire (s.w.g. 20), crocodile clip and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 4.5.

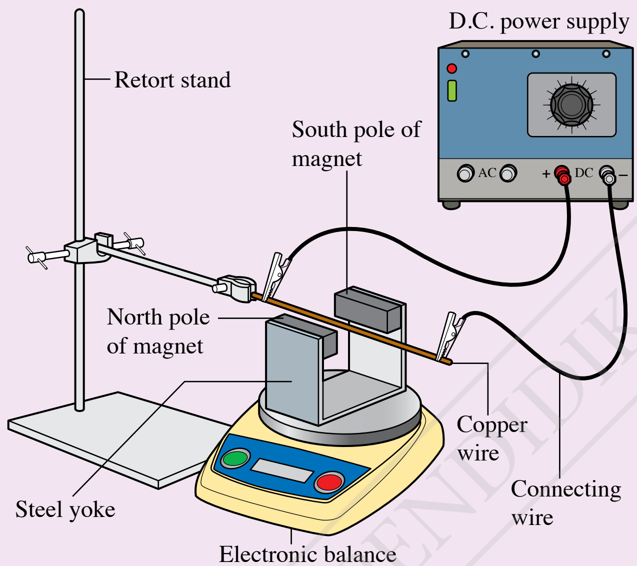


Figure 4.5

2. Adjust the output to 1 V on the D.C. power supply. Reset the reading of the electronic balance to zero.
3. Turn on the power supply and record the reading of the electronic balance. Then, turn off the power supply.
4. Repeat steps 2 and 3 with output voltage 2 V. Record your results in Table 4.1.
5. Add another pair of Magnadur magnets on the steel yoke and repeat steps 2 and 3. Record your results in Table 4.1.

Results:

Table 4.1

Voltage / V	Number of magnets	Reading of electronic balance / g
1	One pair	
2	One pair	
1	Two pairs	

Note

The interaction between the magnetic fields of the current in the copper wire and the Magnadur magnets will produce a catapult field. The catapult field exerts a force vertically upwards on the copper wire. At the same time, the Magnadur magnets experience a reaction force with the same magnitude but in the opposite direction. This force acts on the pan of the electronic balance to give a reading that represents the magnitude of the force. Hence, a larger force will produce a larger reading of the electronic balance.

SCAN ME

Video of force measurement

http://bit.ly/3lf051t

Note

The north pole and the south pole of the Magnadur magnet can be determined by bringing a bar magnet near the Magnadur magnet. Remember that like poles repel while opposite poles attract.

Discussion:

1. What is the relationship between the voltage applied across the copper wire and the current in the wire?
2. How does the magnitude of the current affect the magnitude of the force acting on the current-carrying conductor?
3. What is the effect of the strength of the magnetic field on the magnitude of the force acting on the current-carrying conductor?

From Activity 4.3, it is found that the magnitude of the force acting on the current-carrying conductor in a magnetic field increases when the magnitude of the current and the strength of the magnetic field increases. The effect of the increase in current and the strength of magnetic field on the force can be observed from the height of swing of the copper frame as shown in Figure 4.6.

Brain-Teaser

How can the strength of the magnetic field and the current be increased?

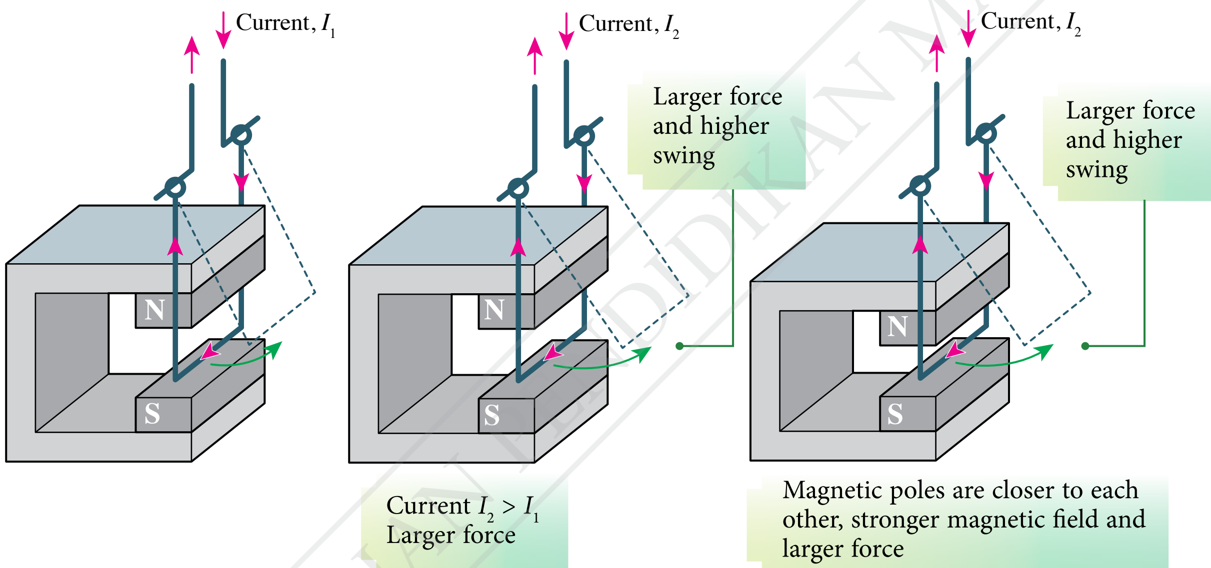


Figure 4.6 Effects of current and magnetic field on force

Figure 4.7 shows another way to study the factors that affect the magnitude of the force acting on a current-carrying conductor in a magnetic field. The distance travelled, *d*, by the conductor represents the magnitude of the force. The larger the force, the further the distance travelled by the conductor.

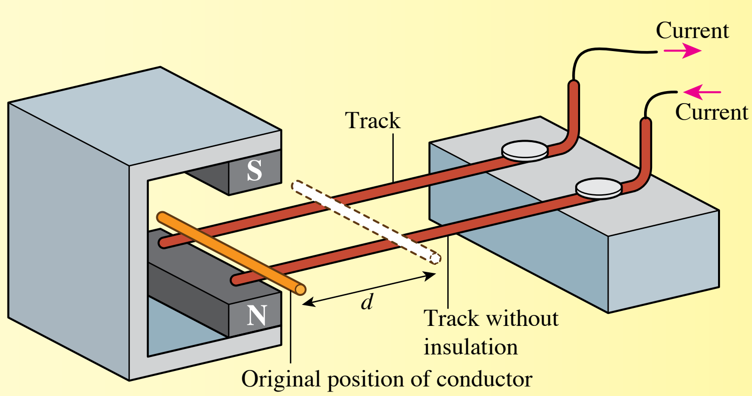


Figure 4.7 Distance travelled, d, by a conductor when electric current flows through it

LS 4.1.3

Effect of a Current-carrying Coil in a Magnetic Field

Figure 4.8 shows a rectangular coil formed with a piece of copper wire. When the coil is connected to a power supply, current can flow through the coil in the direction of $A \rightarrow B \rightarrow C \rightarrow D$ or $D \rightarrow C \rightarrow B \rightarrow A$. What is the effect on the coil if the coil carries a current in a magnetic field?

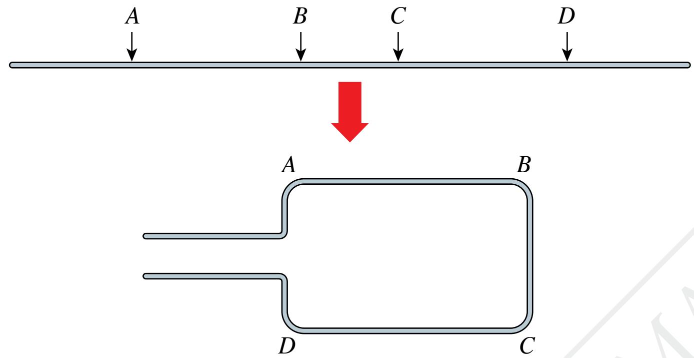


Figure 4.8 *A rectangular coil formed with a copper wire*

Activity 4.4

ISS | ICS

Aim: To observe the turning effect on a current-carrying coil in a magnetic field

Instructions:

1. Carry out this activity in pairs.
2. Scan the given QR code to watch a video on the turning effect on a current-carrying coil in a magnetic field.
3. Download Figure 4.9 from the given website and complete the diagram by:
   (a) labelling the direction of the current in sections *AB*, *BC* and *CD*
   (b) labelling the direction of the force on the coil at sections *AB* and *CD*
   (c) mark the direction of rotation of the coil

SCAN ME Video of turning effect on a current-carrying coil
http://bit.ly/2YwcXXr

SCAN ME Worksheet (Figure 4.9)
http://bit.ly/3gqdyAa

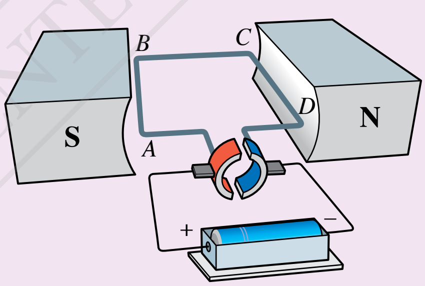


Figure 4.9

The current-carrying coil in a magnetic field will rotate about the axis of rotation. This rotation is due to a pair of forces of equal magnitude but in opposite directions acting on the sides of the coil. This pair of forces is produced by the interaction between the current-carrying coil and the magnetic field from the permanent magnet.

Figure 4.10 shows the pair of forces acting on sides *AB* and *CD* of a current-carrying coil. The interaction between the magnetic field from the current-carrying coil and the magnetic field from the permanent magnet as shown in Figure 4.11 produces a catapult field as shown in Figure 4.12. The catapult field exerts a force on sides *AB* and *CD* of the coil respectively. This pair of forces rotates the coil. The turning effect on a current-carrying coil in a magnetic field is the working principle of the direct current motor.

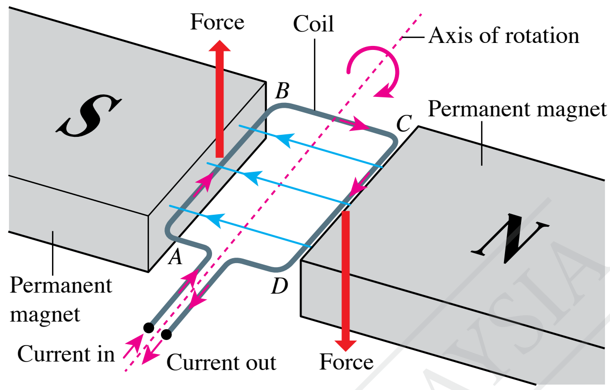


Figure 4.10 *A pair of forces acting in a magnetic field causes the coil to rotate*

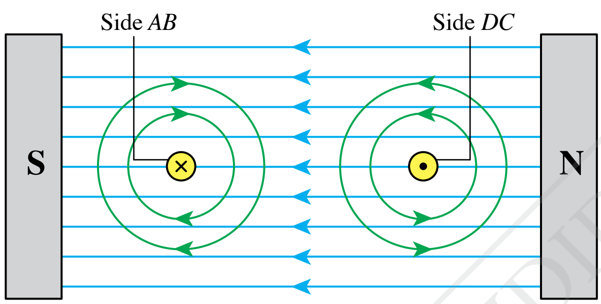


Figure 4.11 *Direction of magnetic field around sides AB and CD*

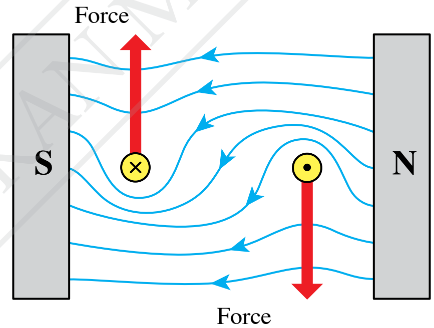


Figure 4.12 *Catapult fields is produced*

Direct Current Motor

Small electrical appliances such as children's toys, portable drills and the hard disk of a computer have a small direct current motor. Larger direct current motors are found in machines such as electric vehicles, lifts and rollers in factories. The direct current motor changes electrical energy to kinetic energy by using the turning effect of a current-carrying coil in a magnetic field. What is the working principle of a direct current motor?

Activity 4.5

ISS ICS

Aim: To gather information on the working principle of a direct current motor

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code and watch the video of the working principle of the direct current motor.
3. Refer to other materials to obtain additional information.
4. Prepare a multimedia presentation entitled ‘The Working Principle of Direct Current Motors’.

SCAN ME
Video of direct current motor and its working principle
http://bit.ly/2CRxX3c

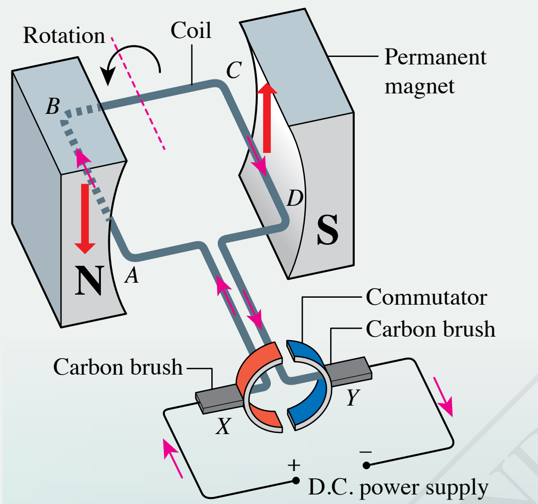
LS 4.1.4 4.1.5

Figure 4.13 shows a direct current motor during the first half of its rotation and the second half of its rotation. An important component in a direct current motor is the commutator that rotates with the rectangular coil. The carbon brushes in contact with the commutator are in their fixed positions.

Brain-Teaser

Why is the commutator not a full ring but a ring split into two halves? Can the commutator be split into more sections?

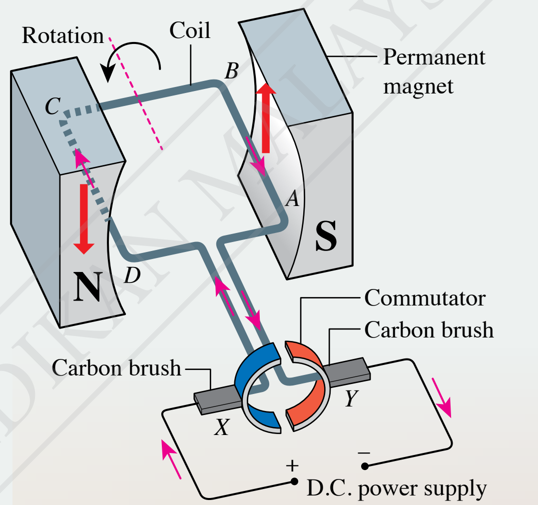
First Half Rotation



First-half rotation
Direction of current in the coil: *ABCD*

- Carbon brush *X* in contact with red half of the commutator
- Carbon brush *Y* in contact with blue half of the commutator
- Direction of current in the coil *A*→*B*→*C*→*D*
- Side *AB* of the coil: force acts downwards. Side *CD* of the coil: force acts upwards
- Coil rotates in one direction

Second Half Rotation



Second-half rotation
Direction of current in the coil: *DCBA*

- Carbon brush *X* in contact with blue half of the commutator
- Carbon brush *Y* in contact with red half of the commutator
- Direction of current in the coil *D*→*C*→*B*→*A*
- Side *AB* of the coil: force acts upwards. Side *CD* of the coil: force acts downwards
- Coil rotates in the same direction as the first half rotation

Figure 4.13 *Working principle of a direct current motor*

Factors Affecting the Speed of Rotation of an Electric Motor

Photograph 4.2 shows a portable device that can function as a screwdriver or a drill. The direct current motor in the device rotates at a low speed when turning a screw. A high speed is necessary when the device is used to drill a hole in the wall. What are the factors that affect the speed of rotation of an electric motor?

Photograph 4.2
Screwdriver and drill

Activity 4.6

Aim: To study the factors that affect the speed of rotation of an electric motor

Apparatus: Direct current power supply and a pair of Magnadur magnets

Materials: Insulated copper wire (s.w.g. 26), two large paper clips, two pieces of thumb tacks and connecting wires

Instructions:

1. Set up the arrangement of apparatus as shown in Figure 4.14.

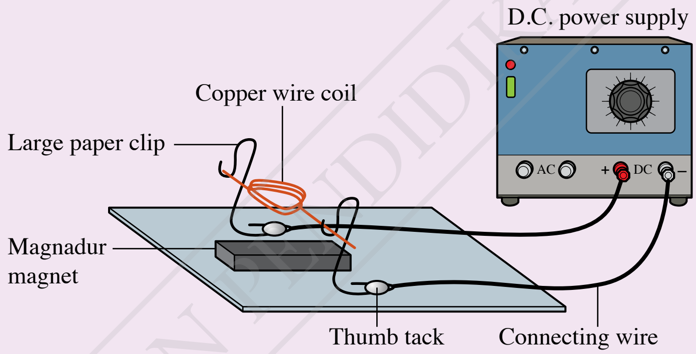


Figure 4.14

2. Adjust the voltage of the power supply to 4.0 V. Turn on the power supply and observe the speed of rotation of the motor.
3. Repeat step 2 using a voltage of 6.0 V.
4. Add one more Magnadur magnet to produce a stronger magnetic field. Turn on the power supply and observe the speed of rotation of the motor.
5. Add more turns to the copper coil. Turn on the power supply and observe the speed of rotation of the motor.

Safety Precaution

- Switch off the power supply immediately after an observation has been made.
- Current should flow for only a short time so that the coil will not become too hot.

Discussion:

1. What is the relationship between the current in the coil and the voltage supplied?
2. Describe the change in the speed of rotation of the motor when:
   (a) the voltage supplied is increased
   (b) the strength of the magnetic field is increased
   (c) the number of turns of the coil is increased
3. State the factors that affect the speed of rotation of a motor.

SCAN ME
Video of rotation of an electric motor
http://bit.ly/32imlPr

LS 4.1.6

Activity 4.6 shows that the speed of rotation of an electric motor increases when:

Current in the coil increases	Strength of magnetic field increases	Coil with more turns is used

Activity 4.7

CPS / ICS

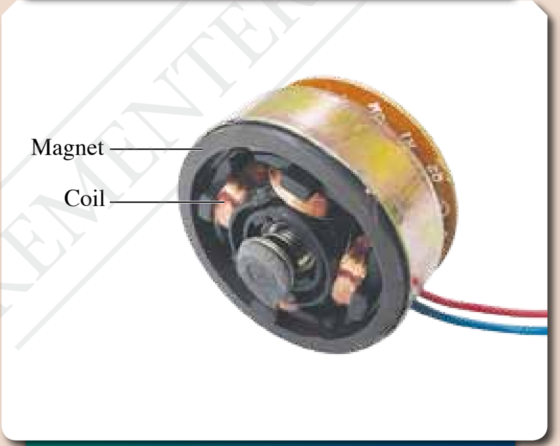
Aim: To study the direct current motors found in used devices to identify the arrangement of the coil and the commutator

Instructions:

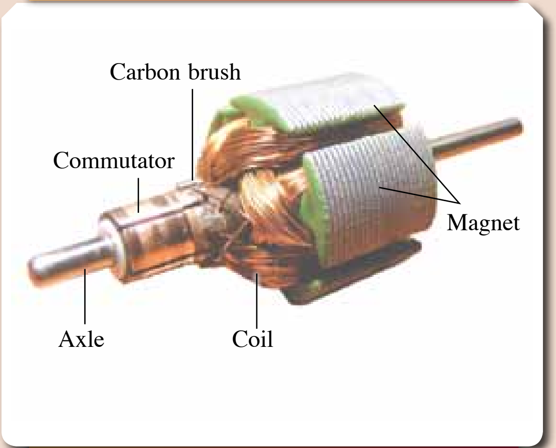
1. Collect a few direct current electric motors from used devices.
2. With the aid and guidance of your teacher, dismantle each motor and identify the coil, the magnet and the commutator.
3. Observe the position of the coil and the magnet in the motor.
4. Observe also the number of sections in the commutator.
5. Prepare a brief report that compares and contrasts the arrangement of the coil, magnet and commutator in direct current motors.

While carrying out Activity 4.7, you may have come across electric motors which do not have a commutator and carbon brushes. Photograph 4.3 shows a brushless motor and a brushed motor. What is the advantage of brushless motors?

Brushless Motor



Brushed Motor



Photograph 4.3 *Brushless motor and brushed motor*

Activity 4.8

ICS

Aim: To study and report on the advantages of brushless motor compared to brushed motor

Instructions:

1. Carry out a Three Stray, One Stay activity.
2. Scan the QR code given or refer to other reference materials to:
   (a) understand the working principle of brushless motor
   (b) study the advantages of brushless motor compared to brushed motor
3. Report the findings of your study.

SCAN ME
Differences between brushless motor and brushed motor
http://bit.ly/2YwZUBi

Table 4.2 shows the comparison between brushless motor and brushed motor.

***Table 4.2** Comparison between brushless motor and brushed motor*

Brushless motor	Brushed motor
Similarities	
Has a magnet and a coil	
Uses magnetic force to produce rotation	
Differences	
Coil is stationary, magnet rotates	Magnet is stationary, coil rotates
No carbon brushes, therefore no friction between the brushes and the commutator	Friction between the carbon brush and the commutator causes the carbon brush to wear out
No sparking at the commutator	Sparking at the commutator
Soft operational sound	Louder operational noise

Activity 4.9

STEM CPS ICS

Aim: To design a simple and efficient homopolar motor

Materials: Neodymium magnet, AA dry cell and copper wire (s.w.g. 18 to 22)

Instructions:

1. Carry out this activity in groups.
2. Gather information on homopolar motors from the aspect of:
   (a) the working principle of homopolar motors
   (b) the shape and size of the neodymium magnet
   (c) various designs of the copper wire that can be tried out
3. Use the K-W-L Data Strategy Form.

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

4. Sketch the design of a homopolar motor.
5. Construct the homopolar motor according to the suggested design.
6. Operate the homopolar motor that you have constructed.
7. Observe the rotation produced and identify the aspects of the design that need to be improved.
8. Discuss the steps of improvement that can be carried out.
9. Improve the homopolar motor if necessary and test the rotation.
10. Based on your experience in designing and constructing the homopolar motor, discuss ways to construct a more efficient motor at a low cost.
11. Present the outcome.

EAC History

In the year 1821, Michael Faraday constructed and demonstrated the operation of a homopolar motor at the Royal Institute, London.

Formative Practice 4.1

1. With the aid of a labelled diagram, explain the meaning of catapult field.
2. Figure 4.15 shows the arrangement of apparatus to study the effect of a force on a current-carrying conductor.

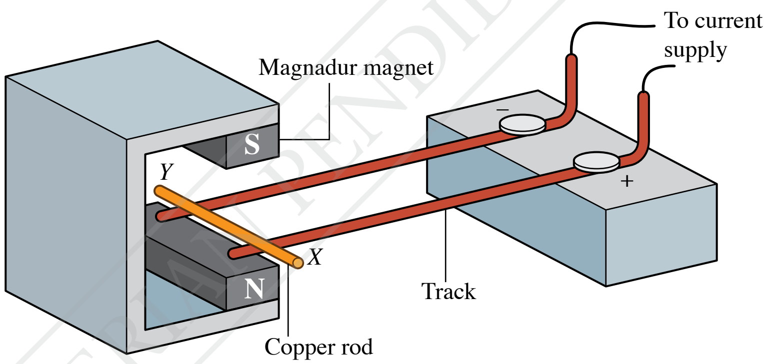


Figure 4.15

(a) What is the direction of the current in the copper wire *XY* when the switch of the direct current power supply is turned on?
(b) Explain the motion of the copper wire *XY* and state the direction of the motion.

3. State three factors that affect the speed of rotation of a motor.
4. (a) Compare and contrast the structure of a brushed motor with a brushless motor.
(b) State two advantages of brushless motor compared to brushed motor.

4.2 Electromagnetic Induction

Photograph 4.4 shows a musician plucking an electric bass guitar. The guitar pickup consisting of four magnets and copper coils produces an electric signal by electromagnetic induction. How does electromagnetic induction produce an electric current without the use of dry cells?

Photograph 4.4 *Components in an electric bass guitar pickup*

Activity 4.10

Aim: To study electromagnetic induction in a straight wire and a solenoid

A Straight wire

Apparatus: A pair of Magnadur magnets, copper rod and sensitive centre-zero galvanometer or digital multimeter

Material: Connecting wires with crocodile clips

Instructions:

1. Set up the apparatus as shown in Figure 4.16.

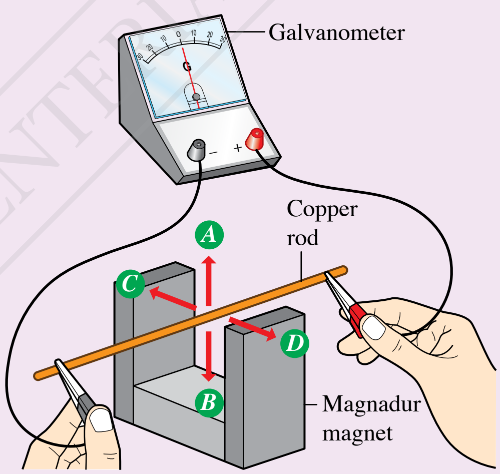


Figure 4.16

SCAN ME
Video on electromagnetic induction in a straight wire
https://bit.ly/34ulaiS

2. Hold the copper rod stationary between the poles of the magnet as shown in Figure 4.16. Observe the reading of the galvanometer.

3. Move the copper rod quickly in direction *A* as shown in Figure 4.16. Observe the deflection of the galvanometer pointer.
4. Repeat step 3 in directions *B*, *C* and *D*.
5. Hold the copper rod with your left hand. Lift up the Magnadur magnet with your right hand. Move the Magnadur magnet in direction *A* and direction *B* with the copper rod stationary in between the poles of the magnet. Observe the deflection of the galvanometer pointer.
6. Complete Table 4.3 with a tick (✓) for the direction of deflection of the pointer of the galvanometer.

Results:

Table 4.3

State of Magnadur magnet	State of copper rod	Deflection of galvanometer pointer		
		To the left [–]	Zero [0]	To the right [+]
Stationary	Stationary			
Stationary	Moves in direction *A*			
Stationary	Moves in direction *B*			
Stationary	Moves in direction *C*			
Stationary	Moves in direction *D*			
Moves in direction *A*	Stationary			
Moves in direction *B*	Stationary			

Discussion:

1. What causes the deflection of the galvanometer pointer?
2. State the direction of the magnetic field between the poles of the magnet.
3. What are the directions of motion of the copper rod that causes the cutting of magnetic field lines?
4. Explain the condition where a current is produced in the copper rod.

B Solenoid

Apparatus: Bar magnet, solenoid (at least 400 turns) and sensitive centre-zero galvanometer or digital multimeter

Material: Connecting wires with crocodile clips

Instructions:

1. Set up the arrangement of apparatus as shown in Figure 4.17.
2. Hold the bar magnet stationary near the solenoid as shown in Figure 4.17. Observe the reading of the galvanometer.
3. Push the bar magnet into the solenoid. Observe the deflection of the galvanometer pointer.
4. Hold the bar magnet stationary in the solenoid. Observe the reading of the galvanometer.
5. Pull the bar magnet out of the solenoid. Observe the deflection of the galvanometer pointer.
6. Hold the magnet stationary. Move the solenoid towards and away from the bar magnet. Observe the deflection of the galvanometer pointer.
7. Complete Table 4.4 with a tick (✓) for the direction of deflection of the galvanometer pointer.

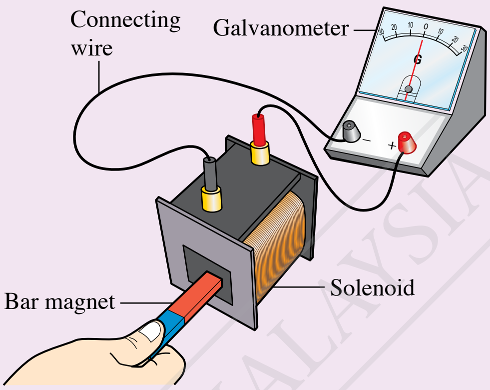


Figure 4.17

Results:

Table 4.4

State of bar magnet	State of solenoid	Deflection of galvanometer pointer		
		To the left [–]	Zero [0]	To the right [+]
Stationary	Stationary			
Moves into the solenoid	Stationary			
Moves out of the solenoid	Stationary			
Stationary	Moves towards the bar magnet			
Stationary	Moves away from the bar magnet			

Discussion:

1. What do you observe about the deflection of the galvanometer pointer when:
   (a) the bar magnet is moved towards the solenoid?
   (b) the bar magnet is moved away from the solenoid?
2. State the condition where a current is produced in the solenoid.

When a piece of copper wire is moved across magnetic flux, an electromotive force (e.m.f.) is induced in the wire. This phenomenon is known as **electromagnetic induction**. If the wire is connected to form a complete circuit, a deflection of the galvanometer pointer is observed as shown in Figure 4.18. This shows that induced current is produced. An electromotive force is also induced in the wire if the magnet is moved towards the stationary wire as shown in Figure 4.19.

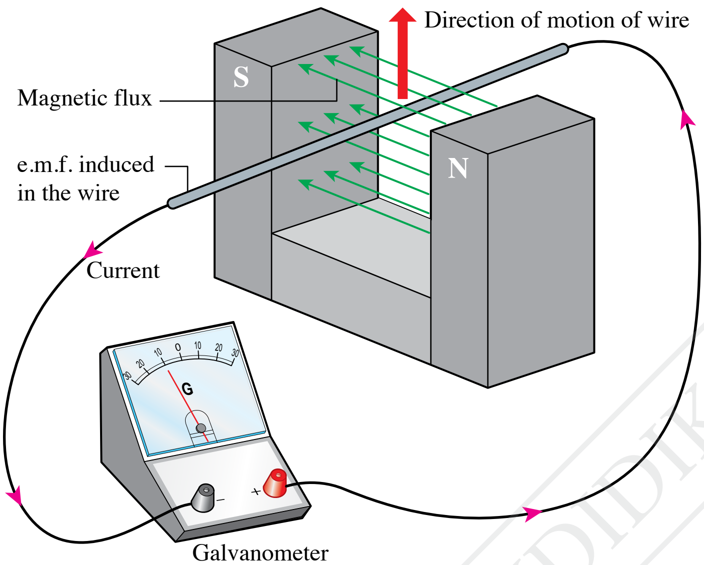
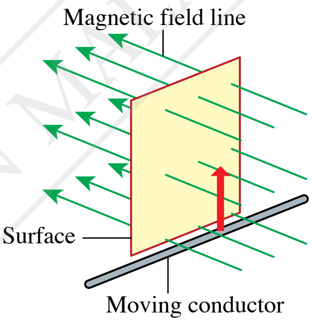


Figure 4.18 *Magnets are stationary while conductor is moved*

Info GALLERY

Magnetic flux refers to magnetic field lines that pass through a surface.



A conductor that moves and cuts magnetic field lines can be said to cut magnetic flux.

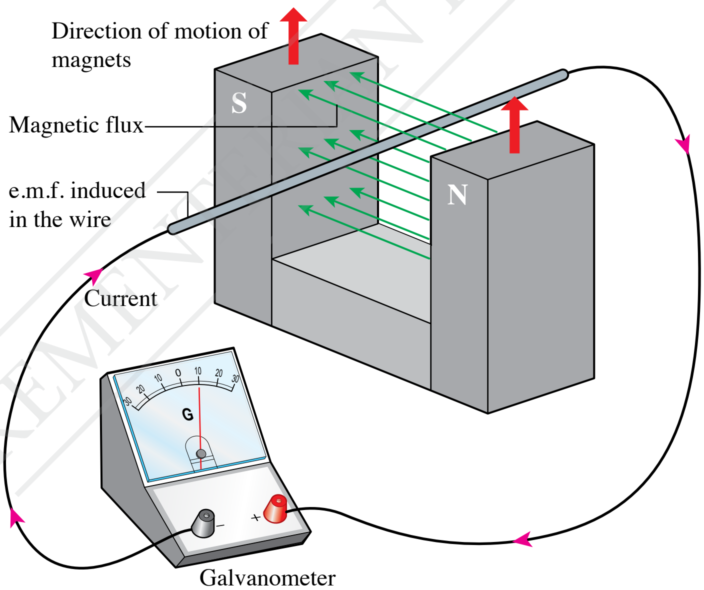


Figure 4.19 *Magnets are moved while conductor is stationary*

AR

SCAN ME
Video of electromagnetic induction for a copper wire
http://bit.ly/34t4c47

LS 4.2.1

When a bar magnet is moved towards or away from a solenoid, the turns of the solenoid cut the magnetic field lines. Electromagnetic induction occurs and an e.m.f. is induced across the solenoid as shown in Figure 4.20.

Figure 4.21 shows the ends of the solenoid are connected to a galvanometer to form a complete circuit. The induced electromotive force will produce an induced current in the circuit and the galvanometer pointer shows a deflection.

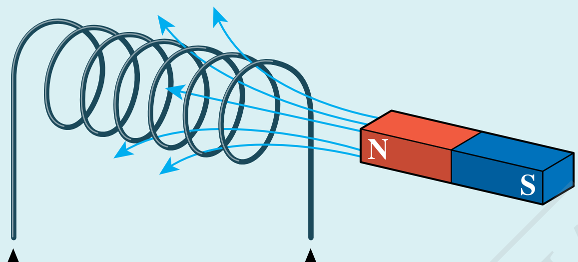


Figure 4.20 *Magnetic field lines are cut by the solenoid and e.m.f. is induced*

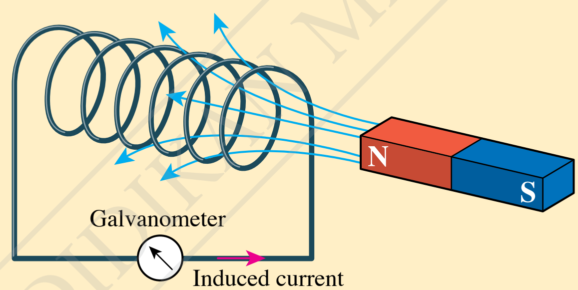


Figure 4.21 *Induced current in a complete circuit*

Activity 4.10 shows that an induced e.m.f. is produced by the cutting of magnetic field lines when a magnet and a conductor move towards or away from each other. **Electromagnetic induction** is the **production of an induced e.m.f. in a conductor when there is relative motion between the conductor and a magnetic field or when the conductor is in a changing magnetic field**.

Info GALLERY

Relative motion between two objects is the motion that results in the two objects becoming closer to each other or further away from each other.

A *B*

Relative motion occurs between objects *A* and *B* if:
- object *A* is stationary and object *B* moves towards or away from *A*
- object *B* is stationary and object *A* moves towards or away from *B*
- both objects *A* and *B* move with different velocities

No relative motion between objects *A* and *B* if:
- both objects *A* and *B* are stationary
- both objects *A* and *B* move with the same speed in the same direction

Factors Affecting the Magnitude of the Induced e.m.f.

Figure 4.22 shows an induction lamp made by a pupil. He found that the LED lights up with different brightness when the magnet in the PVC pipe is shaken at different speeds. What are the factors that affect the magnitude of induced e.m.f.?

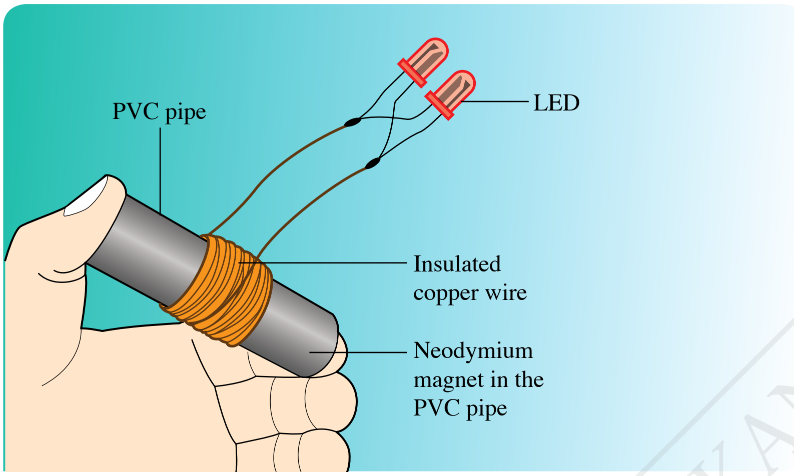


Figure 4.22 *A self-made induction lamp*

Let's Try

Construction of an induction lamp

http://bit.ly/36hR3IU

http://bit.ly/2Yyqq0V

Activity 4.11

Aim: To study the factors affecting the magnitude of induced e.m.f.

Apparatus: Two solenoids with 400 and 800 turns respectively, two bar magnets and sensitive centre-zero galvanometer

Materials: Connecting wires and rubber band

Instructions:

1. Set up the apparatus as shown in Figure 4.23.
2. Push a bar magnet slowly into the solenoid with 400 turns. Record the maximum reading shown on the galvanometer.
3. Push the bar magnet quickly into the solenoid with 400 turns. Record the maximum reading shown on the galvanometer.
4. Push a bar magnet slowly into a solenoid with 800 turns. Record the maximum reading shown on the galvanometer.
5. Use a rubber band to tie two bar magnets together with like poles side by side.
6. Push the two bar magnets slowly into the solenoid with 800 turns. Record the maximum reading shown on the galvanometer in Table 4.5.

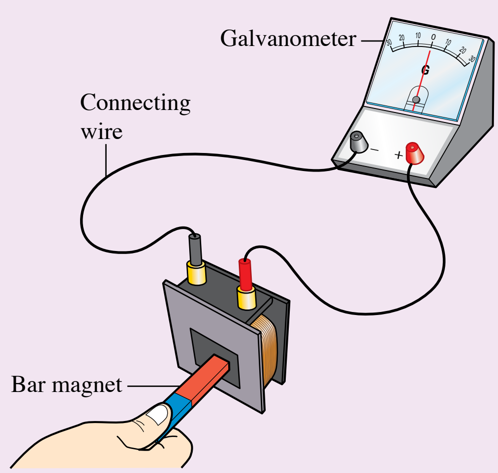


Figure 4.23

Results:

Table 4.5

Number of magnets	Speed of magnet	Number of turns of solenoid	Maximum reading of galvanometer		
			First attempt	Second attempt	Average
One	Slow	400			
One	Fast	400			
One	Slow	800			
Two	Slow	800			

Discussion:

1. Why does the galvanometer pointer deflect when a magnet is pushed into the solenoid?
2. Which factor is studied when the bar magnet is pushed at different speeds into the solenoid?
3. Which factor is studied when the number of magnets pushed into the solenoid is different?
4. How is the magnitude of induced e.m.f. affected by:
   (a) the speed of magnet?
   (b) the number of turns of solenoid?
   (c) the strength of magnetic field?

The results of Activity 4.11 show that the magnitude of induced e.m.f. is affected by the speed of relative motion between the magnet and the conductor, the number of turns of the solenoid and the strength of the magnetic field.

For the relative motion of a straight wire and magnet, the induced e.m.f. increases when:

- the speed of relative motion increases
- the strength of the magnetic field increases

For the relative motion of a solenoid and magnet, the induced e.m.f. increases when:

- the speed of relative motion increases
- the number of turns of the solenoid increases
- the strength of the magnetic field increases

EAC History

Michael Faraday (1791-1867) discovered electromagnetic induction in the year 1831. He successfully constructed an electric dynamo. The electric dynamo was used to generate electrical power.

The magnitude of the e.m.f. increases if more magnetic field lines are cut in a certain period of time. **Faraday's law** **states that the magnitude of induced e.m.f. is directly proportional to the rate of cutting of magnetic flux**.

LS 4.2.2

Direction of Induced Current in a Straight Wire and Solenoid

You have observed that the direction of the induced current changes when there is a change in the direction of the relative motion between the conductor and the magnet in Activity 4.10. Carry out Activity 4.12 and 4.13 to study the direction of the induced current in a straight wire and solenoid.

SCAN ME
To determine the direction of current using a galvanometer
https://bit.ly/3lhdUMY

Activity 4.12

Aim: To study the direction of the induced current in a straight wire

Apparatus: Thick copper wire, a pair of Magnadur magnets, sensitive centre-zero galvanometer or digital multimeter, a dry cell with holder, 1 kΩ resistor and switch

Material: Connecting wires with crocodile clips

SCAN ME
Video on ways to use multimeter
https://bit.ly/3gqj3Pa

Instructions:

1. Set up the apparatus as shown in Figure 4.24.

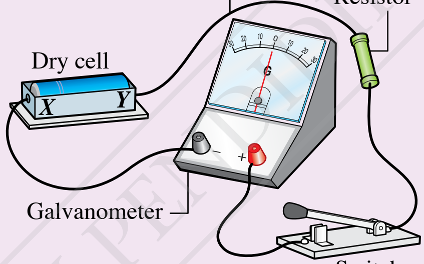


Figure 4.24

2. Connect the dry cell with its positive terminal at *Y* and negative terminal at *X*.
3. Turn on the switch. Observe the direction of deflection of the galvanometer pointer (to the left or to the right) and record your observation in Table 4.6. Determine the direction of the current through the dry cell (*X* to *Y* or *Y* to *X*).
4. Reverse the dry cell so that the positive terminal is at *X* and negative terminal at *Y* and repeat step 3.
5. Remove the dry cell from the circuit and replace with a piece of thick copper wire. Place the thick copper wire between the pair of Magnadur magnets as shown in Figure 4.25.
6. Move the copper wire upwards (direction *A*). Observe and record the direction of deflection of the galvanometer pointer and the direction of the current through the copper wire in Table 4.6.
7. Repeat step 6 by moving the copper wire downwards (direction *B*).

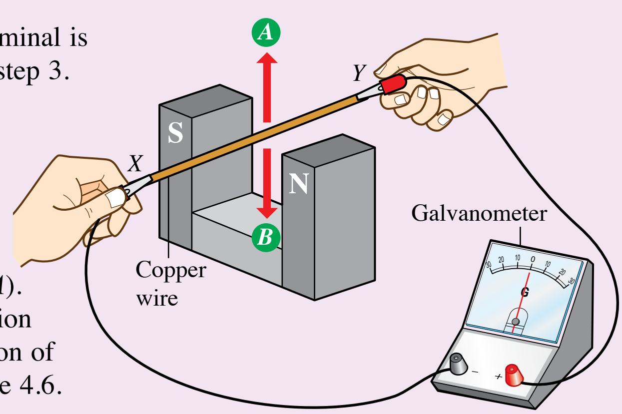


Figure 4.25

Results:

Table 4.6

Situation	Direction of deflection of galvanometer pointer (to the left or to the right)	Direction of current (*X* to *Y* or *Y* to *X*)
Dry cell (positive terminal at *Y*, negative terminal at *X*)		
Dry cell reversed (negative terminal at *Y*, positive terminal at *X*)		
Copper wire moved upwards (direction *A*)		
Copper wire moved downwards (direction *B*)		

Discussion:

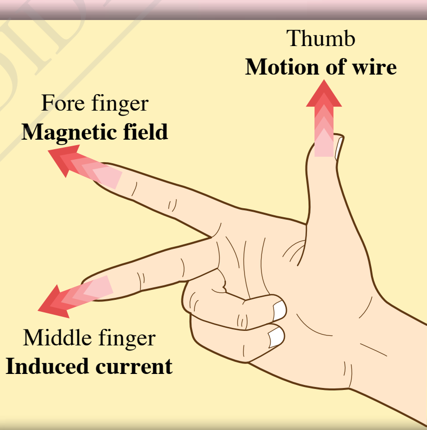
1. Try to relate the direction of the magnetic field lines, direction of motion of the copper wire and direction of the induced current by using the Fleming's right-hand rule.
2. Suggest other ways to change the direction of the induced current other than the direction of motion of the copper wire.

Fleming's right-hand rule

The direction of the induced current in a straight wire can be determined by using Fleming's right-hand rule as shown in Figure 4.26.

BRIGHT Info

The motion of the magnet downwards is equivalent to the motion of the wire upwards.



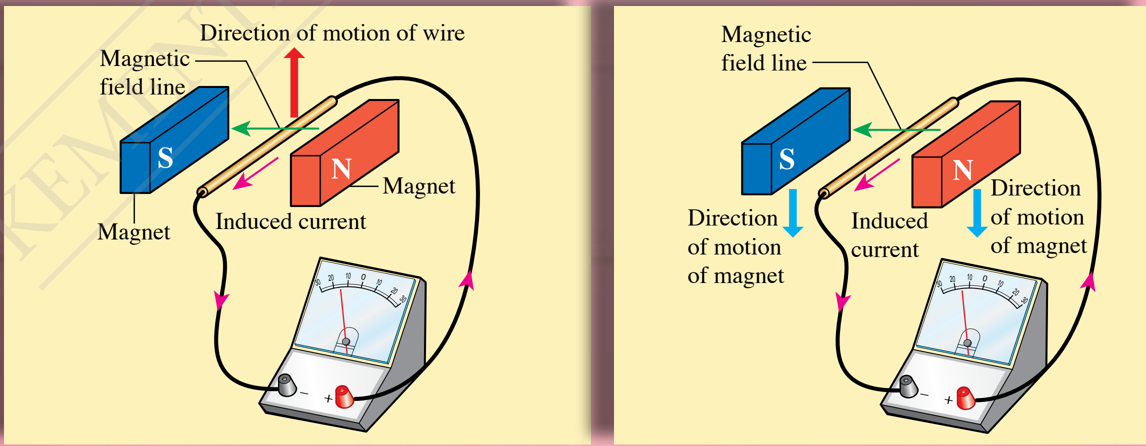


Figure 4.26 *Fleming's right-hand rule to determine the direction of induced current for straight wire*

Activity 4.13

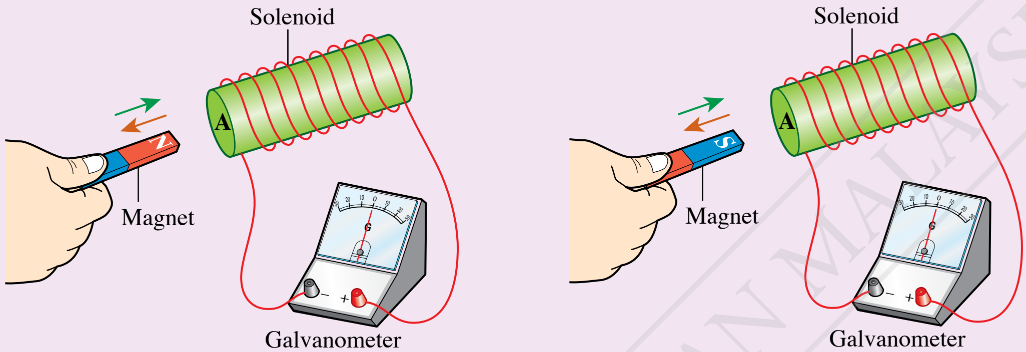
Aim: To study the direction of the induced current in a solenoid

Apparatus: Solenoid, bar magnet and sensitive centre-zero galvanometer or digital multimeter

Material: Connecting wires with crocodile clips

Instructions:

1. Set up the apparatus as shown in Figure 4.27.



(a) *(b)*

Figure 4.27

2. Move the north pole of the bar magnet as shown in Figure 4.27(a):
   (a) towards end *A* of the solenoid
   (b) away from end *A* of the solenoid
3. Observe the deflection of the galvanometer pointer and determine the polarity of the magnetic field at end *A* of the solenoid. Scan the QR code for the guideline on determination of the polarity at a solenoid.
4. Move the south pole of the bar magnet as shown in Figure 4.27(b):
   (a) towards end *A* of the solenoid
   (b) away from end *A* of the solenoid
5. Observe the deflection of the galvanometer pointer and determine the polarity of the magnetic field at end *A* of the solenoid.
6. Record your observations and results in Table 4.7.

Let's Recall

Magnetic field produced by current in a solenoid

http://bit.ly/3lfvroV

Results:

Table 4.7

Polarity of bar magnet	Motion of bar magnet at end *A* of the solenoid	Direction of deflection of galvanometer pointer (to the left or to the right)	Magnetic polarity at end *A* of the solenoid (north or south)
North	Towards		
	Away from		
South	Towards		
	Away from		

Discussion:

1. What is the effect of the motion of the bar magnet on the polarity of the magnet at end *A* of the solenoid?
2. Predict the polarity of the magnet produced at end *A*:
   (a) when the south pole of the bar magnet is pushed towards it
   (b) when the south pole of the bar magnet is pulled away from it

Note

Induced current is produced in the solenoid by the relative motion between the bar magnet and the solenoid.

For a solenoid, Lenz's law is used to determine the magnetic polarity at the end of the solenoid when current is induced. **Lenz's law states that the induced current always flows in a direction that opposes the change of magnetic flux that causes it**. Figure 4.28 shows that Lenz's law is used to determine the direction of induced current in a solenoid.

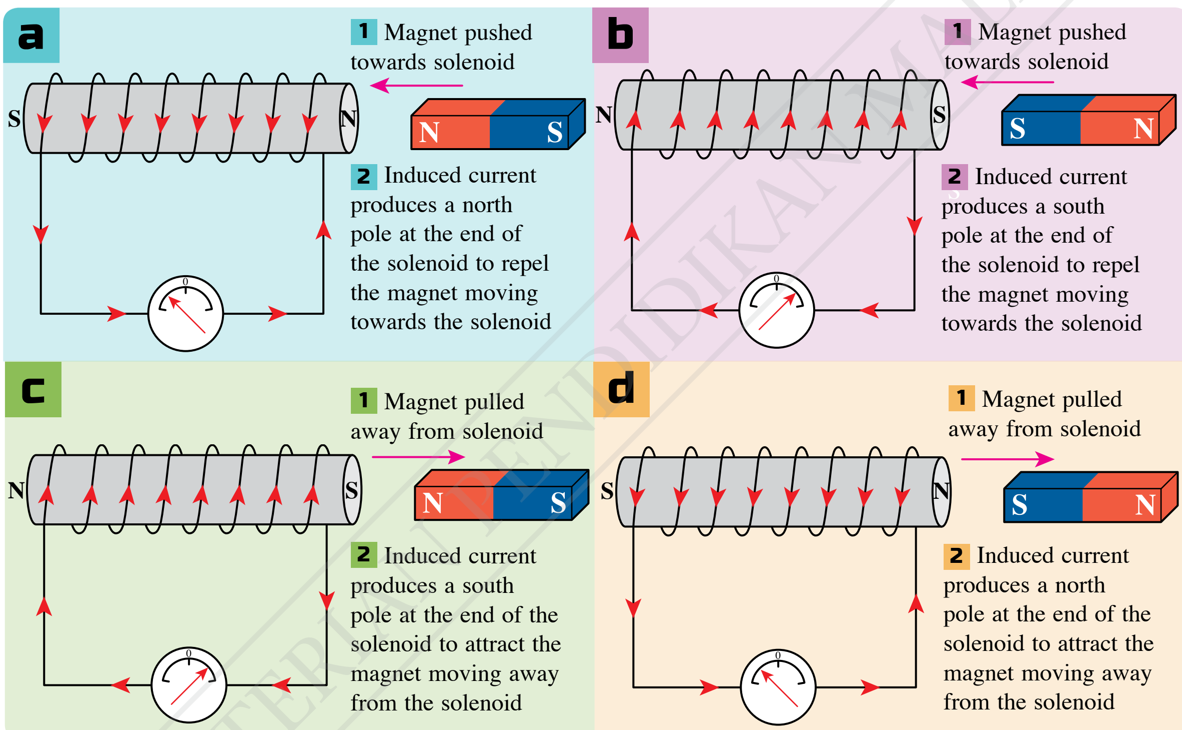


***Figure 4.28** Lenz's law used to determine the direction of induced current in a solenoid*

Direct Current Generator and Alternating Current Generator

Photograph 4.5 shows wind turbines electric generators that apply electromagnetic induction to produce induced e.m.f. There are two types of generators – the direct current generator and alternating current generator. What is the working principle of these current generators?

***Photograph 4.5** Wind turbines at Kuala Perlis*

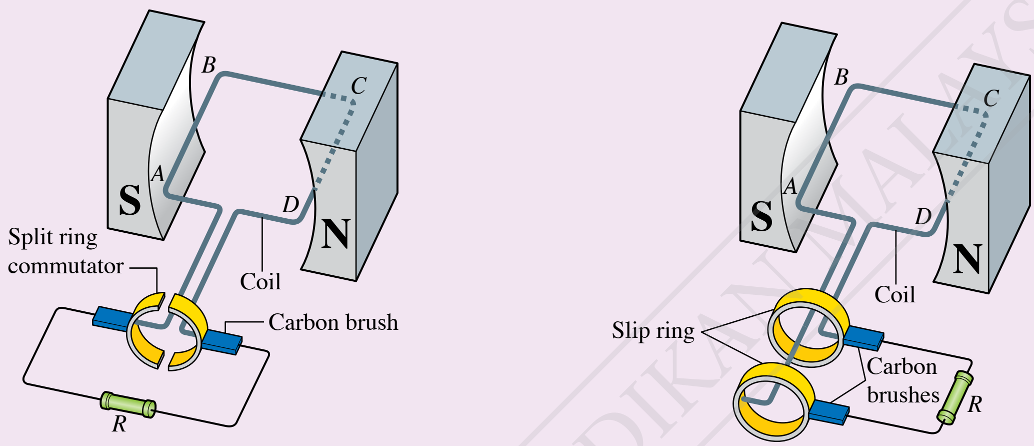
LS 4.2.3 4.2.4

Activity 4.14

Aim: To gather information on the structure and working principle of the direct current generator and alternating current generator

Instructions:

1. Carry out this activity in groups.
2. Examine Figure 4.29 that shows the structure of the direct current generator and alternating current generator.



(a) *Direct current generator* (b) *Alternating current generator*

Figure 4.29

3. Surf the Internet to gather more detailed information on the structure and working principle of the direct current generator and alternating current generator.
4. Prepare a multimedia presentation entitled 'Structure and Working Principle of the Direct Current Generator and Alternating Current Generator'.

SCAN ME
Video of direct current generator and alternating current generator
http://bit.ly/3aQATtC

Table 4.8 *Working principle of the direct current generator and alternating current generator*

Direct current generator	Alternating current generator
Similarities	
Applies electromagnetic induction	
Coil is rotated by an external force	
Coil cuts magnetic flux	
e.m.f. is induced in the coil	
Differences	
Ends of the coil are connected to a split ring commutator	Ends of the coil are connected to two slip rings
The two sections of the commutator exchange contact with the carbon brush every half rotation	Slip rings are connected to the same carbon brush
Output is direct current	Output is alternating current

Activity 4.15

STEM | CPS | ICS

Aim: To construct a functional prototype current generator (dynamo) by modifying an electric motor

Instructions:

1. Carry out this activity in groups.
2. Compare and contrast the structures and working principles of the direct current motor and the direct current generator.
3. Gather and study the following information from reading materials or websites:
   (a) the method of converting a motor to a dynamo
   (b) the ways to produce rotation in a dynamo
4. Based on the information you studied, suggest a design for the prototype dynamo and the way to operate it.
5. Construct the dynamo by modifying electric motor according to the suggested design and test the dynamo.
6. From the results of testing the dynamo, discuss the improvements that need to be made.
7. Make the improvements to the prototype dynamo and test the dynamo again.
8. Present the design of your dynamo.

Note
Use the K-W-L strategy data form

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

Formative Practice 4.2

1. What is the meaning of electromagnetic induction?
2. (a) State Faraday's law.
   (b) Use Faraday's law to explain the effect of the speed of rotation of the coil on the magnitude of the induced e.m.f. in a current generator.
3. Figure 4.30 shows a simple pendulum with a bar magnet as the bob oscillating near a copper ring.
   (a) Explain the production of current in the copper ring when the bar magnet is moving towards the ring.
   (b) At the position of the observer in front of the ring as shown in Figure 4.30, state whether the current in the copper ring is clockwise or anti-clockwise.
   (c) Explain the effect of the current in the copper ring on the motion of the bar magnet.

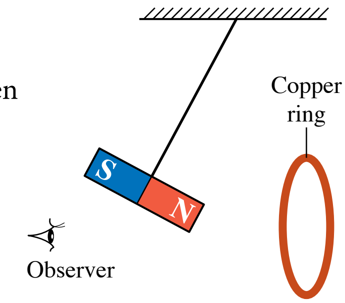


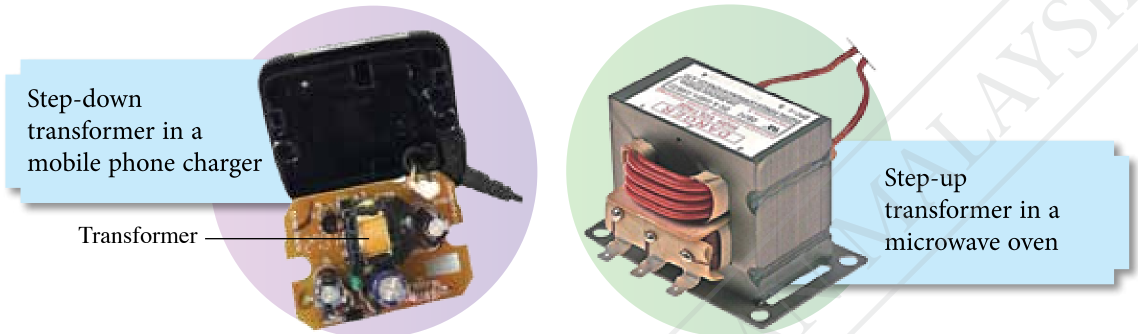
Figure 4.30

4.3 Transformer

Working Principle of a Simple Transformer

Photograph 4.6 shows a step-up transformer and a step-down transformer that are used in electrical devices. How does a transformer change an input voltage to an output voltage with a different value?

SCAN ME
EduwebTV: Transformer
http://bit.ly/31ppvBD



Photograph 4.6 *Types of transformers used in electrical devices*

Activity 4.16

ISS ICS

Aim: To gather information on the working principle of a simple transformer

Instructions:

1. Carry out this activity in groups.
2. Examine Figure 4.31 that shows the circuit diagram for a simple transformer.

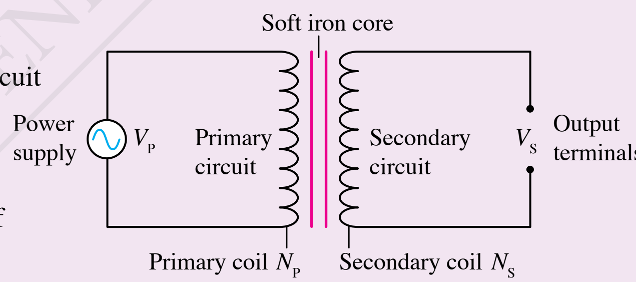


Figure 4.31

3. Surf websites or refer to the Form 3 Science Textbook to search for information on the working principle of the transformer and gather information on the following:
   (a) type of power supply in the primary circuit
   (b) type of current in the primary circuit
   (c) magnetic field produced by the current in the primary coil
   (d) function of the soft iron core
   (e) the phenomenon of electromagnetic induction in the secondary coil
   (f) the magnitude of the voltage induced across the secondary coil
   (g) relationship between V_P, V_S, N_P and N_S, where
   V_P = voltage across the primary coil or input voltage
   V_S = voltage across the secondary coil or output voltage
   N_P = number of turns of the primary coil
   N_S = number of turns of the secondary coil
4. Present the findings.

SCAN ME
Transformer
https://fla.st/2P4tXzN

LS 4.3.1

Figure 4.32 shows the structure of a simple transformer and Figure 4.33 shows the flow map for the working principle of a simple transformer.

Brain-Teaser

Why does the transformer not work with a direct current power supply?

BRIGHT Info

Step-down transformer:
$N_S < N_P \Rightarrow V_S < V_P$

Step-up transformer:
$N_S > N_P \Rightarrow V_S > V_P$

SCAN ME

Video on the working principle of a transformer

http://bit.ly/32BBjR1

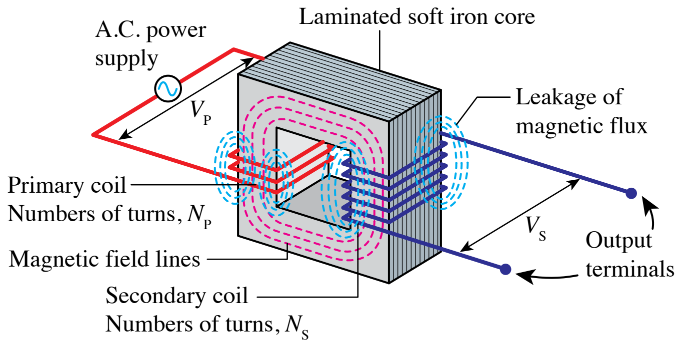


Figure 4.32 *Structure of a simple transformer*

Primary circuit

- A.C. power supply produces an alternating current in the primary coil.
- → The alternating current produces a magnetic field that changes in magnitude and direction.
- → The magnetic flux from the primary coil is linked to the secondary coil through the soft iron core.

Secondary circuit

- → The changing magnetic field induces an alternating voltage across the secondary coil.
- → $\dfrac{V_s}{V_p} = \dfrac{N_s}{N_p}$

Figure 4.33 *Working principle of a simple transformer*

Ideal Transformer

Figure 4.34 shows an electrical equipment connected to the output terminals of a transformer. The transformer receives input power from the power supply and supplies the output power to the electrical equipment. Therefore, electrical energy is transferred from the primary circuit to the secondary circuit.

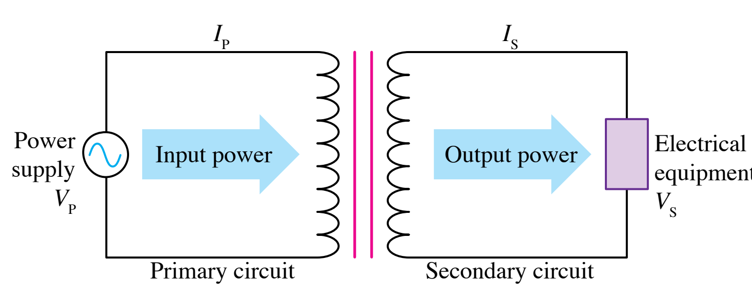


Figure 4.34 *Electrical equipment connected to the output terminals*

LS 4.3.1 4.3.2

A transformer that is in operation experiences a loss of energy. Therefore, the output power is less than the input power. The efficiency of the transformer, η is defined as

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$

SCAN ME
Sample calculation for ideal transformers
http://bit.ly/2FVgecr

Nowadays, there are transformers with very high efficiencies, up to 99%. An **ideal transformer** is a **transformer that does not experience any loss of energy, that is the efficiency, η is 100%.**

For an ideal transformer, efficiency of the transformer, $\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\% = 100\%$

Therefore, output power = input power

$$V_P I_P = V_S I_S$$

Ways to Increase the Efficiency of a Transformer

The working principle of a transformer involves processes such as the flow of current in the copper coils, the change of magnetic field and electromagnetic induction. These processes cause loss of energy and the transformer is unable to operate at an optimum level. Most of the energy is lost in the form of heat energy.

Activity 4.17

ISS ICS

Aim: To gather information and discuss the causes of energy loss in a transformer

Instructions:

1. Examine Table 4.9 that shows four main causes of energy loss and their effects.

Table 4.9

Causes of energy loss	Effects of energy loss
Resistance of coils	• The primary and secondary coils consist of wires that are very long. • When current flows in the coils which have resistance, heating of the wires occurs. • Heating of the wires causes heat energy to be released to the surroundings.
Eddy currents	• The changing magnetic field induces eddy currents in the iron core. • The eddy currents heat up the iron core. • The hot iron core releases heat energy to the surroundings.
Hysteresis	• The iron core is magnetised and demagnetised continuously by the changing magnetic field. • The energy supplied for magnetisation is not fully recovered during demagnetisation. The difference in energy is transferred to the iron core to heat it up.
Leakage of magnetic flux	• The magnetic flux produced by the primary current is not fully linked to the secondary coil.

LS 4.3.2 4.3.3

2. Scan the QR code and print Table 4.9.
3. Discuss the ways to increase the efficiency of transformers and complete Table 4.9.
4. Present the outcome of your discussion in the form of a suitable thinking map.

SCAN ME
Worksheet (Table 4.9)
http://bit.ly/2YvuYVE

The efficiency of a transformer can be increased by reducing the loss of energy in the transformer. Table 4.10 shows ways to reduce the loss of energy in a transformer.

Table 4.10 *Ways to reduce energy loss in a transformer*

Causes of energy loss	Ways to reduce energy loss in a transformer
Resistance of coils	Use thicker copper wire so that the resistance of the coil is smaller.
Eddy currents	Use a laminated iron core that consists of thin iron sheets glued together with insulation glue.
Hysteresis	Use soft iron as the core. Soft iron requires a smaller amount of energy to be magnetised.
Leakage of magnetic flux	The secondary coil is wound on the primary coil so that all the magnetic flux produced by the primary current will pass through the secondary coil.

In the operation of a transformer, eddy currents are a cause of energy loss. However, eddy currents can be beneficial to human beings. Photograph 4.7 shows an induction cooker. Figure 4.35 shows a high-frequency alternating current in the coil producing a magnetic field that changes with a high frequency. This magnetic field induces eddy currents at the base of the pan. The eddy currents heat up the base of the pan.

Photograph 4.7 *Induction cooker*

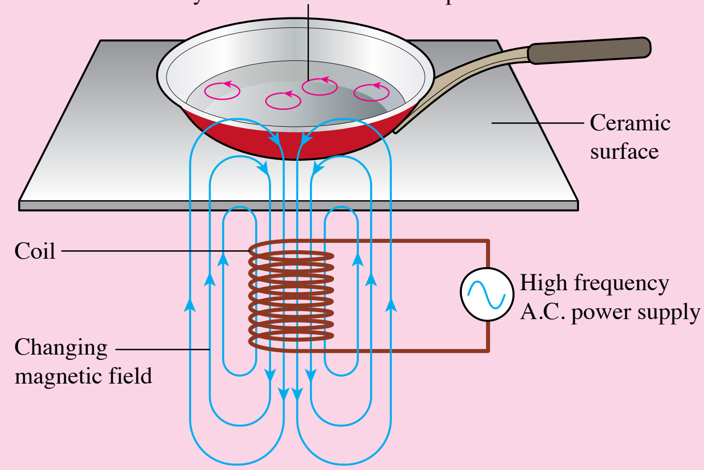


Figure 4.35 *Eddy currents in the induction cooker*

Uses of Transformers in Daily Life

Transformers have a wide range of uses. The following are some examples of machines that use step-down transformers and step-up transformers.

Step-down transformer	Step-up transformer
• Notebook computer charger • Photocopy machine • Welding machine	• Microwave oven • Defibrillator • X-ray machine

Activity 4.18

ISS ICS

Aim: To search for information on the applications of transformers in daily life

Instructions:

1. Carry out a Hot Seat activity.
2. Gather information on the applications of transformers in daily life such as:
   (a) electrical appliances
   (b) electrical energy transmission and distribution systems
3. Information can be obtained from websites or by referring to your Form 3 Science Textbook.
4. Present your findings in the form of a folio.

Example 1

A transformer that is connected to a 240 V power supply supplies 27 W of power at a voltage of 18 V to an electronic equipment, as shown in Figure 4.36. Assuming the transformer is ideal:

(a) calculate the number of turns of the primary coil.
(b) calculate the current in the secondary circuit.
(c) calculate the current in the primary circuit.

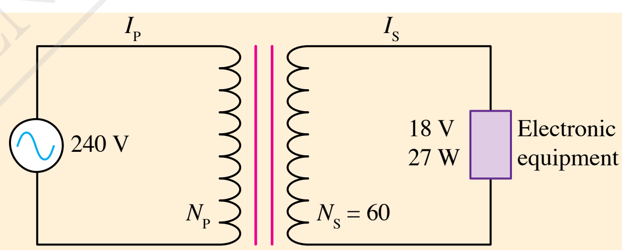


Figure 4.36

Solution

(a) $V_P = 240$ V, $V_S = 18$ V, $N_S = 60$

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

$$\frac{18}{240} = \frac{60}{N_P}$$

$$N_P = \frac{240 \times 60}{18} = 800$$

(b) Output power = 27 W

$$V_S I_S = 27$$

$$18 \times I_S = 27$$

$$I_S = \frac{27}{18}$$

$$= 1.5 \text{ A}$$

(c)

$$V_P I_P = V_S I_S$$

$$240 \times I_P = 18 \times 1.5$$

$$I_P = \frac{18 \times 1.5}{240}$$

$$= 0.1125 \text{ A}$$

Electrical Energy Transmission and Distribution System

Transformers play an important role in the transmission and distribution of electricity from the power station to the consumers. Figure 4.37 shows the use of the step-up transformer and step-down transformer in the system.

SCAN ME
Video of electrical energy transmission and distribution system
http://bit.ly/3jadhmt

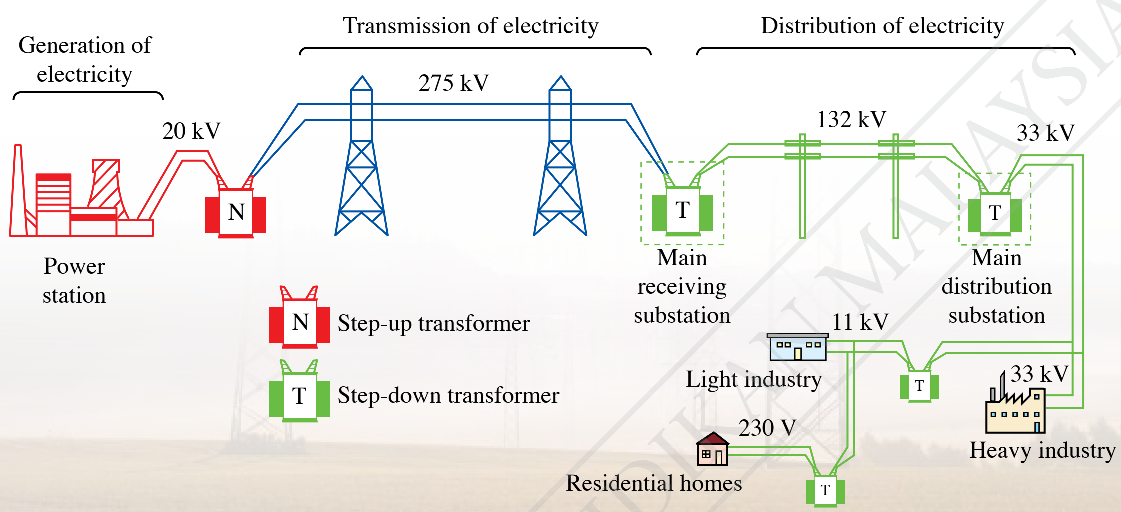


Figure 4.37 *Electrical energy transmission and distribution system from the power station*

At the stage of transmission of electrical energy, step-up transformers are used to increase the voltage in the power cable so that the current in the power cable becomes small. This reduces the loss of electrical energy from the power cable. During the distribution of electrical energy, step-down transformers are used to decrease the voltage in the power cable in stages to a suitable value for industrial and residential consumers.

Formative Practice 4.3

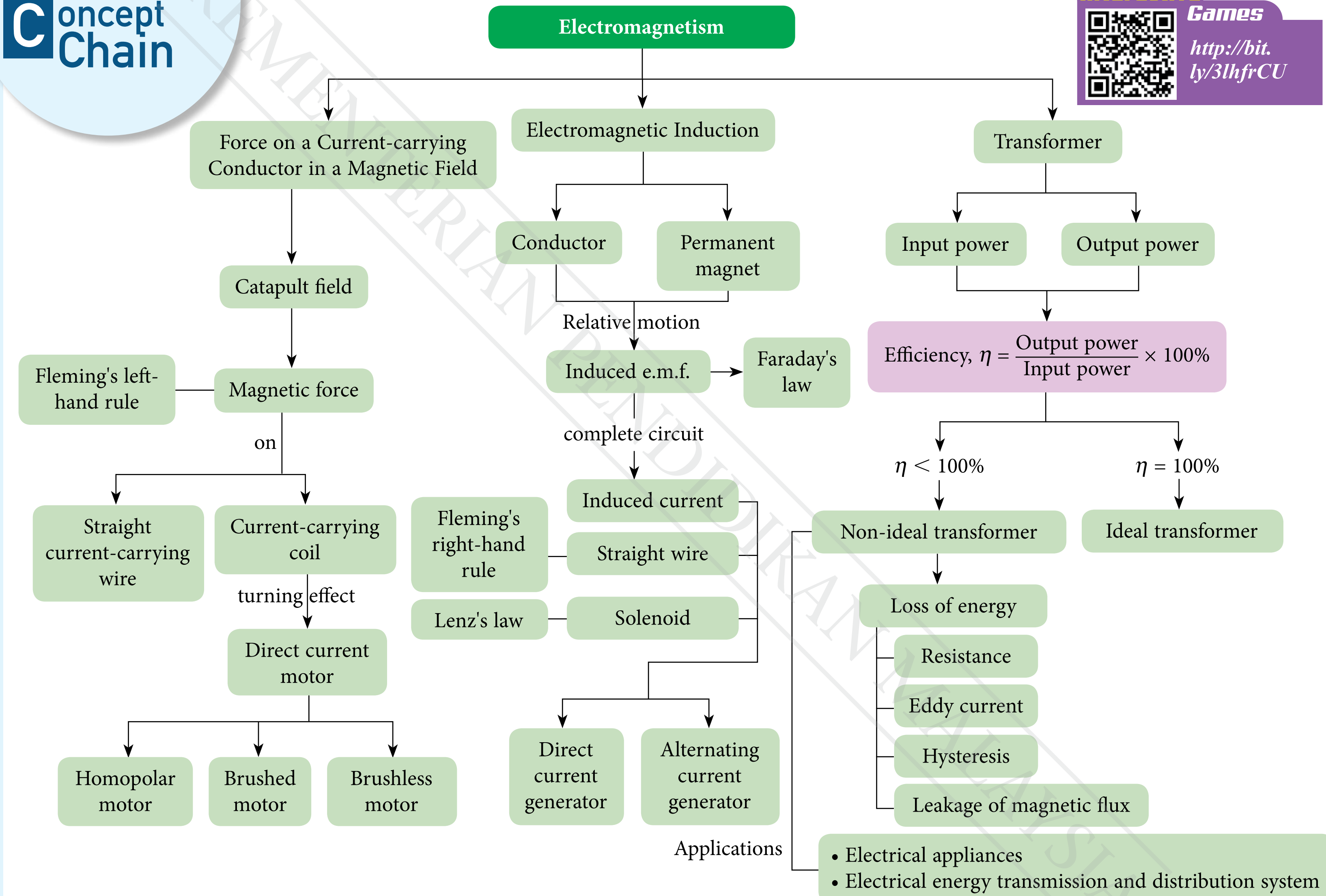
1. A step-down transformer is connected to an alternating current power supply. Explain the working principle of the transformer.
2. A pupil collects the following information on a transformer:

Primary voltage = 120 V	Secondary voltage = 6 V
Primary current = 0.25 A	Secondary current = 4.80 A

   (a) Calculate the efficiency of the transformer.
   (b) Explain two factors that cause the transformer to be non-ideal.
3. Explain how an induction cooker can heat up food in a steel pot.
4. Transformers are used in the electrical energy transmission and distribution system. State the type of transformer used:
   (a) before transmission of electrical energy
   (b) at the distribution substation

Concept Chain

Interactive Games
http://bit.ly/3lhfrCU



Self-Reflection

SCAN ME
Download and print Self-Reflection
http://bit.ly/3lqPDwg

1. New things I have learnt in the chapter 'Electromagnetism' are ____________.
2. The most interesting thing I have learnt this chapter is ____________.
3. The things I still do not fully understand are ____________.
4. My performance in this chapter.
   Poor | 1 | 2 | 3 | 4 | 5 | Very good
5. I need to ____________ to improve my performance in this chapter.

Summative Practice

QUIZ PORTAL
http://bit.ly/3grEJum

1. Figure 1 shows a conductor hanging from a sensitive spring balance in between a pair of Magnadur magnets.

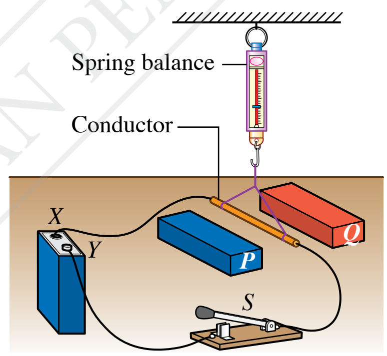


Figure 1

   (a) Suggest the polarity of dry cell *X*, *Y* and the polarity of magnets *P*, *Q* such that the reading of the spring balance increases when switch *S* is turned on.
   (b) Explain why the reading of the spring balance can increase in 1(a).
   (c) Suggest improvements that need to be made to further increase the reading of the spring balance.

2. With the aid of a labelled diagram, explain how Fleming's left-hand rule is used to determine the direction of the force on a current-carrying conductor in a magnetic field.

3. Figures 2 and 3 show the induced currents produced when there is relative motion between a bar magnet and a solenoid.

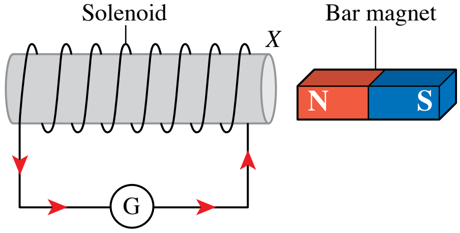


Figure 2

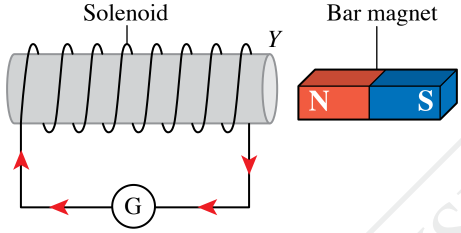


Figure 3

(a) What is the meaning of induced current?

(b) Based on the direction of the current given in Figures 2 and 3, state the magnetic polarities at ends *X* and *Y* of the solenoid.

(c) State the direction of motion of the bar magnet in Figure 2 and Figure 3.

(d) Suggest two ways to increase the magnitude of the induced current in Figure 3.

4. A transformer is used to step down voltage from 240 V to 6 V for an electronic equipment. The current in the primary coil is 0.18 A. What is the current in the secondary coil? State the assumption that needs to be made in your calculation.

5. Figure 4 shows two identical metal balls and a copper tube. One of the balls is a neodymium magnet while the other is a steel ball.

Figure 4

Design an activity that can identify which ball is the neodymium magnet. Explain the physics principle used in your activity.

6. Figure 5 shows a wooden block with a bar magnet tied to it sliding with an acceleration down a smooth track.

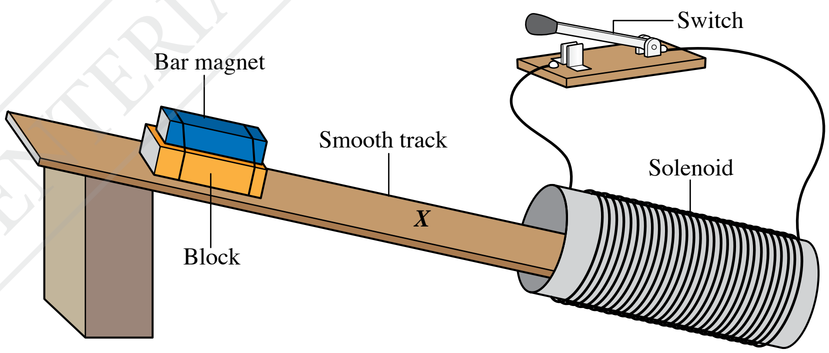


Figure 5

When the block arrives at mark *X* on the track, the switch is turned on.

(a) What is produced in the solenoid? Explain your answer.

(b) Explain the motion of the block after the switch is turned on.

(c) Based on your answers in 6(a) and (b), discuss the effectiveness of electromagnetic braking in stopping a moving object.

7. Figure 6 shows a transformer with a bulb at its output terminals.

(a) Calculate the value of I_S.

(b) What assumption needs to be made in your calculation in 7(a)?

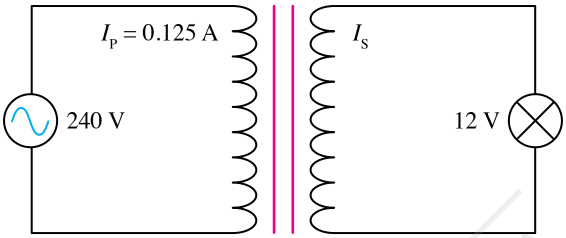


Figure 6

8. A pupil investigated the operation of a transformer and gathered data as shown in Figure 7. Calculate the efficiency of the transformer and suggest improvements to the design of the transformer to increase its efficiency.

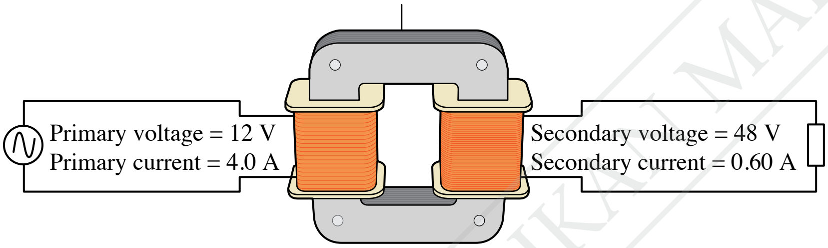


Figure 7

21st Century Challenge

9. Figure 8 shows the design of a simple direct current motor that can produce a force to rotate a disc connected to the axle of the motor. A pupil who constructed the motor according to the design made the following observations:

- speed of rotation of the disc is slow
- speed of rotation of the disc cannot be controlled
- rotation of the disc is not smooth
- the dry cell loses its power in a short time

Study the design of the motor and suggest improvements to the design that can overcome the weaknesses identified by the pupil.

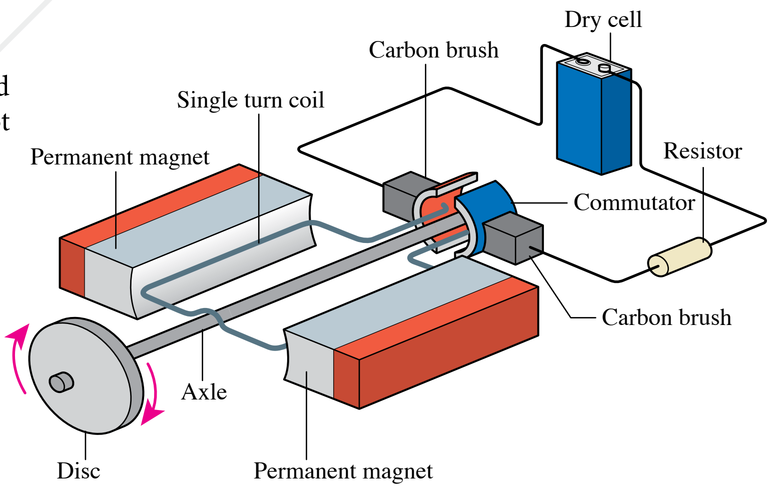


Figure 8

CHAPTER 5

Electronics

What are thermionic emission and cathode rays?

What are the function and uses of a semiconductor diode?

What are the functions of a npn transistor or pnp transistor?

How does a transistor function in an amplifier circuit?

How does a transistor function as an automatic light-controlled switch and heat-controlled switch?

You will learn:

Learning Standards and List of Formulae in Chapter 5

Information Portal

The invention of the semiconductor diode and transistor in the 20th century has led to the Digital Revolution. This period has transformed life as we know it due to the technological development from mechanical and analog to digital. Diodes and transistors in the form of electronic microchips, which are central of all of our electronic devices are easily available and have many benefits. The light emitting diode or LED is used as the source of light. LED is also used as indicator lamp in industrial machines.

In addition, Artificial Intelligence (AI) is increasingly dominating our lives. Many of the devices today can function automatically, such as robots and self-driving cars. Most of the electronic chips today are designed to be increasingly smaller. Smaller chips not only save space and electrical power but also improve the overall efficiency of the system.

https://bit.ly/31M6J7Q

Importance of the Chapter

In the era of the Fourth Industrial Revolution (IR 4.0), understanding the nature of electrons, applications of diodes and transistors, artificial intelligence (AI) and 5G internet enables electronic engineers and algorithm experts to create smart electronic devices and automation systems. Such progress can improve the industry's productivity and national revenue.

Futuristic Lens

Artificial intelligence (AI) enables in-depth studies on robots and self-driving cars. Research into this field also contributes to the development of smart cities which are more nature-friendly to maintain a sustainable lifestyle.

https://bit.ly/2QItiEc

5.1 Electron

Thermionic Emission and Cathode Rays

You have learnt that current, *I* is the rate of flow of charges in a conductor. An electric current is produced when charged particles (electrons) flow in a conductor. Can electrons move through a vacuum without a conductor?

Activity 5.1

ISS ICS

Aim: To generate idea on thermionic emission and cathode rays

Instructions:

1. Carry out this activity in groups.
2. Scan the QR code to watch the video on thermionic emission and cathode rays.
3. Based on the video, discuss the following:
   (a) What is thermionic emission?
   (b) What are the functions of the 6 V power supply and the extra high tension (E.H.T) power supply?
   (c) Why must the tube be in a state of vacuum?
   (d) How can cathode rays be produced in a vacuum tube?
4. Present your findings.

SCAN ME
EduwebTV: Thermionic emission and cathode rays
https://bit.ly/3gJuQII

Figure 5.1 explains the thermionic emission and the production of cathode rays in a vacuum tube using extra high tension (E.H.T.) power supply.

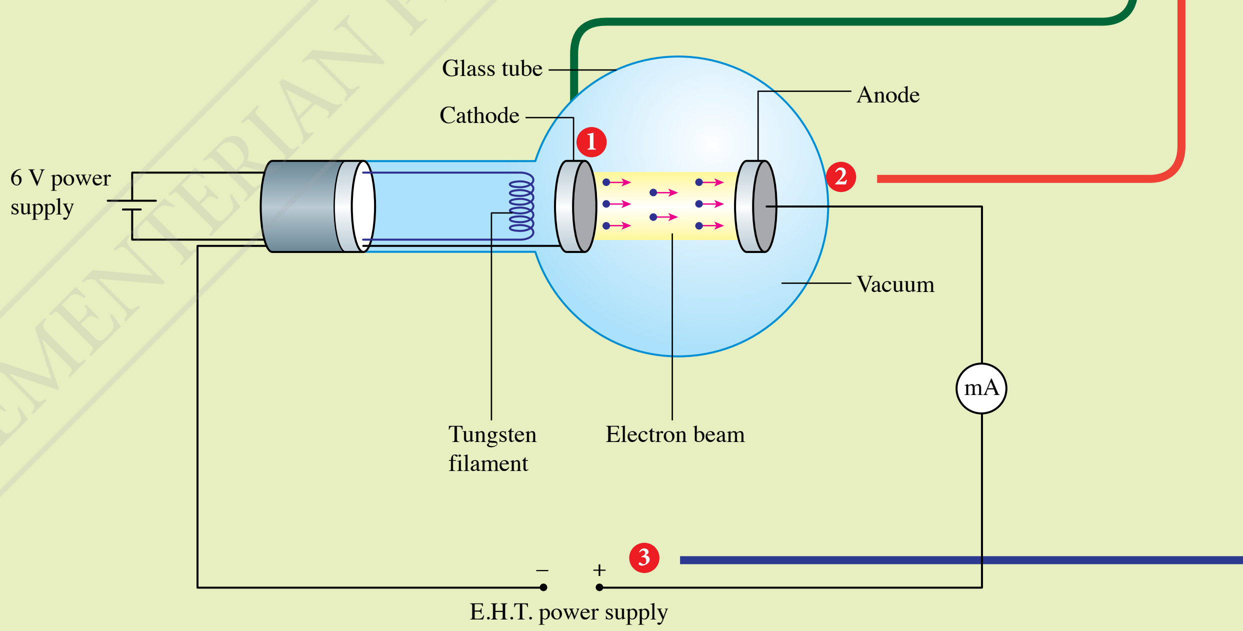
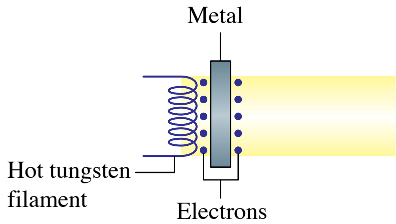


***Figure 5.1** Thermionic emission and production of cathode rays in a vacuum tube*

LS 5.1.1

1

There are many free electrons in a metal wire, for example, tungsten filament. When the 6 V d.c. power supply is switched on, the temperature of the tungsten filament will rise and the free electrons will gain sufficient kinetic energy to leave the metal surface. **Thermionic emission** is **the emission of free electrons from a heated metal surface**.



Info GALLERY

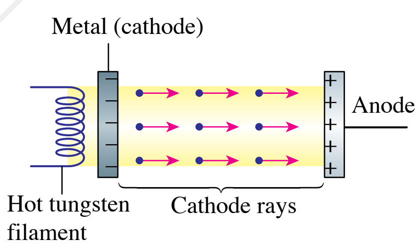
If a layer of metal oxide like barium oxide or strontium oxide is coated on the metal surface cathode in the vacuum tube, the temperature required to release the electrons will be reduced.

2

In a glass vacuum tube, the electrons are able to accelerate towards the anode without colliding with air molecules. Hence, there is no energy loss and electrons move with the maximum velocity.

3

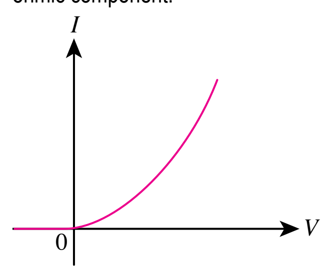
- When a vacuum tube is connected to an E.H.T. power supply, the electrons emitted from the cathode will be attracted to the anode at high velocity to form an electron beam. This **high velocity electron beam** is known as **cathode rays**. The electron beam will complete the E.H.T. power supply circuit and the milliammeter reading will show that a current is flowing.



- If the connection to the E.H.T. power supply is reversed, the milliammeter will not show any reading.

Info GALLERY

The graph below shows a graph of current against voltage for a thermionic diode. This shows that a thermionic diode is a non-ohmic component.



Graph of I against V

Effects of Electric Field and Magnetic Field on Cathode Rays

Cathode rays are **beams of electrons moving at high speed in a vacuum**. The characteristics of cathode rays can be studied using a deflection tube and a Maltese cross tube. Carry out Activity 5.2 and Activity 5.3 to study the effects of electric field and magnetic field on the direction of cathode rays.

Activity 5.2

Teacher's demonstration

Aim: To study the effects of an electric field on cathode rays using a deflection tube

Apparatus: Deflection tube, 6 V power supply, E.H.T. power supply and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 5.2.

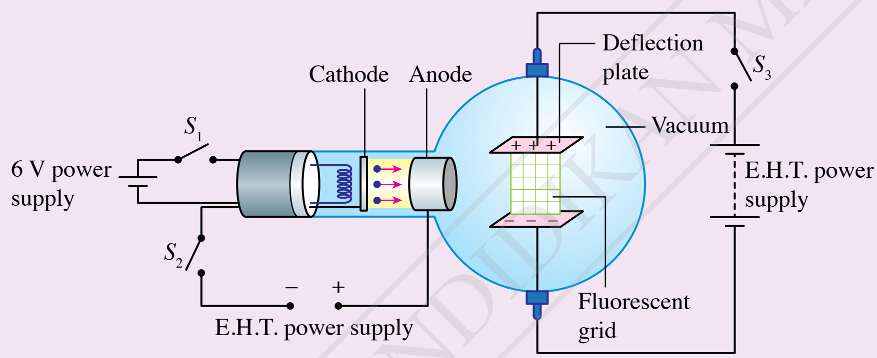


***Figure 5.2** Deflection tube*

2. Turn on switch S_1 for the 6 V power supply and switch S_2 for the E.H.T. power supply. Record your observations.
3. Turn on switch S_3 at the E.H.T. power supply that is connected to the deflection plates. Observe the cathode rays deflection on the fluorescent grid.
4. Reverse the connection at the E.H.T. power supply that is, connected to the deflection plates and repeat step 3.
5. Record all your observations.

SCAN ME
Demonstration video of a deflection tube
https://bit.ly/2Z92QZ9

Discussion:

State your observations on the fluorescent grid when:

(a) switches S_1 and S_2 are turned on
(b) switches S_1, S_2 and S_3 are turned on
(c) switches S_1, S_2 and S_3 are turned on and the potential difference at the deflection plates is reversed

Safety Precaution

- Do not touch any metal part of the deflection tube while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observations are made.

Activity 5.3 Teacher's demonstration

Aim: To study the effects of a magnetic field on cathode rays using a Maltese cross tube

Apparatus: Maltese cross tube, 6 V power supply, E.H.T. power supply, bar magnet and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 5.3.

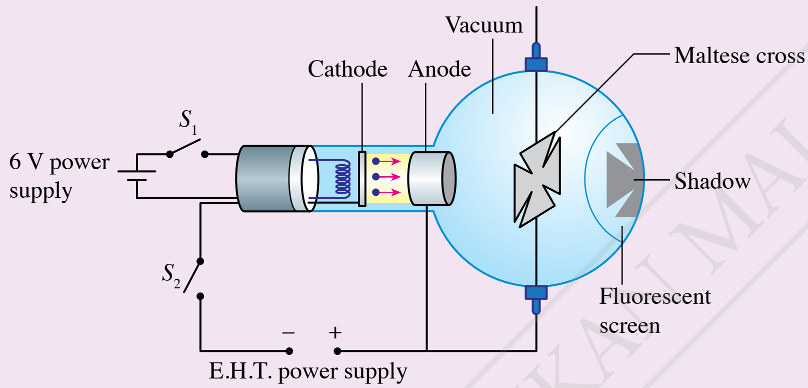


***Figure 5.3** Maltese cross tube*

2. Turn on switch S_1 of the 6 V power supply. Observe the shadows formed on the fluorescent screen. Record your observation.
3. Turn on switch S_2 and observe the shadow formed on the fluorescent screen again.
4. Bring the north pole of a magnet to the right side of the Maltese cross tube and observe changes of the shadow.
5. Record all your observations.

Discussion:

1. State your observations of the shadow formed on the fluorescent screen when:
   (a) switch S_1 is turned on
   (b) switches S_1 and S_2 are turned on
   (c) switches S_1 and S_2 are turned on and the north pole of a magnet is brought to the side of the Maltese cross tube.
2. Explain your observations when the north pole of a magnet is brought to the right side of the Maltese cross tube.

SCAN ME
Demonstration video of a Maltese cross tube
https://bit.ly/3bf1SPR

Safety Precaution

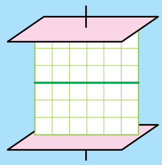
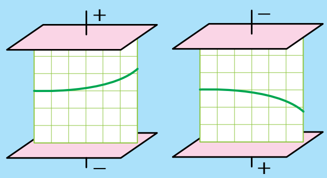
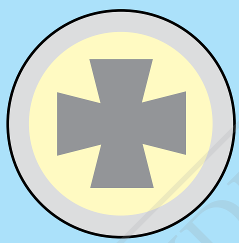
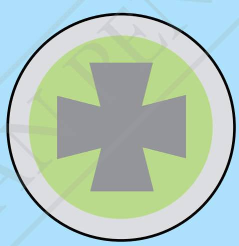
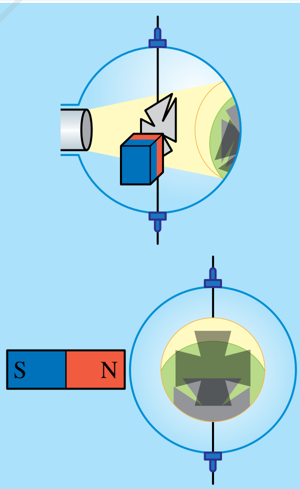
- Do not touch any metal part of the Maltese cross tube while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observations are being recorded.

Note

Ensure that the Maltese cross tube is properly earthed when the experiment is running.

Table 5.1 summarises the effects on electric field and a magnetic field on cathode rays.

***Table 5.1** Observations and explanations on the characteristics of cathode rays*

Apparatus	Condition of switch	Observations	Explanation
Deflection tube	S_1 and S_2 are turned on		• Cathode rays travel in a straight line.
	S_1, S_2 and S_3 are turned on		• Cathode rays **can be deflected by an electric field**. They are deflected towards the positive plate in a parabolic path. • Cathode rays are **negatively charged**.
Maltese cross tube	S_1 is turned on		• Light from the hot tungsten filament is be blocked by an opaque object (Maltese cross) to form a shadow. Light travels in a straight line.
	S_1 and S_2 are turned on		• Cathode rays are **blocked** by Maltese cross to form a shadow. Cathode rays **travel in a straight line**. • Cathode rays also **produce a fluorescent effect** on the screen surrounding the shadow. This shows that cathode rays **possess momentum and kinetic energy**.
	S_1 and S_2 are turned on and magnet is placed near the tube		• One shadow is due to the light from the hot tungsten filament. • The other shadow is due to the deflection of the cathode ray by the bar magnet that is placed near the tube. • The deflection of cathode rays can be determined by Fleming's left-hand rule.

Velocity of an Electron in a Cathode Ray Tube

Figure 5.4 shows the formation of cathode rays in a vacuum tube. The electrical potential energy, E of an electron is given by:

$$E = eV$$

where E = electrical potential energy
e = charge of an electron
V = potential difference between the cathode and the anode of the E.H.T. power supply

The charge of an electron is 1.6×10^{-19} C

SCAN ME
Demonstration video of a cathode ray tube
https://bit.ly/34TKCye

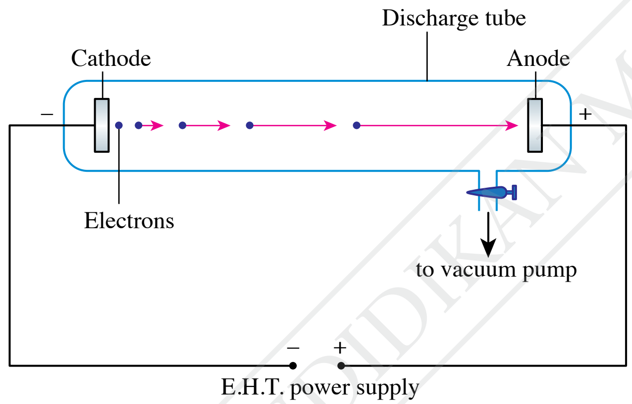


Figure 5.4 *Cathode ray tube*

When the E.H.T. power supply is turned on, electrons are attracted by the positively charged anodes. As there are no air molecules in the vacuum tube, electrons will accelerate to the anode without any collision. These electrons will achieve maximum velocity, v_{max} when they reach the anode.

Applying the principle of conservation of energy,

The electrical potential energy = the maximum kinetic energy

$$eV = \frac{1}{2}mv^2_{max}$$

where e = charge of an electron
V = potential difference between cathode and anode
m = mass of an electron
v_{max} = maximum velocity of an electron

The charge of an electron is 1.6×10^{-19} C and the mass of an electron is 9.11×10^{-31} kg

Brain-Teaser

Before the invention of plasma and LCD televisions, the old versions of televisions were bulky because they used a cathode ray tube. What innovation has led to the invention of plasma and LCD television?

LS 5.1.3

Example 1

LET'S ANSWER

https://bit.ly/3bgsC25

Figure 5.5 shows an electron beam that is accelerated from the cathode to the anode in a vacuum. The potential difference across the cathode and the anode is 550 V.
[Mass of an electron, $m = 9.11 \times 10^{-31}$ kg, charge of an electron, $e = 1.6 \times 10^{-19}$ C]
(a) What is the electrical potential energy of an electron?
(b) What is the kinetic energy of an electron when it reaches at the anode?
(c) What is the maximum velocity of an electron when it reaches at the anode?

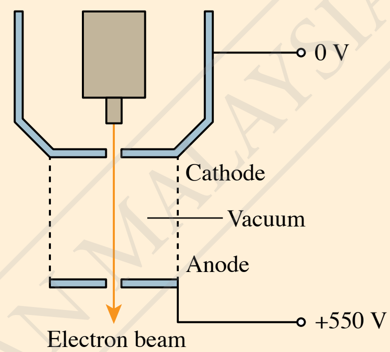


Figure 5.5

Solution

Potential difference across cathode and anode, $V = 550$ V
Charge of an electron, $e = 1.6 \times 10^{-19}$ C
Mass of an electron, $m = 9.11 \times 10^{-31}$ kg

(a) Electrical potential energy of an electron $= eV$

$$= 1.6 \times 10^{-19} \times 550$$
$$= 8.8 \times 10^{-17}\text{ J}$$

(b) Applying the principle of conservation of energy:
Kinetic energy gained by an electron
= Electrical potential energy of an electron
$= 8.8 \times 10^{-17}$ J

(c)
$$\frac{1}{2}mv_{max}^2 = eV$$
$$v_{max} = \sqrt{\frac{2eV}{m}}$$
$$= \sqrt{\frac{2 \times 8.8 \times 10^{-17}}{9.1 \times 10^{-31}}}$$
$$= 1.39 \times 10^{7}\text{ m s}^{-1}$$

Formative Practice 5.1

1. (a) What are thermionic emission and cathode rays?
   (b) State the characteristics of cathode rays.
2. (a) State the function of the components of a cathode ray tube below:
   (i) heating filament
   (ii) cathode
   (iii) anode
   (iv) fluorescent screen
   (b) Why must a cathode ray tube be in a state of vacuum?
3. When an electron beam moves from the cathode to the anode in a vacuum tube, state:
   (a) the type of motion of the electron beam
   (b) the transformation of energy
   (c) the relationship between the voltage of E.H.T. power supply and the velocity of the electron
4. When an E.H.T. with power of 800 V is connected across the cathode and the anode, what is the velocity of the electron? What is the effect on the velocity of the electron if the voltage is increased by four times?
   [Charge of an electron, $e = 1.6 \times 10^{-19}$ C, mass of an electron, $m = 9.11 \times 10^{-31}$ kg]

5.2 Semiconductor Diode

You have learnt that the transmission of electrical power to consumers through a network is in the form of alternating current (A.C.). However, in everyday life, many electrical devices can only function with direct current (D.C.). Therefore, the alternating current has to be converted into a direct current. Photograph 5.1 shows a semiconductor diode which functions to convert alternating current into direct current.

Photograph 5.1 *Semiconductor diode*

Activity 5.4

Aim: Discuss the function of a semiconductor diode

Apparatus: Diode, dry cell, cell holder, bulb and connecting wires

Instructions:

1. Connect the diode in forward biased as shown in Figure 5.6, that is, the positive terminal of the dry cell is connected to the anode and the negative terminal to the cathode.
2. Observe the bulb and record your observation.
3. Reverse the connection of the dry cell so that the diode is in reverse biased as shown in Figure 5.7, that is, the positive terminal of the dry cell is connected to the cathode and the negative terminal to the anode.
4. Observe the bulb and record your observation.

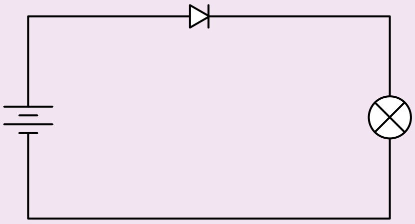


Figure 5.6 *Circuit A*

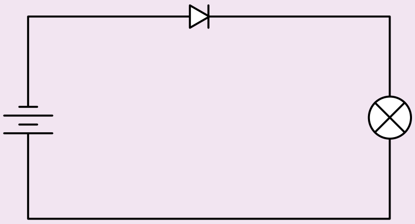


Figure 5.7 *Circuit B*

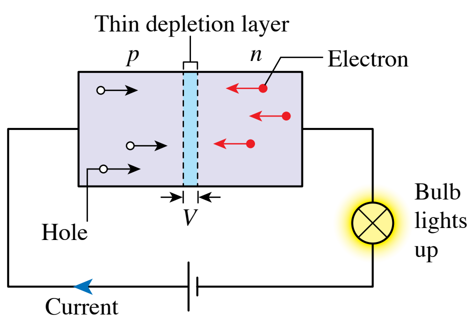
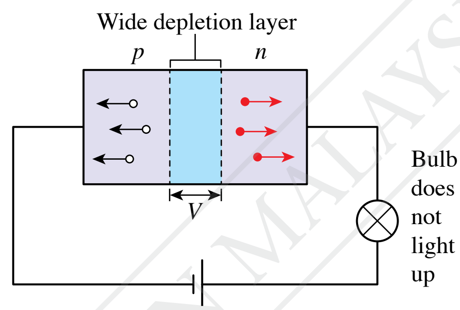
Discussion:

1. What is the function of the diode in this activity?
2. State the condition when a diode allows current to pass through it.
3. If the dry cell is changed to alternating current power supply, what will happen to the bulb?

The Function of a Semiconductor Diode

A semiconductor diode is an **electronic component which allows electric current to flow in one direction only**. A semiconductor diode is formed by joining a p-type semiconductor and an n-type semiconductor to form a p-n junction. Table 5.2 explains the diode connections.

***Table 5.2** Diode connection in a simple circuit*

Forward Biased Circuit	Reverse Biased Circuit
	
When a diode is forward biased, the holes will move towards the n-type semiconductor while the electrons will move towards the p-type semiconductor.	When a diode is reverse biased, the holes and the electrons will both move away from the depletion layer in opposite directions.
Depletion layer becomes thinner.	Depletion layer becomes thicker.
Junction voltage, V across the depletion layer decreases and the resistance of the diode becomes very small.	Junction voltage, V across the depletion layer increases until it reaches the potential difference of the battery. The resistance of the diode becomes very high.
The current passes through the diode, causing the bulb to light up.	The current stops flowing and the bulb does not light up.

Info GALLERY

P-type semiconductors and n-type semiconductors are produced through a doping process, in which foreign atoms are added into a lattice structure of a pure semiconductor. The majority charge carriers for p-type semiconductors are holes whereas the majority charge carriers for n-type semiconductors are electrons. The holes act as positive charge carriers.

The Use of Semiconductor Diode and Capacitor in the Rectification of Alternating Current

Photograph 5.2 shows a smartphone is being connected to an alternating current power supply at home. However, the smartphone can only be charged with a direct current. How does a semiconductor diode convert an alternating current to a direct current?

***Photograph 5.2** A smartphone is connected to an alternating current power supply*

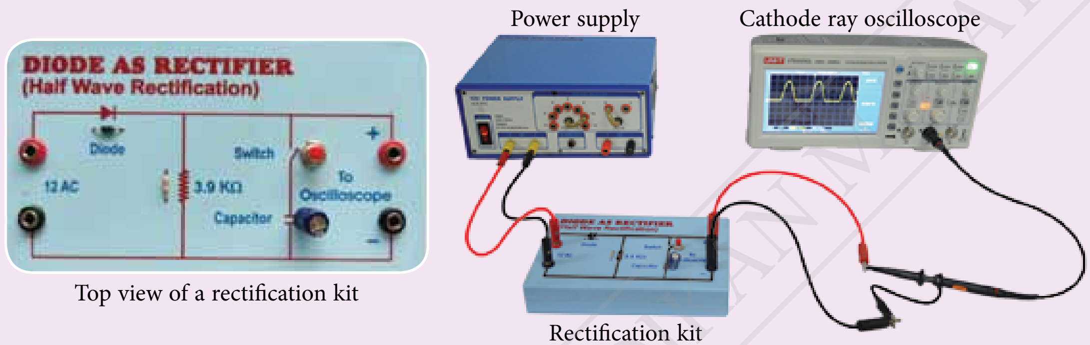
The process of converting an alternating current into a direct current is known as **rectification**. There are two types of rectification which are half-wave rectification and full-wave rectification.

Activity 5.5

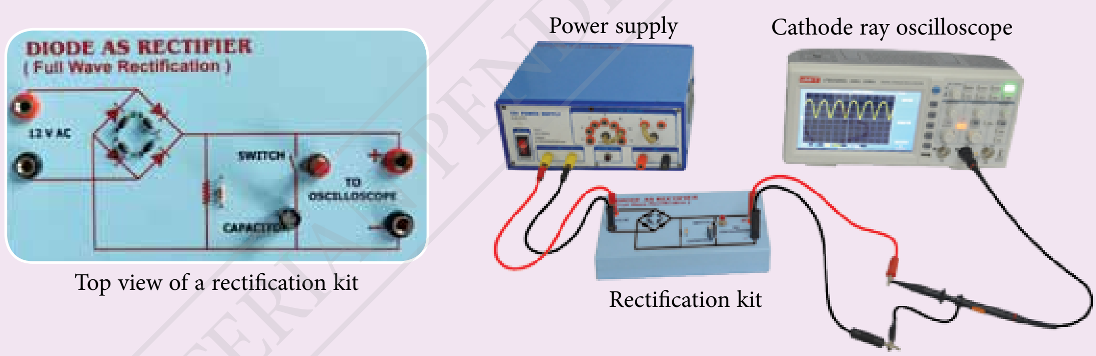
Aim: To build a rectification circuit

Apparatus: Rectification kits, cathode ray oscilloscope, 100 Ω resistor, power supply and connecting wires

Instructions:



Photograph 5.3 *Half-wave rectification kit*



Photograph 5.4 *Full-wave rectification kit*

1. Connect the 100 Ω resistor to a 2 V alternating current power supply. Adjust the cathode ray oscilloscope until a clear sinusoidal waveform appears on the screen. Observe the sinusoidal waveform and record your observation.
2. Connect the half-wave rectification kit as shown in Photograph 5.3. Observe the trace display on the screen and record your observation.
3. Repeat step 2 with the full-wave rectification kit as shown in Photograph 5.4.

Discussion:

State the use of the semiconductor diode in a rectification circuit.

Half-wave Rectification

A complete cycle of alternating current consists of two half cycles: a positive half cycle and a negative half cycle. During the positive half cycle, the semiconductor diode is **forward biased** and allows current to flow through it. During the negative half cycle, the semiconductor diode is **reverse biased** and there is no current flow. This half-cycle rectification process is called **half-wave rectification** as shown in Figure 5.8.

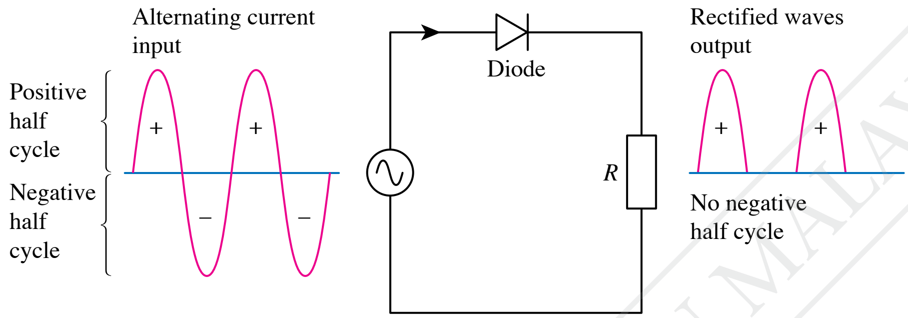


Figure 5.8 *Half-wave rectification*

Full-wave Rectification

The arrangement of four diodes as shown in Figure 5.9 and Figure 5.10 is called a **bridge rectifier**. This arrangement allows a complete cycle of current to flow in the same direction through the load, *R*.

Positive half cycle

- Diodes D_1 and D_2 are forward biased while D_3 and D_4 are reverse biased.
- Therefore, D_1 and D_2 allow current to flow while D_3 and D_4 prevent current from flowing as shown in Figure 5.9

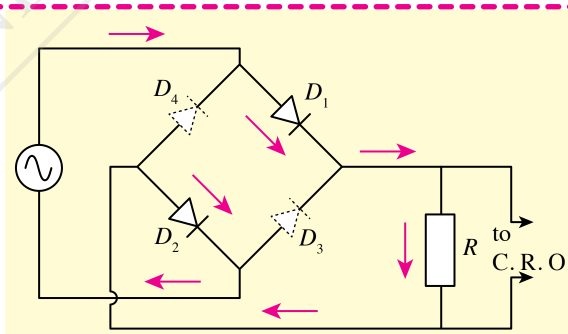


Figure 5.9

Negative half cycle

- Diodes D_3 and D_4 are forward biased while D_1 and D_2 are reverse biased.
- Therefore, D_3 and D_4 allow current to flow while D_1 and D_2 prevent current from flowing as shown in Figure 5.10

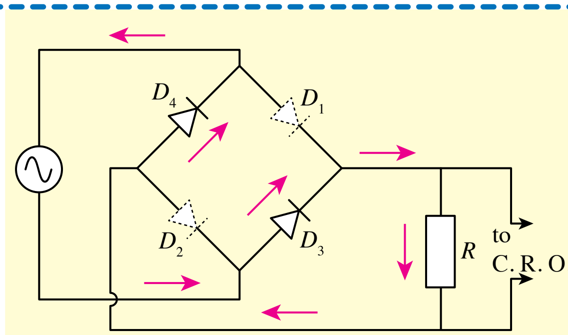


Figure 5.10

Full-wave rectification is a process where both halves of every cycle of an alternating current is made to flow in the same direction. Full-wave rectification displayed on the cathode ray oscilloscope screen is shown in Figure 5.11.

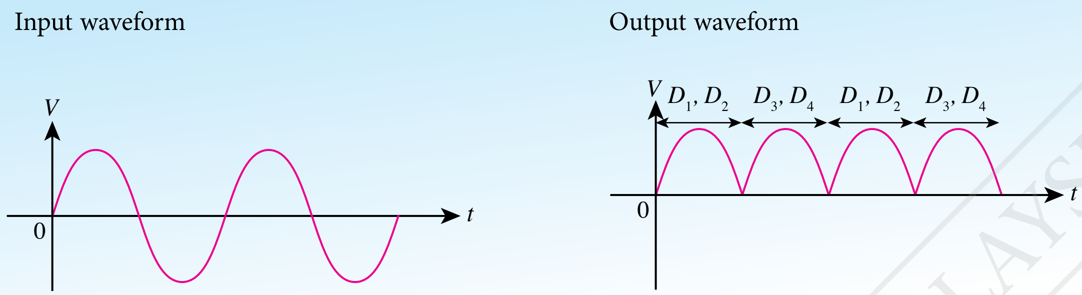
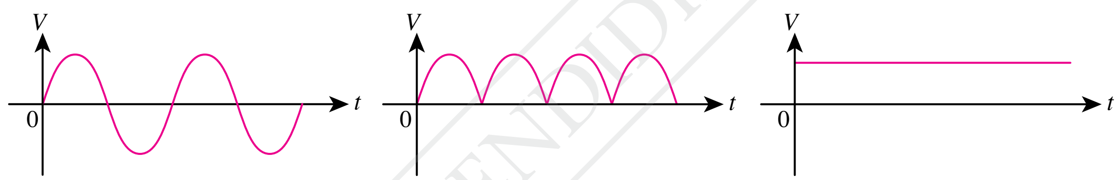


Figure 5.11 *Display of full-wave rectification on the cathode ray oscilloscope*

Info GALLERY

These are several types of currents common in electronic studies. A smooth direct current is essential for a circuit to function well.



(a) Example of an alternating current *(b) Example of a direct current* *(c) Example of a steady direct current*

Capacitors in Smoothing Direct Current

Half-wave and full-wave rectifications produce a direct current which is not smooth. Therefore, a capacitor is used to smooth the current in a rectification circuit.

Activity 5.6

Aim: To collect information on the function of a capacitor in a rectification circuit

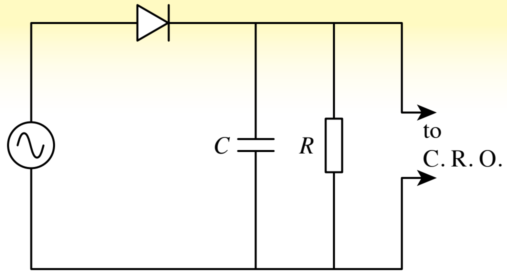
Instructions:

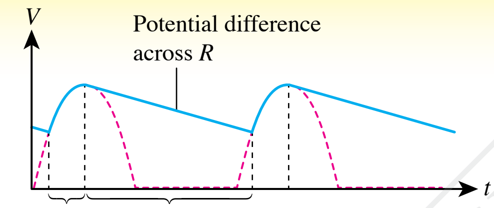
1. Carry out the activity in pairs.
2. Collect information related to:
   (a) the function of a capacitor in a rectification circuit
   (b) the factors influencing the effect of current smoothing such as capacitance value and capacitor type
3. You may obtain information from a website or reading resources in the school resource centre.
4. Present your findings.

SCAN ME
Video on capacitors
https://bit.ly/3bfVtDU

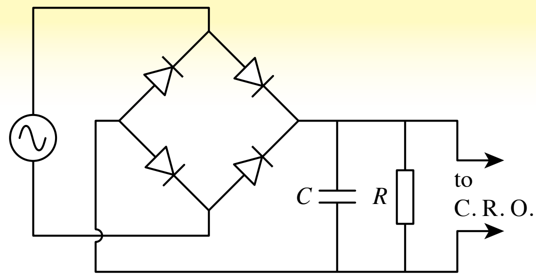
LS 5.2.2

Smoothing of Half-wave Rectification Output





Smoothing of Full-wave Rectification Output



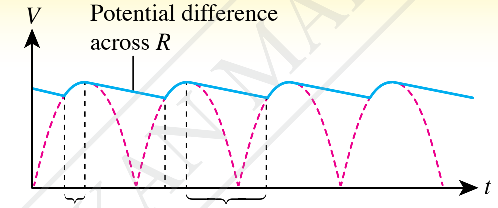


***Figure 5.12** Smoothing of full-wave and half-wave rectification output by a capacitor*

- Capacitor, C is connected in parallel to the load, R. When the power supply is turned on, the output current becomes smooth.
- When the potential difference increases, the capacitor will be charged and energy is stored in the capacitor.
- When the potential difference decreases, the capacitor will discharge so that the output current does not fall to zero. The energy stored in the capacitor will maintain the potential difference across the resistor, R.
- The smoothed output waveform shows that the capacitor is functioning as current smoother.

Formative Practice 5.2

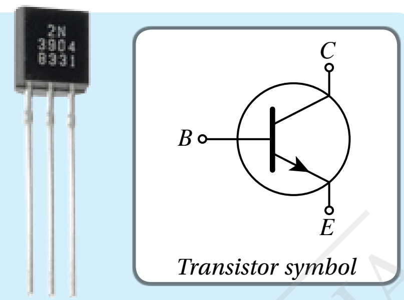
1. What is the meaning of the following terms?
   (a) Semiconductor diode
   (b) Forward biased
   (c) Rectification
2. Draw a full-wave rectification circuit using four semiconductor diodes. Then, sketch the voltage output displayed on the cathode ray oscilloscope if one of the semiconductor diodes is burnt.
3. (a) Name the electronic component that is used to smooth the output current of the full-wave rectification circuit.
   (b) Explain the working principle of the electronic component in 3(a).

5.3 Transistor

Photograph 5.5 shows a transistor. A transistor is an electronic component that has three terminals, namely emitter, *E*, base, *B* and collector, *C*. What is the function of a transistor?

Emitter, *E* supplies charge carriers to the collector. Base, *B* is a thin layer in the middle of a transistor to control the flow of charge carriers from emitter to the collector. Collector, *C* receives charge carriers from the emitter.

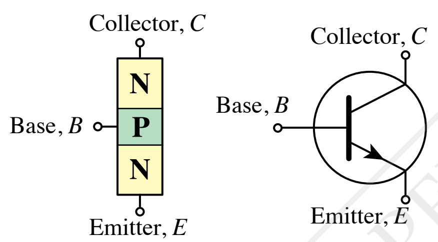
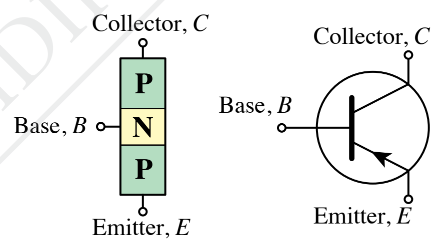
There are two types of transistors: the npn transistor and the pnp transistor as shown in Table 5.3.



***Photograph 5.5** Transistor*

SCAN ME
EduwebTV: Transistor
https://bit.ly/3bdul8w

***Table 5.3** npn transistor and pnp transistor*

npn transistor	pnp transistor
	
The arrow in the symbol shows the direction of current from *B* to *E*.	The arrow in the symbol shows the direction of current from *E* to *B*.

Activity 5.7

ISS ICS

Aim: To collect information on
- npn transistor and pnp transistor
- transistor circuit connected with a npn transistor and a pnp transistor

Instructions:

1. Carry out the activity in groups.

2. Gather information from various reading resources and websites on:
(a) the terminals of a transistor
(b) npn and pnp transistors

3. Discuss a transistor circuit based on the following:
(a) base circuit and collector circuit
(b) minimum voltage applied to the base circuit of the transistor to turn on the collector circuit
(c) resistance at the base circuit to limit the base current

4. Present your findings in a suitable mind map.

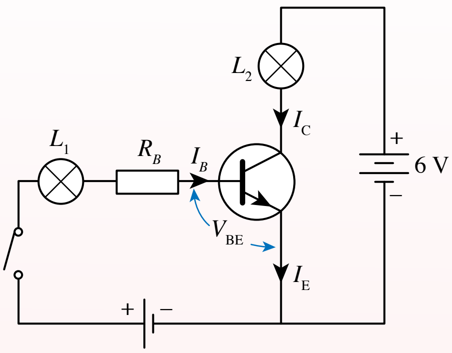
LS 5.3.1

Transistors are widely used in digital circuits like computers. What are the characteristics of transistor circuits? How are npn transistors and pnp transistors connected in a circuit?

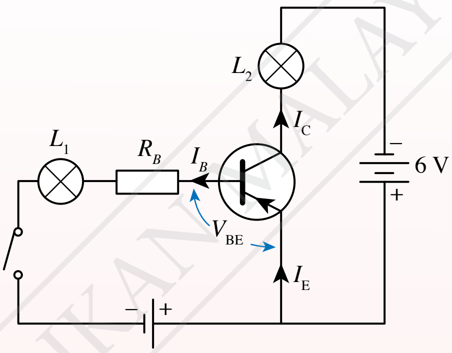
A transistor circuit consist of two main parts which are a base circuit and a collector circuit. Figure 5.13 shows an npn transistor circuit and a pnp transistor circuits.

BRIGHT Info

For pnp transistors, the polarity of the battery for both base circuit and collector circuit has to be reversed. Hence the directions of flow of the base current, I_B, collector current, I_C and emitter current, I_E are also reversed.



(a) npn transistor



(b) pnp transistor

***Figure 5.13** Transistor circuits*

- When the switch is open, bulb L_1 does not light up as the circuit is incomplete and the base current, I_B is zero.
- Bulb L_2 does not light up although the collector circuit is complete because the transistor is not turned on and the collector current, I_c is zero.
- When the switch is closed, bulb L_1 is dim because R_B has a high resistance and the base current, I_B is very small. Bulb L_2 lights up very brightly because the collector current, I_c is large compared with the base current, I_B.
- A small base current can produce a minimum base voltage, V_{BE} to turn on the collector circuit.
- The base current, I_B can control the flow of the collector current, I_c. This enables the transistor to act as a switch.
- The resistance at the base circuit, R_B is large to limit the base current, I_B so that the transistor will not become too hot and burn.

A Transistor Functions as a Current Amplifier

A transistor can magnify an electric current. In Figure 5.14, the voice of the singer can be amplified by an amplifier system.

Figure 5.14

Activity 5.8

Aim: To study the use of a transistor as a current amplifier

Apparatus: Transistor circuit kit, resistors (2.2 kΩ, 3.9 kΩ, 4.7 kΩ, 6.8 kΩ, 8.2 kΩ), milliammeter (0 – 1 mA), milliammeter (0 – 100 mA), 6 V power supply, 1.5 V dry cell, cell holder and connecting wires

Instructions:

1. Arrange the circuit as shown in Figure 5.15 using a 2.2 kΩ resistor.

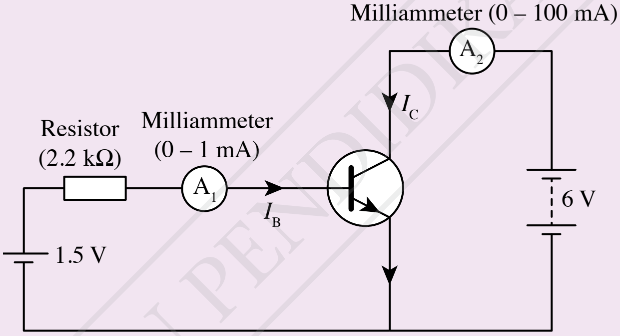


Figure 5.15

2. Record the readings of A_1 as I_B and A_2 as I_C in Table 5.4.
3. Replace the 2.2 kΩ resistor with the 3.9 kΩ, 4.7 kΩ, 6.8 kΩ and 8.2 kΩ resistors and repeat step 2.

Results:

Table 5.4

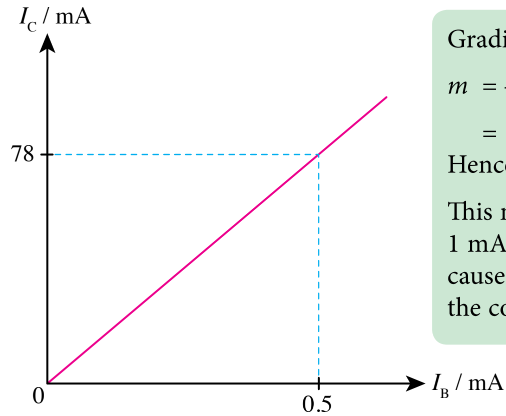
Resistance / kΩ	2.2	3.9	4.7	6.8	8.2
I_B / mA					
I_c / mA					

Discussion:

1. Based on the results in Table 5.4, plot the graph of I_C against I_B.
2. Determine the gradient of your graph and calculate the amplification factor of the amplifier, β.

$$\beta = \frac{I_C}{I_B}$$

Based on Activity 5.8, you will obtain a graph of I_C against I_B which shows a straight line passing through the origin with a positive gradient as shown in Figure 5.16. This proves that when there is no base current flow ($I_B = 0$), then there is no collector current ($I_C = 0$). When the base current, I_B increases, the collector current, I_C also increases. The gradient of the graph is the amplification factor, β of the transistor.



Gradient of graph,

$$m = \frac{78.0 - 0}{0.5 - 0}$$
$$= 156$$

Hence, $\beta = 156$

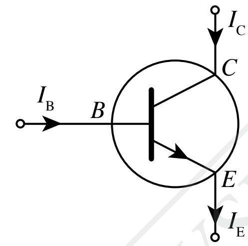
This means that a change of 1 mA in the base current will cause a change of 156 mA in the collector current.

Figure 5.16 *Graph of I_C against I_B*

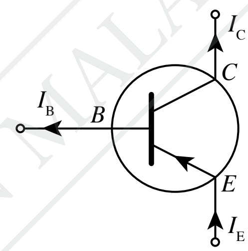
A small increase in the base current, I_B will cause a big change in the collector current, I_C. Hence, a transistor can function as a current amplifier.

BRIGHT Info

npn transistor



pnp transistor



- If $I_B = 0$, then $I_C = 0$
- $I_B < I_C < I_E$
- $\beta = \frac{I_C}{I_B}$

In a transistor circuit, the power supply or battery will supply a fixed potential difference. The transistor requires a potential difference, V_{BE} which is more than the minimum voltage for it to function. To acquire this small potential difference, a potential divider circuit can be used.

In the potential divider method, two resistors with resistances, R_1 and R_2 should be connected in series with a power supply, V_{in} as shown in Figure 5.17. As the same current is flowing through both the resistors, the relationship between the voltage and the resistance is shown by the following equation:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

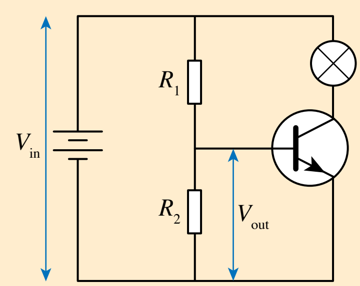


Figure 5.17 *Potential divider*

Info GALLERY

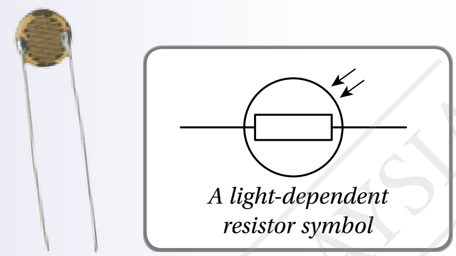
The minimum voltages, V_{BE} to turn on the silicon transistor and germanium transistor are 0.7 V and 0.3 V respectively.

The Use of a Transistor as an Automatic Switch

In a transistor circuit, the current does not flow in the collector circuit unless there is a current flowing in the base circuit. This means that a transistor can function as a switch by turning the base current on or off. The potential divider method studied earlier can be applied to control the base current to turn the transistor on or off automatically.

Light-dependent resistor in a light-controlled switch

- Light-dependent resistor (LDR) is a type of resistor. Its resistance changes with the intensity of light. The LDR resistance value is high when the light intensity is low and vice versa.
- In the dark, LDR resistance is very high. Based on the concept of potential divider, voltage across LDR, V_{LDR} will increase. When the V_{LDR} value exceeds the minimum voltage across B and E, base current, I_B will flow and turn on the transistor. This condition causes high collector current, I_C to flow in the collector circuit and the bulb will light up.
- Under bright conditions, resistance of LDR is low. Thus, V_{LDR} will decrease. When the value of V_{LDR} is less than the minimum voltage across B and E, then no base current, I_B flows to turn on the transistor. This situation causes collector current, I_C not to flow and the bulb does not light up.
- This circuit is used in automatic street lights.



Photograph 5.6 *A light-dependent resistor*

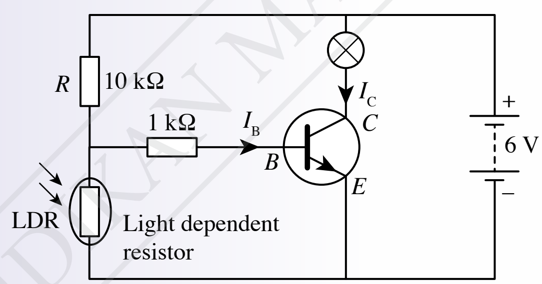
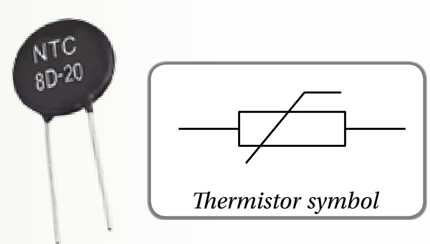


Figure 5.18 *A light-controlled switch circuit*

Thermistor in a heat-controlled switch

- A thermistor is a resistor. Its whose resistance changes with its surrounding temperature. The resistance is high under room temperature conditions (low temperature).
- As the surrounding temperature increases, the resistance becomes low and voltage across the thermistor decreases. Based on the concept of potential divider, when the voltage across the thermistor decreases, the voltage across the resistor R, V_R will increase. When the value of V_R exceeds the minimum voltage across B and E, the base current, I_B will flow and the transistor will be turned on. This situation will result in a high collector current I_C flowing in the circuit causing the bulb to light up.
- This circuit is suitable as an automatic switch in a temperature-controlled system.



Photograph 5.7 *A thermistor*

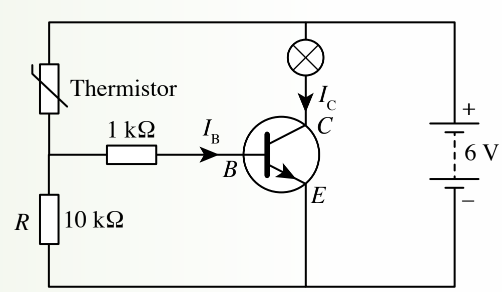


Figure 5.19 *A temperature-controlled alarm circuit*

Activity 5.9

Aim: To study the function of a transistor as an automatic switch using a transistor kit

SCAN ME
Method to carry out Activity 5.9 without transistor kit
https://bit.ly/3bbJqaK

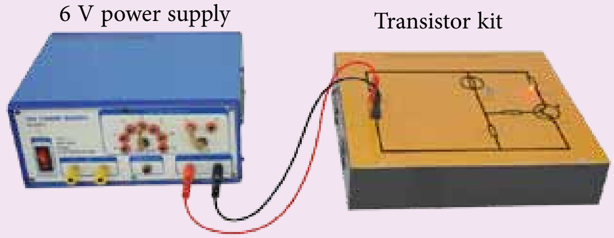
A Light-controlled switch

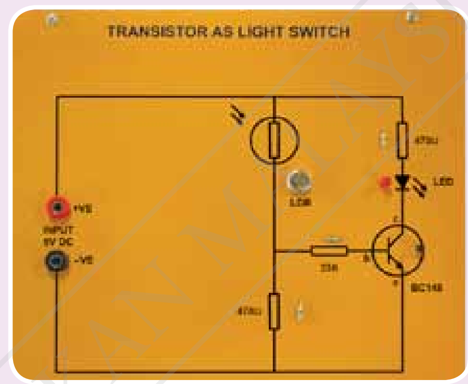
Apparatus: Light-controlled switch transistor kit, 6 V power supply and connecting wires

Instructions:

6 V power supply

Transistor kit





Top view of a transistor kit

***Photograph 5.8** A light-controlled switch transistor kit*

1. Connect the light control switch transistor kit to a 6 V direct current power supply.
2. Switch on the power supply and observe whether the LED lights up.
3. Then, cover the LDR with a finger. Observe whether the LED lights up.

Discussion:

1. Explain your observations:
   (a) after the power supply is switched on
   (b) while the LDR is covered with a finger
2. How does the transistor function as an automatic light control switch?

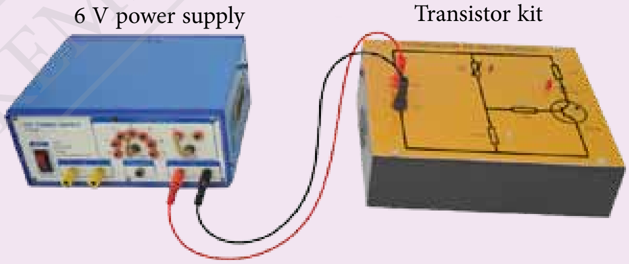
B Heat-controlled switch

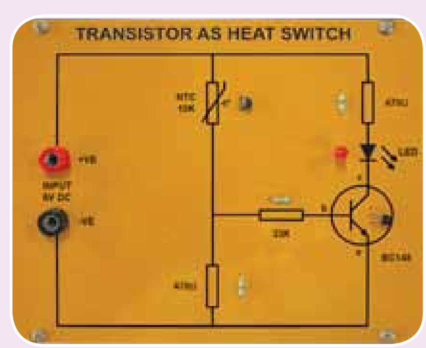
Apparatus: Heat-controlled switch transistor kit, 6 V power supply and connecting wires

Instructions:

6 V power supply

Transistor kit





Top view of a transistor kit

***Photograph 5.9** A heat-controlled switch transistor kit*

LS 5.3.2

1. Connect the heat-controlled switch transistor kit to a 6 V direct current power supply.
2. Switch on the power supply and observe whether the LED lights up.
3. Rub your hands together until they become warm and then touch the thermistor. Observe whether the LED lights up.

Discussion:

1. Explain your observations:
   (a) after the power supply is switched on
   (b) when the thermistor is touched with warm fingers
2. How does the transistor function as an automatic heat-controlled switch?
3. What modifications are needed to be made so that the LED can be replaced with an electric bell?

Formative Practice 5.3

1. Figure 5.20 shows the symbol for an electronic device.
   (a) What is the name of the electronic device?
   (b) What is the function of terminal *X* on the electronic device?

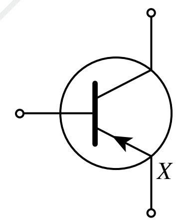


Figure 5.20

2. Figure 5.21 shows a transistor circuit which consists of two circuits, namely circuits *A* and *B*. When switch *S* is closed, bulb *P* is lighted dimly while bulb *Q* lights up brightly.

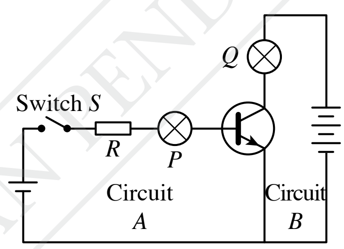


Figure 5.21

   (a) Name circuit *A* and circuit *B*.
   (b) Why does bulb *P* light up dimly when switch, *S* is closed?
   (c) Draw the modifications to the transistor circuit if the npn transistor is replaced with a pnp transistor.

3. Figure 5.22 shows a temperature-controlled alarm circuit. Resistor, *R* has a resistance of 10 kΩ. The potential difference across *XY* must be at least 5.5 V to turn on the 6 V, 60 mA bulb. What is the resistance of the thermistor when the bulb lights up?

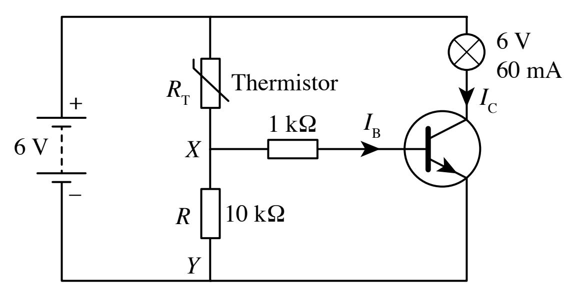
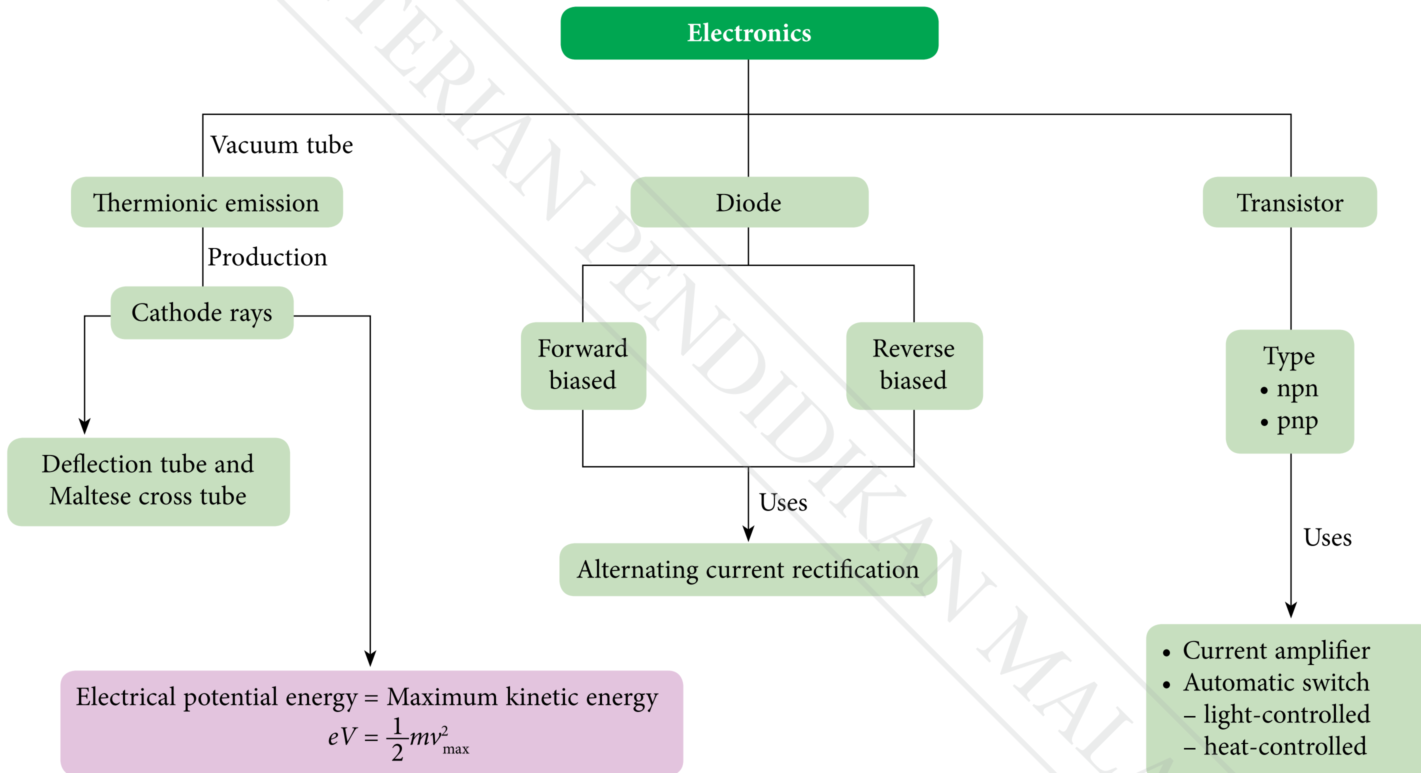


Figure 5.22

Concept Chain

Interactive Games
https://bit.ly/32FXnKd



Self-Reflection

SCAN ME
Download and print Self-Reflection
https://bit.ly/34Prhyj

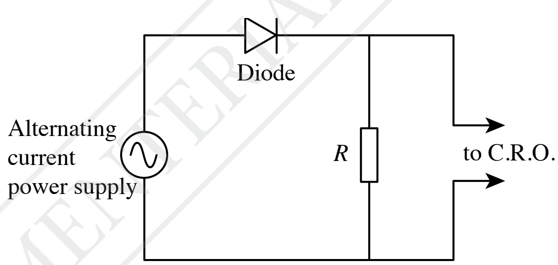
1. New things I have learnt in the chapter on 'Electronics' are ______________.
2. The most interesting thing I have learnt in this chapter is ______________.
3. The things I still do not fully understand are ______________.
4. My performance in this chapter.
   Poor | 1 | 2 | 3 | 4 | 5 | Very good
5. I need to ______________ to improve my performance in this chapter.

QUIZ PORTAL
https://bit.ly/2YUeNSh

Summative Practice

1. (a) Using appropriate electronic symbols, draw a forward biased semiconductor diode in an electronic circuit.
   (b) What will happen if the battery connection in 1(a) is reversed?

2. Figure 1 shows a half-wave rectification kit connected to an alternating current power supply and a cathode ray oscilloscope (C.R.O.).



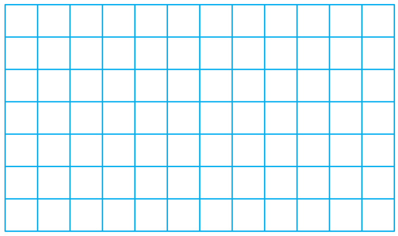
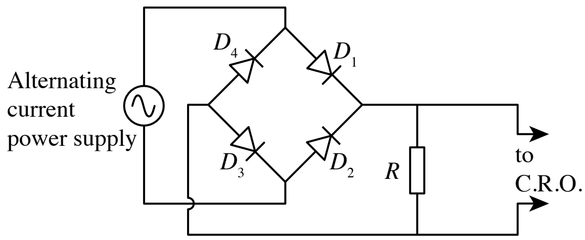


Figure 1

   (a) Sketch what is displayed on the cathode ray oscilloscope screen.
   (b) If a capacitor is connected in parallel with the resistor, *R*, sketch the changes to what is displayed on the cathode ray oscilloscope screen.

3. Figure 2 shows a full-wave rectification kit connected to an alternating current power supply and a cathode ray oscilloscope.



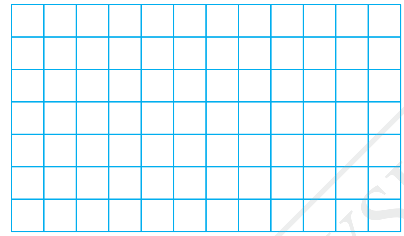
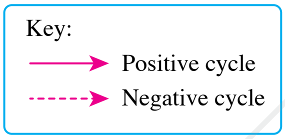


Figure 2

(a) Draw arrows to show the flow of current through the diode during the positive half cycle and the negative half cycle.

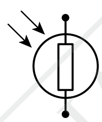
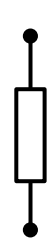
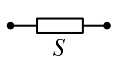
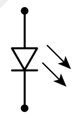
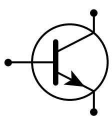
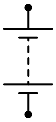


(b) Sketch what is displayed on the cathode ray oscilloscope screen if a capacitor is connected parallel to the resistor, *R*. What is the role of the capacitor?

(c) What will happen to the output current if the connection to diode, D_1 is reversed?

4. Table 1 shows the main components that are required for a transistor to function as an automatic light-controlled switch.

Table 1

 LDR	 *R*	 *S*
LED 		

(a) Draw an automatic switch transistor circuit using the components provided in the table above.

(b) Discuss whether the LED is lighted when the LDR is under bright conditions.

(c) State the modification of the automatic switch transistor circuit to an automatic temperature-controlled alarm circuit so that the alarm will ring when its surrounding temperature becomes very high.

5. Figure 3 shows an electronic circuit used to study the function of a npn transistor in the circuit. Readings I_B and I_C are obtained from microammeter, A_1 and miliameter A_2 respectively. The rheostat is adjusted to obtain different values of I_B and I_C as shown in Table 2.

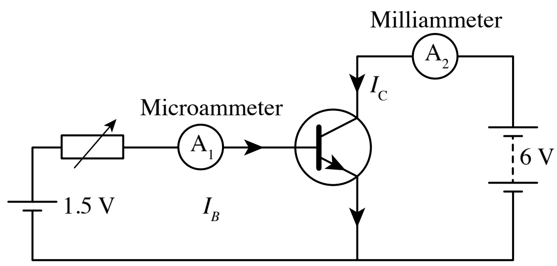


Figure 3

Table 2

I_B / µA	I_C / mA
0	0
20	2.1
40	4.2
60	6.3
80	8.4

(a) Plot the graph of I_C against I_B.

(b) Based on your graph in 5(a):

(i) state the relationship between I_B and I_C and explain your answer

(ii) state the roles of the transistor in the circuit and explain your answer

(c) Draw a new electronic circuit if the npn transistor is replaced with a pnp transistor.

21st Century Challenge

6. Amar carried out an electronic project to create an automatic switch circuit for a fire alarm system. Figure 4 shows an incomplete electronic circuit. Table 3 shows the symbols of nine possible components which may be used to complete the circuit.

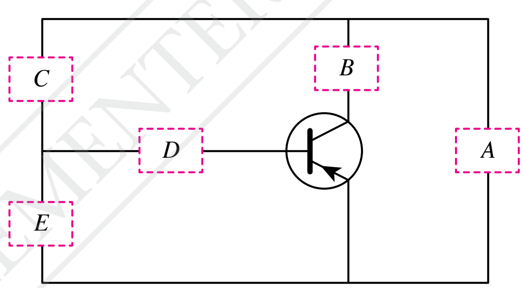


Figure 4

Table 3

Capasitor	Diode	Thermistor
Rheostat	Electric bell	Battery
Resistor	Transformer	A.C. power supply

(a) Based on your knowledge of electronics, select any suitable components from Table 3 to complete the transistor circuit as an automatic switch for a fire alarm system.

(b) State the justification for each of your choice.

CHAPTER 6

Nuclear Physics

What is radioactive decay?

What is half-life?

How can the uranium decay series be used to determine the age of rocks and Earth?

What is meant by nuclear fission and nuclear fusion?

What is the relationship between nuclear energy and mass defect?

Is it feasible to build a nuclear power plant in Malaysia?

You will learn about:

List of Learning Standards and Formulae in Chapter 6

Information Portal

Hydrogen nuclei fusions occur naturally in the core of the Sun at about 15.6 million Kelvin and 250 billion times the Earth's atmospheric pressure. Over 560 million tons of hydrogen fuse to become helium in an instant. The nuclear energy released in the fusion reaction is the source of light and heat energy for the Sun and stars in the outer space.

Nowadays, scientists have succeeded in designing small-sized Tokamak fusion reactors in the laboratory. The heat produced by the nuclear reaction (nuclear fusion) is used to generate electrical power. If such technology can be commercialised, the dependence on the consumption of fuel sources like petroleum and coal to generate electrical power can be overcome in the future.

http://bit.ly/2FKLFpR

Importance of the Chapter

Knowledge of nuclear physics allows engineers and scientists to design safer nuclear power plants to generate electrical energy. This knowledge can also be applied to manage the nuclear plant waste carefully and efficiently to prevent environmental pollution and to ensure the well-being of the ecosystem of the earth. Such advancements will bring about the sustainability of energy resources and improve the productivity of our country.

Futuristic Lens

Research on the construction of nuclear fusion reactors to meet the increasing demand for electrical power generation may be achieved in the future. Energy from nuclear fusion is an alternative energy that is capable of reducing the consumption of petroleum and coal. This alternative energy is more efficient, has zero carbon footprint and has minimal impact on our earth's ecosystem if it is well coordinated.

http://bit.ly/2EfUt6H

6.1 Radioactive Decay

Radioactive decay is a process in which an unstable nucleus becomes more stable by emitting radioactive radiation. This process is random and spontaneous. There are three types of radioactive radiation, namely alpha particle (α), beta particle (β) and gamma ray (γ).

Info GALLERY

A radioactive decay is random and spontaneous because it is not influenced by temperature, pressure and other physical factors.

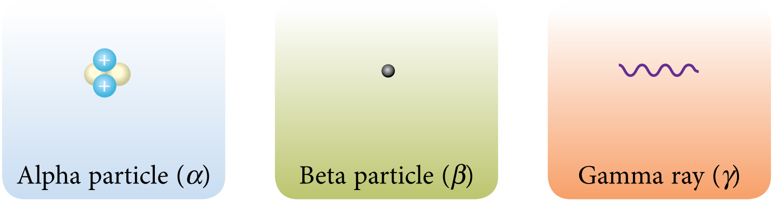


***Figure 6.1** Three types of radioactive radiation*

LET'S RECALL

Radioactivity

http://bit.ly/3ghCObR

Activity 6.1

ISS ICS

Aim: To discuss radioactive decay equations

Instructions:

1. Carry out this activity in groups.
2. Gather information from various reading resources or websites on the changes in a nucleus after a radioactive decay.
3. Discuss:
   (a) examples of decay equations for α-decay, β-decay and γ-decay
   (b) the changes in the composition of the nucleus after each type of radioactive decay
4. Present your findings.

Equation for Alpha (α) Decay

Alpha particle is a helium nucleus which consist of two protons and two neutrons. During alpha decay, an unstable nucleus releases an alpha particle to become a more stable nucleus of a new element. Figure 6.2 shows the process of alpha decay.

The general equation for an α-decay is as follows:

$${}^{A}_{Z}\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + {}^{4}_{2}\text{He}$$

α-particle

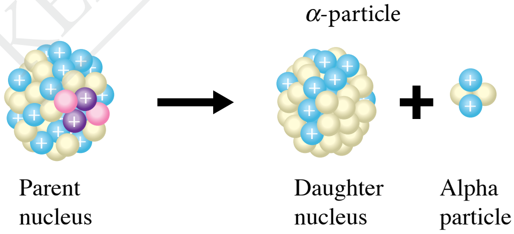


***Figure 6.2** Alpha decay*

Parent nucleus has proton number, Z and nucleon number, A. After α-decay, the daughter nucleus has proton number, $Z - 2$ and nucleon number, $A - 4$.

Example of an α-decay:

$${}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$$

Equation for Beta (β) Decay

Beta particle is a fast-moving electron. During beta decay, a neutron in an unstable nucleus decomposes into one proton and one electron as shown below:

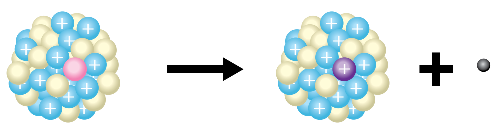
$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

The resulting proton remains in the nucleus while the electron is emitted with high kinetic energy as β-particle as shown in Figure 6.3.

The general equation for β-decay is as follows:

$$^{A}_{Z}\mathbf{X} \rightarrow {}^{A}_{Z+1}\mathbf{Y} + {}^{0}_{-1}e$$

β-particle



Parent nucleus   Daughter nucleus   Beta particle

***Figure 6.3** Beta decay*

After β-decay, the proton number for the daughter nucleus becomes $Z + 1$ but the nucleon number, A does not change.

Example of a β-decay:

$$^{24}_{11}\mathrm{Na} \rightarrow {}^{24}_{12}\mathrm{Mg} + {}^{0}_{-1}e$$

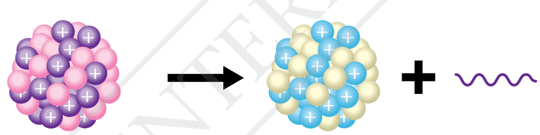
Equation for Gamma (γ) Decay

Gamma rays are high-frequency electromagnetic wave. During gamma decay, an unstable nucleus releases its excess energy to become more stable, as shown in Figure 6.4. Gamma rays have no mass and are neutral (not charged).

The general equation for γ-decay is as follows:

$$^{A}_{Z}\mathbf{X} \rightarrow {}^{A}_{Z}\mathbf{X} + \gamma$$

γ-ray



Radioactive nucleus in an excited state   Nucleus with less energy   Gamma ray

***Figure 6.4** Gamma decay*

After γ-decay, there are no changes in the proton number and nucleon number for the nucleus. The nucleus is less energetic after gamma decay.

Example of a γ-decay:

$$^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{27}\mathrm{Co} + \gamma$$

During a radioactive decay, some nuclei can emit more than one radiation. For example, during the disintegration of uranium-234, its nucleus emits α-particle and γ-ray. Examples of its decay equation and a simpler decay equation are as follows:

Decay equation:

$$^{234}_{92}\mathrm{U} \rightarrow {}^{230}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} + \gamma$$

Simpler decay equation:

$$^{234}_{92}\mathrm{U} \xrightarrow{\alpha,\,\gamma} {}^{230}_{90}\mathrm{Th}$$

Half-life

When a sample of radioactive material decays, the number of parent nuclei which has not decayed decreases with time while the number of daughter nuclei increases. Let us do the following activities to get an idea about half-life.

Activity 6.2

ISS ICS

Aim: Watch the animated video to get an idea about the half-life and discuss the decay series of a radioactive source

SCAN ME
Video of half-life
http://bit.ly/2CPwomw

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code to watch the video on half-life and browse the Internet for more information on half-life.
3. Based on the video and the information obtained from the website, discuss:
   (a) What is half-life?
   (b) What is radioactive decay series?
   (c) State the types of radiation emitted, the elements produced and the time taken for the uranium-238 decay series.
   (d) Explain the importance of the uranium-238 decay series in determining the age of rocks and the age of the Earth.
4. Prepare a short multimedia presentation and present it in class.

The half-life, $T_{\frac{1}{2}}$ is **the time taken for a sample of radioactive nuclei to decay to half of its initial number**. After one half-life, the number of nuclei that are not decayed will be half of its initial value.

When an unstable radioactive nucleus decays, the new nucleus that is formed may also be unstable. The new nucleus will experience a series of continuous decay until a stable nucleus is formed. Figure 6.5 shows a complete decay series from uranium-238 to lead-206 and their respective half-life.

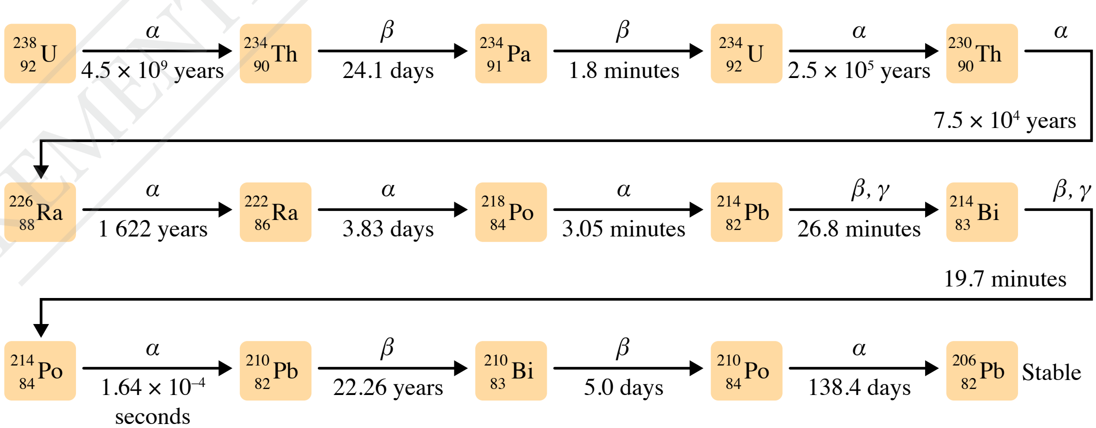


***Figure 6.5** Uranium-238 decay series*

Uranium-238 is a radioactive element with a long half-life, that is, about 5 000 million years. This element is trapped during the formation of rocks. The trapped uranium-238 will decay and eventually form a stable lead-206 as shown in Figure 6.6. This decay process takes a long time because the decay rate is low. By determining the ratio of lead-206 to uranium-238 in a rock sample, the age of the rock can be estimated. The higher the ratio, the older the rock. This geological method of measurement can also estimate the age of our Earth. Do you know the age of our Earth?

Info GALLERY

Radioactive material is usually stored in a thick sealed container made of lead for safety purposes.

Info GALLERY

Radioisotopes are isotopes with unstable nuclei that can emit radioactive radiation.

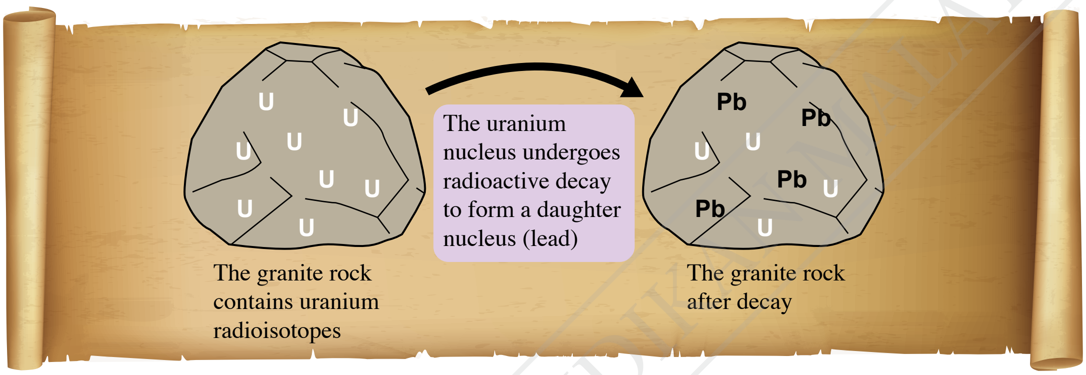


***Figure 6.6** Determining the age of granite rock*

To Determine the Half-life of a Radioactive Substance from its Decay Curve

Radioactive substance will experience random and spontaneous radioactive decay. The number of nuclei which has not disintegrated decreases with time. Different radioactive substances decay at different rates. A decay rate can be determined from a decay curve. Let us carry out a radioactive decay simulation to draw a decay curve.

Career Booth

Geologists use radioactive dating techniques to determine the age of rocks.

Activity 6.3

Aim: To draw a decay curve

Apparatus: 10 plastic bags containing 60 dice per bag

Material: Graph paper

Instructions:

1. Divide the class into 10 groups. Each group is provided with a plastic bag containing 60 pieces of dice each.
2. Throw the 60 dice on top of the table.
3. Remove all dice which display the number “3”. Record the number of dice left.
4. Throw the remaining dice again on the table and remove the dice which display the number “3”. Record the number of dice left.

5. Repeat step 4 for 20 times.
6. Scan the QR code and print Table 6.1.
7. Record the results of all the 10 groups in Table 6.1.

SCAN ME
Worksheet (Table 6.1)
http://bit.ly/3j098S5

Results:

Table 6.1

Number of throws	Number of dice left, N										
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	Average
0											
1											
2											
3											

G1= Group 1

Data analysis:

Plot the graph of the number of dice left against the number of throws.

Discussion:

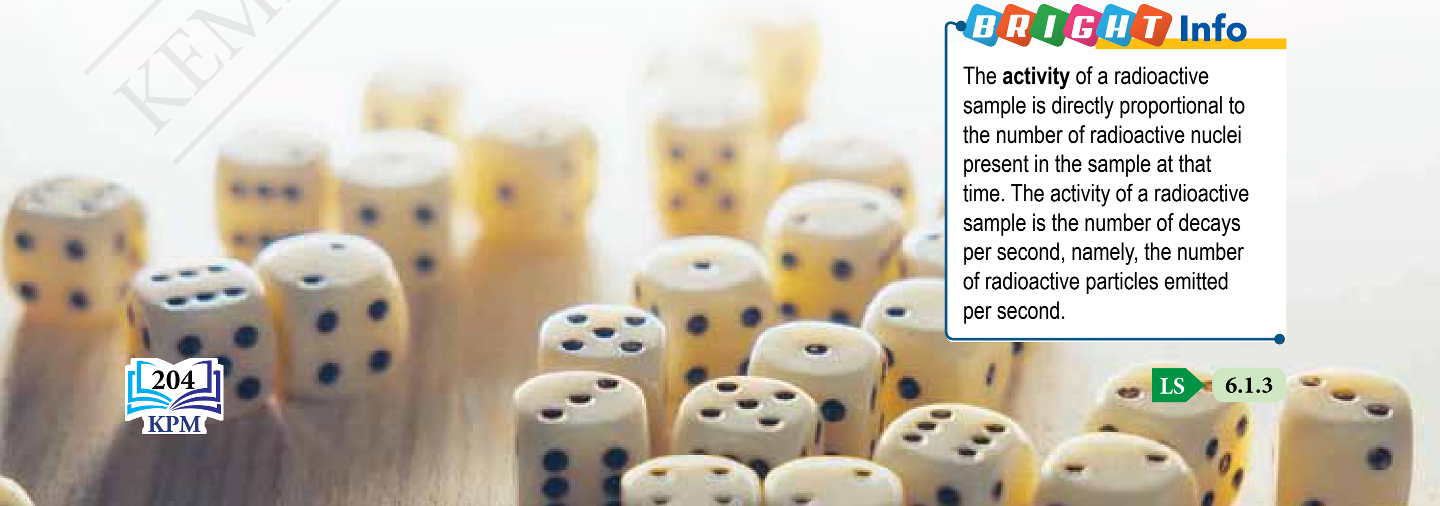
1. From your graph, determine the following:
   (a) the number of throws when the number of dice left becomes 30, 15 and 7.5
   (b) the average time interval, for the number of dice left to be halved if each throw represents a time of one minute
2. Will the results of your class change if this activity is repeated with the dice displaying number "1" for each throw?
3. What are the characteristics of the radioactive decay in this activity?

In Activity 6.3, each dice represents one radioactive nucleus. The dice displaying the number "3" represents a decayed nucleus. The remaining dice are considered as nuclei that have not decayed. The number of dice that displays the number "3" represents the **activity** of the radioactive sample. Your class results will not change if the activity is repeated with a dice displaying the number "1" for a throw because the probability for all numbers is the same.

SCAN ME
Graphical simulation of radioactive decay in Activity 6.3
http://bit.ly/2EdQzLp

BRIGHT Info

The **activity** of a radioactive sample is directly proportional to the number of radioactive nuclei present in the sample at that time. The activity of a radioactive sample is the number of decays per second, namely, the number of radioactive particles emitted per second.



LS 6.1.3

The concept of half-life can also be expressed in the form of a decay series as follow:

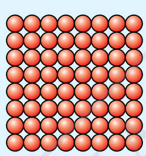
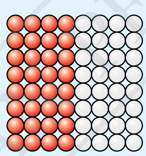
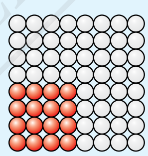
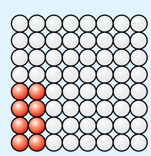
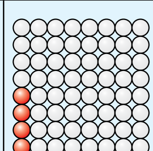
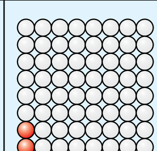
$$N_0 \xrightarrow[T_{\frac{1}{2}}]{} \left(\frac{N_0}{2}\right) \xrightarrow[T_{\frac{1}{2}}]{} \left(\frac{N_0}{4}\right) \xrightarrow[T_{\frac{1}{2}}]{} \left(\frac{N_0}{8}\right) \xrightarrow[T_{\frac{1}{2}}]{} \cdots \xrightarrow[T_{\frac{1}{2}}]{} \left(\frac{1}{2}\right)^n N_0$$

Number of radioactive nuclei that has not decayed, $N = \left(\frac{1}{2}\right)^n N_0$

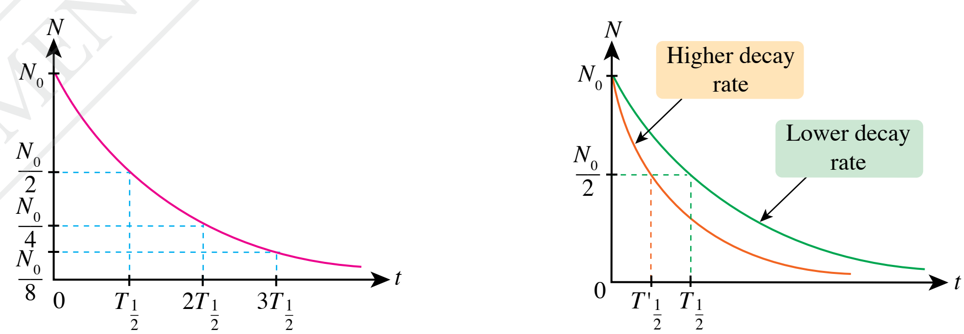
where N_0 = the initial number of radioactive nuclei
n = number of half-life (limited to positive integers)
$T_{\frac{1}{2}}$ = half-life of radioactive substances

Table 6.2 shows the change in the number of radioactive nuclei in five half-life.

***Table 6.2** The change in the number of radioactive nuclei in five half-life*

Half-life	**Initial condition**	$T_{\frac{1}{2}}$	$2T_{\frac{1}{2}}$	$3T_{\frac{1}{2}}$	$4T_{\frac{1}{2}}$	$5T_{\frac{1}{2}}$
Number of radioactive nuclei has not decayed	N_0	$\frac{1}{2}N_0$	$\left(\frac{1}{2}\right)^2 N_0 = \frac{1}{4}N_0$	$\left(\frac{1}{2}\right)^3 N_0 = \frac{1}{8}N_0$	$\left(\frac{1}{2}\right)^4 N_0 = \frac{1}{16}N_0$	$\left(\frac{1}{2}\right)^5 N_0 = \frac{1}{32}N_0$
Number of decayed radioactive nuclei	$N_0 - N_0 = 0$	$N_0 - \frac{1}{2}N_0 = \frac{1}{2}N_0$	$N_0 - \frac{1}{4}N_0 = \frac{3}{4}N_0$	$N_0 - \frac{1}{8}N_0 = \frac{7}{8}N_0$	$N_0 - \frac{1}{16}N_0 = \frac{15}{16}N_0$	$N_0 - \frac{1}{32}N_0 = \frac{31}{32}N_0$
● Radioactive nuclei that has not decayed ○ Decayed radioactive nuclei						

The curved graph for a radioactive decay is as shown in Figure 6.7(a). The shorter the half-life of a radioactive sample ($T'_{\frac{1}{2}} < T_{\frac{1}{2}}$), the higher the rate of decay as shown in Figure 6.7(b).



(a) (b)

***Figure 6.7** Curved graph for a radioactive decay*

Solving Problems Involving Half-Life

Example 1

A sample of radioactive material stored in the laboratory has an initial activity of 480 s^{-1}. If its half-life is 6 minutes, how much is its activity after 30 minutes?

LET'S ANSWER
http://bit.ly/32b5cqV

Solution

Step 1: Identify the problem → **Step 2:** Identify the information given → **Step 3:** Identify the formula that can be used → **Step 4:** Solve the problem numerically

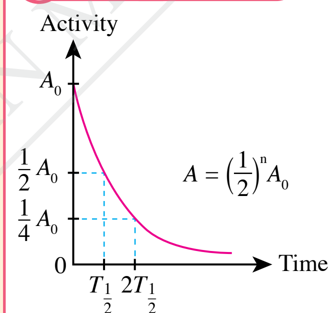
1. Activity of radioactive material, $t = 30$ minutes
2. Initial activity of radioactive material, $A_0 = 480\ s^{-1}$
   Half-life, $T_{\frac{1}{2}} = 6$ min
3. Final activity, $A = \left(\frac{1}{2}\right)^n A_0$
4. Number of half-life in 30 min,

$$n = \frac{t}{T_{\frac{1}{2}}} = \frac{30\text{ min}}{6\text{ min}} = 5 \text{ half-life}$$

Sample activity after 30 minutes

$$A = \left(\frac{1}{2}\right)^5 \times 480\ s^{-1} = 15\ s^{-1}$$

Info GALLERY



Example 2

A radioactive material stored in the laboratory has a half-life of 10 days. Calculate the number of days taken for the activity of a sample of radioactive material to reduce to 25% of its initial activity.

Solution

100% —($T_{\frac{1}{2}}$, 10 days)→ 50% —($T_{\frac{1}{2}}$, 10 days)→ 25%

Number of days taken = 2 × 10
= 20 days

Therefore, after 20 days, the activity of the remaining radioactive material is 25% of its initial activity.

Example 3

The ratio of nuclei of argon-40 to potassium-40 in a sample of volcanic rocks is 3 : 1. In the early formation of the rocks, there was no argon element trapped in it. If potassium-40 decays to argon-40 with a half-life of 1 250 million years, estimate the age of the rocks.

Solution

Table 6.3

Half-life	Initial condition	$T_{\frac{1}{2}}$	$2T_{\frac{1}{2}}$
Number of potassium-40 nuclei that has not decayed	N_0	$\frac{1}{2}N_0$	$\frac{1}{2}\left(\frac{1}{2}N_0\right) = \frac{1}{4}N_0$
Number of argon-40 nuclei formed	0	$N_0 - \frac{1}{2}N_0 = \frac{1}{2}N_0$	$N_0 - \frac{1}{4}N_0 = \frac{3}{4}N_0$
Ratio of Argon-40 : potassium-40	–	1 : 1	3 : 1

Table 6.3 shows the method of estimating the age of rocks. The ratio of nuclei of argon-40 to potassium-40 in the rock sample is 3 : 1 after two half-lives.

Thus, the age of the rock = 2 × 1 250 million years
= 2 500 million years

Formative Practice 6.1

1. Complete the radioactive decay equation. Identify *A*, *B* and *C*.

(a) $^{228}_{88}\text{Ra} \rightarrow A + ^{0}_{-1}e$ (b) $^{209}_{84}\text{Po} \rightarrow ^{205}_{82}\text{Pb} + B$ (c) $C \rightarrow ^{1}_{1}p + ^{0}_{-1}e$

2. The decay series of a radioactive source is $^{238}_{92}\text{U} \rightarrow \ldots \rightarrow ^{206}_{82}\text{Pb}$. Determine the number of α-particles and β-particles that are emitted.

3. Table 6.4 shows the record of the activity of a radioactive sample stored in the laboratory.

Table 6.4

Date	10 January 2020	20 January 2020	30 January 2020
Activity / s^{-1}	1 520	380	95

(a) Determine the half-life of the radioactive sample.

(b) Sketch a radioactive decay curve for the sample.

6.2 Nuclear Energy

The sun provides light and heat energy to Earth since millions of years ago. Hydrogen nuclear fusion occurs in the core of the Sun under very high pressure. In this nuclear reaction, two hydrogen nuclei fuse to form a helium nucleus and release nuclear energy. This energy is radiated to the surface of the Sun in the form of light and heat energy as shown in Photograph 6.1.

Nuclear energy is known as **atomic energy, released during nuclear reactions such as radioactive decay, nuclear fission and nuclear fusion**.

Photograph 6.1 *Light and heat energy radiated to the surface of Sun*

My Glorious Malaysia

The history of nuclear energy in Malaysia started with the establishment of the Tun Ismail Atomic Research Centre (PUSPATI) under the Ministry of Science, Technology and Environment on 19 September, 1972. Now, the centre is known as the Malaysian Nuclear Agency (ANM).

Activity 6.4

ISS ICS

Aim: To compare nuclear fission and nuclear fusion

Instructions:

1. Carry out a Table Talkers activity.
2. Study the keywords in the cards given.
3. Scan the QR code to watch the videos on nuclear fission and nuclear fusion.
4. Each group needs to:
   (a) explain the keywords in the cards with reference to the videos
   (b) compare the two reactions

Discussion:

Create a mind map comparing the two reactions.

SCAN ME
Video of nuclear fission
http://bit.ly/2rADgP6

SCAN ME
Video of nuclear fusion
http://bit.ly/3kYY3mh

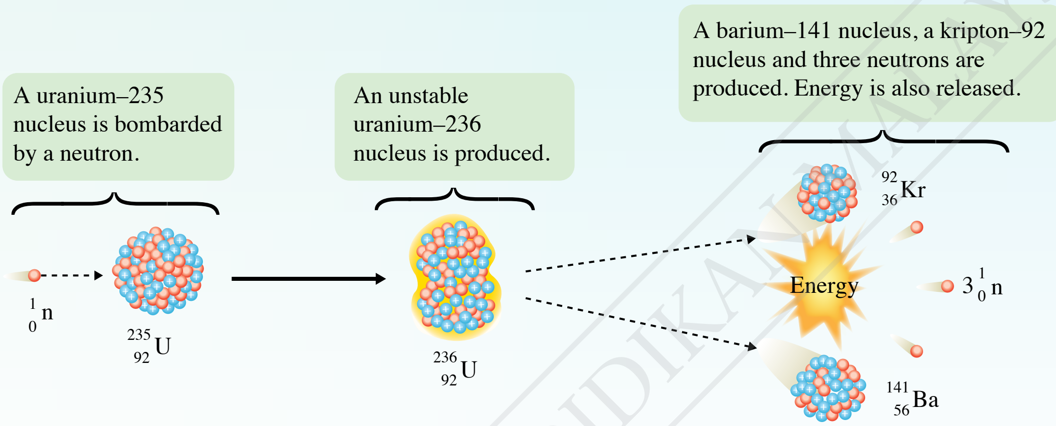
LS 6.2.1

Nuclear fission and nuclear fusion are two nuclear reactions that produce nuclear energy. There is a loss of mass (mass defect) occurs during these nuclear reactions. Figure 6.8 shows a nuclear fission while Figure 6.9 shows a nuclear fusion.

Nuclear fission

Nuclear fission is a **nuclear reaction when a heavy nucleus splits into two or more lighter nuclei while releasing a large amount of energy.**

Example:



$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$

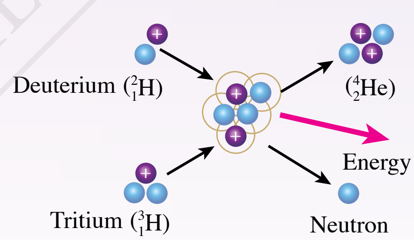
Figure 6.8 *Nuclear fission involving uranium–235 bombarded by a single neutron*

Nuclear fusion

Nuclear fusion is a **nuclear reaction in which small and light nuclei fuse to form a heavier nucleus while releasing a large amount of energy. This nuclear reaction happens under extremely high temperature and pressure.**

Example:

Nuclear fusion between deuterium and tritium occurs to form a heavier helium nucleus. Energy and one neutron is also released.



SCAN ME
Eduweb TV: Nuclear energy
http://bit.ly/2Ync0R7

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$$

Figure 6.9 *Nuclear fusion between deuterium and tritium*

The Relationship between Energy Released During Nuclear Reaction and Mass Defect

Atomic mass unit (amu) is a measurement of the mass of an atom. The mass of an atom is too small and difficult to measure using units such as grams or kilograms. Therefore, a relative comparison between the mass of an atom with the mass of one carbon-12 atom is used. Isotope carbon-12 is used as a reference because carbon can be found in many compounds found on Earth. Carry out Activity 6.5 to discuss amu by using the mass of one carbon-12 atom and the Avogadro number.

Activity 6.5

CPS

Aim: Discuss the atomic mass unit (amu) using the mass of one carbon-12 atom and the Avogadro number

SCAN ME
Worksheet (Figure 6.10)
http://bit.ly/31fBn9g

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code and print Figure 6.10.
3. Discuss with your partner and complete Figure 6.10

The Avogadro number is the number of atoms found in 1 mole of carbon-12, that is, N_A = ________________ atom

↓

The mass of one carbon-12 atom is 12 amu.

↓

1 amu is defined as a mass equal to ________________ that of the mass of a carbon-12 atom.

↓

Mass of one mole of carbon-12 = ________________ kg

↓ Therefore,

The mass of one carbon-12 atom is ______________________.

↓ From the definition of atomic mass unit (amu):

$$1 \text{ amu} = \frac{\square}{\square} \times \frac{\square}{\square}$$

= ________________________ kg

Figure 6.10 *Definition of atomic mass unit (amu)*

In a nuclear reaction or radioactive decay, the total mass of the decay products is always less than the total mass of the radioactive nucleus. This loss of mass is known as **mass defect**, *m*. Figure 6.11 shows an example of a change in total before decay mass before and after a nuclear fission.

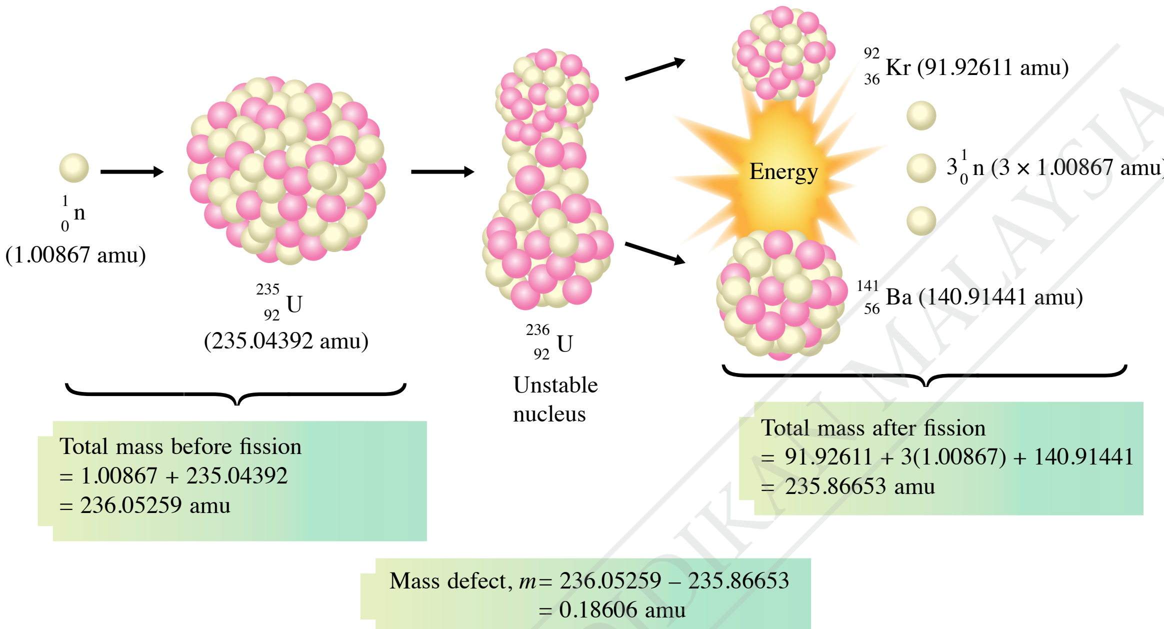


Figure 6.11 *Example of mass defect in nuclear fission*

The relationship between the energy released during nuclear reaction and the mass defect can be summarised by the following equation:

$$E = mc^2$$

where E = total energy released
m = mass defect
c = the speed of light in vacuum

1 amu = 1.66×10^{-27} kg

Based on knowledge of amu and the equation $E = mc^2$, we can calculate the nuclear energy produced from radioactive decay processes and nuclear reactions.

EAC History

Albert Einstein stated that mass and energy are interchangeable. The relationship between the two quantities is expressed in the equation $E = mc^2$.

Info GALLERY

Nuclear energy can be expressed in the unit of megaelectronvolts, MeV.

1 MeV = 1.6×10^{-13} J

Solving problems involving Nuclear Energy due to Radioactive Decay and Nuclear Reactions

Example 1

The equation below shows radium-226 decaying into radon-222 by emitting alpha particle.

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

Given that the mass of $^{226}_{88}$Ra is 226.54 amu, $^{222}_{86}$Rn is 222.018 amu and $^{4}_{2}$He is 4.003 amu, calculate the nuclear energy released.
[1 amu = 1.66×10^{-27} kg and speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}]

LET'S ANSWER
http://bit.ly/2Q9FTQs

Solution

Step 1: Identify the problem → **Step 2:** Identify the information given → **Step 3:** Identify the formula that can be used → **Step 4:** Solve the problem numerically

1. Nuclear energy that is released

2. Mass $^{226}_{88}$Ra = 226.54 amu
   Mass $^{222}_{86}$Rn = 222.018 amu
   Mass $^{4}_{2}$He = 4.003 amu
   Speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}
   1 amu = 1.66×10^{-27} kg

3. Nuclear energy released, $E = mc^2$

4. Mass defect, m = 226.54 – (222.018 + 4.003)
   = 0.519 amu
   Mass defect, m (in kg) = $0.519 \times 1.66 \times 10^{-27}$
   = 8.6154×10^{-28} kg
   $E = mc^2$
   $= 8.6154 \times 10^{-28} \times (3.00 \times 10^{8})^2$
   $= 7.75 \times 10^{-11}$ J

Example 2

The Sun is the source of energy to the Earth. This energy is produced by the nuclear fusion in the core of the Sun as shown in the following equation:

$$^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n} + \text{energy}$$

Calculate the nuclear energy released in joules.
[Mass of $^{2}_{1}$H = 2.014 amu, mass of $^{3}_{1}$H = 3.016 amu, mass of $^{4}_{2}$He = 4.003 amu, mass of $^{1}_{0}$n = 1.009 amu, 1 amu = 1.66×10^{-27} kg and the speed of light in a vacuum, $c = 3.0 \times 10^{8}$ m s^{-1}]

Solution

Mass defect, m
= (2.014 + 3.016) – (4.003 + 1.009)
= 5.030– 5.012
= 0.018 amu

Thus, $m = 0.018 \times 1.66 \times 10^{-27}$ kg
$m = 2.988 \times 10^{-29}$ kg
$E = mc^2$
$= 2.988 \times 10^{-29} \times (3.0 \times 10^{8})^2$
$= 2.69 \times 10^{-12}$ J

Generation of Electrical Energy in a Nuclear Reactor

Photograph 6.2 shows a nuclear reactor. What is the nuclear reaction that takes place in the nuclear reactor to generate electrical energy?

Info GALLERY

Malaysia does not have any nuclear reactors for generating electrical energy. **TRIGA PUSPATI** (RTP), a nuclear research reactor located in Bangi was built for research purposes related to the fields of nuclear science and education.

http://bit.ly/325TRIGA

Photograph 6.2 *A nuclear reactor*

Activity 6.6

ISS ICS

Aim: To find information on the generation of electrical energy in a nuclear reactor

Instructions:

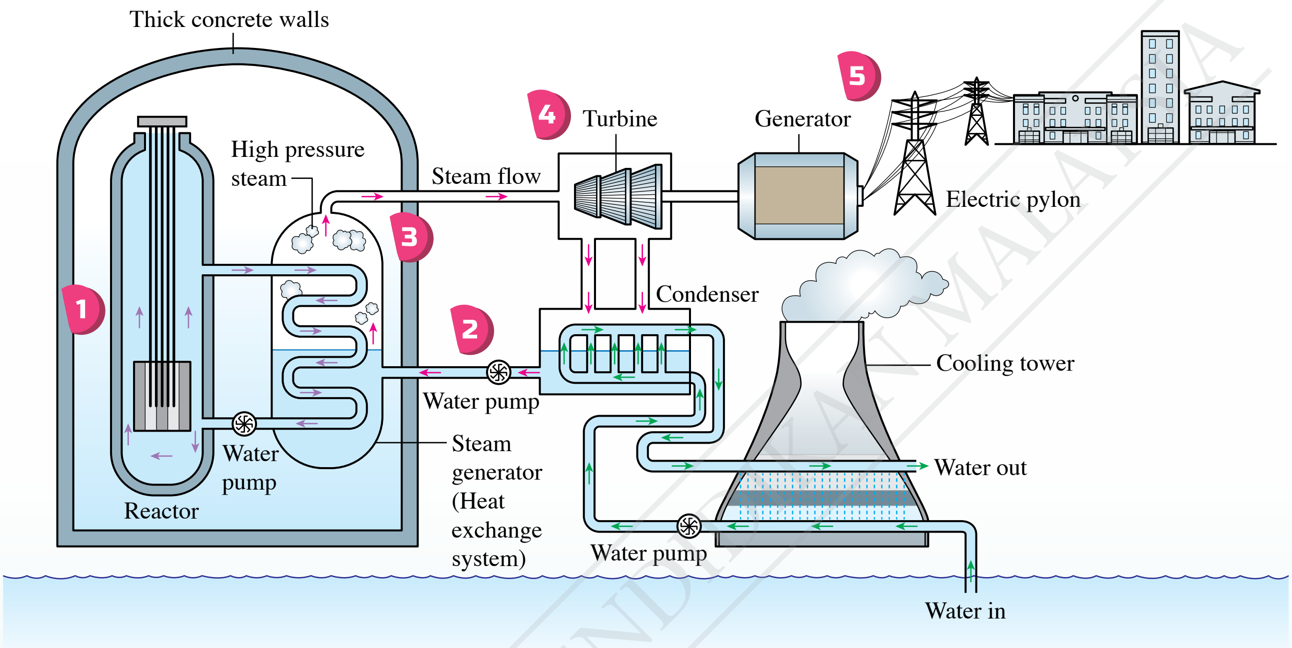
1. Conduct an Envoys activity.
2. Scan the QR code given or refer to any reference materials on the generation of electrical energy in a nuclear reactor.
3. Discuss the following:
   (a) What nuclear reaction is taking place in the nuclear reactor?
   (b) What is the energy change in the nuclear reactor?
   (c) Why is nuclear fusion not currently used in the electrical energy generation industry?
4. Present your findings.

SCAN ME
Video of working principles of a nuclear reactor
http://bit.ly/2FGK9F3

LS 6.2.4

Figure 6.12 shows the structure of a nuclear reactor and the process of electrical energy generation at a nuclear power station.

SCAN ME
Video of function of each section in a nuclear reactor
http://bit.ly/3ghpyUv



1 Nuclear fission of uranium-235 and its chain reaction produce heat energy.

2 Water is pumped into the reactor core to absorb the heat energy that is produced by the nuclear fission.

3 The boiling of water produces high pressure steam. This steam will be channelled to the turbine.

4 The turbine is rotated by the high pressure steam which in turn rotates the magnet or coil in the generator. The steam will condense into water.

5 The electrical energy generated is sent consumers via a power supply transmission system.

Figure 6.12 *The structure of a nuclear reactor and the process of generating electrical energy*

In a nuclear reactor, the fission of uranium-235 nucleus produces two daughter nuclei, three fast moving neutrons and releases a large amount of energy. These neutrons will bombard other uranium nuclei and release more neutrons through continuous nuclear fission. These continuous reactions is known as a **chain reaction**. Figure 6.13 shows the chain reaction of uranium-235.

SCAN ME
Video of a chain reaction in the core of a nuclear reactor
http://bit.ly/ChaRea8

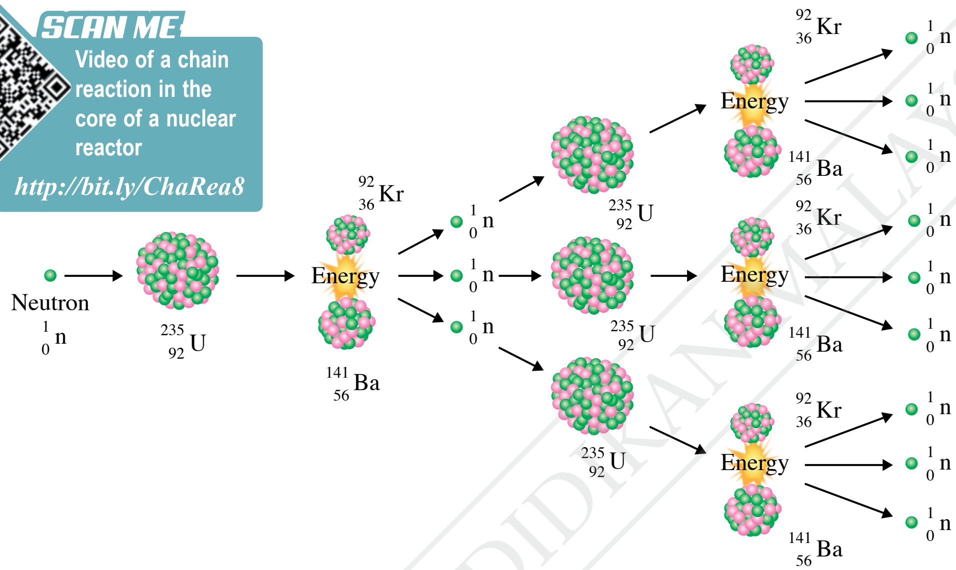


Figure 6.13 *Chain reaction of uranium-235*

The chain reaction that takes place in the reactor core needs to be controlled. The reactor needs to have a structure which can prevent the leakage of radioactive radiation to the surroundings. How can we control the energy produced during the chain reaction and ensure that a nuclear reactor is safe for electricity generation?

Activity 6.7

ISS ICS

Aim: To discuss a chain reaction and ways to control the energy produced in a nuclear reactor

Instructions:

1. Carry out a Talk Partners activity.
2. Scan the QR code given or refer to the reading resources to obtain information on chain reactions and ways of controlling energy produced in a nuclear reactor core.
3. Based on the information obtained:
   (a) write the equation for the fission of a uranium-235 nucleus when it is bombarded by a neutron
   (b) discuss ways of controlling the energy produced during a chain reaction in a nuclear reactor.
4. Present your findings.

SCAN ME
Video on ways of controlling energy in a nuclear reactor
http://bit.ly/3Vid215

LS 6.2.4

Figure 6.14 shows the control of rate of nuclear reaction and safety features in a nuclear reactor.

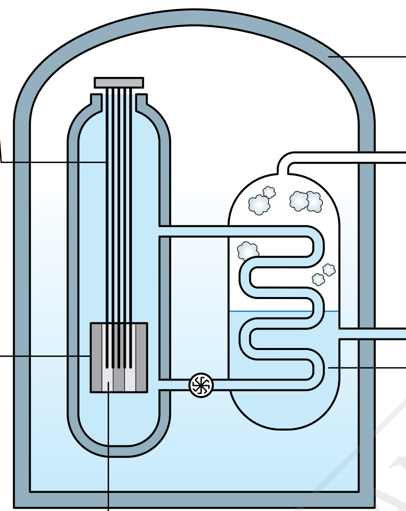
Control of rate of nuclear reaction:

Control rod

- Controls the reaction rate by absorbing excess neutrons.
- Made of boron or cadmium.

Moderator

- Slows down the fast moving neutrons released so that nuclear fission can occur.
- Made from materials such as graphite or water.



Safety features:

Thick concrete walls

Prevent radioactive radiations from leaking into the surroundings.

Water as a cooling agent

Absorbs heat energy from the chain reactions to generate steam. This can control the reactor temperature.

Uranium rods

Used as fuels for producing nuclear energy through nuclear fission reaction.

Figure 6.14 *Control of rate of nuclear reaction and safety features in a nuclear reactor*

The Use of Nuclear Energy as an Alternative Source to Generate Electrical Energy

In Malaysia, electricity is generated using sources like coal, natural gas and water. The hydro dam in Bakun, Sarawak as shown in Photograph 6.3 is the second largest dam in Asia that is used to generate electrical energy. However, countries like the United States, Japan, France, India and China have been using nuclear energy to generate electrical energy. Let us carry out the following activity to compare the electrical energy generation from a power plant using coal, hydropower and nuclear energy.

Photograph 6.3 *Hydro dam in Bakun, Sarawak*

Activity 6.8

Logical Reasoning | ISS | ICS

Aim: To find information to compare the generation of electrical energy from power plants that use coal, hydropower and nuclear energy

Instructions:

1. Carry out this activity in groups.
2. Obtain information on electrical energy generation from power plants that use coal, hydropower and nuclear energy.
3. The aspects that need to be considered when searching for information are as follows:
   (a) costs of construction, operation and maintenance
   (b) location of power plant
   (c) impact on ecosystems and carbon footprint
   (d) safety and health issues
   (e) technology and expertise
   (f) waste management issues
4. Based on the information obtained, hold a forum to discuss the feasibility of building a nuclear power plant in Malaysia.

SCAN ME
Video of electricity generation
http://bit.ly/37ElecWbJ

Nuclear energy is now the alternative source to generate electrical energy to meet the growing energy demand and to replace the reliance on fossil fuel.

However, the use of this energy is still a highly debatable issue. In your opinion, should nuclear energy be used as an alternative source to generate electrical energy in Malaysia?

Formative Practice 6.2

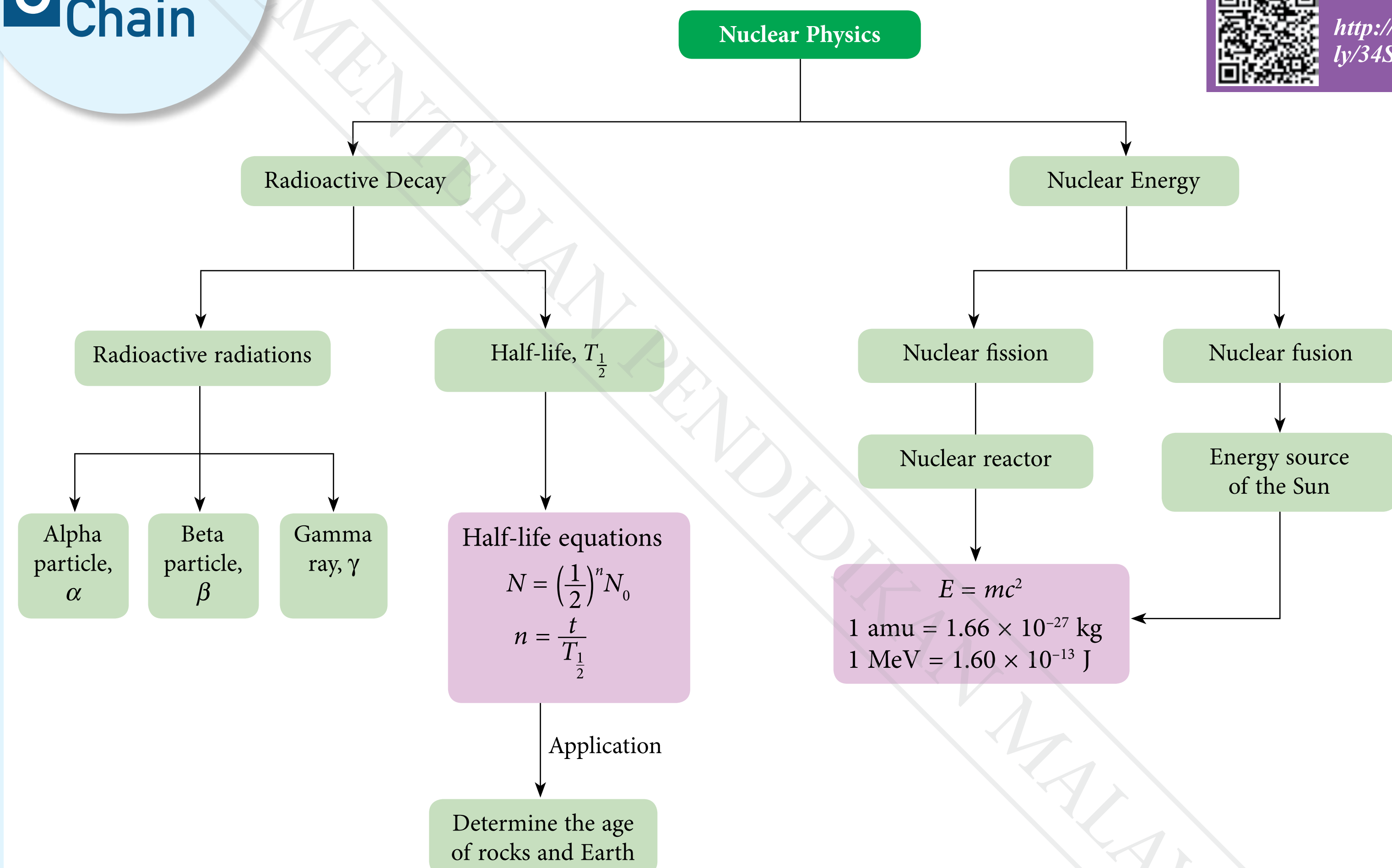
1. What is meant by nuclear fission and nuclear fusion?
2. Describe the chain reaction that occurs in a nuclear reactor.
3. Explain how a nuclear reactor generates electrical energy.
4. A nuclear reaction is represented by the following equation:

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{55}Cs + ^{93}_{37}Rb + 2\,^{1}_{0}n + \text{energy}$$

The mass defect is 0.19585 amu. Calculate the energy that is released by the reaction.

Concept Chain

Interactive Games
http://bit.ly/34SRhM



Self-Reflection

SCAN ME
Download and print Self-Reflection
http://bit.ly/3gi5xC

1. New things that I have learnt from the chapter 'Nuclear Physics' are ______.
2. The most interesting thing that I have learnt in this chapter is ______.
3. The things I still do not fully understand are ______.
4. My performance in this chapter.

   Poor | 1 | 2 | 3 | 4 | 5 | Very good
5. I need to ______ to improve my performance in this chapter.

Summative Practice

QUIZ PORTAL
http://bit.ly/2D3VKVT

1. What is meant by:
   (a) radioactive decay
   (b) half-life
   (c) nuclear energy
2. The following shows the equation for a radioactive decay:

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{X} + \text{Y}$$

   (a) Identify *X* and *Y* in the decay equation.
   (b) How many α and β-particles will be released when $^{222}_{86}\text{Rn}$ decays to $^{210}_{82}\text{Pb}$?
3. (a) Astatine-218 has a half-life of 1.6 s. How long will it take for 99% of the nucleus in one sample of astatine-218 to disintegrate?
   (b) Radium-226 has a half-life of 1 600 years. What percentage of the sample of radium-226 will be left after 8 000 years?

4. During the formation of rocks, radioisotope uranium-238 is trapped. The decay rate of uranium-238 is low and the end result of the decay series is lead-206. Table 1 shows the composition of samples of rock *A* and rock *B*.

Table 1

	Sample *A*	Sample *B*
Ratio of uranium-238 to lead-206	5 : 1	7 : 1

(a) Between the samples of rock *A* and rock *B*, which one is older? Justify your answer.

(b) The composition of the lead nucleus is unlikely to be greater than the uranium nucleus in the rocks sample. Explain your answer.

5. Carbon-14 has a half-life of 5 730 years.

(a) What is the fraction of undecayed carbon in a fossil sample at the end of 1.719×10^4 years?

(b) Based on your answer to 5(a), sketch a graph of the decay curve for carbon-14 in the fossil sample.

6. In a nuclear reaction as shown in Figure 1, the total mass of the particles that are produced is less than the initial mass of the particles. The nuclear reaction experiences a mass defect. The lost mass is converted into energy.

(a) Name the nuclear reaction and write the equation involved.

(b) Calculate the mass defect and the nuclear energy that is released.
[Mass $^{2}_{1}H$ = 2.01410 amu, mass $^{3}_{1}H$ = 3.01605 amu, mass $^{4}_{2}He$ = 4.00260 amu, mass $^{1}_{0}n$ = 1.00866 amu, 1 amu = 1.66×10^{-27} kg and speed of light in vacuum, $c = 3.00 \times 10^{8}$ ms^{-1}]

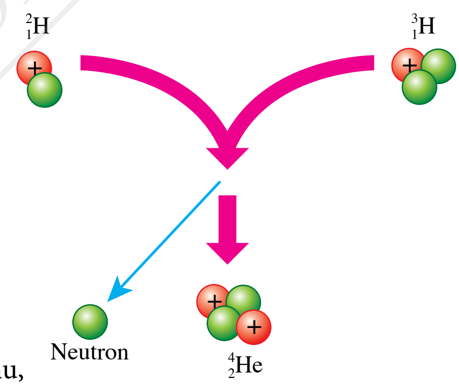


Figure 1

7. A radioactive decay series of a source of uranium-235 is

$$^{235}_{92}U \rightarrow \cdots \rightarrow {}^{207}_{82}Pb$$

(a) What is the number of α-particles and β-particles emitted?

(b) Draw a graph of the nucleon number against atomic number that is possible for the decay series.

8. Figure 2 shows the conversion of energy that occurs from nuclear energy to electrical energy in a nuclear reactor.

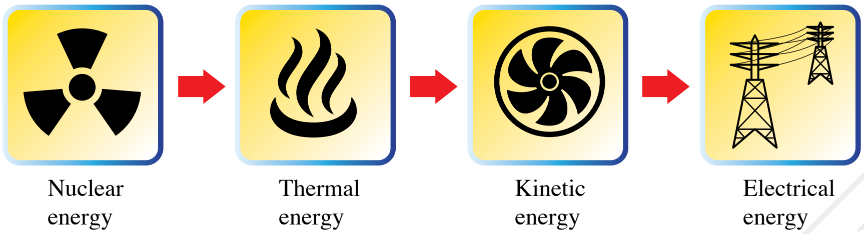


Figure 2

(a) How is nuclear energy produced in a reactor?

(b) How is heat energy converted to kinetic energy in the rotation of a turbine? Explain your answer.

(c) The kinetic energy from the turbine rotation can produce electrical energy. How does this process happen? Explain.

(d) Usually, high cooling towers are built at nuclear power stations. Explain the reason.

21st Century Challenge

9. A nuclear agency plans to build a nuclear power plant in our country to meet the growing demand for energy. However, nuclear fission requires very expensive uranium or plutonium fuels. Furthermore, the issue of radioactive waste management and the threat of environmental pollution is worrying the public.

Imagine that you are a nuclear scientist assigned to construct the nuclear power station. Discuss the considerations that need to be made based on the following aspects:

- location of the nuclear power plant
- walls for the reactor core
- walls for the reactor building
- cooling agents
- energy control methods
- radioactive waste management
- safety measures

Justify each of your suggestions.

CHAPTER 7

Quantum Physics

How did the idea of the quantum theory arise?

What is the meaning of quantum energy and photon?

What is wave-particle duality?

What are the characteristics of photoelectric effect?

You will learn:

- 7.1 The Quantum Theory of Light
- 7.2 The Photoelectric Effect
- 7.3 Einstein's Photoelectric Theory

Learning Standards and List of Formulae in Chapter 7

Information Portal

The understanding of properties and behaviours of matter in the atomic scale enables quantum computers to be invented. Quantum computers are supercomputers that can process large amounts of information in a very short time. For example, complex chemical reactions can be quickly simulated to enable the building of a chemical reaction model. This technology can be applied in astronomy and the stock market. This is because the mechanism behind astronomical phenomena is complex, while stock market changes rapidly. Thus, the development of detailed models by supercomputers helps us to understand complex phenomena and make appropriate decisions.

https://bit.ly/3j7WZdV

Importance of the Chapter

The understanding of quantum physics helps researchers to create sophisticated computer systems with large memory and very high processing speed. The development of these inventions can propel competent and dynamic experts and physicists to respond to the increasingly challenging quantum era.

Futuristic Lens

The encryption process is essential to ensure the security and confidentiality of information of an organisation, financial institution or government. Knowledge in quantum physics allows the development of a more secure encryption algorithm system and a new digital signature.

https://bit.ly/2Eprehr

7.1 Quantum Theory of Light

In Form 4, you learned that the electromagnetic spectrum is a continuous spectrum. This spectrum consists of seven types of waves with different frequencies and wavelengths as shown in Figure 7.1.

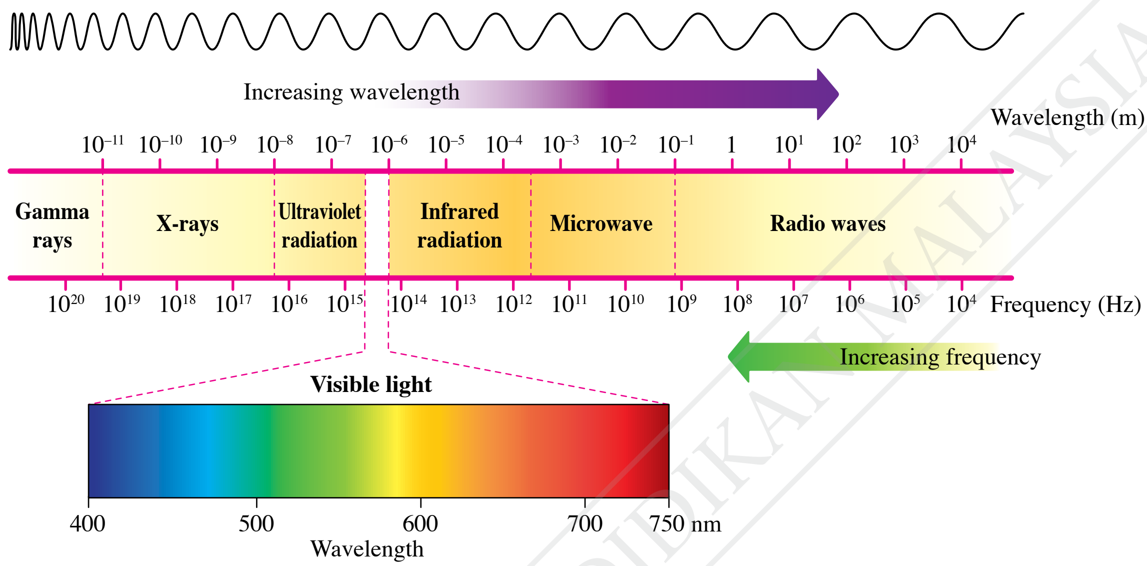


***Figure 7.1** Electromagnetic spectrum*

All objects emit electromagnetic radiation. Cold objects emit waves with low frequencies, such as radio waves or microwave, while hot objects emit waves with higher frequency, such as visible light and ultraviolet radiation. Do humans also emit electromagnetic radiation?

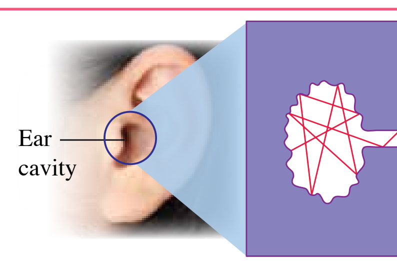
A **black body** is an idealised body that is able to absorb all electromagnetic radiation that falls on it. A black body can also emit thermal radiation depending on its temperature. The radiation emitted forms a continuous spectrum and is unaffected by the nature of the black body surface. Thus, an object emitting electromagnetic radiation which is determined by its temperature is known as a black body radiator.

Info GALLERY

Thermal radiation is electromagnetic radiation that includes visible light and radiation that cannot be seen by the human eye such as infrared radiation.

Info GALLERY

The rays of light that enter the ear cavity will undergo repeated reflections on the inner walls of the ear cavity. At each reflection, parts of the rays are absorbed by the inner walls of the ear until all the rays are absorbed. Thus, the ear cavity acts like a black body.



As the temperature of an object rises, the object acts as a black body radiator and emits thermal radiation of all wavelengths. Figure 7.2 shows a graph of radiation intensity against wavelengths of three types of black bodies at different temperatures. Usually, every curved graph of the black body spectrum is narrower on its left, which is an area with short wavelengths and high frequencies. With increasing temperatures, the wavelength approaching maximum radiation intensity will also get shorter.

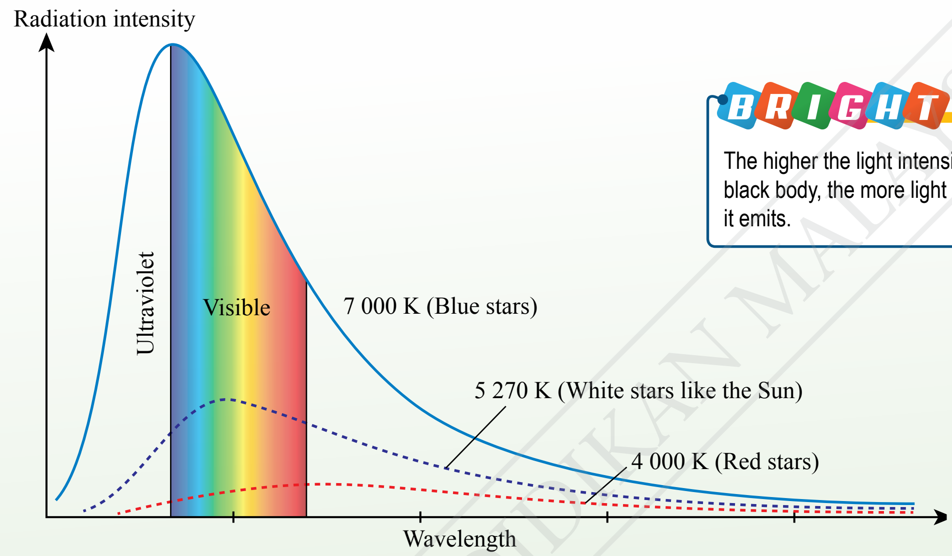
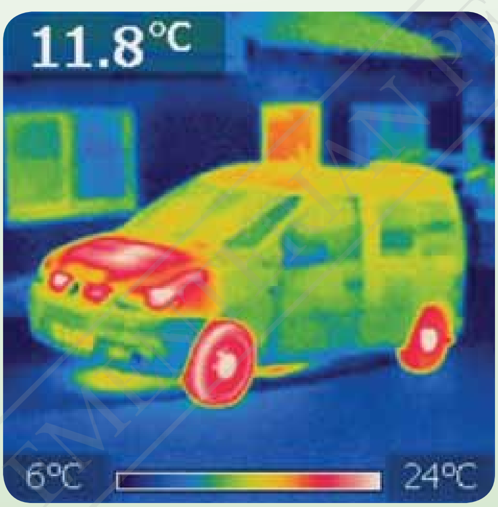


Figure 7.2 *Graph of radiation intensity against wavelength*

BRIGHT Info

The higher the light intensity of a black body, the more light energy it emits.



(a) Thermographic image of a car

SCAN ME
Video of infrared thermometer
https://bit.ly/2QjK78d

(b) Oven heating element

(c) Thermal radiation in light bulbs at different temperatures

Photograph 7.1 *Examples of black bodies in daily life*

Ideas that Sparked the Quantum Physics Theory

Light is an electromagnetic wave that is produced from the vibration of an electric charge. In a hot object, electrons vibrate rapidly and randomly in any direction and produce light. As the object becomes hotter, the vibrations of the electrons become more energetic and more light will be emitted. The electrons in a hot object will vibrate in a continuous frequency range. According to classical theory, electrons vibrating at the same frequency should have the same energy content. The vibration frequency of the electrons also has no limits. Thus, the light energy produced by the vibration of electrons can reach unlimited high values.

However, experimental results involving black-body radiation are inconsistent with classical physics theory. Based on the graph of radiation intensity against wavelength for black-body radiation, the light intensity on the left side of the peak does not continue to increase with the increase of wave frequency as predicted by classical theory. This controversy in the concept of light energy has sparked the theory of quantum physics.

Classical Theory

Isaac Newton
(1643 – 1727)

The particle nature of light

- Described light as a single stream of particles or corpuscles in 1704.
- Unsuccessful in explaining the phenomenon of light refraction due to failure in comparing the speed of light in glass and air.

Thomas Young
(1773 – 1829)

Double-slit experiment

- Conducted double-slit experiment on light in 1801 and showed that light is a wave.
- Unable to explain the radiation spectrum produced by black bodies.

John Dalton
(1766 – 1844)

Dalton Atomic Model

- Matter consists of basic particles that cannot be further divided called **atoms**.
- Same elements have the same type of atoms.
- Unable to explain the light spectrum produced by atoms.

J. J. Thomson
(1856 – 1940)

Discovery of Electrons

- Discovered negatively charged subatomic particles called **electrons** in 1897.
- Designed experiment to study the behaviour of electrons.
- Unable to explain the line spectrum of light produced by atoms.

SCAN ME
Isaac Newton
https://bit.ly/3hpP4YX

SCAN ME
Thomas Young
https://bit.ly/34oRofj

SCAN ME
John Dalton
https://bit.ly/2CRvhTc

SCAN ME
J. J. Thomson
https://bit.ly/2YpGTo4

***Figure 7.3** The development of quantum theory from classical theory*

Activity 7.1

ISS / ICS

Aim: To gather information on the development of quantum theory

Instructions:

1. Carry out a Gallery Walk activity.
2. Obtain information from various reading materials and websites about the findings of the following physicists which contribute to the development of quantum theory.

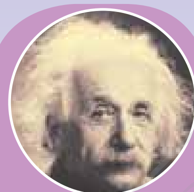
Isaac Newton	John Dalton	Max Planck	Niels Bohr
Thomas Young	J. J. Thomson	Albert Einstein	Louis de Broglie

3. Present your findings in the form of a mind map.

Quantum Theory

Max Planck
(1858 – 1947)

- Introduced the concept of **quantum** (discrete energy) in 1900
- The electromagnetic wave emitted by a black body is in discrete form known as quantum of energy.
- The energy in each quantum is directly proportional to the wave frequency.
- The intensity of the radiation is low for the high frequency waves.



Albert Einstein
(1879 – 1955)

- Introduced the **photon** concept in 1905.
- The photon energy is directly proportional to the light waves frequency.
- **Einstein's quantum theory of light** was successful in explaining the characteristics of the photoelectric effect that could not be explained by classical theory.

Niels Bohr
(1885 – 1962)

- Explained the production of line spectrum by hydrogen atoms.
- The electrons in an atom orbit around its nucleus on certain shells only.
- The transition of electrons from a higher energy level shell to a lower energy level shell emits photons.

Louis de Broglie
(1892 – 1987)

- Introduced the hypothesis on the wave nature of particles in 1924.
- Einstein and de Broglie postulated the idea of the **wave-particle duality** of light and all subatomic particles.

SCAN ME
Max Planck
https://bit.ly/3hpF02h

SCAN ME
Albert Einstein
https://bit.ly/3jlRdFV

SCAN ME
Niels Bohr
https://bit.ly/2QiRi0e

SCAN ME
Louis de Broglie
https://bit.ly/3aYrtw7

LS 7.1.1

Quantum of Energy

The electromagnetic spectrum may be a continuous spectrum or a line spectrum. Figures 7.4 and 7.5 show examples of a continuous spectrum and a line spectrum respectively.

SCAN ME
The line spectrum of several elements
https://bit.ly/3j6k4xC

Continuous spectrum

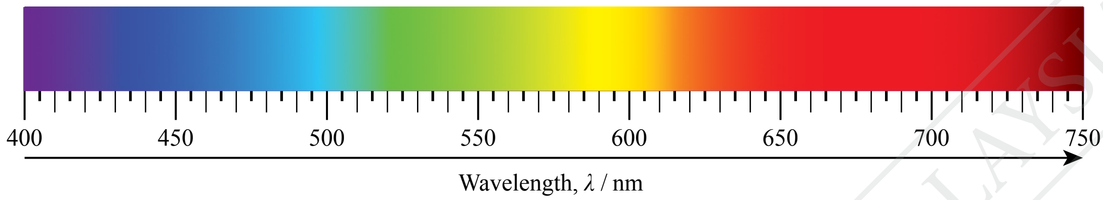


Figure 7.4 *Visible light spectrum*

Line spectrum

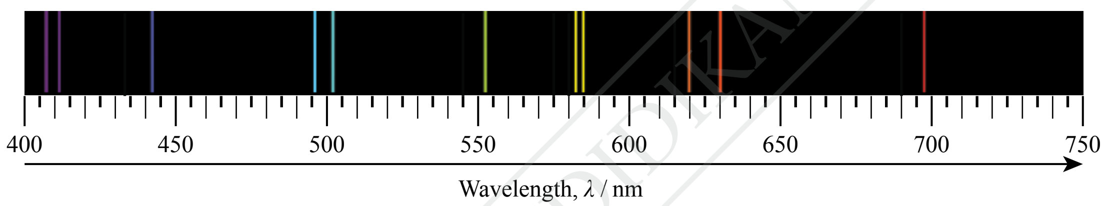


Figure 7.5 *Line spectrum of hot mercury vapour lamp*

The dispersion of white light by a prism produces a continuous spectrum consisting of seven visible colours. This spectrum has a wavelength range from 400 nm to 750 nm. The visible light spectrum is said to be continuous because there is no separation gap between each colour in the spectrum.

The line spectrum produced by an excited atom is a series of coloured lines with unique wavelengths and frequencies. Each element produces a spectrum with a series of its own distinctive lines. Therefore, the line spectrum can be used to identify the presence of an element. Table 7.1 shows the frequency and quantum of energy values of the line spectrum produced by a mercury vapour lamp.

Table 7.1 *Frequency and energy quantum values of a line spectrum from a mercury vapour lamp*

Line spectrum colour	Frequency, f / 10^{14} Hz	Energy quantum , E / 10^{-19} J
Violet	7.41	4.91
Blue	6.88	4.56
Green	5.49	3.65
Yellow-orange	5.19	3.44

Activity 7.2

ISS / ICS

Aim: To compare the concepts of continuous energy and discrete energy

Instructions:

1. Carry out this activity in groups.
2. Gather information related to the concepts of continuous energy and discrete energy on the following aspects:
   (a) the visible light spectrum
   (b) the line spectrum of mercury lamps and other lamps
   (c) differences between continuous energy and discrete energy
3. You can obtain information from websites or various reading sources.
4. Present your findings using a graphical map.

Quantum of energy is **discrete energy packet and not a continuous energy**. The energy depends on the frequency of the waves. According to Max Planck and Albert Einstein's quantum theory, light energy exists in the form of an energy packet known as a photon. Photons are light energies transferred in quantum of energy. The **photon** energy is directly proportional to the frequency of light waves. The higher the frequency of light waves, the higher the energy quantum of a photon.

$$E \propto f$$
$$E = hf$$

where E = photon energy
h = Planck's constant (6.63×10^{-34} J s)
f = frequency of light waves

Info GALLERY

Light is a type of electromagnetic wave. It also behaves as a particle. Other types of waves in the electromagnetic spectrum can also behave as particles.

Example 1

Compare the energy of a 400 nm and a 750 nm light photons.

Solution

LET'S ANSWER
https://bit.ly/34tx1NS

Step 1:	Step 2:	Step 3:	Step 4:
Identify the problem	Identify the information given	Identify the formula to be used	Solve the problem numerically

1. Energy of a 400 nm photon
   Energy of a 750 nm photon

2. Planck's constant, $h = 6.63 \times 10^{-34}$ J s
   Speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}
   Wavelength, $\lambda_1 = 400 \times 10^{-9}$ m
   Wavelength, $\lambda_2 = 750 \times 10^{-9}$ m

3. $c = \lambda f$, then $f = \dfrac{c}{\lambda}$
   $E = hf = \dfrac{hc}{\lambda}$

4. $E_1 = 6.63 \times 10^{-34} \left(\dfrac{3.00 \times 10^{8}}{400 \times 10^{-9}}\right)$
   $= 4.97 \times 10^{-19}$ J
   $E_2 = 6.63 \times 10^{-34} \left(\dfrac{3.00 \times 10^{8}}{750 \times 10^{-9}}\right)$
   $= 2.65 \times 10^{-19}$ J

The shorter the wavelength of light, the higher the photon energy.

LS 7.1.2 7.1.4

Wave-Particle Duality

Electromagnetic radiation such as light is said to have wave properties because it exhibits the phenomena of diffraction and interference. Objects like marbles are said to have particle properties because they possess momentum and kinetic energy and can collide with each other.

Activity 7.3

ISS | ICS

Aim: To observe the wave properties of a particle and how the de Broglie wavelength changes with mass and particle velocity

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code to view the simulation of the wave properties of particles. Based on the simulation, discuss the following:
   (a) the wave nature of particles
   (b) the relationship between the de Broglie wavelength and the mass and velocity of the particle
3. Present your findings.

SCAN ME
Wavelength simulation
http://bit.ly/39xNYqu

In 1924, Louis de Broglie ('de Broy') (1892 – 1987), a quantum physicist, had put forward a hypothesis stating that all particles can exhibit wave characteristics. However, it is experimentally difficult to show the wave characteristics of particles with large masses. Louis de Broglie predicted that the wave characteristics can be exhibited by light particles, for example electrons. He stated that the relationship between the momentum of a particle, p and its wavelength, λ is as follows:

$$\lambda = \frac{h}{p}$$

where λ = wavelength
h = Planck's constant
p = momentum of particle

Value of Planck's constant is 6.63×10^{-34} J s.

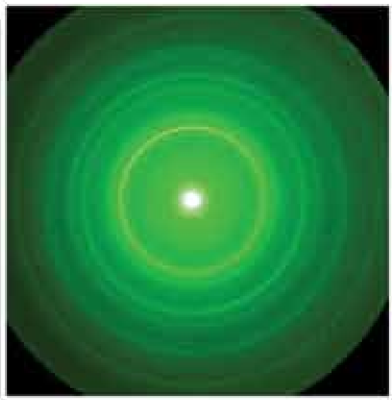
The greater the momentum of the particle, the shorter the wavelength. Since the value of the momentum of particle can be determined by $p = mv$, the following formula can also be obtained.

$$\lambda = \frac{h}{mv}$$

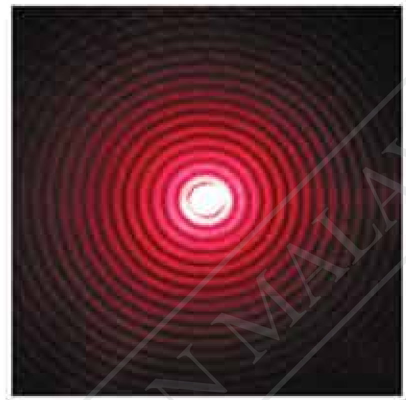
where m = mass of particle
v = velocity of particle

Since the value of h is very small, particles of large masses will have de Broglie wavelengths which are too short to be detected. Therefore, the wave characteristics cannot be observed.

In 1927, the presence of wave properties of electrons was confirmed through electron diffraction experiments. Photograph 7.2 shows the diffraction pattern of electrons through a thin layer of graphite. This pattern resembles the light diffraction pattern through an aperture as shown in Photograph 7.3. This confirmed de Broglie's hypothesis.

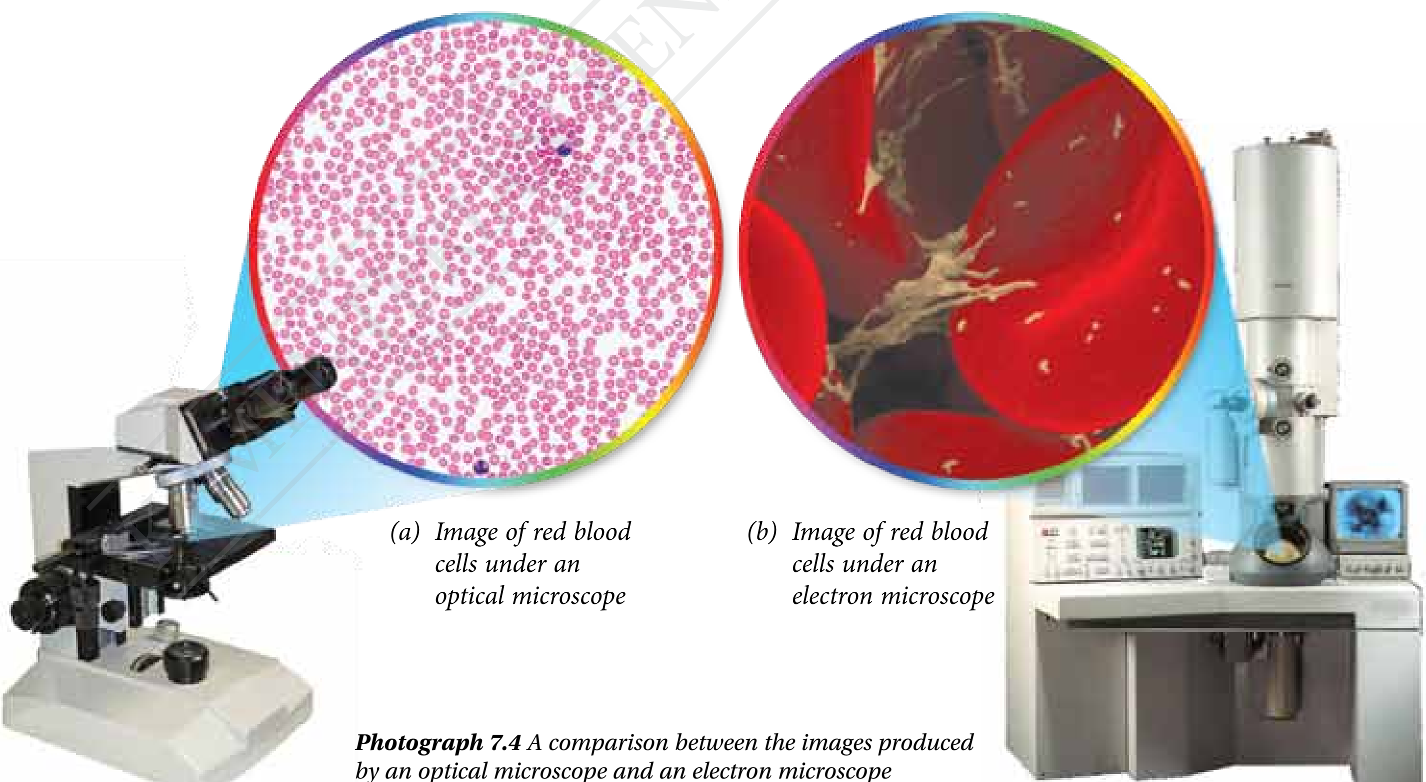


Photograph 7.2 *Diffraction pattern of electrons through a thin layer of graphite*



Photograph 7.3 *Diffraction pattern of red laser light through an aperture*

The de Broglie wavelength of an electron beam is approximately 1000 – 10 000 times shorter compared to the wavelength of light. This property is very important for higher magnification of electron microscope. A comparison between the images produced by an optical microscope and an electron microscope is shown in Photograph 7.4.



(a) Image of red blood cells under an optical microscope

(b) Image of red blood cells under an electron microscope

Photograph 7.4 *A comparison between the images produced by an optical microscope and an electron microscope*

Electrons are said to have wave-particle duality because they exhibit the properties of both particles and waves. Light also possesses both wave and particle properties. Therefore, light and electrons are said to have wave-particle duality. This duality is also found in all kinds of radiation in the electromagnetic wave spectrum as well as in subatomic particles like protons and neutrons.

Light energy, E is transmitted in energy packets known as photons

$$E = hf$$

where h = Planck's constant
f = frequency of light waves

For electromagnetic waves, the relationship between the wave speed, c with the wavelength, λ is $c = f\lambda$, then $f = \frac{c}{\lambda}$, and

$$E = \frac{hc}{\lambda}$$

Problem Solving for Photon Energy and Power

Energy for one photon, $E = hf$
Assuming that n photons are being emitted per second, then photons power, P which is the total energy transfer per second is

$$P = nhf = \frac{nhc}{\lambda}$$

Example 1

LET'S ANSWER
https://bit.ly/34HxegP

A 50 W lamp emits red light with a wavelength, $\lambda = 7.0 \times 10^{-7}$ m.
What is the number of photons emitted per second?

Solution

Step 1: Identify the problem
Step 2: Identify the information given
Step 3: Identify the formula to be used
Step 4: Solve the problem numerically

1. Number of photons emitted per second, n

2. Wavelength, $\lambda = 7.0 \times 10^{-7}$ m
Power, P = 50 W
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}

3. $P = \frac{nhc}{\lambda}$
Then, $n = \frac{P\lambda}{hc}$

4. $n = \frac{50 \times 7.0 \times 10^{-7}}{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}$
$= 1.76 \times 10^{20}$ s^{-1}

Example 2

A red laser pen emits light with a wavelength of 670 nm. If the number of photons emitted is 3.37×10^{18} per second, what is the output power of the laser pen?

Solution

Wavelength, λ = 670 nm
$= 6.7 \times 10^{-7}$ m

Number of photons emitted per second, $n = 3.37 \times 10^{18}\ s^{-1}$

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Speed of light in vacuum, $c = 3.00 \times 10^{8}\ m\ s^{-1}$

Output power of the laser pointer, $P = \frac{nhc}{\lambda}$

$$= \frac{(3.37 \times 10^{18})(6.63 \times 10^{-34})(3.00 \times 10^{8})}{6.7 \times 10^{-7}}$$

= 1.00 W

Example 3

Assuming that 10% of the output power of a 100 W bulb is used to emit 2.92×10^{19} photons per second, what is the average wavelength of the light in nm?

Solution

Output power of photons emitted, $P = 10\% \times 100$ W
= 10 W

Number of photons emitted per second, $n = 2.92 \times 10^{19}\ s^{-1}$

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Speed of light in vacuum, $c = 3.00 \times 10^{8}\ m\ s^{-1}$

Average wavelength of light, $\lambda = \frac{nhc}{P}$

$$= \frac{(2.92 \times 10^{19})(6.63 \times 10^{-34})(3.00 \times 10^{8})}{10}$$

$= 5.81 \times 10^{-7}$ m

= 581 nm

Formative Practice 7.1

1. What is the frequency and energy of a photon with a wavelength of 10 nm?
2. How many photons are emitted per second by a 50 W green light lamp?
   [Frequency of green light, $f = 5.49 \times 10^{14}$ Hz]
3. Given that the mass of an electron is 9.11×10^{-31} kg:
   (a) what is the de Broglie wavelength of an electron beam with 50 eV kinetic energy?
   [1 eV = 1.60×10^{-19} J]
   (b) name a phenomenon that shows the wave properties of electrons.

7.2 Photoelectric Effect

When a metal surface is illuminated by a beam of light at a certain frequency, electrons can be emitted from the metal. This phenomenon is known as **photoelectric effect**.

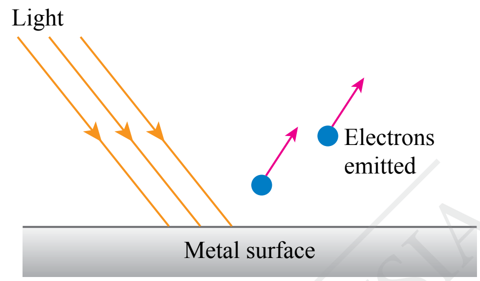


Figure 7.6 *Photoelectric effect*

Activity 7.4

ISS / ICS

Aim: To study photoelectric effect

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code to watch a simulation on photoelectric effect.
3. Based on the simulation, study photoelectric effect.
4. Present your findings.

SCAN ME
Simulation of photoelectric effect
http://bit.ly/2SGY8PM

The characteristics of photoelectric effect can be studied by arranging a photocell in the circuit as shown in Figure 7.7.

SCAN ME
Demonstration video of photoelectric effect
https://bit.ly/2EsWSuu

1 When a light sensitive metal surface (cathode) is illuminated with a certain light beam, electrons will be emitted from the metal surface. These electrons are called photoelectrons.

2 The emitted photoelectrons are attracted to the anode which has positive potential.

3 The movement of the photoelectrons from the cathode to the anode produces a current inside the circuit. The milliammeter shows the value of the current.

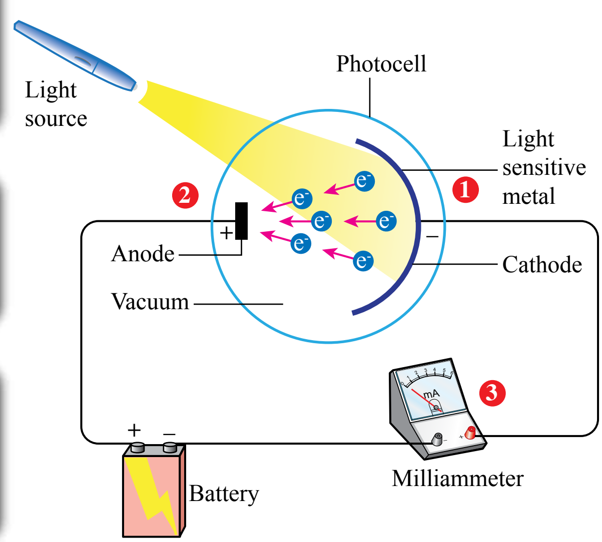


Figure 7.7 *Apparatus to show photoelectric effect*

Formulae such as $E = hf$ and $\lambda = \frac{h}{p}$, involve Planck's constant, h. How can the value of this constant, h be determined in the laboratory?

Activity 7.5

Aim: To determine the value of Planck's constant using the Planck's constant kit

Apparatus: Planck's constant kit (9 V battery, 1 kΩ potentiometer, LEDs of different colours, milliammeter and voltmeter)

Instructions:

1. Using the red LED, connect the Planck's constant kit as shown in Figure 7.8.
2. Scan the QR code to print Table 7.2.
3. Adjust the knob on the potentiometer to obtain the voltage, $V = 0.2$ V. Record the milliammeter reading in Table 7.2.
4. Repeat step 3 for $V = 0.4$ V, 0.6 V, 0.8 V, ..., 3.0 V.
5. Draw a graph of current against voltage. Based on the graph intercept value on the voltage axis, determine the activation voltage, V_a of the red LED.
6. Repeat steps 3 to 5 using orange, green and blue LEDs.

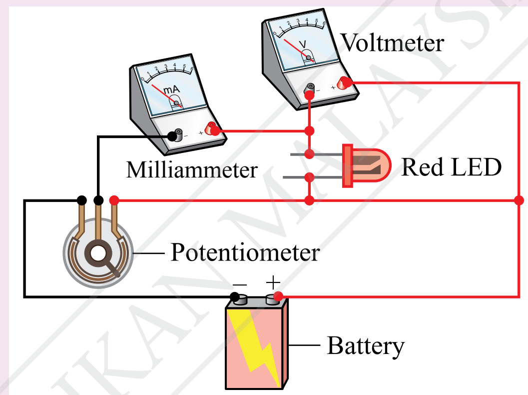


Figure 7.8

SCAN ME
Worksheet (Table 7.2)
https://bit.ly/2RpGiyZ

SCAN ME
Video to determine the value of Planck's constant
https://bit.ly/2QoFVUC

Results:

Table 7.2

LED colour ____________

Voltage, *V* / V	Current, *I* / mA
0.20	
0.40	
0.60	

Data analysis:

1. Based on the value of the activation voltage that is obtained from the graph of current, I against voltage, V for each LED colour, complete Table 7.3.

Table 7.3

LED Colour	Wavelength, λ / nm	Activation voltage, V_a / V	$\frac{1}{\lambda}$ / m^{-1}
Red	623		
Orange	586		
Green	567		
Blue	467		

2. Based on Table 7.3, plot the graph of V_a against $\frac{1}{\lambda}$.
3. Based on the graph plotted, determine the gradient, m of the graph and calculate Planck's constant, h. Given

$h = \frac{me}{c}$, where e = charge of an electron (1.60×10^{-19} C)
c = speed of light in vacuum (3.00×10^{8} m s^{-1})

SCAN ME
Determine the value of Planck's constant through the gradient of the graph
https://bit.ly/32pUDAv

Discussion:
What is the relationship between the activation voltage and the LED light wavelength?

The activation voltage, V_a can be obtained through V-intercept from the graph of I against V as shown in Figure 7.9. The activation voltage, V_a has a linear relationship with $\frac{1}{\lambda}$ as shown in Figure 7.10. Gradient of a graph of V_a against $\frac{1}{\lambda}$, m is equal to the value of $\frac{hc}{e}$. Therefore, the value of Planck's constant can be determined as $\frac{me}{c}$.

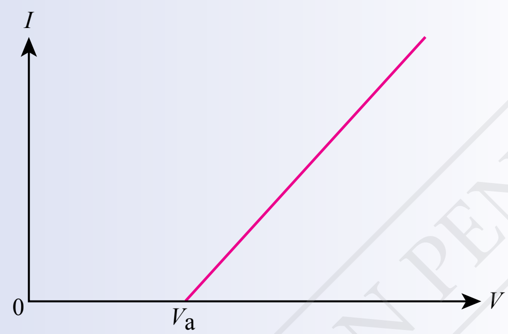


Figure 7.9 *Graph of I against V*

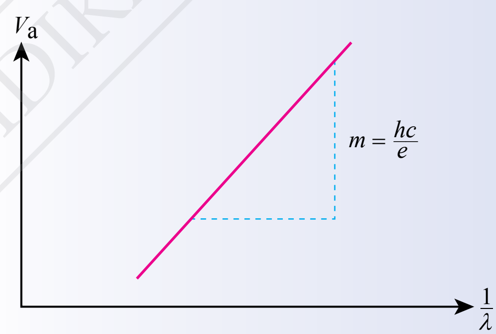


Figure 7.10 *Graph of V_a against $\frac{1}{\lambda}$*

The Characteristics of the Photoelectric Effect

Activity 7.6 ISS / ICS

Aim: To gather information on the four characteristics of the photoelectric effect

Instructions:
1. Carry out a Gallery Walk activity.
2. Obtain information from various reading materials and websites on the following four characteristics of the photoelectric effect:
   (a) the effect of frequency on the photoelectric effect
   (b) the existence of a threshold frequency
   (c) the effect of the intensity of light on the kinetic energy of photoelectron
   (d) the instantaneous emission of photoelectrons when light shines on it
3. Present your findings.

Photoelectric effect occurs when light strikes the surface of a metal. The electrons in the metal absorb energy from the light and escape from the metal surface. According to classical theory, light in wave form is a spectrum with continuous energy and photoelectric effect should be able to occur at any light wave frequency. Bright light which has high energy should be able to emit electrons quickly. Dim light has low energy so the electrons need a longer time to absorb enough energy to escape from the metal surface.

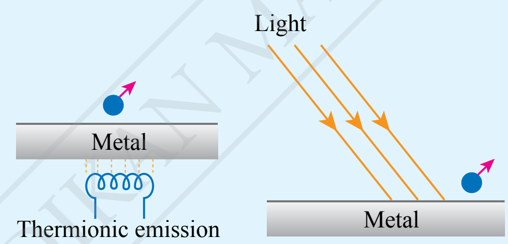
However, the results of the photoelectric effect experiments show that the emission of photoelectrons only apply to light waves with frequencies that exceed a certain value without being affected by the intensity of the light. Photoelectrons are also emitted instantaneously at those light frequencies even at low light intensities.

1. The higher the frequency of the photon of light, the higher the kinetic energy of the photoelectrons emitted from the metal surface.

2. The minimum frequency of light needed for a metal to emit electrons is known as the threshold frequency, f_0 for that metal.

3. The kinetic energy of photoelectrons does not depend on the intensity of light. An increase in the light intensity does not produce photoelectrons with a higher kinetic energy.

4. Photoelectrons are emitted instantaneously when a metal surface is illuminated by light.



- The emission of electrons from a metal surface by thermionic emission may take some time.
- The emission of electrons from a metal surface by photoelectric effect is instantaneous.

Figure 7.11 *The characteristics of photoelectric effect*

The threshold frequency, f_0 is the minimum frequency required to produce photoelectric effect on a metal.

Formative Practice 7.2

1. What is meant by photoelectric effect?
2. Will a bright light emit more photoelectrons from a metal surface compared to a dim light of the same frequency?
3. State four characteristics of photoelectric effect that are obtained experimentally.
4. Why are photoelectrons emitted instantaneously from a metal surface when it is illuminated by a light of certain frequency?
5. Does an increase in the light intensity increase the kinetic energy of the photoelectrons? Why?

7.3 Einstein's Photoelectric Theory

In 1905, Albert Einstein introduced a photoelectric theory that successfully explained all the characteristics of photoelectric effect in related experiments. He was awarded the Nobel Prize in 1921 for this achievement. This theory is named **Einstein's Photoelectric Theory**.

Einstein applied Max Planck's idea of energy quantum. He suggested that energy is carried by light particles called photons. The energy of each photon is directly proportional to the frequency of light, f and can be determined by the following equation.

$$E = hf$$

where h = Planck's constant (6.63×10^{-34} J s)

Each quantum of light is a discrete packet of energy. There are many energy packets in a beam of light that shines on the metal surface. When a photon arrives at a metal surface, the photon energy will be fully absorbed by an electron in the metal. This energy is used to release the electron from the metal and the extra energy will become the kinetic energy of the photoelectron. Usually, the electrons on a metal surface will acquire maximum kinetic energy compared to the electrons inside the metal.

For the electrons on the metal surface,

photon energy = minimum energy required to release a photoelectron + maximum kinetic energy of a photoelectron

$$E = W + K_{max}$$

$$hf = W + \frac{1}{2}mv^2_{max}$$

$$\frac{1}{2}mv^2_{max} = hf - W$$

Einstein's Photoelectric Equation is in accordance with the Principle of Conservation of Energy.

At the threshold frequency, f_0, photoelectrons are emitted without any kinetic energy, $\frac{1}{2}mv^2_{max} = 0$

Then, $0 = hf_0 - W$

$W = hf_0$

Substitute $W = hf_0$ into $\frac{1}{2}mv^2_{max} = hf - W$

$$\frac{1}{2}mv^2_{max} = hf - hf_0$$

$$\frac{1}{2}mv^2_{max} = h(f - f_0)$$

Work Function and Threshold Frequency for Photoelectric Effect

The minimum energy required for a photoelectron to be emitted from a metal surface is known as **work function**. **The minimum frequency for a light photon to produce photoelectric effect** is called **threshold frequency**.

The relationship between the maximum kinetic energy of photoelectrons, K_{max} and the light frequency, f is shown by the graph in Figure 7.12. The graph is a straight line with a positive gradient and not passing through the origin. The threshold frequency, f_0 is the value of the intercept on the frequency axis.

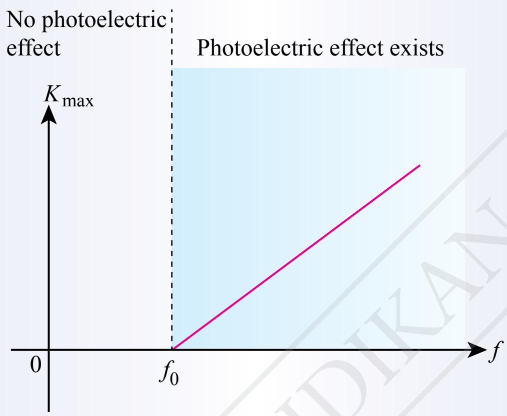


Figure 7.12 *Graph of K_{max} against f*

The relationship between work function and threshold frequency of a metal can be determined by the relationship $W = hf_0$. Photoelectrons will acquire kinetic energy when light frequency exceeds threshold frequency. The higher the threshold frequency of a metal, the higher the work function. This means the minimum energy required for photoelectric effect to occur is higher. Different metals have different threshold frequencies as shown in Figure 7.13.

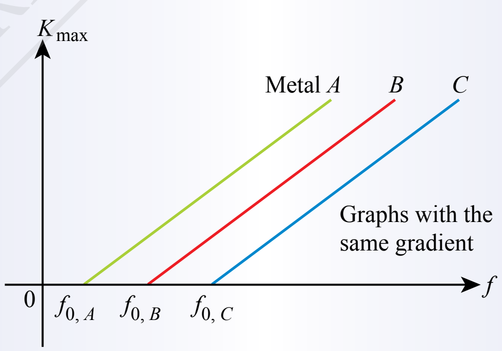


Figure 7.13 *Graphs of K_{max} against f for different types of metals*

Activity 7.7

Aim: To observe threshold frequencies of different metals

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code to observe computer simulations using violet, blue, green, yellow, orange and red lights to understand that different metals have different threshold frequencies.
3. Gather information on the types of metal and the threshold frequencies for each colour of light observed.
4. Present your findings.

SCAN ME
Simulations of threshold frequencies
http://bit.ly/2SGY8PM

Activity 7.8

Aim: To determine work function of metals using a formula

Instructions:

1. Carry out this activity in pairs.
2. Examine the following equations:

Using Einstein's equation, $K_{max} = hf - W$

If $K_{max} = 0$ and $f = f_0$

$$hf_0 - W = 0$$

then, $W = hf_0$

3. Determine work function for each type of metal and complete Table 7.4.

Table 7.4

Type of metal	Threshold frequency, f_0 / 10^{14} Hz	Work function, $W = hf_0$ / J
Ta	1.03	
Ti	1.05	
Mo	1.11	
Au	1.23	
Pd	1.24	
Ir	1.27	
Pt	1.36	

Problem Solving Using Einstein's Photoelectric Equation

Example 1

LET'S ANSWER
https://bit.ly/2YwWUsj

A blue light with a frequency of 6.67×10^{14} Hz is shone on a clean caesium metal surface. What is the maximum kinetic energy of photoelectrons emitted?
[Work function of caesium = 3.43×10^{-19} J, Planck's constant = 6.63×10^{-34} J s]

Solution

Step 1: Identify the problem	Step 2: Identify the information given	Step 3: Identify the formula to be used	Step 4: Solve the problem numerically

1. Maximum kinetic energy of the photoelectron, K_{max}
2. Frequency, $f = 6.67 \times 10^{14}$ Hz
   Work function, $W = 3.43 \times 10^{-19}$ J
   Planck's constant, $h = 6.63 \times 10^{-34}$ J s
3. $hf = W + K_{max}$
4. $(6.63 \times 10^{-34})(6.67 \times 10^{14}) = 3.43 \times 10^{-19} + K_{max}$
   $K_{max} = 4.42 \times 10^{-19} - 3.43 \times 10^{-19}$
   $= 9.92 \times 10^{-20}$ J

Example 2

Figure 7.14 shows the change in kinetic energy of photoelectrons released from lithium for different light frequencies. Determine the threshold frequency from the graph and calculate the work function of lithium.
[Planck's constant, $h = 6.63 \times 10^{-34}$ J s]

Solution

Threshold frequency, $f_0 = 5.6 \times 10^{14}$ Hz
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Work function, $W = hf_0$
$= (6.63 \times 10^{-34})(5.6 \times 10^{14})$
$= 3.71 \times 10^{-19}$ J

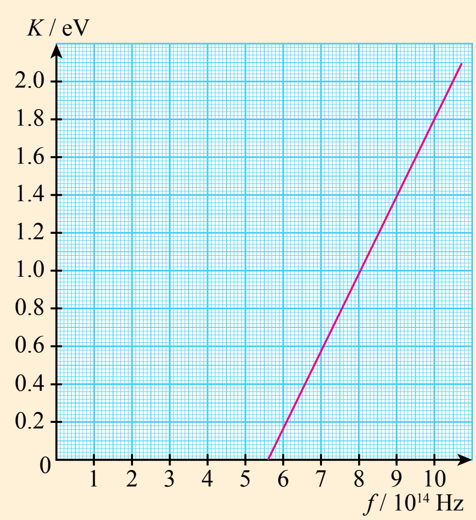


Figure 7.14

Example 3

What is the maximum velocity of the photoelectron emitted when a monochromatic light (λ = 550 nm) is shone on a metal which has a work function of 2.00 eV?
[Given $hc = 1.243 \times 10^3$ eV nm, 1 eV = 1.60×10^{-19} J, mass of electron, $m = 9.11 \times 10^{-31}$ kg]

Solution

Wavelength, λ = 550 nm
$hc = 1.243 \times 10^3$ eV nm
1 eV = 1.60×10^{-19} J
Mass of electron, $m = 9.11 \times 10^{-31}$ kg

$$E = \frac{hc}{\lambda} = \frac{1.243 \times 10^3 \text{ eV nm}}{550 \text{ nm}} = 2.26 \text{ eV}$$

Then $\frac{1}{2}mv^2_{max} = 2.26 - 2.00 = 0.26$ eV

$$\frac{1}{2}mv^2_{max} = 0.26 \times 1.60 \times 10^{-19} \text{ J} = 4.16 \times 10^{-20} \text{ J}$$

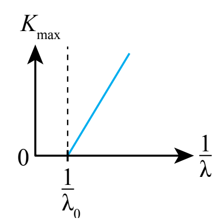
$$v_{max} = \sqrt{\frac{2 \times 4.16 \times 10^{-20}}{9.11 \times 10^{-31}}} = 3.02 \times 10^5 \text{ m s}^{-1}$$

Example 4

When a photocell is shone on with a red light (λ_1 = 750 nm) and then with a blue light (λ_2 = 460 nm), the maximum kinetic energy of the photoelectron emitted by the blue light is two times that of the red light.
(a) What is the work function of the photoelectric material in the photocell?
(b) What is the threshold wavelength of the photoelectric material?

Info GALLERY

The maximum wavelength of light needed for a metal to emit electrons is known as threshold wavelength, λ_0 for the metal.



Solution

Wavelength of the red light, $\lambda_1 = 750 \times 10^{-9}$ m
Wavelength of the blue light, $\lambda_2 = 460 \times 10^{-9}$ m
Maximum kinetic energy of the photoelectron of the red light, K_1
Maximum kinetic energy of the photoelectron of the blue light, $K_2 = 2K_1$
Work function = W
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Speed of light in vacuum, $c = 3.00 \times 10^8$ m s^{-1}

(a)
$$hf = W + K$$
$$\frac{hc}{\lambda} = W + K$$
$$6.63 \times 10^{-34} \times \left(\frac{3.00 \times 10^8}{750 \times 10^{-9}}\right) = W + K_1$$
$$2.65 \times 10^{-19} = W + K_1 \text{ ------ (1)}$$
$$6.63 \times 10^{-34} \times \left(\frac{3.00 \times 10^8}{460 \times 10^{-9}}\right) = W + K_2$$
$$4.32 \times 10^{-19} = W + 2K_1 \text{ ------ (2)}$$
(1) × 2 – (2):
$$2.65 \times 10^{-19} \times 2 - 4.32 \times 10^{-19} = (2W - W) + (2K_1 - 2K_1)$$
$$W = 9.80 \times 10^{-20} \text{ J}$$

(b)
$$\frac{hc}{\lambda_0} = W,$$
$$\lambda_0 = 6.63 \times 10^{-34} \times \left(\frac{3.00 \times 10^8}{9.80 \times 10^{-20}}\right)$$
$$= 2.03 \times 10^{-6} \text{ m}$$

Generating Photoelectric Current in a Photocell Circuit

Figure 7.15 shows a photocell circuit consisting of a glass vacuum tube. The semi-cylindrical cathode is coated with a light-sensitive metal and connected to the negative potential. The anode is a metal rod fixed at the axis of the semi-cylindrical cathode and connected to the positive potential. When the photocell is illuminated by light, the production of photoelectric current is produced in the circuit. Table 7.5 are two examples of common photocells.

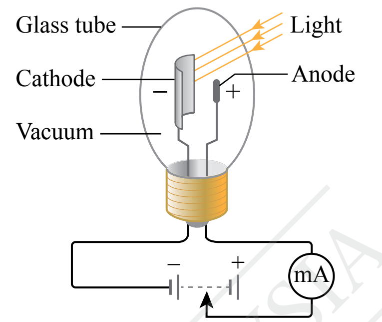
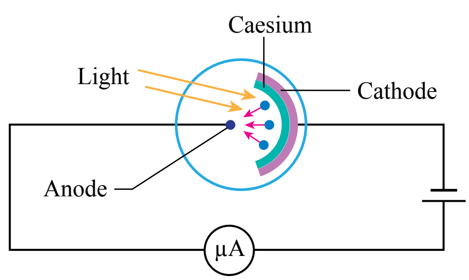
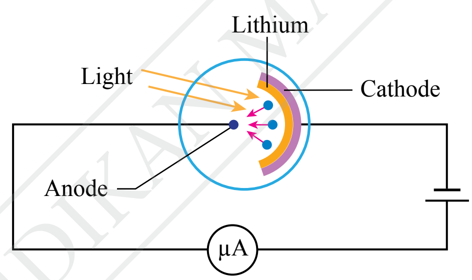


Figure 7.15 *A photocell circuit*

Table 7.5 *Production of photoelectric current by photocells coated with caesium and lithium*

Caesium	Lithium
	
Work function of caesium, W = 2.14 eV	Work function of lithium, W = 2.50 eV
Threshold frequency, $f_0 = 5.16 \times 10^{14}$ Hz	Threshold frequency, $f_0 = 6.03 \times 10^{14}$ Hz
Maximum wavelength to produce photoelectric current, λ = 579 nm	Maximum wavelength to produce photoelectric current, λ = 496 nm

On the whole, the higher the work function, the shorter the maximum wavelength required to produce photoelectric current. As the light intensity increases, the photoelectric current in the photocell circuit also increases.

Activity 7.9

ISS / ICS

Aim: To observe how photoelectric current is produced in a photocells coated with caesium through computer animations

Instructions:

1. Carry out this activity in pairs.
2. Scan the QR code to view a simulation related to the production of photoelectric current in photocells coated with caesium.
3. Based on the simulation, explain how the photoelectric current is produced in a photocell coated with caesium.
4. Present your findings.

SCAN ME
Animation video on the production of photoelectric current
https://bit.ly/3hriJRr

Photoelectric Effect Applications

Figure 7.16 shows some examples of applications of photoelectric effect.

Applications of Photoelectric Effect

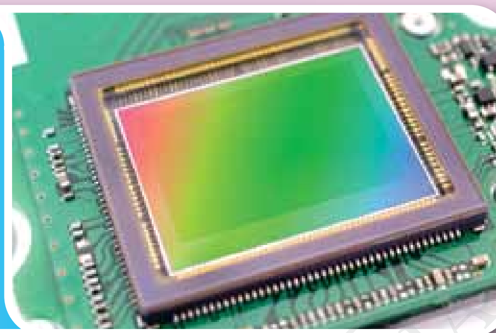
LED lamps along the road which are powered by solar cells are energy efficient and environmentally friendly. In daylight, the photoelectric effect of solar cells enables electrical energy to be stored in the battery. At night, the LED lamps will light up with the power from the battery.

The Noor Complex Solar Power Plant located in the Sahara Desert is the world's largest concentrated solar power plant. This station is expected to be completed in 2020 and is capable of producing 580 MW capacity for use by 1 million residents.

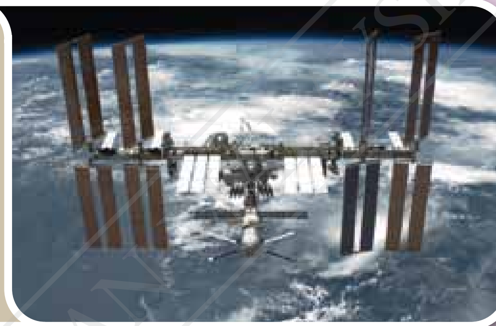
Light detectors at the automatic doors use infrared beam and photocells as switches. When the light path is disturbed, photoelectric current in the photocell circuit will be disconnected and the door will remain open.

***Figure 7.16** Examples of applications of photoelectric effect*

The image sensor is a main component in high-resolution cameras. This component is used to convert light into electrical signals which can be processed to form digital images.



The operation of the ISS (International Space Station) depends on the source of electrical energy generated from solar panels. The ISS has 16 wings of solar panels and each wing which measures 35 m × 12 m has 33 thousand solar cells. These panels are capable of generating 84 – 120 kW of electricity.



Activity 7.10

ISS ICS

Aim: To gather information on the applications of photoelectric effect

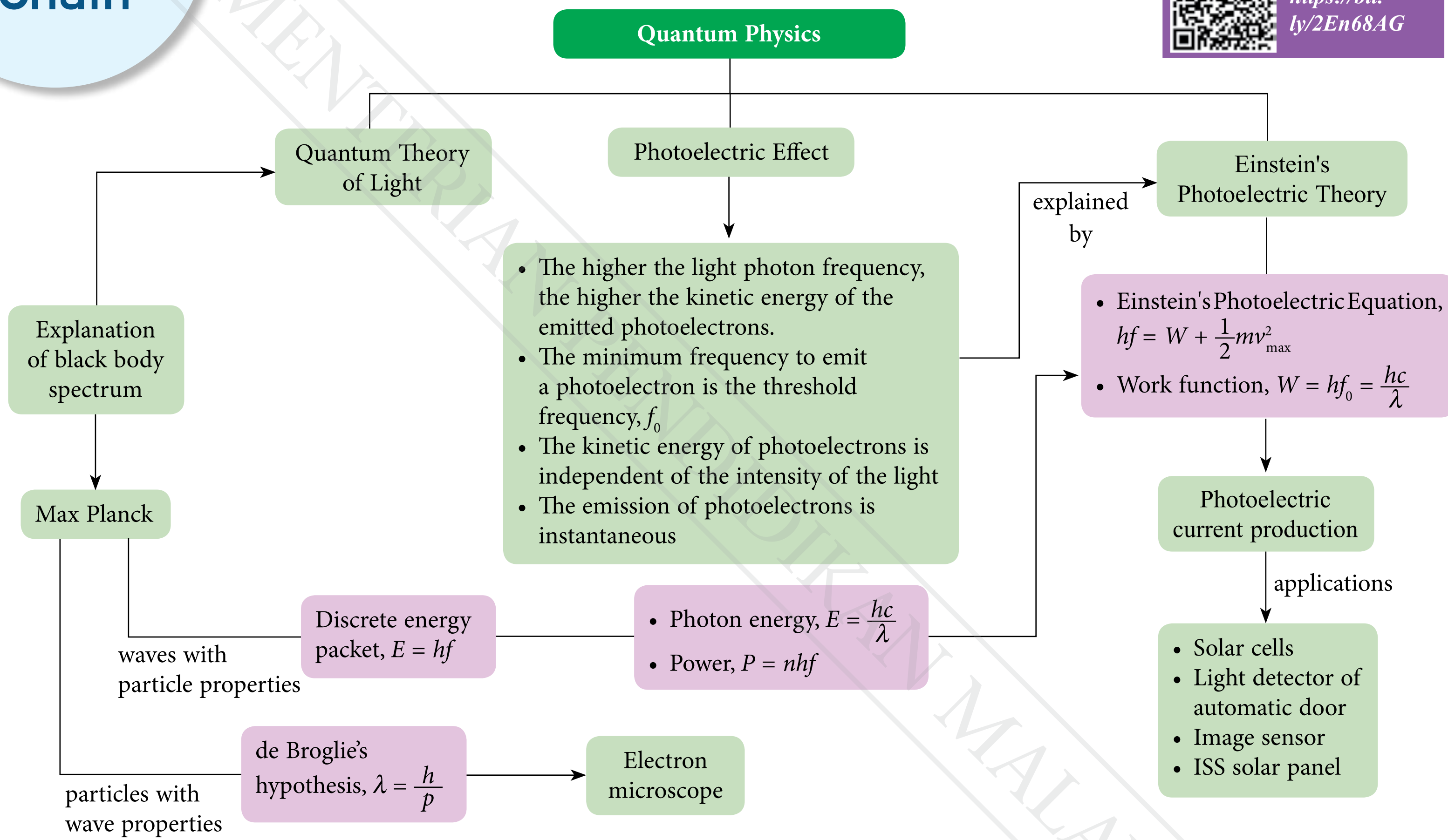
Instructions:

1. Carry out a Round Table activity.
2. You can obtain information from reading materials or website about other applications of photoelectric effect.
3. Present your findings in a mind map.

Formative Practice 7.3

1. (a) State Einstein's Photoelectric Equation.
   (b) State the meaning of:
   (i) work function
   (ii) threshold frequency
   (iii) the relationship between work function and threshold frequency
2. (a) Sketch a graph to show the relationship between the maximum kinetic energy of photoelectrons and the frequency of light shone on a metal.
   (b) What are the physical quantities represented by the gradient and the intercepts of the graph sketched in 2(a)?
3. When a metal with a work function of 4.32×10^{-19} J is shone on by a violet light ($\lambda = 4 \times 10^{-7}$ m), what is the maximum kinetic energy of an emitted photoelectron?
   [Planck's constant, $h = 6.63 \times 10^{-34}$ J s, speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}]

Concept Chain



Self-Reflection

1. New things I have learnt in the chapter on 'Quantum Physics' are ____________.
2. The most interesting thing I have learnt in this chapter is ____________.
3. The things I still do not fully understand are ____________.
4. My performance in this chapter.

   Poor | 1 | 2 | 3 | 4 | 5 | Very good
5. I need to ____________ to improve my performance in this chapter.

Summative Practice

Values that can be used in solution:
Planck's constant, $h = 6.63 \times 10^{-34}$ J s
Speed of light in vacuum, $c = 3.00 \times 10^{8}$ m s^{-1}
Mass of electron, $m_e = 9.11 \times 10^{-31}$ kg
1.00 eV = 1.60×10^{-19} J

1. State the meaning of the following terms:
   (a) black body
   (b) quantum of energy

2. The minimum energy required for the photoelectron to escape from the sodium metal surface is 2.28 eV.
   (a) Will sodium show photoelectric effect for a red light with a wavelength of 680 nm shone on it?
   (b) What is the threshold wavelength of sodium?

3. Wavelength of the yellow line of the sodium spectrum is 590 nm. How much kinetic energy does one electron have when its de Broglie wavelength is equal to the yellow line of the sodium spectrum?

4. A laser light beam with a wavelength of 555 nm and a power of 5.00 mW is aimed at an object without any light reflected. Calculate:
   (a) the momentum of a photon in the laser beam
   (b) the number of photons per second in the laser light beam hitting the object

5. The de Broglie wavelength of an electron is 1.00 nm.
   (a) State Louis de Broglie's hypothesis of the wave properties of electrons.
   (b) Calculate the momentum of the electron.
   (c) Calculate the velocity of the electron.
   (d) Calculate the kinetic energy of the electron.

6. (a) Why is a large cavity with a small hole able to act as a black body?
   (b) The temperature of a black body is 4 500 K and it looks orange-yellow. Describe the colour changes in the black body as the body is heated to a temperature of 9 000 K.

7. Photograph 1 shows a communication satellite in outer space. A quantum communication attempt was performed with a laser pulse of 60 mW and a wavelength of 800 nm.

Photograph 1

   (a) What is the momentum of one photon from the laser pulse?
   (b) How much energy does one photon carry?
   (c) What is the number of photons per second?
   (d) What is the total momentum transferred by the laser pulse per second?

8. Complete Table 1 with information on the wavelength and photon energy for several components of waves in the electromagnetic spectrum.

Table 1

Wavelength	Photon energy	Region in the electromagnetic spectrum
500 nm		
	50 eV	
	5.0×10^{-21} J	

9. Figure 1 shows a photocell constructed using semiconductor material that can be activated by a light with a maximum wavelength of 1 110 nm.

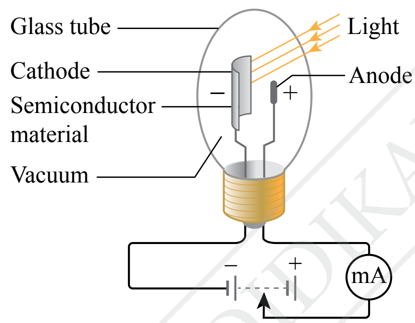


Figure 1

(a) What is the threshold frequency and work function of the semiconductor?

(b) Why does the semiconductor look opaque at room temperature?

10. Muthu conducted an experiment on a grain of sand falling through a small hole. Given the mass of the grain of sand is 5×10^{-10} kg, the diameter of the sand is 0.07 mm, the velocity of the sand falling through the hole is 0.4 m s^{-1} and the size of the hole is 1 mm:

(a) Estimate the de Broglie wavelength of the sand.

(b) Will the falling sand produce a diffraction pattern when passing through the small hole? Explain your answer.

11. When a photodiode is shone on with a red light (λ = 700 nm) and a blue light (λ = 400 nm), the maximum kinetic energy of the photoelectrons emitted by the blue light is two times that of the red light.

(a) What is the work function of the photodiode?

(b) What is the threshold wavelength of the photodiode?

(c) What is the de Broglie wavelength of the photoelectron emitted by UV light (λ = 131 nm) from the photodiode?

21st Century Challenge

12. Amin conducted an experiment to determine the work function and threshold wavelength for a material *X*. The arrangement of the apparatus is as shown in Figure 2.

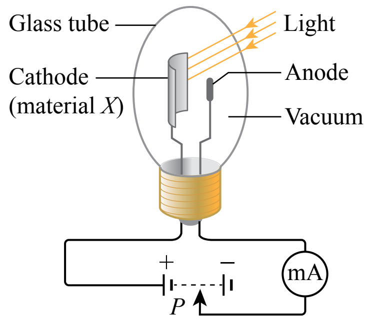


Figure 2

When the cathode coated with material *X* is illuminated by a light beam of wavelength, λ, the emitted photoelectrons will move towards the anode and give a reading in milliammeter. If the connection to the power supply is reversed, the potential difference at the anode is set to negative and that will prevent the arrival of the negatively charged photoelectrons. If the potential divider, *P* is adjusted until the stopping potential, V_s results in a zero milliammeter reading, then V_s is a measure of the maximum kinetic energy, K_{max} of the photoelectrons emitted, of which $K_{max} = eV_s$. Table 2 shows the experimental results for the values of λ and the corresponding values of V_s.

Table 2

λ / nm	V_s / V
135	7.53
172	5.59
227	3.98
278	2.92
333	2.06
400	1.43

(a) Based on Einstein's Photoelectric Equation, derive an equation that relates λ and V_s.

(b) Plot a suitable graph to determine the Planck's constant, work function and threshold wavelength for material *X*.

(c) Calculate the wavelength of light for the production of a 10.0 eV photoelectron using the work function in (b).

(d) What is the de Broglie wavelength for the 10.0 eV photoelectron?

(e) Why is material *X* a critical component in a night vision device?

Answers

Scan the QR code for complete answers

https://bit.ly/34WEgOA

ONLY SELECTED ANSWERS ARE PROVIDED HERE

Chapter 1 Force and Motion II

Summative Practice

1. Therefore, worker *Y* has to apply a force that makes an angle of 88.58° with the direction of the force from worker *X*.

2. (a) *F* = 188 N at an angle of 33° with the direction of the force applied by *P*.

(b) – Advantages: The tree will fall in the direction of the resultant force. A larger angle will ensure that there is a large space between *P* and *Q*. The tree will fall on to the ground without endangering *P* and *Q*.

– Disadvantage: The large angle between the directions of the forces produces a resultant force with a smaller magnitude.

(c) The direction of the resultant force makes a smaller angle with the direction of the force by *P*. The tree will fall nearer to *P*. Therefore, *P* has to be more careful.

3. 5 493.6 N m^{-1}

4. The resultant force of the two forces has the largest magnitude when the forces act on an object in the same direction.
If the force 17 N and the force 13 N are in the same direction, resultant force = 17 + 13
= 30 N

The resultant force of the two forces has the smallest magnitude when the forces are in opposite directions.
If the force 17 N and the force 13 N are in opposite directions, resultant force = 17 + (–13)
= 4 N

Therefore, the resultant forces of 17 N and 13 N has magnitude between 4 N and 30 N.

5. Stage I: Resultant force = 0 N
Stage II: Resultant force = 450 N to the East
Stage III: Resultant force = 0 N

6. (a) Horizontal component = 9.83 N
Vertical component = 6.88 N

(b) The horizontal component moves the knife forward.
The vertical component pushes the knife downward.

7. *T* = 4.0 N
S = 6.93 N

Chapter 2 Pressure

Summative Practice

2. (a) *A* and *B* are at the same level in a stationary liquid.

(b) 972 kg m^{-3}

4. (a) Pressure at point *X* = atmospheric pressure
Pressure at point *Y* = 0

(b) Since point *X* and point *Z* are at the same level,
Pressure at point *X* = pressure at point *Z*
Pressure at point *X* = atmospheric pressure, and
Pressure at point *Z* = pressure due to mercury column + 0
Atmospheric pressure = pressure due to mercury column
Therefore, the height of the mercury column, *h* is a measure of atmospheric pressure.

(c) 100 862 Pa

6. (a) 800 N cm^{-2}

(b) Pascal's principle

(c) Cross-sectional area of slave cylinder

$= \dfrac{\pi \times 2.5^2}{4}$

$= 4.91\ cm^2$

Braking force = 3 928 N

7. Mass of wooden block = 2.98 kg
Weight of wooden block = 29.23 N
Buoyant force = 31.78 N
Buoyant force > weight of block
There is a resultant force upwards
The block moves up with an acceleration

Chapter 3 Electricity

Summative Practice

1. – The filament lamps require high resistance to produce light.
– The coiled filament causes the wire length to increase.
– The resistance is directly proportional to the length of the wire.
– The longer the filament wire, the higher the resistance.
– The higher the resistance, the brighter the lamp.

2. (a) (i) 4.5 Ω
(ii) 1.33 A
(iii) 3.99 V

(b) Bulb *X* is the brightest compared to bulb *Y* and bulb *Z*. Bulb *Y* and bulb *Z* have the same brightness.

(c) (i) 6 Ω
(ii) 1.0 A
(iii) 3 V

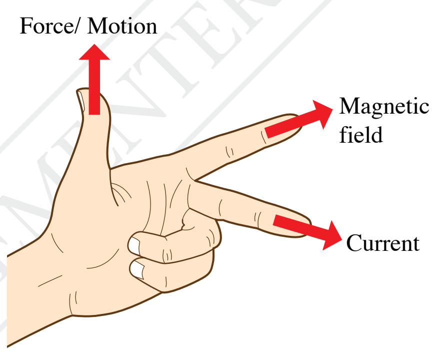
(d) Bulb *X* and bulb *Y* glow with equal brightness. Bulb *Z* does not light up.

3. (a) The electromotive force, e.m.f. is the energy transferred or work done by a source of electrical energy to move one coulomb of charge in a complete circuit.

Chapter 4 Electromagnetism

Summative Practice

2. Fore finger: Direction of magnetic field
Middle finger: Direction of current
Thumb: Direction of force



3. (a) Induced current is the current produced in a conductor when there is relative motion between the conductor and a magnet that causes the conductor to cut magnetic field lines.

(b) *X*: north pole
Y: south pole

(c) Figure (a): Direction of motion of magnet to the left
Figure (b): Direction of motion of magnet to the right

(d) Increase the number turns of the solenoid
Increase the speed of motion of the magnet

4. $I_S = 7.2$ A
The loss of energy from the transformer can be neglected, that is the transformer is ideal.

7. (a) 2.5 A

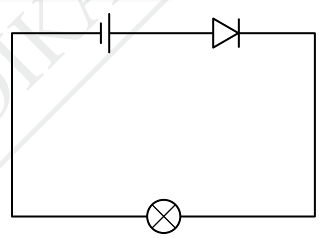
(b) The transformer is ideal

8. 60.00 %
– Use laminated soft iron core
– The secondary coil is wound on top of the primary coil

Chapter 5 Electronics

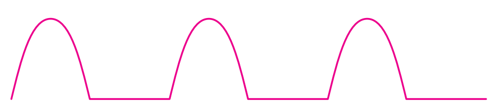
Summative Practice

1. (a)

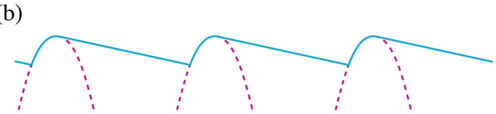


(b) The bulb does not light up because the diode is in reverse biased state.

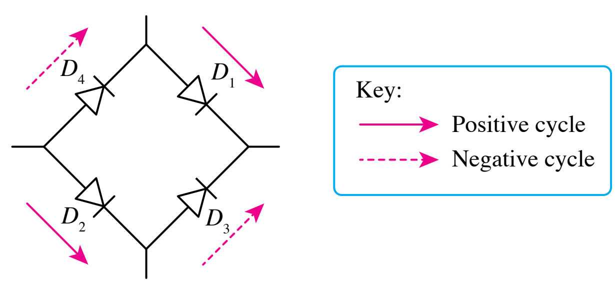
2. (a)



(b)



3. (a)



(c) Half-wave rectification will occur

4. (b) Under bright conditions, LDR resistance becomes low. Therefore, the voltage across LDR decreases but the voltage across R is increased. The I_B is low and the transistor is turned off. The I_C will be low and the LED will hot light up.

(c) the LED with an alarm, the resistor with a thermistor and the LDR with a resistor.

Chapter 6 Nuclear Physics

Summative Practice

1. (a) A radioactive decay is a random and spontaneous process by which an unstable nucleus will decay by emitting radioactive radiation to become a more stable nucleus.

(b) The half life, $T_{\frac{1}{2}}$, is the time taken for a sample of radioactive nuclei to decay to half of its initial number.

(c) Nuclear energy is the energy produced by reactions in atomic nuclei.

2. (a) X is the helium nucleus or α-particle, Y is γ-ray.

(b) 3 α-particles and 2 β-particles are released.

3. (a) 11.2 s

(b) $n = 5$

so after $5T_{\frac{1}{2}}$, only 3.125% of the sample remains.

4. (a) A is the older sample. The ratio of uranium-238 to plumbum-206 is smaller.

(b) Suppose that during the rock formation, only uranium-238 was trapped. The oldest rock formed on Earth is about 4.28 billion years. The half-life of uranium-238 is 4.5 billion years. Therefore, the decay process of uranium-238 in a rock sample has gone through less than one half-life. Hence, less than half of the uranium-238 nuclei in the sample of rock had decayed to form lead-206 nuclei. So the number of lead-206 nuclei cannot be more than the remaining uranium-238 nuclei.

6. (a) Nuclear fusion

$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ + energy

(b) 2.82×10^{-12} J

8. (a) The chain reaction resulting from neutron bombardment on the uranium-235 nuclei produces a large amount of nuclear energy in the reactor.

(b) Heat energy boils the cold water. The high pressure steam produced is capable of rotating a turbine at extremely high speed.

(c) The rotation of a turbine switch on a dynamo which will generate electrical energy by electromagnetic induction.

Chapter 7 Quantum Physics

Summative Practice

1. (a) A black body is an ideal body that is able to absorb all the electromagnetic rays that fall on it.

(b) Quantum of energy is a discrete packet of energy and not a continuous energy.

2. (a) Work function of sodium metal
$= 3.65 \times 10^{-19}$ J
Photon energy of the red light
$= 2.93 \times 10^{-19}$ J
Photoelectric effect does not occur because of the photon energy of the red light is lower than work function of sodium metal.

(b) 545 nm

3. 6.93×10^{-25} J

4. (a) 1.19×10^{-27} kg m s^{-1}

(b) 1.40×10^{16} s^{-1}

5. (a) Louis de Broglie hypothesized that particles such as electrons could have wave properties.

de Broglie wavelength, $\lambda_e = \frac{h}{p}$

p is the electron momentum

(d) 2.41×10^{-19} J

6. (a) The rays of light that enter the large cavity will undergo repeated reflections on the inner walls of the cavity. At each reflection, part of the rays are absorbed by the inner walls of the cavity. Reflections continue to occur until all the rays are absorbed and none of them can leave the cavity. Thus, the cavity acts like a black body.

7. (a) 8.29×10^{-28} kg m s^{-1}

(b) 2.49×10^{-19} J

(c) 2.41×10^{17} s^{-1}

Glossary

A black body
An idealised body that is able to absorb all electromagnetic radiation that falls on it

An electric field
The region around a charged particle where any electric charge in the region will experience an electric force

Atmospheric pressure
Pressure due to the weight of the layer of air acting on the surface of the earth.

Buoyant force
The force acting upwards on an object immersed in a liquid when there is pressure difference between the lower surface and upper surface of the object

Catapult field
Resultant magnetic field produced by the interaction between the magnetic field from a current-carrying conductor and the magnetic field from a permanent magnet

Elasticity
The property of material that enables an object to return to its original shape and size after the force applied on it is removed

Electromagnetic induction
Production of an e.m.f. in a conductor when there is relative motion between the conductor and a magnetic field or when the conductor is in a changing magnetic field

Electromotive force (e.m.f.)
The energy transferred or work done by an electrical source to move one coulomb of charge in a complete circuit

Forces in equilibrium
When the forces acting on an object to produce a zero resultant force

Half-life
The time taken for a sample of a radioactive nuclei to decay to half of its initial number

Ideal transformer
Transformer that does not experience any loss of energy, that is the efficiency, η is 100%

Nuclear energy
Atomic energy released during nuclear reactions such as radioactive decay, nuclear fission and nuclear fusion.

Nuclear fission
Nuclear reaction when a heavy nucleus splits into two or more lighter nuclei while releasing a large amount of energy

Nuclear fusion
Nuclear reaction in which small and light nuclei fuse to form a heavier nucleus while releasing a large amount of energy

Resolution of forces
The process of resolving a force into two components

Resultant force
The single force that represents the vector sum of two or more forces acting on an object

Semiconductor diode
An electronic component which allows electric current to flow in one direction only

Thermionic emission
The emission of free electrons from a heated metal surface

Threshold frequency
The minimum frequency for a light photon to produce photoelectric effect

Work function
The minimum energy required for a photoelectron to be emitted from a metal surface

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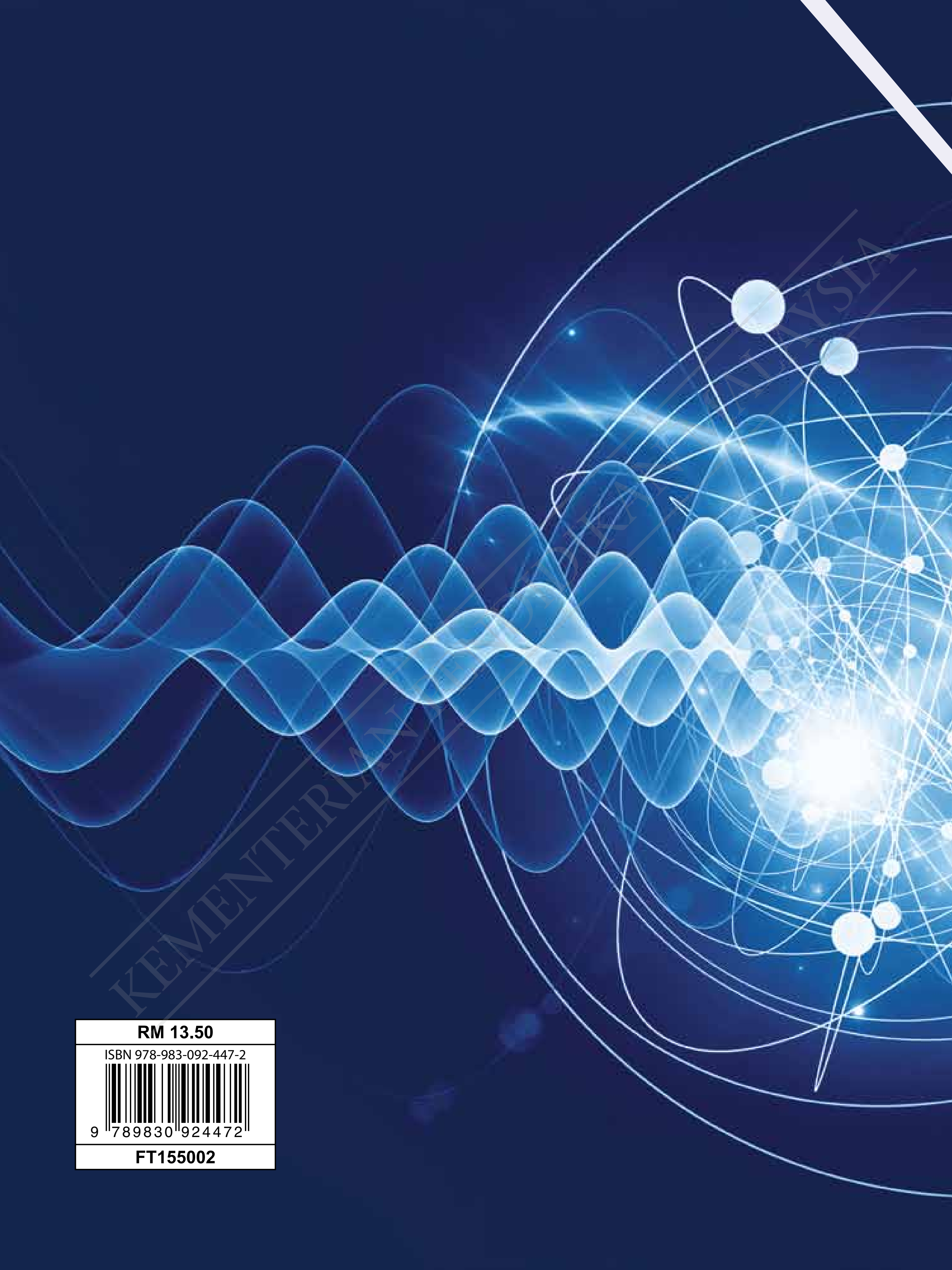

RM 13.50

ISBN 978-983-092-447-2

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