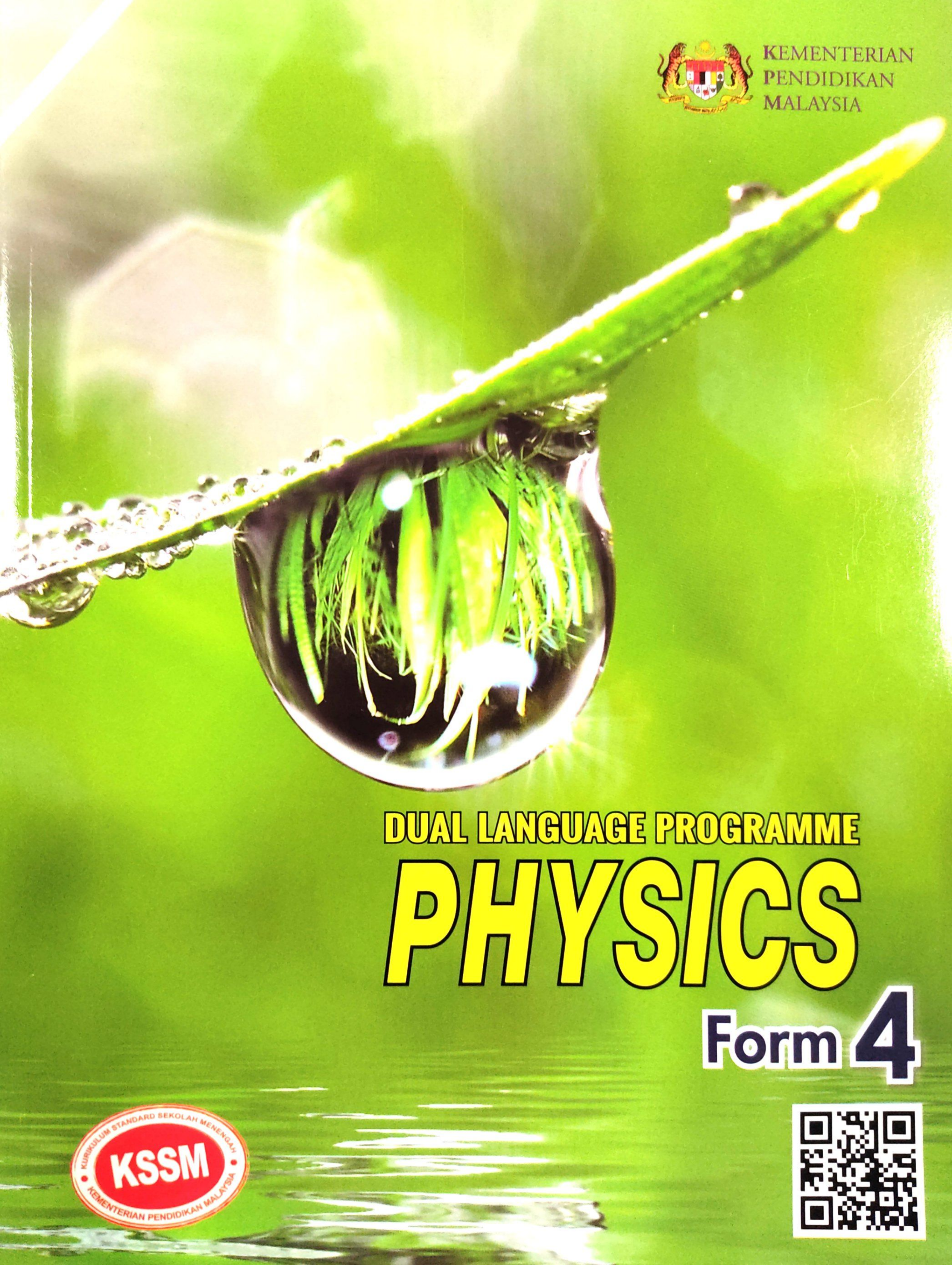
KEMENTERIAN
PENDIDIKAN
MALAYSIA



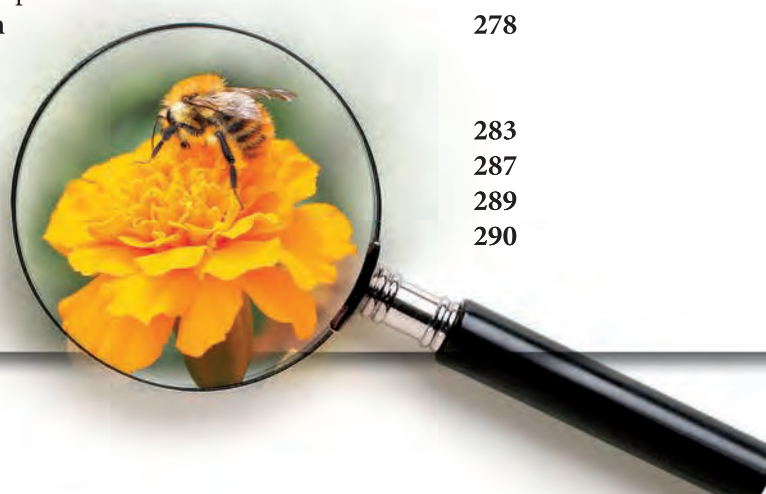
DUAL LANGUAGE PROGRAMME

PHYSICS

Form 4

KURIKULUM STANDARD SEKOLAH MENENGAH
KSSM
KEMENTERIAN PENDIDIKAN MALAYSIA

Contents



KURIKULUM STANDARD SEKOLAH MENENGAH

PHYSICS

Form 4

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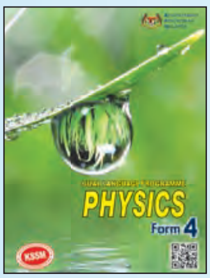
Introduction

The Form 4 Physics *Kurikulum Standard Sekolah Menengah* (KSSM) textbook is written based on the *Dokumen Standard Kurikulum dan Pentaksiran* (DSKP) for Form 4 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. Special features incorporated in this book are as follows:



Scan the 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)

STEM STEM
Activities are project-based with Science, Technology, Engineering and Mathematics (STEM) approach. The STEM approach is a teaching and learning approach that applies knowledge, skills and values of STEM.

21st Century Skills
Activities involve:
- Critical Thinking and Problem-solving Skills CPS
- Interpersonal and Self-reliance Skills ISS
- Information and Communication Skills ICS

21st Century Learning Activities
Activities emphasize on pupil-centred learning and elements of Higher Order Thinking Skills (HOTS).

Learning Standards 1.1.1
Learning Standards on each page.

Computational Thinking
Activities involve:
- Decomposition
- Pattern Recognition
- Abstraction
- Algorithms
- Logical Reasoning
- Evaluation

Thinking tools
Various thinking tools such as graphic organisers, mind maps and thinking maps help pupils master thinking skills.

Malaysiaku MY PRIDE
Information on patriotic elements, culture and achievements of Malaysians

Cross Curricular Corner
Information across curriculum related to a topic

INTEGRATION OF LANGUAGE
INTEGRATION OF HISTORY

CAREER INFO
Information on career related to physics

Activities include:

Discussion
Project
Individual
Multimedia
Sharing of information
Problem-solving
Simulation
Extensive reading
Experiment

KPM

Gateway to SCIENCE TECHNOLOGY and SOCIETY

Information on the applications of science and technology to society

Info File

Additional interesting information on a topic

Conceptual Framework

A summary at the end of each chapter in the form of a concept map

Interactive QUIZ

An interactive quiz at the end of every chapter by scanning QR code

HOTS questions to evaluate pupils' ability to apply knowledge, skills and values to solve problem, make decision, be innovative and inventive.

SMART INFO

Short notes to help pupils understand

DIY

Simple activity for pupils to carry out on their own

Scan QR code to gather additional information from websites

Formative Practice

Questions to test pupils' understanding at the end of each chapter

SELF-REFLECTION

Evaluation of pupils' understanding of the chapter learned

Enrichment Corner

Enrichment exercises with HOTS questions of Level 5 (Evaluating) and Level 6 (Creating)

Performance Evaluation

Questions of various level of Lower and Higher Order Thinking Skills to test pupils' understanding at the end of each chapter.

Guideline to scan AR (Augmented Reality) for Three-dimensional Animations

Scan this QR code to download the application.

PHYSICS Form 4

Then, use the application to scan the page with the AR icon (pages 88, 91 and 256).

Page 88

Theme 1

Elementary Physics

Physics is the study of matter and energy as well as phenomena happening around us.

The topics in this theme focuses on the base quantities and their units that are needed to derive other physical quantities. Attention is also given to the scientific method in aspects such as the interpretation of graphs and scientific investigation.

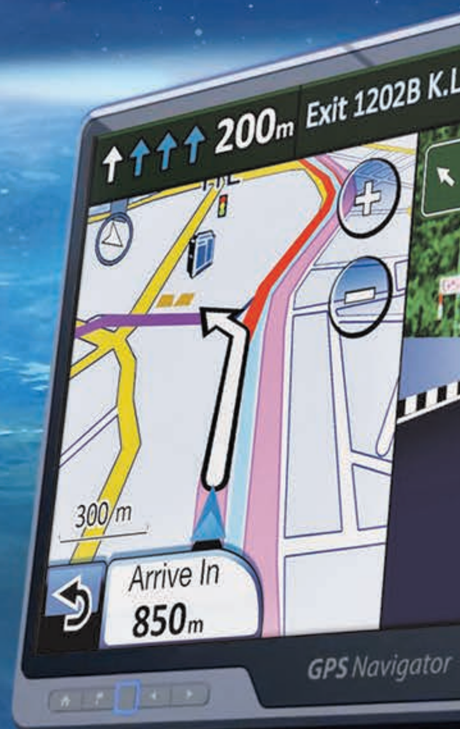
CHAPTER 1

MEASUREMENT

What are physical quantities?

How are base quantities and their respective units used to form derived quantities?

Why are the skills in interpreting and analysing graphs important?



Let's Study

1.1 Physical Quantities
1.2 Scientific Investigation

Information Page

Measurement plays an important role in investigating natural phenomena and inventing modern equipment to solve problems in our lives. The invention of sophisticated modern equipment such as *Global Positioning System* (GPS), seismometers, computers, smartphones and others has helped us in various fields.

GPS determines the location of a person or a place by measuring time and distance using satellites. Accuracy in the measurement of time and distance is very important in GPS to determine exact locations.

How does GPS work?

http://bt.sasbadi.com/p4003a

Learning Standards and List of Formulae

1.1 Physical Quantities

Measurement is a method to determine the value of a physical quantity. **Physical quantities** consist of base quantities and derived quantities.

The results of accurate measurements enable us to make right decisions.

Figure 1.1 shows examples of measurements involving physical quantities. State the physical quantities.

Height of Mount Kinabalu is 4 095 m.

National Paralympic athlete, Mohamad Ridzuan Puzi created a world record with a recorded time of 11.87 s in the 100 m sprint event (T36 category) in the 2018 Asian Para Games.

Speech of the tiger, *Panthera tigris* is 49 km h^{-1} to 65 km h^{-1}.

***Figure 1.1** Examples of measurements of physical quantities*

You have studied base quantities in Form 1.

Can you identify the base quantities in Figure 1.2?

***Figure 1.2** Physical quantities*

Time, length, electric current, thermodynamic temperature, mass, luminous intensity and amount of substance are **base quantities**. The rest of the quantities in Figure 1.2 are **derived quantities**.

Recall

Physical quantities and their units

1.1.1

A physical quantity must be stated in **magnitude** with its **unit**. Observe Figure 1.3.

Physical quantity | **Magnitude**

Length = 100 m — **Unit**

Figure 1.3 *Example of measurement of a physical quantity*

Look at your ruler. Can you see the units in centimetres and inches on the ruler? Centimetre is an example of a **metric unit** while inch is an example of an **imperial unit**. Observe Photograph 1.1.

Photograph 1.1 *Metric unit and imperial unit on a ruler*

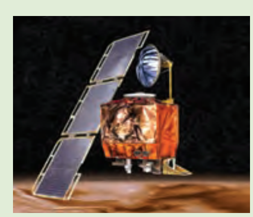
Nowadays we are more familiar with the metric units. The imperial units are seldom used. Photograph 1.2 shows a tyre pressure gauge which displays both the metric unit and the imperial unit.

Photograph 1.2 *Metric unit and imperial unit on a tyre pressure gauge*

Other examples of imperial units are gallons, miles, feet and yards. Do you know that imperial units can be converted to metric units and vice versa?

INTEGRATION OF HISTORY

In 1999, the spaceship *Mars Climate Orbiter* suddenly disappeared in outer space. This was caused by a mistake in the units of measurement used by the engineers. One group of engineers used the imperial unit while the other used the metric unit. This caused the spaceship to crash onto the surface of Mars.



1.1.1

Base Quantities and Derived Quantities

Base quantity is a physical quantity which cannot be derived from another physical quantity. Table 1.1 shows seven base quantities.

Table 1.1 *Base quantities and their respective S.I. units and symbols*

Base quantity and its symbol		S.I. unit and its symbol	
Length	l	metre	m
Mass	m	kilogram	kg
Time	t	second	s
Thermodynamic temperature	T	kelvin	K
Electric current	I	ampere	A
Luminous intensity	I_v	candela	cd
Amount of substance	n	mole	mol

Other physical quantities as shown in Table 1.2 can be described in terms of base quantities. These physical quantities are known as **derived quantities**.

Table 1.2 *Examples of derived quantities and their respective symbols*

Derived quantity and its symbol		Formula
Volume	V	$V = l^3$
Density	ρ	$\rho = \frac{m}{V}$
Velocity	v	$v = \frac{l}{t}$
Charge	Q	$Q = I \times t$

Info File

Amount of substance normally used in Chemistry refers to the quantity of an element or a compound.

Info File

In 1960, International System of Units known as S.I. was agreed upon at the 11th General Conference on Weights and Measures (*Conférence Générale des Poids et Mesures, CGPM*) in Paris, France. This system has facilitated works in the fields of science, sports, trade, medicine and others.

Describing Derived Quantities in Terms of Base Quantities and S.I. Base Units

A derived quantity is related to the base quantities through a **formula**. The derived unit is related to the base units in a similar manner. Study the example shown in Figure 1.4 on page 7.

Derived quantity	Formula	In terms of base quantities	S.I. unit
Density	$\rho = \dfrac{m}{V}$	$\dfrac{m}{l \times l \times l}$	kg m^{-3}

Figure 1.4 Example of describing a derived quantity

Activity 1.1

CPS ISS

Aim: To discuss derived quantities in terms of base quantities and S.I. base units

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Scan the QR code to download and print Table 1.3.
3. Discuss and complete the table.

Download Table 1.3

http://bt.sasbadi.com/p4007

Table 1.3

Derived quantity and its symbol		Formula	In terms of base quantities	In terms of S.I. base units	S.I. unit (Specific unit) if any
Area	A	$A = l^2$			–
Volume	V	$V = l^3$			–
Density	ρ	$\rho = \dfrac{m}{V}$	$\dfrac{m}{l \times l \times l} = \dfrac{m}{l^3}$		–
Velocity	v	$v = \dfrac{l}{t}$		m s^{-1}	–
Acceleration	a	$a = \dfrac{v}{t}$	$\dfrac{l}{t \times t} = \dfrac{l}{t^2}$		–
Force	F	$F = m \times a$		kg m s^{-2}	newton (N)
Momentum	p	$p = m \times v$	$m \times \dfrac{l}{t} = \dfrac{ml}{t}$		–
Pressure	P	$P = \dfrac{F}{A}$		kg m^{-1} s^{-2}	pascal (Pa)
Energy or Work	W	$W = F \times l$	$\dfrac{ml}{t^2} \times l = \dfrac{ml^2}{t^2}$		joule (J)
Charge	Q	$Q = I \times t$		A s	coulomb (C)

Scalar Quantities and Vector Quantities

Figure 1.5 shows two situations during a Physical Education lesson. In both situations, the teacher instructs his pupils to run a distance of 50 metres. What is the difference between situation 1 and situation 2?

CAREER INFO

Metrology is a scientific study of measurements and standards. Many scientists apply advanced technologies of measurements to determine the standards of fundamental units. In Malaysia, Standard and Industrial Research Institute of Malaysia (SIRIM) is responsible to prepare the standards of all measurements.

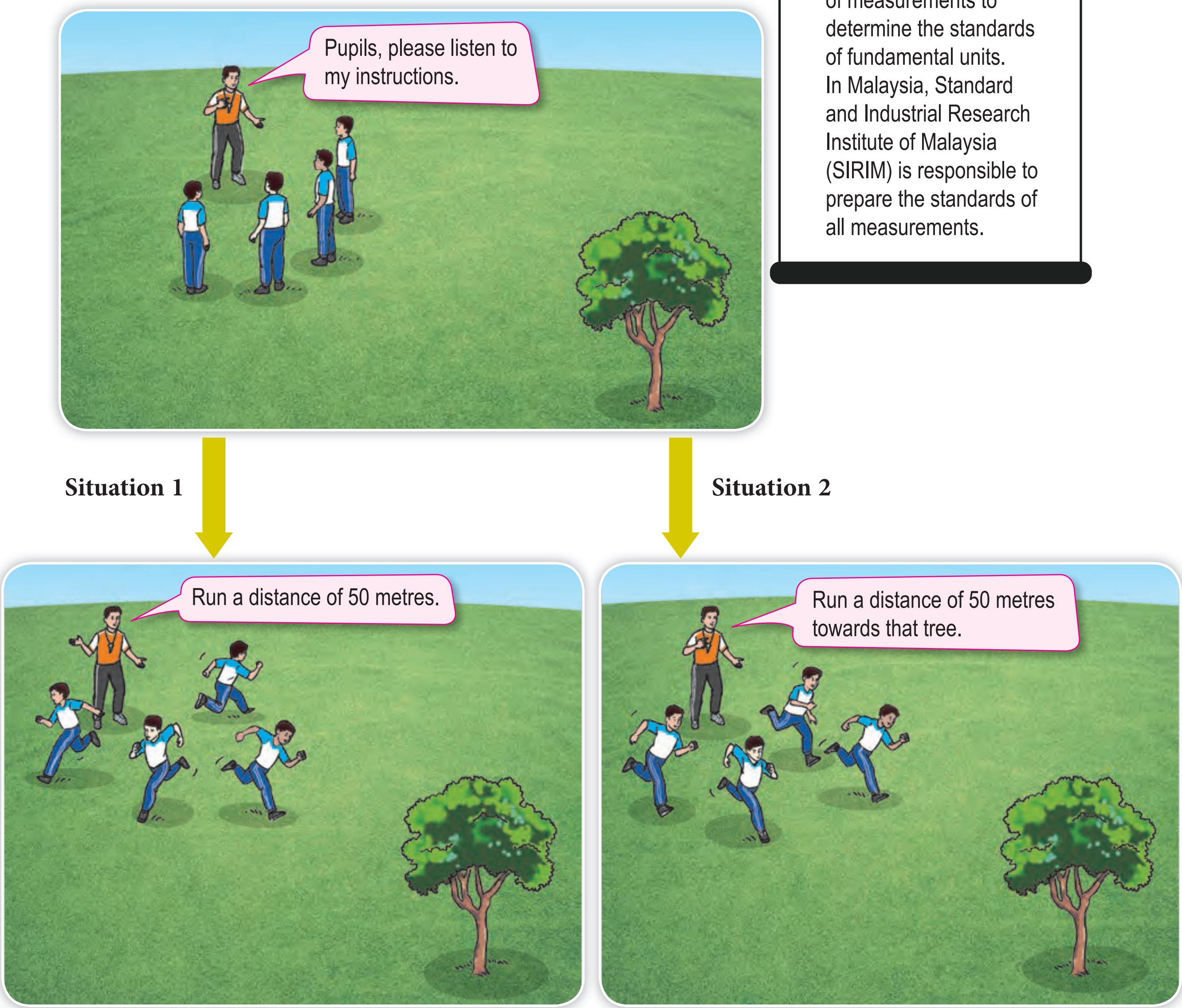


Figure 1.5 *Two situations during a Physical Education lesson*

Scalar quantities are physical quantities that have magnitude only while **vector quantities** are physical quantities that have both magnitude and direction. Identify the situations that involve scalar and vector quantities in Figure 1.5 above.

Table 1.4 shows examples of scalar and vector quantities. What other examples of scalar and vector quantities do you know?

***Table 1.4** Examples of scalar and vector quantities*

Scalar quantities		Vector quantities
Distance	Time	Displacement
Area	Volume	Velocity
Length	Speed	Force
Work	Energy	Acceleration
Temperature	Density	Momentum

Video of scalar and vector quantities

http://bt.sasbadi.com/p4009

Formative Practice 1.1

1. Figure 1.6 shows Encik Fendi taking a measurement of Wei Li.

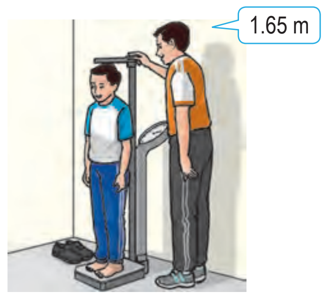


Figure 1.6

(a) State the measured physical quantity.

(b) What is the measured base unit, symbol of the unit, magnitude of the physical quantity and symbol of the physical quantity in the situation shown in Figure 1.6?

2. (a) What is the difference between scalar quantity and vector quantity?

(b) Read the following passage.

> Puan Aishah wants to travel to Kota Kinabalu. The distance from her house to Kota Kinabalu is 333 km. She drives her car at a speed of 80 km h^{-1} along a highway. She wants to reach Kota Kinabalu in 3 hours. Therefore, she increases the speed of her car with an acceleration of 1.2 m s^{-2}.

Identify the scalar quantities and vector quantities involved in the situation described above.

3. Rina and her friends took part in a Treasure Hunt held in conjunction with Science Day in their school. Each group had to find several objects hidden in the school compound within 30 minutes as listed in Figure 1.7.

- ☐ Container filled with 500 mℓ of pond water
- ☐ A unique piece of rock of mass 950 g
- ☐ Rope of length 1.5 m
- ☐ Camping canvas of area 7.2 m^2

Figure 1.7

Identify the base quantities and derived quantities in the above situation.

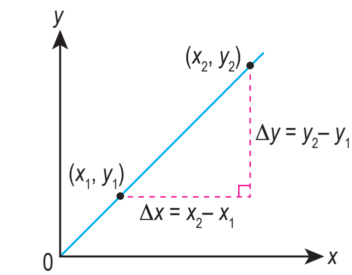
1.1.4

1.2 Scientific Investigation

We can plot graphs using data from scientific investigation and interpret the shapes of the graphs to determine the relationship between two physical quantities.

Interpretation of Graphs of Different Shapes

1



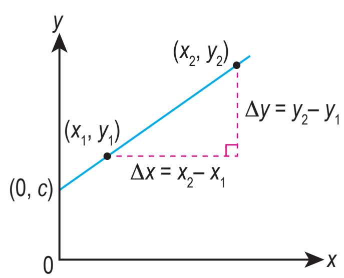
Type of graph:
A straight line that passes through the origin

Interpretation of graph:
- y is directly proportional to x
- Gradient of graph, $m = \dfrac{\Delta y}{\Delta x}$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

- Linear equation, $y = mx$

2



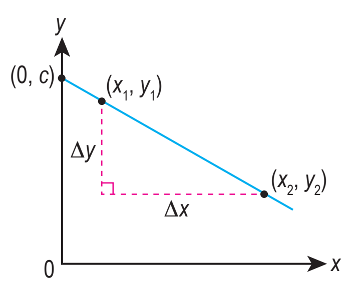
Type of graph:
A straight line with a positive gradient that does not pass through the origin

Interpretation of graph:
- y increases linearly with x
- Gradient of graph, $m = \dfrac{\Delta y}{\Delta x}$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

- y-intercept $= c$
- Linear equation, $y = mx + c$

3



Type of graph:
A straight line with a negative gradient that does not pass through the origin

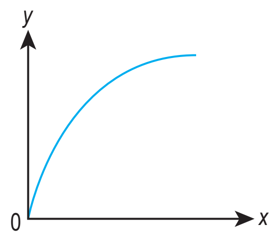
Interpretation of graph:
- y decreases linearly with x
- Gradient of graph, $m = \dfrac{\Delta y}{\Delta x}$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

- y-intercept $= c$
- Linear equation, $y = mx + c$

1.2.1

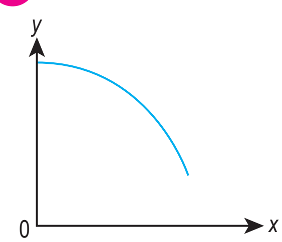
4



Type of graph:
A curve with a positive gradient that passes through the origin

Interpretation of graph:
- y increases with x

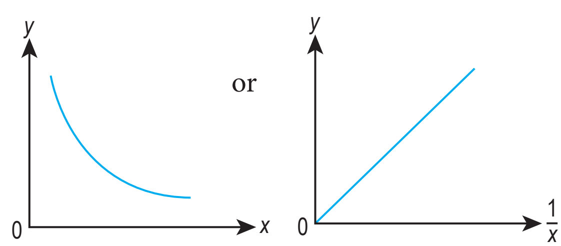
5



Type of graph:
A curve with a negative gradient that does not pass through the origin

Interpretation of graph:
- y decreases with x

6



Type of graph:
- A curve with a negative gradient that does not cut both axes
- A straight line y against $\frac{1}{x}$ with a positive gradient that passes through the origin

Interpretation of graph:
- y is inversely proportional to x

Figure 1.8 *Examples of shapes of graphs showing the relationship between two physical quantities*

Activity 1.2

ISS CPS

Aim: To discuss the shapes of graphs showing the relationship between two physical quantities

Instructions:
1. Carry out a Think-Pair-Share activity.
2. Scan the QR code to download and print Activity 1.2 worksheet. Complete the worksheet.

Download Activity 1.2 worksheet

http://bt.sasbadi.com/p4011

1.2.1

Analysing Graphs to Summarise an Investigation

In general, there are five important aspects in analysing graphs.

1 The **relationship** between two variables.

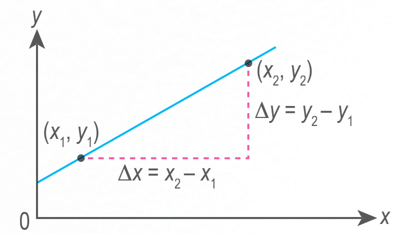
Method:
Interpret the shape of graph obtained.

Recall
Gradient and intercept

2 The **gradient** of the graph.

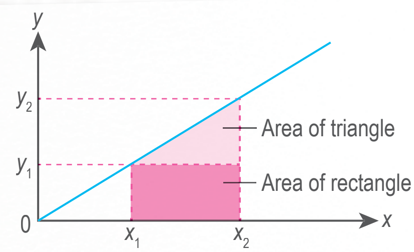
Method:
Calculate the gradient of the graph, $m = \dfrac{\Delta y}{\Delta x}$

$= \dfrac{y_2 - y_1}{x_2 - x_1}$



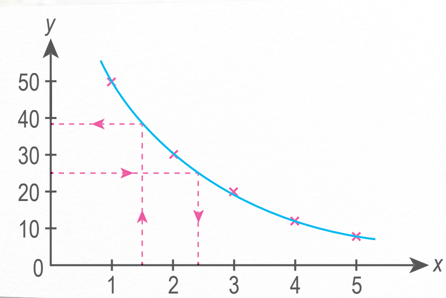
3 The **area under the graph**.

Method:
Calculate the area under the graph using the relevant formula for the area.



4 The **interpolation** to determine the value of a physical quantity.

Method:
If the value of x is given, determine the value of y using interpolation and vice versa.



5 The **extrapolation** to make a prediction.

Method:
1. Extrapolate the graph.
2. Determine the value of x or y concerned.

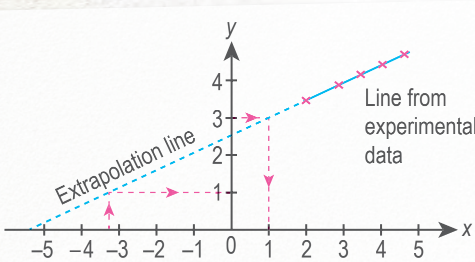


Figure 1.9 *Analysing graphs*

Activity 1.3

Abstraction CPS ISS

Aim: To plot and analyse a graph using a set of given data

Farah carried out an experiment to investigate the relationship between force, F and extension of a spring, x using the apparatus set up as shown in Figure 1.10. The results of the experiment are shown in Table 1.5. Assist Farah to analyse the graph and summarise the investigation.

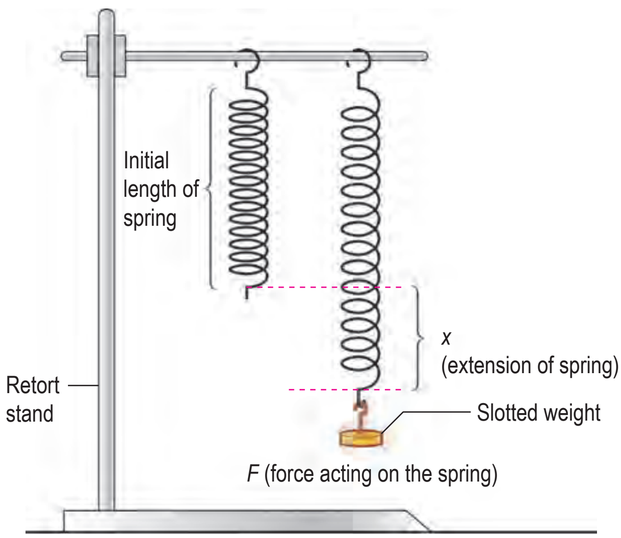


Figure 1.10

Table 1.5

Force, F / N	Extension of spring, x / cm
0.5	0.8
1.0	1.6
1.5	2.4
2.0	3.2
2.5	4.0
3.0	4.8
3.5	5.6
4.0	6.4

Instructions:

1. Work in groups.
2. Plot a graph of F against x.
3. Analyse your graph based on the following aspects:
   (a) State the relationship between F and x.
   (b) Calculate the gradient of graph, k. Show on the graph, how you determine the value of k.
   (c) The equation that relates F and x is $F = kx$, where k is the spring constant. Determine the value of k in S.I. unit.
   (d) Area under the graph represents the work done in stretching a spring. Determine the work needed to stretch the spring by 5 cm.
   (e) Determine the value of F when x = 3.5 cm.
   (f) Predict the value of x when F = 5.0 N.
4. Present your graph and the analysis of the graph.

Scientific Investigation and Complete Experimental Report

Figure 1.11 shows a situation in a playground. Read the conversations below.

Recall
Scientific method and complete experimental report

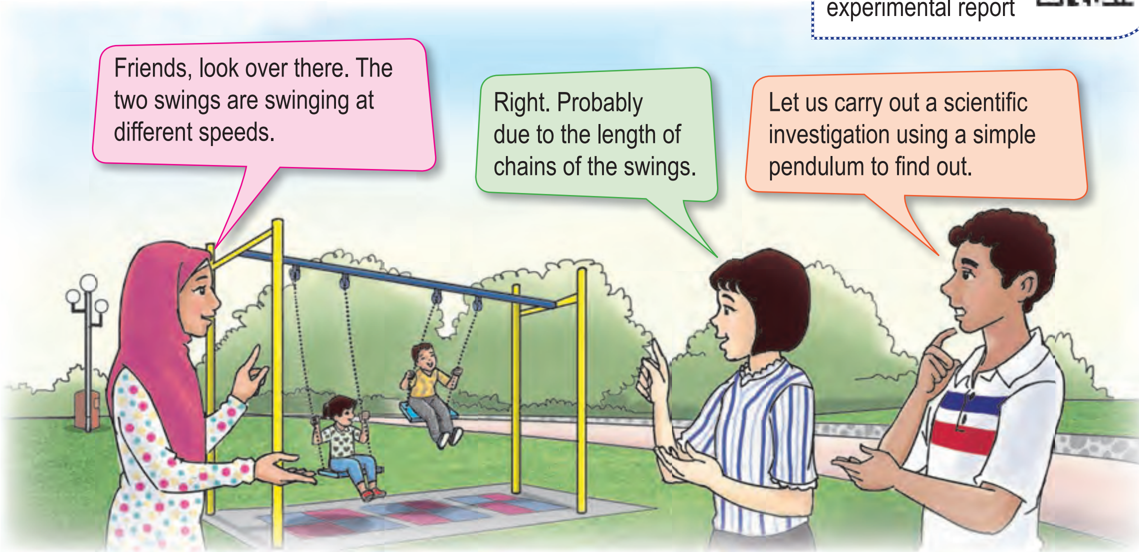


***Figure 1.11** Situation in a playground*

Experiment 1.1

Inference: The period of oscillation of a simple pendulum depends on its length.

Hypothesis: The longer the length of the simple pendulum, the longer its period of oscillation.

Aim: To investigate the relationship between the length of a simple pendulum, l and the period of oscillation of the simple pendulum, T.

Variables:

(a) Manipulated variable: Length of pendulum, l

(b) Responding variable: Period of oscillation of pendulum, T

(c) Constant variable: Mass of pendulum bob

Apparatus: Retort stand, protractor, pendulum bob, stopwatch, metre rule and G-clamp

Materials: 100 cm thread and two small pieces of plywood

Procedure:

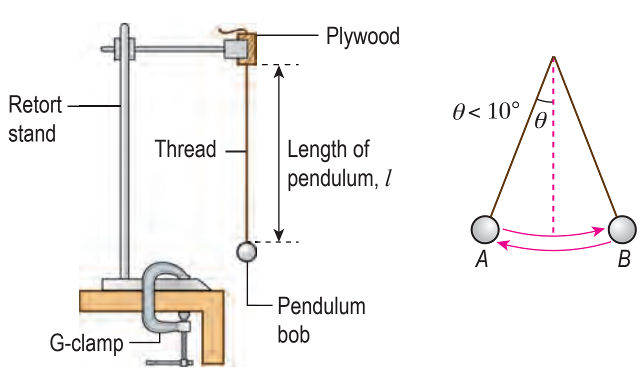


Figure 1.12

1.2.3

1. Set up the apparatus as shown in Figure 1.12.
2. Adjust the length of pendulum, l = 20.0 cm.
3. Displace the pendulum bob at an angle of less than 10° from the vertical and release it.
4. Measure and record the time, t_1 taken for 20 complete oscillations.
5. Repeat step 4 and record the time as t_2.
6. Calculate the average time, $t_{average} = \frac{(t_1 + t_2)}{2}$.
7. Calculate the period of oscillation, $T = \frac{t_{average}}{20}$ and the value of T^2.
8. Repeat steps 2 to 6 with length of pendulum, l = 30.0 cm, 40.0 cm, 50.0 cm, 60.0 cm and 70.0 cm.
9. Record the data in Table 1.6.

Results:

Table 1.6

Length of pendulum, l / cm	Time for 20 complete oscillations, t / s			T / s	T^2 / s^2
	t_1	t_2	$t_{average}$		
20.0					
30.0					
40.0					
50.0					
60.0					
70.0					

Analysis of data:

1. Plot a graph of T against l and a graph of T^2 against l on separate sheets of graph paper.
2. State the shape of the graph and the relationship between the variables in each graph.
3. Determine the gradient, m of the graph of T^2 against l. State the value of m in S.I. unit. Show clearly how you obtain the answer.
4. Given $T^2 = 4\pi^2\frac{l}{g}$ where g is the Earth's gravitational acceleration.

   Relate gradient, m to the value of g and then determine the value of g in this experiment.

Conclusion:
What conclusion can you make in this experiment?

Prepare a complete report on this experiment.

Discussion:

1. Why does the time for 20 complete oscillations need to be taken in this experiment?
2. Why is the measurement of time taken for 20 complete oscillations repeated?
3. State one precaution that should be taken to increase the accuracy of the results of this experiment.
4. Compare the value of g obtained from this experiment with the standard value of g, that is 9.81 m s^{-2}. Justify the difference in the values of g.

Formative Practice 1.2

1. Graphs play an important role in scientific investigations.
   (a) What are the uses of graphs?
   (b) Explain the main steps taken in the process of plotting a graph.

2. Figure 1.13 shows a graph obtained from a study to investigate the relationship between volume, V and temperature, θ of a fixed mass of gas. Based on the graph given in Figure 1.13, answer the following questions.

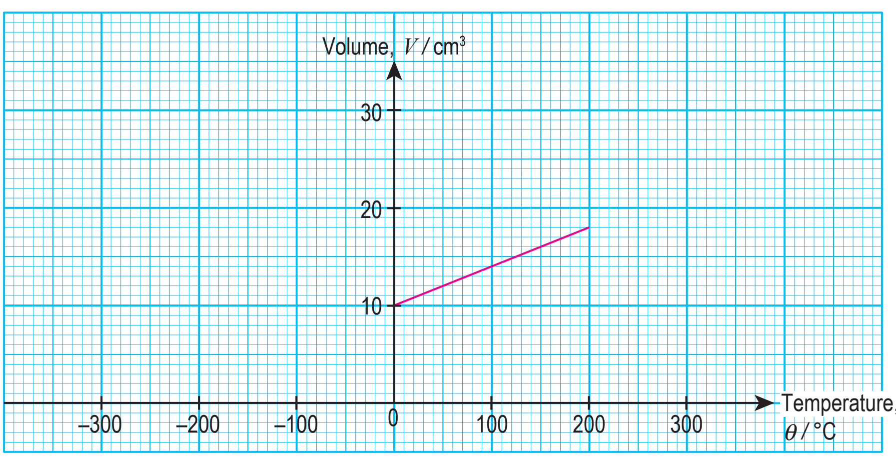


Figure 1.13

   (a) What happens to V when θ increases?
   (b) Determine the value of θ when the volume is zero. Show on the graph, how you determine the value of θ.
   (c) Determine the value of V when θ = 300°C. Show on the graph, how you determine the value of V.

Conceptual Framework

Measurement

- **Physical quantities**
  - Scalar quantities
  - Vector quantities
  - **Base quantities**
    - Length, l
    - Mass, m
    - Time, t
    - Electric current, I
    - Thermodynamic temperature, T
    - Luminous intensity, I_v
    - Amount of substance, n
  - **Derived quantities**
    - Examples
      - Area, $A = l \times l$
      - Volume, $V = l \times l \times l$
      - Density, $\rho = \dfrac{m}{l \times l \times l} = \dfrac{m}{V}$
      - Velocity, $v = \dfrac{l}{t}$
      - Acceleration, $a = \dfrac{l}{t \times t} = \dfrac{v}{t}$
      - Force, $F = ma = m \times \dfrac{l}{t \times t}$
- **Scientific investigations**
  - Interpreting graphs of different shapes
  - Analysing graphs to summarise an investigation
    - Relationship between two physical quantities
    - Gradient of graph
    - Area under the graph
    - Interpolation of graph
    - Extrapolation of graph
  - Writing a complete experimental report

Interactive QUIZ

http://bt.sasbadi.com/p4017

SELF-REFLECTION

1. New things I learnt in this chapter on measurement are ________.

2. The most interesting thing I learnt in this chapter on measurement is ________.

3. Things I still do not fully understand or comprehend are ________.

4. My performance in this chapter,

   Poor 1 2 3 4 5 Excellent

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

Download and print Self-reflection Chapter 1

http://bt.sasbadi.com/p4018

Performance Evaluation

1. (a) State seven base quantities and their S.I. units.

   (b) Power, P can be defined using the formula, $P = \dfrac{\text{Force} \times \text{Length}}{\text{Time}}$. Derive the unit for P in terms of S.I. base units.

2. Figure 1 shows a graph of speed, v against time, t obtained from the speed test of a car.

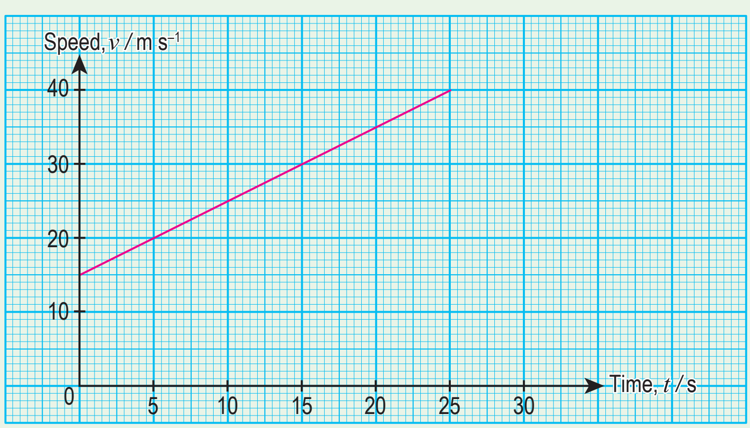


Figure 1

   (a) Determine the gradient of the graph v against t.

   (b) Determine the y-intercept of the graph when $t = 0$.

   (c) State the relationship between speed, v and time, t.

3. Hashim carried out an experiment to investigate the relationship between the mass of slotted weights and the period of oscillation, T of a spring as shown in Figure 2.

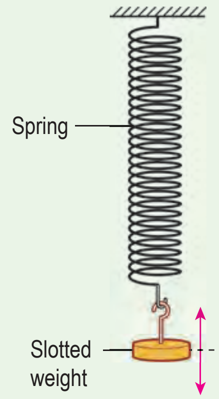


Figure 2

Hashim measured the time, t for 20 complete oscillations for different masses of slotted weights. The data obtained is shown in Table 1.

Table 1

Mass of slotted weights, m /g	20	40	60	80	100
Time for 20 oscillations, t / s	26.0	36.0	44.4	51.0	57.2
Period of oscillation, T					
T^2					

(a) Complete Table 1 by calculating the values of derived data T and T^2. State the appropriate units for both the physical quantities.

(b) Plot a graph of T^2 against m with appropriate scales. Draw the best fit line.

(c) Determine the gradient of the graph. Show clearly how it is done.

(d) If the experiment is done on the Moon, what is likely to happen to the gradient of the graph?

(e) How can an oscillating spring with slotted weights be used as a time measuring device with unit of measurement in seconds? ($T^2 = 4\pi^2 \frac{m}{k}$)

4. Encik Ahmad measured the time taken by five pupils in a 400 m run. Table 2 shows the recorded time.

Table 2

Pupil	Time, t / s	Speed, v / m s^{-1}
A	58.79	
B	60.06	
C	57.68	
D	59.87	
E	57.99	

(a) Complete the table by calculating the speed of the five pupils.

(b) Suggest an appropriate device that Encik Ahmad can use in this situation.

(c) Based on the data in Table 2, which pupil is the fastest runner?

(d) State one way to increase the accuracy of the recorded time.

5. Table 3 shows the formula for three physical quantities.

Table 3

Physical quantity	Formula
Force, F	$F = m \times a$
Area, A	$A = l \times l$
Time, T	–

(a) If force, F, area, A and time, T are chosen as new base quantities, then the mass, m and length, l become new derived quantities. State the mass, m and length, l in terms of F, A and T.

(b) What are the constraints faced by physicists if *FAT* is made as a new basic physical quantity?

6. Figure 3 shows graphs obtained from several experiments. Based on the shape of each graph, determine the relationship between the two physical quantities, p and q.

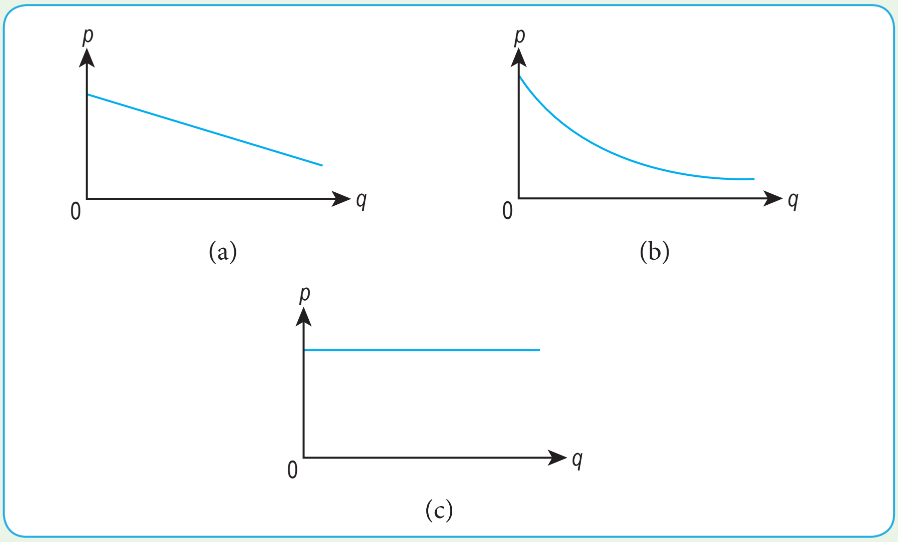


Figure 3

7. Figure 4 shows the reading on a mechanical stopwatch at the start and the end of an experiment. The mechanical stopwatch is used to measure the time taken for 20 complete oscillations of a simple pendulum of length, l.

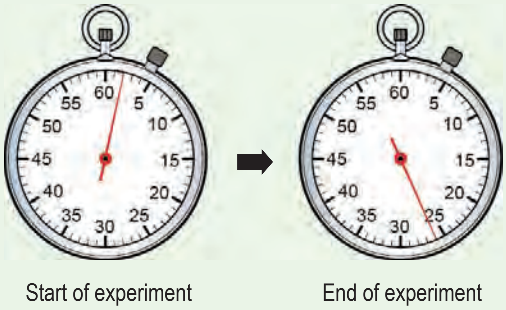


Figure 4

(a) (i) What is the time taken for the pendulum to make 20 complete oscillations?

(ii) Why is it necessary to take the time for 20 complete oscillations?

(iii) Suggest two ways to improve the experiment.

(b) (i) Determine the period of oscillation, T of this pendulum.

(ii) The relationship between length, l and period, T, of a simple pendulum is given by the equation, $l = \left(\frac{g}{4\pi^2}\right)T^2$.

Using the value of T in (b)(i), calculate the length of the pendulum, l.

[$g = 10 \text{ m s}^{-2}$]

8. Newton's Law of Gravitation can be expressed as follows:

$$F = \frac{GMm}{r^2}$$

F is the force
G is the gravitational constant
M and m are the masses
r is the distance between two bodies

(a) Based on the equation, give an example for each of the following:
 (i) base quantity (ii) derived quantity (iii) vector quantity

(b) Derive the unit of G in terms of S.I. base units.

Enrichment Corner

9. A driver wants to know the petrol consumption per km of a car in a journey of 300 km at constant speed. He installed a measuring device to record the remaining volume of petrol at every 50 km interval from the starting point. Table 4 shows the readings obtained.

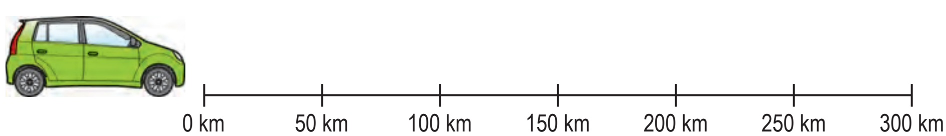


Figure 5

Table 4

Distance, s / km	50	100	150	200	250	300
Volume of petrol, V / ℓ	40	34	28	23	16	9

(a) The driver forgot to record the volume of petrol at the starting point of the journey. How can the driver estimate the volume of petrol at the start of the journey?

(b) Determine the petrol consumption of the car for the first 80 km. Show how you obtain the answer.

(c) If the petrol consumption of the car for every 50 km travelled can be saved by 10%, show the new values of V for every corresponding s in a table.

(d) Plot a graph of the new V against s.

Theme 2

Newtonian Mechanics

Newtonian mechanics is a branch of physics that studies the motion of an object. The topics in this theme investigate the concepts and factors that cause changes in the motion of an object.

CHAPTER 2

FORCE AND MOTION I

How is linear motion of an object investigated?

What causes the changes in the state of motion of an object?

Why are Newton's Laws of Motion important in the study of motion of an object?

Let's Study

2.1 Linear Motion
2.2 Linear Motion Graphs
2.3 Free Fall Motion
2.4 Inertia
2.5 Momentum
2.6 Force
2.7 Impulse and Impulsive Force
2.8 Weight

Information Page

Have you seen a personal transporter (PT) before? PT is a smart personal transporter as shown in the photograph. The device is used by security personnel to patrol in airports or shopping malls. This device is also used by tourists to make tours in tourist areas such as Perdana Botanical Gardens and Putrajaya.

This device is environmentally friendly because it runs on batteries. Fully charged batteries allow a rider to travel as far as 28 km on level roads.

Do you know that this transporting device does not have an accelerator or brakes? So, how does this device accelerate or stop? The rider needs to lean forward for the PT to start moving. If turning is required, the rider needs to turn his body to the left or to the right. To stop the device, the rider needs to stand upright.

Video on PT movement

http://bt.sasbadi.com/p4025a

Learning Standards and List of Formulae

2.1 Linear Motion

Photograph 2.1 shows various objects in motion. How do you describe motion in daily life? Motion in a straight line is called **linear motion.**

Photograph 2.1 *Various types of moving objects*

Linear motion can be described in terms of **distance, displacement, speed, velocity** and **acceleration**. Figure 2.1 shows a taxi waiting for passengers in a parking lot. The position of the taxi remains unchanged with time. Therefore, the taxi is said to be at **rest**.

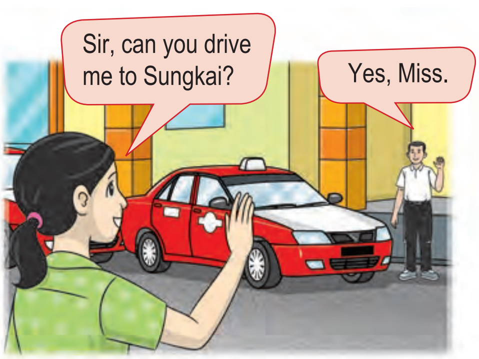


Figure 2.1 *Taxi at rest*

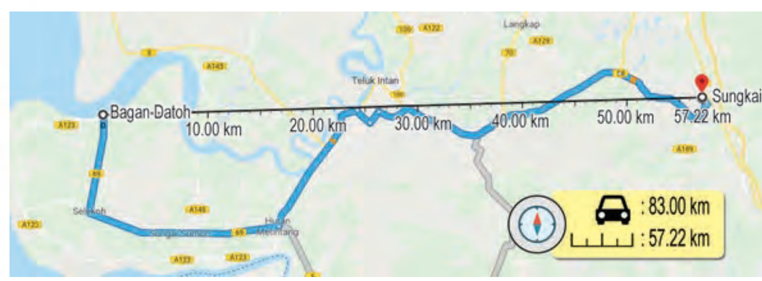


Figure 2.2 *Journey from Bagan Datoh to Sungkai*

Madam Chong wants to go to Sungkai from Bagan Datoh. Figure 2.2 shows the route marked in blue to be taken by the taxi through a distance of 83.00 km. However, after reaching Sungkai, the position of the taxi is 57.22 km due East from Bagan Datoh. In fact, 83.00 km and 57.22 km due East are the **distance** and the **displacement** respectively of the taxi movements. Table 2.1 shows the comparison between distance and displacement.

Table 2.1 *Comparison between distance and displacement*

Distance	Displacement
Length of route covered by an object	Shortest distance between the initial position and the final position in a specific direction
Its magnitude depends on the route covered by the object	Its magnitude is the straight-line distance between the initial position and the final position
A scalar quantity	A vector quantity

While riding in a taxi, Madam Chong observed that at times, the reading on the speedometer remains constant and at other times, the reading on the speedometer varies even along straight roads. Her observation can be summarised as shown in Figure 2.3.

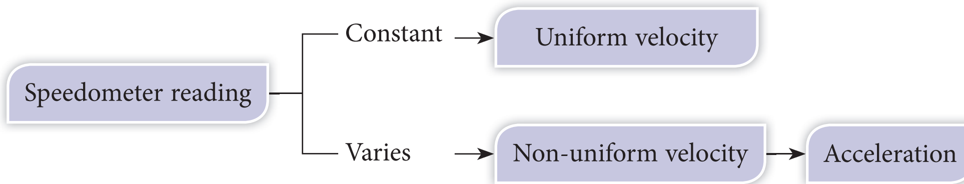
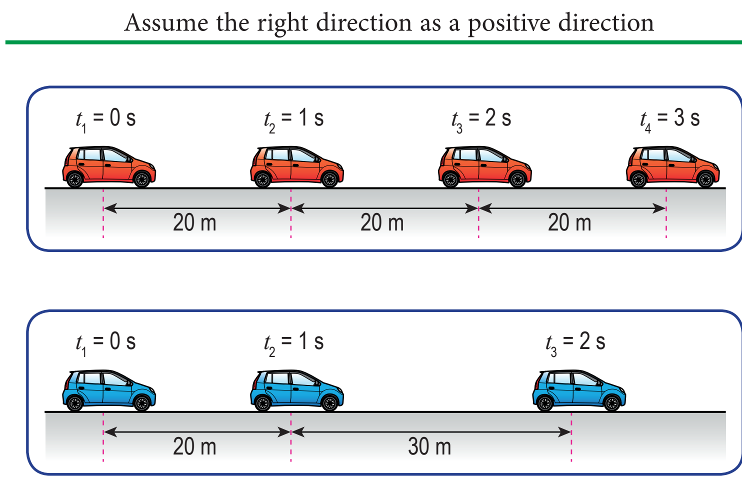


Figure 2.3 *Speedometer reading and motion of vehicle*

Figure 2.4 illustrates the difference in motions between uniform and non-uniform velocity of a car. Observe the displacement and the time intervals for both cars. Assume that the motion to the right is positive and to the left is negative.



The car is moving at **uniform velocity** because its rate of change of displacement remains the same.

The car is moving at **non-uniform velocity** because its rate of change of displacement is increasing.

Figure 2.4 *Motions at uniform and non-uniform velocity*

In Figure 2.4, the displacement of the blue car increases at equal time intervals. Therefore, the blue car is moving at increasing velocity. In this case, the blue car accelerates in the same direction as the motion of the car.

Conversely, if the displacement decreases at equal time intervals, the velocity decreases as shown in Figure 2.5. The car accelerates but in the opposite direction to the motion of the car.

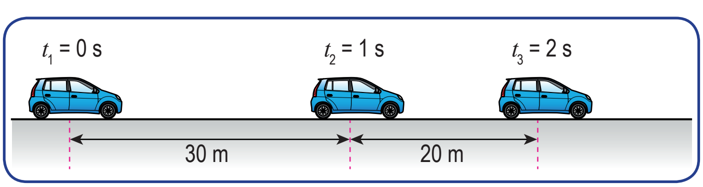


Figure 2.5 *Motion with decreasing velocity*

Examples of motion at non-uniform velocity

http://bt.sasbadi.com/p4027

Determining Distance, Displacement, Speed, Velocity and Acceleration

The motion of an object is investigated by determining the values of its distance travelled, displacement, speed, velocity and acceleration. The formulae to determine speed, velocity and acceleration are as follows:

Malaysiaku MY PRIDE

The Smart Tunnel in Kuala Lumpur has a dual function. It functions as a storage space and passage of flood flow as well as an alternative route with a shorter distance.

http://bt.sasbadi.com/p4028

$$\text{Speed} = \text{rate of change of distance travelled}$$
$$= \frac{\text{distance travelled}}{\text{time taken}}$$
$$v = \frac{d}{t}$$

$$\text{Velocity} = \text{rate of change of displacement}$$
$$= \frac{\text{displacement}}{\text{time taken}}$$
$$v = \frac{s}{t}$$

$$\text{Acceleration} = \text{rate of change of velocity}$$
$$= \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken for change of velocity}}$$
$$a = \frac{v - u}{t}$$

Observe the following examples to understand how to determine distance, displacement, speed, velocity and acceleration in linear motion.

Example 1

Figure 2.6 shows Radzi's run from *A* to *B* and then back to *C*. The total time taken is 20 s. Determine the
(a) distance
(b) displacement
(c) speed
(d) velocity
of Radzi's motion.

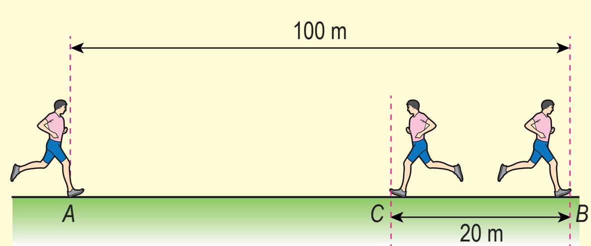


Figure 2.6

Solution:

(a) Distance = Length of route covered
= $AB + BC$
= 100 m + 20 m
= 120 m

(b) Displacement = Distance between initial position and final position in a specific direction
= $AB + BC$
= (100 m) + (–20 m)
= 80 m (to the right)

(c) Speed $= \dfrac{\text{Distance travelled}}{\text{Time taken}}$
$= \dfrac{120 \text{ m}}{20 \text{ s}}$
$= 6 \text{ m s}^{-1}$

(d) Velocity $= \dfrac{\text{Displacement}}{\text{Time taken}}$
$= \dfrac{80 \text{ m}}{20 \text{ s}}$
$= 4 \text{ m s}^{-1}$ (to the right)

Example 2

Muthu moves from O to B along the route OAB as shown in Figure 2.7. The time taken is 15 s.
Determine the
(a) distance
(b) displacement
(c) speed
(d) velocity
of Muthu's motion.

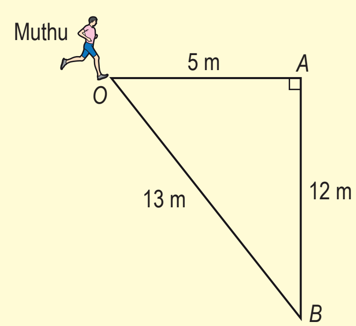


Figure 2.7

Solution:

(a) Distance = $OA + AB$
= 5 m + 12 m
= 17 m

(b) Displacement = Shortest straight line distance from O to B
= OB
= $\sqrt{5^2 + 12^2}$
= 13 m (in the direction of OB)

(c) Speed $= \dfrac{\text{Distance travelled}}{\text{Time taken}}$

$= \dfrac{17 \text{ m}}{15 \text{ s}}$

$= 1.13 \text{ m s}^{-1}$

(d) Velocity $= \dfrac{\text{Displacement}}{\text{Time taken}}$

$= \dfrac{13 \text{ m}}{15 \text{ s}}$

$= 0.87 \text{ m s}^{-1}$ (in the direction of *OB*)

Example 3

After landing on the runway, a plane slows down so that its velocity reduces from 75 m s^{-1} to 5 m s^{-1} in 20 s. What is the acceleration of the plane?

Info File

Deceleration is a condition in which the velocity of motion of an object is decreasing.

Solution:

Initial velocity, $u = 75 \text{ m s}^{-1}$, final velocity, $v = 5 \text{ m s}^{-1}$, time, $t = 20$ s

Acceleration, $a = \dfrac{v - u}{t}$

$= \dfrac{5 - 75}{20}$

$= -3.5 \text{ m s}^{-2}$

A ticker timer fitted with ticker tape as shown in Figure 2.8 is used to investigate linear motion of objects in the laboratory.

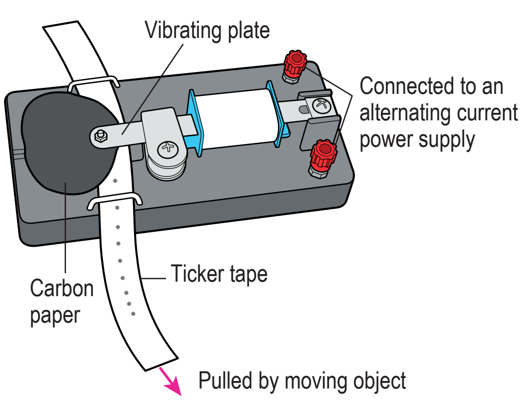


Figure 2.8 Ticker timer with ticker tape

A ticker timer works on alternating current of frequency 50 Hz to make 50 ticks in 1 second on a ticker tape.

The time interval between two adjacent dots is called one tick.

Therefore, 1 tick: $\dfrac{1}{50}$ s = 0.02 s

5 ticks: 5 × 0.02 s = 0.10 s

10 ticks: 10 × 0.02 s = 0.2 s

Figure 2.9 shows part of a ticker tape that is pulled by an object moving linearly.

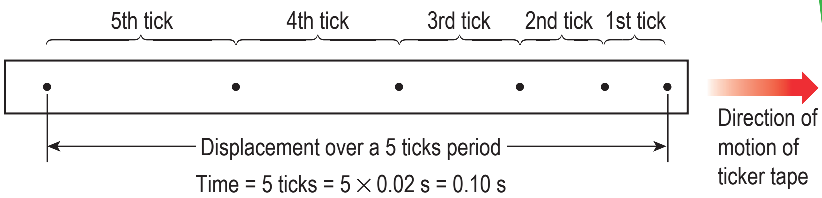


***Figure 2.9** Part of a ticker tape pulled by an object*

Info File

When an object moves along a straight line and does not go backwards, its distance and displacement are of the same value.

A ticker tape records the displacement of a moving object as well as the time taken. Subsequently, the velocity and acceleration can be calculated. Figures 2.10 and 2.11 show the calculations of velocity and acceleration of the linear motion of an object.

Calculating velocity

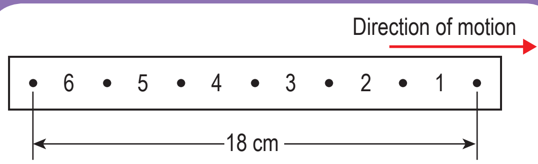


Figure 2.10

Displacement, s = 18 cm

Time taken, t = 6 ticks
= 6 × 0.02 s
= 0.12 s

$$\text{Velocity, } v = \frac{s}{t} = \frac{18\text{ cm}}{0.12\text{ s}} = 150\text{ cm s}^{-1}$$

Calculating acceleration

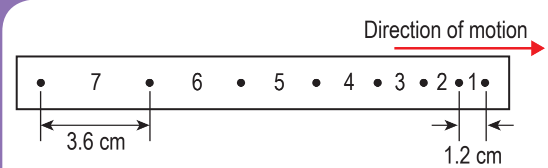


Figure 2.11

Initial velocity, u = velocity at the first tick

$$= \frac{1.2\text{ cm}}{0.02\text{ s}} = 60\text{ cm s}^{-1}$$

Final velocity, v = velocity at the seventh tick

$$= \frac{3.6\text{ cm}}{0.02\text{ s}} = 180\text{ cm s}^{-1}$$

Time between the final and initial velocity,
t = (7 – 1) ticks
= 6 ticks
= 6 × 0.02 s
= 0.12 s

$$\text{Acceleration, } a = \frac{v - u}{t} = \frac{(180 - 60)\text{ cm s}^{-1}}{0.12\text{ s}} = 1\,000\text{ cm s}^{-2}$$

We already know how to calculate velocity and acceleration of the linear motion of an object.

Let us carry out an activity using a ticker timer and ticker tape to determine the velocity and acceleration of a trolley.

2.1.2

Activity 2.1

Aim: To use a ticker tape to determine the displacement, velocity and acceleration of a trolley

Apparatus: Ticker timer, trolley, runway, alternating current power supply, retort stand and wooden block

Materials: Ticker tape and connecting wires

Instructions:

1. Set up the apparatus as shown in Figure 2.12. Raise one end of the runway slightly so that the trolley can move slowly down the runway.

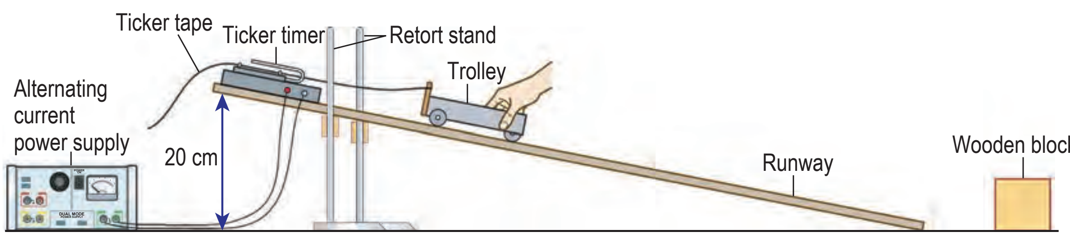


Figure 2.12

2. Attach a 100 cm ticker tape to the trolley, switch on the ticker timer and release the trolley. Observe the ticker tape obtained.
3. From the ticker tape, determine the displacement and calculate the average velocity of the trolley.
4. Raise the end of the runway further so that the trolley moves with a higher velocity down the runway.
5. Repeat steps 2 and 3. Then, calculate the acceleration of the trolley.
6. Rearrange the apparatus as shown in Figure 2.13.

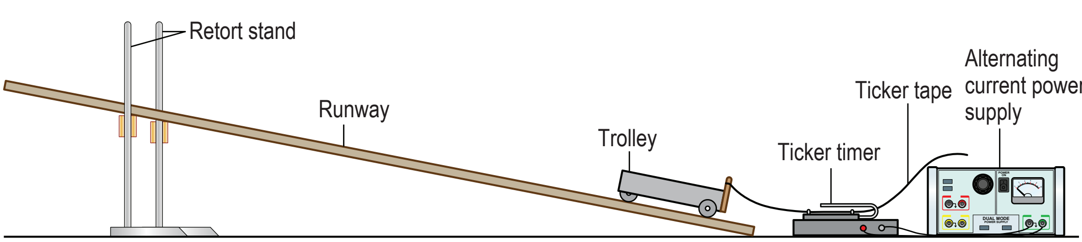


Figure 2.13

7. Push the trolley from the bottom of the runway and allow it to move up.
8. Stop the trolley when it starts to descend the runway.
9. From the ticker tape obtained, determine the deceleration of the trolley.

Discussion:

Discuss the patterns of motion obtained from the ticker tape.

If a long ticker tape is used, a large number of dots can be recorded on the ticker tape. As such, the ticker tape can be divided into strips with an equal number of ticks. These strips are cut and attached side by side on a piece of graph paper to form a ticker tape chart as shown in Figure 2.14.

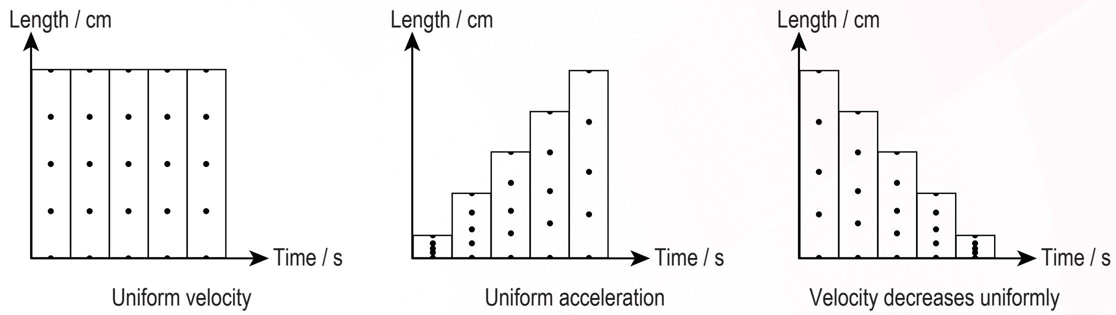


Figure 2.14 *Ticker tape chart*

Other than ticker timer, **photogate system and electronic timer** can be used to study linear motion more accurately. Figure 2.15 shows a photogate system and an electronic timer used with a non-motorised trolley moving on an inclined aluminium runway.

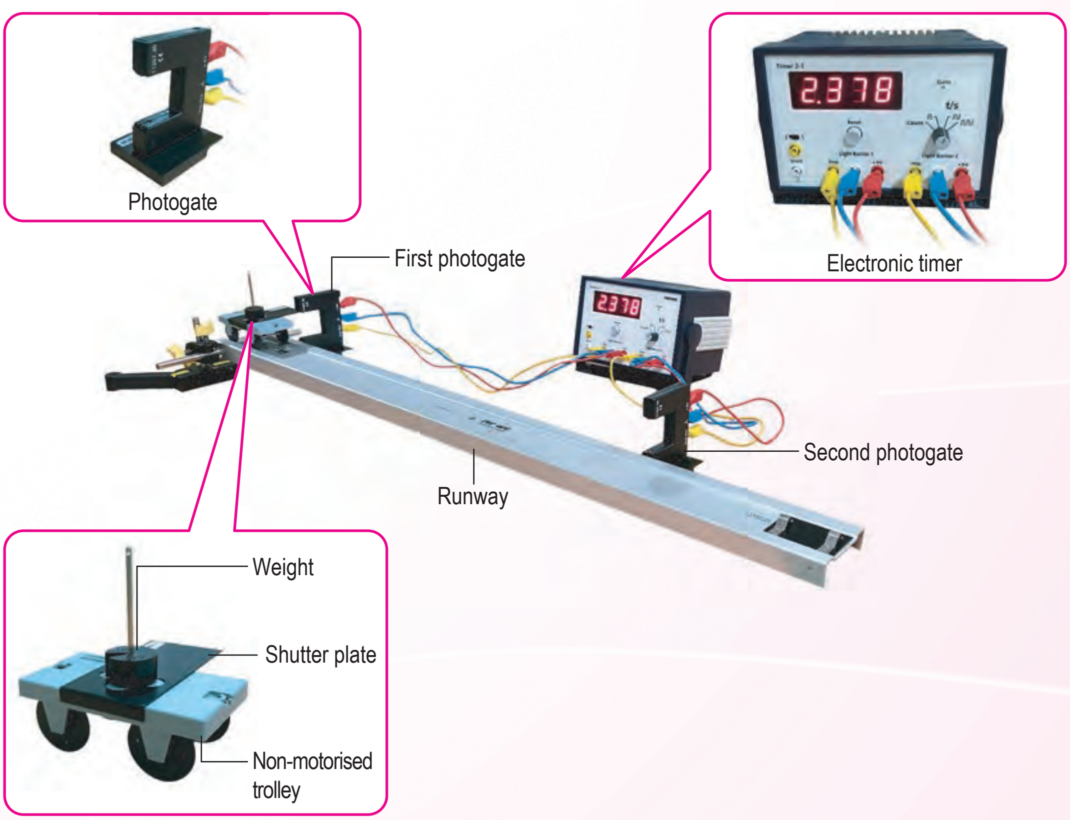


Figure 2.15 *Photogate system and electronic timer*

Activity 2.2

Aim: To use a photogate system and an electronic timer to determine the velocity and acceleration of a moving trolley

Apparatus: Photogate system and electronic timer, trolley and runway

Instructions:

1. Set up the apparatus as shown in the manual of the QR code.
2. Raise one end of the runway to a height of 15 cm.
3. Adjust the distance of separation between the two photogates, s = 40.0 cm.
4. Turn the electronic timer switch to the symbol . Release the trolley from the high end of the runway and catch the trolley after it passes the second photogate.
5. Record the total time, t in Table 2.2.
6. Remove the first photogate.
7. Turn the electronic timer switch to the symbol . Release the trolley again from its original point.
8. Record the time interval, Δt in Table 2.2.
9. Repeat steps 3 to 8 for s = 50.0 cm, 60.0 cm, 70.0 cm and 80.0 cm.

Manual on the use of photogate system and electronic timer

http://bt.sasbadi.com/p4034

Results:

Table 2.2

Distance of separation between two photogates, s / cm	40.0	50.0	60.0	70.0	80.0
Total time, t / s					
Time interval, Δt / s					
Final velocity, $v = \frac{s}{\Delta t}$ / cm s^{-1}					
Acceleration, $a = \frac{v}{t}$ / cm s^{-2}					

Discussion:

1. Based on the results in the table, determine the average acceleration of the trolley.
2. When s increased from 40.0 cm to 80.0 cm, the total time, t increased but the time interval Δt decreased. Why?

The use of a photogate system and electronic timer is more accurate because no ticker tape is attached to the trolley. As such, there will be no friction between the ticker tape and ticker timer affecting the motion of the trolley. An electronic timer can measure the time interval to an accuracy of 0.001 second compared to 0.02 second for a ticker timer. This short time interval enables us to determine velocity and acceleration of the trolley more accurately.

Solving Problems of Linear Motion Using Linear Motion Equations

Figure 2.16 shows a car moving with uniform acceleration.

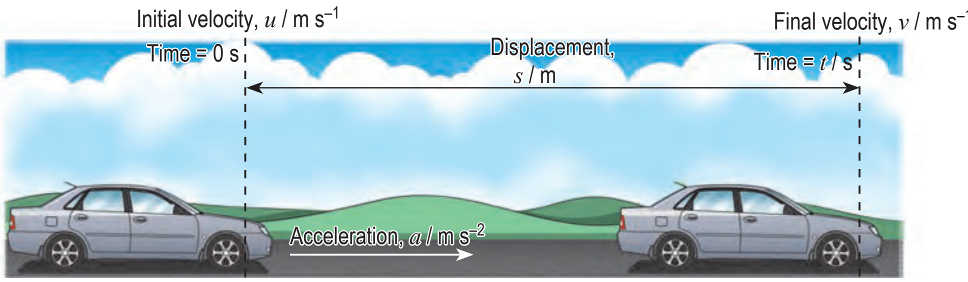


***Figure 2.16** Car moving with uniform acceleration*

Five physical quantities of linear motion with uniform acceleration can be expressed as four linear motion equations.

First linear motion equation

$$\text{Acceleration} = \frac{\text{Final velocity} - \text{initial velocity}}{\text{Time taken for change of velocity}}$$

$$a = \frac{v - u}{t}$$

$$at = v - u$$

$$\boldsymbol{v = u + at} \quad \text{\_\_\_\_\_\_ (1)}$$

Second linear motion equation

Displacement = Average velocity × time

$$\text{Displacement} = \left(\frac{\text{Initial velocity} + \text{final velocity}}{2}\right) \times \text{time}$$

$$\boldsymbol{s = \frac{1}{2}(u + v)t} \quad \text{\_\_\_\_\_\_ (2)}$$

Third linear motion equation

Substitute equation (1) into equation (2)

$$s = \frac{1}{2}[u + (u + at)]t$$

$$s = \frac{1}{2}(2u + at)t$$

$$\boldsymbol{s = ut + \frac{1}{2}at^2} \quad \text{\_\_\_\_\_\_ (3)}$$

Fourth linear motion equation

Square equation (1)

$$v^2 = (u + at)^2$$

$$v^2 = u^2 + 2uat + a^2t^2$$

$$v^2 = u^2 + 2a\left(ut + \frac{1}{2}at^2\right)$$

$$\boldsymbol{v^2 = u^2 + 2as} \quad \text{\_\_\_\_\_\_ (4)}$$

From equation (3)

$$s = ut + \frac{1}{2}at^2$$

Example 1

A school bus moves from rest with an acceleration of 2 m s^{-2} for 5 s. Calculate its velocity after 5 s.

Solution:

Step 1
List the given information in symbols.

Initial velocity, u = 0 m s^{-1}
Time, t = 5 s
Acceleration, a = 2 m s^{-2}
Final velocity, v = ?

Step 2
Identify and write down the formula used.

$$v = u + at$$

Step 3
Substitute numerical values in the formula and perform the calculations.

$$v = 0 + (2)(5)$$
$$= 10 \text{ m s}^{-1}$$

Example 2

As a sports car moves along a straight track, its velocity is 40 m s^{-1}. After 3 seconds, the sports car has reached 50 m s^{-1}. Calculate its displacement.

Solution:

Initial velocity, u = 40 m s^{-1}
Final velocity, v = 50 m s^{-1}
Time, t = 3 s
Displacement, s = ?

$$s = \frac{1}{2}(u + v)t$$
$$= \frac{1}{2}(40 + 50)(3)$$
$$= 135 \text{ m}$$

Example 3

An athlete starts his run from rest and achieves a maximum velocity after accelerating uniformly for 8.0 s. If the displacement of the athlete is 40 m, determine his acceleration.

Solution:

Initial velocity, u = 0 m s^{-1}
Time, t = 8.0 s
Displacement, s = 40 m
Acceleration, a = ?

$$s = ut + \frac{1}{2}at^2$$
$$40 = (0)(8) + \frac{1}{2}(a)(8^2)$$
$$40 = 0 + \frac{64a}{2}$$
$$a = \frac{2 \times 40}{64}$$
$$= 1.25 \text{ m s}^{-2}$$

Example 4

Maria rides a bicycle at a velocity of 8 m s^{-1}. She brakes suddenly and stops after a distance of 2 m. What is the acceleration of Maria and her bicycle?

Solution:

Initial velocity, u = 8 m s^{-1}
Final velocity, v = 0 m s^{-1}
Displacement, s = 2 m
Acceleration, a = ?

$$v^2 = u^2 + 2as$$
$$0^2 = 8^2 + 2(a)(2)$$
$$-4a = 64$$
$$a = -16 \text{ m s}^{-2}$$

Negative value shows that Maria accelerates at 16 m s^{-2} in the opposite direction to the motion of the bicycle.

Formative Practice 2.1

1. Explain the difference between
   (a) distance and displacement
   (b) speed and velocity

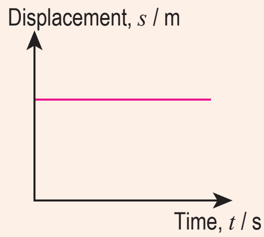
2. A car moving along a straight road at a velocity of 30 m s^{-1} reduces its velocity at a constant rate until it stops after 5 s. What is the acceleration of the car?

3. Aina rides a smart personal transporter at the Perdana Botanical Gardens. The transporter accelerates uniformly from a velocity of 1 m s^{-1} to a velocity of 5 m s^{-1} in 0.5 minutes. Calculate the displacement of the transporter.

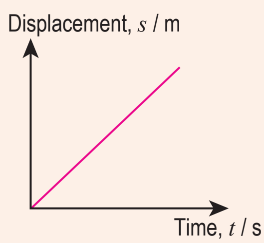
2.2 Linear Motion Graphs

Interpretation of graphs is important to understand the type of linear motion of an object. Figure 2.17 shows the interpretation of the types of linear motion from graphs.

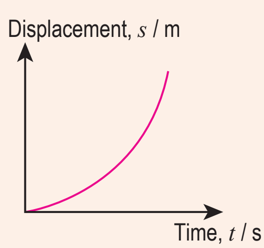
Displacement-time graph



(a) Object at rest

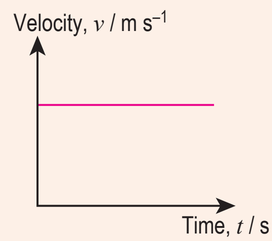


(b) Object moving with uniform velocity

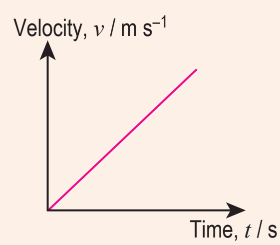


(c) Object moving with acceleration

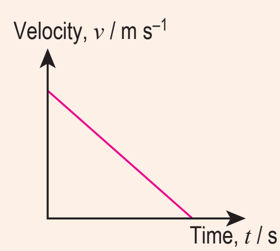
Velocity-time graph



(a) Object moving with uniform velocity

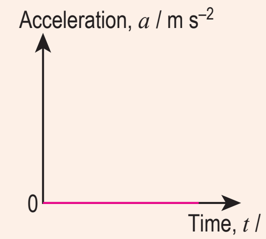


(b) Object moving with uniform acceleration

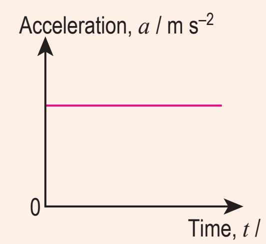


(c) Object moving with uniformly decreasing velocity

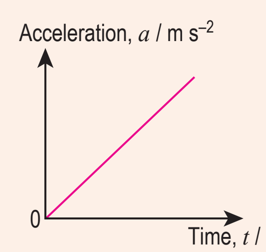
Acceleration-time graph



(a) Object moving with zero acceleration



(b) Object moving with uniform acceleration



(c) Object moving with increasing acceleration

For displacement-time graph:
Gradient of the graph = velocity

For velocity-time graph:
Gradient of the graph = acceleration
Area under the graph = displacement

Figure 2.17 Interpretation of types of linear motion from graphs

2.2.1

Analysis of Displacement-Time Graph to Determine Distance, Displacement and Velocity

Figure 2.18 shows the initial point and the final point of a motorcycle ridden to the right (positive direction) and then to the left (negative direction). The displacement-time graph in Figure 2.19 shows the linear motion of the motorcycle.

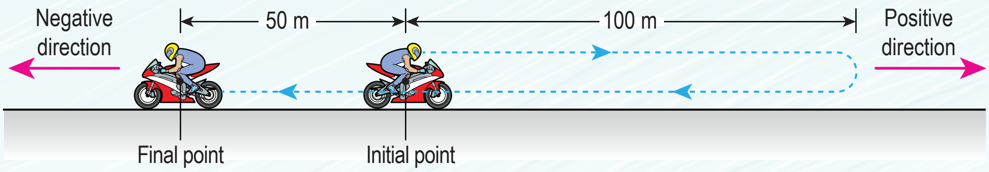


Figure 2.18 *Motion of a motorcycle being ridden*

Section *AB*:
Motorcycle is ridden for a distance of 100 m to the right for 5 seconds.

Gradient of graph $= \dfrac{100 - 0}{5 - 0}$
$= 20 \text{ m s}^{-1}$

Therefore, velocity of motorcycle is 20 m s^{-1} to the right.

Section *BC*:
Motorcycle stops for 3 seconds.

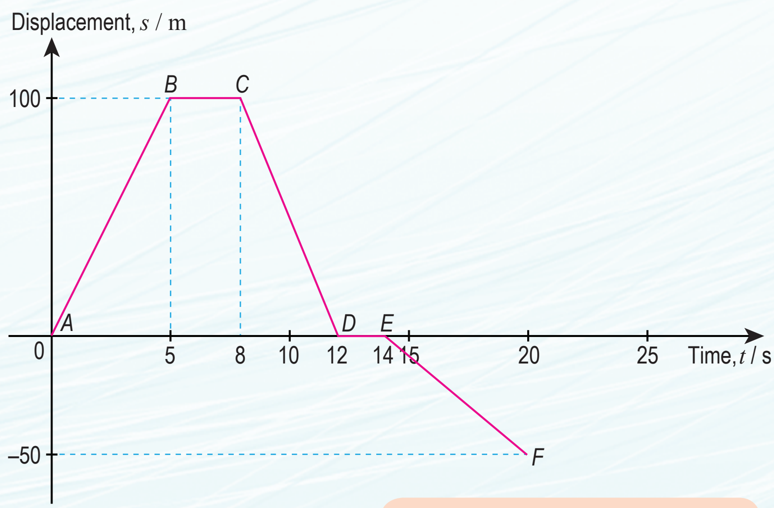
Gradient of graph $= 0 \text{ m s}^{-1}$

Therefore, velocity of motorcycle is 0 m s^{-1}.

Section *CD*:
Motorcycle is ridden back to initial point *A* in 4 seconds.

Gradient of graph $= \dfrac{0 - 100}{12 - 8}$
$= -25 \text{ m s}^{-1}$

Therefore, velocity of motorcycle is 25 m s^{-1} to the left.



Section *DE*:
Motorcycle is stationary at initial point for 2 seconds.

Gradient of graph $= 0 \text{ m s}^{-1}$

Therefore, velocity of motorcycle is 0 m s^{-1}.

Section *EF*:
Motorcycle is ridden to the left for a distance of 50 m for 6 seconds.

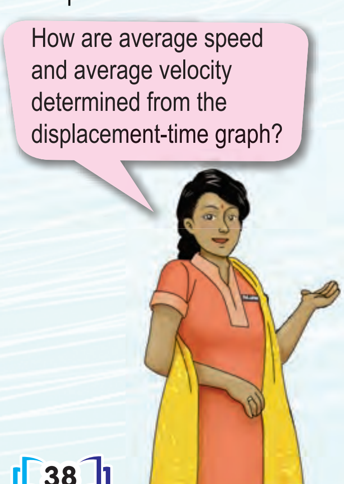
Gradient of graph $= \dfrac{-50 - 0}{20 - 14}$
$= -8.33 \text{ m s}^{-1}$

Therefore, velocity of motorcycle is 8.33 m s^{-1} to the left.

Distance travelled = 100 + 100 + 50
= 250 m

Displacement = 100 + (–100) + (–50)
= –50 m

Figure 2.19 *Analysis of displacement-time graph*



Distance travelled is 250 m in a total time of 20 s. Therefore, its average speed is

$= \dfrac{250}{20}$

$= 12.5 \text{ m s}^{-1}$

Overall displacement is –50 m in a total time of 20 s. Therefore, average velocity is

$= \dfrac{-50}{20}$

$= -2.5 \text{ m s}^{-1}$

Analysis of Velocity-Time Graph to Determine Distance, Displacement, Velocity and Acceleration

Figure 2.20 shows the linear motion of a bicycle. Figure 2.21 shows the velocity-time graph showing the motion of the bicycle.

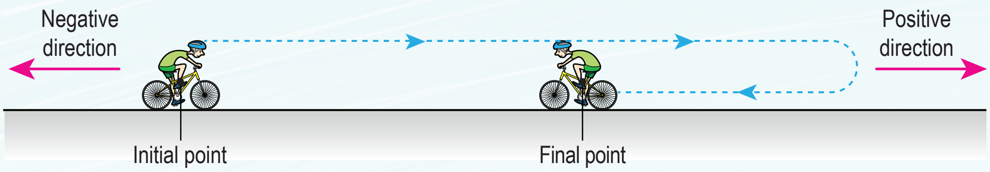
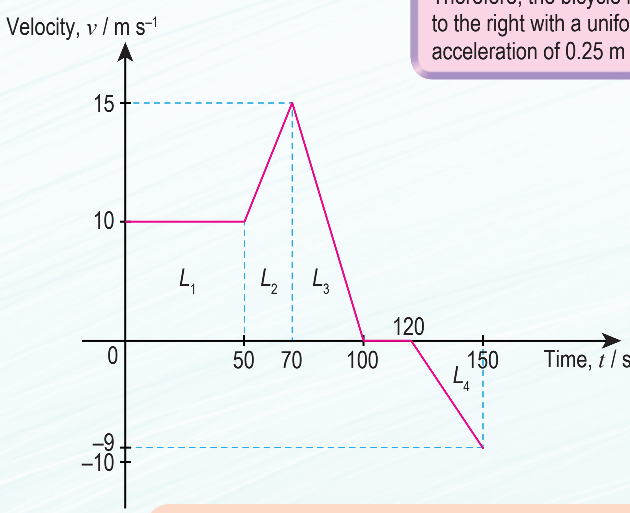


Figure 2.20 *Linear motion of a bicycle*

Time interval: 0 – 50 seconds
Gradient of the graph = 0 m s^{-2}
Therefore, the bicycle is moving to the right with a uniform velocity of 10 m s^{-1}.

Time interval: 50 – 70 seconds
Gradient of the graph $= \dfrac{15 - 10}{70 - 50}$
$= 0.25$ m s^{-2}
Therefore, the bicycle is moving to the right with a uniform acceleration of 0.25 m s^{-2}.

Time interval: 70 – 100 seconds
Gradient of the graph $= \dfrac{0 - 15}{100 - 70}$
$= -0.5$ m s^{-2}
Acceleration of bicycle = –0.5 m s^{-2}
The velocity of the bicycle gradually decreases. The bicycle accelerates at –0.5 m s^{-2} (in the opposite direction to the motion of the bicycle).



Time interval: 100 – 120 seconds
Gradient of the graph = 0 m s^{-2}
Its velocity is 0 m s^{-1}. Therefore, the bicycle has stopped and is at rest for 20 seconds.

Time interval: 120 – 150 seconds
Gradient of the graph $= \dfrac{-9 - 0}{150 - 120}$
$= -0.3$ m s^{-2}
Acceleration of bicycle = –0.3 m s^{-2}
The velocity of the bicycle gradually increases. The bicycle accelerates at –0.3 m s^{-2} (in the same direction as the motion of the bicycle).

Area, L_1 = 500 m, L_2 = 250 m, L_3 = 225 m, L_4 = 135 m
Total overall distance $= L_1 + L_2 + L_3 + L_4$
$= 500 + 250 + 225 + 135$
$= 1\,110$ m
Displacement to the right $= L_1 + L_2 + L_3$
$= 500 + 250 + 225$
$= 975$ m
Displacement to the left $= L_4$
$= 135$ m
Total displacement $= L_1 + L_2 + L_3 + L_4$
$= 500 + 250 + 225 + (-135)$
$= 840$ m to the right

Figure 2.21 *Linear motion of a bicycle*

Average speed and average velocity can be determined from the rate of change of the total distance and also from the rate of change of the total displacement. Try to determine the average speed and average velocity for the velocity-time graph above.

2.2.3

Activity 2.3

ICS

Aim: To use Tracker software to map the motion of a table tennis ball in the form of graphs

Apparatus: Retort stand, wooden block and metre rule

Materials: Table tennis ball and cellophane tape

Instructions:

1. Work in groups.
2. Scan the QR code to download Tracker software.
3. Set up the apparatus as shown in Figure 2.22 using two metre rules arranged in the shape of a "V" to form an inclined runway.

Download Tracker software

http://bt.sasbadi.com/p4040a

Instruction video on using Tracker software

http://bt.sasbadi.com/p4040b

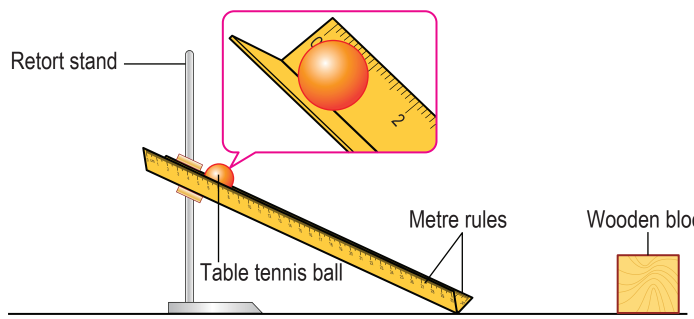


Figure 2.22

4. Record a video of the motion of the table tennis ball along a straight line.
5. Use Tracker software to analyse the motion of the table tennis ball in the video using displacement-time, velocity-time and acceleration-time graphs.
6. Figure 2.23 shows examples of graphs that you can obtain using the software.

Graph of horizontal displacement against time | Graph of vertical displacement against time | Graph of speed against time

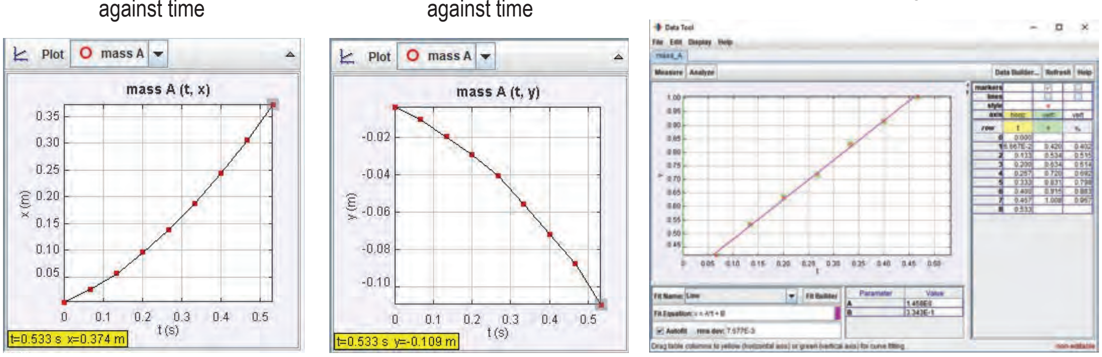


***Figure 2.23** Examples of graphs obtained*

7. Discuss and interpret the motion of the table tennis ball based on the graphs obtained.
8. Analyse the motion of the table tennis ball from the graphs.
9. Present your interpretation and analysis of the graphs.

Interpreting and Sketching Graphs

Interpreting displacement-time graphs can help to sketch velocity-time graphs and vice versa. Velocity-time graphs can also be interpreted into acceleration-time graphs and vice versa. The skill in interpreting and sketching graphs is important to solve linear motion problems. Study the examples given.

Example 1

Figure 2.24 shows the displacement-time graph of an object in linear motion.

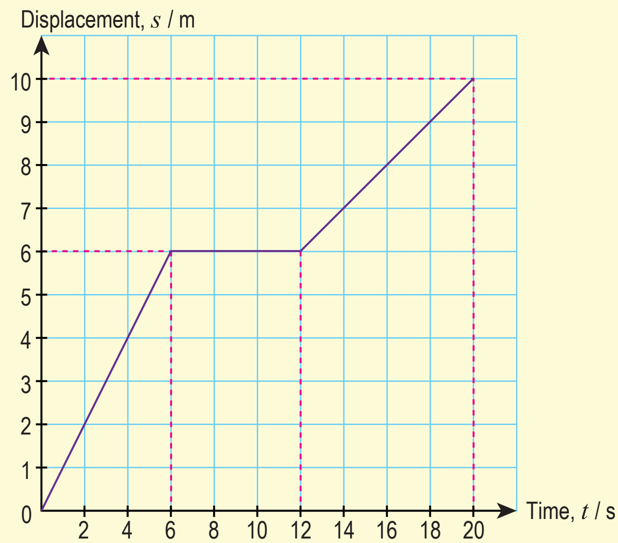


Figure 2.24

(a) Determine the velocity of the object at each stage of its motion.
(b) Interpret the displacement-time graph in Figure 2.24 to sketch a velocity-time graph.

Solution:

(a) Velocity = Gradient of displacement-time graph

Table 2.3

0 s to 6 s	$v_1 = \dfrac{6-0}{6-0}$ $= 1 \text{ m s}^{-1}$
6 s to 12 s	$v_2 = \dfrac{6-6}{12-6}$ $= 0 \text{ m s}^{-1}$
12 s to 20 s	$v_3 = \dfrac{10-6}{20-12}$ $= 0.5 \text{ m s}^{-1}$

(b) Velocity-time graph

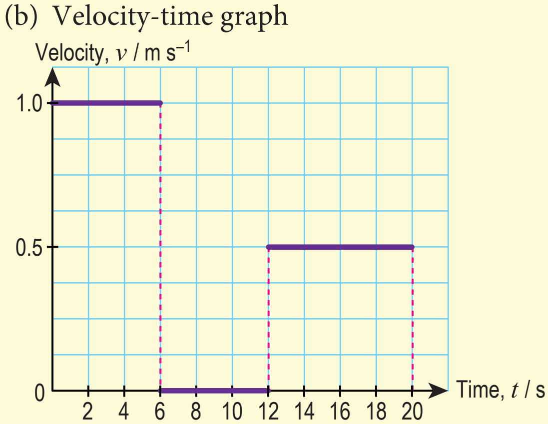


Figure 2.25

Example 2

Figure 2.26 shows the velocity-time graph that is plotted based on the linear motion of a car driven by Encik Kassim. He drives his car at a speed of 30 m s^{-1} and applies the brakes when he sees an obstruction on the road.

Interpret the velocity-time graph of the motion of his car and sketch

(a) displacement-time graph

(b) acceleration-time graph

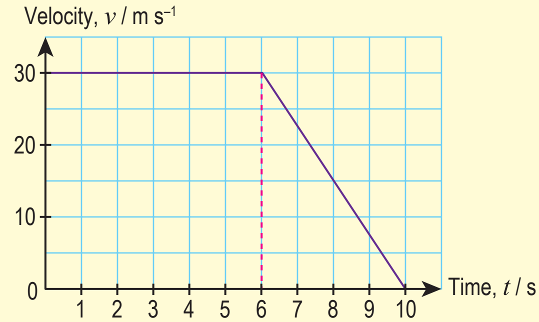


Figure 2.26

Solution:

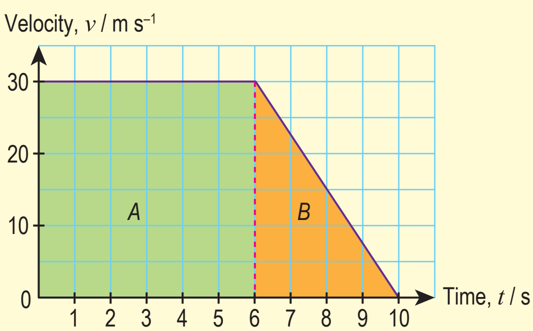


Figure 2.27

Table 2.4

Time	Displacement	Acceleration
0 s – 6 s	Displacement = area A = 30 × 6 = 180 m	Acceleration = gradient of the graph = 0 m s^{-2}
6 s – 10 s	Displacement = area B $= \frac{1}{2} \times 30 \times 4$ = 60 m	Acceleration $= \frac{0 - 30}{10 - 6}$ = –7.5 m s^{-2}

Displacement after 10 s,

s = 180 + 60

= 240 m

SMART INFO

To determine displacement, the area under the graph needs to be calculated. To simplify the calculation of area, the graph can be divided into several areas as shown in Figure 2.27.

(a) Displacement-time graph

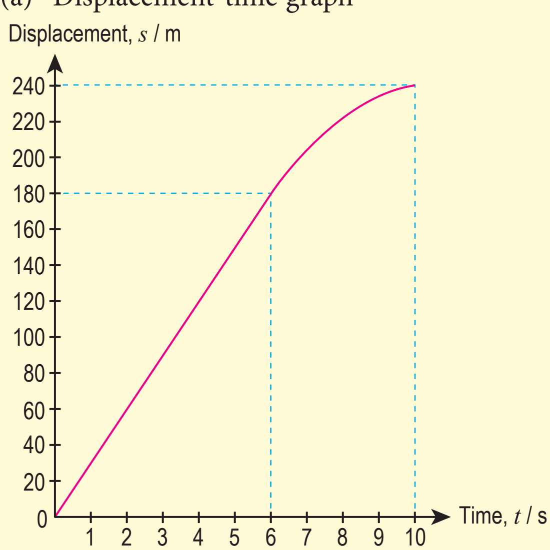


Figure 2.28

(b) Acceleration-time graph

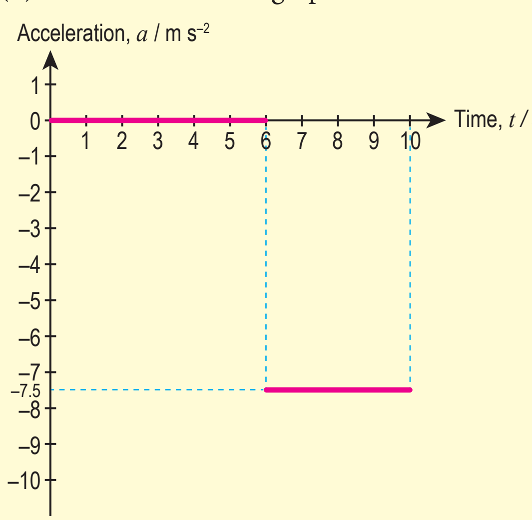


Figure 2.29

Solving Problems Involving Linear Motion Graphs

Example 1

The velocity-time graph in Figure 2.30 shows the motion of Hasri. Determine his
(a) acceleration
(b) displacement
(c) average velocity

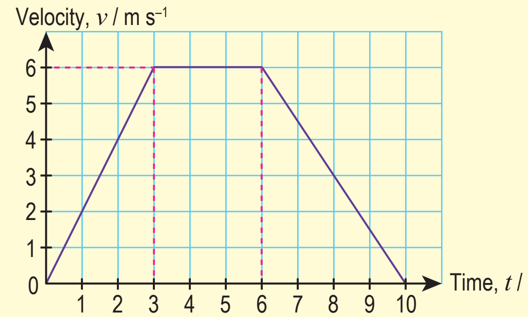


Figure 2.30

Solution:

(a) Acceleration = gradient of the graph

From 0 s – 3 s:

Acceleration $a_1 = \dfrac{6-0}{3-0}$

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

From 3 s – 6 s:

Acceleration $a_2 = 0 \text{ m s}^{-2}$

From 6 s – 10 s:

Acceleration $a_3 = \dfrac{0-6}{10-6}$

$= -1.5 \text{ m s}^{-2}$

(b) Displacement, s = area under the graph

= area of trapezium

$= \dfrac{1}{2}(3 + 10)(6)$

= 39 m

(c) Average velocity, $v = \dfrac{\text{Total displacement}}{\text{Time taken}}$

$= \dfrac{39}{10}$

$= 3.9 \text{ m s}^{-1}$

Example 2

Figure 2.31 shows the velocity-time graph of the linear motion of a car. Interpret the velocity-time graph and sketch a graph of:
(a) displacement against time
(b) acceleration against time

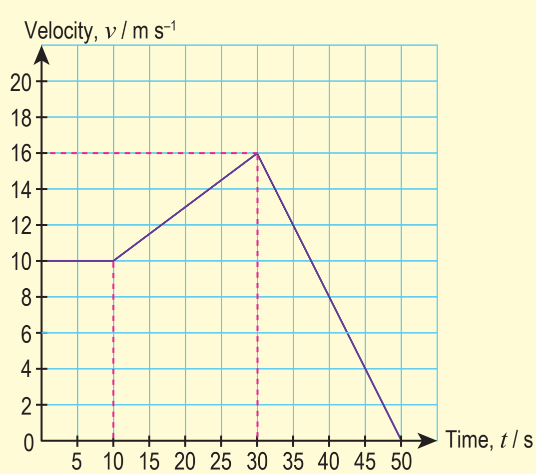


Figure 2.31

2.2.5

Solution:

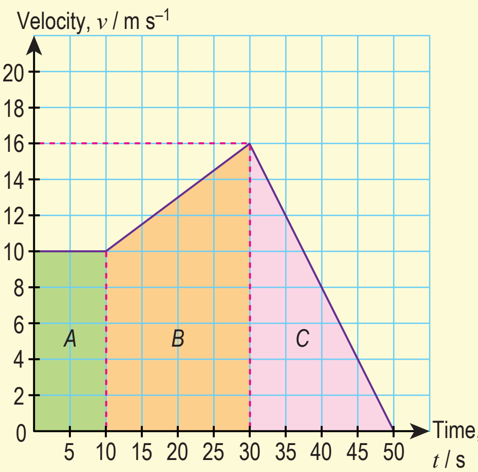


Figure 2.32

Table 2.5

Time	Displacement	Acceleration
0 s – 10 s	Displacement = area A = 10×10 = 100 m	Acceleration = gradient of the graph = 0 m s^{-2}
10 s – 30 s	Displacement = area B = $\frac{1}{2}(10 + 16)(20)$ = 260 m	Acceleration = $\frac{16 - 10}{30 - 10}$ = 0.3 m s^{-2}
30 s – 50 s	Displacement = area C = $\frac{1}{2} \times 20 \times 16$ = 160 m	Acceleration = $\frac{0 - 16}{50 - 30}$ = –0.8 m s^{-2}

Displacement after 30 s = 100 + 260
= 360 m

Displacement after 50 s = 100 + 260 + 160
= 520 m

(a) Displacement-time graph

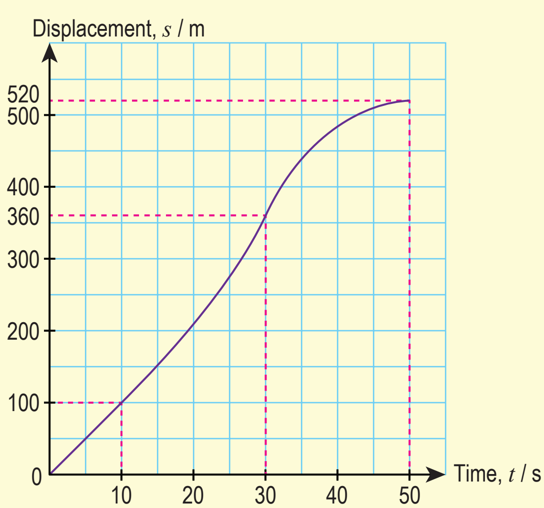


Figure 2.33

(b) Acceleration-time graph

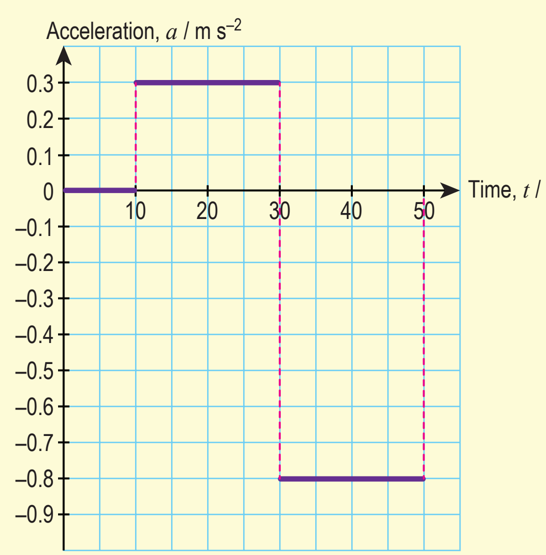


Figure 2.34

Formative Practice 2.2

1. How do you determine
   (a) velocity from a graph of displacement against time?
   (b) acceleration from a graph of velocity against time?
   (c) displacement from a graph of velocity against time?

2. Based on Figure 2.35, describe the motion of the object from O to D.

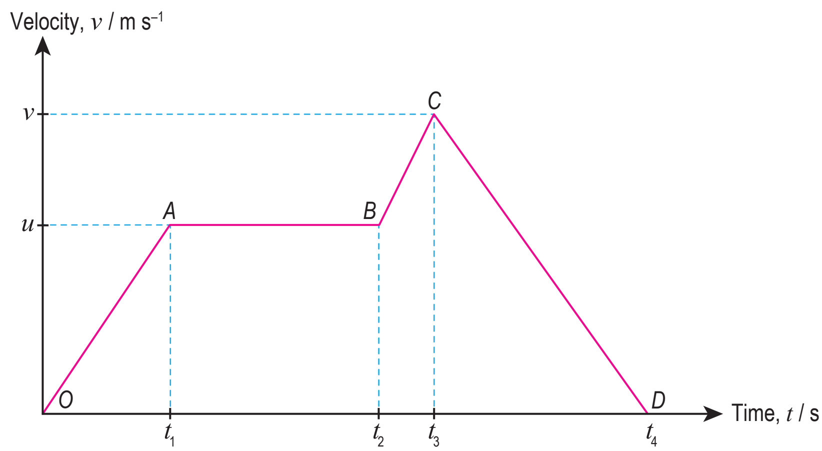


Figure 2.35

3. Figure 2.36 shows Rokiah taking 3 minutes to walk to the sundry shop located 400 m to the right of her house. After 1 minute, she buys an ice cream and walks to the playground located 300 m from the sundry shop in 2 minutes. She sits and rests on a bench near the playground for 2 minutes. Then, using a shortcut to return to her house, Rokiah reaches her house in 2 minutes.
   (a) What is the average velocity of the motion of Rokiah from
      (i) house to the sundry shop?
      (ii) sundry shop to the playground?
      (iii) playground to the house?
   (b) Calculate Rokiah's average speed.

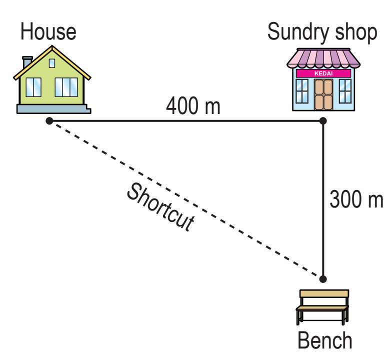


Figure 2.36

4. A car is driven from rest and accelerated at 4 m s^{-2} for 8 s along a straight road. The car is driven at the constant velocity for 20 s and then its brakes are applied. The car reduces its velocity at the rate of 2 m s^{-2} till it stops. Sketch a graph of:
   (a) acceleration against time
   (b) velocity against time
   (c) displacement against time

2.3 Free Fall Motion

Free Fall Motion and Gravitational Acceleration

An object experiences **free fall** if the motion of the object is affected only by **gravitational force**. This implies a free falling object **does not experience the action of other forces** such as air resistance or friction.

Photograph 2.2 shows a coconut falling from a coconut tree. Is this a free fall motion?

Carry out Activity 2.4 and Activity 2.5 involving free fall motion.

***Photograph 2.2** Coconut falling from a coconut tree*

Activity 2.4

Aim: To watch a video on free fall motion

Instructions:
Scan the QR code or visit the website to watch a video on free fall motion.

Discussion:
What are your observations on the free fall motion shown in the video?

Video on free fall motion

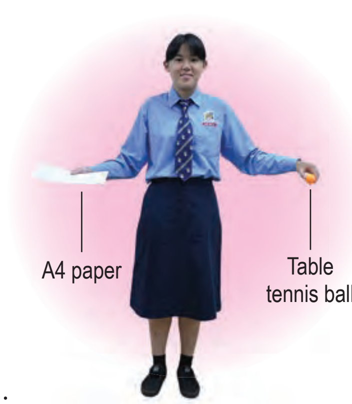
http://bt.sasbadi.com/p4046

Activity 2.5

Aim: To investigate the motion of falling objects

Materials: Table tennis ball and a piece of A4 paper

Instructions:
1. Work in pairs.
2. Hold a piece of A4 paper in the right hand and a table tennis ball in the left hand as shown in Photograph 2.3.
3. Release the paper and table tennis ball simultaneously from the same height.
4. Observe the motion of the paper and table tennis ball.
5. Repeat steps 2 to 4 with the A4 paper crumpled into a ball.



Photograph 2.3

Discussion:
1. Why do the falling paper and table tennis ball reach the floor at different times in the first try?
2. The paper used in step 2 and step 5 is the same piece of paper. Why does the paper before and after being crumpled fall at different rates?

2.3.1

In daily life, we see that heavy objects fall and reach the ground faster than light objects. This is due to other forces such as air resistance. Observe Figure 2.37.

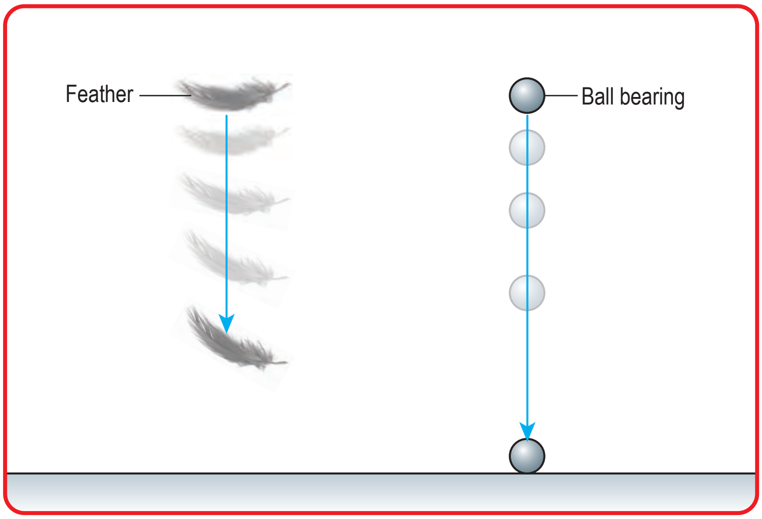


Figure 2.37 *Motion of falling objects in air*

INTEGRATION OF **HISTORY**

From 384–322 B.C., Aristotle concluded that the rate of an object falls depends on the weight, shape and orientation of the object. However, Galileo Galilei (1564–1642) discovered that objects fall with the same acceleration if air resistance is ignored.

Objects of different masses fall with the same acceleration if air resistance does not exist. This can happen in a vacuum. Observe Figure 2.38. A feather and a ball bearing released in a vacuum will reach the floor at the same time. The free fall that you watched in the video in Activity 2.4 was actually performed in a vacuum.

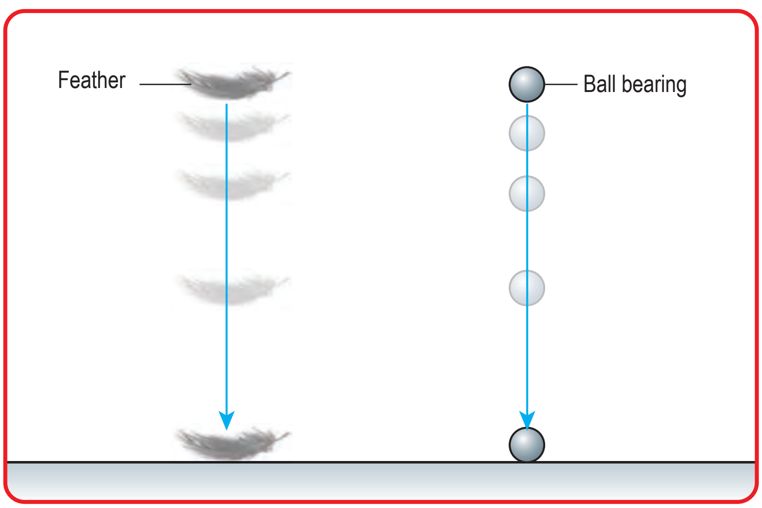


Figure 2.38 *Free fall in a vacuum*

Video of object falling in normal condition and in a vacuum

http://bt.sasbadi.com/p4047

The acceleration of a free falling object caused by gravitational force is known as **gravitational acceleration**, *g*. The average value of Earth's gravitational acceleration is 9.81 m s^{-2}. The velocity of a free falling object increases by 9.81 m s^{-1} per second in uniform gravitational field close to the surface of the Earth. When a heavy object falls in the gravitational field, air resistance can be ignored. The object is in **free fall** motion.

2.3.1

Determining the Value of Gravitational Acceleration

An object that falls freely in the gravitational field has gravitational acceleration. As such, the value of gravitational acceleration can be determined by measuring the acceleration of a heavy object such as a steel ball in a physics laboratory. Let us use a photogate system and an electronic timer to determine gravitational acceleration, g.

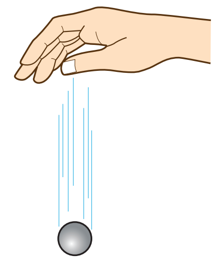


Figure 2.39 *Releasing a steel ball*

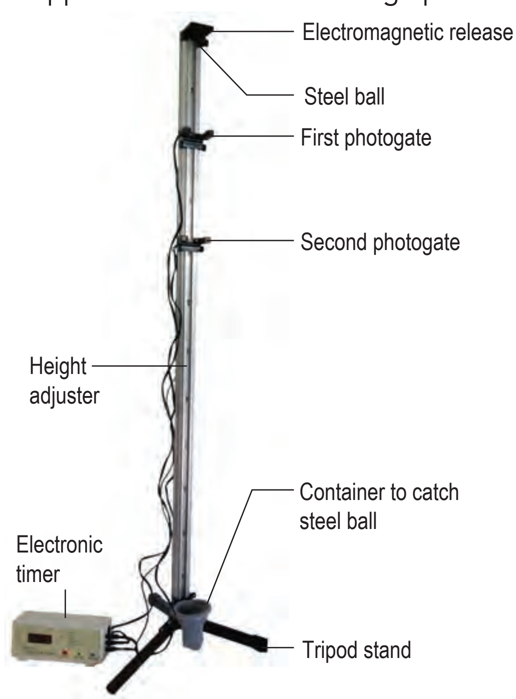
Experiment 2.1

Aim: To determine Earth's gravitational acceleration

Apparatus: Photogate system and electronic timer, electromagnetic release, steel ball and container to catch steel ball released

Procedure:

1. Scan the QR Code or visit the website given to download the manual on the use of the photogate and electronic timer.
2. Set up the apparatus as shown in Photograph 2.4.



Photograph 2.4

Manual for the use of photogate and electronic timer for the experiment on free fall

http://bt.sasbadi.com/p4048a

Alternative method using ticker tape

http://bt.sasbadi.com/p4048b

3. Place the second photogate so that the distance is 30.0 cm away from the first photogate.
4. Ensure the steel ball can fall through both photogates into the container.
5. Release the steel ball from the electromagnetic release.
6. Record the time when the steel ball passes through the first photogate as t_1 and the second photogate as t_2 in Table 2.6.
7. Repeat steps 3 to 6 with distances 40.0 cm, 50.0 cm, 60.0 cm and 70.0 cm.

Results:

Table 2.6

Distance between two photogates, h / cm	Time when the steel ball passes through photogates		Gravitational acceleration, g / m s^{-2}
	t_1 / s	t_2 / s	
30.0			
40.0			
50.0			
60.0			
70.0			

Analysis of data:

1. Determine the value of g using the formula $g = \dfrac{2h}{t_2^2 - t_1^2}$.
2. Calculate the average value of g.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

1. Compare the average value of g from this experiment with the standard value of g at the equator, 9.78 m s^{-2}. Why are these two values different?
2. Explain one precaution to improve the accuracy of the results in this experiment.

The value of gravitational acceleration, g changes from one place to another. For example, the value of g at the equator is 9.78 m s^{-2} while the value of g at the Earth's poles is 9.83 m s^{-2}. This is because Earth is actually not a perfect sphere.

Figure 2.40 shows that the distance from the equator to the centre of the Earth is further than the distance from the poles to the centre of the Earth. As such, the value of g is smaller at the equator than at the Earth's poles. Generally, the value of gravitational acceleration on the surface of the Earth, g used in calculations is 9.81 m s^{-2}.

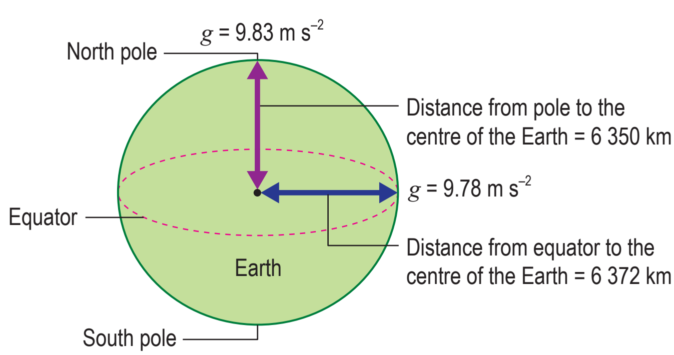


Figure 2.40 *Different distances from the centre of the Earth*

Solving Problems Related to Free Falling Objects

Objects thrown vertically upwards or released and falls downwards experience gravitational acceleration, g. Therefore, the equations of linear motion below can be applied to free falling objects.

$$v = u + gt \qquad s = ut + \frac{1}{2}gt^2 \qquad v^2 = u^2 + 2gs$$

In solving problems, our assumptions are upward motion is motion in the positive direction and downward motion is motion in the negative direction as shown in Figure 2.41.

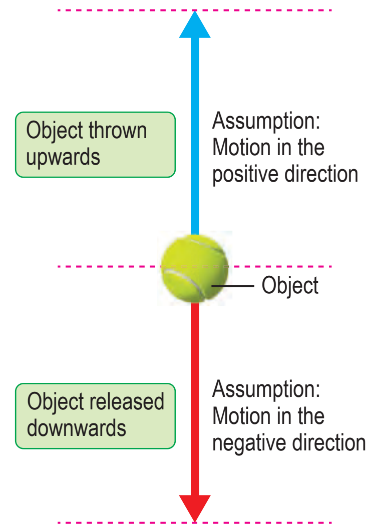


***Figure 2.41** Assumption of direction of an object's vertical motion*

Example 1

Amirah threw a ball vertically upwards with an initial velocity of 10 m s^{-1}. Calculate the:
(a) time for the ball to achieve maximum height
(b) maximum height that can be reached by the ball
Ignore air resistance. [g = 9.81 m s^{-2}]

SMART INFO
Ball moves upwards, u is positive but g is negative.

Solution:

(a) **Step 1**
List the given information in symbols.

Initial velocity , u = 10 m s^{-1}
Final velocity at maximum height, v = 0 m s^{-1}
Acceleration, g = –9.81 m s^{-2}

Step 2
Identify and write down the formula used.

$v = u + gt$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$0 = 10 - 9.81t$$
$$t = \frac{10}{9.81}$$
$$= 1.02 \text{ s}$$

(b)
$$v^2 = u^2 + 2gs$$
$$0 = 10^2 + 2(-9.81)s$$
$$s = \frac{10^2}{2 \times 9.81}$$
$$= 5.10 \text{ m}$$

SMART INFO
The equation $s = ut + \frac{1}{2}gt^2$ can also be used.
$$s = ut + \frac{1}{2}gt^2$$
$$= 10(1.02) + \frac{1}{2}(-9.81)(1.02)^2$$
$$= 5.10 \text{ m}$$

2.3.2 2.3.3

Example 2

Chan released a stone from a cliff of 10 m height. Determine
(a) the time taken for the stone to reach the bottom of the cliff
(b) the velocity of the stone just before it touches the ground
Ignore air resistance. [$g = 9.81$ m s^{-2}]

Solution:

(a) $s = ut + \frac{1}{2}gt^2$

$-10 = (0)t + \frac{1}{2}(-9.81)t^2$

$2 \times (-10) = (-9.81)t^2$

$t = \pm\sqrt{\frac{-20}{-9.81}}$

$= 1.43$ s

($t = -1.43$ is ignored)

(b) $v^2 = u^2 + 2gs$

$= 2 \times (-9.81) \times (-10)$

$v = \pm\sqrt{2 \times (-9.81) \times (-10)}$

$= \pm 14.0$ m s^{-1}

$v = -14.0$ m s^{-1}

($v = 14.0$ m s^{-1} is ignored because the stone moves downwards).

SMART INFO

Formula $v = u + gt$ can also be used

$v = -9.81 \times 1.43$

$= -14.0$ m s^{-1}

Formative Practice 2.3

1. What is meant by free fall?
2. A light hollow plastic ball and a solid steel ball of the same size are released from the cliff of a hill. Will both balls reach the foothill at the same time? Explain your answer.
3. An object thrown vertically upwards reached a maximum height of 5.0 m. Calculate:
   (a) the velocity of the object when thrown
   (b) the time taken for the object to reach its maximum height
   (c) the time required for the object to return to its original level
   Ignore air resistance. [$g = 9.81$ m s^{-2}]
4. A tennis ball that is released falls vertically from a building of height 50 m. Calculate:
   (a) the time taken for the ball to reach the base of the building
   (b) the velocity of the ball just before hitting the base of the building
   (c) the vertical distance passed at the third second
   Ignore air resistance. [$g = 9.81$ m s^{-2}]

2.3.3

2.4 Inertia

Concept of Inertia

Figure 2.42 shows objects placed on a table remain stationary even though the table cloth under the objects is jerked by the entertainer. This is due to **inertia**.

Inertia is the tendency of an object to remain at rest or, if moving, to continue its motion in a straight line at uniform velocity. The concept of inertia is explained in Newton's First Law of Motion.

Newton's First Law of Motion
Newton's First Law states that an object will remain at rest or move at uniform velocity unless acted upon by an external force.

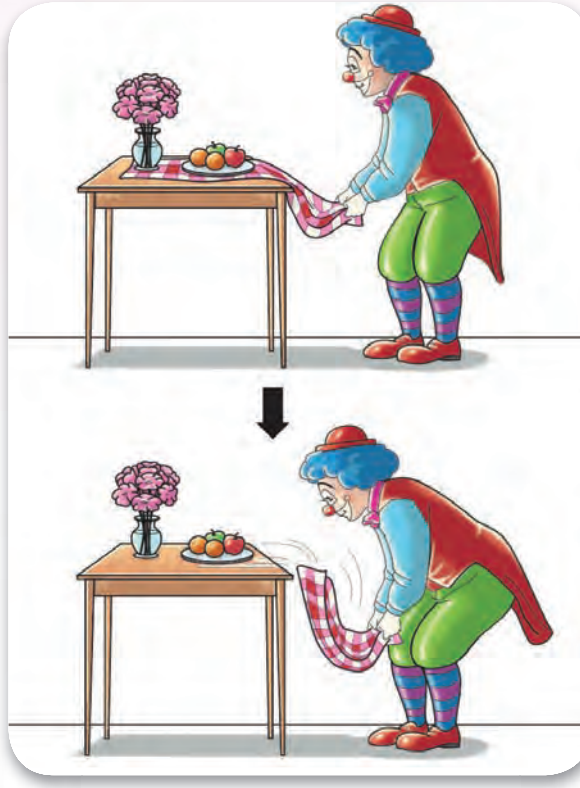


Figure 2.42 *An entertainer jerks a table cloth without moving the objects on the table*

Activity 2.6

Aim: To demonstrate the concept of inertia

Materials: Glass filled with water, coin and thin cardboard

Instructions:

1. Arrange the materials as shown in Figure 2.43.

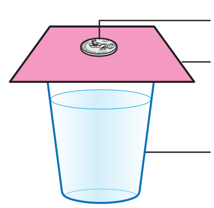


Figure 2.43

2. Jerk the cardboard under the coin horizontally.

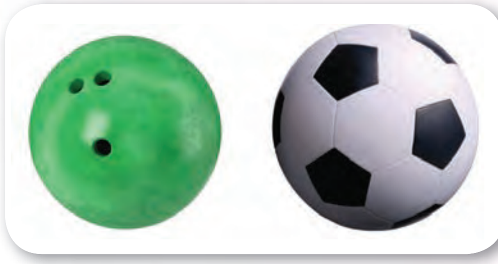
Discussion:

1. Why is the coin not moving with the thin cardboard?
2. What happens if the cardboard is pulled slowly? Explain your answer by referring to Newton's First Law of Motion.

2.4.1

Recognising the Relationship between Inertia and Mass

Photograph 2.5 shows a bowling ball and a football. Is it easier to move a bowling ball or a football? Which ball is difficult to stop when in motion?



***Photograph 2.5** Two balls of different masses*

An object with a bigger mass is more difficult to set in motion or stop from moving as compared to a lighter object. What is the relationship between mass and inertia? Let us carry out an experiment using a simple inertial balance.

Experiment 2.2

Inference: Inertia of an object depends on its mass

Hypothesis: The larger the mass of an object, the larger the inertia of the object

Aim: To study the relationship between inertia and mass

Variables:

(a) Manipulated variable: Mass of plasticine, m
(b) Responding variable: Period of oscillation, T
(c) Constant variable: Distance between G-clamp and plasticine

Apparatus: Stopwatch, G-clamp, ruler and jigsaw blade

Materials: Plasticine of mass 20.0 g, 30.0 g, 40.0 g, 50.0 g and 60.0 g

Procedure:

1. Set up the apparatus as shown in Figure 2.44.
2. Fix a piece of 20.0 g plasticine to the free end of the jigsaw blade.
3. Displace the free end of the jigsaw blade horizontally and release it so that the plasticine oscillates.
4. Record the time, t_1 for 10 complete oscillations of the plasticine in Table 2.7.
5. Repeat steps 3 and 4 and record the time as t_2.
6. Repeat steps 2 to 5 using plasticine of mass 30.0 g, 40.0 g, 50.0 g and 60.0 g.

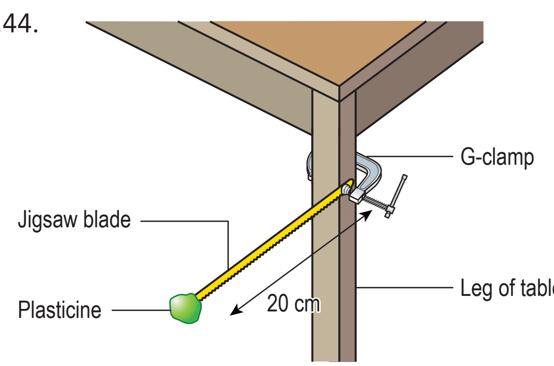


Figure 2.44

Results:

Table 2.7

Mass of plasticine m / g	Time for 10 complete oscillations, t / s			Period of oscillation T / s
	t_1	t_2	$t_{average}$	
20.0				
30.0				
40.0				
50.0				
60.0				

Analysis of data:

1. Determine the period of oscillation, T of the plasticine, with the following equation:

$$T = \frac{t_{average}}{10}, \text{ where } t_{average} = \frac{t_1 + t_2}{2}$$

2. Plot a graph of T^2 against m.
3. Based on your graph, state the relationship between period of oscillation, T and mass of plasticine, m.
4. Explain how the relationship between mass and inertia is determined from this experiment.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

1. How can this apparatus set up be used to determine the mass of an object?
2. Explain one precaution to improve the accuracy of the results.

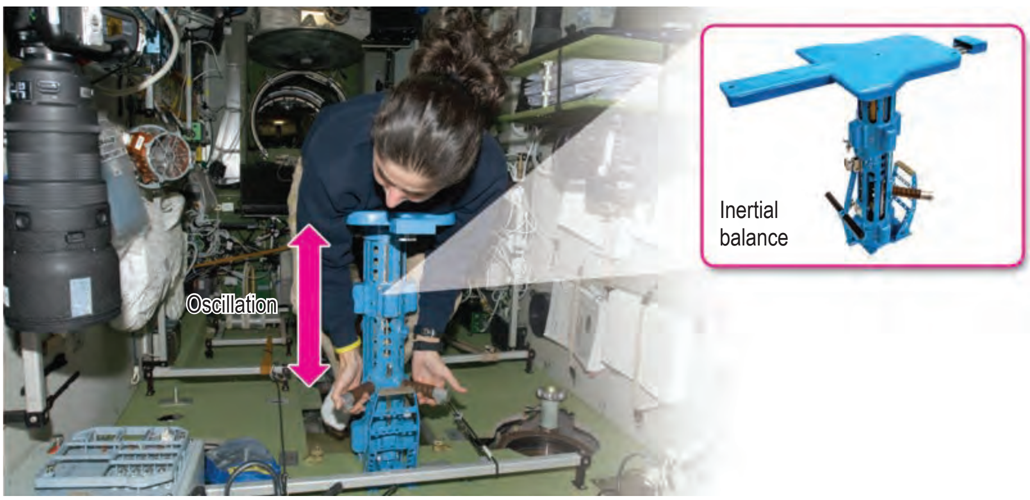
Experiment 2.2 shows that the inertia of an object is related to its mass. The horizontal oscillations in an inertial balance are not influenced by gravitational force. The period of horizontal oscillation of the inertial balance depends only on the mass of the plasticine. The larger the mass of an object, the larger the inertia of the object.

Effects of Inertia in Daily Life

Astronauts in a spaceship such as the International Space Station (ISS) are in a condition of zero gravity. Under the condition of zero gravity, only the inertial balance can be used to measure mass. Photograph 2.6 shows a special type of inertial balance used by astronauts. The periods of oscillation of astronauts are used to determine their body mass.

Inertial balance video

http://bt.sasbadi.com/p4055



Photograph 2.6 *An astronaut using an inertial balance*

Inertia can have good and bad effects to our daily lives. Let us discuss situations that involve inertia.

Activity 2.7

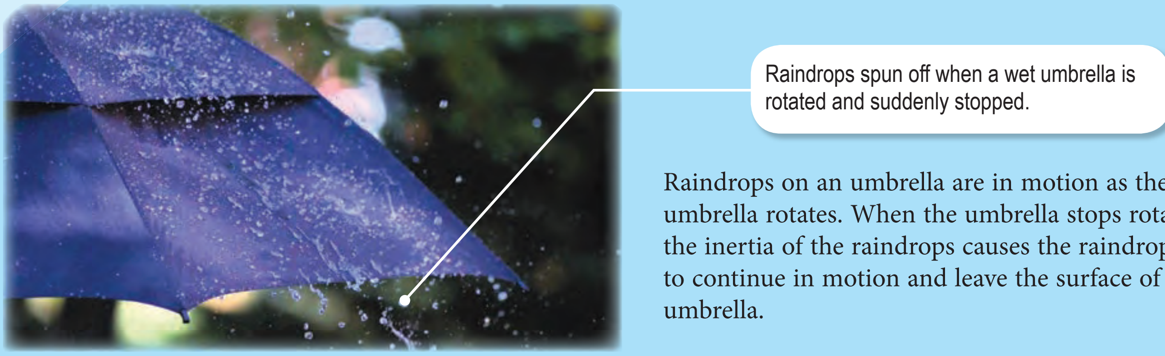
ISS ICS

Aim: To discuss situations in daily life that involve inertia

Instructions:
1. Carry out a Hot Seat activity.
2. Gather information on situations in daily life that involve inertia.
3. Discuss whether the situations have good or bad effects on human.
4. Suggest a method to reduce the bad effects of inertia.
5. Choose a group representative to answer questions from other groups.

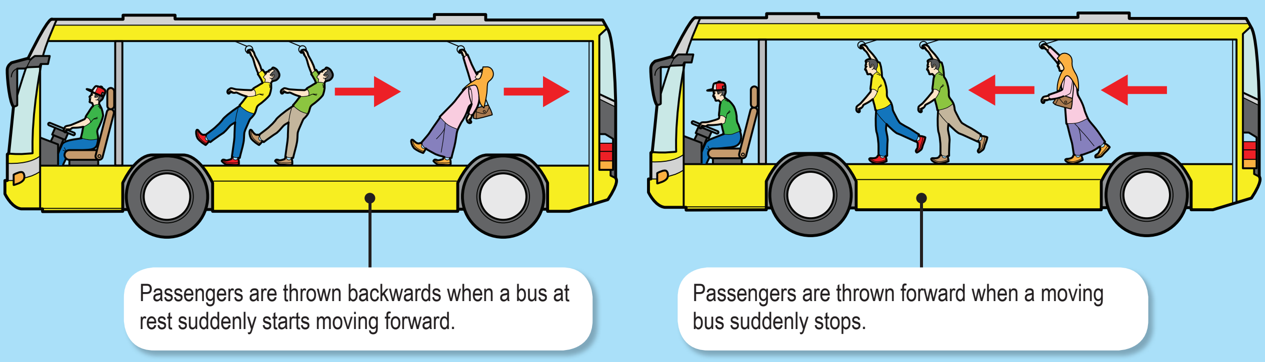
Several examples of daily life situations that involve inertia and its effects are as follows.

Situation 1



Raindrops on an umbrella are in motion as the umbrella rotates. When the umbrella stops rotating, the inertia of the raindrops causes the raindrops to continue in motion and leave the surface of the umbrella.

Situation 2

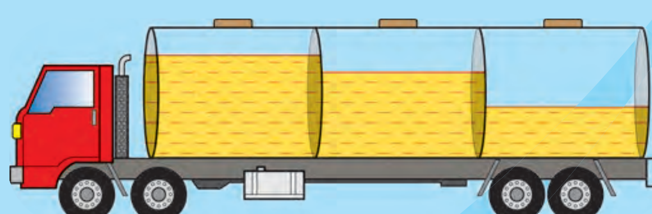


The inertia of the passengers keeps them in their initial state of rest or motion.

Situation 3

Chilli sauce or tomato sauce in a bottle flow out when the glass is moved quickly downwards and then suddenly stopped. The inertia of the sauce causes it to continue moving downwards and out of the bottle.

Situation 4



Oil tanker trucks have large inertia. In fact, an oil tanker truck has its storage tank divided into several separate tanks. The separated tanks reduce the impact of the inertia of the petrol.

2.4.3

Situation 5

Riders on a roller coaster in a recreation park are assigned to seats through a specialised safety system. The roller coaster carriage moves at sudden changes of speed and direction.

When the carriage of the roller coaster changes its direction of motion suddenly, the inertia of the riders keeps them in their original state of motion. The safety system ensures the riders remain in their seats and are not thrown out during the motion.

Situation 6

Driver and passengers of a car are advised to wear seat belts.

When a car stops abruptly, the driver and passengers in the car are thrown forward because of inertia. Seat belts prevent them from being thrown forward and hurting themselves.

Formative Practice 2.4

1. Explain the concept of inertia.
2. Brian wishes to pull a table cloth without toppling the things on top of the table cloth. How can Brian do it? Explain your answer.
3. Study the following statements:

   Statement 1: Objects can continue moving only if a force acts on them.
   Statement 2: Rockets in outer space can move without any engine thrust.
   Statement 3: Force is required to change the state of motion of objects.

   (a) Which of the statements can be explained correctly using Newton's First Law of Motion?
   (b) Give reasons of your choice.

2.4.3

2.5 Momentum

Photograph 2.7 A fast moving car and a lorry on the road

Photograph 2.7 shows a fast moving car and a lorry carrying a heavy load on the road. Which vehicle is more difficult to stop if both are driven at the same velocity?

Momentum is a vector quantity. All moving objects have momentum. The direction of momentum is the same as the direction of the velocity of an object. An object moving with high velocity or large mass has a large momentum. Momentum, p of a moving object can be calculated using the following formula:

$p = mv$, where p = momentum
m = mass
v = velocity

S.I. unit for momentum is kg m s^{-1}

INTEGRATION OF LANGUAGE

The word momentum originates from Latin that means *movement*. Isaac Newton described it as "*quantity of motion*".

Activity 2.8

Aim: To study how the mass and velocity of an object influence the effect of stopping the object

Materials: Two marbles of different masses, ruler with a groove in the centre, two books of equal thickness, thin cardboard and sticky tape

Instructions:

1. Arrange the materials as shown in Figure 2.45. Raise one end of the ruler using one thick book.
2. Release the marble from the top end of the ruler so that it hits the cardboard.
3. Measure the displacement, s_1 of the cardboard and record it in Table 2.8.
4. Repeat steps 2 to 3 and record the displacement as s_2.
5. Calculate $s_{average} = \frac{s_1 + s_2}{2}$ and record it.
6. Repeat steps 1 to 5 using two books of equal thickness.
7. Repeat steps 1 to 5 using a marble of larger mass.

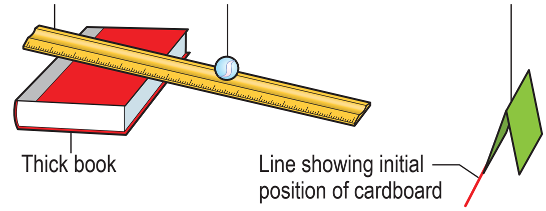


Figure 2.45

Results:

Table 2.8

Mass	Number of books	Displacement of cardboard, s / cm		
		s_1	s_2	$s_{average}$
Small	1			
Small	2			
Large	1			

Discussion:

1. What is represented by the displacement of the cardboard?
2. How does the velocity of the marble influence the displacement of the cardboard?
3. How does the mass of the marble influence the displacement of the cardboard?

The marble that is released from a high position moves downwards at a high velocity and displaces the cardboard further. This also happens when the marble has larger mass. The displacement of the cardboard represents the difficulty in stopping the marble. Objects with larger momentum are more difficult to stop.

Example

A lorry of mass 20 000 kg moves with a velocity of 22 m s^{-1}. A car of mass 2 000 kg moves with a velocity of 30 m s^{-1}.

(a) What is the momentum of the lorry and the car?

(b) If the lorry moves with the same velocity as the car, what is the momentum of the lorry?

Solution:

(a)

Step 1
List the given information in symbols.

Mass of lorry, m = 20 000 kg
Velocity of lorry, v = 22 m s^{-1}

Step 2
Identify and write down the formula used.

Momentum of lorry,
$p = mv$

Step 3
Substitute numerical values in the formula and perform the calculations.

p = 20 000 kg × 22 m s^{-1}
= 440 000 kg m s^{-1}
= 440 000 N s

Momentum of the car, p = 2 000 kg × 30 m s^{-1}
= 60 000 kg m s^{-1}
= 60 000 N s

(b) Momentum of the lorry moving at the velocity of the car
= 20 000 kg × 30 m s^{-1}
= 600 000 kg m s^{-1}
= 600 000 N s

SMART INFO

From Chapter 1, the unit newton (N) in base unit is kg m s^{-2}.

Unit for momentum:
kg m s^{-1} = (kg m s^{-2}) s
= N s

2.5.1

Applications of the Concept of Momentum in Daily Life

You have learned the concept of momentum. Carry out Activity 2.9 to understand the applications of momentum in daily life.

Activity 2.9 ICS

Aim: To discuss the applications of the concept of momentum in daily life

Instructions:

1. Work in groups.
2. Visit websites to gather information on the applications of momentum in daily life and present the results of your findings.

Applying the Principle of Conservation of Momentum in Collisions and Explosions

Figures 2.46(a) and (b) show two firemen putting out a fire. In Figure 2.46(b) both firemen are thrown backwards when water at high speed gushes out of the hose. Why does this happen?

(a) *(b)*

Figure 2.46 *Firemen putting out a fire*

Water gushing out of the hose at high speed has a high forward momentum. Due to this, two or more firemen are needed to balance the momentum by holding the hose tightly.

Activity 2.10 ICS

Aim: To study a situation involving the Principle of Conservation of Momentum in daily life

Instructions:

1. Work in groups.
2. Gather information on a situation which involves the Principle of Conservation of Momentum in daily life.
3. Present your findings using multimedia presentation.

2.5.1 2.5.2

Activity 2.11

Aim: To investigate the Principle of Conservation of Momentum

Apparatus: Ticker timer, alternating current power supply, runway, trolleys, wooden block and retort stand

Materials: Ticker tape, cellophane tape, plasticine, pin and cork

Instructions:

1. Work in groups.
2. Set up the apparatus as shown in Figure 2.47.

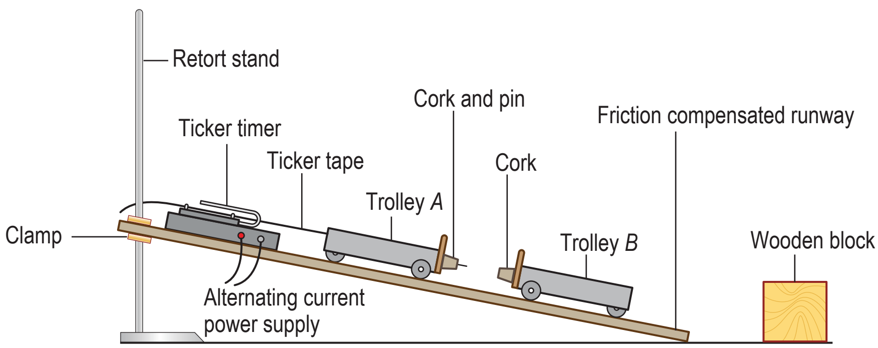


Figure 2.47

3. Raise one end of the runway so that it is friction compensated.
4. Switch on the ticker timer and push trolley *A* hard towards trolley *B*.
5. Determine the following velocity in cm per 10 ticks:
   (a) Velocity of trolley *A* before collision, u_1.
   (b) Common velocity of trolleys *A* and *B* after collision, v
6. Record the results in Table 2.9 on page 62.
7. Repeat steps 4 to 6 for 1 trolley colliding with 2 trolleys at rest.
8. Repeat steps 4 to 6 for 2 trolleys colliding with 1 trolley at rest as shown in Figure 2.48.

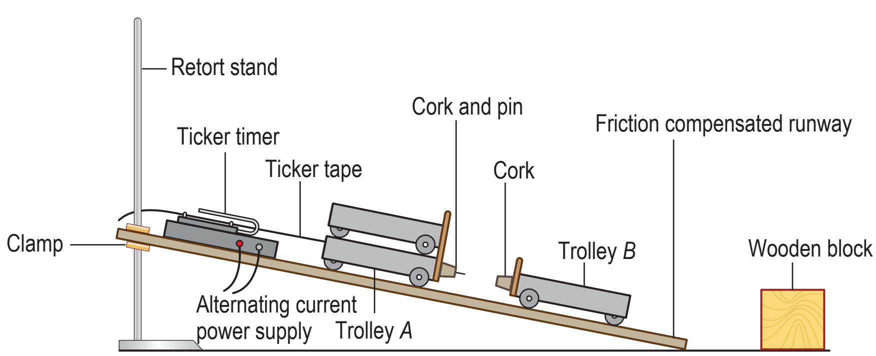


Figure 2.48

9. Repeat steps 4 to 6 for 3 trolleys colliding with 1 trolley.

Results:

Table 2.9

Before collision					After collision		
Trolley *A*		Trolley *B*		Total momentum	Trolley *A* and trolley *B*		Total momentum
m_1	u_1 (cm per 10 ticks)	m_2	u_2	$m_1u_1 + m_2u_2$	$m_1 + m_2$	v (cm per 10 ticks)	$(m_1 + m_2)v$
1		1	0		2		
1		2	0		3		
2		1	0		3		
3		1	0		4		

Discussion:

1. What is a friction compensated runway?
2. Compare the total momentum before and after collision.
3. Is the total momentum conserved? Explain your answer.

In Activity 2.11, you may find that the total momentum before and after collision differs slightly. This difference is due to external forces such as friction that cannot be compensated completely.

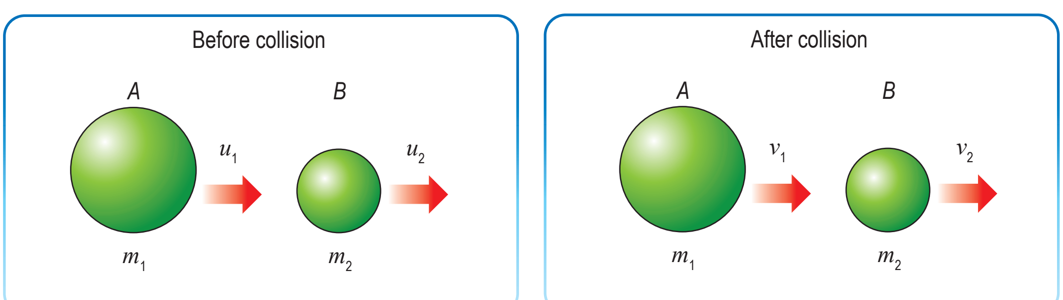


Figure 2.49 *A system of two objects before and after collision*

Figure 2.49 shows a system of two objects before and after collision. The Principle of Conservation of Momentum states that the total momentum before collision is equal to the total momentum after collision if no external force is acting on it.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Figure 2.50 shows the launching of a rocket. Launching of a rocket is an example of explosion. Explosion refers to a situation where an object at rest breaks up into two or more parts. Before launch, the rocket is at rest at the base of the launch pad with zero momentum. During launch, hot gases move downwards and the rocket moves upwards. Explosion is also a closed system which does not involve external forces. As such, total momentum is also conserved in explosion.

$$\text{Total momentum before explosion} = \text{total momentum after explosion}$$
$$0 = m_1v_1 + m_2v_2$$
$$m_1v_1 = -m_2v_2$$

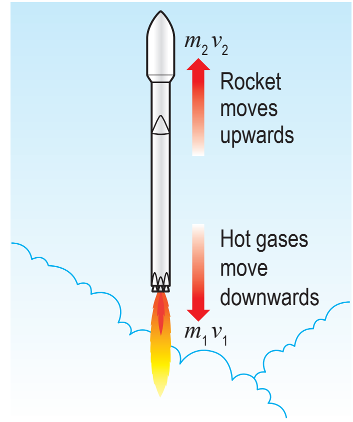


Figure 2.50 *Launching of a rocket*

Activity 2.12

ICS STEM

Aim: To build and launch a water rocket

Instructions:

1. Work in groups.
2. Gather information on the following:
   (a) materials needed to build and launch a water rocket
   (b) ways to build a water rocket
   (c) safety precautions to be taken
3. Discuss the required information and complete the K-W-L Chart as a guide in the search for information.
4. Design, build and launch your group's water rocket in your school field.
5. Prepare a report on how the Principle of Conservation of Momentum is applied in the water rocket launching technology.

K-W-L Chart

http://bt.sasbadi.com/p4063

Formative Practice 2.5

1. What is meant by momentum and conservation of momentum?
2. A lorry of mass 1 000 kg moves at a velocity of 5.0 m s^{-1}. It collides with a car of mass 800 kg moving at a velocity of 2.0 m s^{-1} in the same direction. If the lorry moves at a velocity of 3.4 m s^{-1} in the same direction after the collision, calculate the velocity of the car.

2.6 Force

Most of our daily activities involve forces. A force can change the state of motion of an object. How does a force change the momentum of an object in motion along a straight line?

Recall

Force and Motion

Activity 2.13

Aim: To investigate the relationship between force and acceleration and the relationship between mass and acceleration

Apparatus: Ticker timer, alternating current power supply, runway, three trolleys and retort stand

Materials: Ticker tape, cellophane tape, three elastic strings with a knotted loop at each end

(A) To investigate the relationship between force and acceleration with a fixed mass

Instructions:

1. Set up the apparatus as shown in Figure 2.51.
2. Switch on the ticker timer and pull the trolley down the runway with one elastic string (one unit of force).
3. Calculate the acceleration of the trolley using the ticker tape obtained and record it in Table 2.10.
4. Repeat steps 2 to 3 using two elastic strings and three elastic strings with each of the strings stretched to the same length as that of the first elastic string in step 2.
5. Plot the graph of acceleration, a against force, F and state the relationship between acceleration, a and force, F.

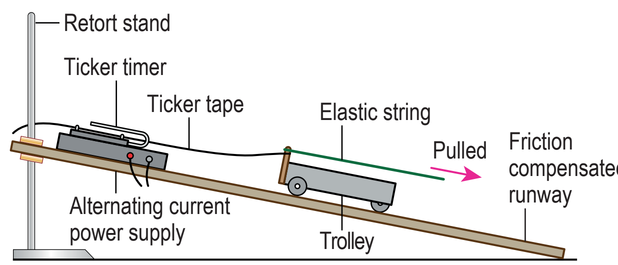


Figure 2.51

Guide to carrying out Activity 2.13

http://bt.sasbadi.com/p4064b

Results:

Table 2.10

Force, F	u / cm s^{-1}	v / cm s^{-1}	t / s	a / cm s^{-2}
1 elastic string				
2 elastic strings				
3 elastic strings				

(B) To investigate the relationship between mass and acceleration at a constant force

Instructions:

1. Repeat steps 1 and 2 in (A) by pulling the trolley using two elastic strings stretched together.
2. Repeat step 1 in (B) using two trolleys as shown in Figure 2.52 and then three trolleys.

2.6.1

3. Calculate the acceleration of the trolley from the ticker tape obtained and record it in Table 2.11.
4. Plot a graph of acceleration, a against the reciprocal of mass, $\frac{1}{m}$ and state the relationship between acceleration, a and mass, m.

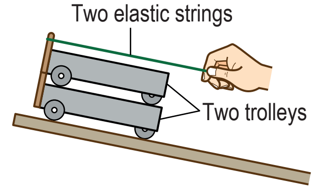


Figure 2.52

Results:

Table 2.11

Mass	u / cm s^{-1}	v / cm s^{-1}	t / s	a / cm s^{-2}
1 trolley, m				
2 trolleys, $2m$				
3 trolleys, $3m$				

The results of Activity 2.13 shows that the acceleration of an object depends on the applied force and the mass of the object.

F – Force
m – Mass
a – Acceleration

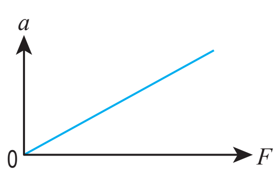


***Figure 2.53** Acceleration-force graph*

Acceleration is directly proportional to the applied force when the mass of an object is fixed

$a \propto F$
m constant

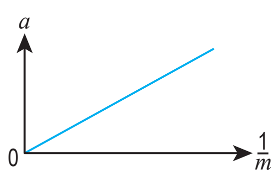


***Figure 2.54** Acceleration-reciprocal of mass graph*

Acceleration is inversely proportional to mass of an object when a constant force is applied on the object

$a \propto \frac{1}{m}$
F constant

Combining the two relationships:
$a \propto \frac{F}{m}$
Therefore, $F \propto ma$

The relationship between force, F, mass, m and acceleration, a for an object in motion is

$$F \propto ma$$
$$F \propto m\frac{(v-u)}{t}$$
$$F \propto \frac{(mv-mu)}{t}$$

Expression of **Newton's Second Law of Motion**

Info File

Change of momentum = $mv - mu$

Rate of change of momentum = $\frac{(mv-mu)}{t}$

Newton's Second Law of Motion states that the rate of change of momentum is directly proportional to the force and acts in the direction of the applied force. From the relationship
$F \propto ma$
$F = kma$, k is a constant

In S.I. units, 1 N is the force that produces an acceleration of 1 m s^{-2} when applied on a mass of 1 kg.
As such,
1 N = $k \times$ 1 kg $\times$ 1 m s^{-2}
$k = 1$
Therefore, $F = ma$

2.6.1

Solving Problems Involving the Formula $F = ma$

Example 1

A worker pulls a load of mass 80 kg along a horizontal surface by a force of 160 N. If the surface is smooth and without any resistance that opposes the motion of the object, what is the acceleration of the load?

Solution:

Step 1 List the given information in symbols.	Mass, m = 80 kg Force, F = 160 N
Step 2 Identify and write down the formula used.	$F = ma$
Step 3 Substitute numerical values into the formula and perform the calculations.	$160 = 80 \times a$ $a = \frac{160}{80}$ $= 2\ \text{m s}^{-2}$

Example 2

A car of mass 1 200 kg moves with a velocity of 30 m s^{-1}. When the brakes of the car are applied, the car stops in 5 seconds. Calculate the average braking force of the car.

Solution:

Deceleration of car, $a = \frac{v - u}{t}$

$= \frac{0 - 30}{5}$

$= -6\ \text{m s}^{-2}$

Average braking force, $F = ma$

$= 1\ 200\ \text{kg}(-6\ \text{m s}^{-2})$

$= -7\ 200\ \text{N}$ (Negative sign shows that the force acts in the opposite direction to the motion of the car)

Formative Practice 2.6

1. A force, F acts on a body of mass 5 kg.
   (a) If the body accelerates uniformly from 2 m s^{-1} to 8 m s^{-1}, determine the value of F.
   (b) If F = 10 N, determine the displacement of the body 6 seconds after the body starts to move from rest.
2. A force of 80 N acts on a stationary object for 7 seconds and causes the object to reach a velocity of 35 m s^{-1}. Calculate:
   (a) the mass of the object.
   (b) the displacement of the object.

2.6.2

2.7 Impulse and Impulsive Force

Photograph 2.8 shows the action of a long jump athlete bending his legs while landing. What is the effect of this action?

The action of bending his legs is to reduce the magnitude of the impulsive force acting on his body. **Impulse** is a change of momentum.

Photograph 2.8 *Long jump athlete bending his legs*

$$\text{Impulse, } J = mv - mu = Ft$$

F = applied force

t = time of action of the force

Impulsive force is the rate of change of momentum in a collision or impact in a short period of time. The formula for impulsive force is as follows.

$$\text{Impulsive force, } F = \frac{mv - mu}{t}$$

t = impact time

$mv - mu$ = change of momentum

If change of momentum, $mv - mu$ is constant, then $F \propto \frac{1}{t}$. If t is small, then the magnitude of F is big or vice versa.

Activity 2.14

ISS ICS

Aim: To discuss impulse and impulsive force

Instructions:

1. Work in groups.
2. Gather the following information from appropriate websites.
   (a) effect of follow through action on magnitude of impulse.
   (b) situations and applications in daily life that involve impulse.
   (c) situations and applications in daily life that involve impulsive force, including safety features in vehicles.
3. Prepare a brief multimedia presentation and present it.

Video on impulse, momentum and impulsive force

http://bt.sasbadi.com/p4067

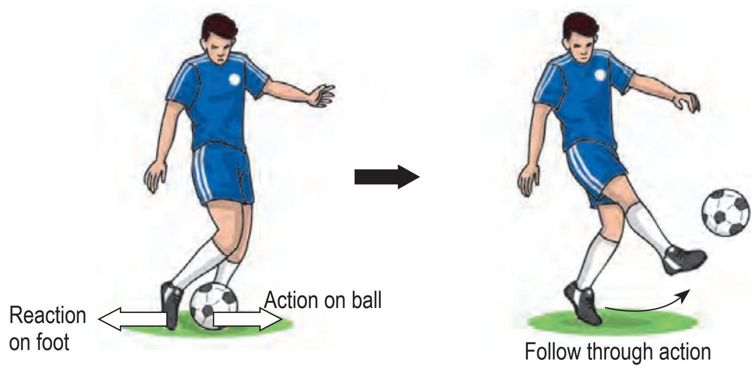
2.7.1

In fact, all the situations that you studied in Activity 2.14 involve a pair of forces, action and reaction. The relationship between action and reaction is explained in Newton's Third Law of Motion. **Newton's Third Law of Motion** states that for every action there is a reaction of equal magnitude, but in the opposite direction. Study the examples of situations and the explanations given below.

Action and reaction force

http://bt.sasbadi.com/p4068

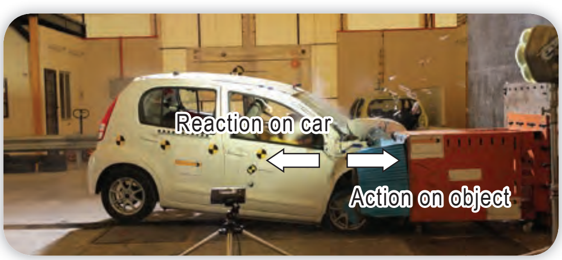
Increasing the magnitude of impulse by follow through action



A follow through action after a strong kick produces a large impulse. As a result, the ball experiences a large change in momentum and moves at a high velocity.

Figure 2.55 *Follow through in football*

Reducing impulsive force by extending impact time



Collision causes a car to stop and experience a change in momentum. The crumple zone of the car extends the impact time during collision. As a result, the magnitude of the impulsive force on the car is reduced.

Photograph 2.9 *Car collision test*

Increasing impulsive force by reducing impact time

A pestle moving at high velocity is stopped by a hard mortar in a short interval of time. A large impulsive force is produced.

Photograph 2.10 *Using a mortar and pestle*

Solving Problems Involving Impulse and Impulsive Force

Example 1

A plasticine ball of mass 0.058 kg is thrown at a velocity of 10 m s^{-1} and hits the wall. It sticks to the wall. What is the impulse of the plasticine?

Solution:

Step 1
List the given information in symbols.

Mass, m = 0.058 kg
Initial velocity, u = 10 m s^{-1}
Final velocity, v = 0 m s^{-1}

Step 2
Identify and write down the formula used.

Impulse, $J = mv - mu$

Step 3
Substitute numerical values into the formula and perform the calculations.

$J = 0.058(0) - 0.058(10)$
$= 0 - 0.058(10)$
$= 0 - 0.58$
$= -0.58$ N s (in the opposite direction to the velocity of the plasticine)

Example 2

A golfer hits a golf ball of mass 45.93 g at a velocity of 50 m s^{-1}. If the impact time is 0.005 s, what is the impulsive force acting on the golf ball?

Solution:

$m = 0.04593$ kg, $u = 0$ m s^{-1}, $v = 50$ m s^{-1}, $t = 0.005$ s

$$\text{Impulsive force, } F = \frac{mv - mu}{t}$$
$$= \frac{0.04593(50) - 0.04593(0)}{0.005}$$
$= 459.3$ N (acting in the same direction as the velocity of the golf ball)

Formative Practice 2.7

1. In a car collision test, a car of mass 1 500 kg hits the wall with a speed of 15 m s^{-1}. The car bounces back with a speed of 2.6 m s^{-1}. If the collision time is 0.15 s, calculate the:
   (i) impulse in the collision
   (ii) impulsive force acting on the car
2. A football player kicks a ball of mass 450 g with a force of 1 500 N. The contact time of his shoe with the ball is 0.008 s. What is the impulse on the ball? If contact time is increased to 0.013 s, what is the velocity of the ball?

2.8 Weight

Photograph 2.11 Lifting a barbell

Photograph 2.11 shows a man lifting a barbell. Earth's gravitational pull acting on the barbell contributes to the weight of the barbell. The weight of the barbell makes it difficult for the man to lift it.

The barbell will drop to the ground with an acceleration if the man releases it. According to Newton's Second Law of Motion,

$$F = ma$$

$$\downarrow \quad \downarrow$$

$$W = mg$$

- Gravitational force acting on the barbell is its weight, W.
- Acceleration of the barbell is gravitational acceleration, g.

Weight is a vector quantity which has the same direction with gravitational force, that is towards the centre of Earth. → Unit for weight: N

Unit for mass: kg → $W = mg$

$g = \dfrac{W}{m}$

Unit for g: N kg^{-1}

Physical quantity, g with unit N kg^{-1} is the gravitational field strength. Gravitational field strength, g is the force acting per unit mass caused by gravitational pull. For objects on the surface of the Earth, gravitational field strength, g is 9.81 N kg^{-1}. Each 1 kg mass experiences a force of gravity of 9.81 N. Can you calculate your weight on the surface of the Earth?

Photograph 2.12 shows an astronaut wearing a full spacesuit when exploring the Moon. It is easier for the astronaut to walk on the Moon compared to walking on Earth. Why is this so?

Photograph 2.12 Astronaut wearing a full spacesuit on the Moon

Astronaut's movements on the Moon

http://bt.sasbadi.com/p4070

Malaysiaku MY PRIDE

Dato. Dr. Sheikh Muszaphar Shukor bin Sheikh Mustapha is the first astronaut of Malaysia.

2.8.1

Mass of astronaut's suit on Earth is 81.65 kg.

$W_{Earth} = 81.65 \text{ kg} \times 9.81 \text{ N kg}^{-1}$
$= 800.99 \text{ N}$

Gravitational field strength on the Moon is $\frac{1}{6}$ of the gravitational field strength on Earth.

$W_{Moon} = \frac{1}{6} \times 800.99 \text{ N}$
$= 133.50 \text{ N}$

Activity 2.15

ISS STEM

Aim: To create a vehicle model by applying Newton's Laws of Motion

Instructions:

K-W-L Chart

http://bt.sasbadi.com/p4071

1. Work in groups. Gather information on the applications of Newton's Laws of Motion in the creation of cars. Give emphasis to the following:
   (a) shape of vehicle model
   (b) type of engine, transmission system, suspension system, steering system and braking system
   (c) safety aspects of driver and passengers
   (d) aspects of comfort of driver and passengers in the vehicle
   (e) type of fuel
2. Discuss the required information and complete the K-W-L Chart as a guide in your search for information.
3. Create the vehicle model.
4. Present the applications of Newton's Laws of Motion of your group's vehicle model.

Formative Practice 2.8

1. What is the meaning of gravitational field strength?
2. State the differences between mass and weight.
3. A 10 kg object has a weight of 150 N on a planet.
   (a) What is the gravitational field strength on the planet?
   (b) Is the planet bigger than Earth? Give reasons for your answer.
4. An astronaut of mass 60 kg is assigned to explore the Moon. What is the astronaut's weight on the Moon's surface?

2.8.1

Conceptual Framework

Force and Motion I

- Linear motion
- Type of motion
  - At rest
  - Uniform velocity
  - Non-uniform velocity
- Distance and displacement
- Speed and velocity
- Acceleration

Linear motion equations

- $v = u + at$
- $v^2 = u^2 + 2as$
- $s = \frac{1}{2}(u + v)t$
- $s = ut + \frac{1}{2}at^2$

Graphs

- displacement-time
- velocity-time
- acceleration-time

- Interpret type of motion
- Analyse graph
- Convert and sketch
  - displacement-time graph into velocity-time graph and vice versa
  - velocity-time graph into acceleration-time graph and vice versa

- Free fall
- Value of gravitational acceleration

Inertia and mass

Newton's First Law of Motion

Momentum

Principle of Conservation of Momentum
$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Collision and explosion

Force

- Gravitational field strength
- Weight

Newton's Second Law of Motion

Impulse

Impulsive force

Action and reaction

Newton's Third Law of Motion

Interactive QUIZ

http://bt.sasbadi.com/p4072

SELF-REFLECTION

1. New things I learnt in this chapter on force and motion are ____________.
2. The most interesting thing I learnt in this chapter on force and motion is ____________.
3. Things I still do not fully understand or comprehend are ____________.
4. My performance in this chapter,

   Poor 1 2 3 4 5 Excellent

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

Download and print Self-reflection Chapter 2

http://bt.sasbadi.com/p4073

Performance Evaluation

1. A car moves from rest with an acceleration of 2.0 m s^{-2}. Calculate:
   (a) velocity of car after 5.0 s.
   (b) distance travelled in 5.0 s.
   (c) distance travelled in the fifth second.
2. Encik Nizam drives a car at a speed of 108 km h^{-1}. Suddenly he sees a car in front moving very slowly. Therefore, Encik Nizam slows down his car to a speed of 72 km h^{-1}. The displacement made by the car is 125 m. If the acceleration of the car is uniform, calculate
   (a) acceleration of Encik Nizam's car
   (b) time taken for the speed of the car to reduce from 108 km h^{-1} to 72 km h^{-1}.
3. Swee Lan rows a boat forward. She uses an oar to push the water backwards. Why is the boat able to move forward?
4. A car of mass 1 200 kg at rest is moved by a force of 150 N. Determine the acceleration of the car and time taken for the car to reach a velocity of 1.5 m s^{-1}.
5. Gravitational field strength on the Moon is 6 times lower than that on Earth. If a stone weighing 2 N is carried back from the Moon to Earth, calculate the weight of the stone on Earth.
6. A bullet of mass 10 g is fired from a gun of mass 2.0 kg. If the recoil velocity of the gun after firing the shot is 0.5 m s^{-1}, calculate the velocity of the bullet.

7. Photograph 1 shows a car moving along a road. Initially, the car moves at a uniform velocity of 18 m s^{-1} for 15 s. Then, the car accelerates at 1.5 m s^{-2} for 5 s. Subsequently, the car starts to decelerate to 15 m s^{-1} in 5 s. The car continues to move at this speed for 10 s and finally decelerates again and stops at time, t = 50 s.

Photograph 1

Based on the given information, sketch the velocity-time graph for the motion of the car. Show the values of velocity and time in your sketch.

8. A rubber ball is released from a height, H. The ball drops vertically downwards and upon hitting the floor, bounces back a height, h ($h < H$). If the velocity of downward motion is negative, sketch the velocity-time graph for the motion of the rubber ball.

9. A car at rest starts to move when a bus moves at a uniform velocity of 15 m s^{-1} passes by its side. The car reaches a velocity of 20 m s^{-1} in 10 seconds and continues to move at a constant velocity in the same direction with the bus. The graph in Figure 1 shows the motion of the car and the bus along a straight road.

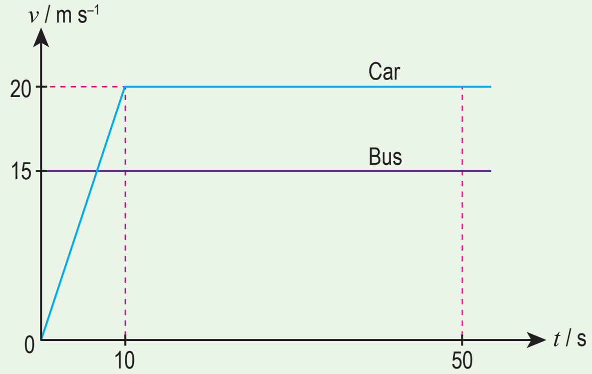


Figure 1

(a) Calculate the time taken for the car to reach the same speed as the bus.

(b) What is the displacement of the car when it reaches the speed of the bus?

(c) Calculate the distance travelled by the car and bus at time, t = 50 s.

(d) At time, t = 50 s, is the car in front of the bus?

10. Photograph 2 shows the launching of a spacecraft using a rocket at a launch pad.

Photograph 2

(a) Explain how the release of hot gases through the rocket's exhaust enables the rocket to accelerate upwards.

(b) How can the acceleration of this rocket be increased?

11. Photograph 3 shows a hovercraft which can move on land or on the surface of water swiftly because of the support from a layer of air trapped under the hovercraft. The hovercraft of mass of 25 000 kg starts from rest and its engine produces a thrust, F of 22 000 N.

(a) Determine the initial acceleration of the hovercraft if there is no friction at that instant.

(b) What is the function of the layer of air trapped under the hovercraft?

Photograph 3

Enrichment Corner

12. Kok Chew and Zulkefli wish to determine Earth's gravitational acceleration. They plan to release a table tennis ball from the third level of their school building. Discuss the suitability of the table tennis ball in this experiment.

13. Assume that you are an engineer who is assigned to invent a model of fast train in Malaysia. This train is required to travel at high speeds using levitation above the railway. Draw your model of the fast train and list its properties by taking into consideration its shape, materials, mechanism and safety aspects.

CHAPTER 3

GRAVITATION

What are Newton's Universal Law of Gravitation and Kepler's Laws?

Why is it important to know the values of the gravitational acceleration of planets in the Solar System?

How do man-made satellites help to improve human life?

Let's Study

3.1 Newton's Universal Law of Gravitation
3.2 Kepler's Laws
3.3 Man-made Satellites

Information Page

There are various types of man-made satellites revolving in their respective orbits in outer space. Satellites are invented for communication purposes, weather forecasts and Earth observations. Why are these satellites able to revolve in their respective orbits?

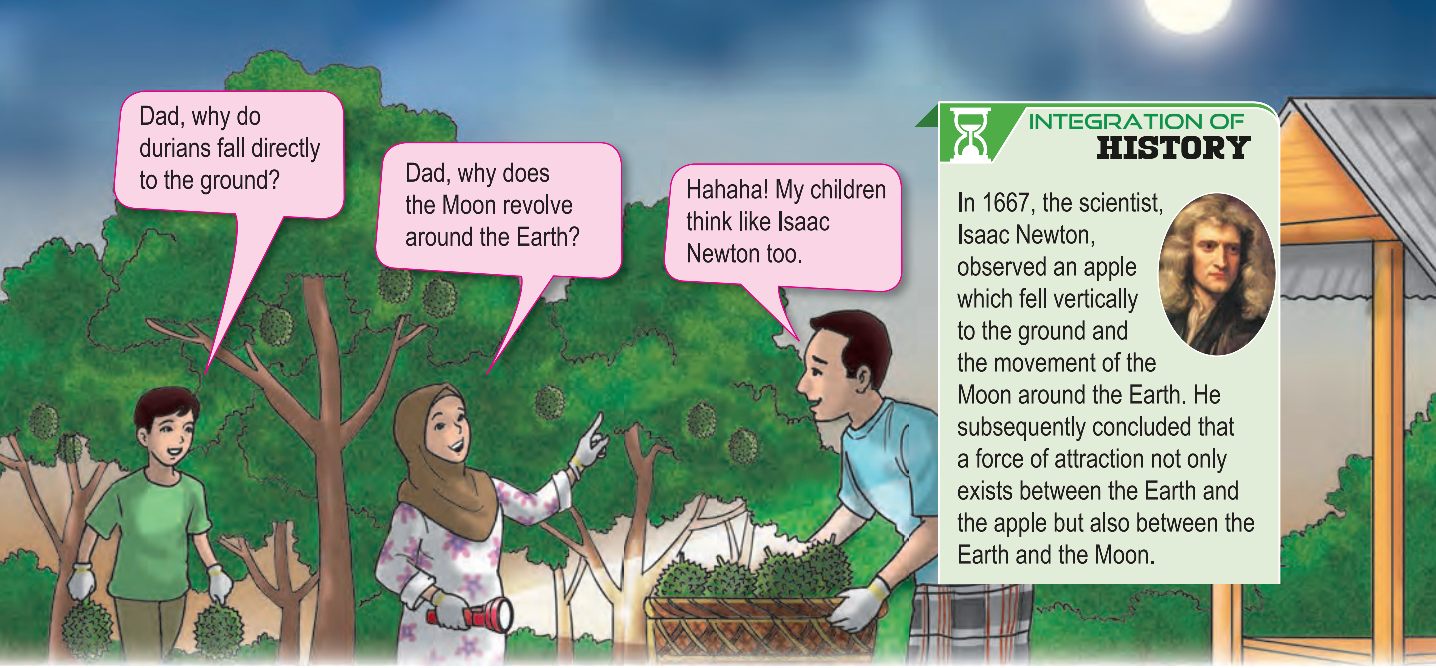
Several hundred years ago, Isaac Newton, a scientist, conceptualised a universal law connecting all heavenly bodies and also man-made satellites. Curiosity about the universe has encouraged scientists to launch spaceships and satellites which can overcome the Earth's gravity. At present, there are spaceships which are moving far away from Earth. Such spaceships enable photographs of planets to be taken to benefit scientific inventions and technology.

Animated launching of satellite

http://bt.sasbadi.com/p4077a

Learning Standards and List of Formulae

3.1 Newton's Universal Law of Gravitation



INTEGRATION OF HISTORY

In 1667, the scientist, Isaac Newton, observed an apple which fell vertically to the ground and the movement of the Moon around the Earth. He subsequently concluded that a force of attraction not only exists between the Earth and the apple but also between the Earth and the Moon.

Figure 3.1 *Situation at a durian orchard*

Activity 3.1

Pattern Recognition | ICS | ISS

Aim: To discuss gravitational force between two bodies in the universe

Instructions:

1. Carry out a Hot Seat activity in groups.
2. Study Figure 3.2 and discuss the three situations below.

A person who jumps up will return to the ground. What force causes the person to return to the ground?

Air molecules remain in the atmosphere without escaping to outer space. What force acts between the molecules in the atmosphere and the Earth?

The Moon revolves around the Earth without drifting away from its orbit. The Earth exerts a pulling force on the Moon. Does the Moon also exert a force on the Earth?

Figure 3.2 *Situations involving gravitational force between two bodies*

3. Surf the web to gather relevant information.
4. Choose a group representative to answer questions from other groups.

Gravitational force is known as **universal force** because it acts between any two bodies in the universe. Figure 3.3 shows the gravitational force between the Sun, the Earth and the Moon. How can the gravitational force between two bodies be explained?

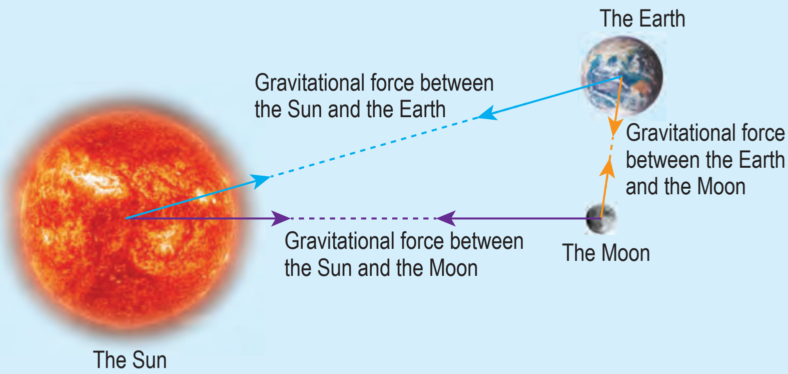


Figure 3.3 *Gravitational force as a universal force*

Gravitational force

http://bt.sasbadi.com/p4079

In the year 1687, Isaac Newton presented two relationships that involve gravitational force between two bodies:

- gravitational force is directly proportional to the product of the masses of the two bodies, that is $F \propto m_1 m_2$
- gravitational force is inversely proportional to the square of the distance between the centres of the two bodies, that is $F \propto \frac{1}{r^2}$

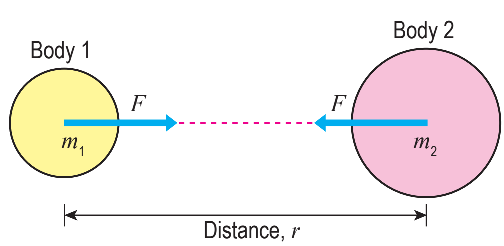


Figure 3.4 *Gravitational force between two bodies*

The two relationships above are formulated in Figure 3.5 to obtain **Newton's Universal Law of Gravitation**.

$$F \propto m_1 m_2$$

$$F \propto \frac{1}{r^2}$$

$$F \propto \frac{m_1 m_2}{r^2}$$

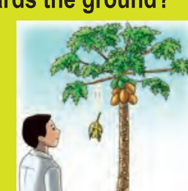
Figure 3.5 *Formulation of Newton's Universal Law of Gravitation*

Info File

1. Gravitational force exists between two bodies.
2. Both bodies experience gravitational force of the same magnitude.

Info File

Why does a fallen leaf move towards the ground?



Both the leaf and the Earth experience the same gravitational force. This causes the leaf and the Earth to move towards one another. As the mass of the Earth is very much larger than the mass of the leaf, gravitational force does not have an apparent effect on the Earth's movement. As such, we only observe the leaf falling to the ground.

Newton's Universal Law of Gravitation states that the gravitational force between two bodies is directly proportional to the product of the masses of both bodies and inversely proportional to the square of the distance between the centres of the two bodies.

Info File

The value of gravitational constant, G can be determined through experiment.

Newton's Universal Law of Gravitation can be expressed as follows:

$$F = \frac{Gm_1m_2}{r^2}$$

F = gravitational force between two bodies
m_1 = mass of first body
m_2 = mass of second body
r = distance between the centre of the first body and the centre of the second body
G = gravitational constant ($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2})

SMART INFO

$$F = \frac{Gm_1m_2}{r^2}$$

Two bodies of masses m_1 and m_2 that are separated at a distance of r, experience a gravitational force of F respectively.

If you know the masses of two bodies and the distance between the centres of the two bodies, you can calculate the magnitude of the gravitational force between the two bodies. Study the examples given.

Example 1

Calculate the gravitational force between a durian and the Earth.
Mass of durian = 2.0 kg
Mass of the Earth = 5.97×10^{24} kg
Distance between the centre of the durian and the centre of the Earth
= 6.37×10^6 m

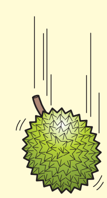


Figure 3.6

Solution:

Step 1
List the given information in symbols.

m_1 = 2.0 kg
m_2 = 5.97×10^{24} kg
r = 6.37×10^6 m
G = 6.67×10^{-11} N m^2 kg^{-2}

Step 2
Identify and write down the formula used.

Gravitational force,
$$F = \frac{Gm_1m_2}{r^2}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$F = \frac{(6.67 \times 10^{-11}) \times 2.0 \times (5.97 \times 10^{24})}{(6.37 \times 10^6)^2}$$
$$= 19.63 \text{ N}$$

Example 2

A rocket at a launching pad experiences a gravitational force of 4.98×10^5 N. What is the mass of the rocket?
[Mass of the Earth = 5.97×10^{24} kg, distance between the centre of the Earth and the centre of the rocket = 6.37×10^6 m]

Solution:

Gravitational force, $F = 4.98 \times 10^5$ N
Mass of the Earth, $m_1 = 5.97 \times 10^{24}$ kg
Mass of rocket = m_2
Distance between the centre of the Earth and the centre of the rocket,
$r = 6.37 \times 10^6$ m
$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Gravitational force,

$$F = \frac{Gm_1m_2}{r^2}$$

$$4.98 \times 10^5 = \frac{(6.67 \times 10^{-11}) \times (5.97 \times 10^{24}) \times m_2}{(6.37 \times 10^6)^2}$$

$$m_2 = \frac{(4.98 \times 10^5) \times (6.37 \times 10^6)^2}{(6.67 \times 10^{-11}) \times (5.97 \times 10^{24})}$$

$$= 5.07 \times 10^4 \text{ kg}$$

Solving Problems Involving Newton's Universal Law of Gravitation

Gravitational force acts between any two bodies, including those on the Earth, planets, the Moon or the Sun. What are the effects of mass and distance between two bodies on gravitational force?

Activity 3.2

Logical Reasoning CPS

Aim: To solve problems involving Newton's Universal Law of Gravitation for two bodies at rest on the Earth

Instructions:
1. Work in pairs.
2. Imagine you and your partner are bodies at rest on the Earth.
3. Record your mass, m_1 and the mass of your partner, m_2 in Table 3.1.

Table 3.1

Pair	Mass, m / kg		r / m	F / N
	m_1	m_2		
1			2.0	
			4.0	
2			2.0	
			4.0	

4. Calculate the gravitational force, F using both your masses and the distances given in the table.
5. Change partners and repeat steps 3 and 4.

Discussion:
1. How do the masses of two bodies influence the gravitational force between them?
2. What is the effect of distance between two bodies on gravitational force between them?
3. Why is the magnitude of gravitational force between you and your partner small?

3.1.1 3.1.2

The effects of mass and distance between two objects on gravitational force are shown in Figure 3.7.

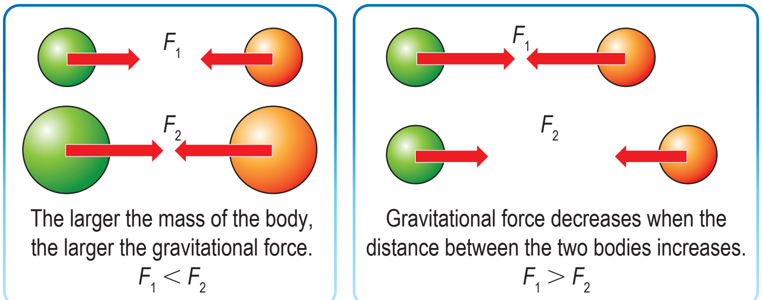


Figure 3.7 *Effects of mass and distance between two bodies on gravitational force*

Gravitational force between two bodies depends on the mass of the bodies, as well as the distance between them.

Info File

Even though gravitational force is a universal force, two persons on the Earth's surface will not feel the effect of the gravitational force. This is because the gravitational force between two bodies of small mass has a very small magnitude. For example, two persons of masses 50 kg and 70 kg respectively, only experience a gravitational force of 2.3×10^{-7} N if they stand at a distance of 1 m from each other.

Activity 3.3

Abstraction CPS

Aim: To solve problems involving Newton's Universal Law of Gravitation for
- (i) objects on the Earth's surface
- (ii) the Earth and satellite
- (iii) the Earth and the Sun

Instructions:
1. Work in pairs.
2. Study Figure 3.8 and answer the questions.

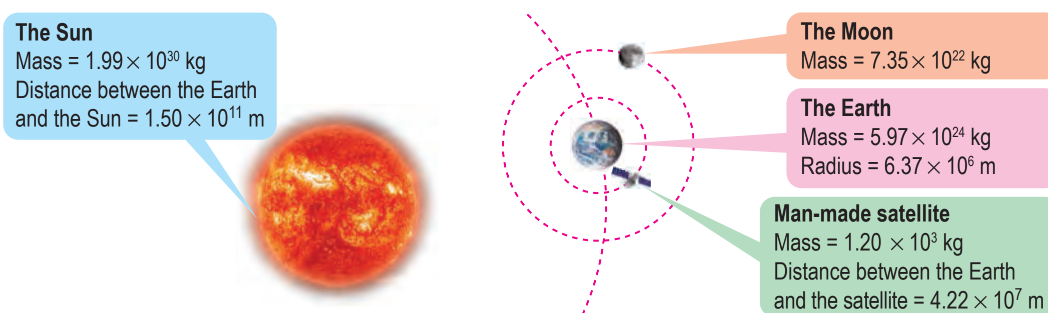


Figure 3.8 *The Sun, the Earth, the Moon and a man-made satellite*

Discussion:
1. What is the gravitational force on the man-made satellite before it is launched?
2. Compare:
   (a) the mass of the Earth, the mass of the man-made satellite and the mass of the Sun
   (b) between the Earth-satellite distance and the Sun-Earth distance.
3. Predict the difference in the magnitude of the gravitational force between the Earth and the man-made satellite and the gravitational force between the Sun and the Earth.
4. Calculate:
   (a) the gravitational force between the Earth and the man-made satellite
   (b) the gravitational force between the Earth and the Sun.
   Does your answer match your prediction in question 3?
5. The gravitational force between the Earth and the Moon is 2.00×10^{20} N. What is the distance between the centre of the Earth and the centre of the Moon?

Relating Gravitational Acceleration, g on the Surface of the Earth with Universal Gravitational Constant, G

According to Newton's Second Law of Motion, gravitational force can be expressed as $F = mg$. From Newton's Universal Law of Gravitation, gravitational force is expressed as $F = \frac{Gm_1m_2}{r^2}$.

What is the relationship between g and G?

Info File

From Newton's Second Law of Motion, $F = ma$.

When involving gravitational acceleration, g,

$F = mg$

Activity 3.4

Algorithms CPS

Aim: To derive the formula for gravitational acceleration, g using the formulae $F = mg$ and $F = \frac{GMm}{r^2}$

Instructions:

1. Work in pairs.
2. Scan the QR code and download Figure 3.9 from the website given.
3. Discuss and complete Figure 3.9 to derive the relationship between g and G.

Download Figure 3.9

http://bt.sasbadi.com/p4083

M = mass of the Earth
m = mass of the object
r = distance between the centre of the Earth and the centre of the object

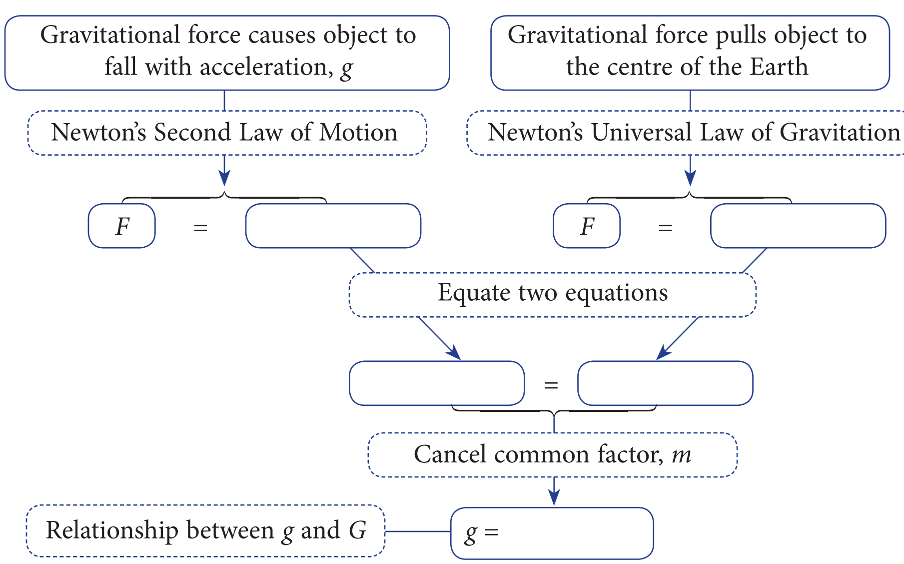


***Figure 3.9** Relationship between g and G*

Discussion:

1. What is the relationship between gravitational acceleration, g and gravitational constant, G?
2. What are the factors that influence the value of gravitational acceleration?

Activity 3.5

Logical Reasoning CPS

Aim: To discuss the variation in the values of g with r

Instructions:

1. Work in pairs.
2. Calculate the value of gravitational acceleration for the five distances given in Figure 3.10.

Gravitational acceleration below the surface of the Earth

http://bt.sasbadi.com/p4084

- Mass of the Earth, M $= 5.97 \times 10^{24}$ kg
- Radius of the Earth, R $= 6.37 \times 10^{6}$ m
- Gravitational constant, G $= 6.67 \times 10^{-11}$ N m^2 kg^{-2}

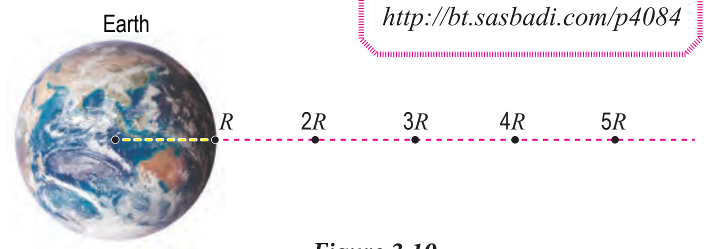


Figure 3.10

3. Complete Table 3.2.

Table 3.2

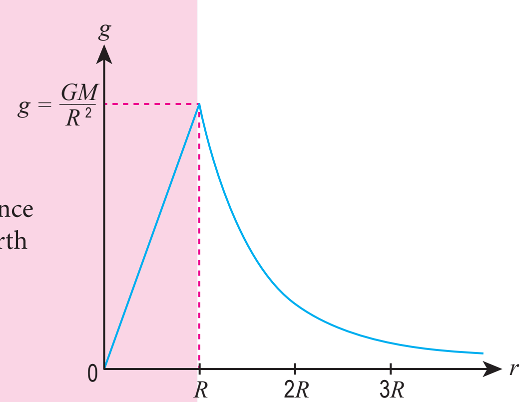
Distance from centre of the Earth, r	R	$2R$	$3R$	$4R$	$5R$
Gravitational acceleration, g / m s^{-2}					

Discussion:

1. What is the value of gravitational acceleration on the Earth's surface?
2. Plot a graph of g against r.
3. How does the value of gravitational acceleration change when the distance from the centre of the Earth increases?
4. Discuss the condition where the value of gravitational acceleration is almost zero.

Figure 3.11 shows a sketch of a graph with various values of gravitational acceleration, g and distance, r from the centre of the Earth.

Value g is **directly proportional** to the distance from the centre of the Earth for $r < R$.



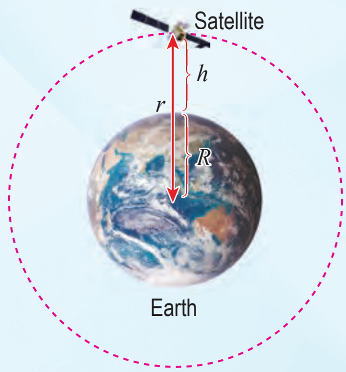
Value g is **inversely proportional** to the square of the distance from centre of the Earth for $r \geq R$.

Figure 3.11 *Variation of g with r*

Figure 3.12 shows a satellite at height, h from the surface of the Earth. R is the radius of the Earth and r is the distance of the satellite from the centre of the Earth, which is the radius of the orbit.

At height, h from the surface of the Earth, distance from the centre of the Earth is $r = (R + h)$.

With this, gravitational acceleration, $g = \dfrac{GM}{(R+h)^2}$



On the surface of the Earth, height, $h = 0$.
Therefore,
r = radius of the Earth, R.

Gravitational acceleration on the surface of the Earth, $g = \dfrac{GM}{R^2}$, where M is the mass of the Earth.

***Figure 3.12** A satellite at height, h from the surface of the Earth*

Example 1

Mass of the Earth is 5.97×10^{24} kg and radius of the Earth is 6.37×10^6 m. Calculate gravitational acceleration on the surface of the Earth. [$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}]

Solution:

Step 1
List the given information with symbols.

$M = 5.97 \times 10^{24}$ kg
$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
$r = 6.37 \times 10^6$ m

Step 2
Identify and write down the formula used.

$$g = \frac{GM}{r^2}$$

Step 3
Make numerical substitution into the formula and perform the calculations.

$$g = \frac{(6.67 \times 10^{-11}) \times (5.97 \times 10^{24})}{(6.37 \times 10^6)^2}$$
$$= 9.81 \text{ m s}^{-2}$$

Example 2

A radar imaging satellite orbits around the Earth at a height of 480 km. What is the value of gravitational acceleration at the position of the satellite?
[$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M = 5.97 \times 10^{24}$ kg, $R = 6.37 \times 10^6$ m]

Solution:

Height of orbit, h = 480 km
= 480 000 m

$$g = \frac{GM}{(R+h)^2}$$
$$= \frac{(6.67 \times 10^{-11}) \times (5.97 \times 10^{24})}{(6.37 \times 10^6 + 480\ 000)^2}$$
$$= 8.49 \text{ m s}^{-2}$$

Importance of Knowing the Value of Gravitational Acceleration

Gravitational force is a universal force. Therefore, the formula $g = \frac{GM}{R^2}$ can be used to calculate gravitational acceleration on the surface of other bodies such as planets, the Moon and the Sun. Which planet has the largest gravitational acceleration? Which planet has the smallest gravitational acceleration?

Space debris

http://bt.sasbadi.com/p4086a

Activity 3.6

Logical Reasoning | CPS | ISS

Aim: To compare different gravitational accelerations for the Moon, the Sun and the planets in the Solar System

Instructions:

1. Carry out the Think-Pair-Share activity.
2. Gather information on the mass, M and radius, R of the Sun, the Moon as well as the other remaining planets in the Solar System.
3. Present the gathered information in a table.
4. Calculate the gravitational acceleration, g for each of the bodies.

Discussion:

1. Which planet has the largest gravitational acceleration?
2. Which planet has gravitational acceleration closest to the gravitational acceleration of the Earth?
3. What factors determine the value of the gravitational acceleration of a planet?

When the value of the gravitational acceleration on the surface of a planet is known, the **magnitude of the gravitational force** acting on an object on the surface of the planet can be calculated. Knowledge on the value of gravitational acceleration plays an important role in space exploration and continuity of life.

Activity 3.7

Logical Reasoning | ICS | ISS

Aim: To discuss the importance of knowledge on gravitational acceleration of planets in space exploration and continuity of life

Instructions:

1. Work in groups.
2. Gather information on the importance of knowledge on gravitational acceleration of planets in space exploration and continuity of life.
3. Present the results of your discussion in the form of i-Think map.

Gravitational acceleration

http://bt.sasbadi.com/p4086b

We live on Earth where gravitational acceleration is 9.81 m s^{-2}. While exploring space whether far from Earth or near other planets, the body of astronauts can be exposed to low or high gravity conditions. What are the effects of gravity on the growth of humans?

Activity 3.8

Logical Reasoning ISS ICS

Aim: To gather information on the effects of gravity on the growth of humans

Instructions:

1. Carry out the Round Table activity.

Table 3.3

Factor	Effect of low gravity	Effect of high gravity
Difference in density		
Bone fragility		
Size of lungs		
Blood circulatory system		
Blood pressure		

2. Based on Table 3.3, gather information on the effects of gravity on the growth of humans by visiting websites or from other suitable reading materials.
3. Complete Table 3.3.
4. Present a multimedia presentation entitled Effects of Gravity on the Growth of Humans.

Effects of gravity

http://bt.sasbadi.com/p4087

Centripetal Force in the Motion of Satellites and Planets

Figure 3.13 shows three positions of a satellite which orbits around the Earth at a uniform speed. Observe the direction of the velocity of the satellite at each position.

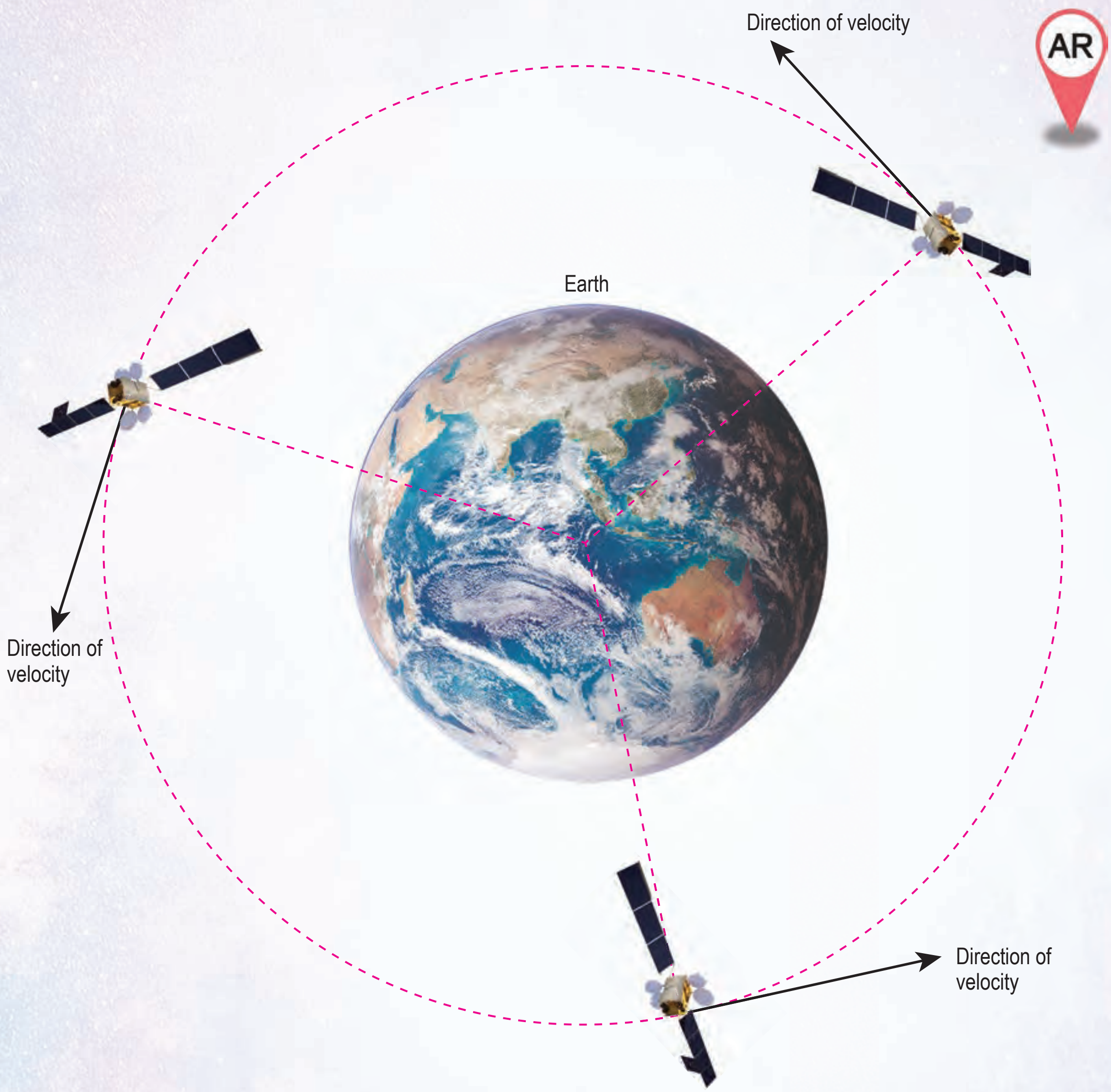


Figure 3.13 *Satellite in circular motion*

An object in circular motion always experiences changes in the direction of its motion even though its speed is fixed. In Chapter 2, you learnt that a force is required to change the direction of motion of a body. What force acts on a body which is in a circular motion?

SMART INFO

When a body moves in a circle at uniform speed, the body is said to be in uniform circular motion.

Activity 3.9

Aim: To understand centripetal force using Centripetal Force Kit

Apparatus: Centripetal Force Kit (a plastic tube, rubber stopper, slotted weight holder, three 50 g slotted weights, crocodile clip, thick string) and ruler

Instructions:

1. Set up the apparatus as shown in Figure 3.14 for circular motion of radius, r = 50 cm. The total mass of the slotted weights and its holder is 100 g.

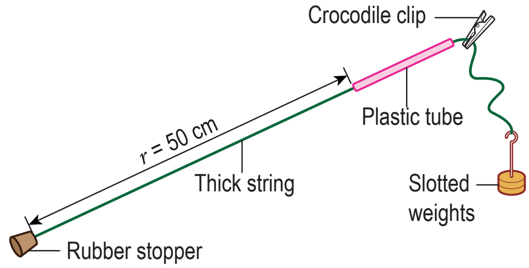


Figure 3.14

SMART INFO

The slotted weights cause a tension in the string that acts as centripetal force during the circular motion of the rubber stopper.

2. Hold the plastic tube in your right hand and the slotted weights in your left hand. Rotate the rubber stopper at a constant speed in a horizontal circle above your head as shown in Figure 3.15. Make sure that the crocodile clip stays at a distance of about 1 cm from the lower end of the plastic tube so that the radius is fixed.

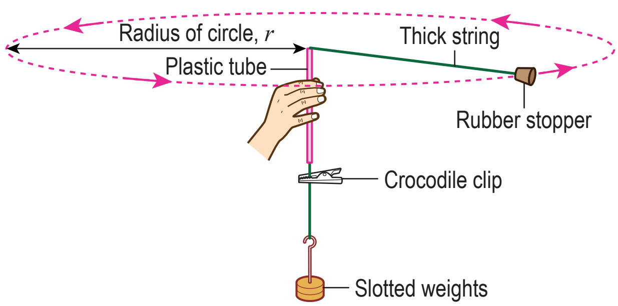


Figure 3.15

Video demonstrating the use of Centripetal Force Kit

http://bt.sasbadi.com/p4089

3. Release the slotted weights and continue rotating the rubber stopper. Observe the speed of motion of the rubber stopper.
4. Repeat steps 1 to 3 with a total mass of 200 g of slotted weights. Compare the speed of motion of the rubber stopper with the speed of motion in step 3.
5. Repeat step 4. When the rubber stopper is rotating, pull the lower end of the string downwards so that the rubber stopper rotates with a decreasing radius. Feel how the tension in the string acting on your left hand changes.

Discussion:

1. When the rubber stopper makes a circular motion, the stretched string exerts a force on the rubber stopper. What is the direction of the force?
2. What is the relationship between the speed of the rubber stopper and the centripetal force?
3. How does the centripetal force change when the rubber stopper makes a circular motion with a smaller radius?

For a body in circular motion, a force acts on the body in a direction towards the centre of the circle. This force is called **centripetal force**.

Figure 3.16 shows the tension in the rope that acts as the centripetal force for the motion of the rubber stopper. The magnitude of the centripetal force depends on the mass of the body, the linear speed and the radius of the circle. Centripetal force can be calculated using the formula:

$F = \dfrac{mv^2}{r}$, where F = centripetal force
m = mass
v = linear speed
r = radius of circle

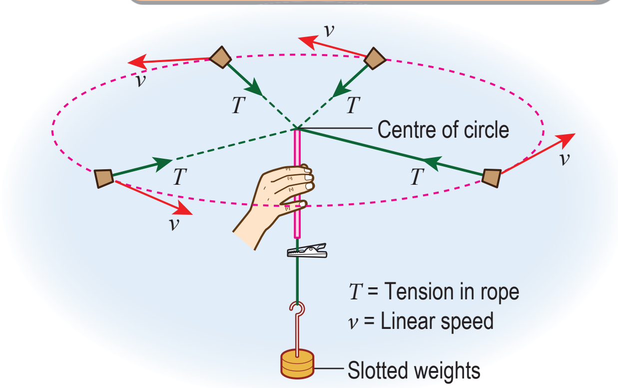


***Figure 3.16** Tension in the string acting as centripetal force*

SMART INFO

When a body is rotated at a certain uniform speed with the string almost horizontal, the effect of gravitational force on the circular motion of the body can be ignored. Though the speed is uniform, the direction of motion of the body keeps changing.

SMART INFO

Linear speed shows how fast a body moves in a circular motion.

Example 1

Figure 3.17 shows a hammer throw athlete swinging an iron ball in a horizontal circle before releasing it. What is the centripetal force that acts on the iron ball when the iron ball is moving at a speed of 20 m s^{-1}?

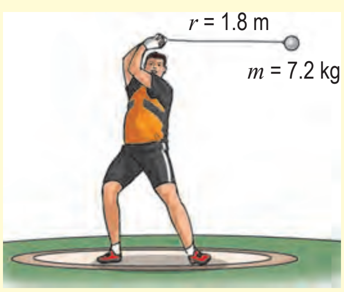


Figure 3.17

Solution:

Step 1
List the given information with symbols.

m = 7.2 kg
v = 20 m s^{-1}
r = 1.8 m

Step 2
Identify and write down the formula used.

$F = \dfrac{mv^2}{r}$

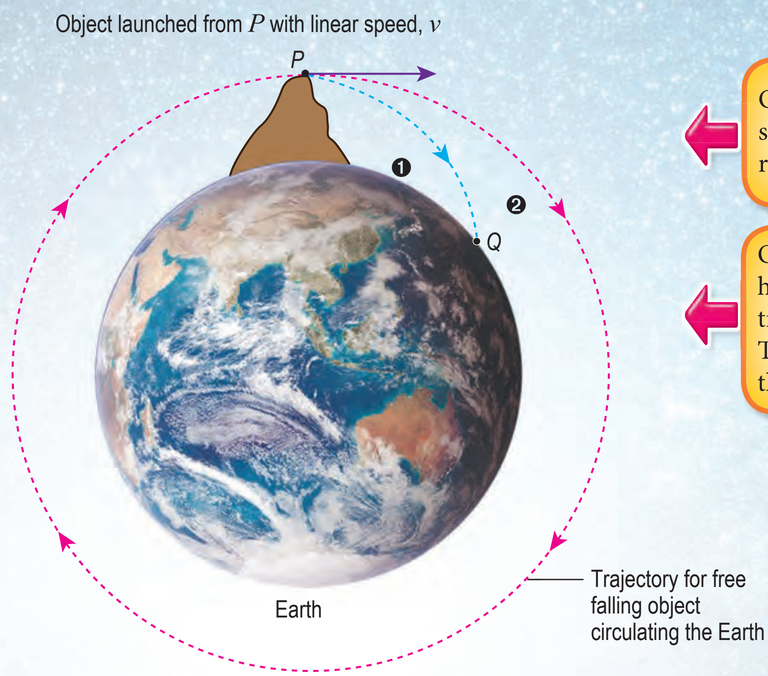
Step 3
Make numerical substitution into the formula and perform the calculations.

Centripetal force, $F = \dfrac{7.2 \times 20^2}{1.8}$
$= 1\ 600$ N

3.1.5

Can a satellite orbit the Earth without being driven by a rocket engine? The possibility of such movement was predicted by Isaac Newton in the 17th century as shown in Figure 3.18.

AR



Object launched with low linear speed will follow trajectory ❶ and reaches the Earth at Q.

Object launched with sufficiently high linear speed will follow trajectory ❷ circulating the Earth. The object will not return to the Earth.

Simulation of prediction of Isaac Newton

http://bt.sasbadi.com/p4091b

Figure 3.18 *Prediction of Isaac Newton*

The prediction of Newton is now a reality with so many man-made satellites orbiting around the Earth without being driven by any thrust. Satellites always experience gravitational force acting towards the centre of the Earth. The gravitational force on satellites acts as centripetal force.

By comparing the formula for force, $F = ma$

and formula for centripetal force, $F = \frac{mv^2}{r}$, we obtain:

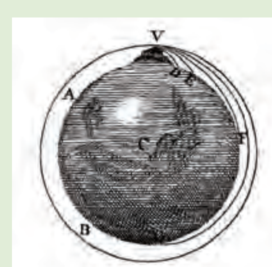
Centripetal acceleration, $a = \frac{v^2}{r}$,

where v = linear speed of satellite

r = radius of the orbit of satellite

INTEGRATION OF HISTORY

Although Isaac Newton did not have the facilities to carry out simulation or experiment, he was able to visualise the experiment on the movement of bodies around the Earth. His original sketch is shown below.



3.1.5

Example 1

Figure 3.19 shows a weather satellite orbiting the Earth at a height, h = 480 km. Linear speed of the satellite is 7.62×10^3 m s^{-1}. The radius of the Earth, R is $R = 6.37 \times 10^6$ m. What is the centripetal acceleration of the satellite?

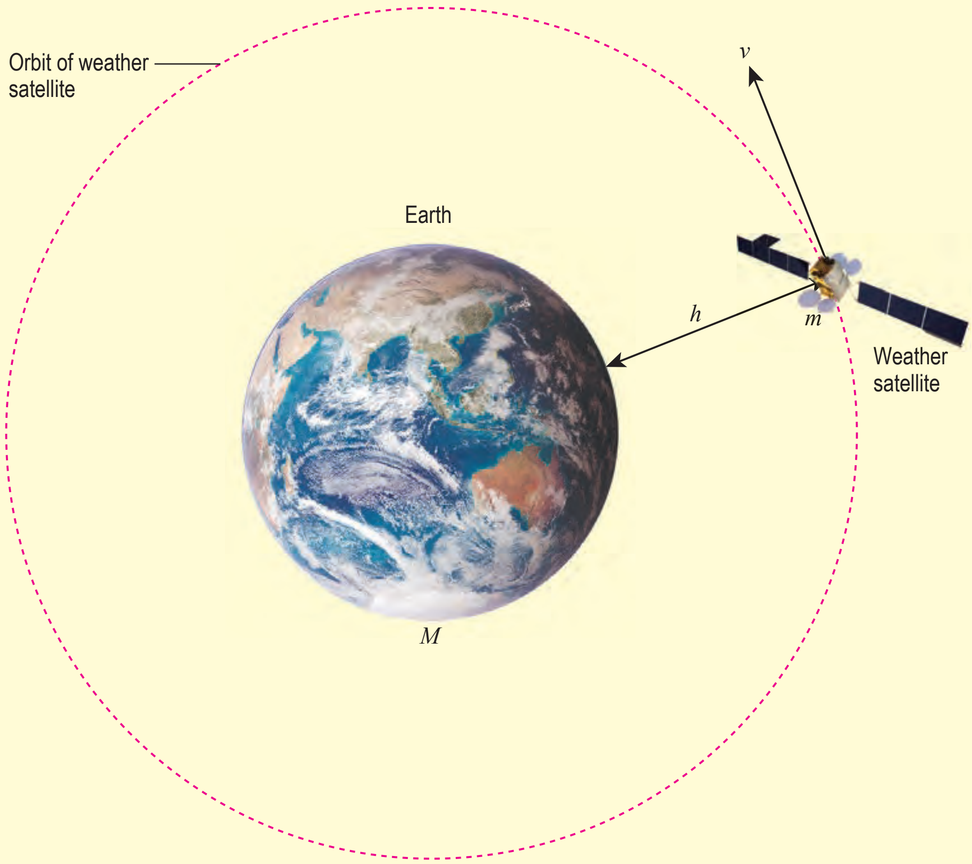


Figure 3.19

Solution:

Step ❶
List the given information in symbols.

Height of satellite, h = 480 km
= 480 000 m
Linear speed of satellite, $v = 7.62 \times 10^3$ m s^{-1}
Radius of the Earth, $R = 6.37 \times 10^6$ m

Step ❷
Identify and write down the formula used.

$$a = \frac{v^2}{r}$$

Step ❸
Substitute numerical values into the formula and perform the calculations.

$$a = \frac{v^2}{(R + h)}$$
$$= \frac{(7.62 \times 10^3)^2}{(6.37 \times 10^6 + 480\ 000)}$$
$$= 8.48 \text{ m s}^{-2}$$

Mass of the Earth and the Sun

Formula for the mass of the Earth and the Sun can be derived by using the formula of Newton's Universal Law of Gravitation and the formula for centripetal force.

Activity 3.10

Algorithms CPS

Aim: To determine the mass of the Earth and the Sun

Instructions:

1. Observe Figure 3.20.
2. Figure 3.20 shows the orbit of the Moon around the Earth.

SMART INFO

Circumference of a circle with radius r, is $2\pi r$.

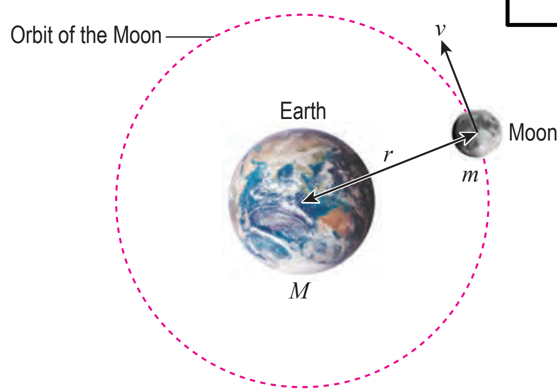


Figure 3.20

M = mass of the Earth
m = mass of the Moon
r = radius of the Moon's orbit
T = period of revolution of the Moon around the Earth
v = linear speed of the Moon

3. Discuss and complete the boxes below.

Distance travelled by the Moon when making one complete orbit around the Earth	=	
Linear speed of the Moon, v	=	$\frac{\text{Distance}}{\text{Time}}$
v	=	

4. Scan the QR code, download and print Figure 3.21 from the website given. Complete it to determine the formula for the mass of the Earth.

Download Figure 3.21

http://bt.sasbadi.com/p4094

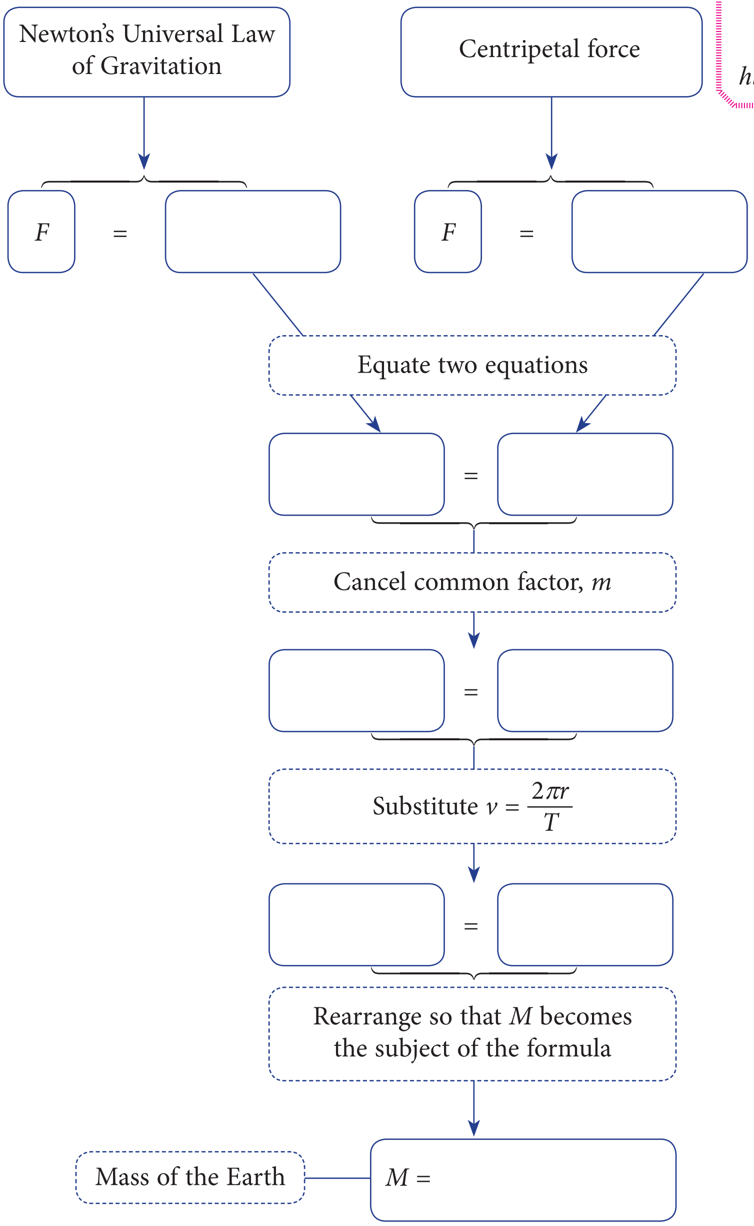


Figure 3.21 *Determining formula for the mass of the Earth*

Discussion:

1. What is the formula to determine the mass of the Earth?
2. Period of revolution of the Moon around the Earth, T is 2.36×10^6 s and radius of the Moon's orbit, r is 3.83×10^8 m. Calculate the mass of the Earth, M.
3. The Earth revolves around the Sun in a period of one year and the radius of the orbit is 1.50×10^{11} m. Calculate the mass of the Sun.

Formula used to determine the mass of the Earth or the Sun	$M = \dfrac{4\pi^2 r^3}{GT^2}$
Data needed to calculate the mass of the Earth	• radius of the orbit of any satellite or the Moon • period of revolution
Data needed to calculate the mass of the Sun	• radius of the orbit of any planet • period of revolution of planet concerned

Figure 3.22 *Formula and data used to calculate the mass of the Earth and the Sun*

Formative Practice 3.1

1. State Newton's Universal Law of Gravitation.
2. State two factors which influence the magnitude of the gravitational force between two bodies.
3. A piece of space junk of mass 24 kg is at a distance of 7.00×10^6 m from the centre of the Earth. What is the gravitational force between the space junk and the Earth?
[$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, mass of the Earth = 5.97×10^{24} kg]
4. A weather satellite orbits the Earth at a height of 560 km. What is the value of gravitational acceleration at the position of the satellite?
[$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, mass of the Earth = 5.97×10^{24} kg, radius of the Earth = 6.37×10^6 m]
5. A man-made satellite of mass 400 kg orbits the Earth with a radius of 8.2×10^6 m. Linear speed of the satellite is 6.96×10^3 m s^{-1}. What is the centripetal force acting on the satellite?
6. Figure 3.23 shows Mercury orbiting the Sun with a radius of 5.79×10^{10} m and a period of revolution of 7.57×10^6 s. Calculate the mass of the Sun.

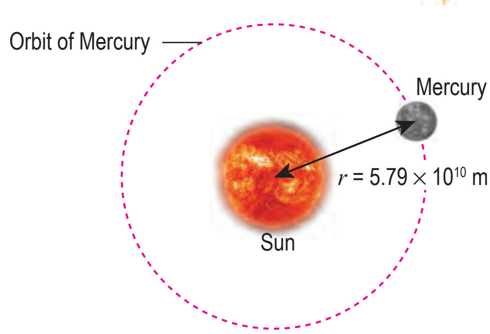


Figure 3.23

3.2 Kepler's Laws

Kepler's First, Second and Third Laws

When you were in Form 3, you knew about Kepler, a German astronomist, mathematician and astrologist who modified the heliocentric model according to Kepler's Law. Do you know that there are three Kepler's Laws? Let us get to know these three laws.

Kepler's First Law	All planets move in elliptical orbits with the Sun at one focus (Law of Orbits)

Carry out Activity 3.11 to get a clear picture regarding Kepler's first law.

INTEGRATION OF HISTORY

Johannes Kepler worked as an assistant to astronomist Tycho Brahe. His strong determination motivated him to study Brahe's astronomical data. Finally, Kepler succeeded in formulating three laws that describe the movement of planets around the Sun.

Activity 3.11

Aim: To sketch the shape of an ellipse based on the concept of dual foci of ellipse

Materials: Pencil, 20 cm thread, two thumbtacks, A4 paper, softboard and cellophane tape

Instructions:

1. Scan the QR code and print the template from the website given on a piece of A4 paper. Place it on a softboard.
2. Stick the thumbtacks at points F_1 and F_2 on the softboard.
3. Tie two ends of the thread to the two thumbtacks respectively.
4. Tighten the thread with the tip of a pencil as shown in Figure 3.24.
5. Move the pencil from the major axis to the left of F_1 to the major axis to the right of F_2 to sketch half an ellipse.
6. Repeat step 5 below major axis to obtain the shape of a complete ellipse.
7. Remove the thumbtacks and thread.
8. Draw a small circle to represent the Sun at F_1.
   Draw a small circle to represent the Earth on the circumference of the ellipse.

Template Activity 3.11

http://bt.sasbadi.com/p4096

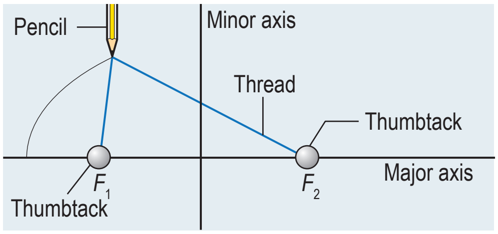


Figure 3.24

Discussion:

1. Describe how the distance between the Earth and the Sun changes when the Earth makes a complete orbit around the Sun.
2. Discuss how the shape of the Earth's orbit would be if the major axis is almost as long as the minor axis.

The planets in the Solar System have **elliptical** shaped orbits. Figure 3.25 shows the Sun always stays on a focus of the ellipse. The **major axis** is longer than the **minor axis**. Most orbits of the planets in the Solar System have major axis and minor axis of almost the same length. As such, the shape of the elliptical orbit of the planets in the Solar System is almost round. Planets can be assumed to make circular motion around the Sun. The **radius of orbit** is the average value of the distance between the planet and the Sun.

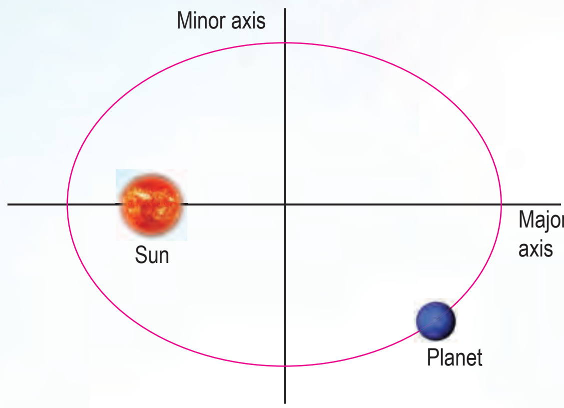


Figure 3.25 *Orbit of planet around the Sun*

Kepler's Second Law	A line that connects a planet to the Sun sweeps out equal areas in equal times (Law of Areas).

Observe Figure 3.26. If a planet takes the same amount of time to move from *A* to *B* and from *C* to *D*, the area *AFB* is the same as the area *CFD*. Distance *AB* is longer than distance *CD*. This means the planet is moving at a higher linear speed from *A* to *B* than from *C* to *D*.

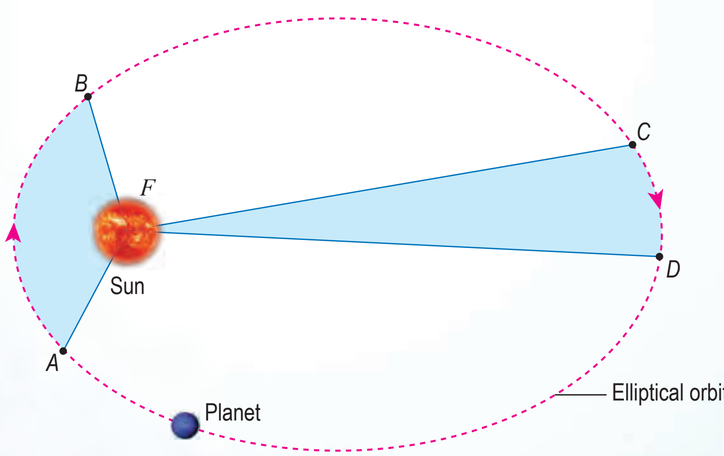


Figure 3.26 *Motion of planet in its orbit*

Kepler's Third Law	The square of the orbital period of any planet is directly proportional to the cube of the radius of its orbit (Law of Periods).

Mathematically,
$T^2 \propto r^3$
T = orbital period of a planet
r = radius of orbit

A planet which orbits with a larger radius has a longer orbital period. As such, planets which are further from the Sun take a longer time to complete one orbit around the Sun.

For example, the Earth takes 1 year to make one complete orbit while Saturn takes 29.5 years. Figure 3.27 shows the orbits and orbital periods of planets.

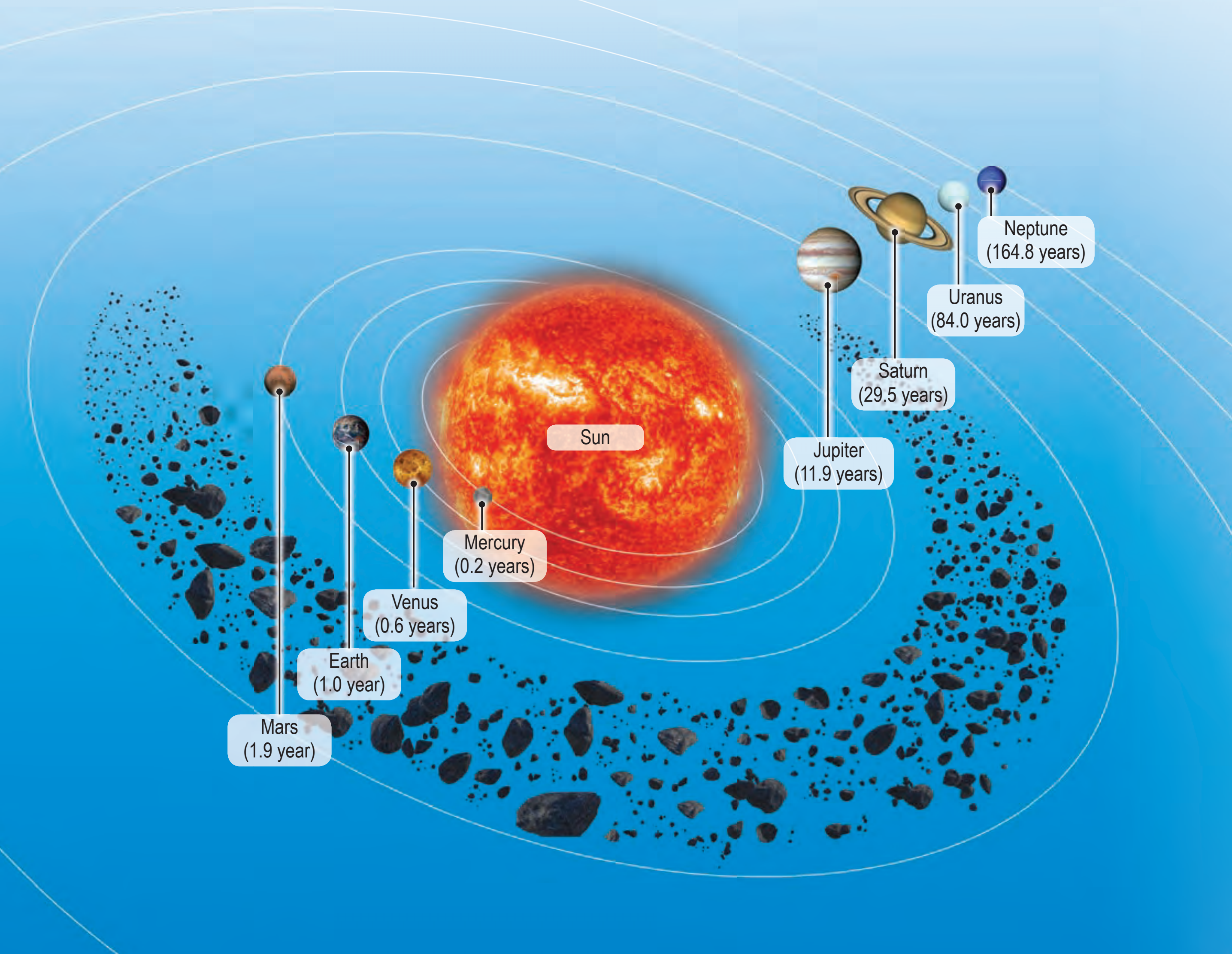
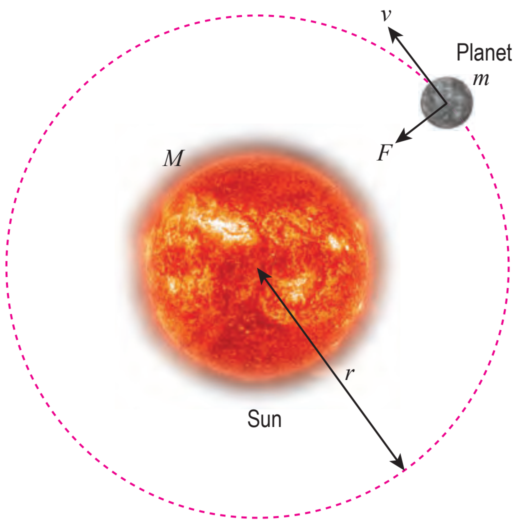


Figure 3.27 Orbits and orbital periods of planets

Kepler's third law can be formulated using **Newton's Universal Law of Gravitation** and concept of **circular motion**. Planets make circular motions around the Sun. The **centripetal force** is the same as the gravitational force between the Sun and the planet. Observe Figure 3.28 which shows the orbit of a planet around the Sun.

Assuming that the orbit of the planet around the Sun is circular, we can derive the relationship between the orbital period of the planet and the radius of the orbit as in Kepler's third law.



Mass of the Sun = M
Mass of the planet = m
Radius of orbit = r
Gravitational force = F
Linear speed of planet = v
Orbital period = T

***Figure 3.28** Orbit of a planet*

Gravitational force acting on the planet, $F = \dfrac{GMm}{r^2}$

The gravitational force acts as a centripetal force for the planet to make circular motion around the Sun.

Centripetal force, $F = \dfrac{mv^2}{r}$

Therefore,

Centripetal force = Gravitational force

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v^2 = \frac{GM}{r} \text{ .... [1]}$$

Linear speed of planet, $v = \dfrac{\text{Distance travelled in one complete orbit}}{\text{Orbital period}}$

$$= \frac{2\pi r}{T} \text{ .... [2]}$$

Substitute [2] into [1]:

$$\left(\frac{2\pi r}{T}\right)^2 = \frac{GM}{r}$$

$$T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$$

SMART INFO

Perimeter of orbit = $2\pi r$

As GM is constant, $T^2 \propto r^3$

$T^2 \propto r^3$ is Kepler's third law.

3.2.2

Figure 3.29 shows the formulation of Kepler's third law. When Kepler's third law is applied in the system of planets and the Sun, M is referred to as the mass of the Sun. Kepler's third law can also be applied to the system of satellites and the Earth, with M referring to the mass of the Earth.

Kepler's third law, that is $T^2 \propto r^3$

can be formulated by equating

centripetal force, $F = \dfrac{mv^2}{r}$

gravitational force, $F = \dfrac{GMm}{r^2}$

$v = \dfrac{2\pi r}{T}$

As such

the relationship between orbital period of planet, T and radius of its orbit, r is

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

$$T^2 = kr^3$$

where the constant, $k = \dfrac{4\pi^2}{GM}$

__Figure 3.29__ Formulating Kepler's Third Law

Solving Problems Using Kepler's Third Law Formula

From Kepler's third law, relationship between orbital period, T and radius of orbit, r is

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

Compare two planets.

For planet 1, $T_1^2 = \left(\dfrac{4\pi^2}{GM}\right) r_1^3$ .... (1)

For planet 2, $T_2^2 = \left(\dfrac{4\pi^2}{GM}\right) r_2^3$ .... (2)

(1) ÷ (2) gives $\dfrac{T_1^2}{T_2^2} = \dfrac{r_1^3}{r_2^3}$

The equation $\dfrac{T_1^2}{T_2^2} = \dfrac{r_1^3}{r_2^3}$ can be used to calculate the orbital period, T or radius of orbit, r.

Example 1

Figure 3.30 shows the planets, Earth and Mars, orbiting the Sun.

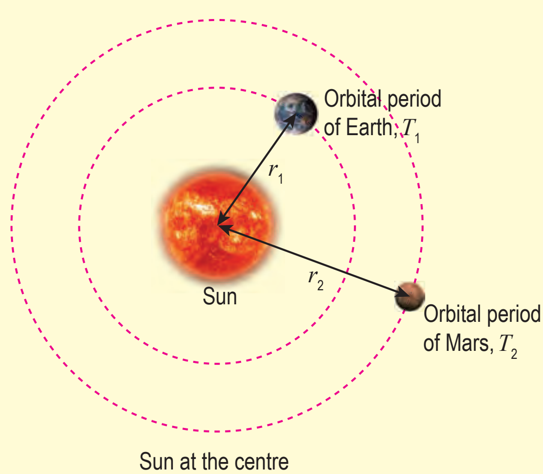


Figure 3.30

(a) The radius of the orbit of planet Mars can be determined by comparing the orbit of Mars with the orbit of the Earth. What information is needed to determine the radius of the orbit of Mars?

(b) The radius of the orbit of the Earth is 1.50×10^{11} m, orbital period of the Earth and Mars is 1.00 year and 1.88 years respectively. Calculate the radius of the orbit of Mars.

Solution:

(a) Radius of the orbit of the Earth, orbital period of the Earth and orbital period of Mars.

(b)

Step 1
List the given information in symbols.

Radius of orbit of the Earth, $r_1 = 1.50 \times 10^{11}$ m
Radius of orbit of Mars $= r_2$
Orbital period of the Earth, $T_1 = 1.00$ years
Orbital period of Mars, $T_2 = 1.88$ years

Step 2
Identify and write down the formula used.

$$\frac{T_1^{\,2}}{T_2^{\,2}} = \frac{r_1^{\,3}}{r_2^{\,3}}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$\frac{1.00^2}{1.88^2} = \frac{(1.50 \times 10^{11})^3}{r_2^{\,3}}$$

$$r_2^{\,3} = \frac{(1.50 \times 10^{11})^3 \times 1.88^2}{1.00^2}$$

$$r_2 = \sqrt[3]{\frac{(1.50 \times 10^{11})^3 \times 1.88^2}{1.00^2}}$$

$$= 2.28 \times 10^{11} \text{ m}$$

SMART INFO

The equation $\frac{T_1^{\,2}}{T_2^{\,2}} = \frac{r_1^{\,3}}{r_2^{\,3}}$ involves the orbital period of a planet divided by the orbital period of another planet. The same unit needs to be used for both periods.

Example 2

Figure 3.31 shows that a research satellite needs to orbit at a height of 380 km to capture clear images of the surface of the Earth. What is the orbital period of the satellite?

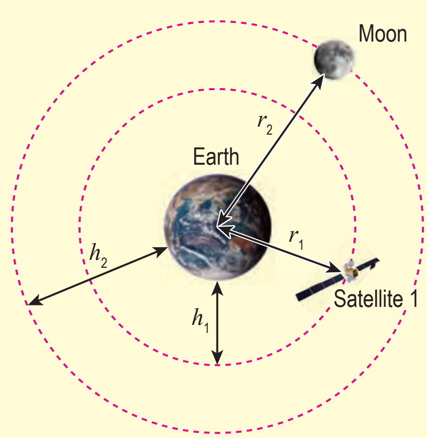


Figure 3.31

[Radius of the orbit of the Moon $= 3.83 \times 10^8$ m, orbital period of the Moon = 655.2 hours]

Solution:

Radius of orbit of the satellite, $r_1 = (6.37 \times 10^6) + (380 \times 10^3)$
$= 6.75 \times 10^6$ m

Radius of orbit of the Moon, $r_2 = 3.83 \times 10^8$ m

Orbital period of the satellite $= T_1$

Orbital period of the Moon, $T_2 = 655.2$ hours

$$\frac{T_1^{\,2}}{T_2^{\,2}} = \frac{r_1^{\,3}}{r_2^{\,3}}$$

$$\frac{T_1^{\,2}}{655.2^2} = \frac{(6.75 \times 10^6)^3}{(3.83 \times 10^8)^3}$$

$$T_1^{\,2} = \frac{(6.75 \times 10^6)^3 \times 655.2^2}{(3.83 \times 10^8)^3}$$

$$T_1 = \sqrt{\frac{(6.75 \times 10^6)^3 \times 655.2^2}{(3.83 \times 10^8)^3}}$$

$= 1.53$ hours

Formative Practice 3.2

1. State Kepler's first law.

2. (a) State Kepler's second law.

(b) Figure 3.32 shows the orbit of a planet around the Sun. Compare the linear speed of the planet at positions X, Y and Z.

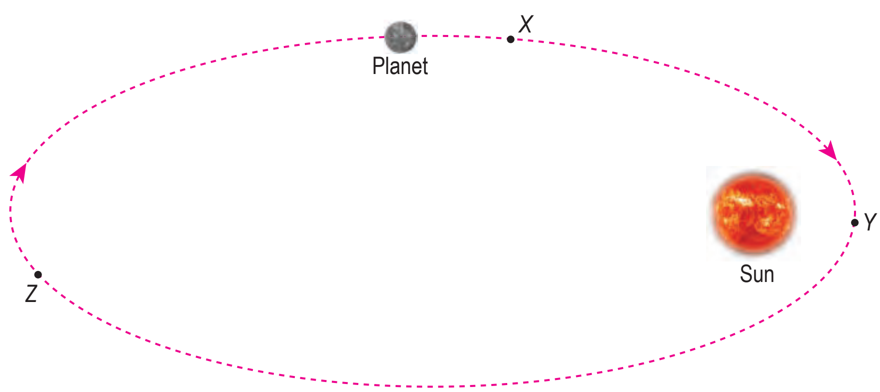


Figure 3.32

3. (a) State Kepler's third law.

(b) At what height should a satellite be if the satellite is required to orbit the Earth in a period of 24 hours?

[Orbital period of the Moon = 27.3 days, radius of orbit of the Moon = 3.83×10^8 m]

3.3 Man-made Satellites

Orbit of Satellite

Figure 3.33 shows the International Space Station, ISS, and MEASAT satellite. ISS can be seen from the Earth because of its large size and orbits at a height of 408 km. MEASAT satellite is difficult to be seen because of its small size and orbits at a height of 35 786 km. Satellites move in orbits at specific heights and suitable linear speeds.

Formulae for **centripetal force** and **Newton's Universal Law of Gravitation** are used to establish and determine the linear speed of satellites. Figure 3.34 shows the orbit of a satellite around the Earth.

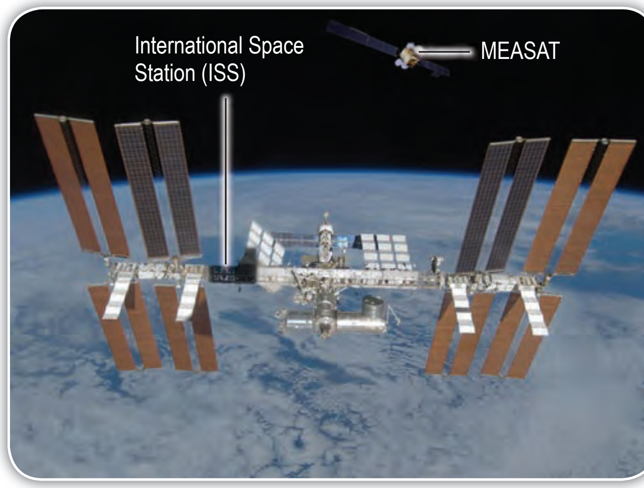
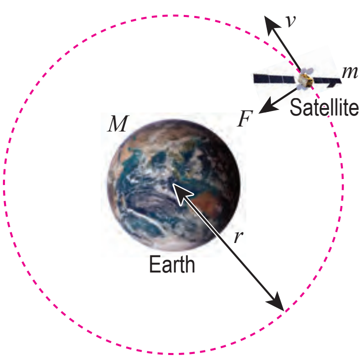


Figure 3.33 *Man-made satellite orbiting the Earth*



Mass of the Earth = M
Mass of satellite = m
Radius of orbit of satellite = r
Linear speed of satellite = v
Orbital period = T

Position and path of ISS

http://bt.sasbadi.com/p4103

Figure 3.34 *Orbit of a satellite*

A satellite moving in a circular orbit around the Earth experiences centripetal force, which is gravitational force.

Gravitational force between satellite and the Earth, $F = \dfrac{GMm}{r^2}$

Centripetal force on satellite, $F = \dfrac{mv^2}{r}$

Centripetal force = Gravitational force

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

$$v^2 = \frac{GM}{r}$$

$$v = \sqrt{\frac{GM}{r}}$$

CAREER INFO

Astronautical engineering involves the field of Physics on orbital mechanics, outer space environment, guidance and control of height, telecommunications, aerospace structure and rocket propulsion.

As GM is constant, linear speed of the satellite only depends on the radius of its orbit. If a satellite is at a height, h above the surface of the Earth,

Radius of its orbit, $r = R + h$
that is R = radius of the Earth

Therefore, linear speed of the satellite, $v = \sqrt{\frac{GM}{R + h}}$

Man-made satellites can be launched to keep orbiting at specific heights around the Earth at radius of orbit, r if the satellite is given linear speed, $v = \sqrt{\frac{GM}{r}}$. Figure 3.35 shows a Global Positioning System (GPS) satellite at an altitude of 20 200 km from the Earth.

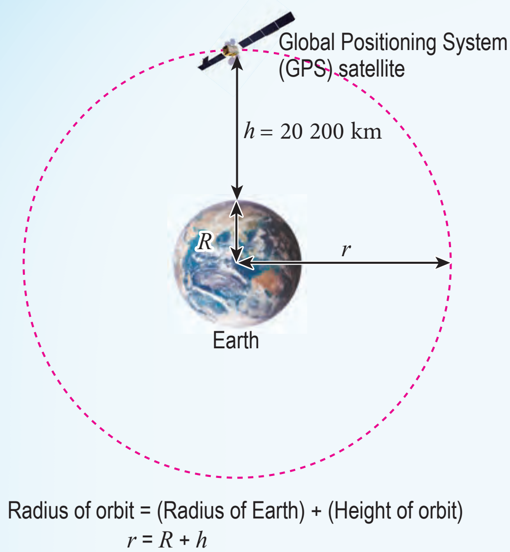


Figure 3.35 *GPS satellite orbits the Earth*

How does GPS work?

http://bt.sasbadi.com/p4104

Height, $h = 20\ 200 \times 1000$ m
$= 2.02 \times 10^7$ m

Radius of orbit, $r = (6.37 \times 10^6) + (2.02 \times 10^7)$
$= 2.657 \times 10^7$ m

Linear speed of satellite, $v = \sqrt{\frac{GM}{r}}$

$= \sqrt{\frac{(6.67 \times 10^{-11}) \times (5.97 \times 10^{24})}{2.657 \times 10^7}}$

$= 3.87 \times 10^3$ m s^{-1}

In a stable orbit, linear speed of satellite is $v = \sqrt{\frac{GM}{r}}$. This linear speed is high enough for the satellite to move in a circular orbit around the Earth. Centripetal acceleration is the same as gravitational acceleration.

If the linear speed of the satellite becomes less than the required linear speed, the satellite will fall to a lower orbit and continue to revolve towards the Earth until it enters the atmosphere. The movement of the satellite at a high linear speed against air resistance will generate heat and eventually causes the satellite to burn.

Geostationary and Non-Geostationary Satellites

Figure 3.36 shows two types of satellites orbiting the Earth, which is geostationary satellite and non-geostationary satellite. Study the features of the satellites.

Geostationary satellite

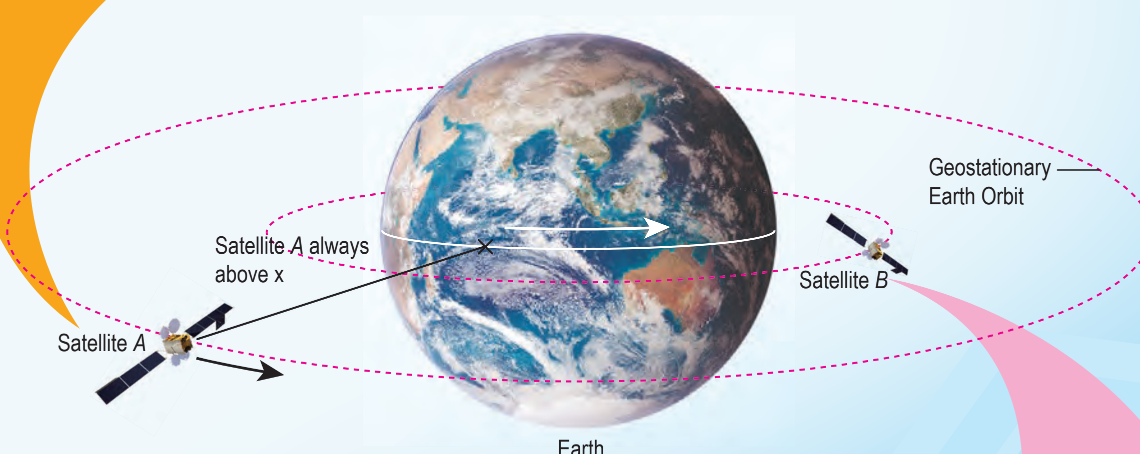
- In a special orbit named the Geostationary Earth Orbit
- Moves around the Earth in the same direction as the direction of the Earth's rotation on its axis
- Orbital period T = 24 hours, that is the same as the period of rotation of the Earth
- Always above the same geographical location

Geostationary satellite

http://bt.sasbadi.com/p4105a

Non-geostationary satellite

http://bt.sasbadi.com/p4105b



Non-geostationary satellite

- Normally in a lower or higher orbit than the Geostationary Earth Orbit
- Orbital period is shorter or longer than 24 hours
- Above different geographical locations at different times

Figure 3.36 *Geostationary and non-geostationary satellites*

Activity 3.12

ICS

Aim: To gather information on geostationary and non-geostationary satellites in terms of functions and lifespans

Instructions:

1. Work in groups.
2. Surf the internet to gather information on functions and lifespans for one geostationary satellite and one non-geostationary satellite.
3. Present your findings in the form of a folio and display it at the Resource Centre of your school.

Discussion:

1. What are the advantages of a non-geostationary satellite?
2. Why do communication satellites need to be in geostationary orbits?

Figure 3.37 shows the comparison between geostationary and non-geostationary satellites as well as examples of the satellites.

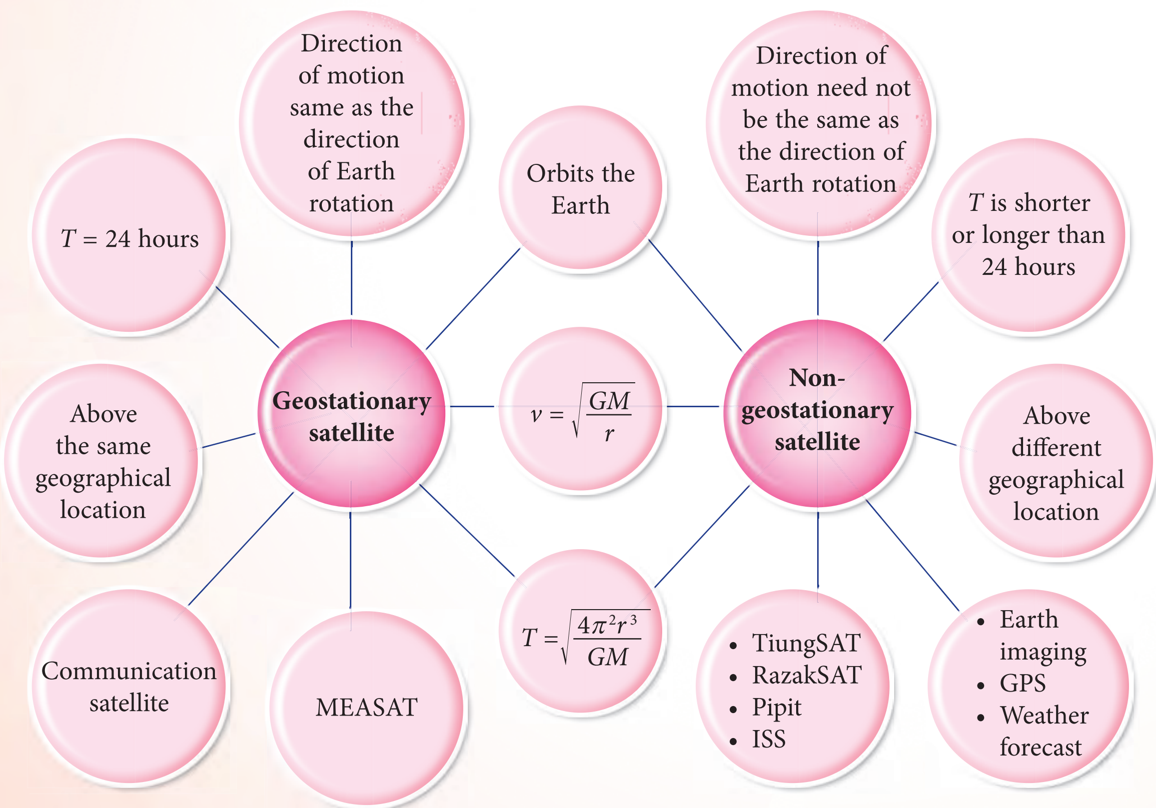


Figure 3.37 *Comparison between geostationary and non-geostationary satellites*

Escape Velocity

Escape velocity, v is the minimum velocity needed by an object on the surface of the Earth to overcome the gravitational force and escape to outer space.

If the distance of an object from the centre of the Earth is r, the mass of the object is m, and the mass of the Earth is M, then the object possesses gravitational potential energy, $U = -\frac{GMm}{r}$.

Figure 3.38 shows an object launched at escape velocity, v. This object can overcome gravitational force and move an infinite distance from the Earth.

Escape velocity

http://bt.sasbadi.com/p4107a

http://bt.sasbadi.com/p4107b

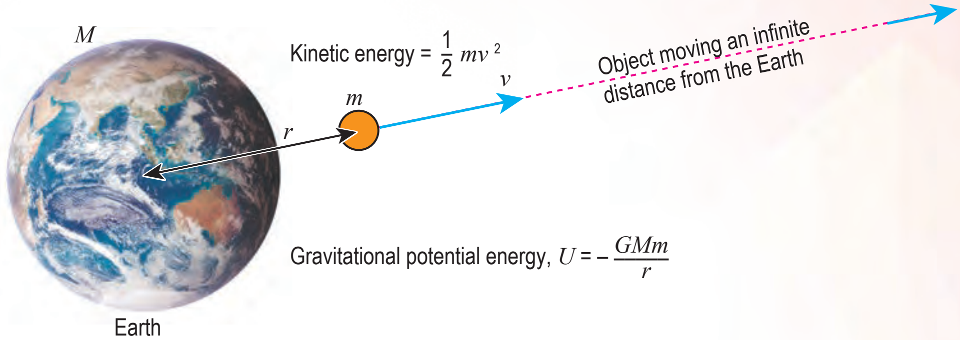


Figure 3.38 *Object launched at escape velocity*

Escape velocity is achieved when the minimum kinetic energy of an object is able to overcome its gravitational potential energy. As such:

Minimum kinetic energy + Gravitational potential energy = 0

that is, $\frac{1}{2}mv^2 + \left(-\frac{GMm}{r}\right) = 0$

$$v^2 = \frac{2GM}{r}$$

Escape velocity, $v = \sqrt{\frac{2GM}{r}}$

Info File

For an object on the surface of the Earth, its distance from the centre is the same as the radius of the Earth, R.

Escape velocity of the object is

$v = \sqrt{\frac{2GM}{R}}$

Mass of the Earth, $M = 5.97 \times 10^{24}$ kg
Radius of the Earth, $R = 6.37 \times 10^{6}$ m

Escape velocity from the Earth, $v = \sqrt{\frac{2GM}{R}}$

$= \sqrt{\frac{2 \times (6.67 \times 10^{-11}) \times (5.97 \times 10^{24})}{(6.37 \times 10^{6})}}$

$= 1.12 \times 10^{4}\text{ m s}^{-1}$

$= 11.2 \times 10^{3}\text{ m s}^{-1}$

$= 11.2\text{ km s}^{-1}$

Info File

As the Earth has a large mass, escape velocity from the Earth has a high value, 11 200 m s^{-1} or 40 300 km h^{-1}.

Escape velocity, v of an object depends on the mass of the Earth, M and distance, r of the object from the centre of the Earth. Escape velocity does not depend on mass of the object, m.

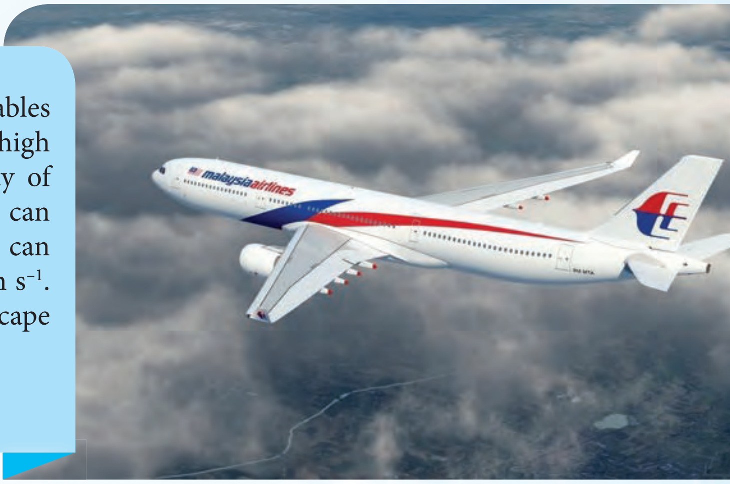
3.3.3

Benefits and Implications of Escape Velocity

High escape velocity of the Earth, that is 11 200 m s^{-1} has benefits and implications on humans. One of the benefits is the Earth is able to maintain a layer of atmosphere around it. Molecules in the atmosphere move at average linear speed of 500 m s^{-1}, that is lower than the escape velocity from the Earth. As such, air molecules that are moving randomly will not be able to escape from the Earth into outer space.

Figure 3.39 *Earth's atmosphere*

High escape velocity of the Earth also enables commercial aircrafts or fighter jets to fly to high levels in the atmosphere without the possibility of escaping into outer space. Commercial aircrafts can fly at linear speed of 250 m s^{-1} while fighter jets can achieve supersonic linear speed of up to 2 200 m s^{-1}. Both their linear speeds are lower than the escape velocity from the Earth.



Photograph 3.1 *Commercial aircraft*

The launching of rockets requires large quantities of fuel to produce high thrust that enables the rocket to achieve escape velocity of the Earth. Hence, it can send the spacecraft into outer space.

Photograph 3.2 *Rocket launching*

Solving Problems Involving Escape Velocity

You have calculated escape velocity from the Earth using the formula $v = \sqrt{\dfrac{2GM}{R}}$. In fact, this formula can also be used to calculate escape velocity from other bodies such as the Moon, Mars and the Sun.

Activity 3.13

Logical Reasoning CPS

Aim: To discuss escape velocity from planets

Instructions:

1. Work in pairs.
2. Copy and complete Table 3.4 by calculating the value of escape velocity.

Table 3.4

Planet	Mass, M / kg	Radius, R / m	Escape velocity, v / m s^{-1}
Venus	4.87×10^{24}	6.05×10^{6}	
Mars	6.42×10^{23}	3.40×10^{6}	
Jupiter	1.90×10^{27}	6.99×10^{7}	

Escape velocity of Mars is low, therefore the gases are easier to escape to outer space. This causes the density of the atmosphere on Mars to be low (100 times less dense than Earth's atmosphere). Jupiter on the other hand has such a high escape velocity that hot gases on its surface cannot escape into outer space. Knowledge on escape velocity is important to determine how spacecrafts can land and take off safely from a planet.

Recall

Characteristics of planets in the Solar System

http://bt.sasbadi.com/p4109

Example 1

The Moon and the Sun are two bodies in the Solar System. Table 3.5 shows the values of the mass and radius of the Moon and the Sun. Compare:

(i) gravitational acceleration on the Moon and the Sun

(ii) escape velocity from the Moon and from the Sun

based on data provided in Table 3.5.

Table 3.5

Body	Mass, M / kg	Radius, R / m
Moon	7.35×10^{22}	1.74×10^{6}
Sun	1.99×10^{30}	6.96×10^{8}

3.3.4

Solution:

(i) Gravitational acceleration is calculated using the formula $g = \dfrac{GM}{R^2}$

The Moon

$$g = \frac{(6.67 \times 10^{-11}) \times (7.35 \times 10^{22})}{(1.74 \times 10^{6})^2}$$
$$= 1.62 \text{ m s}^{-2}$$

The Sun

$$g = \frac{(6.67 \times 10^{-11}) \times (1.99 \times 10^{30})}{(6.96 \times 10^{8})^2}$$
$$= 274.0 \text{ m s}^{-2}$$

(ii) Escape velocity is calculated using the formula $v = \sqrt{\dfrac{2GM}{R}}$

The Moon

$$v = \sqrt{\frac{2 \times (6.67 \times 10^{-11}) \times (7.35 \times 10^{22})}{1.74 \times 10^{6}}}$$
$$= 2.37 \times 10^{3} \text{ m s}^{-1}$$

The Sun

$$v = \sqrt{\frac{2 \times (6.67 \times 10^{-11}) \times (1.99 \times 10^{30})}{(6.96 \times 10^{8})}}$$
$$= 6.18 \times 10^{5} \text{ m s}^{-1}$$

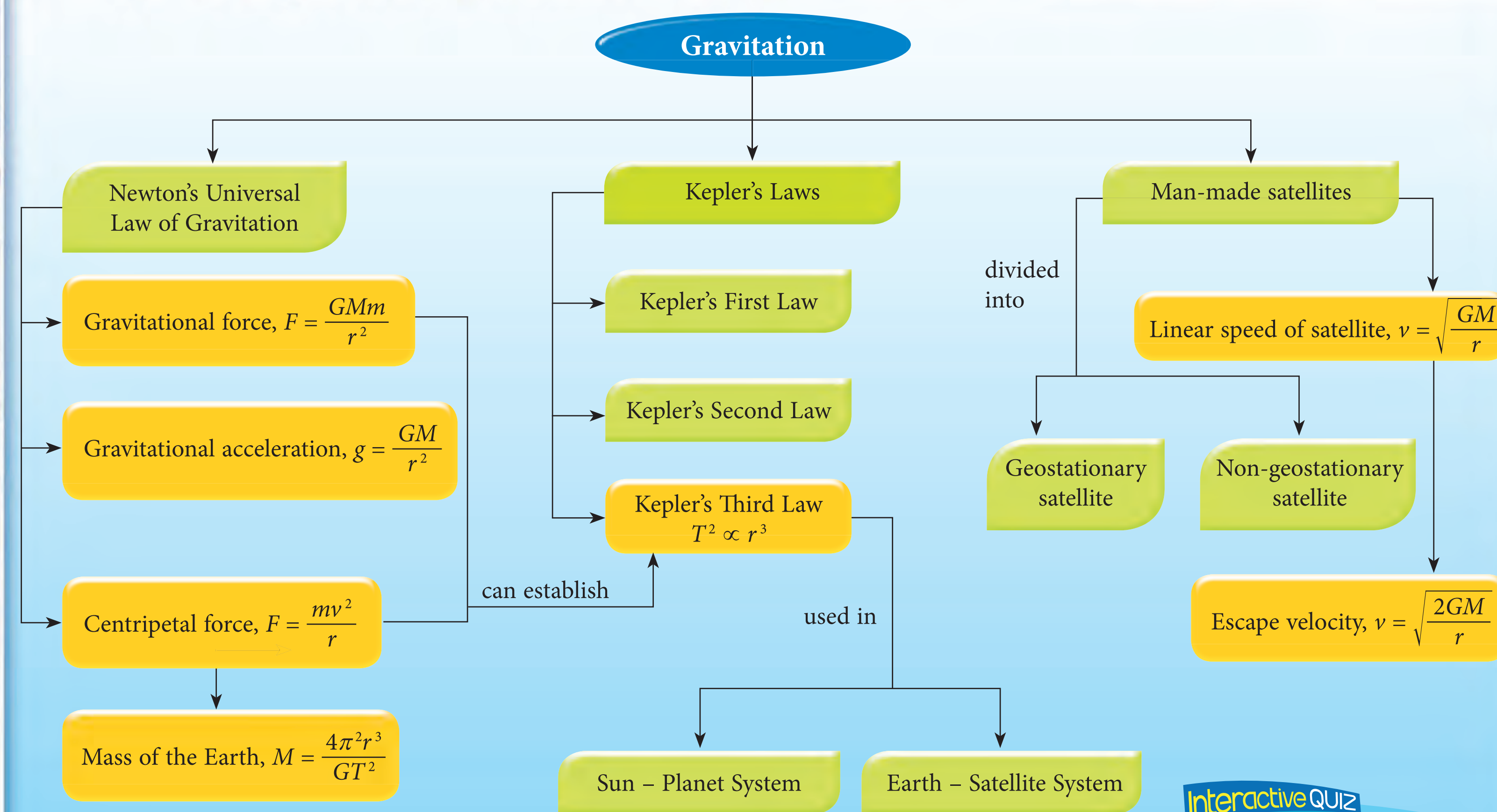
- The Moon has low gravitational acceleration and escape velocity because the mass of the Moon is smaller than that of the Sun.
- The Sun is the largest body in the Solar System. Gravitational acceleration on the Sun and escape velocity from the Sun have the highest values compared with those of the Moon as well as other planets.

Formative Practice 3.3

1. Compare and contrast geostationary and non-geostationary satellites.
2. What factors determine the linear speed of satellites orbiting the Earth?
3. State two factors which influence the value of escape velocity from a planet.
4. Discuss whether escape velocity from the Earth for spacecraft X of mass 1 500 kg is different from spacecraft Y of mass 2 000 kg.
5. Proba-1 satellite orbits the Earth at a height of 700 km. What is the linear speed of this satellite?

   [$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, mass of the Earth = 5.97×10^{24} kg, radius of the Earth = 6.37×10^{6} m]

Conceptual Framework



Interactive QUIZ

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SELF-REFLECTION

1. New things I learnt in this chapter on gravitation are ______.
2. The most interesting thing I learnt in this chapter on gravitation is ______.
3. Things I still do not fully understand or comprehend are ______.
4. My performance in this chapter,

   Poor | 1 | 2 | 3 | 4 | 5 | Excellent

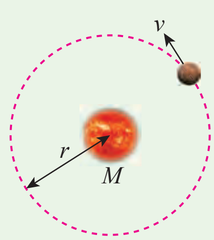
5. I need to ______ to improve my performance in this chapter.

Download and print Self-reflection Chapter 3

http://bt.sasbadi.com/p4112

Performance Evaluation

1. Figure 1 shows planet Mars orbits the Sun in a circular motion with orbital period, T.



m = mass of Mars
M = mass of the Sun
r = radius of orbit of Mars
v = linear speed of Mars

Figure 1

(a) For planet Mars, write the formula for:
   (i) gravitational force in terms of m, M and r
   (ii) centripetal force in terms of m, v and r
   (iii) linear speed in terms of r and T

(b) Derive an expression for the mass of the Sun in terms of r and T by using the three formulae in (a).

(c) Radius of orbit of Mars is $r = 2.28 \times 10^{11}$ m and its orbital period is $T = 687$ days. Calculate the mass of the Sun.

2. A satellite orbits the Earth with radius, r and orbital period, T.
(a) Write down the linear speed of the satellite in terms of r and T.
(b) Use other suitable formulae to establish the formula for linear speed of the satellite in terms of r and M. M is the mass of the Earth.
(c) Why does the linear speed of a satellite orbiting the Earth not depend on the mass of the satellite?

3. Figure 2 shows the orbit of planet Uranus.

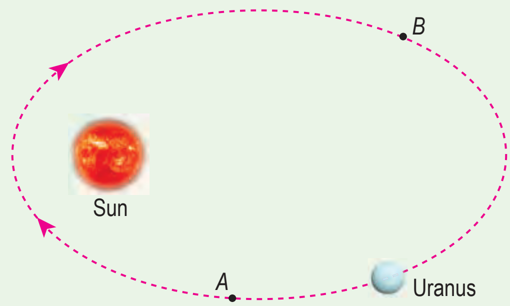


Figure 2

Describe the change in linear speed of planet Uranus when it moves from point A to point B.

4. Figure 3 shows the Earth, the Moon and a satellite.

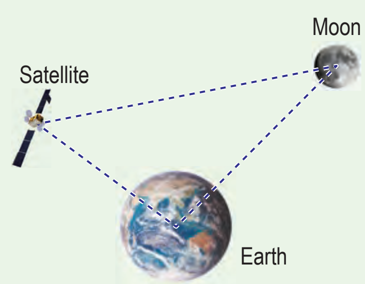


Figure 3

(a) Which pair of bodies experience the smallest gravitational force?
Give a reason for your answer.
(b) Calculate the gravitational force between the Earth and the satellite.
[Mass of the Earth = 5.97×10^{24} kg, mass of satellite = 1.2×10^{3} kg, distance between centre of the Earth and centre of the satellite = 7.87×10^{6} m]

5. (a) What are the factors that determine the value of the gravitational acceleration?
(b) A satellite is at a distance of 4.20×10^{7} m from the centre of the Earth.
What is the value of the gravitational acceleration at this position?
[Mass of the Earth = 5.97×10^{24} kg]

6. Figure 4 shows the Earth and planet Neptune.

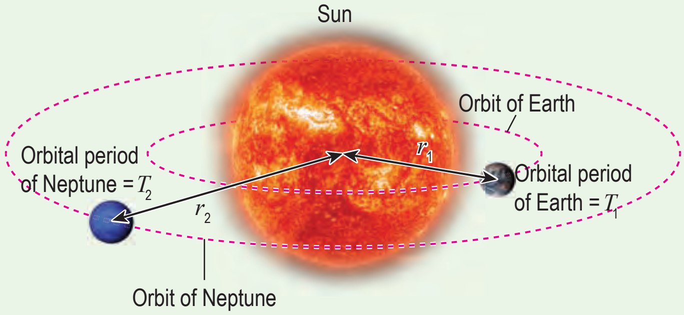


Figure 4

(a) Write down the relationship between orbital period and radius of orbit for the Earth and Neptune.

(b) Orbital period of the Earth is 365 days and radius of orbit of the Earth is 1.50×10^{11} m. Calculate the radius of orbit of Neptune if its orbital period is 5.98×10^4 days.

7. The Earth orbits the Sun with radius of orbit of 1.50×10^{11} m and orbital period of 1 year. Radius of orbit of planet Saturn is 1.43×10^{12} m. What is the orbital period of Saturn?

8. A spacecraft orbits the Earth at a height of 1 600 km. Calculate the escape velocity for the spacecraft.
[$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, mass of the Earth = 5.97×10^{24} kg, radius of the Earth = 6.37×10^6 m]

9. Figure 5 shows planet Saturn with rings made up of small particles around it. Planet Saturn has a mass of 5.68×10^{26} kg and radius of 6.03×10^7 m.

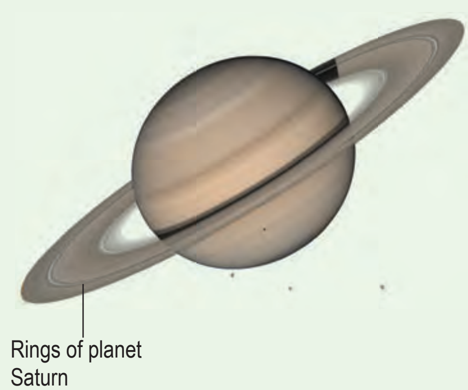


Figure 5

(a) Calculate the escape velocity of planet Saturn.

(b) Discuss the possibility of the small particles in the rings of planet Saturn escaping into the outer space.

10. Figure 6 shows three bodies A, B and C. It is given that the gravitational force between A and B is P.

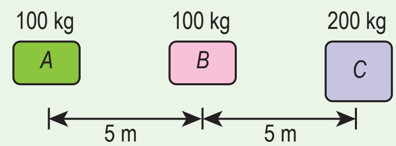


Figure 6

State in terms of P, the gravitational force between
(i) B and C
(ii) A and C

11. Table 1 shows information on three types of orbits X, Y and Z for a satellite orbiting the Earth.

Table 1

Orbit	Shape of orbit	Height of orbit / m	Orbital period / hours
X	Ellipse	6.70×10^3	1.41
Y	Circle	3.59×10^7	24.04
Z	Circle	5.43×10^7	41.33

A space agency wishes to launch two satellites, P and Q to orbit the Earth. Satellite P is an Earth imaging satellite that can capture images of various locations on the surface of the Earth while satellite Q is a communication satellite.

Using the information in Table 1, determine which orbit is suitable for satellite P and satellite Q. Explain your choice.

12. Assume you are a scientist. Your group has found a new system of bodies. This system is made up of a star at the centre and five planets in a circular orbit around the star. Table 2 shows information on this system of bodies.

Table 2

Body	Mass / kg	Radius of body / m	Radius of orbit / m
Star	5.90×10^{29}	6.96×10^8	–
Planet A	2.80×10^{22}	1.07×10^6	2.86×10^{10}
Planet B	6.30×10^{23}	2.30×10^6	9.85×10^{10}
Planet C	7.40×10^{22}	3.41×10^6	1.15×10^{11}
Planet D	4.60×10^{25}	1.32×10^7	5.32×10^{11}
Planet E	1.90×10^{21}	2.42×10^5	2.13×10^{12}

(a) Calculate the gravitational acceleration, escape velocity and orbital period of each planet.

(b) How do the values of gravitational acceleration, escape velocity and orbital period influence the suitability of a new planet to be inhabited by humans?

(c) Choose the most suitable planet to be inhabited by humans. Give a reason for your choice.

Enrichment Corner

13. Assuming humans have successfully inhabited planet Mars. You and a group of scientists are required to invent a system of man-made satellites around Mars. These man-made satellites consist of weather satellites, planet surface mapping satellites and communication satellites. Table 3 shows information on planet Mars.

Table 3

Mass / kg	6.42×10^{23}
Radius of planet / m	3.40×10^{6}
Period of revolution / hours	24.6

Based on the information in Table 3, propose the characteristics of the satellite orbit in terms of orbital height, orbital period, linear speed of satellite, launch base as well as other suitable factors.

Theme 3

Heat

Heat is closely related to human life. Topics in this theme discuss concepts and laws related to heat energy. We will investigate the aspects of changes in phases of matter, especially changes in the properties of gas. Three gas laws, Boyle's Law, Charles' Law and Gay-Lussac's (pressure) Law, will also be introduced.

CHAPTER 4 Heat

Why is water suitable to be used as a cooling agent?

What is the importance of specific heat capacity of a substance?

What influences the behaviour of gas molecules?

Let's Study

4.1 Thermal Equilibrium
4.2 Specific Heat Capacity
4.3 Specific Latent Heat
4.4 Gas Laws

Information Page

Kitchen is where a lot of the concepts related to heat energy can be applied. When we heat up water in a kettle, the rate of increase in water temperature depends on the quantity of water heated. When the water boils, its temperature will no longer increase. When the same quantity of oil and water are heated separately at the same time, oil will be hotter first. All these examples involve the relationship and interaction between physical properties of matter such as temperature, pressure, volume and heat. Applications of the concept of heat have greatly helped our daily life.

Video on application of physics concepts in the kitchen

http://bt.sasbadi.com/p4119a

Learning Standards and List of Formulae

4.1 Thermal Equilibrium

Observe Photograph 4.1. When a cold metal spoon is put into a cup of hot coffee, the spoon and the coffee are said to be in thermal contact because heat energy can be transferred between the two bodies. How can the metal spoon cool down the hot coffee? What is the final condition of the spoon and the coffee?

Photograph 4.1 *A cold metal spoon in a cup of hot coffee*

Activity 4.1

Aim: To show thermal equilibrium between two bodies in thermal contact

Apparatus: Two retort stands, two thermometers, 250 mℓ beaker labelled *A*, 50 mℓ beaker labelled *B*, measuring cylinder and stopwatch

Materials: 50°C hot water, tap water and tissue paper

Instructions:

1. Wrap beaker *A* with tissue and fill it with 150 mℓ of tap water.
2. Fill 40 mℓ of 50°C hot water into beaker *B*.
3. Place beaker *B* into beaker *A*. Then, place thermometer *A* and thermometer *B* into beaker *A* and beaker *B* respectively as shown in Figure 4.1.

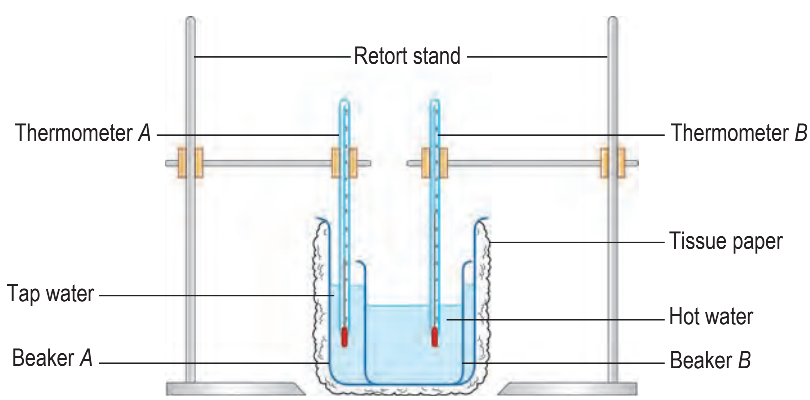


Figure 4.1

4. Record the readings of thermometer *A* and thermometer *B* every 30 s until the readings of both thermometers are the same. (This activity can normally be carried out in five minutes)

Results:

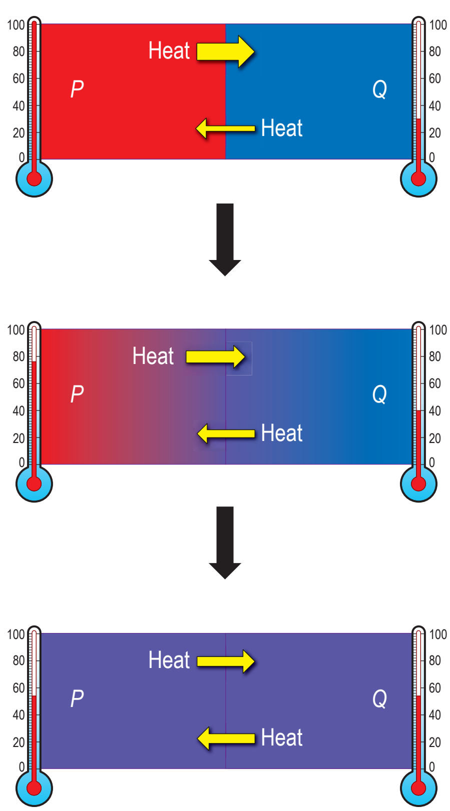
Table 4.1

Time, t / s	Temperature of thermometer A / °C	Temperature of thermometer B / °C
0		
30.0		
60.0		

Discussion:

1. Why is beaker *A* wrapped with tissue paper?
2. Describe the changes in temperature of the hot water and tap water.
3. What causes the changes in temperature?

When two objects are **in thermal contact**, the temperature of the hot object will drop while the temperature of the cold object will rise until the **temperature** of both objects become the same. Net heat transfer between the two objects becomes zero. Both objects are said to be in **thermal equilibrium**. Figure 4.2 explains the flow of heat between two objects in thermal contact until thermal equilibrium is reached.



Hot object, *P* is in thermal contact with cold object, *Q*. The rate of heat transfer from *P* to *Q* is higher than the rate of heat transfer from *Q* to *P*.

There is a net transfer of heat from *P* to *Q*. Therefore, temperature of *P* drops and temperature of *Q* rises.

Temperature of *P* and temperature of *Q* become the **same**. The rate of heat transfer from *P* to *Q* is the same as the rate of heat transfer from *Q* to *P*. **Net heat transfer** between *P* and *Q* becomes zero. *P* and *Q* are in a state **of thermal equilibrium**.

Figure 4.2 *Flow of heat energy and thermal equilibrium*

Thermal Equilibrium in Daily Life

Thermal equilibrium causes two objects in thermal contact to reach the same temperature. Figure 4.3 shows examples of thermal equilibrium in daily life.

Figure 4.3 *Thermal equilibrium in daily life*

Activity 4.2

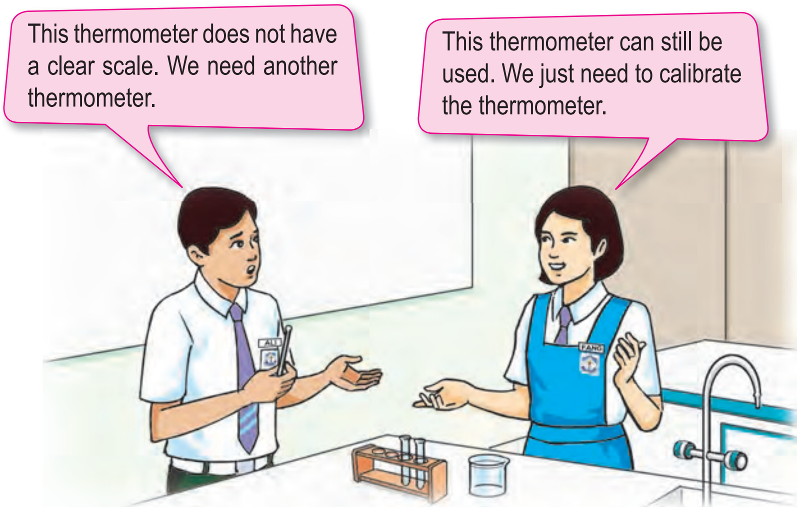
ISS ICS

Aim: To discuss situations and applications of thermal equilibrium in daily life

Instructions:

1. Carry out this activity in groups.
2. Gather information on situations and other applications of thermal equilibrium in daily life. The information can be obtained from reading resources or websites.
3. Discuss the flow of heat energy until thermal equilibrium is achieved.
4. Draw a mind map based on your findings.

To Calibrate a Liquid-in-glass Thermometer Using Two Fixed Points



A thermometer that does not have a scale can be calibrated using two fixed temperature points. Two fixed points used for distilled water are melting point of ice, 0°C and boiling point of water, 100°C.

Info File

The process of calibrating uses the thermometric property of liquids in glass. Thermometric property means a physical property which can be measured (such as length of column of liquid) which changes with temperature.

Gateway to SCIENCE, TECHNOLOGY and SOCIETY

Cooking thermometer is used to measure the temperature of food during and after food preparation. Poor control of time and temperature can cause food poisoning. As such, periodic calibration of the thermometer is very important.

Activity 4.3

Aim: To calibrate a liquid-in-glass thermometer using boiling point of distilled water and melting point of ice

Apparatus: Thermometer, ruler, 250 mℓ beaker, immersion heater, power supply and retort stand

Materials: Ice, distilled water and masking tape

Instructions:

1. Cover the scale of the thermometer with masking tape so that the scale cannot be seen.
2. Prepare two beakers. Fill beaker *A* with ice and a small amount of distilled water. Fill beaker *B* with distilled water and put in an immersion heater.
3. Put a thermometer into beaker *A*. Wait until there is no more change in the level of liquid column. Then, mark the level of liquid column on the stem of the thermometer. Label this level as 0°C (Figure 4.4).
4. Remove the thermometer from beaker *A* and switch on the immersion heater in beaker *B*.
5. When the distilled water in beaker *B* is boiling, put the thermometer into beaker *B*. Wait until there is no more change in the level of liquid column. Then, mark the level of liquid column on the stem of the thermometer. Label this level as 100°C (Figure 4.4). Switch off the immersion heater.

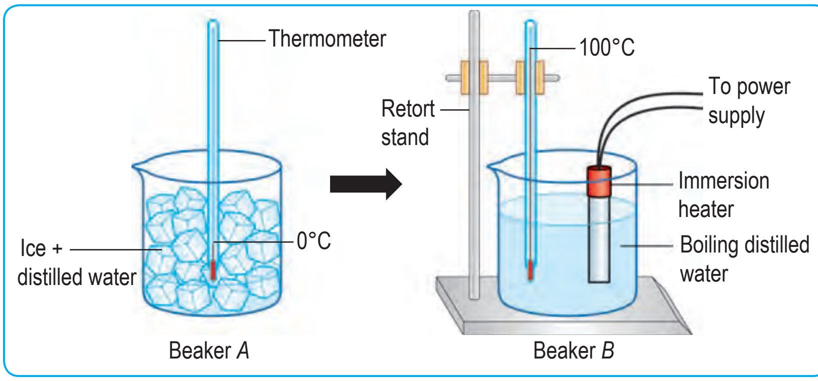


Figure 4.4

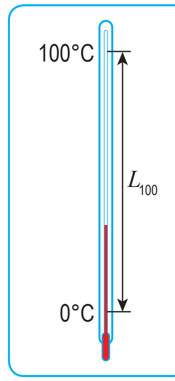


Figure 4.5

6. Measure the length from the 0°C mark to the 100°C mark as L_{100} (Figure 4.5).
7. Prepare beaker *C* and fill it with tap water.
8. Put the calibrated thermometer into beaker *C*. Wait until there is no more change in the level of the liquid column. Then, mark the level of the liquid column on the stem of the thermometer. Label this level as θ°C.
9. Measure the length from the 0°C mark to the θ°C mark as L_θ.
10. Calculate the temperature of tap water using the formula, $\theta = \frac{L_\theta}{L_{100}} \times 100°C$

Discussion:

1. The bulb of the thermometer should not touch the base or side wall of the beaker while taking measurement. Explain.
2. Why should you wait until there is no more change in the level of the liquid column before making a mark on the stem of the thermometer?

Calibration is a process of making a scale of reading on a thermometer. 0°C is the fixed lower limit and 100°C is the fixed upper limit. The length of liquid column between the fixed lower limit and the fixed upper limit is divided into 100 equal divisions. The thermometer is then calibrated and can be used to measure temperature between 0°C and 100°C.

Formative Practice 4.1

1. State what happens to two objects in thermal equilibrium.
2. Is our body in thermal equilibrium with the environment? Explain your answer.
3. Aisyah uses an uncalibrated laboratory thermometer to determine the temperature of a liquid, θ°C. She finds that the length of the liquid column when the thermometer is put into the liquid is as shown in Figure 4.6. Calculate the temperature of the liquid, θ°C.

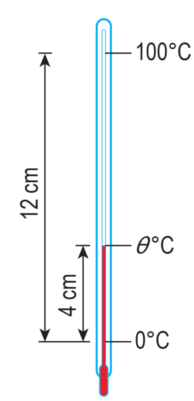


Figure 4.6

4.1.2

4.2 Specific Heat Capacity

***Figure 4.7** Difference in temperature of sand and sea water at the beach*

Figure 4.7 shows two different situations. The sun heats up the sand and sea water at the same period of time. However, sand gets hot quickly and sea water gets hot slowly.

This can be explained based on the concept of **heat capacity**. Different objects have different heat capacity. Sand has a low heat capacity and gets hot quickly while sea water has a high heat capacity and gets hot slowly.

Heat capacity, ***C*** of an object is the quantity of heat needed to raise the temperature of the object by 1°C.

$C = \dfrac{Q}{\Delta\theta}$, that is Q = quantity of heat supplied
$\Delta\theta$ = change in temperature

Unit for C = J °C^{-1}

When 100 J of heat is supplied to objects *X* and *Y*, object *X* experiences a rise in temperature of 1°C and object *Y* 2°C. What are the respective heat capacity of objects *X* and *Y*?

Heat capacity for object *X*, $C_X = \dfrac{100\text{ J}}{1°\text{C}}$
$= 100\text{ J °C}^{-1}$

Heat capacity for object *Y*, $C_Y = \dfrac{100\text{ J}}{2°\text{C}}$
$= 50\text{ J °C}^{-1}$

Object *X* has a higher heat capacity than object *Y*.
Therefore, the increase in temperature of object *X* is less than object *Y*.

Heat capacity of an object increases when the mass of the object increases. For example, the water in a full kettle takes a longer time to boil compared to the water in a half-filled kettle. This shows that water of bigger mass has a higher heat capacity compared to water of smaller mass. Figure 4.8 shows several daily situations involving heat capacity.

Figure 4.8 Daily situations which involve heat capacity

Specific Heat Capacity of Substance

Figure 4.9 shows a material engineer tries to choose a suitable metal as building material. He needs a material that does not heat up easily. Since the heat capacity of a material differs with its mass, he needs to make his choice based on **specific heat capacity** instead – which means he has to choose the material based on the heat capacity of every 1 kg of each material.

Specific Heat Capacity

http://bt.sasbadi.com/p4127

Figure 4.9 *A material engineer is comparing specific heat capacity between different metals*

Specific heat capacity, *c* of a substance is the quantity of heat needed to raise the temperature of 1 kg mass of the substance by 1°C.

$c = \dfrac{Q}{m\Delta\theta}$, where Q = quantity of heat supplied (J)
m = mass (kg)
$\Delta\theta$ = change of temperature (°C or K)

Unit for c = J kg^{-1} °C^{-1} or J kg^{-1} K^{-1}

Quantity of heat, Q that is absorbed or released by an object can be determined using the formula $Q = mc\Delta\theta$.

For example, the specific heat capacity of the metal aluminium is 900 J kg^{-1} °C^{-1}. This means 1 kg of aluminium requires 900 J of heat to raise its temperature by 1°C.

SMART INFO

Heat capacity, $C = \dfrac{Q}{\Delta\theta}$

Specific heat capacity, $c = \dfrac{Q}{m\Delta\theta}$

Every substance has its own value of specific heat capacity. Table 4.2 shows examples of substances and their specific heat capacity.

***Table 4.2** Specific heat capacity of different substances*

Type of substance	Substance	Specific heat capacity, c / J kg^{-1} °C^{-1}	Type of substance	Substance	Specific heat capacity, c / J kg^{-1} °C^{-1}
Liquid	Water	4 200	Metal	Aluminium	900
	Sea water	3 900		Iron	450
	Ethanol	2 500		Copper	390
	Paraffin	2 100		Gold	300
	Cooking oil	1 850		Mercury	140
	Olive oil	1 890		Lead	130
Gas	Methane	2 200	Non-metal	Polycarbonate	1 250
	Steam (at 100°C)	2 020		Wood	1 700
				Concrete	850
	Neon	1 030		Sand	800
	Air	1 000		Glass	670

Water is a substance which has high specific heat capacity. Water needs to absorb a large amount of heat to have a small rise in temperature. This makes water a good cooling agent. Metal on the other hand has lower specific heat capacity compared to non-metal. Therefore, objects made from metal get hot quickly when supplied with an amount of heat.

Experiment 4.1

Aim: To determine the specific heat capacity of water

Apparatus: Power supply, immersion heater, beaker, stopwatch, thermometer, retort stand and electronic balance

Materials: Water and tissue paper

Procedure:

1. Wrap a beaker with tissue paper.
2. Place the beaker on top of an electronic balance and reset the reading of the balance to zero.
3. Fill the beaker with water until it is three-quarter full.
4. Record the reading of the mass of the water, m shown on the electronic balance.
5. Set up the apparatus as shown in Figure 4.10.

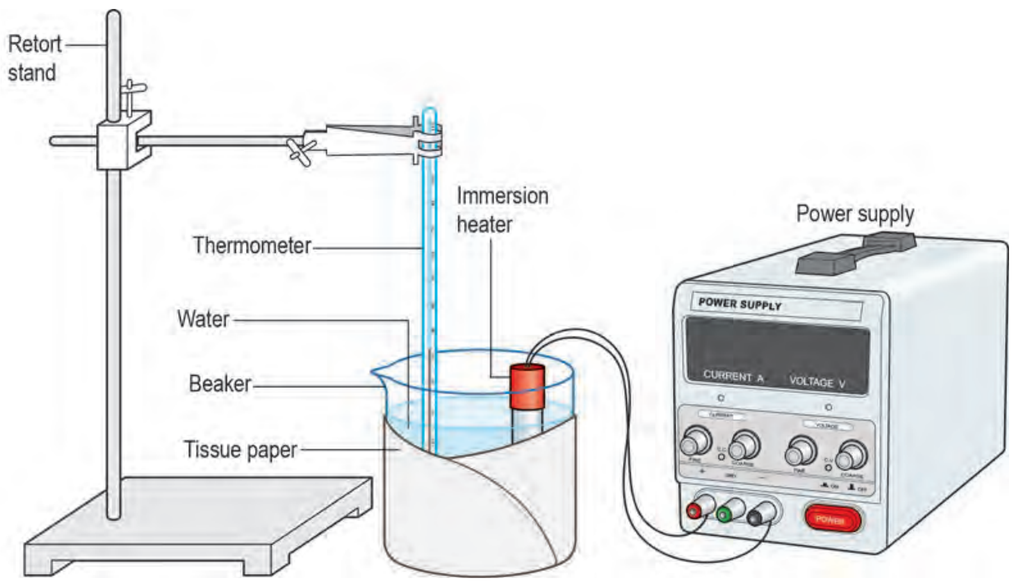


Figure 4.10

6. Record the initial temperature of the water, θ_1.
7. Switch on the immersion heater and start the stopwatch at the same time.
8. Observe the change in the thermometer reading.
9. After five minutes, switch off the immersion heater. Record the highest thermometer reading as the final water temperature, θ_2.

SMART INFO

Immersion heater converts **electrical energy** to **heat energy**. The heat energy supplied by the immersion heater is

$Q = Pt$, where

P = power of heater and

t = period of time heater is switched on

Change in water temperature, $\Delta\theta = \theta_2 - \theta_1$.

For this experiment, the equation $Q = mc\Delta\theta$ is expressed as $Pt = mc(\theta_2 - \theta_1)$.

Results:

Table 4.3

Power of immersion heater, P / W	
Heating time, t / s	
Mass of water, m / kg	
Initial temperature of water, θ_1 / °C	
Final temperature of water, θ_2 / °C	

Analysis of data:

Calculate the specific heat capacity of water using the formula, $c = \dfrac{Pt}{m(\theta_2 - \theta_1)}$.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

1. Why does the beaker need to be wrapped with tissue paper?
2. Why is the final water temperature, θ_2 not taken as soon as the five-minute heating time ends?
3. Given specific heat capacity of water is 4 200 J kg^{-1} °C^{-1}, compare the value of specific heat capacity of water obtained from the experiment with the value given. Explain the difference between the two values (if any).
4. Suggest methods to increase the accuracy of the result of this experiment.

Experiment 4.2

Aim: To determine the specific heat capacity of aluminium

Apparatus: Power supply, immersion heater, 1 kg aluminium block, stopwatch, thermometer and retort stand

Material: Tissue paper

Procedure:

1. Set up the apparatus as shown in Figure 4.11.

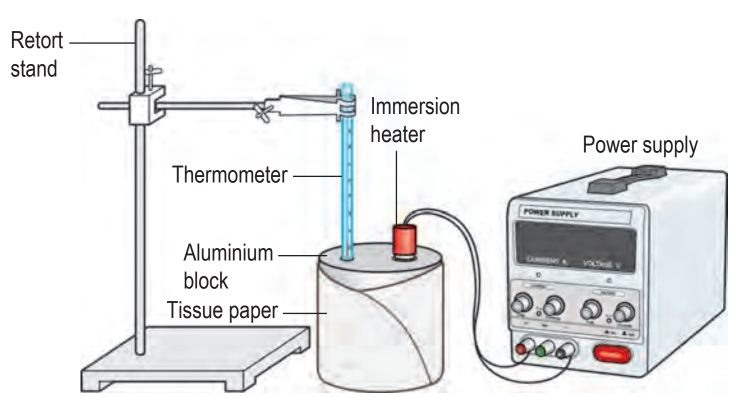


Figure 4.11

2. Record the initial temperature of the aluminium block, θ_1.
3. Switch on the immersion heater and start the stopwatch at the same time.
4. After five minutes, switch off the immersion heater. Record the highest thermometer reading as the final temperature of the aluminium block, θ_2.

Results:

Table 4.4

Power of immersion heater, P / W	
Heating time, t / s	
Mass of aluminium, m / kg	
Initial temperature of aluminium, θ_1 / °C	
Final temperature of aluminium, θ_2 / °C	

Analysis of data:

Calculate the specific heat capacity of aluminium using the formula, $c = \dfrac{Pt}{m(\theta_2 - \theta_1)}$.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. What can be done to obtain a better thermal contact between the bulb of the thermometer and the aluminium block?
2. Given specific heat capacity of aluminium is 900 J kg^{-1} °C^{-1}, compare the value of specific heat capacity of aluminium obtained from the experiment with the value given. Explain the difference between the two values (if any).

Applications of Specific Heat Capacity

Knowledge on specific heat capacity is very important in daily life, material engineering and also understanding several natural phenomena.

Selection building materials of traditional houses in various climate zones

Wood has a high specific heat capacity and gets hot slowly. In warm weather regions, traditional houses are built from wood which functions as an insulator of heat from the scorching sun. In cold weather regions, traditional houses are also built from wood. Heat from fires lit in the wooden houses cannot flow out because wood functions as a good heat insulator.

Warm climate

Cold climate

Cooking utensils

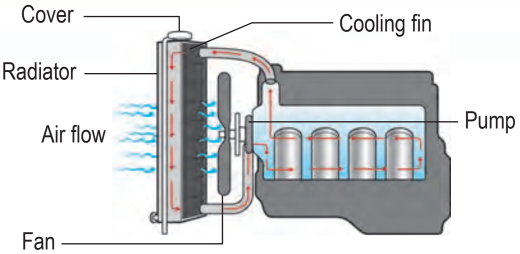
Metal wok

Clay pot

Woks are made of metal with low specific heat capacity. As such, food can be fried at high temperature in a short time. Clay pots on the other hand are made of clay which has a high specific heat capacity. As such, food can stay hot for a long time.

Car radiator system

Burning of fuel in car engines produces large amounts of heat. This heat needs to be released to avoid overheating the engine. Water has a high specific heat capacity and is used as a cooling agent. A pump will pump water into the engine block. Water will flow through the engine block to absorb heat produced. Hot water flows to the radiator. Cold air is sucked in by fans so that heat in the hot water can be released quickly through cooling fins.



Video on car radiator system

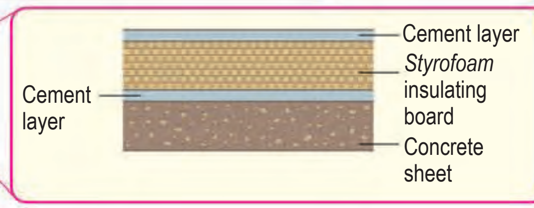
http://bt.sasbadi.com/p4132

4.2.4

Outer layer of space capsule

Space capsule on its journey back to Earth encounters air resistance when entering the atmosphere. This friction increases the temperature and causes the space capsule to burn. Therefore, the outer layer of a space capsule is made from substance with a high specific heat capacity and melting point.

Production of latest materials in the construction of green buildings



The Diamond Building, Energy Commission is built with an insulating concrete roof, that is a roof fitted with insulators using *styrofoam* boards. *Styrofoam* has a high specific heat capacity and can reduce the absorption of heat from the surroundings to reduce the temperature inside the building.

The Diamond Building

http://bt.sasbadi.com/p4133

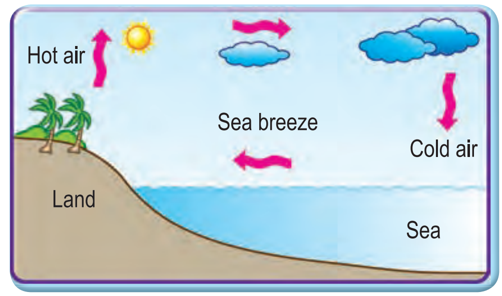
Cooking utensils

The body of a pot is made of aluminium which has a low specific heat capacity. This enables the pot to heat up quickly. However, the handle of the pot is made from plastic which has a high specific heat capacity. This ensures that the handle of the pot gets hot slowly and is safe to handle.

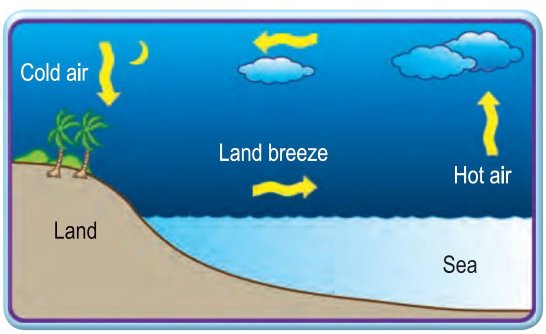
4.2.4

Sea breeze

Land has a lower specific heat capacity than the sea. Therefore, temperature on land rises more quickly than temperature in the sea during daytime. The air on land becomes hot and rises upwards. Cold air from the sea moves towards land as sea breeze.



Land breeze



Sea has a higher specific heat capacity than land. So, temperature in the sea drops more slowly than temperature on land at night. Hot air above the sea rises upwards. Cold air above the land moves towards the sea as land breeze.

Activity 4.4

ISS ICS

Aim: To search for information on applications of specific heat capacity

Instructions:

1. Carry out a Round Table activity.
2. Gather information on applications of specific heat capacity related to:
   (a) Daily life
   (b) Material engineering
   (c) Natural phenomena
3. The information can be obtained from reading materials in the library or on the Internet.
4. One group member writes the information on a piece of paper. The paper is then passed clockwise so other group members can add their information.
5. Present your group findings in your class.

4.2.4

Solving Problems Involving Specific Heat Capacity

Example 1

A 0.5 kg metal block is heated by a 50 W electric heater for 90 s. The temperature of the block rises from 20°C to 45°C. Calculate the specific heat capacity of the metal.

Solution:

Step 1
List the given information in symbols.

Temperature rise, $\Delta\theta = 45 - 20$
$= 25°C$
Mass of block, $m = 0.5$ kg
Power of heater, $P = 50$ W
Heating time, $t = 90$ s

Step 2
Identify and write down the formula used.

$$c = \frac{Q}{m\Delta\theta} = \frac{Pt}{m\Delta\theta}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$c = \frac{(50)(90)}{(0.5)(25)} = 360 \text{ J kg}^{-1} \text{ °C}^{-1}$$

Assumption: All heat supplied by the electric heater is absorbed by the metal block. No heat is lost to the surroundings.

Example 2

20 g of boiling water at 100°C is poured into a glass containing 200 g of water at 28°C. Calculate the final temperature of the mixture of water.

Solution:

20 g water, 100°C $\xrightarrow[Q_1]{\text{Heat is released}}$ Temperature of mixture, y $\xleftarrow[Q_2]{\text{Heat is absorbed}}$ 200 g water, 28°C

Let y = final temperature of mixture
For boiling water:
Mass, $m_1 = 20$ g
$= 0.02$ kg
Temperature change, $\Delta\theta_1 = (100 - y)$°C
For water at 28°C:
Mass, $m_2 = 200$ g
$= 0.20$ kg
Temperature change, $\Delta\theta_2 = (y - 28)$°C
Specific heat capacity of water, $c = 4\,200$ J kg^{-1} °C^{-1}

$$\begin{aligned} Q_1 &= Q_2 \\ m_1c\Delta\theta_1 &= m_2c\Delta\theta_2 \\ 0.02\,(4\,200)(100 - y) &= 0.20\,(4\,200)(y - 28) \\ 8\,400 - 84y &= 840y - 23\,520 \\ 924y &= 31\,920 \\ y &= 34.55°C \end{aligned}$$

Therefore, the final temperature of the mixture of water is 34.55°C.

Assumption: No heat is absorbed or released to the surrounding. Heat transfer only occurs between the boiling water and the water at 28°C. Therefore, heat released by the boiling water is the same as the heat absorbed by the water at 28°C.

Activity 4.5

CPS STEM

Aim: To build a model of a cluster home which can overcome the problem of extreme temperatures

Instructions:

1. Work in groups.
2. Read and understand the following information.

Cluster homes are homes which resemble terrace houses. However, three walls of the house are shared with the houses behind and beside it (Figure 4.12).

Photograph 4.2 shows an example of a cluster home which has only one door for exit and entrance, while windows are only in the front part of the home. The shape of the home can minimize the use of land. However, when our country experienced the El Nino phenomenon with extreme rise in temperature, residents of terrace cluster homes experienced extreme heat.

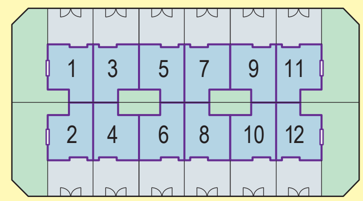


Figure 4.12 *Plan of cluster home*

Photograph 4.2 *Example of cluster home*

3. Based on the above information, analyse the situation by listing the facts and problems related to the condition of extreme temperature in cluster homes.
4. Brainstorm several solutions to the problems. Sketch a model based on your solutions.
5. Build the model based on the sketch.
6. Display and present the model.

Formative Practice 4.2

1. What is the difference between heat capacity and specific heat capacity?
2. How much heat energy is needed to increase the temperature of a 0.2 kg mass of gold by 10°C?
   [Given the value of specific heat capacity of gold is 300 J kg^{-1} $°C^{-1}$]
3. A container contains 200 g of water at initial temperature of 30°C. An iron nail of mass 200 g at temperature of 50°C is immersed in the water. What is the final water temperature? State the assumptions you need to make in your calculations.
   [Given the value of specific heat capacity of water is 4 200 J kg^{-1} $°C^{-1}$ and that of iron is 450 J kg^{-1} $°C^{-1}$]

4.2.5

4.3 Specific Latent Heat

Latent Heat

Elements can exist in three states: solid, liquid and gas. The difference in the arrangement and movement of molecules among the three states of matter shows that there are stronger molecular bonds in solid than in liquid and gas. As gas molecules move freely at random, the bond between gas molecules is the weakest.

Figure 4.13 shows the changes in phase of matter. During the changes in the phase of matter such as melting and boiling, the temperature remains constant even though heat is being supplied continually. Heat that is absorbed during melting and boiling without change in temperature is known as **latent heat**. During condensation and freezing, latent heat is released without temperature change.

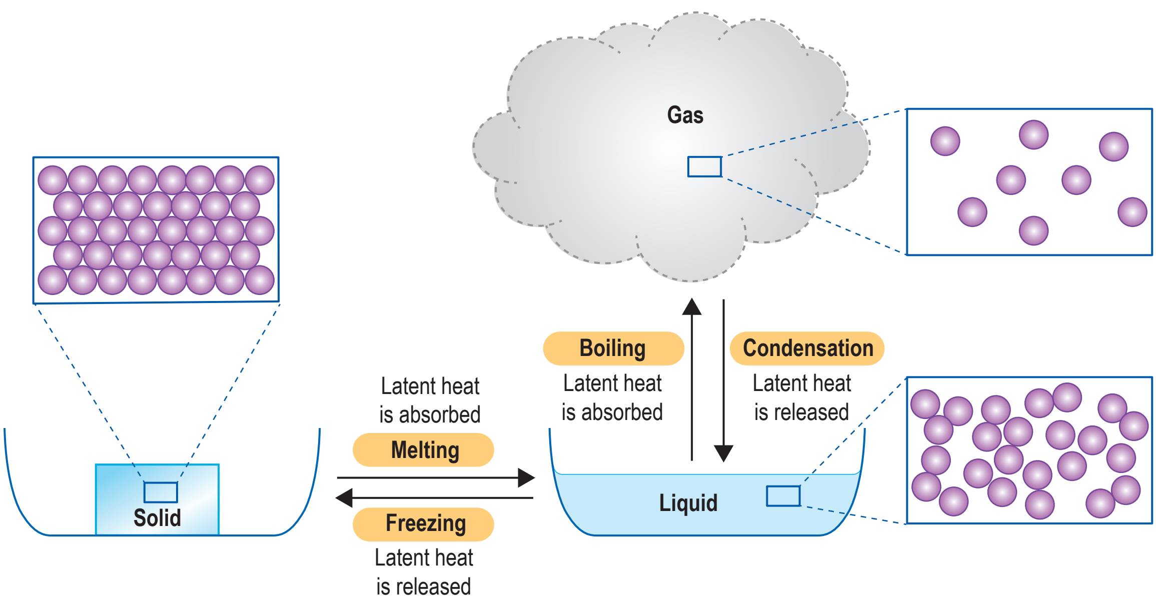


Figure 4.13 *Changes in phases of matter*

Specific Latent Heat

The quantity of heat needed to change the state of matter of an object depends on the mass of the object and its material. **Specific latent heat**, l of a substance is the quantity of heat, Q that is absorbed or released during a change of phase of 1 kg of the substance without any change in its temperature.

Latent Heat

http://bt.sasbadi.com/p4137

An object of mass, m absorbs a quantity of heat, Q during a change of phase. Therefore, specific latent heat of the substance of the object is

$$l = \frac{Q}{m}$$

S.I. unit for specific latent heat is J kg^{-1}.

4.3.1 4.3.2

Specific latent heat of fusion, l_f of a substance is the quantity of heat, Q that is absorbed during melting or the quantity of heat released during freezing of 1 kg of the substance without any change in temperature.

Specific latent heat of vaporisation, l_v of a substance is the quantity of heat, Q that is absorbed during boiling or the quantity of heat released during condensation of 1 kg of the substance without any change in temperature.

Figure 4.14 shows the heating curve when an object changes its state from solid to gas.

Info File

Based on the Kinetic Theory of Matter, the higher the average kinetic energy of a molecule, the higher the temperature of the object. Latent heat absorbed during melting and boiling does not increase the average kinetic energy of the molecule. Therefore, melting and boiling occur at constant temperature.

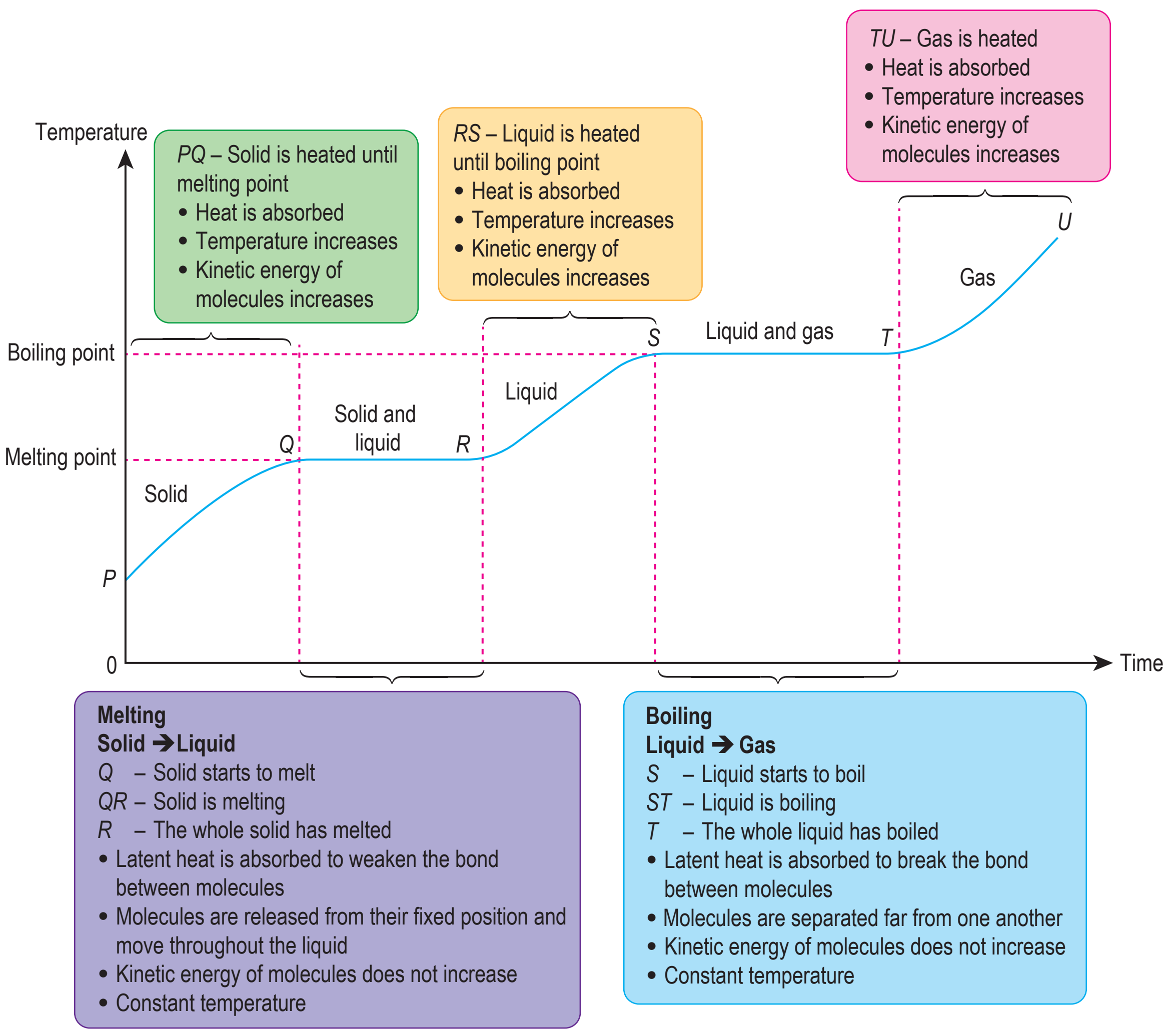


Figure 4.14 *Heating curve*

Figure 4.15 shows the cooling curve when an object changes its state from gas to solid.

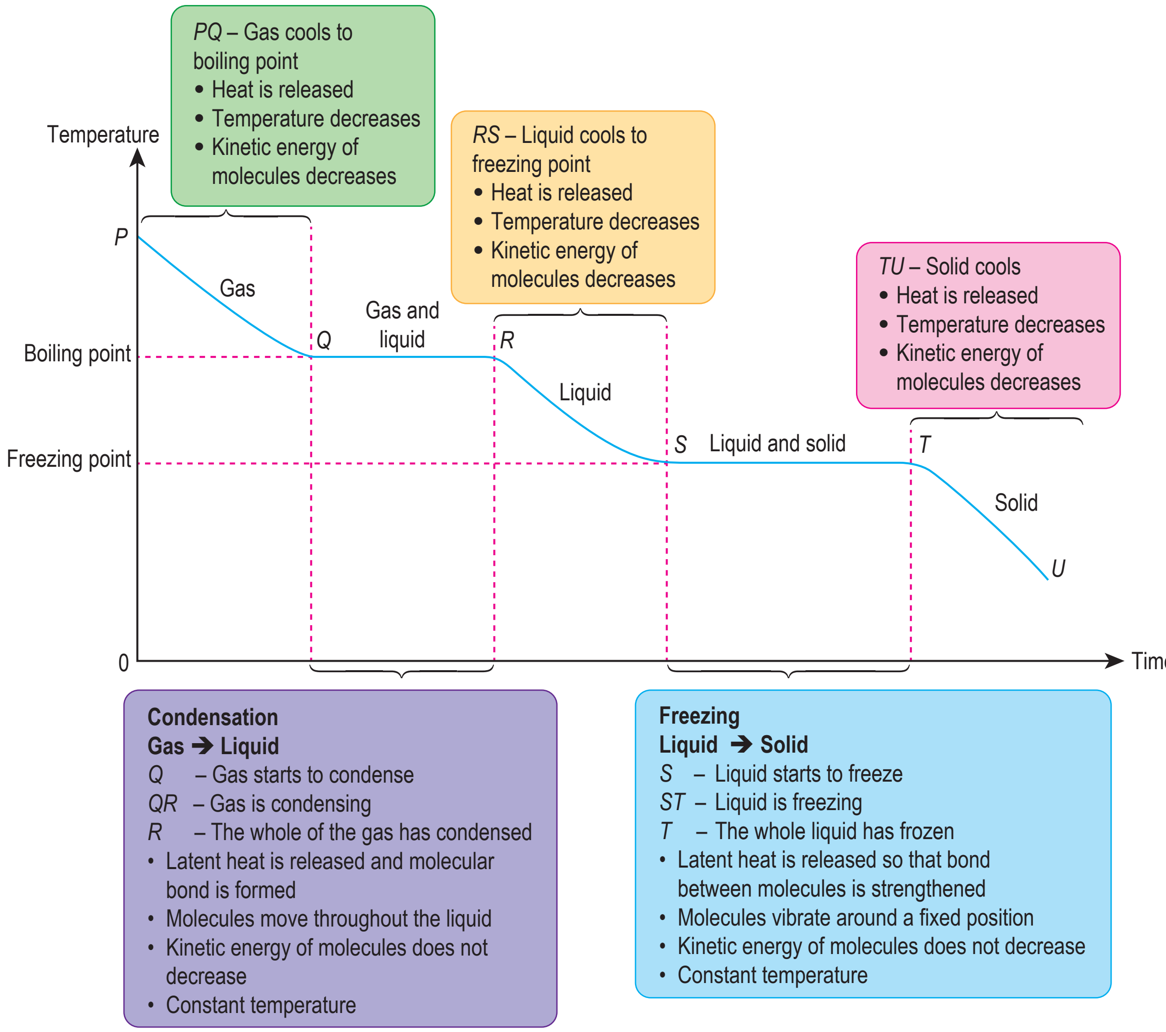


Figure 4.15 *Cooling curve*

Activity 4.6

Logical Reasoning

Aim: To compare and discuss:
- specific latent heat of fusion of ice and wax
- specific latent heat of vaporisation of water and oil

Instructions:
1. Carry out a Think-Pair-Share activity.
2. Study the information given in Table 4.5.

Table 4.5

Substance	Phase at room temperature	Melting point / °C	Specific latent heat of fusion, l_f / J kg^{-1}	Boiling point / °C	Specific latent heat of vaporisation, l_v / J kg^{-1}
Wax	Solid	46 to 68	1.45×10^5 to 2.10×10^5	–	–
Lead	Solid	327	0.25×10^5	1 750	8.59×10^5
Copper	Solid	1 083	2.07×10^5	2 566	47.3×10^5
Ice	Solid	0	3.34×10^5	–	–
Water	Liquid	–	–	100	22.6×10^5
Petrol	Liquid	–	–	35 to 200	3.49×10^5
Diesel	Liquid	–	–	180 to 360	2.56×10^5
Olive oil	Liquid	6	2.67×10^5	–	–
Ethanol	Liquid	−114	1.04×10^5	78	8.55×10^5
Oxygen	Gas	−219	0.14×10^5	−183	2.13×10^5
Nitrogen	Gas	−210	0.26×10^5	−196	2.00×10^5

3. Based on the information above, discuss the following questions:
   (a) Compare the specific latent heat of fusion for ice and wax. Then, state the difference between ice and wax in terms of strength of bond between molecules.
   (b) Compare the specific latent heat of vaporisation for water and petrol. Then, state the difference between water and petrol in terms of strength of bond between molecules and distance of separation between molecules in gaseous phase.
   (c) For a specific substance, why is specific latent heat of vaporisation larger than specific latent heat of fusion?
4. Present the results of your discussion in a graphic form.

Note:
- Petrol and diesel are different types of hydrocarbons and have different boiling points.

Based on Activity 4.6, each substance has a different specific latent heat. How is the value of specific latent heat determined?

Experiment 4.3

Aim: (i) To determine specific latent heat of fusion of ice, l_f
(ii) To determine specific latent heat of vaporisation of water, l_v

A Specific latent heat of fusion of ice, l_f

Apparatus: Immersion heater, filter funnel, beaker, electronic balance, power supply, stopwatch and retort stand

Material: Crushed ice

Procedure:

1. Place the beaker for the experiment set and the control set on the electronic balance respectively. Reset the readings of both electronic balances to zero.
2. Set up the apparatus as shown in Figure 4.16. Initially, both beakers and electronic balances are not below their respective filter funnels.

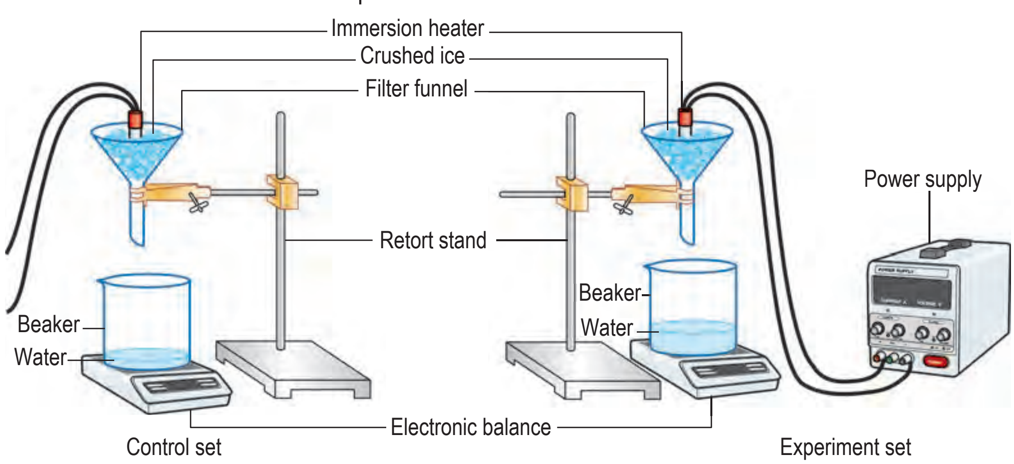


Figure 4.16

3. Switch on the immersion heater for the experiment set only. When water is dripping out of the filter funnel at a fixed rate, place the beakers and electronic balances respectively below the filter funnels. Start the stopwatch.
4. After time, t = 10 minutes, record the reading of the mass of water collected in the beaker of experiment set, m_1 and control set, m_2.
5. Switch off the immersion heater and record the power of the heater, P.

Results:

Table 4.6

Mass of water collected in beaker of experiment set, m_1 / kg	
Mass of water collected in beaker of control set, m_2 / kg	
Power of heater, P / W	
Heating time, t / s	

4.3.3

Analysis of data:

Calculate the specific latent heat of fusion of ice using the formula, $l = \dfrac{Pt}{(m_1 - m_2)}$.

Conclusion:

What conclusion can be made from this experiment?

B Specific latent heat of vaporisation of water, l_v

Apparatus: High power immersion heater (500 W), power supply, beaker, electronic balance and stopwatch

Materials: Water and tissue paper

Procedure:

1. Set up the apparatus as shown in Figure 4.17.
2. Switch on the immersion heater and wait until the water boils.
3. When the water boils, start the stopwatch and at the same time, record the reading on the electronic balance, m_1.
4. After time, t = 5 minutes, record the reading on the electronic balance, m_2.
5. Switch off the immersion heater and record the power of the heater, P.

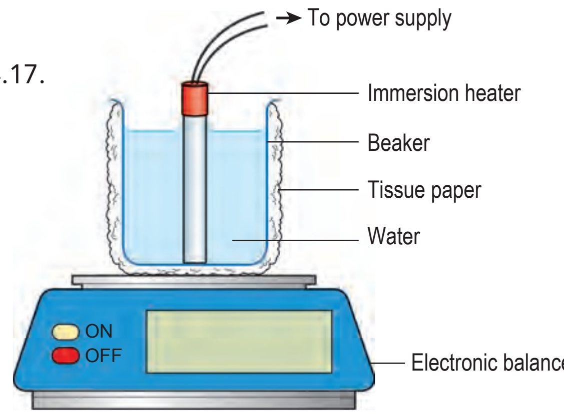


Figure 4.17

Results:

Table 4.7

Initial reading of electronic balance, m_1 / kg	
Final reading of electronic balance, m_2 / kg	
Time taken, t / s	
Power of heater, P / W	

Analysis of data:

Calculate the specific latent heat of vaporisation of water using the formula, $l = \dfrac{Pt}{(m_1 - m_2)}$.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. Why does a control set need to be prepared for experiment A but not for experiment B?
2. Given specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1}, compare the value of specific latent heat of fusion of ice obtained from experiment A with the value given. Explain the difference between the two values (if any).
3. Given specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}, compare the value of specific latent heat of vaporisation of water obtained from experiment B with the value given. Explain the difference between the two values (if any).
4. Suggest ways to increase the accuracy of the results of this experiment.

Observe Figure 4.18 which shows the changes of phase of water when latent heat is absorbed and released.

When ice melts, the ice molecules absorb latent heat of fusion causing ice to change from solid to liquid.

When water boils, the water molecules absorb latent heat of vaporisation causing water to change from liquid to gas.

When water vapour condenses, the water vapour molecules release latent heat of vaporisation causing water vapour to change from gas to liquid.

***Figure 4.18** Changes in phase of water*

Absorption of latent heat during melting and evaporation can be used to give the effect of cooling. Latent heat released during condensation however is used for the purpose of heating.

Activity 4.7

Aim: To show that evaporation causes cooling

Apparatus: 250 mℓ beaker, drinking straw and white tile

Materials: Alcohol and water

Instructions:

1. Set up the apparatus as shown in Figure 4.19.
2. Pour 100 mℓ alcohol into a beaker.
3. Touch the outside of the beaker and the water around the base of the beaker. Record your observations.
4. Blow air repeatedly into the alcohol.
5. Touch the outside of the beaker. Record your observations.

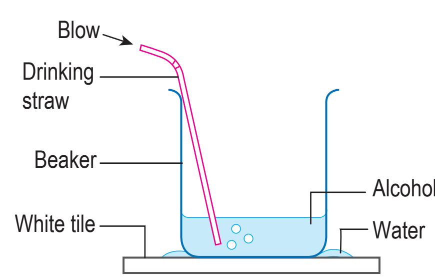


Figure 4.19

Discussion:

1. What happens to the alcohol when air is blown into it?
2. Compare the level of coldness of the beaker before and after air is blown into the alcohol. Explain your answer.
3. State the effect of evaporation.

Specific latent heat of vaporisation is required in the change of phase from liquid to gas. This heat is absorbed from the surrounding. When a liquid evaporates, the liquid molecules absorb this heat to break the bond between molecules. The surrounding loses heat. Therefore, evaporation causes cooling to the surrounding.

4.3.4

Figure 4.20 shows examples of phase change of matter that involve specific latent heat.

Specific Latent Heat

- Melting
  - Cooling drinks and food with ice cubes
- Evaporation
  - Cooling body on hot day
  - Cooling system of refrigerator
  - Cooling system of air conditioner
- Boiling
  - Cooling as liquid nitrogen boils
- Condensation
  - Process of steaming food
  - Heating espresso coffee

Video on cooling with liquid nitrogen

http://bt.sasbadi.com/p4144a

Video on heating espresso coffee

http://bt.sasbadi.com/p4144b

Figure 4.20 *Examples involving specific latent heat*

Activity 4.8

ISS ICS

Aim: To discuss applications of specific latent heat in daily life

Instructions:

1. Work in groups.
2. Gather information on applications of specific latent heat in daily life:
   (a) Evaporation of sweat
   (b) Steaming food
3. Discuss how specific latent heat is applied in each situation.
4. Present the findings in the form of a mind map.

Applications of Specific Latent Heat in Daily Life

Cooling system in refrigerator

A refrigerator uses the cooling effect from evaporation. During circulation of the cooling agent, heat is absorbed from inside the refrigerator and released outside.

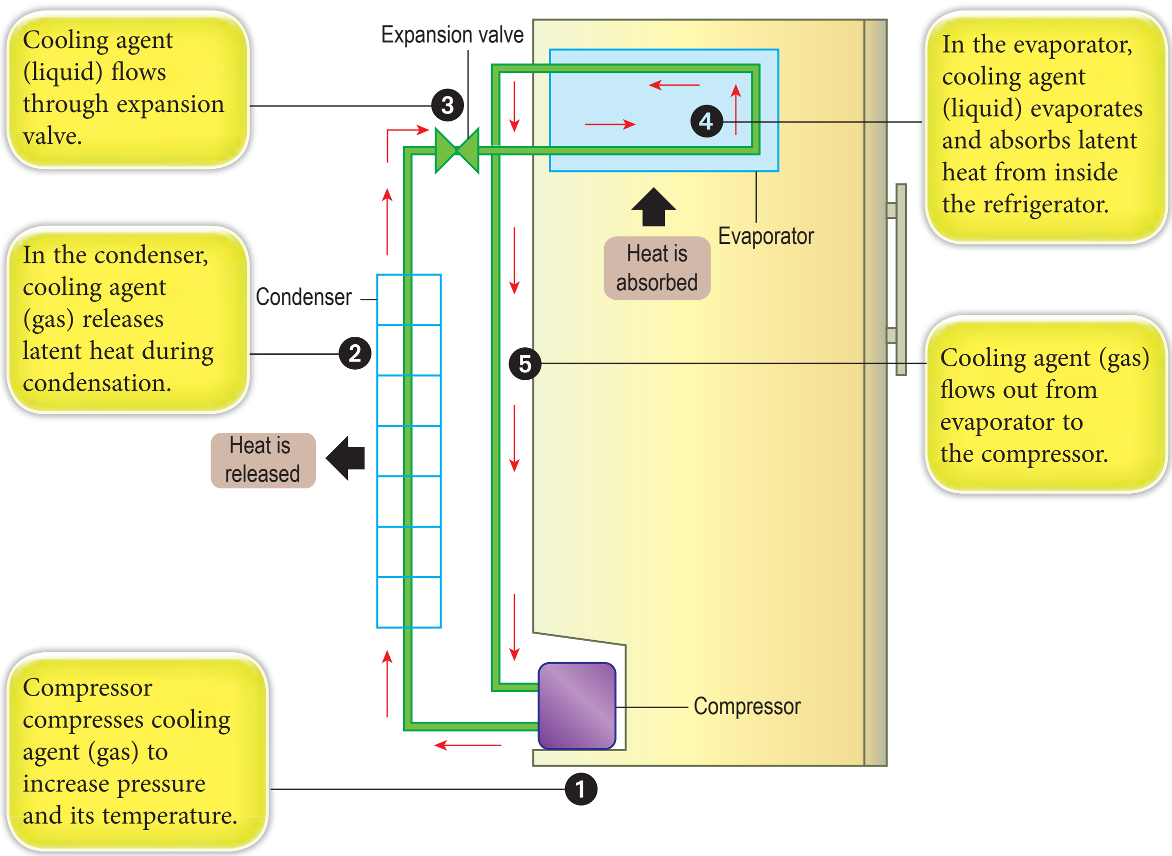


Figure 4.21 Cooling system in a refrigerator

Evaporation of sweat

We sweat on hot days or while doing heavy work. When sweat evaporates, heat is absorbed from the body causing a cooling effect. The rate of evaporation will increase when there is air circulation.

DIY

Wet your right hand. Put your right hand which is wet and your left hand which is dry in front of a table fan. What difference can you feel on your right and left hands?

4.3.4

Solving Problems Involving Latent Heat

Example 1

Figure 4.22 shows a 480 W immersion heater used to melt ice in a container. In 120 s, the reading of the electronic balance decreases by 0.172 kg.

(a) What is the mass of ice that has melted during the heating period?

(b) Calculate the specific latent heat of fusion of ice, l_f.

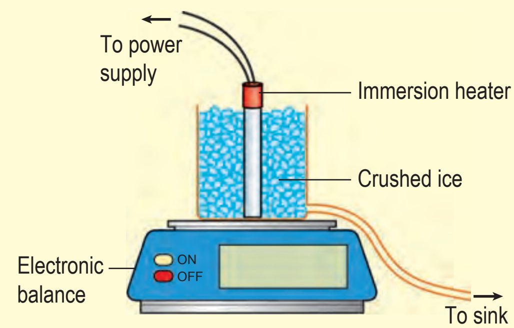


Figure 4.22

Solution:

(a) Make assumptions:
- (i) Ice is melted by heat from the immersion heater only.
- (ii) All water from the melting ice flows out of the container.

Relate the change in the readings of the electronic balance to the mass of ice which has melted:

Mass of ice melted = Decrease in the reading of the electronic balance

$m = 0.172$ kg

(b) Make assumptions:
- (i) All heat supplied by the immersion heater is absorbed by the melting ice.
- (ii) No transfer of heat from the surrounding into the apparatus.

Step 1
List the given information in symbols.

$m = 0.172$ kg
$P = 480$ W
$t = 120$ s

Step 2
Identify and write down the formula used.

$Pt = ml_f$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$480 \times 120 = 0.172 \times l_f$$
$$l_f = \frac{480 \times 120}{0.172}$$
$$= 3.35 \times 10^5 \text{ J kg}^{-1}$$

4.3.5

Example 2

What is the amount of heat supplied by a water heater to change 0.75 kg of water at 30°C to steam at 100°C? State the assumptions you make in your calculations.
[Specific heat capacity of water, $c_{water} = 4.20 \times 10^3$ J kg^{-1} °C^{-1},
specific latent heat of vaporisation of water, $l_v = 2.26 \times 10^6$ J kg^{-1}]

Solution:

0.75 kg water at 30°C $\xrightarrow{Q_1 = mc\Delta\theta}$ 0.75 kg water at 100°C $\xrightarrow{Q_2 = ml}$ 0.75 kg steam at 100°C

Make assumptions:
(i) All heat supplied by the heater is absorbed by the water.
(ii) No loss of heat to the surrounding during heating and change of phase.

There are two stages of change:
(i) increase in water temperature from 30°C to its boiling point of 100°C
(ii) change of phase from water to steam without change in temperature.

Amount of heat supplied,
$$\begin{aligned} Q &= Q_1 + Q_2 \\ &= mc\Delta\theta + ml \\ &= [0.75 \times 4.2 \times 10^3 \times (100 - 30)] + (0.75 \times 2.26 \times 10^6) \\ &= 1.92 \times 10^6 \text{ J} \end{aligned}$$

Formative Practice 4.3

1. Figure 4.23 shows an electric steamer. Explain how the fish is heated.

2. What is the amount of heat released when 0.8 kg of water at 25°C cools until it becomes ice at –6°C? State the assumptions you make in your calculations.
[Specific heat capacity of water, $c_{water} = 4.2 \times 10^3$ J kg^{-1} °C^{-1}, specific heat capacity of ice, $c_{ice} = 2.0 \times 10^3$ J kg^{-1} °C^{-1} and specific latent heat of fusion of ice, $l_f = 3.34 \times 10^5$ J kg^{-1}]

Figure 4.23

4.4 Gas Laws

Photograph 4.3 Air cushion wrap being compressed

Pressure, Temperature and Volume of Gas

Photograph 4.3 shows an air cushion wrap used in packaging of goods. When it is compressed, the air inside gives resistance. This observation can be explained in terms of the behaviour of gas molecules based on the Kinetic Theory of Gas.

Activity 4.9

ISS ICS

Aim: To observe the behaviour of gas molecules through computer simulation

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Scan the QR code to see the simulation on the behaviour of gas molecules. Based on the simulation, discuss:
   (a) movement of gas molecules
   (b) space filled by gas molecules
   (c) direction of motion of molecules
   (d) collisions between gas molecules and the walls of the container
   (e) effects of increasing and decreasing of pressure, temperature and volume of gas on the behaviour of the gas molecules
3. Present your findings.

Simulation of behaviour of gas molecules

http://bt.sasbadi.com/p4148

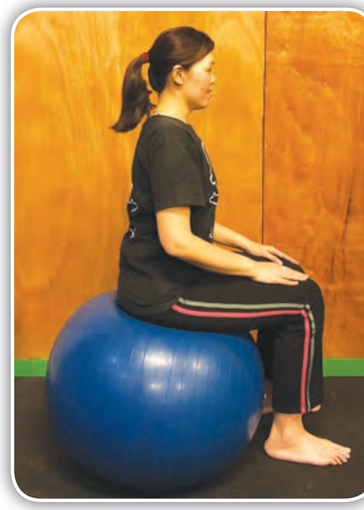
Table 4.8 explains pressure, temperature and volume of gas in a closed container based on the Kinetic Theory of Gas.

Table 4.8 *Pressure, temperature and volume of gas based on the Kinetic Theory of Gas*

Characteristic of gas	Description
Pressure	• Gas molecules always move randomly. • When gas molecules collide with the wall of the container and rebound, a force is exerted on the wall of the container. • Force per unit area is the pressure of the gas.
Temperature	• Average kinetic energy of gas molecules increases with temperature.
Volume	• Gas molecules move freely and fill the entire space of the container. • Volume of gas is the same as the volume of its container.

Table 4.9 S.I. unit and other units for pressure, temperature and volume of gas

Quantity	S.I. unit	Symbol for S.I. unit	Other units
Pressure, P	pascal	Pa	cm Hg
Temperature, T	kelvin	K	°C, °F
Volume, V	$(\text{metre})^3$	m^3	mm^3, cm^3, $m\ell$



Photograph 4.4 Exercise ball being compressed

Relationship between Pressure and Volume of Gas

Photograph 4.4 shows an exercise ball being compressed when someone sits on it. What happens to the air pressure inside the ball?

Experiment 4.4

Inference: Volume of gas influences pressure of gas

Hypothesis: The smaller the volume of gas, the higher the gas pressure

Aim: To determine the relationship between volume and pressure of a fixed mass of gas at constant temperature

Variables:
(a) Manipulated variable: Volume, V
(b) Responding variable: Pressure, P
(c) Constant variable: Temperature and mass of air

Apparatus: 100 $m\ell$ syringe, rubber tube, pressure gauge and retort stand

Procedure:

1. Set up the apparatus as shown in Figure 4.24.

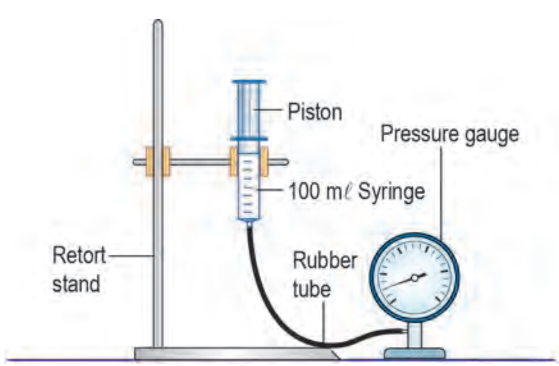


Figure 4.24

DIY

Visit the following websites to carry out virtual experiments on Boyle's Law

http://bt.sasbadi.com/p4149a

http://bt.sasbadi.com/p4149b

2. Adjust the piston so that the volume of air in the syringe is 100 mℓ. Then, connect the end of the syringe to a pressure gauge.
3. Take initial readings of the volume and pressure of the air in the syringe. Record the readings in Table 4.10.
4. Push the piston slowly until the volume of air in the syringe becomes 90 mℓ. Take the reading of the air pressure and record it in the table.
5. Repeat step 4 with volumes 80 mℓ, 70 mℓ and 60 mℓ.
6. Record all pressure, P in Table 4.10.

Results:

Table 4.10

Volume, V / mℓ	Pressure, P / kPa	$\frac{1}{V}$ / mℓ$^{-1}$
60		
70		
80		
90		
100		

Analysis of data:
Plot a graph of pressure, P against volume, V and a graph of P against $\frac{1}{V}$.

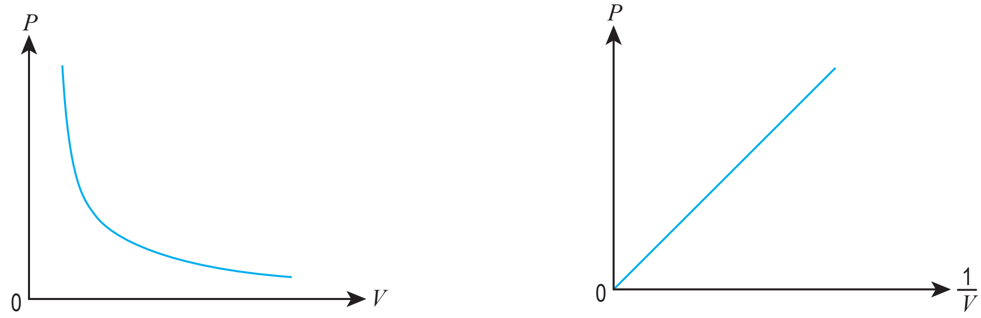
Conclusion:
What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:
1. Why is a syringe of larger volume used?
2. Why is the piston pushed slowly into the syringe?

Experiment 4.4 shows that gas pressure increases when the volume of gas decreases. What is the relationship between pressure and volume of gas at constant temperature?

Figure 4.25 shows the relationship between pressure and volume of gas.



(a) Graph P against V

(b) Graph P against $\frac{1}{V}$

Figure 4.25 *Relationship between pressure and volume of gas*

Graph of P against V shows that pressure decreases with volume. Graph of P against $\frac{1}{V}$ however shows a straight line passing through the origin. This shows that pressure is inversely proportional to volume.

Boyle's Law states that pressure is inversely proportional to volume for a fixed mass of gas at constant temperature.

$$P \propto \frac{1}{V}$$

$$P = k\left(\frac{1}{V}\right)$$

Where k is a constant

P = gas pressure (Pa)

V = gas volume (m^3)

As such, $PV = k$

If a gas experiences a change in pressure and volume from condition 1 to condition 2,

since $PV = k$, condition 1 of gas, $P_1V_1 = k$

condition 2 of gas, $P_2V_2 = k$

therefore, $P_1V_1 = P_2V_2$

INTEGRATION OF **HISTORY**

Robert Boyle (1627–1691) is a scientist who emphasised the use of scientific method when carrying out investigations. Through data from experiments, he concluded that the volume of gas is inversely proportional to its pressure.

http://bt.sasbadi.com/p4151a

Boyle's Law

http://bt.sasbadi.com/p4151b

Figure 4.26 shows a fixed mass of gas compressed at constant temperature. When the volume of gas decreases, the same number of molecules move in a smaller space. Therefore, the number of molecules per unit volume increases. This causes the rate of collisions between molecules and the walls of the container to increase. Force per unit area on the wall of the container also increases. As such, gas pressure increases.

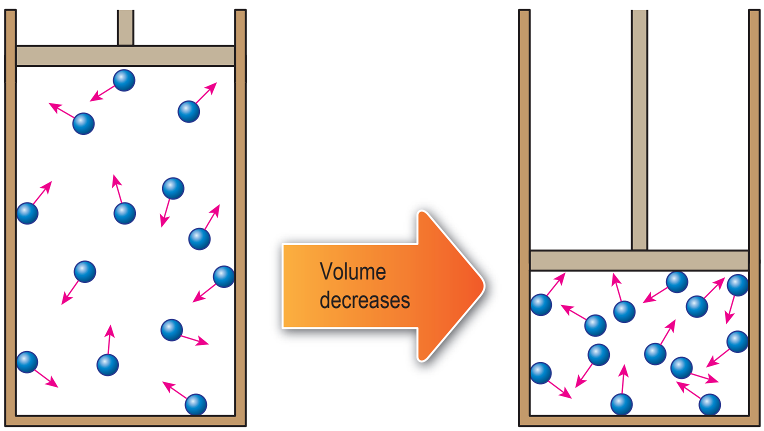
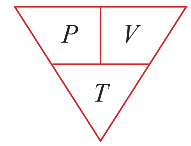


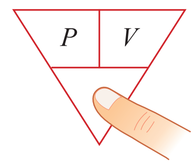
***Figure 4.26** Fixed mass of a gas compressed at constant temperature*

SMART INFO

PVT triangle:



For Boyle's Law, temperature is constant.



PV = constant

$P_1V_1 = P_2V_2$

Example 1

Air in a closed syringe has a volume of 60 cm^3 and pressure of 108 kPa. The piston of the syringe is pushed to compress the air to a volume of 48 cm^3. Calculate the pressure of the compressed air.

Solution:

Step 1
List the given information in symbols.

P_1 = 108 kPa
P_2 = compressed air pressure
V_1 = 60 cm^3
V_2 = 48 cm^3

Step 2
Identify and write down the formula used.

Temperature of gas does not change.
Boyle's Law formula is used.
$P_1V_1 = P_2V_2$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$108 \times 60 = P_2 \times 48$$

$$P_2 = \frac{108 \times 60}{48}$$

$$= 135 \text{ kPa}$$

Relationship between Volume and Temperature of Gas

Photograph 4.5 shows an empty plastic bottle filled with air in a refrigerator. What happened to the volume of air in the bottle?

(a) Empty plastic bottle before being cooled

(b) Empty plastic bottle after being cooled

Photograph 4.5 *Condition of plastic bottle in refrigerator before and after being cooled*

Experiment 4.5

Inference: Temperature of a gas influences the volume of gas

Hypothesis: The higher the temperature, the larger the volume of gas

Aim: To determine the relationship between temperature and volume of a fixed mass of gas at constant pressure

Variables:

(a) Manipulated variable: Temperature, θ

(b) Responding variable: Volume, V represented by length of column of air, L in capillary tube

(c) Constant variable: Pressure and mass of air

Apparatus: Capillary tube containing air trapped by a column of concentrated sulphuric acid, 500 mℓ beaker, thermometer, ruler, Bunsen burner, tripod stand, wire gauze, stirrer and retort stand

Materials: Water, ice and rubber band

Procedure:

1. Set up the apparatus as shown in Figure 4.27.

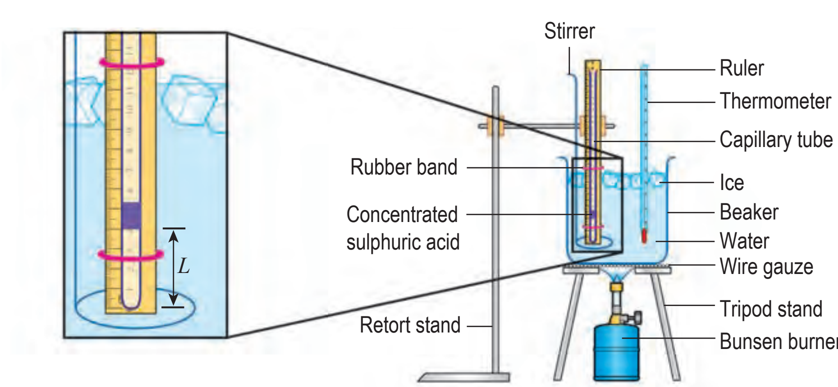


Figure 4.27

2. Heat the water slowly and stir it continuously until the temperature of the water reaches 30°C.
3. Take the reading of the column of air, L in the capillary tube. Record the reading in Table 4.11.
4. Repeat steps 2 and 3 for temperatures 40°C, 50°C, 60°C, 70°C and 80°C.
5. Record all lengths of column of air, L in Table 4.11.

Results:

Table 4.11

Temperature, θ / °C	Length of column of air, L / cm
30	
40	
50	
60	
70	
80	

Analysis of data:

1. Plot a graph of length of column of air, L against temperature, θ. θ-axis has to cover the range of 0°C to 100°C.
2. Extrapolate graph of L against θ until θ = 0°C.
3. Plot another graph of L against θ with θ-axis covering the range of –300°C to 100°C.
4. Extrapolate graph of L against θ until L = 0 cm.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

1. Why must the water be continuously stirred while being heated?
2. What assumption needs to be made so that the length of the column of air trapped in the capillary tube can represent the volume of the trapped air?

   [Key: Volume of column of air, V = length of column of air, $L \times$ cross sectional area of capillary tube, A]

Volume of gas increases when the temperature of the gas rises. At 0°C, the air trapped in the capillary tube still has a certain volume. This shows that at 0°C, gas molecules are still moving and filling up the space in the container.

Figure 4.28 shows the graph of V against θ extrapolated until $V = 0\ cm^3$.

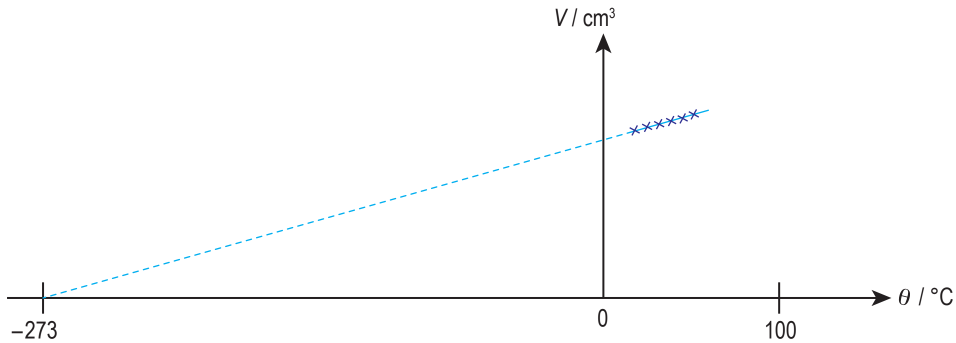


***Figure 4.28** Extrapolation of graph V against θ*

At temperature of –273°C, gas molecules no longer move and are unable to fill the space. As such, volume of gas becomes zero. The temperature of –273°C is the lowest temperature possible and is known as absolute zero. On the kelvin scale, absolute zero is given the value 0 kelvin or 0 K. Temperature that is stated in unit kelvin is absolute temperature.

***Table 4.12** Temperature in units of degree Celsius, °C and kelvin, K for three temperature points*

Temperature point	Temperature, θ / °C	Temperature, T / K
Absolute zero	–273	0
Melting ice	0	273
Steam	100	373

Conversion of units between degree Celsius, °C and kelvin, K can be done using the following equation:

$$T = \theta + 273$$

For θ°C and T K

Figure 4.29 shows the graph of V against T.

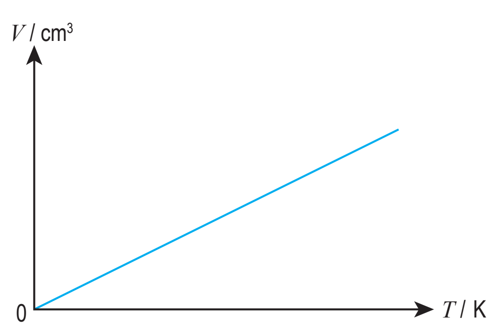


***Figure 4.29** Graph of V against T for a gas*

The graph of V against T for gas shows a straight line passing through the origin. This shows that the volume of gas is directly proportional to absolute temperature.

INTEGRATION OF HISTORY

Jacques Charles (1746–1823) a French physicist and chemist investigated how the volume of gas depends on the temperature of gas. He built the first hydrogen balloon and succeeded in raising the balloon to a height of 3.2 km.

http://bt.sasbadi.com/p4155

Charles' Law states that volume is directly proportional to absolute temperature for a fixed mass of gas at constant pressure.

$$V \propto T$$

$$V = kT$$

where k is a constant

T = absolute temperature (K)

V = volume of gas (m^3)

As such, $\dfrac{V}{T} = k$

If a gas experiences a change in volume and temperature from condition 1 to condition 2,

since $\dfrac{V}{T} = k$, condition 1 of gas: $\dfrac{V_1}{T_1} = k$

condition 2 of gas: $\dfrac{V_2}{T_2} = k$

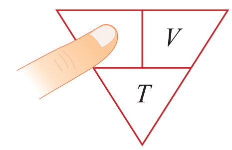
therefore, $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$

Charles' Law

http://bt.sasbadi.com/p4156

SMART INFO

For Charles' Law, pressure is constant.



$\dfrac{V}{T}$ = constant

$\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$

Figure 4.30 shows a fixed mass of gas being heated at constant pressure. When the temperature of the gas increases, the average kinetic energy of its molecules increases, and the molecules move with higher velocity. To keep a constant gas pressure, the volume of gas increases so that the rate of collision of gas molecules with the walls of the container is unchanged.

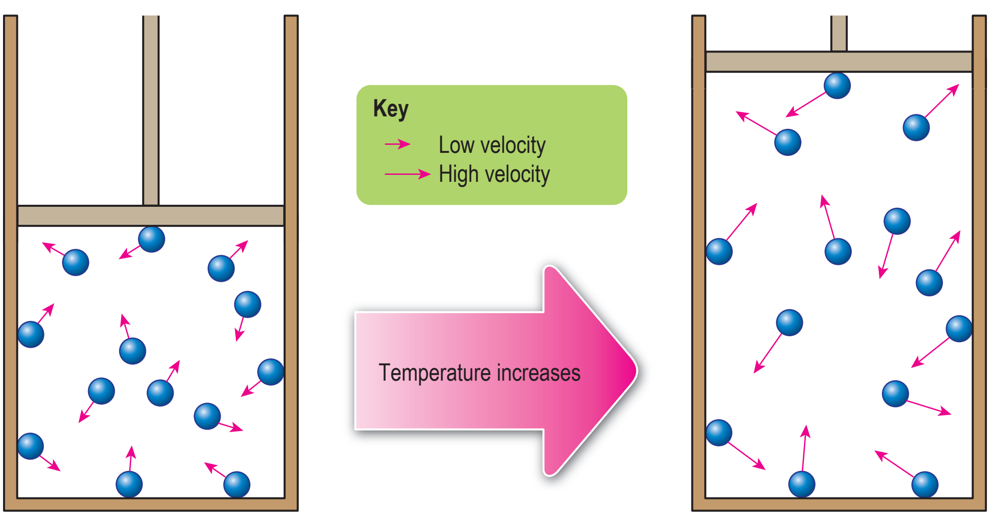


Figure 4.30 *Fixed mass of gas heated at constant pressure*

Example 1

An air bubble has a volume of 1.2 cm^3 at a temperature of 27°C. What is the volume of the air bubble if its temperature increases to 47°C?

Solution:

Step 1
List the given information in symbols.

$V_1 = 1.20 \text{ cm}^3$
V_2 = Final volume of air
$T_1 = (27 + 273) = 300 \text{ K}$
$T_2 = (47 + 273) = 320 \text{ K}$

Step 2
Identify and write down the formula used.

Gas pressure is constant.
Charles' Law formula is used.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$\frac{1.2}{300} = \frac{V_2}{320}$$

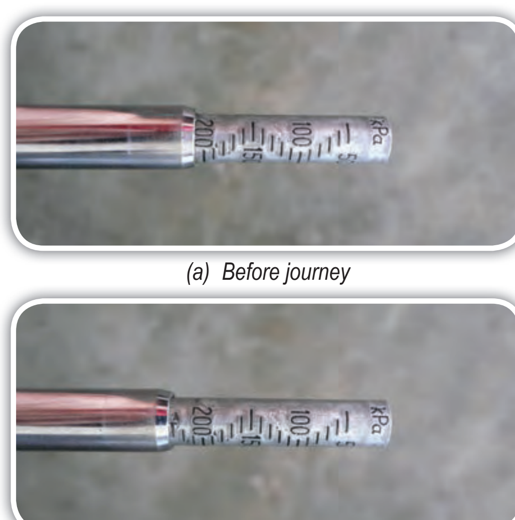
$$V_2 = \frac{1.2 \times 320}{300}$$

$$= 1.28 \text{ cm}^3$$

Relationship between Pressure and Temperature of Gas

Photograph 4.6 shows air pressure in the tyre of a car being measured on a hot day. The driver of the car touched the tyre after the journey and found that the tyre is hotter than before the journey. Photograph 4.7 shows the readings of the pressure gauge before and after the journey. What happened to the air pressure inside the tyre?

Photograph 4.6 *Air pressure of tyre being measured*



(a) Before journey

(b) After journey

Photograph 4.7 *Readings of air pressure*

Experiment 4.6

Inference: Temperature of gas influences pressure of gas

Hypothesis: The higher the temperature, the higher the gas pressure

Aim: To determine the relationship between temperature and pressure for a fixed mass of gas at constant volume

Variables:

(a) Manipulated variable: Temperature, θ

(b) Responding variable: Pressure, P

(c) Constant variable: Volume and mass of air

Apparatus: Round-bottom flask, large beaker, thermometer, pressure gauge, Bunsen burner, wire gauze, tripod stand, stirrer, retort stand and wooden block

Materials: Water and ice

Procedure:

1. Set up the apparatus as shown in Figure 4.31.

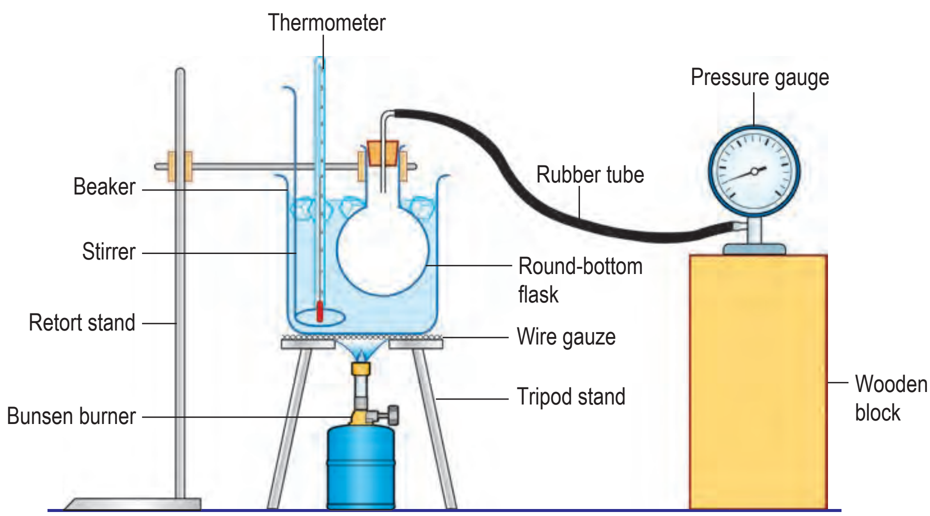


Figure 4.31

2. Heat the water slowly and stir it continuously until the temperature of the water reaches 30°C.
3. Take the reading of the air pressure, P inside the flask. Record the reading in Table 4.13.
4. Repeat steps 2 and 3 with temperatures 40°C, 50°C, 60°C, 70°C and 80°C.
5. Record all readings of air pressure, P in Table 4.13.

Results:

Table 4.13

Temperature, θ / °C	Air pressure, P / kPa
30	
40	
50	
60	
70	
80	

Analysis of data:

1. Plot a graph of pressure, P against temperature, θ. θ-axis has to cover the range of –300°C to 100°C.
2. Extrapolate the graph until P = 0 kPa. Determine the temperature when P = 0 kPa.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report on this experiment.

Discussion:

1. What is the advantage of using a round-bottom flask to heat the air?
2. The thermometer is placed in the large beaker filled with water. What is the assumption made so that the thermometer reading is the same as the temperature of the air in the round-bottom flask?

Experiment 4.6 shows that gas pressure increases when temperature of the gas rises. Figure 4.32 shows the graph of P against θ extrapolated until P = 0 kPa.

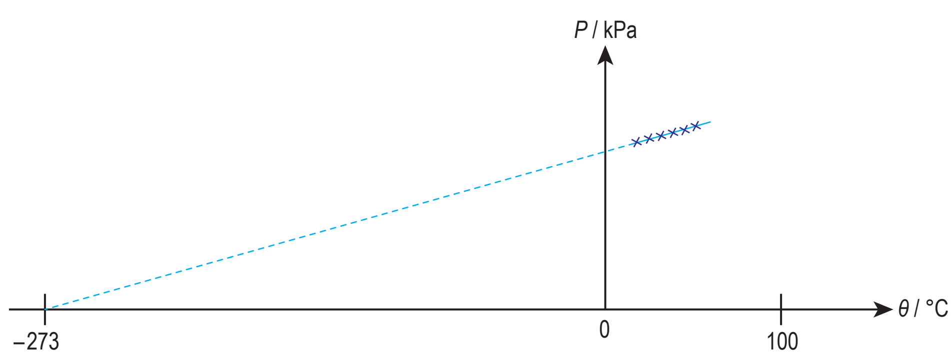


Figure 4.32 *Extrapolation of graph P against θ*

Graph of P against θ shows that gas pressure increases linearly when temperature of the gas rises. At 0°C, gas molecules are still moving and the gas has pressure. At –273°C (absolute zero), gas molecules no longer move and do not collide with the walls of the container. Hence, gas pressure becomes zero. Figure 4.33 shows the graph of P against T.

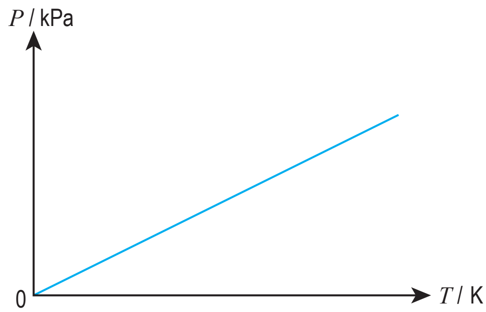


Figure 4.33 *Graph of P against T*

Graph of P against T of gas is a straight line through the origin. This shows that gas pressure is directly proportional to absolute temperature.

Gay-Lussac's Law states that pressure is directly proportional to absolute temperature of a fixed mass of gas at constant volume.

$$P \propto T$$

$$P = kT$$

where k is a constant

P = pressure (Pa)

T = absolute temperature (K)

As such, $\dfrac{P}{T} = k$

If a gas experiences change in pressure and temperature from condition 1 to condition 2,

since $\dfrac{P}{T} = k$, condition 1 of gas: $\dfrac{P_1}{T_1} = k$

condition 2 of gas: $\dfrac{P_2}{T_2} = k$

therefore, $\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$

INTEGRATION OF **HISTORY**

Joseph Louis Gay-Lussac (1778–1850) is a French physicist and chemist who made quantitative investigation about the characteristics of gas. He also investigated the magnetic field of the Earth and composition of the atmosphere at high altitudes. In addition, he found two new elements, boron and iodine.

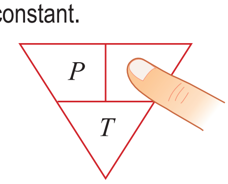
http://bt.sasbadi.com/p4160a

Gay-Lussac's Law

http://bt.sasbadi.com/p4160b

SMART INFO

For Gay-Lussac's Law, volume is constant.



$\dfrac{P}{T}$ = constant

$\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$

Figure 4.34 shows a fixed mass of gas being heated at constant volume. When the temperature of the gas increases, average kinetic energy of its molecules increases, and the molecules move with higher velocity. As the volume of gas does not change, the rate of collision of gas molecules with the walls of the container increases. Force per unit area on the wall of the container also increases. As such, gas pressure increases.

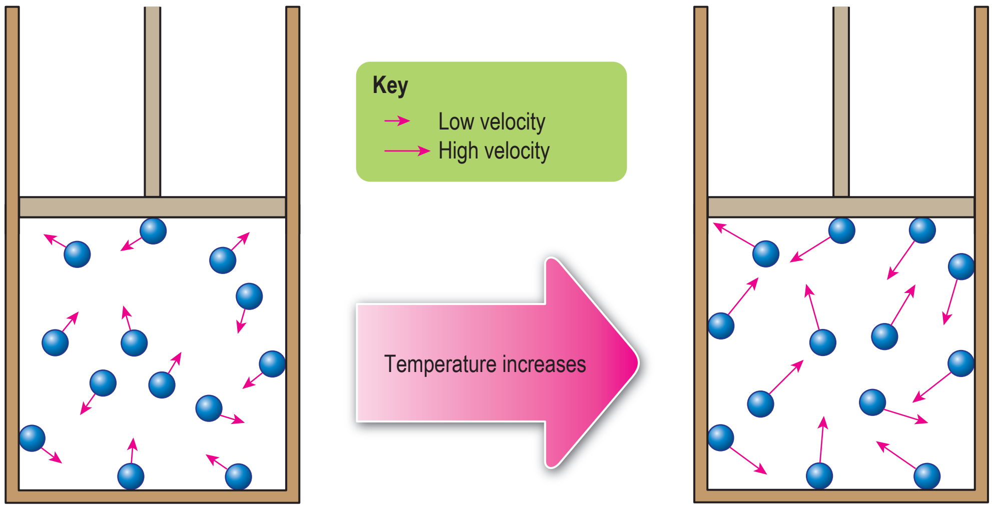


Figure 4.34 *Fixed mass of gas heated at constant volume*

Example 1

Gas in a closed steel cylinder has a pressure of 180 kPa at a temperature of 25°C. What is the gas pressure when the cylinder is heated to a temperature of 52°C?

Solution:

Step 1
List the given information in symbols.

$P_1 = 180$ kPa
P_2 = Final pressure of air
$T_1 = (25 + 273) = 298$ K
$T_2 = (52 + 273) = 325$ K

Step 2
Identify and write down the formula used.

Volume of gas is constant.
Gay-Lussac's Law formula is used.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$\frac{180}{298} = \frac{P_2}{325}$$

$$P_2 = \frac{180 \times 325}{298}$$

$$= 196.3 \text{ kPa}$$

Solving Problems Involving Pressure, Temperature and Volume of a Fixed Mass of Gas Using Formulae from the Gas Laws

Example 1

Photograph 4.8 shows a syringe with its nozzle closed. Air in the syringe has an initial volume of 7.5 cm^3 and pressure of 105 kPa. The air is compressed to a volume of 2.5 cm^3. What is the pressure of the air?

Photograph 4.8

Solution:

Step 1
List the given information in symbols.

P_1 = 105 kPa
P_2 = compressed air pressure
V_1 = 7.5 cm^3
V_2 = 2.5 cm^3

Step 2
Identify and write down the formula used.

$$P_1V_1 = P_2V_2$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$105 \times 7.5 = P_2 \times 2.5$$

$$P_2 = \frac{105 \times 7.5}{2.5}$$

$$= 315 \text{ kPa}$$

Example 2

Air of volume 0.24 m^3 in an expandable cylinder is heated from 27°C to 77°C at constant pressure. What is the volume of the air at 77°C?

Solution:

V_1 = 0.24 m^3
V_2 = Final volume of air
T_1 = (27 + 273)
= 300 K
T_2 = (77 + 273)
= 350 K

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.24}{300} = \frac{V_2}{350}$$

$$V_2 = \frac{0.24 \times 350}{300}$$

$$= 0.28 \text{ m}^3$$

Example 3

Initial pressure and temperature of air in the tyre of a car are 210 kPa and 25°C respectively. After a journey, the air pressure in the tyre is 240 kPa. Calculate the temperature of the air in the tyre in °C.

Solution:

Assume the volume of the tyre does not change. Gay-Lussac's Law is used.

$P_1 = 210$ kPa
$P_2 = 240$ kPa

$T_1 = 25°C + 273$
$= 298$ K

T_2 = Final temperature of air

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{210}{298} = \frac{240}{T_2}$$

$$T_2 = \frac{240 \times 298}{210}$$
$$= 340.6 \text{ K}$$

Final temperature of air $= 340.6 - 273$
$= 67.6°C$

Formative Practice 4.4

1. State the physical quantities that are constant in Boyle's Law, Charles' Law and Gay-Lussac's Law.
2. A syringe contains 50 cm^3 of air at a pressure of 110 kPa. The end of the syringe is closed and its piston slowly pushed until the volume of air becomes 20 cm^3. What is the pressure of the compressed air?
3. An air bubble trapped under a leaf in a lake has a volume of 1.60 cm^3 at a temperature of 38°C. Calculate the volume of the bubble if the temperature of the water in the lake drops to 26°C.
4. Pressure in a gas cylinder is 175 kPa at a temperature of 27°C. Heat from a nearby furnace causes the gas pressure to increase to 300 kPa. What is the temperature of the gas inside the cylinder?
5. Figure 4.35 shows an apparatus set up to study the relationship between pressure and temperature for air inside a round-bottom flask.
   (a) Identify four aspects in the apparatus set up that can jeopardise the accuracy of the results of the experiment.
   (b) Suggest modifications to improve the set up.

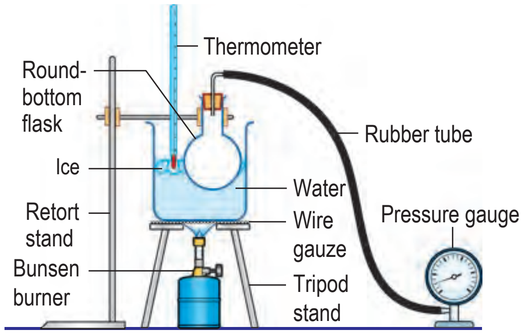


Figure 4.35

Conceptual Framework

Heat

- Thermal Equilibrium
  - Thermal equilibrium in daily life
    - Heating object
    - Cooling object
  - Calibrate a liquid-in-glass thermometer using two fixed points
    - Melting point of ice, 0°C
    - Boiling point of water, 100°C
- Specific Heat Capacity
  - $c = \dfrac{Q}{m\Delta\theta}$
    - Applications
      - Daily life
      - Material engineering
      - Natural phenomena
- Specific Latent Heat
  - Specific latent heat of fusion
  - Specific latent heat of vaporisation
    - $Q = ml$
      - Electric heating: $Pt = ml$
      - Applications in life
        - Cooling system in refrigerator
        - Evaporation of sweat
        - Steaming food
- Gas Laws
  - Relationship between pressure and volume of gas
    - Boyle's Law $P_1V_1 = P_2V_2$
  - Relationship between pressure and temperature of gas
    - Gay-Lussac's Law $\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$
  - Relationship between volume and temperature of gas
    - Charles' Law $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$

Interactive QUIZ

http://bt.sasbadi.com/p4164

SELF-REFLECTION

1. New things I learnt in this chapter on heat are ______________.
2. The most interesting thing I learnt in this chapter on heat is ______________.
3. Things I still do not fully understand or comprehend are ______________.
4. My performance in this chapter,

   Poor | 1 | 2 | 3 | 4 | 5 | Excellent

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

Download and print Self-reflection Chapter 4

http://bt.sasbadi.com/p4165

Performance Evaluation

1. Photograph 1 shows a steam injector machine which can inject steam into water in a container.
   (a) What is the meaning of latent heat?
   (b) Explain how water in the container is heated by steam injected into it.
   (c) What is the advantage of heating water using the injection of steam?

Photograph 1

2. Tick (✓) for situations that show thermal equilibrium.

Situation	Tick (✓)
(a) A hot object and a cold object placed side by side.	
(b) An object is heated by a nearby source of fire.	
(c) Two objects at the same temperature and in contact so that heat can be transferred between them but without net heat transfer.	
(d) Two objects at the same temperature but separated by a heat barrier.	

3. Block A has a high specific heat capacity and block B has a low specific heat capacity. If both blocks have the same mass,

(a) which block needs more energy to raise its temperature by 10°C?

(b) which block heats up more quickly if supplied with the same amount of heat? Explain your answer.

4. (a) Define specific latent heat.

(b) The mass of a melting ice cube reduces by 0.68 kg. What is the amount of heat absorbed from the surrounding by the ice cube?

[Specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1}]

5. (a) What is meant by specific latent heat of vaporisation?

(b) Figure 1 shows the graph of mass of water, m against time, t when water in a beaker is heated by a 1 800 W electric heater. At time t = 360 s, the water starts to boil.

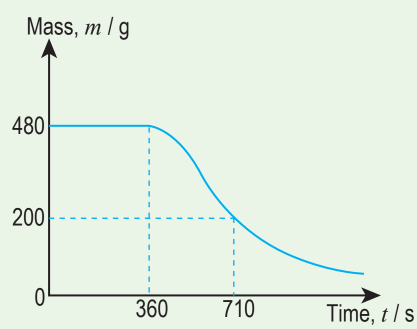


Figure 1

Calculate:

(i) mass of water that becomes steam from t = 360 s until t = 710 s.

(ii) specific latent heat of vaporisation of water.

6. A gold ring of mass 5.5 g experiences a rise in temperature from 36°C to 39°C. How much heat energy is absorbed by the ring?

[Specific heat capacity of gold = 300 J kg^{-1} °C^{-1}]

7. Photograph 2 shows the power rating label of an electric kettle.

(a) What is the maximum power of this electric kettle?

(b) Calculate the time taken by this kettle to change 0.5 kg of boiling water at 100°C into steam at 100°C when the kettle operates at maximum power.

[Specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}]

Photograph 2

(c) What assumptions are made in your calculations in 7(b)?

8. Air in the tyre of a car has a pressure of 220 kPa at initial temperature of 27°C. After a race, the temperature of the air increases to 87°C.

(a) Calculate the air pressure in the tyre after the race.

(b) What assumptions did you make in **8**(a)?

9. An air bubble is trapped under a leaf floating on the water surface of a lake. The volume of the air bubble is 3.6 cm^3 when the temperature is 20°C.

(a) What is the volume of the air bubble when the water temperature rises to 38°C?

(b) State three assumptions that need to be made in your calculations in **9**(a).

10. Figure 2 shows ice cubes being heated by a 500 W immersion heater for 80 seconds. The melted ice cubes are collected in a beaker.
[Specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1}]

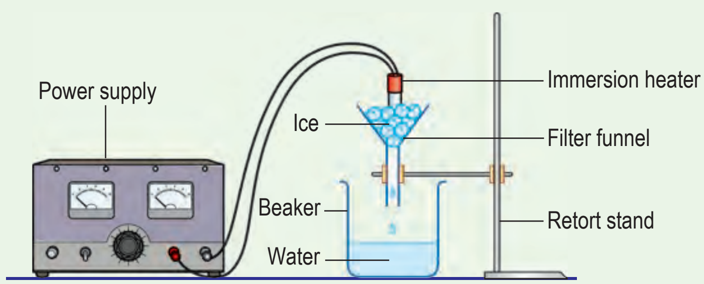


Figure 2

(a) What is meant by specific latent heat of fusion?

(b) Why does the temperature remain unchanged when the ice cubes are changing into liquid?

(c) Calculate:

(i) energy absorbed by the ice cubes.

(ii) mass of melted ice cubes.

(d) What assumptions are made in your calculations in **10**(c)?

11. An electric kettle is filled with 500 g of water at 30°C. The power of the heating element of the kettle is 0.8 kW. Assume that all heat from the heating element is transferred to the water.
[Specific heat capacity of water = 4 200 J kg^{-1} $°C^{-1}$]

(a) Calculate:

(i) heat energy needed to increase the temperature of the water to 100°C.

(ii) time taken by the kettle to heat water to a temperature of 100°C.

(b) Why is the handle of the kettle made of plastic?

(c) Why is the heating element of the kettle made of metal?

(d) The heating element of the kettle is located at the base of the kettle. Explain why.

12. A substance has a mass of 250 g. The substance loses 5 625 J of heat when cooled. There is a 25°C drop in temperature.

(a) Calculate the specific heat capacity of the substance. Identify the substance based on Table 4.2 on page 128.

(b) Explain the use of the substance based on its specific heat capacity.

13. Photograph 3 shows a bamboo steamer. Amin receives an order from a supermarket to supply 400 steamed buns per day. Suggest and explain the design of the steamer needed. The steamer should be durable, and able to prepare a large quantity of steamed buns in a short time.

Photograph 3

Enrinchment Corner

14. Khairi orders a cup of coffee in a restaurant. He finds that the coffee is too hot. Photograph 4 shows two suggested ways to cool the coffee.

Method *A*

Method *B*

Photograph 4

(a) Discuss the suitability of methods *A* and *B* to cool the coffee in the cup.

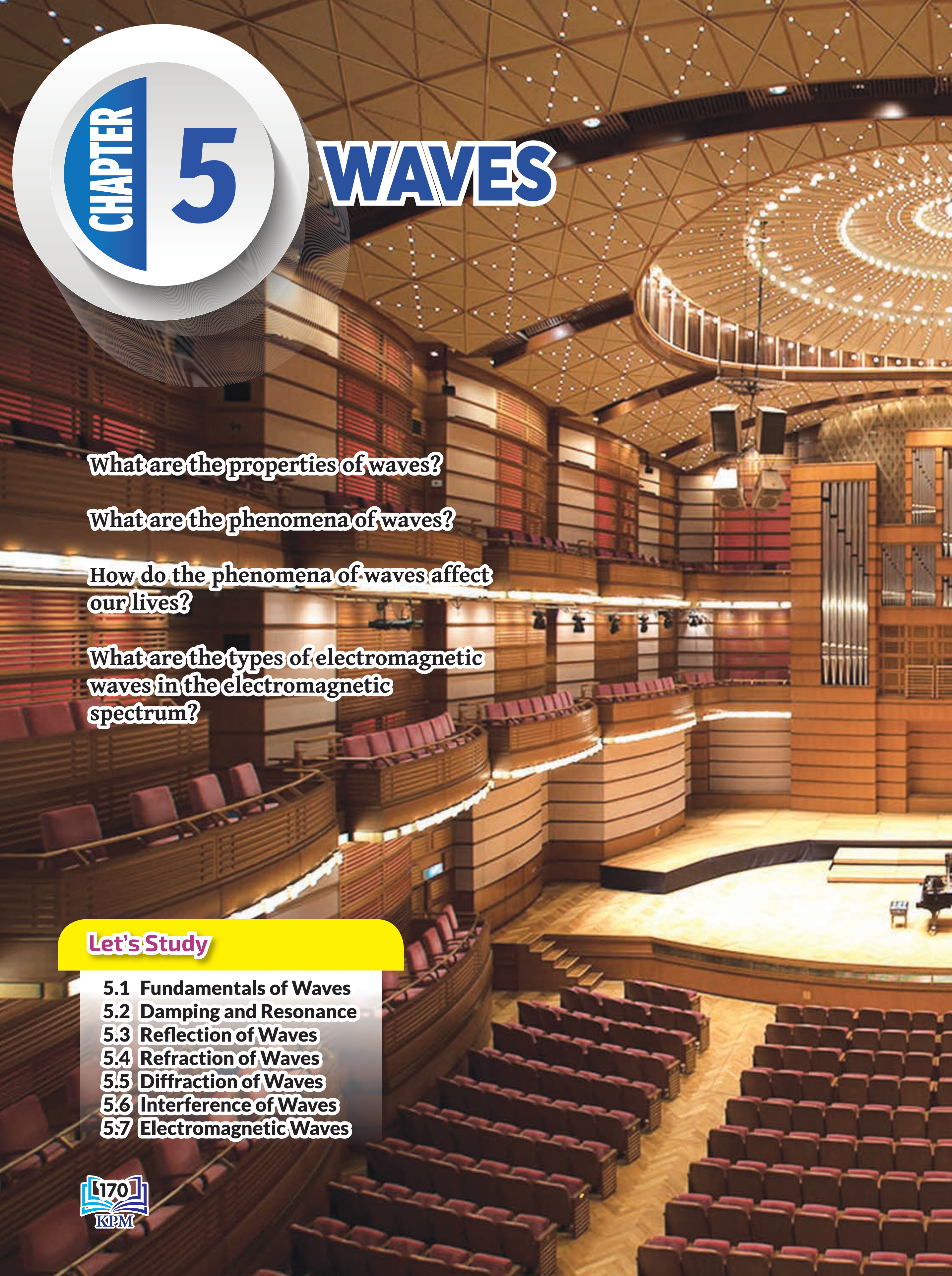
(b) State your choice. Give reasons for your choice.

Theme 4

Waves, Light and Optics

Concepts and phenomena of waves, light and optics have many applications in our lives.

The topics in this theme discuss propagation of waves, properties of light and electromagnetic waves. This knowledge is applied in wireless communication, home appliances, medicine, industry and others.



CHAPTER 5 WAVES

What are the properties of waves?

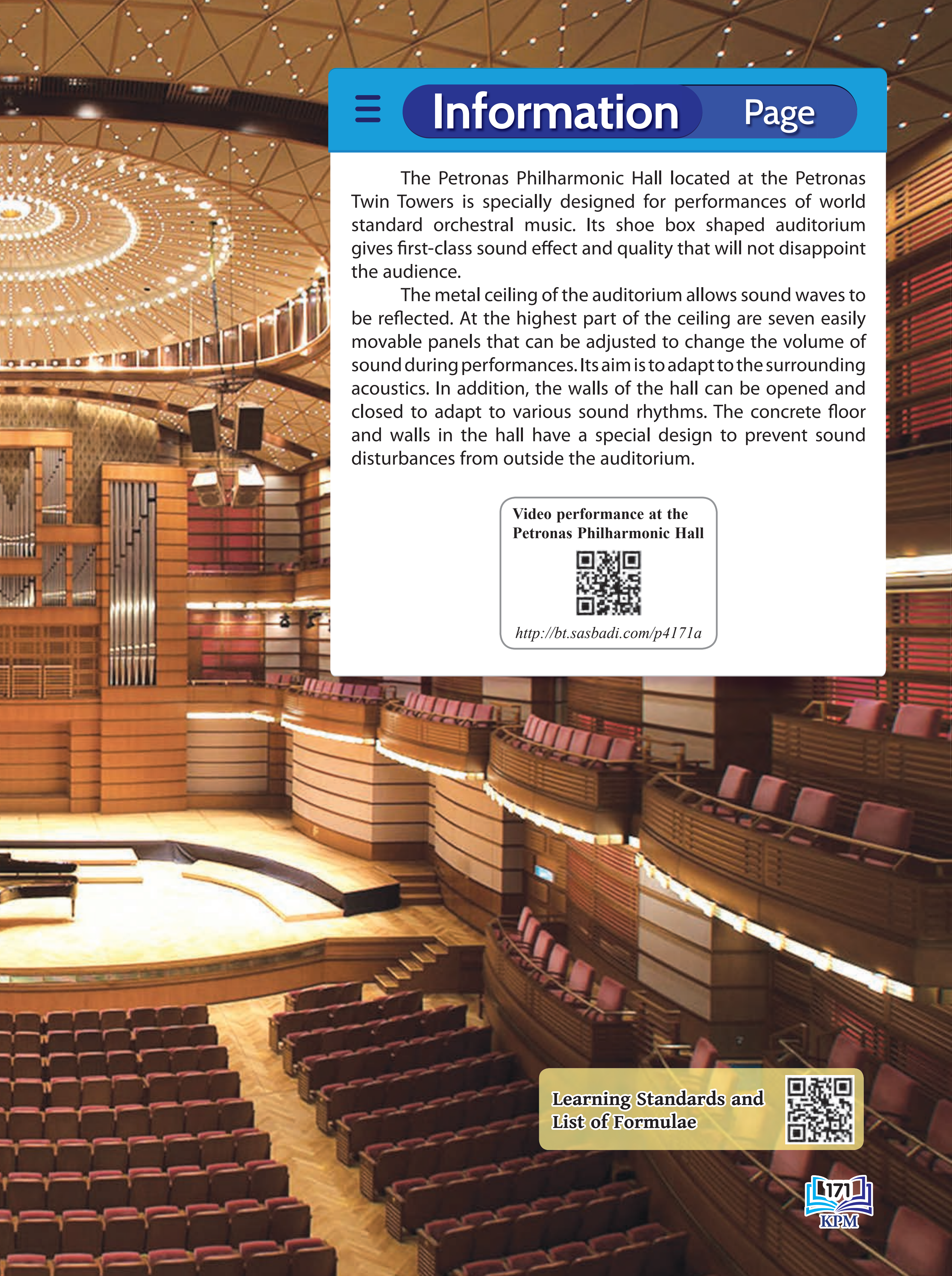
What are the phenomena of waves?

How do the phenomena of waves affect our lives?

What are the types of electromagnetic waves in the electromagnetic spectrum?

Let's Study

5.1 Fundamentals of Waves
5.2 Damping and Resonance
5.3 Reflection of Waves
5.4 Refraction of Waves
5.5 Diffraction of Waves
5.6 Interference of Waves
5.7 Electromagnetic Waves



Information Page

The Petronas Philharmonic Hall located at the Petronas Twin Towers is specially designed for performances of world standard orchestral music. Its shoe box shaped auditorium gives first-class sound effect and quality that will not disappoint the audience.

The metal ceiling of the auditorium allows sound waves to be reflected. At the highest part of the ceiling are seven easily movable panels that can be adjusted to change the volume of sound during performances. Its aim is to adapt to the surrounding acoustics. In addition, the walls of the hall can be opened and closed to adapt to various sound rhythms. The concrete floor and walls in the hall have a special design to prevent sound disturbances from outside the auditorium.

Video performance at the Petronas Philharmonic Hall

http://bt.sasbadi.com/p4171a

Learning Standards and List of Formulae

5.1 Fundamentals of Waves

Waves

When you read the word **waves**, what examples of waves do you think of? Photographs 5.1 and 5.2 show two examples of waves. How are waves formed?

Photograph 5.1 *Object falling on the surface of water produces water waves*

Photograph 5.2 *Striking a leather membrane covered drum, kompang produces sound waves*

Activity 5.1

Aim: To study the production of waves by an oscillating system and a vibrating system

Apparatus: Spring, retort stand, iron bob, tray, tuning fork and table tennis ball

Materials: Water, thread and cellophane tape

Instructions:

A Oscillation of iron bob at the end of a spring

1. Set up the apparatus as shown in Figure 5.1.
2. Adjust the height of the spring so that the iron bob hangs close to the surface of the water without touching it.
3. Pull the iron bob down untill it touches the water surface and then release it.
4. Observe what happens to the surface of the water.

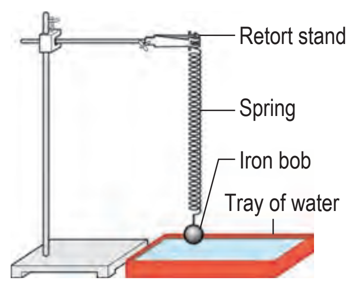


Figure 5.1

B Vibration of a tuning fork

1. Attach the tuning fork to the clamp of the retort stand.
2. Tap on the arm of the tuning fork and listen to the sound produced.
3. Use a table tennis ball to touch the arm of the tuning fork as shown in Figure 5.2.
4. Observe the movement of the table tennis ball.

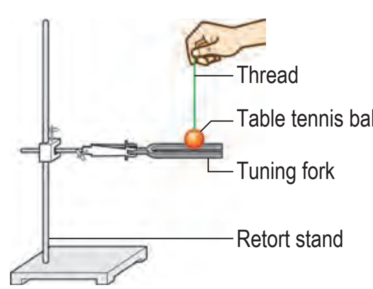


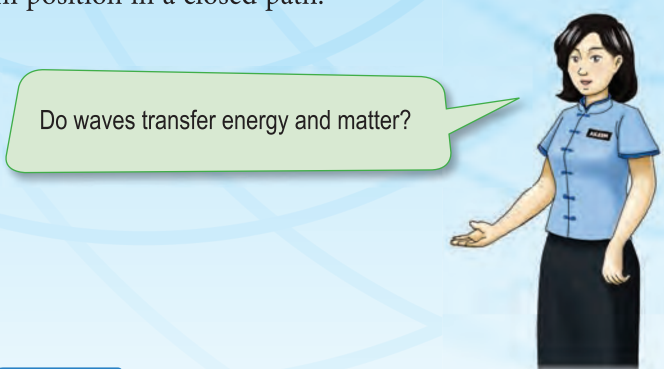
Figure 5.2

Discussion:

1. Describe the movement of the iron bob after it is pulled and released.
2. What is formed on the surface of the water in the tray?
3. Describe the movement of the table tennis ball when it touches the tuning fork which produces sound.
4. Relate the vibration of the table tennis ball to the sound heard.

Waves can be produced by an oscillating or a vibrating system. For example, the oscillation of an iron bob on the water surface produces water waves.

The vibration of a tuning fork in the air produces sound waves. **Oscillation** and **vibration** are repetitive motions about an equilibrium position in a closed path.



DIY

Mexican wave

http://bt.sasbadi.com/p4173

Try to produce the Mexican wave in class with your friends. Discuss the characteristics of the wave you can identify in this movement.

Activity 5.2

Aim: To generate the idea that waves transfer energy without transferring matter

Materials: Slinky spring and ribbon

Instructions:

1. Tie a ribbon to the slinky spring as shown in Figure 5.3.
2. Let two pupils hold each end of the slinky spring.
3. Move end *A* of the slinky spring from side to side while end *B* is fixed.
4. Observe the movement of the waves along the slinky spring and the movement of the ribbon.

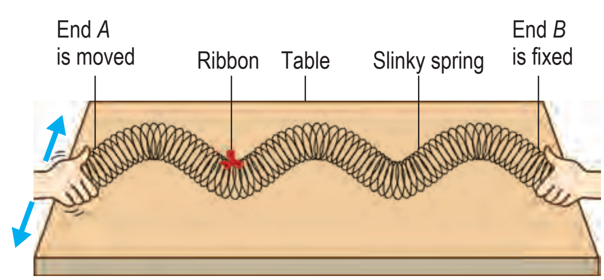


Figure 5.3

Discussion:

1. What is felt by the pupil at end *B* after the slinky spring is moved from side to side?
2. What is the direction of energy transfer along the slinky spring?
3. Describe the movement of the ribbon tied to the slinky spring.

Through Activity 5.2, we can conclude that waves are produced when a medium vibrates at a fixed position. Propagation of the waves transfers energy from one place to another without transferring the matter of the medium.

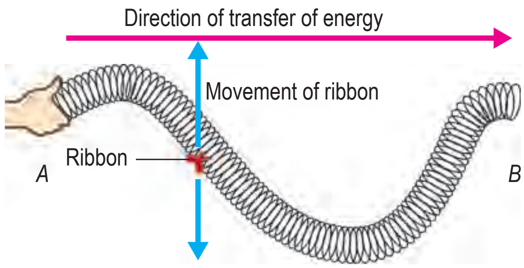


Figure 5.4 *Waves transfer energy without transferring matter*

Movement of waves from end *A* to end *B* transfers energy from *A* to *B*.

The ribbon only vibrates about in a fixed position. The ribbon does not move in the direction in which the energy is transferred by the waves.

Types of Waves

Figure 5.5 shows the shape of the slinky spring at five consecutive instances after end *A* has been moved as in Activity 5.2. The shape of the slinky spring as waves propagate through it is known as **wave profile**.

Waves can be classified from the aspect of propagation of the wave profile. The wave profile in Figure 5.5 propagates with time along the direction of propagation of the wave. This wave is known as a **progressive wave**.

Photograph 5.3 shows an example of a progressive wave produced by the vibrations on the surface of the water. A wave profile propagates outwards in all directions.

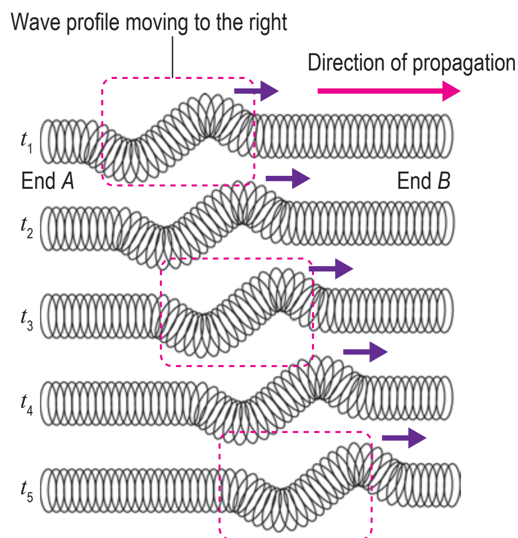
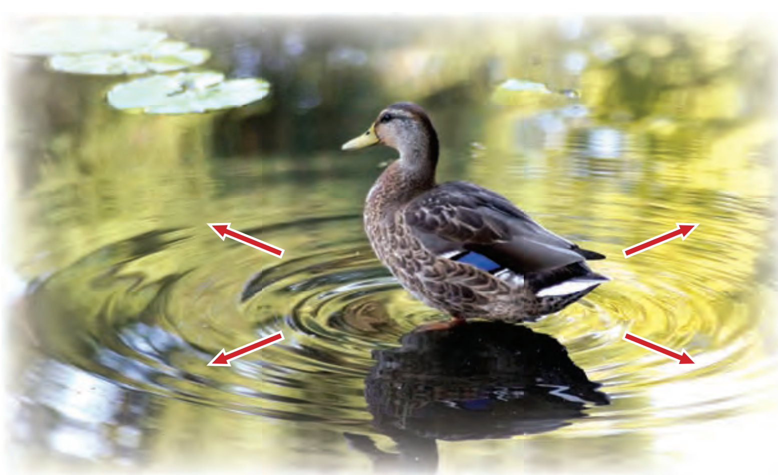


Figure 5.5 *Wave profile at five consecutive instances*



Photograph 5.3 *Progressive waves on the water surface*

Video of progressive wave on surface of water

http://bt.sasbadi.com/p4174a

Progressive waves can propagate through a medium as transverse waves or longitudinal waves. Scan the QR code to watch the animation of **transverse waves** and **longitudinal waves**.

Transverse waves and longitudinal waves

http://bt.sasbadi.com/p4174b

Figure 5.6 shows a wave profile at five consecutive instances of a guitar string that is being plucked. Does the wave profile move to the left or right?

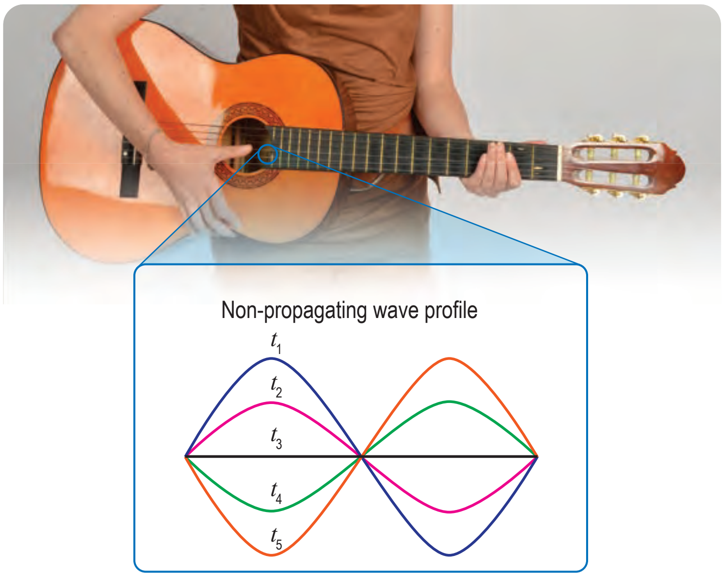


***Figure 5.6** A wave profile at five consecutive instances*

Info File

Stationary wave is produced when two identical progressive waves moving in opposite directions collide with one another.

Wave produced along a guitar string being plucked is an example of a **stationary wave**. A stationary wave is a wave where the profile of the wave does not propagate with time. Scan the QR code given to observe the profile of a stationary wave. Stationary waves are also produced by musical instruments such as ukulele, flute and drum when these instruments are played.

Profile of a stationary wave

http://bt.sasbadi.com/p4175

Waves can also be classified as mechanical waves or electromagnetic waves. Figure 5.7 shows the characteristics of a mechanical wave and an electromagnetic wave.

Mechanical wave

- Requires a medium to transfer energy from one point to another
- Made up of vibrating particles of a medium
- Water waves, sound waves and seismic waves on the surface of the Earth are examples of mechanical waves.

Electromagnetic wave

- Does not require a medium to transfer energy
- Made up of oscillating electric and magnetic fields perpendicular to one another
- Radio waves, light waves and gamma rays are examples of electromagnetic waves.

***Figure 5.7** Characteristics of a mechanical wave and an electromagnetic wave*

Comparison between Transverse Wave and Longitudinal Wave

There are two types of progressive waves, transverse wave and longitudinal wave. What are the similarities and differences between these two waves?

Activity 5.3

Aim: To compare transverse wave and longitudinal wave

Materials: Ribbon and slinky spring

A Transverse wave

Instructions:

1. Tie two short ribbons to a slinky spring.
2. Let two pupils hold each end of the slinky spring.
3. Move end *P* left and right repeatedly until a pattern of a wave is formed as shown in Figure 5.8.
4. Observe the propagation of the wave along the slinky spring and the movement of the ribbons.
5. Draw the wave profile formed and mark the direction of propagation of the wave.
6. Mark the direction of the ribbons.

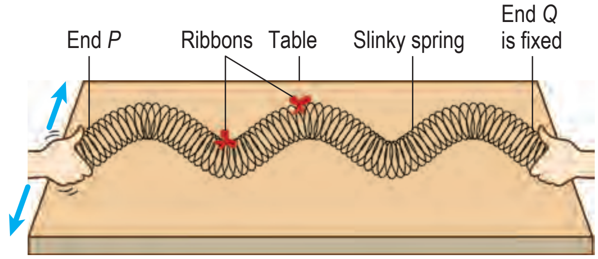


Figure 5.8

Discussion:

Compare the direction of propagation of the wave and the direction of movement of the ribbons.

B Longitudinal wave

Instructions:

1. Repeat activity A by moving the end *P* of the slinky spring forward and backward repeatedly until waves are formed as shown in Figure 5.9.
2. Observe the propagation of the waves along the slinky spring and the movement of the ribbons.
3. Sketch the shape of the entire length of the slinky spring and mark the direction of propagation of the waves.
4. Mark the direction of movement of the ribbons.

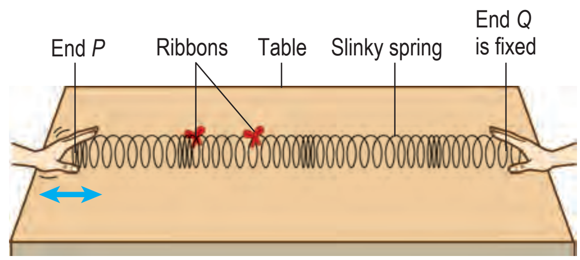


Figure 5.9

Discussion:

Compare the direction of propagation of the wave and the direction of movement of the ribbons.

Transverse wave

- Particles of the medium vibrate in the direction perpendicular to the direction of propagation of the wave.
- Made up of consecutive crests and troughs.

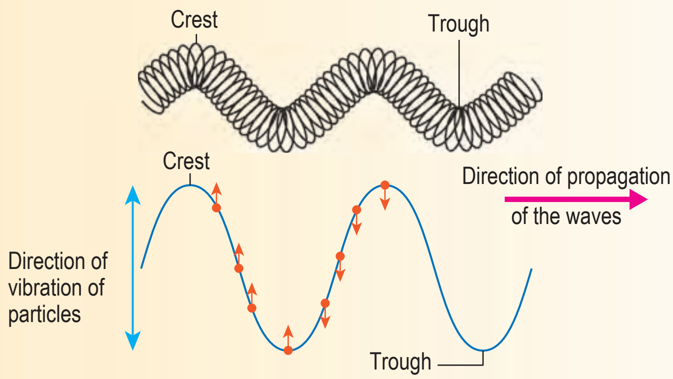


Figure 5.10 *Transverse wave*

- Radio waves, light waves and water waves are examples of transverse waves.

Info File

Earthquakes produce P-waves and S-waves. S-wave is a transverse wave and P-wave is a longitudinal wave. Both waves have different speeds. Analysis of the time difference between the two waves helps to determine the epicentre of earthquakes.

CAREER INFO

A seismologist investigates, predicts and reports earthquakes.

Longitudinal wave

- Particles of the medium vibrate in the direction parallel to the direction of propagation of the wave.
- Made up of consecutive **compressions** (compressed regions) and **rarefactions** (stretched regions).

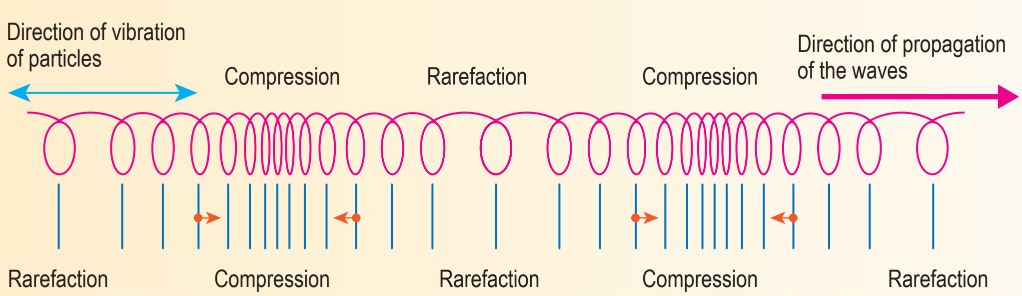


Figure 5.11 *Longitudinal wave*

- Sound wave is an example of longitudinal wave.

Characteristics of Waves

Figure 5.12 shows the profile of a water wave in a pond. What changes can you observe as the wave propagates across the water surface?

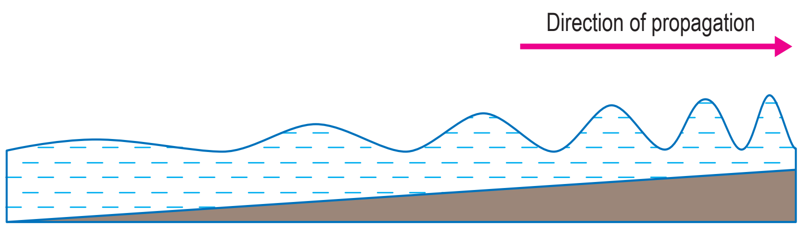


Figure 5.12 *Profile of water wave*

Changes in wave profile

http://bt.sasbadi.com/p4178a

To answer this question, you need to know the definition of terms related to waves.

Table 5.1 *Definition of terms related to waves*

Term	Definition
Amplitude, A	Maximum displacement of a particle from its equilibrium position
Period, T	The time taken by a particle to make one complete oscillation or by a source to produce one complete cycle of wave
Frequency, f	Number of complete oscillations made by a particle or number of cycles of wave produced by a source in one second
Wavelength, λ	Distance between two consecutive points in phase
Wave speed, v	Distance travelled per second by a wave profile

Info File

- Equilibrium position is the original position of the particle before a system oscillates.
- For waves of frequency, f:
  $f = \frac{1}{T}$
- Displacement is the distance of a particle from the equilibrium position.

Carry out Activity 5.4 to explain the definition of terms related to waves.

Activity 5.4

ICS ISS

Aim: To define terms related to waves

Instructions:

1. Work in groups.
2. Scan the QR code and watch the video about waves.
3. Gather information from websites which explain the definition of terms related to waves.
4. Present your findings in the form of an interesting multimedia presentation.

Waves

http://bt.sasbadi.com/p4178b

Figure 5.13 illustrates the amplitude, points in phase and wavelength of a transverse wave. Identify several other distances that are equal to one wavelength.

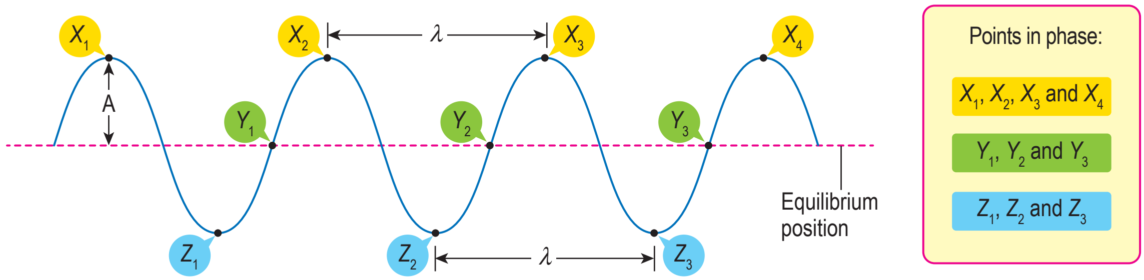


Figure 5.13 *A transverse wave*

Figure 5.14 shows the points in phase and wavelength of a longitudinal wave. Can you define its wavelength in terms of compression or rarefaction?

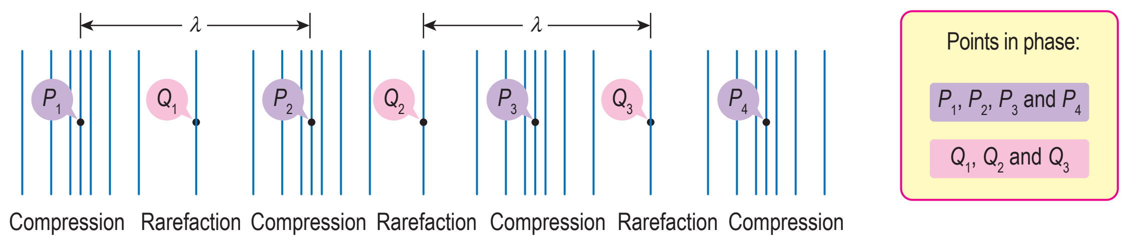


Figure 5.14 *A longitudinal wave*

Figure 5.15 shows the profile of a transverse wave at one instance and after a period, T of the wave. In time, $t = T$, the wave profile propagates through the same distance as the wavelength, λ.

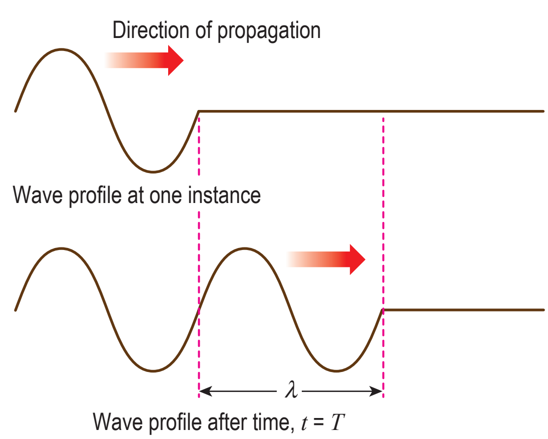


Figure 5.15 *A wave profile*

From the equation, speed $= \dfrac{\text{Distance travelled by a wave profile}}{\text{Time}}$

Speed of wave, $v = \dfrac{\lambda}{T}$

$= \left(\dfrac{1}{T}\right)\lambda$

Frequency of wave, $f = \dfrac{1}{T}$

Therefore, speed of wave, $v = f\lambda$

Sketch and Interpret Wave Graphs

Figure 5.16 shows the profile of a transverse wave at a certain instance.

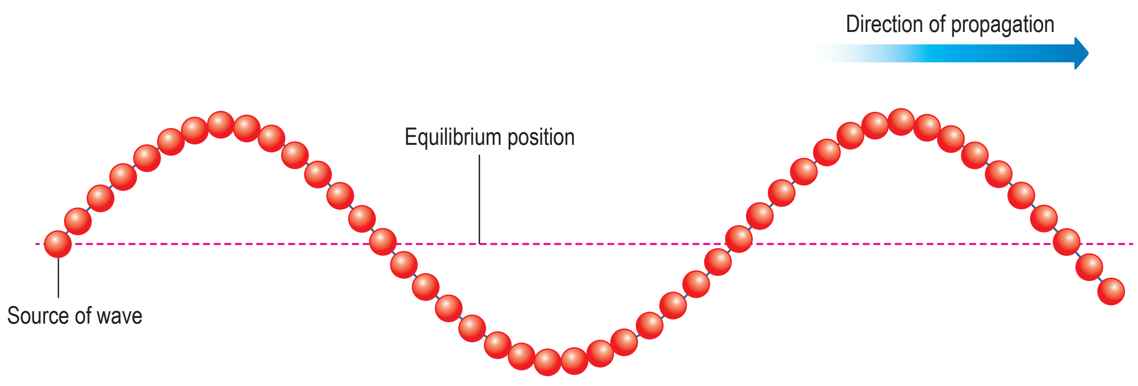


Figure 5.16 *Profile of a transverse wave*

Particles along the wave oscillate up and down about the equilibrium position. Scan the QR code given to observe the change in displacement of the particles. Two types of graphs can be drawn to show the variation of the displacement of wave particles, which are graph of displacement against time and graph of displacement against distance.

Simulation of a wave profile

http://bt.sasbadi.com/p4180a

Activity 5.5

ICS

Aim: To sketch a graph of displacement against time and a graph of displacement against distance

Instructions:

1. Group in pairs.
2. Scan the QR code to observe the method of sketching a graph of displacement against time and a graph of displacement against distance.
3. Sketch a graph of displacement against time for a wave with:
   (a) Amplitude, A = 5 cm
   (b) Period, T = 0.4 s
4. Sketch a graph of displacement against distance for a wave with:
   (a) Amplitude, A = 5 cm
   (b) Wavelength, λ = 4 cm

Video on method of sketching a graph of displacement against time

http://bt.sasbadi.com/p4180b

Video on method of sketching a graph of displacement against distance

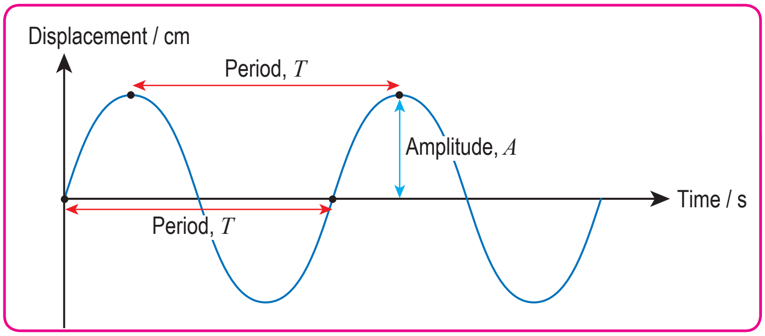
http://bt.sasbadi.com/p4180c

A graph of displacement against time and a graph of displacement against distance respectively give information on the terms related to waves as shown in Figure 5.17.

SMART INFO

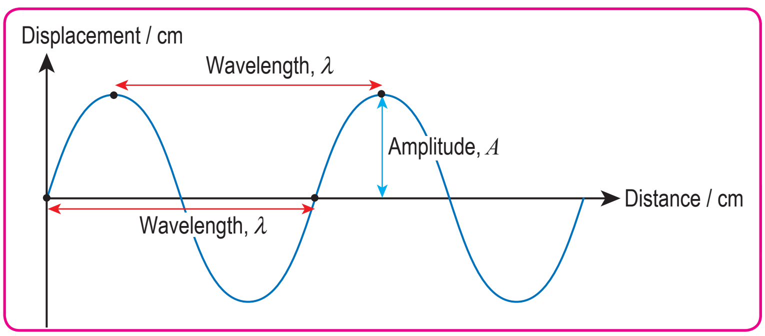
Speed of a wave, $v = f\lambda$ can be calculated from the information obtained from a graph of displacement against time and a graph of displacement against distance.

Graph of displacement against time



Information obtained:
Amplitude, A
Period, T
Frequency, $f = \dfrac{1}{T}$

Graph of displacement against distance



Information obtained:
Amplitude, A
Wavelength, λ

***Figure 5.17** Information of waves that can be interpreted from the graphs*

Activity 5.6

CPS

Aim: To interpret graph of waves

Instructions:

1. Work in groups.
2. Study the graph of displacement against time and the graph of displacement against distance for a wave propagating along a piece of rope.

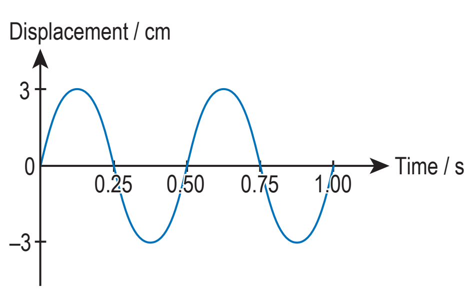


***Figure 5.18** Graph of displacement against time*

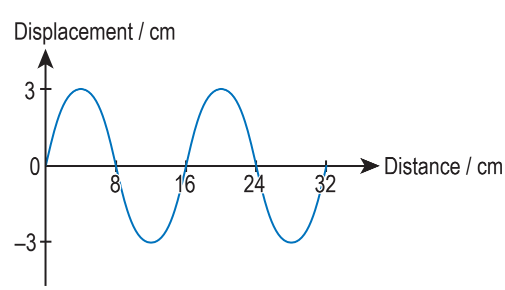


***Figure 5.19** Graph of displacement against distance*

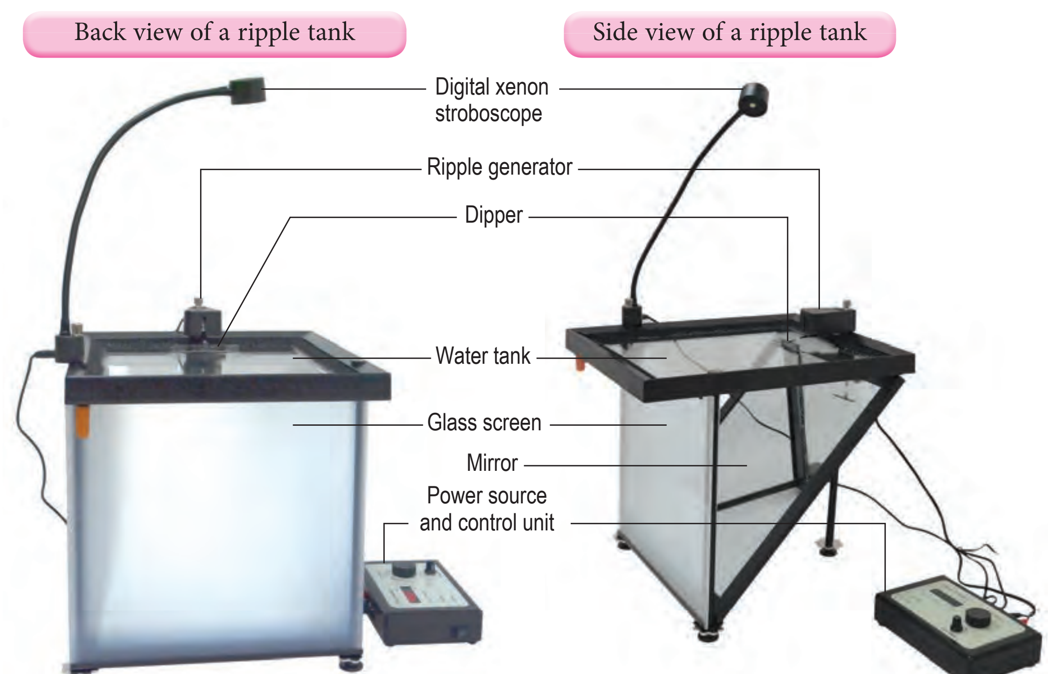
3. Discuss and interpret the following characteristics of waves in both the graphs:
   (a) Amplitude, A
   (b) Period, T
   (c) Frequency, f
   (d) Wavelength, λ
   (e) Wave speed, v

Determining Wavelength, λ, Frequency, f and Wave Speed, v

A ripple tank is used in the laboratory to study water waves. It consists of a water tank made from perspex or glass, ripple generator, digital xenon stroboscope, mirror, glass screen and dipper.

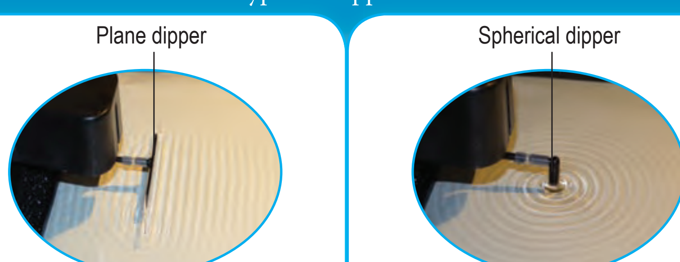
Video demonstrating the use of a ripple tank

http://bt.sasbadi.com/p4182



Photograph 5.4 *Ripple tank*

There are two types of dippers that can be used



Plane dipper produces plane waves.

Spherical dipper produces circular waves.

Photograph 5.5 *Types of waves produced by different types of dippers*

Activity 5.7

Aim: To determine the wavelength, frequency and wave speed

Apparatus: Ripple tank and its accessories, digital xenon stroboscope and ruler

Materials: Distilled water

Instructions:

1. Arrange the apparatus as in Photograph 5.6.
2. Switch on the plane dipper and adjust the frequency of the digital xenon stroboscope so that the image on the screen looks stationary.
3. Use a ruler to measure the wavelength of the water wave, that is the distance between two consecutive bright fringes.

Photograph 5.6

Discussion:

1. What is the frequency of the water wave?
2. What is the wavelength of the water wave?
3. What is the wave speed?

Note: If there is no digital xenon stroboscope, handheld stroboscope can be used.

Formative Practice 5.1

1. Figure 5.20 shows a graph of displacement against time for a wave.

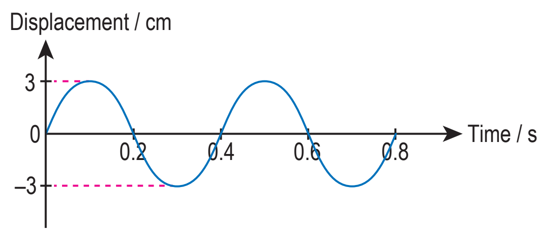


Figure 5.20

   (a) What is meant by amplitude?
   (b) Determine the period of oscillation, T. Then, calculate the frequency of oscillation.

2. Compare and contrast progressive wave and stationary wave.

3. Figure 5.21 shows a slinky spring being moved forward and backward at one of its ends.
   (a) What type of wave is produced by a slinky spring?
   (b) Mark "X" at the rarefaction part of the wave in Figure 5.21.
   (c) What is the wavelength, λ of the wave?

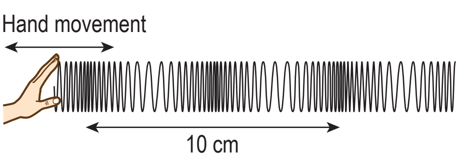


Figure 5.21

5.2 Damping and Resonance

Damping and Resonance for an Oscillating and Vibrating System

An oscillating system that is displaced and then left to oscillate without the action of external forces, will oscillate at its **natural frequency**. What happens to the amplitude of the oscillating system?

Activity 5.8

Aim: To observe the phenomenon of damping on an oscillating system

Apparatus: Simple pendulum made up of a plastic bag filled with granulated sugar tied to a 120 cm long thread, retort stand and G-clamp

Materials: Fine granulated sugar, black paper and sharp pencil

Instructions:

1. Set up the apparatus as shown in Figure 5.22.

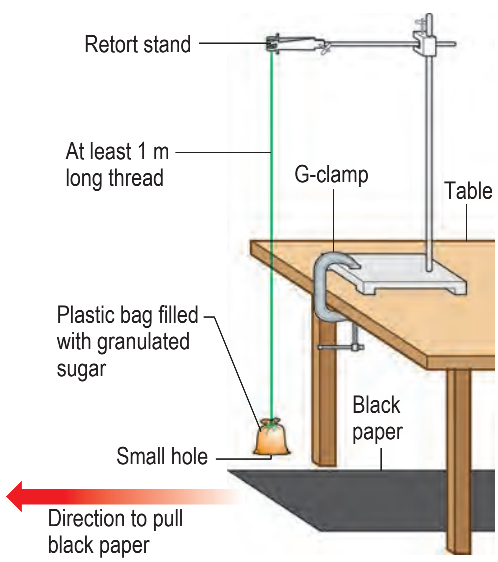


Figure 5.22

2. Use a sharp pencil to prick the bottom of the plastic bag filled with granulated sugar.
3. Displace the plastic bag to the side and release it to oscillate slowly near the floor.
4. Pull the black paper which is under the plastic bag slowly with uniform speed.
5. Observe the pattern formed by the granulated sugar on the black paper.
6. Sketch the pattern formed.

Discussion:

1. What changes happen to the amplitude of oscillation of the plastic bag?
2. Why does the oscillation of the plastic bag stop after some time?

Figure 5.23 shows the graph of displacement against time for the oscillation in Activity 5.8.

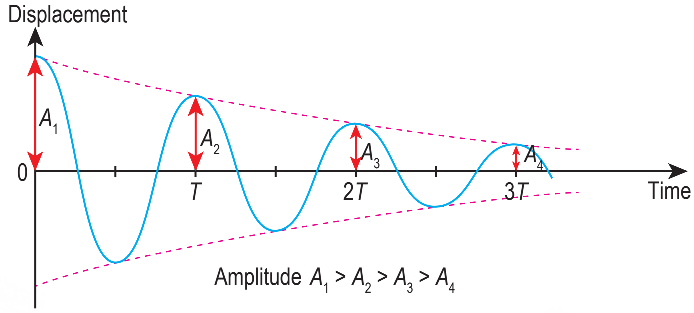


***Figure 5.23** Graph of displacement against time for the oscillation of the simple pendulum*

Observe that the amplitude for the oscillation decreases with time. Figure 5.24 shows the graph of amplitude against time for the oscillation of the simple pendulum.

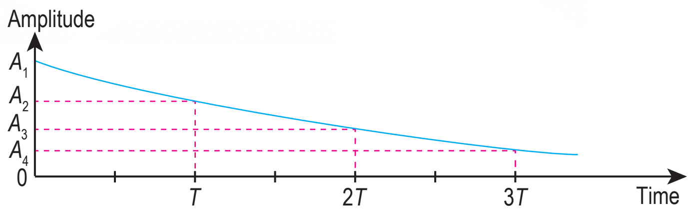


***Figure 5.24** Graph of amplitude against time for the oscillation of the simple pendulum*

Info File

The oscillation of a simple pendulum experiences significant external damping but insignificant internal damping. For the vibration of a spring, both external and internal damping happen significantly.

Info File

Periodic force is a force which acts at specific time intervals. Periodic force does not act continuously.

An oscillation with its amplitude decreasing with time shows that the system experiences a gradual loss of energy. Finally the oscillation stops. This phenomenon is known as damping. Oscillating systems experience loss of energy due to:

External damping	Oscillating system loses energy to overcome friction or air resistance.
Internal damping	Oscillating system loses energy because of the stretching and compression of the vibrating particles in the system.

Damping is the reduction in amplitude in an oscillating system due to loss of energy. During damping, the oscillating frequency remains constant while the oscillating amplitude decreases.

The effect of damping can be overcome by applying periodic external force on the oscillating system. The periodic external force transfers energy into the oscillating system to replace the energy lost. The system is said to be in a forced oscillation.

5.2.1

When a periodic force is applied to an oscillating system at its natural frequency, the oscillating system is said to be at **resonance**.

During resonance:
- System oscillates with its natural frequency.
- System oscillates with maximum amplitude.

Activity 5.9

Aim: To study the production of resonance using Tuning Fork Kit and Barton's pendulum

A Tuning Fork Kit

Apparatus: Tuning fork kit is made up of two tuning forks of the same frequency, hammer and tablet installed with sound meter application

Instructions:

1. Set up the apparatus as shown in Figure 5.25.
2. Open the sound meter application on the tablet. Observe and record the reading displayed.
3. Strike tuning fork *P* with a hammer.
4. Move tuning fork *Q* away from tuning fork *P* without touching its prongs.
5. Use the sound meter application to record the level of loudness of sound produced by tuning fork *P* and tuning fork *Q* separately.

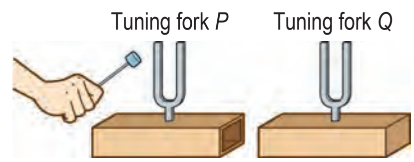


Figure 5.25

Discussion:

1. Is sound detected by the tablet when it is near tuning fork *P* and *Q*?
2. Why does tuning fork *Q* produce sound without being struck? Explain.

B Barton's Pendulum

Apparatus: Retort stand, brass bob and G-clamp

Materials: Thread, string, small paper cup and cellophane tape

Instructions:

1. Prepare the apparatus setup as shown in Figure 5.26.
2. Ensure brass bob *X* and paper cup *C* are at the same horizontal level so that pendulums *X* and *C* are of the same length.
3. Displace pendulum *X* and release it.
4. Observe the oscillations of pendulums *A*, *B*, *C* and *D*.
5. Identify the pendulum which oscillates with the largest amplitude.

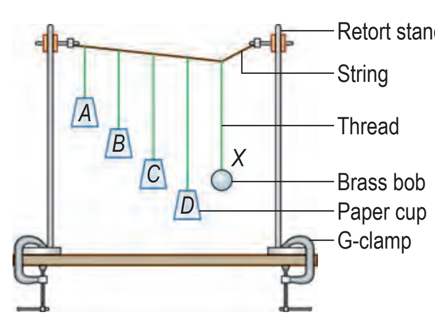


Figure 5.26

Discussion:
1. Which pendulum oscillates with the largest amplitude?
2. Why does that pendulum oscillate with the largest amplitude?

The vibrations of tuning fork *P* have forced tuning fork *Q* to vibrate in resonance with *P*. Energy is transferred from tuning fork *P* to tuning fork *Q*. Tuning fork *Q* vibrates with maximum amplitude and produces sound that can be detected.

The oscillation of brass pendulum *X* transfers energy to pendulums *A*, *B*, *C* and *D* causing all pendulums to oscillate. Resonance happens to pendulum *C* because pendulum *C* has the same natural frequency as pendulum *X*. Pendulum *C* oscillates with the largest amplitude.

Effects of Resonance in Daily Life

Activity 5.10

ISS ICS

Aim: To show a video on effects of resonance in daily life

Instructions:
1. Work in groups.
2. Examples of the effects of resonance in daily life are as follows:

   In 1940, the hanging bridge *Tacoma Narrows* in Washington, USA collapsed due to strong winds which caused the bridge to oscillate with large resonance and amplitude.

   The *London Millennium Footbridge* was opened in June 2000. This bridge experienced unexpected oscillations when 2 000 pedestrians walked on it.

   Resonance is used in the tuning of musical instruments.
3. Search for videos on the effects of resonance given and present your videos.
4. Search for more examples of resonance.

Video on examples of resonance

http://bt.sasbadi.com/p4187

Formative Practice 5.2

1. What is the meaning of damping?
2. Sketch a graph of displacement against time for a system experiencing damping.
3. State three examples of the effects of resonance in our daily lives.
4. How can resonance overcome damping of an oscillating system?

5.2.1 5.2.2

5.3 Reflection of Waves

You have studied that light and sound waves can be reflected. In reality, all waves can be reflected. Photograph 5.7 shows sea waves reflected by an embankment. Scan the QR code to watch the video on the reflection of waves.

Video on reflection of waves

http://bt.sasbadi.com/p4188

Photograph 5.7 *Sea waves reflected by an embankment*

Wavefront

The phenomenon of reflected waves can be studied with the help of a ripple tank and its accessories. Figure 5.27 shows plane waves produced by a ripple tank.

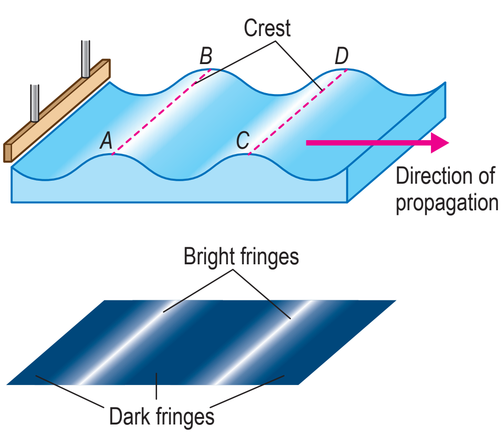


Figure 5.27 *Wavefront*

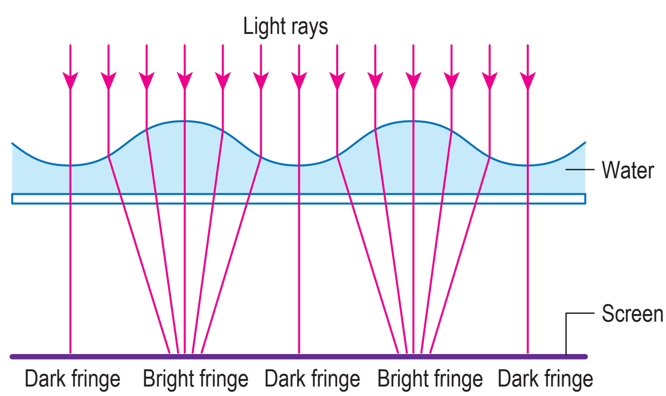
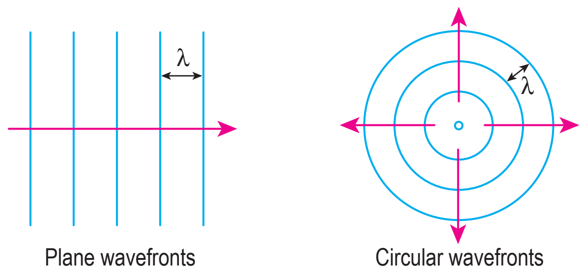


Figure 5.28 *Formation of bright and dark fringes*

All points along line *AB* are in phase as the points are of the same distance from the source of vibration and have the same displacement. Line *AB* which joins the points in phase in a wave is known as **wavefront**. Line *CD* is also a wavefront. When light rays move through water in a ripple tank, alternate bright and dark fringes can be seen on the screen as shown in Figure 5.27. Figure 5.28 shows the formation of bright and dark fringes by light rays.

Figure 5.29 shows the wavefronts for plane waves and circular waves. Study the direction of propagation and wavelength of these waves.



- Direction of propagation of the wave is perpendicular to the wavefront.
- Wavelength, λ is the same as the distance between two consecutive wavefronts.

***Figure 5.29** Plane and circular wavefronts*

What is the effect on the characteristics of waves when a wave is reflected?

Activity 5.11

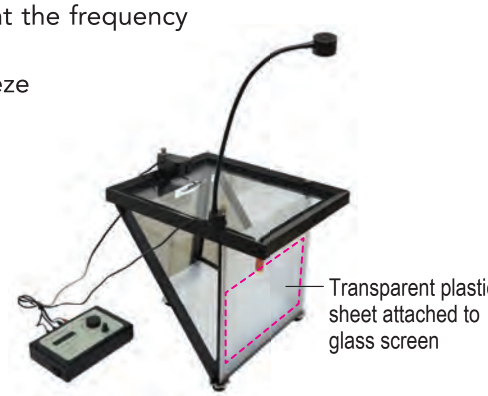
Aim: To study the reflection of waves for plane waves

Apparatus: Ripple tank and its accessories, plane reflector, digital xenon stroboscope, ruler and protractor

Materials: Transparent plastic sheet, marker pen, cellophane tape and distilled water

Instructions:

1. Set up the apparatus as shown in Photograph 5.8.
2. Switch on the wave generator and adjust so that the frequency of vibration is low.
3. Adjust the frequency of the stroboscope to freeze the movement of the waves.
4. Place the plane reflector into the water tank.
5. Use a marker pen to mark on the plastic sheet the position of:
   (a) plane reflector
   (b) three consecutive incident wavefronts
   (c) three consecutive reflected wavefronts
6. Remove the plastic sheet and use a marker pen to draw:
   (a) shape of plane reflector
   (b) three incident wavefronts and reflected wavefronts
   (c) direction of propagation of incident wave and reflected wave
   (d) normal line
7. Determine the following values:
   (a) angle of incidence, i and angle of reflection, r
   (b) incident wavelength and reflected wavelength

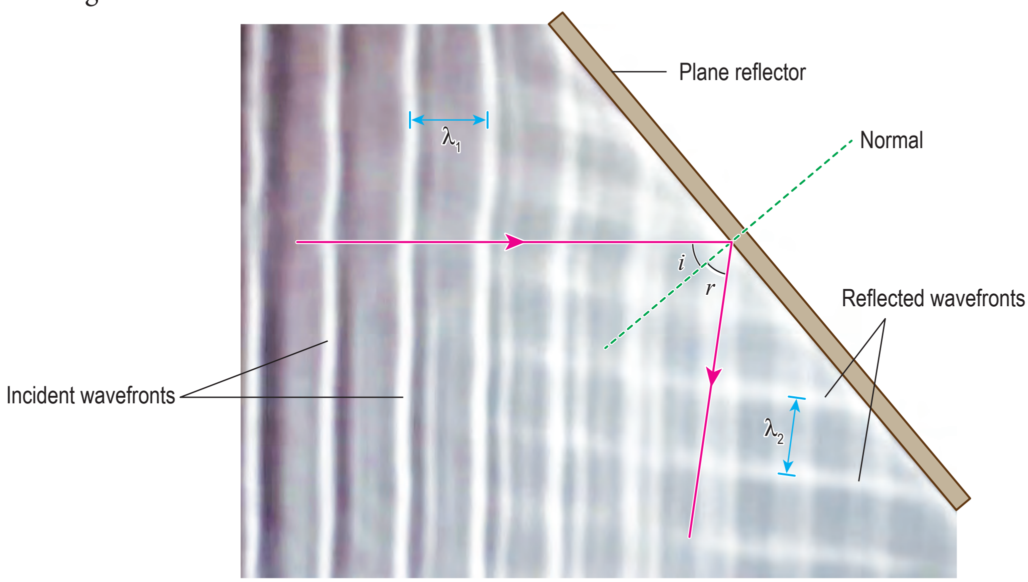


Photograph 5.8

Discussion:

1. Compare angle of incidence and angle of reflection.
2. Compare incident wavelength and reflected wavelength.
3. Can the stroboscope freeze the movement of incident waves and reflected waves at the same time?
4. Based on your answer in question 3, compare the frequency of incident wave and frequency of reflected wave.
5. From your answers in questions 2 and 4, compare the speed of incident wave with reflected wave.

Photograph 5.9 shows reflected plane water waves in a ripple tank. The phenomenon of reflected waves only cause the wave direction to change while other characteristics of the wave do not change.



Photograph 5.9 *Reflection of plane water waves by a plane reflector*

Table 5.2 summarizes the effects of reflection on the characteristics of waves.

Table 5.2 *Effects of reflection on characteristics of waves*

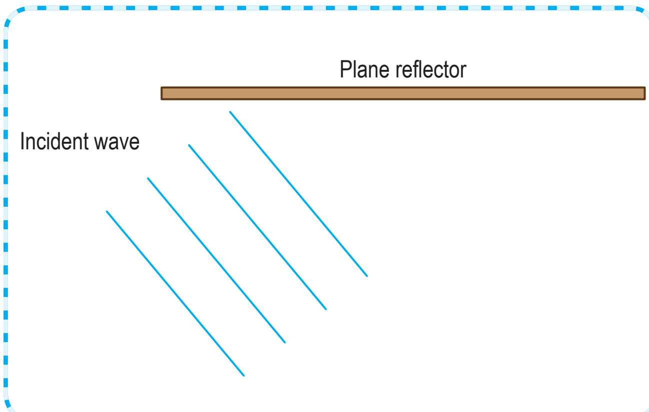
Characteristic of wave	Effect after reflection of wave
Angle of incidence and angle of reflection	Angle of incidence = angle of reflection
Wavelength	No change
Frequency	No change
Wave speed	No change
Direction of propagation	Changes with the condition that the angle of incidence is the same as angle of reflection

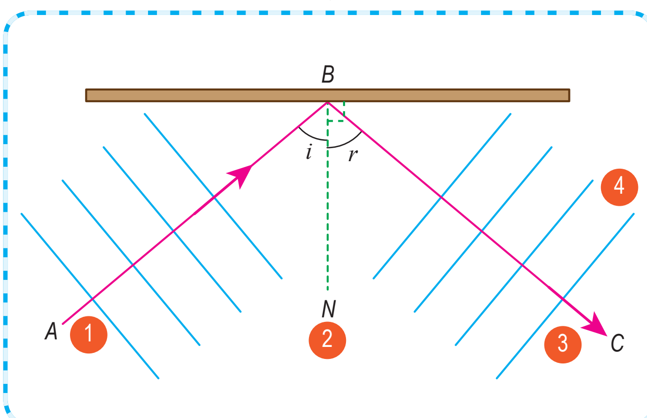
Drawing Diagram of Reflection of Water Waves

Figure 5.30 shows the steps to draw a diagram of reflection of water waves.

Video on completing diagram of reflection of wave

http://bt.sasbadi.com/p4191





Step 1 Draw an arrowed line *AB* perpendicular to incident wavefront to represent the direction of propagation of incident wave.

Step 2 Draw the normal *BN* which is perpendicular to the plane reflector.

Step 3 Draw an arrow *BC* with the condition angle *CBN* is the same as angle *ABN* to represent the direction of propagation of reflected wave.

Step 4 Draw lines perpendicular to *BC* to represent reflected wavefronts. The reflected wavelength must be the same as the incident wavelength.

Figure 5.30 *The steps to draw reflection of water waves*

Applications of Reflection of Waves in Daily Life

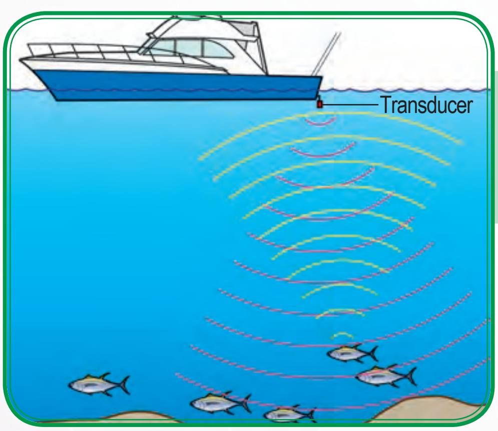
The phenomenon of reflection of waves can be applied in our daily lives. Figure 5.31 shows some examples of the application of reflection of waves.

CAREER INFO

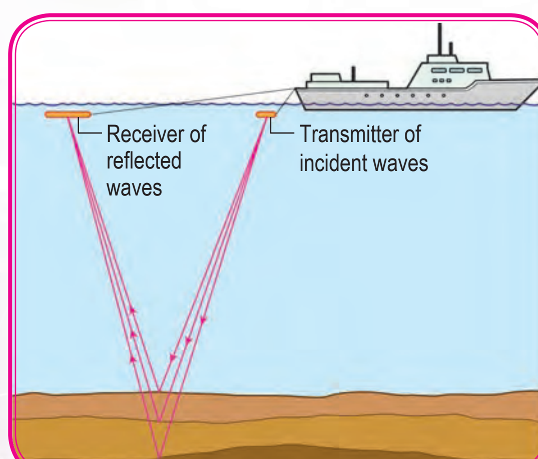
Officers of Science (Physics) in the diagnostic imaging and radiotherapy division in hospitals maintain and callibrate all apparatus that produce electromagnetic and sound waves so that they are safe to use.

Ultrasonic waves are used in the medical field to examine a foetus or other internal organs.

Radio waves from communication satellites are reflected by the parabolic dish and focussed onto the antenna on the feed horn.



Technology of ultrasonic reflection which is known as SONAR helps to detect areas which have a lot of fish. Transducer transmits waves into the water and these waves are reflected by the fish to the transducer.



Patterns of reflected sound waves caused by different rocks enable the location, depth and structure of the seabed which contain sources of natural gas to be identified.

Figure 5.31 *Applications of reflected waves in daily life*

Solving Problems Involving Reflected Waves

Example 1

Ultrasonic waves of frequency 25 kHz are transmitted from a ship to the seabed to determine the depth of the sea. These waves travel at a speed of 1 500 m s^{-1} in the water. Time between sending the ultrasonic wave and receiving the reflected wave is 120 ms.

Determine

(a) depth of sea, and

(b) ultrasonic wave length.

Solution:

The ultrasonic wave takes 120 ms to travel from the ship to the seabed and back to the ship. Distance travelled by the wave is two times the depth of the sea.

(a)

Step 1
List the given information in symbols.

Speed of the wave, v = 1 500 m s^{-1}
Time interval, t = 120 ms

Step 2
Identify and write down the formula used.

Distance travelled = Speed × time

$$2d = vt$$

Step 3
Substitute numerical values into the formula and perform the calculations

$$\text{Depth, } d = \frac{vt}{2} = \frac{1\,500(120 \times 10^{-3})}{2} = 90 \text{ m}$$

(b)

$$v = f\lambda$$

$$1\,500 = (25 \times 10^{3})\lambda$$

$$\lambda = \frac{1\,500}{25 \times 10^{3}} = 0.06 \text{ m}$$

Formative Practice 5.3

1. Copy Figure 5.32 and draw the wavefront and the direction of the reflected water waves.

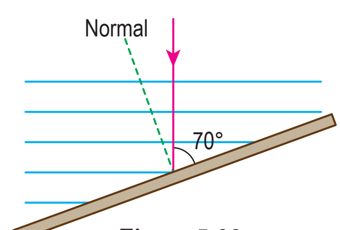


Figure 5.32

2. Figure 5.33 shows the use of ultrasonic waves by a ship to determine the depth of the sea. The interval time between transmission and receiving of echo of the ultrasonic sound is 0.06 seconds. Speed of the ultrasonic wave in the water is 1 500 m s^{-1}. Determine the depth of the sea.

Figure 5.33

5.4 Refraction of Waves

Photograph 5.10 Refraction of sea waves in Imsouane, Morocco (Source: Image ©2019 CNES/Airbus)

Photograph 5.10 shows the curving wavefront of the sea when approaching the shoreline. The curve of the wavefront is caused by a phenomenon of refraction of waves.

Refraction of waves is the change in direction of propagation of waves caused by **the change in the velocity of waves** when the waves propagate from one medium to another. What is the effect of refraction on the characteristics of waves?

SMART INFO

- Speed of water wave is influenced by depth of water.
- Speed of sound wave is influenced by density of air.
- Speed of light wave is influenced by optical density of medium.

Activity 5.12

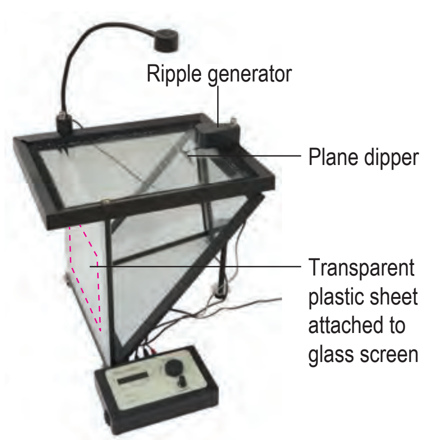
Aim: To study refraction of waves for plane waves

Apparatus: Ripple tank and its accessories, digital xenon stroboscope, plane dipper, ruler, protractor and perspex sheets

Materials: Transparent plastic sheets, marker pen, cellophane tape and distilled water

Instructions:

1. Set up the apparatus as shown in Photograph 5.11.



Photograph 5.11

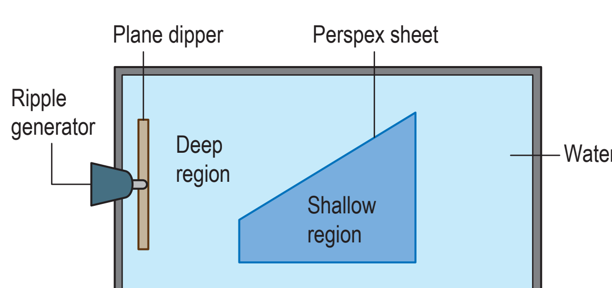


Figure 5.34

5.4.1

2. Switch on the ripple generator and adjust so that plane waves of low frequency are produced.
3. Observe the plane wavefront produced.
4. Place the perspex sheet into the water as shown in Figure 5.34 so that the wave propagates from the deep region to the shallow region of the water.
5. Observe the movement of the wavefront in the deep and shallow regions.
6. Adjust the frequency of the stroboscope to freeze the movement of the wave. Observe the pattern of the waves.
7. Use a marker pen to mark on the plastic sheet the position of:
   (a) boundary between the deep and the shallow regions
   (b) three consecutive incident wavefronts
   (c) three consecutive refracted wavefronts
8. Remove the plastic sheet and use a marker pen to draw:
   (a) boundary between the deep and the shallow regions
   (b) three incident wavefronts and refracted wavefronts
   (c) direction of propagation of incident wave and refracted wave
   (d) normal line
9. Determine the following values:
   (a) angle of incidence, i and angle of refraction, r
   (b) incident wavelength and refracted wavelength
10. Repeat steps 4 to 9 for waves that propagate from the shallow to the deep water region as in Figure 5.35.

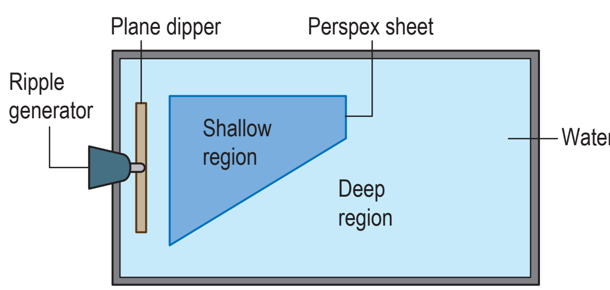


Figure 5.35

Discussion:

1. Compare angle of incidence and angle of refraction for both situations.
2. Compare incident wavelength and refracted wavelength for both situations.
3. Is the stroboscope able to freeze the movements of incident wave and refracted wave at the same time?
4. Based on your answer in question 3, compare the frequency of incident wave and the frequency of refracted wave.
5. From your answer in questions 2 and 4, compare the speed of incident wave and the speed of refracted wave.

From Activity 5.12, you will obtain the refraction of plane water wave. Figure 5.36 shows the refraction of plane water wave.

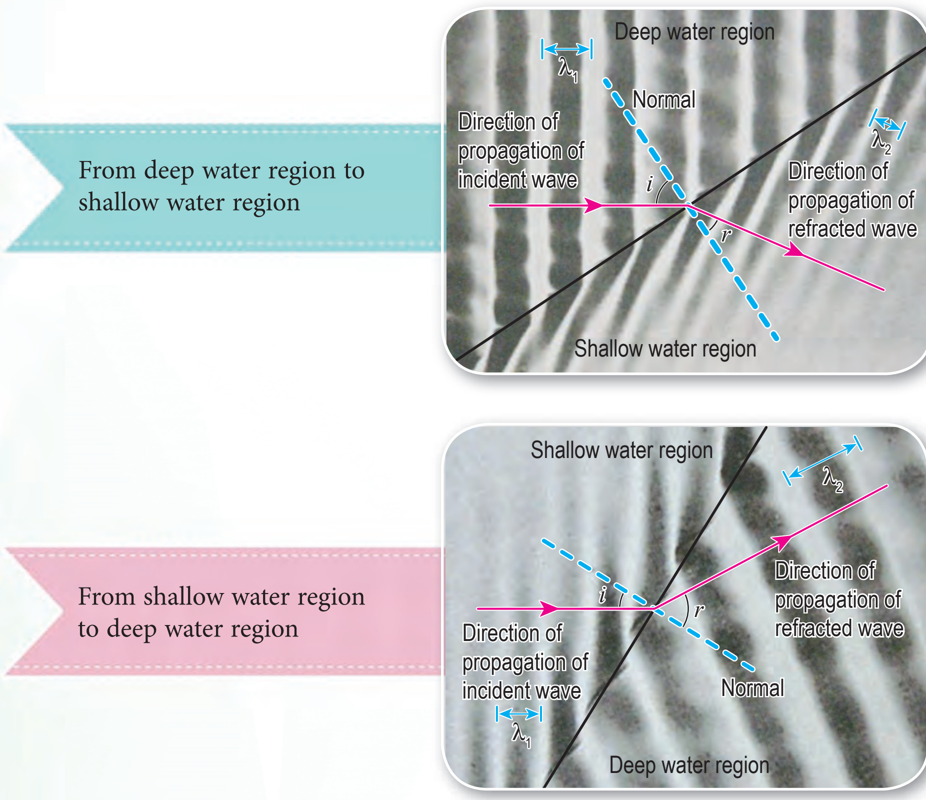


Figure 5.36 *Refraction of plane water waves*

Table 5.3 summarizes the effects of refraction on the characteristics of waves.

Table 5.3 *Effects of refraction on the characteristics of waves*

Characteristic of wave	From deep water region to shallow water region	From shallow water region to deep water region
Angle of incidence and angle of refraction	Angle of incidence > angle of refraction	Angle of incidence < angle of refraction
Wavelength	Decreasing	Increasing
Frequency	No change	No change
Wave speed	Decreasing	Increasing
Direction of propagation	Refracted towards the normal	Refracted away from the normal

Drawing Diagram of Refraction of Plane Water Waves

Figure 5.37(a) shows plane wavefronts in deep water region approaching shallow water region. Figure 5.37(b) which shows wavefronts of refracted waves can be drawn using four steps.

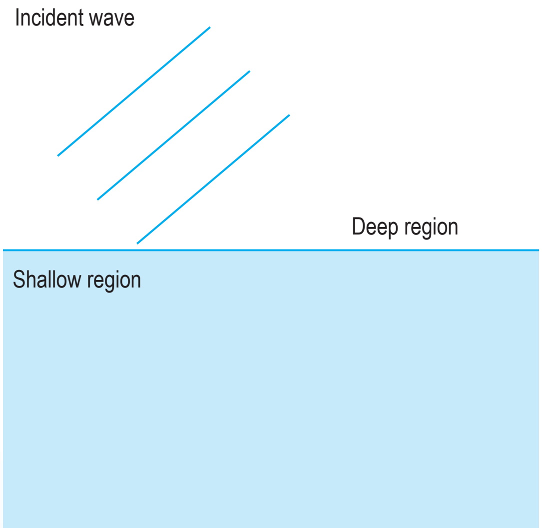


Figure 5.37(a)

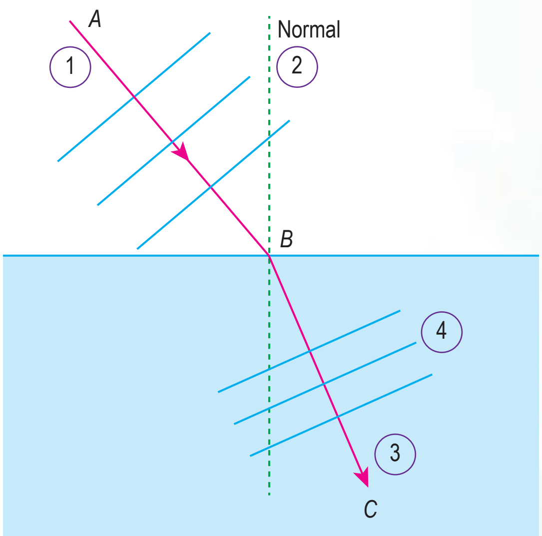


Figure 5.37(b)

The steps to draw refraction of plane water waves are as follows:

Step 1:

Draw an arrowed line *AB* perpendicular to the incident wavefront to represent direction of propagation of the incident wave.

Step 2:

Draw the normal which is perpendicular to the boundary of the deep region and shallow region at *B*.

Step 3:

Draw an arrowed line *BC*, which is nearer the normal than *AB* to represent the direction of propagation of the refracted wave.

Step 4:

Draw three lines perpendicular to *BC* to represent the refracted wavefronts. The lines have to be closer to one another compared to the incident wavefronts.

If water wave propagates from shallow region to deep region, direction of propagation of the refracted wave is bent away from the normal.

5.4.2

Activity 5.13

Aim: To discuss and draw diagrams of refraction of plane water waves that propagate at a specific angle of incidence at two different depths

Instructions:

1. Work in pairs.
2. Scan the QR code to download Figure 5.38 from the website given.

Download Figure 5.38

http://bt.sasbadi.com/p4198

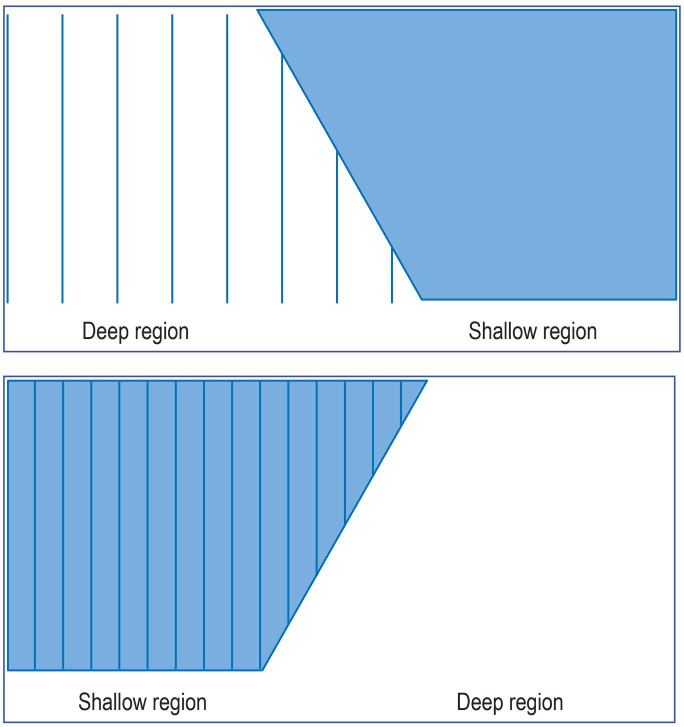


Figure 5.38

3. Discuss and complete the diagrams of refraction of water waves in Figure 5.38.

Phenomena of Refraction of Waves in Daily Life

Activity 5.14

Logical Reasoning | ISS | ICS

Aim: To discuss the natural phenomena of refraction of waves

Instructions:

1. Work in pairs.
2. Search for information on the natural phenomena of refraction of waves.
3. Present your findings in the form of an interesting multimedia presentation.

During the day, air that is closer to the surface of the earth is hotter than the air above. Sound moves faster in hot air than in cold air. As such, sound is refracted away from the ground. Thus, an observer cannot hear sound clearly during the daytime.

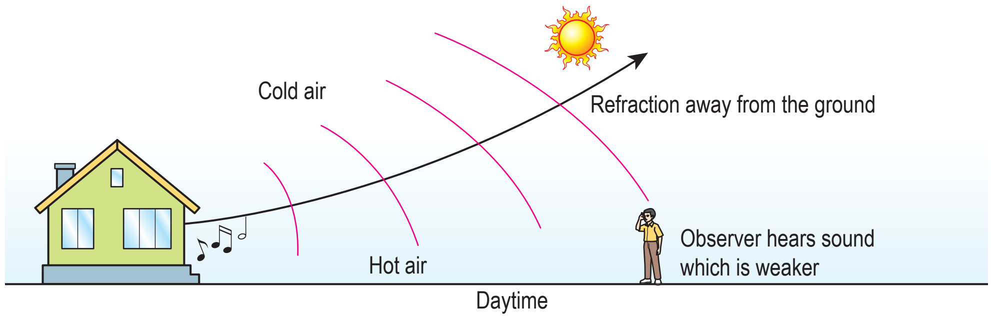


Figure 5.39 *Sound is not heard clearly during the day*

During the night, air that is closer to the surface of the earth is colder. Sound is refracted towards the ground. This causes the observer to hear sound more clearly during the night. Observe Figure 5.40.

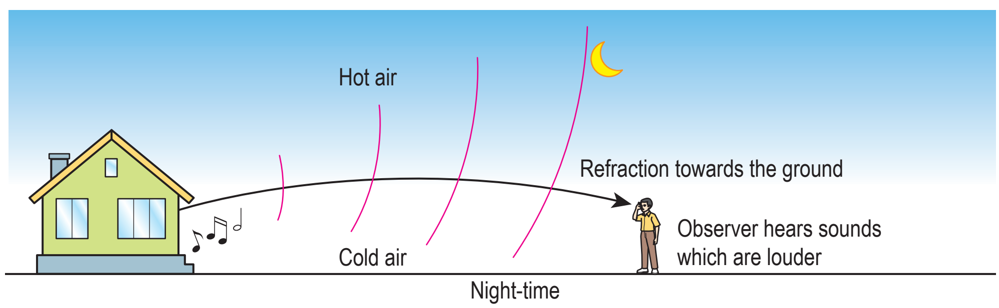


Figure 5.40 *Sound is heard more clearly during the night*

Figure 5.41 shows the phenomenon of refraction of sea waves. The cape is the shallow water region while the bay is the deep water region. Away from the shoreline, the wavefront of the water is almost straight and parallel because water waves move at a uniform speed.

When the wavefront of the water propagates to the cape, the speed of the water waves decreases causing the wavelength to be shorter. Wavefront of water approaching the bay moves at a higher speed and the wavelength is longer. This causes the wavefront to curve and follow the shape of the shoreline.

Refraction of water waves causes water wave energy to converge towards the cape. Water wave energy diverges from the bay and spread out to a wider region. Thus, the amplitude of waves at bay is smaller than at the cape.

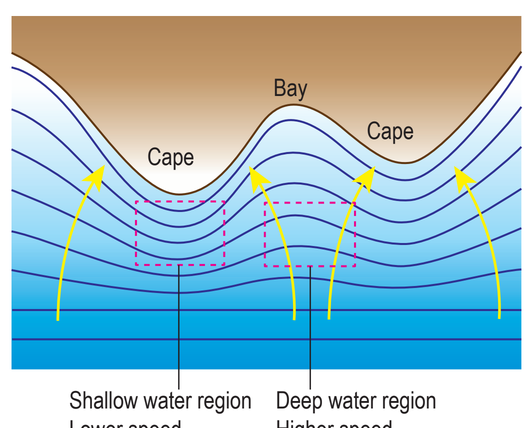


Figure 5.41 *Refraction of sea waves*

Solving Problems Involving Refraction of Waves

Refraction of waves is caused by the change in speed of waves. For water waves, speed of wave changes when the depth of water changes. This also causes wavelength to change. However, the frequency of waves does not change because wave frequency is determined by the frequency of vibrations at the source of the wave.

Figure 5.42 shows changes in speed and wavelength when water waves propagate from deep region to shallow region.

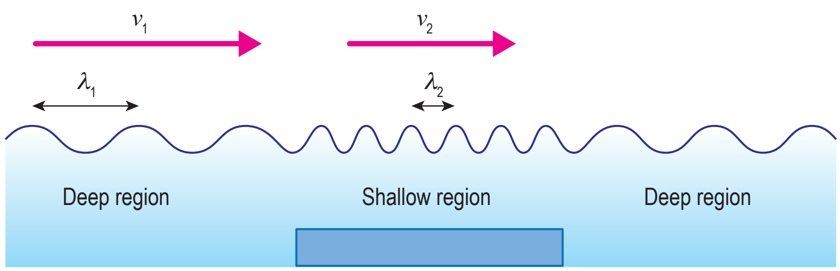


Figure 5.42 *Propagation of water waves from deep region to shallow region*

From formula of speed of wave, $v = f\lambda$,

in deep region: $v_1 = f\lambda_1$ .... (1)

in shallow region: $v_2 = f\lambda_2$ .... (2)

(1) ÷ (2) gives $\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$,

that is $\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$

Example 1

A plane wave which has a wavelength of 2 cm and speed of 8 cm s^{-1} propagates across a shallow region. When the wave enters the deep region, wave speed becomes 12 cm s^{-1}. Determine the value of the wavelength in the deep region.

Solution:

Step 1
List the given information in symbols.

Shallow region: λ_1 = 2 cm, v_1 = 8 cm s^{-1}
Deep region: v_2 = 12 cm s^{-1}, λ_2 = ?

Step 2
Identify and write down the formula used.

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

$$\frac{8}{2} = \frac{12}{\lambda_2}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$\lambda_2 = \frac{12 \times 2}{8}$$
$$= 3 \text{ cm}$$

Example 2

Figure 5.43 shows propagation of water wave from region P to region Q of different depths. Speed of the wave is 18 cm s^{-1} in region P. Determine the speed of the wave in region Q.

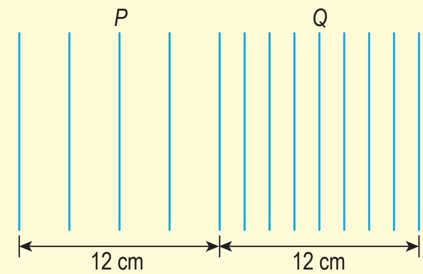


Figure 5.43

Solution:

λ in region P, $\lambda_1 = \dfrac{12}{4}$
$= 3$ cm

λ in region Q, $\lambda_2 = \dfrac{12}{8}$
$= 1.5$ cm

Region P: $\lambda_1 = 3$ cm, $v_1 = 18$ cm s^{-1}

Region Q: $\lambda_2 = 1.5$ cm, $v_2 = ?$

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

$$\frac{18}{3} = \frac{v_2}{1.5}$$

$$v_2 = \frac{18 \times 1.5}{3}$$

$$= 9 \text{ cm s}^{-1}$$

Formative Practice 5.4

1. What phenomenon of waves happens when sea waves are approaching the beach? Explain your answer with the help of a diagram.

2. Figure 5.44 shows plane water waves of frequency 10.0 Hz propagating from deep region to the boundary of shallow region PQ. Speed of the water wave in the deep region is 30 cm s^{-1}.
   (a) Calculate the wavelength, λ.
   (b) Calculate the speed of the water wave in the shallow region if the wavelength in this region is 1.5 cm.
   (c) Using arrows, draw the direction of propagation of the wave in the shallow region and then sketch the wavefronts of water waves refracted in this region.
   (d) Compare frequency, wavelength and speed in the deep and shallow regions.

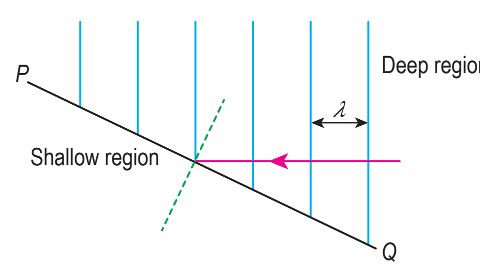


Figure 5.44

5.5 Diffraction of Waves

Photograph 5.12 shows the embankment built in Marang, Terengganu. What causes the wavefront of the seawater in region *A* and region *B* to have different shapes?

The wavefront of the seawater changes from plane wavefront in region *A* to circular wavefront in region *B*. This shows that sea waves spread out while propagating through the gap in the embankment.

Photograph 5.12 shows the phenomenon of **diffraction of waves**. Diffraction of waves can happen to water, light and sound waves.

Photograph 5.12 *Embankment at Marang, Terengganu*

(**Source:** *Image ©2019 TerraMetrics*
Image ©2019 Maxar Technologies)

Activity 5.15

Aim: To show diffraction of water, light and sound waves

A Diffraction of water waves

Apparatus: Ripple tank and its accessories, digital xenon stroboscope and barriers

Materials: Distilled water

Instructions:

1. Set up the apparatus as shown in Figure 5.45.
2. Adjust the speed of the ripple generator so that waves can be seen clearly on the screen using the stroboscope.
3. Place the barriers to form a gap with size almost similar to the wavelength of the wave produced.
4. Switch off the ripple generator and wait until the water in the ripple tank becomes calm.
5. Switch on the ripple generator again.
6. Observe the shape of the wavefront before and after passing through the gap.
7. Draw the shape of the wavefront after passing through the gap and record the characteristics of the wavefront before and after passing through the gap in Table 5.4.

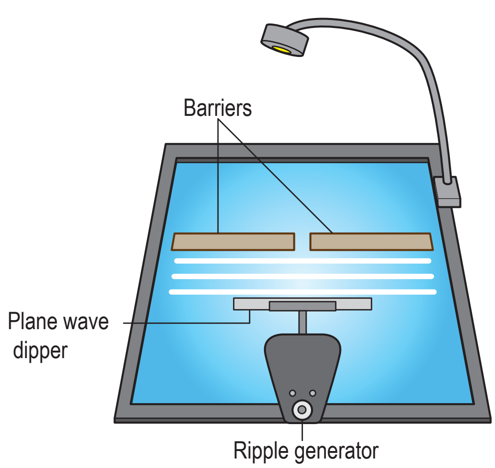


Figure 5.45

Results:

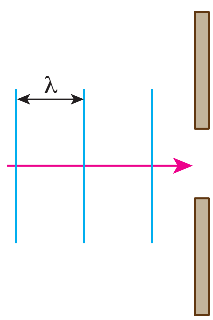


Figure 5.46

Table 5.4

Characteristic of wave	Comparison before and after the gap
Wavelength	
Frequency	
Wave speed	
Amplitude	
Direction of propagation	

Discussion:

Compare the shape of the incident wavefront with the wavefront that has passed through the gap.

B Diffraction of light waves

Apparatus: Laser pen, retort stand, single narrow slit, single wide slit, small sized pin hole, large sized pin hole and white screen

Instructions:

1. Set up the apparatus as shown in Figure 5.47. Use a single wide slit.

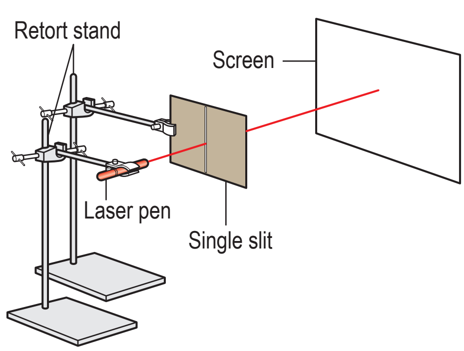
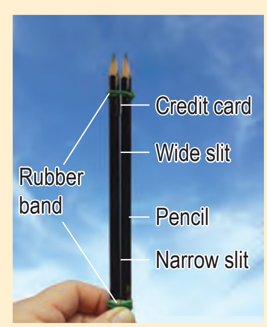


Figure 5.47

2. Direct the laser light ray through the single slit. Observe the pattern formed on the screen and draw the pattern in Table 5.5.
3. Repeat steps 1 and 2 using:
   (a) a single narrow slit
   (b) a large pin hole
   (c) a small pin hole

DIY

You can also carry out this activity using a self-made adjustable single slit as shown below.



Demonstration using self-made adjustable single slit

http://bt.sasbadi.com/p4203

Results:

Table 5.5

Wide slit	Narrow slit
Large pin hole	**Small pin hole**

Discussion:

1. What is the difference in the image formed by the single wide slit and single narrow slit?
2. Compare the image formed by the small pin hole with the large pin hole.

Sound generator application

http://bt.sasbadi.com/p4204

C Diffraction of sound waves

Apparatus: Tablet, small loudspeaker that can be connected to tablet

Instructions:

1. Set up the apparatus as shown in Figure 5.48 at a corner of a building.
2. Scan the QR code to download the sound generator application from the website given.
3. Generate a sound of frequency of 500 Hz from the application.
4. Stand at position *X* as shown in Figure 5.48 and listen to the sound from the loudspeaker.
5. Repeat step 4 by standing at position *Y*.
6. Record your observations in Table 5.6.

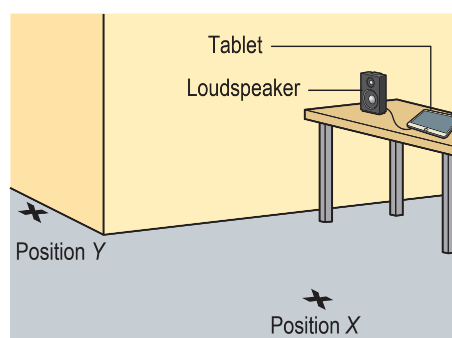


Figure 5.48

Results:

Table 5.6

Position	Sound heard
X	
Y	

Discussion:

1. Can the sound from the loudspeaker be heard at positions *X* and *Y*?
2. Explain why sound can be heard at position *Y* even though the loudspeaker cannot be seen.

Diffraction of waves is the spreading of waves when the waves propagate through a slit or side of a barrier. The effects of diffraction on the characteristics of waves are summarized in Table 5.7.

SMART INFO

The larger the amplitude, the larger the energy carried by the wave.

Table 5.7 *Effects of the diffraction on characteristics of waves*

Characteristic of wave	Change caused by diffraction	Explanation
Wavelength	No change	Wave speed does not change.
Frequency	No change	No change to source of frequency.
Speed	No change	No change in medium before and after diffraction.
Amplitude	Decreased	Wave energy diverges and spread out to a wider region
Direction of propagation	From one direction to many directions	Wavefront spreads.

The figures below show the pattern of diffraction of water, light and sound waves.

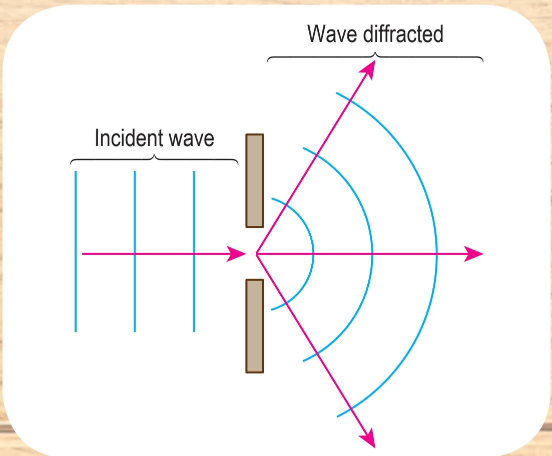


Figure 5.49 *Diffraction pattern of water wave*

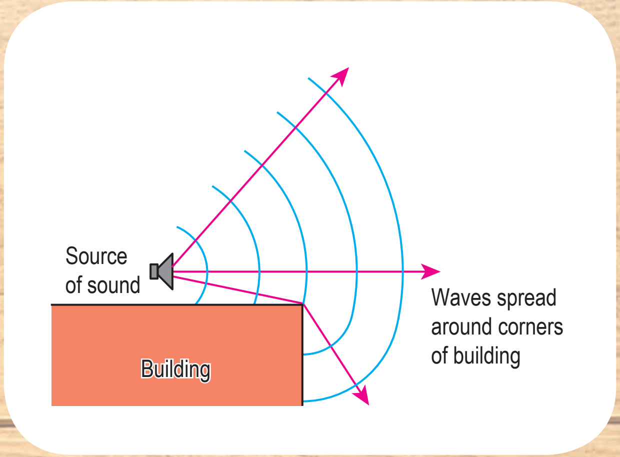


Figure 5.50 *Diffraction pattern of sound wave*

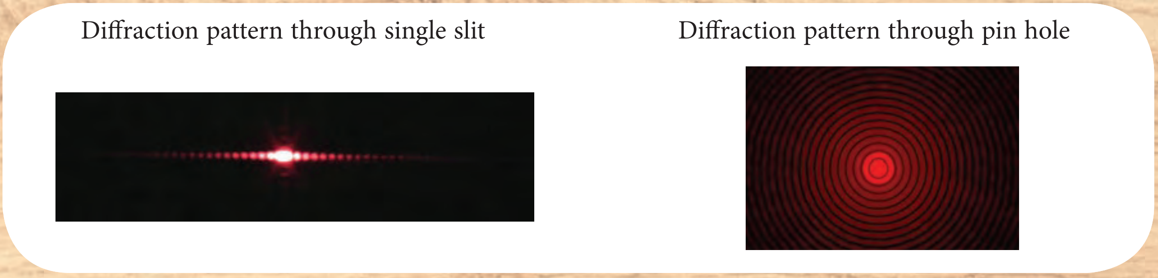


Figure 5.51 *Diffraction patterns of light waves*

5.5.1

Factors that Influence Diffraction of Waves

Activity 5.16

Aim: To study the factors which influence diffraction of water waves

Apparatus: Ripple tank and its accessories, digital xenon stroboscope and barriers

Materials: Distilled water

Instructions:

A Effect of size of slit on diffraction of water waves

1. Prepare the ripple tank and switch on the ripple generator.
2. Observe the wavelength on the glass screen.
3. Adjust the size of the slit so that it is larger than the wavelength.
4. Observe the diffracted wave and draw the pattern in Table 5.8.
5. Repeat steps 3 and 4 with a slit size that is almost the same as the wavelength.

Computer simulation of diffraction of waves

http://bt.sasbadi.com/p4206

The following simulation can only be seen using a computer *http://bt.sasbadi.com/p4206a*

B Effect of wavelength on diffraction of water waves

1. Adjust the size of the slit to about 1 cm.
2. Adjust the frequency of the ripple generator to produce a wavelength shorter than the size of the slit.
3. Observe the diffracted wave and draw the pattern in Table 5.9.
4. Repeat steps 2 and 3 using a wavelength that is almost the same as the size of the slit.

Results:

Table 5.8

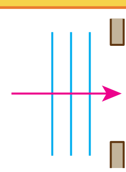
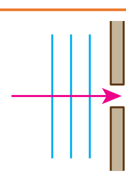
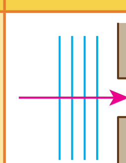
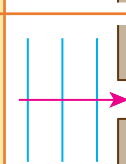
Size of slit	Pattern of diffraction
Wide slit	
Narrow slit	

Table 5.9

Wavelength	Pattern of diffraction
Short	
Long	

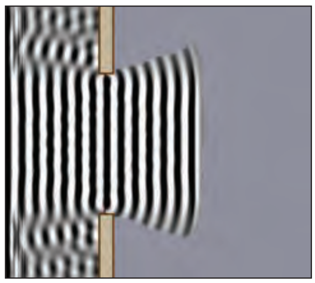
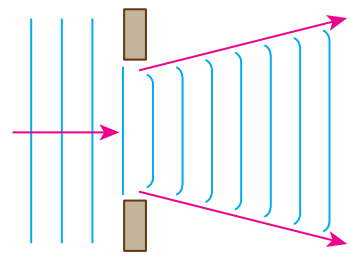
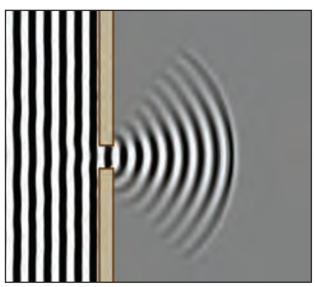
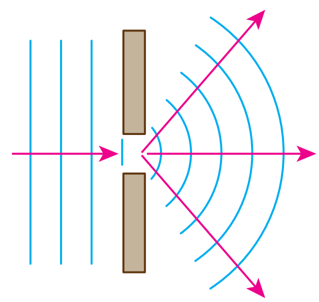
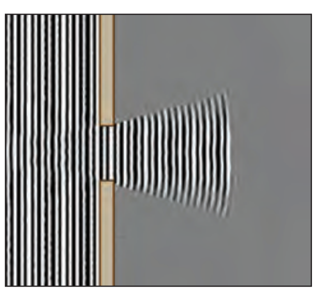
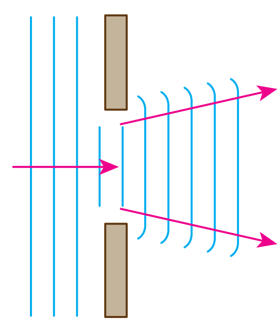
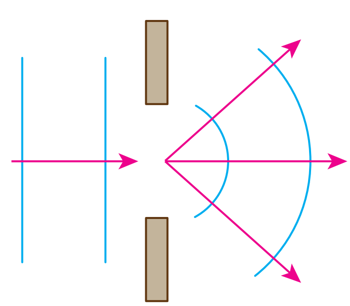
Discussion:

1. Compare the patterns of diffracted waves through a wide slit and a narrow slit.
2. Compare the patterns of diffracted waves of short and long wavelengths passing through a slit.

Patterns of Diffracted Water Waves

Table 5.10 shows the patterns of diffracted water waves in a simulated ripple tank and sketches of the wavefront. Study the effects of the size of slit and wavelength on the diffraction of water waves.

Table 5.10 *Effects of size of slit and wavelength on pattern of diffracted waves*

Factor	Pattern of diffraction	Sketch of wavefront	Notes
Wide slit			Fixed wavelength
Narrow slit			
Short wavelength			Fixed slit size
Long wavelength			

Diffraction of waves is influenced by the size of slit and wavelength. Figure 5.52 presents the effects of diffraction of waves.

Effects of diffraction of waves

- Fixed wavelength
  - Wide slit size → Spreading of waves is less significant
  - Narrow slit size → Spreading of waves is more significant
- Fixed size of slit
  - Short wavelength → Spreading of waves is less significant
  - Long wavelength → Spreading of waves is more significant

Figure 5.52 *Factors which influence diffraction of waves and their effects*

Diffraction of Waves in Daily Life

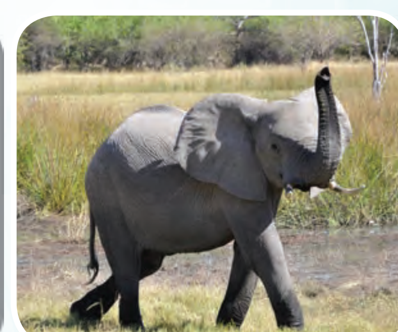
Figure 5.53 provides examples of diffraction of water, light and sound waves.

Diffractions of Waves

Water waves	Light waves	Sound waves
Diffraction of water waves produces calm of water regions suitable for docking of ships and water recreational activities.	Holograms produced by effects of diffraction of light are used as safety features on bank cards such as debit cards and credit cards	Infrasonic waves produced by elephants have long wavelength to facilitate long distance communication between elephants.

Kok Beach in Langkawi

Hologram on a bank card



Elephant producing infrasonic waves

Figure 5.53 *Diffraction of water, light and sound waves*

Activity 5.17

ISS ICS

Aim: To gather information on applications of diffraction of water, light and sound waves in daily life

Instructions:

1. Work in groups.
2. Surf websites to search for information on the applications of diffraction of water, light and sound waves in daily life that benefit mankind.
3. Present your findings in the form of an interesting multimedia presentation.

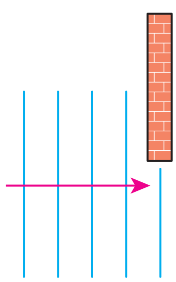
Diffraction of waves

http://bt.sasbadi.com/p4209

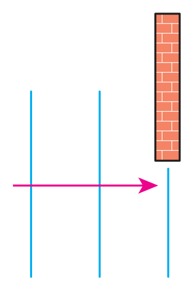
Formative Practice 5.5

1. Complete the following diagrams by drawing the patterns of diffracted waves.

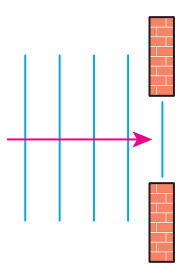
(a)



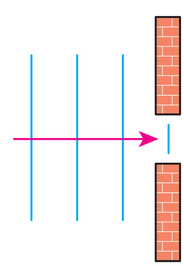
(b)



(c)



(d)



2. Figure 5.54 shows a plan of the living room and bedroom. A child lying on the bed cannot see the television in the living room but can still hear the sound from the television.
   (a) By drawing wavefronts, explain how the phenomenon of diffraction enables the child to hear sound from the television.
   (b) State another phenomenon which causes sound to propagate from the television to the child.

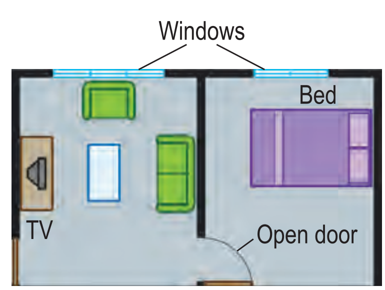


Figure 5.54

5.6 Interference of Waves

Principle of Superposition of Waves

DIY

Try to vibrate two small balls such as tennis balls on the surface of water. Can you see the pattern produced when the two waves overlap?

Photograph 5.13 *Superposition of two circular waves*

Photograph 5.13 shows two circular waves on the surface of water are in superposition. What happens when the two waves are in superposition?

Activity 5.18

ICS

Aim: To study superposition of waves using computer simulation

Instructions:

1. Work in pairs.
2. Scan the first QR code given to read about wave interference.
3. Scan the second QR code to carry out simulation to superposition as follows:
   (a) crest and crest with the same displacement
   (b) trough and trough with the same displacement
   (c) crest and trough with the same displacement
4. Draw the wave profiles before, during and after superposition for each simulation in step 3.
5. Record your observations in the form of a tree map.

Computer simulation of superposition of waves

http://bt.sasbadi.com/p4210a

http://bt.sasbadi.com/p4210b

Discussion:

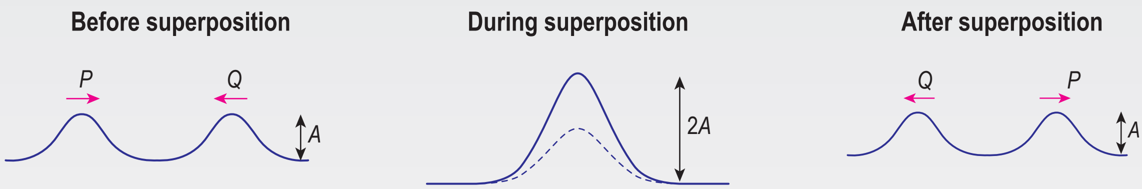
1. Which superposition produces a larger displacement?
2. Which superposition produces zero displacement?

The **principle of superposition** states that when two waves overlap, the resultant displacement is the sum of the individual displacements of the two waves.

Interference with Coherent Source of Waves

Interference of waves is the superposition of two or more waves from a **coherent** source of waves. Two sources of waves are coherent when the **frequency of both waves is the same** and the **phase difference is constant**. Superposition of waves produces constructive interference and destructive interference.

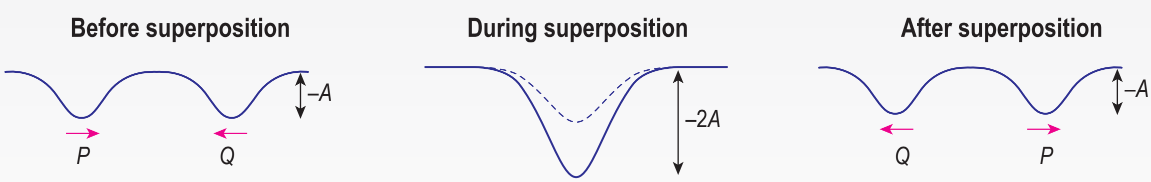
Constructive interference occurs when two **crests** are in superposition.



Combined displacement = $A + A = 2A$

Figure 5.55 *Constructive interference between two crests*

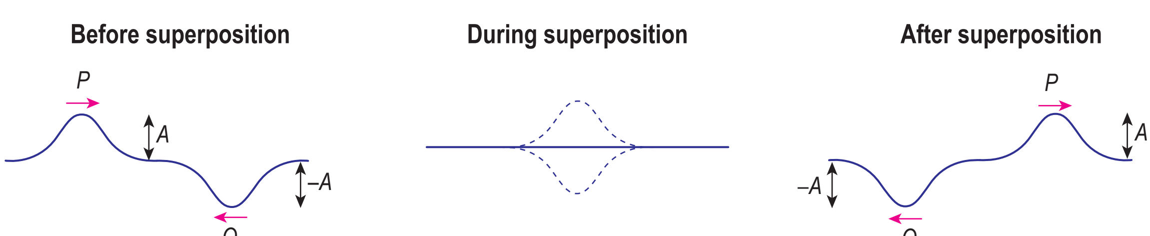
Constructive interference also occurs when two **troughs** are in superposition.



Combined displacement = $(-A) + (-A) = -2A$

Figure 5.56 *Constructive interference between two troughs*

Destructive interference occurs when a **crest** and a **trough** are in superposition to produce zero combined displacement.



Combined displacement = $A + (-A) = 0$

Figure 5.57 *Destructive interference between a crest and a trough*

5.6.1

Activity 5.19

Aim: To show interference with two coherent sources of waves

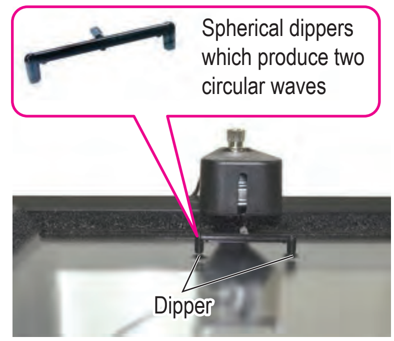
A Pattern of interference for water waves

Apparatus: Ripple tank and its accessories and digital xenon stroboscope

Materials: Distilled water

Instructions:

1. Prepare the ripple tank and attach a pair of spherical dippers as in Photograph 5.14.
2. Adjust the frequency of the ripple generator so that a clear pattern can be seen on the glass screen.
3. Observe the pattern of interference formed on the screen.
4. Repeat steps 1 and 2 using two spherical dippers which have a smaller gap between the two dippers. Observe the change in the interference pattern.
5. Adjust the ripple generator to obtain a lower wave frequency. Observe the change in the interference pattern.



Photograph 5.14

Discussion:

1. Why must the base of the ripple tank be on a horizontal plane?
2. What causes the formation of bright and dark regions in the interference pattern?
3. Suggest an alternative way to produce two coherent circular water waves.

B Pattern of interference for light waves

Apparatus: Laser pen, retort stand, two pieces of double-slit with different distance of separation and white screen

Instructions:

1. Set up the apparatus as shown in Figure 5.58.
2. Direct the laser light ray through the double-slit. Observe the pattern formed on the screen.
3. Repeat step 2 with a double-slit with a larger distance of separation between the slits.

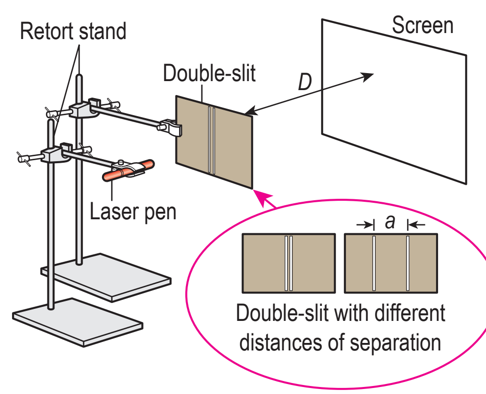


Figure 5.58

Discussion:

1. What phenomenon occurs when light passes through each slit?
2. What pattern is formed on the screen when two light rays superpose after passing through the double-slit?
3. Explain the formation of dark fringes in the interference pattern.

5.6.1

C Pattern of interference for sound waves

Apparatus: Audio generator, two identical loudspeakers, metre rule, microphone and cathode ray oscilloscope (C.R.O)

Instructions:

1. Set up the apparatus as shown in Figure 5.59. Two loudspeakers are placed 1.0 m apart from each other.

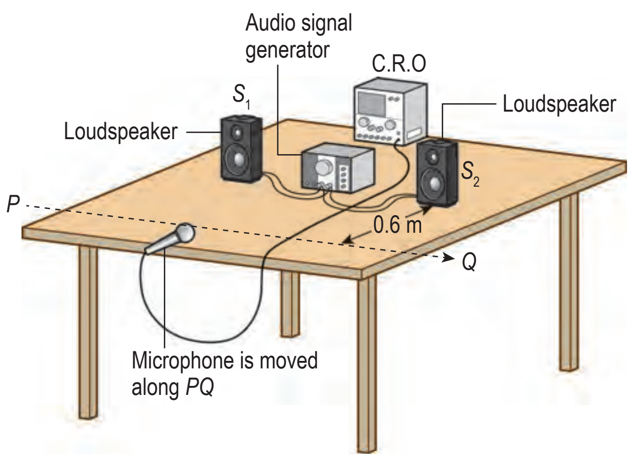
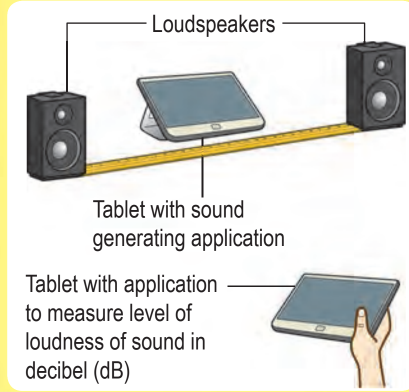


Figure 5.59

You can also use 2 tablets for this activity with the following apparatus setup:



2. Adjust the audio generator to a frequency of 1 000 Hz.
3. Switch on the audio generator. Adjust the C.R.O. until a clear waveform is displayed on the screen.
4. Move the microphone slowly along the straight line *PQ* which is at a perpendicular distance of 0.6 m from the loudspeakers.
5. Observe the waveform on the C.R.O. screen when loud sound and soft sounds are detected.
6. Repeat steps 4 and 5 with the loudspeakers placed 0.5 m apart.

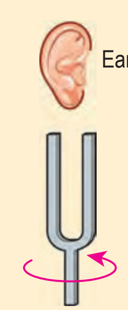
Discussion:

1. Why do the two loudspeakers need to be connected to the same audio generator?
2. Relate the waveform displayed on the C.R.O. screen with the sound heard when you walk in front of the loudspeakers.

DIY

Interference of sound waves using tuning fork

Tuning fork is struck and then rotated slowly near the ear.



In Activity 5.19, can you identify the constructive and destructive interferences for water, light and sound waves?

Interference of water waves

Figure 5.60 shows the pattern of interference of water waves produced by two coherent sources S_1 and S_2 in a ripple tank.

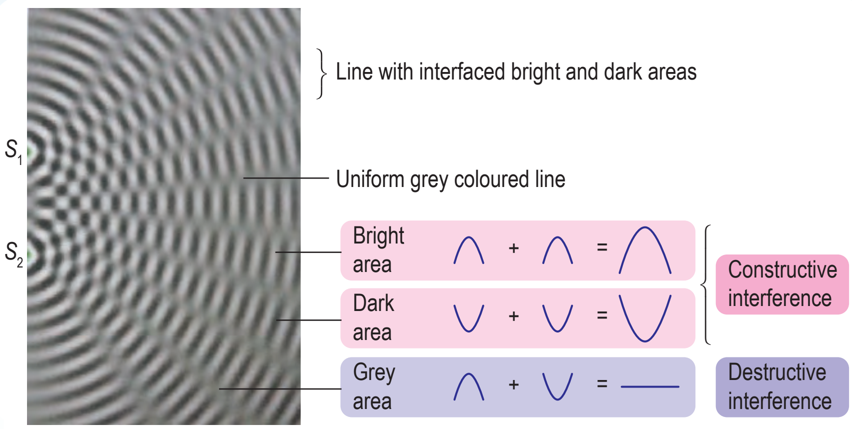


Figure 5.60 *Interference pattern for water waves*

Interference of light waves

Figure 5.61 shows the interference pattern formed on the screen with light from a laser pen. Diffracted light waves that appear from the double-slit are coherent. Superposition of waves from the double-slit produces a pattern made up of bright fringes and dark fringes. Constructive interference produces bright fringes while destructive interference produces dark fringes.

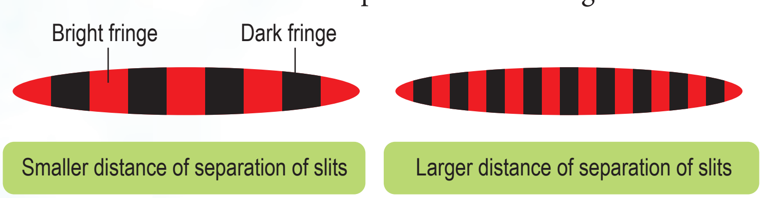


Figure 5.61 *Interference pattern for light waves*

INTEGRATION OF HISTORY

Activity on interference of light waves is also known as Young's double-slit experiment after the name of a physicist, Thomas Young. He successfully showed that light has wave characteristics through experiments which produce bright and dark fringes.

Interference of sound waves

Sound waves cannot be seen. Observer can only hear loud sounds in constructive interference regions and soft sound in destructive interference regions. Figure 5.62 shows a waveform displayed on a C.R.O. screen.

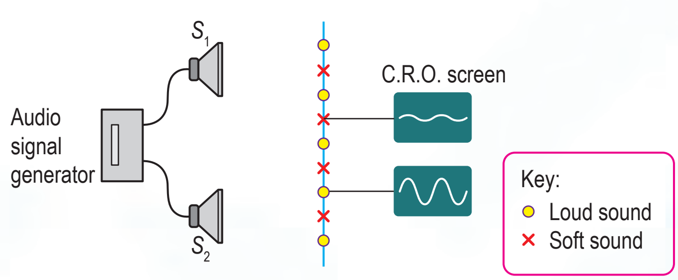


Figure 5.62 *Pattern of interference for sound waves*

Drawing Patterns of Wave Interference

Interference of water, light and sound waves can be analysed by drawing their patterns of interference as shown in Figure 5.63. Points P and Q are antinodes, the points where constructive interference occurs. Point R is a node, the point where destructive interference occurs.

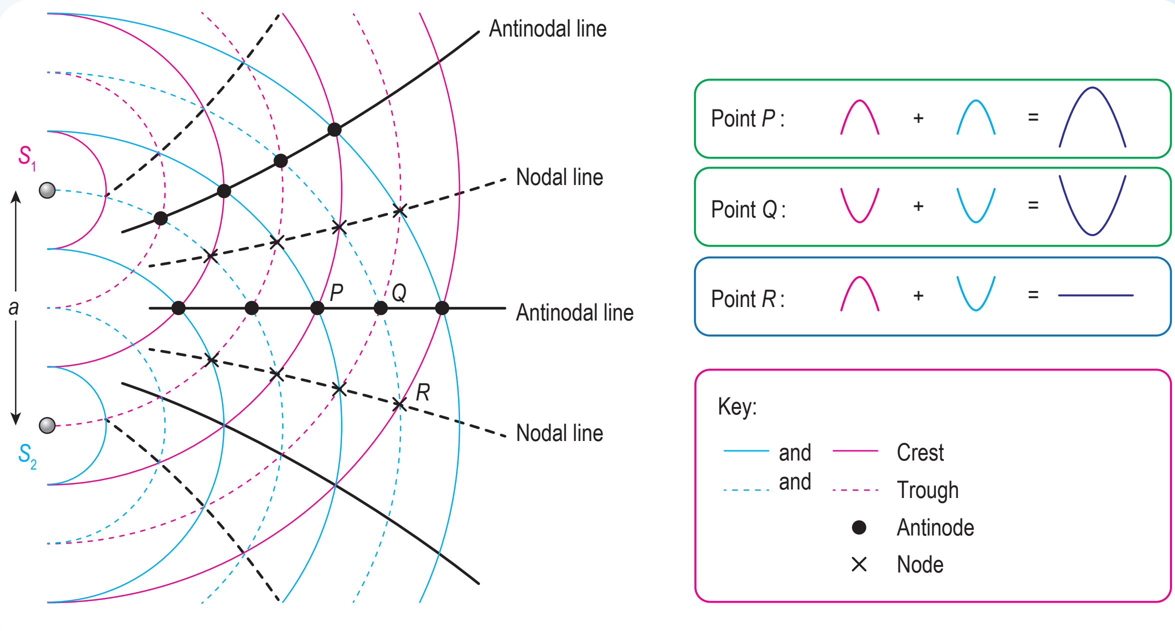


Figure 5.63 Interference pattern of waves

Activity 5.20

Aim: To draw pattern of interference of waves

Materials: A4 size white paper, compass, colour pencil and ruler

Instructions:

1. Work in groups.
2. Draw the pattern of interference A as shown in Figure 5.63.
   Use the following measurements:
   (a) Distance between coherent sources, a = 4 cm.
   (b) Wavefronts of radii 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 6 cm and 7 cm.
3. On the diagram that you have drawn in step 2:
   (a) Mark all the antinodes and nodes
   (b) Draw three antinodal lines and two nodal lines
4. Draw the pattern of interference B with the following measurements:
   (a) Distance between coherent sources, a = 6 cm.
   (b) Wavefronts of radii 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 6 cm and 7 cm.
5. Draw the pattern of interference C with the following measurements:
   (a) Distance between coherent sources, a = 4 cm.
   (b) Wavefronts of radii 1.5 cm, 3.0 cm, 4.5 cm, 6.0 cm and 7.5 cm.

6. On the diagrams that you have drawn in steps 4 and 5, draw three antinodal lines and two nodal lines.

Discussion:

1. Based on the patterns of interference *A* and *B*, describe the difference in the pattern of interference when the distance of separation between sources increases.
2. Based on the patterns of interference *A* and *C*, describe the difference in the pattern of interference when wavelength increases.
3. How does the distance between antinodal lines change at positions further from the coherent sources?

Relationship between Variables of Interference of Waves

In the pattern of interference of waves, there are four variables namely λ, a, x and D which are related to the interference pattern of waves.

λ = wavelength
a = distance of separation between two coherent sources
x = distance of separation between two adjacent antinodal lines or two adjacent nodal lines
D = the perpendicular distance from the sources and the position where the value of x is measured

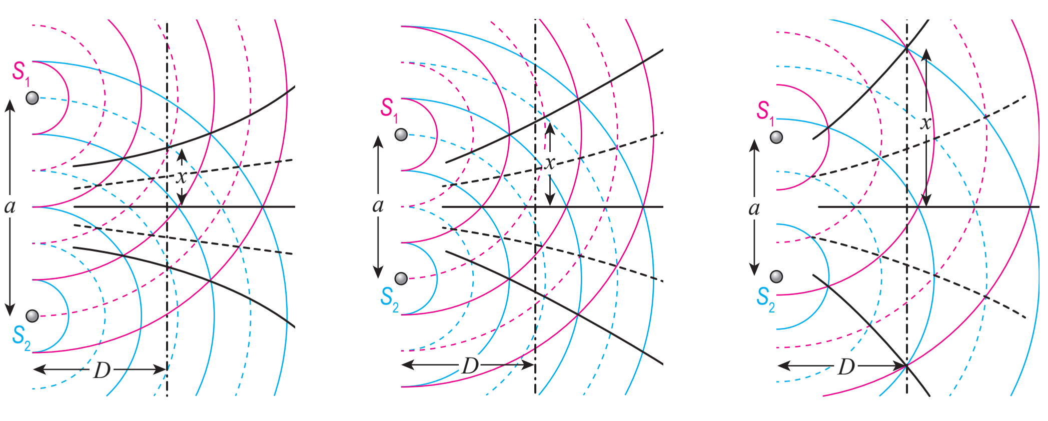
Activity 5.21

Algorithms ICS

Aim: To study the relationship between λ, a, x and D

Instructions:

1. Work in pairs.
2. You are given three patterns of interference of waves in Figure 5.64.



Pattern 1 Pattern 2 Pattern 3

Figure 5.64 *Pattern of interference of waves*

5.6.2 5.6.3

3. From Pattern 1 and Pattern 2:
   (a) Determine the constant variable.
   (b) What is the relationship between x and a?
4. From Pattern 2 and Pattern 3:
   (a) Determine the constant variable.
   (b) Compare the wavelength, λ.
   (c) What is the relationship between x and λ?
5. From Pattern 3, determine the relationship between x and D.

In the pattern of interference of water, sound and light waves, variables λ, a, x and D are mutually dependent on one another. Through Activity 5.21, we can interrelate the four variables as $x = \frac{\lambda D}{a}$. From the formula, we can determine the wavelength, λ as follows:

$$\lambda = \frac{ax}{D}$$

Solving Problems Involving Interference of Waves

Example 1

Figure 5.65 shows Young's double-slit experiment which produces interference pattern on the screen. The distance between adjacent bright fringes is 4.5 mm. What is the wavelength of the light used?

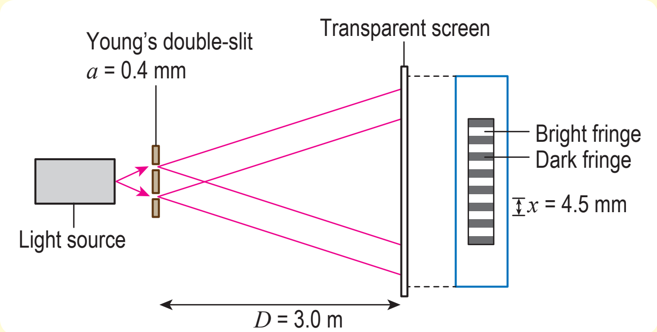


***Figure 5.65** Young's double-slit experiment*

Solution:

Separation of slit, $a = 0.4$ mm
$= 0.4 \times 10^{-3}$ m

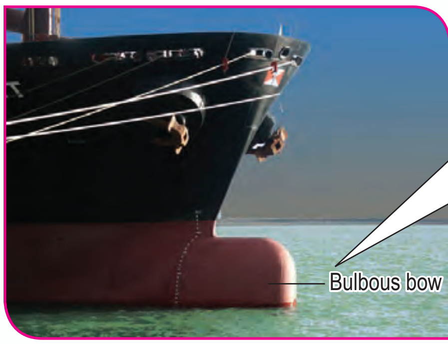
Distance between adjacent bright fringes, $x = 4.5$ mm
$= 4.5 \times 10^{-3}$ m

Distance between screen and double slit, $D = 3.0$ m

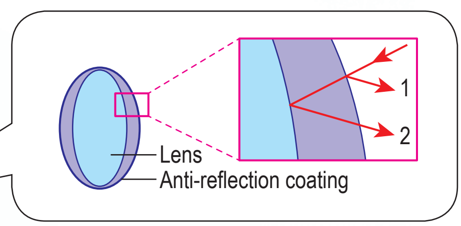
$$\text{Wavelength, } \lambda = \frac{ax}{D} = \frac{(0.4 \times 10^{-3})(4.5 \times 10^{-3})}{3.0} = 6.0 \times 10^{-7} \text{ m}$$

Applications of Interference of Waves in Daily Life

Knowledge on interference of waves is widely used in our daily life. Figure 5.66 shows examples of applications of interference of water, light and sound waves.



Bulbous bow generates water waves which interfere destructively with the water waves around the hull. This causes the water around the ship to become calmer and thus, reduces water drag.



Coating on the surface of anti-reflection lens causes reflected light to interfere destructively. This helps to improve vision.

Microphone and transmitter system in head phones used on aeroplanes produces sound waves which interfere destructively with the surrounding noise.

Figure 5.66 *Applications of interference of waves in daily life*

Activity 5.22

ICS ISS

Aim: To search for information related to application of interference of waves in daily life

Instructions:

1. Work in groups.
2. Surf the Internet to search for information related to applications of interference of waves in daily life.
3. Present your findings in the form of an interesting multimedia presentation.

Formative Practice 5.6

1. Figure 5.67 shows Young's double-slit experiment.

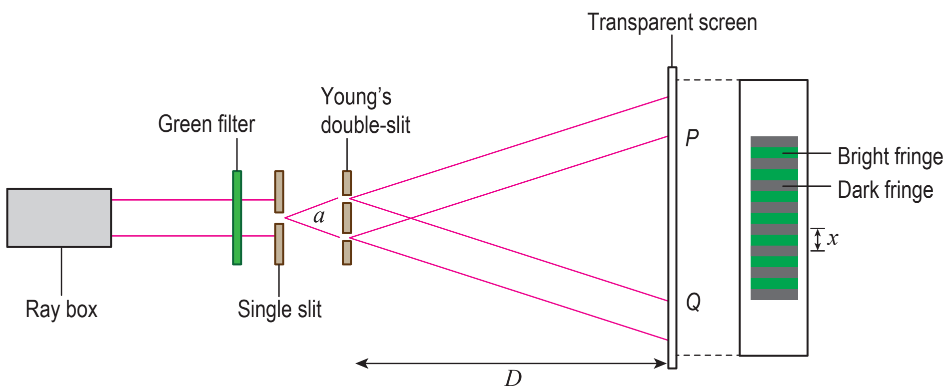


Figure 5.67

(a) State the phenomenon that occurs when light passes through the single slit.

(b) What will happen to the two light rays in the area *PQ* on the screen?

(c) Describe the formation of bright fringes and dark fringes.

(d) In the apparatus set up of this experiment, a = 0.30 mm, D = 2.5 m and x = 4.6 mm. Calculate the wavelength, λ of the green light.

5.7 Electromagnetic Waves

Characteristics of Electromagnetic Waves

Figure 5.68 shows briefly the history of early scientific discoveries which brought about the present knowledge regarding electromagnetic waves.

1801

Thomas Young showed that light is a wave through experiments on interference of light.

1862

James Maxwell put forth the theory that light is an electromagnetic wave.

1887

Heinrich Hertz generated a different kind of electromagnetic wave, that is radio wave.

Early 20th century

Electromagnetic waves are made up of:

1. Gamma ray
2. X-ray
3. Ultraviolet ray
4. Visible light
5. Infrared ray
6. Microwave
7. Radio wave

Figure 5.68 *History of electromagnetic waves*

Electromagnetic waves are made up of an electric field and a magnetic field that oscillate perpendicularly to one another, as shown in Figure 5.69. What are the characteristics of electromagnetic waves?

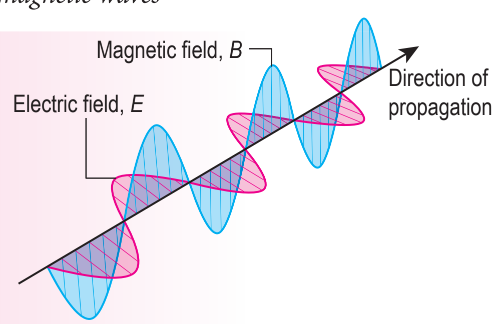


Figure 5.69 *Electromagnetic waves*

Activity 5.23

ICS

Aim: To search for information related to the characteristics of electromagnetic waves

Instructions:

1. Work in groups.
2. Search for information related to the characteristics of electromagnetic waves for the following aspects:
   (a) types of waves
   (b) requirement of medium for propagation
   (c) speed in vacuum
   (d) speed in medium
   (e) wave phenomena
3. Present your findings using a suitable mind map and put up on a notice board for information sharing.

5.7.1

Electromagnetic waves:
- are transverse waves
- do not need medium for propagation
- can propagate through vacuum
- have speed in vacuum, $c = 3.00 \times 10^8$ m s^{-1}, and move with lower speed in any medium.
- show phenomena of reflection, refraction, diffraction and interference under suitable conditions

Info File
- For electromagnetic waves, the formula $v = f\lambda$ is rewritten as $c = f\lambda$.
- Continuous spectrum means no specific boundary which separates two adjacent types of waves.

Electromagnetic Spectrum

Seven types of electromagnetic waves form a continuous spectrum known as electromagnetic spectrum. Figure 5.70 shows the electromagnetic spectrum.

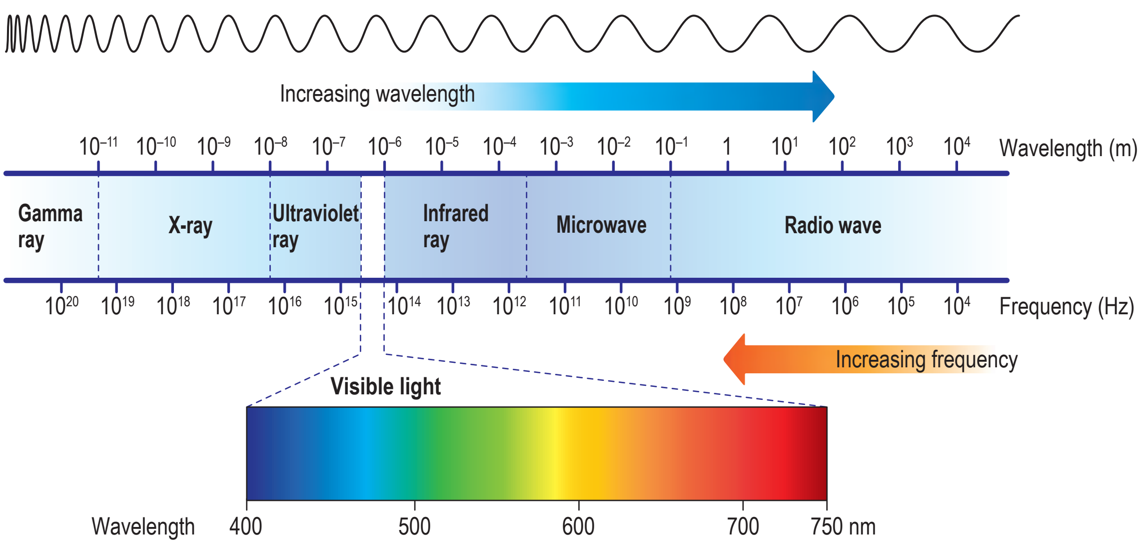


***Figure 5.70** Electromagnetic spectrum*

The energy carried by electromagnetic waves is directly proportional to its frequency. This means gamma ray and X-ray carry large amount of energy. These waves need to be handled properly as not to endanger the users.

DIY

Smartphone as a remote control device

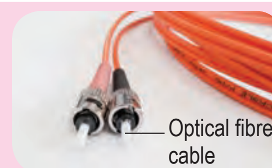
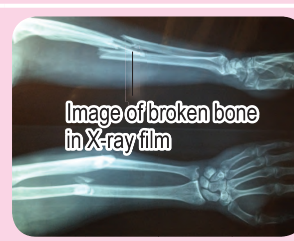
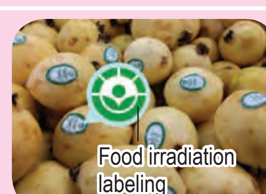
Surf the Internet to get guidelines on how to configure smartphones to function as television or air conditioner remote control.

Applications of Electromagnetic Waves

Electromagnetic spectrum is made up of seven types of electromagnetic waves and covers a very wide range of wavelengths. As such, applications of electromagnetic waves encompass various fields. With the rapid advancements in science and technology, new applications are discovered from time to time. What applications of electromagnetic waves do you know?

5.7.1 5.7.2 5.7.3

Table 5.11 Application for each type of electromagnetic wave in daily life

Type of wave	Application
Radio wave	• Long distance radio communication • Local radio and TV broadcasting • Wireless communication (*Bluetooth, Wifi, Zigbee and Z-Wave*) • Millimeter-wave machine to scan body of passengers at airport 
Microwave	• International communication through use of satellite • Mobile phone framework • Communication between electronic devices: *Wifi, Bluetooth, Zigbee, Z-Wave* • Detection of plane radar and speed trap • Cooking using microwave oven 
Infrared ray	• For cooking (oven, grill and toaster) • For night vision (infrared camera and infrared binoculars) • Drying paint on car • Treatment of muscle pain • Remote control device for television and DVD player 
Visible light	• Enables living things to see • Photography • Photosynthesis in green plants • Laser light used in cutting of metal, measurement of land and sending of information through optical fibres 
Ultraviolet ray	• Hardens tooth filling material • Determines authenticity of currency notes • Treatment of jaundice in babies • Purification of drinking water • Sterilising surgical instruments and food • Insect traps 
X-ray	• Detects fractures or broken bones and examines internal organs • Checking of welding connections • Baggage scanning at airport • Determines authenticity of paintings 
Gamma ray	• Kills cancer cells in radiotherapy • Sterilisation of surgical and medical equipment in bulk • Used in food processing industry so that food can last longer 

5.7.3

Activity 5.24

Evaluation | CPS | ICS | STEM

Aim: To gather information regarding application of each component of the electromagnetic spectrum in daily life to raise awareness through STEM approach

Instructions:

1. Work in groups.
2. By referring to Table 5.11 on page 222, gather more detailed information regarding applications of electromagnetic waves.
3. Choose the electromagnetic wave that is used widely by each group of society and gather the following information:
   (a) factors that cause over-exposure to the electromagnetic wave that you have chosen
   (b) potential harmful effects to users due to exposure to the electromagnetic wave
   (c) steps to be taken to reduce exposure to the electromagnetic wave
4. Discuss information that is needed and complete the K-W-L Chart.
5. Present the information in the forms of a printed and an electronic pamphlets.
6. Get feedback from friends and teachers regarding the pamphlet prepared. Then, improve the pamphlet before distribution.

Download K-W-L Chart

http://bt.sasbadi.com/p4223

Formative Practice 5.7

1. Figure 5.71 shows an electromagnetic spectrum.

A	X-ray	*B*	Visible light	Infrared ray	*C*	Radio wave

Figure 5.71

What are waves *A*, *B* and *C*?

2. Arrange the electromagnetic waves below according to the order of increasing frequency.

Infrared ray | X-ray | Microwave | Gamma ray | Radio wave

3. In the air, blue light with a wavelength of 420 nm moves at a speed of 3.00×10^8 m s^{-1}. The speed of the blue light reduces to 2.25×10^8 m s^{-1} when passing through a liquid. What is the wavelength of the blue light in the liquid?

5.7.3

Conceptual Framework

Waves

- Fundamentals of waves
  - Types of waves
    - Progressive wave
    - Stationary wave
    - Transverse wave
    - Longitudinal wave
    - Mechanical wave
    - Electromagnetic wave
    - Characteristics of waves
      - Amplitude
      - Period
      - Frequency
      - Wavelength
      - Wave speed
    - Graph of waves
      - Graph of displacement-time
      - Graph of displacement-distance
- Damping and resonance
  - Natural frequency
    - Damping
      - External damping
      - Internal damping
    - Resonance
- Reflection of waves
- Refraction of waves
- Diffraction of waves
  - Wavelength factor
  - Slit size factor
  - Applications of diffraction
    - Water wave
    - Light
    - Sound
- Interference of waves
  - Coherent sources
    - Principle of superposition
      - Constructive interference
      - Destructive interference
      - Formula $\lambda = \frac{ax}{D}$
- Electromagnetic waves
  - Characteristics of electromagnetic waves
    - Components
      - Gamma ray
      - X-ray
      - Ultraviolet ray
      - Visible light
      - Infrared ray
      - Microwave
      - Radio wave

Interactive QUIZ

http://bt.sasbadi.com/p4224

SELF-REFLECTION

1. New things I learnt in the chapter on waves are ________.
2. The most interesting thing I learnt in the chapter on waves is ________.
3. Things I still do not fully understand or comprehend are ________.
4. My performance in this chapter,

   Poor 1 2 3 4 5 Excellent

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

Download and print Self-reflection Chapter 5

http://bt.sasbadi.com/p4225

Performance Evaluation

1. Figure 1 shows a port and the area around it.
   (a) State the wave phenomena that occur when sea waves
      (i) collide with the embankment of the port at *A*,
      (ii) move towards the beach at *B*, and
      (iii) pass through the entrance of the port at *C*.
   (b) Draw the wavefronts after the waves pass *C*.
   (c) What is the effect on the waves if the entrance of the port is widened?

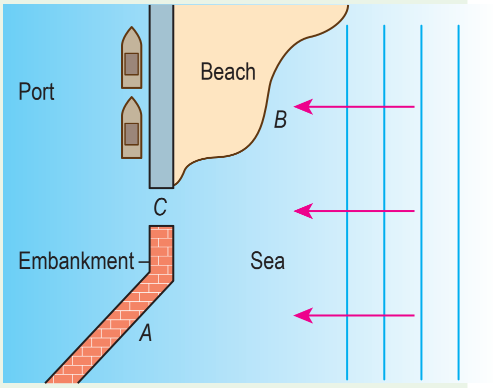


Figure 1

2. Figure 2 shows the wavefront of water waves approaching a barrier. Complete Figure 2 by sketching the wavefront after passing around the barrier.

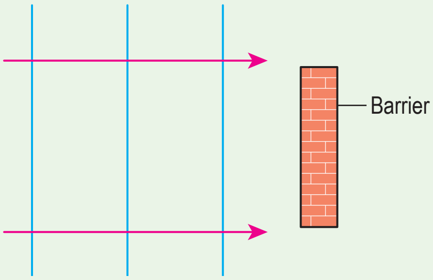


Figure 2

3. Figure 3 shows superposition of two coherent plane waves.

(a) What is a coherent wave?

(b) State the points where the following occur

(i) constructive interference,

(ii) destructive interference.

(c) Explain with suitable diagrams, interference at point

(i) *Q*,

(ii) *R*, and

(iii) *S*.

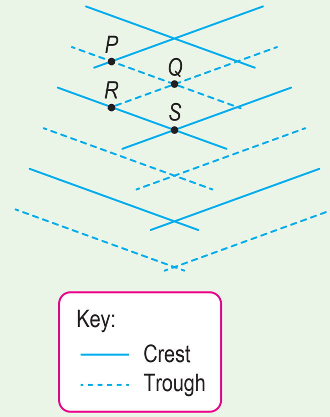


Figure 3

4. Figure 4 shows the apparatus set up of Young's double-slit experiment.

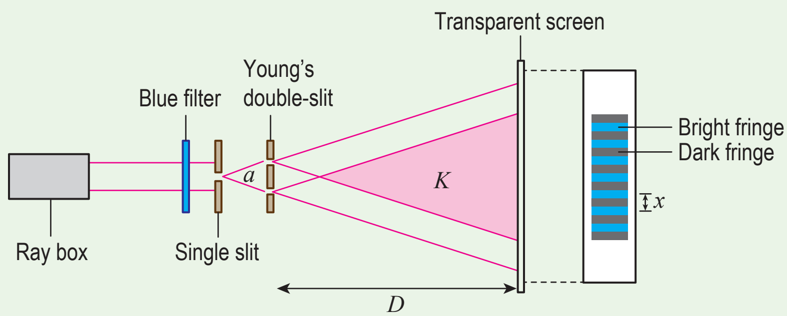


Figure 4

(a) What happens to the light rays at area *K*?

(b) Explain the formation of bright fringes and dark fringes on the screen.

(c) You are given the following information:

- Distance between double slits, $a = 0.30$ mm
- Distance between double-slits and screen, $D = 2.70$ m
- Separation distance between two adjacent bright fringes, $x = 4.0$ mm

Calculate the wavelength, λ of blue light in this experiment.

5. A student moves a slinky spring repeatedly at a frequency of 5 Hz so that a transverse wave is produced as shown in Figure 5.

(a) Determine the amplitude, period and wavelength of the wave.

(b) Calculate the wave speed along the slinky spring.

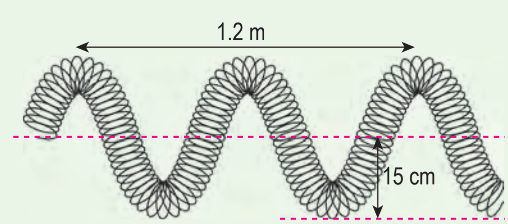


Figure 5

6. A judge blew a whistle which produced a sound of frequency 500 Hz and a wavelength of 0.67 m in the air. What is the wave speed of the sound?

7. Figure 6 shows a tuning fork vibrating and producing sound waves.

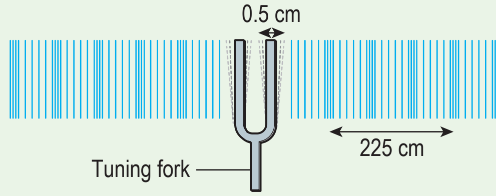


Figure 6

Based on Figure 6, determine the
(a) amplitude of the sound waves,
(b) wavelength of the sound waves,
(c) speed of the sound waves produced when the tuning fork vibrates with a frequency of 440 Hz.

8. Figure 7 shows an image of water waves moving from a deep water region to a shallow water region.

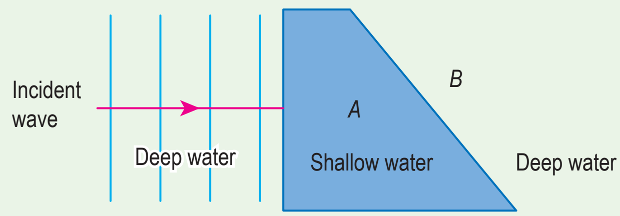


Figure 7

(a) In Figure 7, draw the pattern of wavefront in region *A* and region *B*.
(b) Given that the speed of water waves in the shallow water region and deep water region are 4.0 m s^{-1} and 9.0 m s^{-1} respectively. Wavelength of water waves in the shallow water region is 2 m. Calculate the wavelength of water waves in the deep water region.

9. Figure 8 shows the graph of displacement against time which represents the oscillation of a pendulum.

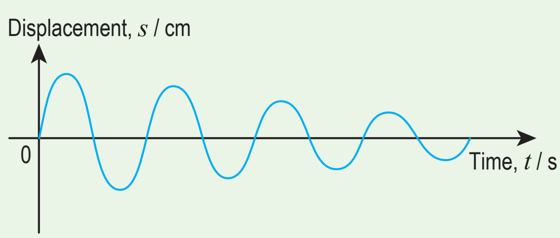


Figure 8

Based on the graph, answer the following questions:
(a) What happens to the amplitude of the oscillating pendulum?
(b) What phenomenon is experienced by the oscillating pendulum?
(c) What is the main reason for the phenomenon?
(d) How is the pendulum able to keep oscillating?

10. Figure 9 shows the pattern of interference produced by three coloured lights in an experiment.

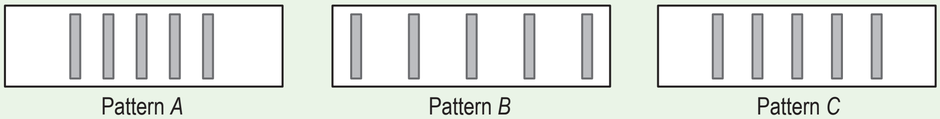


Figure 9

Table 1 shows the coloured lights used in this experiment and the values of wavelength. Complete Table 1 by matching the coloured lights with patterns *A*, *B* and *C*.

Table 1

Colour	Wavelength / nm	Pattern of interference
Blue	400	
Green	550	
Red	700	

Justify your answer.

11. Figure 10 shows a system of communication which involves direct transmission of electromagnetic wave signals from a transmitting station to a receiving station. The distance between the two distant stations and the shape of the Earth cause the receiving station to be unable to receive clear signals directly from the transmitter. You are required to give several proposals to improve the quality of transmission of signal.

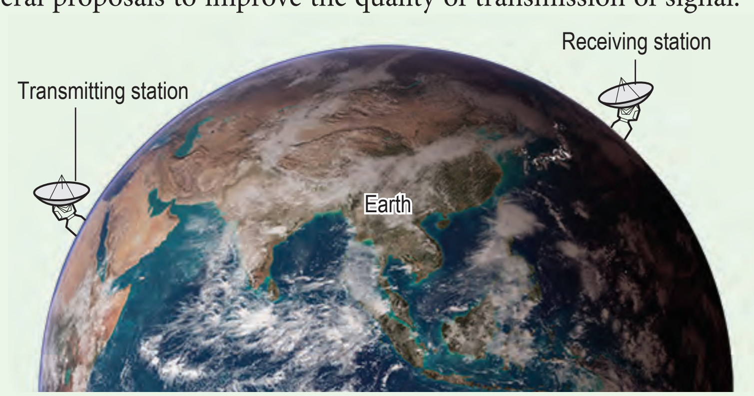


Figure 10

Explain your proposal based on the following aspects:
(a) type of wave broadcasted
(b) frequency of wave
(c) method which enables the wave to propagate through a further distance
(d) locations of transmitter and receiver

Enrichment Corner

12. Kompleks Pendaratan Ikan LKIM is a place where fishermen anchor their ship and bring ashore their catch. The river estuary becomes the entrance for ships to dock at the complex. Photograph 1 shows an example of a river estuary.

Photograph 1

*(**Source**: Image ©2019 TerraMetrics, Image ©2019 Maxar Technologies)*

Assume you are an engineer who is an expert in reflection, refraction and diffraction of waves. You are required to propose characteristics of the design of the building structure to ensure the fishermen's ships can pass through the river estuary safely based on the following aspects:

(a) building structure that can reduce the height of waves
(b) characteristics of the building structure that can reduce the effects of erosion
(c) depth of the river estuary to enable ships to pass through the estuary safely

13. Your new school hall is supplied with a Public Address (PA) system which consists of two loudspeakers, a microphone and a control station made up of an amplifier equipped with USB and DVD slots. You are required to propose the installation of the PA system so that the sound can be heard clearly by the audience. Sketch the layout of the hall and explain your proposal based on the following aspects:

(a) location of loudspeakers
(b) distance between loudspeakers
(c) location of microphone
(d) location of control station

CHAPTER 6 Light and Optics

What are the concepts and principles related to light and optics?

How are the concepts of light and optics used to explain natural phenomena and applied in daily life?

Why are fibre optics and small lenses used in optical instrument technology?

Let's Study

6.1 Refraction of Light
6.2 Total Internal Reflection
6.3 Image Formation by Lenses
6.4 Thin Lens Formula
6.5 Optical Instruments
6.6 Image Formation by Spherical Mirrors

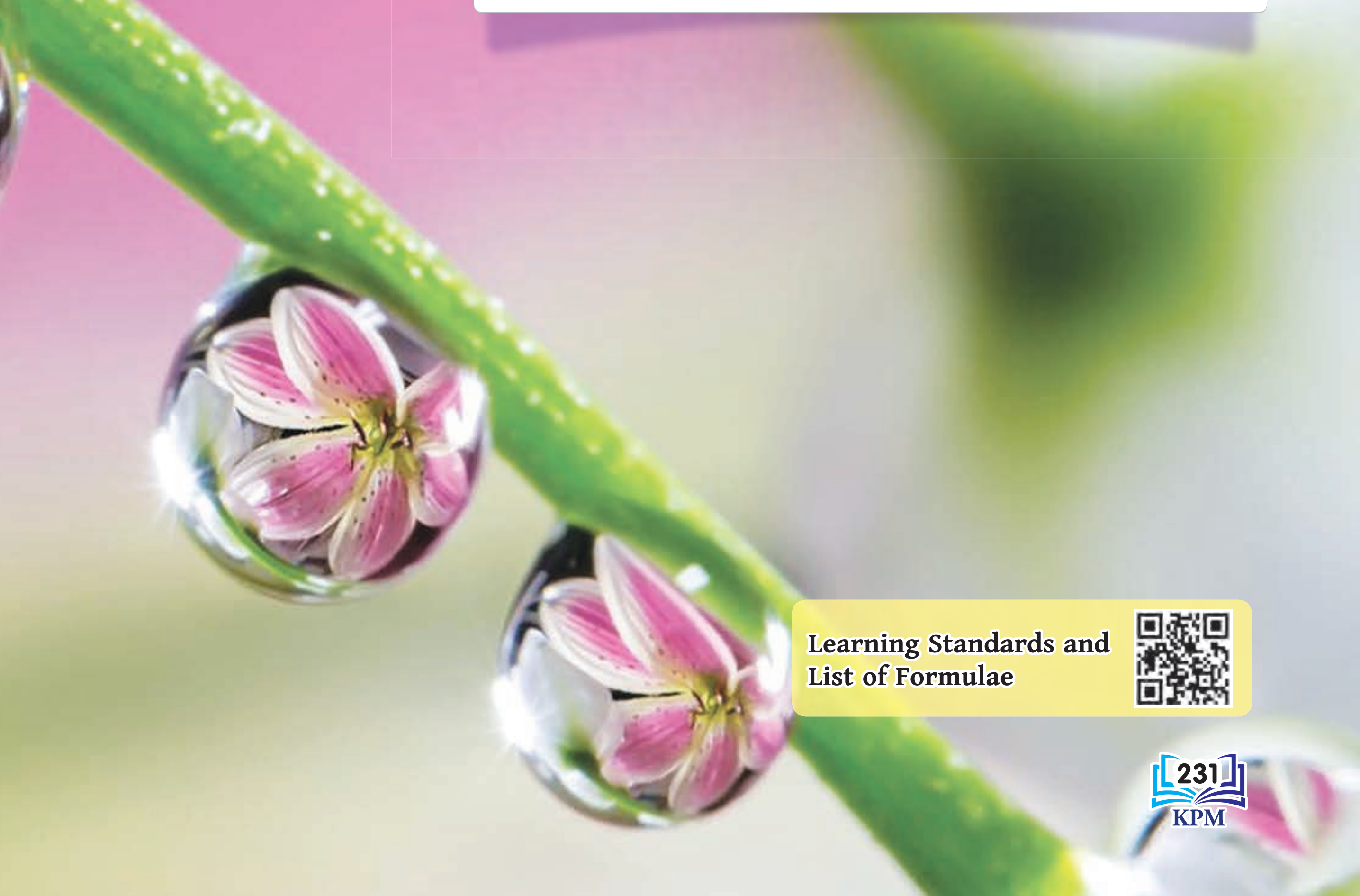
Information Page

Dew drops on grass can function as liquid magnifying lenses that form images of objects around them. The effect of light refraction is influenced by the size and shape of the dew drops.

The thickness of the human eye lens is controlled by cilia muscles so as to have different focal lengths to form images in the range of human vision. The concept of focal length adjustment is applied by scientists and engineers to invent liquid camera lens in smartphones. The focal length of the liquid lens can be adjusted using electric field in the electronic system of the smartphone. As such, one liquid lens can replace a set of lenses installed in the smartphone camera. The saving of space allows the overall thickness of smartphones to be reduced.

Video on liquid camera lens

http://bt.sasbadi.com/p4231a



Learning Standards and List of Formulae

6.1 Refraction of Light

Observe Figure 6.1. What causes the phenomena?

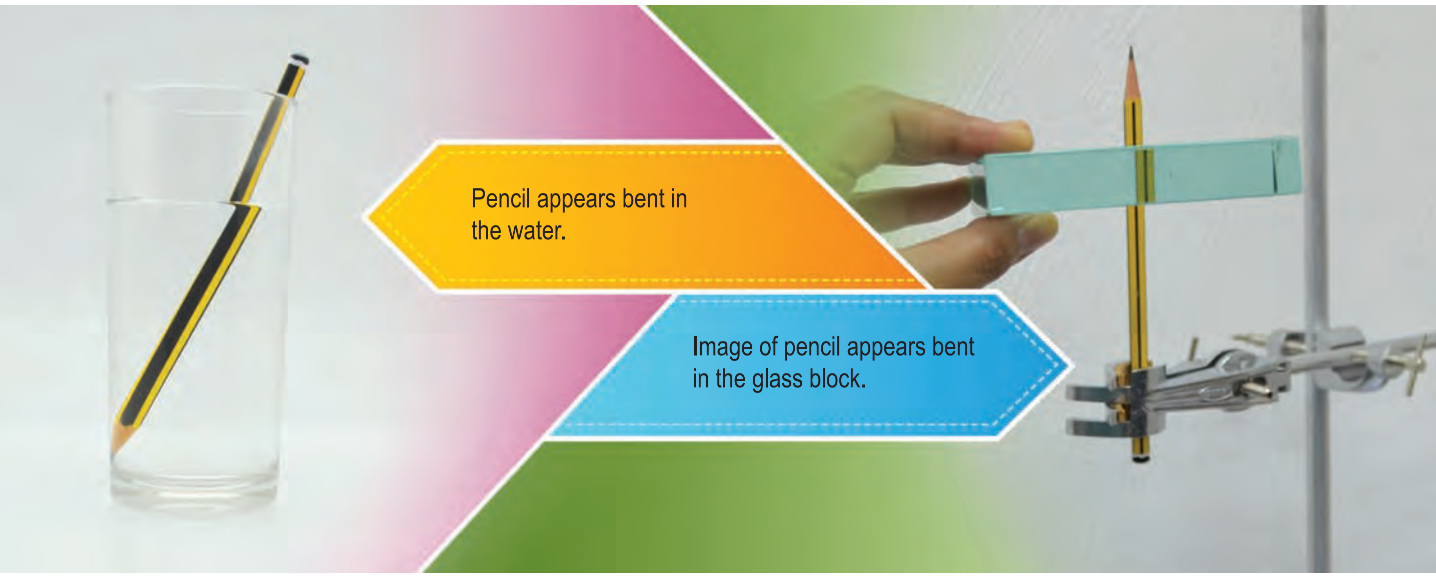


Figure 6.1 Phenomena of refraction of light

These phenomena are known as **refraction of light**. They occur due to the change in velocity of light when travelling through mediums of different optical densities as shown in Figure 6.2.

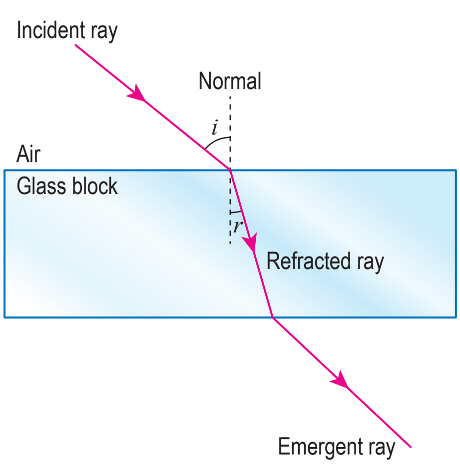


Figure 6.2 Refraction of light

SMART INFO

Optical density is not the same as density which is defined as mass per unit volume. For example, the density of oil is lower than that of water causing it to float on the surface of water. On the other hand, the optical density of oil is higher than the optical density of water.

Based on Figure 6.3, light rays bend towards the normal when light travels from a medium of low optical density (air) to a medium of high optical density (glass block). This is because the velocity of light decreases when light travels from an optically less dense medium to a denser medium. Due to this, the angle of refraction, r is smaller than the angle of incidence, i.

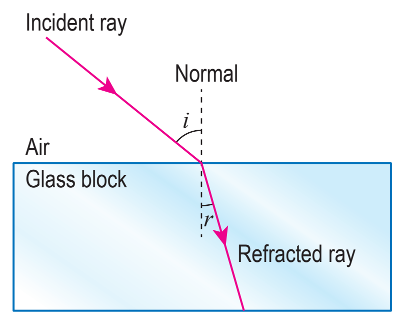


***Figure 6.3** Refraction of light from air to glass block ($i > r$)*

Based on Figure 6.4, the light ray bends away from the normal when light travels from a medium of high optical density (glass block) to a medium of low optical density (air). This is because the velocity of light increases when light travels from an optically denser medium to a less dense medium. Due to this, the angle of refraction, r is bigger than the angle of incidence, i.

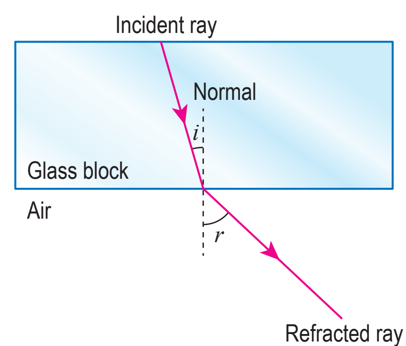


***Figure 6.4** Refraction of light from glass block to air ($i < r$)*

Refractive Index

Refractive index, n determines the degree to which light bends when travelling from vacuum to a medium. As such, we can define refractive index as the ratio of speed of light in vacuum to the speed of light in medium.

$$\textbf{Refractive index}, n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}$$

where $c = 3.0 \times 10^8$ m s^{-1}

Info File

When optical density increases, value of refractive index, n will increase. Value of n is always more than or equal to 1. The value n depends on the wavelength, λ of the light used. Change in temperature can also change the value n of a medium.

Activity 6.1

ISS ICS

Aim: To compare refractive index of different mediums and relate the refractive index of a medium to its optical density

Instructions:

1. Work in groups.
2. Gather information from reading resources or websites regarding refractive index for several different mediums such as air, water, cooking oil, ice, glass, diamond and other mediums.
3. Discuss:
   (a) The relationship between refractive index of the selected mediums and their optical densities.
   (b) What are the physical factors that influence the value of refractive index of a medium?
   (c) Which medium has the highest value of refractive index?
4. Present your findings.

Snell's Law

Table 6.1 shows the refractive indices for several mediums. Figure 6.5 shows light rays travelling from water into three different mediums.

Table 6.1 *Refractive indices for several mediums*

Medium	Refractive index
Vacuum and air	1.00
Olive oil	1.46
Perspex	1.50
Glass (crown)	1.52
Glass (flint)	1.66
Diamond	2.42

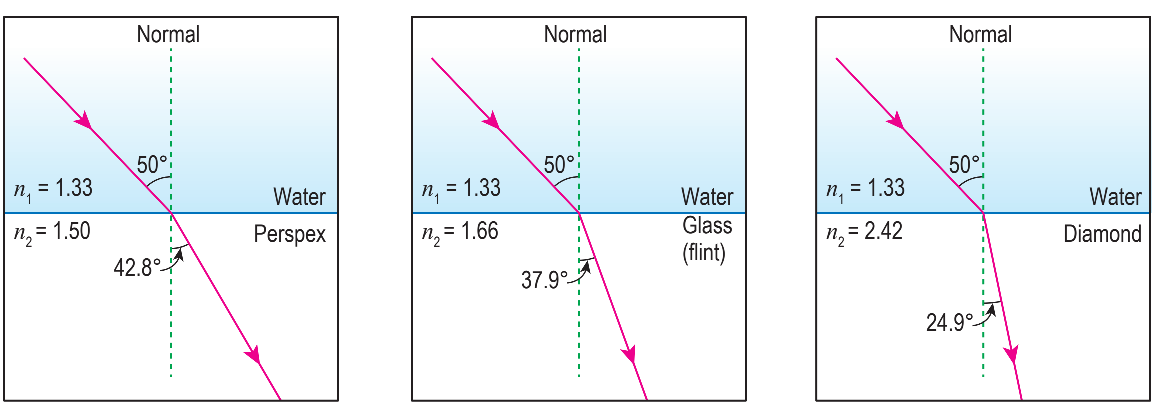


Figure 6.5 *Light rays travelling from water into three different mediums*

Based on Figure 6.5, the value of $n_1 \sin \theta_1$ is the same as $n_2 \sin \theta_2$ for the three different mediums. According to the law of refraction of light, when light travels from one medium to another:

- The incident ray, refracted ray and normal meet at one point and are in the same plane.
- Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$, $\dfrac{n_2}{n_1} = \dfrac{\sin \theta_1}{\sin \theta_2}$, where n_1 = refractive index of medium 1
  n_2 = refractive index of medium 2
  θ_1 = angle of incidence in medium 1
  θ_2 = angle of refraction in medium 2

When medium 1 is air ($n_1 = 1$) and medium 2, $n_2 = n$

$$n = \frac{\sin i}{\sin r}$$

i is the angle of incidence in air, r is the angle of refraction in medium 2

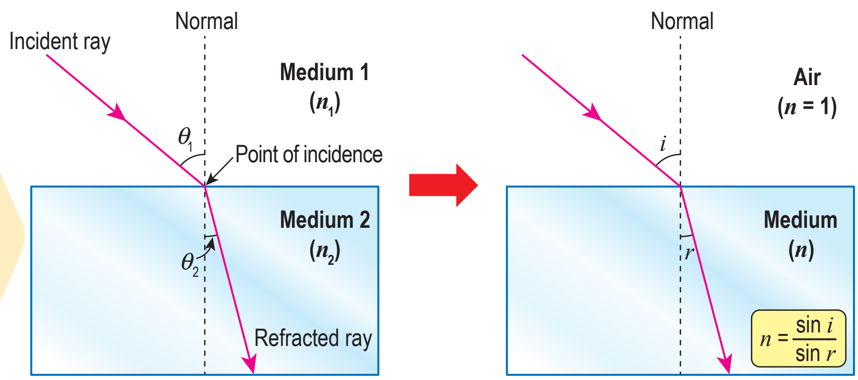


Figure 6.6 Law of refraction of light

Observe Figure 6.7. Why does light ray bend when entering a glass block?

Angle of refraction depends on the angle of incidence and the value of refractive index of the glass block.

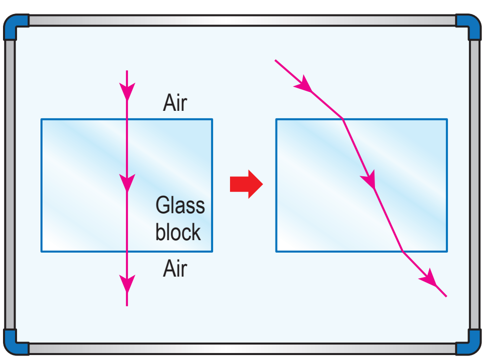


Figure 6.7 Bending of light ray

6.1.3 6.1.4

Experiment 6.1

Inference: Angle of refraction depends on angle of incidence
Hypothesis: The larger the angle of incidence, i, the larger the angle of refraction, r
Aim: To determine the refractive index of glass block

Variables:
(a) Manipulated variable: Angle of incidence, i
(b) Responding variable: Angle of refraction, r
(c) Constant variable: Refractive index of glass block

Apparatus: Ray box with single slit, protractor and ruler

Materials: Glass block, white paper and pencil

Procedure:

1. Set up the apparatus on a piece of white paper (as shown in Figure 6.8).
2. Trace the outline of the glass block on the white paper and draw a normal line at point *O*.
3. Draw five lines at different angles of incidence, i = 20°, 30°, 40°, 50° and 60° using a protractor to represent five incident rays.
4. Direct the light ray from the ray box at angle of incidence, i = 20°. Draw the emergent ray *PQ*.
5. Remove the glass block and draw the refracted ray *OP*. Measure the angle of refraction, r and record the reading in Table 6.2.
6. Put the glass block back in place. Repeat steps 4 and 5 with angle of incidence, i = 30°, 40°, 50° and 60°.
7. Calculate the value of sin i and sin r. Record the values in Table 6.2.

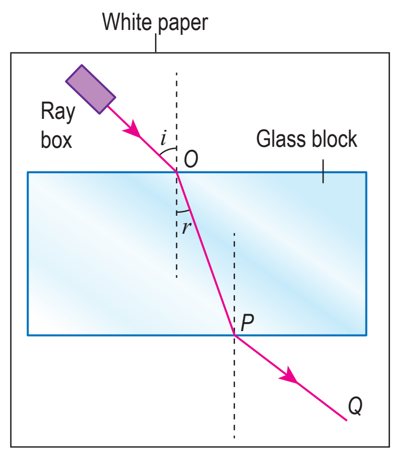


Figure 6.8

Note: This experiment can also be carried out using perspex.

Results:

Table 6.2

Angle of incidence, i / °	Angle of refraction, r / °	sin i	sin r
20			
30			
40			
50			
60			

Analysis of data:

1. Plot a graph of r against i and a graph of sin i against sin r on a different graph paper.
2. Calculate the gradient of the graph of sin i against sin r.
3. State the relationship between angle of incidence, i and angle of refraction, r when light moves from air into the glass block.

Info File

If a laser pointer is used in this experiment, apparatus set up needs to be rearranged.

Demonstration video on refraction of laser ray

http://bt.sasbadi.com/p4236

Conclusion:
What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:
1. What is the value of refractive index of the glass block?
2. State one precaution that needs to be taken to increase the accuracy of readings in this experiment.

Real Depth and Apparent Depth

Observe Figure 6.9. Why does the position of the image of the fish appear closer to the water surface?

This situation is caused by refraction of light. When light rays from the fish travel from water to air, light is refracted away from normal. This effect of refraction of light causes the image of the fish to be closer to the water surface as seen by an observer.

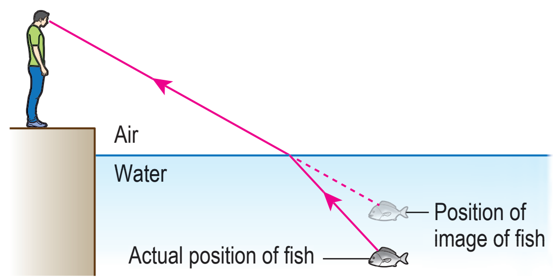


Figure 6.9 *Effect of refraction of light*

Activity 6.2

ICS

Aim: To draw a ray diagram to show real depth, H and apparent depth, h

Figure 6.10 shows a coin, placed under a glass block with a thickness of 8.0 cm. Ray *OPQ* is the path of light from the centre of the coin, to the eye of the observer. You are required to draw another light ray, *OP′Q′* from point *O* to the eye of the observer. You can download and print Figure 6.10 from the website given.

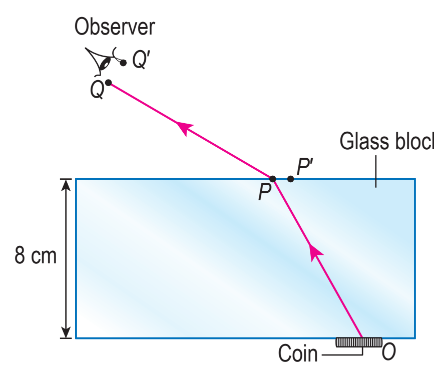


Figure 6.10

Download Figure 6.10

http://bt.sasbadi.com/p4237

Instructions:
1. Work in pairs.
2. Draw lines *QP* and *Q′P′* and extend both lines into the glass block until they meet.
3. Mark the meeting point as point *X*. *X* is the apparent position for the centre of the coin, that is the image for point *O*.
4. Complete your ray diagram by drawing line *OP′*.
5. Measure:
   (a) Real depth, H, which is the distance from *O* to the surface of the glass block.
   (b) Apparent depth, h, which is the distance from *X* to the surface of the glass block.
6. Calculate the value of $\frac{H}{h}$. Compare the value of $\frac{H}{h}$ with the refractive index of the glass block, n. Relate real depth, H, apparent depth, h, and refractive index of the glass block, n.

6.1.4 6.1.5

Figure 6.11 shows that a diving instructor who is at the poolside sees the position of the diver closer to the water surface. Figure 6.12 shows a diver who is at the base of the pool sees his instructor further away from him. Can you explain these situations?

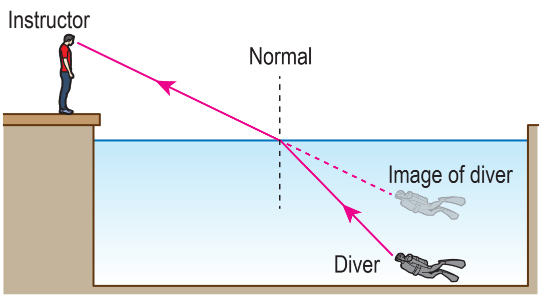


Figure 6.11 Position of image of diver from the viewing angle of instructor

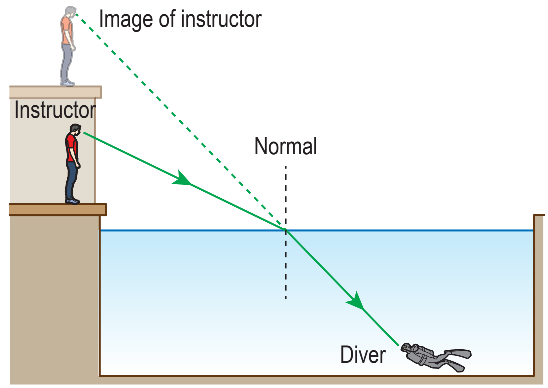


Figure 6.12 Position of image of instructor from the viewing angle of diver

Experiment 6.2

Inference: Position of an image is influenced by position of object and refractive index of different mediums

Hypothesis: The greater the real depth of an object, the greater the apparent depth

Aim: To determine the refractive index of water using non-parallax method

Variables:

(a) Manipulated variable: Real depth, H

(b) Responding variable: Apparent depth, h

(c) Constant variable: Refractive index of water, n

Apparatus: 1 000 mℓ beaker, ruler and retort stand with two clamps

Materials: Cork, two pins, cellophane tape and water

Procedure:

1. Set up the apparatus as shown in Figure 6.13.

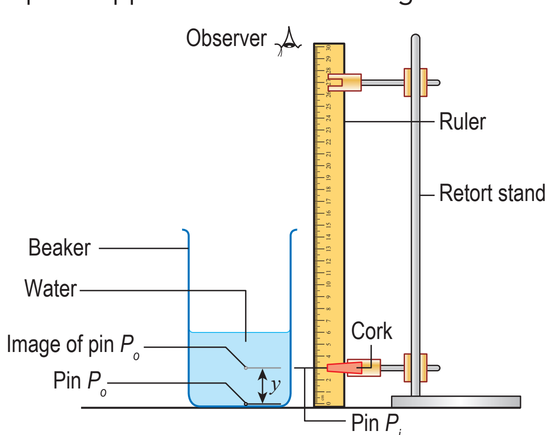


Figure 6.13

Info File

Non-parallax method is an important method to determine position of image accurately in optical experiments.

2. Stick a pin P_o with cellophane tape to the base of the beaker.
3. Fill the beaker with water to a depth of 6.0 cm. This depth is real depth, H.
4. Observe the image of pin P_o from above the water surface.
5. Adjust the position of pin P_i vertically until it appears in line with the image of pin P_o. At this level, position of pin P_i is at the same level as the image of pin P_o.
6. Measure the distance y between pin P_i and the base of the beaker. Record the reading in Table 6.3.
7. Repeat this experiment with real depth, H = 7.0 cm, 8.0 cm, 9.0 cm and 10.0 cm.

Results:

Table 6.3

Real depth, H / cm	y / cm	Apparent depth, h / cm
6.0		
7.0		
8.0		
9.0		
10.0		

Analysis of data:

1. Determine the value of apparent depth, h which is equal to the distance between pin P_i and the water surface using the formula, $h = (H - y)$.
2. Plot a graph of H against h.
3. Determine the gradient of the graph.
4. Relate real depth, apparent depth and refractive index of water.
5. State the value of refractive index of water.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. If water is replaced by cooking oil in this experiment, what will happen to the gradient of the graph?
2. State one precaution that needs to be taken to improve the accuracy of the results.
3. Discuss the advantage of non-parallax method compared to the method used in Experiment 6.1 to determine the refractive index of a substance.

Based on the above experiment, the relationship between the refractive index of a medium, n, real depth, H and apparent depth, h is:

$$n = \frac{\text{real depth}}{\text{apparent depth}} = \frac{H}{h}$$

6.1.6

Solving Problems Involving Refraction of Light

Example 1

Figure 6.14 shows a light ray travelling from air into a plastic block at an angle of 60°. The refractive index of plastic is 1.49.

Calculate:

(a) angle of refraction, r.

(b) speed of light in plastic.

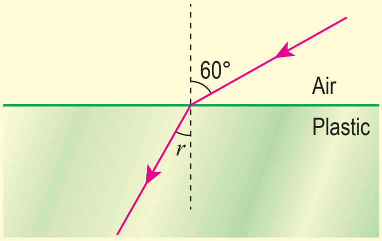


Figure 6.14

Solution:

(a)

$$n = \frac{\sin i}{\sin r}$$

$$\sin r = \frac{\sin i}{n}$$

$$= \frac{\sin 60°}{1.49}$$

$$r = \sin^{-1}\left(\frac{\sin 60°}{1.49}\right)$$

$$= 35.54°$$

(b)

$$n = \frac{c}{v}$$

$$v = \frac{c}{n}$$

$$= \frac{3.0 \times 10^8}{1.49}$$

$$= 2.01 \times 10^8 \text{ m s}^{-1}$$

Example 2

When a coin inside a beaker containing a solution is observed, image of the coin is seen at a height equal to $\frac{2}{7}$ of the depth of the solution. What is the refractive index of the solution?

Solution:

Based on Figure 6.15,

Apparent depth, $h = H - \frac{2}{7}H$

$$= \frac{5}{7}H$$

Refractive index of solution, $n = \frac{H}{h}$

$$= \frac{H}{\frac{5}{7}H}$$

$$= \frac{7}{5}$$

$$= 1.4$$

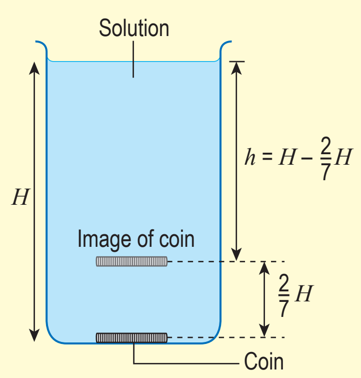


Figure 6.15

6.1.7

Formative Practice 6.1

1. Figure 6.16 shows the path of light which travels from medium 1 to medium 2.

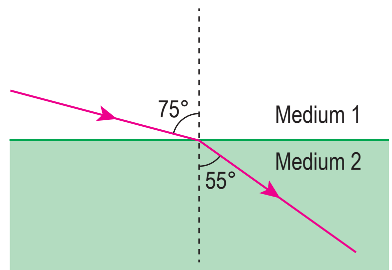


Figure 6.16

(a) Write an equation to relate the light that travels through the mediums.
(b) Determine the refractive index for medium 2 if the speed of light in medium 1 is 3.0×10^8 m s^{-1}.
(c) What is the speed of light in medium 2?

2. Figure 6.17 shows a tank filled with oil to a height of 3 m. The oil has a refractive index of 1.38. What is the apparent depth of the tank as seen by the observer from above the tank?

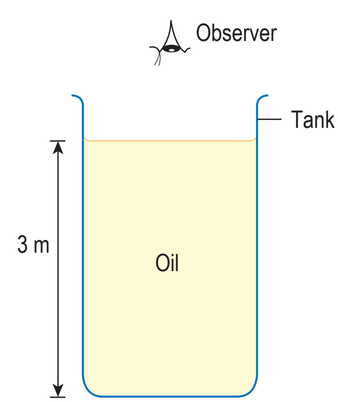


Figure 6.17

6.2 Total Internal Reflection

Photograph 6.1 shows a turtle below the surface of water. A reflected image of the turtle can be seen on the boundary of water and air. Why does this happen?

This phenomenon is known as **total internal reflection** of light. Total internal reflection only occurs when light travels from a medium of high optical density to a medium of low optical density.

Photograph 6.1 *Phenomenon of total internal reflection*

Activity 6.3

Aim: To observe the phenomenon of total internal reflection and determine the critical angle of glass

Apparatus: Semi-circular glass block, ray box, power supply and protractor

Material: White paper

Instructions:

1. Draw a straight line *AB* and a perpendicular line *PQ* on a piece of white paper.
2. Set up the apparatus as shown in Figure 6.18. Point *O* is the centre of the semi-circular glass block.

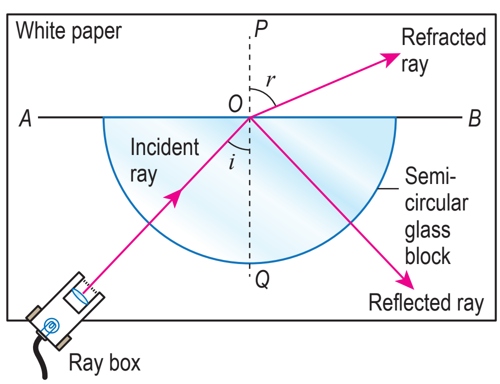


Figure 6.18

3. Switch on the ray box so that a ray of light is directed along *QO*. Observe the refracted ray in air.
4. Shift the ray box so that a ray of light is directed to point *O* with a small angle of incidence, *i*. Observe the refracted ray in air and the reflected ray in the semi-circular glass block.
5. Repeat step 4 with an increasingly bigger angle of incidence, *i* until it is almost 90°.
6. Adjust the position of the ray box so that the refracted ray travels along *OB*, that is angle of refraction, *r* = 90°. Mark the path of the incident ray.

7. Remove the glass block. Draw the incident ray and measure the angle of incidence. This angle of incidence is known as the critical angle of glass, c.
8. Place the glass block back to its original position. Observe the refracted ray and reflected ray when:
   (a) angle of incidence is smaller than the critical angle, and
   (b) angle of incidence is larger than the critical angle.

Discussion:

1. What is the critical angle of glass?
2. Describe the propagation of light ray through the glass block when the angle of incidence is smaller than the critical angle.
3. What happens to the light ray travelling through the glass block when
   (a) the angle of incidence is smaller than the critical angle?
   (b) the angle of incidence is larger than the critical angle?

Figure 6.19 shows light rays travelling from glass (high optical density) to air (low optical density) for three different angles of incidence.

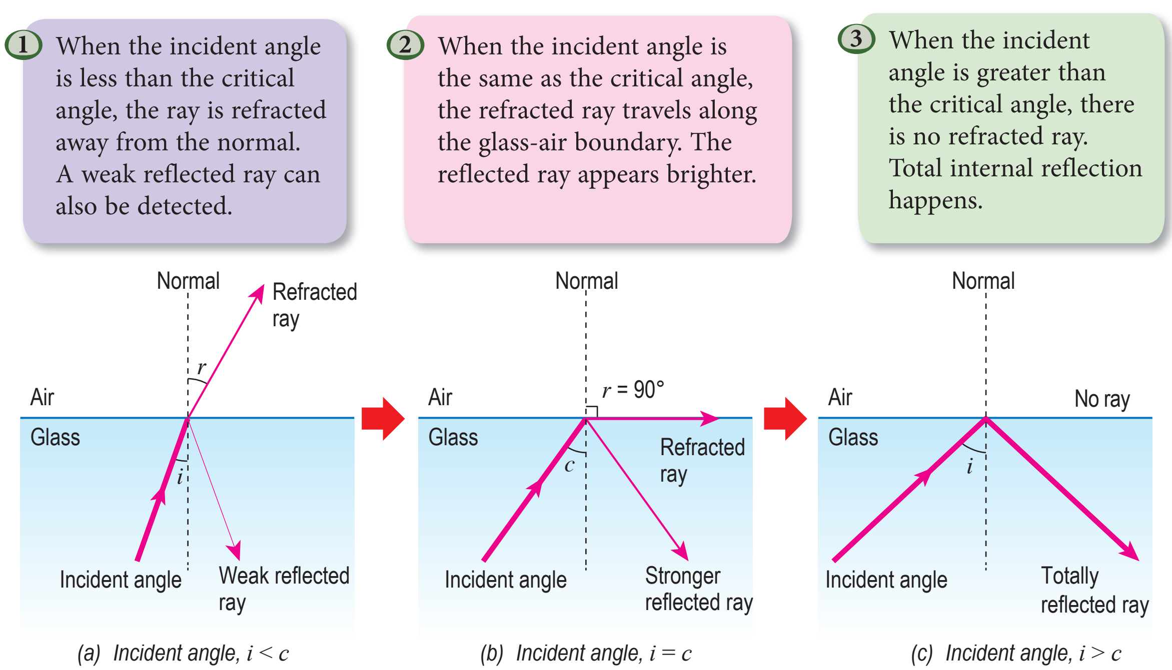


Figure 6.19 *Light ray travelling from glass to air*

The phenomenon of total internal reflection happens when light travels from a medium of high optical density to a medium of low optical density, with the angle of incidence larger than the critical angle. **Critical angle**, c is the angle of incidence in the medium of high optical density when the angle of refraction in the medium of lower optical density is equals to 90°. Does the critical angle of a medium depend on its refractive index?

6.2.1

Activity 6.4

Algorithms

Aim: To discuss the relationship between critical angle and refractive index

Instructions:

1. Work in pairs.
2. Study Figure 6.20 that shows a light ray travelling from glass to air with an angle of incidence, i equals to the critical angle, c.

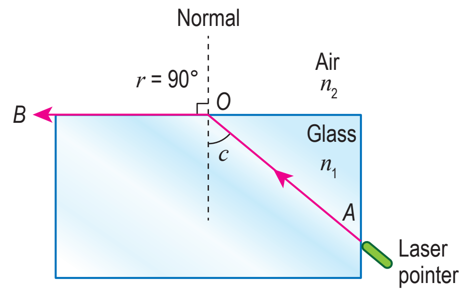


Figure 6.20 Relationship between critical angle and refractive index

3. Discuss and complete the following statements.
   (a) Snell's Law for light ray travelling from glass to air is:

$n_1 \sin \theta_1 = n_2 \sin \theta_2$, where n_1 = refractive index of ____________
n_2 = refractive index of ____________
θ_1 = angle of incidence in ____________
θ_2 = angle of refraction in ____________

   (b) Value $\theta_1 = c$, θ_2 = ____________ and n_2 = ____________.
   With this, n_1 sin ____________ = n_2 sin ____________.

$$n_1 = \frac{1}{\boxed{}}$$

In general, the relationship between the critical angle, c and the refractive index, n for a medium in air is $n = \frac{1}{\sin c}$. If the refractive index of diamond is 2.42, then the critical angle for diamond can be calculated as follows:

$$\sin c = \frac{1}{2.42}$$
$$= 0.4132$$
$$c = \sin^{-1}(0.4132)$$
$$= 24.4°$$

Critical angle for diamond, c is 24.4°.

Critical angle for a medium depends on the optical density of the medium. The higher the refractive index of a medium, the smaller the critical angle of the medium.

6.2.2

Natural Phenomena and Applications of Total Internal Reflection in Daily Life

Photograph 6.2 *Night view of the River of Life and Blue Pool, Jamek Mosque, Kuala Lumpur*

The beauty of decorative lamps shown in Photograph 6.2 is due to total internal reflection. Can you state other phenomena involving total internal reflection?

Activity 6.5

ISS ICS

Aim: To gather information and discuss natural phenomena which involve total internal reflection

Instructions:

1. Work in groups.
2. Gather information from various reading resources and websites regarding:
   (a) natural phenomena which involve total internal reflection.
   (b) applications of total internal reflection in daily life.
3. Present your findings in the form of a mind map.

Activity 6.6

Aim: To observe the phenomenon of total internal reflection in a water stream

Apparatus: 1.5 litre plastic bottle, plastic basin, laser pointer, wooden block and retort stand

Materials: Water and cellophane tape

Instructions:

1. Punch a hole at the side of a plastic bottle. Then, seal the hole with cellophane tape.
2. Set up the apparatus as shown in Figure 6.21(a).

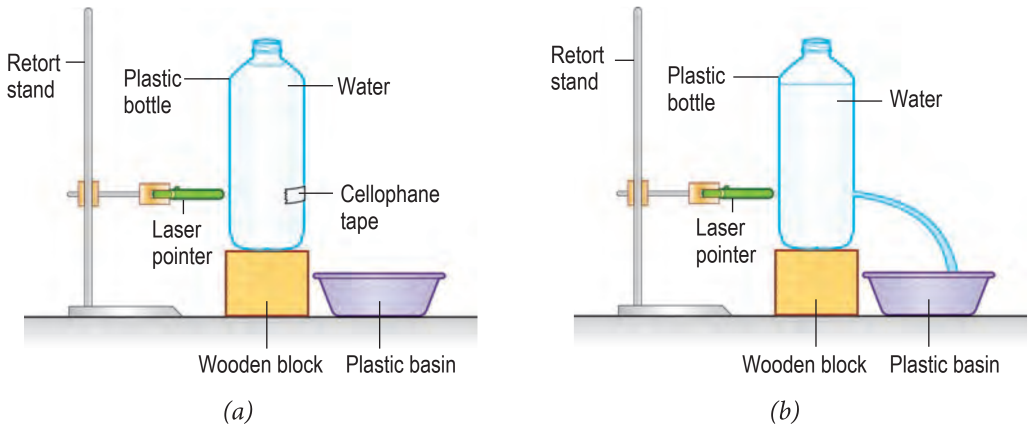


Figure 6.21

3. Carry out this activity in a dark room for clearer observation.
4. Remove the cellophane tape so that water flows out from the hole into the basin.
5. Direct the laser beam towards the hole as shown in Figure 6.21(b). Observe the colour of the water stream.
6. Record your observations.

Demonstration video on total internal reflection

http://bt.sasbadi.com/p4246

Discussion:

What will happen if the water stream is replaced by an oil stream?

Note: This activity can also be carried out using an optical fibre kit.

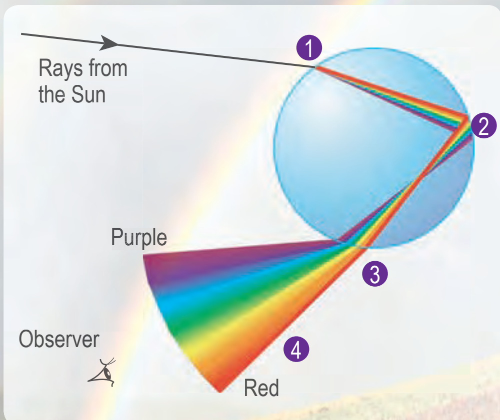
Based on Activity 6.6, a laser beam which enters the water stream experiences repeated total internal reflection until it comes out from the end of the water stream. This situation shows that the water stream acts as a light pipe to guide the laser beam from one end to another end.

If the water stream is replaced by an oil stream, light beams will experience total internal reflection even more times. This is because the refractive index of oil is higher than the refractive index of water. The critical angle of oil is smaller than the critical angle of water.

Natural Phenomena that Involve Total Internal Reflection

Formation of rainbow

Formation of rainbow is a phenomenon caused by refraction, dispersion and total internal reflection when light passes through water droplets in the air. Figure 6.22 shows the formation of rainbow.



1 When white light from the Sun enters water droplets, the light experiences refraction and disperses into different colours.

2 All these different colours experience total internal reflection on the surface of the water droplets.

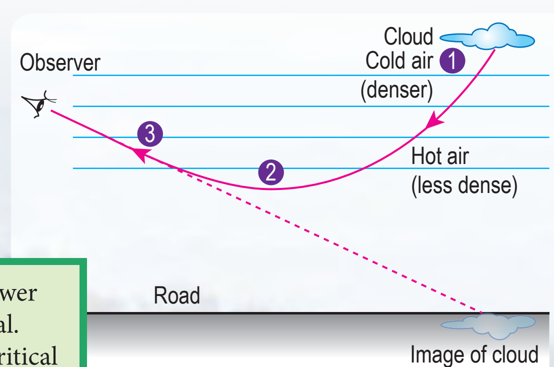
3 Light rays reflected experience refraction and dispersion again when moving from water to air.

4 Colours of the rainbow are seen by the observer.

Figure 6.22 *Formation of rainbow*

Mirage

On a hot and bright day, a car driver sees the blurry image of a puddle of water on the surface of the road ahead. When he gets nearer to the puddle of water, he discovers that the puddle of water does not actually exist. This natural phenomenon is known as **mirage** which is caused by refraction and total internal reflection of light. Figure 6.23 shows the process of formation of mirage.



1 Layers of air above the road have different optical densities. The layer of air just above the road surface is hotter than the upper layers. The layer of hot air has smaller optical density than cold air.

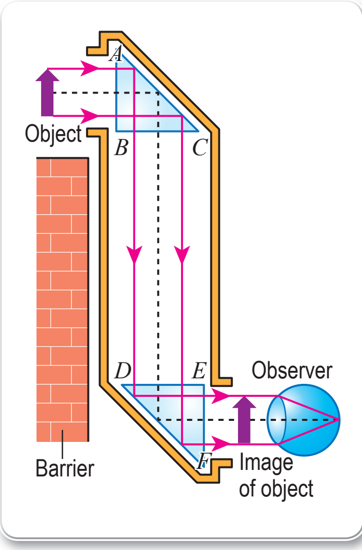
2 Light which travels from the upper layer to the lower layer are gradually refracted away from the normal. When the angle of incidence is greater than the critical angle of air, total internal reflection occurs.

3 Reflected light rays are then gradually refracted towards the normal and reach the eyes of the observer. The observer will see the image of a cloud as a puddle of water on the road surface.

Figure 6.23 *Formation of mirage*

6.2.3

Applications of Total Internal Reflection in Daily Life

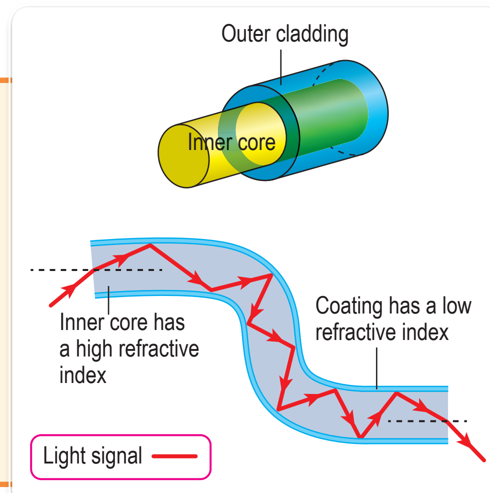


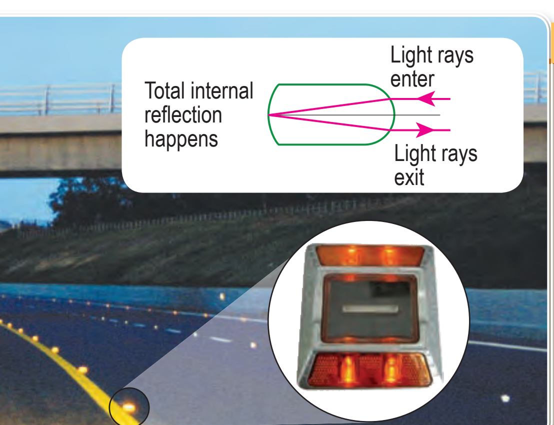
Prism periscope

- Used to see objects behind a barrier.
- Made up of two right angle prisms fitted at both ends of a long tube.
- Light rays from an object travel along the normal to the side *AB* of the upper prism (pass through the opening of the periscope). The light rays reach side *AC* without refraction. The angle of incidence is 45° and is larger than the critical angle of the prism, which is 42°. Therefore, total internal reflection happens at side *AC* and the light rays are reflected downwards.
- The reflected light rays travel downwards along the normal to side *DE* of the lower prism.
- Once again, the reflected light rays experience total internal reflection at side *DF*. Finally, the reflected light rays emerge from side *EF* without refraction and enter the eyes of observer. The image formed is upright and of the same size as the object.

Optical fibre

- Widely used in the fields of telecommunication and medicine.
- Made from pure glass or plastic fibres.
- Inner core which has a high refractive index is surrounded by a layer of cladding with a low refractive index.
- Light signals enter one end of the optic fibre and experience total internal reflection continuously in the inner core until they reach the other end. As such, signals can be sent rapidly without disturbances from electric signals.





Cat's eye reflector

- Used for the purpose of safety for road users at night.
- Light rays from car headlights enter the reflector and experience total internal reflection on the back surface of the reflector.

CAREER INFO

Doctors use endoscope to examine the internal organs. Engineers use fibre optics to examine the interior of complex machines. Communication experts use fibre optics for sending data speedily.

Figure 6.24 *Applications of total internal reflection in daily life*

Solving Problems Involving Total Internal Reflection

Example 1

Figure 6.25 shows a light ray travelling from air to a prism with refractive index of 1.49.
(a) Calculate the critical angle of the prism.
(b) Complete the path of the light ray until it exits the prism.

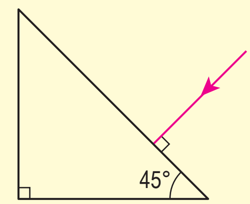


Figure 6.25

Solution:

(a) $\sin c = \dfrac{1}{n}$

$= \dfrac{1}{1.49}$

$c = \sin^{-1}\left(\dfrac{1}{1.49}\right)$

$= 42.2°$

Critical angle of prism, c is 42.2°.

(b)

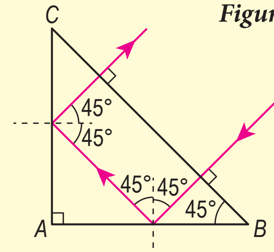


Figure 6.26

In Figure 6.26, angle of incidence (i = 45°) is larger than critical angle (c = 42.2°) at the sides AB and AC. Total internal reflection happens and light ray emerges from the side of BC along its normal.

Example 2

Figure 6.27 shows the path of light ray travelling through optical fibre from end A to end B.
(a) Explain the change in direction of the light ray at points Q, R, S, T and U.
(b) If the refractive index of the optical fibre is 1.51, determine the value of angle x.
(c) Why must the material of optical fibres be of high optical purity?

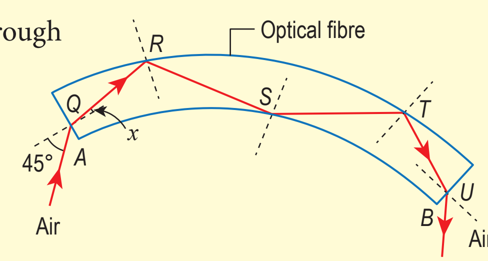


Figure 6.27

Solution:

(a) At point Q, refracted light bends towards the normal. At points R, S and T, total internal reflection happens. At point U, refracted light bends away from normal.

(b) $n_1 \sin \theta_1 = n_2 \sin \theta_2$

$1 \times \sin 45° = 1.51 \sin x$

$\sin x = 1 \times \dfrac{\sin 45°}{1.51}$

$= 0.468$

$x = \sin^{-1}(0.468)$

$= 27.9°$

(c) High purity material allows the critical angle along the fibre optic to be consistent. All signals which enter the fibre will experience total internal reflection.

6.2.4

Formative Practice 6.2

1. Figure 6.28 shows the path of light which travels from air to a prism.

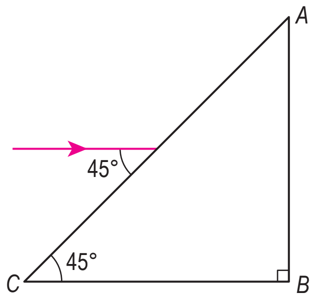


Figure 6.28

(a) Determine the angle of refraction of light ray in the prism. The refractive index of the prism is 1.50.

(b) Will the light ray experience total internal reflection at the side *AB* of the prism? Explain your answer.

2. Figure 6.29 shows a fine optical fibre made up of inner core which has a high refractive index surrounded by cladding material of a low refractive index.

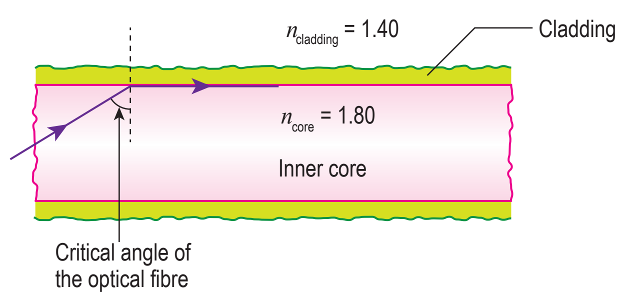


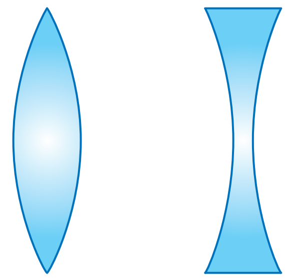
Figure 6.29

(a) Determine the critical angle of the optical fibre.

(b) What is the advantage of fine optical fibre?

6.3 Image Formation by Lenses

Lens is a piece of transparent material such as glass, perspex or plastic which has two surfaces with at least one surface curved. There are two main types of lenses, convex lens and concave lens as shown in Figure 6.30.



(a) Convex lens (b) Concave lens

Figure 6.30 *Types of lenses*

Lenses

http://bt.sasbadi.com/p4251

Activity 6.7

Aim: To show convex lens as converging lens and concave lens as diverging lens

Apparatus: Convex lens, concave lens, ray box, power supply, three slit plate, pencil and ruler

Material: White paper

Instructions:

1. Set up the apparatus as shown in Figure 6.31.

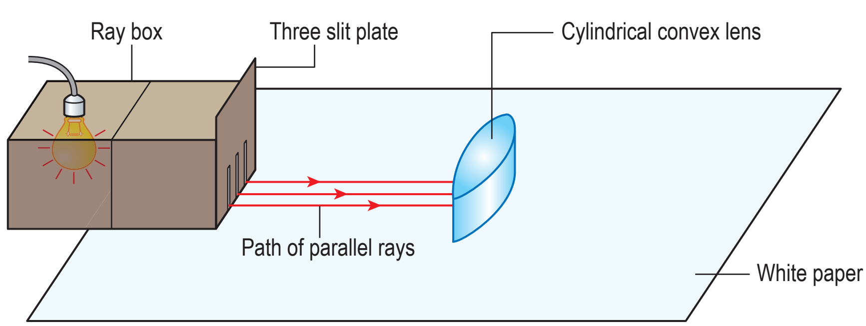


Figure 6.31

2. Trace the shape of the convex lens on white paper.
3. Direct three parallel rays of light from the ray box towards the convex lens. Observe the beams of light after passing through the convex lens and record your observations.
4. Make two marks on each path of light before and after passing through the lens. Remove the convex lens and draw a ray diagram for the paths of light.
5. Measure the distance between the centre of the lens, P and the point of focus, F of the three paths of light. Record your reading.
6. Repeat steps 2 to 4 by replacing the convex lens with a concave lens.

6.3.1

7. Determine the point, F where the three beams of light appear to diverge.
8. Measure the distance between the centre of the lens, P and point F. Record your reading.

Discussion:

What happens to the three beams of light after passing through:
(a) convex lens (b) concave lens

The above activity shows that parallel light rays which pass through convex lens will converge at a **focal point**, ***F***. Therefore, convex lenses are known as **converging lenses**. On the other hand, parallel light rays passing through concave lens appear to be diverging from a focal point, F. Therefore, concave lenses are known as **diverging lenses**. Table 6.4 shows the differences between convex lens and concave lens.

Table 6.4 *Differences between convex lens and concave lens*

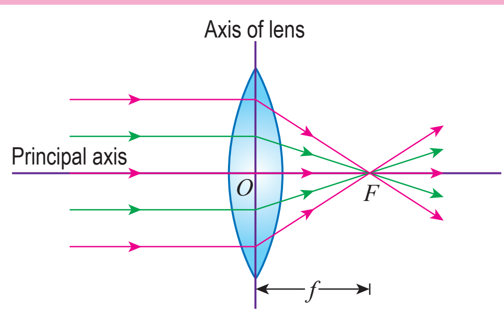
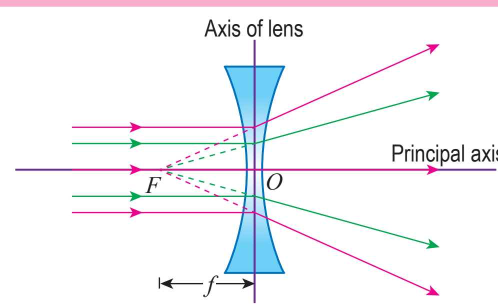
Convex lens	Concave lens
	
Focal point of convex lens is **real** because refracted light rays converge at this point. As such, focal length, f is said to be **positive**.	Focal point of concave lens is **virtual** because refracted light rays appear to diverge from this point. As such, focal length, f is said to be **negative**.

Table 6.5 *Explanation of optical terms used*

Optical term	Explanation
Optical centre, O	Point at the centre of the lens. Light rays passing through the optical centre are not refracted.
Principal axis	Straight line through the optical centre of a lens and the centre of curvature of both surfaces of the lens.
Axis of lens	Straight line through the optical centre and perpendicular to the principal axis.
Focal point, F	Point located at the principal axis of a lens. • For convex lens, light rays parallel to the principal axis will converge at this point after passing through the lens. • For concave lens, light rays parallel to the principal axis appear to diverge from this point after passing through the lens.
Object distance, u	Distance between object and optical centre of a lens
Image distance, v	Distance between image and optical centre of a lens
Focal length, f	Distance between focal point, F and optical centre, O of a lens

Focal Length for Convex Lens

Convex lenses of different thickness have different focal lengths.

Activity 6.8

Aim: To observe real image and estimate focal length of a convex lens using distant object

Apparatus: Convex lens, metre rule, lens holder and white screen

Instructions:

1. Set up the apparatus as shown in Figure 6.32.
2. Place the convex lens on the lens holder and position it towards an open window.

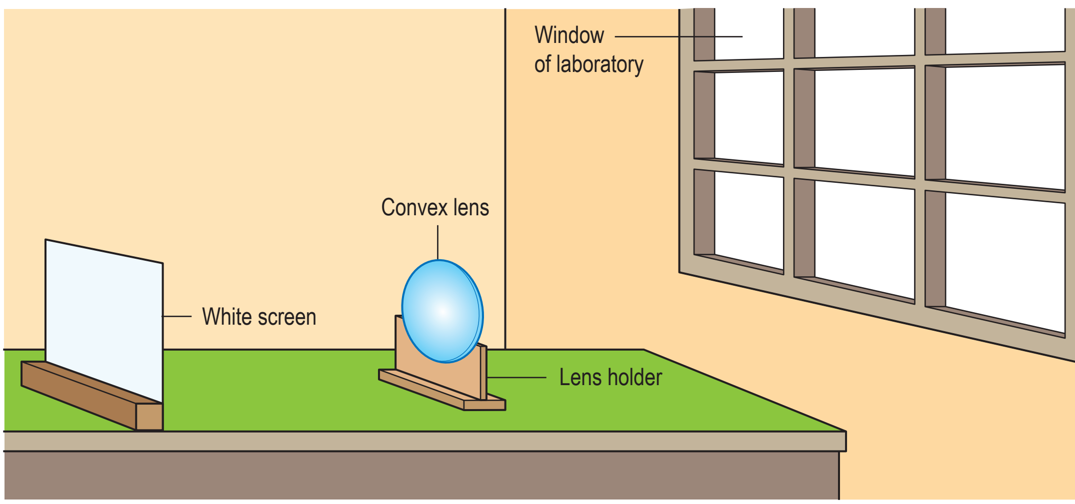


Figure 6.32

3. Place the white screen behind the lens and adjust its position closer or further from the lens until a sharp image is formed on the screen.
4. Measure the focal length of the lens, that is the distance between optical centre of the convex lens and the screen. Record your reading.

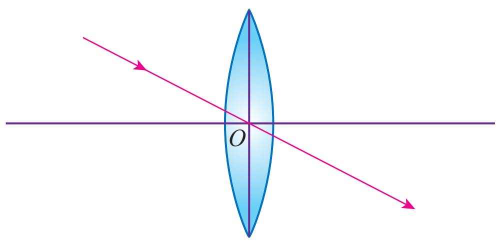
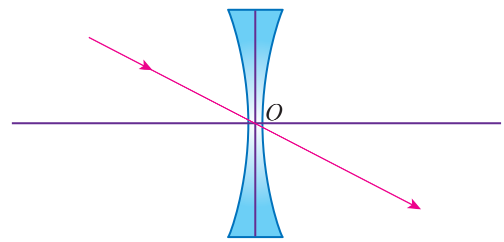
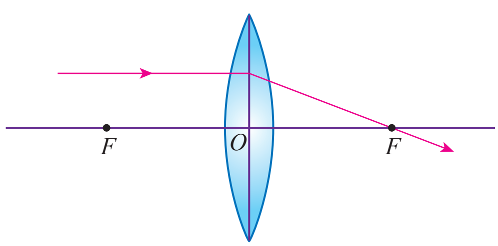
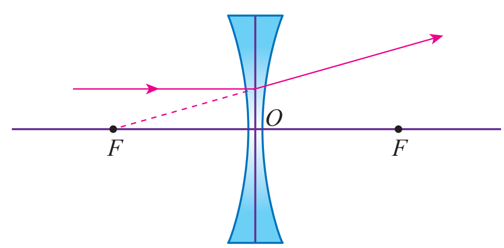
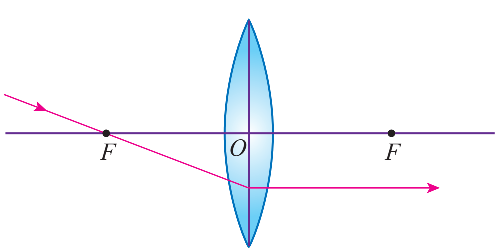
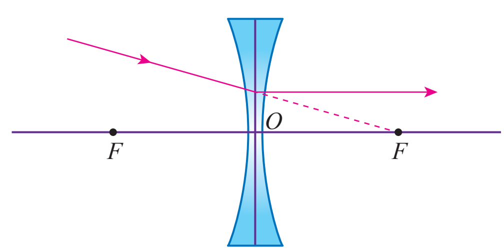
Discussion:

Why is the activity above not suitable to be used to estimate the focal length of a concave lens?

Position and Characteristics of Images Formed by Lenses

Ray diagrams can be used to determine the position and characteristics of images formed by convex lens and concave lens. There are three rays used in the construction of a ray diagram (See Table 6.6).

***Table 6.6** Rays used in the drawing of a ray diagram*

Convex Lens	Concave Lens
1. Ray which passes through the optical centre travels in a straight line through the optical centre without being refracted.  	**1.** Ray which passes through the optical centre travels in a straight line through the optical centre without being refracted. 
2. Ray which is parallel to the principal axis is refracted and passes through the focal point, *F*.  	**2.** Ray which is parallel to the principal axis is refracted and appears to come from focal point, *F*. 
3. Ray which passes through the focal point, *F* is refracted parallel to the principal axis.  	**3.** Ray which travels towards focal point, *F* is refracted parallel to the principal axis. 

Activity 6.9

Aim: To determine the position and characteristics of images formed by convex lens and concave lens for different object distances

Apparatus: Convex lens (f = 10 cm), concave lens (f = –10 cm), ray box with transparent paper marked with an arrow as object, power supply, lens holder, white screen and metre rule

Material: Graph paper

Download table

http://bt.sasbadi.com/p4255a

A Convex lens

Instructions:

1. Set up the apparatus as shown in Figure 6.33.

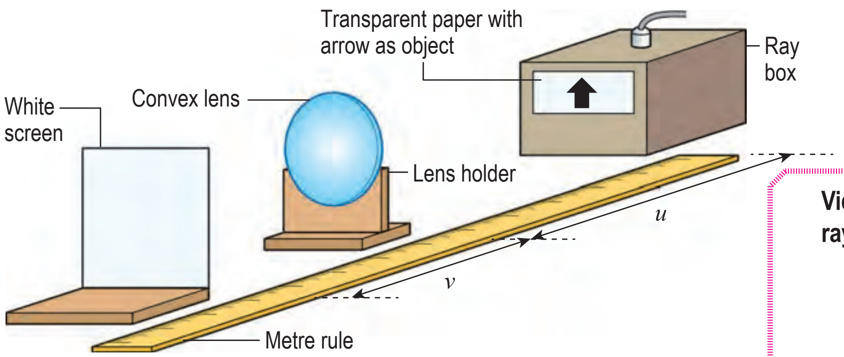


Figure 6.33

Video on steps to draw ray diagram

http://bt.sasbadi.com/p4255b

2. Place the convex lens so that its object distance, u = 30.0 cm, that is $u > 2f$. Adjust the position of the screen until a sharp image of the arrow is formed on the screen.
3. Observe the image formed on the screen and record its characteristics in a table. You can download and print the table from the website given.
4. Choose a suitable scale and draw the ray diagram for convex lens of f = 10.0 cm and u = 30.0 cm on a piece of graph paper. You can scan the QR code given for steps to draw complete ray diagrams.
5. Determine the position of image and record it in the table downloaded.
6. Repeat steps 2 to 5 for object distance u = 20.0 cm, 15.0 cm and 8.0 cm.

B Concave lens

Instructions:

1. Hold the concave lens at object distance, u = 20.0 cm, 15.0 cm and 10.0 cm in front of your eyes and look at the writing in your Physics textbook through the concave lens. Record the characteristics of the images you see in the table downloaded.
2. Draw the ray diagrams for concave lens of f = –10.0 cm with u = 20.0 cm, 15.0 cm and 10.0 cm on a piece of graph paper.

Discussion:

1. State the positions of convex lens which form real image and virtual image.
2. What are the common characteristics for real images formed by a convex lens?
3. What are the characteristics of images formed by a concave lens?

Table 6.7 and Table 6.8 show ray diagrams as well as characteristics of images for convex lens and concave lens respectively.

Table 6.7 *Formation of image by convex lens*

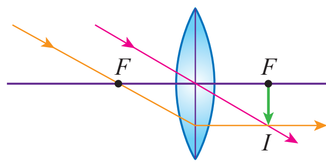
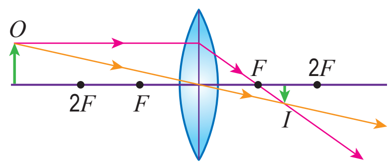
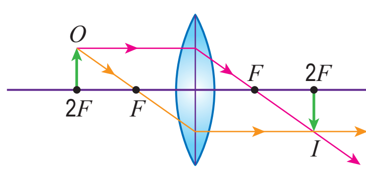
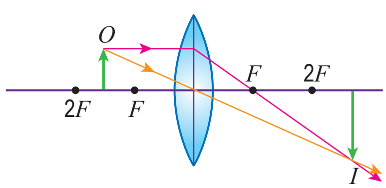
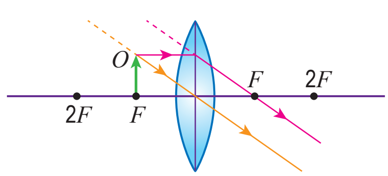
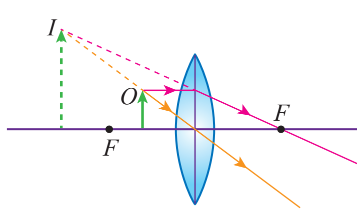
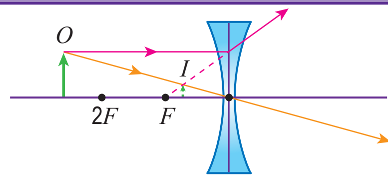
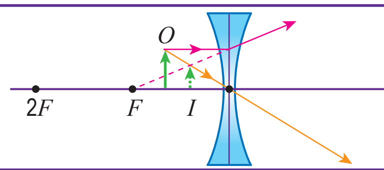
Object position	Ray diagram	Image position	Characteristics of image
Object at infinity		• Image distance: $v = f$ • Image at F	• Real • Inverted • Diminished
Object O beyond $2F$ ($u > 2f$)		• Image distance: $f < v < 2f$ • Image between F and $2F$	• Real • Inverted • Diminished
Object O at $2F$ ($u = 2f$)		• Image distance: $v = 2f$ • Image at $2F$	• Real • Inverted • Same size as object
Object O between F and $2F$ ($f < u < 2f$)		• Image distance: $v > 2f$ • Image beyond $2F$	• Real • Inverted • Magnified
Object O at F ($u = f$)		• Image at infinity	• Virtual • Upright • Magnified
Object O between F and optical centre ($u < f$)		• Image distance: $v > u$	• Virtual • Upright • Magnified

Table 6.8 Formation of image by concave lens

Object position	Ray diagram	Image position	Characteristics of image
Object O beyond $2F$ ($u > 2f$)		• Between optical centre and focal point • Image distance: $v < f$	• Virtual • Upright • Diminished
Object O between F and optical centre ($u < f$)		• Between optical centre and focal point • Image distance: $v < f$	• Virtual • Upright • Diminished

Linear Magnification

Observe Photograph 6.3. When an object is seen through a magnifying glass at a distance less than its focal length, the image formed is magnified. The size of the image formed by a convex lens depends on the position of the object.

Photograph 6.3 *Image magnified through a magnifying glass*

Activity 6.10

ICS

Aim: To generate ideas on magnification of image with the help of ray diagrams

Instructions:

1. Work in pairs.
2. Visit the websites given on the simulation of magnification using convex lens.
3. Choose a suitable object height. Begin with this object at a position far from the convex lens.
4. Move the object slowly closer to the lens. Observe how the position and size of the image change.
5. Sketch ray diagrams for the following situations:
   (a) Image size smaller than object size.
   (b) Image size larger than object size.

Discussion:

1. Which position of the convex lens forms
   (a) a magnified image?
   (b) a diminished image?
2. What is the relationship between image height, object height, image distance and object distance?

Simulation of magnification of image

http://bt.sasbadi.com/p4257a

http://bt.sasbadi.com/p4257b

6.3.3 6.3.4

Activity 6.10 shows that image size formed by a lens depends on the position of the object from the centre of the lens. Comparison between image size and object size is made based on the ratio of image height to object height. This ratio is known as **linear magnification**, ***m***.

$$\text{Linear magnification, } m = \frac{\text{image height, } h_i}{\text{object height, } h_o}$$

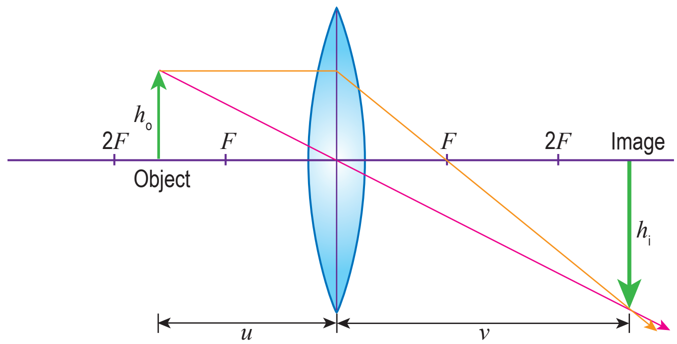


Figure 6.34 *Formation of image by convex lens*

Based on Figure 6.34, ratio of image height to object height is also the same as the ratio of image distance to object distance.

$$\text{Linear magnification, } m = \frac{\text{image distance, } v}{\text{object distance, } u}$$

As such, linear magnification can be formulated as,

$m = \dfrac{h_i}{h_o} = \dfrac{v}{u}$, where h_i = image height
h_o = object height
v = image distance
u = object distance

Info File

Linear magnification, m does not have a unit.

$m < 1$	Image diminished
$m = 1$	Image same size as object
$m > 1$	Image magnified

Formative Practice 6.3

Figure 6.35 shows an image seen through a convex lens with focal length of 10 cm.

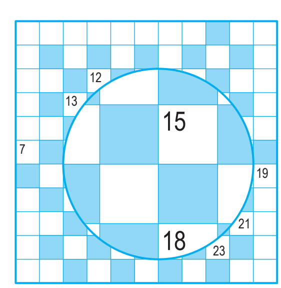


Figure 6.35

1. What are the characteristics of the image?
2. Draw a ray diagram to show how the image in the figure is formed.
3. Suggest a suitable position to place the object to produce an inverted image.

6.4 Thin Lens Formula

You have studied the use of ray diagrams to determine the position and characteristics of images formed by convex lens and concave lens. Other than ray diagrams, **thin lens formula** can be used to solve problems regarding lenses.

Thin lens formula gives the relationship between object distance, u, image distance, v and focal length, f for a lens as:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

(a) *Position of camera lens close to object produces a large image*

(b) *Position of camera lens far from object produces a small image*

Photograph 6.4 *Position of camera lens from object*

Photograph 6.4 shows the images for different object distances with a camera lens of the same focal length.

Experiment 6.3

Inference: Image distance is influenced by object distance

Hypothesis: When the object distance increases, the image distance decreases

Aim: (i) To study the relationship between object distance, u and image distance, v for a convex lens

(ii) To determine the focal length of a thin lens using lens formula

Variables:

(a) Manipulated variable: Object distance, u

(b) Responding variable: Image distance, v

(c) Constant variable: Focal length, f

Apparatus: Convex lens (f = 10.0 cm), lens holder, 6 V bulb, a wooden block, power supply, cardboard with a small triangular shaped hole, white screen and metre rule

6.4.1

Procedure:

1. Set up the apparatus as shown in Figure 6.36.

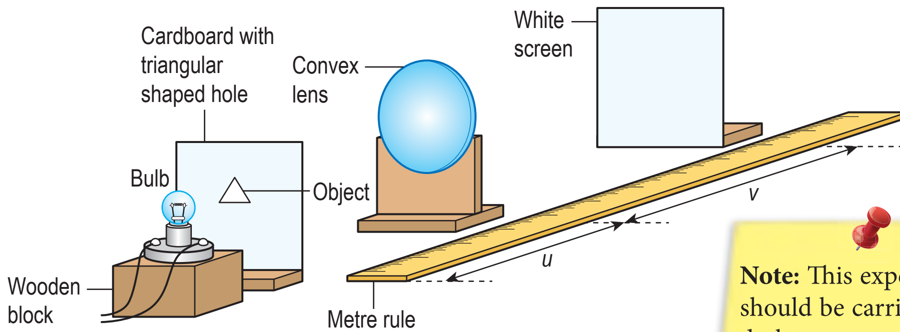


Figure 6.36

Note: This experiment should be carried out in a dark room.

2. Switch on the bulb and start the experiment with object distance, u = 15.0 cm. Adjust the position of the screen until a sharp image is formed.
3. Measure the image distance, v and record the reading in Table 6.9.
4. Repeat steps 2 and 3 with object distance, u = 20.0 cm, 25.0 cm, 30.0 cm and 35.0 cm. Record the readings in Table 6.9.

Video demonstration of non-parallax method

http://bt.sasbadi.com/p4260

Results:

Table 6.9

u / cm	v / cm	$\frac{1}{u}$ / cm^{-1}	$\frac{1}{v}$ / cm^{-1}
15.0			
20.0			
25.0			
30.0			
35.0			

Analysis of data:

1. Plot a graph of $\frac{1}{v}$ against $\frac{1}{u}$.
2. Determine the gradient of the graph, m.
3. Determine the intercepts for both axes.
4. Using lens formula and the graph plotted, determine the focal length of the lens in this experiment.

Conclusion:

What conclusion can be made from this experiment?

Prepare a complete report for this experiment.

Discussion:

State a precaution to be taken to increase the accuracy of the results of this experiment.

Solving Problems Involving Thin Lens Formula

Table 6.10 Sign convention used in thin lens formula

	Positive (+)	Negative (–)
Focal length, f	Converging lens or convex lens	Diverging lens or concave lens
Image distance, v	• Real image • On the opposite side of the object	• Virtual image • On the same side as the object

Example 1

A thin convex lens has a focal length of 12 cm. Determine the characteristics and the position of the images formed and linear magnification when the object distance is:

(a) 18 cm

(b) 4 cm

Solution:

(a) $u = +18$ cm

$f = +12$ cm

Thin lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

$$= \frac{1}{12} - \frac{1}{18}$$

$$v = +36 \text{ cm}$$

Linear magnification, $m = \frac{v}{u}$

$$= \frac{36}{18}$$

$$= 2$$

Image is real, inverted and magnified. Image is located 36 cm from the lens and on the opposite side of the object. Image is magnified 2 times.

(b) $u = +4$ cm

$f = +12$ cm

Thin lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

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

$$v = -6 \text{ cm}$$

Linear magnification, $m = \frac{v}{u}$

$$= \frac{6}{4}$$

$$= 1.5$$

Image is virtual, upright and magnified. Image is located 6 cm from the lens and on the same side as the object. Image is magnified 1.5 times.

6.4.2

Example 2

An object with a height of 9 cm is placed 60 cm from a concave lens with a focal length of 30 cm. Determine the position and size of the image formed. State the characteristics of the image formed.

Solution:

$u = +60$ cm
$f = -30$ cm

Thin lens formula, $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-30} - \frac{1}{60}$$

$$v = -20 \text{ cm}$$

Linear magnification, $m = \dfrac{h_i}{h_o} = \dfrac{v}{u}$

$$\frac{h_i}{9} = \frac{20}{60}$$

$$h_i = 3 \text{ cm}$$

Image is virtual, upright and diminished. Image is 20 cm from the lens and is on the same side as the object. Image height is 3 cm.

Example 3

Figure 6.37 shows a straight wire placed along the principal axis of a thin convex lens with a focal length of 12 cm. *X* and *Y* are 24 cm and 18 cm respectively from the lens. A cricket takes 6 seconds to move from *X* to *Y*. What is the speed of the cricket's image?

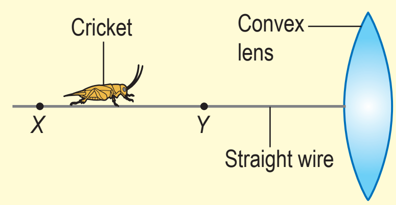


Figure 6.37

Solution:

$u_1 = +18$ cm $\quad u_2 = +24$ cm $\quad f = +12$ cm

Thin lens formula, $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

$$\frac{1}{v_1} = \frac{1}{f} - \frac{1}{u_1} = \frac{1}{12} - \frac{1}{18}$$

$$v_1 = +36 \text{ cm}$$

$$\frac{1}{v_2} = \frac{1}{f} - \frac{1}{u_2} = \frac{1}{12} - \frac{1}{24}$$

$$v_2 = +24 \text{ cm}$$

Speed of the cricket's image $= \dfrac{36 - 24}{6}$

$= 2 \text{ cm s}^{-1}$

Formative Practice 6.4

1. A concave lens with a focal length of 25 cm forms a virtual image of an ant at a distance of 20 cm from the optical centre of the lens.
   (a) What is the original position of the ant?
   (b) Draw a ray diagram to show the formation of a virtual image of the ant.
2. A small bulb is at a distance of 1.6 m from the screen and a thin convex lens with a focal length of 30 cm is placed between the bulb and the screen. Determine two positions of the convex lens that can produce a sharp image on the screen.

6.5 Optical Instruments

Use of Lenses in Optical Instruments

Lenses in optical instruments have many benefits in our daily lives.

Activity 6.11

Aim: To study the use of lenses in optical instruments

Instructions:

1. Work in groups.
2. Gather information from reading resources or websites on the use of lenses in optical instruments, such as magnifying glass, compound microscope and telescope in the following aspects:
   (a) Use of lenses in the optical instrument
   (b) Function of the lenses used
3. Present your findings.

Use of lenses in optical instruments

http://bt.sasbadi.com/p4263

Activity 6.12

ISS ICS

Aim: To justify the usage of lenses in optical instruments

Apparatus: Magnifying glass, compound microscope and telescope

Instructions:

1. Place the magnifying glass, compound microscope and telescope on separate tables.
2. Divide the class into three groups. Each group is given 20 minutes to observe objects through the optical instruments and study the structure of the optical instruments.
3. Record the findings.

Discussion:

1. State the characteristics of the images formed by the lenses used in magnifying glass, compound microscope and telescope.
2. Justify the usage of lenses in magnifying glass, compound microscope and telescope.

(a) Magnifying glass

(b) Microscope

(c) Telescope

Photograph 6.5

6.5.1

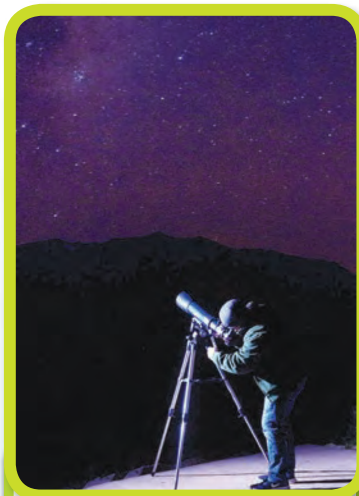
Figure 6.38 shows the uses of lenses in optical instruments such as magnifying glass, compound microscope and telescope.

- I am a gemologist. I use a magnifying glass to identify and evaluate gemstones.

- I am an ophthalmologist. I use a magnifying glass to examine eyes.

- I am a microbiologist. I use a microscope to examine various microorganisms.

- I am a geologist. I use a microscope to study and identify specimens of rocks and minerals.



- I am an astronomer. I use a telescope to study celestial objects.

Figure 6.38 Uses of lenses in optical instruments

Video on the discovery of image of black hole using *Event Horizon Telescope*

http://bt.sasbadi.com/p4264

INTEGRATION OF HISTORY

In 1609, Galileo Galilei (1564–1642) invented the telescope to observe the four Moons which orbited Jupiter. This success triggered a revolution in astronomical studies.

INTEGRATION OF HISTORY

In the mid-17th century, Antonie van Leeuwenhoek (1632–1723) successfully invented the single-lensed microscope that can make linear magnifications of 300 times. He succeeded in observing and drawing microorganisms.

Designing and Building Compound Microscopes and Telescopes Using Convex Lenses

Activity 6.13

ISS ICS

Aim: To design and build a compound microscope and a telescope using convex lenses

Instructions:

1. Work in groups.
2. Gather information on compound microscope and telescope from reading resources or websites based on the following:
   (a) Type of lens used and its function
   (b) Criteria for choosing objective lens and eyepiece lens of a compound microscope which can produce the largest image
   (c) Criteria for choosing objective lens and eyepiece lens of a telescope which can produce the clearest and brightest image
   (d) Draw ray diagrams to show the formation of images in compound microscope and telescope
3. Discuss the information and complete the K-W-L Chart as a guide to design and build your compound microscope and telescope. You can download and print the form from the website given.
4. Sketch the design of your compound microscope and telescope.
5. Build your compound microscope and telescope based on your sketch.
6. Comment on the effectiveness of the design and improve on the design produced.
7. Present your group's design, and the compound microscope and telescope built.

Video on the working principle of microscope

http://bt.sasbadi.com/p4265a

Video on the working principle of telescope

http://bt.sasbadi.com/p4265b

Download K-W-L Chart

http://bt.sasbadi.com/p4265c

Compound Microscope

- Made up of two convex lenses with short focal lengths. Objective lens has focal length, f_o and eyepiece lens has focal length, f_e. Focal length f_o is less than focal length f_e.
- Distance between objective lens and eyepiece lens > $f_o + f_e$.
- Object distance is between f_o and $2f_o$. Objective lens forms the first image, I_1 which is real, inverted and magnified. I_1 lies between F_e and the optical centre of the eyepiece lens and becomes the object for the eyepiece lens.
- Eyepiece lens functions as a magnifying glass. Eyepiece lens forms the final image, I_2 which is **virtual**, **magnified** and **inverted** compared to object O (Figure 6.39).
- Normally, eyepiece lens is adjusted so that the final image, I_2 is at the near point of the observer's eye to achieve the clearest vision.

Info File

Normal adjustment of a compound microscope can be done by adjusting the eyepiece lens so that the final image is formed at the near point of the eye, which is 25 cm away.

Magnification of compound microscope

http://bt.sasbadi.com/p4266

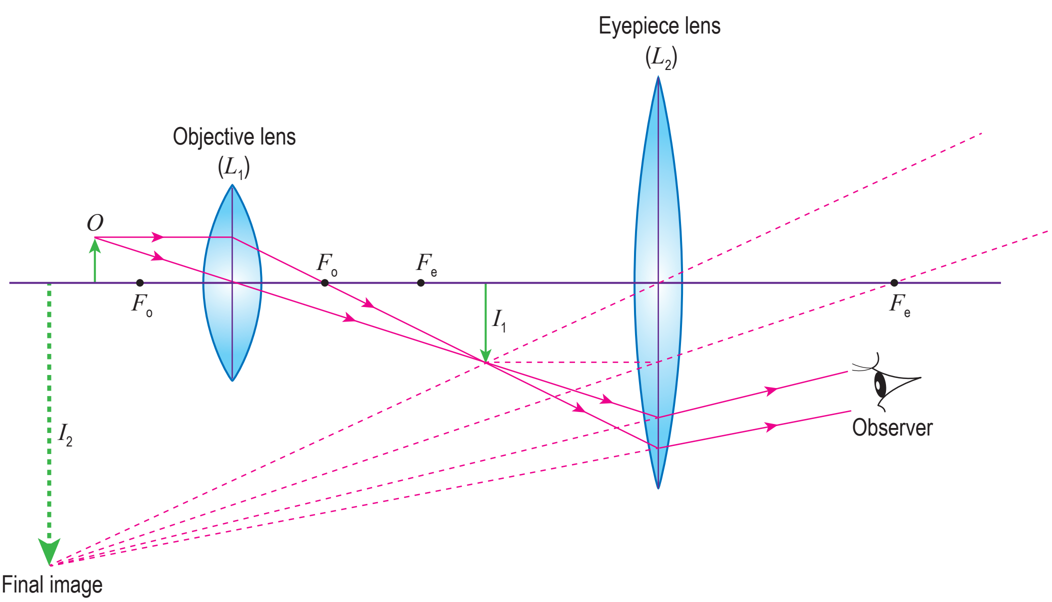


Figure 6.39 *Formation of image by a compound microscope*

Telescope

- Made up of two convex lenses. Objective lens has a long focal length, f_o and eyepiece lens has a short focal length, f_e. Distance between objective lens and eyepiece lens is $f_o + f_e$.
- Parallel rays from a distant object can be focused at the focal plane of the objective lens to form the first image, I_1 which is real, inverted and diminished. The first image, I_1 acts as the object for the eyepiece lens. Eyepiece lens forms the final image, I_2 which is **virtual**, **magnified** and **inverted** compared to the object (Figure 6.40).
- Normally, image I_2 is located at infinity. This is known as **normal adjustment**.

Info File

Normal adjustment of telescope can be done by adjusting the distance between the objective lens and the eyepiece lens, $L = f_o + f_e$. This enables the final image to be formed at infinity for a comfortable vision.

Magnification of telescope at normal adjustment, M is

$$M = \frac{f_o}{f_e}.$$

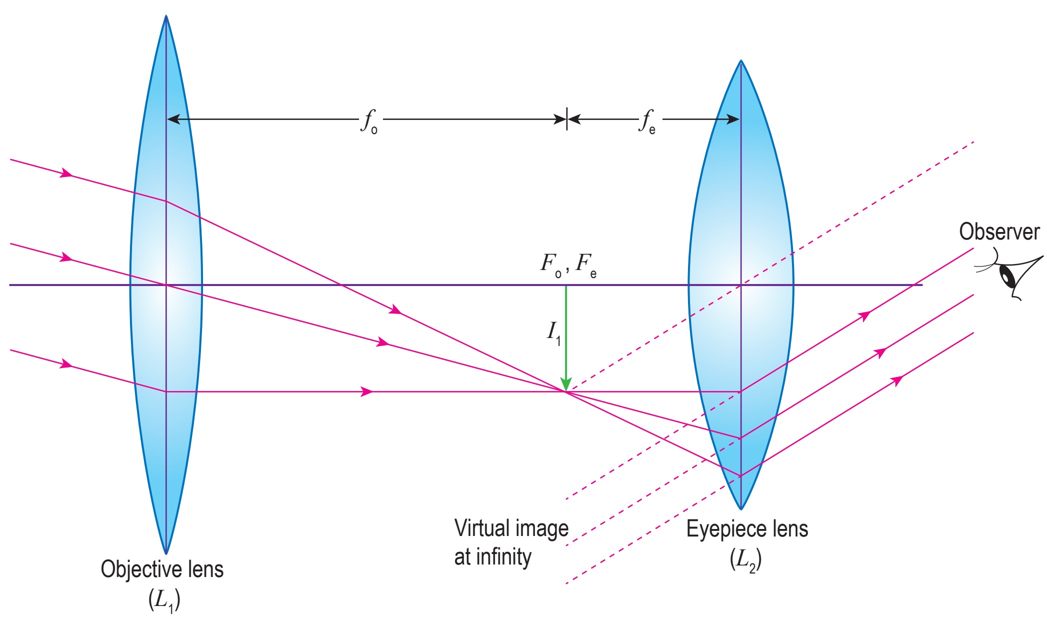


Figure 6.40 *Formation of image by a telescope*

Applications of Small Lenses in Optical Instrument Technology

The advancement of technology in optical instruments has successfully produced small lenses. These lenses are widely used in smartphone cameras and closed circuit television (CCTV).

Activity 6.14

ISS ICS

Aim: To discuss the application of small lenses in optical instruments

Instructions:

1. Work in groups.
2. Gather information on the application of small lenses in smartphone cameras and CCTV based on the following aspects:
   (a) Use of small lenses in optical instruments
   (b) Function of the small lenses

Photograph 6.6 *Lenses in a smartphone camera*

Photograph 6.7 *Small size CCTV*

Small lenses in smartphones

http://bt.sasbadi.com/p4268

3. Present your findings in graphic form.

Normally, smartphones and CCTV have cameras of high resolution to capture pictures and record videos clearly. As such, lens is the most important component in smartphone cameras and CCTV. Thin smartphones and small size CCTV have small size convex lens. This lens can form an image that is **real**, **diminished** and **inverted** at the sensor. Minimum distance between the sensor and the centre of the lens has to be the same as the focal length of the camera lens as shown in Figure 6.41. As the focal length of the camera lens cannot be of zero value, the overall thickness of a smartphone and CCTV is limited to the focal length of the camera lens.

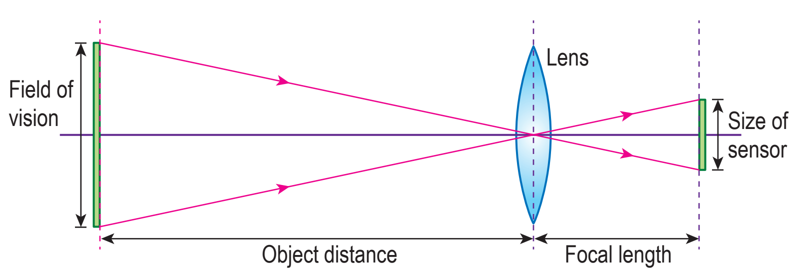


Figure 6.41 *Formation of image by small lens in smartphone camera and CCTV*

Activity 6.15

Logical Reasoning ISS ICS

Aim: To discuss the limitation to the thickness of a smartphone due to the thickness of camera lens

Instructions:

1. Work in groups.
2. Discuss the limitation to the thickness of a smartphone due to the thickness of camera lens.
3. You can obtain information through reading resources or websites.
4. Present your findings.

Formative Practice 6.5

A pupil is supplied with an eyepiece lens which has focal length, $f_e = 7$ cm and four pieces of objective lenses *A*, *B*, *C* and *D* as shown in Table 6.11.

Table 6.11

Lens	Focal length of objective lens, f_o / cm	Magnification of telescope, M	Diameter of objective lens / cm
A	14		5.0
B	14		10.0
C	70		5.0
D	70		10.0

1. Complete Table 6.11.
2. State two lenses which can produce the largest image.
3. State two lenses which can produce the brightest image.
4. Based on your answers in **2** and **3**, state the most suitable lens to be used as the objective lens of a telescope. Explain your answer.

6.6 Image Formation by Spherical Mirrors

Spherical mirrors are part of a sphere that has been cut as shown in Figure 6.42. If the inner surface of the part that has been cut reflects light, the mirror is a **concave mirror**. If the outer surface of the part that has been cut reflects light, the mirror is a **convex mirror**.

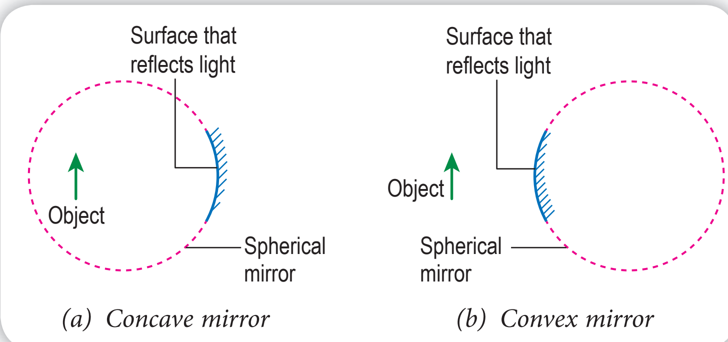


Figure 6.42 *Spherical mirror*

Photograph 6.8 *Images formed by surface of spoon*

Look at Photograph 6.8. Concave surface and convex surface of a steel spoon act as concave mirror and convex mirror respectively. Can you state the characteristics of the images formed by concave surface and convex surface of the spoon?

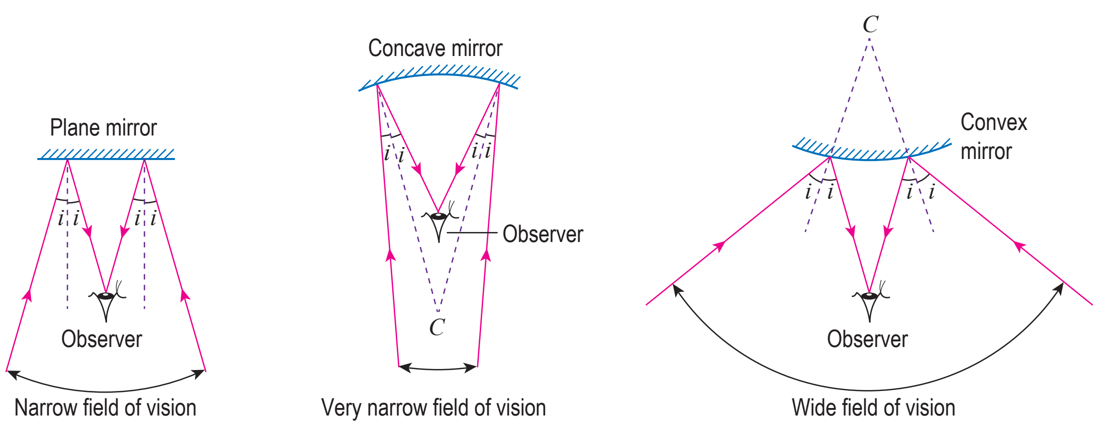


Figure 6.43 *Fields of vision in front of plane mirror, concave mirror and convex mirror*

Figure 6.43 shows the fields of vision of an observer in front of a plane mirror, concave mirror and convex mirror of the same size.

Formation of image by spherical mirrors

http://bt.sasbadi.com/p4270

Activity 6.16

ICS

Aim: To gather information on optical terms related to spherical mirrors

Instructions:

1. Work in groups.
2. Gather information from various reading resources and websites regarding the following terms:
   - principal axis
   - object distance, u
   - focal length, f
   - radius of curvature of mirror, r
   - focal point, F
   - image distance, v
   - centre of curvature, C
3. Present your findings.

Figure 6.44 shows the optical terms as used in spherical mirror ray diagrams. Table 6.12 explains these optical terms.

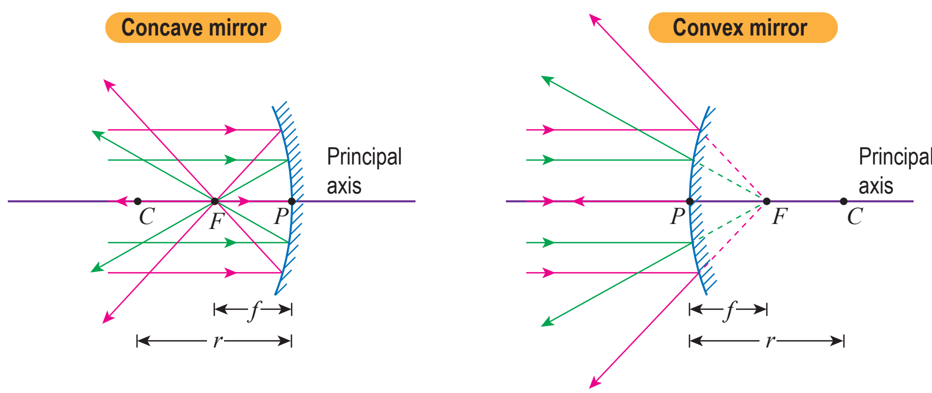


Figure 6.44 *Ray diagrams of spherical mirrors*

Table 6.12 *Explanation of optical terms related to spherical mirrors*

Optical Term	Explanation
Principal axis	Straight line passing through the centre of curvature, C and pole of the spherical mirror, P
Centre of curvature, C	Centre of sphere which produces a concave or convex mirror
Radius of curvature of mirror, r	Distance between the pole of spherical mirror, P and the centre of curvature, C
Focal point, F	A point on the principal axis of the spherical mirror, • for concave mirror, light rays which are parallel to the principal axis will converge at this point • for convex mirror, light rays which are parallel to the principal axis appear to diverge from this point
Object distance, u	Distance between object and the pole of spherical mirror, P
Image distance, v	Distance between image and the pole of spherical mirror, P
Focal length, f	Distance between focal point, F and the pole of spherical mirror, P

6.6.1

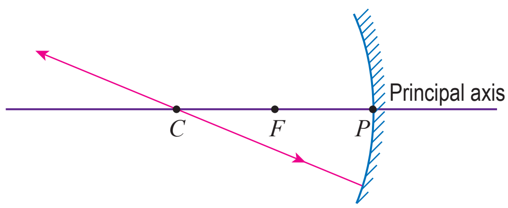
Guide to Drawing Spherical Mirror Ray Diagrams

Look at the guide in Table 6.13 to draw ray diagrams of spherical mirrors.

Table 6.13 *Guide on drawing ray diagrams of spherical mirrors*

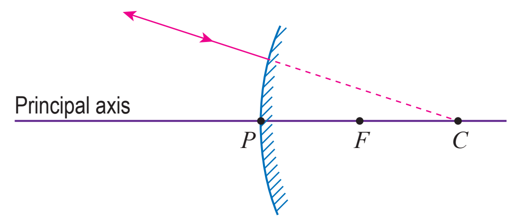
<table>
<tr><th>Concave mirror</th><th>Convex mirror</th></tr>
<tr><td>

1. Light ray passing through C is reflected back to its original path.



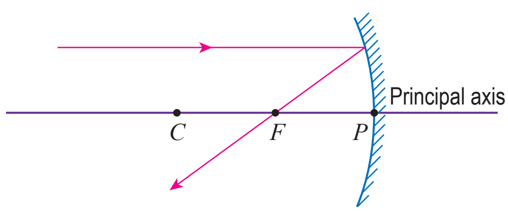
</td><td>

1. Light ray travelling towards C is reflected back to its original path



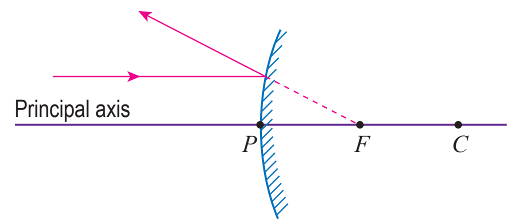
</td></tr>
<tr><td>

2. Light ray parallel to principal axis is reflected to the focal point, F.



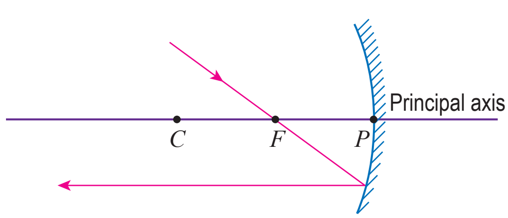
</td><td>

2. Light ray parallel to principal axis is reflected as if it originates from the focal point, F.



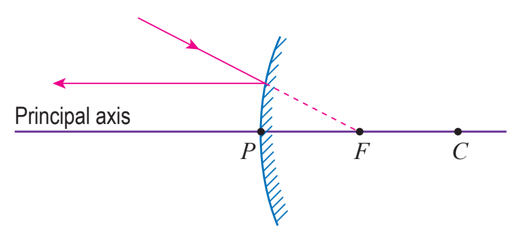
</td></tr>
<tr><td>

3. Light ray passing through F is reflected parallel to the principal axis.



</td><td>

3. Light ray travelling towards F is reflected parallel to the principal axis.



</td></tr>
</table>

SMART INFO

Radius of curvature of mirror, r is two times the focal length of the spherical mirror, f, that is $r = 2f$.

6.6.1

Activity 6.17

ICS

Aim: To draw ray diagrams to show the image position and determine the characteristics of images formed by a concave mirror and a convex mirror

Instructions:

1. Work in groups.
2. Visit the websites given and carry out the simulation in the websites.
3. Based on the simulation, complete Table 6.14 and Table 6.15. You can download and print the tables from the websites given.
4. Draw ray diagrams to show the image position and state the characteristics of images formed by concave mirror and convex mirror.

Simulation of images for concave mirror and convex mirror

http://bt.sasbadi.com/p4273a

Download Table 6.14 and Table 6.15

http://bt.sasbadi.com/p4273b

***Table 6.14** Position and characteristics of images by a concave mirror*

Object position	Ray diagram	Image position	Characteristics of image
Object at infinity			
Object beyond C ($u > 2f$)			
Object at C ($u = 2f$)			
Object between F and C ($f < u < 2f$)			
Object at F ($u = f$)			
Object between F and P ($u < f$)			

***Table 6.15** Position and characteristics of images by a convex mirror*

Object position	Ray diagram	Image position	Characteristics of image
Object beyond F ($u > f$)			
Object between F and P ($u < f$)			

6.6.1

Table 6.16 Position and characteristics of images by a concave mirror

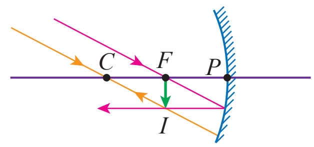
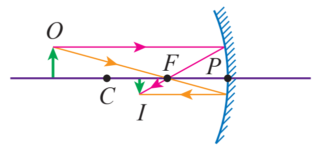
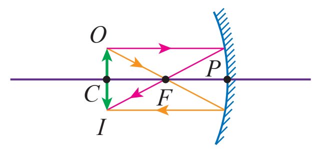
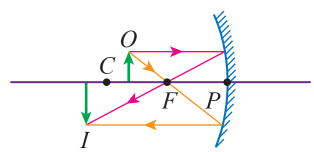
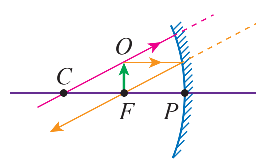
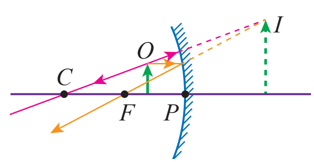
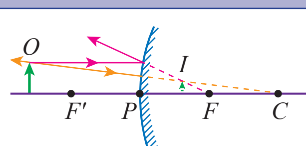
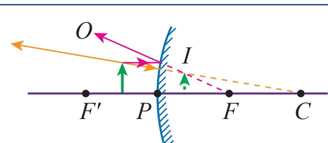
Object position	Ray diagram	Image position	Characteristics of image
Object at infinity		• Image distance: $v = f$ • In front of mirror	• Real • Inverted • Diminished
Object beyond C ($u > 2f$)		• Image distance: $f < v < 2f$ • In front of mirror	• Real • Inverted • Diminished
Object at C ($u = 2f$)		• Image distance: $v = 2f$ • In front of mirror	• Real • Inverted • Same size as object
Object between F and C ($f < u < 2f$)		• Image distance: $v > 2f$ • In front of mirror	• Real • Inverted • Magnified
Object at F ($u = f$)		• Image at infinity • Behind mirror	• Virtual • Upright • Magnified
Object between F and P ($u < f$)		• Image distance: $v > u$ • Behind mirror	• Virtual • Upright • Magnified

Table 6.17 Position and characteristics of images by a convex mirror

Object position	Ray diagram	Image position	Characteristics of image
Object beyond F ($u > f$)		• Image distance: $v < f$ • Behind mirror	• Virtual • Upright • Diminished
Object between F and P ($u < f$)		• Image distance: $v < f$ • Behind mirror	• Virtual • Upright • Diminished

6.6.1

Applications of Concave Mirror and Convex Mirror in Daily Life

Photograph 6.9 shows a blind spot mirror. This mirror is a convex mirror. What is the use of this mirror?

Photograph 6.9
Blind spot mirror

Activity 6.18

ISS ICS

Aim: To gather information to justify the use of concave mirror and convex mirror in daily life

Instructions:

1. Work in groups.
2. You can gather information from reading resources in the library or the websites regarding:
   (a) the use of concave mirror and convex mirror in daily life.
   (b) the importance of the mirrors.
3. Present your findings in a mind map.

Applications of Concave Mirrors in Daily Life

Cosmetic mirror
A concave mirror is used as a cosmetic mirror to produce a magnified image for applying make up.

Dental mirror
A dental mirror forms an upright and magnified image to examine the teeth.

Reflector in car headlight
A parabolic concave mirror is used as a reflector in car headlights to maintain light intensity even at a distance.

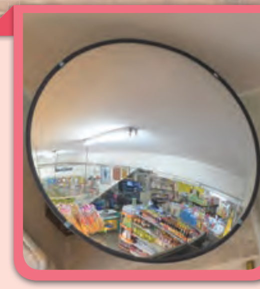
Figure 6.45 *Applications of concave mirrors in daily life*

6.6.2

Applications of Convex Mirrors in Daily Life

Blind spot mirror
A convex mirror is placed at sharp corners to widen the field of vision of the driver.

Security mirror in buildings
Convex mirrors are used in buildings or shopping centres for surveillance purposes.



Vehicle rear mirror
Vehicle rear mirrors provide a wide field of vision to enable the driver to see vehicles coming from behind.

Figure 6.46 *Applications of convex mirrors in daily life*

Formative Practice 6.6

1. Figure 6.47 shows a pupil looking in the direction of a plane mirror and a convex mirror of the same size.
   (a) Complete the path of light for both types of mirrors.
   (b) Which type of mirror can produce a wider field of vision?

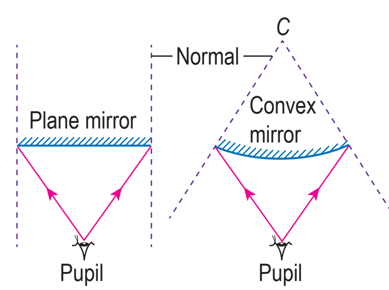


Figure 6.47

2. Adelia holds a shiny steel spoon with its back (convex surface) facing her eyes at a distance of approximately 30 cm. She sees an upright image of herself. However, when the spoon is changed so that the front (concave surface) of the spoon is facing her eyes, an inverted image is observed.
   (a) Explain this situation.
   (b) Why is an upright image not seen on the front surface of the spoon at that distance?

Conceptual Framework

Light and Optics

- **Refraction of Light**
  - Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
  - Refractive index, n
    - $n = \dfrac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \dfrac{c}{v}$
    - $n = \dfrac{\sin i}{\sin r}$
    - $n = \dfrac{\text{real depth}}{\text{apparent depth}} = \dfrac{H}{h}$
- **Total Internal Reflection**
  - Critical angle, c
    - $n = \dfrac{1}{\sin c}$
      - Applications
        - Natural phenomena
          - Rainbow
          - Mirage
        - Daily life
          - Optical fibre
          - Prism periscope
          - Cat's eye reflector
- **Formation of Image**
  - Lens
    - Convex lens
    - Concave lens
      - Thin lens formula: $\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$
        - Optical instruments
          - Magnifying glass
          - Compound microscope
          - Telescope
          - Small lens in smartphone cameras and closed circuit television (CCTV)
  - Spherical mirror
    - Concave mirror
    - Convex mirror
      - Applications in daily life
        - Concave mirror
          - Reflector in car headlights
          - Dental mirror
          - Cosmetic mirror
        - Convex mirror
          - Blind spot mirror
          - Security mirror in buildings
          - Rear view mirror of vehicles

Interactive QUIZ

http://bt.sasbadi.com/p4277

SELF-REFLECTION

1. New things I learnt in this chapter on light and optics are ______________.
2. The most interesting thing I learnt in the chapter on light and optics is ______________.
3. Things I still do not fully understand or comprehend are ______________.
4. My performance in this chapter,

   Poor | 1 | 2 | 3 | 4 | 5 | Excellent

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

Download and print Self-reflection Chapter 6

http://bt.sasbadi.com/p4278

Performance Evaluation

1. Diamond is a precious stone that always appears shiny. Critical angle of diamond in air is 24°.
   (a) (i) What is the meaning of critical angle?
       (ii) Determine the value of refractive index of diamond.
   (b) Figure 1 shows three diamonds of different shapes. A ray enters each diamond as shown in Figure 1. Complete the path of light rays until the ray emerges again into air in Figure 1.

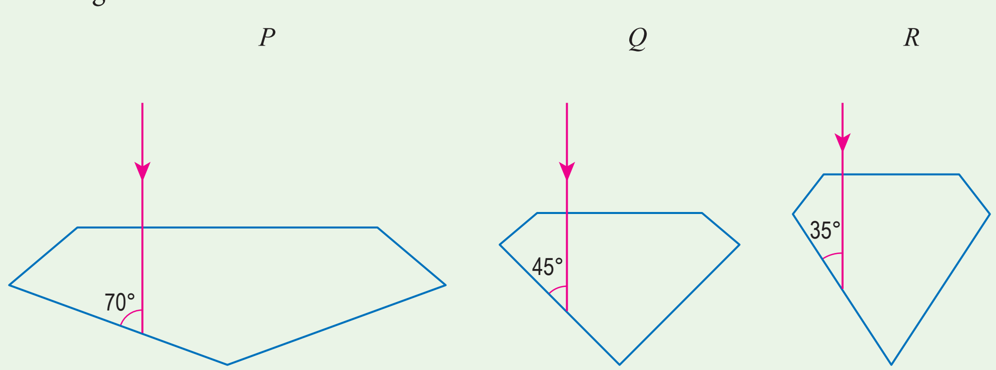


Figure 1

   (c) State the physics concepts involved in this phenomenon.

2. Figure 2 shows a glass block with a refractive index of 1.50 placed between the eyes of the observer, E and the object P. If the thickness of the glass is 30.0 cm, what is the distance between object P and its image?

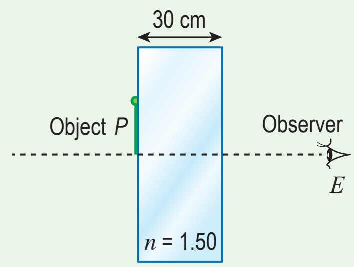


Figure 2

3. Figure 3 shows a light ray travelling from air to water and then entering a glass block. The refractive index of water is 1.33.

(a) Determine angle x.

(b) If speed of light in air is 3.0×10^8 m s^{-1}, what is the speed of light in water?

(c) Between water and glass, which medium has a higher optical density? Explain your answer based on Figure 3.

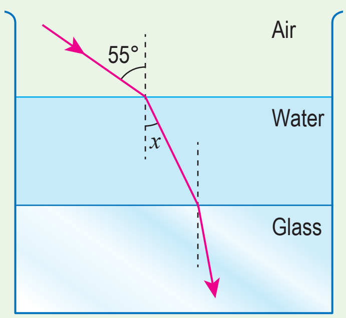


Figure 3

4. Mariam carried out an experiment with a semi-circular glass block and a ray box. Figure 4 shows the path of light ray entering the glass block at point R and travelling towards the centre of the semi-circular glass block, point S.

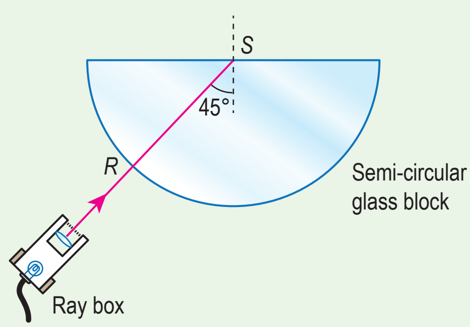


Figure 4

(a) Why does the light ray not change direction at point R?

(b) If the refractive index of the glass block is 1.52, determine the critical angle in this medium.

(c) Draw the path of light ray after point S and mark the value of the angle of the light ray with the normal at point S.

5. When light from a star travels into the Earth's atmosphere, its direction of travel will change. This situation is shown in Figure 5. The change of direction is represented by the angle $\Delta\theta = i - r$.

   (a) Speed of light in air is 299 910 km s^{-1} and speed of light in vacuum is 3.00×10^8 m s^{-1}.

      (i) Calculate the refractive index of air.

      (ii) Explain the value of refractive index obtained.

   (b) Value of $\Delta\theta$ on a hot night is different from that on a cold night. State a logical reason for the difference.

   (c) Rajiv returns from school in a school van on a hot and bright day. Rajiv can see a puddle of water on the surface of the road ahead. When the van reaches the location of the puddle of water, Rajiv discovers that the puddle of water does not actually exist. Explain this phenomenon.

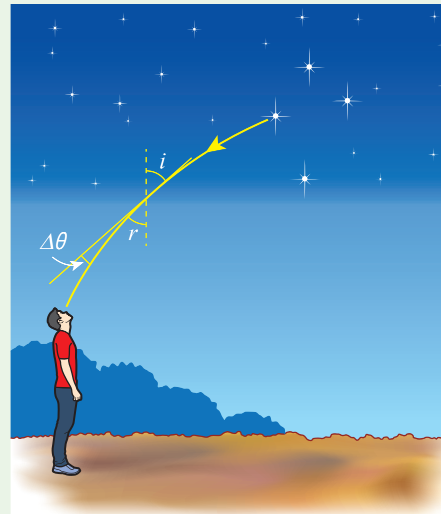


Figure 5

6. Figure 6 shows an object and its virtual image formed by a convex lens.

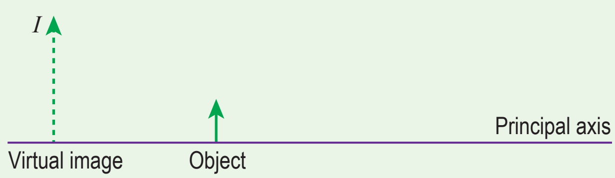


Figure 6

   (a) One of the characteristics of image I in Figure 6 is that it is virtual. State the other characteristics of image I.

   (b) Complete the ray diagram in Figure 6 and determine the position of the lens and focal point of the lens. Mark the position of the focal point of the lens with, F.

   (c) If the object is slowly moved away from the lens, state two changes that might happen to the image without drawing a ray diagram.

7. A sailor in the navy is looking at the situation on the surface of the sea through a submarine periscope. He found that the Sun is setting. The captain of the submarine told the sailor that the Sun had in fact already set.

   (a) Is the statement of the captain of the submarine true? Explain your answer.

   (b) Explain the formation of image in a prism periscope for object with obstruction in front with the help of suitable ray diagrams.

8. A lighted candle is placed in front of a concave mirror with a focal length of 2.4 cm. A white screen is moved behind the candle to catch a sharp image as shown in Figure 7.

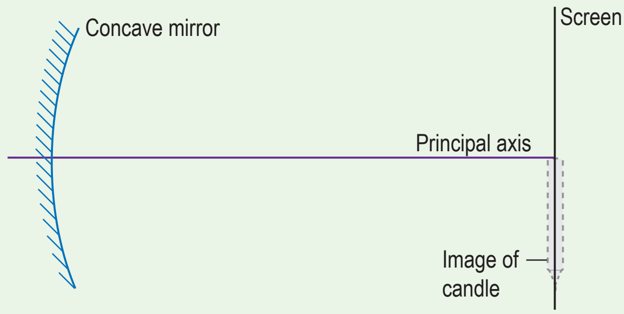


Figure 7

(a) On Figure 7,
  (i) mark the focal point of the mirror with *F* and centre of curvature with *C*.
  (ii) draw a complete ray diagram to determine the position of the object.

(b) How can the magnification of the image be increased?

9. (a) Explain the way to construct a compound microscope using two lenses. In your answer, state the type of lens that you chose, estimate the focal length of the lenses and characteristics of the image formed by each lens.

(b) Why is an astronomical telescope not suitable to be used to see distant objects on the surface of the Earth?

(c) How can you modify a compound microscope to become an astronomical telescope?

10. Table 1 shows the speed of light in vacuum and two materials for making optical fibre.

Table 1

Medium	Speed of light / m s^{-1}
Vacuum	3.00×10^8
Material I	2.01×10^8
Material II	1.96×10^8

(a) Identify suitable mediums to be used as core and cladding of optical fibre. Explain your answer.

(b) Determine the critical angle of the optical fibre.

(c) Why must the surface of optical fibre be very smooth?

Enrichment Corner

11. Amin carries out an experiment to investigate the relationship between real depth, H and apparent depth, h for an object in a liquid. The apparatus set up is shown in Figure 8. Pin A is placed at the base of a tall beaker. Liquid is poured into the beaker until pin A is at a depth of 5.0 cm. The real depth, H for pin A is the distance of the pin from the surface of the liquid.

Another pin, pin B is adjusted until the image of pin B in the plane mirror is in line with the image of pin A when observed from above as shown in Figure 9.

Apparent depth, h for pin A is the same as the distance between the image of pin B and the surface of the liquid. Distance x, can be determined by measuring the distance between pin B and the plane mirror. The distance from the surface of the liquid to the plane mirror, z is also measured.

This procedure is repeated for real depth of liquid, H = 10.0 cm, 15.0 cm, 20.0 cm, 25.0 cm and 30.0 cm. All readings are recorded in Table 2.

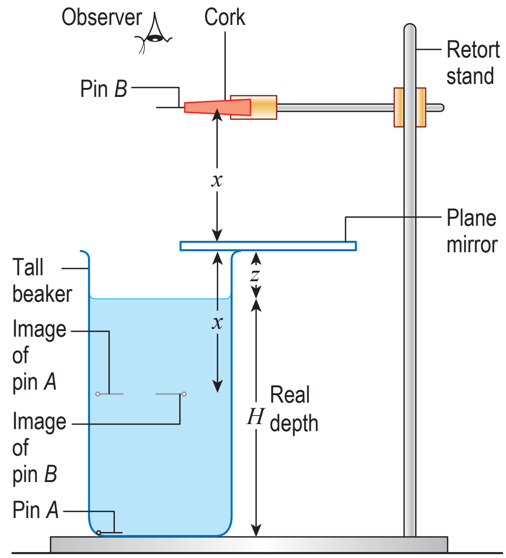


Figure 8

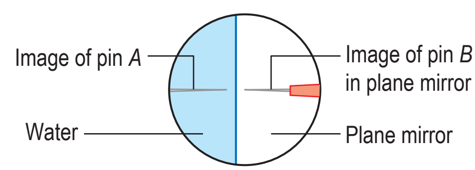


Figure 9

Table 2

H / cm	x / cm	z / cm	h / cm
5.0	30.8	27.0	
10.0	29.5	22.0	
15.0	28.3	17.0	
20.0	27.0	12.0	
25.0	25.8	7.0	
30.0	24.6	2.0	

(a) Based on the results of this experiment, determine the relationship between h and H and then deduce the value of the refractive index of the liquid.

(b) Draw suitable ray diagrams regarding the formation of images that can be seen by Amin.

(c) Discuss the importance of plane mirror and non-parallax method in this experiment.

Answers

ONLY SELECTED ANSWERS ARE PROVIDED HERE

Scan the QR code for complete answers
http://bt.sasbadi.com/p4283

Chapter 1 Measurement

Performance Evaluation

1. (a)

Base quantity	S.I. unit
Length	metre
Mass	kilogram
Time	second
Thermodynamic temperature	kelvin
Electric current	ampere
Luminous intensity	candela
Amount of substance	mole

(b) kg m^2 s^{-3}

2. (a) 1 m s^{-2}
(b) 15 m s^{-1}
(c) v increases linearly with t

3. (a)

T / s	1.30	1.80	2.22	2.55	2.86
T^2 / s^2	1.69	3.24	4.93	6.50	8.18

(c) 0.0817 s^2 g^{-1}
(d) Unchanged because the period of oscillation of a loaded spring does not depend on the value of the gravitational acceleration.
(e) From the graph of T^2 against m, use the method of extrapolation to determine the value of m when T^2 = 1.0 s, so T is equal to 1.0 s. Substitute the slotted weights with plasticine of mass m, about 12 g.

4. (a)

Pupil	Time, t / s	Speed, v / m s^{-1}
A	58.79	6.80
B	60.06	6.66
C	57.68	6.93
D	59.87	6.68
E	57.99	6.90

(b) You use an electronic stopwatch to measure the time of their motion.
(c) Pupil *C* is the fastest.
(d) Use an electronic sensor to prevent errors in measurement caused by the reaction time of humans when starting and stopping the stopwatch.

5. (a) In the old system, $F = mlt^{-2}$
$m = Ft^2l^{-1}$
Therefore, in *FAT* system
$l = A^{½}$, and
$m = FT^2l^{-1}$
$= FT^2A^{-\frac{1}{2}}$

(b) – No measuring instrument can measure force and area accurately.
– No instrument or object is used as standards for force and area
– Units for derived quantity become very complex and hinder effective communication among physicists

6. (a) – Straight line that does not pass through the origin and has a negative gradient.
– p decreases linearly with q
(b) – Curve that does not pass through the origin and has a negative gradient.
– p decreases with q
(c) – Horizontal straight line with zero gradient
– p constant or p does not depend on q

Chapter 2 Force and Motion I

Performance Evaluation

1. (a) 10.0 m s^{-1}
(b) 25.0 m
(c) 9.0 m

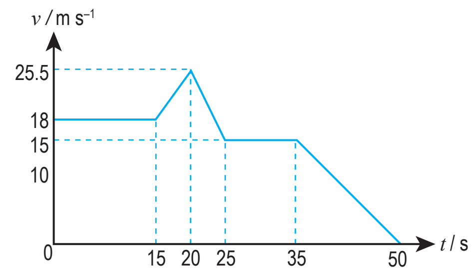
2. (a) –2.0 m s^{-2}
(b) 5 s

3. When Swee Lan paddles a boat on the river backwards, a force of action F is applied on the river water and simultaneously a force of reaction of the same magnitude but in the opposite direction to the direction of F acts on the boat. Therefore, the boat moves forward.

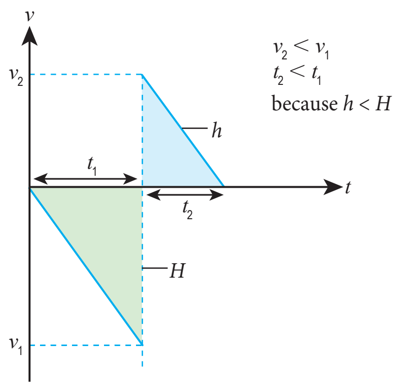
4. 12 s

5. 12 N

6. 100 m s^{-1}

7. 

$v = 25.5 \text{ m s}^{-1}$

8. 

9. (a) 7.5 s
   (b) 56.25 m
   (c) For the car, x_c = 900 m
   For the bus, x_b = 750 m
   (d) x_c is longer than x_b, therefore the car is in front of the bus

10. (a) Before the launch, the rocket carries a spacecraft at rest at the launch pad with zero momentum. During the launch, a large amount of fast moving hot gases is released through the exhaust. This creates/cause high downward momentum. According to the principle of conservation of momentum, an equally high but opposite momentum is produced. Hence, an upthrust gives an acceleration to the rocket.
    (b) Acceleration of the rocket can be increased by reducing the mass of the rocket.

Chapter 3 Gravitation

Performance Evaluation

1. (a) (i) $F = \dfrac{GMm}{r^2}$
   (ii) $F = \dfrac{mv^2}{r}$
   (iii) $v = \dfrac{2\pi r}{T}$
   (b) $M = \dfrac{4\pi^2 r^3}{GT^2}$
   (c) 1.99×10^{30} kg

2. (a) $v = \dfrac{2\pi r}{T}$
   (b) $v = \sqrt{\dfrac{GM}{r}}$
   (c) A free falling satellite orbits around Earth with a centripetal acceleration that equals to the gravitational acceleration. The gravitational acceleration does not depend on the mass of the object.

3. Kepler's Second Law states that a line that connects a planet to the Sun sweeps out equal areas in equal times. The shorter the distance of the plant from the Sun, the faster the velocity of the planet. From *A* to *B*, the speed of planet Uranus increases to a maximum value and then decreases.

4. (a) Satellite and the Moon as a pair
   (b) 7.71×10^3 N

5. (a) – Mass of the Earth
   – Distance from the centre of the Earth
   (b) 0.23 m s⁻²

6. (a) $\dfrac{T_1^{\,2}}{T_2^{\,2}} = \dfrac{r_1^{\,3}}{r_2^{\,3}}$
   (b) 4.49×10^{12} m

7. 29.44 years

8. 9 996 m s⁻¹

9. (a) 3.54×10^4 m s⁻¹
   (b) Small particles are unlikely to escape because of the very high escape velocity.

10. (i) $F_{BC} = 2P$
    (ii) $F_{AC} = 0.5P$

Chapter 4 Heat

Performance Evaluation

1. (a) Heat is absorbed or released during changes in phase without any change in temperature.
   (b) When steam is condensed into water, latent heat is released to heat up the water.
   (c) – Rapid heating.
   – Direct heating of water, that is without wasting heat to heat up the container.

2. (c) ✓

3. (a) Block *A*.
   (b) Block *B*. Block with a low specific heat capacity experiences higher increase in temperature.

4. (a) Specific latent heat is the quantity of heat absorbed or released by 1 kg of substance during a change in its phase without any change in its temperature.
   (b) 2.27×10^5 J

5. (a) Specific latent heat of vaporisation, l_v, of a substance is the quantity of heat absorbed by 1 kg of the substance when boiling or the quantity of heat released by 1 kg of the substance when condensing without any change in its temperature.

(b) (i) 0.28 kg
(ii) 2.25×10^6 J kg^{-1}

6. 4.95 J

7. (a) 2 200 W
(b) 513.6 s

8. (a) 264 kPa
(b) Volume of tyre remains unchanged

9. (a) 3.82 cm^3
(b) – Mass of the trapped air remains unchanged
– Pressure of the trapped air is constant
– Trapped air and water are in thermal equilibrium. The temperatures of water and air are the same.

10. (a) Specific latent heat of fusion, l_f, of a substance is the quantity of heat absorbed by 1 kg of the substance when melting or the quantity of heat released by 1 kg of the substance when freezing without any change in its temperature.
(b) Heat absorbed does not increase the average kinetic energy of the molecules. This heat is used to weaken the bonds between the molecules of ice.
(c) (i) 40 000 J (ii) 0.12 kg
(d) – All the heat absorbed by the ice is supplied by the immersion heater. No heat is lost to the surroundings.
– The ice does not absorb heat from the surroundings.

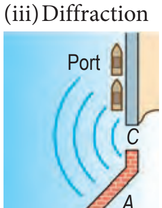
11. (a) (i) 147 000 J (ii) 183.75 s
(b) Plastics have high specific heat capacities and are good heat insulators.
(c) Metals have low specific heat capacities and are good heat conductors.
(d) Water rises when heated and cold water sinks through convection. So, all the water is heated. Therefore, the heating element of a kettle is fitted at the base of the kettle.

12. (a) Aluminium
(b) Aluminium has a low specific heat capacity and is a good conductor of heat. Therefore, aluminium is suitable for making cooking utensils.

Chapter 5 Waves

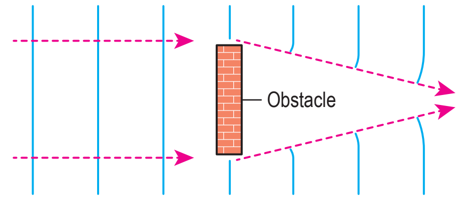
Performance Evaluation

1. (a) (i) Reflection
(ii) Refraction
(iii) Diffraction
(b)

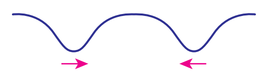


(c) Less diffraction and higher amplitude compare to diffraction through a narrow entrance.

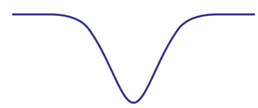
2.



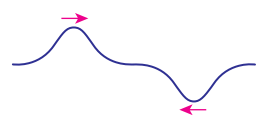
3. (a) – Same frequency
– Constant phase difference
(b) (i) *Q*, *S*
(ii) *P*, *R*
(c) (i) Before superposition



During superposition

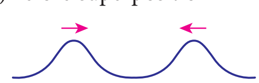


(ii) Before superposition

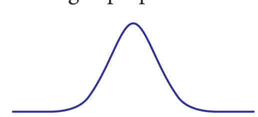


During superposition

(iii) Before superposition



During superposition



4. (a) Superposition of waves/Interference
(b) Bright fringes are formed when waves undergo constructive interference.
Dark fringes are formed when waves undergo destructive interference.
(c) 4.44×10^{-7} m

5. (a) Amplitude = 15 cm, Period = $\frac{1}{f} = \frac{1}{5} = 0.2$ s
(b) 3.0 m s^{-1}

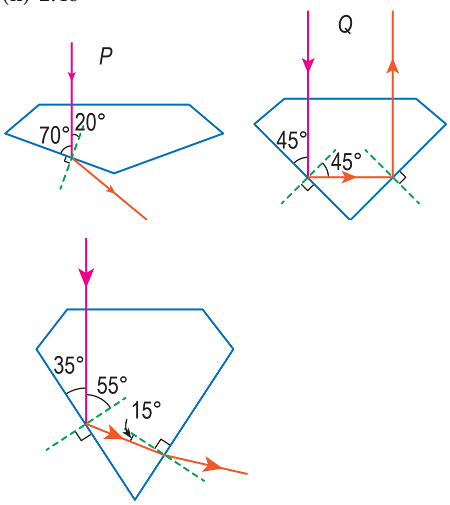
6. 335 m s^{-1}

7. (a) 0.25 cm
(b) 75 cm
(c) 33 000 cm s^{-1}

Performance Evaluation

1. (a) (i) Critical angle is the angle of incidence when light travels from diamond into air at the angle of refraction of 90°.
(ii) 2.46

(b)



(c) Total internal reflection and refraction of light

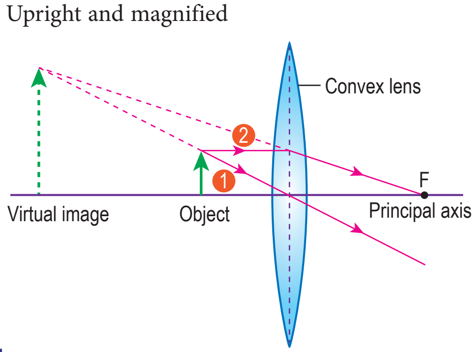
2. 10 cm

3. (a) 38.02°
(b) 2.26×10^8 m s^{-1}
(c) Glass has a higher optical density because when light travels from water to glass, the light is refracted towards the normal.

4. (a) *RS* is the radius of a semi-circle and is the normal to the incident ray at point *R*, $i = 0$, so $r = 0$.
(b) 41.14°

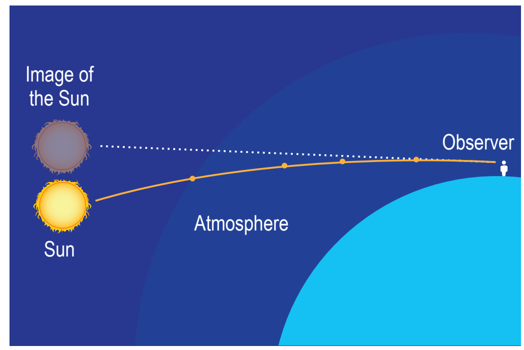
5. (a) (i) 1.0003
(ii) The value of the refractive index of air is almost equal to 1, that is the speeds of light in air and in vacuum are almost the same.
(b) The value $\Delta\theta$ on a hot night is different from that on a cold night because the optical density of air depends on temperature.

6. (a) Upright and magnified
(b)

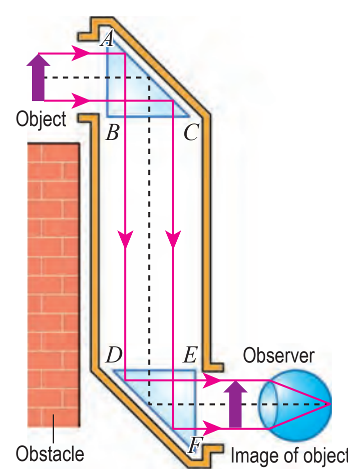


(c) A real, inverted, diminished and formed on the opposite side of the object from the lens.

7. (a) The captain's statement is true. The light ray that enters the atmosphere is refracted by the layers of air having different optical densities. Therefore, a virtual image of the Sun is formed above the actual position of the Sun.



(b) The light rays from the object travel towards the side *AB* of the upper prism along the normal to *AB* through an opening in the periscope. The light rays reach the side *AC* without refraction. The angle of incidence is 45° and is larger than the critical angle of the prism, 42°. Therefore, total internal reflection happens at the side *AC* and the light is reflected downwards. The reflected light rays travel towards the side *DE* of the lower prism along the normal to *DE*. Once again, the light ray experiences total internal reflection at the side *DF*. In the end, the light rays emerge from side *EF* without refraction and enters the eye of the observer. The final image formed is upright and equal in size to the object.



Glossary

Accuracy	Degree of closeness of the value of measurement to the actual value
Angle of incidence	The angle between an incident ray and the normal
Angle of refraction	The angle between the refracted ray and the normal
Apparent depth	Distance between the image of an object in an optical medium and the surface of the optical medium facing the observer
Boiling point of water	Constant temperature at which water changes into steam
Bright fringe	Light band formed by constructive interference
Concave	A shape that is curved inwardly
Convex	A shape that is curved outwardly
Dark fringe	Light band with minimum brightness formed by destructive interference
Diffraction	Spreading of waves when the wave moves around corners and edges
Displacement	Shortest distance between the starting position and the final position in a specified direction
Energy	Ability to do work
Force	Rate of change of momentum acting on an object in the direction of change of momentum of the object
Gas laws	Laws that relate absolute temperature, pressure and volume of a fixed mass of gas
Geostationary	Always above the same geographical location on Earth
Gravitational force	Force of attraction between any two bodies
Heliocentric model	Model of the Solar System in which the Sun is at the centre and the planets move around the Sun
Linear	Straight line
Linear magnification	Ratio of image height to object height
Magnitude	Numerical value of a physical quantity
Melting point of ice	Constant temperature at which ice changes into water

Momentum	Product of mass and velocity of a moving object
Normal line	A line perpendicular to the tangent at a point on a surface
Optical density	A property of a transparent medium that influences the speed of propagation of light in the medium
Orbit	A closed path through which object in space moves around a planet or a star
Real depth	Distance between an object in an optical medium and the surface of the optical medium facing the observer
Real image	Image that can be formed on a screen
Refraction	Bending of light when light ray propagates through medium of different optical densities
Ripple generator	Device fitted with a motor or vibrator to produce water waves
Superposition	Overlapping of two waves at a point
Temperature	Degree of hotness of a substance
Vacuum	Space entirely devoid of matter
Virtual image	Image that cannot be formed on a screen

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