CHAPTER 1

Measurement of Physical Quantities

PHYSICS WATCH

Scan this page to watch a clip about physical measurements of a baby.

QUESTIONS

- What do you understand by the term *average*?
- Other than head circumference, what are two other important measurements taken to monitor a baby's growth pattern?
- What are some other physical quantities that are commonly used as measurements in daily life?

From the day you were born, you were being measured. You wouldn't remember, but your parents probably took you to the clinic several times to have you measured. The measurements taken were then plotted to monitor your growth pattern.

Head circumference is an important measurement to monitor during the first two years of a baby's life. The average head circumference of a newborn is about 33 cm. By monitoring the baby's head circumference, we can detect if the baby's head and the brain inside it are growing normally.

1.1 Physical Quantities

In this section, you will learn the following:
- Describe the use of rulers and measuring cylinders to find a length or a volume.
- Describe how to measure a variety of time intervals using clocks and digital timers.
- Determine an average value for a small distance and for a short interval of time by measuring multiples.

Physics is the study of our natural world — from the very large (e.g. the solar system) to the very small (e.g. the atom). The study of physics is related to two main ideas: matter and energy. The knowledge we have gained in the field of physics is the result of the work of many scientists. These scientists have conducted many experiments to verify their ideas on matter and energy. When they carry out experiments, they need to make accurate measurements in order to obtain reliable results.

What are physical quantities?

WORD ALERT

Magnitude: size

Look at the sign in Figure 1.1. You may have noticed similar signs along bridges where vehicles can pass underneath. In physics, height is a physical quantity — '3.8' is the numerical magnitude and 'm' is the unit.

A **physical quantity** is a quantity that can be measured. It consists of a numerical magnitude and a unit.

There are altogether seven basic physical quantities, or base quantities. Table 1.1 shows the seven base quantities and their corresponding SI units. **SI units** are the units of measurement in the widely used International System of Units (abbreviated SI from French: *Système International d'Unités*).

Figure 1.1 *The sign warns drivers on the clearance limit to pass underneath the bridge. In which other places can you find similar signs?*

ENRICHMENT INFO

Do you know?

1. The length from your wrist to your elbow is the same as the length of your foot.
2. Your mouth produces 1 *l* of saliva a day.
3. Breathing generates about 0.6 g of carbon dioxide every minute.
4. On average, people can hold their breath for about one minute. The world record is 21 min 29 s.

Table 1.1 *The seven base quantities and their SI units*

Base quantity	SI unit	Symbol for SI unit
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Other common physical quantities such as area, volume and speed are derived from the seven base quantities. They are called *derived quantities*. For example, speed is derived from length (i.e. distance travelled) and time. Table 1.2 gives examples of how some common physical quantities are derived from the base quantities.

Table 1.2 *Some common derived quantities and their SI units*

Physical quantity	How it is derived from base quantities	Symbol for SI unit
Area	Length × width	m^2
Volume	Length × width × height	m^3
Speed	$\frac{\text{Length}}{\text{Time}}$	m/s

PHYSICS WATCH

Scan this page to watch a clip about how unit errors can cause a disaster.

In the past, people used parts of their bodies and things around them as units of measurement. That was how measuring terms such as the foot, yard and horsepower came about. Unfortunately, such methods of measurement created much confusion because the measurement varied from individual to individual. It was not until 1968 that scientists agreed to adopt one universal set of units — the SI units.

Prefixes for SI units

Using decimal notation, the distance between air molecules can be expressed as 0.000 000 01 m. If we need to mention this quantity a number of times, it would be tedious to use this type of notation. Instead of using decimal notation, it is more convenient to use prefixes to represent the quantity. For example, when measuring short distances such as $\frac{1}{1\,000\,000}$ of a metre, we simply express it as one micrometre.

Thus, 0.000 000 01 m can be expressed as 0.01 µm (micrometre), where µ represents the submultiple 10^{-6}. The prefixes listed in Table 1.3 are useful for expressing physical quantities that are either very big or very small.

Table 1.3 *Some common prefixes and their symbols*

	Factor	Prefix	Symbol
Multiples	10^9	giga-	G
	10^6	mega-	M
	10^3	kilo-	k
Submultiples	10^{-1}	deci-	d
	10^{-2}	centi-	c
	10^{-3}	milli-	m
	10^{-6}	micro-	µ
	10^{-9}	nano-	n

Standard form

Another convenient and acceptable way of expressing physical quantities is to use the **standard form**. Standard form is a way of writing numbers, in which one integer (1 to 9) is multiplied by an appropriate power of 10. For example, 0.005 67 and 16 800 will be expressed in standard form as 5.67×10^{-3} and 1.68×10^4. In the case of 0.01 µm, it can also be expressed as 1×10^{-8} m. Some other common quantities expressed in standard form are shown below:

- One kilometre (km) is 1×10^3 m.
- One milliampere (mA) is 1×10^{-3} A.
- Three megajoules (MJ) is 3×10^6 J.
- Six microcoulombs (µC) is 6×10^{-6} C.
- Eight nanoseconds (ns) is 8×10^{-9} s.

How do we measure length?

In physics, length is an important quantity that is often used. For example, we measure length to find out how far an object has moved, how much space an object occupies (i.e. the object's volume) and how far apart two objects are.

The SI unit for **length** is the **metre (m)**. There is a wide range of lengths in this world from the width of a human hair to the radius of the Earth. It is necessary to use the appropriate instruments and methods to measure different types of length.

The metre rule and measuring tape

The metre rule and measuring tape (Figure 1.2) are instruments that are commonly used to measure length.

A metre rule can measure lengths of up to one metre. A steel measuring tape is suitable for measuring straight distances longer than a metre, while a cloth measuring tape is suitable for measuring the length along a curved surface, such as a person's waist.

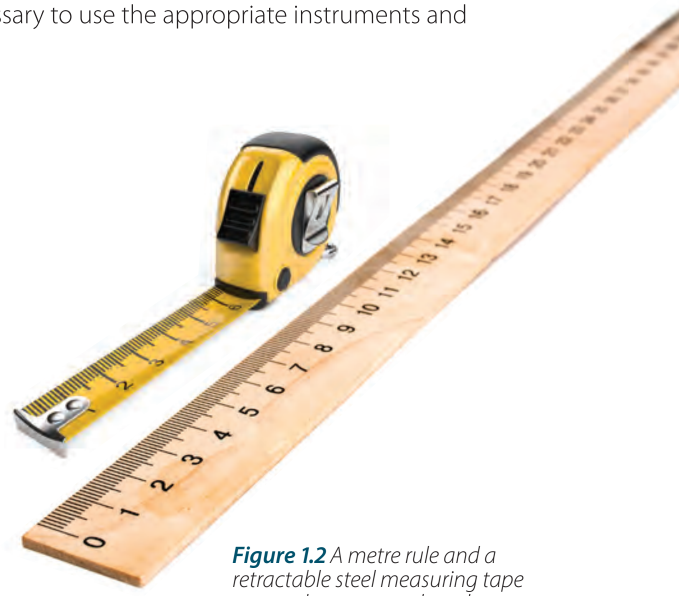


Figure 1.2 *A metre rule and a retractable steel measuring tape are used to measure lengths.*

What is the precision of an instrument?
The smallest unit an instrument can measure is known as its **precision**. What is the smallest unit on a metre rule? It is 0.1 cm or 1 mm. Therefore, the precision of a metre rule is 1 mm.

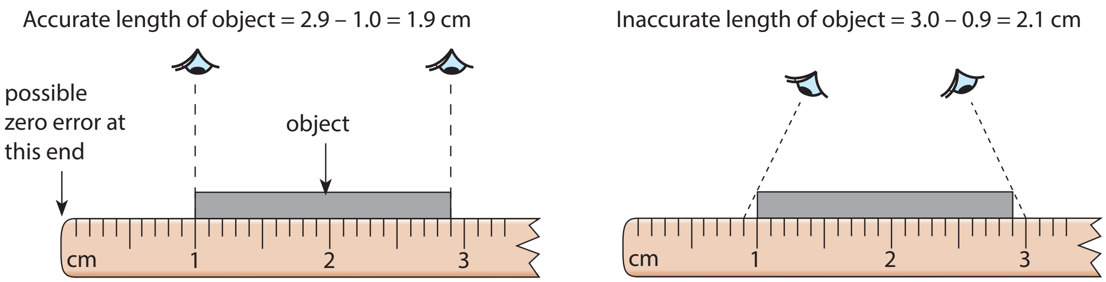
The thickness of a piece of paper is less than the precision of a metre rule (i.e. 1 mm). Therefore, you cannot measure the paper's thickness directly using a metre rule. You will have to estimate its thickness.

ENRICHMENT THINK

A stack of paper is shown in Figure 1.3. How would you estimate the thickness of a sheet of paper in the stack?

Figure 1.3 *A stack of paper*

How do we avoid errors in measurement?
When you use a metre rule, your eyes should be positioned such that your line of sight is perpendicular to the rule (Figure 1.4(a)). In other words, you must look at the rule 'straight on', not at an angle. If this is not done, an error will be introduced into the measurement (Figure 1.4(b)). This type of error is called **parallax error**.



(a) Accurate measurement **(b)** Inaccurate measurement

Figure 1.4 *How to take accurate readings by avoiding parallax errors*

QUICK CHECK

When using a metre rule to measure length, I must be careful to avoid parallax error.

True or false?

A metre rule may have its zero mark at the very end of the rule. It may no longer be suitable for measuring if the zero-mark end is worn. The worn end of the rule may introduce errors into the readings. Hence, it is better to measure from another point and subtract it from the final reading (Figure 1.4(a)). Taking several readings and calculating the **average** also minimises errors.

The vernier calipers

A pair of vernier calipers (Figure 1.5) has a main scale and a sliding vernier scale. It is a useful tool for measuring both the internal and external diameters of small objects. Vernier calipers are able to measure to a precision of 0.01 cm.

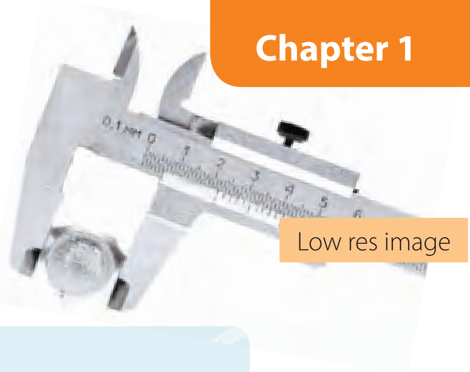


Figure 1.5 *Measuring the diameter of a bolt using vernier calipers*

How do we use the vernier calipers?

Figure 1.6 shows how a pair of vernier calipers is used.

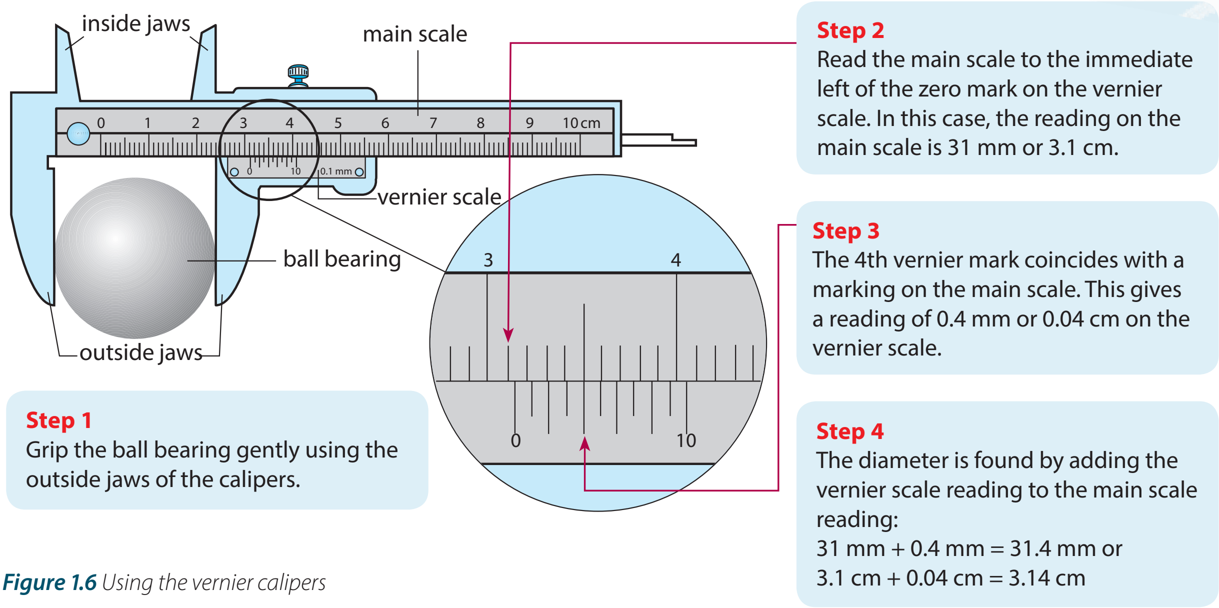


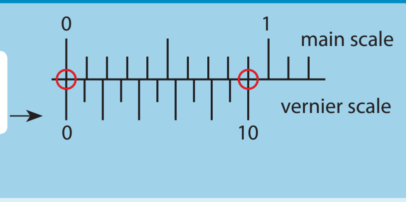
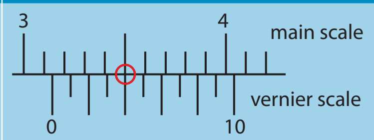
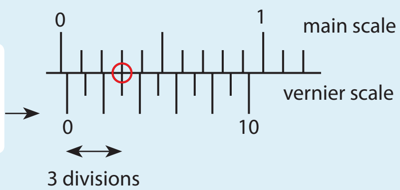
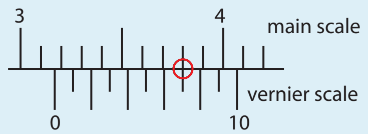
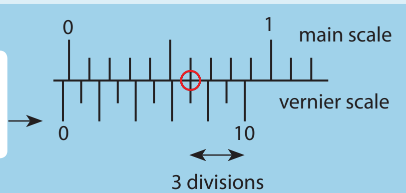
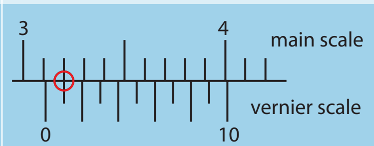
Figure 1.6 *Using the vernier calipers*

How do we avoid errors when using the vernier calipers?

Before using the vernier calipers, we need to examine the instrument for **zero error**.

First, ensure the jaws are touching each other. Then check if the zero mark on the main scale coincides with the zero mark on the sliding vernier scale. Table 1.4 shows how to correct for zero errors on the vernier calipers.

Table 1.4 *Checking and correcting zero errors when using the vernier calipers*

Type of zero error		Example of observed reading	Corrected reading
No zero error The zero marks of the two scales coincide.		 Reading = 3.14 cm	3.14 cm (No correction required)
Positive zero error The zero mark of the vernier scale is slightly to the right of the main scale.	 Zero error = +0.03 cm	 Reading = 3.17 cm	3.17 – (+0.03) = 3.14 cm
Negative zero error The zero mark of the vernier scale is slightly to the left of the main scale.	 Zero error = –0.03 cm	 Reading = 3.11 cm	3.11 – (–0.03) = 3.14 cm

How do we measure volume?

The SI unit for **volume** is the **cubic metre (m^3)**. What are the basic methods of measuring the volumes of solids and liquids?

Volume of regular solids

A metre rule or vernier calipers can be used to measure the dimensions of a regular solid. The volume of the solid can then be determined by using the appropriate formula. Here are some examples:

(a) Volume of a rectangular block = $l \times b \times h$, where l = length, b = breadth and h = height

(b) Volume of a cylinder = $\frac{1}{4}\pi d^2 h$, where d = diameter and h = height

(c) Volume of a sphere = $\frac{4}{3}\pi\left(\frac{d}{2}\right)^3$, where d = diameter

Volume of irregular solids

How do we find the volume of small objects that sink?
By means of a measuring cylinder, we can find the volume of a small object, $V = V_2 - V_1$, where V_1 = volume of water before putting in the object and V_2 = volume reading after putting in the object (Figure 1.7).

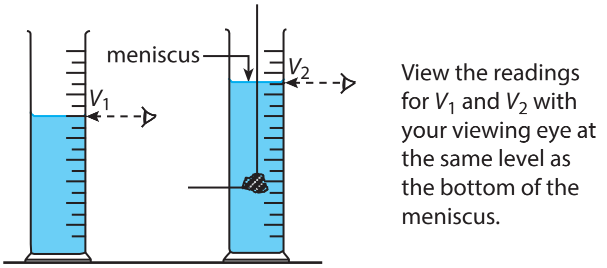


Figure 1.7 Finding the volume of a small object that sinks

How do we find the volume of small objects that float?
For small objects (such as a piece of cork) that float, a sinker such as a lump of metal is used. The sinker ensures that the small object is totally immersed in the water (Figure 1.8).

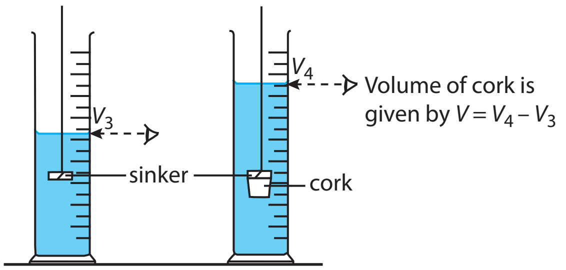


Figure 1.8 Finding the volume of a small object that floats

How do we find the volume of large objects that sink?
For large objects (such as a stone) that sink, we use a displacement can and a measuring cylinder to find the volume (Figure 1.9).
Note: In the case of large objects that float, we can use a sinker in the same way as in Figure 1.8.

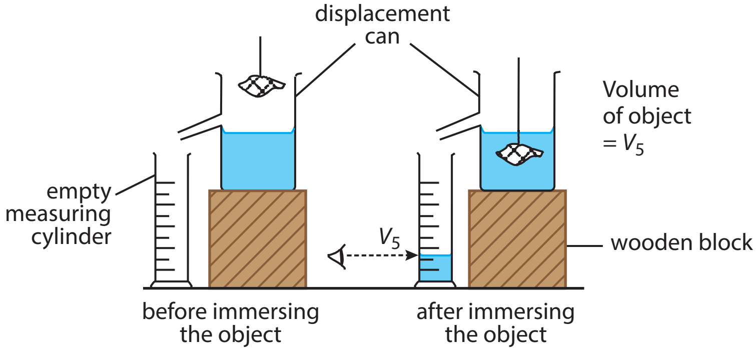


Figure 1.9 Finding the volume of a large object that sinks

Volume of liquids

The volume of a liquid can be found by pouring the liquid into a measuring cylinder and reading the volume V directly (Figure 1.10). Ensure that the measuring cylinder is resting on a flat horizontal surface and that any bubbles in the liquid are removed.

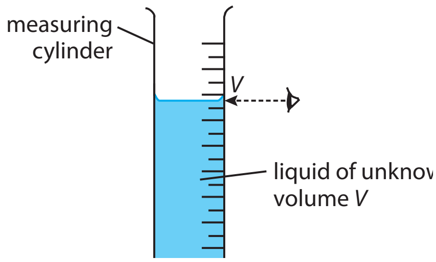


Figure 1.10 Measuring the volume of a liquid

LINK PWB
Practical 1A, pp. XX–XX

How do we measure time?

Imagine that you are stranded on an island. You do not have a watch or a mobile phone. How would you be able to tell the time? We can tell time by observing events that repeat at **regular intervals** or **periods**. Examples of such events are seasons, phases of the Moon, sunsets and positions of the Sun.

The SI unit for **time** is the **second (s)**. The year, month, day, hour and minute are other units for measuring time.

Scientific work cannot rely on the observation of natural events, which are not fixed. For example, the time interval between a sunrise and a sunset is different in winter and summer. The time intervals for scientific work have to be fixed; they cannot change. Can you think of recurrent motions that can be used to measure time for scientific work?

Using a pendulum to measure time

A simple pendulum can be used to measure time. It consists of a heavy object, called a bob (e.g. a metal ball), that is attached to one end of a string. The other end of the string is fixed. When a pendulum swings freely, it will move back and forth at regular intervals.

Each complete to-and-fro motion is one oscillation (Figure 1.11).

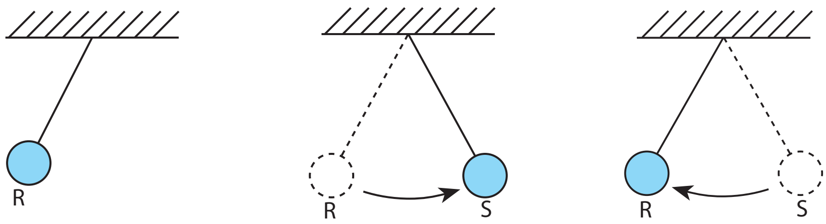


Figure 1.11 When the bob moves from R to S and back to R, the pendulum completes one oscillation. In what other ways can the bob swing to produce one complete oscillation?

WORD ALERT

Motion: movement

Calibrated: adjusted

The **period** of a simple pendulum is the time taken for one complete oscillation.

The period of a pendulum depends on its length. Pendulum clocks can be calibrated to measure time accurately by adjusting the length of the pendulum.

For scientific work, time intervals have to be precisely measured. The period of the oscillations must not change. Most modern timepieces are calibrated using precise timekeeping devices called atomic clocks (Figure 1.12).

Instruments used to measure time

The common instruments used to measure intervals of time in hours, minutes and seconds include clocks and stopwatches.

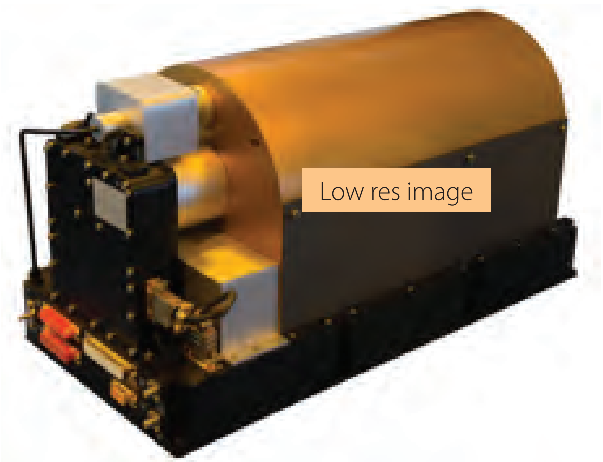


Figure 1.12 This atomic clock used in some satellites can measure time to within 0.45 nanoseconds over 12 hours.

Pendulum clock

All timepieces use some kind of periodic motion to measure time. Pendulum clocks keep time using a pendulum's periodic swing.

Clocks and stopwatches

The oscillations of springs and the natural vibrations of crystals are other periodic motions that can be used to keep time. Most clocks and watches today use quartz crystals. Quartz crystals are small, accurate and require very little electrical energy.

Figure 1.13 shows several instruments that measure time. Depending on the accuracy and precision needed, the instruments used will vary.

Most stopwatches can measure time to a precision of 0.01 s. Digital stopwatches usually show readings up to two decimal places. However, we usually take readings to the nearest one decimal place. This is because we need to start and stop a stopwatch by hand, unlike the electronic sensor used in a data logger. This manual operation introduces a random error called *human reaction time*. Human reaction time is about 0.3–0.5 s for most people.

Figure 1.13 *Which time measuring instrument would you use to measure the time taken by a runner to run a 100 m race? Why?*

ENRICHMENT ACTIVITY

Use the Internet to find an online reaction time test. Find out what is your average reaction time. Compare your reaction time with those of your classmates.

Let's Investigate 1A

Objective

To calibrate a simple pendulum to measure time in seconds

Apparatus

Pendulum, stopwatch, metre rule, retort stand and clamp

Procedure

1 Tie the pendulum to the clamp and measure the length l of the string in metres (Figure 1.14).

2 Measure the time taken for the pendulum to make 20 oscillations.

3 Vary the length l of the string between 50 and 90 cm and repeat step 2.

4 Complete Table 1.5.

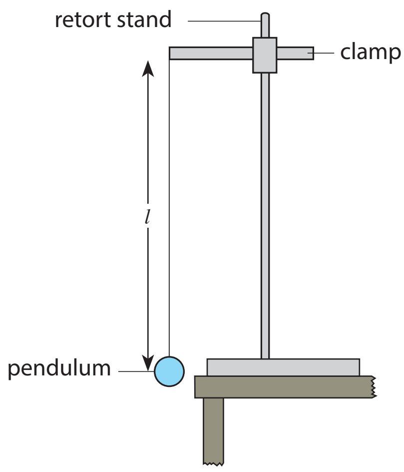


Figure 1.14

Table 1.5

Length l/m	Time for 20 oscillations			Period T/s	T^2/s^2
	t_1/s	t_2/s	t_{ave}/s $\left[t_{ave} = \frac{(t_1 + t_2)}{2}\right]$		
0.500					
0.600					
0.700					
0.800					
0.900					

5 Plot a graph of period T/s against length l/m, and find the length of the pendulum with a period of one second. Plot also a graph of T^2/s^2 against length l/m.

Calculation

The period of the pendulum, T, is found by dividing t_{ave} by 20s, i.e, $T = \frac{t_{ave}}{20}$.

Results and discussion

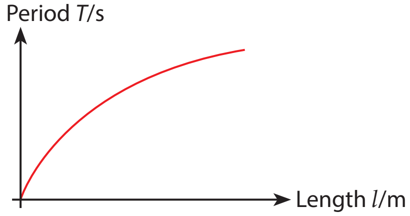


Figure 1.15

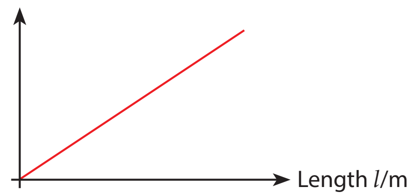


Figure 1.16

How does this experiment allow us to use a pendulum to measure time in seconds?

The length of the pendulum with a period of one second can be read off the graph. By using a pendulum of this length, we can measure time by counting the number of oscillations (e.g. if 1 oscillation takes 1 s, then 60 oscillations take 60 s or 1 min).

What can we observe about the graph of T against l?

The period increases with length but not linearly (Figure 1.15).

What does the plot of T^2 against l tell us?

It tells us that the square of the period is directly proportional to the length. This produces a straight-line graph when we plot T^2 against l (Figure 1.16). By extending the straight-line graph, we can easily predict the period of the pendulum for lengths that are not included in the graph we have plotted.

WORD ALERT

Linearly: in a straight line

LINK

PWB

Practical 1B, pp. XX–XX

Worked Example 1A

A student checks the accuracy of an antique clock (Figure 1.17). He uses a digital stopwatch to find the period of the clock's pendulum.

(a) If X and Y are the two extreme positions of each oscillation, state the path of one complete oscillation.

(b) The student's timings for two separate measurements of 20 oscillations are 35.70 s and 34.98 s. Calculate the average period of the clock's pendulum.

Solution

(a) X to Y and back to X **or** Y to X and back to Y.

(b) Average time for 20 oscillations

$= \frac{35.70 \text{ s} + 34.98 \text{ s}}{2} = 35.34 \text{ s}$

Average period of the clock's pendulum $= \frac{35.34 \text{ s}}{2} = 1.767 \text{ s}$

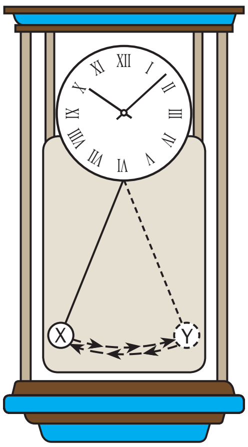


Figure 1.17

QUICK CHECK

In an experiment to find the period of a simple pendulum, we take the time for one complete oscillation.

True or false?

Let's Practise 1.1

1 The world's smallest playable guitar is 10 μm long. Express the guitar's length in standard form.

2 A pair of vernier calipers is used to measure the diameter of a ball bearing. What is the reading of the vernier calipers shown in Figure 1.18?

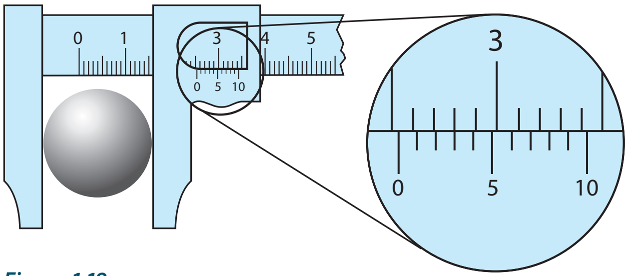


Figure 1.18

3 **(a)** What is the SI unit of volume?

(b) How do we measure the volume of a small irregular object that floats on water?

4 Figure 1.19 shows a voltmeter scale with a strip of mirror mounted under the needle. Suggest how this may help reduce errors when readings are taken.

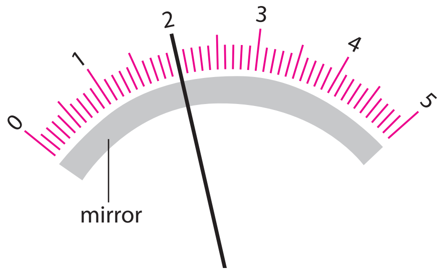


Figure 1.19

5 Figure 1.20 shows an oscillating pendulum. If the time taken for the pendulum to swing from A to C to B is 3 s, what is the period of the pendulum?

6 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

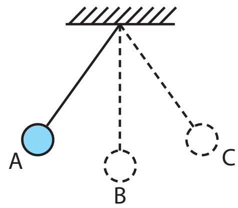


Figure 1.20

LINK TWB

Exercises 1A–1B, pp. X–X

S

1.2 Scalars and Vectors

In this section, you will learn the following:

- S Understand the terms *scalar quantity* and *vector quantity*.
- S Know some examples of scalar and vector quantities.
- S Determine, by calculation or graphically, the resultant of two vectors at right angles.

What are scalars and vectors?

You have learnt that a physical quantity consists of a numerical magnitude and a unit.

A physical quantity can be of two types: scalar or vector.

A **scalar quantity** is a physical quantity that has **magnitude only**.

For example, speed is a scalar quantity because it tells us how fast or slow an object is moving. It does not tell us which direction the object is heading.

To describe speed in a specific direction, we use the term *velocity*. Velocity tells us both how fast or slow an object is moving and in which direction. We say velocity is a vector quantity.

A **vector quantity** is a physical quantity that has both **magnitude and direction**.

Table 1.6 shows some common scalars (scalar quantities) and vectors (vector quantities).

Table 1.6 *Common scalars and vectors*

Scalar	Vector
Speed	Velocity
Distance	Displacement
Time	Force
Mass	Acceleration
Volume	Momentum
Energy	Weight
Temperature	Electric field strength
Electric current	Gravitational field strength

HELPFUL NOTES

Which type of physical quantities have magnitude only and which have both magnitude and direction? To know, remember this line:

Sam **M**agoo has a **V**ery **M**ild **D**iarrhoea.

Can you tell now?

LINK

Why is distance a scalar quantity and displacement a vector quantity?

Find out more in Chapter 2.

Vector diagrams

How are vector quantities represented?

Let us take a common example of a vector quantity, namely, force.

A force is a vector — it has both magnitude and direction. Its SI unit is the newton (N). At any time, two or more forces may be acting on an object. The forces may have different magnitudes and directions. In such cases, we can use vector diagrams to add up these forces.

In a vector diagram, a vector quantity is represented by an arrow. The length of the arrow is proportional to the magnitude of the vector. The direction of the arrow indicates the direction of the vector. Figure 1.21 shows the vector diagram of a force of 20 N in the direction 45° north of east.

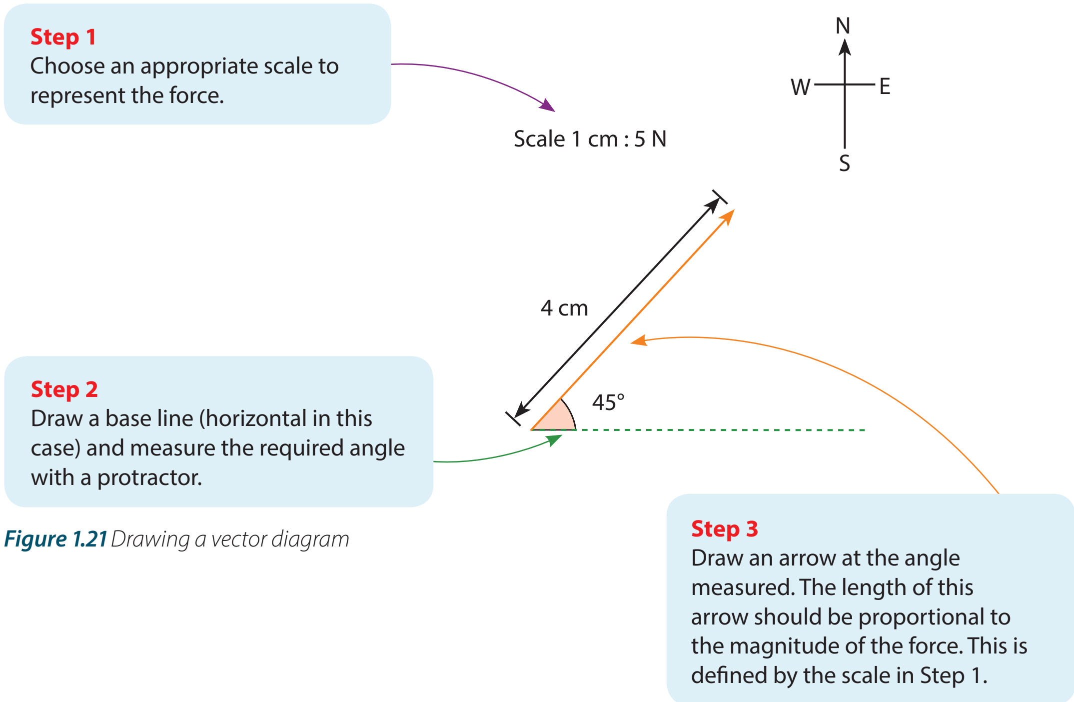


Figure 1.21 *Drawing a vector diagram*

How do we add vectors?

Scalars, such as distance and speed, have magnitude and no direction. When we add scalars, we add their magnitudes only.

Unlike scalars, vectors have both magnitude and direction. When we add two or more vectors, we cannot add their magnitudes only. We need to find a single vector that produces the same effect as the vectors combined. The single vector, called the **resultant vector**, must be equivalent to the individual vectors combined in terms of magnitude and direction.

Adding parallel vectors

Let us assign the direction towards the right as positive. Figure 1.22 shows two parallel forces of magnitudes 3 N and 5 N acting on a block. Both forces act in the same direction (i.e. towards the right). The resultant force is 8 N (i.e. 3 N + 5 N = 8 N) and is directed towards the right. A resultant vector is usually indicated by a double-headed arrow.

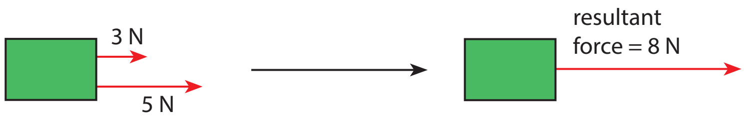


Figure 1.22 *Addition of vectors acting in the same direction*

In Figure 1.23, the two forces are still parallel but act in opposite directions. The resultant force is 2 N (i.e. 5 N + (–3 N) = 2 N) and is directed towards the right.

Figure 1.23 *Addition of vectors acting in opposite directions*

In Figure 1.24, two parallel forces of 3 N act on the block in opposite directions.

This produces zero resultant force.

Figure 1.24 *Addition of vectors that are equal in magnitude but act in opposite directions*

Adding non-parallel vectors

Figure 1.25 shows two non-parallel forces, $F_1 = 4$ N and $F_2 = 3$ N, acting on a block at right angle to each other. How can we add the two forces to obtain the resultant force R?

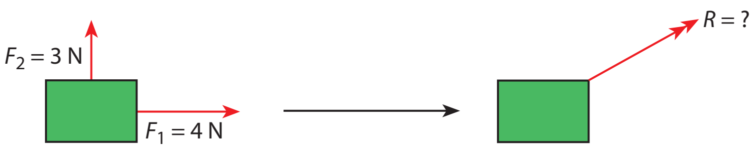


Figure 1.25 *Addition of non-parallel vectors*

QUICK CHECK

When adding vectors, I must consider both magnitude and direction.

True or false?

Figure 1.26 shows how we can obtain the resultant force R graphically by drawing a parallelogram. The resultant force R is the diagonal of the parallelogram.

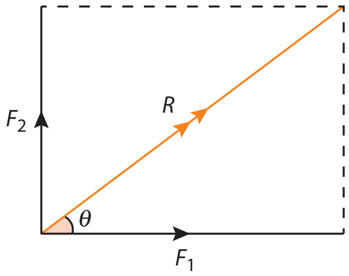


Figure 1.26 *Adding vectors using the parallelogram method (Scale 1 cm: 1 N)*

By measuring the angle θ and the length the diagonal, we obtain the resultant force $R = 5$ N at an angle $\theta \approx 37$°C to the horizontal.

We can also obtain the resultant force R by calculation.

Using Pythagoras' Theorem,

$$R = \sqrt{F_1^2 + F_2^2} = \sqrt{4^2 + 3^2} = \sqrt{25} = 5 \text{ N}$$

$$\tan\theta = \frac{F_2}{F_1} = \frac{3}{4} = 0.75$$

$$\theta = 36.9°$$

Hence, the resultant force R has a magnitude of $R = 5$ N, making an angle of $\theta = 36.9°$ with the horizontal.

By using either the parallelogram method or the calculation method, we arrive at the same answer: the resultant force has a magnitude of 5 N, and acts at an angle of 36.9° to the horizontal.

Let's Practise 1.2

1 Distinguish between a scalar quantity and a vector quantity. Give one example of each.

2 Figure 1.27 shows the forces acting on a box. What is the resultant force?

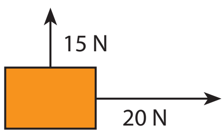


Figure 1.27

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

TWB **LINK**

Exercises 1C–1D, pp. XX–XX

Exercise 1E Let's Reflect, p. XX

Let's Map It

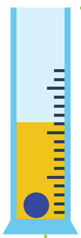
PHYSICAL QUANTITIES

examples with SI units

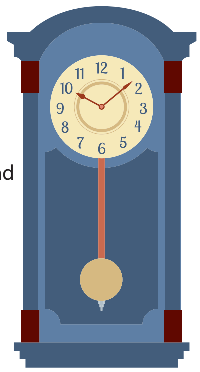
- Length (m) — can be measured using:

Instrument	Precision	Measuring range
Measuring tape	1 mm	Several metres
Metre rule	1 mm	Several cm to1 m
Vernier calipers	0.1 mm	1 cm to 15 cm

- Volume (m³) — can be measured using:
  - Measuring cylinder for liquids and small irregular solids
  - Formulae for regular solids
  - Displacement method for large irregular solids



- Time (s) — can be measured using:
  - Clocks and digital timers (e.g. pendulum clocks and stopwatches)
  - based on: Periodic motions called oscillations



can be classified into

- S Scalar quantities — have only: S Magnitude
- S Vector quantities — have both:
  - S Magnitude
  - S Direction
  - S Represented by vector diagrams
  - S Addition of two vectors to give the resultant vector can be determined graphically or by calculation.

Let's Review

Section A: Multiple-choice Questions

1 In a particular experiment, you are required to measure the distance between two points. The two points are between 0.7 m and 0.8 m apart. Which of the following instruments should you use to obtain a reading that has a precision of 0.001 m?

A A half-metre rule
B A metre rule
C A ten-metre measuring tape
D A metre rule and a pair of vernier calipers

2 Figure 1.28 shows two vernier scales. The top vernier scale shows the reading when the vernier calipers are closed. The bottom vernier scale shows the reading when the diameter of a steel ball bearing is being measured.

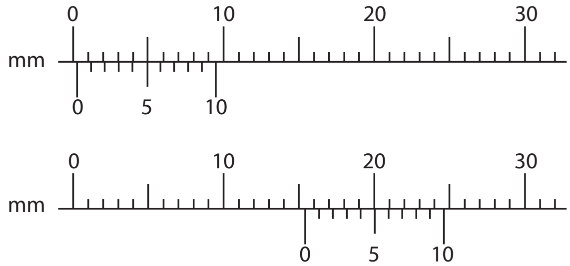


Figure 1.28

What is the diameter of the ball bearing?

A 1.49 cm B 1.50 cm
C 1.59 cm D 1.61 cm

3 When using a measuring cylinder, one precaution to take is to

A check for zero error.
B look at the meniscus from below the level of the water surface.
C obtain more readings by looking from more than one direction.
D position the eye in line with the base of the meniscus.

4 Figure 1.29 shows a simple pendulum.

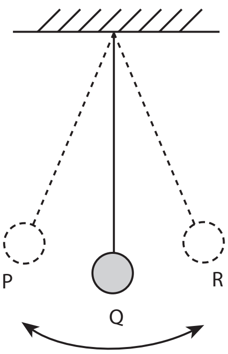


Figure 1.29

Which of the following statements about the period of the pendulum is/are **not** true?

1 It is independent of the mass of the bob.
2 It increases as the length of the pendulum increases.
3 It is the time taken for the bob to swing from Q to P and back to Q.

A 1 and 2 only B 1 and 3 only
C 2 and 3 only D 3 only

5 S Figure 1.30 shows two forces acting at right angle to each other.

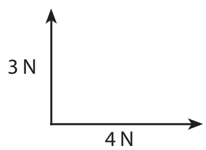
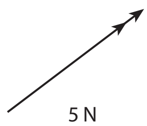
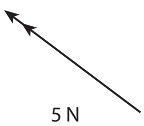
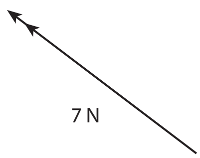


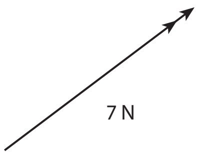
Figure 1.30

Which of the following shows the resultant force?

A


B


C


D


Let's Review

Section B: Short-answer and Structured Questions

1 Identify the physical quantity, numerical magnitude and unit in the following statements:
(a) The length of a table is found to be five metres.
(b) The time the pendulum takes to complete a single oscillation is two seconds.
(c) A typical car has a mass of one thousand kilograms.

2 A student measures the width of a glass slide using a pair of vernier calipers.

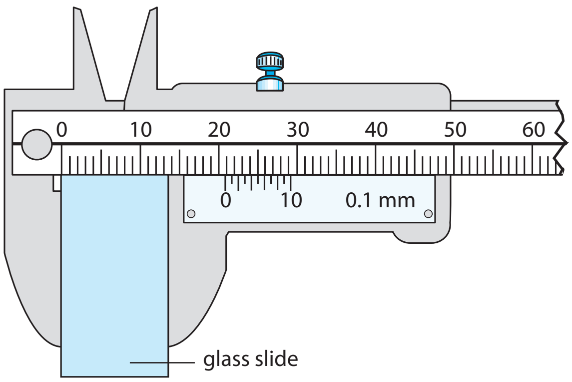


Figure 1.31

(a) In Figure 1.31, what is the measurement of the width of the glass slide?
(b) List the precision of the following measuring instruments: vernier calipers and metre rule.
(c) Explain why the method shown in Figure 1.31 will not yield an accurate measurement.
How would you obtain a more accurate measurement of the width of the glass slide?

3 Describe the method you would use to find the volume of the following:
(a) a matchbox
(b) the cork stopper of a bottle
(c) some liquid perfume in a very small bottle

4 A student conducted an experiment to measure the acceleration due to gravity g of a simple pendulum.
The data obtained were tabulated in Table 1.7.

Table 1.7

Length of thread l/m	0.35	0.65	1.00	1.45	1.95
Time for 20 oscillations t/s	24.1	32.4	40.1	47.5	56.3

The relation between the period T, the length l of the pendulum and the acceleration due to gravity g is

$T = 2\pi\sqrt{\frac{l}{g}}$. Find the value of g using the graphical method.

5 Ⓢ Figure 1.32 shows a lorry that is stuck in muddy ground being pulled by two jeeps. Each jeep exerts a force of 3000 N at an angle of 45° to the horizontal. Using a vector diagram, determine the resultant force on the lorry.

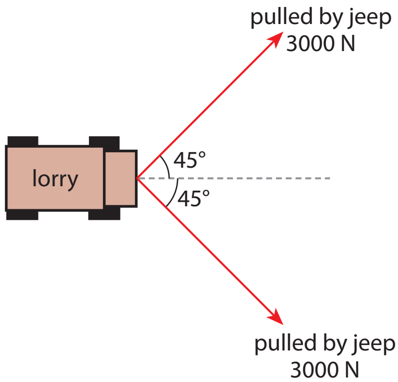


Figure 1.32

CHAPTER

2 Motion

PHYSICS WATCH

Scan this page to watch a clip about average speed.

In track and field, the 100-metre race has always been the crowd's favourite. The short-distance race tests an athlete's ability to accelerate to his or her maximum speed.

In the August 2016 Rio Olympics, the winner of the men's 100-metre final, a Jamaican, clocked an amazing time of 9.81 seconds as he crossed the finishing line! With this win, he became the first person in history to win the 100-metre race three times in three consecutive Olympics. His 100-metre timings for the August 2012 London Olympics and the August 2008 Beijing Olympics are 9.63 seconds and 9.69 seconds respectively. His best ever is 9.58 s during the 2009 World Athletics Championship in Berlin.

What an amazing record! If you dream of becoming a fine sprinter, get into MOTION!

QUESTIONS

- Who is this incredible sprinter from Jamaica?
- Can you spot him in the photo? Is he ahead of the others at this point?
- How did he eventually win the race?

2.1 Speed, Velocity and Acceleration

In this section, you will learn the following:

- Define *speed* and *velocity*.
- Recall and use the equation average speed = $\frac{\text{total distance}}{\text{total time}}$.
- **S** Define *acceleration*.
- **S** Recall and use the equation $a = \frac{\Delta v}{\Delta t}$.

What is speed?

If Usain Bolt were to race against a cheetah in a 100-metre sprint, will the winner be the human king of speed or the animal king of speed (Figure 2.1)?

To find out, we need to compare their speeds. Speed refers to how fast something moves.

Speed is the distance travelled per unit time.

Speed = $\frac{\textbf{distance travelled}}{\textbf{time taken}}$

Its SI unit is **metre per second (m/s)**.

Based on Usain Bolt's 100-metre fastest record time of 9.58 s,

Speed = $\frac{\text{distance travelled}}{\text{time taken}} = \frac{100\text{ m}}{9.58\text{ s}} = 10.4$ m/s

Figure 2.1 *Who is the real king of speed?*

Compare this with the cheetah's average running speed shown in Figure 2.2.

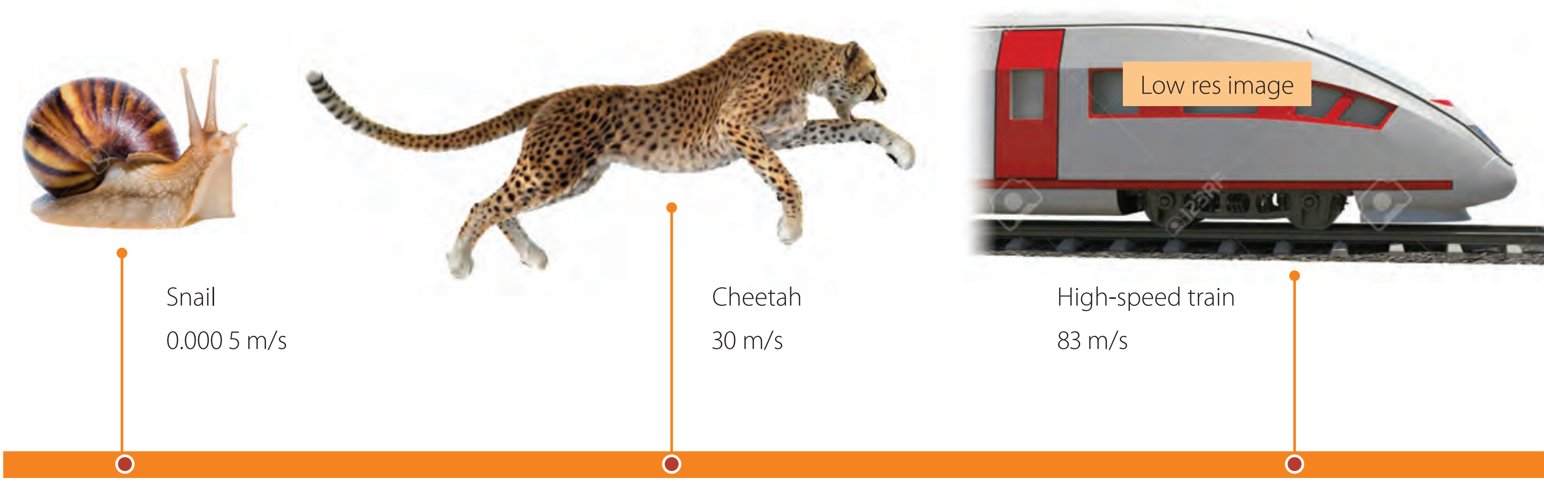


Figure 2.2 *Average speeds of some animals and objects*

What is average speed?

Table 2.1 shows the results for men's running events at the 2016 Rio Olympics.

Table 2.1 *Results for men's running events at the 2016 Rio Olympics*

Athlete	Country	Event/m	Time/s	Speed/m/s
Usain Bolt	Jamaica	100	9.81	10.2
Usain Bolt	Jamaica	200	19.78	10.1
Wayde van Niekerk	South Africa	400	43.03	9.30
David Lekuta Rudisha	Kenya	800	102.15	7.83

The speeds shown in the table are actually average speeds. **Average speed** assumes that each athlete ran at the same speed throughout the entire distance.

$$\textbf{Average speed} = \frac{\textbf{total distance travelled}}{\textbf{total time taken}}$$

In reality, the athletes did not run at the same speed throughout their races. The speed at one instant is different from the speed at another instant. The speed of an object at a particular instant is known as its *instantaneous* speed.

WORD ALERT

Instant: a point in time

Worked Example 2A

A car travels 6 km in 5 min. Calculate its average speed in m/s.

Solution

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

$$= \frac{6 \times 1000 \text{ m}}{5 \times 60 \text{ s}}$$

$$= 20 \text{ m/s}$$

QUICK CHECK

The actual speed of a car is always the same as its average speed.

True or false?

How does the average speed of a car compare with the other objects and animals shown in Figure 2.2?

ENRICHMENT INFO

Animal Migration

Animal migration is the seasonal movement of animals from one place to another in search of feeding and breeding grounds. Humpback whales are observed to make some of the longest migrations of any mammals. One of their common migratory routes is between Alaska and Hawaii. The route is about 4830 km one way. The humpback whales can swim from Alaska to Hawaii in 36 days. This works out to an average speed of 5.6 km/h in choppy waters!

LINK

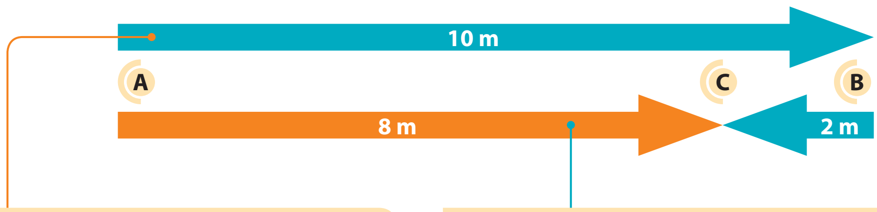
Recall the two types of physical quantities, namely, scalars and vectors, that you have learnt in Chapter 1.

HELPFUL NOTES

For any object moving in a straight line, we can assign a direction from a reference point as positive. As an example, refer to Figure 2.3. If we assign the direction to the right of A as positive, the displacement of the moving object at B is +10 m.

How is distance different from displacement?

Figure 2.3 shows the motion of an object from point A to point B and then to point C. We shall use it to illustrate the difference between *distance* and *displacement*.



Distance
- The total length covered by a moving object regardless of the direction of motion
- Has magnitude only
- SI unit: metre (m)
- Distance travelled by the object from A to B, and then to C
  = 10 m + 2 m
  = 12 m

Displacement
- The distance measured in a straight line in a specified direction
- Has both magnitude and direction
- SI unit: metre (m)
- Displacement of the object travelling from A to B, and then to C
  = 10 m − 2 m
  = 8 m (from A to C)
- Refers to the shortest distance and direction of an object from the starting point

Figure 2.3 *Difference between distance and displacement*

Worked Example 2B

Figure 2.4 shows a car that travels 5 km due east and makes a U-turn to travel another 7 km along the same road.

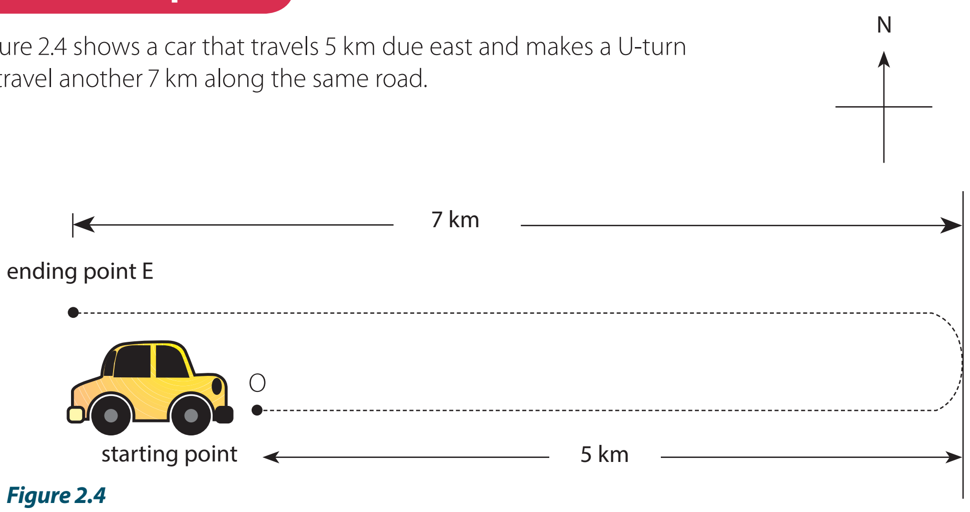


Figure 2.4

Calculate
(a) the distance covered;
(b) its displacement.

Solution

(a) Distance covered = 5 km + 7 km = 12 km

(b) Taking the direction due east of the starting point as positive,
Displacement = 5 km − 7 km = −2 km
It is at a point 2 km due west from the starting point.

HELPFUL NOTES

The *magnitude* of displacement is the distance measured along a straight line from the starting point to the final point.

Its *direction* is taken from the starting point to the final point.

How is velocity different from speed?

When determining the velocity of an object, we need to know the speed of the object and the direction in which it is travelling. When calculating velocity, we use displacement instead of distance.

Velocity is speed in a given direction. Its SI unit is **metre per second (m/s)**.

$$\textbf{Velocity} = \frac{\textbf{displacement}}{\textbf{time taken}}$$

Similarly, as in the case of average speed,

$$\textbf{Average velocity} = \frac{\textbf{total displacement}}{\textbf{total time taken}}$$

Worked Example 2C

If the runner in Figure 2.5 takes 25 s to run 200 m, calculate her average speed and average velocity.

Solution

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}} = \frac{200\text{ m}}{25\text{ s}}$$
$$= 8\text{ m/s}$$

$$\text{Average velocity} = \frac{\text{total displacement}}{\text{total time taken}} = \frac{50\text{ m}}{25\text{ s}}$$
$$= 2\text{ m/s}$$ (from her initial position to her final position)

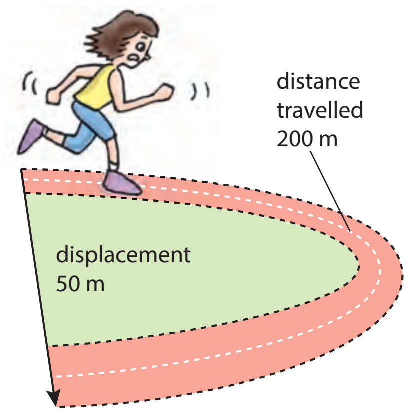


Figure 2.5

QUICK CHECK

Speed is the same as velocity.

True or false?

What is acceleration?

Understanding acceleration

An object is accelerating when its velocity changes. Figure 2.6 shows that an object undergoes acceleration when its speed or direction changes, or when both its speed and direction change.

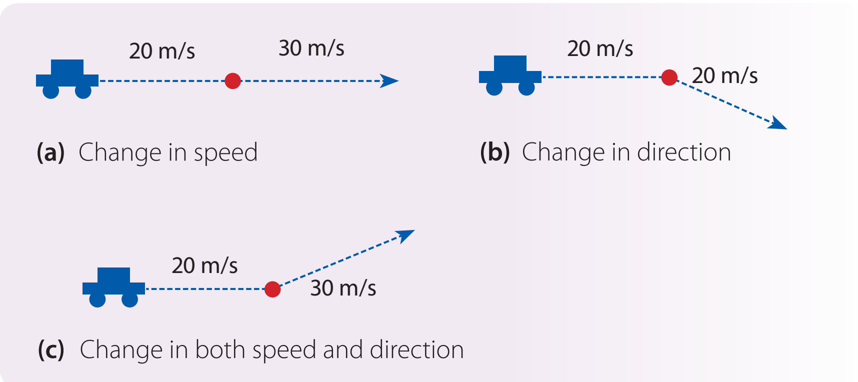


***Figure 2.6** When acceleration occurs*

ENRICHMENT
THINK

In groups of two, discuss whether each of the following events involves acceleration:

1 A space shuttle blasting off
2 An airplane landing
3 A lift approaching a given floor
4 A train leaving a station
5 A car coming to a stop

When the change (increase or decrease) in the velocity of an object for every unit of time is the same, the object undergoes **constant** or **uniform** acceleration (Table 2.2).

Table 2.2 *Object moving with uniform acceleration*

Time/s	Velocity/m/s			
1	20		80	
		+20		−20
2	40		60	
		+20		−20
3	60		40	
		+20		−20
4	80		20	
		+20		−20
5	100		0	

From Table 2.2, when the velocity of the object is increasing by 20 m/s every second, the acceleration is 20 m/s². When the velocity of the object is decreasing by 20 m/s every second, the object is said to be undergoing a **deceleration** of 20 m/s.

Calculating acceleration

Acceleration is the change of velocity per unit time. Its SI unit is **metre per second per second (m/s²)**.

$$\textbf{Acceleration } a = \frac{\text{change of velocity}}{\text{time}} = \frac{(v-u)}{t} = \frac{\Delta v}{\Delta t}$$

where v = final velocity, u = initial velocity and t = total time taken

Worked Example 2D

A car at rest starts to travel in a straight path. It reaches a velocity of 12 m/s in 4 s (Figure 2.7). Calculate its acceleration.

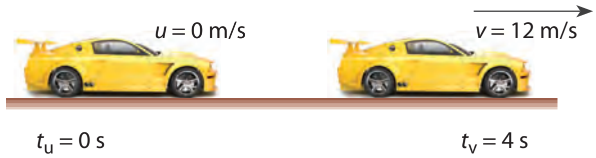


Figure 2.7

Solution

We assign the direction to the right as positive.

Given: Initial velocity v_1 = 0 m/s (since the car starts from rest)

Final velocity v_2 = 12 m/s

Time taken = 4 s

$$a = \frac{\Delta v}{\Delta t} = \frac{v-u}{t_v - t_u} = \frac{(12-0)\text{ m/s}}{(4-0)\text{ s}} = 3\text{ m/s}^2$$

The acceleration is 3 m/s² in its travelling direction.

Let's Practise 2.1

1 A toy car travels 96 m in 12 s. Calculate its average speed.

2 The velocity of a golf ball rolling in a straight line changes from 8 m/s to 14 m/s in 10 s. Calculate its acceleration.

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

QUICK CHECK

An object is accelerating when its speed changes. True or false?

ENRICHMENT ACTIVITY

Find out whether a stone undergoes acceleration when it is whirled in circles.

1 Tie a string to a small stone.
2 Whirl the stone in circles as shown in Figure 2.8.
3 In small groups, discuss whether the stone undergoes acceleration. Explain your answer.

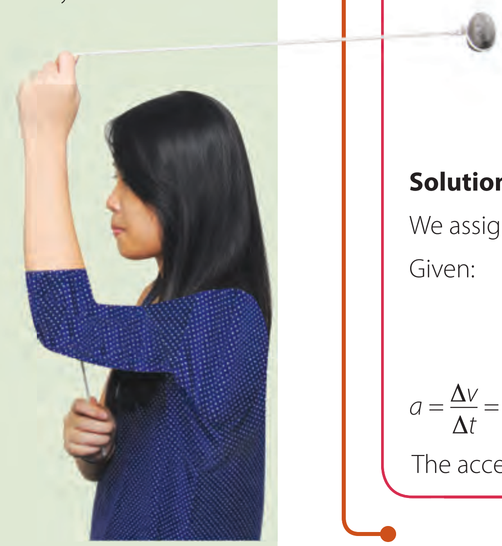


Figure 2.8 *Whirling a stone*

LINK TWB

Exercises 2B, pp. XX-XX

2.2 Graphs of Motion

In this section, you will learn the following:

- Sketch, plot and interpret distance–time and speed–time graphs.
- Determine qualitatively, from given data or the shape of a distance–time graph or speed–time graph, when an object is at rest, moving with constant speed, accelerating or decelerating.
- Calculate speed from a distance–time graph.
- Calculate the area under a speed–time graph to determine distance travelled.
- S Determine when an object is moving with constant or changing acceleration from given data or the shape of a speed–time graph.
- S Calculate acceleration from a speed–time graph.
- S Know what is meant by deceleration and use this in calculations.

Distance–time graphs

By studying the distance–time graph of an object (Figure 2.9), we can get some information about the motion of the object. In what way will the distance–time graph change if the object travels a longer distance at a uniform speed?

The motion of the object is described in Table 2.3.

Table 2.3 *Motion of an object*

Section	Motion of an object
A to B	The graph is a horizontal line. The distance travelled does not change with time. The object is not moving.
B to C	The graph has a constant positive gradient. The distance travelled increases uniformly. The object is moving at a uniform speed.
C to D	The graph is a horizontal line. The distance travelled does not change with time. The object is not moving.
D to E	The graph has a constant positive gradient. The distance travelled increases uniformly. The object is moving at a uniform speed. The graph is less steep here compared to section B to C. Therefore, the object has a lower speed here.

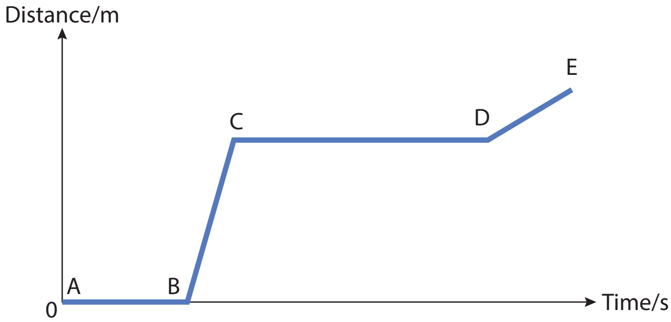


Figure 2.9 *Distance–time graph of a moving object*

ENRICHMENT ACTIVITY

Sketch a distance–time graph for your journey from your home to your school. Then, exchange graphs with a classmate and discuss the differences between your graphs.

Gradient of distance–time graphs

The gradient of a distance–time graph of an object gives the speed of the object.

Figure 2.10 shows a car travelling away from the starting point O. The car travels in one direction only.

Figure 2.10 *Motion of a car*

PHYSICS WATCH

Scan this page to explore distance–time graph simulation.

The distance–time graphs below show four possible journeys of the car.

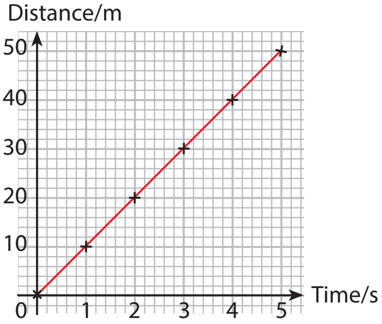


Figure 2.11 *Car travelling at a uniform speed*

Time/s	0	1	2	3	4	5
Distance/m	0	10	20	30	40	50

- The graph has a constant gradient.
- The distance increases 10 m for every second.
- Gradient = $\dfrac{50-0}{5-0} = 10$

$\therefore$ Speed = 10 m/s

QUICK CHECK

For an object that is not moving, its distance–time graph is a horizontal line.

True or false?

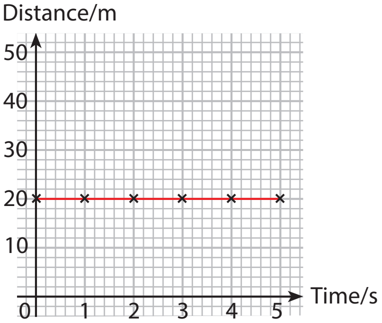


Figure 2.12 *Car stopped or car at rest*

Time/s	0	1	2	3	4	5
Distance/m	20	20	20	20	20	20

- The graph has zero gradient.
- The distance remains at 20 m.
- Speed = 0 m/s

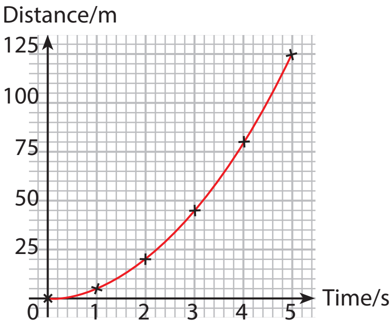


Figure 2.13 *Car travelling with an increasing speed*

Time/s	0	1	2	3	4	5
Distance/m	0	5	20	45	80	125

- The graph has an increasing gradient.
- The speed of the car increases. It travels faster each second.

QUICK CHECK

The constant gradient of a slope in a distance–time graph indicates that an object is moving at a uniform speed.

True or false?

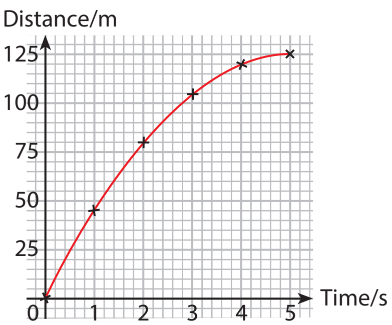


Figure 2.14 *Car travelling with a decreasing speed*

Time/s	0	1	2	3	4	5
Distance/m	0	45	80	105	120	125

- The graph has a decreasing gradient.
- The speed of the car decreases. It travels slower each second.

Speed–time graphs

Area under speed–time graphs

Figure 2.15 shows the speed–time graph for an object moving from one place to another over a time interval of 24 seconds. Based on the graph, how can we describe the motion of the object? What is the distance travelled by the object?

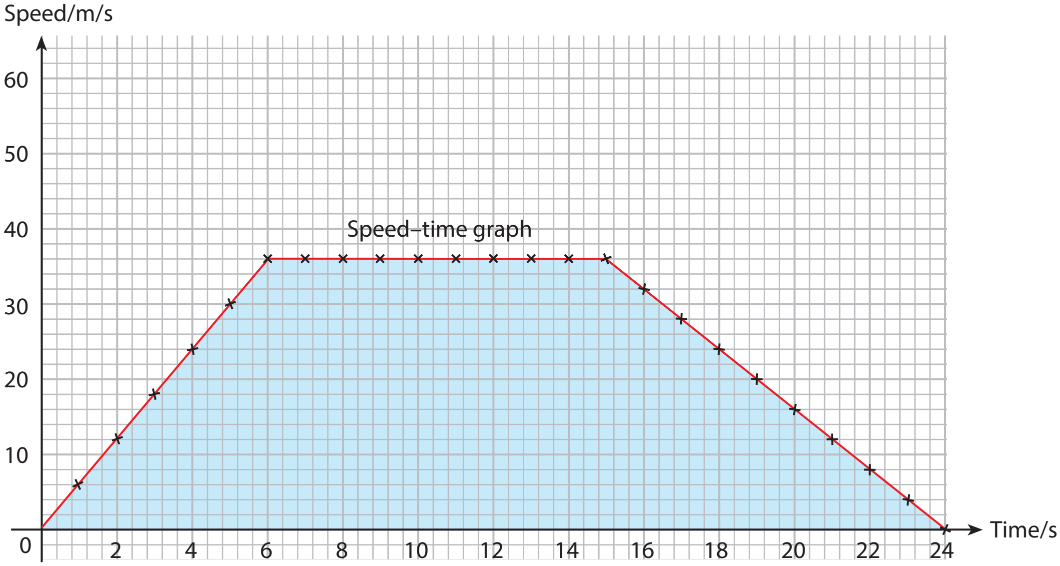


Figure 2.15 *Speed–time graph of an object moving from one place to another*

At $t = 0$ s, the object is at rest. From $t = 0$ s to 6 s, the speed of the object increases uniformly from 0 m/s to 36 m/s, and remains constant at 36 m/s from 6 s to 15 s. From 15 s to 24 s, the speed of the object decreases from 36 m/s to 0 m/s.

For an object travelling with uniform acceleration, the area under its speed–time graph gives the distance it travels.

From Figure 2.15, the total area under the speed–time graph

= area of the trapezium

$= \frac{1}{2} \times \text{sum of parallel sides} \times \text{height} = \frac{1}{2} \times (9 + 24) \times 36 = 594$

Therefore, the total distance travelled by the object is 594 m.

WORD ALERT

Trapezium: a four-sided shape with two parallel sides

Worked Example 2E

Figure 2.16 shows the speed–time graph for an object moving with a uniform speed.

What is the total distance travelled from $t = 0$ s to $t = 10$ s?

Solution

Area under speed–time graph

= area of the rectangle

$= 10 \times 6$

$= 60$

Total distance travelled from $t = 0$ s to $t = 10$ s is 60 m.

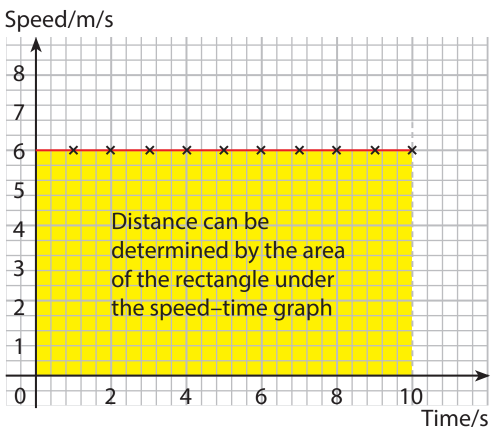


Figure 2.16

HELPFUL NOTES

In Figure 2.15, the object accelerates from rest to 36 m/s in 6 s. It then remains at this speed for 9 s (acceleration = 0 m/s^2). Finally, it decelerates to 0 m/s in 9 s.

In Figure 2.16, the object travels at 6 m/s (acceleration = 0 m/s^2) throughout the journey.

Gradient of speed–time graphs

The gradient of a speed–time graph gives the acceleration of the object.

Based on Figure 2.15 on page 25, the acceleration of the object can be calculated as shown in Table 2.4.

Table 2.4 *Calculating the acceleration of the object*

Time interval	Initial speed *u* and final speed *v*	Acceleration
0 s to 6 s	u = 0 m/s, v = 36 m/s	$\frac{(36 - 0)\text{ m/s}}{(6 - 0)\text{ s}} = 6\text{ m/s}^2$
6 s to 15 s	u = 36 m/s, v = 36 m/s	$\frac{(0 - 0)\text{ m/s}}{(15 - 6)\text{ s}} = 0\text{ m/s}^2$
15 s to 24 s	u = 36 m/s, v = 0 m/s	$\frac{(0 - 36)\text{ m/s}}{(24 - 15)\text{ s}} = -4\text{ m/s}^2$

Uniform and non-uniform acceleration

A train leaves a station and travels along a straight track towards the next station.

Figure 2.17 shows how the speed of the train varies with time over the whole journey.

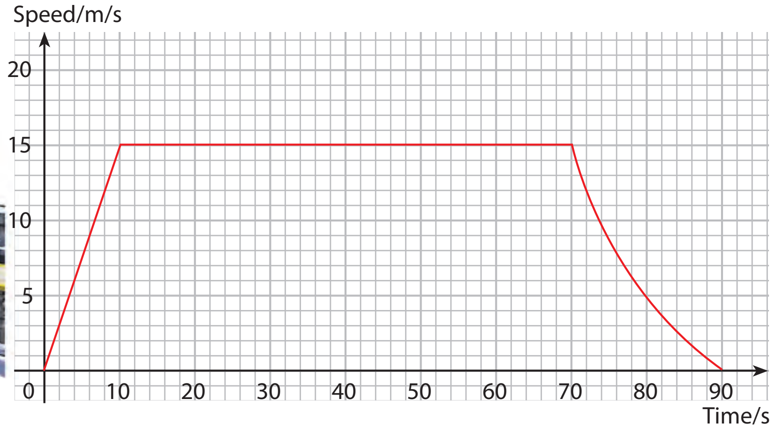


Figure 2.17 *Speed–time graph of a train*

QUICK CHECK

The non-uniform acceleration of an object is shown by the changing gradient of the speed–time graph.

True or false?

Table 2.5 describes how the motion of the train changes over the whole journey (Figure 2.17).

Table 2.5 *Motion of the train*

Time interval	Speed of train	Acceleration of train
0 s to 10 s	• The speed is increasing uniformly. • The gradient remains constant.	The acceleration of the train is uniform.
10 s to 70 s	• The speed remains constant at 15 m/s. • The gradient is zero.	The acceleration of the train is zero.
70 s to 90 s	• The speed is decreasing non-uniformly. • The gradient is becoming less negative (the slope becomes less steep).	• The acceleration of the train is **negative** (deceleration) and non-uniform. • The deceleration of the train is decreasing.

Worked Example 2F

A motorist approaches a traffic light junction at 15 m/s. The traffic light turns red when he is 30 m from the junction. He takes 0.4 s before applying the brakes and his car slows down at a rate of 3.75 m/s^2 for a time interval of Δt before coming to a stop at time *T*.

Figure 2.18 shows the speed–time graph of this motorist.

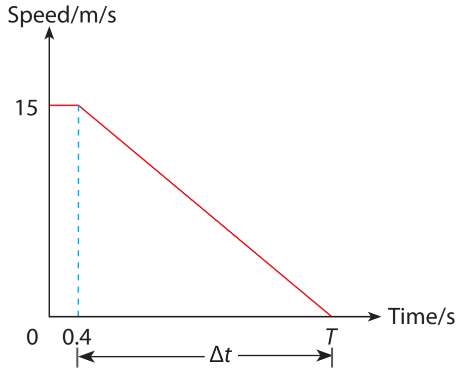


Figure 2.18

(a) Describe in words the speed and acceleration of the car between

  (i) $t = 0$ s and t = 0.4 s;

  (ii) $t = 0.4$ s and t = *T* s.

(b) What do you call this duration of 0.4 s?

(c) Calculate the value of Δt.

(d) What is the total distance travelled by the car from $t = 0$ s to $t = T$ s?

(e) Is the motorist able to stop his car in time?

WORD ALERT

Duration: length of time, period

Solution

(a) (i) The car travels at a uniform speed of 15 m/s with zero acceleration.

  (ii) The speed of the car decreases from 15 m/s to zero with a uniform deceleration of 3.75 m/s^2.

(b) Human reaction time

(c) Given: Uniform deceleration = 3.75 m/s^2 (i.e. acceleration $a = -3.75$ m/s^2)

Change in velocity Δv = final velocity – initial velocity = (0 –15) = –15 m/s

(d) By definition, $a = \frac{\Delta v}{\Delta t} = -3.75 \text{ m/s}^2 = \frac{-15 \text{ m/s}}{\Delta t}$

$\therefore \Delta t = 4$ s

(e) Distance = area under speed–time graph

$= \text{area of trapezium} = \frac{1}{2} \times (0.4 \text{ s} + 4.4 \text{ s}) \times 15 \text{ m/s}$

$= 36$ m

Since the distance of his car is more than 30 m, the motorist is unable to stop his car in time.

HELPFUL NOTES

The symbol Δ means *change*. So Δt means *change in t*, i.e., final *t* minus initial *t*.

Let's Practise 2.2

1 Figure 2.19 shows the distance–time graph of an object from its starting point.

Describe the motion of the object in terms of both its distance from the starting point and its speed at

(a) $t = 0$ s;

(b) $t = 20$ s;

(c) $t = 40$ s.

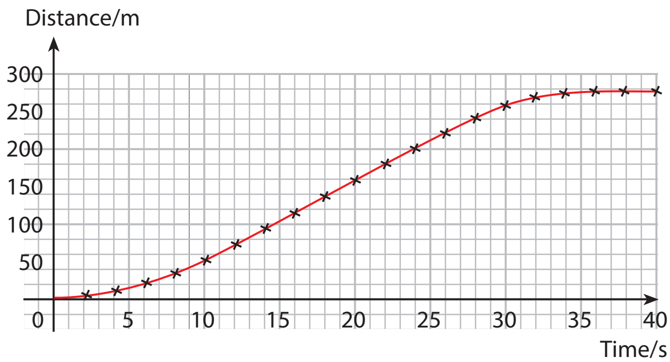


Figure 2.19

LINK PWB
Practical 2, pp. XX–XX

LINK TWB
Exercises 2B–2C, pp. XX-XX

2 Ⓢ The speed–time graph of a car is shown in Figure 2.20.
Describe the motion of the car in terms of both its speed and acceleration for the following time intervals:

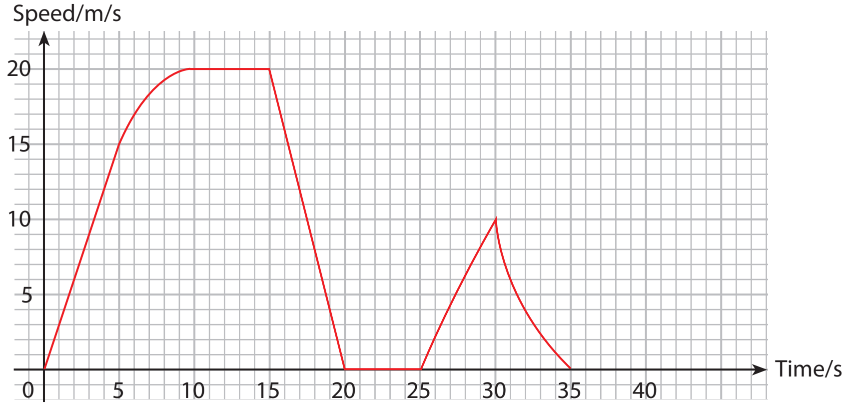


Figure 2.20

(a) $t = 0$ s to $t = 5$ s
(b) $t = 5$ s to $t = 10$ s
(c) $t = 10$ s to $t = 15$ s
(d) $t = 15$ s to $t = 20$ s
(e) $t = 20$ s to $t = 25$ s
(f) $t = 25$ s to $t = 30$ s
(g) $t = 30$ s to $t = 35$ s

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

2.3 Acceleration of Free Fall

In this section, you will learn the following:

- State that the acceleration of free fall g for an object near to the surface of the Earth is approximately constant and is approximately 9.8 m/s^2.
- Ⓢ Describe the motion of objects falling in a uniform gravitational field with and without air resistance.

What did Galileo discover?

If we drop a large stone and a small pebble from the same height at the same time, which object will hit the ground first?

In the 17th century, Galileo Galilei discovered that all objects fell at the same acceleration due to the Earth's gravity, regardless of mass or size. To make his discovery, Galileo did a series of experiments and careful observations. Galileo's finding was different from Aristotle's widely accepted claim (Figure 2.21).

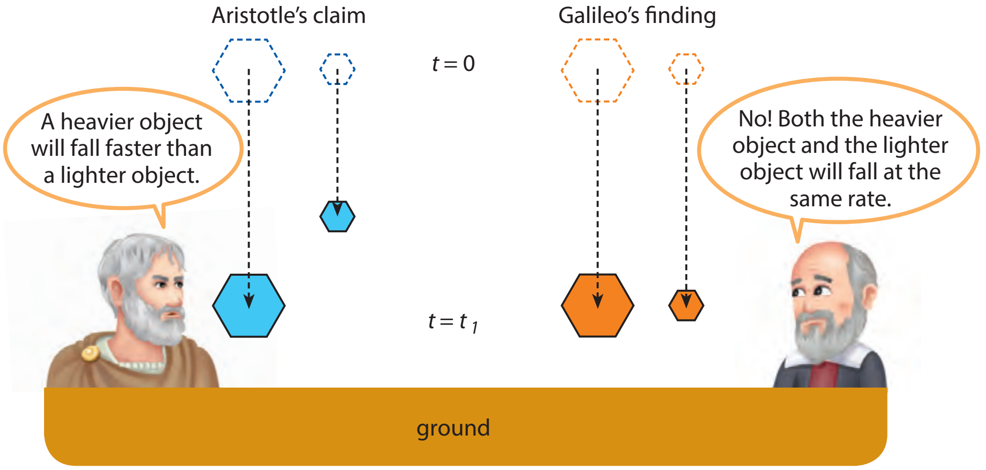


Figure 2.21 *If you were a scientist in the 17th century, would you have accepted Galileo's finding? Why?*

Acceleration due to gravity, ***g***, is a constant for objects close to the Earth's surface. The value of g is generally taken to be 9.8 m/s^2. For simplicity in calculations, we will approximate this value to 10 m/s^2 throughout this book, unless otherwise stated.

PHYSICS WATCH

Scan this page to watch a clip of the feather and hammer experiment.

How do objects fall without air resistance?

An object can only be in **free fall** if the only force acting on it is its own weight. Figure 2.22 shows the paths taken by a feather and by a hammer falling in a vacuum.

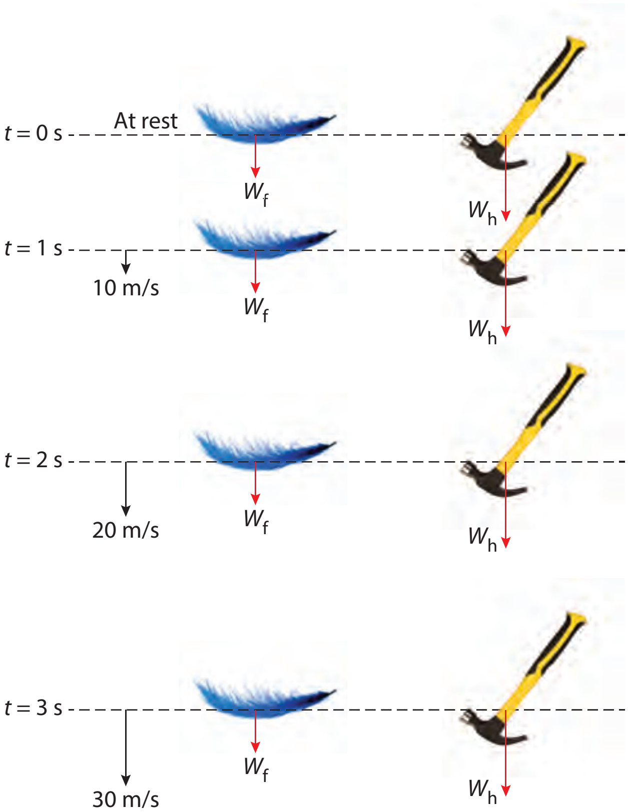


Figure 2.22 *A feather and a hammer in free fall*

From Figure 2.23, we can make the following deductions:

- The direction of motion for the two objects is downward.
- They fall towards the centre of the Earth.
- Their speed under gravity increases by 10 m/s every second.
- That means both objects have a uniform acceleration of 10 m/s^2.
- The acceleration of free-falling objects does not depend on their mass or size.
- All objects fall freely at a uniform acceleration of 10 m/s^2 near the Earth's surface. Figure 2.23 describes the motion of free-falling objects.

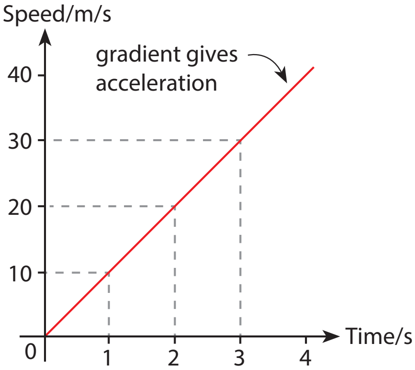


Figure 2.23 *Speed–time graph of free-falling motion*

WORD ALERT A-Z

Negligible: so small that it can be ignored

Worked Example 2G

Object A was dropped from the third floor. The time taken for the object to reach the ground was 1.34 s. Assume that air resistance was negligible. Figure 2.24 shows the path of the free-falling object.

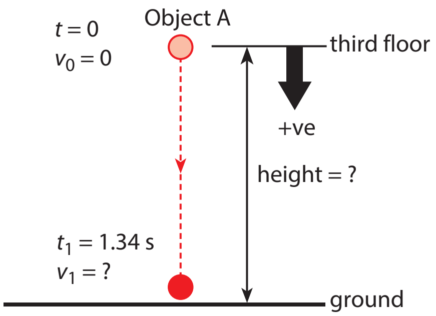


Figure 2.24

(a) Calculate the speed of object A just before it hit the ground.

(b) Calculate the height of the third floor from the ground.

(c) Object B, which was lighter than object A, was dropped from the same third floor. State and explain whether there would be any change in the speed–time graph of object B compared to that of object A.

Solution

Since air resistance was negligible, the object was in free fall (i.e. accelerating at 10 m/s^2).
Given: Time taken t to reach the ground is $t_1 = 1.34$ s

To visualise the problem, we sketch the path and the speed–time graph for free-falling object A (Figure 2.25).

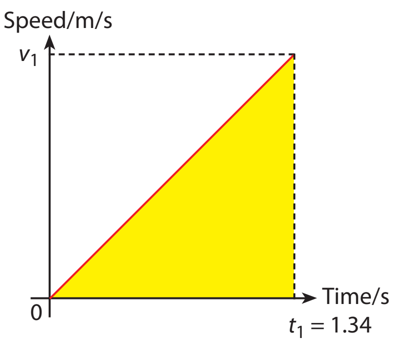


Figure 2.25

(a) Gradient of speed–time graph $= \dfrac{v_1 - 0}{1.34 - 0}$

Uniform acceleration due to gravity = 10 m/s^2

$$\therefore \quad \frac{v_1 - 0}{1.34 - 0} = 10$$

$$v_1 = 13.4 \text{ m/s}$$

The speed of object A just before it hit the ground was 13.4 m/s.

(b) Area under speed–time graph $= \dfrac{1}{2} v_1 t_1 = \dfrac{1}{2} \times 13.4 \text{ m/s} \times 1.34 \text{ s} = 9 \text{ m}$

The height of the third floor from the ground was 9 m.

(c) No. Both object A and object B would have the same speed–time graph, since they fell at a constant acceleration of 10 m/s^2.

How do objects fall with air resistance?

When you run fast, do you feel air brushing against you? If you do, you are experiencing air resistance.
A parachutist makes use of air resistance to land safely on the ground (Figure 2.26).

Air resistance is a form of frictional force. It has the following characteristics:

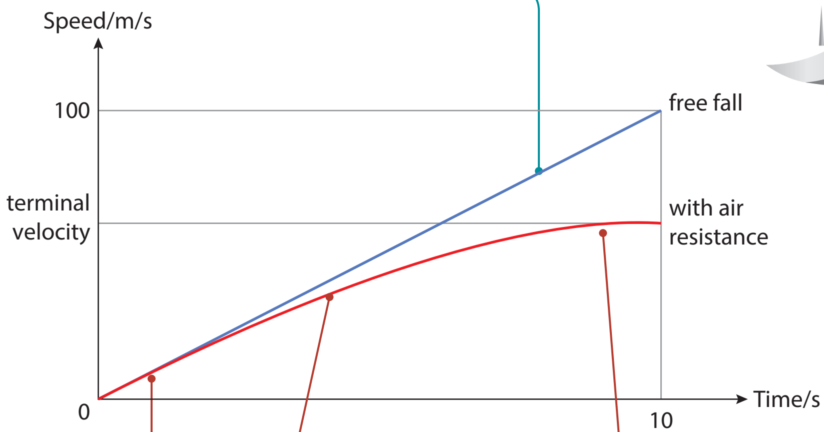
- It opposes the motion of moving objects.
- It increases with the surface area (or size) of moving objects.
- It increases with the density of air.
- It increases with the speed of moving objects.

Figure 2.27 describes the motion of a small piece of paper in free fall and the motion of the same paper experiencing air resistance.

Figure 2.26 *Air resistance at work*

Paper in free fall

- The only force acting on an object in free fall is its own weight.
- The paper accelerates uniformly at 10 m/s^2 as it falls. It reaches a speed of 100 m/s in 10 s.



Paper experiencing air resistance

- An object experiences greater air resistance when its speed increases.
- The paper accelerates at 10 m/s^2 initially.

- The acceleration starts to decrease due to the increasing air resistance.

- When the weight of the paper balances the air resistance, its acceleration decreases to zero.
- The paper continues to fall at a uniform velocity known as **terminal velocity**.

Figure 2.27 *Motion of falling paper with and without air resistance*

QUICK CHECK

A feather falls at the same acceleration as a stone in the absence of air resistance.

True or false?

Worked Example 2H

A window cleaner drops a sponge from a window at time $t = 0$ s. Figure 2.28 shows the speed–time graph of the sponge falling.

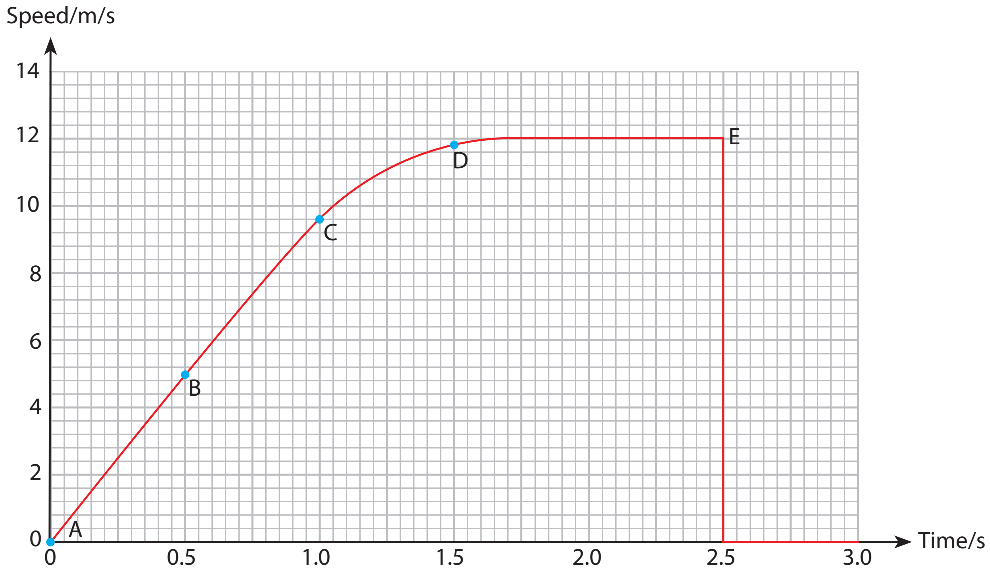


Figure 2.28

(a) Describe the motion of the sponge between A and E.

(b) Calculate the distance that the sponge falls through between $t = 0$ s and $t = 0.6$ s.

Solution

(a) From A to B, the speed of the sponge increases uniformly at a rate of 10 m/s^2.
From B to D, its speed is still increasing but at a decreasing rate.
The acceleration decreases.
From D to E, the sponge has zero acceleration and reaches its terminal velocity of 12 m/s.

(b) Distance = Area under speed–time graph $= \frac{1}{2} \times 0.6 \text{ s} \times 6.0 \text{ m/s} = 1.8 \text{ m}$

Let's Practise 2.3

1 An object is released from an unknown height and falls freely for 5 s before it hits the ground.
   (a) Sketch the speed–time graph for a time interval of 5 s, assuming there is negligible air resistance.
   (b) Calculate the speed of the object just before it hits the ground.
   (c) Calculate the unknown height.

2 S Why does a feather reach terminal velocity faster than a hammer, even though both are released from the same height?

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

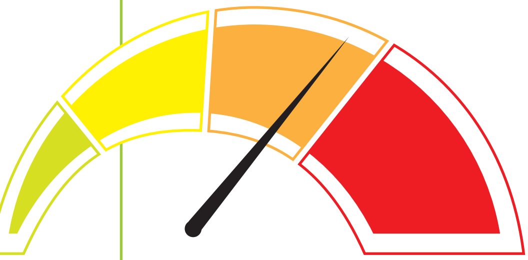
LINK TWB

Exercises 2D–2E, pp. XX-XX
Exercise 2F Let's Reflect, p. X

Let's Map It

MOTION

is described in terms of



Speed (m/s)
- scalar

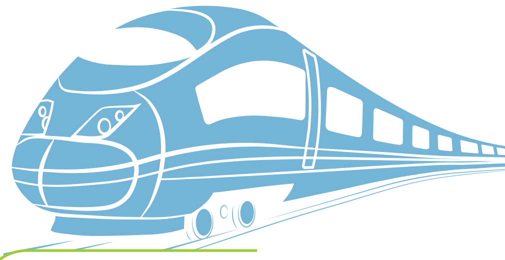
involves
- Distance (m)

can be found by
- Area under speed–time graph

can be found by
- Speed = $\frac{\text{distance travelled}}{\text{time taken}}$
- Average speed = $\frac{\text{total distance travelled}}{\text{total time taken}}$
- Gradient of distance–time graph

Velocity (m/s)
- vector

involves
- Displacement (m)



can be found by
- Velocity = $\frac{\text{displacement}}{\text{time taken}}$

Acceleration (m/s²)
- vector

can be found by
- (S) Acceleration = $\frac{\text{change in velocity}}{\text{time}}$
- (S) Gradient of speed–time graph

example
- Acceleration of free fall, $g = 9.8$ m/s²
  - (S) without air resistance, object falls with constant acceleration
  - (S) with air resistance, object falls with decreasing acceleration and may reach terminal velocity

Let's Review

Section A: Multiple-choice Questions

1 The average speed of a car is 35 km/h. If it travels at this speed for 45 minutes, what is the distance it has travelled?

A 0.78 km **B** 26.25 km
C 129 km **D** 467 km

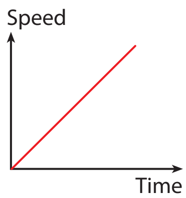
2 **S** A car accelerates uniformly from 5 m/s to 13 m/s in 4.0 s. What is the acceleration of the car?

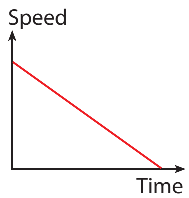
A 0.50 m/s^2 **B** 0.80 m/s^2
C 1.25 m/s^2 **D** 2.00 m/s^2

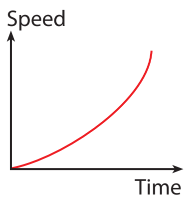
3 **S** A ball is thrown vertically upwards at 1.2 m/s. It decelerates uniformly at 10 m/s^2. What is the time taken for the ball to reach zero speed?

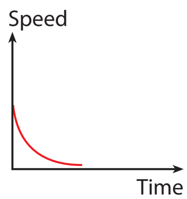
A 0.12 s **B** 2.4 s
C 6.0 s **D** 12 s

4 **S** Which speed–time graph shows the motion of an object which decelerates non-uniformly?

A


B


C


D


Section B: Short-answer and Structured Questions

1 A car travelled from town A to town B, and then to town C. It took 0.5 hour to travel 50 km from town A to town B. The car stopped for 0.25 hour in town B. Then it travelled another 30 km to town C in 1.25 hour.

Calculate the average speed of the car for the whole journey.

2 Figure 2.29 shows the speed–time graph for a car in motion.

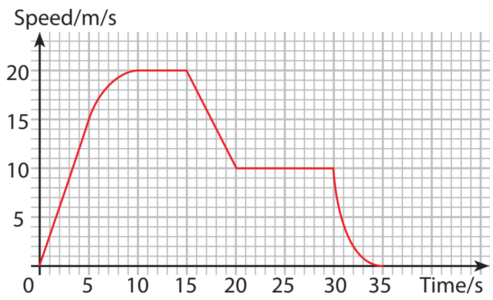


Figure 2.29

Describe the motion of the car between

(a) $t = 0$ s and $t = 10$ s;
(b) $t = 10$ s and $t = 15$ s;
(c) $t = 15$ s and $t = 20$ s;
(d) $t = 20$ s and $t = 30$ s;
(e) $t = 30$ s and $t = 35$ s.

3 **S** A train travels along a straight track from one station to another. Figure 2.30 shows how the speed of the train varies with time over the whole journey.

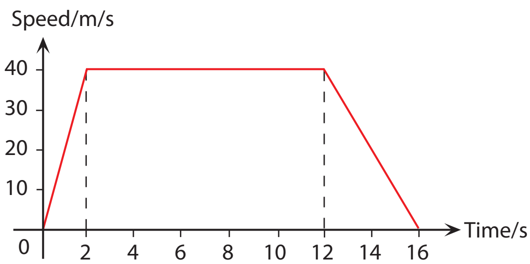


Figure 2.30

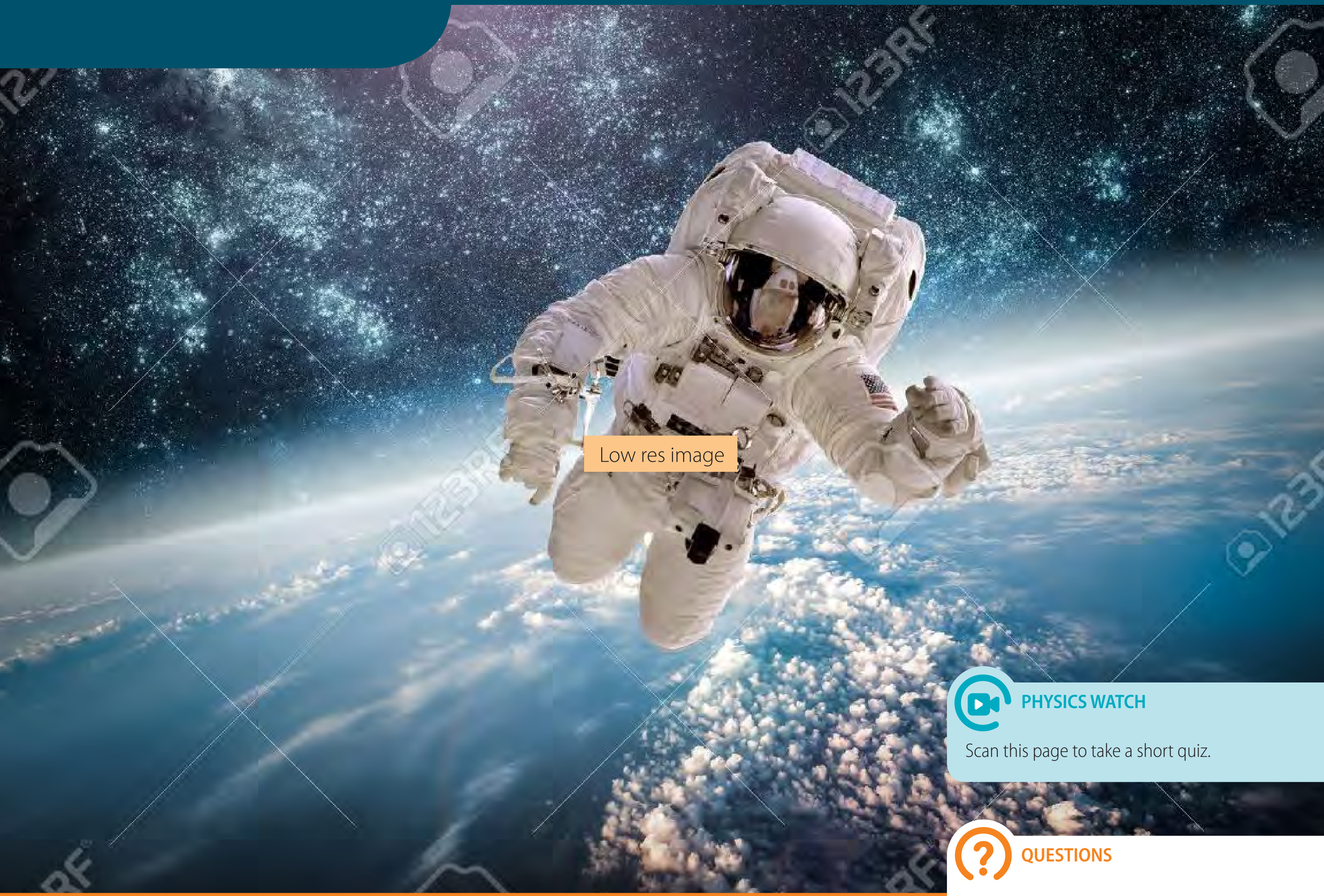
(a) State the time interval over which the train is decelerating.
(b) Determine the acceleration of the train.
(c) Determine
  (i) the distance between the two stations;
  (ii) the average speed of the train over the whole journey.

4 **S** A feather was released from rest in vacuum. It was then released from rest in air. In both situations, the feather was released from the same significant height.

(a) Compare and discuss the motion of the feather in vacuum and in air.
(b) Sketch the speed–time graphs of the motion of the feather in vacuum and in air.

CHAPTER 3

Mass, Weight and Density



PHYSICS WATCH

Scan this page to take a short quiz.

QUESTIONS

- Why does a spacecraft use a lot of energy to go into space?
- The astronaut in the photo is floating in space. Does the astronaut still have weight?
- Why is the astronaut able to bounce about easily on the Moon but not on the Earth?

A lot of energy is used to power a spacecraft when it is launched from the Earth towards space. Once in space, the spacecraft separates from its main engine and rocket boosters. It then fires its own engine to put it into orbit around the Earth. While in orbit, an astronaut sometimes leave the spacecraft to be out in open space.

When the spacecraft wants to land on the Moon, the engine is fired again to steer the spacecraft. Once on the Moon, the astronaut from the spacecraft can do some moonwalking. Unlike on the Earth, the astronaut is able to bounce about easily on the Moon.

3.1 Mass and Weight

In this section, you will learn the following:

- State what is meant by the term *mass* and *weight*.
- Ⓢ Describe, and use the concept of, weight as the effect of a gravitational field on a mass.
- Define *gravitational field strength*.
- Recall and use the equation $g = \frac{W}{m}$ and know that this is equivalent to the acceleration of free fall.
- Know that weights (and masses) may be compared using a balance.

Is mass the same as weight?

When we say that a person weighs 100 kilograms, we actually mean that the person has a body mass of 100 kilograms. When we buy a 5-kilogram bag of rice, we are buying a bag of rice that has a *mass* of 5 kilograms, not a bag of rice that *weighs* 5 kilograms.

In physics, weight and mass are two very different quantities. In everyday language, we often misuse the term *weight* when we mean *mass*. So, what is the difference between mass and weight?

What is mass?

Mass is a measure of the quantity of matter in an object at rest relative to the observer. Its SI unit is the **kilogram (kg)** .

The object has to be at rest when the observer measures the amount of matter in it. Why is this so?

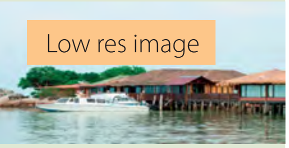
Scientists have found that when an observer looks at an object moving at very high speeds (near to the speed of light), the observer sees that the object has a different mass from when it is stationary. However, such high speeds do not happen in everyday life. These observations take place in specially built laboratories that study small particles moving at very high speeds. The mass of an object is a fixed quantity under normal circumstances.

Thus, we can say that mass is a property of a body that does not change with its location or shape. The mass of a body depends on the number and composition of atoms and molecules that make up the body. It is a scalar quantity.

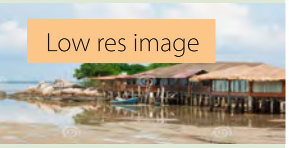
ENRICHMENT *INFO*

Tides

High tides and low tides are observed in places near the sea. Have you ever wondered what causes the tides?



(a) High tide



(b) Low tide

Figure 3.1 *Places near the sea experience tides*

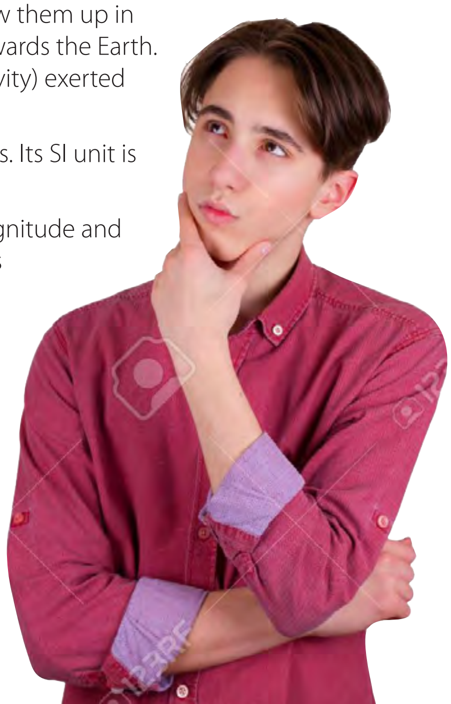
Gravitational force of attraction exists between the Earth and the Moon. The high and low tides are the effects of the Moon's gravitational force on the Earth.

What is weight?

Do you know why objects fall to the ground after you throw them up in the air? This is because a force called weight pulls them towards the Earth. This force is the gravitational pull (gravitational force or gravity) exerted by the Earth.

Weight is the gravitational force on an object that has mass. Its SI unit is the **newton (N)**.

Since weight is a force, it is a vector quantity with both magnitude and direction. The direction of weight is downward, i.e., towards the centre of the Earth.



What is a gravitational field?

You have learnt earlier that the weight of an object with mass is due to the gravitational force acting on it. This weight is the effect of a gravitational field on a mass.

A **gravitational field** is a region of space in which a mass exert a force of attraction on another mass.

For example, the Earth with a huge mass has a gravitational field surrounding it. As such, any object within the Earth's gravitational field will experience a force exerted by the Earth on it. The gravitational force experienced is the strongest at the surface of the Earth. It gets weaker further away due to a decreasing gravitational field strength.

What is gravitational field strength?

The weight of an object depends on the strength of the gravitational force acting on it. For example, an object weighs less on the Moon than on the Earth. This is because the Moon's gravitational field strength is weaker than the Earth's gravitational field strength.

Gravitational field strength *g* is defined as the gravitational force per unit mass.

In equation form: $g = \frac{W}{m}$ where g = gravitational field strength (in N/kg)

W = weight (in N)

m = mass of the object (in kg)

On the Earth, the gravitational field strength g is approximately 10 N/kg. This means that a 1-kg mass on the Earth's surface experiences a force of 10 N due to the Earth's gravitational field.

On the other hand, the same 1-kg mass on the Moon experiences a gravitational force of only 1.6 N. This is because the gravitational field strength on the Moon is 1.6 N/kg.

Imagine if we were to weigh an elephant on the Earth's surface and the Moon's surface (Figure 3.2). The elephant would weigh much more on the Earth's surface than on the Moon's surface even though its mass remains unchanged.

PHYSICS WATCH

Scan this page to explore a simulation on mass and weight.

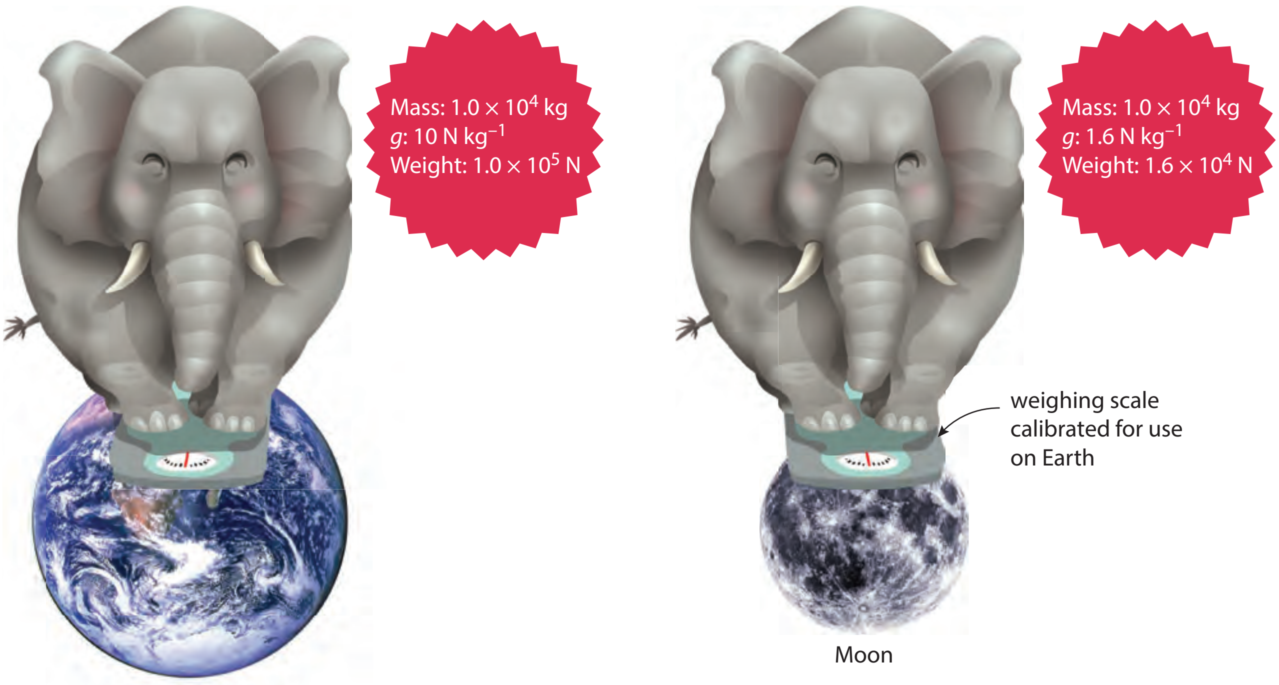


***Figure 3.2** The elephant 'loses' weight when it is on the Moon!*

WORD ALERT

Directly proportional: to increase or decrease by the same number of times

LINK

You will learn more about the equation $F = ma$ in Chapter 4.

HELPFUL NOTES

The gravitational field strength $g = \frac{W}{m}$ is equivalent to the acceleration of free fall. However, the weight W of an object of mass m is $W = mg$ regardless of whether it is at rest or free-falling.

How are mass and weight related?

From the equation $g = \frac{W}{m}$, we have $W = mg$. Thus, the weight or gravitational force W acting on an object is directly proportional to its mass m. For example, if we double the mass of the object, the weight or gravitational force acting on the object becomes doubled.

Worked Example 3A

A mobile phone has a mass of 75 g. Calculate its weight if g is 10 N/kg.

Solution

Mass of mobile phone $m = 75\text{ g} = 75 \times 10^{-3}\text{ kg} = 0.075\text{ kg}$

Weight of mobile phone $W = mg = 0.075\text{ kg} \times 10\text{ N/kg} = 0.75\text{ N}$

Gravitational field strength and acceleration due to gravity

On the Earth, the gravitational field strength g near its surface is 10 N/kg.

Therefore, the weight W (in N) of an object of mass m (in kg) is given by:

$W = mg$

$= m \times 10\text{ N/kg}$ ------------- (1)

If the object were to free-fall under gravity without air resistance, we can find its acceleration using the equation:

$F = ma$ where F = resultant force (in N)

m = mass (in kg)

a = acceleration (in m/s^2)

Consider an object of mass m (in kg) free-falling under gravity without air resistance. It is free-falling at an acceleration of $a = g = 10\text{ m/s}^2$ due to its weight W (in N). So, we have

$F = ma$

$W = mg$

$= m \times 10\text{ m/s}^2$ --------------- (2)

By equating equations (1) and (2), we have

$W = mg$

$= m \times 10\text{ N/kg}$

$= m \times 10\text{ m/s}^2$

Therefore, $10\text{ N/kg} = 10\text{ m/s}^2$. This shows that gravitational field strength near the Earth's surface $g = \frac{W}{m} = 10\text{ N/kg}$ is equivalent to the acceleration of free fall $g = \frac{W}{m} = 10\text{ m/s}^2$.

What do common weighing instruments measure?

Common weighing instruments, such as the electronic balance (Figure 3.3), spring balance and bathroom scale, actually measure the weight of an object, not its mass. These instruments, however, are calibrated to give readings in grams (g) or kilograms (kg).

Using these instruments, an object will have different mass readings at different gravitational field strengths. For example, if an astronaut steps on a bathroom scale on the Moon, the reading will be lower than the reading taken on the Earth. This is because the gravitational field strength on the Moon (1.6 N/kg) is less than that on the Earth (10 N/kg).

This means that a weighing scale calibrated for use on the Earth cannot be used on the Moon. The weighing scale has to be calibrated to the Moon's gravitational field strength in order to give accurate mass measurements on the Moon.

Figure 3.3 *The electronic balance is a commonly used laboratory instrument for measuring mass. In fact, electronic balances measure weight, but they are calibrated to give readings for mass.*

How is mass measured?

The mass of an object can be measured using a beam balance (Figure 3.4). Unlike a weighing scale, a beam balance does not have to be calibrated for different gravitational field strengths.

A beam balance compares the gravitational force acting on an object with that acting on standard masses. As both the object and the standard masses experience the same gravitational field strength, the mass reading taken for a given object, whether on the Earth or on the Moon, will be the same.

Table 3.1 shows how mass is different from weight.

Figure 3.4 *Simple beam balance used to measure mass*

Table 3.1 *Differences between mass and weight*

Mass	Weight
• An amount of matter	• A gravitational force
• A scalar quantity (i.e. has only magnitude)	• A vector quantity (i.e. has both magnitude and direction)
• SI unit: kilogram (kg)	• SI unit: newton (N)
• Independent of the gravitational field strength	• Dependent on the gravitational field strength
• Measured with a beam balance or a calibrated electronic balance	• Measured with a spring balance

Worked Example 3B

The acceleration of free fall on the Moon is 1.6 m/s^2. The acceleration of free fall on the Earth is 10 m/s^2. A rock has a mass of 10 kg on the Earth. Calculate the weight of the rock on

(a) the Earth; **(b)** the Moon.

Solution

We know that

- the mass of the rock does not change whether on the Earth or on the Moon;
- weight = mass × acceleration of free fall.

(a) Therefore, the weight of the rock on the Earth = 10 kg × 10 m/s^2 = 100 N

(b) The weight of the rock on the Moon = 10 kg × 1.6 m/s^2 = 16 N

(Note: 1 kg m/s^2 = 1 N)

QUICK CHECK

As a satellite is launched from the Earth into space, its weight decreases while its mass remains unchanged.

True or false?

Let's Practise 3.1

1 Give four differences between mass and weight.
2 Why is the mass of a body not affected by changes in the physical environment such as location?
3 The Moon has a gravitational field strength one-sixth that of the Earth's. If a person has a mass of 60 kg on the Earth, how much will he weigh on the Moon?
4 The gravitational field strength of Jupiter is 22.9 N/kg. An astronaut weighs 1200 N on the Earth. What will his weight be on Jupiter? Assume the gravitational field strength of the Earth is 10 N/kg.
5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 3A, pp. XX–XX

3.2 Density

In this section, you will learn the following:

- Define *density* and recall and use the equation $\rho = \frac{m}{V}$.
- Describe how to determine the density of a liquid and certain solids.
- Determine whether an object floats based on density data.
- S Determine whether one liquid will float on another liquid based on density data.

What is density?

When we talk about density, we are talking about how much mass is packed into a given space.

The **density** of a substance is defined as its mass per unit volume.

In some cases, density can be used to identify substances. For example, the density of pure gold is 19 300 kg/m^3. If the density of a gold ring is not 19 300 kg/m^3, then it is not made of pure gold — it must have some impurities in it.

To calculate the density of a substance, we need to know its mass *m* and its volume *V*. Density ρ (Greek letter 'rho', pronounced 'row') is given by

$\boldsymbol{\rho = \frac{m}{V}}$ where ρ = density

m = mass of the object

V = volume of the object

The SI unit of density is the **kilogram per cubic metre (kg/m³)**.

If mass is measured in kilograms (kg) and volume in cubic metres (m^3), the unit of density would be the SI unit. However, if mass is measured in grams (g) and volume in cubic centimetres (cm^3), the unit of density would be gram per cubic centimetre (g/cm^3).

As most objects we handle daily have relatively small masses and volumes, the unit g/cm^3 is more commonly used. The densities of some common substances are shown in Table 3.2.

Table 3.2 *Densities of common substances*

Substance	Density /g/cm^3
Gases	
Dry air	0.00123
Oxygen	0.00143
Liquids	
Turpentine	0.87
Oil	0.92
Pure water	1
Seawater	1.025
Mercury	13.6
Solids	
Polystyrene	0.016
Cork	0.24
Pine wood	0.5
Ice	0.917
Glass	2.5
Iron	7.874
Gold	19.3

HELPFUL NOTES

To convert density values from g/cm^3 to kg/m^3, we simply multiply them by 1000.

Substances that float on water have lower densities than water. Substances that sink in water have higher densities than water.

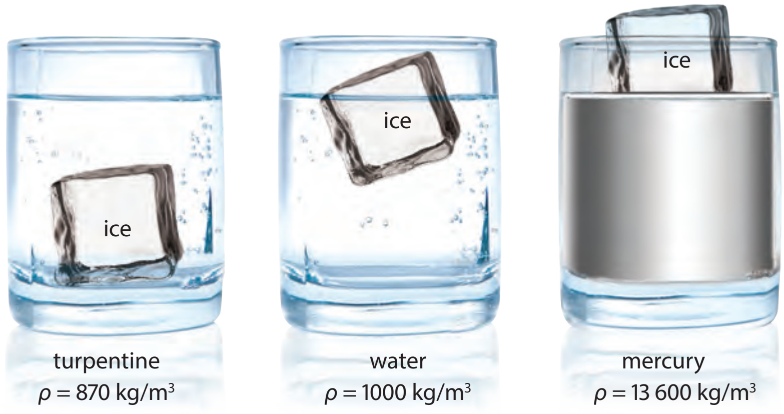


Figure 3.5 *Ice cubes placed in three different liquids. The density of the liquid determines whether the ice cube floats or sinks.*

Why does a heavy steel ship float?

A small iron ball sinks in water, but a large and heavy ship (Figure 3.6) floats! Why?

A large ship is an object that is made up of more than one material. In addition to steel, it contains a large volume of air in the various rooms and cabins. Therefore, we will have to consider the average density of the ship. The average density of an object is calculated by dividing its total mass by its total volume.

For example, a ship of mass 7.68×10^7 kg is 268 m long, 32 m wide and 25 m high. What is the average density of the ship?

Assuming a cuboidal shape,

the volume of the ship = 268 m × 32 m × 25 m = 214 400 m^3;

the mass of the ship = 7.68 × 107 kg.

Therefore, the average density of the ship:

$$\text{Average density} = \frac{\text{mass}}{\text{volume}} = \frac{7.68 \times 10^7\ \text{kg}}{214\,400\ \text{m}^3} = 358\ \text{kg/m}^3$$

The average density of the ship is actually less than the density of seawater, which is about 1025 kg/m^3. Therefore, the ship is able to float!

Figure 3.6 *Why does a large and heavy ship float, while an iron ball sinks?*

ENRICHMENT *ACTIVITY*

Place a solid cube of modelling clay in water and watch it sink to the bottom of the tank of water.

Now, if you have a much smaller cube of the same modelling clay, will it float or sink in the water?

If it sinks again, can you think of a way to make it float?

ENRICHMENT *INFO*

Submarine

A submarine is an interesting watercraft that can sink, float or be at rest at any position in the ocean. How is it possible?

The feature that gives a submarine of a fixed size or volume this capability is the special tanks known as ballast tanks. These ballast tanks can be filled with different amounts of air or water to vary the total mass of the submarine.

Let's Investigate 3A

Objective
To determine the density of a liquid

Apparatus
Burette, beaker, electronic balance, retort stand

Procedure

1 Find the mass m_1 of a dry, clean beaker.

2 Run a volume V of liquid from the burette into the beaker (Figure 3.7).

3 Find the mass m_2 of the beaker and the liquid.

Precaution
When reading the volume of the liquid, make sure that your eyes are level with the base of the meniscus of the liquid.

Calculation
If the masses are measured in g and the volume in cm³, then the density ρ of the liquid is

$$\rho = \frac{m_2 - m_1}{V}\ \text{g/cm}^3 = \frac{m_2 - m_1}{V} \times 1000\ \text{kg/m}^3.$$

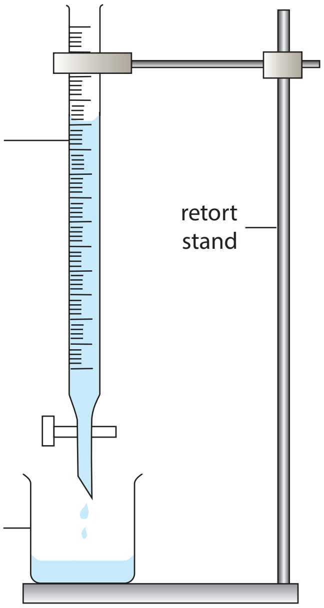


Figure 3.7

Let's Investigate 3B

Objective
To determine the density of regular objects (Figure 3.8)

Apparatus
Vernier callipers, metre rule, electronic balance

Procedure

1 Find the mass m using the electronic balance.

2 Determine the volume V by taking appropriate measurements and then calculating the volume using the following formulae:

(a) Cuboid — measure the length l, breadth b and height h

$V = l \times b \times h$

(b) Cylinder — measure the diameter d and length l

$V = \frac{\pi d^2}{4} \times l$

(c) Sphere — measure the diameter d

$V = \left(\frac{4}{3}\right)\pi\left(\frac{d}{2}\right)^3$

Precaution
Check the instruments used for zero error, and avoid parallax error when taking readings.

Calculation
If the mass of the object is in g and the volume in cm³, then density ρ of the object $= \frac{m}{V}$ g/cm³ $= \frac{m}{V} \times 1000$ kg/m³.

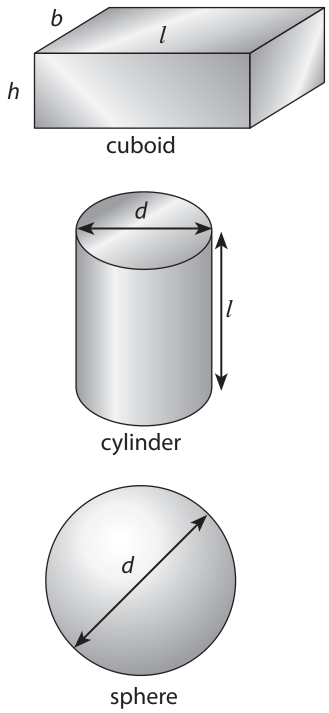


Figure 3.8

QUICK CHECK

If a block of metal is broken into two equal parts, the density of each part is half the density of the original metal block.

True or false?

Let's Investigate 3C

Objective
To determine the density of irregularly shaped objects that sink in liquid (such as a glass stopper in water)

Apparatus
Measuring cylinder, glass stopper, string, electronic balance, water, small towel, scissors

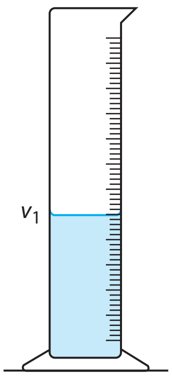


Figure 3.9

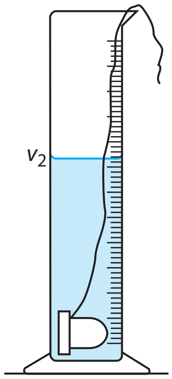


Figure 3.10

Procedure

1 Measure the mass m of the glass stopper using the electronic balance.
2 Fill the measuring cylinder with water to about one-third of its depth. Note the volume reading V_1 (Figure 3.9).
3 Tie a piece of string to the glass stopper and then lower it gently into the water. Note the new volume reading V_2 (Figure 3.10).
4 Determine the volume of the glass stopper, given by $V_2 - V_1$.
5 Remove the glass stopper from the measuring cylinder and dry it with the towel.
6 Repeat steps 2 to 5 twice with different values of V_1 and obtain the corresponding values of V_2 and $(V_2 - V_1)$.
7 Determine the volume V of the glass stopper by taking the average value of the three sets of data for $(V_2 - V_1)$.

Precaution
Check the instruments used for zero error, and avoid parallax error when taking readings.

Calculation
If the mass of the glass stopper is in g and the volume in cm^3,
then density ρ of the glass stopper $= \frac{m}{V}$ g/cm^3 $= \frac{m}{V} \times 1000$ kg/m^3.

LINK

Recall what zero error and parallax error are from Chapter 1.

LINK

PWB Practical 3A, pp. XX–XX

ENRICHMENT THINK

Can balloons carry you up into the sky?

In 1982, Mr. Larry Walters from USA, attached 45 helium weather balloons to a lawn chair, sat on it and soared into the sky.

He reportedly reached a height of 5000 m before bursting the balloons one by one with a pellet gun. On his way down, the balloons' loose cables got entangled with power lines. This resulted in a 20-minute blackout in Long Beach, USA! After his misadventure, Larry was nicknamed the "Lawn Chair Pilot".

Based on what you have learnt about density, can you explain why balloons can lift a person into the sky? Can they lift a person to outer space? Why?

WORD ALERT

Conversely: on the other hand, in the opposite way

Worked Example 3C

A cube of side 2.0 cm has a density of 6.0 g/cm³. A hole of volume 1.0 cm³ is drilled into the cube. The hole is filled up with a certain material of density 5.0 g/cm³. Calculate the density of this composite cube in **(a)** g/cm³; **(b)** kg/m³.

Solution

(a) Mass of 1.0 cm³ of the material of density 5.0 g/cm³ $= 5.0 \text{ g/cm}^3 \times 1.0 \text{ cm}^3 = 5.0 \text{ g}$

Volume of cube after a hole of 1.0 cm³ is drilled $= (2.0 \times 2.0 \times 2.0) \text{ cm}^3 - 1.0 \text{ cm}^3$

$= 7.0 \text{ cm}^3$

Mass of cube after a hole of 1.0 cm³ is drilled $= 6.0 \text{ g/cm}^3 \times 7.0 \text{ cm}^3 = 42.0 \text{ g}$

$$\therefore \text{Density of composite cube} = \frac{\text{mass of composite cube}}{\text{volume of composite cube}}$$

$$= \frac{(42.0 + 5.0) \text{ g}}{(7.0 + 1.0) \text{ cm}^3}$$

$$= 5.9 \text{ g/cm}^3$$

(b) To convert to kg/m³, recall that 1 kg = 1000 g (or $1 \text{ g} = 10^{-3} \text{ kg}$)

Since 1 m = 100 cm,

$1 \text{ m}^3 = (100)^3 \text{ cm}^3 = 10^6 \text{ cm}^3$ (or $1 \text{ cm}^3 = 10^{-6} \text{ m}^3$).

$$\text{Therefore, } 1 \text{ g/cm}^3 = \frac{1 \text{ g}}{1 \text{ cm}^3} = \frac{10^{-3} \text{ kg}}{10^{-6} \text{ m}^3} = 1000 \text{ kg/m}^3.$$

Thus, $5.9 \text{ g/cm}^3 = 5.9 \times 10^3 \text{ kg/m}^3$.

Worked Example 3D

In an experiment, a solid material of unknown density is placed in three different liquids. Table 3.3 shows the results of the experiment.

Table 3.3

Liquid	Density of liquid/(kg/m³)	Observation
Mercury	14 000	The object floats
Seawater	1100	The object floats
Paraffin	700	The object sinks

Which of the following shows the density of the object?

A Exactly 700 kg/m³

B Between 700 kg/m³ and 1100 kg/m³

C Exactly 1100 kg/m³

D Between 1100 kg/m³ and 14 000 kg/m³

Explain your choice.

Solution

B. For any solid material to float in a liquid, the density of the material must be lower than the density of the liquid. Conversely, for any solid material to sink in a liquid, its density must be higher than the density of the liquid. Based on the density values of the three different liquids, this means that the density of the solid material is lower than 1100 kg/m³ and higher than 700 kg/m³.

Worked Example 3E

A physics teacher showed some students a simple experiment. She prepared some water, glycerine and mercury in three small separate beakers. The teacher poured the water into a measuring cylinder, followed by glycerine and then mercury. The students observed that the three liquids did not mix but instead settled into three distinct layers in a certain order. Table 3.4 shows the densities of the three liquids.

Table 3.4

Liquid	Density of liquid/(kg/m^3)
Mercury	13 600
Glycerin	1260
Water	1000

Low res images

Which of the following shows the correct order of the three liquids starting from the bottom of the measuring cylinder?

A Water, glycerine, mercury

B Glycerine, water, mercury

C Mercury, glycerine, water

D Mercury, water, glycerine

Explain your choice.

Solution

C. When any two liquids that do not mix are placed in the same container, the liquid with the lower density will float on top of the liquid with the higher density. Based on the density values of the three immiscible liquids, mercury with the highest density will sink to the bottom of the measuring cylinder. Water with the lowest density will float to the top. Glycerine, with a density lower than mercury and higher than water, will form the middle layer.

WORD ALERT

Immiscible: do not mix when put together

Let's Practise 3.2

1 Define *density* and state its SI unit.

2 Given that the density of water is 1000 kg/m^3, what is the mass of 1.0 cm^3 of water in grams?

3 How would you measure the density of an irregularly shaped object that sinks in water?

4 The mass of a measuring cylinder is 60.0 g. When 30 cm^3 of olive oil is poured into it, the total mass is 87.6 g. What is the density of olive oil in g/cm^3?

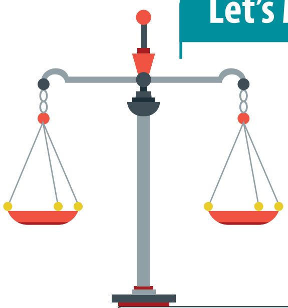
5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

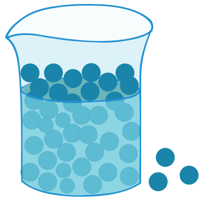
TWB LINK

Exercises 3B–3C, pp. XX-XX

Exercise 3D Let's Reflect, p. XX

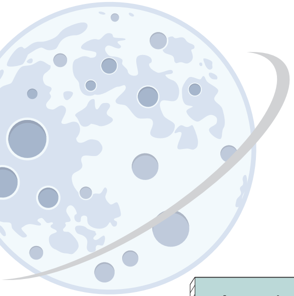
Let's Map It





MASS m
(SI unit: kg)

- values may be compared using →
  - Electronic balance
  - Beam balance
- is defined as → A measure of the quantity of matter in an object at rest relative to the observer
- is related to → WEIGHT W and DENSITY ρ

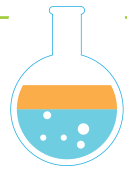


WEIGHT W
(SI unit: N)

- values may be compared using → Electronic balance; Beam balance
- is defined as → A gravitational force on an object that has mass → $W = m \times g$ → where → Gravitational field strength g is the force per unit mass. → which is equivalent to → Acceleration of free fall g
- can be described as → (S) The effect of a gravitational field on a mass

DENSITY ρ
(SI unit: kg/m³)

- is defined as → Mass per unit volume → $\rho = \frac{m}{V}$ → Based on density data, we can determine
  - whether an object floats;
  - (S) whether one liquid will float on another liquid, given the two liquids do not mix.



Let's Review

Section A: Multiple-choice Questions

1 Which of the following statements is correct?

A The mass of an object can be measured with a spring balance.

B The weight of an object can be measured with a beam balance.

C The mass of an object does not change with location.

D The weight of an object can never change.

2 A rock on the Moon has a mass of 0.5 kg. It is brought to the Earth, where the gravitational field strength is stronger. On the Earth, the rock will have

A less mass and less weight.

B less mass and the same weight.

C the same mass and the same weight.

D the same mass and more weight.

3 A measuring cylinder contains 20 cm^3 of water. When ten identical steel balls are immersed in the water, the water level rises to 50 cm^3. If one ball has a mass of 27 g, what is the density of the steel in g/cm^3?

A 0.9

B 8.1

C 9.0

D 13.5

Section B: Short-answer and Structured Questions

1 Explain the following observations:

(a) The mass of a piece of rock, measured using a beam balance, is the same on the Earth and on the Moon.

(b) The weight of the same piece of rock, measured using a spring balance, is different on the Earth and on the Moon.

2 A breakfast cereal packet carries the following label: *This package is sold by weight, not volume. Some settling of the contents may have occurred during transport.*

If settling occurs, what changes, if any, will occur to the

(a) mass of the contents;

(b) weight of the contents;

(c) volume of the contents;

(d) density of the contents?

3 **(a)** A boy made a model ship with a mass of 1.1 kg and a volume of 900 cm^3. Will it float on water? (Take the density of water to be 1000 kg/m^3.)

(b) A piece of gold has a mass of 10.0 g and a density of 19.3 g/cm^3.

(i) What is the volume occupied by the piece of gold?

(ii) When the piece of gold is placed in a beaker of mercury of density 13 600 kg/m^3, explain whether it will float or sink?

4 Figure 3.11 shows a rectangular solid block of dimensions 20 cm by 10 cm by 15 cm. It has a cylindrical hole bored at its centre.

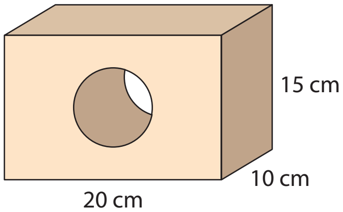


Figure 3.11

The mass of the block is 14.9 kg, and it is made of a material that has a density of 5 g/cm^3.

(a) What is the mass of the block in gram?

(b) What is the volume of the block before the cylindrical hole is bored at its centre?

(c) What is the cross-sectional area of the hole in cm^2?

5 Ⓢ Two liquids A and B are poured into a tall beaker half-filled with water. It is observed that three distinct layers are formed with the water layer in between liquid A above it and liquid B below it.

(a) Is the density of liquid A greater than water?

(b) If the density of water is 1000 kg/m^3, what can you deduce about the densities of liquid A and liquid B?

CHAPTER

4 Forces

This man is getting ready to fly his *wau bulan*. *Wau bulan* is a type of kite traditionally flown in Kelantan, a state in Malaysia. The lower part of the kite is shaped like a crescent moon. That is how the kite got its name — *bulan* means *moon* in Malay.

A typical *wau bulan* measures 2.5 m in width and 3.5 m in height. Its frame is made of bamboo. A large *wau bulan* can be very heavy and would need several people to launch it into the sky. When there is a strong wind, the *wau bulan* is lifted up. The forces acting on it enable it to fly as high as 500 m in the air. To control the height and path of the kite, a few people on the ground hold and pull the string attached to it.

PHYSICS WATCH

Scan this page to watch a clip what keeps a kite flying in the air.

QUESTIONS

- A main force is responsible to enable the *wau bulan* to fly. Where does this force come from?
- What other forces are acting on the kite when it is flying in the air?
- A big *wau bulan* will not fly when the wind is not strong enough. Why?

4.1 Forces

In this section, you will learn the following:

- Know the effects of forces.
- Sketch, plot and interpret load–extension graphs and describe the associated experimental procedures.
- S Define *spring constant*.
- S Recall and use the equation $k = \frac{F}{x}$.
- S Define and use the term *limit of proportionality*, and identify this point on a load–extension graph.

LINK

Recall what you have learnt in Chapter 2 about the acceleration of free fall, *g*.

What are some effects of forces?

You have learnt that gravitational force causes objects close to the Earth's surface to fall with the acceleration of free fall, *g* (about 9.8 m/s^2). This is one effect of a force. Figure 4.1 shows some other effects of forces.

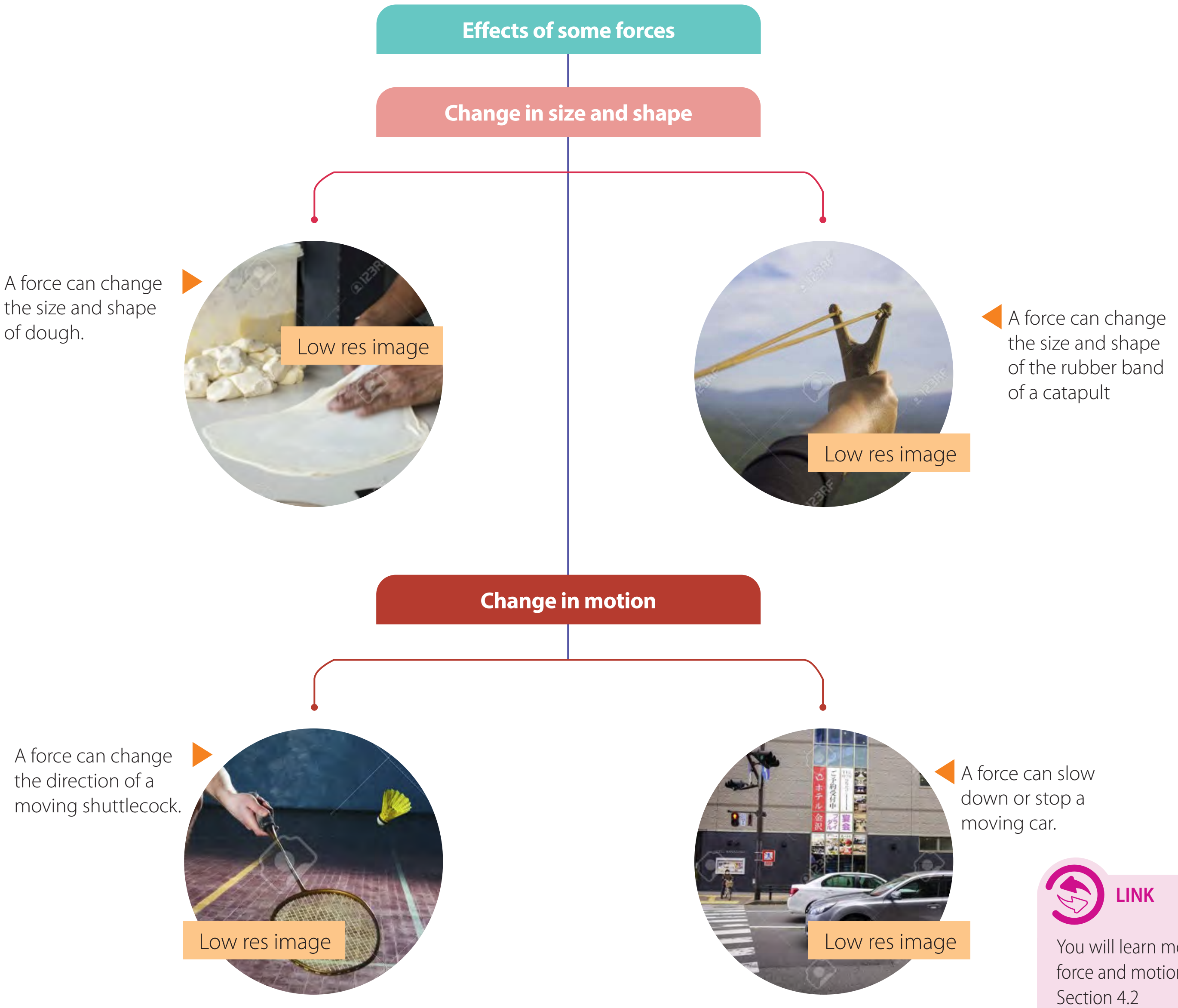


Figure 4.1 *Effects of some forces*

LINK

You will learn more about force and motion in Section 4.2

How can we study the effects of forces?

How much force is needed to cause an object to move? How much force can an object endure before it breaks? To find out, we need to study the effects of forces.

A simple study can be done to find out the effects of different loads on an elastic solid. An elastic solid is an object that changes in size and shape when a force is applied, and returns to its original size and shape when the force is removed. Examples of elastic solids are rubber bands and springs.

WORD ALERT

Endure: withstand, cope with

Extends: stretches

Load–extension graph

Figure 4.2 shows the effects of different loads on a spring. When a load is attached to the spring, the spring extends. We can calculate the extension of the spring by taking the difference between the extended length and the original length.

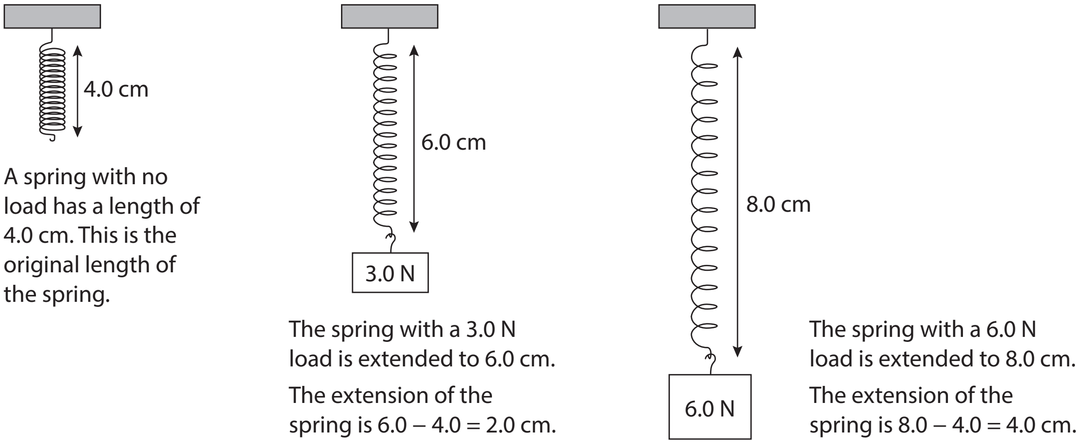
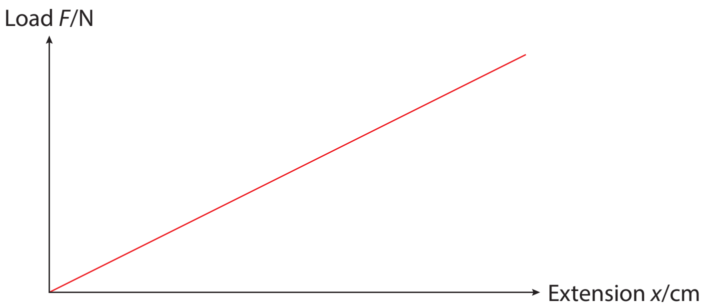


Figure 4.2 *The extension of the spring depends on the amount of force applied.*

From Figure 4.2, the extension of the spring is doubled from 2.0 cm to 4.0 cm when the load is doubled from 3.0 N to 6.0 N. The load, i.e. the force applied, is directly proportional to the extension.



When the load is not too heavy, the load–extension graph shows a straight line passing through the origin (i.e. load is directly proportional to extension).

Figure 4.3 *A sketch of load–extension graph for an elastic solid*

HELPFUL NOTES

The size of extension of a spring when pulled depends on the type of material it is made of. However, the force applied is always proportional to the extension.

We can plot a **load–extension graph** (Figure 4.3) to show the relationship between the force and the extension of an elastic solid. This relationship can help us determine the magnitude of an unknown force on an elastic solid.

Let's Investigate 4A

Objective
To investigate the relationship between force and the extension of a spring

Materials
Metre rule, spring, standard 1 N loads, hanger, retort stand

Procedure

1 Set up the experiment as shown in Figure 4.4.
2 Measure the length l_0 of the spring without any load, i.e. force $F = 0$ N. Position your eye correctly to avoid parallax error. Record this length using Table 4.1.
3 Attach a 1 N load to the hanger on the spring. Measure the new length l of the spring and record this length for $F = 1$ N.
4 By adding 1 N loads, measure and record the new lengths of the spring for F values of 2 N, 3 N, 4 N and 5 N.
5 After you have recorded the length of the spring for $F = 5$ N, remove a 1 N load. You now have a 4 N force applied on the spring. The spring should return to the length you have recorded for $F = 4$ N.
6 Remove another 1 N load so that $F = 3$ N, and check the length of the spring. Repeat this for F equals 2 N, 1 N and 0 N.
7 Calculate the extension $x = l - l_0$ for each row of Table 4.1.
8 Plot a graph of F/N (y-axis) against x/mm (x-axis).

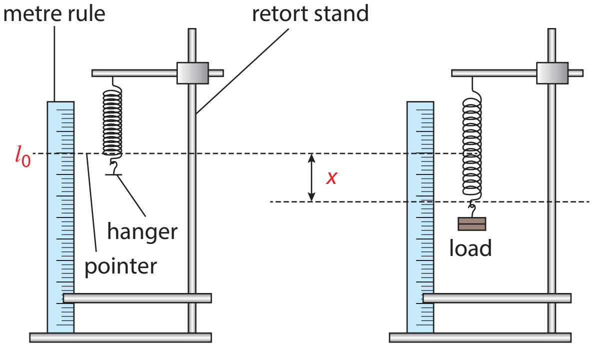


***Figure 4.4** Experimental set-up to investigate the extension of a spring*

Table 4.1

F/N	0	1	2	3	4	5
l/mm	l_0					
x/mm	0					

Discussion and conclusion
By using the data recorded in Table 4.1, we can plot the load–extension graph for the spring. The graph will look similar to the one in Figure 4.3 on page 50.

The load–extension graph for the spring shows that the force applied is directly proportional to the extension of the spring.

We can measure the extension of the spring when a load of unknown weight is attached to it, and plot a graph. We can then use the graph to determine the unknown weight.

LINK

Recall what you have learnt in Chapter 1 about how to avoid parallax error.

HELPFUL NOTES

We can conduct similar experiments to obtain the load–extension graphs for other elastic solids. Instead of the spring, we can use elastic bands or polythene strips.

LINK

Practical 4A, pp. XX–XX

QUICK CHECK

The load–extension graph of spring A has a steeper gradient than that of spring B. Spring A is more elastic than spring B.

True or false?

Worked Example 4A

A student measures the length of a spring. He then attaches different loads to the spring. He measures the length of the spring for each load. Table 4.2 shows his results.

(a) Plot the load–extension graph.

(b) Deduce the relationship between force and extension based on the graph.

(c) The student attaches a load of unknown weight to the spring and measures the length of the spring. The length is found to be 21.0 cm. What is the weight of this load?

Table 4.2

Load *F*/N	Length/cm
0	16.0
1.0	18.0
2.0	20.0
3.0	22.2
4.0	23.8
5.0	26.0

Solution

(a) To plot the load–extension graph, we need to calculate the extension for each load. Table 4.3 shows the values obtained.

Table 4.3

Load *F*/N	Extension *x*/cm
0	16.0 – 16.0 = 0
1.0	18.0 – 16.0 = 2.0
2.0	20.0 – 16.0 = 4.0
3.0	22.2 – 16.0 = 6.2
4.0	23.8 – 16.0 = 7.8
5.0	26.0 – 16.0 = 10.0

Figure 4.5 shows the graph of Load *F*/N against Extension *x*/cm.

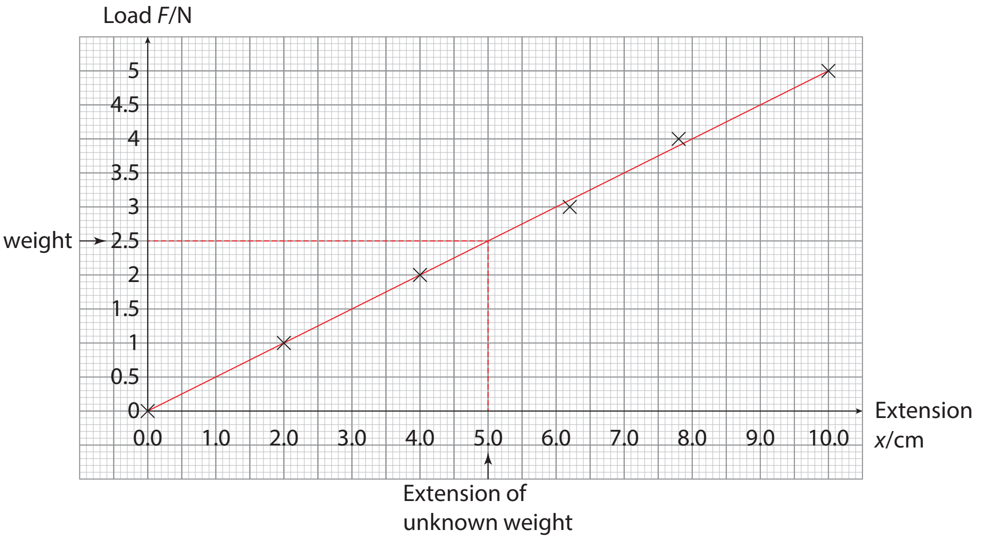


Figure 4.5

(b) The weight of the load is the force acting on the spring. The load–extension graph is a straight line passing through the origin. This shows that force is directly proportional to the extension for the spring.

(c) For the unknown weight, the extension $x = 21.0 - 16.0 = 5.0$ cm

From the graph, when the extension is 5.0 cm, the load is 2.5 N.

Spring constant and limit of proportionality

Recall that the load–extension graph for a spring is a straight line with a positive gradient. This means that for any point along the graph, the ratio of load F to extension x always gives the same value, i.e. a constant. This constant is called the spring constant and is given by

$$k = \frac{F}{x}$$ where k = spring constant

F = force

x = extension

The **spring constant** is defined as the force per unit extension.

The unit for k depends on the units for force F and extension x. When F is in N and x is in cm, the unit for k is N/cm. Similarly, when F is in N and x is in mm, the unit for k is N/mm. Since the SI unit for length is m, and force is N, the SI unit for the spring constant is **newton per metre (N/m)**.

Refer to Worked Example 4A on page 52. What is the spring constant of the spring?

We can take any values of force F and extension x to calculate the spring constant.

So, for F = 5 N and x = 10 cm,

$$k = \frac{F}{x} = \frac{5}{10} = 0.5 \text{ N/cm}$$

However, the force or load is proportional to the extension only when value of F is not too large. There is a point beyond which the extension is no longer directly proportional to the load. This point is called the **limit of proportionality** as shown in Figure 4.6.

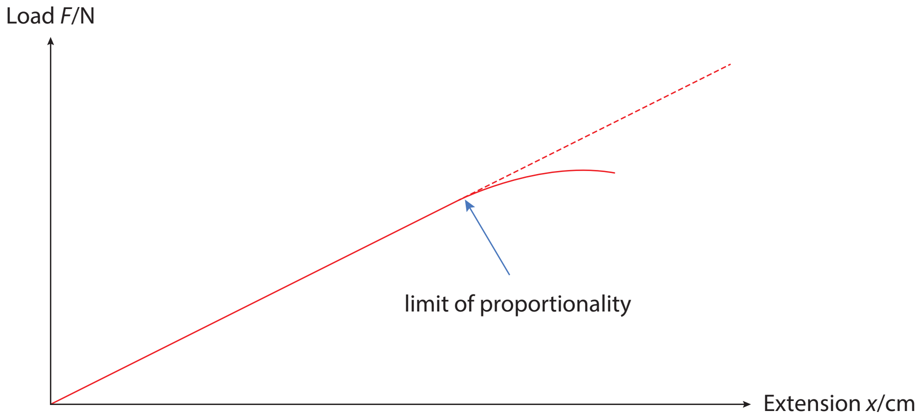


Figure 4.6 *Load–extension graph showing the limit of proportionality*

ENRICHMENT THINK

When a spring is stretched within its limit of proportionality, will it always return to its original size and shape? What happens when it is stretched beyond its limit of proportionality?

Worked Example 4B

Two girls want to weigh a watermelon, but they do not have a kitchen scale. So they use a spring and a 1 kg bag of sugar to measure. When suspended, the bag of sugar stretches the spring by 50 mm, while the watermelon stretches the spring by 75 mm. Assuming that the extension of the watermelon is within the limit of proportionality,

(a) calculate the spring constant of the spring;

(b) calculate the weight of the watermelon.

(Take g = 10 N/kg.)

Solution

Weight of 1 kg bag of sugar = 1 × 10 = 10 N

(a) Spring constant $k = \frac{F}{x} = \frac{10 \text{ N}}{50 \text{ mm}} = 0.2 \text{ N/mm}$

(b) Weight $W = kx = 0.2 \text{ N/mm} \times 75 \text{ mm} = 15 \text{ N}$

WORD ALERT

Suspended: made to hang freely

Let's Practise 4.1

1 A student measured the length of a spring which was found to be 25.0 cm. She then attached an 8 N weight to the spring. She measured the new length, which was found to be 29.0 cm.

(a) Calculate the extension of the spring.

(b) The student decided to plot a load–extension graph for the spring. She repeated the step above to obtain the extension of the spring for the following weights: 2 N, 4 N, 6 N and 10 N. Sketch a graph to show what her load–extension graph would look like.

(c) S Calculate the spring constant of the spring.

(d) S Using your answer in **(c)**, calculate the extension of the spring when the load is 14 N.

(e) S The student decided to increase the weight on the spring up to 14 N. Table 4.4 shows her results.

(i) Use the table to plot the load–extension graph.

(ii) Explain why the extension of the spring for $F = 14$ N was different from the calculated value in **(d)**.

Table 4.4

***F*/N**	0	2	4	6	8	10	12	13	14
***x*/cm**	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0

LINK TWB

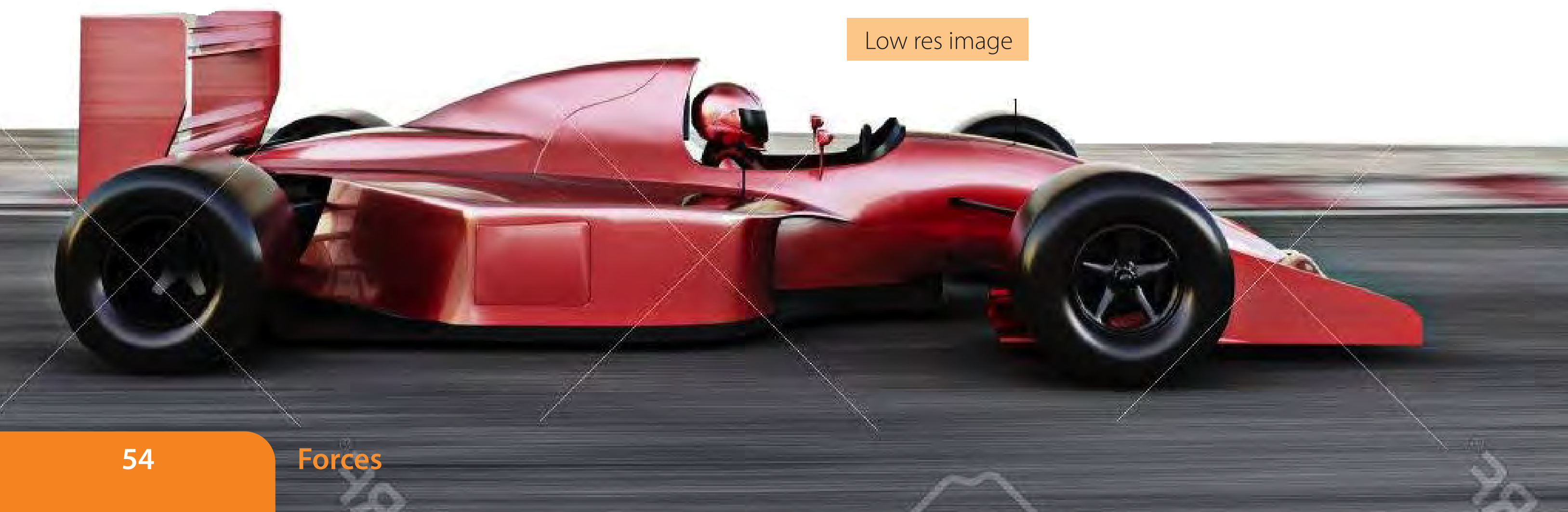
Exercise 4A, pp. XX–XX

2 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

4.2 Forces and Motion

In this section, you will learn the following:

- Determine the resultant force.
- State the effects of a resultant force.
- Know that an object either remains at rest or continues in a straight line at constant speed unless acted on by a resultant force.
- Describe *solid friction*.
- Know that friction acts on an object moving through a liquid or a gas.
- S Recall and use the equation $F = ma$ and know that the force and the acceleration are in the same direction.
- S Describe, qualitatively, motion in a circular path due to a force perpendicular to the motion.



How can we determine the resultant force on an object?

A force is a vector quantity with both magnitude and direction. When more than one force acts on an object, we need to consider the direction of each force in order to determine the resultant force. Figure 4.7 shows how to determine the resultant force on a ball with two or more forces acting along the same straight line.

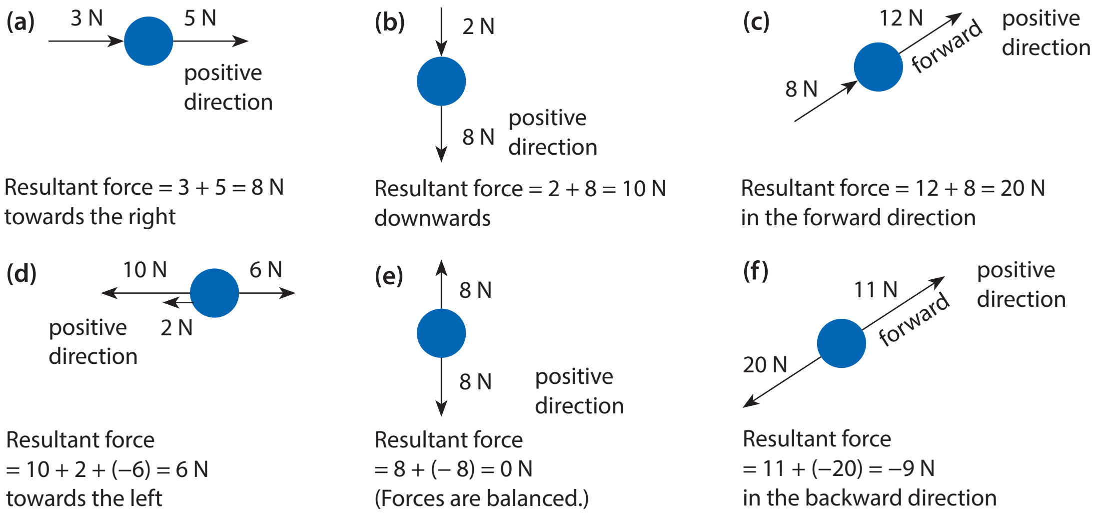


Figure 4.7 *Calculating the resultant force acting on a ball*

LINK

Recall what you have learnt in Chapter 1 about how to add vectors.

HELPFUL NOTES

When determining the resultant force for forces acting in a straight line, remember to assign one direction as positive. The opposite direction will be negative. The sign of the resultant force, after adding the forces, will tell you the direction of the resultant force.

How does a resultant force affect motion?

Imagine holding a ball in your hands. What happens when you throw the ball upwards? What is the resultant force on the ball? It is the gravitational force acting downwards. This downward resultant force causes all objects near the Earth to accelerate towards the Earth. It also changes the direction of an object moving upwards so that it falls back downwards (Figure 4.8).

A resultant force may change the velocity of an object by changing its direction of motion or its speed.

What happens when the resultant force is zero?

Balanced forces

When the forces acting on an object are balanced, the resultant force acting on the object is zero. The motion of the object with zero resultant force depends on the initial state of the object.

- If an object is at rest, it will remain at rest (stationary) until it is acted on by a resultant force.
- If an object is moving with zero resultant force, it will continue to move in a straight line with constant speed until it is acted on by a resultant force.

Figure 4.8 *The ball falls back downwards after being thrown upwards due to the gravitational force acting on it.*

PHYSICS WATCH

Scan this page to explore the effect of resultant force on motion.

HELPFUL NOTES

Do you notice that N is equivalent to kg m/s^2? In fact, this is the definition of the newton: 1 N is the resultant force acting on an object of 1 kg mass when the object accelerates at 1 m/s^2.

Can an object move at constant speed in a straight line when the resultant force is zero? A trolley must be constantly pushed or it will stop moving. This is because a force that opposes motion, is always present between two moving surfaces. When the pushing force on the trolley is zero, this opposing force becomes the new resultant force which stops the trolley.

Unbalanced forces

A resultant force may change the velocity of an object by changing its direction of motion or its speed.

When the forces acting on an object are unbalanced, the resultant force acting on the object is not zero. The resultant force causes the object to move in a different direction, or to accelerate or decelerate.

S When a resultant force causes an object to move, the object will accelerate in the direction of the resultant force.

The resultant force F acting on an object of mass m is related to the acceleration of the object by the following equation:

$\boldsymbol{F = ma}$ where F = force (in N)

m = mass (in kg)

a = acceleration (in m/s^2)

Worked Example 4C

Figure 4.9 shows the forces acting on an object at rest. The mass of the object is 20 kg.

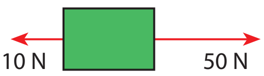


Figure 4.9

(a) Calculate the resultant force on the object.

(b) What effect does this resultant force have on the object?

(c) S What is the velocity of the object after 2 s?

Solution

(a) Let the right direction be positive.

Resultant force = 50 N + (–10 N) = 40 N towards the right

(b) The resultant force changes the velocity of the object. It causes the object to accelerate.

(c) S Using $F = ma$, $a = \frac{40}{20} = 2$ m/s^2 towards the right

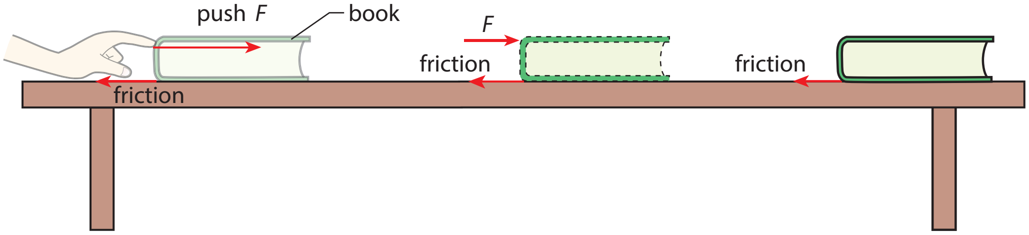
Since $a = \frac{\text{change in velocity}}{\text{time taken}} = \frac{v - 0}{2}$

The velocity v of the object after 2 s = 2 × a = 2 × 2 = 4 m/s towards the right.

What are the effects of friction?

Friction is a force that impedes motion.

Solid friction is the type of friction that occurs when two solid surfaces are in contact with or slide against each other. In Figure 4.10, we see that a force greater than the friction must be applied so that there is a non-zero resultant force to make the object move. The object will stop if we remove the applied force.



① To make the book move across the table, we apply a force that is greater than the friction between the table and the book. The resultant force towards the right makes the book move in the same direction.

② Once the book is moving, we apply a force of the same magnitude as the friction such that the resultant force is zero.

③ When we stop applying a force, the resultant force is only the friction, towards the left. As the direction of the resultant force is opposite to the motion of the book, the book stops moving.

Figure 4.10 *Friction acts in the opposite direction to motion*

Friction between two moving surfaces produces heating. For example, our hands feel warm when we rub them together.

Friction does not only oppose motion between solid surfaces. Objects moving through a liquid or a gas experience friction too. A swimmer is slowed by friction between the water and her body. A car moving on a road, or an aeroplane flying in the air experiences air resistance, which opposes the motion of the vehicle.

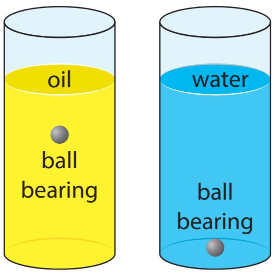
Friction is a resistive force because it acts in the opposite direction to motion.

In liquids and gases, friction is usually called **drag** (Figure 4.11).

Drag

In liquids

- A ball bearing falls more slowly in oil than in air or in water as there is more drag acting on the ball bearing falling in oil.



In air

- The parachutist slows down when she opens the parachute as there is air resistance opposing her downward motion.

Figure 4.11 *Motion through a liquid or a gas will experience drag.*

WORD ALERT

Impedes: slows down or prevents something

Resistive: opposing, acting against

PHYSICS WATCH

Scan this page to watch a clip on the forces acting on a skydiver.

QUICK CHECK

An object cannot move when the resultant force acting on it is zero.

True or false?

How does a force cause an object to move in a circular path?

An object moving in a circular path with a constant speed is shown in Figure 4.12. An object in a circular path has the following properties:

- The direction of its velocity is changing all the time.
- A non-zero resultant force acts on it to keep the object in a circular path.
- The direction of the force changes as the object moves.
- The force is perpendicular to the motion of the object.

Figure 4.12 shows the directions of the velocity and force when the object is at positions (1), (2), (3) and (4). At each position, the **perpendicular** force pulls the moving object towards the centre of the circle.

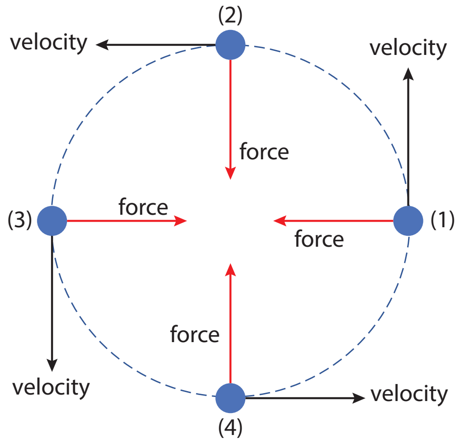


Figure 4.12 *Motion in a circular path is due to a force perpendicular to the motion.*

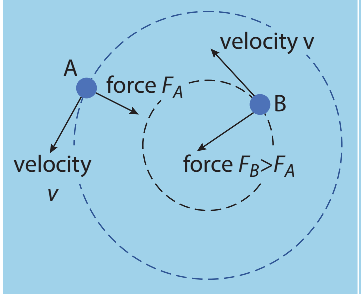
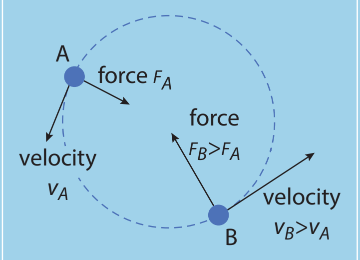
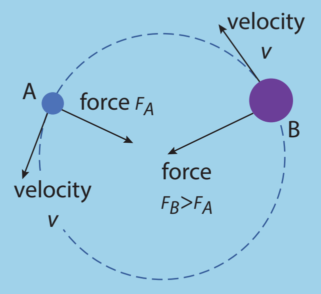
WORD ALERT A-Z

Perpendicular: at a 90° angle to a given line, plane or surface

Force and circular motion

The magnitude of the force required to keep an object moving in a circular path depends on three quantities — mass of the object, speed of the object and the radius of the circular path. Table 4.5 shows how force is related to these three quantities for an object in circular motion.

Table 4.5 *Force, mass, speed and radius of circular path for an object in circular motion*

Constant mass and speed	Constant mass and radius	Constant speed and radius
 *Figure 4.13*	 *Figure 4.14*	 *Figure 4.15*
Figure 4.13 shows the forces on two objects of the same mass and moving with the same speed. The force on object B is greater. As a result, the radius of the circular path for object B is smaller.	Figure 4.14 shows two objects with the same mass and moving in the same circular path. The force on object B is greater. As a result, the speed of object B is greater than the speed of object A.	In Figure 4.15, the mass of object B is greater than that of object A. For object B to move at the same speed as object A and in the same circle, the force on object B must be greater than that on object A.
With mass and speed of the object constant, the radius of the circular path decreases if the force increases.	**With mass of the object and radius of circular path constant, the speed of the object increases if the force increases.**	**To keep speed of the object and radius of circular path constant, an increased mass of the object requires an increased force.**

Let's Practise 4.2

1 Read each of the following descriptions carefully. State if it is true or false. Correct any description which is false.

(a) The resultant force on a moving object is zero. The object stops moving.

(b) The resultant force on an object is zero. The object remains at rest.

(c) An object is moving to the right. A resultant force towards the right acts on it. The object slows down.

(d) An object is moving downwards. An upward force with magnitude equals to the weight of the object acts on the object. The resultant force is zero and the object falls at constant speed.

(e) Friction acts in the direction opposite to the motion of an object.

(f) Friction can cause heating.

(g) There is no friction in liquids or gases.

(h) S Acceleration = force × mass

(i) S A resultant force on a moving object is perpendicular to its velocity. This force has no effect on the motion of the object.

(j) S An object is moving in a circular path. The resultant force on the object increases. If the object continues moving at the same speed, it must continue to move with a smaller radius.

2 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

TWB LINK

Exercise 4B, pp. XX–XX

4.3 Turning Effect of Forces

In this section, you will learn the following:

- Describe the moment of a force and give everyday examples.
- Define the moment of a force as moment = force × perpendicular distance from the pivot; recall and use this equation.
- Apply the principle of moments to situations with one force on each side of the pivot.
- S Apply the principle of moments to other situations, including those with more than one force on each side of the pivot.
- State that, when there is no resultant force and no resultant moment, an object is in equilibrium.
- S Describe an experiment to demonstrate that there is no resultant moment on an object in equilibrium.

What is the moment of a force?

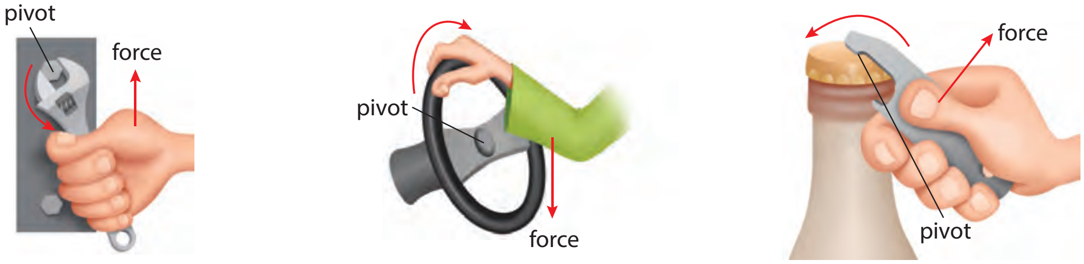
A force acting on an object can cause the object to turn. This effect is known as the *turning effect of a force*. An example of this can be seen when we open a door. We apply a force to swing the door about its hinge (Figure 4.16).

The turning effect can be large or small. How can we measure the turning effect of a force?

Figure 4.16 *Turning effect depends on where the force is applied*

The turning effect is measured by a physical quantity known as *moment of a force*.

In Figure 4.17, we observe that objects turn about a fixed location, called the **pivot**.



Tightening a bolt | Turning a steering wheel | Opening a bottle cap

Figure 4.17 *Using the turning effect of a force in our daily lives*

To produce a turning effect, the force applied must be at a distance from the pivot.

If the force is applied at the pivot, there is no turning effect. This would be like trying to open a door by pushing at the hinge — the door would not open.

Figure 4.18 shows a simplified diagram of a door being pulled. The hinge is the pivot and the force *F* applied is shown by an arrow. Distance *d* is the perpendicular distance from the pivot to the line of action of the force.

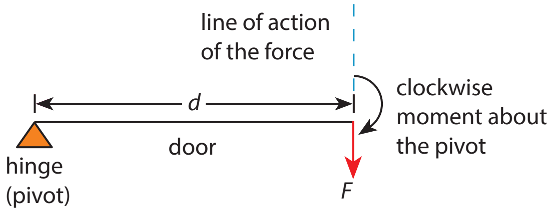


Figure 4.18 *Simplified diagram of a door being pulled*

Moment of a force is defined as the product of the force and the perpendicular distance from the pivot.

Its SI unit is **newton metre (N m)**.

Moment of a force = $F \times d$

where F = force (in N)

d = perpendicular distance from the pivot (in m)

Moment of a force is a vector quantity.
Its direction can be clockwise (Figure 4.18) or anti-clockwise (Figure 4.19).

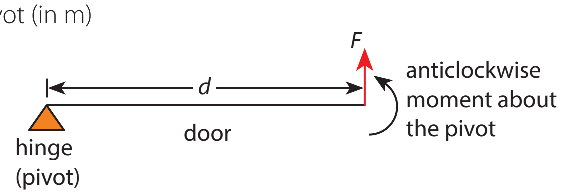


Figure 4.19 *Simplified diagram of a door being pushed*

If the force applied is 5 N and the perpendicular distance is 0.3 m, the moment of a force

- in Figure 4.18 = 5 × 0.3 = 1.5 N m clockwise;
- in Figure 4.19 = 5 × 0.3 = 1.5 N m anticlockwise.

Worked Example 4D

The minimum moment to open a door is 20.5 N m. The door must be opened with a force of 50 N at the handle. Calculate the minimum distance of the handle from the hinge.

Solution

Given: Moment = 20.5 N m , minimum force F = 50 N

Moment = Fd

$$\therefore d = \frac{\text{moment}}{F} = \frac{20.5 \text{ N m}}{50 \text{ N}} = 0.41 \text{ m}$$

The handle should be at least 0.41 m away from the hinge.

What is the principle of moment?

Figure 4.20 shows two forces F_L and F_R acting on a steering wheel. The pivot is at the centre of the wheel. What is the resultant moment?

The moments are both in the anticlockwise direction.

Moment of F_L = 4 N × 12 cm = 48 N cm

Moment of F_R = 4 N × 12 cm = 48 N cm

We can find the resultant moment by adding the moments together.

Resultant moment = 48 N cm + 48 N cm = 96 N cm

The wheel turns in the anti-clockwise direction.

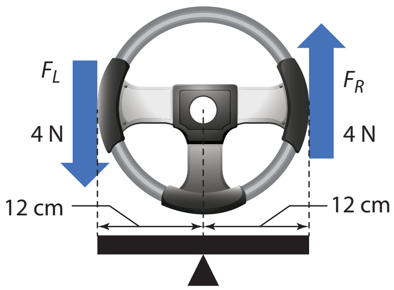


Figure 4.20 *Two forces on a steering wheel acting in opposite directions*

Suppose the force F_R is **reversed** so that it is in the same direction as F_L (Figure 4.21). What effect does the reversing of force have on the resultant moment?

Now, the moments are both in opposite directions.

Moment of F_L = 48 N cm anticlockwise

Moment of F_R = 48 N cm clockwise

Take the anti-clockwise direction to be positive.

Resultant moment = 48 N cm + (−48) N cm = 0 N cm

There is no resultant moment. The wheel does not turn.

When the total clockwise moment is equal to the total anticlockwise moment, there is no resultant turning effect about a pivot. This is the **principle of moments**.

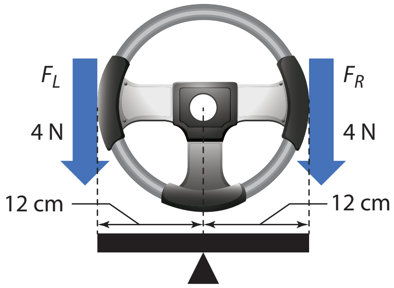


Figure 4.21 *Two forces on a steering wheel acting in the same direction*

WORD ALERT

Reversed: made to go in the opposite way

Worked Example 4E

A man holds a stiff fishing rod with two hands. A 30 N fish hangs at one end. Figure 4.22 shows the positions of the man's hands and the fish on the rod, with the right hand as the pivot and the left hand applying a force F. The rod is horizontal, stationary and very light, such that the effect of its weight is negligible. Calculate the force F.

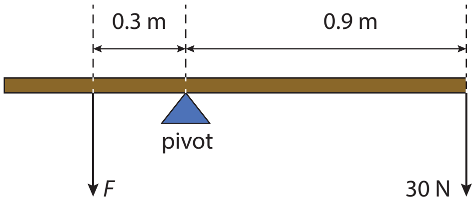


Figure 4.22

Solution

Clockwise moment of the fish's weight = 30 N × 0.9 m = 27 N m

Anticlockwise moment of F = F × 0.3 m = 0.3 F N m

Using the principle of moments,

(0.3 m)F = 27 N m

$$F = \frac{27 \text{ N m}}{0.3 \text{ m}} = 90 \text{ N}$$

QUICK CHECK

When calculating moments, we can assign the clockwise direction as positive.

True or false?

Worked Example 4F

Figure 4.23 shows a similar diagram as Figure 4.22 in Worked Example 4E. This time, consider the pivot to be at the left hand and the force *F* applied using the right hand. Calculate the force *F*.

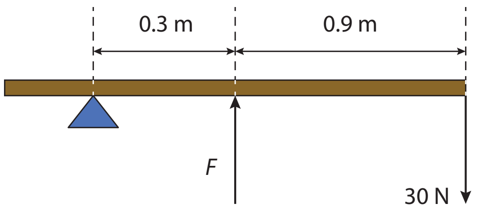


Figure 4.23

Solution

Perpendicular distance of the fish from the pivot = 0.9 m + 0.3 m = 1.2 m

Clockwise moment of the fish's weight

= 30 N × 1.2 m = 36 N m

Anticlockwise moment of *F* = *F* × 0.3 m = 0.3 *F* N m

Using the principle of moments,

(0.3 m)*F* = 36 N m

$$F = \frac{36 \text{ N m}}{0.3 \text{ m}} = 120 \text{ N}$$

Worked Example 4G

Figure 4.24 shows a hand winch. Figure 4.25 shows a simplified diagram of the hand winch. The hand winch is used to move a load of 3000 N. Calculate the minimum force required to turn the drum.

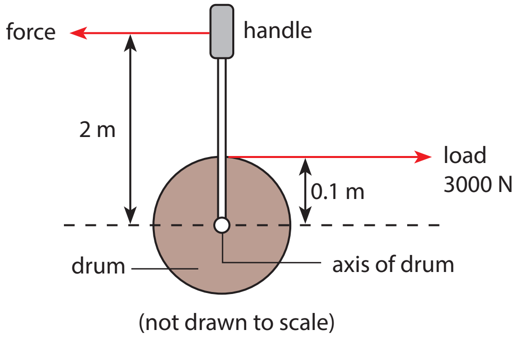


Figure 4.24

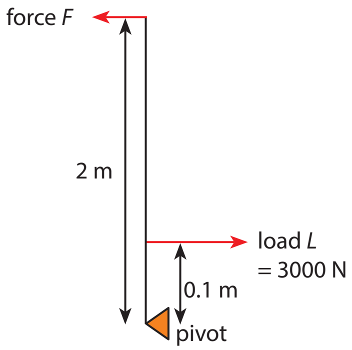


Figure 4.25

Solution

Clockwise moment of load *L* about the pivot = 3000 N × 0.1 m = 300 N m

Anticlockwise moment of force *F* about the pivot = *F* × 2 m = 2*F* N m

Taking anticlockwise direction to be positive, resultant moment = (2*F* – 300) N m

To turn the drum, resultant moment > 0.

(2 m)*F* – (300 N m) > 0

$$F > \frac{300 \text{ N m}}{2 \text{ m}} > 150 \text{ N}$$

The minimum force required to turn the drum is 150 N.

What happens when an object is in equilibrium?

When there is no resultant force, an object either remains at rest or moves at a constant speed along the same straight line.

When there is no resultant moment, the total anti-clockwise moments equal the total clockwise moments, and the object does not turn.

When there is no resultant force and no resultant moment, an object is in equilibrium.

PHYSICS WATCH

Scan this page to explore the principle of moments.

S

Let's Investigate 4B

Objective

To demonstrate that there is no resultant moment on an object in equilibrium

Materials

Metre rule, optical pin, retort stand, 50 g and 100 g masses, split cork, plasticine, thread

Procedure

1 Set up the experiment as shown in Figure 4.26.
2 Balance the metre rule at the 50 cm mark using an optical pin as shown.
3 Check that the metre rule can rotate freely about the pin in both directions.
4 Balance the metre rule about the pivot by fixing some plasticine to the end that tends to move up. The attached plasticine remains a part of the metre rule for the rest of the experiment.

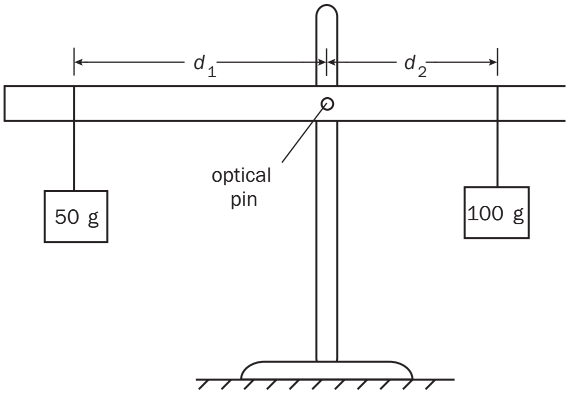


Figure 4.26

5 Using a loop of thread, hang mass $m_1 = 50$ g on one side of the rule at a distance $d_1 = 45.0$ cm from the pivot.
6 Balance the rule horizontally by hanging mass $m_2 = 100$ g on the other side. Measure and record the distance d_2 from the mass m_2 to the pivot (Figure 4.26) in Table 4.6.
7 Repeat steps 5 and 6, using 40.0 cm, 35.0 cm, 30.0 cm, and 25.0 cm for d_1.
8 Calculate the anticlockwise moment, clockwise moment and resultant moment at each distance. Remember that the force exerted by m_1 is about 0.5 N and that exerted by m_2 is about 1 N.

Table 4.6

d_1/cm	Anticlockwise moment/N cm	d_2/cm	Clockwise moment/N cm	Resultant moment/N cm
45.0				
40.0				
35.0				
30.0				
25.0				

Observation and conclusion

From Table 4.6, we observe that whenever the anticlockwise moment is equal to the clockwise moment, the resultant moment is zero. The metre rule does not turn and stays in equilibrium.

PWB LINK

Practical 4B, pp. XX–XX

Let's Practise 4.3

1 Write the word equation for moment of a force.
2 What are the conditions for an object to be in equilibrium?
3 A uniform metre rule is balanced at its midpoint as shown in Figure 4.27.

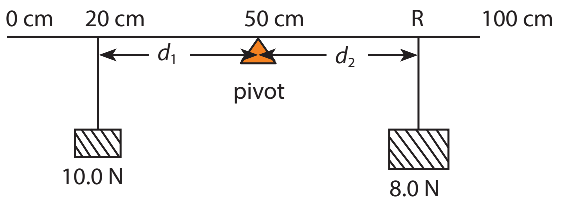


Figure 4.27

(a) Calculate distance d_1.
(b) Calculate the moment of 10.0 N weight.
(c) The ruler is in equilibrium. Find the position R.

4 S Figure 4.28 shows the forces on a pole AB lying horizontally on the ground. Calculate the minimum vertical force *F*, needed to lift the pole.

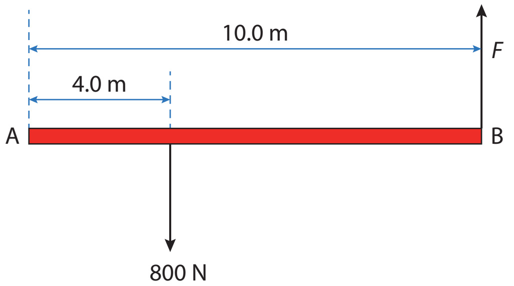


Figure 4.28

5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 4C, pp. XX–XX

4.4 Centre of Gravity

In this section, you will learn the following:
- State what is meant by *centre of gravity*.
- Describe an experiment to determine the position of the centre of gravity of an irregularly-shaped plane lamina.
- Describe qualitatively the effect of the position of the centre of gravity on the stability of simple objects.

What is centre of gravity?

At which point can you balance a uniform metre rule on the tip of your finger?

If you place your finger at the 30 cm mark or the 60 cm mark, the metre rule will topple. Gravitational force causes the metre rule to turn and fall.

What happens if you place your finger at the 50 cm mark?

WORD ALERT A-Z

Topple: to lose balance and fall down

When your finger is at the 50 cm mark, the metre rule balances perfectly (Figure 4.29). Why is this so?

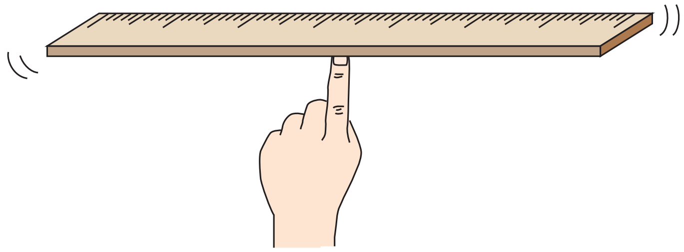


Figure 4.29 *Balancing a metre rule on the tip of a finger*

Gravitational forces pull at every part of an object. The resultant gravitational force on the object is its weight. It acts through a point known as the centre of gravity.

The **centre of gravity** of an object is the point through which the weight of the object acts.

When the object is balanced at its centre of gravity, the object does not turn because there is no resultant moment of its weight. The object does not move because the support exerts an upward force to balance its weight (Figure 4.30). The object is said to be in equilibrium.

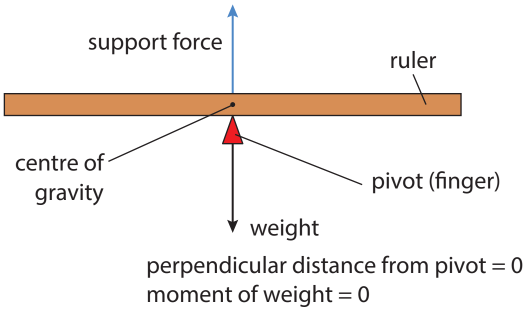


Figure 4.30 *Forces acting on the metre rule*

The centre of gravity of the metre rule is at the 50 cm mark. Thus, you can balance the rule on your finger tip at the 50 cm mark.

How to locate the centre of gravity of an object

For an object of regular shape and uniform density, the centre of gravity is at its geometrical centre. Examples of regular shapes are rectangles, triangles, circles, cuboids, spheres and rings. The centre of gravity of an object may also lie outside the object. A ring is an example of such an object (Figure 4.31).

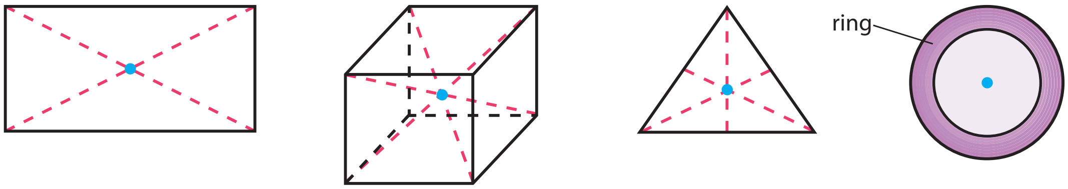


Figure 4.31 *The blue dots represent the centre of gravity of regularly-shaped objects*

To locate the centre of gravity of an irregularly-shaped plane lamina, we can use a plumb line.

To make a plumb line, attach a weight (e.g. a pendulum bob) to one end of a long string. Then hang the plumb line from a pin and let it move freely about the pin. When the plumb line is perfectly still, *F* and *W* balance each other out such that the resultant force and the resultant moment are both zero (Figure 4.32). The string is on the same straight line that passes through the centre of gravity of the weight.

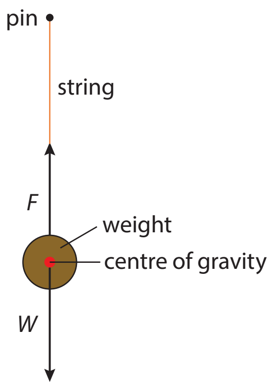


Figure 4.32 *Forces acting on a plumb line*

ENRICHMENT THINK

Other than a ring, can you think of one other object where the centre of gravity lies outside the object?

WORD ALERT

Lamina: a piece of a material that is thin and flat

QUICK CHECK

The centre of gravity of an object can lie outside the object.

True or false?

Let's Investigate 4C

Objective
To locate the centre of gravity of an irregularly-shaped plane lamina using a plumb line

Materials
irregularly-shaped lamina, plumb line with a pendulum bob, retort stand, split cork, pin

Procedure

1 Make three small holes near the edge of the lamina. The holes should be as far apart as possible from one another. The holes must be small so that not too much of the lamina is removed. An example is given for reference (Figure 4.33).

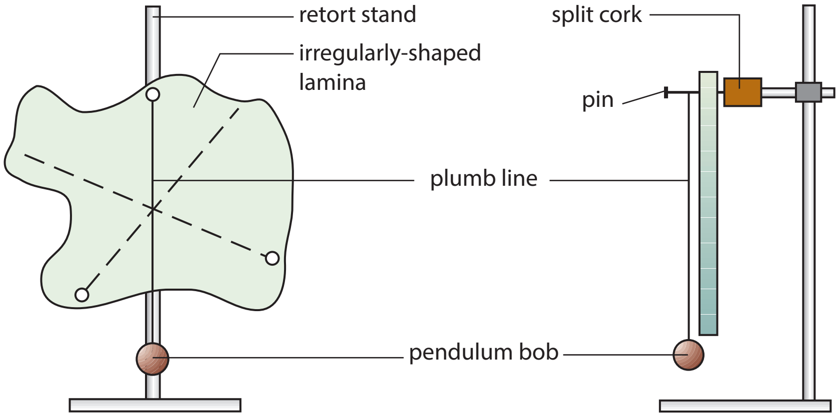


Figure 4.33

2 Hang the lamina freely from a pin on one of the holes.
3 Hang a plumb line from the pin in front of the lamina.
4 When the plumb line is steady, draw dotted lines on the lamina to trace the plumb line.
5 Repeat steps 2 to 4 for the other two holes.

Conclusion
The point of intersection of the three lines is the position of the centre of gravity.

LINK PWB
Practical 4C, pp. XX–XX

Worked Example 4H

A student wants to measure the weight of a uniform metre rule. She hangs a weight of 2.5 N at the 80 cm mark. Then she adjusts the position of the ruler on a pivot until it balances perfectly as shown in Figure 4.34. What is the weight of the ruler? (Note: The centre of gravity of a uniform metre rule is at the 50 cm mark.)

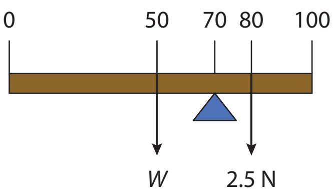


Figure 4.34

Solution
Perpendicular distance from pivot for 2.5 N force
= 80 − 70 = 10 cm

Clockwise moment of 2.5 N force = 2.5 × 10 = 25 N cm

Perpendicular distance from pivot for the weight of ruler = 70 − 50 = 20 cm

Anticlockwise moment of $W = W \times 20 = 20W$ N cm

Using the principle of moments, $20W = 25$

$$W = \frac{25}{20} = 1.25 \text{ N}$$

How does the centre of gravity affect the stability of an object?

Consider a book with six faces — two broad and four narrow. Suppose we make it stand upright on one of its narrow faces (Figure 4.35(a)). If we give it a slight push, the book will topple (Figure 4.35(b)). The book is unstable.

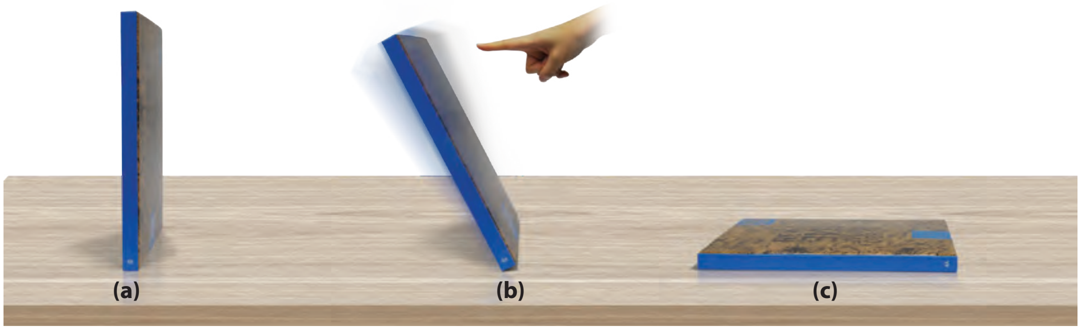
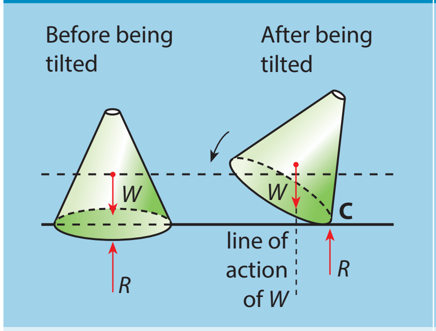
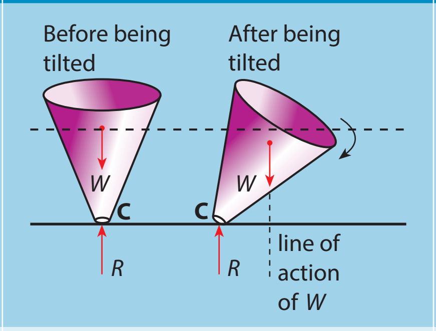
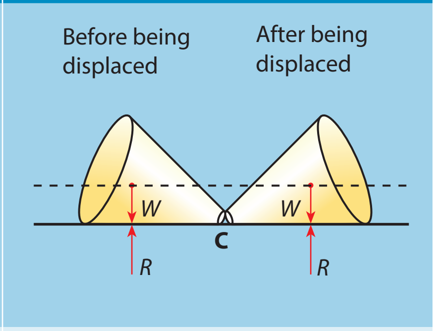


Figure 4.35 *A book standing on one of its narrow surfaces is unstable, but the same book lying flat on its broad surface is stable.*

However, if we lay the book flat on one of the broad faces and give it a slight push, the book will not topple (Figure 4.35(c)). It is stable.

The weight of an object acting through its centre of gravity causes it to topple when the resultant moment is not zero. Table 4.7 shows how we can try to balance a paper cone in three ways. The two forces acting on the cone are its weight *W* and the contact force *R*. Notice that the paper cone topples more easily in certain situations.

Table 4.7 *Types of equilibrium*

Stable equilibrium	Unstable equilibrium	Neutral equilibrium
		
If the cone is slightly tilted, • its centre of gravity rises before returning to its original height; • the line of action through its weight *W* still lies within its base; • the moment of its weight about the contact point **C** causes the cone to return to its original position.	If the cone is slightly tilted, • its centre of gravity drops; • the line of action through its weight *W* lies outside its base; • the moment of its weight about the contact point **C** causes the cone to topple.	If the cone is slightly **displaced**, • its centre of gravity remains at the same height; • the lines of action through its weight *W* and contact force *R* coincide; • the moment of its weight about the contact point **C** is zero; it stays in the position to which it is displaced.

From Table 4.7, we can conclude that the stability of an object depends on the location of its centre of gravity and the width of its base.

A-Z **WORD ALERT**

Displaced: shifted, moved from its original place

ENRICHMENT *INFO*

Defying Gravity

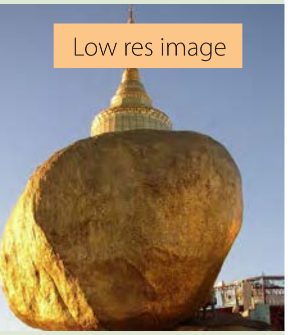


Figure 4.38 *Kyaiktoyo pagoda or Golden Rock*

The Kyaiktoyo pagoda in Myanmar is a sacred site for Buddhists. It sits on top of a huge heavy rock resting at the edge of a cliff. Many worshippers meditate underneath the rock, perhaps hoping to be in a state of equilibrium just like the rock. How does this rock stay put? The answer could be its centre of gravity.

ENRICHMENT *ACTIVITY*

Make your own balancing toy using suitable materials such as sticks, modelling clay, paper clips, cork, cardboard, etc.

What principles have you used in order to make your toy balance?

Compare your toy with those of your classmates.

LINK TWB

Exercises 4D–4E, pp. XX–XX

Exercise 4F Let's Reflect, p. XX

To increase the stability of an object,

- its centre of gravity should be kept as low as possible (i.e. more mass packed at its bottom);
- its base area should be kept as wide as possible.

Many objects in our daily lives are designed to increase their stability. Racing cars, Bunsen burners, table lamps and standing fans have large and heavy bases to lower their centre of gravity. Look around you. What other examples can you give?

Worked Example 4I

Figure 4.36 shows the rest position and the displaced position of a balancing toy. Its centre of gravity is indicated by the letter G. Explain briefly why the toy eventually returns to its rest position after being released from its displaced position.

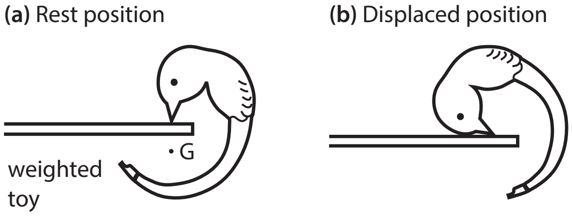


Figure 4.36

Solution

The centre of gravity is the point through which the weight of an object acts. When the toy is at rest, its centre of gravity G is directly below the pivot (i.e. its beak).

When the toy is displaced, G is moved upwards and to the right (Figure 4.37). Its weight now has a turning effect about the pivot. The moment of the weight about the pivot causes the toy to rotate clockwise towards its rest position.

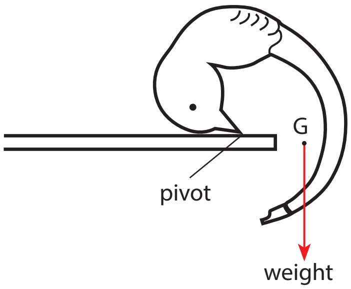


Figure 4.37

Let's Practise 4.4

1 **(a)** What is the centre of gravity of an object?

(b) Is the centre of gravity of an object the same whether it is near the surface of the Earth or the Moon? Explain.

2 **(a)** How does the position of the centre of gravity affect the stability of an object?

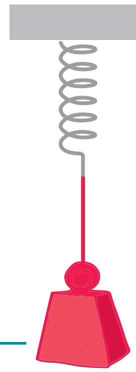
(b) A minibus is travelling on the road carrying heavy loads on its roof rack. There are no passengers inside the minibus. When turning a corner, the driver drives very slowly. Explain why.

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

Let's Map It

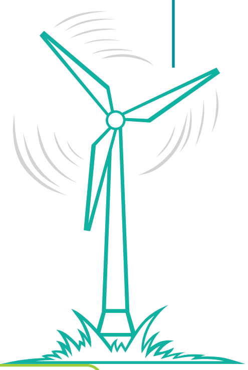
FORCES *F* (SI unit: N)

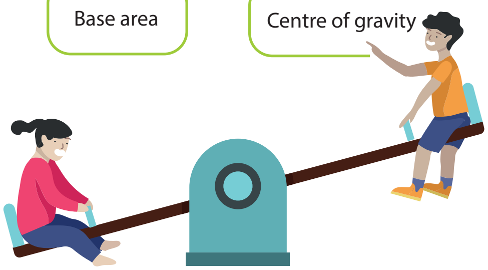
- **cause** → Objects to change in size and/or shape
  - **such as** → A spring
    - **whose spring constant k is a ratio given by** → S $k = \frac{F}{x}$ where F = load, x = extension
      - **represented using** → S Load-extension graph within the limit of proportionality



- **affect** → Motion
  - **described by** → S Resultant force F (N) = mass (kg) × accelleration (m/s)
    - **applies to**
      - Balanced forces (Resultant F = O N)
        - **for an object**
          - At rest
          - Moving at a constant velocity
      - Unbalanced forces (Resultant $F \neq$ O N)
        - **for an object**
          - S Moving in a circle
          - Accelerating due to a push or pull
          - Decelerating due to friction or drag

- **produce** → Turning effect known as moment of a force (SI unit: N m)
  - **defined as** → Moment (N m) = force (N) × perpendicular distance of the force from the pivot
    - **can be**
      - Anticlockwise
      - Clockwise
        - **for an object in equilibrium** → Principle of moments: Sum of clockwise moments = sum of anticlockwise moments
          - **which relate to** → Stability of an object
            - **affected by its**
              - Base area
              - Centre of gravity





Let's Review

Section A: Multiple-choice Questions

1 What quantities of an object can a force change?
- **A** Mass and length
- **B** Speed and length
- **C** Speed and weight
- **D** Weight and mass

2 A feather is floating downwards at constant speed. What is the resultant force on the feather?
- **A** Air resistance
- **B** Gravitational force
- **C** Pointing downwards
- **D** Zero

3 S A resultant force of 4 N causes an object to accelerate at 2 m/s^2. What force is needed to make the same object accelerate at 3 m/s^2?
- **A** 2 N
- **B** 4 N
- **C** 6 N
- **D** 8 N

4 S Figure 4.38 shows a car moving in a circular path. In which direction is the resultant force acting on the car?

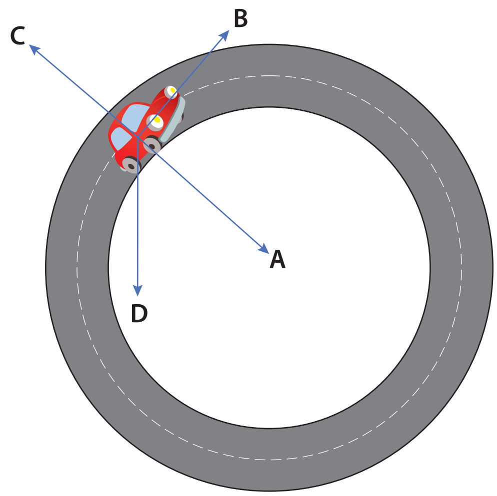


Figure 4.38

5 Which of the following is the SI unit for moment of a force?
- **A** kg
- **B** kg m
- **C** N
- **D** N m

6 Which statement describes an object in equilibrium?
- **A** The resultant force is zero.
- **B** The resultant moment is zero.
- **C** The resultant force and resultant moment are zero.
- **D** There is no force acting on the object.

7 A boy is planning to design a water bottle. Which procedure should he follow to design the most stable water bottle?
- **A** Make the centre of gravity high and the base area large.
- **B** Make the centre of gravity high and the base area small.
- **C** Make the centre of gravity low and the base area large.
- **D** Make the centre of gravity low and the base area small.

Section B: Short-answer and Structured Questions

1 Figure 4.39 shows the forces acting on a toy boat.

Figure 4.39

(a) Calculate the resultant force on the boat.
(b) Some time later, the boat moves at constant speed. What is the resistive forces acting on the boat?

2 **(a)** What is the unit of the moment of a force?
(b) A girl and her brother are sitting on a see-saw. The girl weighs 500 N. Her brother weighs 700 N. Figure 4.40 shows their positions on the see-saw.

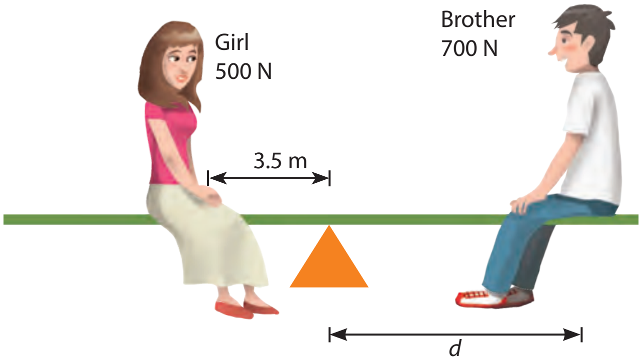


Figure 4.40

Let's Review

(i) The see-saw is in equilibrium. State how the see-saw can be in equilibrium.

(ii) Calculate how far from the pivot should the brother should be sitting.

3 Figure 4.41 shows a load of 3000 N balanced by a concrete block of weight *W*, on the arm of a crane. The concrete block can be moved along the arm.

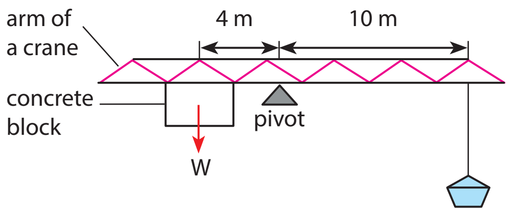


Figure 4.41

(a) What is the moment of the load?

(b) Using the principle of moments, calculate the weight *W* of the concrete block.

(c) The load is replaced by a new load weighing 1800 N. What is the new distance of *W* from the pivot when the arm is balanced?

4 S Figure 4.42 shows a uniform 1 m plank XY weighing 200 N hinged to a wall at X. A 500 N force acts downwards on the plank 20 cm from X. The plank is held horizontally by a force *F* acting upwards from Y. Using X as pivot, calculate the magnitude of force *F*.

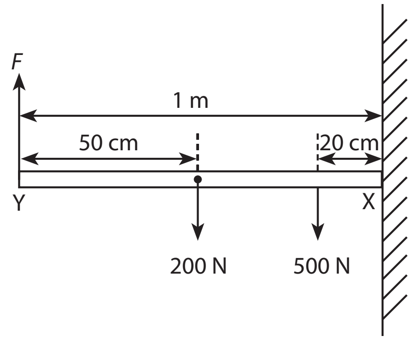


Figure 4.42

CHAPTER 5 Momentum

PHYSICS WATCH

Scan this page to watch a clip on the impact of a collision.

Trains are an important means of transport in many parts of the world. In India alone, more than 20 million people board trains to move from one place to another every day. However, we hear of train accidents happening now and then. When fast-moving trains or trains carrying heavy loads collide, it poses a great danger to human lives and causes great damage. Engineers have been conducting case studies to find ways to increase safety for passengers and reduce damage. In some studies, trains were purposely crashed into concrete walls — without passengers, of course! This was done to investigate the impact upon collision.

QUESTIONS

- Name two physical quantities of the train that will affect the impact of a collision.
- State how each of the two physical quantities affects the impact of a collision.

5.1 What Is Momentum?

In this section, you will learn the following:

- Define momentum as mass × velocity.
- Recall and use the equation $p = mv$.

An object has momentum when it is in motion.

A fast-moving object has more momentum than a slower-moving object of the same mass (Figure 5.1).

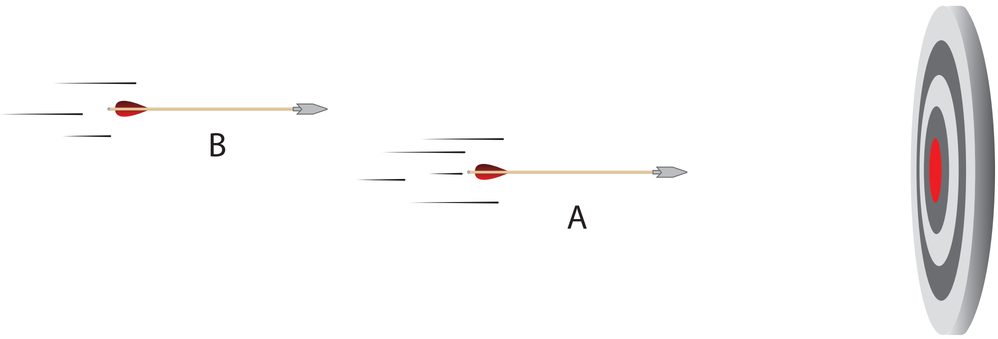


Figure 5.1 *Two identical arrows move towards a target at different speeds. Which of the two arrows has more momentum?*

A massive moving object has more momentum than a lighter moving object of the same velocity (Figure 5.2).

Figure 5.2 *An elephant and a dog are moving at the same velocity to chase the hunter. Which animal has more momentum?*

Mass and velocity are two physical quantities that determine the momentum of an object.

Momentum is defined as the product of mass and velocity.

Its SI unit is **kilogram metre per second (kg m/s)**.

Momentum = mass × velocity

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

Momentum is a vector quantity. It has both magnitude and direction.

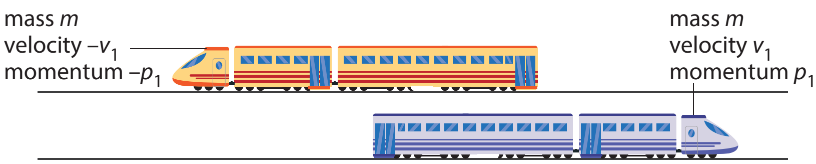


Figure 5.3 *The trains have different momentums as the trains are travelling in different directions.*

LINK

Is mass a vector or a scalar quantity? What about velocity?

Recall what you have learnt in Chapter 1.

QUICK CHECK

The momentum of an object can have a negative value.

True or false?

HELPFUL NOTES

To calculate momentum in its SI unit (kg m/s), the unit for mass (m) should be kilogram (kg) and the unit for velocity (v) should be metre per second (m/s).

Worked Example 5A

Calculate is the momentum of

(a) a runner of mass 50 kg running at 4 m/s;
(b) a man of mass 70 kg walking at 1.2 m/s;
(c) a soccer ball of mass 400 g (0.4 kg) moving at 25 m/s;
(d) a car of total mass 1000 kg travelling at 18 km/h (5 m/s).

Solution

By definition, momentum = mass × velocity

(a) momentum of the runner = 50 kg × 4 m/s = 200 kg m/s
(b) momentum of the man = 70 kg × 1.2 m/s = 84 kg m/s
(c) momentum of the soccer ball = 0.4 kg × 25 m/s = 10 kg m/s
(d) momentum of the car = 1000 kg × 5 m/s = 5000 kg m/s

Worked Example 5B

(a) What is the speed of a bus with mass 8000 kg and momentum of 88 000 kg m/s?
(b) A car travelling at 12 m/s has a momentum of 14 400 kg m/s. Calculate its mass.

Solution

(a) Given: Mass m = 8000 kg
Momentum p = 88 000 kg m/s

By definition, $p = mv$

$$v = \frac{p}{m} = \frac{88\,000 \text{ kg m/s}}{8\,000 \text{ kg}} = 11 \text{ m/s}$$

(b) Given: Momentum, p = 14 400 kg m/s
Velocity, v = 12 m/s

By definition, $p = mv$

$$m = \frac{p}{v} = \frac{14\,400 \text{ kg m/s}}{12 \text{ m/s}} = 1200 \text{ kg}$$

Let's Practise 5.1

1 Fill in the correct physical quantities in the word equation:
momentum = ________________ × ________________
2 What is the SI unit of momentum?
3 Is momentum a scalar or a vector quantity?
4 Calculate the momentum of a ball of mass 0.4 kg moving at 12 m/s.
5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 5A, pp. XX–XX

5.2 Momentum, Impulse and Force

In this section, you will learn the following:
- Define impulse as force × time for which force acts.
- Recall and use the equation $F\Delta t = \Delta(mv)$.
- Define resultant force as the change in momentum per unit time.
- Recall and use the equation $F = \frac{\Delta p}{\Delta t}$.

How is impulse related to change in momentum?

Mass and velocity are physical quantities associated with momentum. Besides these two quantities, what other physical quantities do you associate with momentum? Do you think of force and time? Figure 5.4 shows a book being pushed across a table with force F for a period of time Δt.

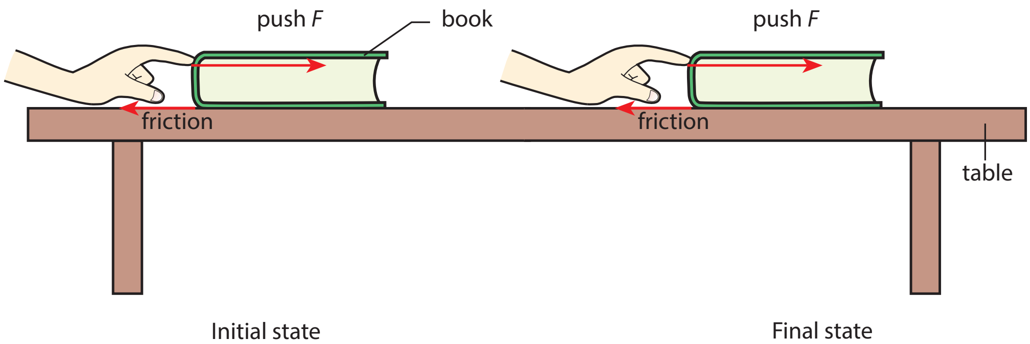


Figure 5.4 *Pushing a book across a table top*

During this period of time Δt when force F acts, the velocity of the book changes. Therefore, its momentum changes. We can write the change in momentum
as $\Delta(mv)$.

The change in momentum can be shown to be equal to the product of the force and the period of time for which the force acts.

$F\Delta t = \Delta(mv)$ or $F\Delta t = \Delta p$

Impulse is the product of force and the period of time for which force acts.

Its SI unit is **newton second (N s)**.

Impulse = force × time = $F\Delta t$

The force applied to an object may not be constant throughout the motion of the object. The force F in the equation in such a situation is the average resultant force acting for a period of time Δt.

Figure 5.5 *The force on the ball by the batter may not be constant from the moment the bat touches the ball to the moment the ball leaves the bat.*

HELPFUL NOTES

Force is a derived quantity, where $F = ma$. The unit of force (newton, N) can be written as kg m/s^2.

Thus, the unit of $F\Delta t$ = kg m/s^2 x s = kg m/s.

The SI unit for impulse (N s) is equivalent to the SI unit for momentum (kg m/s).

WORD ALERT

Constant: stay the same

HELPFUL NOTES

Momentum and impulse are useful concepts for analysing collisions or interactions between two objects.

Worked Example 5C

Figure 5.6 shows a boy kicking a stationary ball of mass 0.4 kg with an average force of 100 N. The ball moved at 5 m/s immediately afterwards. Calculate

(a) the impulse of the force exerted on the ball;

(b) the time of contact between his boot and the ball.

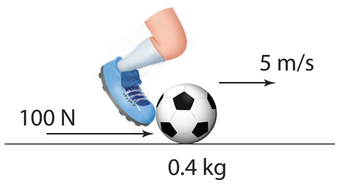


Figure 5.6

Solution

Given: $F = 100$ N, $m = 0.4$ kg, $v_1 = 0$ m/s, $v_2 = 10$ m/s

(a) Impulse = change in momentum = $\Delta(mv)$

$= (0.4 \text{ kg} \times 5 \text{ m/s}) - (0.4 \text{ kg} \times 0 \text{ m/s})$

$= 2$ kg m/s $= 2$ N s

(b) Using $F\Delta t = \Delta(mv)$, $\Delta t = \dfrac{\Delta(mv)}{F} = \dfrac{2 \text{ N s}}{100 \text{ N}} = 0.02$ s

The time of contact between his boot and the ball is 0.02 s.

How is resultant force related to change in momentum?

HELPFUL NOTES

$F = \dfrac{\Delta p}{\Delta t}$ is the same as $F = ma$ for special cases when the mass of the object does not change.

We have learnt that the impulse of a resultant force equals the change in momentum of the object, i.e., $F\Delta t = \Delta p$.

Change in momentum, $\Delta p = F\Delta t$

$$\therefore \boldsymbol{F} = \frac{\Delta \boldsymbol{p}}{\Delta \boldsymbol{t}}$$

Resultant force *F* on an object is the change in momentum per unit time.

The three quantities momentum, impulse and resultant force are all related as shown in Table 5.1.

Table 5.1 *A summary of momentum, impulse and resultant force*

Physical quantity	Symbol	Defining equation	SI unit
Momentum	p	$p = mv$	kg m/s
Impulse	–	Impulse $= F\Delta t$	N s
Resultant force	F	$F = \dfrac{\Delta p}{\Delta t}$	N

The quantities momentum, impulse and force are vector quantities. When these quantities are used in calculations, their directions are indicated as '+' and '–' signs. To perform calculations with vector quantities, assign one direction as positive. The opposite direction is then negative and you can add them like you do for finding forces along the same straight line.

ENRICHMENT INFO

Symbol for Momentum

Have you wondered why the symbol used for momentum is *p*?

The symbol *p* is likely to be derived from the Latin word *petere*, which means "to go". The symbol *m* is not used even though momentum starts with the letter "m" as the same symbol was already in use for mass.

Worked Example 5D

Suppose a car of mass 1250 kg crashes into a concrete wall. The speed of the car is 7.2 m/s just before it hits the wall. Calculate the average force on the car as it hits the wall if it takes

(a) 0.1 s for the car to come to a complete stop;

(b) 0.4 s for the car to come to a complete stop.

Solution

The momentum of the car just before the crash = mass × velocity = 1250 × 7.2 = 90 000 kg m/s in the forward direction

After the crash, the car stops moving. The momentum of the car after the crash = 0 kg m/s.

Change in momentum of the car, $\Delta p = 0 - 90\,000 = -90\,000$ kg m/s

$= -90\,000$ N s

(a) Average force acting on the car, $F = \frac{\Delta p}{\Delta t} = \frac{-90\,000 \text{ N s}}{0.1 \text{ N}} = -900\,000$ N

The negative sign means the force is in the backward direction.

(b) Average force acting on the car, $F = \frac{-90\,000 \text{ N s}}{0.4 \text{ N}} = -225\,000$ N

Worked Example 5D (b) shows that the force is much smaller with a longer stopping time. In order to increase the stopping time during a crash, a car is designed with a 'crumple zone'. This allows the front of the car to collapse when a collision occurs. The car can then come to a stop with a slightly longer time (Figure 5.7).

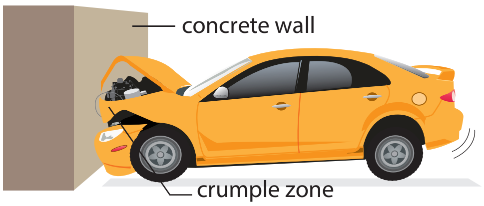


Figure 5.7 *The crumple zone is a safety feature to reduce the force on the car.*

Safety features, such as seat belts and safety helmets, reduce the force by increasing the time taken for the momentum to change to zero. This helps to reduce the disastrous impact of collisions.

Worked Example 5E

A ball of mass 0.625 kg hits the ground at 4 m/s. It bounces back from the ground at 3.8 m/s. Calculate the impulse on the ball.

Solution

Take moving away from the ground (i.e. upwards) as the positive direction.

Given: $m = 0.625$ kg, $u = -4.0$ m/s, $v = 3.8$ m/s

Impulse = change in momentum = Δp

$= (0.625 \text{ kg} \times 3.8 \text{ m/s}) - (0.625 \text{ kg} \times -4.0 \text{ m/s})$

$= 4.88$ kg m/s $= 4.88$ N s

The ground pushes up on the ball with an impulse of 4.88 N s.

ENRICHMENT *THINK*

Suppose you board a bus. All the seats are taken. You and a few others have to stand. The bus picks up speed and continues its journey. Suddenly, all the standing passengers are jolted out of position when the bus reaches the traffic light.

1 Why do you think that happens?

2 What would you expect the bus driver to do to give passengers a more comfortable ride?

PHYSICS WATCH

Scan this page to watch a clip on the effect of the crumple zone of a car.

QUICK CHECK

Impulse on an object can be reduced by decreasing stopping time.

True or false?

Let's Practise 5.2

1 Fill in the correct physical quantity in the word equation:
Impulse = ________ × ________
2 What is the SI unit for impulse?
3 Is impulse a scalar or a vector quantity?
4 The resultant force is the change in ________________________ per unit _______________.
5 A boy kicks a ball, which is resting on the ground. The boy's boot is in contact with the ball for 0.040 s. The average force on the ball is 150 N. Calculate the impulse of the boot on the ball.
6 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 5B, pp. XX–XX

5.3 The Principle of Conservation of Momentum

In this section, you will learn the following:
- Apply the principle of the conservation of momentum to solve simple problems.

What happens to the momentum of moving objects when they collide?

When two moving objects collide, the total momentum of the two objects just before the collision is the same as the total momentum of the objects immediately after the collision. This is also known as the **principle of conservation of momentum**.

PHYSICS WATCH

Scan this page to watch a clip on how the Newton's cradle works.

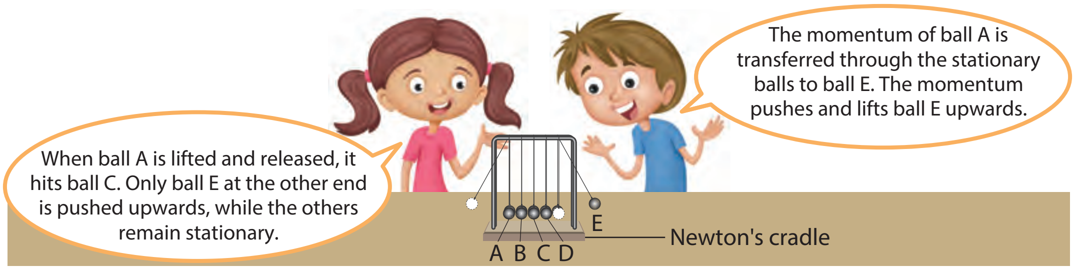


Figure 5.8 *Newton's cradle is a device used to show the principle of conservation of momentum.*

Worked Example 5F

Trolley A of mass 2 kg travelling at 2 m/s collided with a stationary trolley B of mass 3 kg. The two trolleys stuck together after the collision. Figure 5.9 shows what happened before and after the collision.

(a) Calculate

(i) the velocity of the two combined trolleys immediately after they collided;

(ii) the impulse experienced by trolley B;

(iii) the change in momentum experienced by trolley A.

(b) Comparing your answers to (ii) and (iii), what do you observe?

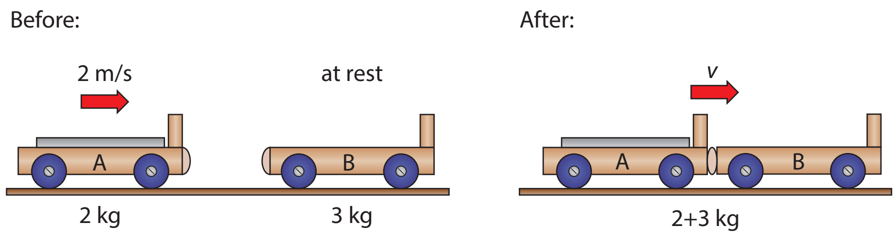


Figure 5.9 *Collision of two trolleys in a straight line*

Solution

(a) Given: Mass of trolley A, $m_1 = 2$ kg, mass of trolley B, $m_2 = 3$ kg

velocity of trolley A, $v_1 = 2$ m/s, velocity of trolley B, $v_2 = 0$ m/s

Total momentum before collision $= m_1v_1 + m_2v_2 = 2 \text{ kg} \times 2 \text{ m/s} + 3 \text{ kg} \times 0 \text{ m/s}$

$= 4$ kg m/s

Total momentum after collision $= (m_1 + m_2)v = (2 + 3) \text{ kg} \times v \text{ m/s} = 5v$ kg m/s

Applying the principle of conservation of momentum,

Total momentum after collision = total momentum before collision

$$5v = 4$$

$$v = \frac{4}{5} = 0.8 \text{ m/s}$$

The speed of the combined trolleys was 0.8 m/s.

(b) After the collision, momentum of trolley B $= 3 \text{ kg} \times 0.8 \text{ m/s} = 2.4$ kg m/s

Impulse = change in momentum = 2.4 N s − 0 N s

= 2.4 N s in the forward direction

The impulse experienced by trolley B is 2.4 N s in the forward direction.

(c) Before the collision, momentum of trolley A $= 2 \text{ kg} \times 2 \text{ m/s} = 4$ kg m/s

After the collision, momentum of trolley A $= 2 \text{ kg} \times 0.8 \text{ m/s} = 1.6$ kg m/s

Change in momentum = 1.6 kg m/s − 4 kg m/s = −2.4 kg m/s

(d) Impulse experienced by trolley A = change in momentum of trolley A = −2.4 N s

Therefore, trolley A experienced a backward impulse of 2.4 N s, while trolley B experienced a forward impulse of 2.4 N s.

ENRICHMENT *ACTIVITY*

1 Take two identical balls of the same mass and size. Place one ball at rest. Launch one ball at a speed such that it collides with the other ball.

2 Take two balls of different masses and sizes. Place the heavier ball at rest. Launch the lighter ball at a speed such that it collides with the heavier ball.

Describe what happens in each case. Share your findings with the class.

QUICK CHECK

The total momentum of a system is always conserved.

True or false?

Worked Example 5G

Ball A of mass 0.12 kg is moving forward at a speed of 0.40 m/s in a straight line on a smooth surface. It collides with a stationary ball B of mass 0.09 kg. Ball B moves forward at a velocity of 0.40 m/s. Figure 5.10 shows the balls before and after the collision. What is the velocity of ball A after the collision?

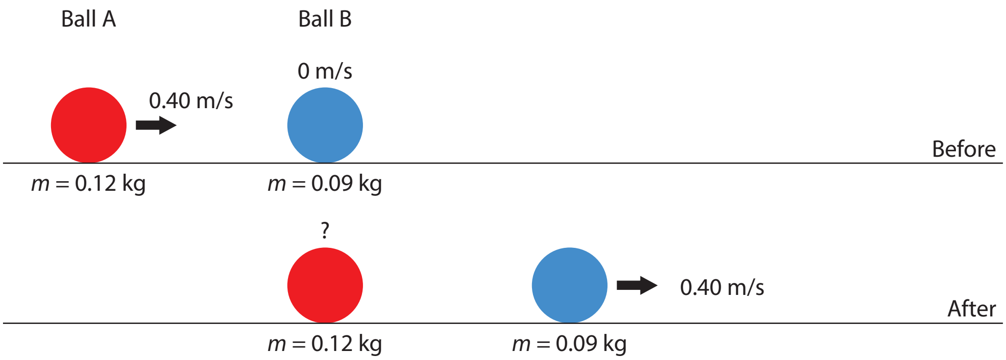


Figure 5.10

Solution

Let the speed of ball A after the collision be v m/s.

Total momentum before collision = 0.12 kg × 0.40 m/s + 0.09 kg × 0 m/s

= 0.048 kg m/s in the forward direction

Total momentum after collision = 0.12 kg × v m/s + 0.09 kg × 0.40 m/s

= (0.12v + 0.036) kg m/s in the forward direction

Applying the principle of conservation of momentum,

Total momentum after collision = total momentum before collision

(0.12v + 0.036) kg m/s = 0.048 kg m/s

$$v = \frac{(0.048 - 0.036)\text{ kg m/s}}{0.12\text{ kg}} = 0.10\text{ m/s}$$

LINK PWB

Practical 5, pp. XX–XX

Let's Practise 5.3

1 What is the principle of conservation of momentum?

2 A car of mass 1200 kg is travelling at 8.0 m/s. It collides with a lorry of mass 2800 kg travelling at 2 m/s in the same direction. After the collision, the two vehicles stick together. Calculate their speed immediately after the collision.

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercises 5C–5D, pp. XX–XX

Exercise 5F Let's Reflect, p. XX

Let's Map It

MOMENTUM p

SI unit: kg m/s

Vector quantity

is defined as

The product of mass and velocity

$p = mv$

where
p = momentum
m = mass
v = velocity

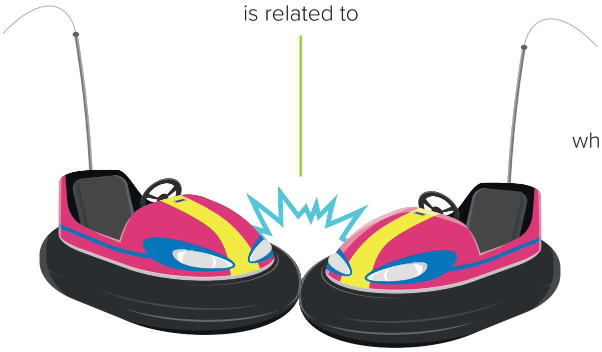
is conserved in collisions between objects governed by

The principle of conservation of momentum

which states that

When objects collide, the total momentum of the objects before a collision is the same as the total momentum of the objects after the collision, provided there is no external force acting.

is related to



Impulse

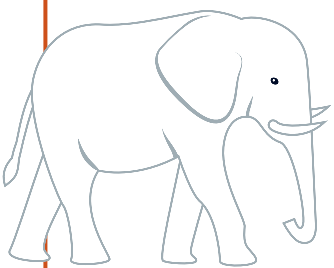
where

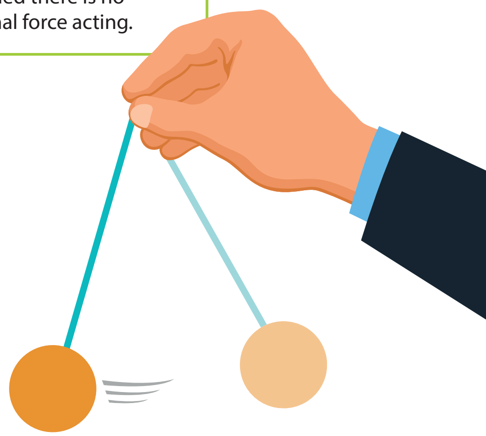
Impulse = change in momentum
$F\Delta t = \Delta p$

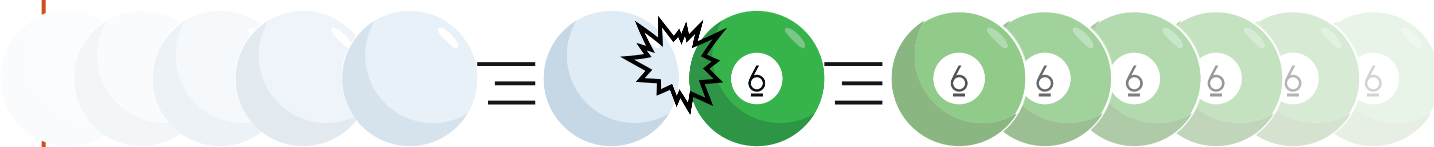
Force

where

Resultant force $F = \frac{\Delta p}{\Delta t}$







Let's Review

Section A: Multiple-choice Questions

1 Which statement defines momentum?

A Momentum = mass × velocity

B Momentum = mass × velocity × velocity

C Momentum = $\frac{\text{mass}}{\text{velocity}}$

D Momentum = $\frac{\text{velocity}}{\text{mass}}$

2 A truck of mass 10 000 kg is moving at 5.0 m/s. Calculate the momentum of the truck.

A 5.0×10^{-4} kg m/s

B 2.0×10^{3} kg m/s

C 5.0×10^{4} kg m/s

D 2.5×10^{5} kg m/s

3 Which statement defines impulse?

A Impulse = mass × velocity

B Impulse = mass × acceleration

C Impulse = force × distance

D Impulse = force × time for which force acts

4 A bullet of mass 0.05 kg was fired into a wooden block of mass 1.95 kg resting on a frictionless horizontal surface. Upon collision, the bullet and the block were stuck together. Immediately after the collision, the bullet and the block moved at a constant velocity of 15 m/s. With what speed did the bullet hit the block?

A 15 m/s

B 30 m/s

C 585 m/s

D 600 m/s

5 A basketball player is bouncing a ball on the ground. The ball hits the ground 10 times in 20 seconds. The average change in momentum for each collision is 15 kg m/s. What is the force that the ground exerts on the ball?

A 0.75 N

B 2 N

C 7.5 N

D 20 N

Section B: Short-answer and Structured Questions

1 **(a)** Complete the word equation:
momentum = __________ × __________

(b) Figure 5.11 shows an empty freight car moving at 8 m/s towards a stationary loaded car as shown. It collides with the loaded car and the cars stick together after the collision.

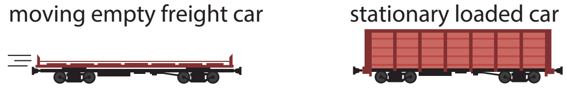


Figure 5.11

The mass of the empty freight car is 2000 kg.

(i) Calculate the momentum of the empty freight car before the collision.

(ii) The mass of the loaded car is 8000 kg. With what speed do the combined cars start to move?

2 A resultant force of 16 N acts for 5 s on an object. The mass of the object is 2 kg. Calculate

(a) the change in momentum of the object;

(b) the impulse of the force;

(c) the change in speed of the object.

3 Two ice skaters A and B are stationary on a skating rink. The mass of skater A is 80 kg. The mass of skater B is 50 kg. They face each other and push each other off. Skater A moves off in a straight line with velocity of 0.5 m/s. Calculate

(a) the momentum of skater A;

(b) the momentum of skater B;

(c) the velocity of skater B.

CHAPTER 6

Energy, Work and Power

PHYSICS WATCH

Scan this page to watch a clip of a roller coaster ride.

What energy conversions take place?

QUESTIONS

- Why is a powerful motor needed to launch the roller coaster cars to their starting positions?
- How do you think the speeds of the roller coaster cars will vary as they move along the high points and low points of the tracks?
- If you were to ride the roller coaster, at which point would you feel the greatest thrill? Why do you think so?

Standing at 42.5 metres, the *Battlestar Galactica* at the Universal Studios, Singapore, is the tallest duelling roller coaster in the world. It's *Human* versus *Cyclon*. By means of a powerful motor, these two roller coaster cars are launched towards their high starting positions at high speeds. Once ready, they will move along tracks designed to produce near misses. Are you game for some adventure? Let the duel begin.

6.1 Energy

In this section, you will learn the following:

- State that energy may be stored in different forms.
- Describe how energy is transferred between stores during events and processes.
- S Recall and use the expressions *kinetic energy* $= \frac{1}{2}mv^2$ and *change in gravitational potential energy* $= mg\Delta h$.
- Know and apply the principle of conservation of energy to simple examples using flow diagrams.
- S Apply the principle of conservation of energy to complex examples involving multiple stages including the interpretation of Sankey diagrams.

WORD ALERT

Capacity: ability

LINK

You will learn more about work done in Section 6.2 of this chapter.

What is energy?

What does the term *energy* bring to mind? Someone exercising vigorously? Tidal waves crashing against the shore? You would probably relate energy with strong forces that produce motion.
In physics:

Energy is the capacity to do work. The SI unit of energy is the **joule (J)**.

Work usually means making a body or an object move to achieve a purpose. For example, when a person rows a boat, work is done. In order to do work, energy is transferred between objects or converted from one form to another. Figure 6.1 shows the different forms of energy.

Different Forms of Energy

Potential energy

Potential energy is the stored energy in a system. This form of energy is due to the state, shape or position of the system. There are different types of potential energy. Each of these types of potential energy can be converted into other forms of energy.

Kinetic energy

Kinetic energy is the energy of a body due to its motion. Thus, wind has kinetic energy and so do sea waves, a spinning frisbee and a rolling soccer ball.

Kinetic energy can be used to do work. For example, wind and sea waves can be used to turn turbines, which convert kinetic energy to electrical energy.

Chemical potential energy

Chemical potential energy is the energy stored in a substance due to the *position of the atoms or electrons* in the substance. The food that we eat, fossil fuels and batteries contain chemical potential energy.

Elastic (strain) energy

Elastic (strain) energy is the energy stored in a body due to its *elastic deformation*. A spring or rubber band possesses elastic potential energy when it is compressed or stretched. This energy can be converted to kinetic energy when the spring or rubber band is released.

Gravitational potential energy

Gravitational potential energy is the energy stored in a body due to its height from the ground. An object has gravitational potential energy when it is raised to a height above the ground. When the object is released, its gravitational potential energy is converted to kinetic energy as it falls.

Electrostatic potential energy

Electrostatic potential energy is the energy stored in the *electric fields of static charges*. A capacitor is a common device that stores electrostatic potential energy in the flash unit of a camera. When the flash is used, the electrostatic potential energy from the capacitor is converted to light energy to brighten up the scene .

Figure 6.1 *The different forms of energy*

Electrical energy

Electrical energy is the energy of an *electric charge due to its motion and position*. It is used extensively in our everyday lives.

Lightning has electrical energy.

Internal (thermal) energy

Internal or thermal energy is the energy stored in a body due to its *temperature*. The particles of a hotter body possess more internal energy than those of a colder body. Internal energy is transferred from the hotter body to the colder body.

A hot metal has a high internal energy.

Electromagnetic, sound and other waves

Light is an *electromagnetic wave* that is visible to the eye. It is made up of electric and magnetic fields oscillating at a certain range of frequency within the electromagnetic spectrum.

Sound is a *mechanical wave* that travels through a medium. It is caused by vibrating particles. We hear sound when the vibrating particles cause our ear drum to vibrate.

LEDs are used to convert electrical energy to light energy to light up the streets.

Nuclear energy

Nuclear energy is the energy *released during a nuclear reaction*. It can be found in the nuclei of atoms of radioactive substances such as uranium.

Nuclear power plants generate electricity from nuclear energy.

LINK

How is electrical energy related to electricity? Find out more in Chapter 16.

ENRICHMENT *INFO*

Solar Wind Power

You have probably heard of solar power and wind power. But what is solar wind power?

Solar wind is a stream of energised charged particles that flow out from the Sun. In theory, it is possible to capture this stream of particles using satellite and transmit it back to Earth.

The potential is huge. It is believed that solar wind power could meet our energy needs more than a hundred billion times compared to solar power or wind power alone.

Figure 6.2 An aurora, a natural light display, as seen in the Earth's sky near the polar regions is caused by solar wind.

ENRICHMENT *THINK*

Nuclear energy is useful, but it can be very dangerous. Should we promote the use of nuclear energy? Discuss.

We can use formulae to calculate the amount of energy a body has.

To find out the amount of **kinetic energy**, we use the following equation:

$$E_k = \frac{1}{2}mv^2$$

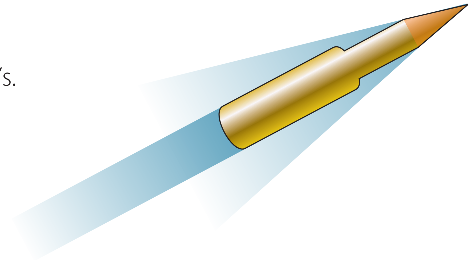
where E_k = kinetic energy (in J)
m = mass of the body (in kg)
v = speed of the body (in m/s)

To find out the amount of **gravitational potential energy**, we use the following equation:

$$\Delta E_p = mg\Delta h$$

where E_p = gravitational potential energy (in J)
m = mass of the body (in kg)
g = gravitational field strength (in N/kg)
h = height (in m)

Worked Example 6A



A bullet of mass 0.02 kg travels at a speed of 1200 m/s. Calculate its kinetic energy.

Solution

Kinetic energy of bullet $= \frac{1}{2}mv^2$

$= \frac{1}{2}(0.02)(1200)^2$

$= 14\,400$ J

Worked Example 6B

A package of 5 kg is lifted vertically through a distance of 10 m at a constant speed (Figure 6.3). Taking the acceleration due to gravity to be 10 m/s², calculate the gravitational potential energy gained by the package.

Solution

Gravitational potential energy of the package = mgh

$= (5)(10)(10)$

$= 500$ J

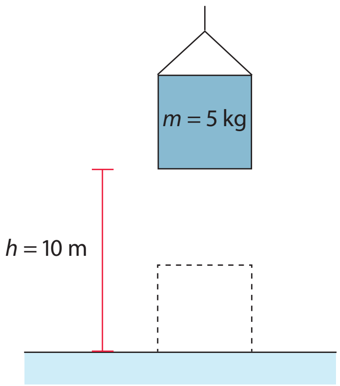


Figure 6.3

What is the principle of conservation of energy?

If you strike a match, you will get a burning flame. The chemical energy found in the substance of the match head is converted to thermal and light energy. When work is done, energy is converted from one form to another. The total amount of energy before and after the conversion is the same as shown in Figure 6.4.

Figure 6.4 *When energy is converted from one form to another, the total amount remains constant.*

The **principle of conservation of energy** states that energy cannot be created or destroyed. It can be converted from one form to another or transferred from one body to another. The total amount of energy remains constant.

Examples of energy conversions

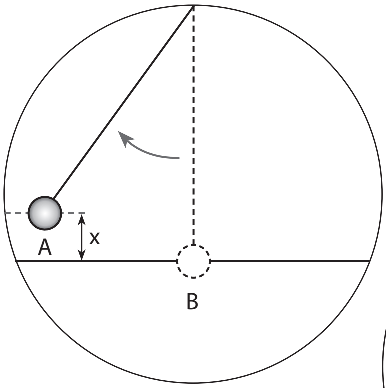
(a) An ideal pendulum swinging

Figure 6.5 illustrates what happens when an ideal pendulum is swinging. The energy conversions taking place is shown by the **flow diagram**. An ideal pendulum will swing forever, with its gravitational potential energy converting to kinetic energy and vice versa. Since the total amount of energy is conserved, energy is not lost from the pendulum, and hence it does not stop swinging.

Figure 6.5 *Energy conversion in an ideal pendulum*

① The pendulum bob is displaced to position A at height x above the horizontal level.

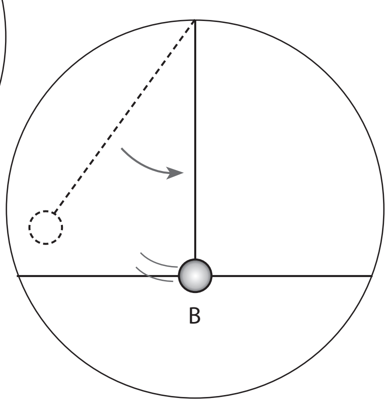
It gains gravitational potential energy as it is at a height above its original position, B.



② When the bob is released, it swings downwards, and the gravitational potential energy is converted to kinetic energy.

Since energy cannot be created or destroyed, the kinetic energy gained must have been converted from the gravitational potential energy lost.

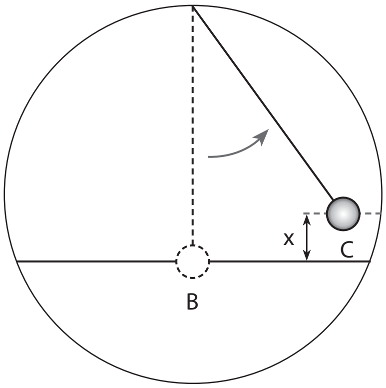
The swinging pendulum bob has maximum kinetic energy when it reaches B.

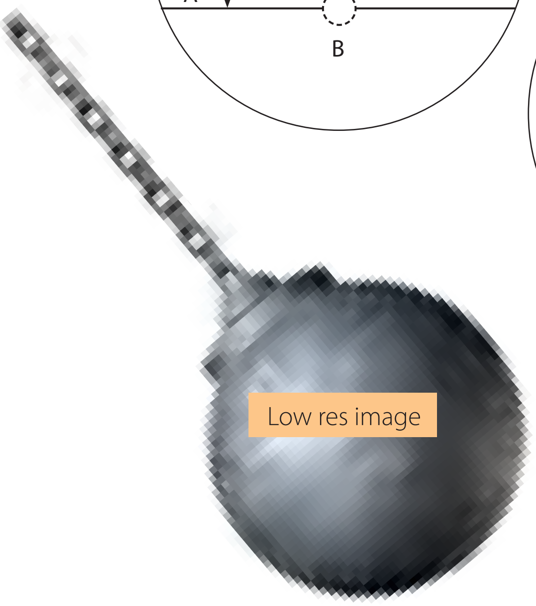


③ As the bob swings to the other side, its kinetic energy is converted back to gravitational potential energy.

The gravitational potential energy gained is converted from the kinetic energy lost. Thus, the pendulum bob slows down as it gains height.

At position C, where the height is maximum, it only has gravitational potential energy. This gravitational potential energy is converted to kinetic energy when it swings to its original position again at B.





Flow diagram:

Gravitational potential energy at A → Kinetic energy at B → Gravitational potential energy at C

WORD ALERT

Vice versa: the other way round (in this case: kinetic energy changing back to gravitational potential energy)

Conserved: kept the same

ENRICHMENT
THINK

1 Using the principle of conservation of energy, work out an equation to show that the maximum speed of a swinging ideal pendulum is independent of the mass of the pendulum. What does the maximum speed depend on?

2 In the real world, a swinging pendulum will eventually come to a stop. Explain what happens in terms of energy conversion.

QUICK CHECK

In Worked Example 6C, the energy changes of the pendulum between points can be explained by the principle of conservation of energy.

True or false?

ENRICHMENT THINK

Refer to Figure 6.7. One of the explanations is scientifically correct.

In what way(s) are the other two explanations not scientifically correct?

Worked Example 6C

Figure 6.6 shows a pendulum of mass 0.4 kg oscillating in a vacuum. If P is the lowest position of the pendulum where its maximum speed is 1.5 m/s, calculate

(a) the maximum kinetic energy of the pendulum;

(b) the maximum gravitational potential energy of the pendulum as it rises to its greatest height at Q;

(c) the greatest height, h.

(Take $g = 10$ N/kg)

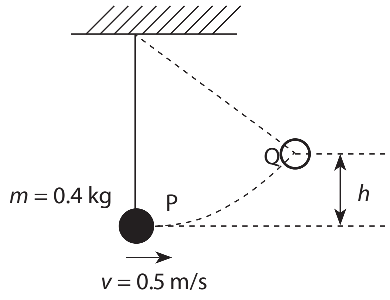


Figure 6.6

Solution

(a) Maximum kinetic energy at P $= \frac{1}{2}mv^2 = \frac{1}{2}(0.4)(1.5)^2 = 0.45$ J

(b) Loss of kinetic energy at P = gain in gravitational potential energy at Q.
Therefore, maximum gravitational potential energy at Q = 0.45 J

(c) Maximum gravitational potential energy $= mgh = 0.45$ J

$\therefore h = \frac{0.45}{mg} = \frac{0.45}{(0.4)(10)} = 0.113$ m

(b) A robot waiter on the move

Have you been to a restaurant and had your food served by a robot waiter? Figure 6.7 shows a singing robot waiter with flashing lights moving across the floor. It is carrying a food tray. The robot uses electrical energy to perform its functions. What happens to the electrical energy inside the robot?

The three restaurant guests give their own explanations. Which explanation is scientifically correct?

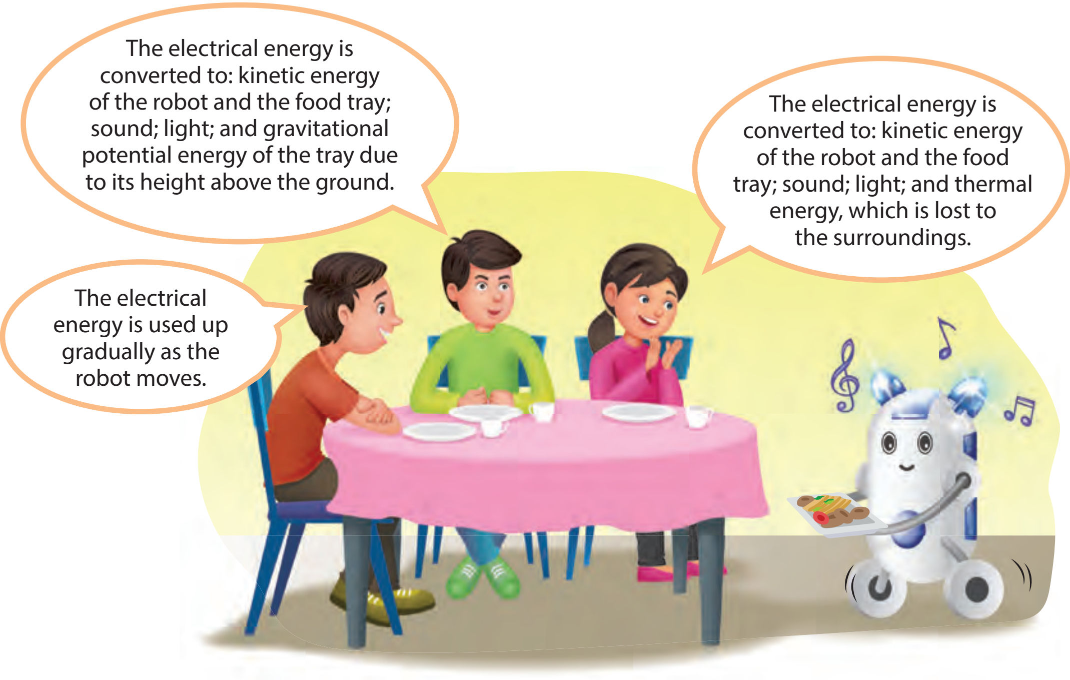
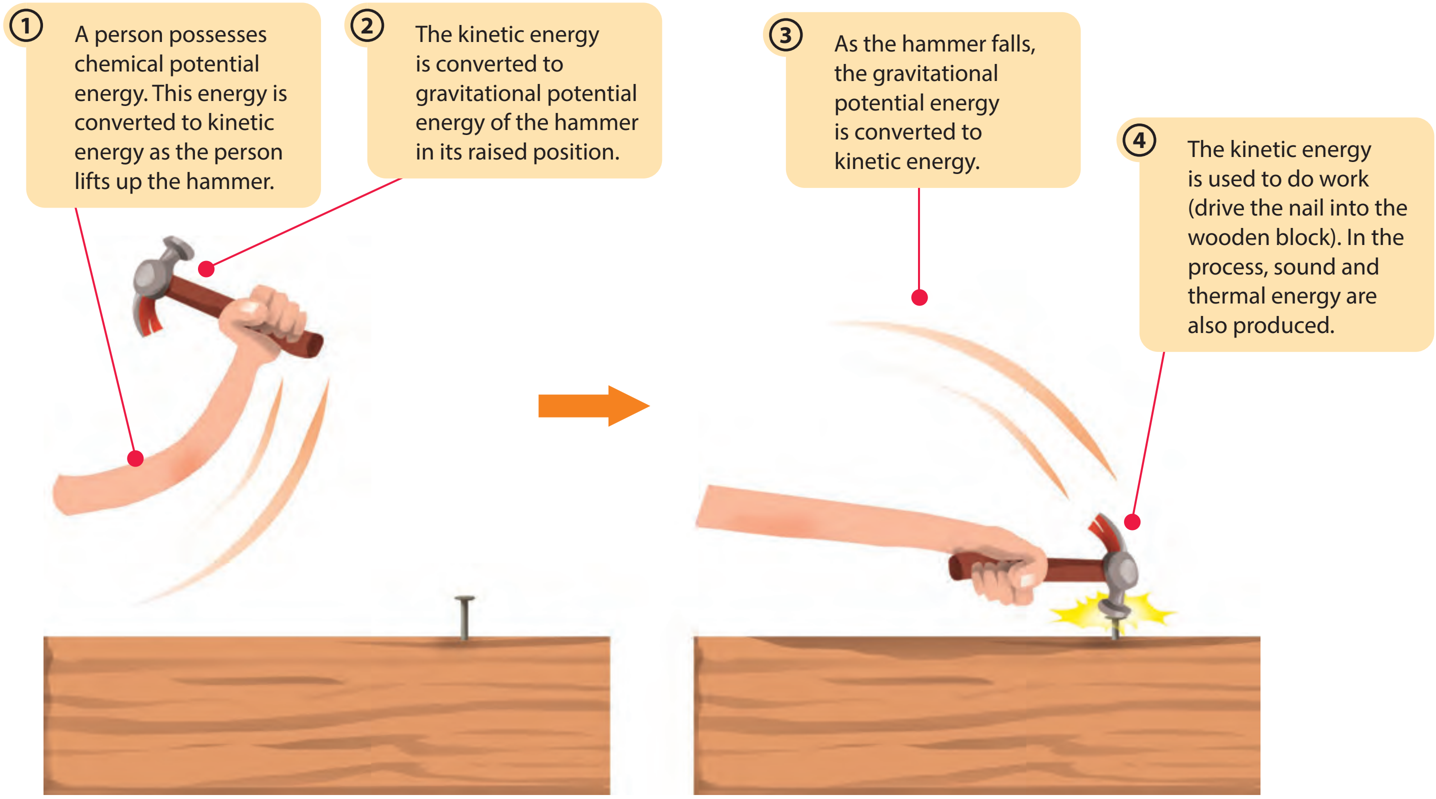


Figure 6.7 *What happens to the electrical energy used by the robot waiter?*

(c) Hammering a nail

Figure 6.8 shows the energy conversion when a nail is hammered. We can use a **Sankey diagram** to represent the energy conversion involving multiple stages. A Sankey diagram begins with the energy input on the left and branches out into useful energy output and wasted energy. The useful energy output branch points to the right and wasted energy branch points downwards.



Sankey diagram:

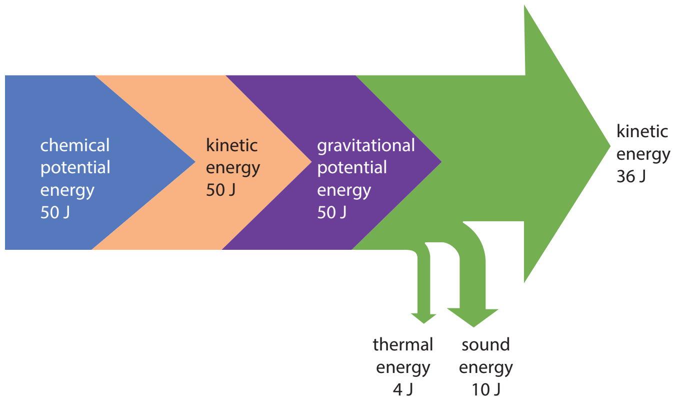


Figure 6.8 *Hammering a nail involves several energy conversions*

In the Sankey diagram above, chemical energy is the energy input which is first converted into kinetic energy, then into gravitational potential energy before being converted into other forms of energy. The final kinetic energy branch is the thickest since most of the energy is converted into it as useful output energy. The other two branches are much thinner because only small amounts of the energy are converted to sound and thermal energy as wasted energy.

In any event or processes that occur in the real world, not all the energy can be fully converted from one form to another. The energy tends to be dissipated, i.e., become more spread out among the objects and surroundings.

WORD ALERT

Dissipated: scattered, dispersed

Let's Practise 6.1

1 State the energy conversions that take place when
   (a) water is boiled using an electric kettle;
   (b) a light bulb is connected to a dry cell.
2 A ripe mango hangs from the branch of a tree. Using the principle of conservation of energy, explain what happens to the mango's gravitational potential energy when it falls to the ground.
3 A softball player throws a ball into the air and catches it on the way down. Ignoring the air resistance that acts on the ball, state the energy conversions that take place by means of a flow diagram.
4 S A 2.0 kg flower pot accidentally falls from a height of 45 m towards the ground. What is the
   (a) gravitational potential energy of the flower pot before the fall;
   (b) speed of the flower pot just before it hits the ground assuming negligible air resistance? (Take $g = 10$ N/kg)
5 S When a roller coaster is set in motion from a high place, its gravitational potential energy is converted to kinetic energy and other forms of energy.
   (a) How does the roller coaster first obtain its gravitational potential energy?
   (b) Since energy is conserved, why could the roller coaster not continue its motion perpetually?
   (c) Use a Sankey diagram to show how the principle of conservation of energy can be applied from the launching station of the roller coaster to the highest starting position.
6 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

WORD ALERT

Perpetually: continue without stopping

LINK TWB

Exercises 6A–6B, pp. XX–XX

6.2 Work

In this section, you will learn the following:

- Understand that mechanical or electrical work done is equal to the energy transferred.
- Recall and use the equation for mechanical working, $W = Fd = \Delta E$.

LINK

Recall the concept of force that you have learnt in Chapter 4.

What is work done?

Look at Figure 6.9. What is the lady doing? What is the boy doing?

Both the lady and the boy are exerting force on objects. Is work being done in both situations?

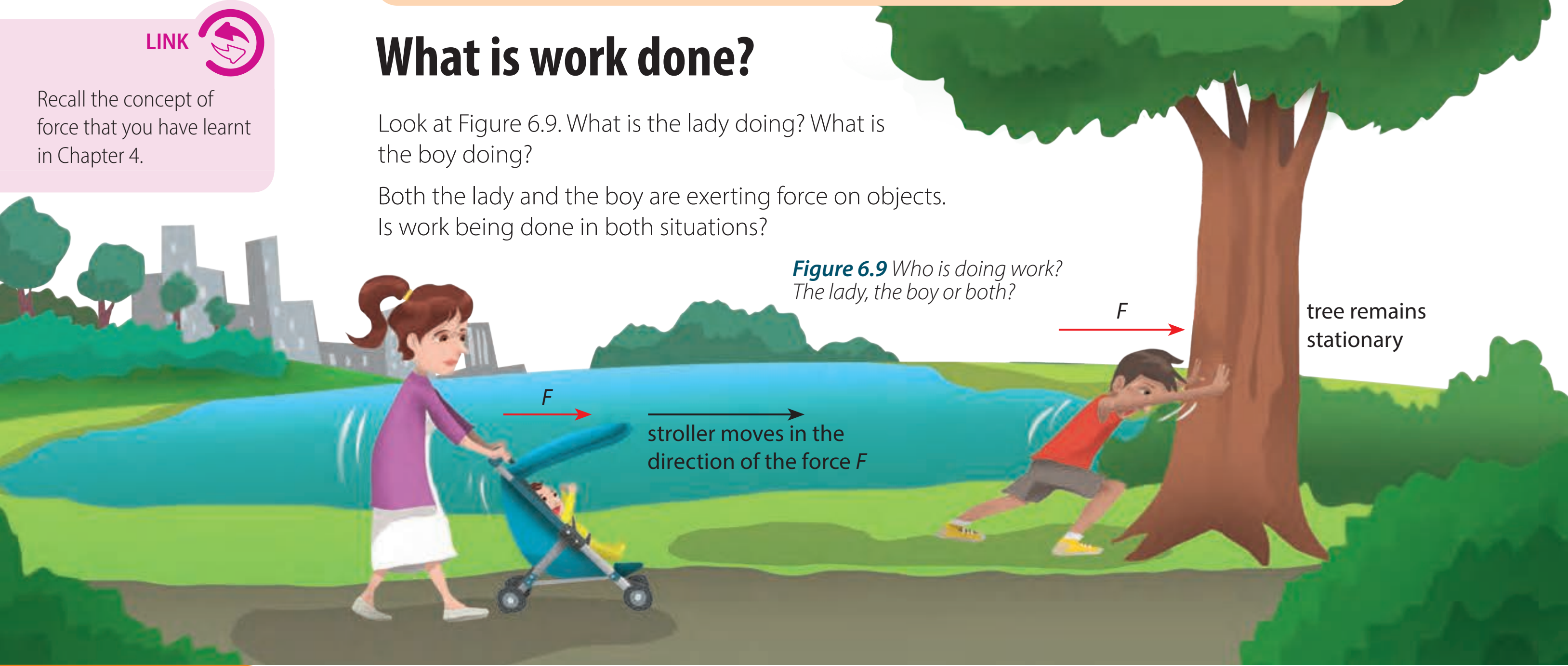


Figure 6.9 *Who is doing work? The lady, the boy or both?*

In physics, work is done only when an object moves under the influence of a force. Therefore, in Figure 6.9, the lady is doing work, but the boy is not.

Work done by a constant force on an object is the product of the force and the distance moved by the object in the direction of the force.

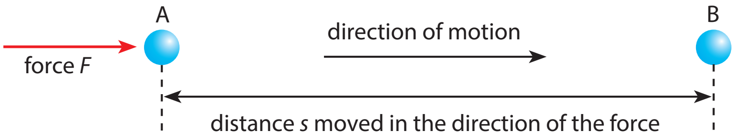


Figure 6.10 *Illustrating work done*

Using Figure 6.10, we can represent the work done W by the force F in moving the object from point A to point B with the following equation:

$\boldsymbol{W = F \times s}$ where W = work done by a constant force F (in J)
F = constant force (in N)
s = distance moved by the object in the direction of the force (in m)

The SI unit of work is the **joule (J)**. Both work done and energy have the same unit — joule. This is because work done is equal to energy transferred. The work done by the lady in Figure 6.9 is equal to the energy transferred into kinetic energy of the stroller with the baby.

Recall the example of the robot waiter on page 88. Similarly, the work done by the robot is the measure of electrical energy which is transferred into kinetic energy, sound, light and thermal energy, which is lost to the surroundings.

From the equation, we can deduce the following:

One joule is the work done by a force of one newton, which moves an object through a distance of one metre in the direction of the force.

Worked Example 6D

A librarian pushes a trolley of books for shelving (Figure 6.11). The horizontal force F exerted by the librarian on the trolley is 8 N and the trolley moves a distance of 5 m in the direction of the force.

(a) Calculate the work done on the trolley.

(b) Explain what happened to the mechanical work done.

Solution

(a) Given: Force $F = 8$ N
Distance moved $s = 5$ m

Work done
$W = F \times s = 8 \text{ N} \times 5 \text{ m} = 40 \text{ J}$

(b) The mechanical work done by the force F in moving the trolley is transferred into kinetic energy of the trolley.

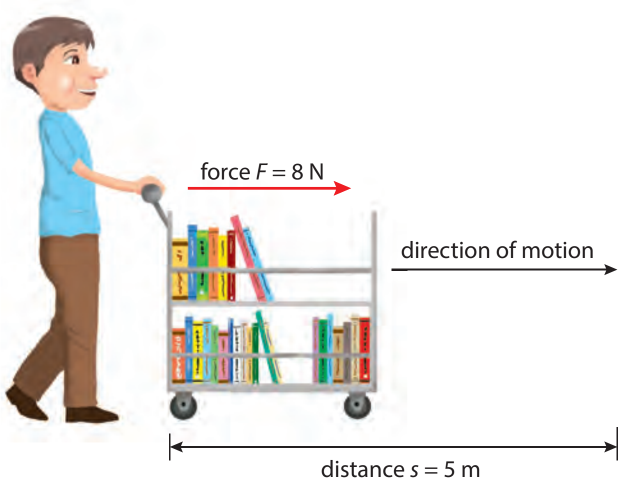


Figure 6.11

ENRICHMENT *INFO*

Another Real-world Example of No Work Done

A student is queuing at the library counter to borrow some books. He holds the books in a stationary position. While doing so, he balances the weight W of the books by exerting an upward force F of magnitude W. To check out the books, the student walks across a horizontal floor to the counter over a distance s.

Using the definition of work done, there is no work done by the upward force F. This is because the distance moved in the direction of force F is zero.

Worked Example 6E

The trolley of books pushed by the librarian in Worked Example 6D has a mass of 80 kg. After pushing the trolley over a horizontal distance, he reaches the bottom of a gentle incline with a certain speed *v*. The vertical height of the incline is 0.5 m. In order to maintain the same speed *v* up the incline, the librarian exerts a much larger force of 40 N to push the trolley over a distance of 10 m along the incline.

Assuming negligible air resistance and frictional effects at the moving parts of the trolley,

(a) calculate the work done by the 40 N force on the trolley along the incline;

(b) S calculate the gain in gravitational potential energy of the trolley.

(Take $g = 10$ N/kg)

Solution

Given: Mass $m = 80$ kg
Vertical height $h = 0.5$ m
Force $F = 40$ N
Distance moved along the incline, $s = 10$ m

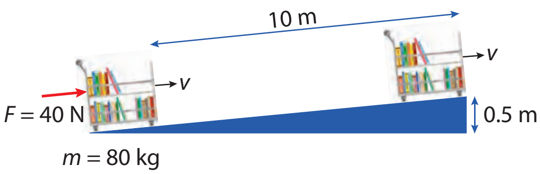


Figure 6.12

(a) Work done $W = F \times s = 40 \text{ N} \times 10 \text{ m} = 400 \text{ J}$

(b) S Gain in gravitational potential energy = $mgh = 80 \text{ kg} \times 10 \text{ N/kg} \times 0.5 \text{ m} = 400 \text{ J}$

QUICK CHECK

Refer to Worked Example 6E. Work is done by the force of 40 N to push the trolley over a distance of 10 m up the incline at a constant speed. This work done is transformed into gain in gravitational potential energy of the trolley.

True or false?

Let's Practise 6.2

1 A mother carrying her baby in a stationary position does no work. Explain.

2 Define the joule.

3 A box is placed on a smooth floor. A force of 8.0 N acts horizontally on the box. The distance moved by the box in the direction of the force is 3.0 m.

(a) Calculate the work done by the force.

(b) Calculate the gain in the kinetic energy of the box.

5 A 50-N package is lifted 10 m vertically at a constant speed.

(a) Calculate the work done by the force of 50 N on the package.

(b) S Calculate the gravitational potential energy gained by the package.

6 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 6C, pp. XX–XX

6.3 Energy Resources

In this section, you will learn the following:

- Describe how electricity or other useful forms of energy may be obtained.
- Describe advantages and disadvantages of the methods for obtaining energy.
- S Show an unde rstanding that energy is released by nuclear fusion in the Sun.
- S Know that research is being carried out to investigate how energy released by nuclear fusion can be used to produce electrical energy on a large scale.
- S Understand that the Sun is the source of energy for most of our energy.
- Show a qualitative understanding of efficiency.
- S Recall and use the equations:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{power input}} \times 100\%$$

How can we obtain energy?

We consume large amounts of energy every day to improve the quality of our lives. For example, we need electrical energy to run machines and to light up the lamps. We need chemical potential energy in petrol and diesel to drive cars and buses, and we need gas to cook food and heat water. A lot of energy is used to light up buildings and streets at night (Figure 6.13).

Figure 6.13 *Jakarta looks beautiful at night. Large amounts of energy is used to light up the city.*

Examples of major energy resources

Major energy resources

We depend on some major energy resources to produce electricity and other useful forms of energy (Table 6.1). These energy resources have some advantages and disadvantages.

Table 6.1 *Major energy resources*

Energy resources and how useful forms of energy are produced	Advantages	Disadvantages
Fossil fuels • Examples of **fossil fuels** are petroleum, natural gas, coal and wood. • Chemical potential energy is stored in the structure of the atoms and molecules. • When the fuel is burnt in air, the atoms and molecules are regrouped due to a chemical reaction. • The chemical potential energy is converted mainly to thermal energy and light for cooking and heating purposes.	• Widely available at a large scale • Relatively cheaper in cost of production	• Environmental pollution from the gases, produced during burning, contributes to global warming • Non-renewable energy resource

Figure 6.14 *Mining for coal*

Table 6.1 Major energy resources [continued]

Energy resources and how useful forms of energy are produced	Advantages	Disadvantages
Biofuels • Examples of biofuels are ethanol, biodiesel and biogas, which are derived from biomass. Biomass comes from living materials such as corn, sugar cane, vegetable oils, animal fats and animal manure. • Chemical potential energy is stored in the biofuels. • The chemical potential energy is converted mainly to thermal energy and light for cooking and heating purposes.  *Figure 6.15* Biofuel plant on a farm processing cow dung to produce biogas	• Widely available at a large scale • Relatively cheaper in cost of production • Renewable energy source	• Environmental pollution from the gases produced during burning contributes to global warming
Hydropower • Water movement provides power to spin turbines to generate electricity. This hydropower or water power can be obtained from ocean waves, tides and water behind hydroelectric dams. • Water behind hydroelectric dams has gravitational potential energy. This energy is converted to kinetic energy by releasing the water and letting it flow downwards. The flowing water will cause the turbines to spin. • As the turbines spin, the kinetic energy of the turbines is converted to electrical energy by the generators connected to the turbines.  *Figure 6.16* Kurobe dam in Japan	• Clean method of producing cheap electricity • Renewable energy resource as the water movement can be continually regenerated	• High cost of building dams, turbines and generators • Damming a river for hydroelectric power station may cause damage to the environment surrounding the river
Geothermal energy • In certain areas, such as volcanic regions, geological forces push large amounts of hot molten rocks near the Earth's surface. These places are known as geothermal hotspots. • Water that makes its way to these geothermal hotspots is heated and subjected to great pressure. • This heated water contains a large amount of thermal energy. It is forced to the surface as boiling water and steam to drive turbines. • Electricity is produced by generators connected to the turbines.  *Figure 6.17* Geothermal power station in Iceland	• Clean source of naturally available thermal energy • Renewable energy resource	• Environmental pollution caused by the release of poisonous gases such as hydrogen sulphide into the atmosphere • Not widely available as they are found only in certain areas around the world

PHYSICS WATCH

Scan this page to watch a clip on how hydroelectric power is generated.

Table 6.1 Major energy resources [continued]

Energy resources and how useful forms of energy are produced	Advantages	Disadvantages
Solar energy • Ⓢ Solar energy comes from the Sun. This energy is released in the Sun by nuclear fusion, where hydrogen atoms combine to form helium atoms. • Solar energy can be converted directly to electricity. Solar cells are used to change solar energy to electrical energy by means of photovoltaic effect. • The infrared electromagnetic waves in the solar energy can be converted to thermal energy, by means of a solar panel or collector with a blackened surface, for heating water. • Solar energy is the source of wind energy. The uneven heating of the Earth's surfaces (land, sea and air) results in the movement of warm and cold air. This produces wind. By means of wind electric generators, wind energy can be converted to electrical energy.	• Less polluting than fossil fuels • Renewable energy resource	• Not always available as there is no sunlight at night, and it is weather-dependent • Uses a lot of space
Nuclear energy • Nuclear fuels such as uranium are used to produce large amounts of thermal energy. • The thermal energy is used in boilers to heat up water into steam, which drives the turbines in the nuclear power station. • Electricity is produced by generators connected to these turbines.	• A low carbon energy resource which helps to reduce greenhouse gas emissions that cause global warming • Higher reliability in supplying uninterrupted power	• Risk of accidents and pollution from the improper disposal of radioactive wastes • Non-renewable energy resource as the amount of nuclear fuel is limited

Figure 6.18 *Solar cells on a roof top harness energy from the Sun.*

Figure 6.19 *Uranium fuel rods inside a nuclear reactor*

PHYSICS WATCH

Scan this page to watch a clip about how a food seller came out with an innovative idea to harness the Sun's energy.

Nuclear fusion reactors for the future

Nuclear fusion is a process where atomic nuclei of light elements combine to form heavier elements. The light elements are deuterium and tritium (isotopes of hydrogen).

Nuclear fusion is relatively safer than nuclear fission and there is plenty of deuterium in seawater. These have encouraged experimental research for many years to make a fusion nuclear reactor on a commercial scale. The energy released from nuclear fusion can be used to produce electrical energy on a large scale.

One promising multi-nation project is the International Thermonuclear Experimental Reactor (ITER) in southern France, to be launched in 2025.

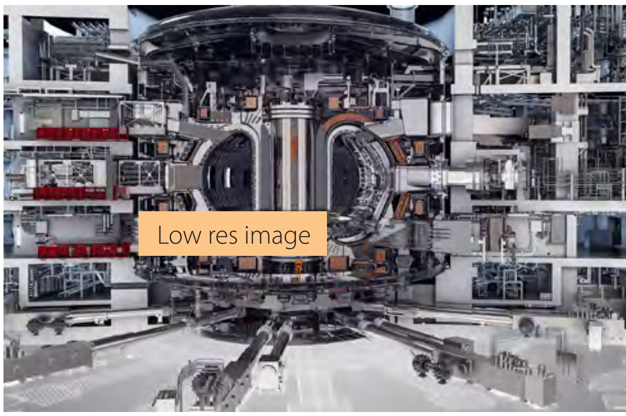


Figure 6.20 *Model of ITER reactor*

ENRICHMENT THINK

Refer to Table 6.1. Why is it most useful to produce electrical energy from the major energy resources?

The Sun as our main source of energy

Based on Table 6.1 on pages 93 to 95, why is radiation from the Sun considered to be the main source of energy for many of the energy resources?

Other than geothermal, nuclear and tidal energy resources, the other energy resources can be traced to the important role of solar energy from the Sun.

- Solar energy is the source of wind energy (see Table 6.1).
- Solar energy is converted to chemical potential energy in plants through photosynthesis. The survival of animals depends on the transfer of this energy through food chains. Fossil fuels come from the remains of plants and animals.
- Solar energy plays an important role in the water cycle. It evaporates water to bring fresh water in the form of rain and snow. These in turn are the sources for hydropower.

What is efficiency?

By the principle of conservation of energy, the total energy output of an ideal machine is equal to its total energy input. However, in reality, the useful energy output of a machine is always less than the energy input. Some energy is dissipated during the energy conversion due to friction. This energy usually takes the forms of thermal and sound energy. The energy that is lost to the surroundings is considered wasted energy output.

Based on the principle of conservation of energy,
total energy input = useful energy output + wasted energy output.

The efficiency of a machine can be calculated using the following formulae:

$$\text{Efficiency} = \frac{\text{useful power output}}{\text{energy input}} \times 100\%, \quad \text{Efficiency} = \frac{\text{useful power output}}{\text{power input}} \times 100\%$$

QUICK CHECK

Refer to Worked Example 6F.
The principle of conservation of energy can be used to explain the 70% of wasted energy output, namely thermal energy and sound energy.

True or false?

Worked Example 6F

A power station uses fossil fuel to generate electricity. What does it mean to say that the efficiency of the power station is only 30%?

Solution
The chemical potential energy in the fossil fuel makes up 100% of the total energy input.
Out of this 100%, only 30% is converted to useful energy output in the form of electrical energy.
The remaining 70% is wasted energy output.

Let's Practise 6.3

1. Give an example of a major source of energy that converts chemical potential energy into thermal energy.
2. Nuclear power stations are less polluting.
   (a) What is the name of the process in the production of nuclear energy?
   (b) State **one** disadvantage of using nuclear energy.
3. What does it mean to say that a solar cell has an efficiency of 45%?
4. (S) A machine produces 35 J of useful output energy for every 50 J of total energy input. Calculate the efficiency of the machine.
5. **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 6D, pp. XX–XX

6.4 Power

In this section, you will learn the following:

- Define *power*.
- Recall and use the equation $P = \frac{W}{t} = \frac{\Delta E}{t}$ in simple systems.

What is power?

To explain what power is, we consider the two scenarios in Figure 6.21.

Two boys have to climb up the stairs as the lift is out of order.

WORD ALERT

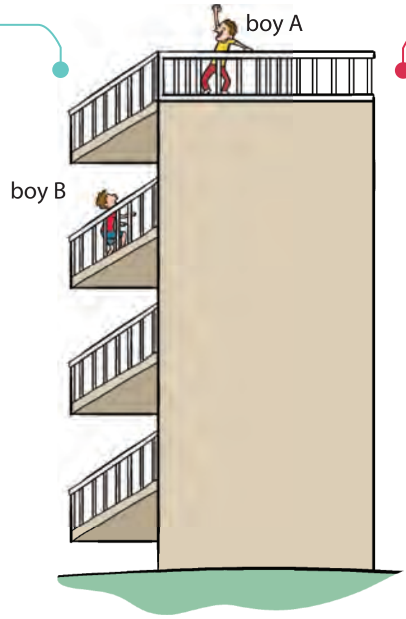
Scenarios: settings, situations

Scenario 1

- Boy A and boy B have equal mass;
- Boy A reached the fourth storey before boy B.

The two boys are of equal mass and travel the same distance. Therefore, they do the *same amount of work*.

- However, since boy A took a *shorter time* to reach the fourth storey as compared to boy B, we say that *boy A has more power*.
- Boy A has more power than boy B because he can do the *same amount of work more quickly*.



Scenario 1

Scenario 2

- Boy A has a larger mass than boy B;
- Boy A and boy B reached the fourth storey at the same time.

Since boy A has a larger mass, he has to do *more work* to carry himself up the four storeys.

- In other words, boy A is able to do *more work* than boy B in the *same amount of time* as boy B.
- Therefore, we say boy A has *more power*.

Figure 6.21 *The amount of work done by the boys and the time taken to do the work determine who has more power.*

Power is defined as the work done or energy transferred per unit time.

The SI unit of power is the **watt (W)**. One watt is defined as the work done or energy transferred of one joule per second, i.e., 1 W = 1 J/s.

In equation form, $\boldsymbol{P = \frac{W}{t} = \frac{\Delta E}{t}}$ where P = power (W)

W = work done (J)

ΔE = energy converted (J)

t = time taken (s)

Note that the product of power P and time taken t tells us the amount of work done or the amount of energy being converted from one form to another.

LINK

Practical 6A, pp. XX–XX

ENRICHMENT ACTIVITY

Flying Wheel Toy

This activity will help you visualise the concept of power $P = \frac{W}{t} = \frac{F \times s}{t}$

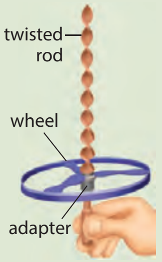


Figure 6.23 *Wheel toy*

Experiment A

1 Launch the wheel by pushing the adapter vertically upwards across the length of the rod as hard as possible.
2 Observe the maximum height that the wheel is able to fly up to.

Experiment B

1 Cut the twisted length of the rod into half.
2 Repeat the steps in Experiment 1.

Questions

1 Which of the maximum heights is higher?
2 Which experiment shows that a greater amount of work is done?
3 In which experiment is the launching power greater, assuming the time taken is the same?

Worked Example 6G

Eugene, who weighs 450 N, runs up ten steps. Each step is 0.20 m high. Calculate Eugene's power if he takes five seconds to run up the steps at a constant speed.

Solution

The upward force F exerted by Eugene's muscles to balance his weight = 450 N

The upward distance s moved by Eugene = height of steps = 0.20 m × 10 = 2.0 m

Using $W = F \times s$, work done W by Eugene = 450 N × 2.0 m = 900 J

Using $P = \frac{W}{t}$, Eugene's power = $\frac{900\text{ J}}{5\text{ s}}$ = 180 W

Worked Example 6H

A filament lamp, rated at 40 W, converts 10% of its electrical energy supply to light energy. Calculate the quantity of light energy given off in five minutes.

Solution

Given: Power $P = 40$ W
Time $t = 5 \times 60\text{ s} = 300\text{ s}$

Energy used by lamp in five minutes = $P \times t = 40\text{ W} \times 300\text{ s} = 1.2 \times 10^4\text{ J}$

Since 10% of this energy is converted to light energy, the amount of light energy given off in five minutes

$= \frac{10}{100} \times 1.2 \times 10^4\text{ J}$

$= 1.2 \times 10^3\text{ J}$

= 1.2 kJ

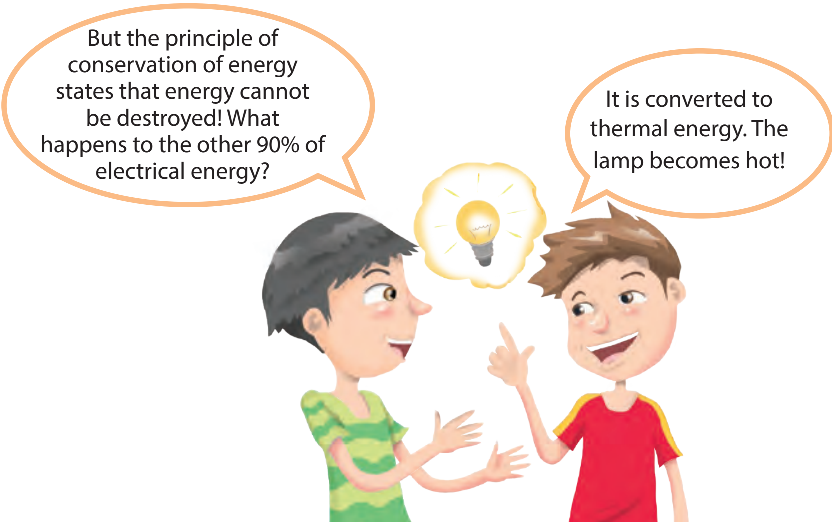


Figure 6.22

Let's Practise 6.4

1 Define the terms power and watt.
2 Calculate the power involved when a force of 50 N moves an object through a distance of 10 m in 5 s.
3 An electric motor in a washing machine has a power output of 1.0 kW. Calculate the work done in half an hour.
4 The same amount of water was poured into two electric kettles, one rated at 500 W and the other at 1000 W. Compare the time taken for both kettles to boil the water.
5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercises 6E-6G, pp. XX–XX
Exercise 6F Let's Reflect, p. X

Let's Map It

ENERGY E (SI unit: J) — is the capacity to do → **WORK W** (SI unit: J)

ENERGY and WORK are related to → **POWER P** (SI unit: W)

ENERGY is governed by → The principle of conservation of energy

states that → Energy cannot be created or destroyed but can be converted from one form to another.

examples of forms of energy →

- **Potential energy**
  - Chemical potential energy
  - Elastic (strain) energy
  - Electrostatic potential energy
  - Magnetic potential energy
  - Nuclear energy
  - Gravitational potential energy
  - S $E_p = mgh$
- **Kinetic energy**
  - S $E_k = \frac{1}{2}mv^2$
  - Electrical energy
  - Thermal energy
  - Light
  - Sound

produced from major energy resources →

- Fuel
- Biofuel
- Water
- Geothermal resources
- Nuclear fission
- Sun
  - energy release by nuclear fusion
  - S source of most of our energy
- Wind

WORK is defined as → S $W = F \times s$

where

F = force

s = distance moved in the direction of the force

POWER is defined as → S $P = \frac{W}{t} = \frac{E}{t}$

where

W = work done

E = energy converted

converted into useful energy by machines depending on their →

Efficiency

- Where some of the energy input is converted to useful energy and some into wasted energy such as heat and sound
- S Can be calculated using the following formulae:

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{useful power output}}{\text{total energy input}} \times 100\%$$

Let's Review

(Take g = 10 N/kg)

Section A: Multiple-choice Questions

1 A car screeches to a stop to avoid colliding with a van. Assuming that the road is level, what energy changes have occurred?

- **A** Kinetic energy → thermal energy
- **B** Kinetic energy → sound energy
- **C** Kinetic energy → light and sound energy
- **D** Kinetic energy → sound and thermal energy

2 (S) A 0.8 kg brick is accidentally dropped from a building. It reaches the ground with a kinetic energy of 240 J. How tall is the building?

- **A** 19 m **B** 30 m
- **C** 192 m **D** 300 m

3 What is the work done by a force of 6.0 N acting horizontally on a body of mass 4.0 kg if the distance moved in the direction of the force is 3.0 m?

- **A** 2 J **B** 12 J
- **C** 18 J **D** 24 J

4 Which of the following energy resources is the odd one out?

- **A** Nuclear energy **B** Geothermal energy
- **C** Wind energy **D** Solar energy

5 A machine is able to lift 200 kg of bricks vertically up to a height of 30 m above the ground in 50 s. What is the power of the machine?

- **A** 0.12 kW **B** 1.2 kW
- **C** 6.0 kW **D** 300 kW

Section B: Short-answer and Structured Questions

1 A cyclist pedals up to the top of a hill.

(a) What kind of energy is being used to do work against gravity?

(b) State the type of energy the cyclist has when he stops at the top of the hill.

(c) When the cyclist moves downhill without pedalling, what type of energy does he gain?

2 Energy cannot be created or destroyed.

(a) State **one** example to show this and explain.

(b) (i) Name **three** sources of non-renewable energy.

(ii) Suggest **two** things that you can do to help reduce the use of non-renewable energy.

3 (S) A simple pendulum consists of a string of length 50.0 cm and a pendulum bob of mass 10 g. The string hangs vertically from a fixed point O with the pendulum bob attached to its lower end at point P (Figure 6.24).

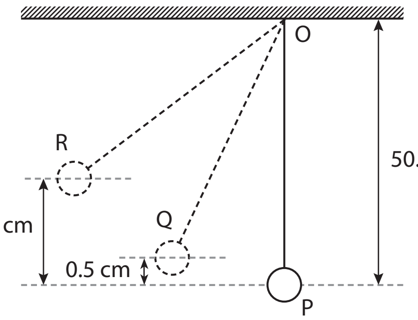


Figure 6.24

The pendulum bob is displaced to point R, 2.0 cm above P and released from rest. Assuming air resistance is negligible, calculate the

(a) gain in potential energy of the pendulum bob at point R;

(b) kinetic energy of the bob at point Q, 0.5 cm above P.

4 (S) A model car of mass 1.5 kg, with a string attached to its front end, is placed on a slope (Figure 6.25). A force of 10 N is applied on the string to move the car up the slope at a constant velocity. The force is applied in a direction that is parallel to the slope.

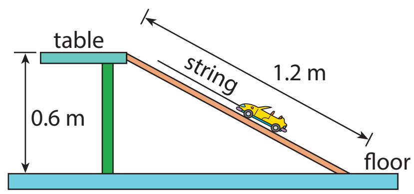


Figure 6.25

(a) With the aid of a diagram, describe how the force in the string can be measured.

(b) Calculate
 (i) the gain in the car's potential energy as it moves from the floor to the table;
 (ii) the work done by the force as it moves the car up the slope from the floor to the table;
 (iii) the efficiency of this arrangement to raise the car.

5 S A roller coaster train at an amusement park has a mass of 1500 kg. It descends from point P, which is 30 m above ground, to point Q, which is 10 m above ground.

(a) Calculate the loss in the gravitational potential energy of the train when it moves from point P to point Q.

(b) If 20% of the gravitational potential energy lost is dissipated, calculate the
 (i) kinetic energy of the train at point Q;
 (ii) speed of the train at point Q.

(c) By means of a Sankey diagram, show the energy conversion between point P and point Q.

6 S The energy input and useful energy output (i.e. electricity) for five power stations were measured. The results are listed in Table 6.2.

Table 6.2

Power station	Energy input/10^{14}J	Useful energy output/10^{13}J
P	10.8	32.8
Q	17.1	21.3
R	2.5	10.1
S	2.1	7.5
T	2.0	4.1

(a) Each of the stations uses a different method to produce electricity.
 (i) Calculate the efficiency of each power station.
 (ii) If you had to build a power station, which power station would you choose to base the design of your power station on? Why?

(b) Assuming that the values in Table 6.2 are the energy outputs of each power station per day, what is the power generated by power station S?

(c) Why is there a difference between the energy input and useful energy output?

CHAPTER

7 Pressure

PHYSICS WATCH

Scan this page to watch a clip of everyday examples that are related to pressure.

The phrase 'to walk on eggs' means to be extra careful. Well, you certainly need to be extra careful in order not to break the eggs when walking on them. Yes, it is possible to stand or walk on eggs without breaking them. Have you ever tried it yourself?

The picture shows a person wearing sports shoes stepping on some eggs. The eggs did not break. The eggs would break easily if a person wearing high-heeled shoes were to step on them. This is because the pressure that acts on the eggs is much greater for a person wearing high-heeled shoes compared to a person wearing sports shoes.

QUESTIONS

- How do you think pressure is related to area?
- Is the pressure you feel when taking an exam the same kind as the pressure exerted onto the eggs?

7.1 Pressure

In this section, you will learn the following:

- Define *pressure*.
- Recall and use the equation $p = \frac{F}{A}$.
- Describe how pressure varies with force and area using everyday examples.

What is pressure?

In Chapter 4, you have learnt about the effects of forces. Pressure is an effect of a force on a surface. When a force presses onto a surface, it **exerts** a pressure on the surface. To measure this effect, we define it using quantities that we can measure.

Pressure is defined as force per unit area. Its SI unit is **pascal (Pa)**.

In equation form, $\boldsymbol{p = \frac{F}{A}}$ where p = pressure (in Pa)
F = force (in N)
A = area (in m^2)

When the force is measured in newton (N) and the area in square metres (m^2), the pressure is newton per square metres (N/m^2). The unit N/m^2 is known as pascal (Pa) in the SI system of units. Square metres (m^2) is a big quantity. Often, the smaller unit square centimetres (cm^2) is used. When the area expressed is in cm^2, pressure is measured in N/cm^2.

WORD ALERT

Exerts: applies, puts

ENRICHMENT ACTIVITY

Psi and *bar* are two common units used to measure pressure.

Use the Internet to find out

(a) the difference between the two units;

(b) the situations in which they are used.

Worked Example 7A

Figure 7.1(a) shows a woman weighing 600 N standing in high heeled shoes.

(a) If the total area of her soles and the heels in contact with the floor is 0.03 m^2, calculate the pressure the woman exerts on the floor.

(b) The area of each heel is 0.00030 m^2. Calculate the pressure the heel exerts on the floor when the woman is standing on one leg as shown in Figure 7.1(b).

(c) Compare the two values of pressure in (a) and (b). How is pressure related to area?

(a) **(b)**

Figure 7.1

Solution

(a) Given: Weight of the woman, $F = 600$ N
Area of contact, $A = 0.03$ m^2

By definition, pressure exerted by the woman on the floor

$$p = \frac{F}{A} = \frac{600\ \text{N}}{0.03\ \text{m}^2} = 20\,000\ \text{N/m}^2 = 2.0 \times 10^4\ \text{Pa}$$

(b) Given: When balancing on one heel, area of contact, A = 0.0003 m^2

$$p = \frac{F}{A} = \frac{600}{0.0003} = 2\,000\,000\ \text{N/m}^2 = 2.0 \times 10^6\ \text{Pa}$$

(c) The pressure in **(b)** is 100 times larger than in **(a)** due to the vastly different contact areas with the ground. When the same force is applied due to a smaller area, the pressure exerted is greater.

Figure 7.2 shows how pressure varies with force and pressure.

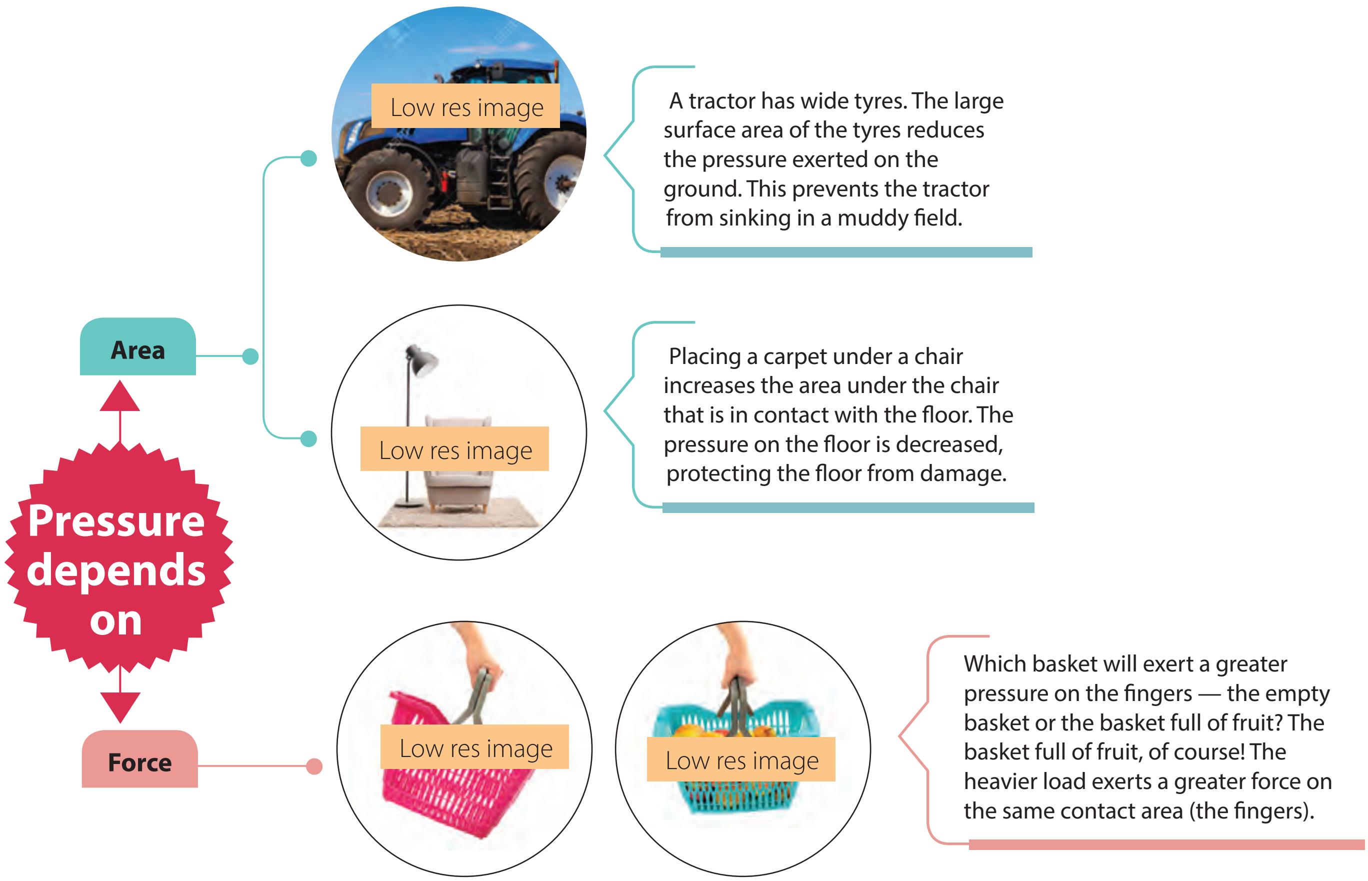


Figure 7.2 *Pressure depends on area and force.*

> **LINK**
>
> Recall the definition of weight from Chapter 3.

The examples of a woman wearing high-heeled shoes, a tractor with wide tyres, and placing a carpet under a chair shows that the force on a surface is due to the weight of objects resting on the surface. However, force can also be exerted by our hands.

Study Figure 7.3 and Figure 7.4. Why does a sharp knife cut more easily than a blunt one? Why is it easy to drive a nail into wood using a hammer?

A sharp knife has a smaller contact surface compared to a blunt one. So, a smaller force is required to exert the same amount of pressure to cut the tomato. Similarly, the head of the nail has a surface area many times bigger than the pointed end of the nail. The force exerted by the hammer is transferred to the pointed end. The pressure at the pointed end is many times bigger than at the head. The high pressure pushes the nail into the wood.

Figure 7.3 *Cutting tomatoes using a sharp kitchen knife*

Figure 7.4 *Driving a nail into a wood using a hammer*

Worked Example 7B

Figure 7.5 shows a block of dimensions 20 cm × 10 cm × 5 cm. The density of the block is 2.0 g/cm^3.

(a) What is the weight of the block? (Take $g = 10$ N/kg.)

(b) On which face must the block rest to exert the greatest pressure? Calculate this pressure.

(c) On which face must the block rest to exert the least pressure? Calculate this pressure.

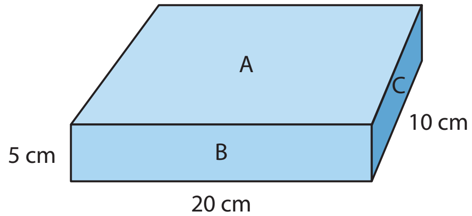


Figure 7.5

Solution

(a) Volume of the block, $V = 5\text{ cm} \times 10\text{ cm} \times 20\text{ cm} = 1000\text{ cm}^3$
Mass of the block, $m = \text{density} \times \text{volume} = 2.0\text{ g/cm}^3 \times 1000\text{ cm}^3 = 2000\text{ g} = 2\text{ kg}$
Weight of the block $= mg = 2\text{ kg} \times 10\text{ N/kg} = 20\text{ N}$

(b) The force exerted by the block is its weight, i.e., $F = 20$ N.
The pressure is the greatest when the area is the smallest.
So the block exert the greatest pressure when it is resting on face C.
Area of face C $= 5\text{ cm} \times 10\text{ cm} = 50\text{ cm}^2$
$\therefore$ Pressure exerted by face C $= \dfrac{F}{A} = \dfrac{20\text{ N}}{50\text{ cm}^2} = 0.4\text{ N/cm}^2$

(c) The pressure is the least when the area is the largest. This is when the block is resting on face A.

(d) Area of face A $= 10\text{ cm} \times 20\text{ cm} = 200\text{ cm}^2$
$\therefore$ Pressure exerted by face A $= \dfrac{F}{A} = \dfrac{20\text{ N}}{200\text{ cm}^2} = 0.1\text{ N/cm}^2$

QUICK CHECK

The greater the force exerted on the same contact surface area, the greater the pressure.

True or false?

LINK PWB

Practical 7, p. XX–XX

Let's Practise 7.1

1 Write out the word equation for pressure.

2 Complete Table 7.1.

Table 7.1

Force /N	Area /m^2	Pressure / Pa
1200	0.5	
	0.08	2000
800		50 000

3 A polystyrene cube of mass 5.0 kg is placed on a horizontal surface. The pressure due to the cube is 89 N/m^2.

(a) What is the force exerted on the surface? (Take $g = 10$ N/kg.)

(b) What is the area of contact between the cube and the surface?

(c) What is the length of the sides of the cube?

Figure 7.6

4 Look at Figure 7.6. Would the table make a deeper mark on the carpet if it is standing upright, or if it is turned upside-down? Explain your answer.

5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 7A, pp. XX-XX

7.2 Pressure in Liquids

In this section, you will learn the following:

- Describe qualitatively how the pressure beneath the surface of a liquid changes with depth and density of the liquid.
- S Recall and use the equation $\Delta p = \rho g \Delta h$ for the change in pressure in a liquid.

A diver experiences pressure from the seawater (Figure 7.7). The deeper the diver dives, the greater the pressure. Why?

You have learnt that pressure is force per unit area. The force acting on the diver is due to the weight of the seawater pushing down on the diver. As the diver goes deeper, there is more water above the diver. When the diver dives deeper, the weight of the water pressing on the diver increases. The force on the diver increases. And so, the pressure increases.

Figure 7.7 *A scuba diver experiences pressure from the seawater.*

ENRICHMENT INFO

How Do Deep-sea Fish Survive Under Pressure?

Fish that live deep under the sea experience great pressure. At 3000 m or more below the sea surface, the amount of pressure would crush a body that contains air. This is because air can be compressed.

Fish that live nearer the sea surface have air sacs to help them float up or sink down in the water. Deep-sea fish do not have air sacs, so they do not get crushed under pressure.

How does depth affect pressure in a liquid?

In Figure 7.8, a tall container with holes at different depths is used to show that water pressure increases with depth. The water spurts out furthest and fastest from the bottom hole. This shows that the pressure is greatest at the bottom of the container.

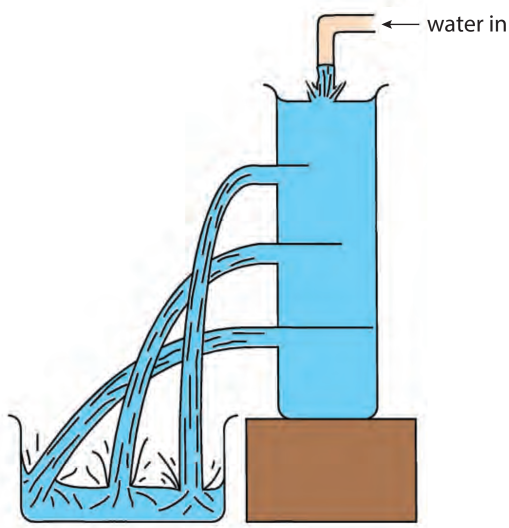


Figure 7.8 *Apparatus to show that water pressure increases with depth*

How does the density of a liquid affect the pressure it exerts?

Recall that for a fixed volume of substance, mass, and therefore, weight increases with density. Figure 7.9 shows two fishbowls, each containing a fish and an equal volume of water. One fishbowl is filled with seawater and the other is filled with tap water. Seawater is more dense than tap water. Which fish experiences a greater pressure?

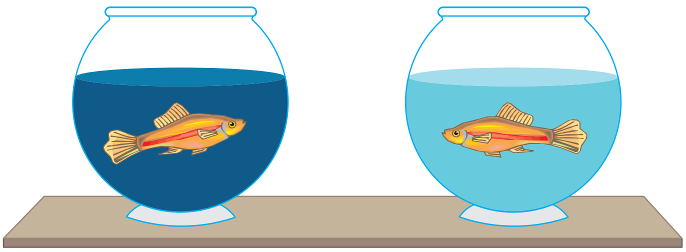


Figure 7.9 *Two liquids of different densities will exert different amounts of pressure.*

The two fish experience different amounts of pressure depending on the density of the water. For the same volume, the weight of seawater is greater than the weight of tap water. Thus, fish A experiences a greater pressure compared to fish B.

We have seen how depth and density affects pressure in a liquid. Therefore, we can conclude the following:

Pressure in a liquid increases with **depth** and **density**.

Worked Example 7C

Figure 7.10 shows four identical containers filled with the same amounts of liquids. Two of the containers contain liquid X and the other two contains liquid Y.

(a) At which point, A or B, is the pressure greater? Explain.

(b) The pressure at C is greater than the pressure at B. What can you conclude from this?

(c) Compare the pressure at A and the pressure at D.

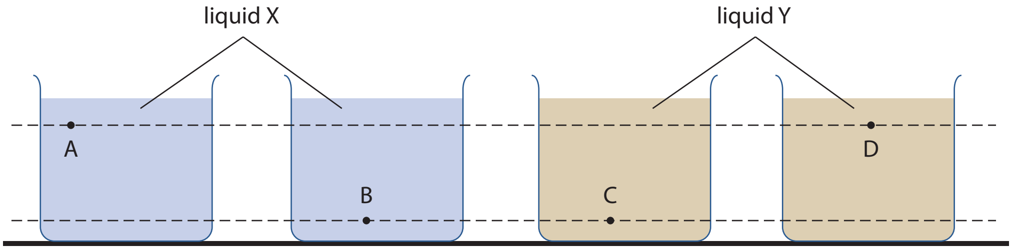


Figure 7.10

Solution

(a) The pressure at B is greater than at A. Liquid pressure increases with depth.

(b) Liquid pressure increases with density. This means liquid Y is more dense than liquid X.

(c) The pressure at A is lesser than the pressure at D.

LINK

Recall how density of a substance depends on its mass and volume from Chapter 5.

QUICK CHECK

Figure 7.11 shows two beakers containing water. The pressure at point P is greater than the pressure at point Q.

True or false?

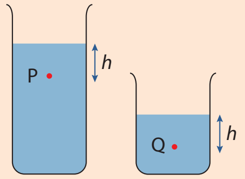


Figure 7.11

Calculating liquid pressure

Figure 7.12 shows a column of liquid. How can we calculate the change in liquid pressure from depth h_1 to depth h_2?

As we go deeper down the liquid column, the pressure increases because there is more liquid pressing down. This increase or change in pressure can be calculated by considering the additional force due to the additional weight of liquid.

Based on Figure 7.12,

Volume of the liquid = base area × height = $A\Delta h$
Mass of the liquid = density × volume = $\rho A \Delta h$

The additional force, ΔF, exerted by the additional liquid on area A, is the same as the weight W of the liquid. This weight is given by $W = mg$.

Earlier, you have learnt that $p = \frac{F}{A}$.

So, $\Delta p = \frac{\Delta F}{A} = \frac{W}{A} = \frac{mg}{A} = \frac{\rho A \Delta h g}{A} = \rho g \Delta h$

Thus, the change in pressure in a liquid is given by the following equation:

Δp = ˜g Δh

Based on the equation above, it is clear that the pressure due to a liquid increases with density and depth.

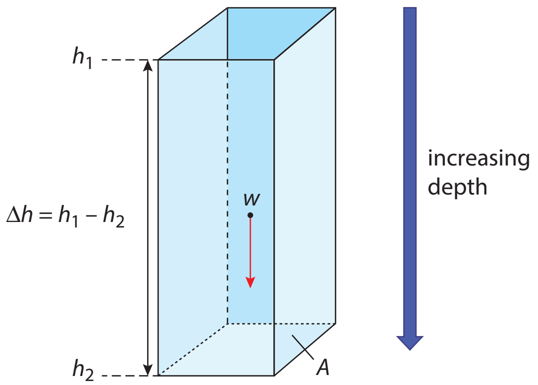


Figure 7.12 *Liquid column of height h, base area A and density ρ*

HELPFUL NOTES

- Depth is measured as height from the surface of the liquid.
- The Greek letter ρ (pronounced as *rho*) is used to represent density of a liquid.

Worked Example 7D

Figure 7.13 shows a small submarine submerged below the surface of the sea. The density of seawater is 1030 kg/m³ and the gravitational field strength is 10 N/kg.

(a) The submarine moves from the surface of the sea to a depth as shown in the diagram. Calculate the change in pressure experienced by the submarine.

(b) The submarine changes its depth. This causes the pressure exerted on it to change by 0.10 MPa. Calculate the change in depth of the submarine.

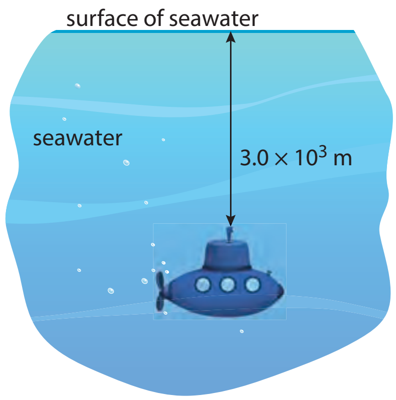


Figure 7.13

WORD ALERT

Submerged: made to sink

Solution

(a) Change in depth of the submarine, $\Delta h = 3.0 \times 10^3$ m

Change in pressure, $\Delta p = \rho g \Delta h$

$= 1030 \text{ kg/m}^3 \times 10 \text{ N/kg} \times 3.0 \times 10^3 \text{ m}$

$= 3.09 \times 10^7$ Pa or 30.9 MPa

(b) From $\Delta p = \rho g \Delta h$, change in depth is $\Delta h = \dfrac{\Delta p}{\rho g}$

When $\Delta p = 0.10 \text{ MPa} = 0.10 \times 10^6$ Pa,

$$\Delta h = \frac{0.10 \times 10^6 \text{ N/m}^2}{1030 \text{ kg/m}^3 \times 10 \text{ N/kg}}$$

$= 9.7$ m

Note that the actual pressure acting on the submarine is the sum of the pressure due to the seawater and the air pressure at the surface of the water.

Let's Practise 7.2

1 When an object is immersed in a liquid, the liquid exerts pressure on the object. Give **two** factors that affects this pressure.

2 Fill in the blanks with the word *greater* or *less*.

(a) The pressure at the bottom of a swimming pool is ________ than the pressure near the surface of the pool.

(b) Oil is less dense than water. The pressure at the bottom of a bottle of oil is ________ than the pressure at the bottom of an identical bottle of water.

3 Write the equation for the change in pressure beneath a liquid surface.

4 A marine biologist dives into the sea to observe marine life. What change in pressure does she experience when she is 5 m below the surface of the sea?

(Take density of seawater = 1025 kg/m³ and $g = 10$ N/kg.)

5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

QUICK CHECK

Consider a column of liquid. The pressure at any point in the liquid depends only on the height of the liquid above it.

True or false?

WORD ALERT

Immersed: dipped

LINK

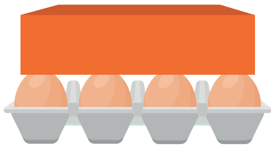
Exercises 7B–7C, pp. XX–XX

Exercise 7D Let's Reflect, p. XX

Let's Map It

PRESSURE
(SI unit: Pa)

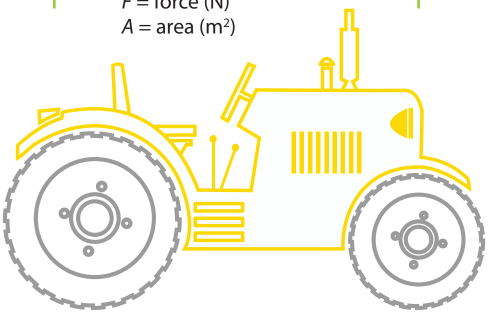
is defined as



Force per unit area

$p = \frac{F}{A}$

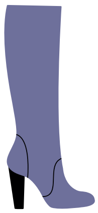
where
p = pressure (Pa or N/m^2)
F = force (N)
A = area (m^2)



depends on

Force
- For the same area, the greater the force, the greater the pressure.

Area
- For the same force, the smaller the area, the greater the pressure.



example

Pressure in liquids

Change in pressure is given by
$\Delta p = \rho g \Delta h$

where
ρ = density of liquid (kg/m^3)
g = gravitational field strength (N/kg)
h = height of liquid column (m)

increases with
- Depth (height measured from surface of liquid)
- Density

Let's Review

Section A: Multiple-choice Questions

1 Which of the following statements define pressure?

A force × depth **B** force × area

C $\frac{\text{force}}{\text{area}}$ **D** $\frac{\text{force}}{\text{depth}}$

2 Figure 7.14 shows a box on a table. The weight of the box is 50 N. What is the pressure exerted on the table by the box?

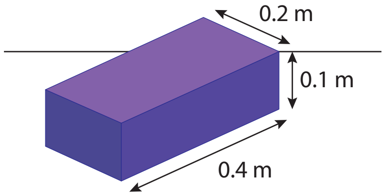


Figure 7.14

A 0.4 Pa **B** 5 Pa

C 500 Pa **D** 625 Pa

3 (S) A diver dives deeper into the sea. She experiences a change in pressure of 1.03×10^5 Pa exerted by the seawater. What is her change in depth? (Take density of seawater = 1030 kg/m^3 and g = 10 N/kg.)

A 1 m **B** 5 m

C 10 m **D** 50 m

Section B: Short-answer and Structured Questions

1 Figure 7.15 shows a girl exercising. The pressure she exerts on the floor in position A is different to that in position B. Explain why.

Figure 7.15

2 Figure 7.15 shows a ball bearing sinking in oil inside a measuring cylinder.

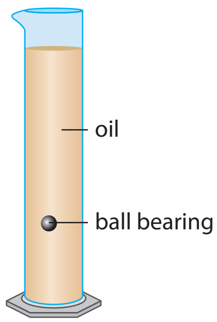


Figure 7.16

(a) Describe how the pressure on the ball bearing changes as it sinks in the oil.

(b) The oil in the measuring cylinder is replaced with an equal volume of water. Water is more dense than oil. Would the change in pressure exerted on the ball bearing be greater in water than in oil as it moves down the container? Explain your answer.

3 (S) Figure 7.17 shows a container of liquid on a table. The density of the liquid is 880 kg/m^3. The base area of the container is 0.02 m^2. The total mass of the container with the liquid inside is 5 kg. Gravitational field strength is 10 kg/N.

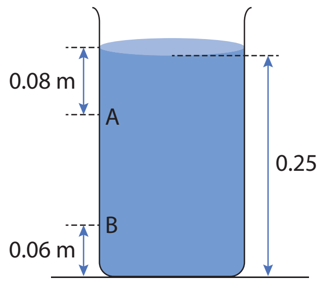


Figure 7.17

(a) Calculate the pressure exerted on the table by the container of liquid?

(b) An object is lowered into the liquid. Calculate the change in pressure experienced by the object when it is lowered from A to B.

CHAPTER

8 Kinetic Particle Model of Matter

PHYSICS WATCH

Scan this page to watch a clip on the three states of water.

A geyser shooting out steam and hot water, a mountain covered in snow and a river flowing into the ocean—these are part of our natural world. Since long ago, people have been curious about the natural materials around them. They tried to classify these materials to understand their properties. The ancient Indians classified matter into five basic elements—earth, water, fire, air and empty space. The ancient Greeks believed there were four basic elements—earth, water, fire and air. Today, most people are familiar with the three states of matter.

QUESTIONS

- What are the three states of matter?
- Look at the photo. Identify examples of matter in the different states.
- What properties did you use to classify these examples?

8.1 The States of Matter

In this section, you will learn the following:
- Know the properties of solids, liquids and gases.
- Know the terms for the changes in state between solids, liquids and gases.

What are the properties of the three states of matter?

All matter can exist in *three states* — solid, liquid and gas. Water is an example of matter. Figure 8.1 shows the three different states of water.

Gas
Steam, the gaseous state of water, is invisible to the naked eye. The mist we see when water boils is actually tiny water droplets formed by steam that has condensed in the cool air.

Properties
- No fixed shape or volume
- Low density
- Compressible
- Can flow and take the shape and volume of the container

Liquid
Water in the liquid state is found in water bodies such as oceans and rivers. Only 1% of the Earth's water is suitable for drinking.

Properties
- Fixed volume but no fixed shape
- High density
- Incompressible
- Can flow and take the shape of the container

Solid
Ice, the solid state of water, exists in many forms, such as snow, glaciers, icebergs and ice cubes.

Properties
- Fixed shape and volume
- High density
- Incompressible
- Cannot flow

Figure 8.1 *Water exists in three states with different properties.*

From Figure 8.1, we can see that the properties of water depend on the state it is in. What happens in each state of water? How does water change from one state to another?

HELPFUL NOTES

Matter in the solid state is usually more dense than in the liquid state. Water is an exception. Ice is less dense than water.

WORD ALERT

Compressible: can decrease in size

Incompressible: cannot decrease in size

QUICK CHECK

The density of oxygen gas is 0.000 14 g/cm^3. The density of liquid oxygen would be greater than this.

True or false?

HELPFUL NOTES

Changing state is a physical change as no new substances are formed.

LINK

How is evaporation related to boiling? Find out more in Chapter 9.

How does matter change from one state to another?

The state of matter depends on the temperature and the pressure the matter is under. Changing the temperature of matter can change it from one state into another.

When a solid is heated, it **melts** into a liquid at its **melting point**. A liquid that is heated will **boil** and become a gas at its **boiling point**. The red arrows in Figure 8.2 show how ice melts into water and boils into steam.

When a gas is cooled to its boiling point, it will **condense** into a liquid. A liquid will **freeze/solidify** into a solid when cooled to its melting point. The blue arrows in Figure 8.2 show how steam condenses into water and freezes/solidifies into ice.

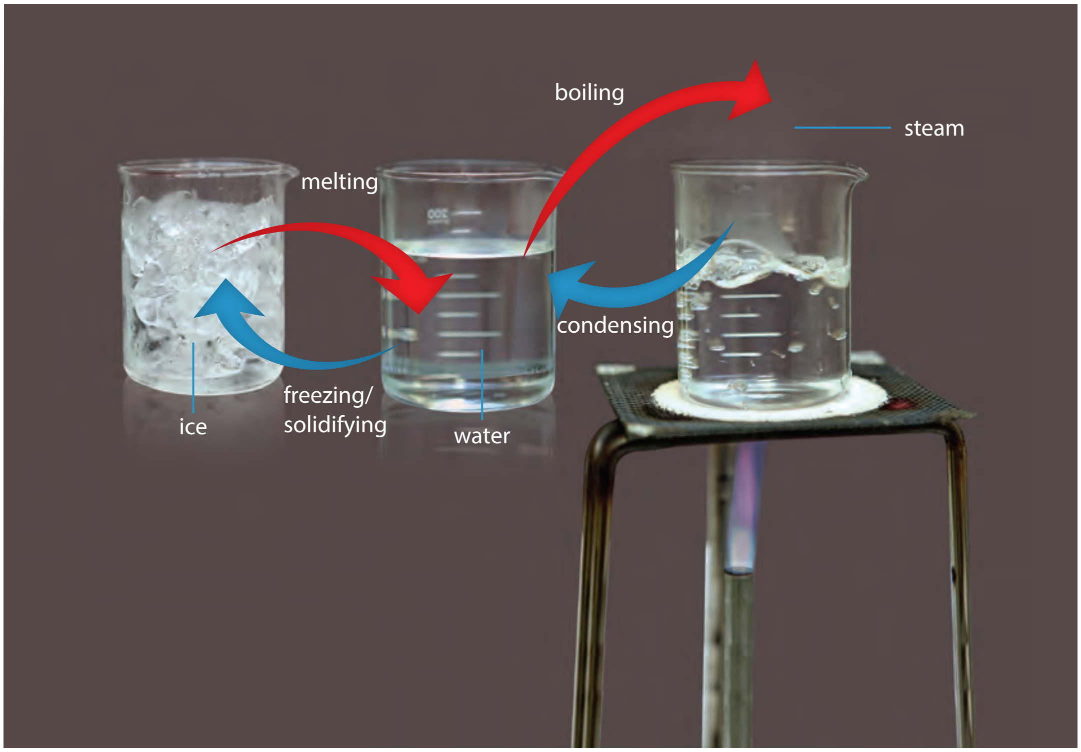


Figure 8.2 *The changes of state between solid, liquid and gas*

Let's Practise 8.1

1 Use the properties of the objects learnt in page 113 explain why
   (a) a gold ring is a solid;
   (b) milk is a liquid;
   (c) air is a gas.

2 **(a)** Explain what is meant by melting point.
   (b) Explain what is meant by condensation.

3 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB

Exercise 8A, pp. XX–XX

8.2 The Particle Model

In this section, you will learn the following:

- Describe the particle structure of solids, liquids and gases, and represent these states using simple particle diagrams.
- S Know that the forces and distances between particles and the motion of the particles affects the properties of solids, liquids and gases.
- Describe the relationship between the motion of particles and temperature, including the lowest possible temperature (–273°C), known as absolute zero, where the particles have least kinetic energy.
- Know that the random motion of microscopic particles in a suspension is evidence for the *kinetic particle model of matter*.
- Describe and explain *Brownian motion*.
- S Know that microscopic particles may be moved by collisions with light, fast-moving molecules and correctly use the terms atoms, molecules and particles.

What is the kinetic particle model of solids, liquids and gases?

All matter is made up of tiny particles called atoms or molecules. Most atoms join together to make molecules. A water molecule is formed from two hydrogen atoms and one oxygen atom (Figure 8.3).

The **kinetic particle model of matter** states that the tiny particles that make up matter are always in continuous random motion. This model is used to help us understand the properties of each state of matter (Figure 8.4).

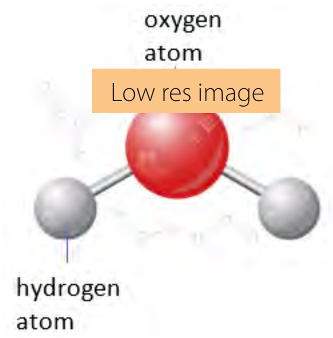
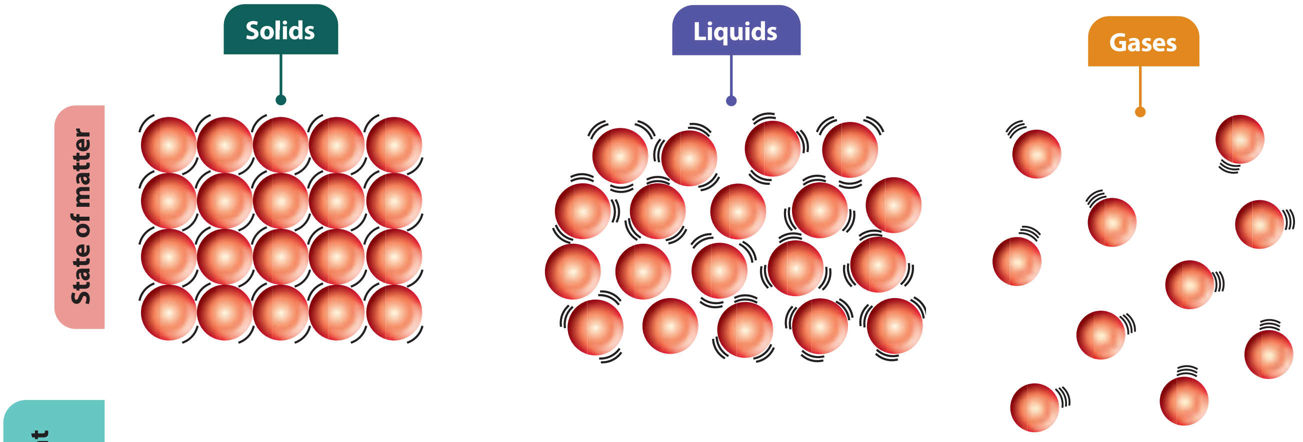


Figure 8.3 *A model of a water molecule*



Particle arrangement and movement

Solids
- Particles are closely packed together.
- Usually in a regular pattern
- Large number of particles per unit volume
- Particles vibrate about a fixed position.

Liquids
- Particles are slightly further apart than in solids.
- Randomly arranged
- Slightly smaller number of particles per unit volume
- Particles are free to move within the liquid.

Gases
- Particles are far apart from one another.
- Randomly arranged
- Small number of particles per unit volume
- Particles move randomly at high speeds.

Figure 8.4 *Kinetic particle model of the three states of matter*

WORD ALERT

Random: without a pattern, cannot be predicted

How does the kinetic particle model explain the properties of solids, liquids and gases?

SOLIDS

Distance

The distance between the particles is small, so solids have a high density and are incompressible.

Force

As they are close together, the particles in solids have strong attractive forces between them. That is why solids have a fixed volume and a fixed shape.

The strong attractive forces hold the particles in fixed positions. That is why solids cannot flow.

LIQUIDS

Distance

The distance between the particles in liquids is slightly greater than in solids. That is why liquids are slightly less dense but are still incompressible and have a fixed volume.

Force

As the particles are slightly further apart, the attractive forces are not as strong as the particles in solids. The particles in liquids can move around freely. That is why liquids can flow. They do not have a fixed shape but take the shape of their container.

GASES

Distance

The distance between the particles in gases is much greater. That is why gases have low density and are compressible.

Force

As the particles are far apart, there is very little attractive force between them. That is why gases have no fixed volume or shape.

The particles move around at high speed, so gases can flow and fill the space they are put into.

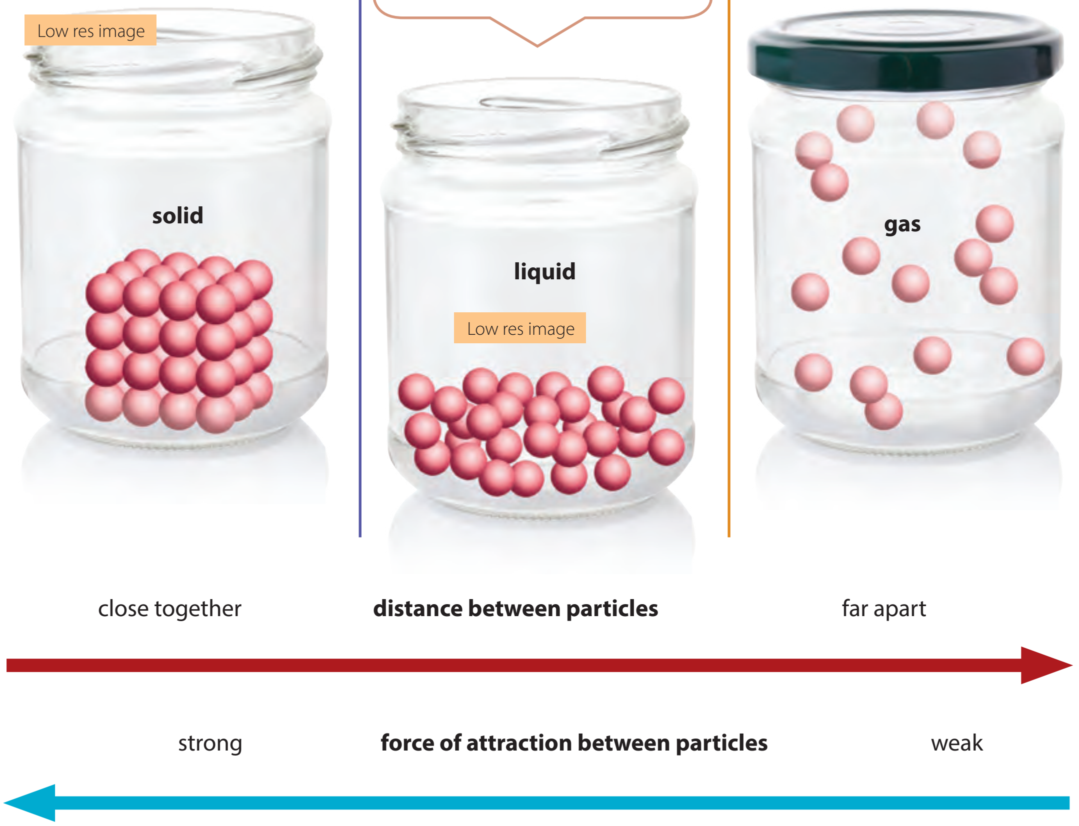


Figure 8.5 *The forces and distances between particles affects the properties of solids, liquids and gases.*

PHYSICS WATCH

Scan this page to watch a clip on the kinetic models of solids, liquids and gases.

What happens to the particles when temperature increases?

When an object is heated, the temperature of the object increases. The average kinetic energy of the particles in the object increases and the particles move or vibrate faster.

When an object is cooled, the temperature of the object decreases. The average kinetic energy of the particles in the object decreases and the particles move more slowly.

The lowest temperature where the particles have the least kinetic energy occurs at **–273°C**. This temperature is also known as **absolute zero.**

What evidence is there to support the kinetic particle model of matter?

The tiny particles that make up matter cannot be seen with the naked eye. Is there evidence to show that these tiny particles are in continuous random motion?

Robert Brown was a botanist who first observed the continuous, random motion of pollen grains suspended in water. He did not know why the pollen grains were moving (Figure 8.6). Many years later, it was found that the random motion of the pollen grains was due to the motion of the water molecules. This constant random motion of the pollen grains in water was named Brownian motion.

Brownian motion refers to the *random movement* of microscopic particles in a fluid due to the collisions by the molecules of the fluid. We can only see microscopic particles under the microscope as the molecules are too small to be seen. Examples of microscopic particles are pollen grains and smoke particles.

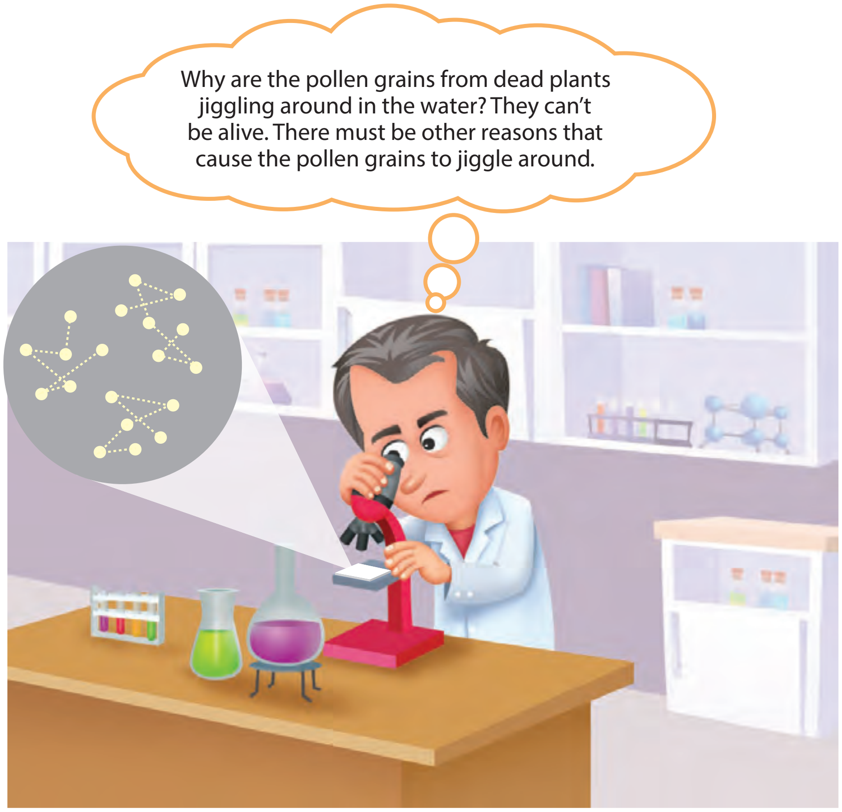


Figure 8.6 *The discovery of the constant random motion of particles by Robert Brown*

Brownian motion is also displayed by smoke particles in air (Let's Investigate 8A).

HELPFUL NOTES

Brownian motion occurs only in fluids. A fluid is any substance that has the ability to flow because the particles can move freely (e.g. liquids and gases).

PHYSICS WATCH

Scan this page to explore Brownian motion.

ENRICHMENT INFO

Tea Brewing

Have you ever observed a cup of hot water changing colour when we place a tea bag in? The spreading of the golden-brown colour of the tea is an example of Brownian motion.

The temperature of the water is important to how fast the tea spreads. The higher the temperature of the water, the faster the spreading of the tea.

Let's Investigate 8A

Objective
To study Brownian motion of smoke particles

Materials
Microscope, torchlight, glass cell containing smoke

Procedure
1 Set up the apparatus as shown in Figure 8.7.
2 Seal a glass cell containing some smoke and place it under the microscope.
3 Focus the microscope such that the smoke particles in the glass cell appear as bright dots. The smoke particles appear as bright dots because they scatter the light that shines on them.
4 Observe the motion of the smoke particles (Figure 8.8).

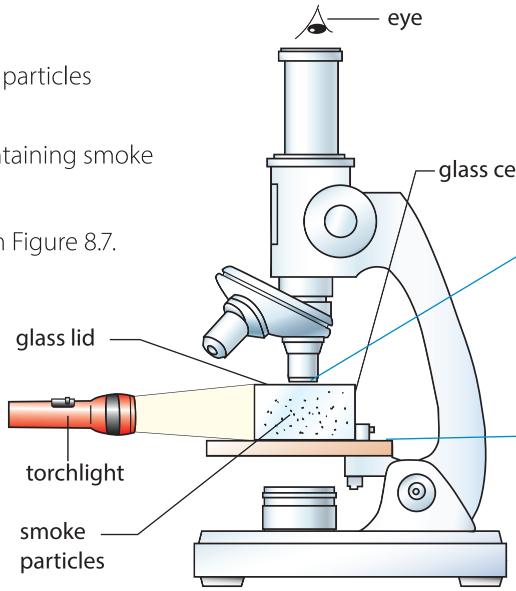


Figure 8.7 Experimental set-up to observe Brownian motion

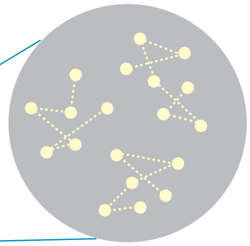


Figure 8.8 Smoke particles moving in a random manner

Observations
1 The smoke particles moved in a random manner.
2 The larger the particles, the less vigorous the motion.

Discussion and conclusion
The smoke particles moved randomly because air molecules were colliding with them randomly. Air molecules are too small to be seen under the microscope. This random motion of smoke particles in air is an example of Brownian motion.

LINK PWB
Practical 8, pp. xx–xx

WORD ALERT A-Z
Vigorous: moving with a great force

QUICK CHECK
Brownian motion occurs in solids.
True or false?

S How does Brownian motion occur?

Air consists mainly of nitrogen molecules, N_2, and oxygen molecules, O_2. These molecules are too small to be seen under the microscope. A smoke particle is a solid lump of many carbon atoms. When light is shone on a mixture of smoke particles in air, the smoke particles can be seen as tiny specks of reflected light. How can a larger, more massive particle be affected by smaller lighter molecules in the air?

There are millions of molecules in the air moving at high speeds in all directions. This means that there are many collisions on each smoke particle happening all the time. The smoke particle is constantly pushed one way and then another. As we cannot see the molecules, the smoke particles appear to be constantly moving small distances in a random path.

Let's Practise 8.2

1 Describe the particle structure and arrangement of ice, water and steam.
2 S Using the kinetic particle model of matter, explain
   (a) why a liquid takes the shape of its container;
   (b) why the density of a gas is less than that of a solid;
   (c) why the smell of the perfume spreads throughout the room.
3 **(a)** Explain what Brownian motion is.
   (b) How would Brownian motion change if the temperature is increased?
4 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB
Exercise 8B, pp. XX–XX

8.3 Gases and the Absolute Scale of Temperature

In this section, you will learn the following:

- Describe the pressure and the changes in pressure of a gas.
- S Describe the pressure and changes in pressure of a gas as *force per unit area*.
- Describe qualitatively, the effect on the pressure of a fixed mass of gas with changing temperature at constant volume and changing volume at constant temperature.
- S Recall and use the equation pV = constant for a fixed mass of gas at constant temperature, including a graphical representation of this relationship.
- Convert temperatures between kelvin and degrees Celsius.
- Recall and use the relationship T (in K) = θ (in °C) + 273.

How do gases exert a pressure?

The kinetic particle model also explains how a gas exerts a pressure. Figure 8.9 is a diagram of gas particles in a container.

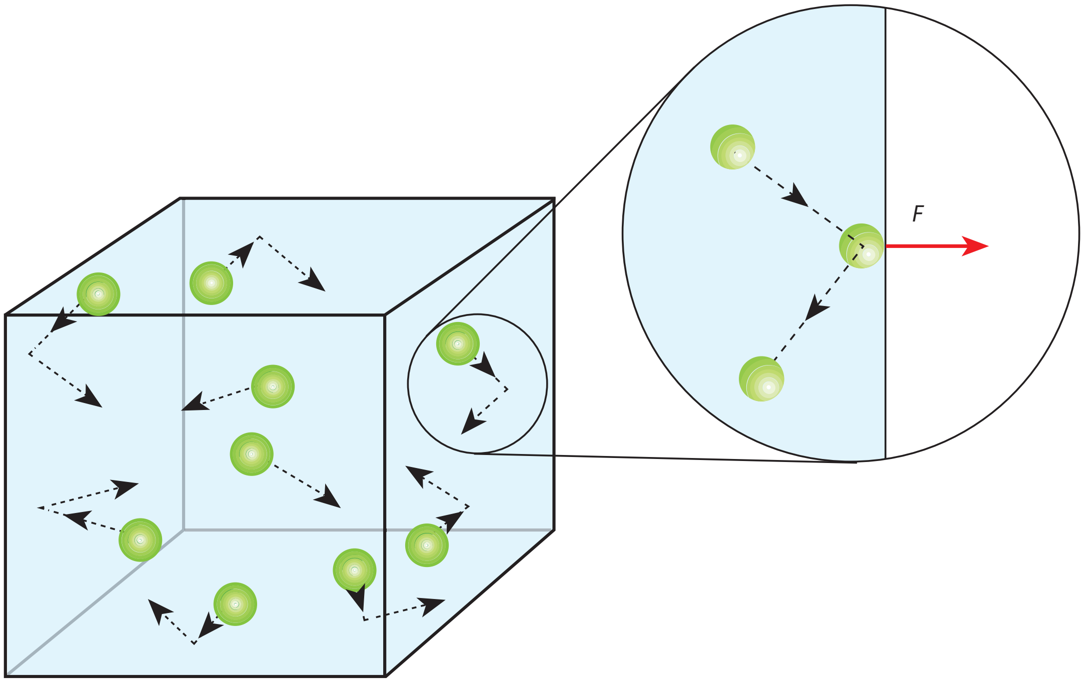


Figure 8.9 *The constant collision of air particles on the walls of the container exerts a pressure on the container.*

The gas particles are moving randomly in all directions. They collide with one another and with the walls of the container. The pressure on the container is caused by the *constant collisions* of many particles with its walls.

S When the particles collide with the walls of the container, they exert a *force* on the wall (Figure 8.9). The force from one collision is small but as there are many particles colliding all of the time, the force exerted is large.

From Chapter 7, we learnt that pressure is force per unit area. Hence, the force exerted by the collisions of gas particles on the container gives rise to the pressure on the container.

LINK

Recall what you have learnt about pressure in Chapter 7.

What do you think will happen to the pressure of the gas in the container if the temperature is increased but the volume stays the same?

How does the pressure of a gas vary with its temperature?

When the temperature of the air in the tyres increases, the pressure of the air in the tyres also increases. Can the kinetic particle model be used to explain this relationship? Let us consider what happens to a fixed mass of air inside a tyre of fixed volume (Figure 8.10).

1. When the car is moving, the tyres get heated. This causes the temperature of the air in the tyres to rise.
2. The air particles collide with the inner surface of the tyres more vigorously and more frequently.
3. Using the kinetic particle model of matter, a rise in the temperature of the air causes an increase in the average speed of the air particles.
4. S The average force per collision between the air particles and the wall of the tyre increases, and since the volume of the tyres is fixed, the pressure inside the tyres increases.

Figure 8.10 *Heat generated in an overinflated car tyre after a long journey could burst the tyre because of increased pressure.*

For a fixed volume and mass of gas, increasing its temperature results in an increase in the speeds of the gas particles (Figure 8.11). This increases the rate at which the particles collide with the walls of the container.

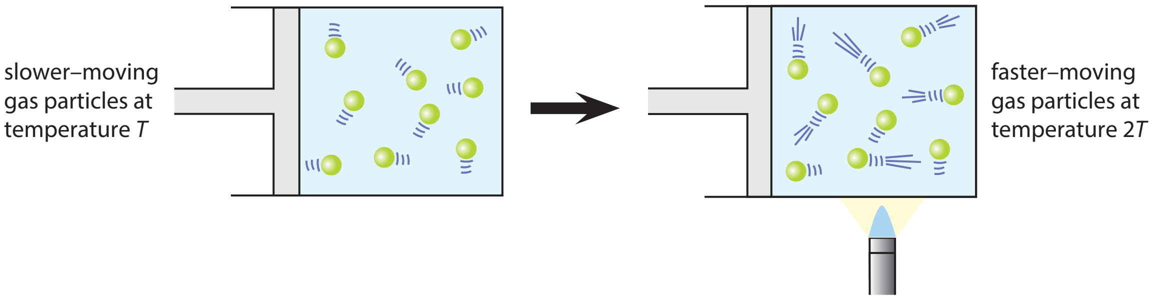


Figure 8.11 *The speed of the gas particles increases as temperature increases.*

From Figure 8.12, we can see that *the gas pressure of a gas at fixed volume and mass increases with temperature.*

What do you think will happen to the pressure of the gas in the container if the volume is increased but the temperature is constant?

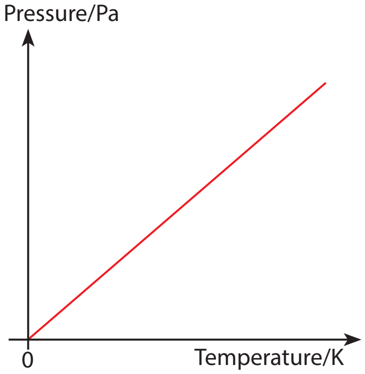


Figure 8.12 *Pressure–temperature graph of a gas at constant volume*

ENRICHMENT *ACTIVITY*

Make a bottle crumple using air pressure!

Pour very hot water into a plastic bottle until it is half full.

(Note: Be careful not to burn yourself with the water!)

Swirl the water around in the bottle for about a minute. Pour the water out and quickly screw the cap tightly onto the bottle.

Pour cold water over the sides of the bottle. The bottle will suddenly crumple.

Can you use the kinetic particle model of matter to explain why the bottle crumples?

PHYSICS WATCH

Scan this page to explore the pressure–temperature relationship of a gas.

How does the pressure of a gas vary with its volume?

Have you noticed how bubbles in a fish tank increase in size as they rise from the bottom of the tank to the top? Do you know why this happens? Using the apparatus in Figure 8.13, let us study the relationship between the pressure and the volume of a gas when its temperature remains constant.

The gas to be studied is trapped in the syringe. Pressure is measured by the pressure gauge, and volume is read from the syringe's scale when the gas is at the same temperature as its surroundings. When the piston is pushed inwards, the pressure registered by the pressure gauge increases. Why?

1. Using the kinetic particle model of matter, a decrease in the volume of gas means that the number of particles per unit volume increases.
2. Therefore, the gas particles collide more frequently with the inner surface of the syringe and this results in a greater pressure as shown on the pressure gauge.

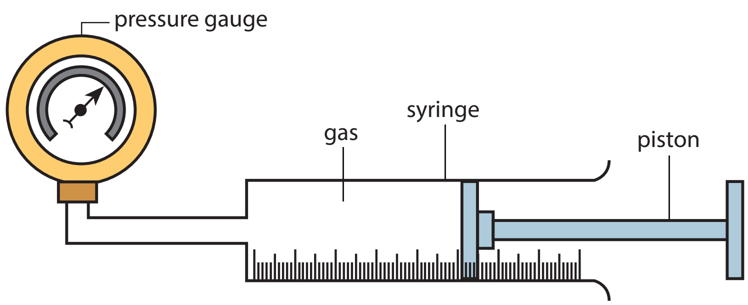
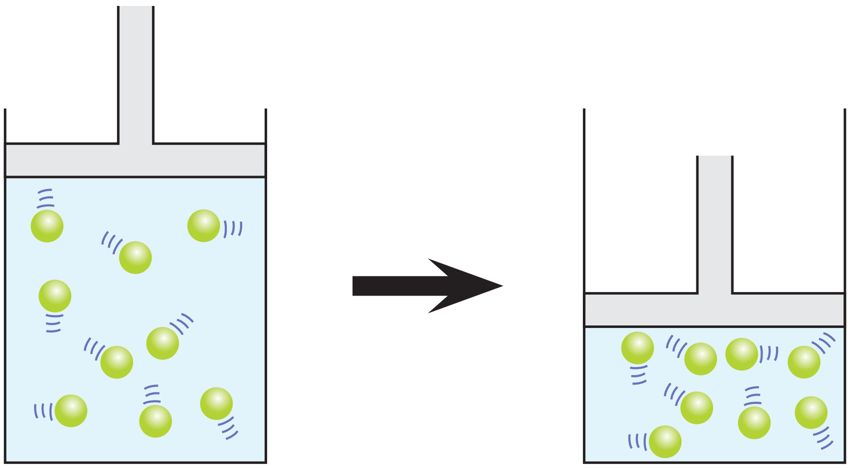


***Figure 8.13** Experimental set-up to study the volume and pressure of a gas at constant temperature*

For a fixed mass of gas at constant temperature, a decrease in volume results in particles having less space to move in (Figure 8.14). Hence, this increases the rate at which particles collide with the walls of the container.



▲ Gas particles at volume 2*V*

▲ Gas particles at volume *V*

***Figure 8.14** The amount of space that the particles can move in decreases as volume decreases.*

The gas pressure of a fixed mass of gas at constant temperature increases when the volume decreases.

QUICK CHECK

When the volume of the gas in Figure 8.14 increases, the pressure decreases.

True or false?

From Figure 8.14, when the volume of the gas is halved, the pressure of the gas is doubled. The decrease in the volume resulting in a proportional increase in pressure is known as **inverse proportionality**. Figure 8.15 is a graph showing the inverse proportion relationship between pressure and volume.

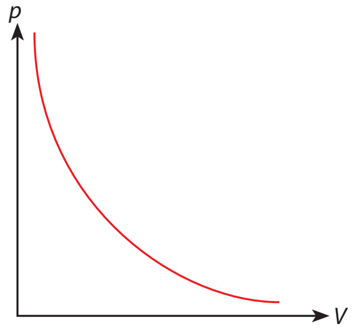


Figure 8.15 *Pressure-volume graph of a gas at constant temperature*

Plotting p against $\frac{1}{V}$ gives a straight line

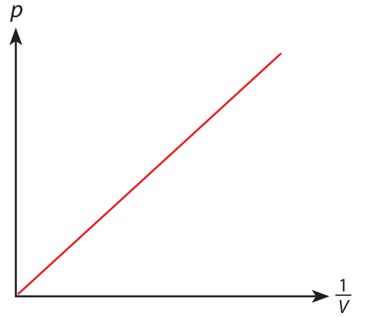


Figure 8.16 *Pressure-1/volume graph of a gas at constant temperature*

HELPFUL NOTES

$\propto$ is a symbol used to represent that a physical quantity is proportional to another physical quantity.

For an inverse proportionality,

$p \propto \frac{1}{V}$ or $p = \frac{k}{V}$ where p = pressure

k = proportionality constant

V = volume

Rearranging the equation $p = \frac{k}{V}$, we will get $\boldsymbol{pV = k}$ or $\boldsymbol{pV = \text{constant}}$

If we have a gas at pressure p_1, volume V_1, and we change the pressure and the volume of the gas to p_2 and V_2 at constant temperature, we can write the equations like this:

Initial $p_1V_1 = k$

Final $p_2V_2 = k$

As k is the same for both equations, we can combine the two equations.

$\therefore \boldsymbol{p_1V_1 = p_2V_2}$

Using the above equation, we can find the change in the pressure and/or the volume of a gas at constant temperature.

ENRICHMENT THINK

A balloon is tied to the top of a jar. A vacuum pump then pumps air out of the jar and the balloon expands (Figure 8.17).

Figure 8.17 *A balloon in a jar expands when air in the jar is removed.*

1 Explain why the balloon expands when air is removed from the jar.
2 Describe what will happen when air is let back into the jar.
3 Which relationship is this demonstrating?

Worked Example 8A

A gas cylinder contains 600 ml of carbon dioxide at a pressure of 2×10^7 Pa. Assuming that the temperature of the gas does not change, calculate the volume of the gas at atmospheric pressure, 1×10^5 Pa.

Solution

Given: $p_1 = 2 \times 10^7$ Pa

$p_2 = 1 \times 10^5$ Pa

$V_1 = 600$ ml

$p_1V_1 = p_2V_2$

$2 \times 10^7 \times 600 = 1 \times 10^5 \times V_2$

$V_2 = 1.2 \times 10^5$ ml

How did absolute zero lead to a new temperature scale?

Most countries use degrees Celsius, °C, to measure temperature. On the Celsius scale, 0°C is the temperature of pure melting ice and 100°C is the temperature of pure boiling water at standard pressure. The scale between these two temperatures is divided into 100 ticks with equal spacing, where the difference between each tick equals to 1°C change (Figure 8.18).

Temperature can also be measured using kelvin, K , which is the SI unit for temperature. The **Kelvin scale** of temperature has absolute zero as 0 kelvin, or 0K. One degree change on the Kelvin scale is the same as one degree change on the Celsius scale. This makes it easy to convert from one temperature scale to another (Figure 8.19).

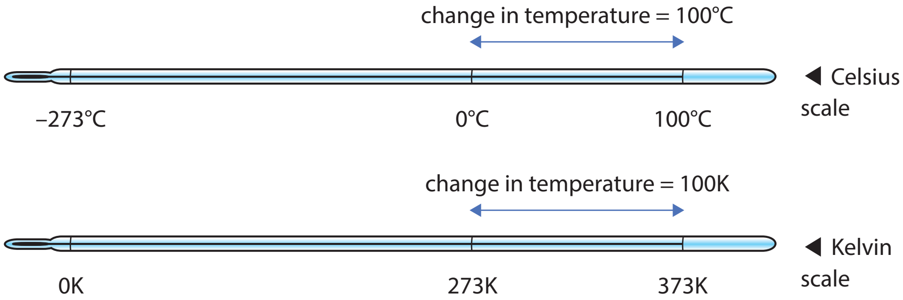


Figure 8.19 Celsius scale and Kelvin scale

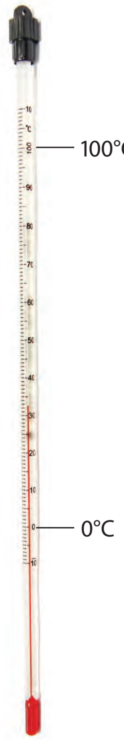


Figure 8.18 A glass thermometer with a Celsius scale

From Figure 8.19, can you see how to convert a temperature (θ) measured in °C into a temperature (T) in K?

T (in K) = θ (in °C) + 273

Worked Example 8B

The temperature in a room is 20°C. What is the temperature of the room in kelvin?

Solution

T (in kelvin) = θ (in °C) + 273

$T = 20 + 273$

$= 293$K

Let's Practise 8.3

1 Using the kinetic particle model of matter, explain
  (a) how the air particles in a container exert pressure on the walls of the container;
  (b) why the pressure of the air increases as the temperature increases.

2 (a) Describe how the pressure of a gas changes with volume when the temperature of the gas is constant.
  (b) Ⓢ Give the equation for the relationship between pressure and volume of a gas when the temperature of the gas is constant.

3 Describe one similarity and one difference between the Celsius and Kelvin temperatures scales.

4 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK

Recall that absolute zero = −273°C in Section 8.2 of this chapter.

HELPFUL NOTES

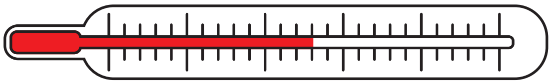
T is usually used to refer to temperature in kelvin and θ is usually used to refer to temperature in degrees Celsius.

TWB LINK

Exercises 8C–8D, pp. XX–XX

Exercise 8E Let's Practise, p. XX

Let's Map It



KINETIC PARTICLE MODEL OF MATTER

- **is proven by** → Brownian motion
- **states that** → Matter is made of tiny particles that are in continuous random motion.
  - **where**
    - Particles have greater kinetic energy at higher temperature
    - Particles have least energy at absolute zero
      - **which** → 0K in kelvin
        - converted using the equation T (in K) = θ (in °C) + 273
      - **which** → −273°C in degree Celsius
  - **which exist in three states known as**

Solids

- Particles are closely packed
- Arranged in a regular pattern
- Large number of particles per unit volume
- Particles vibrate about fixed positions
- S Attractive forces between particles are very strong

Solids → **melting** → Liquids

Liquids → **freezing/ solidifying** → Solids

Liquids

- Particles are slightly further apart
- Randomly arranged
- Slightly smaller number of particles per unit volume
- Particles can move freely within the liquid
- S Attractive forces between particles are moderately strong

Liquids → **boiling** → Gases

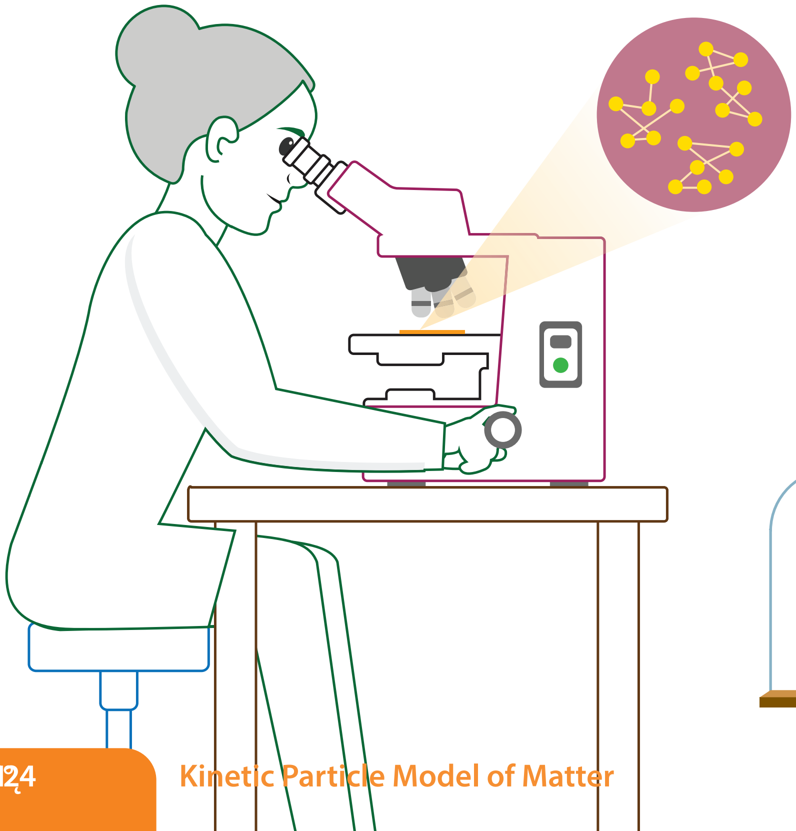
Gases → **condensing** → Liquids

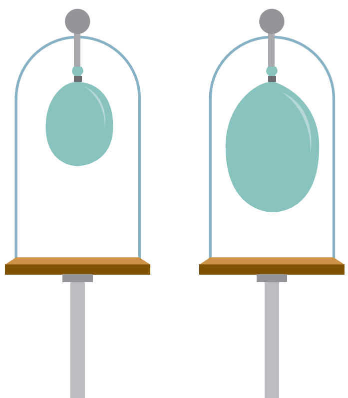
Gases

- Particles are far apart
- Randomly arranged
- Small number of particles per unit volume
- Particles move randomly at high speeds
- S Attractive forces between particles are negligible

where → Gas pressure is due to the collision of gas particles with the walls of the container

- **which increases with** → Temperature at constant volume
- **which decreases with** → Volume at constant temperature
  - **its equation is given by** → S $pV = k$





Let's Review

Section A: Multiple-choice Questions

1 Which states of matter are fluids?
- **A** Liquids and gases only
- **B** Solids and liquids only
- **C** Solids, liquids and gases
- **D** Solids and gases only

2 Which of the following statements about Brownian motion is correct?
- **A** It applies to gases only.
- **B** The motion of smoke particles in air is due to the smoke particles colliding with one another.
- **C** The smoke particles in air can be observed to dance in a regular pattern.
- **D** The smoke particles in air will slow down when the air temperature is decreased.

3 A gas is heated in a sealed container of constant volume. Which of the following will **not** increase?
- **A** The average speed of the gas particles
- **B** The number of particles per unit volume
- **C** The pressure of the gas
- **D** The temperature of the gas

4 Which statement is **not** correct?
- **A** 300K is equal to 27°C.
- **B** –273°C is the coldest temperature possible.
- **C** Ice melts at 273K.
- **D** The lowest temperature on the Celsius scale is 0°C.

5 S Which statement is **not** needed to explain why a gas exerts a pressure on the walls of its container?
- **A** Gas particles cause a force on the walls of the container as they collide.
- **B** Gas particles collide with one another.
- **C** Gas particles collide with the walls of the container.
- **D** Pressure, $p = \frac{\text{force}}{\text{area}}$

Section B: Short-answer and Structured Questions

1 **(a)** What is seen moving in a Brownian motion experiment?

(b) Why is a microscope necessary to observe Brownian motion?

(c) Explain how Brownian motion provides evidence for the kinetic particle model of matter.

2 Figure 8.20 is a diagram of a bicycle pump.

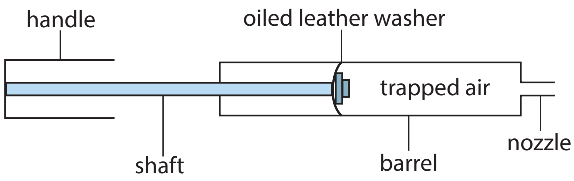


Figure 8.20

When the nozzle of the pump is blocked and the handle is slowly pushed to the right, the temperature of the air in the barrel remains constant, while the pressure of the air rises.

(a) Using the motion of the air particles, explain how the trapped air creates pressure on the washer. Assume that there is no leakage of air past the washer.

(b) Why does the pressure of the air in the barrel increase when the handle is slowly pushed in?

3 S A sample of gas at atmospheric pressure of 1×10^5 Pa has a volume of 100 cm^3.

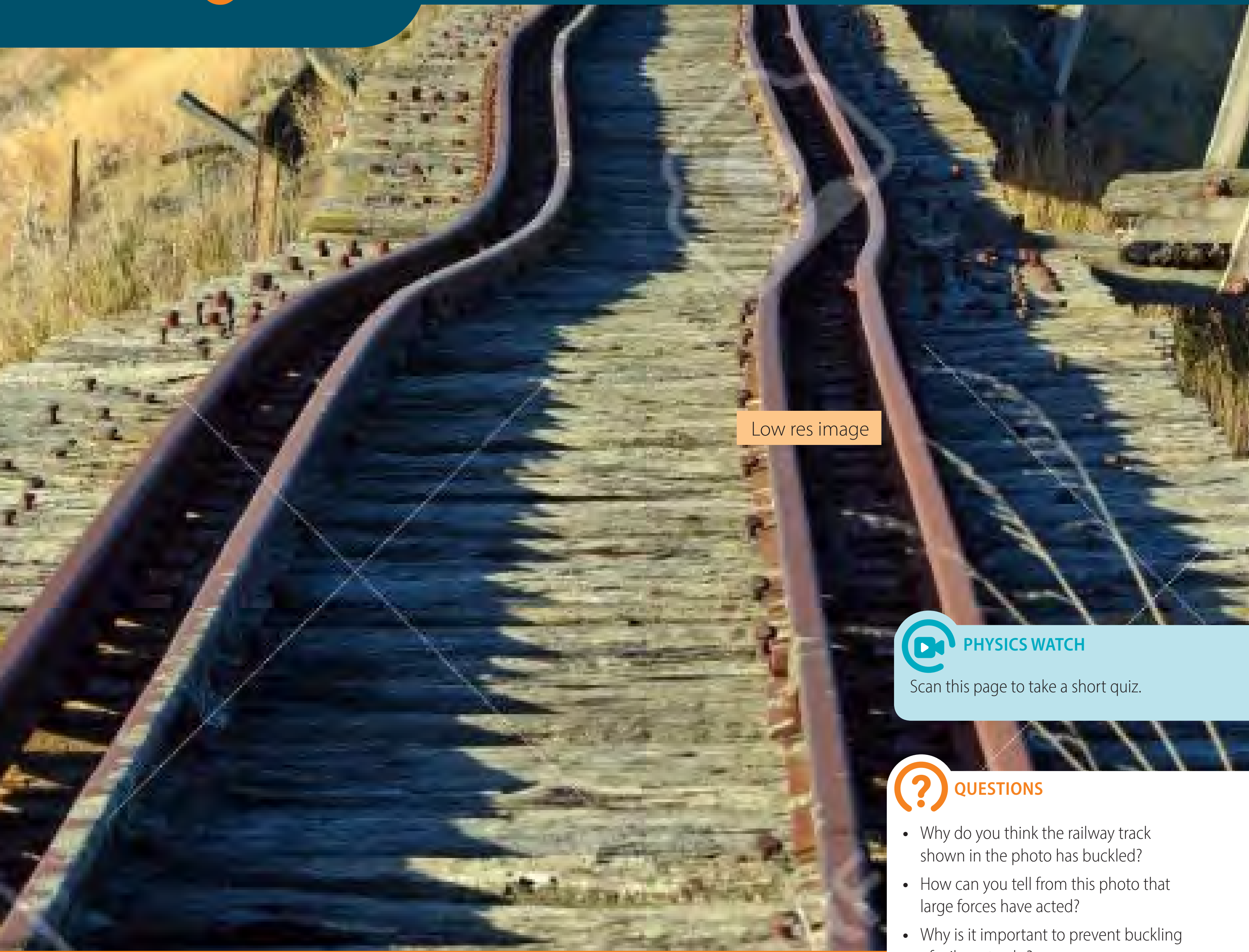
(a) Determine the pressure of the gas when its volume is halved.

(b) Determine the pressure of the gas if the volume is reduced to 85 cm^3.

(c) Determine the volume if the pressure is reduced to 6×10^4 Pa.

CHAPTER 9

Thermal Properties and Temperature



PHYSICS WATCH

Scan this page to take a short quiz.

QUESTIONS

- Why do you think the railway track shown in the photo has buckled?
- How can you tell from this photo that large forces have acted?
- Why is it important to prevent buckling of railway tracks?
- Can you think of ways to prevent this from happening?

The railway track shown in the photo was originally built to be a straight-line track. However, tracks such as this often buckle or bend during hot weather. Engineers need to apply their understanding of thermal properties of matter to reduce the problem of track buckling.

9.1 Thermal Expansion

In this section, you will learn the following:

- Describe qualitatively the thermal expansion of solids, liquids and gases at constant pressure.
- Describe some of the everyday applications and consequences of thermal expansion.
- S Explain, in terms of the motion and arrangement of particles, the relative order of magnitudes of the expansion of solids, liquids and gases as their temperatures rise.

What happens when materials are heated?

Solids, liquids and gases increase in volume or expand when heated. The greater the temperature rise, the greater the expansion. When cooled, the volume will decrease, i.e., it will contract.

The amount that solids expand is so small that it cannot be detected visually. In Figure 9.1 the metal ball just passes through the metal ring at room temperature. After heating, the metal ball has expanded. It is now too big to pass through the metal ring.

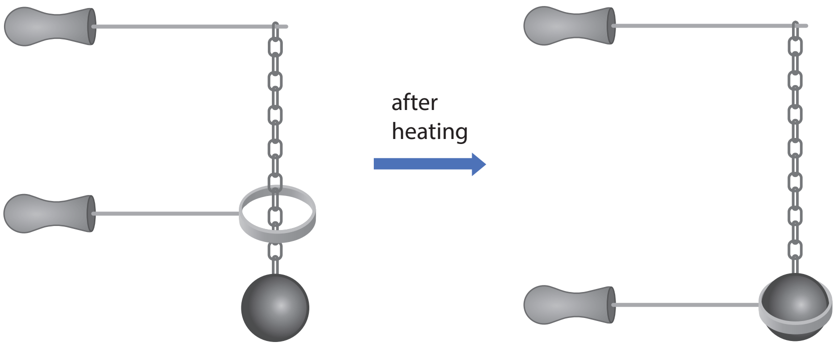


Figure 9.1 Expansion of a metal

PHYSICS WATCH

Scan this page to watch an experiment on thermal expansion and contraction of a solid.

Liquids expand more than solids for the same temperature rise. This is the principle behind liquid-in-glass thermometers (Figure 9.2).

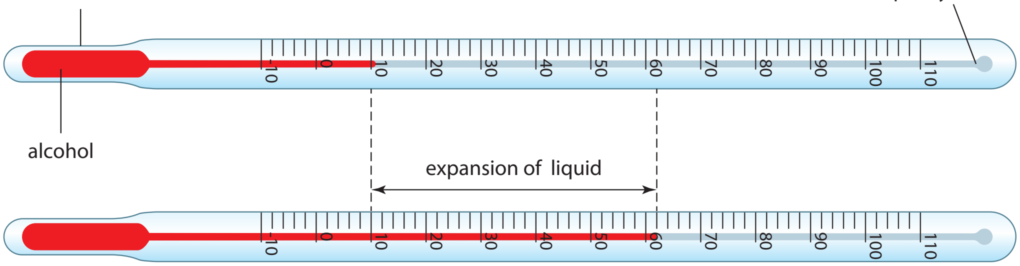


Figure 9.2 Expansion of a liquid in a thermometer

When the bulb of alcohol is heated, you can see the liquid expanding along the thin capillary tube inside.

Gases expand much more than liquids. The warmth of your hands is enough to make air expand by a large amount. As shown in Figure 9.3, the air in the test tube expands and bubbles of air are seen escaping from the tube.

Figure 9.3 Expansion of air

LINK

Recall what you have learnt in Chapter 8 about the effect of particles in matter when it is heated.

QUICK CHECK

Solids expand because their particles become bigger.

True or false?

Why do solids, liquids and gases expand by different amounts?

Heating materials gives the particles more kinetic energy. In solids, the particles vibrate more vigorously. Strong forces between them results in a small expansion.

In liquids, the particles move around faster. The forces between the particles are weaker as compared to solids, so the expansion is greater.

Gas particles move about the fastest as compared to solid and liquid particles. Gases have the greatest expansion because there is little force between the particles.

When materials are heated, the particles themselves do not expand, but the volume that they occupy does (Figure 9.4).

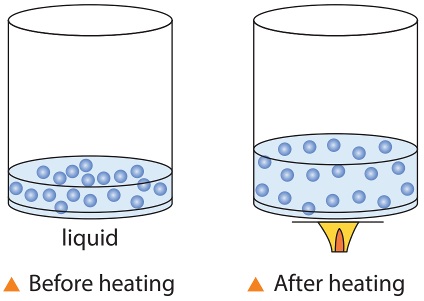


Figure 9.4 The volume of a liquid expands when heated, while the size of the particles remains the same.

What are the applications and consequences of expansion?

As shown in the chapter opener, if there is no space to expand, large forces may act. Engineers must take expansion into account when designing structures.

Railway lines

Some railway lines have expansion gaps to allow for expansion when the lines get hot. (Figure 9.5)

Modern railway lines do not have gaps. This is to allow the trains to move more smoothly. The lines are designed to fit tightly on a hot day. On cold days, the lines contract, but they are still held in place by supporting structures underneath.

Figure 9.5 Expansion gaps in a length of rail

Bridges

Bridges also expand and contract with changes in temperature. Figure 9.6 shows an expansion gap at one end of a concrete bridge. Another way of allowing for expansion is to put one end of the bridge on rollers (Figure 9.7).

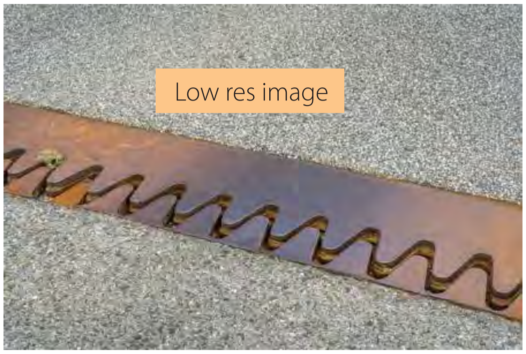


Figure 9.6 *Expansion gaps in a bridge roadway*

Figure 9.7 *Rollers supporting one end of a bridge*

Shrink fitting

Expansion can be used to fix two metal parts together using shrink fitting.

An example is fitting a metal axle into a metal train wheel (Figure 9.8). The metal axle is first made too large for the hole in the metal train wheel. Then, the axle is cooled to shrink so it will fit into the wheel. When the axle warms up and expands, the two metals are firmly held together.

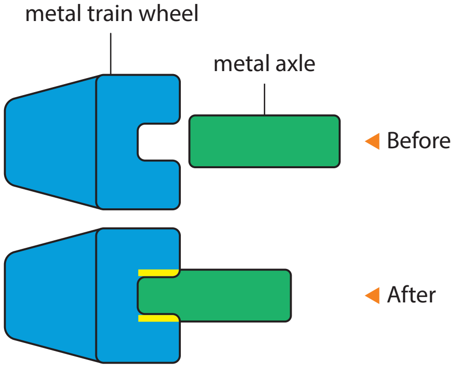


Figure 9.8 *Shrink fitting two metal parts together using thermal expansion*

Let's Practise 9.1

1. What evidence is there that the forces caused by expansion are large?
2. Explain why overhead telephone wires hang more loosely on a hot day.
3. S Explain using the kinetic particle model of matter why solids contract when they are cooled.
4. **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

TWB LINK

Exercise 9A, pp. XX–XX

9.2 Specific Heat Capacity

In this section, you will learn the following:

- Know that a rise in the temperature of an object increases its internal energy.
- S Describe an increase in temperature in terms of an increase in the average kinetic energies of all of the particles in the object.
- S Recall and use the equation $c = \frac{\Delta E}{m\Delta\theta}$.
- S Describe experiments to measure the specific heat capacity of a solid and a liquid.

What is internal energy?

The **internal energy** of a substance is the *total energy of all of its particles*. When the temperature of a substance is above 0 Kelvin, there is internal energy. In Figure 9.9, thermal energy is transferred from the flame of the Bunsen burner to the water. The internal energy of the water increases because the particles have gained kinetic energy. The water becomes hotter. Therefore, the higher the temperature, the greater the internal energy.

The higher the temperature of a substance (measured in °C or K), the greater the internal energy of the substance (measured in J).

The thermal energy from the Bunsen burner causes the water molecules to move faster. Molecules that move faster have greater kinetic energy. The internal energy of the water has increased because the total energy of all of the molecules has increased.

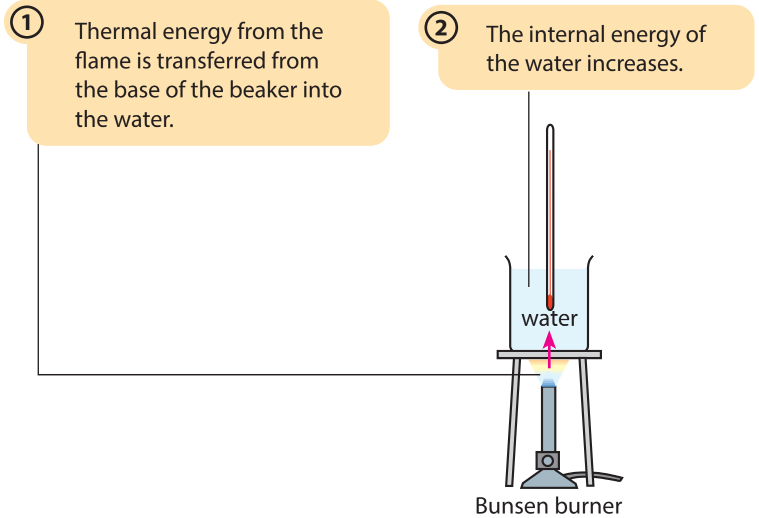


Figure 9.9 *Heating a beaker of water*

S Temperature is a measure of the average kinetic energy of the particles. The higher the temperature, the greater the internal energy.

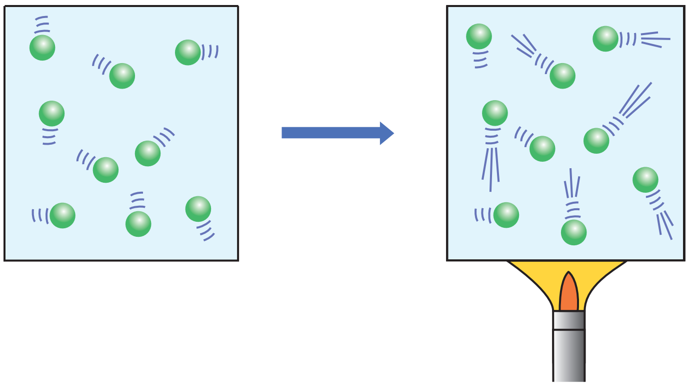


Figure 9.10 *The molecules have higher kinetic energy when heated up.*

What is specific heat capacity?

It is useful to be able to calculate how much energy is needed to heat things. What do you think this depends on?

When you boil water for a drink, the more water you heat, the longer it takes to boil. This shows that

- the thermal energy needed depends on the mass of water being heated.

If the water is colder to begin with, it takes longer to boil. This shows that

- the thermal energy needed depends on the temperature change.

Water takes a lot of thermal energy to heat up compared with other substances. This is why sand on a beach heats up — and cools down — more quickly than the sea. This shows that

- the thermal energy needed depends on the material being heated.

Specific heat capacity *c* is defined as the amount of thermal energy required to raise the temperature of a unit mass (e.g. 1 kg) of a substance by 1°C (or 1 K).

The definition gives us the equation for specific heat capacity:

$$c = \frac{\Delta E}{m\Delta\theta}$$

where ΔE = thermal energy required (in J)

$\Delta\theta$ = temperature change (in K or °C)

m = mass of substance (in kg)

The SI unit of specific heat capacity is the **joule per kilogram per kelvin, J/(kg K)**, or the **joule per kilogram per degree Celcius, J/(kg°C)**.

The equation can be rearranged as $\Delta E = mc\Delta\theta$.

Table 9.1 shows that the specific heat capacity of water is 4200 J/(kg K). This tells us that it takes 4200 joules of energy to change the temperature of 1 kg of water by 1°C.

Table 9.1 *Specific heat capacity of some common materials*

Material	Lead	Mercury	Brass	Zinc	Copper	Iron	Glass	Aluminium	Methylated spirit	Seawater	Water
Specific heat capacity J/(kg K)	130	140	380	390	400	460	670	900	2400	3900	4200

Worked Example 9A

Calculate the temperature change of 1 kg of copper when it is supplied with 4200 J of thermal energy.

Solution

Using $\Delta E = mc\Delta\theta$

$4200 = 1 \times 400 \times (\Delta\theta)$

$\Delta\theta = 10.5$ K

QUICK CHECK

Refer to Table 9.1. It requires more energy to raise the temperature of 1 kg of sea water by 1 K than 1 kg of tap water.

True or false?

HELPFUL NOTES

Remember that a temperature change of 1 K is the same as a temperature change of 1°C.

How is specific heat capacity determined?

Let's Investigate 9A shows how the specific heat capacity of solid can be determined using a cylindrical block of metal. The block has a hole bored for the heater and another for the temperature sensor (Figure 9.11).

Let's Investigate 9A

Objective
To determine the specific heat capacity of a solid

Apparatus and materials
Metal block with holes drilled in for heater and temperature sensor, temperature sensor and data logger, electrical heater, d.c. power supply, ammeter, voltmeter, connecting leads, insulating felt cloth for metal block, electronic balance, stopwatch

Procedure

1. Measure and record the mass, *m*, of the solid with an electronic balance.
2. Wrap the block with felt cloth. This is to reduce heat loss to the surroundings.
3. Connect the d.c. power source to the heater and put the heater into one of the holes of the block. Place the temperature sensor into the other hole (Figure 9.11).
4. Connect the temperature sensor to the data logger. Set the data logger to record temperature.
5. Start recording the temperature. Note the initial temperature θ_1.

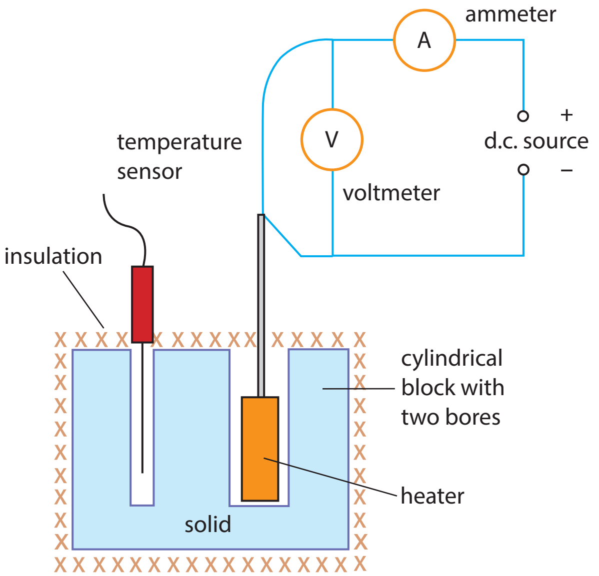


Figure 9.11

6. Switch on the power supply for *t* seconds.
7. After *t* seconds, switch off the heater. Continue recording the temperature for a while. Note the highest temperature θ_T reached.

Calculation

Power *P* of heater = current *I* × voltage *V*

Since it is used for *t* seconds, the thermal energy ΔE provided by the heater = IVt

Assuming all of the thermal energy provided by the heater is absorbed by the solid block,

$\Delta E = mc\Delta\theta$

$IVt = mc\Delta\theta$

where $\Delta\theta = \theta_T - \theta_1$

Therefore, the specific heat capacity of aluminium is given by

$$c = \frac{IVt}{m\Delta\theta}$$

Note: Since we assume that no heat is lost to the surroundings in the calculation above, good insulation is important in this experiment.

LINK

Investigations 9A and 9B use the equation for electrical power, which is explained in Chapter 16.

ENRICHMENT THINK

Not all of the thermal energy from the heater will go into the solid.

1. Explain why.
2. What does this mean about the value used for ΔE in this experiment?
3. How will it affect the result of the experiment?
4. Will the value for *c* be higher or lower than the expected value?

LINK PWB

Practical 9A, pp. XX–XX

Worked Example 9B

An electric heating coil supplies 50 W of power to a metal block of 0.60 kg. In 90 s, the temperature of the block is raised from 20°C to 45°C. Calculate the specific heat capacity of the metal. State the assumption you made to arrive at your answer.

Solution

Given: Power P of heater = 50 W

Time taken t = 90 s

Mass m of block = 0.60 kg

Change in temperature $\Delta\theta$ = 45°C – 20°C

= 25°C

Thermal energy supplied by heater = $P \times t$ = 50 W × 90 s = 4500 J

Assuming no heat is lost to the surroundings,

thermal energy supplied by the heater = thermal energy absorbed by the block

$$Pt = mc(\Delta\theta)$$

Therefore, the specific heat capacity c of the metal $= \dfrac{Pt}{m\Delta\theta}$

$$= \frac{4500\ J}{0.60\ kg \times 25}$$

= 300 J/(kg K)

Worked Example 9C

Some liquid in a copper calorimeter was heated using an electrical heater in order to find its specific heat capacity. The results are given below.

Mass of calorimeter	= 270 g	Time	= 360 s
Mass of liquid	= 260 g	Initial temperature	= 18°C
Potential difference	= 12.0 V	Final temperature	= 30°C
Current	= 3.4 A		

(a) Use the results to find

(i) the energy in joules supplied by the heater;

(ii) the energy in joules absorbed by the calorimeter;

(iii) the specific heat capacity of the liquid.

(b) State the assumptions that have been made in your answer to **(a)(iii)**.

Copper has a specific heat capacity of 400 J/(kg K).

Solution

(a) (i) Energy supplied by heater = IVt = 3.4 A × 12.0 V × 360 s = 14 688 J

(ii) Energy absorbed by calorimeter = $mc\Delta\theta$ = 0.27 kg × 400 J/ (kg K) × (30 – 18)°C = 1296 J

(iii) ΔE = energy supplied by heater – energy absorbed by calorimeter

= 14 688 J – 1296 J

= 13 392 J

Specific heat capacity $c = \dfrac{\Delta E}{m\Delta\theta} = \dfrac{13\,392\ J}{0.26\ kg \times (30 - 18)°C}$ = 4292 J/(kg K)

(c) The assumption is that all of the energy from the heater is absorbed by the calorimeter and water.

WORD ALERT

Calorimeter: an apparatus used to measure heat

HELPFUL NOTES

The principle of conservation of energy, covered in Chapter 6, is useful for solving problems in this chapter.

Let's Investigate 9B

Objective
To determine the specific heat capacity of a liquid

Materials
Polystyrene cup and polystyrene lid with holes for heater and temperature sensor, liquid e.g. water or oil, electronic balance, temperature sensor and data logger, electrical heater, d.c. power supply, ammeter, voltmeter, connecting leads, stopwatch

Procedure

1 Measure and record the mass of liquid *m*.
2 Pour the liquid, whose specific heat capacity *c* we want to determine, into the polystyrene cup.
3 Place the heater and the temperature sensor in the liquid (Figure 9.12).
4 Connect the temperature sensor to the data logger. Set the data logger to record temperature.
5 Start the recording of temperature. Note the initial temperature θ_1.
6 Switch on the power supply for *t* seconds.
7 After *t* seconds switch off the heater. Continue recording the temperature for a while. Note the highest temperature θ_2 reached.

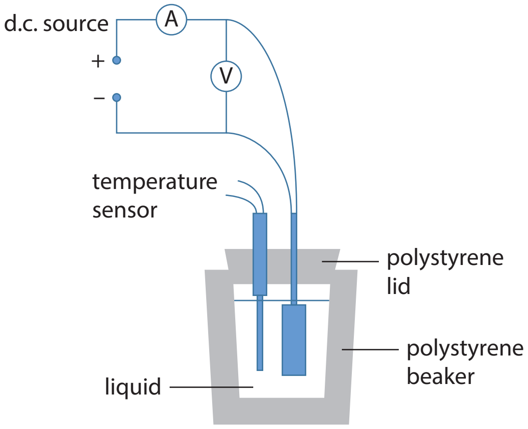


Figure 9.12

Calculation
Thermal energy supplied by heater, $\Delta E = IVt$

Thermal energy absorbed by liquid $= mc\Delta\theta = mc(\theta_2 - \theta_1)$

Assuming all the thermal energy supplied is absorbed by the liquid, (i.e. no heat loss to the surroundings),

thermal energy supplied by heater = thermal energy absorbed by liquid

$$IVt = mc(\theta_2 - \theta_1)$$

Therefore, the specific heat capacity *c* of the liquid is given by $c = \dfrac{IVt}{m(\theta_2 - \theta_1)}$

LINK PWB
Practical 9B, pp. XX–XX

Let's Practise 9.2

1 A beaker contains 100 cm³ of water at 20°C. State whether the following changes would cause the internal energy of the water to increase, decrease or stay the same.
   (a) Heating the water to 40°C
   (b) Boiling the water to 100°C
   (c) Removing 50 cm³ of water from the beaker
   (d) Adding 50 cm³ of water at 20°C to the beaker
2 S Explain why on a hot sunny day the sand at the beach is hotter than the water in the sea.
3 S 100 g of a metal needs 1000 J to raise its temperature by 9°C. Calculate the specific heat capacity of the metal.
4 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK TWB
Exercise 9B, pp. XX–XX

9.3 Changes of State

In this section, you will learn the following:

- Describe *melting* and *boiling* in terms of energy input without a change in temperature.
- Know the melting and boiling temperatures for water at standard atmospheric pressure.
- Describe *condensation* and *solidification* in terms of particles.
- Describe *evaporation* in terms of the escape of more energetic particles from the surface of a liquid.
- Know that evaporation causes cooling of a liquid.
- S Describe the differences between boiling and evaporation.
- S Describe how temperature, surface area and air movement over a surface affect evaporation.
- S Explain the cooling of an object in contact with an evaporating liquid.

What happens to the temperature when materials change state?

Remember from Chapter 8 that melting occurs when a solid changes into a liquid upon being heated. Boiling occurs when a liquid turns into a gas upon being heated. You can find out using the apparatus shown in Figure 9.13 what happens to the temperature of a substance when it changes state.

Start with very cold crushed ice from the freezer. Heat it and record the temperature every minute until the melted ice boils.

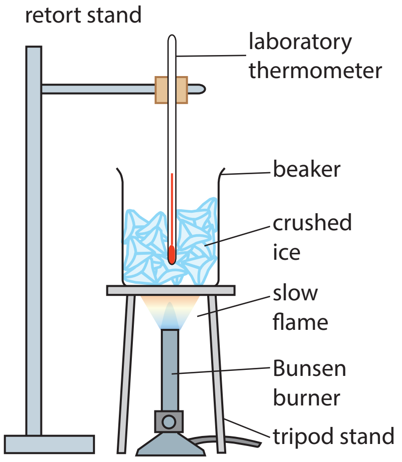


Figure 9.13 *Heating ice*

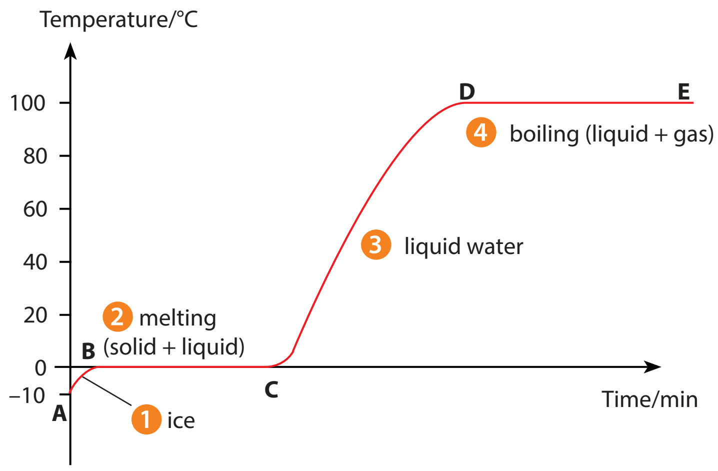


Figure 9.14 *Graph of heating curve of water*

Figure 9.14 shows a graph of temperature against time.

From A to B, the graph is a curve. The temperature of the ice rises from –10°C to 0°C. There is a change of temperature. The thermal energy is being taken in to increase the temperature.

From B to C, the graph is a horizontal straight line. The temperature remains constant at 0°C. Thermal energy continues to be supplied from the Bunsen burner but there is *no change in temperature*. There is a change of state — the ice is melting into water. The thermal energy is being taken in to change state.

From C to D, the temperature rises from 0°C to 100°C. There is a change of temperature. The thermal energy is being taken in to increase the temperature.

From D to E, the temperature remains constant at 100°C. There is *no change in temperature* even though thermal energy is still being absorbed. There is a change of state — the water is boiling and changing into steam. The thermal energy is being taken in to change state.

Why is energy needed when a substance changes its state? The kinetic model of matter can explain this.

During **melting**:

The particles in a solid are held in fixed positions by strong bonds. Energy is needed to break the bonds. When the bonds are broken, the particles can move out of their fixed positions and are slightly further apart from each other. The solid has melted. Melting takes place at the melting point without a change in temperature. From Figure 9.14, you can see that the melting point of pure water is 0°C.

The **melting point of pure water** at standard atmospheric pressure of 1 atmosphere is **0°C**.

During **boiling**:

The particles in a liquid have strong forces between them. Energy is needed to break the bonds and separate the particles further apart. Energy is also required for the particles to overcome the atmospheric pressure in order to escape into the air. When these happen, the liquid has boiled. Boiling takes place at the boiling point without a change in temperature. From Figure 9.14, you can see that the boiling point of water is 100°C.

The **boiling point of pure water** at standard atmospheric pressure of 1 atmosphere is **100°C**.

We have seen how energy is absorbed when a solid melts and a liquid boils. What do you think happens to this energy when a liquid solidifies (i.e. freezes) and a gas condenses?

During **condensation**:

The reverse of boiling occurs. When a gas condenses into a liquid, forces pull the particles closer and energy is released.

During **solidification** (freezing):

The reverse of melting occurs. Strong forces pull the particles in a liquid into fixed positions to form a solid. Energy is released.

Figure 9.15 shows the graph for condensation and solidification.

ENRICHMENT *INFO*

The higher you go above sea level, the lower the atmospheric pressure becomes. This causes water to boil at a lower temperature. On Mount Everest, water boils at about 70°C.

In cold countries, the air warms up before it snows. This is because thermal energy is released by water as it freezes.

A burn from steam at 100°C is more painful than a burn from boiling water. This is because the steam releases more thermal energy on condensing than water cooling from its boiling point.

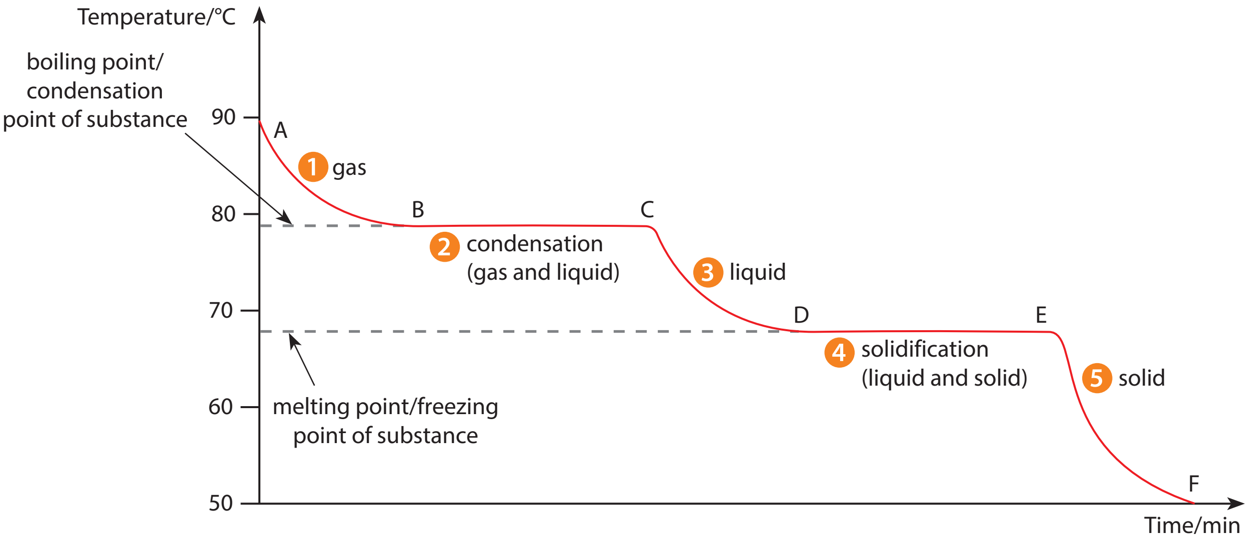


Figure 9.15 *Graph showing the changes of state as matter loses heat*

What is evaporation?

If you observe a floor that has just been mopped, you will notice that the wet surface of the floor soon dries up. The thin layer of water on the surface of the floor has evaporated. Evaporation, like boiling, involves a change of state from liquid to gas.

The kinetic theory of matter explains how evaporation occurs (Figure 9.16).

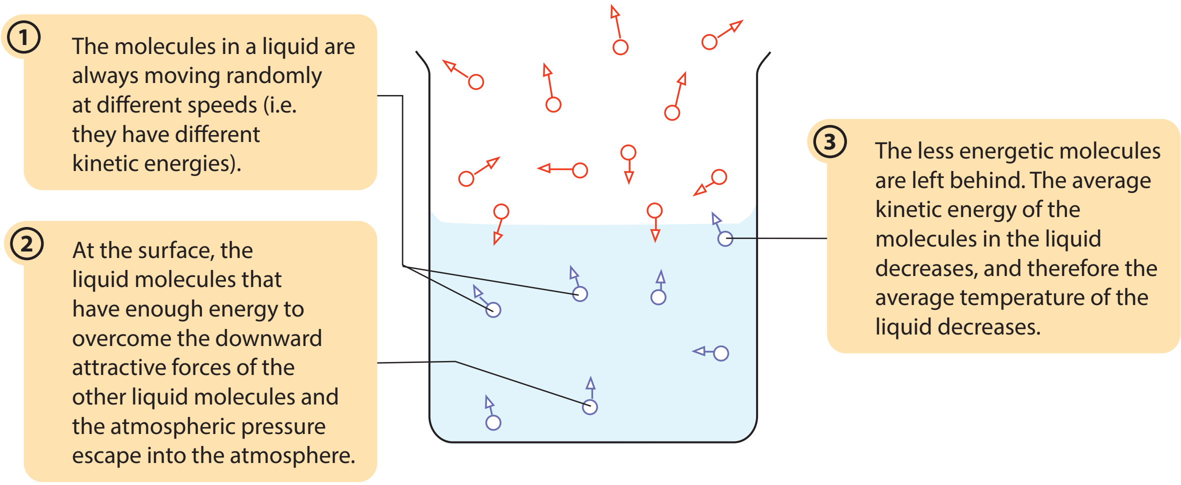


Figure 9.16 *How evaporation occurs*

Evaporation causes cooling

When you step out of a swimming pool on a windy day, you feel cold. This is because the water is evaporating from your skin surface, which results in a decrease in temperature.

Figure 9.17 *The girl feels cold due to the cooling effect of evaporation.*

Why does evaporation cause cooling?

On a hot day, your body perspires. The sweat evaporates from the surface of your skin. During the evaporation process, water molecules with enough kinetic energy escape into the air. These water molecules have to overcome the attractive forces among themselves as well as the pressure of the atmosphere.

The fastest moving molecules escape into the air, leaving behind the molecules with lower kinetic energy. The average kinetic energy of the water molecules in the perspiration thus decreases, resulting in a lower temperature. The evaporated water molecules carry away the body's latent heat into the air, cooling the body down.

ENRICHMENT *ACTIVITY*

Drinking bird toy

The drinking bird is a toy that rocks to and fro, repeatedly dipping its beak into a glass of water.

In groups, use the Internet to research the drinking bird. Use the key phrases 'drinking bird', 'dipping bird' or 'drinking duck'.

Write a series of steps to explain how it works. Your report should include the process of evaporation.

Share your findings to the rest of the class.

Let's Investigate 9C

Objective
To demonstrate that evaporation causes cooling

Materials
A laboratory thermometer (or a temperature sensor connected to a data logger), some absorbent tissue paper, a beaker of water at room temperature, retort stand and clamp, some adhesive tape or a rubber band, a cold air fan

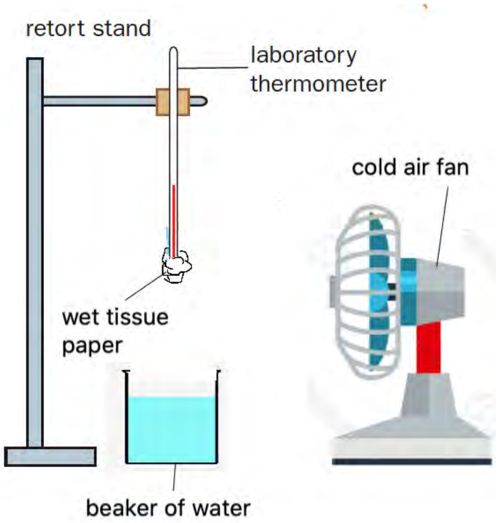


Figure 9.18 Evaporation causes cooling

Procedure
- Cover the thermometer bulb in tissue paper and attach it with adhesive tape or a rubber band.
- Dip the thermometer bulb covered with tissue paper into the water.
- Clamp the thermometer on a retort stand so the bulb is in front of the fan.
- Note the initial temperature.
- Blow cold air over the thermometer bulb for three minutes.
- Note the final temperature.

Observation and discussion
After three minutes the temperature drops by several degrees. The water evaporates into water vapour. This change of state requires thermal energy which is removed from the thermometer, causing it to cool. The cold air fan increases the rate of evaporation. This shows that the evaporation of the water causes cooling.

LINK PWB
Practical 9C, pp. XX–XX

S What is the difference between evaporation and boiling?

Boiling and evaporation both involve a liquid becoming a gas and require thermal energy. Boiling occurs throughout the liquid when it reaches its boiling point, while evaporation occurs at all temperatures. The differences are summarised in Table 9.2.

Table 9.2 Differences between boiling and evaporation

Boiling	Evaporation
• Occurs at a particular temperature	• Occurs at any temperature
• Relatively fast	• Relatively slow
• Takes place throughout the liquid	• Takes place only at the liquid surface
• Bubbles are formed in the liquid	• No bubbles are formed in the liquid
• Temperature remains constant	• Temperature may change
• External thermal energy source required	• External thermal energy source not required

Factors that affect the rate of evaporation are shown in Figure 9.19.

Rate of evaporation is affected by

Temperature

Although evaporation can occur at any temperature, raising the temperature of the liquid will increase the rate of evaporation. A warmer liquid means that a greater number of molecules at the surface layer are energetic enough to escape.

Surface area of the liquid

The rate of evaporation increases when a larger area of liquid is exposed. This is because evaporation only takes place at the exposed surface of a liquid. A larger exposed surface area means more molecules can escape from the liquid.

Movement of air

Moving air removes the liquid molecules as soon as they escape from the liquid surface. This makes the air surrounding the liquid drier. Therefore, the rate of evaporation increases when the surrounding air is moving.

Figure 9.19 What affects the rate of evaporation?

QUICK CHECK

Thermal energy is given out when a gas condenses into a liquid and taken in when a liquid changes into a gas.

True or false?

Let's Practise 9.3

1 Explain why spraying perfume on the skin produces a cooling effect.

2 Explain why energy is needed to turn a solid into a liquid.

3 S Explain why puddles evaporate more quickly on a warm day than a cold day.

4 S Give two factors that make wet clothes on a washing line dry more quickly.

5 S Give one similarity and one difference between evaporation and boiling.

6 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK

Exercises 9C–9D, pp. XX–XX

Exercise 9E Let's Practise, p. XX

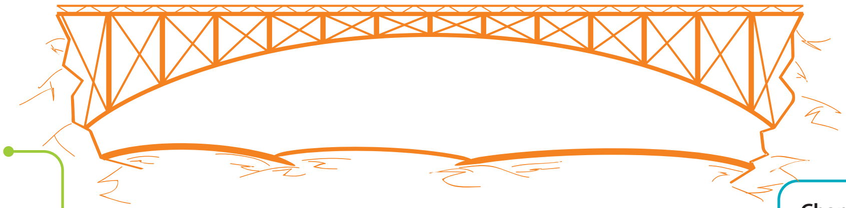
Let's Map It

THERMAL ENERGY

THERMAL ENERGY — causes → **Thermal expansion**
- Particles move further apart
- Gases expand more than liquids
- Liquids expand more than solids

Applications
- Shrink fitting to join metals
- Liquid-in-glass thermometers

E˝ ects
- Expansion of bridges
- Expansion of rails



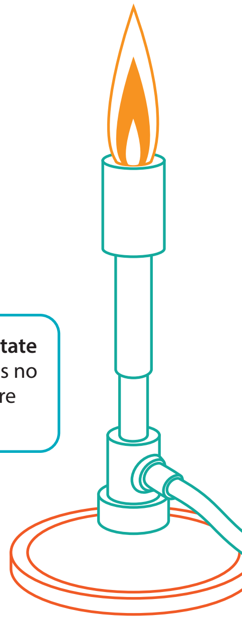
THERMAL ENERGY — increases → **Internal energy**

Internal energy — causes → **Temperature rise**
- S which depends on the specific heat capacity of a substance: $c = \frac{\Delta E}{m\Delta\theta}$

can be used to

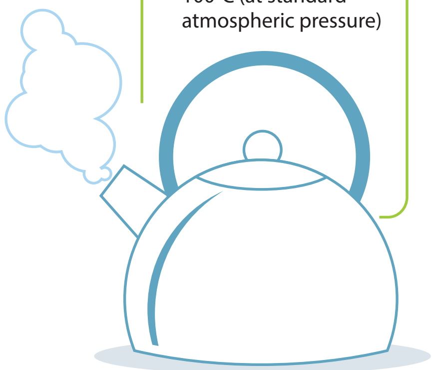
S Measure specific heat capacity of solids and liquids

Internal energy — causes → **Changes of state** (when there is no temperature change)

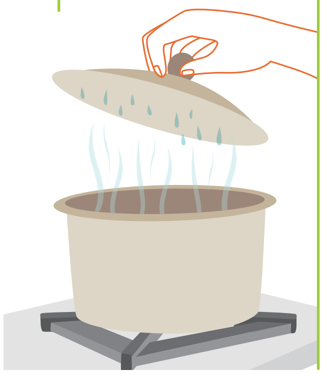


Melting
- Solid to liquid
- Requires energy
- Melting point of pure water = 0°C (at standard atmospheric pressure)

Boiling
- Liquid to gas
- Requires energy
- Occurs at boiling point
- Boiling point of pure water = 100°C (at standard atmospheric pressure)



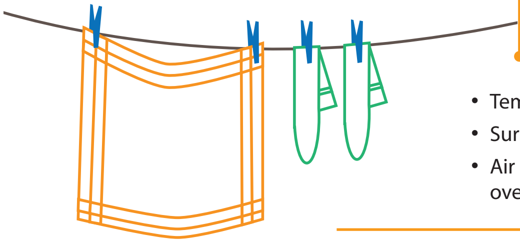
Condensation
- Gas to liquid
- Gives out energy



Solidiÿcation
- Liquid to solid
- Gives out energy

Evaporation
- Liquid to gas
- Requires energy
- Occurs at any temperature
- Causes cooling

affected by
- Temperature
- Surface area
- Air movement over a surface



Let's Review

Section A: Multiple-choice Questions

1 When a solid is melting, the temperature remains constant even though thermal energy is being supplied. Which of the following explains this observation?

- **A** The energy is used to break the bonds between the particles.
- **B** The solid is not absorbing any thermal energy.
- **C** The solid molecules are moving faster.
- **D** The solid is giving out thermal energy.

2 Which statement is true about internal energy?

- **A** The internal energy of an object is zero at 0°C.
- **B** When thermal energy is supplied to an object, its internal energy decreases.
- **C** An object at a high temperature has less internal energy than the same object at a low temperature.
- **D** The internal energy of an object is the total energy of all of the particles of the object.

3 Which statement is correct?

- **A** When a liquid is heated, the molecules move slower.
- **B** When a liquid is heated, the molecules expand.
- **C** When a liquid is cooled, it contracts.
- **D** When a liquid is heated, its volume decreases.

4 S When a 0.24 kg brass cylinder is heated using a 2.0 kW heater, its temperature increases from 30°C to 100°C in 3.2 s. What is the specific heat capacity of brass?

- **A** 125 J/(kg K) **B** 169 J/(kg K)
- **C** 381 J/(kg K) **D** 400 J/(kg K)

5 S Which statement is correct?

- **A** Evaporation causes cooling.
- **B** Evaporation occurs at the boiling point.
- **C** Evaporation occurs when a gas turns into a liquid.
- **D** Evaporation occurs more slowly at higher temperatures.

Section B: Short-answer and Structured Questions

1 **(a)** Outline a demonstration you could do to show that gases expand when they are heated.
(b) Describe **one** use of the fact that liquids expand when they are heated.
(c) Explain how bridges can be built to withstand damage from expansion in hot weather.

2 Some solid wax at room temperature was heated until it melted. Then, its temperature was taken every minute as it cooled down back to room temperature. Figure 9.20 shows a graph of the results.

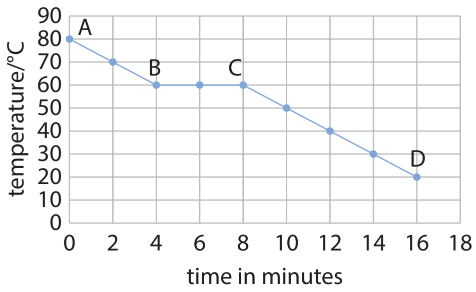


Figure 9.20

(a) Explain what is happening to the wax during
(i) A to B;
(ii) B to C;
(iii) C to D.
(b) Deduce the melting point of wax from this result.

3 S An electric kettle is rated at 25 W. Calculate the
(a) quantity of thermal energy generated in 2 s;
(b) rise in temperature of 150 g of water if the electric kettle is switched on for five minutes and the specific heat capacity of water is 4000 J/(kg K).

4 S The experimental set-up shown in Figure 9.21 was used to determine the specific heat capacity of an unknown metal block.

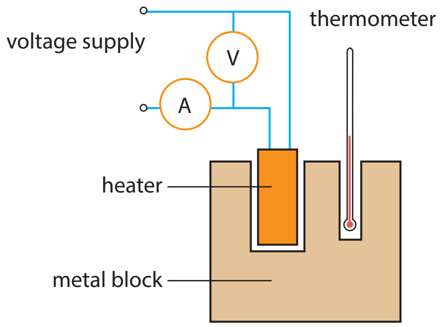


Figure 9.21

The circuit is switched on for a time interval of 500 seconds and the following readings were obtained:

Change in temperature = 50°C

Mass of metal block = 1 kg

Ammeter reading = 5 A

Voltmeter reading = 8 V

Using the above data, calculate the specific heat capacity of the unknown metal block.

CHAPTER 10 Transfer of Thermal Energy

PHYSICS WATCH

Scan this page to watch a clip on how emperor penguins conserve thermal energy.

QUESTIONS

- Observe the body covering, body shape, body size and behaviour of the penguins and discuss how penguins have adapted for a very cold climate.
- Which other animals live in cold countries and how have they adapted?
- How do Arctic explorers or skiers protect themselves in icy weather?

Emperor penguins live in the Antarctic, where temperatures can drop below –50°C. Their bodies have several adaptations to allow them to survive in this extreme cold climate. These adaptations reduce thermal energy transfer from the bodies of the penguins to their surroundings, allowing them to keep warm. They also huddle together and take turns to be in the middle of the huddle. The ways in which thermal energy is transferred will explain how these adaptations work.

10.1 Transfer of Thermal Energy

In this section, you will learn the following:

- Know that thermal energy is transferred from a region of higher temperature to a region of lower temperature.

Why does an object feel hot or cold?

① Prepare three small pails of water labelled P, Q and R at 10°C, 37°C and 50°C respectively.

② Place both your hands in pail Q. Do your hands feel warm or cold?

③ Now, place your right hand in pail P and your left hand in pail R. Do your hands feel warm or cold?

Figure 10.1 *In which pail would your hand feel warm? In which pail would it feel cold?*

Try the activity shown in Figure 10.1. Your hands would feel neither hot nor cold in pail Q. This is because the water in pail Q is at the same temperature as your body temperature — your hands and the water are at *thermal equilibrium*. There is no net gain or loss of thermal energy between your hands and the water.

However, since the temperature of the water in pail R is higher than your body temperature, thermal energy flows from the water to your left hand. Your left hand gains thermal energy from the water, and hence feels warm. Can you now explain why your right hand feels cold?

Thermal energy always flows from *a region of higher temperature* to *a region of lower temperature*. Net flow of thermal energy occurs only when there is a *difference in temperature*.

Thermal energy may be transferred through three processes: conduction, convection and radiation. Which of these processes is involved in the thermal energy transfer between your hand and the water?

10.2 Conduction

In this section, you will learn the following:

- Describe experiments to demonstrate the properties of good thermal conductors and bad thermal conductors (thermal insulators).
- S Know that there are many solids that conduct thermal energy better than thermal insulators but do so less well than good thermal conductors.
- S Describe thermal conduction in all solids.
- S Describe why thermal conduction is bad in gases and most liquids.

How good are different materials at conducting thermal energy?

Have you ever touched a metal spoon that has been left in very hot water?

If you have, you will find that the metal spoon feels hot. This is because thermal energy travels well through metals. This transfer of thermal energy through a solid from the hotter region to the colder region is known as *conduction*.

Conduction is the transfer of thermal energy through solids.

Some materials are better thermal conductors than others. Let us find out what materials are good thermal conductors and what materials are bad thermal conductors in Let's Investigate 10A.

Let's Investigate 10A

Objective
To investigate the transfer of thermal energy through solids

Materials
Bunsen burner, tripod stand, four rods of the same dimensions but made of different materials (copper, steel, aluminium and glass), stopwatch, wax, drawing pins

Procedure

1 Drip a few drops of melted wax on one end of the copper rod.
2 Place a drawing pin on top of the melted wax and allow the wax to harden.
3 Repeat steps 1 and 2 with the other rods. Take note to place the drawing pins at the same position for each rod.
4 Place the rods on a tripod stand. Ensure that the ends of the rods are aligned.
5 Place the Bunsen burner under the ends of the rods without the drawing pin (Figure 10.2).
6 Record the time taken for the drawing pin to fall from each rod in the Table 10.1.

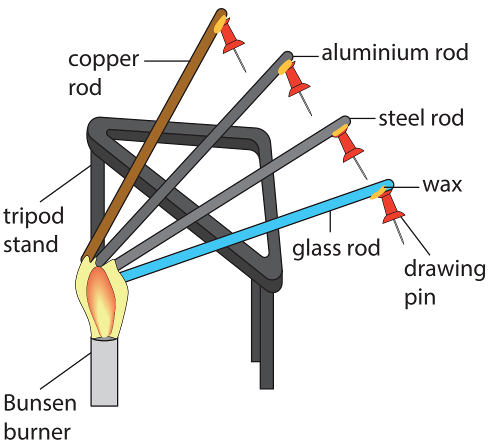


Figure 10.2 *Comparing conduction in different materials*

Table 10.1

Rod	Copper	Steel	Aluminium	Glass
Time taken / s				

Observation

The time taken for the drawing pin to fall was the shortest for the copper rod, and the longest for the glass rod.

Discussion and conclusion

1. For the drawing pins to fall, the wax on the four rods must melt. The wax melted because thermal energy was transferred from the ends of the rods heated by the Bunsen burner (the hotter region) to the ends of the rods at room temperature (the cooler region). The transfer of thermal energy through the rods occurred without any flow of the material the rods were made of. This means that thermal energy was transferred by conduction.
2. The time taken for the drawing pin to fall for each of the four rods was different. This shows that different materials conduct thermal energy at different rates. The time taken is the shortest for copper and longest for glass. From this, we can conclude that copper is the best and glass is the worst thermal conductor among the four materials.

LINK

PWB Practical 10, pp. 67–72

The **thermal conductivity** of a material is dependent on how quickly thermal energy is transferred from the hotter end to the colder end (Figure 10.3). Materials that can transfer thermal energy quickly are good thermal conductors, while materials that transfer thermal energy slowly are bad thermal conductors.

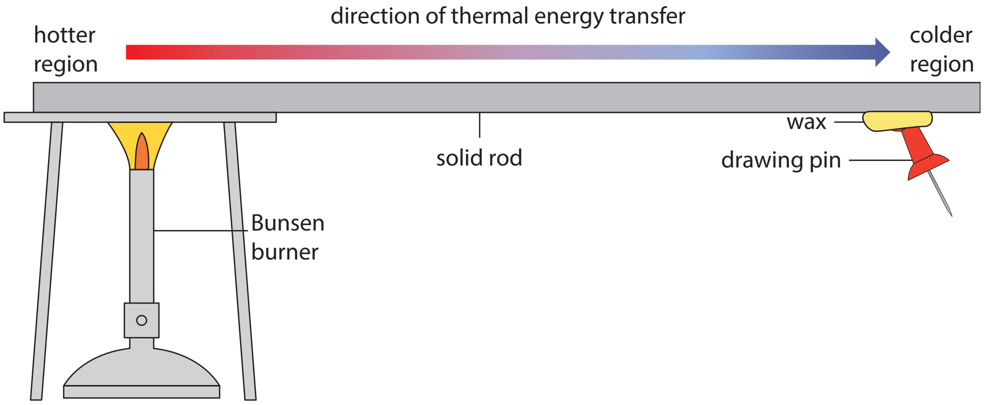


Figure 10.3 Thermal energy is conducted from the hotter end to the colder end.

PHYSICS WATCH

Scan this page to explore factors affecting the rate of thermal conduction.

In general, metals are good thermal conductors. Non-metals such as glass plastic, wood, wool, air and water are bad thermal conductors. Bad thermal conductors are also known as thermal **insulators**.

S

There is a big difference between the **thermal conductivity** of metals and non-metals. However, there are also materials that conduct thermal energy not as well as thermal conductors but better than thermal insulators. Examples of such materials can be found in Table 10.2.

Table 10.2 Comparing the thermal conductivity of different materials

Best conductor → Worst conductor							
Diamond	Copper	Steel	Ice	Polythene	Fibreglass	Polystyrene	Air
Worst insulator → Best insulator							

Fibreglass and polystyrene are good thermal insulators because they contain air.

ENRICHMENT ACTIVITY

Touch the surface of a metal frying pan and an empty plastic lunch box. Do the temperatures feel the same?

Now place a similar-sized ice cube on top of each surface. Predict which ice cube will melt first. Were you right in your prediction? Explain your observations to the class.

How does conduction work?

Why is the rate of conduction much faster in metals than in non-metals?

Both metals and non-metals are made up of tiny particles (atoms or molecules). The difference is that metals contain many *free electrons*, while non-metals do not. These free (or *delocalised*) electrons are not firmly attached to one atom but can move randomly among the atoms of the metal.
We have learnt that particles vibrate about a fixed position in solids. This vibration is also known as *lattice vibration*.

Figure 10.4 describes the process of conduction in non-metals and metals. Note that in metals, thermal energy is transferred through lattice vibrations of particles and movement of free electrons. In non-metals, only lattice vibrations of particles takes place. This explains why metals are better thermal conductors.

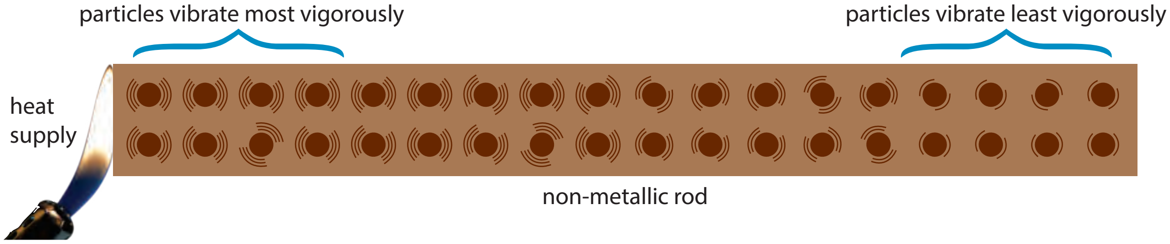
LINK

Recall from Chapter 8 that matter is made up of tiny particles.

HELPFUL NOTES

An atom contains electrons within it. The electrons in most non-metals are attached to one atom. In metals, however, some electrons are free to move.

Non-metals



①
- The particles (atoms or molecules) at the hot end vibrate vigorously about their fixed positions.

②
- They collide with neighbouring particles, making them vibrate more vigorously. (The kinetic energy of the vibrating particles at the hot end is transferred to the neighbouring particles.)
- The neighbouring region of the rod becomes hot.
- Thermal energy has been transferred without the transfer of particles.

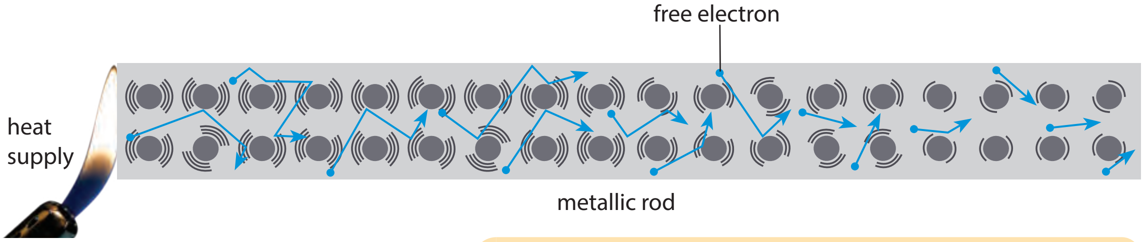
③
- Eventually, the particles at the cooler end of the rod vibrate vigorously.
- The cooler end of the rod becomes hot.

(a) Thermal transfer in non-metals occurs via lattice vibrations of particles.

LINK

Metals are good conductors of thermal energy as well as electricity. The presence of free electrons in metals allow current to flow. You will learn more about this in Chapter 16.

Metals



①
- In addition to the process that takes place in non-metals, another (much faster) mechanism of thermal transfer takes place in metals: free electron diffusion.
- The free electrons at the heated end absorb thermal energy, and hence gain kinetic energy.

②
- The free electrons that gain kinetic energy move at greater speeds, and move to the cooler regions of the rod.
- As these electrons move, they collide with the atoms in the cooler parts of the rod, making them vibrate more vigorously. (Some of the kinetic energy of the moving electrons is transferred to the atoms.)
- Thermal energy is transferred via the motion of the free electrons. The cooler end of the rod becomes hot.

(b) Thermal transfer in metals occurs via lattice vibrations of particles and free electron diffusion.

Figure 10.4 *Transfer of thermal energy in metals and non-metals*

QUICK CHECK

A stone floor feels colder to bare feet than a cloth rug because stone is a better thermal conductor than cloth.

True or false?

Why are liquids and gases bad thermal conductors?

Thermal energy can also be conducted from a hotter region to a colder region in liquids and gases by conduction. But it is not efficient. Can you think why?

We have learnt in Chapter 8 that the particles in liquids and gases are spaced further apart than those in solids. The collisions between the particles are therefore less frequent in liquids and gases. This means that the transfer of kinetic energy from the fast-moving particles (in the hotter region) to neighbouring particles (in the colder region) is slower. This explains why air and water are bad thermal conductors. In the next section, we will learn that how thermal energy is transferred in liquids and gases.

QUICK CHECK

Gases are better thermal conductors than liquids.

True or false?

Let's Practise 10.1 and 10.2

1. How is thermal energy transferred?
2. Why is copper a good material for making a cooking pot?
3. Why do copper cooking pots have plastic handles?
4. S Explain why metals are better thermal conductors than non-metals.
5. S Why is water a bad thermal conductor?
6. **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK

TWB

Exercises 10A–10B, pp. XX–XX

10.3 Convection

In this section, you will learn the following:

- Know that convection is an important method of thermal energy transfer in liquids and gases.
- Explain convection in liquids and gases in terms of density changes.
- Describe experiments to illustrate convection.
- Describe experiments to demonstrate the properties of bad thermal conductors (thermal insulators).

How do liquids and gases transfer thermal energy?

Liquids and gases get hotter by convection.

Convection is the transfer of thermal energy in a fluid (liquid or gas) by means of convection currents due to a difference in density.

Convection in liquids

Water is a transparent liquid and hence, it is difficult to observe convection currents in pure water. Figure 10.5 demonstrates convection currents in water through the help of potassium permanganate crystals, which are purple in colour. These crystals dissolve in the water to form a purple stream.

When the bottom of the flask is heated, the purple streams (shown as purple arrows) rise to the top of the flask. Then, they fan out before sinking back down the sides. The circulating purple arrows represents the convection currents in water.

Convection currents form because of the difference in density in water when heated. When the water at the bottom of the flask is heated, it expands. The expanded water is less dense than the surrounding water because there is more space between the molecules. The warmer, less dense water rises. It cools down at the top of the flask, become denser and sinks down again. This process repeats until the whole flask of water is heated up.

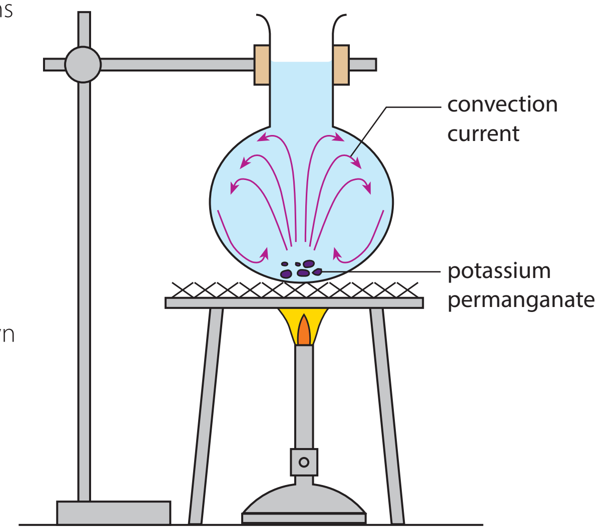


Figure 10.5 *Convection in water*

PHYSICS WATCH

scan this page to watch a clip on convection in water and air.

QUICK CHECK

Hot air balloons rise because hot air is less dense than cold air.

True or false?

ENRICHMENT *THINK*

Still air can be formed by stopping air from moving. Still air is an excellent thermal insulator.

1 Why does the air have to be still?

2 Give an example of something that uses still air for insulation.

LINK TWB

Exercise 10C, pp. XX–XX

Convection in gases

Figure 10.6 demonstrates convection currents in air. The incense stick is used to produce smoke that trace the convection currents.

The candle below the chimney on the right is lit. The incense stick is held over the left chimney. As shown by the black arrows, the smoke is drawn down the left chimney, across to the right chimney, and then rises up above the candle. The black arrows show the circulating convection currents in air.

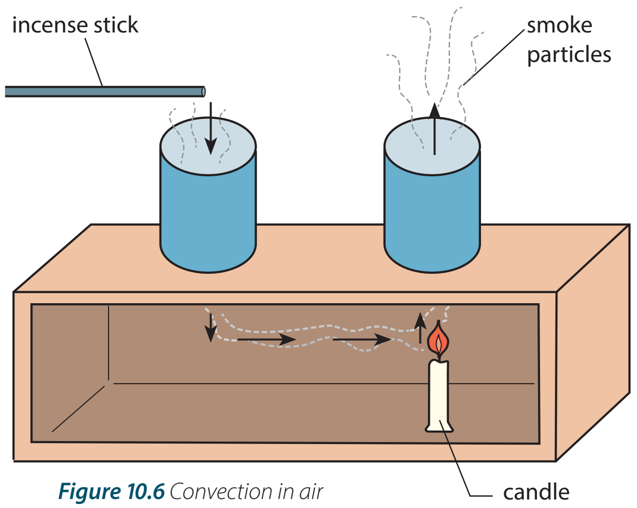


Figure 10.6 *Convection in air*

Convection currents form because of the difference in density in air when heated. When the air above the candle is heated, it expands. As the warm air is less dense than the surrounding air, it rises out of the right chimney. Cooler denser air sinks down the left chimney to take the place left by the warm air, carrying the smoke from the incense stick along. The movement of air forms the smoke trails (indicated by the black arrows) that we observe.

Convection currents occur only in fluids (liquids and gases). They do not occur in solids. This is because convection involves the *bulk movement* of the fluid that carries the thermal energy. This means that for convection currents to occur in a substance, the substance must be able to *flow*.

In solids, the particles are in fixed positions. Hence, solids cannot flow. They can only transfer thermal energy from one particle to another through lattice vibrations (and free electron diffusion in metals) without any bulk movement of the particles (i.e. via conduction).

Conduction in liquids

Thermal energy transfer through conduction still occurs in liquids, but it is much slower compared to convection. To show that liquids are bad thermal conductors, you have to prevent convection currents from forming. To produce convection, a liquid has to be heated from the bottom, like in Figure 10.5.

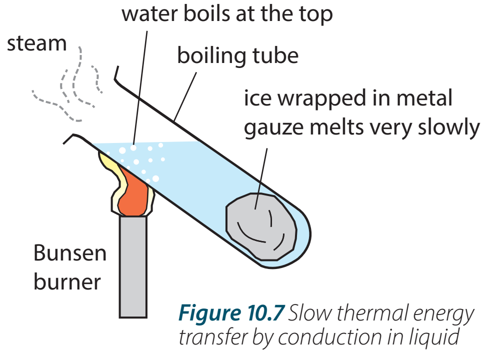


Figure 10.7 *Slow thermal energy transfer by conduction in liquid*

In Figure 10.7, the water in the boiling tube is heated at the top. The only way that the water at the bottom can get hot is by conduction because hot liquids, being less dense, will rise instead of sink to the bottom. An ice cube is wrapped in metal gauze to make it sink to the bottom of the boiling tube. The result is that the water at the top boils while the ice cube at the bottom remains frozen. The transfer of thermal energy by conduction from the hot water at the top of the boiling tube to the ice at the bottom is slow. This shows that water is a bad thermal conductor.

Let's Practise 10.3

1 **(a)** What happens to the density of a material when it is heated?

(b) Explain your answer in **(a)**.

2 Describe the formation of convection currents in a liquid.

3 Why does convection occur when gases and liquids are heated but not when solids are heated?

4 Use an experiment to describe why liquids and gases are bad thermal conductors.

5 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

10.4 Radiation

In this section, you will learn the following:

- Know that thermal radiation is infrared radiation and that all objects emit this radiation.
- Know that thermal energy transfer by thermal radiation does not require a medium.
- S Describe experiments to distinguish between good and bad emitters of infrared radiation.
- S Describe experiments to distinguish between good and bad absorbers of infrared radiation.
- Describe the effect of surface colour and texture on the emission, absorption and reflection of infrared radiation.
- S Describe how the rate of emission of radiation depends on the surface temperature and surface area of the object.
- S Know that for an object to be at a constant temperature it needs to transfer energy away at the same rate that it receives energy.
- S Know what happens to an object if the rate at which it receives energy is less or more than the rate at which energy is transferred away.
- S Know how the temperature of the Earth is affected by factors controlling the balance between incoming radiation and radiation emitted from the Earth's surface.

What is thermal radiation?

Thermal radiation is also known as infrared radiation. All objects absorb and emit infrared radiation, which is an invisible radiation that carries thermal energy.

Infrared cameras can be used to detect infrared radiation. Figure 10.8 shows the infrared radiation emitted by a human face. The image has been colour-coded. The colours range from white indicating the hottest part, through yellow, orange, red, violet, blue and then black, indicating the coldest part.

Thermal radiation is the transfer of thermal energy in the form of invisible waves called infrared radiation which can travel through a vacuum.

Unlike conduction and convection, infrared radiation can travel through a vacuum. It does not require a medium to travel through. The Earth receives a lot of infrared radiation from the Sun as space is a vacuum (Figure 10.9).

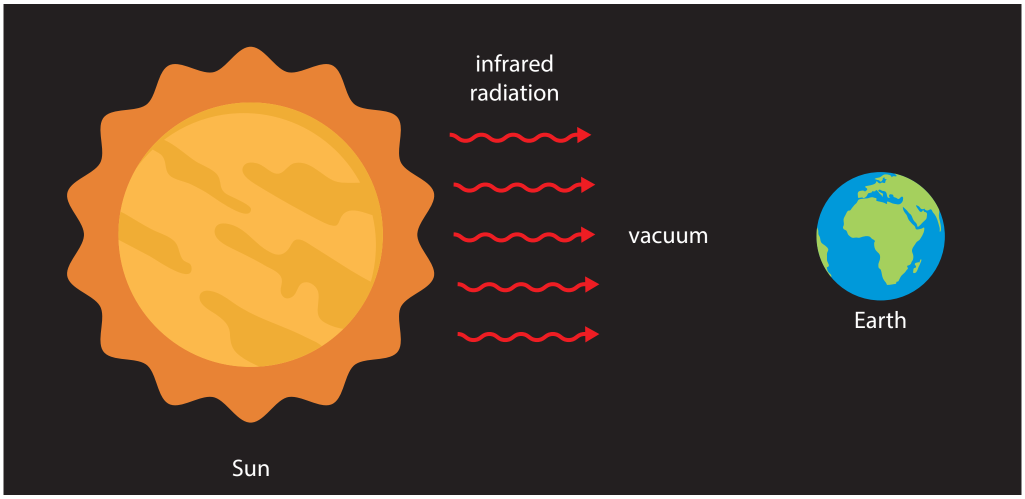


Figure 10.9 Thermal energy from the Sun is transferred to the Earth by thermal radiation only.

Figure 10.8 infrared radiation emitted by a human face

WORD ALERT

Absorb: take in

Emit: give out

ENRICHMENT INFO

Infrared Thermometer

An infrared thermometer measures the temperature of a surface using the infrared radiation the surface emits. As shown in Figure 10.10, the thermometer is pointed near a person's forehead. Infrared radiation emitted by the person is measured and shown as a temperature reading on the thermometer.

The advantage of using this thermometer is that it works from a distance. This reduces the chance of transferring harmful bacteria or viruses from one person to another when the thermometer is shared.

Figure 10.10 An officer measuring the temperature of the girl using an infrared thermometer

How can we investigate emission and absorption of different surfaces?

Emission

When objects emit infrared radiation, the temperature of the object decreases, and the object cools down. Good emitters will give out infrared radiation at a faster rate and cool down more quickly than bad emitters. Let us investigate the emission of infrared radiation through different surfaces (Figure 10.11).

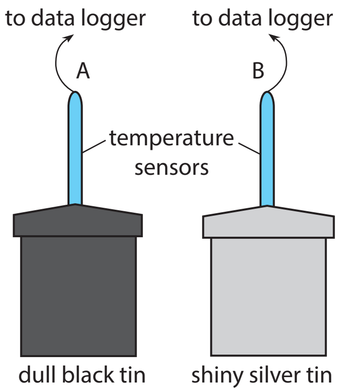


Figure 10.11 *Comparing emission of infrared radiation*

Figure 10.11 shows two tins which were filled with boiling water at the same time.The temperature sensors record the temperature change inside the respective tin.

Figure 10.12 shows the temperature–time graph recorded by the data logger. The temperature of the dull black tin fell at a faster rate than that of the shiny silver tin. They would eventually both reach room temperature. This shows that dull and black surfaces emit infrared radiation at a faster rate than shiny and silver surfaces.

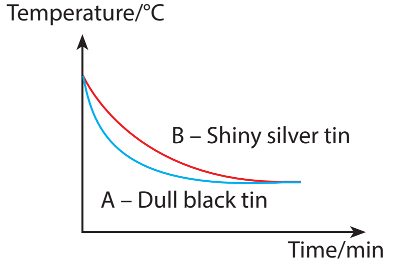


Figure 10.12 *Temperature–time graph*

Absorption

When objects absorb infrared radiation, the temperature of the object increases and the object heats up. Good absorbers will absorb infrared radiation at a faster rate than a bad absorber and heat up more quickly. Let us investigate the absorption of infrared radiation through different surfaces (Figure 10.13).

WORD ALERT

Matte: dull and not shiny

Figure 10.13 shows two temperature sensors at equal distances from a light bulb. Temperature sensor A is wrapped with aluminium foil. Temperature sensor B is wrapped with aluminium foil painted matte black. When the light bulb is switched on, it emits infrared radiation. This radiation will then be absorbed by the two types of foil. The temperature rise in each type of foil is then recorded in a data logger.

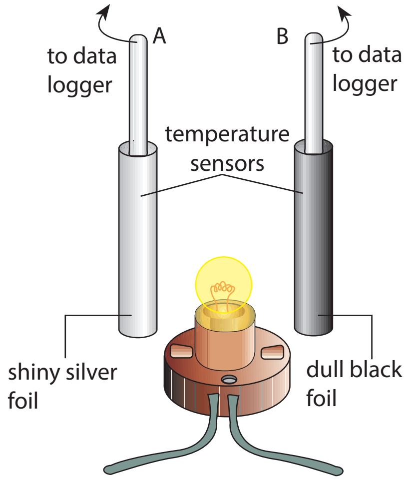


Figure 10.13 *Comparing absorption of infrared radiation*

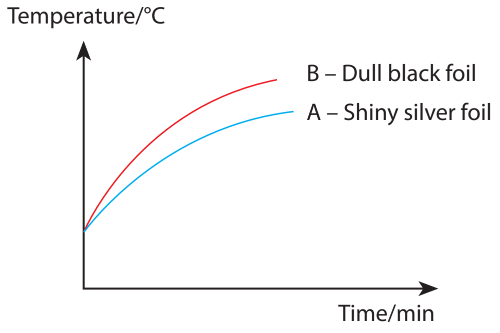


Figure 10.14 *Temperature–time graph*

Figure 10.14 shows the temperature–time graph recorded by the data logger. The temperature rise more quickly for the dull black foil as compared to the shiny silver foil. This shows that the dull black foil absorbs infrared radiation at a faster rate than the shiny silver foil.

From the two experiments, we can conclude that dull black surfaces emit and absorb infrared radiation at a faster rate than shiny silver surfaces. Shiny silver surfaces absorb less and reflect more infrared radiation.

PHYSICS WATCH

Scan this page to watch a clip on absorption and emission of radiation.

What factors affect the emission and absorption of thermal radiation?

The amount of infrared radiation absorbed by or emitted from a surface depends on three factors: surface colour and texture, surface temperature and surface area.

Surface colour and texture

Have you wondered why at the end of a marathon, the runners wrap themselves in what looks like a sheet of tin foil (Figure 10.15)? This foil, also known as a space blanket, was developed by the National Aeronautics and Space Administration (NASA). After a marathon, the body temperature of marathon runners drops drastically. This can cause hypothermia, a serious medical emergency in which the body rapidly loses heat. Space blankets can help to keep them warm by reducing thermal energy emission via infrared radiation. Figure 10.15 shows a marathon runner covered with a space blanket. Using what you have learnt previously in the chapter, can you explain how the space blanket keeps the marathon runner warm?

The space blanket has two shiny surfaces. The shiny outer surface reduces emission of infrared radiation from the runner to the surroundings. The shiny inner surface reflects the infrared radiation back to the runner. These allow the marathon runner to keep himself warm.

From what we have learnt in the earlier section, the amount of infrared radiation absorbed by or emitted from a surface is dependent on the **colour and texture** of the surface.

Dull and black surfaces emit and absorb infrared radiation at a faster rate than shiny and silver surfaces. Shiny and silver surfaces reflect more infrared radiation.

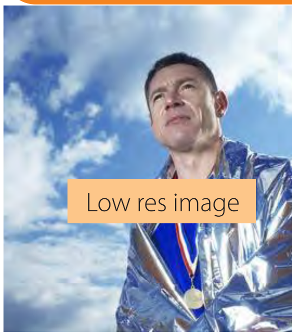


Figure 10.15 *A marathon runner using a space blanket to keep himself warm*

QUICK CHECK

Rooftop solar water heater are painted black because black is a better absorber of infrared radiation.

True or false?

Surface temperature

The higher the temperature of an object's surface relative to the surrounding temperature, the higher the rate of emission of infrared radiation (Figure 10.16).

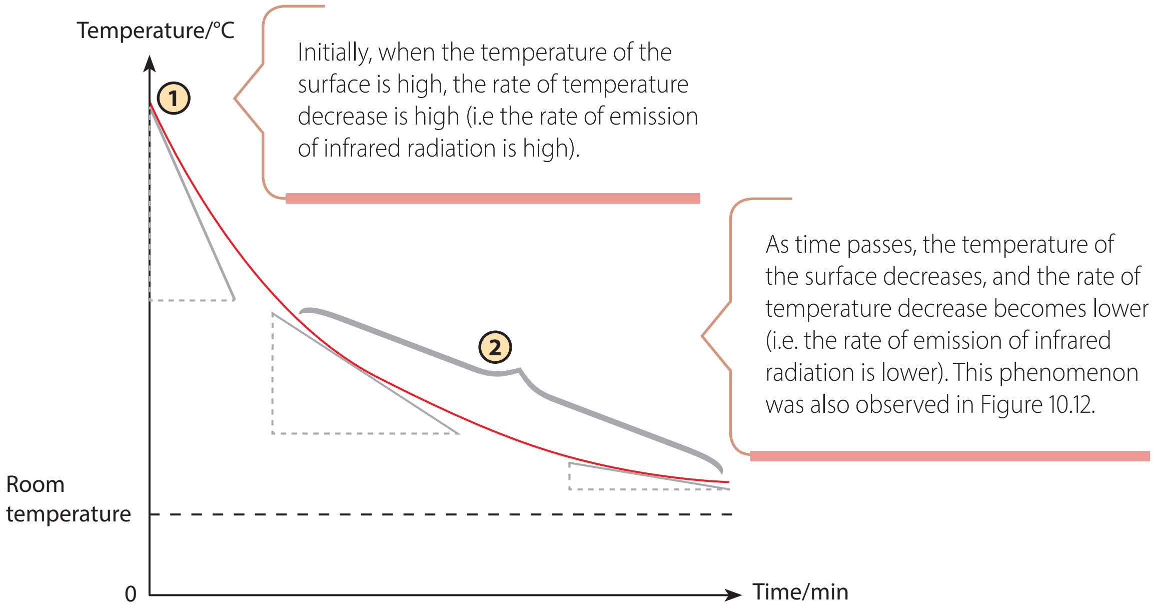


Figure 10.16 *The surface temperature of an object affects its rate of emission of infrared radiation.*

LINK

Recall from Section 10.1 that thermal energy always flows from a region of higher temperature to a region of lower temperature.

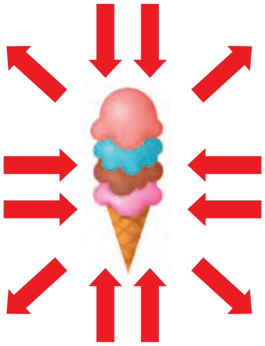
Surface area

If we compare two objects of the same mass and material, but with different surface areas, the object with the larger surface area will emit or absorb infrared radiation at a higher rate.

How does the emission and absorption affect the temperature of an object?

All objects continuously emit and absorb infrared radiation. How will the rates of emission and absorption compare if the object is warming up, cooling down or staying at the same temperature?

If an object absorbs energy at a greater rate than it emits energy, then it is warming up. This will happen if the object is cooler than its surroundings (Figure 10.17 (a)).



- An ice cream outside on a hot day
- Temperature of ice cream = 0°C
- Temperature of surroundings = 30°C
- Infrared radiation absorbed > infrared radiation emitted
- The ice cream warms up.

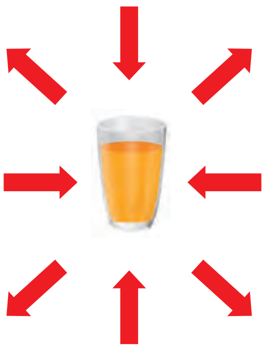
Figure 10.17 ***(a)*** *An ice cream warms up as it absorbs more infrared radiation than it emits.*

If an object emits energy at a greater rate than it absorbs energy, then it is cooling down. This will happen if the object is hotter than its surroundings (Figure 10.17 (b)).

- A cup of hot coffee in an air-conditioned room
- Temperature of coffee = 80°C
- Temperature of surroundings = 20°C
- Infrared radiation absorbed < infrared radiation emitted
- The coffee cools down.

Figure 10.17 ***(b)*** *A cup of hot coffee cools down as it emits more infrared radiation than it absorbs.*

If the rates of emission and absorption of an object are the same, then the temperature of the object will not change. This will happen if the object is at the same temperature as its surroundings (Figure 10.17 (c)).



- A glass of orange juice at 20°C in a room at 20°C
- Temperature of orange juice = 20°C
- Temperature of surroundings = 20°C
- Infrared radiation absorbed = infrared radiation emitted
- The orange juice is in thermal equilibrium with its surroundings.

Figure 10.17 ***(c)*** *A cup of orange juice does not change in temperature as the infrared radiation emitted is the same as the infrared radiation absorbed.*

The temperature of the Earth is maintained at around 15°C due to the greenhouse effect. The greenhouse effect is a natural process that warms the Earth's surface through a balance of absorption and emission of infrared radiation. This is shown in Figure 10.18.

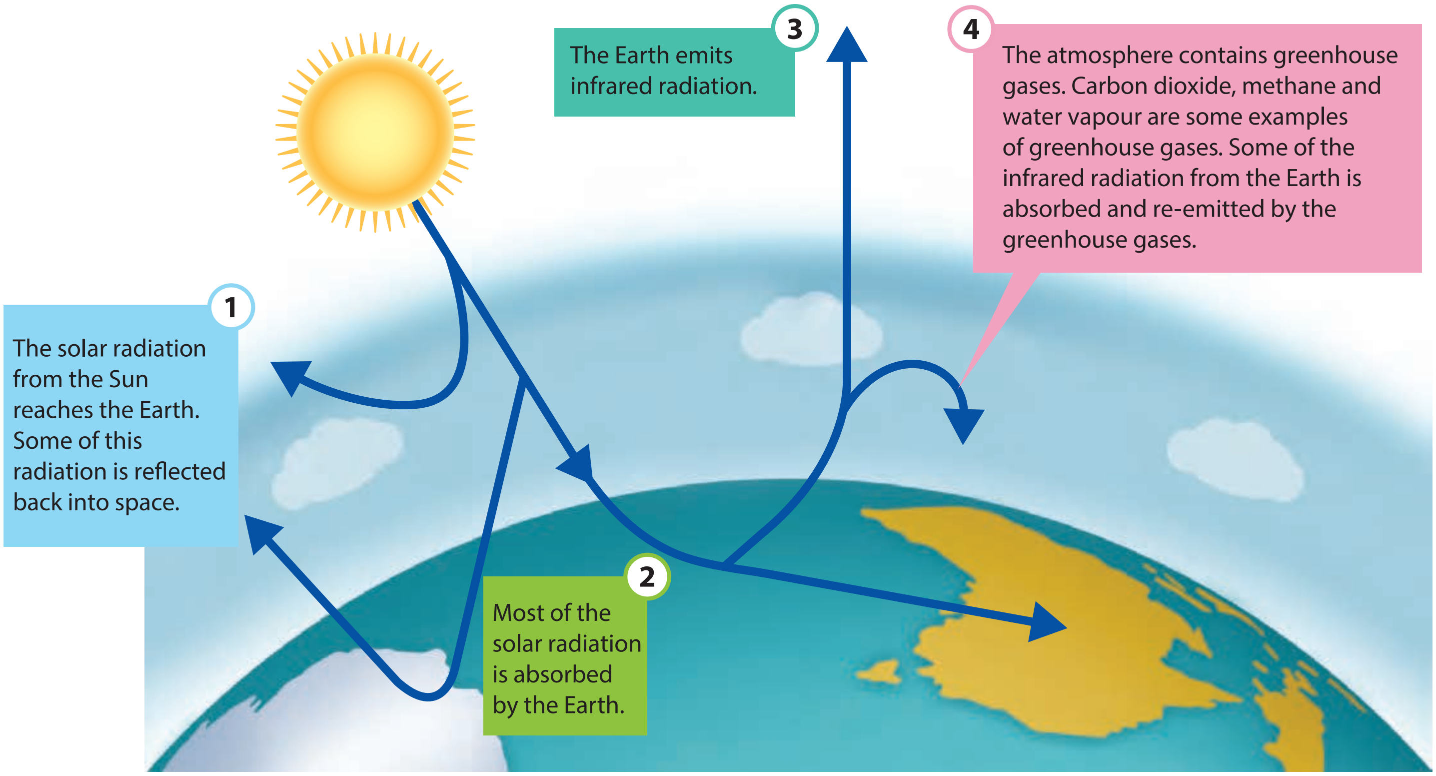


Figure 10.18 *The greenhouse effect is needed to keep the temperature of the Earth suitable for life.*

However, human activity has increased the amount of greenhouse gases in the atmosphere. For example, the use of fossil fuels has increased the amount of carbon dioxide gas. Agriculture, such as rearing of cattle, has increased the amount of methane. The increase in greenhouse gases results in more thermal energy being radiated back to the Earth. This is causing the temperature of the Earth to increase, causing global warming.

Let's Practise 10.4

1 Identify how thermal energy is transferred from the Sun to the Earth. Explain why thermal energy from the Sun cannot reach the Earth by other processes.

2 Why would you feel hot if you wore dark-coloured clothes on a hot day?

3 Describe an experiment to find out how surface colour and texture affects the absorption and emission of infrared radiation.

4 S State three factors that affect the rate of transfer of thermal energy by radiation.

5 S Using thermal energy transfer(s), explain what causes the change in the following objects:

(a) A piece of ice cube from the freezer melts when placed on the table.

(b) A car heats up after being parked under the hot Sun.

6 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

TWB LINK
Exercise 10D, pp. XX–XX

10.5 Applications and Consequences of Thermal Energy Transfer

In this section, you will learn the following:

- Explain some of the basic everyday applications and consequences of conduction, convection and radiation.
- S Explain some of the complex applications and consequences of conduction, convection and radiation.

One method of thermal energy transfer

Consequence of conduction

Have you noticed that a metal object feels colder to the touch than a plastic object even if they are at the same temperature (Figure 10.19)?

The metal pole is a good thermal conductor. It conducts thermal energy away from your warm hand, making it feel cold. Plastic is a good thermal insulator and does not conduct thermal energy away from your hand.

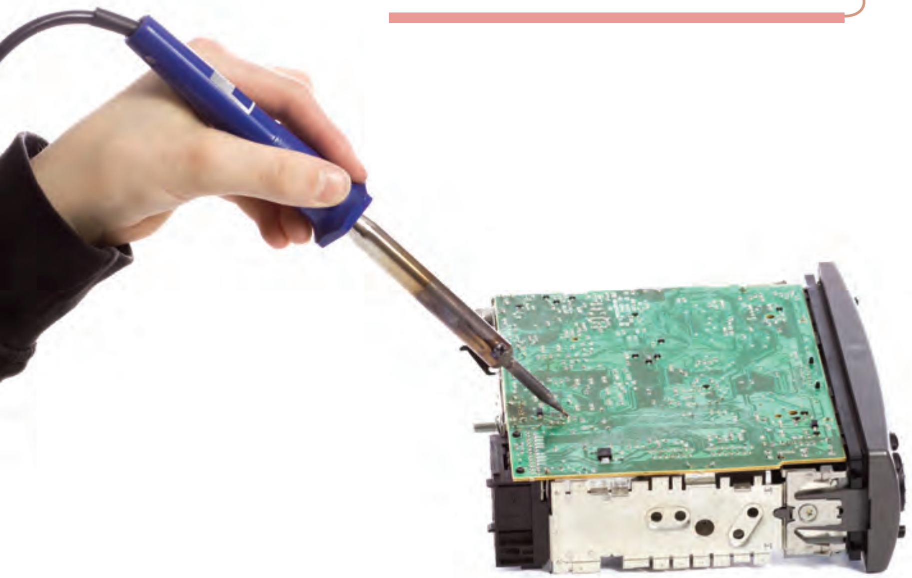
Figure 10.19 Your hand feels cold when you touch a metal pole.

Applications of good thermal conductors

To transfer thermal energy quickly through a substance, good thermal conductors are used. Metals are examples of good thermal conductors. They are commonly used to make the items shown in Figure 10.20.

Cooking utensils

Saucepans, woks and pots are usually made of aluminium or stainless steel.



Soldering irons

Soldering irons are used to build and repair electronic circuits. The tips are made of copper as it is a very good thermal conductor and quickly transfers thermal energy from the soldering iron to the electronic circuit.

Figure 10.20 Examples of items that make use of the good thermal conductivity of metals

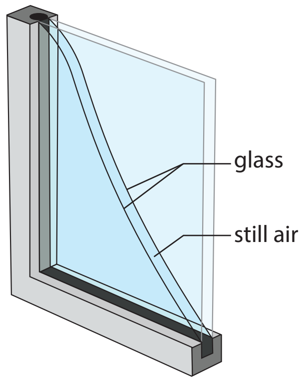
Applications of bad thermal conductors (good thermal insulators)

To reduce thermal energy from being transferred quickly, good thermal insulators are used. Figure 10.20 shows some common uses of good thermal insulators.

Handles of cooking utensils

Handles of cooking utensils like saucepans are made of wood or plastics.

This protects our hands from getting hurt from touching a hot saucepan on the stove.



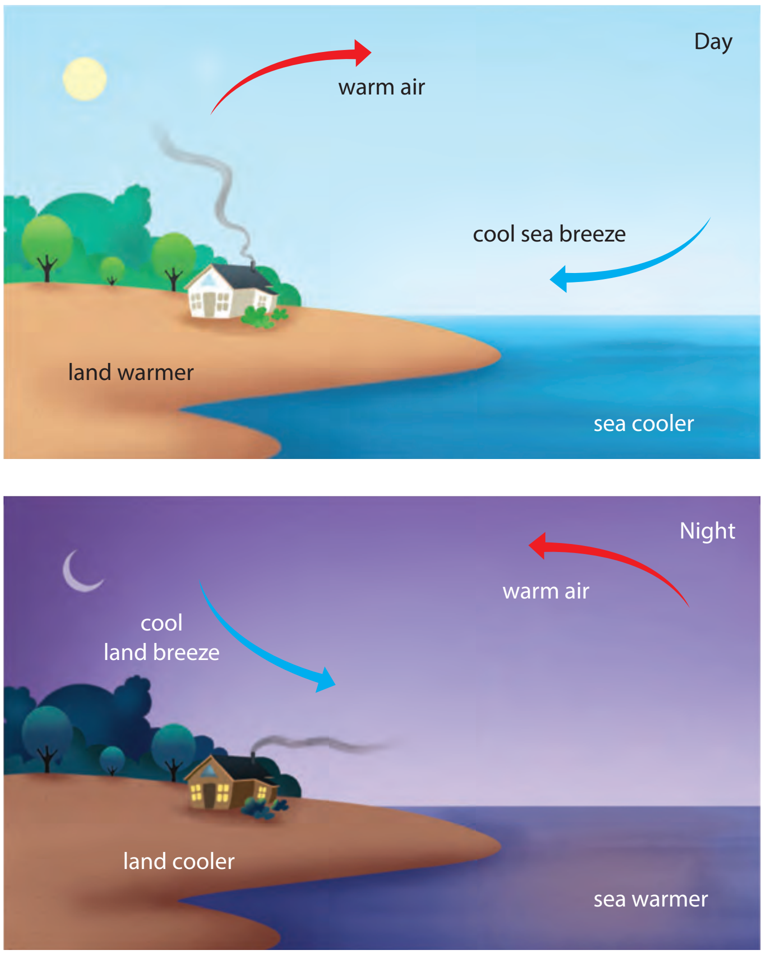
Double-glazed window

A double-glazed window has a layer of still air trapped between two panes of glass. Still air is a good thermal insulator and reduces the thermal energy passing through the window.

Figure 10.21 *Examples of items that use good thermal insulators to reduce thermal energy transfer*

Consequence of convection

There is often a breeze near the sea when there is no wind inland. The direction of the breeze is dependent on the time of the day as shown in Figure 10.22.



During the day, the sand on the beach heats up more quickly than the sea. The warmer air above the sand rises as it is less dense than its surroundings. Cooler air from the sea will be drawn in to take its place. This sets up a convection current, creating a sea breeze.

In the evening, the sand cools more quickly than the sea. The warmer air above the sea rises as it is less dense than its surroundings. Cooler air from the land will be drawn in to take its place, setting up convection currents in the opposite direction. This creates a land breeze.

Figure 10.22 *Convection currents near the sea*

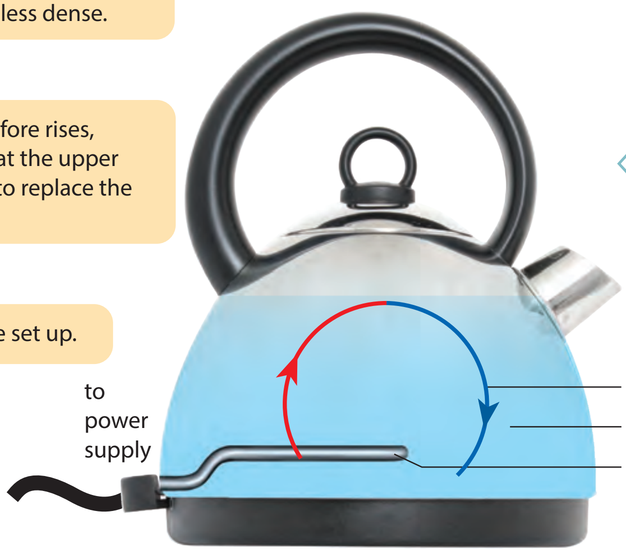
Applications of convection

Figures 10.23 and 10.24 show some examples of appliances that use convection to function.

① When the power is switched on, the water near the heating coil heats up, expands and becomes less dense.

② The heated water therefore rises, while the cooler water at the upper part of the kettle sinks to replace the heated water.

③ Convection currents are set up.



Electric kettles

Have you noticed that the heating coils of electric kettles are always placed at the bottom of the kettle? This enables the transfer of thermal energy in water by convection.

Figure 10.23 *The convection currents in the electric kettle enable the water in the kettle to be heated up more quickly and evenly.*

Air conditioners

Air conditioners are used to cool houses in warm weather. An air conditioner is always installed near the ceiling of a room. It sends cool, dry air into the room. As cool air is denser, it sinks. The warm air below, being less dense, rises and is drawn into the air conditioner where it is cooled. Hence, the circulating convection currents cool the room.

Hot water radiators

Hot water radiators are often used to heat houses in cold weather. Even though they are named "radiators", they heat the air in the room mainly by convection. The air around a radiator is heated up by the radiator and rises. The surrounding cold air is drawn into the radiator, where it is heated up. The circulating convection currents heat up the room.

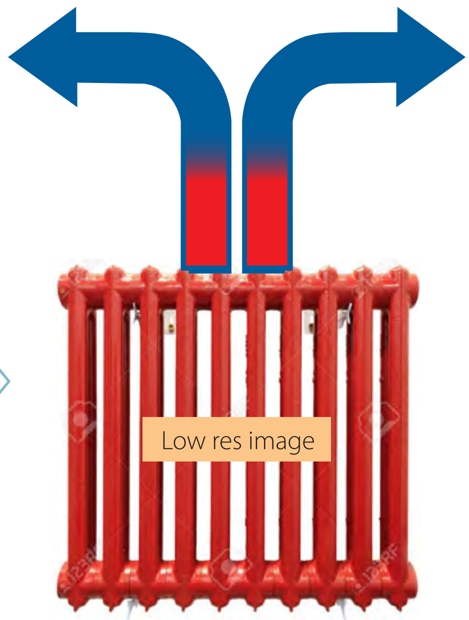


Figure 10.24 *The convection currents by an air conditioner and a radiator help to control the temperature of a room during different parts of the year.*

Consequence of radiation

Infrared radiation from the Sun travels through the vacuum of space and the atmosphere to warm the Earth. The Earth's surface absorbs the radiation, warms up and emits infrared radiation back into space (Figure 10.25).

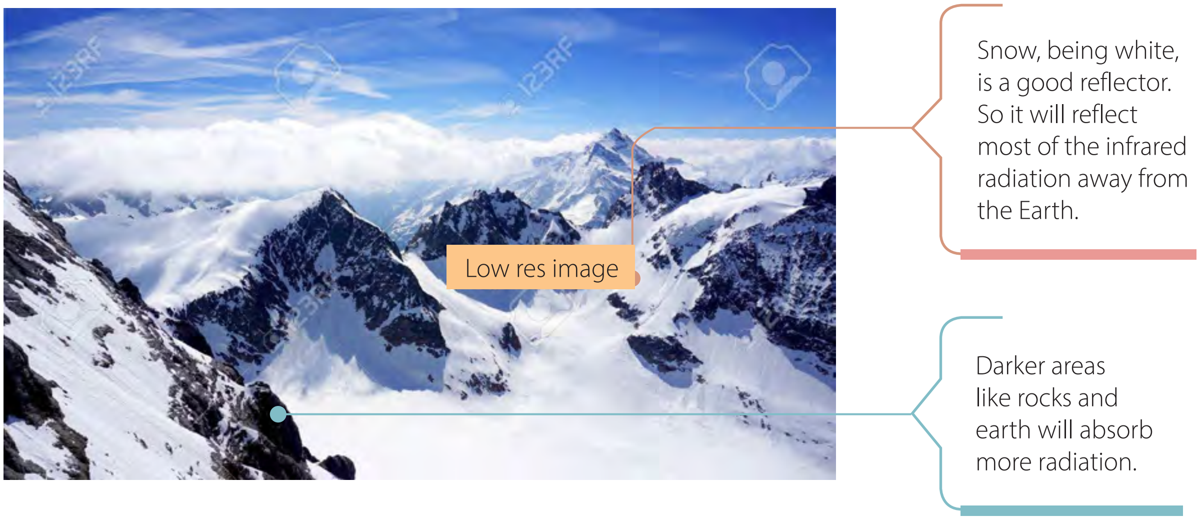


Figure 10.25 *Snow on mountains help to reflect radiation from the Sun.*

Due to global warming, snow is melting at an increasing rate. This can reduce the amount of radiation reflected from the Earth, causing the Earth to warm up even more.

Application of radiation

Greenhouses are used in cold climates to trap thermal energy (Figure 10.26). The temperature of a greenhouse is higher than the temperature outside. This enables plants to grow when it would normally be too cold for them.

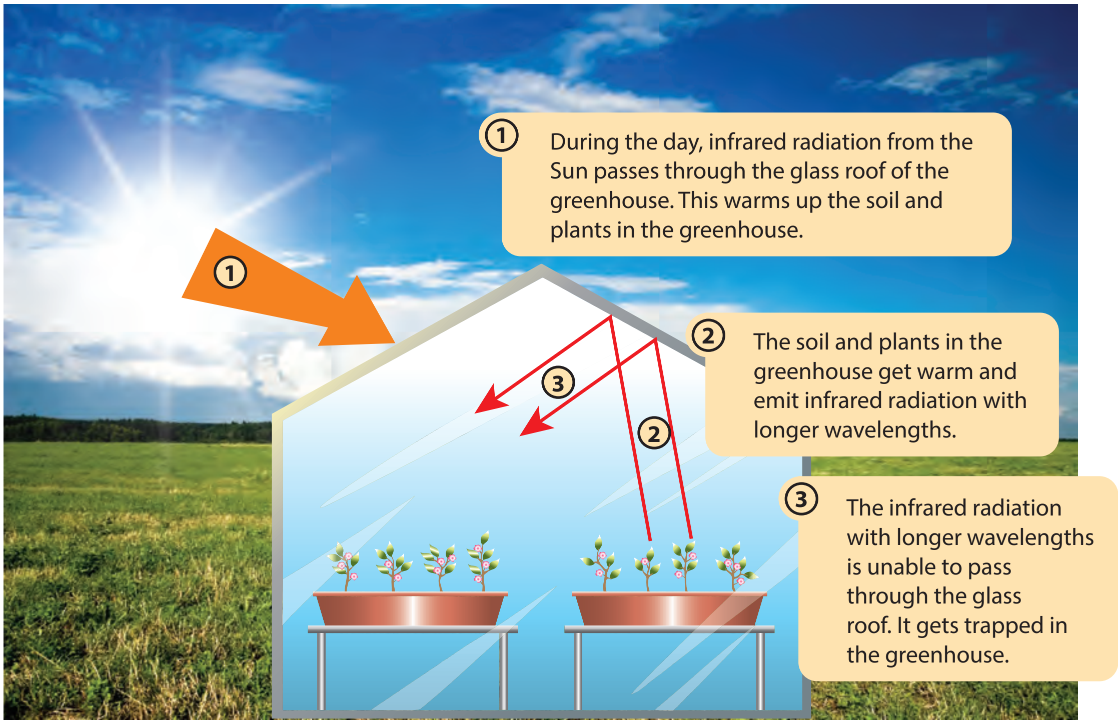


Figure 10.26 *Infrared radiation gets trapped in the greenhouse.*

Figure 10.27 *Boiling water over a campfire*

Multiple methods of thermal transfer

Cooking on a wood fire

Wood burns and releases thermal energy. Thermal energy is then transferred via conduction, convection and radiation to the surroundings. Figure 10.27 shows a pot of water being boiled over burning wood.

The bottom of the metal pot is in contact with the fire so thermal energy will be transferred to the bottom of the metal pot through *conduction*. The ground underneath the fire will also get hot by conduction.

The flames will emit *infrared radiation*. If you place your hands close to the fire (be careful not to touch the flames), you will be able to feel the infrared radiation from the flames warming your hands.

The thermal energy from the burning wood will heat the air around it. The hot air rises up above the fire, as shown by the smoke. Surrounding cold air will be drawn in, forming *convection* currents. The water inside the pan will also heat up by convection.

Car radiator

Combustion engines in petrol-driven cars and motorbikes burn fuel to allow the vehicle to move. During the process, the engine becomes hot and has to be cooled to prevent overheating. One way of doing this is to pump a liquid coolant in metal pipes through the engine and into a radiator. Figure 10.28 explains how thermal energy from the engines is transferred away using a coolant. The arrows represent the movement of the coolant across the engine and the radiator.

(1) Metal tubes carry the hot coolant from the engine to the radiator.

(2) The radiator contains many thin metal fins. Thermal energy is *conducted* through the metal tube into the fins. The fins have a large surface area, so they are in contact with a lot of air. The fins heat up the air around it, and a fan blows the warmer air away, replacing with cooler air, forming *convection* currents.

(3) The tubes and fins are painted black to increase the amount of *infrared radiation* emitted from the hot tubes and fins.

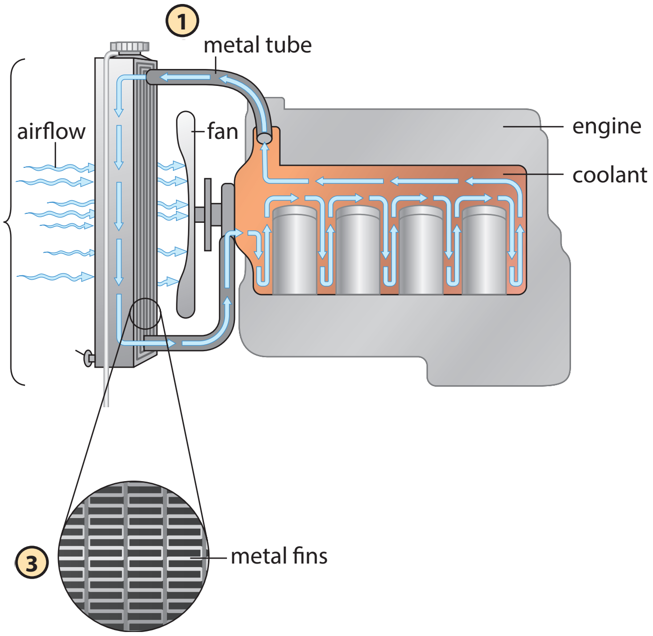


Figure 10.28 *Cooling system of a petrol-driven car*

Let's Practise 10.5

1 A copper saucepan containing water is placed on a flat electric hot plate.
   (a) State the process by which thermal energy is
      (i) transferred from the hot plate to the water;
      (ii) spread throughout the water.
   (b) The sides of the saucepan are well polished. How does this reduce thermal energy loss?

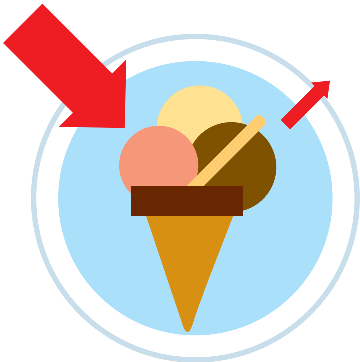
2 **Mind Map** Construct your own mind map for the concepts that you have learnt in this section.

LINK

Exercises 10E–10F, pp. XX–XX
Exercise 10G Let's Reflect, p. XX

Let's Map It

THERMAL ENERGY



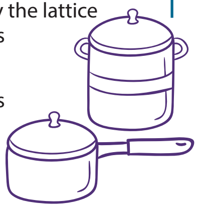
is transferred from

A region of higher temperature to a region of lower temperature until thermal equilibrium is reached.

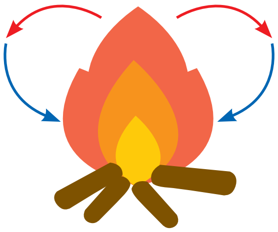
by the processes of

Conduction

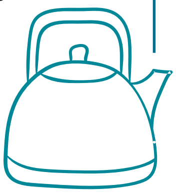
- Through contact between two surfaces
- Requires a medium
- **S** In non-metals, by the lattice vibration of particles
- **S** In metals, by the vibration of particles and free electron diffusion



Convection

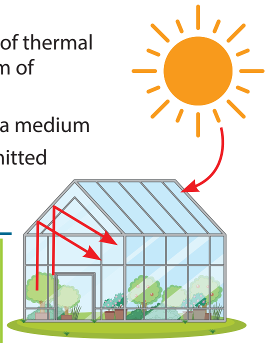


- Through bulk movement of fluids (liquid or gas), forming convection currents
- Requires a medium
- Convection currents form due to changes in the density of the fluid



Radiation

- Through transfer of thermal energy in the form of infrared radiation
- Does not require a medium
- Absorbed and emitted by all objects

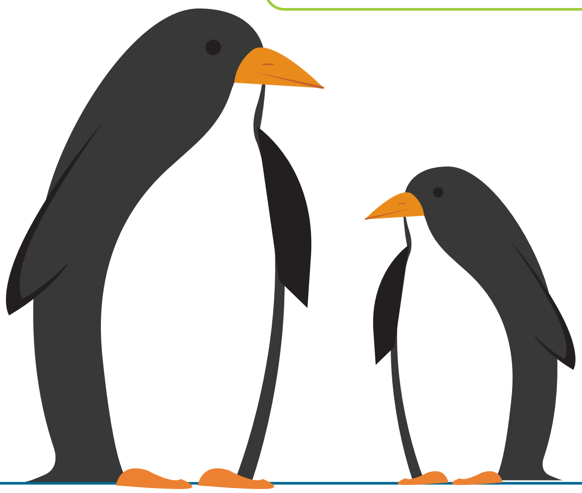


which can be applied in

- Cooking utensils
- Soldering irons
- Double-glazed windows
- Electric kettle
- Air conditioners
- Hot water radiators
- Greenhouse
- **S** Car radiators

where the rate of thermal energy transfer is affected by

- Surface colour and texture
- **S** Surface temperature
- **S** Surface area



Let's Review

Section A: Multiple-choice Questions

1 Ⓢ According to the kinetic theory of matter, thermal energy is transferred from the hot end of a glass rod to the cold end when the molecules from the hot end ______.

- **A** emit infrared radiation to the cold end
- **B** move from place to place so that they collide with the colder molecules and transfer the energy to them
- **C** move to the cold end
- **D** vibrate more vigorously and pass on the energy to the neighbouring molecules

2 In a hot water tank, the heating element should be placed at the bottom because ______.

- **A** conduction cannot take place when the heater is at the top of the tank
- **B** infrared radiation travels faster in the upward direction
- **C** the heated water will rise and this will form convection currents
- **D** the heater must be covered by water at all times

3 Ⓢ In a vacuum flask, the vacuum prevents thermal energy transfer by ______.

- **A** conduction
- **B** conduction and convection
- **C** convection
- **D** radiation

Section B: Short-answer and Structured Questions

1 A cup of hot tea is left on a table. Explain how thermal energy escapes from the tea by

(a) conduction;
(b) convection;
(c) radiation.

2 Explain the following:

(a) A stone floor feels colder to the bare feet than a carpet even though they are at the same temperature.
(b) The freezing compartment is at the top of a refrigerator.
(c) A double-glazed window reduces thermal energy transfer through it.
(d) The hot pipes at the back of a fridge are painted black.
(e) Both the inside and outside of a space blanket are made of a shiny, silvery material.

3 Ⓢ A vacuum flask is used to keep hot liquids hot or cold liquids cold. It is designed to reduce thermal energy from entering or leaving from inside (Figure 10.29).

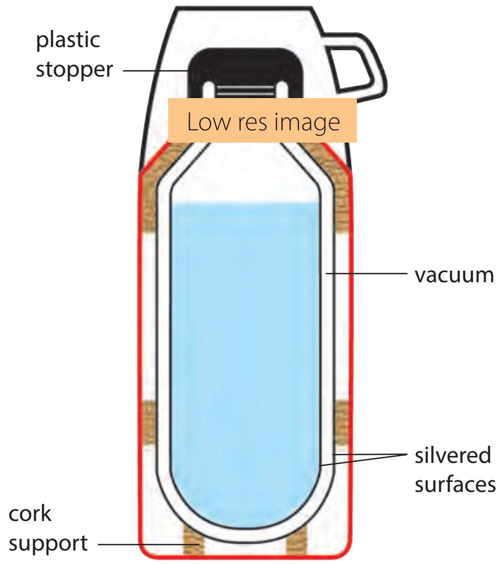


Figure 10.29

Suggest a function of the following parts of the vacuum flask:

(a) The vacuum between the double walls of the glass container
(b) The silvered surfaces of the glass container
(c) The plastic stopper
(d) The cork supports between the inner glass container and outer flask