Motion and energy

8

HAVE YOU EVER WONDERED…

- why objects speed up as they fall to the ground?
- why a boomerang comes back?
- why you sometimes feel heavier than usual when travelling in a lift?
- why it is hard for a heavy truck to stop quickly?

After completing this chapter students should be able to:

- use equipment to gather data and analyse everyday motions
- apply Newton's laws to predict how a balanced or an unbalanced force affects the motion of an object
- use Newton's third law to describe interactions between two objects
- explain that the law of conservation of energy means that the total energy is maintained in energy transfer and transformation
- clarify that an energy transfer or transformation is never 100% efficient
- compare energy changes in interactions such as car crashes, pendulums or lifting and dropping
- use models to describe how energy is transferred and transformed.

8.1 Describing motion

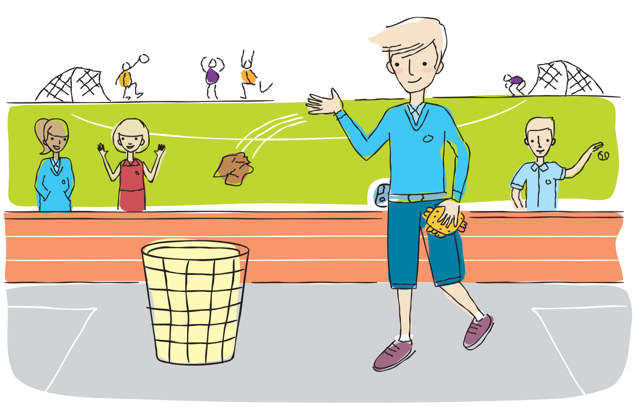
'Ready, set, go!' Many children love to race each other and see who wins. This desire also drives sports people to push their bodies to the limit. Vehicles such as aircraft, racing cars and very fast trains are designed to travel as fast as possible. It is important to be able to measure aspects of motion such as speed. It enables speed limits to be set for safe driving and allows us to estimate travel time.

INQUIRY science 4 fun

Lunchtime marathon

How far do you travel during a typical lunch break and how far do you end up from where you started?

Yes



Collect this ...

- pedometer
- ruler, trundle wheel or tape measure

Do this ...

1. Clip a pedometer onto yourself at school at lunchtime, or for an hour after school once you get home.
2. Record the number of steps you take in this time.
3. Measure the length of a typical step that you take.
4. Calculate the approximate total distance that you covered during the trial.
5. Measure the distance between where you started and where you finished the trial using measuring tape, trundle wheel or by estimating using pace length.

Record this ...

Describe any differences in your answers to steps 4 and 5.
Explain why these were different.

Distance and displacement

When planning a trip around parts of Australia, you would need to consider the **distance**, or how far away places to visit are. You would also need to consider the amount of time you have. In this case, distance would be measured in kilometres, and your time in days or weeks. If considering a trip to the end of your street, distance would be measured in metres and the time would be measured in minutes or even seconds.

You also need to consider where you will end your journey. Your **displacement** is straight-line distance between the finishing and starting points. If you travel from home to the house of a friend who lives 200 km south, then your displacement is 200 km south. Displacement specifies not only the distance from the starting point, but also the direction of the end point from your starting point.

Distance is a **scalar quantity**—it has a size but not direction. Displacement is a **vector quantity**—it has both a size *and* direction. If travelling on a return trip, you can cover a large distance, but your displacement upon returning home is zero. Figure 8.1.1 illustrates a journey that covers a certain distance, but the displacement is zero. Figure 8.1.2 compares the distance travelled with the displacement of a student who walks from their home to school.

Figure 8.1.1 Emily and Lucy take their dog, Harry for a walk and stop at a shop for an ice cream before returning home. The distance they walk is about 600 m, but their displacement is zero.

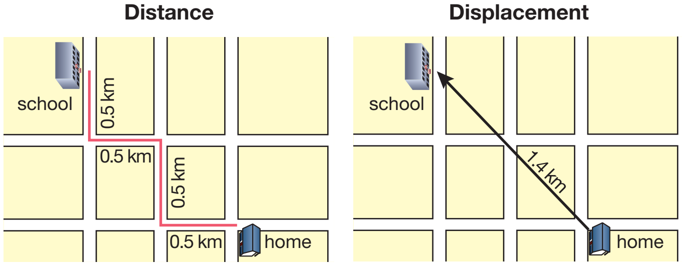


Figure 8.1.2 Greg walks to school and travels a distance of 2 km. His displacement is 1.4 km north-west.

SKILL BUILDER: Using SI units

It is easier to compare things such as distance, temperature and speed if people in different parts of the world agree to describe these in the same units. The International System of Units, called SI units (from the French, Le Système International d'Unités), is a standard that was introduced in 1960. This lists seven key quantities and the standard unit used to measure each. They are shown in Table 8.1.1.

Table 8.1.1 SI units

Quantity	Standard unit	Unit abbreviation
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance (used in senior chemistry)	mole	mol
Luminous intensity (brightness)	candela	cd

Combinations of these units can be used to produce SI units for all other quantities. For example, the SI unit for speed is m/s.

Speed and velocity

Average speed

Speed is a measure of how quickly something moves. Average speed can be calculated as:

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

or

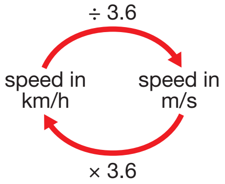
$$v = \frac{d}{t}$$

where v is speed, d is distance travelled and t is time taken.

An object moves faster when it travels a greater distance in a certain time, or covers a set distance in a shorter time.

SKILL BUILDER: Converting units

The speed of a car is usually measured in kilometres per hour (km/h). The SI unit for speed is metres per second (m/s). Speeds can be converted from m/s into km/h and km/h into m/s by multiplying or dividing by 3.6 as shown here.



WORKED EXAMPLE
Speed calculations

Problem 1

Convert the following speeds into km/h.

a 3 m/s

b 12.5 m/s

Solution

a 3 m/s = 3 × 3.6 km/h = 10.8 km/h

b 12.5 m/s = 12.5 × 3.6 km/h = 45 km/h

Problem 2

Convert the following speeds into m/s.

a 54 km/h

b 16.2 km/h

Solution

a 54 km/h = 54 ÷ 3.6 m/s = 15 m/s

b 16.2 km/h = 16.2 ÷ 3.6 m/s = 4.5 m/s

Problem 3

Theo spent 8 hours travelling 400 km from his home in Bundaberg to visit his sister in Toowoomba. Calculate Theo's average speed for the journey.

Solution

$$v = \frac{d}{t}$$

$$= \frac{400}{8}$$

$$= 50 \text{ km/h}$$

Theo's average speed was 50 km/h.

SciFile

Giddy-up?

Humans appear to be getting faster with every new world record set in athletics. Are animals getting faster? Research of data from horse and dog racing has shown that the top speed of a horse has not increased since the 1940s and that of a dog has not increased since the 1970s.

Calculating distance

The formula for average speed can be rearranged to calculate the distance travelled in a certain time as:

distance = average speed × time

or

$$d = v \times t$$

When driving a car, it is vital to stay alert. If a child runs onto the road, or a car breaks down in front of you, you need to react and apply the brakes as quickly as possible. During this **reaction time,** the car still moves forwards and travels a distance called the **reaction distance**. When trying to avoid a collision, this distance is critical. A driver's reaction time is slowed by distractions in the car. Distractions could be caused by:

- other people
- speaking or texting on a mobile phone
- changing the radio station.

Additional factors such as a person's age, fatigue and the influence of drugs and alcohol also slow a person's reaction time.

Once you have reacted and applied the brakes, the car will still cover some additional distance, called the braking distance, as it comes to a stop.

1 p259

8.1

WORKED EXAMPLE
Calculating distance

Problem 1

Trinh rides her bike with a constant speed of 5 m/s. It takes her 3 minutes to get to the milk bar. Calculate how far away it is.

Solution

First, convert the time she took into seconds in order to state the answer in metres.

$t = 3 \times 60 = 180$ s

Trinh has travelled:

$$d = v \times t$$

$$= 5 \times 180$$

$$= 900 \text{ m}$$

The milk bar is 900 m away.

Problem 2

While Trinh is riding, a toddler runs onto the road ahead. If Trinh took 0.5 second to react, how far does she travel before hitting the brakes?

Solution

$$d = v \times t$$

$$= 5 \times 0.5$$

$$= 2.5 \text{ m}$$

Trinh travels 2.5 m before hitting the brakes. She will then travel further as she slows to a stop.

Instantaneous speed

Average speed is the total distance travelled in a journey, divided by the total time taken. Average speed does not give any indication of how slowly or how quickly you may have travelled in a trip, or how long you were caught in a traffic jam or stopped at traffic lights. Figure 8.1.3 shows evenly spaced time intervals of a tennis serve. The racquet moves the greatest distance in the time interval at the end of the serve and so it is moving the fastest at this point. Your speed at a particular instant is called your **instantaneous speed**. The vehicle shown in Figure 8.1.4 is designed to reach an enormous instantaneous speed. In a car, this is indicated by the speedometer. If travelling above the speed limit, you can be caught by a mobile speed camera (Figure 8.1.5), which measures the instantaneous speed of a car.

Figure 8.1.3 The distance moved by this racquet in each time interval provides a measure of its instantaneous speed.

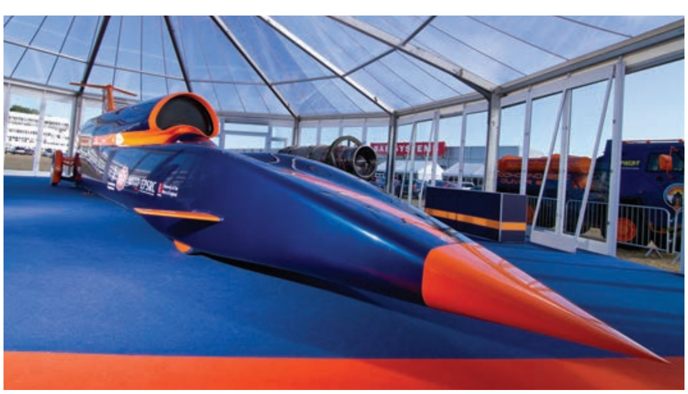


Figure 8.1.4 The Bloodhound SSC is powered by a jet engine and a rocket. Its UK designers hope it will reach an instantaneous speed of 1600 km/h!

Figure 8.1.5 Handheld speed cameras measure the instantaneous speed of a vehicle.

Velocity

You may have heard the term *velocity* used when someone is talking about speed. In science, velocity has a slightly different meaning from speed. **Velocity** is the rate at which displacement changes. In other words, velocity is how displacement changes with time. Displacement is specified with a size and a direction and so velocity must have a direction too. A person may ride a bike at a constant speed of 20 km/h. However, every time they change direction, their velocity changes too. Velocity is a vector quantity, while speed is a scalar quantity

Measuring speed

There are different ways of measuring speed. Light gates can be used to time sporting events such as downhill skiing (Figure 8.1.6). Light gates use a sensor to trigger an electronic timing mechanism when an object breaks through a light beam.

Figure 8.1.6 Light gates can be used to measure time to the millisecond and produce very accurate measurements of an object's speed.

A motion sensor (Figure 8.1.7) sends out pulses of radiation, such as ultrasonic sound waves, microwaves or infrared radiation. The reflection of this radiation from an object provides data about its position and speed.

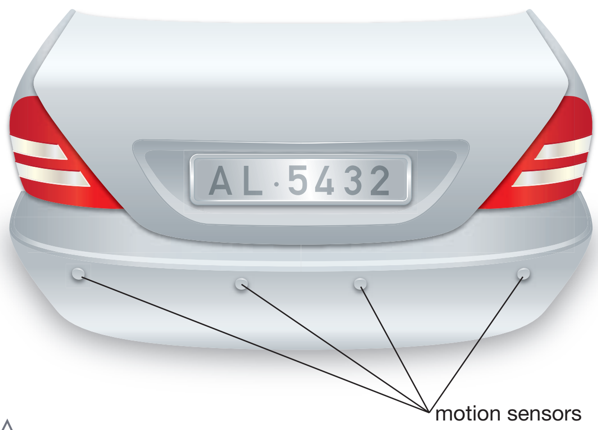


Figure 8.1.7 Motion sensors on the bumper bar of a car provide the driver with information about how close they are to a barrier.

A ticker timer is shown in Figure 8.1.8. It consists of a small electric arm with a pin or hammer on its end. The hammer vibrates up and down 50 times per second, synchronised with the alternating current of 50 Hz supplying its power. The hammer hits a piece of carbon paper that leaves a dot on a strip of paper threaded below it. When the timer is attached to an object moving in a straight line, these dots are a record of its motion (Figure 8.1.9).

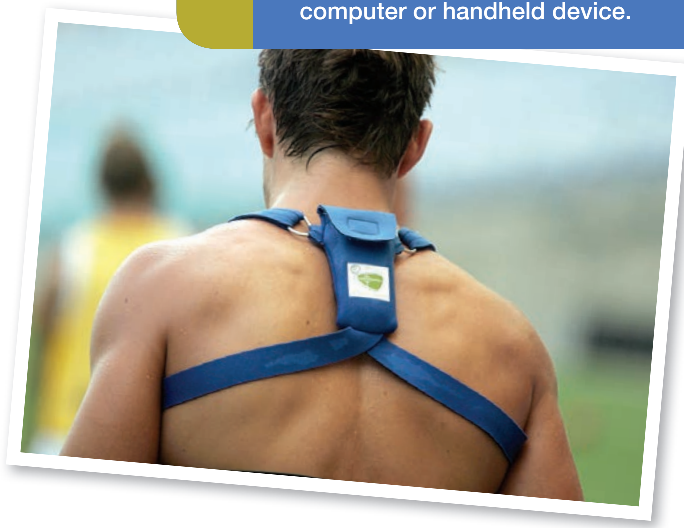
SciFile

GPS in sport

Global positioning system (GPS) equipment is used by a number of sporting teams to record real time data, such as:

- distance travelled by a player
- a player's speed (maximum, minimum, average)
- intensity of impacts
- heart rate.

The data is relayed to a laptop computer or handheld device.



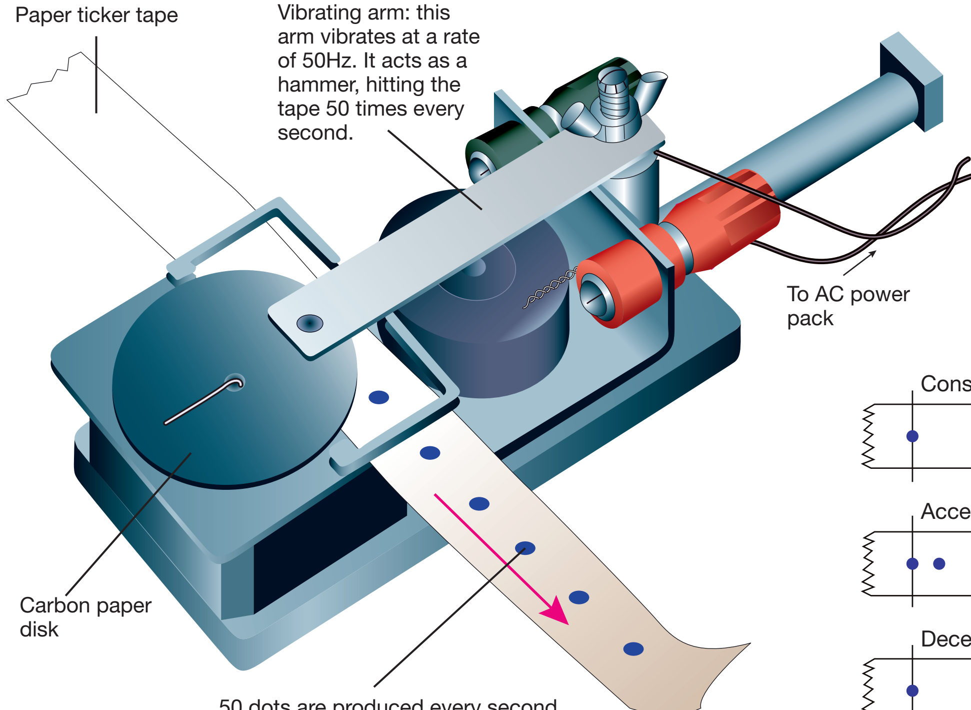


Figure 8.1.8 Analysing the distance between dots recorded on a strip of ticker tape reveals the speed of the moving object used to produce the trace.

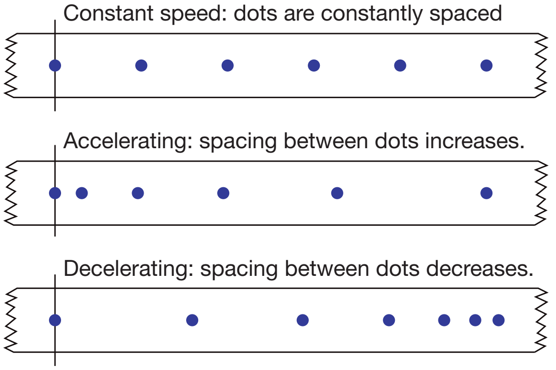


Figure 8.1.9 The spacing of the dots on a ticker tape tells you what type of motion it is. Each new dot represents 0.02 seconds has passed.

Graphing motion

A graph is a useful way of illustrating an object's motion. Time is always placed on the horizontal axis.

Distance–time graphs

A distance–time graph shows how far an object travels as time progresses. A flat line on this graph indicates that the motion has stopped. A line with a steep slope indicates that the object covers greater distance and is moving faster than a line of gentle slope does. The slope is also known as the **gradient**. The slope or gradient of a distance–time graph is equivalent to the object's average speed over a time interval. Figure 8.1.10 shows the distance–time graph of a cyclist.

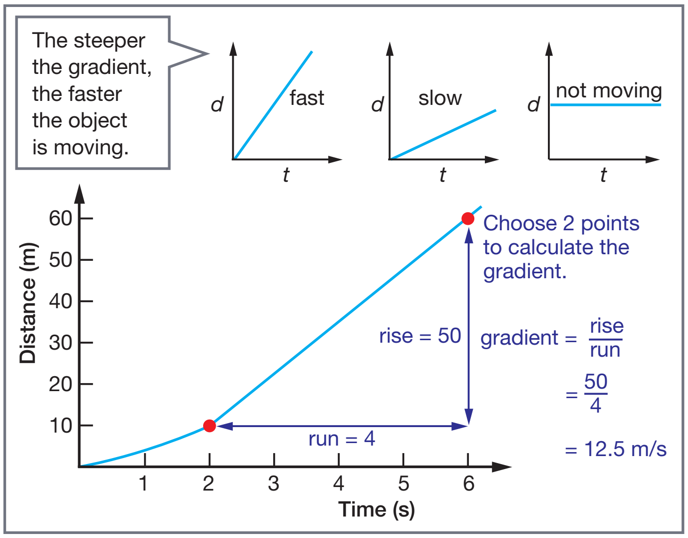


Figure 8.1.10 The cyclist gradually increases speed as they start to pedal. After 2 seconds, the cyclist is travelling at a constant speed of 12.5 m/s.

Displacement–time graphs

Alternatively, an object's displacement can be shown on the vertical axis of a graph instead of distance. In this case, the graph shows how the position of the object changes compared to where it started. Figure 8.1.11 illustrates a displacement–time graph for Mitsu walking to and returning from a friend's house.

8.2

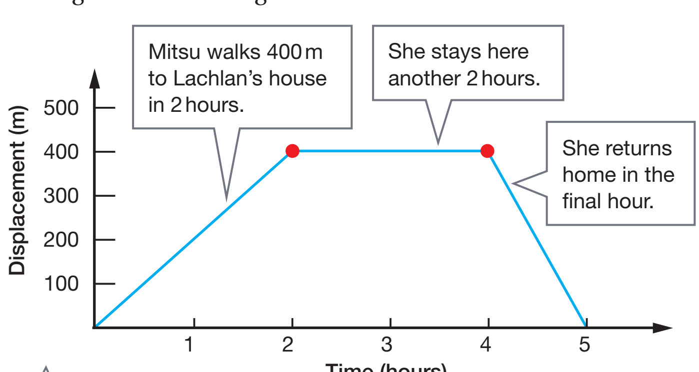


Figure 8.1.11 This graph indicates that Mitsu has travelled out and then returned to her starting point.

Speed–time graphs

A speed–time graph shows how an object's speed changes over time (Figure 8.1.12). An object's speed may:

- be constant, as shown by a flat line
- increase, as shown by the graph rising upwards
- decrease, as shown by the graph falling downwards.

The area below a speed–time graph is the distance the object has travelled up to a given point. This can be calculated as shown in Figure 8.1.13.

2 p260

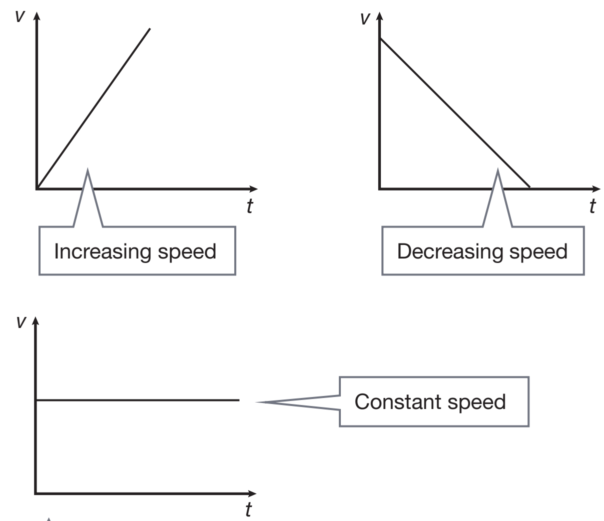


Figure 8.1.12 The slope of a speed–time graph indicates whether motion is speeding up, slowing down or constant.

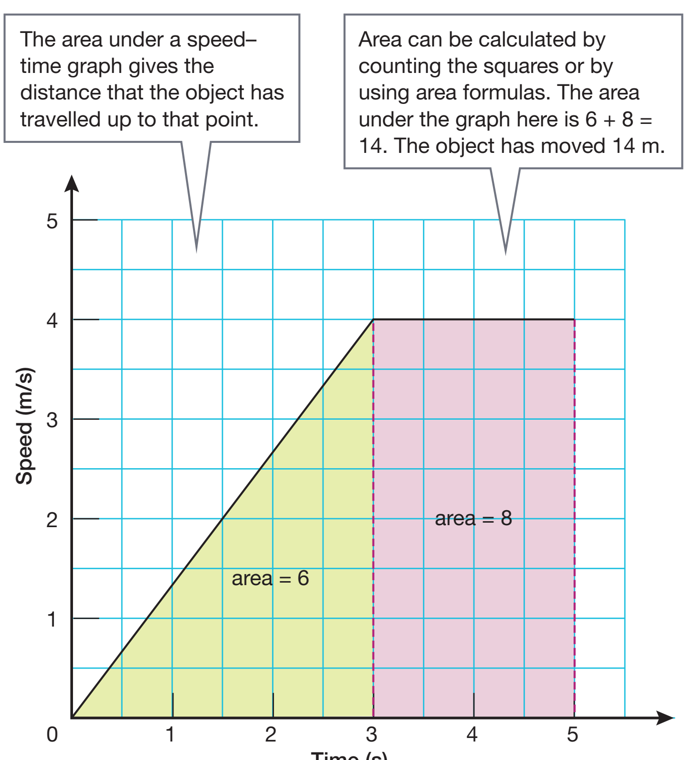


Figure 8.1.13 The area below the graph is the distance the object has travelled.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Errors in science

Figure 8.1.14 Compare the clarity of images of galaxy M100 captured by the Hubble Space Telescope before and after its mirror was corrected.

Error is the difference between the value that is measured with the actual measurement. The smaller this difference, the higher the accuracy of the measurement. **Precision** refers to how close the measured values are to each other.

In 1990, a manufacturing error the size of one-fiftieth the width of a human hair on the surface of a mirror led to months of costly repair to the Hubble Space Telescope (Figure 8.1.14). Measurements can be precise, but not accurate. This is shown in Figure 8.1.15.

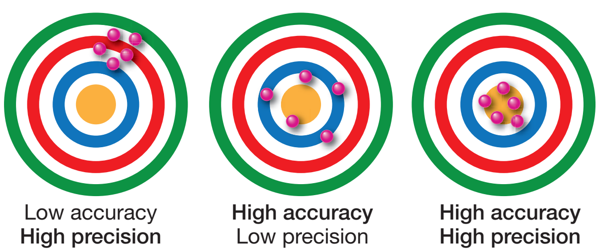


Figure 8.1.15 Measured values can be close together, but still not accurate.

When measuring a physical quantity (such as distance, time or mass) two types of errors can occur. These are systematic and random errors.

Systematic error

Sometimes a set of measurements all differ from the actual value by about the same amount. This type of error is a systematic error. It occurs in the same direction (up or down) and by the same amount each time.
A systematic error can be produced by:

- equipment not being correctly zeroed
- equipment not being correctly assembled or marked
- a change in conditions or temperature over the time a set of measurements is recorded
- an error made in the way a person records a measurement each time.

To eliminate a **systematic error**, new equipment may need to be used or the experimental technique may need to change. This type of error is not removed by completing more measurements.

Random error

A **random error** is when the measurement differs from an actual value in an unpredictable manner. Some random errors are higher than the actual value while some are lower. These errors are caused by:

- an observer's error in reading a scale, possibly caused by parallax error as shown in Figure 8.1.16
- human error in reading an incorrect value.

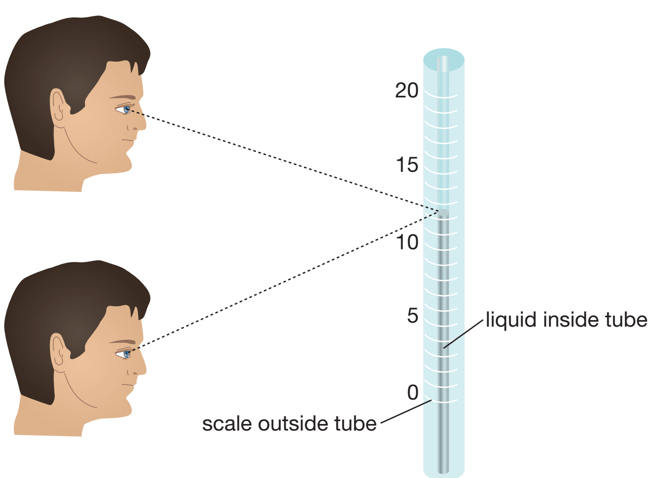


Figure 8.1.16 Parallax error occurs when an observer is above or below the level of the scale they are trying to read.

To eliminate random error, a large number of measurements should be taken. When the mean (or average) of these measurements is calculated, this should be close to the true value required.

8.1 Unit review

Remembering

1 **State** which unit(s) could be used to measure speed.
  - **A** year per metre
  - **B** millimetre per day
  - **C** metre per kilogram
  - **D** kilometre per second

2 **Recall** facts about motion by stating whether the following statements are true or false.
  - **a** Distance is a vector quantity.
  - **b** The SI unit for length is the kilometre.
  - **c** Speed can be converted from metres per second to kilometres per hour by multiplying by 3.6.
  - **d** The area below a speed–time graph is the distance travelled by an object.

Understanding

3 Jo's displacement is 100 m north. **Explain** what this means.

4 **Describe** a journey in which your displacement is zero, and another in which it is not zero.

5 Raj jogs at a constant rate of 5 km/h around the block of streets around his home. Jane thinks that Raj's speed and velocity remain constant. **Explain** whether Jane is correct.

6 **Explain** the difference between a measurement that is accurate and a measurement that is precise.

7 The company producing the mirror for the Hubble Telescope analysed it using different equipment during manufacture. New equipment indicated that there was a problem, but the manufacturers ignored these results, believing the original equipment to be more accurate. **Explain** why it is desirable to use more than one type of measuring device when taking measurements.

Applying

8 **Calculate** the:
  - **i** distance travelled
  - **ii** displacement of each object shown in Figure 8.1.17.

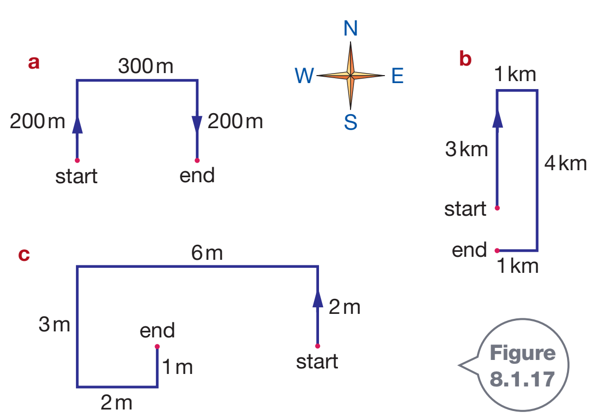


Figure 8.1.17

9 Look at the displacement–time graph of Mitsu walking from home to Lachlan's house, as shown in Figure 8.1.11 on page 255.
  - **a** **Calculate** Mitsu's average speed (in km/h):
    - **i** travelling to Lachlan's house over the first 2 hours (Hint: Convert metres to kilometres.)
    - **ii** while returning from Lachlan's house over the last hour.
  - **b** **Explain** why Mitsu's displacement does not change from 2–4 hours of the journey.
  - **c** **Explain** how you know Mitsu has reached home at the end of the journey.

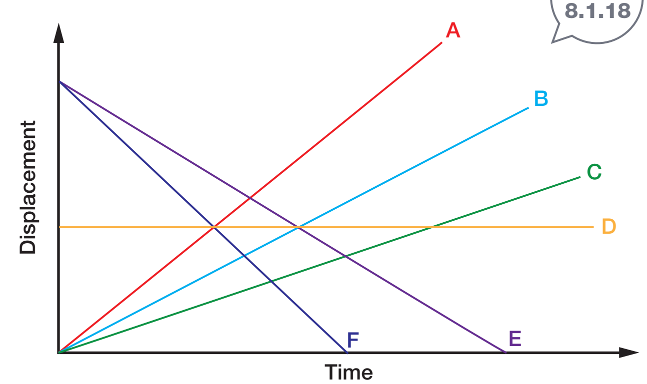
10 Copy the following table into your workbook. It shows typical top running speeds of a number of animals. **Calculate** the missing values to complete the table.

Animal	Speed (m/s)	Speed (km/h)
Cheetah		102
Red kangaroo	17.5	
Giraffe		56
Emu		50
Human	7.5	
Elephant		24
Chicken	4	
Giant tortoise	0.075	

11 **Calculate** the average speed of each of the following in the units specified in the brackets.
  - **a** Tim hikes 10 km in 2 hours in the bush (km/h).
  - **b** A frog leaps 16 m in 4 seconds (m/s).
  - **c** A racing car travels 3 km around a circuit in 6 minutes (km/h).

12 Figure 8.1.18 shows the displacement of six objects over a time period. **Identify** which graph/s represent:
  - **a** a stationary object
  - **b** an object moving backwards
  - **c** the fastest forward-moving object
  - **d** the fastest backward-moving object.

Figure 8.1.18



8.1 Unit review

13 The driver of a car travelling at 80 km/h turned a bend and saw a broken-down car ahead. He took 0.75 second to react, and after he braked the car travelled a further 39.2 metres before stopping. **Calculate** the total distance taken for the car to stop. (Hint: Convert the speed of the car into m/s.)

Analysing

14 **Compare** distance and displacement.

15 Figure 8.1.19 shows the motion of car A and car B. **Analyse** these graphs to determine which car travels further in 20 seconds.

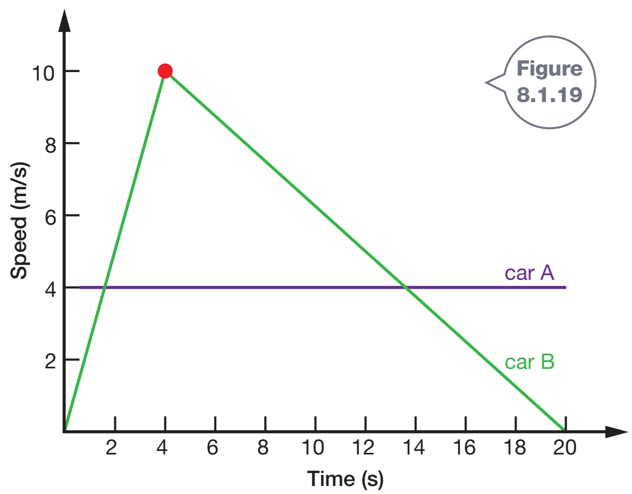


Figure 8.1.19

16 **Classify** the following measuring errors as random or systematic.

- **a** Finn always measures his height against the wall wearing his runners.
- **b** Asha reads a thermometer scale from above.
- **c** Shae miscounted the number of millimetres when measuring the length of an antenna.
- **d** Carl times Min in a running race but his stopwatch takes 0.6 second to click off.

Evaluating

17 The problems with the mirror on the Hubble Space Telescope were caused by incorrect assembly of the device used to measure the shape of this mirror. This resulted in the mirror being manufactured too flat near it edge.

- **a** **Assess** whether the problems were caused by a systematic or random error.
- **b** **Justify** your answer.

Creating

18 Catarina is on yard duty collecting litter at school. She walks 300 m north, then 100 m west, finally turning to walk 300 m south. The journey takes 5 minutes.

- **a** **State** the total distance travelled.
- **b** **Calculate** Catarina's average speed in m/s.
- **c** **Construct** a diagram of Catarina's journey.
- **d** **State** her displacement.
- **e** **Calculate** Catarina's average velocity.

Inquiring

1 **a** Investigate current road statistics in your state and select a key area that influences the number of fatalities such as driver distractions, fatigue, speed, drug or alcohol use.

b Create an advertising campaign (billboard, radio commercial or TV commercial) to raise awareness of this issue.

2 Use a trustworthy website such as the TAC's 'How safe is your car?' to summarise information about the safety of your family car or of a car in which you sometimes travel.

3 The average human reaction time to press a button given a visual signal is 0.2–0.25 seconds. Search the internet using terms like 'reflex tester' or 'reaction time'. Test yourself and calculate your average reaction time, based on 20 tests.

4 Design an experiment that uses a video camera or motion detector to record the motion of a number of objects. Examples include:

- wind-up or battery-operated toys released from a starting point
- a cyclist riding along a street
- students in a running race.

Use your recording to assist you to construct an approximate distance–time graph for each object.

8.1 Practical activities

1 Reaction time

Purpose

To simulate a driving experience and test your reaction time.

SAFETY

Be careful not to fall from the chair. Ensure it is in a stable position on the table by having a partner hold it in place.

Materials

- metre ruler
- table or bench
- calculator

Procedure

1. Work with two partners. Select a 'driver' for this activity. This person should stop reading or writing from here and listen to their partners' instructions.
2. For the non-drivers, copy the table from the results section.
3. Position a chair on top of a bench or table, close to a wall as shown in Figure 8.1.20.

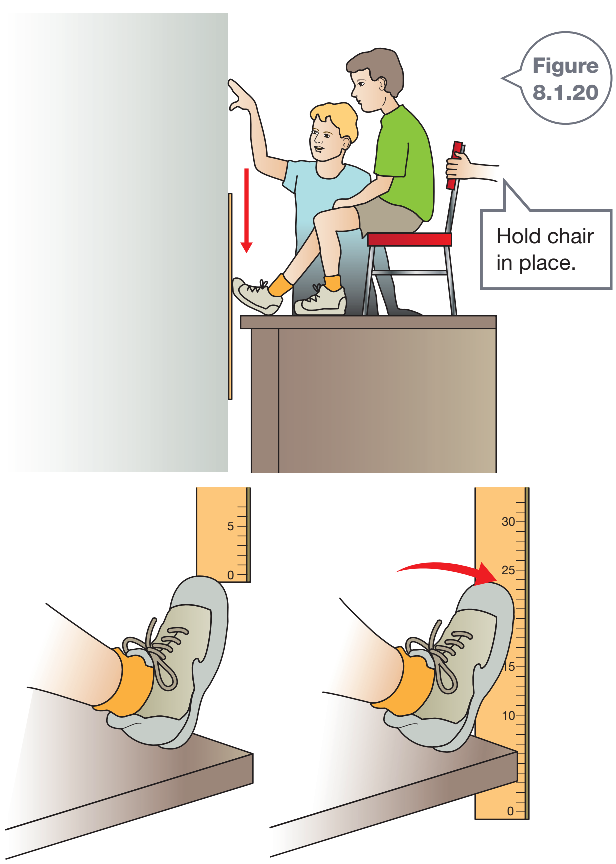


Figure 8.1.20

4. The driver sits on the chair that is held in position by another student. The remaining group member holds the ruler (or brake pedal), flat against the wall so that zero on the ruler is aligned with the driver's toes as shown.
5. Tell the driver that when the ruler starts to fall, they need to 'hit the brakes' and stop it with their foot.
6. Release the ruler and record the distance it falls before the driver stops it.
7. Complete three trials of this test.
8. Repeat the three trials, but keep talking to the driver while performing each trial.
9. Repeat the three trials again, but ask the driver to read or send a text message from a mobile phone, or to read a paragraph of printed text out loud.

Results

1. Copy and complete the following table.

Test conditions	Reaction distance (cm)			Average reaction distance (cm)	Reaction time (s)
	Trial 1	Trial 2	Trial 3		
No distractions					
Distraction (talking)					
Distraction (reading a message)					

2. Calculate the average reaction distance from each set of trials and add them to your table.
3. Calculate the reaction time for each set of results by:
   - taking the square root of the reaction distance (in cm)
   - multiplying your answer by 0.045.

Discussion

1. **State** the spread, or range, of results of reaction time measured in the first three trials.
2. **Describe** the effect of the distractions on the reaction time.
3. Imagine you were driving at 50 km/h (about 14 m/s) and needed to react quickly to a situation ahead. **Calculate** how far your car would travel for each average reaction time recorded in the table.
4. **Discuss** any sources of random or systematic error that could exist in this practical activity. Suggest any improvements that could be made to reduce these errors.

2 Measuring the speed of toy cars

Purpose

To analyse the motion of a toy car using ticker tape or a motion sensor.

Materials

- AC power supply and ticker timer with tape (or motion sensor)
- toy car
- sticky tape
- ruler

Procedure

1. Work with a partner. Attach about 1 metre of ticker tape to the back of a toy car.
2. Carefully thread the tape through a ticker timer.
3. Place the car on a smooth, flat surface.
4. Turn on the ticker timer.
5. Pull the car away in a straight line, varying its speed.
6. Repeat so that both you and your partner have a recorded strip of ticker tape.

Results

1. Mark the first clearly seen dot on your tape, and then mark every fifth dot recorded after this. Number each group of dots as shown in Figure 8.1.21.
2. Cut the tape into seven sections at the points you've marked. Paste these strips in order on a speed-time graph as shown in Figure 8.1.22. Each strip represents 0.1 second (as this is five times 0.02 second recorded for each dot).
3. To label the scale of the vertical axis of the graph (in mm/s), you need to calculate the average speed of each strip of five dots. To do this, copy and complete the following table.

   Note that average speed of each section = $\frac{\text{length of section}}{0.1}$

Section	Total time (s)	Length of section (mm)	Time interval of each section(s)	Average speed of section (mm/s) (length of section/0.1)
1 (dots 0–5)	0.1		0.1	
2 (dots 5–10)	0.2		0.1	
3 (dots 10–15)	0.3		0.1	
4 (dots 15–20)	0.4		0.1	
5 (dots 20–25)	0.5		0.1	
6 (dots 25–30)	0.6		0.1	
7 (dots 30–35)	0.7		0.1	

4. Complete your table and add a scale to the vertical axis of your graph.

Discussion

1. **Describe** the motion of the toy car.
2. **Explain** why a region of tape in which dots are further apart indicates a faster speed than a section in which these are bunched together.
3. **Describe** the pattern of dots made by constant speed.
4. **Identify** possible sources of error in this activity and propose how these could affect the results.

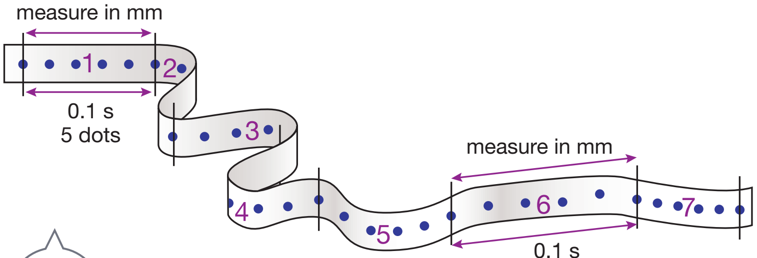


Figure 8.1.21

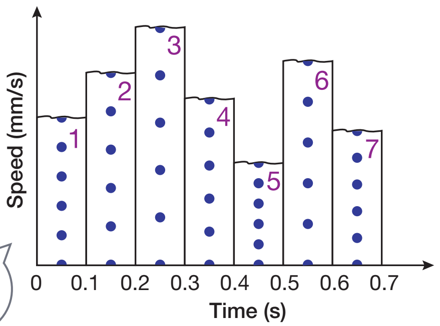
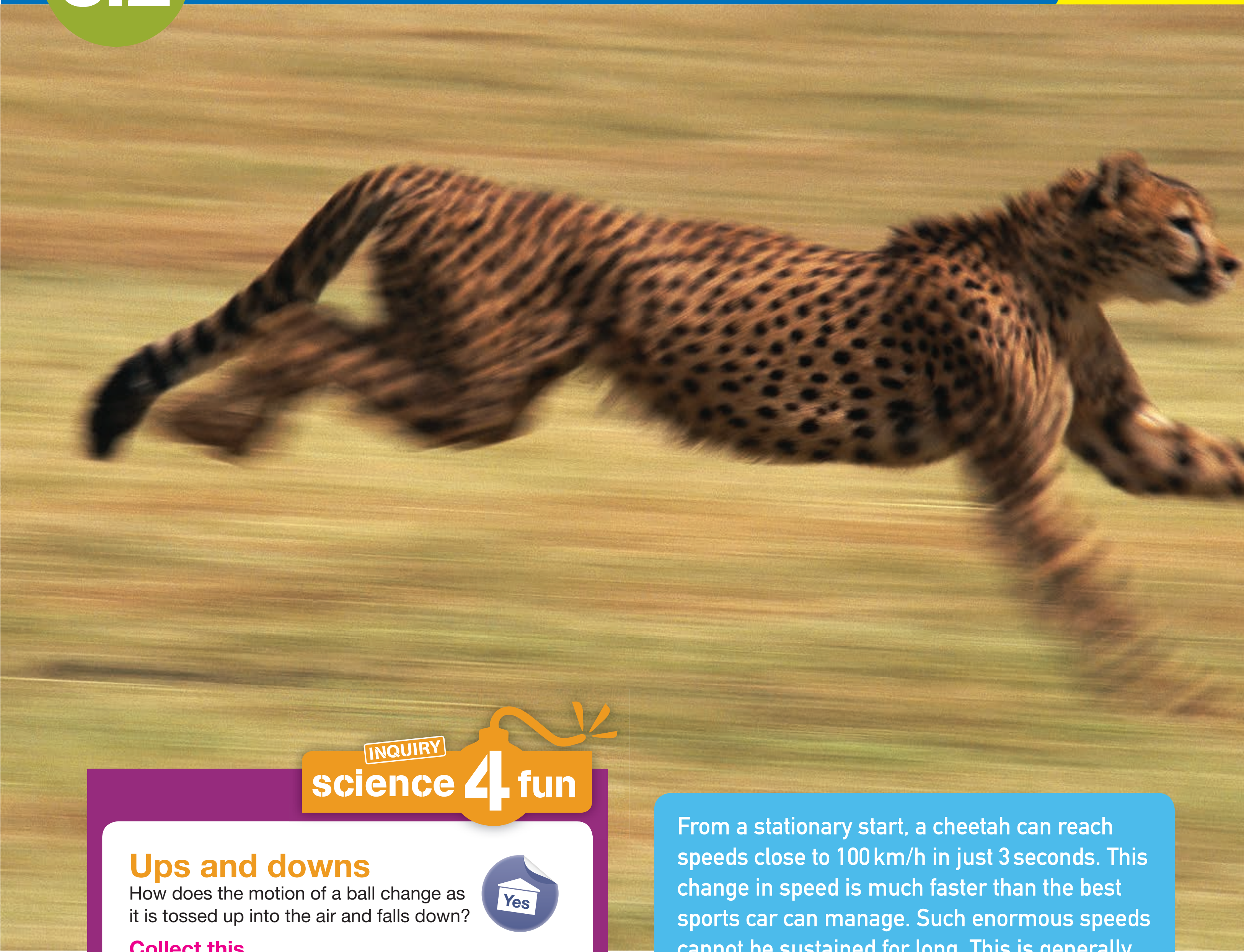


Figure 8.1.22

8.2 Changes in speed



INQUIRY science 4 fun

Ups and downs

How does the motion of a ball change as it is tossed up into the air and falls down?

Yes

Collect this …

- video camera or mobile phone with video
- tennis ball

Do this …

1 Work with a partner. One of you tosses a tennis ball about a metre into the air and tries to catch it while the other records the motion with the camera.

2 Replay the motion slowly and watch it carefully.

Record this …

Describe the motion of the ball, including when it got faster and when it slowed down.

Explain why you think this happened.

From a stationary start, a cheetah can reach speeds close to 100 km/h in just 3 seconds. This change in speed is much faster than the best sports car can manage. Such enormous speeds cannot be sustained for long. This is generally not a problem because the chase of the cheetah is usually over in less than a minute. Changes in velocity are called acceleration.

Calculating acceleration

In everyday language, acceleration is a change in speed. When an object speeds up, it has accelerated. When it slows down, it has decelerated. In science, **acceleration** is the rate of change in velocity. It should be stated with a direction. Like displacement and velocity, acceleration is a vector quantity. A positive acceleration means that something is speeding up in a particular direction and a negative acceleration means it is slowing down in a particular direction.

1 p267

To simplify our ideas of acceleration, we will only consider motion in a straight line. In this case, average acceleration can be calculated using the formula:

$$\text{average acceleration} = \frac{\text{change in speed}}{\text{time}}$$

$$= \frac{\text{final speed} - \text{initial speed}}{\text{time}}$$

or

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

where a is acceleration, v is final speed, u is initial speed and t is time taken.

The formula above can be rearranged to allow the final speed of an object to be calculated:

$$\text{final speed} = \text{initial speed} + (\text{average acceleration} \times \text{time taken})$$

or

$$v = u + at$$

The SI units for acceleration are m/s/s or m/s^2. However, other units can also be used. A car that increases its speed in a direction by 12 km/h every second has an acceleration of 12 km/h/s.

WORKED EXAMPLE
Average acceleration and final speed

Problem 1

A car speeds up to 60 km/h from rest in 5 seconds. Calculate its average acceleration. (Express your answer in km/h/s.)

Solution

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

$$= \frac{60 - 0}{5}$$

$$= 12 \text{ km/h/s}$$

The car increases speed by 12 km/h each second. This is shown in Figure 8.2.1.

Problem 2

A train initially travelling at 30 km/h accelerates at a constant rate of 2 km/h/s for 30 seconds. Calculate its final speed.

Solution

$$v = u + at$$

$$= 30 + (2 \times 30)$$

$$= 90 \text{ km/h}$$

The train is travelling at 90 km/h after 30 seconds.

Table 8.2.1 compares the performance of a number of cars. The shorter the time a car takes to reach 100 km/h, the greater its acceleration.

Table 8.2.1 Time taken for a range of cars to accelerate from 0 to 100 km/h

Car	Time (s)
Nissan GT-R (Figure 8.2.2)	3.5
BMW 135i	5.6
Volkswagen Golf GTI	7.3
Ford FG Falcon	7.3
Holden VE Commodore	8.1
Honda Civic	9.8
Toyota Tarago	17.7

Source: *Wheels Magazine* May 2009

Figure 8.2.2 The time taken for a car to accelerate to 100 km/h is one of many factors to consider when buying a car. Fuel consumption is another factor you might consider.

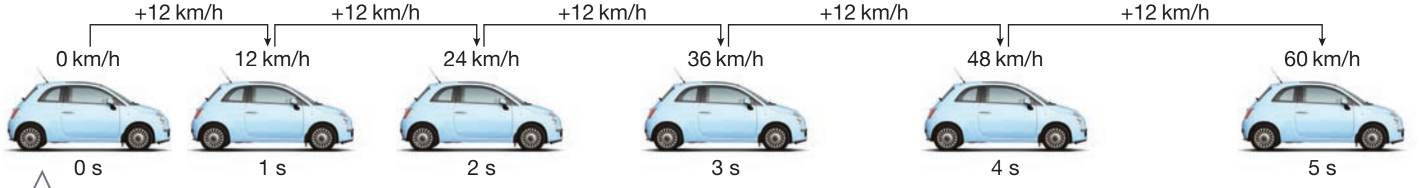


Figure 8.2.1 This car has constant acceleration. Its speed has increased by 12 km/h every second.

Acceleration due to gravity

A falling object (like the person in Figure 8.2.3) accelerates towards Earth because of the force of gravity. This means that it speeds up as it falls. Acceleration due to gravity is 9.8 m/s^2, so the speed of an object increases by almost 10 m/s (or 36 km/h) for every second that it falls. In the first second, the object's speed increases from zero to 36 km/h. One second later, it is falling at about 72 km/h. After 3 seconds, it is falling at about 108 km/h. An acceleration of 9.8 m/s^2 is called '1 g'. You may think it could reach enormous speeds, but friction between the air and a moving object will reduce this acceleration.

Figure 8.2.3 This daredevil is jumping out of a plane wearing a full body suit, complete with nylon 'wings'. This person falls at about 100 km/h, and deploys a parachute to slow their fall (decelerate) before reaching the ground. Wings and parachutes increase air resistance and so they decrease the final terminal velocity of the fall.

The friction between the air and a falling body is called **air resistance**, and the final velocity is called **terminal velocity**.

Human tolerance of g-forces depends upon how big the forces are, how long they last, the direction in which they act and the part of the body they affect. Humans can tolerate horizontal forces much better than vertical forces. Forces experienced in a vertical drop are particularly dangerous as blood flow to the brain can be disrupted and can cause loss of consciousness or death. Your body can withstand high g-forces for a moment with no damage but longer durations are deadly. Some typical g-forces are shown in Table 8.2.2.

Table 8.2.2 Some typical accelerations

Situation	Acceleration (m/s^2)	Number of g's
Free-fall	9.8	1
Space shuttle at take-off	29.4	3
Typical rollercoaster	29.4	3
A sneeze	29.4	3
Slap on the back	39.2	4
Human in a rocket sled (maximum)	455.7	46.2
Car accident at 48 km/h with airbag (force on chest)	588	60
Motorbike accident with no helmet (force on head)	1470–1960	150–200

SciFile

Gee-force!

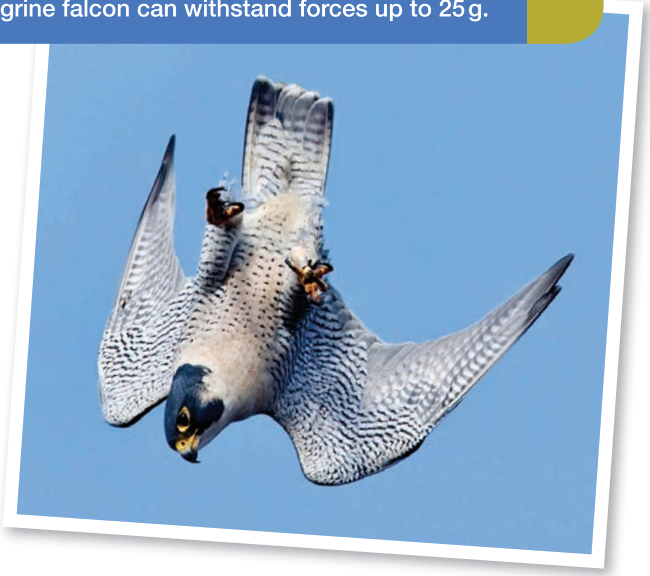
In World War I, pilots diving and looping their aircraft were observed to lose consciousness. American Air Force physician John Strapp decided to test the human g-force limits. He strapped himself into a sled, powered by nine solid fuel rockets on a railway track. Strapp accelerated to 1017 km/h in 5 seconds, before stopping in 1 second. John Strapp's body withstood a momentary force of 46.2 g! Strapp is shown in Figure 8.2.4.

Figure 8.2.4 Six images showing John Strapp accelerating then decelerating rapidly.

Super bird!

The peregrine falcon is a raptor that hunts and kills other birds. Its vision is about eight times stronger than human sight. These raptors knock their prey unconscious in a vertical dive at speeds up to 300 km/h. As it pulls out of a dive, the peregrine falcon can withstand forces up to 25 g.

SciFile



Graphing acceleration

The acceleration of an object can be calculated from the slope or gradient of a velocity–time graph. Constant acceleration is shown on a velocity–time graph as a line rising upwards. A vehicle slowing down, or decelerating, at a constant rate is shown by a line sloping downwards. The motion of an object travelling at a constant velocity (zero acceleration) is shown by a flat line. Figure 8.2.5 shows how the gradient of a velocity–time graph changes with different accelerations.

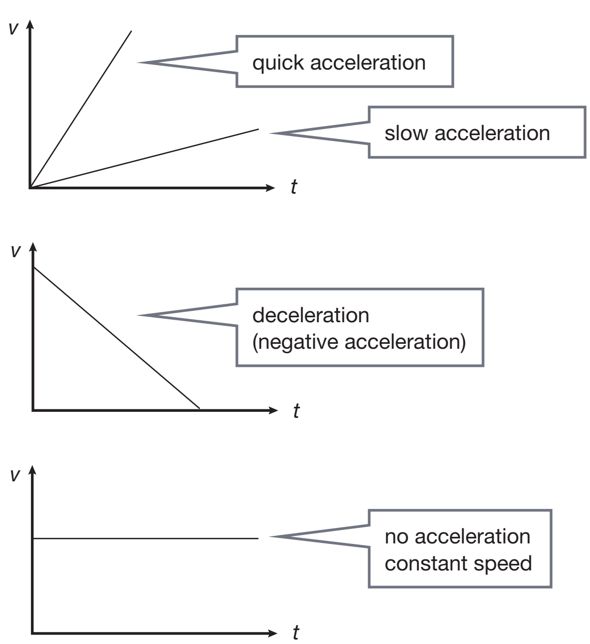


Figure 8.2.5 Acceleration is the gradient of a speed–time graph. This may be positive (speeding up), negative (slowing down) or zero (constant speed).

WORKED EXAMPLE
Interpreting speed–time graphs

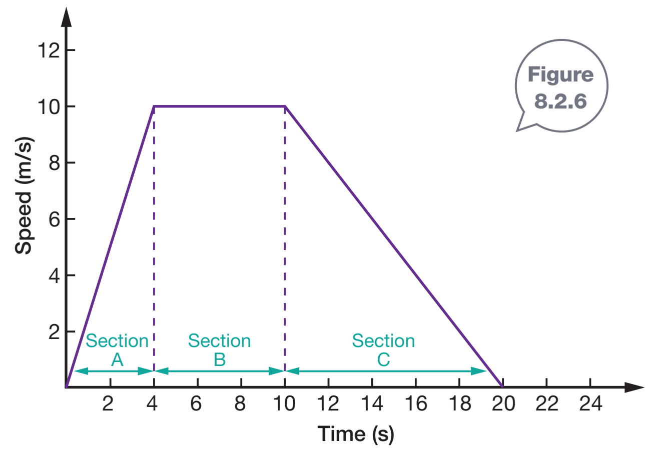


Figure 8.2.6

Problem

Sanjiv rides his scooter as described by Figure 8.2.6.

a Calculate his acceleration in sections A, B and C of his journey.

b Describe his motion in sections A, B and C.

c Calculate the distance Sanjiv covers in section A.

Solution

a Sanjiv's acceleration is the gradient of the graph in each section:

For A: acceleration $= \frac{\text{rise}}{\text{run}} = \frac{10-0}{4} = 2.5\ \text{m/s}^2$

For B: acceleration $= \frac{10-10}{10-4} = 0$

For C: acceleration $= \frac{0-10}{20-10} = -1\ \text{m/s}^2$

b In A: Sanjiv accelerates at 2.5 m/s² until reaching a velocity of 10 m/s.

In B: He travels at a constant velocity of 10 m/s (with zero acceleration).

In C: Sanjiv slows down, or decelerates at 1 m/s² until he comes to a stop.

c The distance covered is the area under this section of the graph:

distance $= \frac{1}{2} \times 4 \times 10 = 20$ m

Sanjiv travels 20 m while accelerating to 10 m/s in section A.

8.3
p268

8.2 Unit review

Remembering

1 **State** the formula used to calculate average acceleration.

2 **List** two different units used to describe acceleration.

3 **List** four factors that affect the response of your body to a g-force.

4 **State** what is represented by the gradient of a velocity–time graph.

Understanding

5 Although acceleration due to gravity is 9.8 m/s², in practice, an object dropped from a height on Earth, such as a ball dropped from a tree, will not accelerate this rapidly. **Explain** why.

6 **Explain** why your body does not tolerate vertical g-forces, particularly those downwards, as well as it tolerates horizontal g-forces.

7 **Explain** the difference in motion between a train travelling at 8 m/s² and another travelling at –8 m/s².

Applying

8 A toy truck was stationary then rolls down a long ramp with a constant acceleration of 0.2 m/s². **Calculate** its speed after:

- a 1 second
- b 2 seconds
- c 3 seconds
- d 10 seconds.

9 **Use** Table 8.2.1 on page 262 to **calculate** the average acceleration of each car as it accelerates to 100 km/h in the time stated. Express your answer in km/h/s and round off to one decimal place.

10 John Strapp accelerated to a speed of 1017 km/h in 5 seconds and then came to a stop in 1 second. Convert this speed into m/s and **calculate** his:

- a average acceleration in reaching 1017 km/h (in m/s²)
- b deceleration in coming to a stop (in m/s²).

11 Figure 8.2.7 illustrates the motion of a leaf floating in a running stream of water.

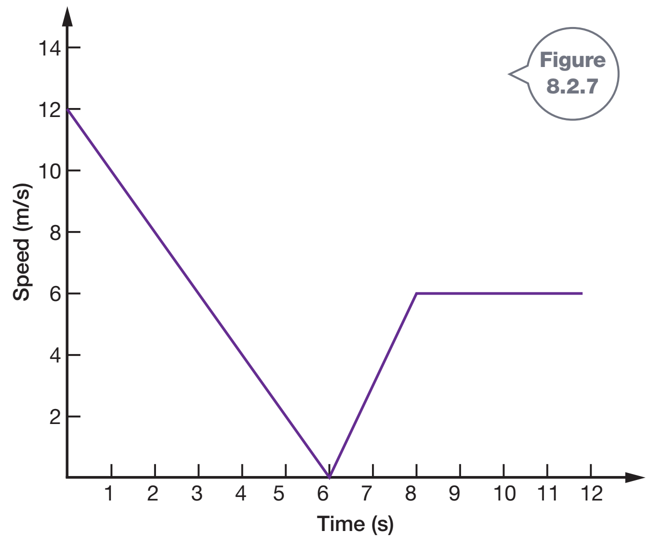


Figure 8.2.7

- a **Describe** its motion over the 12 seconds shown on the graph.
- b **Calculate** the acceleration of the leaf in the first 6 seconds.
- c **Calculate** the distance it travelled in this time.
- d **Calculate** its acceleration between 6 and 8 seconds of its journey.

Analysing

12 **Analyse** the three distance–time graphs shown in Figure 8.2.8 to determine which shows an object:

- a speeding up
- b slowing down
- c travelling at constant speed.

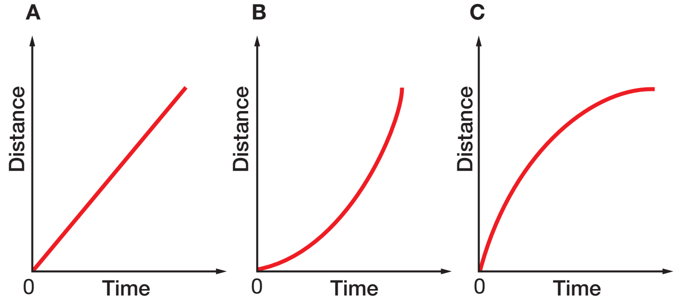


Figure 8.2.8

13 Table 8.2.1 on page 262 shows that different cars take different times to accelerate to 100 km/h. There is also a large difference between the average grams of carbon dioxide emitted per kilometre by them. **Discuss** some of the factors you would consider when purchasing a car.

Creating

14 Table 8.2.3 shows the speed of one cheetah at 5-second intervals as it chased its prey.

Table 8.2.3 Speed of cheetah chasing its prey

Time (s)	0	1	2	3	4	5	6	7	8	9	10
Speed (m/s)	0	6	14	27	27	27	27	20	12	3	0

- **a** **Construct** a speed–time graph from this data.
- **b** **Identify** the time intervals in which the acceleration of the cheetah is:
  - **i** zero
  - **ii** positive
  - **iii** negative.

15 **Construct** a short story that could describe the motion described by Figure 8.2.9.

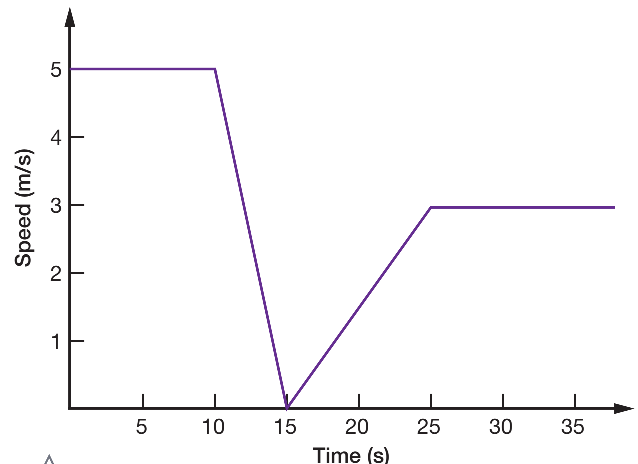


Figure 8.2.9

Inquiring

Figure 8.2.10 Modern mobile phones contain accelerometers.

1 Some handheld devices, such as the phone shown in Figure 8.2.10, contain an accelerometer. This can detect a change in motion when you rotate the device and it automatically rotates the visual display to compensate. List other devices that use accelerometers and describe their function in each.

2 Investigate the g-forces that are experienced on various rides at theme parks. Compile a table that ranks those you have researched from highest to lowest g-force rides.

3 Aristotle was an ancient Greek philosopher. He believed that objects fell towards the Earth because of a homing instinct, and that heavier objects fell faster than lighter objects. These ideas were popular for some 2000 years, but were challenged by the Italian physicist Galileo Galilei (1564–1642).
- **a** Explain how Galileo's approach to science differed from that of Aristotle.
- **b** Describe experiments Galileo conducted with falling bodies.
- **c** State Galileo's conclusion about falling objects.

4 Research the experiments that Galileo performed using ball bearings or marbles rolling down ramps of different inclinations. Repeat some of the experiments and summarise your findings.

8.2 Practical activities

1 Building and testing an accelerometer

An accelerometer is a device that detects acceleration. One is shown in Figure 8.2.11.

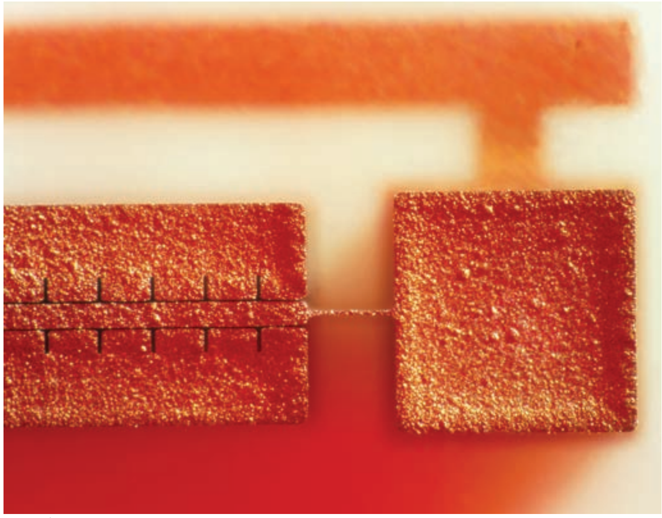


Figure 8.2.11 A micromechanic accelerometer, enlarged 30 times. Tiny movements of the mass on the right are detected by sensors found on the other side of the thin support beam. These devices are used to trigger the release of an airbag in a car.

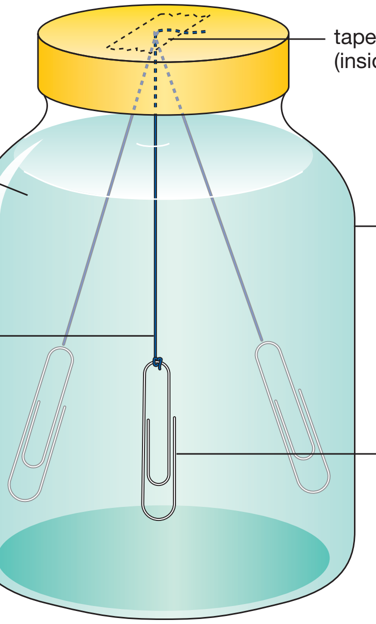


Figure 8.2.12 The suspended paper clip in this accelerometer reacts to acceleration.

Purpose

To design and construct a device that can be used to detect acceleration.

Materials

- materials of your choice

Procedure

1 Design your own accelerometer. Figure 8.2.12 shows an example that may give you some ideas.

2 Construct your device and test its response for positive and negative acceleration.

Discussion

1 **Describe** the design of your accelerometer.

2 **Explain** how it detects acceleration.

3 **Describe** how it responded to positive and negative accelerations.

4 **Identify** any random or systematic errors that could occur when using your accelerometer.

5 **Discuss** any improvements that could be made to your design.

2 Measuring acceleration

Purpose
To determine the acceleration of a trolley rolling down a ramp.

Materials
- ticker timer with power supply and tape (or motion sensor)
- pile of books or bricks to prop up ramp
- protractor
- slotted masses
- masking tape
- ramp
- trolley
- metre ruler

Procedure
1. Set up the ramp at an angle of 30° to the horizontal.
2. If your trolley is very light, add a number of slotted masses to its surface using masking tape.
3. Set up the ticker timer at the top of the ramp. Thread ticker tape through the ticker timer and attach it to the back of the trolley (Figure 8.2.13). (Alternatively, set up motion-sensing equipment.)

Figure 8.2.13

4. Turn on the ticker timer and let the trolley roll down the ramp.
5. Repeat the trial so that everyone in your group has a strip of ticker tape to analyse.

Results
1. Mark sequences of five dot intervals on your tape and analyse these using the procedure outlined in Practical activity 1 on page 267. Record your findings in a table as shown below.
2. Construct a speed–time graph by pasting the numbered sections of ticker tape on a set of axes. Label these axes with a suitable scale.
3. Construct a line of best fit through the dots of each strip as shown in Figure 8.2.14.

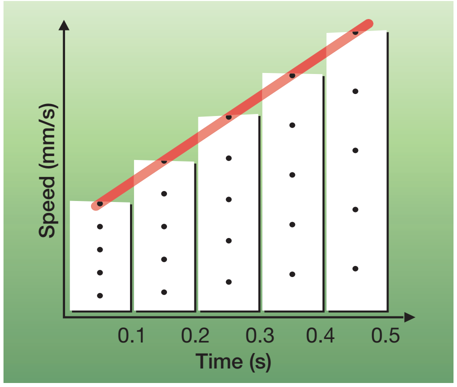


Figure 8.2.14

4. Calculate the average acceleration of the trolley by finding the gradient of the speed–time graph.

Discussion
1. **Describe** the motion of the trolley as it rolled down the ramp.
2. **Propose** one way that the speed of the trolley down the ramp could have been increased.
3. **Discuss** any sources of error that could affect the accuracy of the acceleration you calculated.

Section	Total time (s)	Length of section (mm)	Time interval of each section(s)	Average speed of strip (mm/s) (length of section/0.1)
1 (dots 0–5)	0.1		0.1	
2 (dots 5–10)	0.2		0.1	
3 (dots 10–15)	0.3		0.1	
4 (dots 15–20)	0.4		0.1	
5 (dots 20–25)	0.5		0.1	
6 (dots 25–30)	0.6		0.1	
7 (dots 30–35)	0.7		0.1	