

On the move

6

The thrill of a roller coaster ride allows you to experience sudden changes in motion. When the car suddenly falls, you seem to get 'left behind' just for a while. Such a ride raises many questions about the way that forces affect your motion and energy.

Think about these

Could a kangaroo win the Melbourne Cup?

How do radar guns measure the speed of cars?

Why do you feel pushed to the left when the bus you are in turns right?

How can head restraints protect you in the event of an accident?

Why does the space shuttle seem to take 'forever' to get off the ground?

Why does it hurt when you catch a fast moving ball with your bare hands?

How do rockets and jet engines work?

What does doing work really mean?

Key outcomes

Explain how different forces act together to affect the motion of objects.

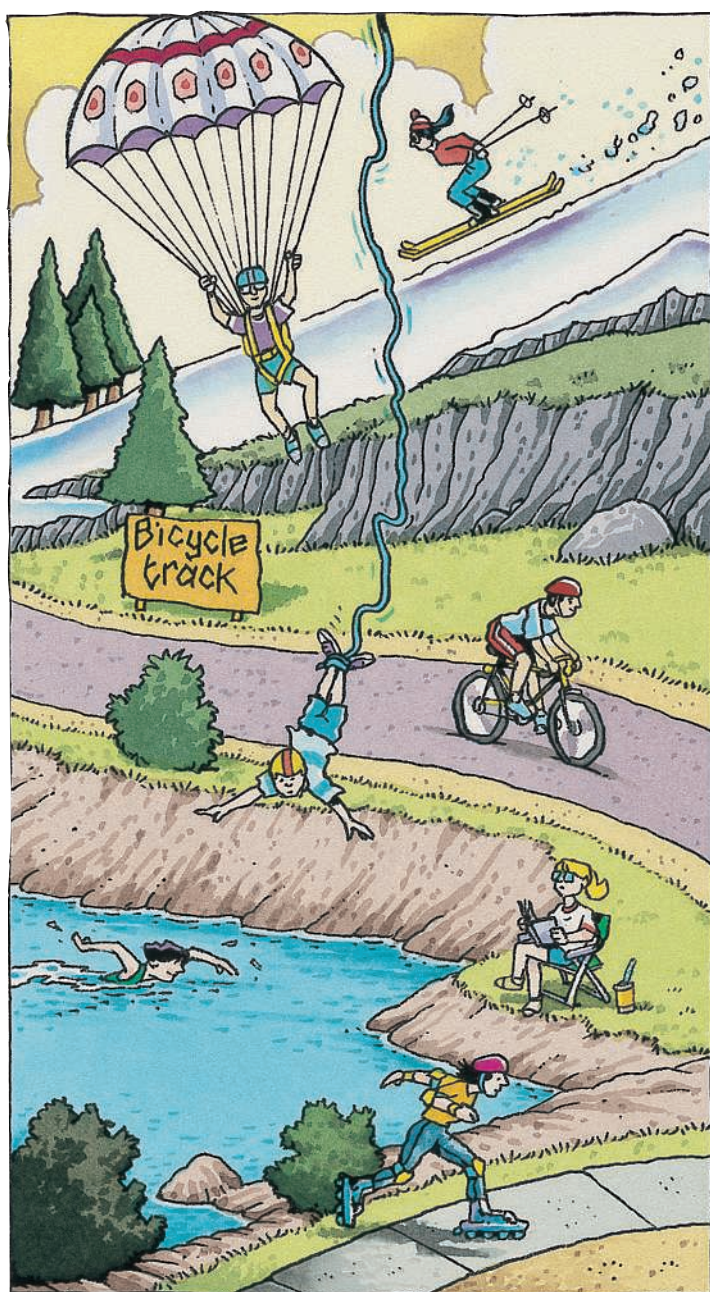
Describe relationships between force, mass, acceleration and velocity, using quantitative data.

YourQuest

A world of forces, energy and motion

THINK

Find out what you already know about forces, energy and motion by examining the illustration below and answering the following questions.



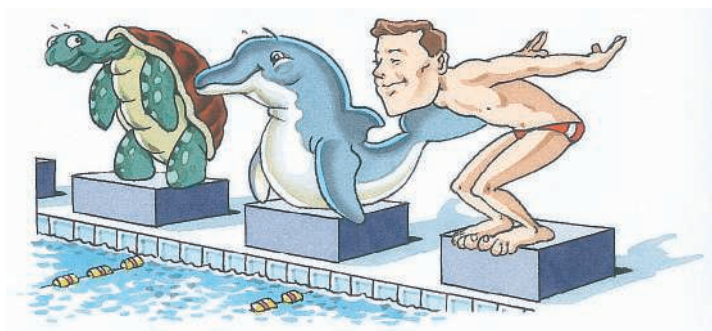
- Copy and complete the table below to list as many of the forces acting on each of the people shown enjoying their leisure time. The number of forces acting on each of them is provided in brackets.

Person	Forces acting on the person
parachutist (3)	
bungee jumper (3)	
skier (2)	
cyclist (5)	
reader (2)	
in-line skater (5)	
swimmer (4)	

- Which of the forces listed in your completed table could be described as a non-contact force?
- Some of the characters in the illustration are accelerating (speeding up); others may be travelling at a steady speed or slowing down.
 - Which three of the characters are the most likely to be accelerating? How do you know?
 - Which three of the characters are most likely to be moving at a non-zero constant speed? How do you know?
- What outside object or substance provides the forward push on the:
 - swimmer?
 - cyclist?
 - in-line skater?
- Which three characters in the illustration are clearly losing gravitational potential energy?
- According to the Law of Conservation of Energy, energy cannot be created or destroyed. It can only be transformed into another form of energy or transferred to another object. What happens to the lost gravitational potential energy of each of the three characters referred to in question 5?

Ready, set, go

Could a kangaroo win the Melbourne Cup? Who would win a race between a sea turtle, a dolphin and Ian Thorpe? You can answer these questions only if you know the **average speed** of each 'competitor' during the race.



Who would win?

Speed is a measure of the **rate** at which an object moves over a distance. In other words, it tells you how quickly distance is covered. The average speed can be calculated by dividing the distance travelled by the time taken. That is:

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

In symbols, this formula is usually expressed as:

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

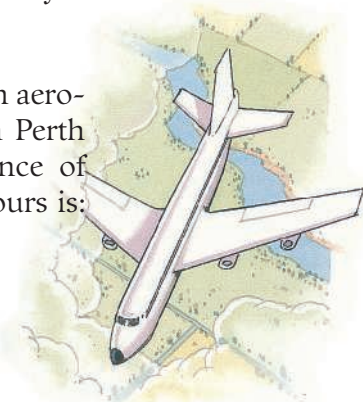
Which unit?

The speed of vehicles is usually expressed in kilometres per hour (km/h). However, sometimes it is more convenient to express speed in units of metres per second (m/s). The speed at which grass grows could be sensibly expressed in units of millimetres per week. Speed must, however, always be expressed as a unit of distance divided by a unit of time.

Some examples

- (a) The average speed of an aeroplane that travels from Perth to Melbourne, a distance of 2730 km by air, in 3 hours is:

$$\begin{aligned} v &= \frac{d}{t} \\ &= \frac{2730 \text{ km}}{3 \text{ h}} \\ &= 910 \text{ km/h.} \end{aligned}$$

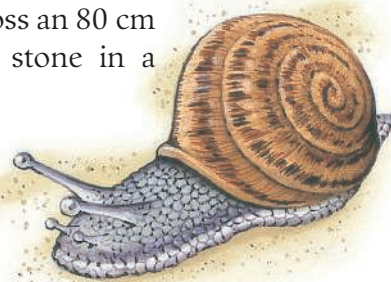


The formula can also be used to express the speed in m/s.

$$\begin{aligned} v &= \frac{d}{t} \\ &= \frac{2\,730\,000 \text{ m}}{3 \times 3600 \text{ s}} \quad (\text{converting kilometres to metres and hours to seconds}) \\ &= 253 \text{ m/s.} \end{aligned}$$

- (b) The average speed of a snail that takes 10 minutes to cross an 80 cm wide concrete paving stone in a straight line is:

$$\begin{aligned} v &= \frac{d}{t} \\ &= \frac{80 \text{ cm}}{10 \text{ min}} \\ &= 8 \text{ cm/min.} \end{aligned}$$



Calculating distance and time

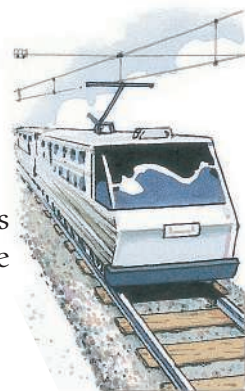
The formula used to calculate average speed can also be used to work out the distance travelled or the time taken.

$$\begin{aligned} \text{Since } v &= \frac{d}{t} \\ d &= vt \text{ and } t = \frac{d}{v}. \end{aligned}$$

More examples

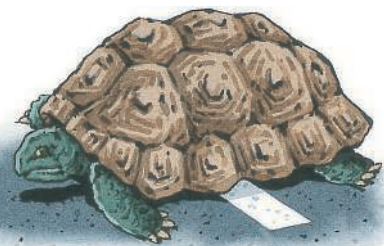
- (a) The distance covered in $2\frac{1}{2}$ hours by a train travelling at an average speed of 70 km/h is:

$$\begin{aligned} d &= vt \\ &= 70 \text{ km/h} \times 2.5 \text{ h} \\ &= 175 \text{ km.} \end{aligned}$$



- (b) The time taken for a giant tortoise to cross a 6 metre wide deserted highway at an average speed of 5.5 cm/s is:

$$\begin{aligned} t &= \frac{d}{v} \\ &= \frac{6.0 \text{ m}}{0.055 \text{ m/s}} \quad (\text{converting } 5.5 \text{ cm/s to } 0.055 \text{ m/s}) \\ &= 109 \text{ s (to the nearest second)} \\ &= 1 \text{ min } 49 \text{ s.} \end{aligned}$$



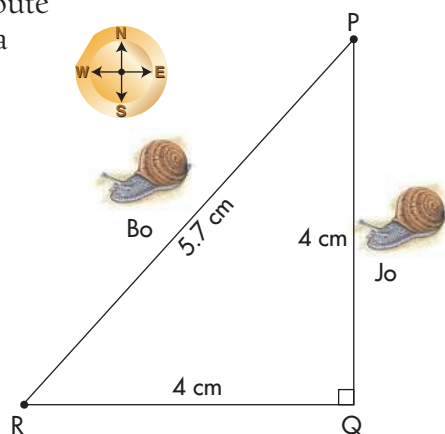
When the direction matters

The term **velocity** is often used instead of speed when talking about how fast things move. However, velocity and speed are different quantities. Velocity is a measure of the rate of change in position, whereas speed is a measure of the rate at which distance is covered. To describe a change in position, the direction must be stated. The velocity has a direction as well as a **magnitude** (a size). When determining speed, the direction of movement does not matter.

At a snail's pace

Imagine a race between two snails, Bo and Jo, between the points P and R shown in the diagram on the right. Bo, being slower but smarter, takes the direct route. Jo, faster but not as clever, takes an indirect route via Q. The race is a dead heat — both snails finish in 1 minute.

The table below describes the motion of the two snails and shows the difference between their speed and velocity.



A race at a snail's pace

The race between Bo and Jo

	Bo	Jo
average speed	$\frac{\text{distance travelled}}{\text{time taken}}$ $= \frac{5.7 \text{ cm}}{1 \text{ min}}$ $= 5.7 \text{ cm/min}$	$\frac{\text{distance travelled}}{\text{time taken}}$ $= \frac{8.0 \text{ cm}}{1 \text{ min}}$ $= 8.0 \text{ cm/min}$
average velocity	$\frac{\text{change in position}}{\text{time taken}}$ $= \frac{5.7 \text{ cm NE}}{1 \text{ min}}$ $= 5.7 \text{ cm/min NE}$	$\frac{\text{change in position}}{\text{time taken}}$ $= \frac{5.7 \text{ cm NE}}{1 \text{ min}}$ $= 5.7 \text{ cm/min NE}$

Notice that when there is no change in direction, the magnitude of the velocity is the same as the speed.

REMEMBER

- Write the formula used to calculate average speed in symbols and state which quantity each symbol represents.
- Explain the difference between speed and velocity. Use an example to support your explanation.

USING DATA

- Determine the average speed of each of the following:
 - a racehorse that wins the 3200 m Melbourne Cup in a time of 3 min 20 s (in m/s)
 - a kangaroo fleeing from a dingo, which bounds a distance of 2.5 km in 3 min (in m/s)
 - a dolphin that just manages to keep up with a speeding boat for a distance of 2 km for a period of 3 min (in km/h)
 - a sea turtle is able to maintain its maximum speed for 0.5 h. In that time it can swim a distance of 16 km (in km/h).
 - Grant Hackett as he completes a 1500 m training swim in 16 min (in km/h)
 - a mosquito that flies a distance of 2 m in 4 s (in cm/s).
- Use your answers to question 3 to suggest answers to the two questions posed at the top of the opposite page.
- How long would it take you to walk from Melbourne to Sydney, a distance of 900 km, if you walked at an average speed of:
 - 5 km/h without stopping?
 - 5 km/h for 10 h each day?
 - 1.5 m/s without stopping?
- How far can a snail crawl if it moves at an average speed of 8.0 cm/min for:
 - 3 min?
 - 3 h?
- In a heat of a swimming trial Leisel Jones swims the 100 m breaststroke event in 68 s. The event is completed in a pool that is 50 m long. She finishes the event at the same end of the pool from which she started. If she begins the event by swimming due north, and takes 35 s to swim the first 50 m, calculate her:
 - average speed for the whole swim
 - average velocity for the first 50 m
 - average velocity for the whole swim.
- A swimmer completes a 1500 m race in 870 s. Calculate the swimmer's average speed in:
 - m/s
 - km/h.

CREATE

- Design a chart with pictures that compares the speeds of a range of animals.

Measuring speed

When German Formula One racing driver Michael Schumacher broke the Australian Grand Prix lap record in 2004, he completed a 5.303 km lap in 84.125 seconds. His average speed was:

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

$$= \frac{5303 \text{ cm}}{84.125 \text{ s}}$$

$$= 63.04 \text{ m/s (about 227 km/h).}$$

However, he was able to speed down the straight at speeds of up to 320 km/h.

Clearly, the average speed does not provide much information about the speed at any particular instant during the race.

Keeping track of the speed

The full story of each lap of Michael Schumacher's race circuit run could be more accurately told if his average speed was measured over many short intervals throughout the event. For example, if stopwatches were placed at every 100 metre point along the track, his average speed for each 100 metre section of the circuit could then be calculated. On the other hand, if stopwatches were placed every metre along the track, his average speed for each 1 metre section could be calculated. By using more stopwatches and placing them closer together, a more accurate estimate of his **instantaneous speed** can be obtained. The instantaneous speed is the speed at any particular instant of time.

There must be better ways!

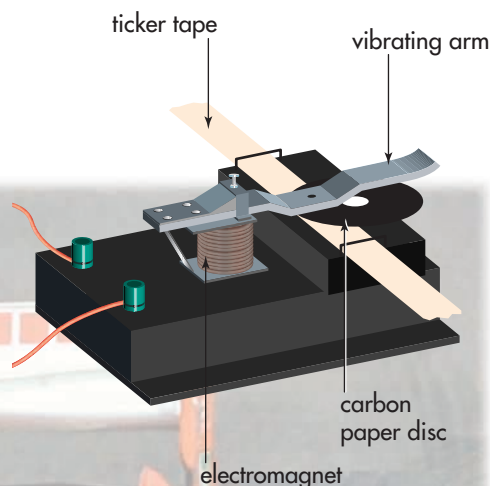
The speedometer inside a vehicle has a pointer which rotates further to the right as the wheels of the car turn faster. It provides a measure of the instantaneous speed.

The police use three different methods to measure the speed of vehicles on the road. These are described below.

- Radar guns and mobile radar units in police cars send out radio waves. The radio waves are reflected from the moving vehicle. However, the frequency of the waves (see page 112) is changed owing to the movement of the vehicle. The change in the frequency depends on the speed of the moving vehicle. The altered waves are detected by the radar gun or mobile unit. Radar provides a measure of the instantaneous speed. One type of radar unit is linked to speed cameras which automatically photograph any vehicle that the radar reveals is travelling above the speed limit.
- Laser guns send out pulses of light which are reflected by the 'target' moving vehicle. The time taken for each pulse to return is recorded and compared with that of previous pulses. This allows the average speed over a very small time interval to be calculated. Laser guns are useful when traffic is heavy because they can target single vehicles with the narrow light beams. Radio waves spread out, and in heavy traffic it is difficult to tell which car reflected the waves.

- Digitectors consist of two cables laid across the road at a measured distance from each other. Each cable contains a small microphone which detects the sound of a moving vehicle as it crosses the cable. The measured time interval between the sounds is used to calculate the average speed of the vehicle between the cables.

When time ticks away



Motion can be recorded with a ticker timer.

A ticker timer provides a simple way of recording motion in a laboratory. When the ticker timer is connected to an AC power supply, its vibrating arm strikes its base 50 times every second. Paper 'ticker' tape attached to the moving object is pulled through the timer. A disc of carbon paper between the paper tape and the vibrating arm ensures that a black dot is left on the paper 50 times every second; that is, a black dot is made every fiftieth of a second.

> TICKER TIMER TAPES

You will need:

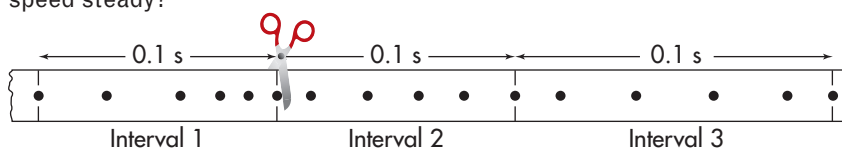
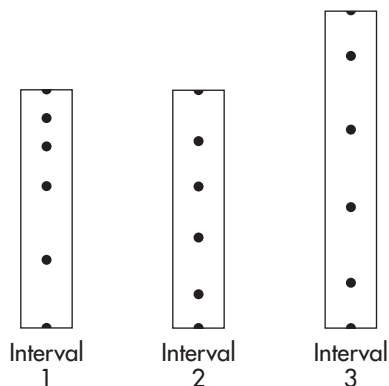
ticker timer
G-clamp
power supply
ticker tape (in 60 cm lengths)
scissors

- Clamp the ticker timer firmly to the edge of a table or bench so that you will be able to pull 60 cm of ticker tape through it. Connect the ticker timer to the AC terminals of the power supply and set the voltage as instructed by your teacher.
- Thread one end of the ticker tape through the ticker timer so that it goes under the carbon paper disc.
- Turn on the power supply and check that the ticker timer leaves a black mark on the ticker tape.
- Hold the end of the ticker tape and walk away from the ticker timer so that the ticker tape moves through at a steady speed.

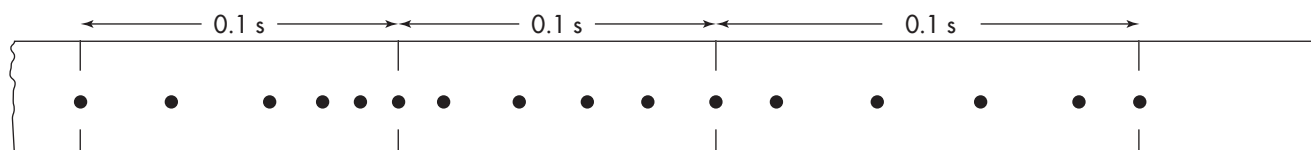
- Remove the ticker tape and mark off the first clear dot made and every fifth dot after the first. (There should be four dots between each of the marked-off dots on the ticker tape.) Measure the distance travelled during each 0.1 s interval and write it on your tape. Label the intervals as interval 1, interval 2, interval 3 etc.

- Cut your ticker tape into 0.1 s intervals and glue the strips in order onto a sheet of paper. Each strip shows the distance travelled during a 0.1 s time interval. The graph therefore shows how the speed changes with time.

1. How much time elapsed between the printing of the first clear dot and the last dot marked off?
2. Calculate the average speed for the motion that took place between the printing of the first clear dot and the last marked dot.
3. Calculate the average speed during each 0.1 s interval.
4. Did you succeed in keeping your speed steady?



Using ticker tape to plot a graph



Each marked interval represents a time of 0.1 s.

The average speed between each pair of dots can be determined by dividing the distance between the dots by the time interval. To make calculating the speed easier, every fifth dot can be marked as shown in the diagram above. Each of the marked intervals on the tape represents five-fiftieths of a second — that is, 0.1 seconds. The average speed during the first interval on the tape shown in the figure above is:

$$v = \frac{4.3 \text{ cm}}{0.1 \text{ s}}$$

$$= 43 \text{ cm/s.}$$

activities

REMEMBER

- 1 Explain the difference between instantaneous speed and average speed. Use an example to support your explanation.
- 2 Which methods are used by the police to measure:
(a) average speed? (b) instantaneous speed?

ANALYSE AND EVALUATE

- 3 Calculate the average speed during the second and third 0.1 s intervals of the ticker tape shown in the diagram above.

INVESTIGATE

- 4 Use data-logging equipment with a motion detector or light gates to record the motion of a toy car or cart down a slope. Use the software to produce a graph of distance versus time and a graph of speed versus time. Comment on the shape of your graphs.

Speeding up

The accelerator of a car is given that name because pushing down on it usually makes the car accelerate. When an object moves in a straight line, its **acceleration** is a measure of the rate at which it changes speed. Acceleration tells you how quickly the speed changes. The average acceleration can be calculated by dividing the change in speed by the time taken for the change. That is:

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

For example, a car travelling at 60 km/h which increases its speed to 100 km/h in 5.0 seconds has an average acceleration of:

$$\begin{aligned}\text{average acceleration} &= \frac{\text{change in speed}}{\text{time taken}} \\ &= \frac{40 \text{ km/h}}{5.0 \text{ s}} \\ &= 8.0 \text{ km/h per second.}\end{aligned}$$

That is, on average, the car increases its speed by 8.0 km/h each second.

If the change in speed is an increase, the acceleration is positive. If the change in speed is a decrease, the acceleration is negative and is called **deceleration**.

Fast starters

The sport of drag racing is a test of acceleration. From a 'standing' start, cars need to cover a distance of 400 metres in the fastest possible time. To do this, they need to reach high speeds very quickly. The fastest drag racing cars can reach speeds of more than 500 km/h in less than 5 seconds.

The average acceleration of a drag racing car that reaches a speed of 506 km/h in 4.6 seconds is:

$$\begin{aligned}\text{average acceleration} &= \frac{\text{change in speed}}{\text{time taken}} \\ &= \frac{506 \text{ km/h}}{4.6 \text{ s}} = 110 \text{ km/h/s.}\end{aligned}$$

This is read as 110 kilometres per hour per second. It means that, on average, the car increases its speed by 110 kilometres per hour each second. Acceleration can also be expressed in m/s/s (that is, metres per second per second) or m/s² (that is, metres per second squared). A change in speed of 506 km/h can be expressed as 141 m/s. The average acceleration of the drag racing car can therefore be expressed as:

$$\begin{aligned}\text{average acceleration} &= \frac{\text{change in speed}}{\text{time taken}} \\ &= \frac{141 \text{ m/s}}{4.6 \text{ s}} = 31 \text{ m/s}^2.\end{aligned}$$

Slowing down

Once the drag racing car has completed the required distance of 400 metres, it needs to stop before it reaches the end of the track. The fastest cars release parachutes so that they can stop in time. The acceleration of a car which comes to rest in 5.4 seconds from a speed of 506 km/h is:

$$\begin{aligned}\text{average acceleration} &= \frac{\text{change in speed}}{\text{time taken}} \\ &= \frac{-506 \text{ km/s}}{5.4 \text{ s}} = -93.7 \text{ km/h/s.}\end{aligned}$$

This negative acceleration can be expressed as a deceleration of 93.7 km/h/s.



The sport of drag racing is a test of acceleration.

> DRAG STRIPS

You will need:

ticker timer

G-clamp

power supply

ticker tape (in 60 cm lengths)

toy car (or dynamics trolley)

sticky tape or masking tape

clear length of bench at least

60 cm long

- Clamp the ticker timer firmly to the edge of a table or bench so that you will be able to pull 60 cm of ticker tape through it. Connect the ticker timer to the AC terminals of the power supply and set the voltage as instructed by your teacher.
- Thread one end of the ticker tape through the ticker timer so that it goes under the carbon paper disc.
- Attach the end of the ticker tape to the toy car or trolley.
- Turn on the power supply and check that the ticker timer leaves a black mark on the ticker tape.

- Model a drag racing car by pushing the toy car or trolley forward, starting from rest, so that it reaches a maximum speed near the halfway mark. Make it come to a gradual stop near the end of the 'track'.
- Remove the ticker tape and mark off the first clear dot and every fifth dot after the first. Each interval between the marks represents a time of $\frac{5}{50}$ of a second, that is, 0.1 seconds. Measure the distance travelled during each 0.1 second interval and write it on your tape. Label the intervals as interval 1, interval 2, interval 3 etc.
- Construct a table like the one on the right in which to record your data. Calculate the average speed during each interval and record it in the table.
- Now cut your ticker tape into 0.1 second intervals and use the strips as described on page 143 to construct a graph of speed versus time.

1. Describe the motion of the toy car or trolley during the period over which it was recorded. Ensure that the words 'speed', 'accelerated' and 'decelerated' are used in your description.
2. Between which intervals was the acceleration:
(a) positive?
(b) negative?
3. During which interval did the greatest average speed occur?
4. When did the greatest positive acceleration take place?

Drag strip speeds

Interval	Distance travelled (cm)	Average speed (cm/s)
Example	3.6	$\frac{3.6 \text{ cm}}{0.1 \text{ s}} = 36$
1		
2		
3		

activities

REMEMBER

- 1 Why is the accelerator pedal in a car called by this name?
- 2 Explain the difference between acceleration and deceleration.

CALCULATE

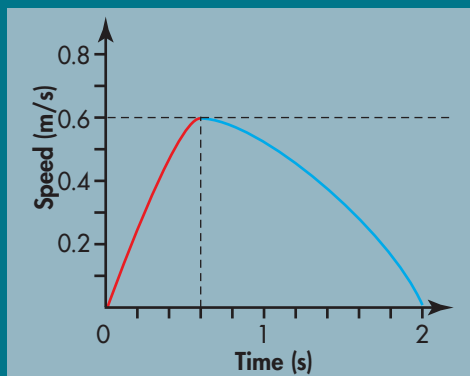
- 3 A car that has stopped at a set of traffic lights 'takes off' when the lights turn green. It increases its speed by 5 m/s during each of the first 3 s after it takes off, and by 3 m/s during the following 2 s.
(a) What is the speed of the car after:
(i) 1 s? (ii) 2 s? (iii) 5 s?
(b) What is the average acceleration of the car during the first 5 s after it takes off?

ANALYSE AND EVALUATE

- 4 Repeat the 'Drag strips' experiment using data-logging equipment and a motion detector or light gates. Use the software to produce a graph of speed versus time. Print a hard copy of your graph.
(a) Use coloured pencils or a highlighter pen to indicate the part of the graph that shows the car or trolley

speeding up. Use a different colour to indicate the part of the graph that shows the car or trolley slowing down.

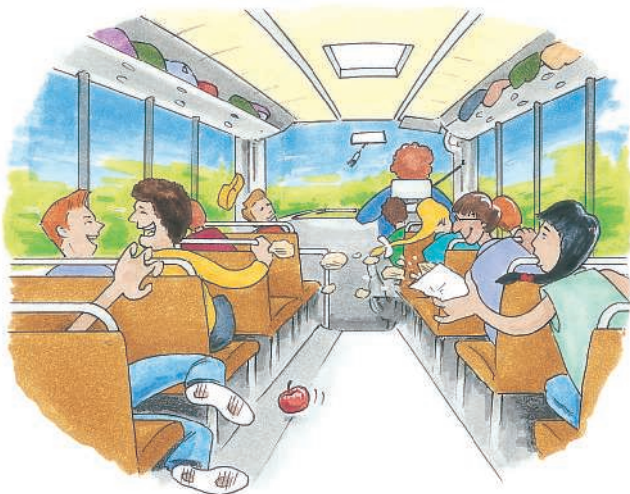
- (b) What is the maximum speed of the car or trolley?
- (c) At what time was the maximum speed reached?
- (d) How would your graph be different if the trolley sped up more quickly, yet reached the same maximum speed?
- (e) Calculate the average acceleration of the toy car in the graph below while it was speeding up.
- (f) Calculate the average acceleration of the car or trolley used in your own experiment.



An example of a speed versus time graph for a toy car

Let's go for a ride

Imagine sitting in a bus on a school excursion. What happens to you when the bus turns a corner, suddenly stops or accelerates after stopping at a railway crossing? The answers to these questions reveal some clues about the relationship between motion and the way that motion is affected by **forces**.



Which way is this bus turning — left or right?

Calculating weight at the Earth's surface

The force of gravitational attraction towards a large object like a planet is called weight. The weight (in newtons) of any object can be calculated using the formula:

$$\text{weight} = mg$$

where m = mass (in kilograms)

g = gravitational field strength (in N/kg).

At the Earth's surface, the gravitational field strength is 9.8 N/kg. That is, the gravitational force acting on each kilogram of mass is 9.8 N.

The weight of a 1 kg object is therefore given by:

$$\begin{aligned}\text{weight} = mg &= 1 \text{ kg} \times 9.8 \text{ N/kg} \\ &= 9.8 \text{ N.}\end{aligned}$$

The weight of a 2000 kg bus is given by:

$$\begin{aligned}\text{weight} = mg &= 2000 \text{ kg} \times 9.8 \text{ N/kg} \\ &= 19\,600 \text{ N.}\end{aligned}$$

Upward push of road: on a horizontal road this force is equal in size to the weight. If the weight and upward push of the road were not in balance, this bus would accelerate downwards through the road or upwards into the air.

upward push
of road

Thrust: the force applied to the driving wheels of the bus by the road. (The driving wheels are the wheels, usually either the front or the rear wheels, that are turned by the motor. All four wheels can be turned by the motor of four-wheel drive vehicles.) The motor turns the wheels so that they push back on the road. As a result, the road pushes forward on the wheels. When the driver turns the steering wheel, the direction of this thrust force changes, allowing the bus to turn.

resistance forces

thrust

Resistance forces: the forces that push against the direction of movement, including **air resistance** and the force of **friction** acting on the wheels that are not turned by the motor. Friction is the force resulting from the movement of one surface over another. It is very much greater when the brakes are applied. When the bus is moving at a constant speed on a straight road, the thrust and resistance forces are in balance.

weight

Weight: the force applied to the bus by the Earth due to gravitational attraction. At the Earth's surface, this force is 9.8 newtons for each kilogram of mass.

The forces acting on a moving bus. The forces are in balance when the bus is not changing speed or direction.

> FORCES ON CARS

You will need:
toy car

- Rest a toy car on a smooth, level surface.
- 1. What forces are acting on the car while it is at rest?
- 2. How do you know that there is more than one force acting on the car while it is at rest?
- Push the car quickly forwards and then let it go.

Explaining the rough ride

Sir Isaac Newton's Laws of Motion were first published in 1687, many years before buses, cars, trains and aeroplanes were invented. However, Sir Isaac would have delighted in explaining the way your body moves in a bus or any other vehicle.

Newton's First Law of Motion states that an object will remain at rest, or will not change its speed or direction, unless it is acted upon by an outside,

3. Are the forces on the car in balance after you stop pushing? How do you know?
4. Which force or forces cause the car to slow down after you stop pushing it forwards?
5. How would the car's motion be different if you pushed it forwards and let it go on:
 - (a) a much smoother surface?
 - (b) a rough surface?

unbalanced force. In all except one of the manoeuvres described in the 'Try this' on the right, an unbalanced force is acting on the bus to change its speed or direction. However, the unbalanced force does not act directly on you, the passenger. You continue moving at the same speed and in the same direction until a seat belt, the inside wall of the bus or another passenger stops you. As you move forward, you are also being pulled downwards by the force of gravity.

A rough ride

Can you remember some rough bus trips you have had? Use your memories of these experiences to help you answer the questions below. You should assume that you are comfortably seated and not wearing a seat belt. The bus seats have no head restraints.

1. What would be your immediate resulting motion (as a passenger on the bus) if the bus performed the following manoeuvres:
 - (a) a very quick start from rest?
 - (b) a forward motion at constant speed?
 - (c) a very sharp right-hand turn?
 - (d) a slow left-hand turn?
 - (e) an emergency stop from a speed of 60 km/h?
 - (f) a forward 'jerk' as the bus is struck from behind by another vehicle?
2. During which type of manoeuvre in question 1 does the bus move with the same speed and direction as the passenger?
3. Explain how properly fitted seat belts would change the resulting motion of the passenger.
4. Explain how a head restraint would change the resulting motion of the passenger in a bus that is struck from behind.

activities

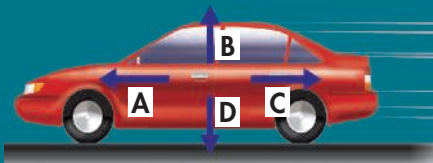
REMEMBER

- 1 Which force prevents a bus from falling through the surface of a road?
- 2 List two forces that resist the forward motion of a bus.
- 3 State Newton's First Law of Motion.

THINK

- 4 Which is greater — the thrust or the resistance forces — when a bus is moving along a horizontal road with:
 - (a) increasing speed?
 - (b) decreasing speed?
 - (c) constant speed?

- 5 Explain in terms of Newton's First Law of Motion why you should never step off a bus, tram or train before it has completely stopped.
- 6 The car shown below is travelling to the left at a constant speed. The four major forces acting on the car are represented by arrows labelled A, B, C and D.



- (a) Which two forces combine to provide the force represented by arrow C?

- (b) How does the size of the force represented by arrow A compare with that of arrow C?
 - (c) Describe two different changes in the forces acting on the car that could cause it to slow down.
- 7 Should seat belts be fitted for the use of all passengers in buses? List the arguments for and against, and state your own opinion.

IMAGINE

- 8 The gravitational field strength on Mars is only 3.7 N/kg. What would your weight be on Mars?

The Newton factor



Don't try this at home!

The expensive crockery on the table in the above illustration is quite safe if the magician is fast enough. Newton's First Law of Motion, also known as the **Law of Inertia**, provides an explanation. The magician is pulling on the tablecloth — not on the expensive crockery. There is a small unbalanced force acting on the crockery due to friction. However, if the tablecloth is pulled away quickly enough, this force does not act for long enough to make the crockery move. If the tablecloth is pulled too slowly, the force of friction on the crockery will pull it off the table as well.

What is this thing called inertia?

Inertia is the property of objects that makes them resist changes in their motion. The inertia of the crockery keeps it on the table. The inertia of the tablecloth is not large enough to allow it to resist the change in motion. Clearly, the greater the mass of an object, the more inertia it has. For example, it takes a much larger force to change the motion of a heavy train than it does to change the motion of a small car.

Remember this:

An object will remain at rest, or will not change its speed or direction unless it is acted upon by an outside, unbalanced force.

Newton's First Law of Motion

Newton's Second Law of Motion

Newton's Second Law of Motion describes how the mass of an object affects the way that it moves when acted upon by one or more forces. In symbols, Newton's second law can be expressed as:

$$a = \frac{F}{m}$$

where a = acceleration

F = the total force on the object

m = the mass of the object.

If the total force is measured in newtons (N) and the mass is measured in kilograms (kg), the acceleration can be determined in metres per second squared (m/s^2).

This formula describes the observation that larger masses accelerate less rapidly than smaller masses acted on by the same total force. It also describes how a particular object accelerates more rapidly when a larger total force is applied. When all of the forces on an object are balanced, the total force is zero.

Newton's second law is often expressed as $F = ma$.

Newton's second law in action

The launching of the space shuttle at Cape Canaveral in Florida is a spectacular sight. At launch, the space shuttle has a mass of about 2.2 million kilograms. (About

experiment

> LOOKING AT INERTIA

You will need:

5 cent and 20 cent coins
sheet of A4 paper

- Place a sheet of A4 paper at the end of a smooth table so that one end of the paper overhangs the end of the table by a few centimetres. Place a 20 cent (or heavier) coin in the centre of the sheet of paper.
 - Pull the paper from underneath the coin very quickly. (You may need to do this a few times so that you can be sure you are pulling it fast enough.) Observe what happens to the coin. Now pull out the paper more slowly and, again, observe what happens to the coin.
1. What happens to the coin when the paper is pulled out quickly?
 2. Are the forces acting on the paper balanced? Explain your answer.
 3. Explain why the coin behaves in the way it does.
 4. How is the behaviour of the coin different if the paper is pulled out more slowly? Suggest a reason for the change in behaviour.
 - Repeat the experiment steps detailed above, only this time use a 5 cent coin.
 5. Is it easier or more difficult to pull the paper out from beneath the lighter coin? Suggest a reason for your answer.



The space shuttle is launched by powerful rockets — yet it seems to take ‘forever’ to get off the ground. Newton’s second law provides an explanation.

86 per cent of this mass is fuel, most of which is burnt during the launch.) There are two forces acting on the space shuttle as it blasts off:

- the downward pull of gravity (weight). The weight of the space shuttle at blast-off is about 22 million newtons.
- the upward thrust resulting from the burning of fuel, which is about 29 million newtons.

The forces acting on the space shuttle are not balanced. The total force on the space shuttle is 7 million newtons upwards.

Newton’s second law can be used to estimate the acceleration of the space shuttle at blast-off:

$$\begin{aligned}
 a &= \frac{F}{m} \\
 &= \frac{7\,000\,000\text{ N upwards}}{2\,200\,000\text{ kg}} \\
 &= 3.2\text{ m/s}^2.
 \end{aligned}$$

In other words, the space shuttle is gaining speed at the rate of only 3.2 m/s (or 11.5 km/h) each second. No wonder the blast off seems to take forever!

Newton’s second law also explains why the small acceleration at blast-off is not a problem. As the fuel is rapidly burnt, the mass of the space shuttle gets smaller. As this happens, the acceleration gradually increases, and the space shuttle gains speed more quickly.

Several hurt when United flight hits turbulence

WELLINGTON, New Zealand (AP) — A United Airlines flight from Sydney to San Francisco detoured to Auckland late Wednesday local time after several people on board were injured when the plane hit severe turbulence over the Pacific Ocean, an airline spokesman said.

The Boeing 747-400 touched down at 10:55 pm at Auckland Airport, 400 miles north of the capital, Wellington, and was met by waiting ambulances.

St John Ambulance duty manager Pat Berry said five passengers from flight UA862 were taken to Auckland’s Middlemore Hospital for treatment.

He said a female cabin attendant broke a leg and a male cabin crew member had back and shoulder injuries from being thrown around in the turbulence.

Berry said three passengers were taken to hospital with ‘bruising and muscular discomfort.’ Two other passengers with minor injuries were treated by ambulance staff at the airport.

Passenger Julie Greenwood told *The New Zealand Herald* newspaper the turbulence lasted about 30 seconds.

‘It was like an earthquake in the air — I was lifted out of my chair twice,’ she said.

Airline spokesman Jonathan Tudor in Auckland told *The Associated Press* that United Airlines flight 862, carrying 269 passengers and 21 crew, had taken off from Sydney at 3:35 pm New Zealand time and flew into ‘clear air turbulence’ after about four hours.

Those who were uninjured would be housed overnight in Auckland hotels, he added. It was not immediately clear when the flight would continue on to San Francisco.

Mary Brander, 77, from Sydney, said the bottom seemed to be falling out of the plane when it struck the turbulence.

‘One minute we were in clear blue sky and it hit,’ she told *The New Zealand Herald*.

Source: © *The Associated Press*,
1 May 2002

activities

REMEMBER

- 1 What is inertia?
- 2 Express Newton’s second law in symbols. State what each symbol represents.
- 3 Explain in terms of Newton’s second law why the acceleration of the space shuttle gradually increases as it rises.

THINK

- 4 Read the newspaper article below left and answer the following questions.
 - (a) Explain why the passengers and crew were injured during the flight.
 - (b) What was really being thrown around — the passengers or the aircraft? Explain your answer.
 - (c) How would a seat belt protect a passenger in an incident like the one described?
 - (d) Explain why a Boeing 747 aircraft needs more distance to turn around than a smaller plane.
- 5 What total force would cause a 1.5 kg glass salad bowl to accelerate across a table at 0.30 m/s²?
- 6 A 10 kg sled is pulled across the snow so that the total force acting on it is 12 N. What is the size of the average acceleration of the sled?

USING DATA

- 7 Two identical toy carts, A and B, each with a mass of 1.0 kg, are pushed across a smooth, level table top with the same force. One of them contains a heavy brick. Cart A accelerates more rapidly than Cart B.
 - (a) Which toy cart contains the brick? How do you know?
 - (b) If the acceleration of cart A is 2.0 m/s², what is the total force acting on each cart?
 - (c) If the acceleration of cart B is 0.5 m/s², what is the mass of the brick?

Science at work: Making cars safe

In 1970, there were about 6 million vehicles being driven on Australia's roads. During that year 3798 people lost their lives in road accidents. Now there are about 14 million vehicles on Australia's roads. Yet the number of lives lost each year in road accidents now averages about 1600.

One of the key reasons for the reduction in the road toll is that the cars we drive today are safer than ever before. Cars are designed by engineers who use scientific knowledge and experimentation to make cars lighter, stronger and, most importantly, safer.

Crash tests

Safety features such as seat belts, collapsible steering wheels, padded dashboards, head restraints, airbags and crumple zones have to be tested by engineers before being introduced. The testing continues after introduction as car manufacturers strive to make cars even safer.

Testing of safety features involves deliberately crashing cars with 'crash test dummies' as occupants. The dummies are constructed to resemble the

human body and numerous sensors are used to detect and measure the effects of a collision.

Before real crash testing takes place, engineers use computer modelling to simulate crashes with 'virtual' cars.

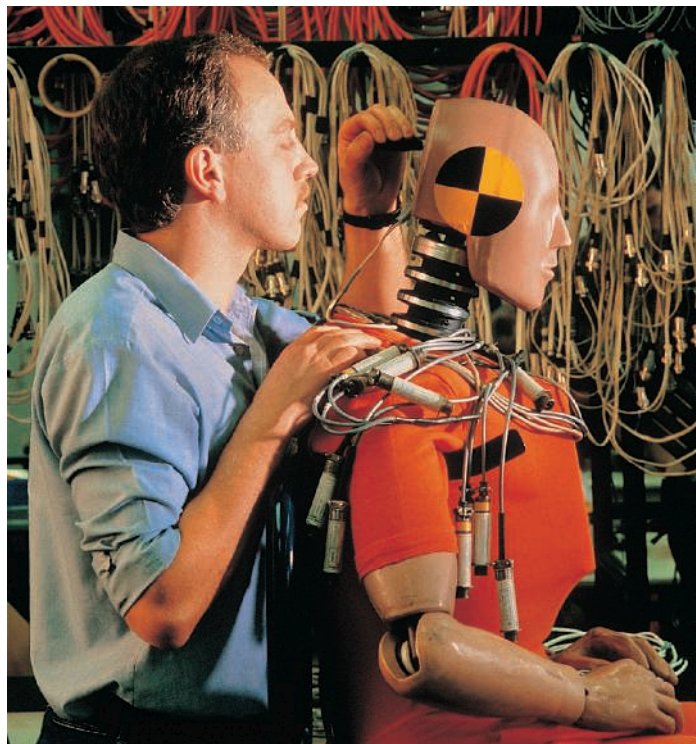
The effect of inertia

Most deaths and serious injuries in road accidents are caused when the occupants collide with the interior of the vehicle or are 'thrown' from the vehicle. In a head-on collision the vehicle stops suddenly. However, unrestrained occupants continue to move at the pre-collision velocity of the vehicle until they collide with the steering wheel, dashboard or windscreen. Seat belts provide an immediate force on the occupants so that they don't continue moving towards the interior of the car. Front airbags reduce injuries caused by collisions between the upper body (which is still moving) and the steering wheel, dashboard or windscreen.

Side airbags are becoming more popular. They protect occupants in the event of a side-on collision. The more recent airbag technology measures the size of the impact and delays inflation until just the right moment. These improvements are the direct result of computer modelling and real crash testing.

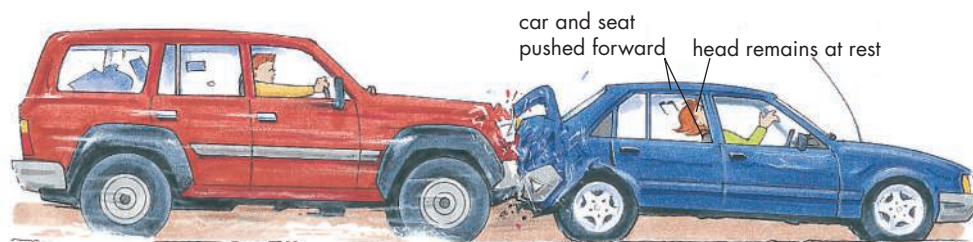
Head restraints on seats reduce neck and spinal injuries, especially in a vehicle that is struck from behind by another vehicle. An impact from the rear pushes a vehicle forwards suddenly. Your body is pushed forwards by your seat. However, without a head restraint, your head remains where it was. The sudden strain on your neck can cause serious spinal injuries. Neck injuries caused this way are often referred to as whiplash injuries. Some new cars have head restraints that automatically move forward and up when a collision occurs.

Computer modelling allows engineers to calculate the forces acting on occupants, and predict the extent and cost of injuries in different types of collisions.



Crash test dummies are used to model the effects of collisions on the human body.





A stationary car is struck from behind by another vehicle. Without a head restraint, your head remains at rest until pulled forwards by your neck.

The zone defence

The occupants of a car sit in a very strong and rigid 'protection zone' designed to prevent outside objects (including the car's engine, other cars and tree trunks) from entering the passenger 'cell' and causing injuries during a collision. The roof panel is supported by strong pillars to make it less likely to be crushed.



The rigid roof panel and strong pillars that support it are part of the 'protection zone'.

The rigid passenger 'cell' is flanked by crumple zones at the front and rear of the vehicle. These zones are deliberately designed to crumple, absorbing and spreading much of the energy transferred to the vehicle during a collision. As a result, less energy is transferred to the 'protection zone' carrying the occupants, reducing the chance of injuries. The crumple zone also allows the vehicle to stop more gradually. Without a crumple zone, the vehicle would stop more suddenly



The 'zone defence' being tested. The front crumple zone absorbs and spreads energy. It also allows the car to stop more gradually.

and perhaps even rebound. Occupants would make contact with the interior at a greater speed, and there would be a greater chance of serious injury or death.

activities

REMEMBER

- 1 List six safety features that are designed to make cars safer in the event of a collision.
- 2 How do engineers test vehicle safety features to make sure that they do what they are designed to do?
- 3 What happens to the motion of an unrestrained occupant when a car suddenly stops because it has collided head-on with another car or object?
- 4 How does each of the following features protect occupants during a collision?
(a) Seat belts?
(b) Airbags?
(c) Head restraints?
- 5 What are crumple zones, and how do they protect the occupants of a vehicle during a collision?
- 6 Why is it important that there is a strong and rigid zone between the two crumple zones of a car?

BRAINSTORM

- 7 The safety features described on these two pages are designed to reduce the chances of serious injury or death when a collision takes place. Scientists and engineers

have designed many other safety features in cars and other vehicles that reduce the chances of a collision actually taking place. Work in a group to brainstorm these features and complete a table like the one below. Some examples are included to help you get started.

Safety features designed to prevent collisions

Feature	How the feature works
Tyre tread	increases friction and makes steering and braking more reliable, especially in wet weather. The tread even pushes water out from beneath the tyre when the road is wet.
Windscreen wipers	keep the windscreen clear to ensure good visibility for the driver.
Speed alarm	the driver selects a maximum speed. If that speed is exceeded an alarm sounds, warning the driver to slow down.

CONNECT AND INVESTIGATE

- 8 Use the Internet to research and report on:
(a) how anti-lock brake systems (ABS) make braking in an emergency situation safer
(b) the benefits of electronic stability control (ESC).

What's your reaction?



Push against a solid wall like the girl in the adjacent photograph. What would happen if the wall didn't push back?

Sir Isaac **Newton's Third Law of Motion** states that for every **action** there is an equal and opposite **reaction**. That is, when an object applies a force to a second object, the second object applies an equal and opposite force to the first object. In the photograph on the left, the girl applies a force (an action) to the wall. The wall applies an equal and opposite force to the girl (a reaction).

In fact, forces always occur in pairs. Sometimes it is painfully obvious. For example,

when you catch a fast-moving softball or cricket ball with your bare hands, your hands apply a force to the ball. The ball applies an equal and opposite force to your hands — causing the pain.



Sometimes the fact that forces occur in pairs is painfully obvious.

Up and away

The force that pushes a jet aeroplane forward is provided by the exhaust gases that stream from its engines. As the jet engines push the exhaust gases backwards (an action), the gases push forwards with an equal and opposite force. This forward push is called the **thrust**. In order to equal or exceed the resistance to the jet's motion, the thrust needs to be very large. The photograph below shows the huge blades inside a jet engine. The blades compress the air flowing into the engine and push it into the combustion chamber behind the blades. In the combustion chamber, fuel is added and burns rapidly in the compressed air. The exhaust gases are forced out of the engine at very high speed.



The huge blades of a jet engine suck in and compress air so that the fuel inside burns rapidly. Exhaust gases are then forced out at high speed.

On the move with Newton's Third Law of Motion

Whether you are getting around on the ground, in the water, in the air and even in outer space, action and reaction forces are needed.

- When an athlete pushes back and down on the starting block, the starting block pushes the athlete forwards and upwards.
- The forward push of the road on the driving wheels of a car occurs only because the wheels push back on the road.
- When you swim through the water, you push back on the water with your arms and legs so that the water pushes you forward.



In order to move forward quickly, the athletes need to push back. Why?

experiment

> JUST A LOT OF HOT AIR

You will need:
a balloon

- Inflate a balloon and hold the opening closed.
 - Release the balloon and observe its motion through the air.
1. What happens to the air inside the balloon when you release the balloon?
 2. Which way does the balloon move as the air is pushed out?
 3. What provides the force that pushes the balloon through the air?
 4. What is similar about the way that the balloon is propelled and the way that a jet engine works?
 5. How is the motion of the balloon different from the motion of a jet engine?

Blast off

The rockets used to launch the space shuttle use an action and reaction pair of forces to propel themselves upwards. Like jet engines, they push exhaust gases rapidly out behind them (an action). As the rocket pushes the gases out, the gases push in the opposite direction on the rocket.

Unlike jet engines, rockets used to launch spacecraft do not use air to burn fuel. They carry their own supply of oxygen so that the fuel can burn quickly enough to lift huge loads into space. The oxygen is usually carried as a liquid or a solid. Once spacecraft are in orbit, smaller rockets can be used to make the craft speed up, slow down or change direction.

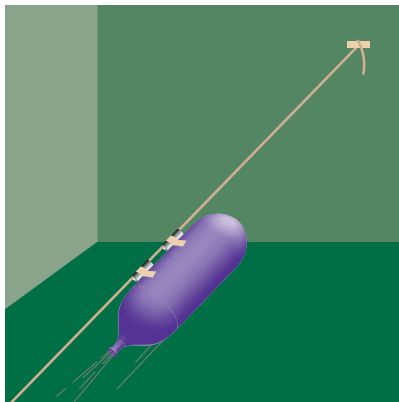
experiment

> BALLOON ROCKET

You will need:
balloon (sausage-shaped if possible)
drinking straw (plastic)
masking tape
scissors
fishing line (about 20 m)

- Cut two short pieces from the drinking straw and thread a length of fishing line through them. Attach the ends of the fishing line to two fixed points so that the line is taut.
- Inflate the balloon and hold it closed while your partner attaches it to the pieces of straw with masking tape as shown in the adjacent diagram.
- Release the balloon and observe its motion along the string. Record the total distance travelled by your balloon rocket.

1. Compare your balloon rocket with those of others in your class. What features of the balloon rocket seemed to determine its range?
2. Suggest how your balloon rocket could be improved.



A balloon rocket

sciFacts

Rockets, believed to have been invented by the Chinese, have been used as weapons since the thirteenth century.



activities

REMEMBER

- 1 State Newton's Third Law of Motion.
- 2 List three pairs of action and reaction forces. Be sure to state what each force is acting on.

THINK

- 3 When you walk forwards, what provides the forward push?
- 4 How are rockets similar to jet engines? How are they different?
- 5 A yacht uses the push of the air on its sails to propel it forwards. If the push of the air on the sails is an action, what is the corresponding reaction?
- 6 What reaction force propels a Murray River paddleboat forwards? State clearly the action force that makes up the other part of the action–reaction pair.

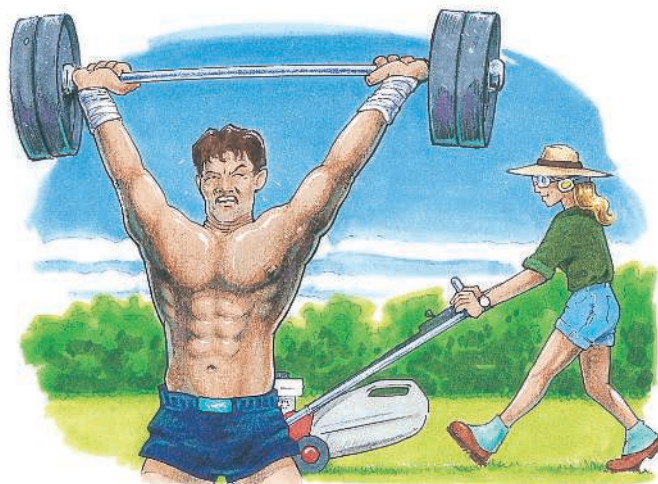
INVESTIGATE

- 7 Find out how a hovercraft works. What action–reaction pairs are involved in its operation? Perhaps you could make a working model of one. Start by making a list of the materials that you will need.

Getting down to work

Who is doing more work?

Whenever you apply a force to an object and the object moves in the direction of the force, **work** is done. The weightlifter does work to lift the barbell — he applies an upward force and the barbell moves up. However, when he holds the barbell above his head, no work is being done on the barbell. The weightlifter is applying an upward force equal to the weight of the barbell, but there is no movement in the direction of the upward force. The gardener is doing work on the lawnmower. The lawnmower is moving forwards because the gardener is pushing forwards on it.



Pushing a pen — your hand is doing work on the pen.

Playing hockey — the stick does work on the ball.



Taking a dive — the force of gravity does work on you.

Up to the next floor — the escalator does work on you.

Doing work — you do it more than you think!

Out of contact

In all but one of the examples in the illustration above, the object doing the work is in contact with the object on which work is done. However, contact is not always necessary for work to be done. The Earth does work on you while you fall because of the gravitational attraction between it and you. When you pick up a small piece of paper with a charged plastic pen, work is done on the paper because of the attraction between the electric charge in the pen and the paper.

Working out work

The amount of work done on an object by a constant force is the product of the size of the force and the distance moved by the object in the direction of the force. That is:

work done = force $\times$ distance travelled in the direction of the force.

If the force is measured in newtons (N) and the distance is measured in metres, work done is measured in units of newton metres (N m).

Doing work — what does it really mean?

Work and energy

Energy can be transferred to an object by doing work on it. Doing work on an object can also convert the energy an object possesses from one form to another. In fact, work is a measure of energy. The amount of energy transferred or converted when 1 newton of force moves an object 1 metre is 1 joule.

If you lift a 5 kilogram bowling ball with a force of 49 newtons (just enough to overcome its weight) through a height of 40 centimetres, the amount of work done is given by:

$$\begin{aligned}\text{work done} &= \text{force} \times \text{distance} \\ &= 49 \text{ N} \times 0.40 \text{ m} \\ &= 19.6 \text{ N m} \\ &= 19.6 \text{ J.}\end{aligned}$$

By doing work on the bowling ball, you have transferred 19.6 joules of energy to it. The additional energy is stored in the ball as **gravitational potential energy**. This stored energy has the potential to be converted

into other forms of energy or transferred to other objects. For example, if you drop the ball, the force of gravity can do work on the ball, increasing its **kinetic energy**. Kinetic energy is the energy associated with movement. If your toe happens to be in the way when the bowling ball reaches floor level, the kinetic energy is transferred to your toe — ouch!

Storing it up

All stored energy is called **potential energy**. Energy can be stored in several different ways.

- Elastic potential energy (also called strain energy) is present in objects when they are stretched or compressed. Stretched rubber bands and springs have elastic potential energy. So do compressed springs like the one shown in the illustration below. When the lid is opened, the elastic potential energy in the compressed spring is converted into kinetic energy, often causing the person who opened it to make loud involuntary sounds!



A jack-in-the-box 'escapes', converting elastic potential energy into kinetic energy.

- Gravitational potential energy is present in objects that are in a position from which they could fall as a result of the force of gravity. The water in a hydroelectric dam has gravitational potential energy. When the water is released, the force of gravity pulls down on it, doing work and converting the gravitational potential energy into kinetic energy.
- Electrical potential energy is present in objects or groups of objects in which positively and negatively charged particles are separated. It is also present when like electric charges are brought close together. The most obvious evidence of electrical potential energy is in clouds during thunderstorms. When enough electrical potential energy builds up, electrons move as lightning between clouds or to the ground.
- Chemical potential energy is present in all substances as a result of the electrical forces that hold atoms together. When chemical reactions take place, the stored energy can be converted to other forms of energy or it can be transferred to other atoms. Chemical potential energy is a form of electrical potential energy.
- Nuclear energy is the energy stored within the nucleus of all atoms. In radioactive substances, nuclear energy is naturally converted to other forms of energy. In nuclear reactions, such as those in nuclear power stations, in nuclear weapons and on the sun and other stars, nuclei are split or combine together. As a result, some of the energy stored in the reacting nuclei is converted into other forms of energy.

activities

REMEMBER

- 1 When you 'go to work' you are not always working. When are you *really* doing work?
- 2 List two examples of work being done on an object when there is no direct contact with another object.
- 3 How can the amount of work done on an object be calculated?

THINK

- 4 Which type of force, other than electrical and gravitational forces, can do work on an object without being in contact with it?
- 5 How much work is done by:
 - (a) a gardener as he pushes on a lawnmower 5 m across a level lawn with a horizontal force of 300 N?
 - (b) three people as they unsuccessfully try to push a bogged car out of the mud? The car does not move. Each of the three people applies a forward force of 400 N to the car.
- 6 An Olympic diver with a weight of 540 N dives into a pool from a height of 10 m.
 - (a) How much work is done on her by the force of gravity?
 - (b) How much of her gravitational potential energy would you expect to be converted into kinetic energy during her dive?
- 7 Name an example of a child's toy that converts:
 - (a) gravitational potential energy into kinetic energy
 - (b) elastic potential energy into kinetic energy.

INVESTIGATE

- 8 Research and report on the life of James Joule. What did Joule achieve to deserve the honour of having the unit of energy named after him?
- 9 Investigate and write a report on the energy changes that take place when you cut the lawn with a lawnmower. Identify the forces that do work while you are mowing the lawn.

Energy ups and downs

The energy changes that take place on a trampoline occur when work is done alternately by the force of gravity and the trampoline itself.

Never created, never destroyed

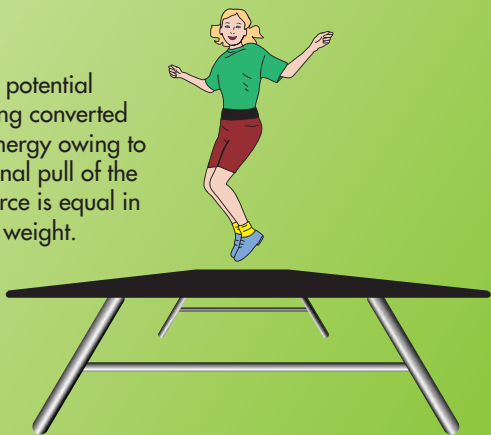


Whenever work is done, energy is transferred to another object or converted into another form of energy. Energy is never created — nor is it ever destroyed. In fact, the total amount of energy in the universe remains constant. This observation is known as the Law of Conservation of Energy. The energy of a bouncing tennis ball is converted from kinetic energy to stored energy and back again. However, because it ‘loses’ energy during these conversions, it never bounces back to its original height. Nevertheless, its energy is not really lost. It is transferred to other objects — the air and the ground.



(a) Going down

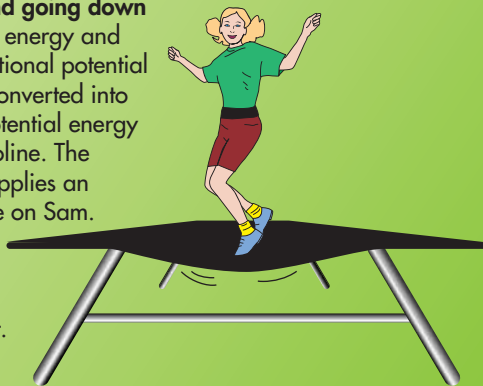
Gravitational potential energy is being converted into kinetic energy owing to the gravitational pull of the Earth. This force is equal in size to Sam's weight.



(b)

In contact and going down

Sam's kinetic energy and more gravitational potential energy are converted into the elastic potential energy of the trampoline. The trampoline applies an upward force on Sam. The size of this force is greater than Sam's weight.



(c) In contact and going up

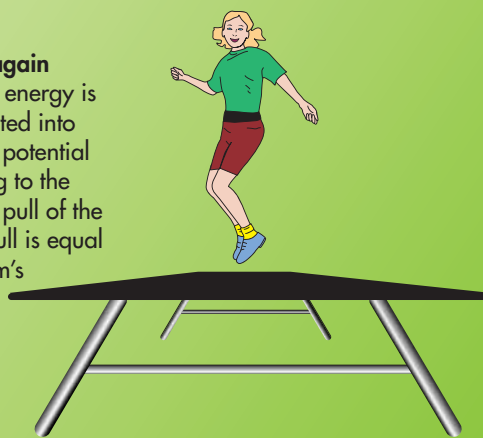
The elastic potential energy of the trampoline is transferred to Sam as kinetic energy and gravitational potential energy. The trampoline is still applying an upward force on Sam.



(d)

On the rise again

Sam's kinetic energy is being converted into gravitational potential energy owing to the gravitational pull of the Earth. This pull is equal in size to Sam's weight.



Follow the bouncing ball

You will need:

tennis ball metre ruler

- Drop the tennis ball from a height of one metre onto a hard surface. Watch the top of the ball closely as it hits the ground and rebounds. Measure the height from the top of the ball and take care that the ball is dropped from rest and not 'assisted' on its way down.
- 1. Construct a flowchart using text descriptions similar to those used in the illustration at the bottom of the opposite page to show the energy changes that take place as the ball:
 - (a) is falling through the air
 - (b) is slowing down while in contact with the ground
 - (c) is speeding up just before leaving the ground
 - (d) is rising through the air.
- 2. Identify the largest force that is acting on the ball as it:
 - (a) falls through the air
 - (b) is in contact with the ground
 - (c) rises through the air.
- Drop the ball again from the same height and measure the height to which it rebounds after a single bounce.
- Repeat your measurements at least five times and find the average bounce height.

The amount of gravitational potential energy lost by the ball as it falls is the same as the amount of work done on the ball by the force pulling it down. The work done by the force of gravity as the ball falls is given by:

$$\begin{aligned}
 \text{work done} &= \text{force} \times \text{distance travelled in the direction of the force} \\
 &= \text{weight of tennis ball} \times \text{height through which it falls} \\
 &= m \times 9.8 \text{ N/kg} \times h_1 \quad \text{where } m \text{ is the mass of the ball} \\
 &\quad \text{(in kilograms) and } h_1 \text{ is the height} \\
 &\quad \text{from which the ball was dropped} \\
 &\quad \text{(in metres).}
 \end{aligned}$$

The amount of gravitational potential energy lost is $9.8 m \times h_1$ joules.

The amount of gravitational potential energy regained by the ball as it rises to its maximum height is equal to the work done by the force of gravity against its direction of motion. That is, the amount of gravitational potential energy regained by the ball is:

$$\begin{aligned}
 \text{work done} &= \text{force} \times \text{distance travelled in the direction of the force} \\
 &= \text{weight of tennis ball} \times \text{height through which it rises} \\
 &= m \times 9.8 \text{ N/kg} \times h_2 \quad \text{where } h_2 \text{ is the height to which} \\
 &\quad \text{the ball rebounds (in metres).}
 \end{aligned}$$

The amount of gravitational potential energy regained is $9.8 m \times h_2$ joules.

The percentage of the tennis ball's initial gravitational potential energy that is regained by the end of the first bounce is:

$$\frac{m \times 9.8 \text{ N/kg} \times h_2}{m \times 9.8 \text{ N/kg} \times h_1} \times \frac{100\%}{1} = \frac{h_2}{h_1} \times \frac{100\%}{1}$$

3. What percentage of your tennis ball's initial gravitational potential energy is regained by the end of the first bounce?
4. Where has the 'lost' energy gone? Is it really lost?

Swing high, swing low

- Push a friend on a swing.
- 1. Construct a flowchart, including text descriptions, like those shown in the illustration on the opposite page to show how the energy of your friend changes through one complete backwards and forwards swing.
- 2. The initial kinetic energy of the person on the swing is zero. From where does the person's initial increase in kinetic energy come?
- 3. In order to keep the person swinging up to the same height over and over again, you can continue to push. If energy is conserved, why do you need to continue to provide additional energy by pushing?

activities

THINK

- 1 When you speed down a playground slide, the amount of kinetic energy that you gain on the way down is less than the amount of gravitational potential energy that you lose.
 - (a) Where does the 'missing' energy go?
 - (b) What can be done to ensure that as much as possible of your initial gravitational potential energy lost is converted into your kinetic energy?

CREATE

- 2 Construct a poster that shows what happens to your gravitational potential energy during either a bungee jump or a roller-coaster ride.
- 3 Design and build a device that uses the gravitational potential energy stored in a tennis ball (or another type of ball) to perform a simple task.

Thinking tools:

Cycle maps and storyboards

1. List actions or steps that are relevant to a particular cycle on small pieces of paper.
2. Order your pieces of paper and then position the steps in a circle.
3. Review your cycle — are any steps in the wrong order, missing or irrelevant? If so make changes.
4. Write your cycle with each step placed in a box and the boxes joined by arrows within your circle.

how to ...?

What patterns can be seen in these events?

question

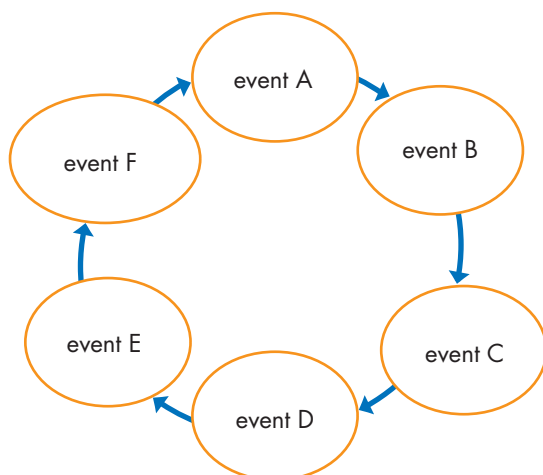
helps you to see repeating sequences of events

why use?

cycle chart;
cyclical map

also called

cycle map



comparison

storyboards

example

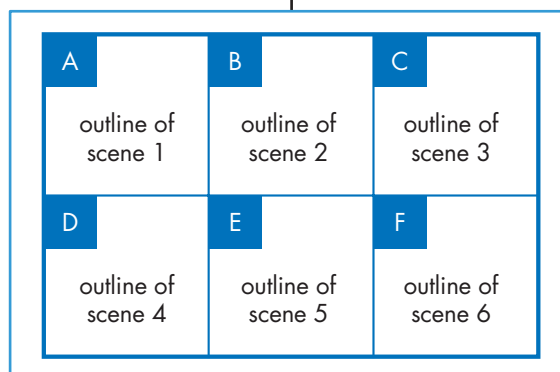
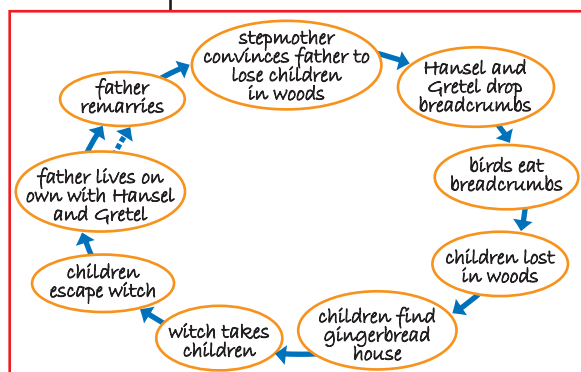
Similarity

Both help you to think about key points in the story of the event or information.

Difference

Cycle maps can repeat the story; storyboards tell the story scene by scene.

example

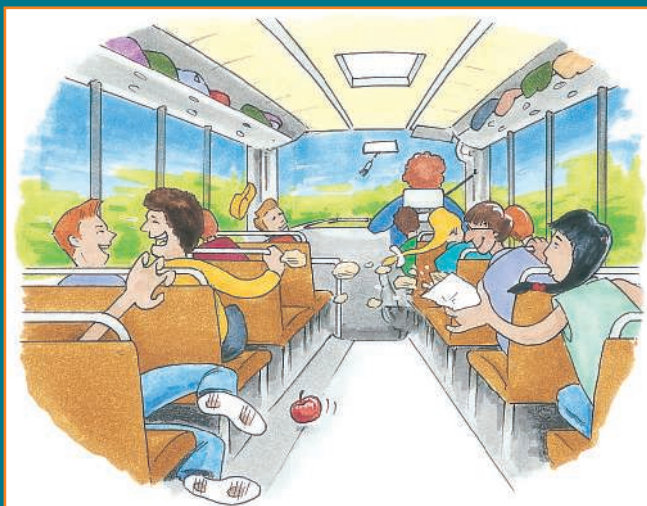
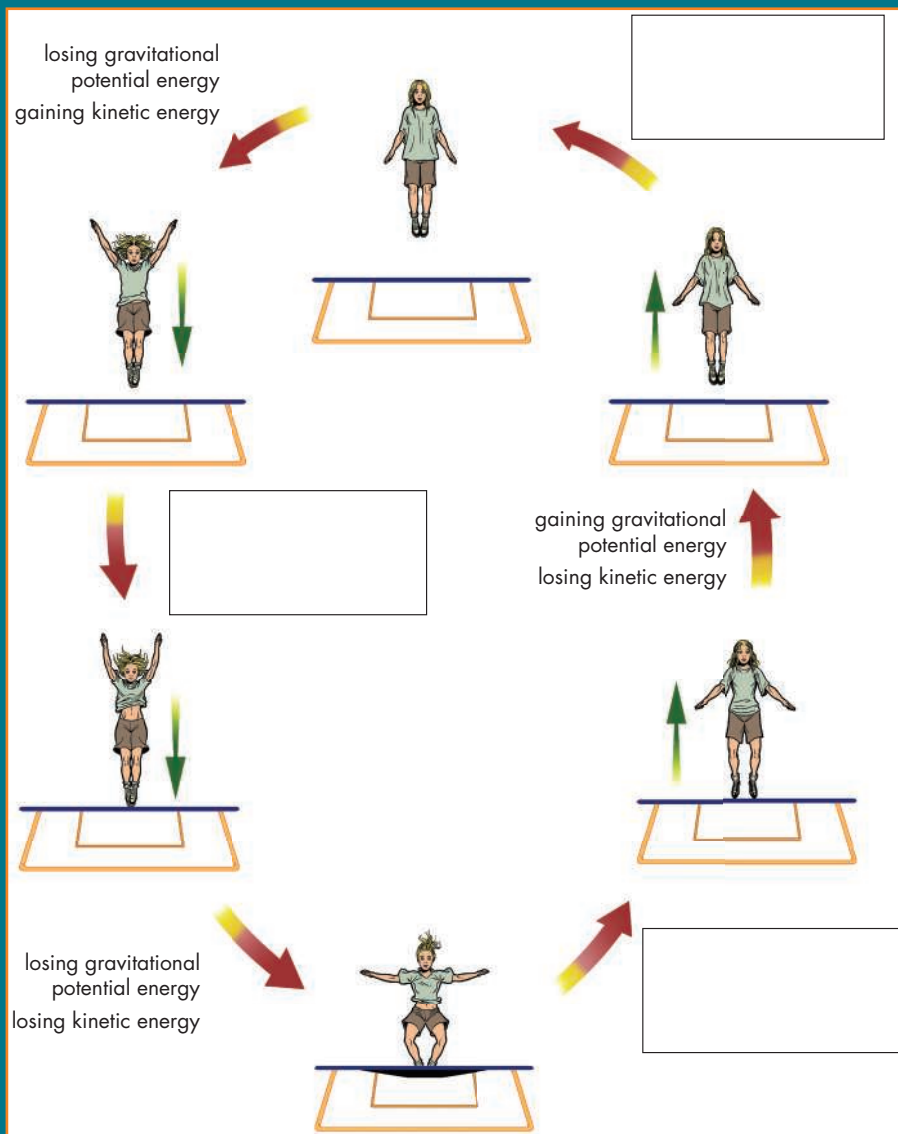


Adapted with permission from Hawker Brownlow Education © 2005 modellearning.com *Thinking Skills and EyeQ: Visual Tools for Raising Intelligence* by Ian Harris, Oliver Caviglioli and Bill Tindall

THINK AND CREATE

Questions 1–5 refer to the cycle map on the right, which represents the motion of a girl on a trampoline. The vertical arrows represent the direction of motion of the girl.

- Some of the boxes describing the energy changes that are taking place are empty. Copy the cycle map below and complete it by describing the missing energy changes in the empty boxes.
- During which stage (or stages) of the trampoline cycle is the girl:
 - accelerating upwards?
 - accelerating downwards?
 - decelerating?
 - moving with zero velocity?
- During which stage (or stages) of the trampoline cycle is the net force acting on the girl:
 - up?
 - down?
- During which stage (or stages) of the trampoline cycle is the force of gravity acting on the girl?
- What is happening to the energy lost by the girl between stages 3 and 4?
- Construct a cycle map that describes the energy changes that take place when a tennis ball is dropped from a height and is allowed to bounce several times.
- Create a storyboard that describes the motion of the passenger in a car as it accelerates from rest, travels in a straight line at constant speed, slows down before turning left, and accelerates again before coming to a sudden stop. Assume that the passenger is wearing a seat belt. Add a commentary to each of the sketches of your storyboard that describes the forces acting on the passenger.



Looking back



1. Complete the equations below.

(a) average speed = $\frac{\text{distance}}{\text{time taken}}$

(b) average velocity = $\frac{\text{displacement}}{\text{time taken}}$

(c) average acceleration = $\frac{\text{change in velocity}}{\text{time taken}}$

(d) acceleration = $\frac{\text{change in velocity}}{\text{time taken}}$



2. The table below provides information about four laps completed by one of the drivers in an Australian Formula One Grand Prix. The distance covered during one complete circuit of the course is 5.3 km.

(a) Make a copy of the table and fill in the empty cells.

Lap no.	Time (s)	Average speed (m/s)	Average speed (km/h)
5	90		
15		60	216
25	110		
35	92	57.6	

(b) Suggest two likely reasons for the lower average speed during lap 25.



3. Complete these statements about Newton's Laws of Motion in your workbook.

(a) An object remains at rest, or will not change its speed or direction unless ...

(b) When an unbalanced force acts on an object, the mass of an object affects ...

(c) For every action, there is ...

4. Explain why the following statement is false: 'A car travelling along a straight road has no forces acting on it'.

5. Explain in terms of Newton's First Law of Motion why it is dangerous to have loose objects inside a moving car.

6. Newton's Second Law of Motion can be expressed as the formula $F = ma$. What quantities do each of the symbols in the formula represent?

7. The diagram at the bottom of the page shows part of the ticker tape record of the motion of a toy car as it is pushed along a table. As the tape moves through the ticker timer, a new black dot is produced every fiftieth of a second (0.02 s). The ticker tape has been divided into four equal time intervals labelled A, B, C and D.

(a) During which time intervals is the speed of the toy car:

(i) increasing?

(ii) decreasing?

(b) During which of the four time intervals is the:

(i) speed of the toy car constant?

(ii) acceleration of the toy car constant?

(c) During which of the four intervals was the total force acting on the toy car zero?

(d) During which of the four intervals was the unbalanced force acting on the toy car in the same direction as that in which the car was moving?

(e) What period of time is represented by each of the four time intervals? Express your answer in decimal form.

(f) What is the average speed during the entire time interval represented by the ticker tape?

8. Who is doing more work — a body-builder holding an 80-kilogram barbell above her head or a student writing the answer to this question? Explain your answer.

9. List the energy changes that take place as a tennis ball dropped from a height of 2 m:

(a) falls towards the ground

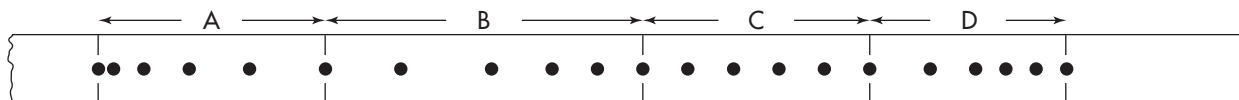
(b) is in contact with the ground

(c) rebounds upwards through the air.

10. List the forces acting on the tennis ball described in question 9 while it is:

(a) moving through the air

(b) in contact with the ground.



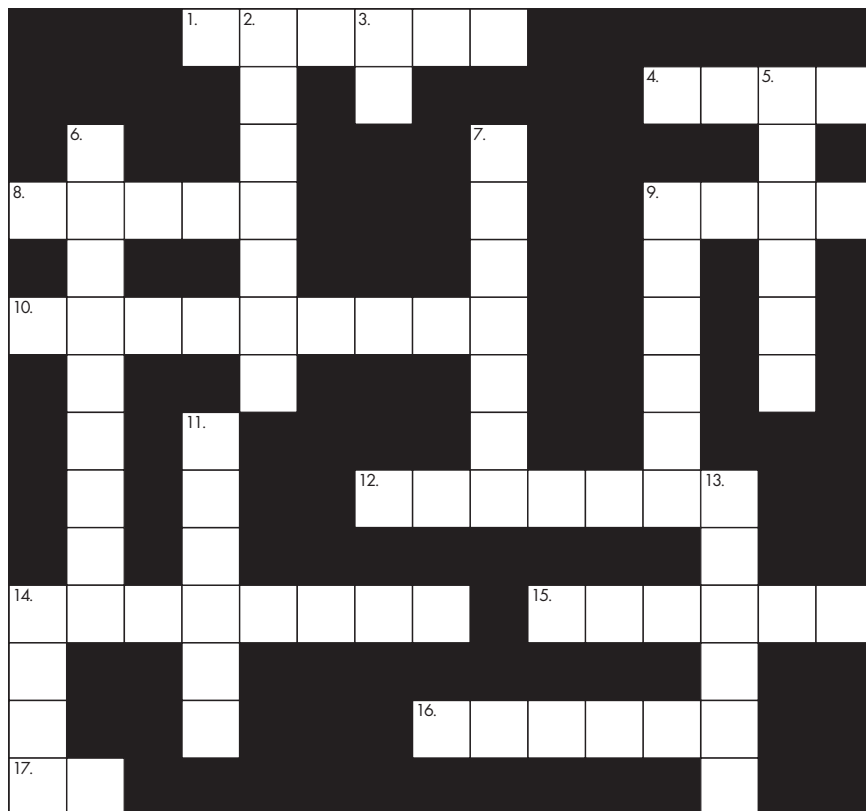
11. Complete the crossword using the following clues.

Across

1. This type of timer provides an easy way of recording motion on paper tape in the school laboratory.
4. You will find these used on ticker-timer tape.
8. A method used by police to measure the instantaneous speed of vehicles
9. This is done whenever you move an object.
10. Another word for size
12. The Chinese invented these to use as weapons.
14. You must use this whenever you are in a car (two words).
15. It cannot be created or destroyed but can be transferred to another object or changed to another form when work is done.
16. This always causes a reaction.
17. Potential energy (abbreviation)

Down

2. The property of an object that makes it resist changes in motion
3. Kinetic energy (abbreviation)
5. The force that pushes a car forward
6. Used to slow very fast drag racing cars in a short time
7. The type of energy that all moving objects have
9. This quantity is equal to the force of gravitational attraction towards the centre of the Earth.
11. The unit of force and a very famous name



13. This type of balance can be used in the laboratory to measure weight.
14. Always wait until trains or buses do this before stepping off.

12. Many older people who drove cars more than 50 years ago make the comment 'They don't make them like they used to' in discussions about crumple zones. They describe how older

cars were stronger and tougher, and therefore safer. Write a letter to a person who has made such a statement explaining why it is better that 'they don't make them like they used to'.

