8 Forces, energy and motion

The thrill of a rollercoaster ride allows you to experience sudden changes in motion. When the car suddenly falls, you seem to get left behind just for a while. When you reach the bottom of the track and the car rises, your stomach seems to sink. And when you round a bend, your body seems to be flung sideways. Such a ride raises many questions about the way in which forces affect motion and energy.

OVERARCHING IDEAS

- Form and function
- Stability and change
- Scale and measurement
- Matter and energy
- Systems

SCIENCE UNDERSTANDING

The motion of objects can be described and predicted using the laws of physics.

Energy conservation in a system can be explained by describing energy transfers and transformations.

Elaborations

Gathering data to analyse everyday motions produced by forces, such as measurement of distance and time, speed, force, mass and acceleration

Recognising that a stationary object, or a moving object with constant motion, has balanced forces acting on it

Using Newton's Second Law to predict how a force affects the movement of an object

Recognising and applying Newton's Third Law to describe the effect of interactions between two objects

Recognising that the Law of Conservation of Energy explains that total energy is maintained in energy transfer and transformation

Recognising that in energy transfer a variety of processes can occur, so that usable energy is reduced and the system is not 100 per cent efficient

Comparing energy changes in interactions such as car crashes, pendulums, lifting and dropping

Using models to describe how energy is transferred and transformed within systems

THINK ABOUT FORCES, ENERGY AND MOTION

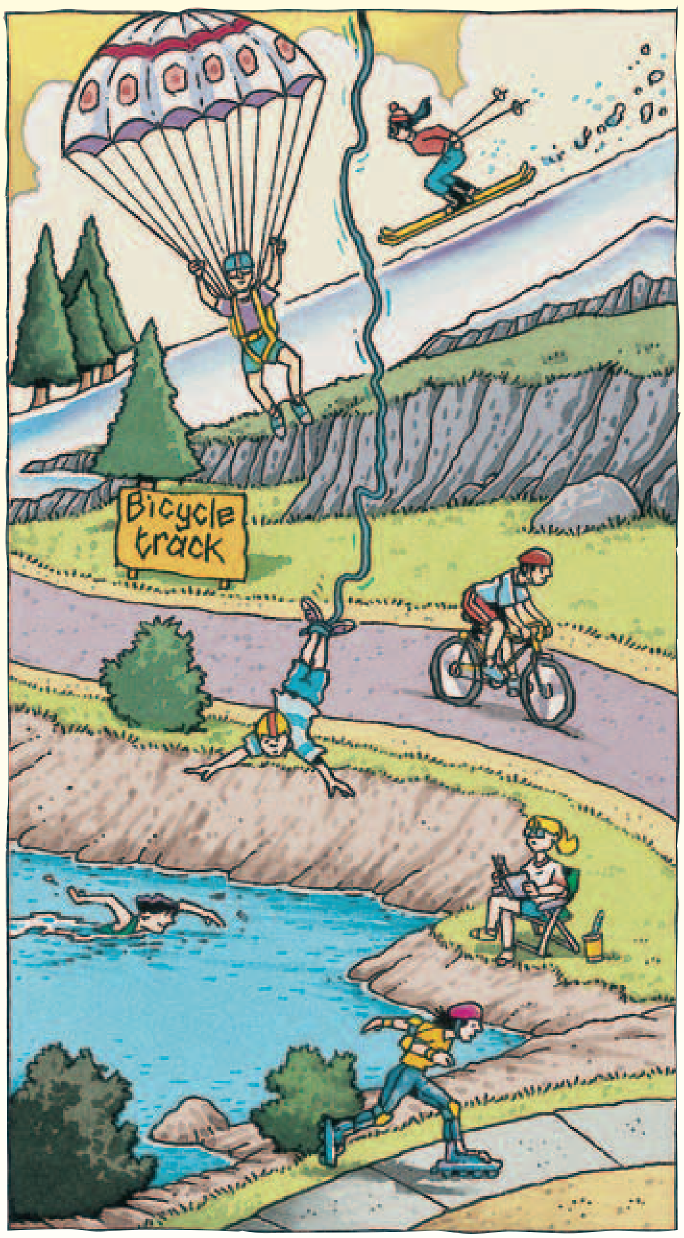
- Could a kangaroo win the Melbourne Cup?
- How do radar guns measure the speed of cars?
- Why do you feel pushed to the left when the bus you are in turns right?
- Why does the space shuttle seem to take forever to get off the ground?
- Why does it hurt when you catch a fast-moving ball with your bare hands?
- What does doing work really mean?
- Why can't a tennis ball bounce higher than the height from which it is dropped?
- Why are cars deliberately designed to crumple in a road crash?

YOUR QUEST

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.



1 Copy and complete the table below to list as many as possible 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)	

2 Which of the forces listed in your completed table could be described as a non-contact force?

3 Some of the characters in the illustration are accelerating (speeding up); others may be travelling at a steady speed or slowing down.
(a) Which three of the characters are the most likely to be accelerating? How do you know?
(b) Which three of the characters are most likely to be moving at a non-zero constant speed? How do you know?

4 What outside object or substance provides the forward push on the:
(a) swimmer
(b) cyclist
(c) in-line skater?

5 Which three characters in the illustration are clearly losing gravitational potential energy?

6 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?

8.1 SCIENCE UNDERSTANDING

Ready, set, go

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

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 sensibly be expressed in units of millimetres per week. Speed must, however, always be expressed as a unit of distance divided by a unit of time.

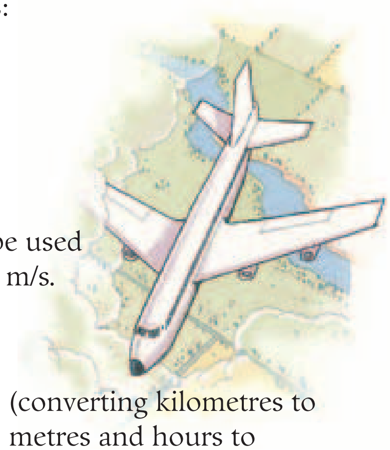
SOME EXAMPLES

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

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

$$= \frac{2730\text{ km}}{3\text{ h}}$$

$$= 910\text{ km/h}.$$



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

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

$$= \frac{2\,730\,000\text{ m}}{3 \times 3600\text{ s}}$$ (converting kilometres to metres and hours to seconds)

$$= 253\text{ m/s}.$$

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

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

$$= \frac{80\text{ cm}}{10\text{ min}}$$

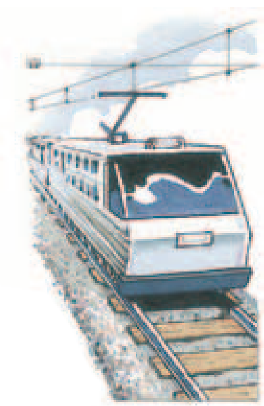
$$= 8\text{ cm/min}.$$

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.

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

$d = vt$ and $t = \frac{d}{v}$.



MORE EXAMPLES

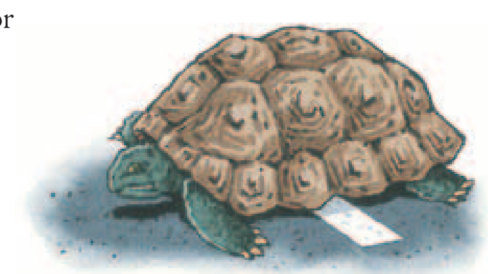
(a) The distance covered in $2\frac{1}{2}$ hours by a train travelling at an average speed of 70 km/h is:

$$d = vt$$

$$= 70\text{ km/h} \times 2.5\text{ h}$$

$$= 175\text{ km}.$$

(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:



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

$$= \frac{6.0\text{ m}}{0.055\text{ m/s}}$$ (converting 5.5 cm/s to 0.055 m/s)

$$= 109\text{ s (to the nearest second)}$$

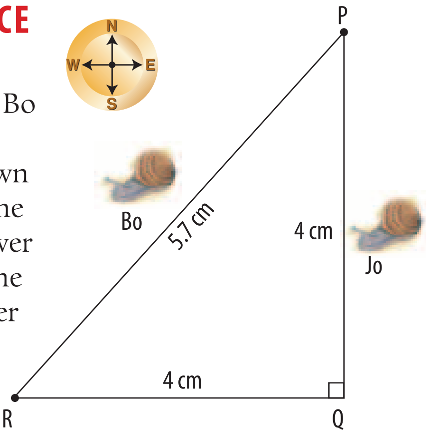
$$= 1\text{ min } 49\text{ s}.$$

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. Velocity has a direction as well as a **magnitude** (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.

The race between Bo and Jo

	Bo	Jo
Average speed	$\frac{\text{Distance travelled}}{\text{time taken}}$ $= \frac{5.7\text{ cm}}{1\text{ min}}$ $= 5.7$ cm/min	$\frac{\text{Distance travelled}}{\text{time taken}}$ $= \frac{8.0\text{ cm}}{1\text{ min}}$ $= 8.0$ cm/min
Average velocity	$\frac{\text{Change in position}}{\text{time taken}}$ $= \frac{5.7\text{ cm NE}}{1\text{ min}}$ $= 5.7$ cm/min NE	$\frac{\text{Change in position}}{\text{time taken}}$ $= \frac{5.7\text{ cm NE}}{1\text{ min}}$ $= 5.7$ cm/min NE

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

UNDERSTANDING AND INQUIRING

REMEMBER

1 Write the formula used to calculate average speed in symbols and state which quantity each symbol represents.

2 Explain the difference between speed and velocity. Use an example to support your explanation.

USING DATA

3 Determine the average speed of each of the following.
  (a) A racehorse that wins the 3200 m Melbourne Cup in a time of 3 min 20 s (in m/s)
  (b) A kangaroo fleeing from a dingo, which bounds a distance of 2.5 km in 3 min (in m/s)
  (c) 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)
  (d) A sea turtle that 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).
  (e) An Olympic swimmer who completes a 1500 m training swim in 16 min (in km/h)
  (f) A mosquito that flies a distance of 2 m in 4 s (in cm/s).

4 Use your answers to question 3 to suggest answers to the two questions posed in the introduction to this section.

5 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:
  (a) 5 km/h without stopping
  (b) 5 km/h for 10 h each day
  (c) 1.5 m/s without stopping?

6 How far can a snail crawl if it moves at an average speed of 8.0 cm/min for:
  (a) 3 minutes (b) 3 hours?

7 In a heat of a swimming trial, a swimmer 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:
  (a) average speed for the whole swim
  (b) average velocity for the first 50 m
  (c) average velocity for the whole swim.

8 A swimmer completes a 1500 m race in 870 s. Calculate the swimmer's average speed in:
  (a) m/s (b) km/h.

CREATE

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

8.2 SCIENCE UNDERSTANDING

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:

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

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

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

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

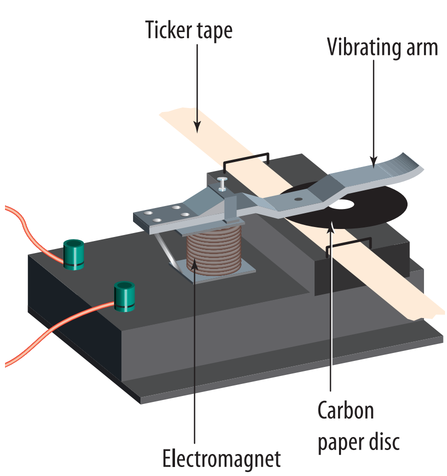
Clearly, the average speed does not provide much information about the speed at any particular instant during the race.

Keeping track of the speed

The full story of each lap of Michael Schumacher's race 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.

WHEN TIME TICKS AWAY

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.



Motion can be recorded with a ticker timer.

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 below. 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 below is:

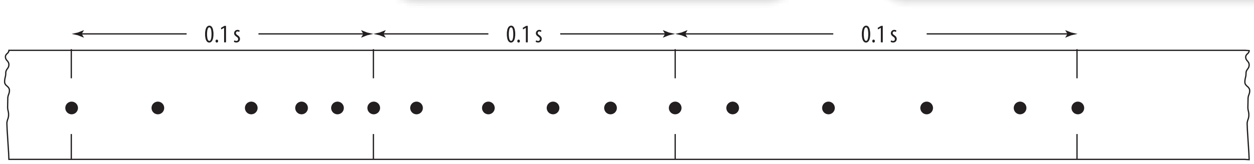
$$v = \frac{4.3\ \text{cm}}{0.1\ \text{s}}$$

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

Motion detectors

In many classrooms, ticker timers have been replaced with **sonic motion detectors**. These devices send out pulses of ultrasound at a frequency of about 40 kHz and then detect the reflected pulses from the moving object. The time taken for the pulses to return allows the device to calculate the distance between itself and the object. A small computer in the motion detector allows it to calculate the speed of the object.

Sonic motion detectors are used on the bumpers of cars to help the driver detect the distance between the car and another object.



Each marked interval represents a time of 0.1 s.

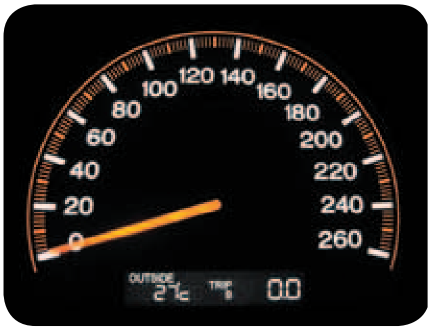
THERE MUST BE BETTER WAYS!

Speedometers

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

Older speedometers use a rotating magnet that rotates at the same rate as the car's wheels. The rotating magnet creates an electric current to flow in a device connected to the base of the pointer. As the car's speed increases, the magnet rotates faster, the electric current increases and the pointer rotates further to the right.

Newer electronic speedometers use a rotating toothed wheel that interrupts a stationary **magnetic field**. An electronic sensor detects the interruptions and sends a series of pulses to a computer, which calculates the speed using the **frequency** of the pulses.



Car speedometers provide a measure of instantaneous speed.

Car speedometers are not 100 per cent accurate. In Australia, an error of up to 10 per cent is common. Speedometers are manufactured according to the diameter of the tyres on the vehicle. Any change in that diameter will make the reading on the speedometer inaccurate.

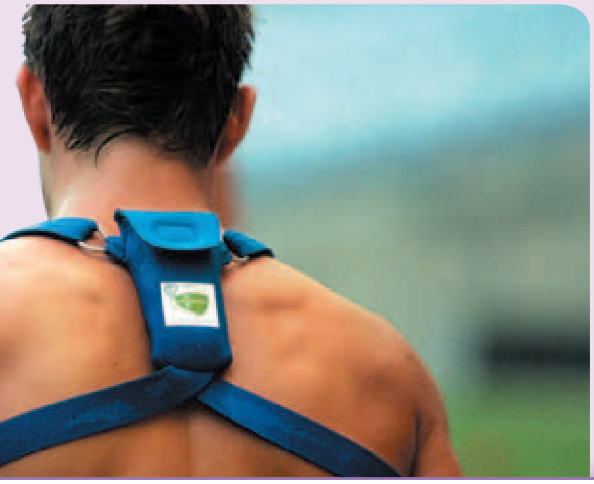
Speed and road safety

One of the major causes of road accidents and subsequent fatalities and injuries is excessive speed or driving at speeds that are unsafe for the road or weather conditions. Speed limits and speed advisories are set in an effort to minimise such accidents. The police use three different methods to monitor driving speeds as accurately as possible to ensure that speeding drivers are penalised.

- **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 section 6.4) is changed owing to the movement of the vehicle. The change in the frequency, called the Doppler effect, 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 that automatically photograph any vehicle that the radar reveals is travelling above the speed limit.
- **Laser guns** send out pulses of light that 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 that 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. Although digitectors were phased out after the 1980s, they are regaining popularity as an alternative to radar and laser guns.

HOW ABOUT THAT!

AFL coaches and sports scientists use GPS locators to track the movement of players around the field. The locators are strapped to the upper back of players. A computer is used to analyse the data to provide information about distance covered, speed, time spent moving at different speeds, maximum speed and acceleration. A built-in sensor also monitors heart rate.



The global positioning system

The **global positioning system (GPS)** uses radio signals from at least four of up to thirty-two satellites orbiting the Earth to accurately map your position, whether you are in a vehicle or on foot. Like radar guns, GPS navigation devices use the Doppler effect to calculate instantaneous speed, usually about once every second.

INQUIRY: INVESTIGATION 8.1

Ticker timer tapes

KEY INQUIRY SKILLS:

- planning and conducting
- processing and analysing data and information

Equipment:

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.

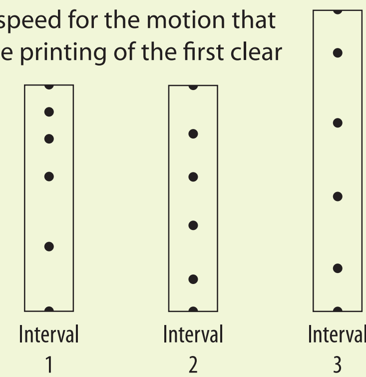
DISCUSS AND EXPLAIN

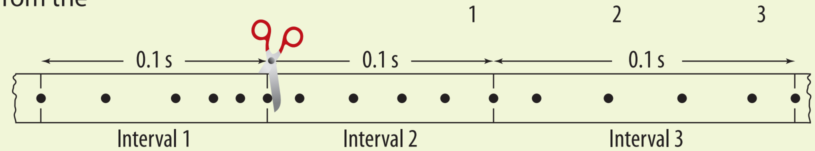
1 How much time elapsed between the printing of the first clear dot and the last dot marked off?

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

UNDERSTANDING AND INQUIRING

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?

THINK

3 Make a list of reasons why a speedometer reading might not be accurate. Include in your list anything that could change the diameter of the vehicle's tyres.

4 After being phased out, digitectors are making a comeback in police detection of speeding drivers. Suggest advantages they might have over radar and laser guns.

PROCESS AND ANALYSE

5 Calculate the average speed during the second and third 0.1 s intervals of the ticker tape shown in Investigation 8.1.

INVESTIGATE

6 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.

work sheets
8.1 Speed and velocity
8.2 Ticker tapes

8.3 SCIENCE UNDERSTANDING

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:

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

We can write this in the form of an equation:

$$a = \frac{\Delta v}{t}.$$

The triangle-shaped symbol is used to represent the change in a value; this symbol (taken from the Greek alphabet) is called delta.

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

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

$$a = \frac{\Delta v}{t}$$

$$= \frac{40 \text{ km/h}}{5.0 \text{ s}}$$

$$= 8.0 \text{ km/h per second.}$$

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 5.0 seconds.

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

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

$$= \frac{506 \text{ km/h}}{4.6 \text{ s}} = 110 \text{ km/h/s.}$$

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/s^2 (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:

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

$$= \frac{141 \text{ m/s}}{4.6 \text{ s}} = 31 \text{ m/s}^2.$$

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 that comes to rest in 5.4 seconds from a speed of 506 km/h is:

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

$$= \frac{-506 \text{ km/s}}{5.4 \text{ s}} = -93.7 \text{ km/h/s.}$$

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.

INQUIRY: INVESTIGATION 8.2

Drag strips

KEY INQUIRY SKILLS:

- planning and conducting
- processing and analysing data and information

Equipment:

ticker timer	*toy car (or dynamics trolley)*
G-clamp	*sticky tape or masking tape*
power supply	*clear length of bench at least 60 cm long*
ticker tape (in 60 cm lengths)	

- 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 and so on.
- Construct a table like the one below 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 in Investigation 8.1 to construct a graph of speed versus time.

DISCUSS AND EXPLAIN

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		

UNDERSTANDING AND INQUIRING

REMEMBER

1 Why is the accelerator 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 sets off when the lights turn green. It increases its speed by 5 m/s during each of the first 3 s after it sets 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 sets off?

PROCESS AND ANALYSE

4 Repeat Investigation 8.2 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 car or trolley used in your own experiment.

work sheet 8.3 Acceleration

8.4 SCIENCE UNDERSTANDING

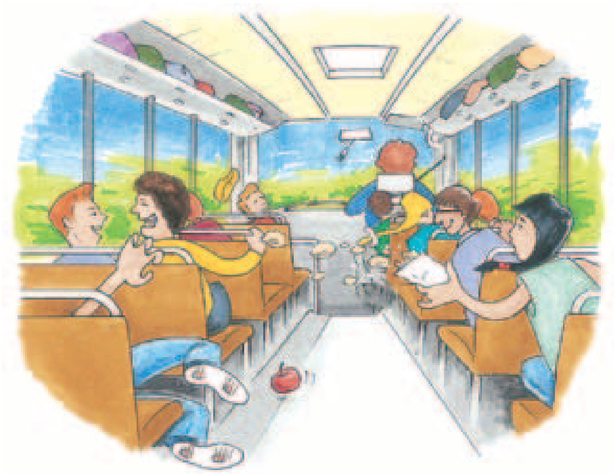
Let's go for a ride

eBookplus eLesson

Science demonstrations
Watch a video from the ABC's *Catalyst* program about Newton's First Law of Motion and dry ice on a balloon.

eles-1076

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?



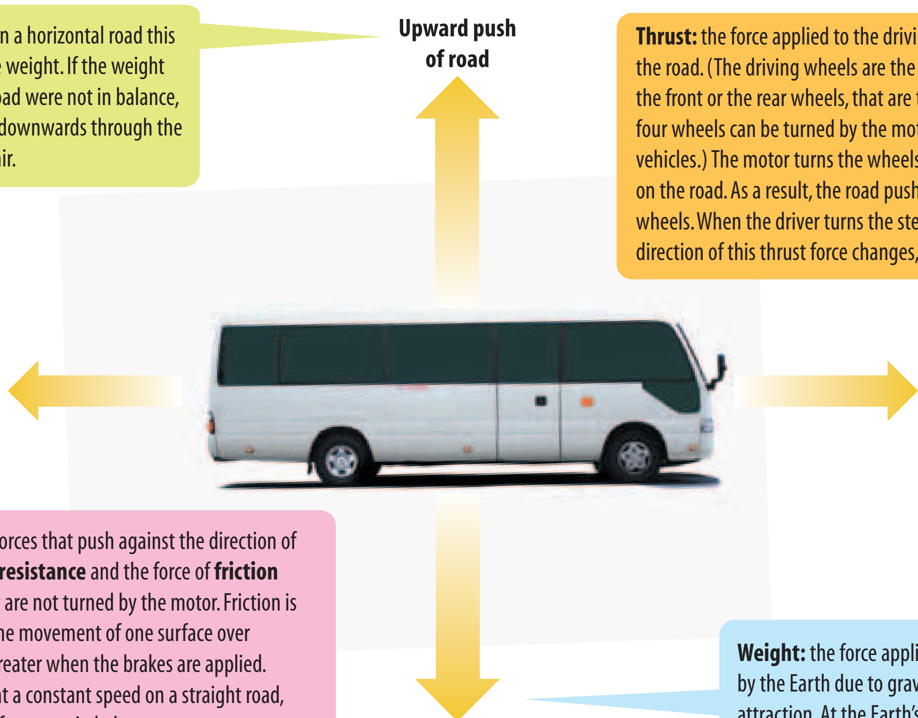
Which way is this bus turning — left or right?

That's an easy question. But to explain why it happens, you need to look at the forces acting on you and the forces acting on the bus.

The diagram below shows the forces acting on a bus moving along a straight, horizontal road at a constant speed. The upward push of the road must be the same as the **weight**. If that was not the case, the bus would fall through the road or be pushed up into the air. If the **thrust** is greater than the **resistance forces** the bus accelerates. If the resistance forces are greater than the thrust the bus slows down, or decelerates.

There are only two significant forces acting on you:

- your weight; that is, the force applied on you by the Earth's gravitational attraction
- the push of the bus seat, which pushes upwards and forwards. The upward part of this force is just enough to balance your weight. The forwards part of this force is what keeps you moving at the same speed as the bus.



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.

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: 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: 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.

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, unbalanced force. In many manoeuvres that you may experience as a passenger on a bus, an unbalanced force is acting on the vehicle to change its speed or direction.

For example, the bus stops suddenly when the brakes are applied. The resistance forces are large and there is no thrust. Your seat is rigidly attached to the bus, so it also stops suddenly. However, the resistance forces are not acting on you. You continue to move forward at the speed that you were travelling at before the brakes were applied until there is a force to stop you. That force could be provided by a seatbelt, the back of any seat in front of you, a passenger in front of you or the windscreen of the bus.

When the bus makes a sudden right turn, the unbalanced force acting on the bus to change its direction is not acting directly on you. You continue to move in the original direction. The inside wall of the bus moves to the right but you don't. So it seems like you've been flung to the left.

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:

$$\text{weight} = mg = 1\ \text{kg} \times 9.8\ \text{N/kg} = 9.8\ \text{N}.$$

The weight of a 2000 kg bus is given by:

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

NEWTON'S FIRST LAW AT WORK

Don't try this at home!

The expensive crockery on the table in the illustration at right 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. Try pulling an A4 sheet paper out from under a 20-cent coin. Then try it with a 5-cent coin.

INQUIRY: INVESTIGATION 8.3

Forces on cars

KEY INQUIRY SKILL:

- questioning and predicting

Equipment:

toy car

- Rest a toy car on a smooth, level surface.
- Push the car quickly forwards and then let it go.

DISCUSS AND EXPLAIN

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?
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?

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.

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.

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

UNDERSTANDING AND INQUIRING

REMEMBER

1 Which force prevents a bus from falling through the surface of a road?

2 Can you remember some rough bus trips you have had? Use your memories of those experiences to help you answer the questions below. You should assume that you are comfortably seated and not wearing a seatbelt. Also assume that the bus seats have no head restraints.
   (a) What would be your immediate resulting motion (as a passenger on the bus) if the bus performed the following manoeuvres?
      (i) A very quick start from rest
      (ii) A forward motion at constant speed
      (iii) A very sharp right-hand turn
      (iv) A slow left-hand turn
      (v) An emergency stop from a speed of 60 km/h
      (vi) A forward jerk as the bus is struck from behind by another vehicle
   (b) During which type of manoeuvre in part (a) does the bus move with the same speed and direction as the passenger?
   (c) Explain how properly fitted seatbelts would change the resulting motion of the passenger.
   (d) Explain how a head restraint would change the resulting motion of the passenger in a bus that is struck from behind.

3 List two forces that resist the forward motion of a bus.

4 State Newton's First Law of Motion.

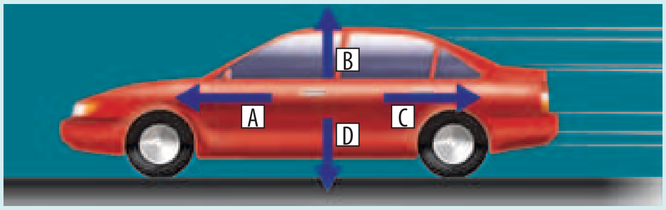
5 What is inertia?

THINK

6 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?

7 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.

8 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.

9 Read the newspaper article above 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 seatbelt protect a passenger in an incident like the one described?

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

work sheets
8.4 Inertia and motion
8.5 Force and gravity

8.5 SCIENCE UNDERSTANDING

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 net force on the object
m = the mass of the object.

The **net force** is the total force acting on the object. If the net 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 a space shuttle at Cape Canaveral in Florida is a spectacular sight. At launch, a space shuttle has a mass of about 2.2 million kilograms. (About 86 per cent of this mass is fuel, most of which is burned during the launch.) There are two forces acting on a space shuttle as it blasts off:

- the downward pull of gravity (weight). The weight of a 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 a 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:

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

$$= \frac{7\,000\,000 \text{ N upwards}}{2\,200\,000 \text{ kg}}$$

$$= 3.2 \text{ m/s}^2.$$

In other words, a space shuttle gains 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 burned, the mass of the space shuttle gets smaller. As this happens, the acceleration gradually increases, and the space shuttle gains speed more quickly.

A 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.

INQUIRY: INVESTIGATION 8.4

Force, mass and acceleration

KEY INQUIRY SKILLS:

- planning and conducting
- processing and analysing data and information
- evaluating

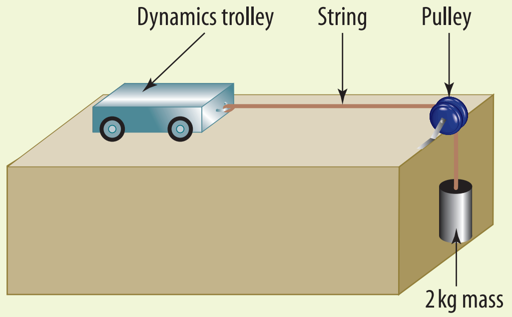
Equipment:

dynamics trolley	*pulley*
string	*four 500 g masses*
one 2 kg mass	*stopwatch*
masking tape	*metre ruler*

- Copy the table below.

Mass on the trolley (g)	Time(s)			
	Trial 1	Trial 2	Trial 3	Average
0				
500				
1000				
1500				
2000				

- On your bench top, use the masking tape and the metre ruler to mark out the starting line and finishing line for a 1-metre course for your dynamics trolley.
- Tie one end of the string to your trolley. Place the trolley at the starting line and bring the string forward so that it passes over the finish line and then hangs over a pulley at the end of the bench. Tie the 2 kg mass to this end of the string. Hold the trolley in place while you do this.
- Start the stopwatch at the same moment the 2 kg mass is dropped and time how long the unladen trolley takes to cross the finish line. Enter the time in the data table. Repeat this step twice more and then determine the average race time.



- Place a 500 g mass on the trolley and repeat the previous step.
- Repeat the experiment for increasing masses of 1000 g and 1500 g.

DISCUSS AND EXPLAIN

1 Which of the trolleys had the fastest race time? How can you tell if it had the greatest acceleration?

2 The equation $d = ut + \frac{1}{2}at^2$ allows you to calculate the size of the acceleration that was acting on the trolley each time, where d = distance, u = starting speed, and t is the average race time to cover the distance. As d = 1 m and u = 0, this equation simplifies so that we get $a = \frac{2}{t^2}$. Use this equation and the average race times in the table to determine the average acceleration of each trolley.

3 The weight of the 2 kg mass provided the force to move the trolley. Calculate the size of this force.

4 Was the weight of the 2 kg mass the only force acting on the trolley? What other forces can you identify that would have affected the trolley's acceleration?

5 Were the forces acting on the trolley each time balanced or unbalanced? How can you tell?

6 Give a general statement about the relationship between the mass of the trolley and its acceleration when a constant force is applied.

UNDERSTANDING AND INQUIRING

REMEMBER

1 Express Newton's second law in symbols.

2 Why does the acceleration of a space shuttle increase as it rises?

THINK

3 What total force would cause a 1.5 kg glass salad bowl to accelerate across a table at 0.30 m/s^2?

4 A 10 kg sled is pulled across the snow so that the total force acting on it is 12 N. What is the average acceleration of the sled?

USING DATA

5 Two identical toy carts, A and B, each with a mass of 1.0 kg, are pushed across a smooth, level tabletop 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/s^2, what is the total force acting on each cart?
(c) If the acceleration of cart B is 0.5 m/s^2, what is the mass of the brick?

work sheet 8.6 Newton's Second Law

8.6 SCIENCE UNDERSTANDING

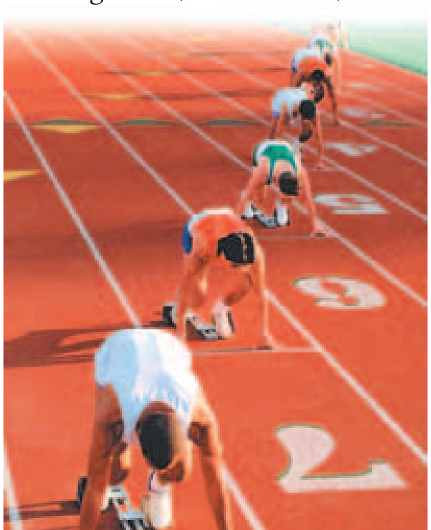
What's your reaction?

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 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.

On the move with Newton's Third Law of Motion

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



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

- 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 water, you push back on the water with your arms and legs so that the water pushes you forward.

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 huge blades inside a jet engine 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.

BLAST OFF

The rockets used to launch spacecraft 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 (a reaction).

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.

eBook*plus* **eLesson**

Newton's Laws
Learn about Newton's laws of motion and see them being applied in everyday life.
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Sometimes the fact that forces occur in pairs is painfully obvious.

HOW ABOUT THAT!

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

INQUIRY: INVESTIGATION 8.5

Just a lot of hot air

KEY INQUIRY SKILLS:

- questioning and predicting
- processing and analysing data and information

Equipment:

a balloon

- Inflate a balloon and hold the opening closed.
- Release the balloon and observe its motion through the air.

DISCUSS AND EXPLAIN

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 in which the balloon is propelled and the way in which a jet engine works?
5 How is the motion of the balloon different from the motion of a jet engine?

INQUIRY: INVESTIGATION 8.6

Balloon rocket

KEY INQUIRY SKILLS:

- processing and analysing data and information
- evaluating

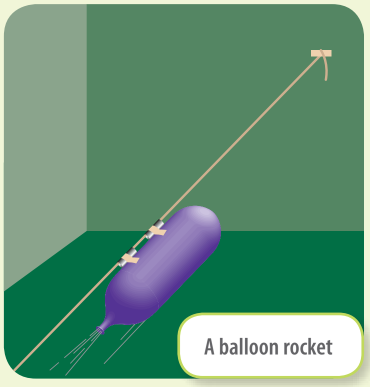
Equipment:

drinking straw (plastic)	*scissors*
masking tape	*fishing line (about 20 m)*
balloon (sausage-shaped if possible)	

- 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 diagram at right.
- Release the balloon and observe its motion along the string. Record the total distance travelled by your balloon rocket.

DISCUSS AND EXPLAIN

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

UNDERSTANDING AND INQUIRING

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.
8 Test your ability to identify Newton's laws in action by completing the **Time Out: 'Newton's Laws'** interactivity. **int-0055**

eBook*plus*

9 Use the **Newton's Laws** weblink in your eBookPLUS to watch interactive animations describing Newton's Laws of Motion. Then test yourself by taking the quiz.

work sheet 8.7 Newton's Third Law

8.7 SCIENCE UNDERSTANDING

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 athlete below does work to lift the weights — he applies an upward force and the weights move up. However, when he holds the weights still beside his head, no work is being done on the weights. The athlete is applying an upward force equal to the downward pull of gravity on each weight, but there is no movement in the direction of that force.

OUT OF CONTACT

In the examples above, the object on which the work is done is in contact with the object doing the work, and moves in the direction of the force applied to it. However, contact is not always necessary for work to be done. The Earth does work on you when 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 × 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).

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 change in 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 below. When the hand is opened, the elastic potential energy in the compressed spring is converted 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 hydro-electric 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 potential 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.

UNDERSTANDING AND INQUIRING

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.

eBook*plus*

10 Use the **Rollercoaster** weblink in your eBookPLUS and your knowledge about forces and motion to build a rollercoaster that is both safe and fun.

Systems: Energy ups and downs

The energy changes that take place while bouncing on a trampoline occur when work is done in turn by the force of gravity, the trampoline or the person using it.

When the girl in the illustrations below is in the air, work is being done by the force of gravity to increase either her gravitational potential energy (going up) or her kinetic energy (going down). When she lands on the trampoline, she does work on the trampoline to convert her kinetic energy into elastic potential energy in the trampoline. As she is pushed back up into the air, the trampoline is doing work on her.

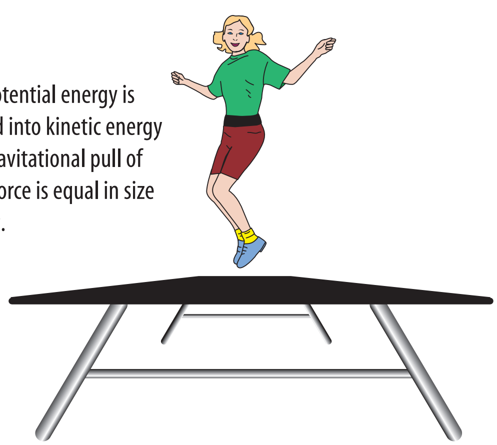
Never created, never destroyed

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 basketball 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.

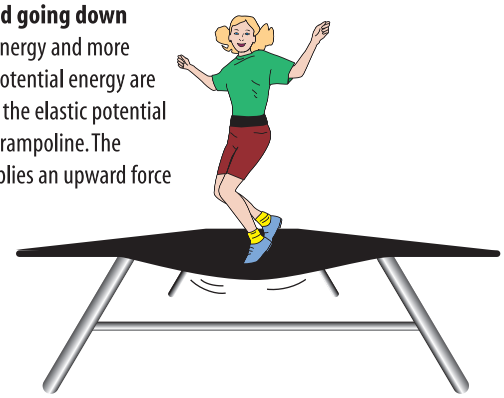
Systems and efficiency

Consider the basketball and the concrete surface to be a system. The **efficiency** of a system as an energy converter is defined as:

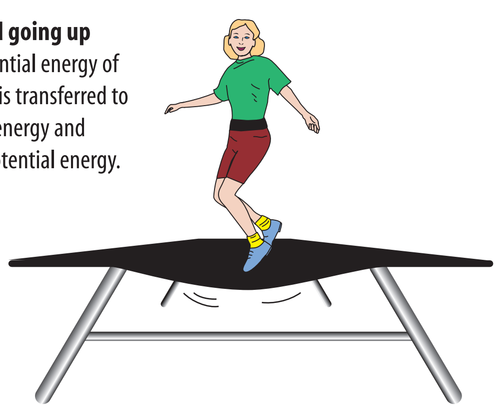
$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%.$$



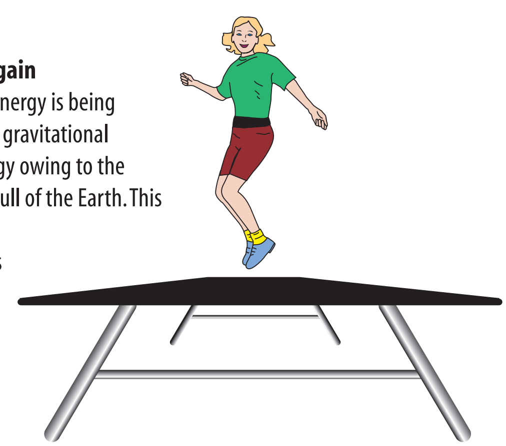
(a)
Going down
Gravitational potential energy is being converted into kinetic energy owing to the gravitational pull of the Earth. This force is equal in size to Sam's weight.



(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.

The 'useful' energy within the system is the sum of the kinetic energy, elastic potential energy and gravitational potential energy of the basketball. The energy input for the basketball is its initial gravitational potential energy. If this system were 100 per cent efficient, the basketball would bounce back to its original height and keep bouncing forever. The useful energy output would be the same as the energy input.

CALCULATING EFFICIENCY

The efficiency of the first bounce of a basketball can be calculated using:

$$\text{efficiency} = \frac{\text{useful energy}}{\text{input energy}} \times 100\%$$
$$= \frac{\text{gravitational potential energy regained after bounce}}{\text{initial gravitational potential energy}}.$$

The initial gravitational potential energy is the same as the amount of gravitational potential energy lost by the ball as it falls. That is equal to 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:

$$\begin{aligned}\text{work done} &= \text{force} \times \text{distance travelled in the direction of the force}\\ &= \text{weight of tennis ball} \times \text{height through which it falls}\\ &= m \times 9.8\ \text{N/kg} \times h_1\end{aligned}$$

where m is the mass of the ball (in kilograms) and h_1 is the height from which the ball was dropped (in metres).

The amount of gravitational potential energy lost; that is, the initial gravitational potential energy, 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:

$$\begin{aligned}\text{work done} &= \text{force} \times \text{distance travelled in the direction of the force}\\ &= \text{weight of tennis ball} \times \text{height through which it rises}\\ &= m \times 9.8\ \text{N/kg} \times h_2\end{aligned}$$

where h_2 is the height to which the ball rebounds (in metres).

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

The efficiency of the first bounce is therefore:

$$\begin{aligned}\text{efficiency} &= \frac{9.8m \times h_2}{9.8m \times h_1} \times 100\%\\ &= \frac{h_2}{h_1} \times 100\%.\end{aligned}$$

For example, if a tennis ball is dropped from a height of 1.2 metres and bounces back to a height of 72 cm, its efficiency is:

$$\begin{aligned}\text{efficiency} &= \frac{h_2}{h_1} \times 100\%\\ &= \frac{72}{120} \times 100\%\\ &= 60\%.\end{aligned}$$

INQUIRY: INVESTIGATION 8.7

Follow the bouncing ball

KEY INQUIRY SKILL:

- processing and analysing data and information

Equipment:

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 to the ground and take care that the ball is dropped from rest and not assisted on its way down.
- 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.

DISCUSS AND EXPLAIN

1 Construct a flowchart using text descriptions similar to those used in the illustrations in this section of the girl on the trampoline to show the energy changes that take place as the ball is:
(a) falling through the air
(b) slowing down while in contact with the ground
(c) speeding up just before leaving the ground
(d) rising through the air.

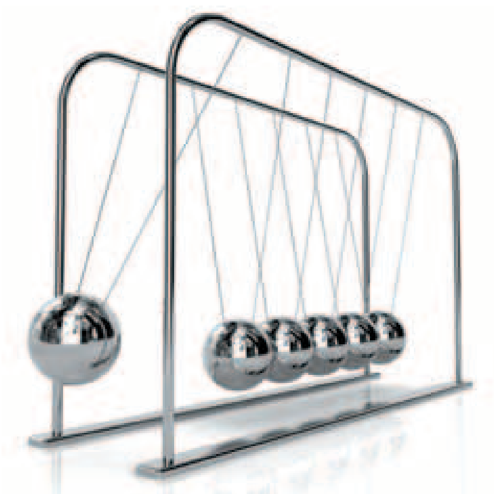
2 Identify the largest force that is acting on the ball as it:
(a) falls through the air
(b) is in contact with the ground
(c) rises through the air.

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

A pendulum is a suspended object that is free to swing to and fro. The most well-known use of pendulums is in clocks, mostly very old ones. A playground swing is simply a large pendulum and provides an excellent model of a system in which energy is alternately transformed from gravitational potential energy to kinetic energy. Without a push, the swing slows to a stop. The potential and kinetic energy of the system have dropped to zero. But that energy is not lost; it has been gradually transferred to the surroundings.



A Newton's cradle is a series of suspended balls that just contact one another. If the last ball is lifted and allowed to drop, the gravitational potential energy is converted to kinetic energy that is then passed along the line of balls until it reaches the last ball, causing it to swing up to almost the same height as the first ball.

INQUIRY: INVESTIGATION 8.8

Swing high, swing low

KEY INQUIRY SKILLS:

- questioning and predicting
- communicating

- Push a friend on a swing.

DISCUSS AND EXPLAIN

1 Construct a flowchart, including text descriptions like those shown in the illustrations at the beginning of this section 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?

UNDERSTANDING AND INQUIRING

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?

2 The girl on the trampoline is able to return to the same height after each bounce. Explain why the system of the girl and the trampoline is not really 100 per cent efficient.

3 Consider the energy that is transferred away from a tennis ball bouncing on a concrete surface.
   (a) To what objects or substances is the gravitational potential energy and kinetic energy of the tennis ball transferred?
   (b) Into what forms of energy is the ball's gravitational potential energy and kinetic energy transformed?

CALCULATE

4 Evaluate the efficiency of the bounce of a cricket ball dropped vertically onto a concrete floor from a height of 1.40 metres if it rebounds to a height of 35 cm.

5 A 50 kg boy drops from a height of 1.0 m onto a trampoline.
   (a) Calculate the weight of the boy. Assume that $g = 9.8$ N/kg.
   (b) How much work is done on the boy by the force of gravity?
   (c) What amount of gravitational potential energy has been lost by the boy at the instant that he makes contact with the trampoline?
   (d) What is the boy's kinetic energy when he makes contact with the trampoline?

CREATE

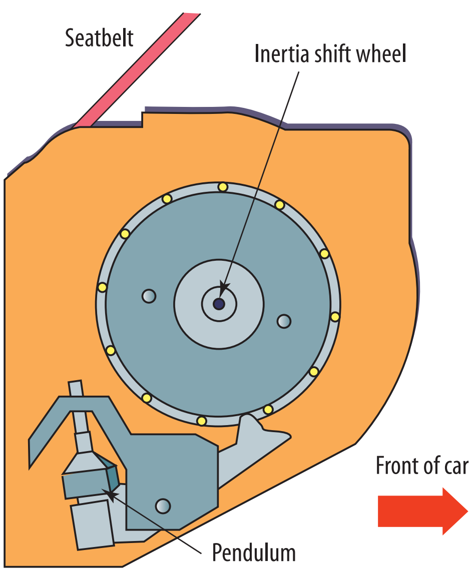
6 Construct a poster that shows what happens to your gravitational potential energy during either a bungee jump or a rollercoaster ride.

7 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.

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 average number of lives lost each year in road accidents now is less than 1500.

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.



This inertia reel seatbelt is shown in the locked position. If rapid deceleration occurs, the small pendulum is able to swing forward with the inertia of the vehicle and lock the reel holding the seatbelt, preventing the passenger from moving forward.

Crash tests

Safety features such as seatbelts, 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.

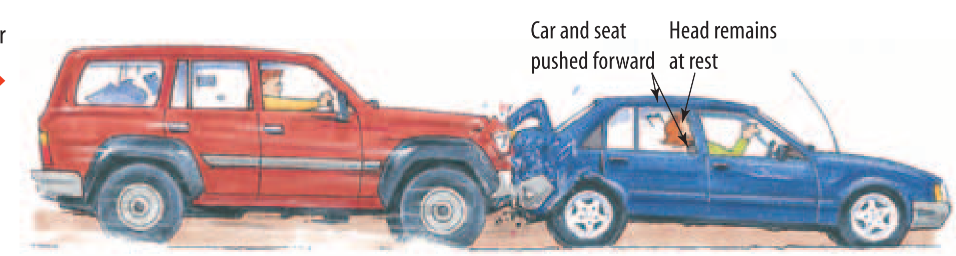
Before real crash testing takes place, engineers use computer modelling to simulate crashes with virtual cars.

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. Seatbelts provide an immediate force on the occupants so that they don't continue moving forwards. 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.



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 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 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.

The zone defence being tested. The front crumple zone absorbs and spreads energy. It also allows the car to stop more gradually. Crash test dummies are used to model the effect of collisions on the human body.

UNDERSTANDING AND INQUIRING

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) Seatbelts
(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 in this section 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 above right. 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.

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).

EVALUATE

9 Collect two or more advertising brochures for recently manufactured passenger vehicles, then answer the following questions.
(a) Outline the features of the cars that relate to the safety of the occupants of the vehicle.
(b) List the claims made about the safety features of the cars that do not make reference to scientific evidence.
(c) Comment on missing scientific evidence that you would want to see included to support claims made in the brochures.

8.10 THINKING TOOLS

Cycle maps and storyboards

how to ...?

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.

why use?

Helps you to see repeating sequences of events

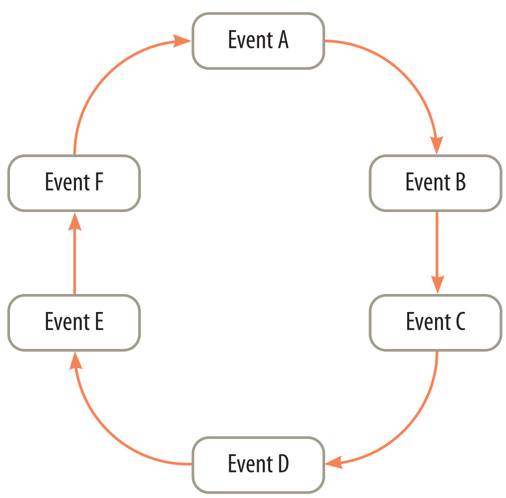
question

What patterns can be seen in these events?

also called

Cycle chart; cyclical map

Cycle map



comparison

Storyboards

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

A Car at rest	B Outline of scene 2	C Outline of scene 3
D Outline of scene 4	E Outline of scene 5	F Outline of scene 6

UNDERSTANDING AND INQUIRING

THINK AND CREATE

1 The cycle map on the right represents the motion of a girl on a trampoline. The vertical arrows represent the direction of motion of the girl.

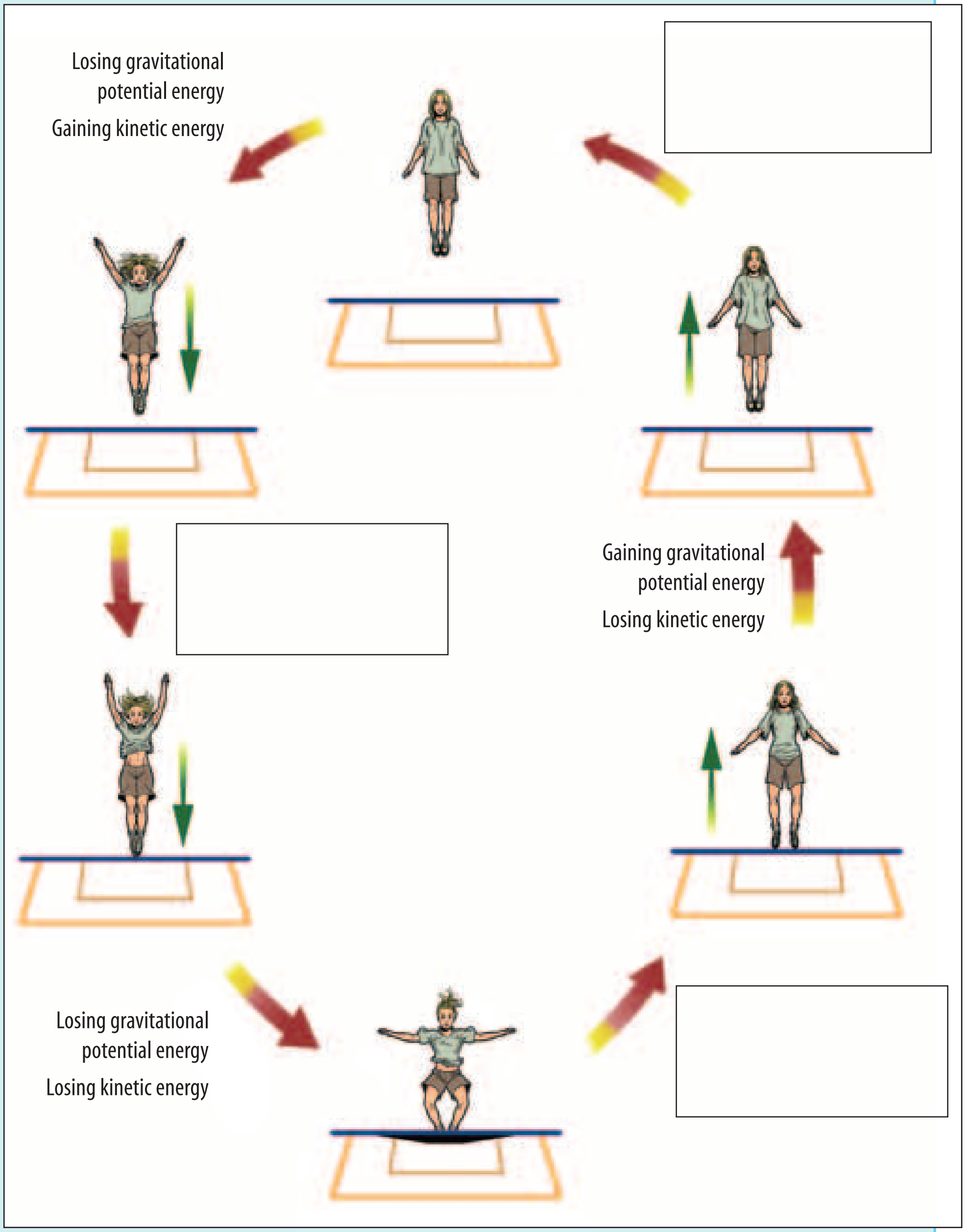
(a) Some of the boxes describing the energy changes that are taking place are empty. Copy the cycle map and complete it by describing the missing energy changes in the empty boxes.

(b) During which stage (or stages) of the cycle is the girl:
 (i) accelerating upwards
 (ii) accelerating downwards
 (iii) decelerating
 (iv) moving with zero velocity?

(c) During which stage (or stages) of the trampoline cycle is the net force acting on the girl:
 (i) up
 (ii) down?

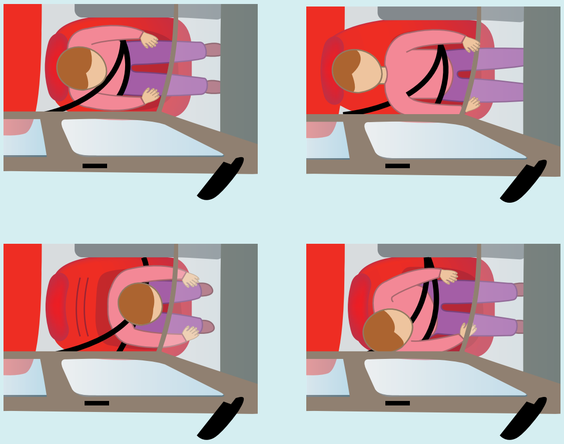
(d) During which stages of the trampoline cycle is the force of gravity acting on the girl?

(e) What is happening to the energy lost by the girl after coming into contact with the trampoline?



2 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.

3 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 seatbelt. Add a commentary to each of the sketches of your storyboard that describes the forces acting on the passenger.



Use images like these of a passenger in a car to construct your storyboard.

STUDY CHECKLIST

DESCRIBING MOTION

- describe straight line motion in terms of distance, change in position, speed, velocity and acceleration using the correct units
- use a ticker timer or other available technology to gather data to determine the speed and acceleration of an object in straight line motion

FORCES AND NEWTON'S LAWS OF MOTION

- identify the forces acting on a motor vehicle in straight line motion on a horizontal surface
- describe the involuntary movement of people and objects in moving vehicles in terms of Newton's First Law of Motion
- define inertia as the resistance of objects to changes in their motion
- recall Newton's Second Law of Motion and use it to predict the effect of the net force acting on an object on its motion
- recall and apply Newton's Third Law of Motion to describe the interactions between two objects

WORK AND ENERGY

- define work as the product of the force acting on an object and the distance travelled by the object in the direction of the force
- equate work to a change in kinetic or potential energy
- distinguish between elastic, gravitational, electrical, chemical and nuclear potential energy
- relate energy transfers and transformations to the Law of Conservation of Energy within a system
- recognise that useful energy is reduced during any energy transfer
- calculate the efficiency of a simple energy transformation
- describe a simple model of energy transformation and transfer within a system

SCIENCE AS A HUMAN ENDEAVOUR

- recognise the need for accurate methods of measuring the speed of vehicles in order to enforce laws designed to discourage excessive speed
- explain the movement of occupants of a vehicle in a motor accident in terms of inertia
- explain the safety features of cars in terms of energy transfer
- appreciate the role of scientists, engineers and computer modelling in the design of safety features in motor vehicles
- use scientific knowledge to evaluate claims made in the advertising of motor vehicles

ICT

eBook*plus* Summary

eLESSONS

Science demonstrations

Watch a video from the ABC's *Catalyst* program about Newton's First Law of Motion and dry ice on a balloon.

Searchlight ID: eles-1076

Newton's Laws

In this eLesson, you will learn about Newton's Laws of Motion and see how they are applied in different situations in everyday life.

Searchlight ID: eles-0036

INTERACTIVITY

Time Out: 'Newton's Laws'

In this exciting interactivity, test your ability to identify Newton's Laws in action before time runs out.

Searchlight ID: int-0055

INDIVIDUAL PATHWAYS

eBook*plus*

Activity 8.1
Revising forces, energy and motion

Activity 8.2
Investigating forces, energy and motion

Activity 8.3
Analysing forces, energy and motion

LOOKING BACK

1 Complete the equations below.

(a) Average speed = $\dfrac{\rule{2cm}{0.4pt}}{\text{time taken}}$

(b) Average velocity = $\dfrac{\rule{2cm}{0.4pt}}{\text{time taken}}$

(c) Average acceleration = $\dfrac{\rule{2cm}{0.4pt}}{\text{time taken}}$

(d) Acceleration = $\dfrac{\rule{2cm}{0.4pt}}{\text{time taken}}$

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 The diagram below 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?

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

7 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?

8 Who is doing more work — a body-builder holding an 80 kg 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

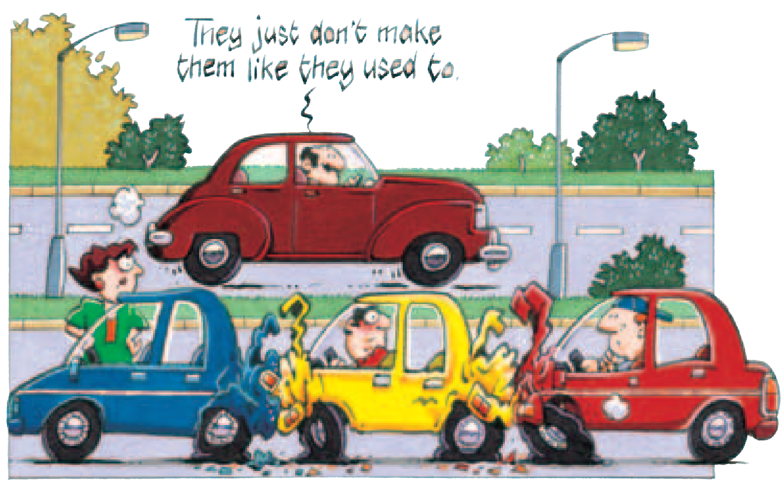
(c) rebounds upwards through the air.

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 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'.

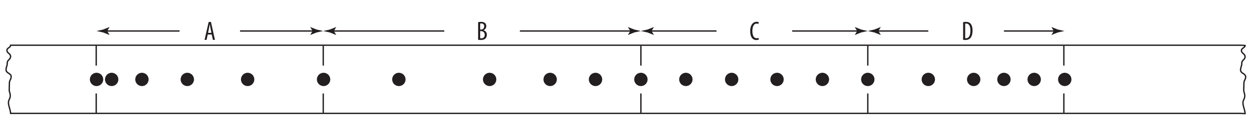


12 Use Newton's Second Law to calculate answers for the following.

(a) A 1400 kg car accelerates at 3 m/s^2. What size force is needed to cause this acceleration?

(b) A force of 160 N causes an object to accelerate at 2 m/s^2. What is the object's mass?

(c) A force of 210 N acts on a mass of 70 kg. What is the acceleration?



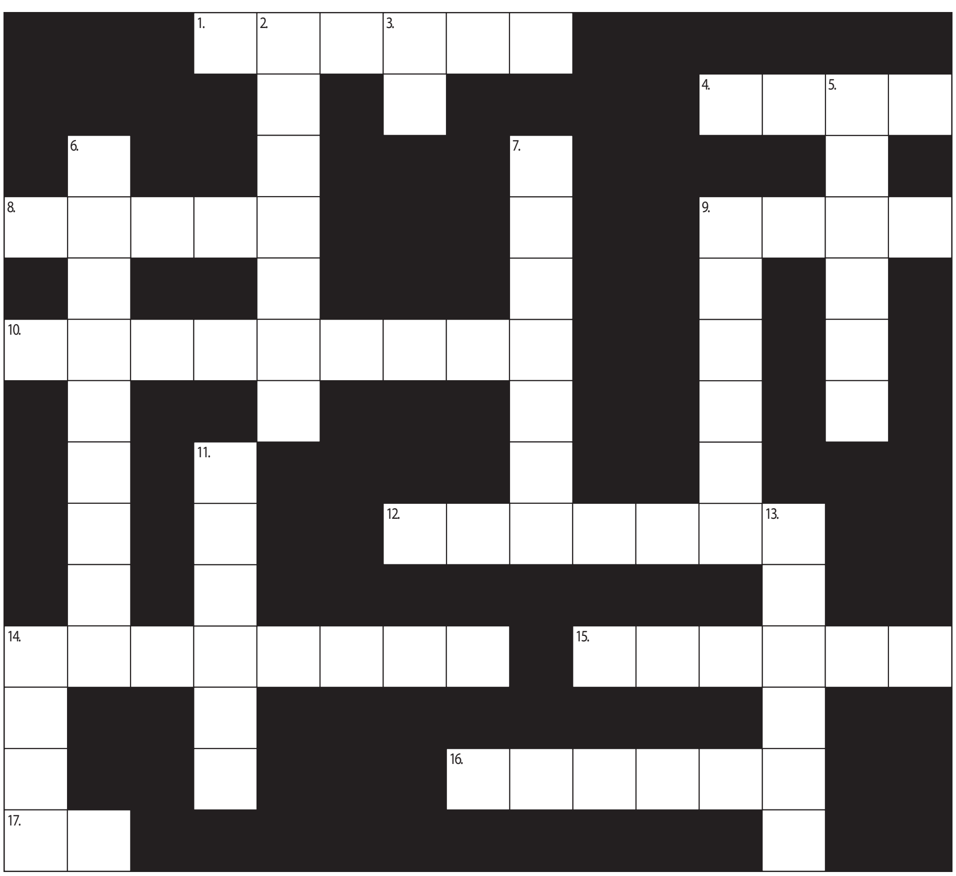
13 Complete the crossword below using the following clues.

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.
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 do this before stepping off.



14 By increasing the time over which a collision occurs, the force of the impact on a car and its passengers can be decreased. List and describe at least two safety features of a car that decrease the force of impact in this way.

15 True or false?

(a) Energy can be created but never destroyed.
(b) Energy can be transferred from one object to another.
(c) Energy can be transformed from one type to another.
(d) Energy cannot be stored.
(e) Energy is measured in joules.

16 Write the rule for calculating work.

17 How much work is done to lift a 5 kg box onto a shelf 1 m above the ground?

work sheet 8.8 Forces, energy and motion: Summary

projectsplus

Rock'n'rollercoaster

SEARCHLIGHT ID: PRO-0116

Scenario

Many psychologists think that the reason rollercoasters are so popular is tied up with the 'rush' that follows stimulation of the fear response. When exposed to the combination of speed, noise, high hills, twists, loops and steep descents of the ride, our brains tell us that there is some element of threat or danger. This triggers our 'fight or flight' instinct, sending adrenaline coursing through our bodies in a way which many people find very stimulating. Of course, some of us just throw up rather than finding it fun!

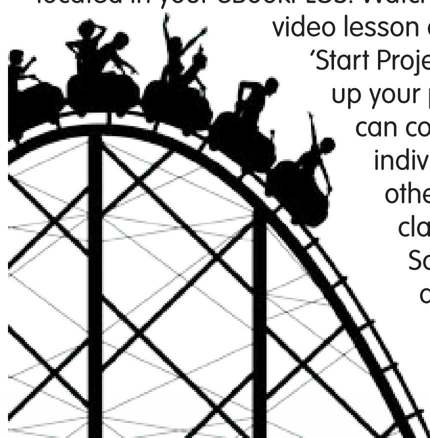
Thrill-ride engineers say that the aim of a good ride is to provide a simulation of danger without actually putting people at risk. By manipulating the characteristics of gravity, periodic motion and speed, these engineers use physics to trick the body into thinking that it is in a lot more trouble than it really is. But the line between a ride that thrills and a ride that kills is a very narrow one, and the structural and mechanical engineers who design and build these rides must test their designs rigorously by using computer models or even physical models before the first steel rail leaves the factory! So how would you, as a team of rollercoaster engineers working at the new theme park Chunderworld, design a rollercoaster that was high on the thrill but zilch on the kill?

Your task

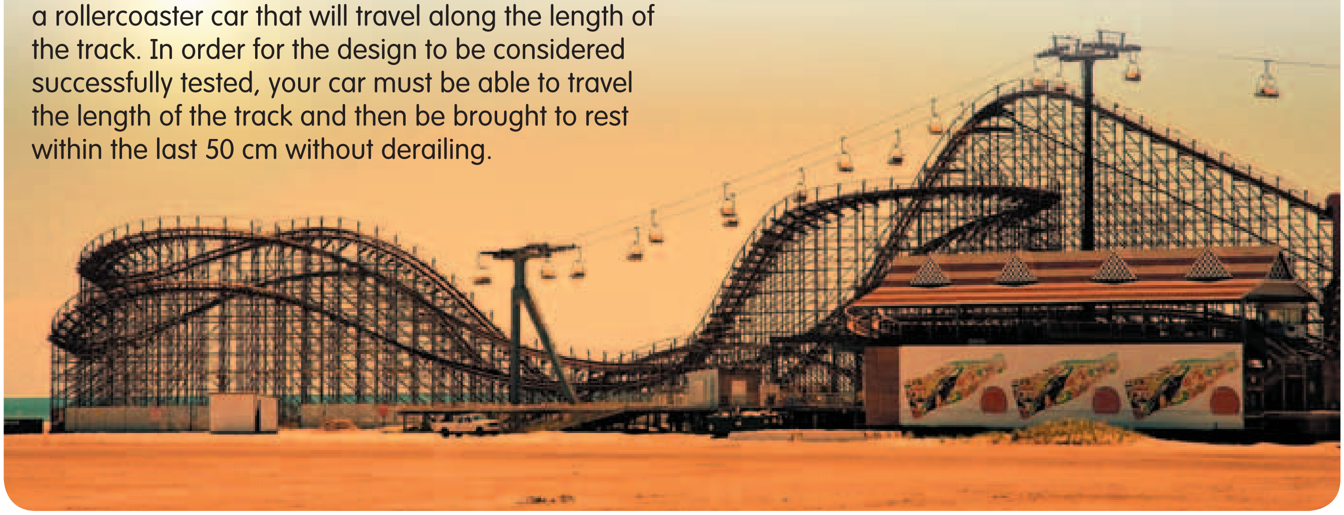
- You will use your knowledge of physics and forces to design and build a model rollercoaster that has a set length and includes a minimum number of loops, hills and turns. Your design will also include a rollercoaster car that will travel along the length of the track. In order for the design to be considered successfully tested, your car must be able to travel the length of the track and then be brought to rest within the last 50 cm without derailing.
- You will draw a plan or diagram of your rollercoaster identifying the positions and types of components used — hill, turn, twist or loop — and the points at which the car has the highest and lowest values of kinetic energy and gravitational potential energy.
- Finally, you will set up a blog which includes:
  (a) a summary of how the kinetic energy and gravitational potential energy values change over the course length
  (b) a log describing the development, building and testing of your rollercoaster and its different sections, including the method used to bring the car to a safe stop at the end
  (c) your drawing/plan of your completed rollercoaster
  (d) video footage of your rollercoaster in action from start to finish.

Process

- Open the ProjectsPLUS application for this chapter located in your eBookPLUS. Watch the introductory video lesson and then click the 'Start Project' button to set up your project group. You can complete this project individually or invite other members of your class to form a group. Save your settings and the project will be launched.



Your ProjectsPLUS application is available in this chapter's Student Resources tab inside your eBookPLUS. Visit www.jacplus.com.au to locate your digital resources.



- Navigate to your Research Forum. Here you will find a number of headings for suggested research topics that may help you with your design. If you wish, you may add other research topics that you find necessary to successfully complete your project.
- Start your research. Make notes of information you discover that will assist you in your design. Enter your findings as articles under your topic headings in the Research Forum. You should each find at least three sources (other than the textbook, and at least one offline such as a book or encyclopaedia) to help you discover extra information about different aspects of rollercoaster design. You can view and comment on other group members' articles and rate the information that they have entered. When your research is complete, print out your Research Report to hand in to your teacher.

- Set up your blog and start with a summary of what you have found out about how energy is transferred and transformed during a rollercoaster ride. Make regular entries in your blog over the course of the project, describing the process of designing, building and testing your rollercoaster from start to finish. Everyone in the group should contribute to the diary/log.
- Visit your Media Centre and download the design specifications for the completed model. Your Media Centre also includes images that you may find useful when creating your plan, or which you may wish to use to make your blog more interesting. The Media Centre also includes weblinks to sites that will allow you to explore the ideas involved in rollercoaster-making as well as how to go about creating a blog.
- Design, build and test your rollercoaster. Each member of the group should be responsible for a section of the ride. Don't forget to update your blog as you go.
- Use a camcorder, digital camera with video mode or other video device to film your rollercoaster in action. Edit and save your video file.
- Add your finished plan and your video to your blog.

MEDIA CENTRE

Your Media Centre contains:

- the design specifications for your model
- a selection of useful weblinks
- a selection of images
- an assessment rubric.

SUGGESTED SOFTWARE

- ProjectsPLUS
- Word or other word-processing software
- CorelDRAW, GIMP, Paint or other drawing software
- Quicktime, Movie Maker, Shockwave or other video-editing software
- Internet access