SCIENCE

Unit 3

Motion and Energy

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Knowing science: Content	SI units	Accuracy and precision	Scalars and vectors
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Science in society	Measurement as part of everyday life; historical unit of length (cubit).		
Science process skills	Converting units (Activity 1)	Measurement	
Language skills	Comprehension	Comprehension	Comprehension

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Language skills		

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LESSON 1

Measuring

About this lesson

Measurement is and always has been an important part of people's lives. A measurement tells us about the property of something. It might tell us how heavy an object is, or how hot, or how long it is. A measurement gives a number to that property.

In this lesson, you'll find out that measuring is what scientists do to collect evidence to support their ideas about how the world works. You'll also look at other aspects of measuring which are important to scientists.

In this lesson you will:

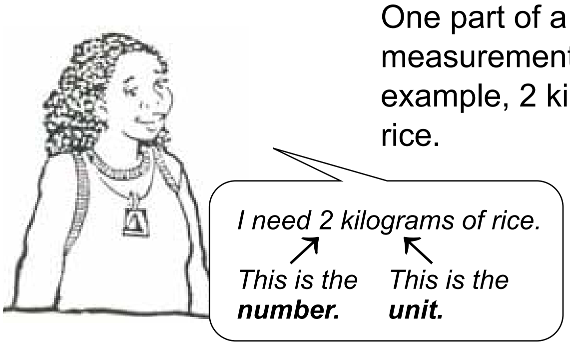
- list the seven basic quantities and their units in the Système International d'Unités (SI)
- give a few examples of derived quantities
- use metric prefixes to change measurements in basic units into smaller and bigger units
- distinguish between accuracy and precision in measurement
- distinguish between scalar and vector quantities
- define distance, displacement, speed and velocity
- calculate average speed and average velocity.

Measuring things is part of everyday life

We measure many different things routinely in everyday life. We measure how much flour we need to make a loaf of bread. We pay for petrol by the litre. Our car's speedometer measures how fast we drive. Our electricity meters measure how much electricity we use. A thermometer measures a sick child's temperature.

Most measurements have two parts

One part of a measurement is a number. The number in a measurement tells us how big the measured quantity is. So for example, 2 kilograms of rice is twice as much as 1 kilogram of rice.



The number tells us the size or magnitude of a measurement. The other part of a measurement is its unit.

Measuring is an important part of science too

Scientists often test their ideas. This involves observation and sometimes measurement to collect information or data. Then scientists share their findings with other scientists. Shared information must be understandable to scientists all over the world.

At different times in history people have used different units to measure the same quantity. For instance, today we measure length in metres, but ancient Egyptians measured length in cubits. A cubit is based on the length of the human arm as the diagram shows. But people's arms are not all the same length! This meant that there was considerable variation in the length of a cubit.

Scientists all need to express their measurements in the same way. They have agreed on a single system of measurement of physical quantities called the Système Internationale d'Unités, or SI for short.

fundamental units or basic units:
one of seven units defined by SI. They are units from which all other units are developed.

derived:
comes from

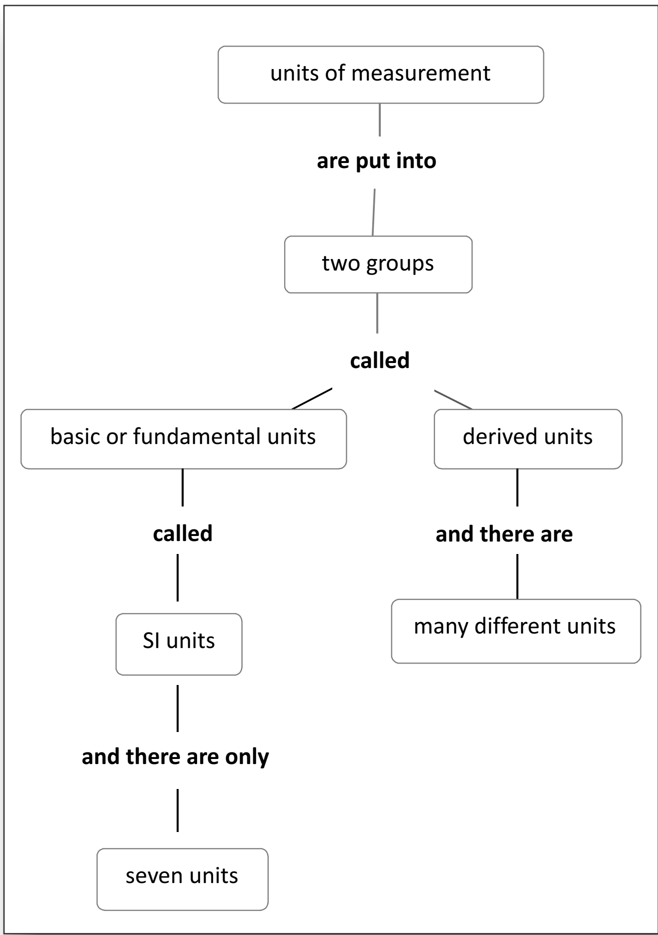
SI

All quantities and their units are either **basic (fundamental)** quantities or they are **derived** quantities. The SI defines the basic quantities in ways which make these units the same magnitude everywhere.

There are only seven basic quantities in the SI, each with its own unit. All other quantities and their units are derived from these seven basic quantities.

The table below shows the seven basic quantities and their units.

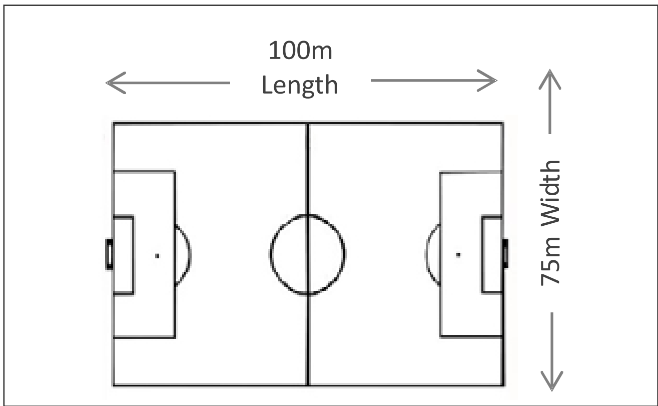
Quantity	Unit (abbreviation of unit)
mass	kilogram (kg)
length	metre (m)
time	second (s)
current strength	ampére (A)
temperature	kelvin (K)
amount of substance	mole (mol)
light intensity	candela (Cd)



Scientists need only seven basic units

Units of Area

Scientists do not need to define a new unit to measure area. Area describes the size of a surface. Area comes from length. You work out area (a derived quantity) by multiplying two lengths (basic quantities).



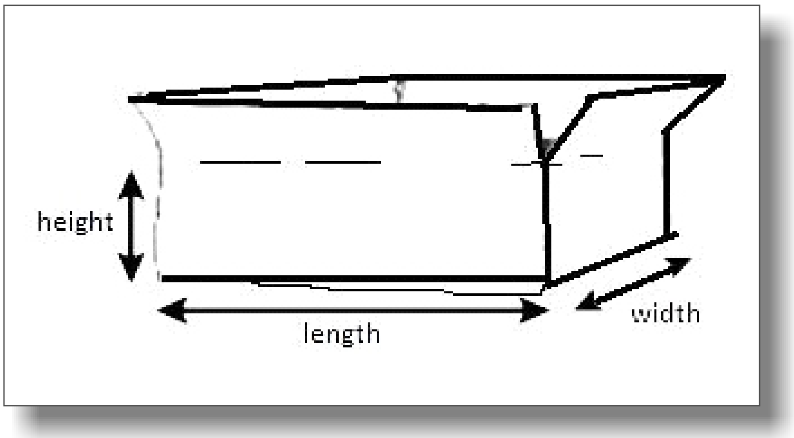
area of soccer field = a length × a length
= 100 m × 75 m
= 7 500 square metres
= 7 500 m2

It is unnecessary to define a square metre as a unit for area because area comes from length and the SI defines the unit for length. Area is therefore a derived quantity. So, a square metre is a **derived** unit.

Units of volume

It is also not necessary for scientists to define a unit for volume because we use three lengths to measure volume. And the unit of length is an SI unit.

$$\text{volume} = \text{a length} \times \text{a length} \times \text{a length}$$



So the unit we use to describe volume is $m \times m \times m$ which is cubic metres or m^3.

A cubic metre is a derived unit.

Units of density

Density is another derived quantity. It comes from mass (a basic quantity) and volume (a derived quantity).

$$density = \frac{mass}{volume}$$

Density is measured in the units of mass divided by the units of volume or in;

$$\frac{kg}{m^3} \text{ or } kgm^3$$

Again scientists do not need to define a unit to use for describing density. The idea of defining basic units leads to a very efficient way for scientists to communicate.

Metric prefixes

> ***prefix:***
> *a word, usually in Latin or Greek that we add before a unit*

It is not always convenient to use SI basic units. For example, the distance between Johannesburg and Cape Town is about 1 500 000 m. We can write this measurement in a more compact way using a metric **prefix**.

We join a metric prefix to a unit to make a more convenient, easier-to-use unit. If we join the prefix kilo to the SI unit of length the unit becomes kilometre. The distance between the two cities then becomes 1 500 km. Prefixes can make the new unit larger or smaller than the base unit.

Prefixes that make the unit smaller

Adding a metric prefix to the name of a unit can make the size of the unit smaller. The table below shows some common metric prefixes and their abbreviations.

submultiple	in words	prefix	symbol of prefix
$\frac{1}{100}$	one hundredth of	centi	c
$\frac{1}{1000}$	one thousandth of	milli	m
$\frac{1}{1\,000\,000}$	one millionth of	micro	μ

submultiple:
a fraction
μ:
a lower case Greek letter m, meaning one millionth of

When you write the prefixes in the table before a unit, the unit in a measurement becomes smaller and the number in the measurement becomes bigger.

For example an ant's body is about 0.003 m long. This is a small number. To make the number bigger, we make the unit in which we express the ant's length smaller than the metre.

We use the prefix milli which means one thousandth of $\left(\frac{1}{1000}\right)$

The table shows that if we multiply both these numbers by 1 000, this becomes 1 m which is the same length as 1 000 mm.

$\left(\frac{1}{1000}\right)$ m is the same length as 1 millimetre.

Then multiply both numbers by the length of the ant's body (in metres). 0.003 m is the same length as 0.003 × 1 000 mm. The ant's body is 3 mm long.

Prefixes that make the unit larger

Adding a metric prefix to the name of a unit can also make the size of the unit bigger. The table below shows some common prefixes that increase the size of a basic unit.

multiple	in words	prefix	symbol of prefix
1 000	one thousand times bigger	kilo	k
1 000 000	one million times bigger	mega	M

When you make a basic unit in a measurement bigger you multiply by a factor. This makes a big number smaller.

Suppose the distance between home and school is 40 000 m. The table shows that 1000 m is the same distances as 1 kilometre. If we divide both these numbers by 1 000, this becomes 1 m.

1 m is the same length as $\frac{1}{1000}\ km$

Then multiply both these two numbers by the distance (in metres) between school and your home.

40 000 m is the same length as $\frac{1}{1000}\ km$.

The distance between home and school is therefore 40 km.

ACTIVITY 1

1. The distance between the Earth and the Sun is 150 000 000 000 m. Express this distance in mega metres.

2. Suppose one grain of sea sand has a mass of 0.000 002 kg. What is the mass of the sand grain in micrograms?

3. The thickness of a human hair is about 0.000 005 metres. What is this measurement in micrometres?

4. Is 5 centimetres longer or shorter than 8 millimetres? Explain your answer.

5. Express a time interval of 5 microseconds (5 μs) in seconds.

6. Suppose you ask someone driving past how far it is to the next town. How helpful is the answer '3 270 132 centimetres'? Change this answer into a more meaningful form.

7. How old is someone whose age is 7 776 023 minutes?

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Other common units of measurement

The SI unit for measuring volume is the cubic metre (m^3). This is a very large volume. So instead, we use the litre to express volume. The litre (ℓ) is a derived unit for volume.

- 1 millilitre is $\frac{1}{1000}$ of a litre (ℓ)
- 1 cubic centimetre (cm^3) is the same volume as 1 millilitre (ml)
- 1 kilogram (kg) is the same mass as 1 000 gram (g)
- 1 milligram (mg) is the same mass as $\frac{1}{1000}$ gram (g)

Reliability in measurement

One of the most important things about the measurements scientists make when they test their ideas is the reliability of these measurements. Measurements are only reliable if they are reproducible. This means that if anyone, anywhere takes the same measurements, their answers will be the same. If the measurements are different, then the data is not reliable and cannot be used as evidence when testing ideas.

Precision

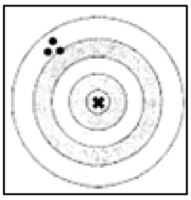
One way of checking is to measure the same thing several times. If a measurement is reliable, then repeated measurements are about the same value. We say that such measurements are precise or have high precision.

Accuracy

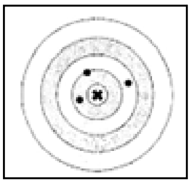
The second way of checking a measurement is to compare the measurement to the correct, accepted or true answer. An accurate measurement gives a value close to the accepted value.

The bow and arrow analogy

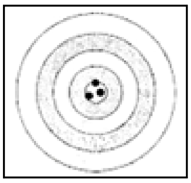
An analogy is a way of explaining something by comparing it to something else. We can use archery to help explain the difference between accuracy and precision.



In this diagram of the target, three arrows (●●●) are close to each other. They have high precision. However, the shots are far from the centre (X) of the target. The shots have low accuracy.



In the second diagram, the arrows land closer to the centre of the target. They have higher accuracy. But the shots are more widely scattered. Their precision is lower.



In the last diagram, the shots are close to the centre of the target. They have high accuracy. The shots are also close to each other and so they also have high precision.

Now try the following activity to see if you understand accuracy and precision.

ACTIVITY 2

1. Suppose you measure the voltage of the battery labeled 9v in the diagram. Your measurement tells you that its voltage is 17.1453 volts.

    a. Is your measurement accurate? Explain.

    b. Is it precise? Explain.

2. You measure the volume of soup in a can to be 451 millilitres. The volume on the label is 450 ml. Is your measurement accurate or precise or both accurate and precise? Explain your choice.

3. Explain why the measurement of the length of the pencil is not likely to be very precise.

4. A plumber measures the diameter of a water pipe three times. His measurements are 9,6 cm, 9,7 cm and 9,8 cm. The accepted value is 9,89 cm.

    a. Are the plumber's measurements accurate?

    b. Are they precise? Justify your answers.

5. Themba measures the length of a line three times. His values are 6.2 cm, 6.4 cm and 6.38 cm. The teacher tells him that the line is 8.5 cm long.
   a. Are Themba's measurements accurate?
   b. Are they precise or are they both accurate and precise?
   c. Explain your answer.

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Some quantities have direction

You have seen earlier that we express most measurements with a number and a unit. We call these quantities **scalar quantities**.

A scalar quantity has **magnitude** and a unit.

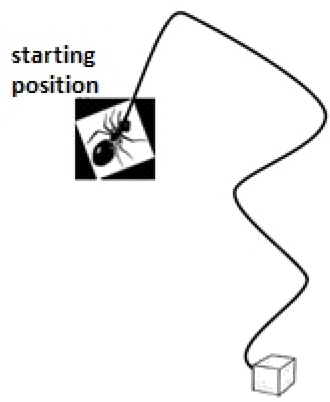
magnitude:
the size of something which we show using a number

Mass, temperature, time, density, volume, distance and speed are examples of scalar quantities.

However, there are some quantities which we must measure by stating three things, not only magnitude and units. The extra information which we use when we describe such quantities is direction. We call such quantities vector quantities.

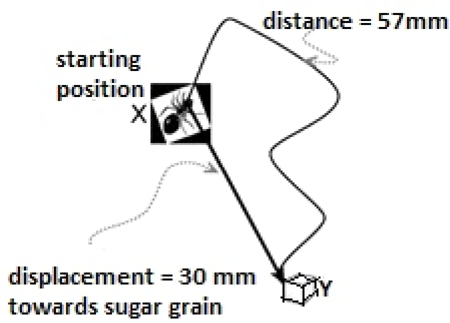
A **vector** quantity has magnitude, a unit and a direction. Displacement and velocity are all vector quantities.

We now look at these two quantities in more detail.



Distance and displacement

Use a pencil to draw the exact path an ant follows to find a grain of sugar. Then carefully put a damp cotton thread on the pencil pathway in the diagram. Cut the thread so that is the same length as the pathway. Stretch out the thread and hold it on a ruler to measure its length (in millimetres).



The length of the thread then gives the **distance** the ant travels to reach the sugar. The **distance** between two points is the length of the pathway between those two points.

The distance the ant travels may be 57 mm. 57 is the magnitude of this measurement and millimetres is its unit of measurement. Distance is a scalar quantity.

If we were to describe the change in position of the ant from its starting point to the sugar grain we could use a ruler to draw a straight arrow pointing from X to Y.

Then, when we measure the length of this straight line and give direction to the ant's change in position, we get a new quantity. This quantity is the **displacement** of the ant.

The **displacement** of a moving object is its change in position in a particular direction.

The displacement of the ant is 30 mm towards the sugar grain. 30 is the magnitude, mm is the unit and 'towards the sugar grain' describes the direction of the ant's displacement. Displacement is therefore a vector quantity.

Speed and velocity

Speed is a familiar quantity we use to describe motion. Speed gives us an idea of how fast something moves when it changes position. So, speed involves measuring the distance an object moves as well as the time taken to move this distance.

$$speed = \frac{distance}{timetaken}$$

$\frac{km}{h}$, km/h and kmh^{-1}

mean the same thing.

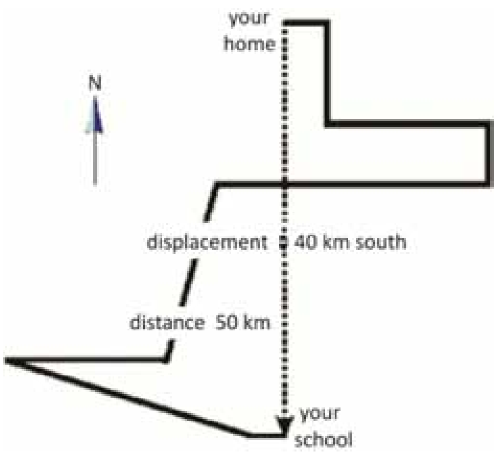
Suppose you travel 50 km to school by taxi. The journey takes you half an hour. How fast does the taxi travel? We can work this out by using the equation below.

$$speed = \frac{distance}{time\ taken} = \frac{50km}{0,5h} = 100kmh^{-1}$$

What is this speed of 100 kmh^{-1}? Is it the fastest speed the driver travels, or is it the slowest speed because the taxi stops at red robots and stop streets! It cannot be the slowest speed which must be 0 kmh^{-1}. Nor can it be the highest speed because when the taxi overtook a car, the speedometer read 140 kmh^{-1}!

Clearly, 100 kmh^{-1} is the average speed of the taxi. You cannot read the taxi's average speed on its speedometer. You can only calculate average speed by using the equation

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



The drawing in the margin shows that the distance between your home and your school is 40 km as the crow flies. Your displacement when you get to school will be 40 km south or 40 km S.

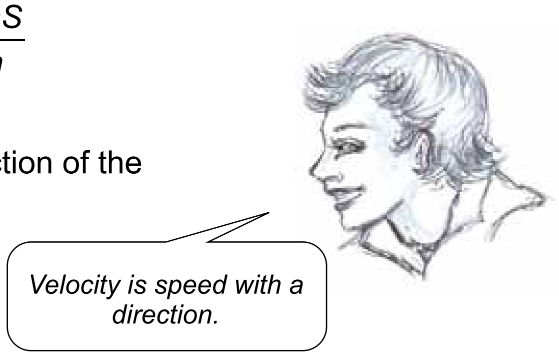
Speed is a scalar quantity. It has a vector equivalent which we call **velocity**. In everyday life the words speed and velocity have much the same meaning. However, in science, speed and velocity have very precise meanings.

The average velocity of your journey to school by taxi is:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}} = \frac{40 km S}{0{,}5 h}$$

$$= 80 kmh^{-1} S$$

The direction of the velocity is the same as the direction of the displacement.



ACTIVITY 3

1. Decide if each of the sentences below describes a distance or a displacement.

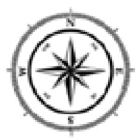
    a. The aeroplane was forced to land 30 km away from the airport.
    b. The robbers buried their loot 200 m away from the road.
    c. The racetrack is 1 km long.

2. Mfanyana and his family drove a total distance of 560 km to Durban. The trip took 8 hours. What was their average speed in km/h?

3. In the 2008 Olympics, Jamaican sprinter Usain Bolt shocked the world when he ran the 100 metre sprint in 9.69 seconds. What was Usain's average speed for the race?

4. A drawing shows three different paths (X, Y and Z) between the same two places. You plan to travel for 30 minutes. Along which path must you move with the highest average speed to arrive at the destination in 30 minutes? Explain.

Compass directions
A compass is an instrument that we use to find direction. The four main compass points are north, south, east and west.



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SUMMARY ACTIVITY

1. Which of the following are fundamental or derived quantities?
    a. length
    b. time
    c. speed
    d. velocity
    e. displacement

2. Which of the following quantities are scalars?
   a. a distance of 100 km,
   b. an average speed of 120 km/h,
   c. a speed of 120 kmh-1,
   d. a velocity of 12 ms-1 east,
   e. a displacement of 5 m towards the door.

3. A car travels 100 m in an easterly direction along a straight road in 5 s.
   a. What distance does the car travel?
   b. What is the car's displacement?
   c. What is the car's average speed?
   d. The same car travels 100 m around a circular racetrack in 5s. It ends up at its starting position. What is the average velocity of the car along the circular race track?

4. You run from your house to a friend's house 5 km away in 30 minutes. You then immediately walk home. The walk home takes 1 hour.
   a. What is the average speed (in km/hr) for the entire trip?
   b. What is the average velocity (in km/hr) for the entire trip?

5. Is the following statement True or False?
   It is possible for an object to move for 10 seconds at a high speed and end up with an average velocity of zero.

   If the statement is true, then give an example of such a motion. If the statement is false, then explain why it is false.

ANSWERS ON PAGE 168

CHECKLIST

Are you able to:

- ❒ list the seven basic quantities and their units in the Système International d'Unités (SI)
- ❒ explain and give a few examples of derived quantities
- ❒ distinguish between scalar and vector quantities
- ❒ define distance, displacement, speed and velocity
- ❒ calculate average speed and average velocity.

Forces and things they do

About this lesson

Concrete objects such as cups, spoons, shoes and balls all have obvious properties. They have shape, colour, mass and sometimes a smell. We can see them and touch them. However, forces are different. They have no shape, smell or colour. We cannot see or touch them. Yet our world is full of forces. Indirect evidence tells us that they exist. Although we cannot see forces, we can often tell when they are present by the things they do. We can sometimes see, feel or hear the effects of forces.

Our study of forces starts off with basic aspects of force; how they may push, pull, stretch, twist things and also how force may relate to movement. We use everyday examples to learn how to describe and represent them.

Before you start this lesson, prepare a list with the heading ‘Effects of Forces’. As you work through this lesson, keep on the lookout for things forces do. Every time you come across an effect that a force may have or something that a force seems to make happen, write it on your list. This icon will remind you!

In this lesson you will:

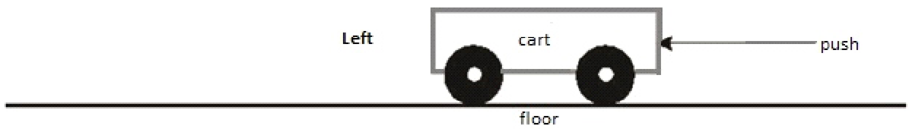
- distinguish between pushing and pulling forces
- identify the agent that exerts a force and the object on which the force acts
- draw arrows to represent forces
- describe the difference between contact forces and action-at-a-distance forces
- list some things that forces do.

Forces as pushes and pulls

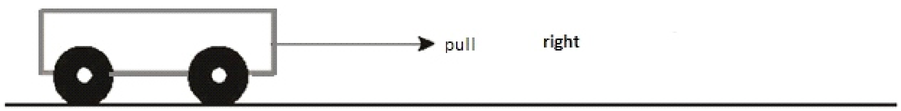
The simplest way of describing a force is to say it is a push or a pull.

You need a force to move the cart in the diagram from one place to another. This force may be a push or a pull.

- The cart will only move to the left when you use your hand to push it. It will not move if you don't touch it! Your hand applies (or exerts) a force on the cart.



- Likewise, this cart will only move to the right when you use your hand to pull it closer to you. Your hand applies (or exerts) a pulling force on the cart.



Force is a vector quantity

Pushes and pulls obviously have direction. You pushed the cart away from you and pulled it closer to you. This means that force is a vector quantity. It has magnitude and direction.

Arrows represent forces

We use arrows to represent the pushing and pulling forces acting on the cart.

- The length of the arrows shows the magnitude of the forces.
- The arrows point in the direction in which the forces act.

SI unit of force

We express force in newton (N). A newton is a derived unit. You will see why in a later lesson.

ACTIVITY 1

1. Can you push a book away from you without touching it?

2. Look at the following actions:

   - lifting a suitcase
   - kicking a football
   - picking an apple from a tree
   - closing a car door

   a. Which of the actions involve pushing something?

   b. Which of the actions involve pulling something?

ANSWERS ON PAGE 168

Twisting, stretching and squashing are also forces

Twisting, stretching and squashing describe the act of applying, or exerting, a force on an object.

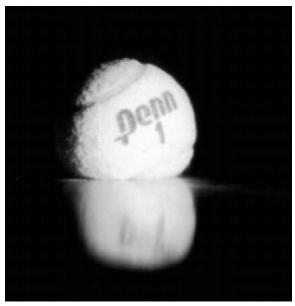
ACTIVITY 2

In this Activity, you will explore changes which take place when you twist, stretch, and squash a sponge. A kitchen or bath sponge works well.

Start by twisting the sponge, then stretch and it. Observe carefully.

1. What do the twisting, stretching and squashing forces do to the shape of the sponge?

2. What happens to the sponge when you stop applying the twisting, stretching and squashing forces?



3. Put the sponge on the table in front of you. Can you change the shape of the sponge without touching the sponge?

4. Now consider a tennis ball. What makes a tennis ball change shape when you hit it? Is this change permanent? Explain your answer.

ANSWERS ON PAGE 168

Agents and objects

We identify two things when we describe a force. These are

- who or what applies the force − the agent

  and
- the thing the force acts on − the object.

In the cart diagrams, it is your hand that pushes the cart. Your hand is the agent. The cart is the object on which the pushing force acts.

We write this $F_{\text{by the hand on the cart}}$ as we describe the twisting force you exert on the sponge as $F_{\text{by the hands on the sponge}}$

When a soccer player kicks a soccer ball, we write $F_{\text{by the boot on the ball}}$

See if you can identify agents and objects in Activity 3.

ACTIVITY 3

1. Describe the agent exerting the force and the object the force acts on in each of the sentences below.

   Write each answer in the $F_{\text{by\_\_\_\_\_\_\_\_ on \_\_\_\_\_\_\_\_}}$ form.

   - Mary throws the ball.
   - Andile moves the table closer to the wall.
   - The wind blows the litter against the fence.
   - The car hits the pedestrian.
   - Sipho pulls the brake handle to stop his bicycle.
   - The hailstones hit the car.
   - The wave pushes the boat high into the air.
   - The batsman hits the cricket ball.
   - The boxer punches his opponent on the jaw.
   - The man pushes the car as hard as he can but it does not move.

2. These two sentences about forces are both untrue.

   - Only living things can exert forces.
   - Forces always cause movement.

   a. Find evidence from the forces described in question 1 to show that these two sentences are false.

   b. Rewrite each sentence to make it correct.

3. Do you think that you need a force to start something moving? Support your answer with an example from question 1.

ANSWERS ON PAGE 169

Contact forces

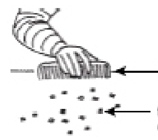
All the interactions between agents and objects described so far in this lesson involve physical contact. The agents exerting the forces and the objects they act on touch each other during interaction. We call forces that act in such situations contact forces.

Common sense tells us that it is impossible to lift a brick without touching it. A crane cannot move a bucket of cement if the bucket is not hanging from the crane.

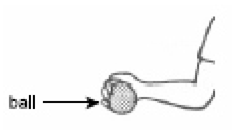
But, is it always necessary for an agent to touch an object? Can things interact without touching? Try Activity 4 to find out.

ACTIVITY 4

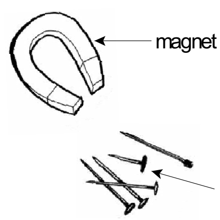
1. Rub a plastic comb on a woollen jersey. Move the comb slowly towards some tiny pieces of paper. Then hold the comb still. Describe what happens to the pieces of paper. Why does the paper act in this way?



2. Hold a ball in your hand. Let the ball go. Why does the ball immediately start moving down when you let it go? What makes the ball start moving? What stops the ball falling when it is in your hand?



3. Hold a magnet above some iron nails on a table. A magnet that sticks to a refrigerator works well. What happens to the nails? Why?



4. The pieces of paper, the ball and the nails all change their position. There must be a force acting on them. Identify the agents causing the movement of the paper, the ball and the nails.

5. Does the paper start moving away from the table before the comb touches it?

6. Is the force that makes the ball fall down a contact force? Explain.

7. Can the magnet and the nails interact without touching? Explain.

ANSWERS ON PAGE 169

COMMENT

Making observations is an essential part of a scientist's work. Scientists have studied things that happen in the space around charges, magnets and the Earth. Their observations led them to create a model to explain these observations. Their model is the idea of a field.

Action-at-a-distance forces

Agents and objects can interact without touching each other.

- The rubbed comb and the paper interact before the comb touches the paper.
- There is no physical contact between the ball and the Earth when the ball starts falling.
- The magnet and the nails interact when the magnet is still at a distance from the nails.

We call the forces that act in these situations **action-at-a-distance** forces or **non-contact** forces.

Scientists have invented an idea to explain how these forces work. Their idea is that an electric charge, the Earth and magnets all change the space surrounding them into **fields**.

- An **electric field** exists around any electric charge. A rubbed comb is an electrostatic charge.
- A **gravitational field** exists around the Earth.
- A **magnetic field** exists around a magnet.

You will learn more about fields in later lessons.

ACTIVITY 5

State whether each of the sentences below describes a contact force or an action-at-a-distance force.

meteorite:
a small piece of rock moving through space

1. A **meteorite** will move faster and faster the closer it comes to Earth.

2. You rub your hands together to warm them on a cold day.

3. You blow the dust off the chair.

4. The Earth moves around the Sun.

5. The fan blows cool air onto your face.

6. The grass exerts a force on the rolling ball.

7. The skydiver falls slowly towards the Earth.

8. The car collides with the wall.

ANSWERS ON PAGE 170

A closer look at forces and motion

Your list of the things forces do should be quite long by now. It should show what twisting, stretching and pulling forces do. It should also show that you need a force to change the position of an object. An object cannot change its position without moving. Have you noticed link between forces and movement? And, what about forces which prevent movement? Is this on your list?

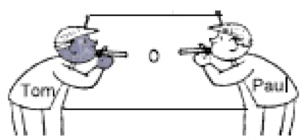
Let's take a closer look at the forces acting when an object moves.

Football

The purpose of playing a game of soccer is to move a ball into your opposition's goal. Movement is the focus of football. And forces exerted by a boot on a ball are responsible for the way a soccer ball moves. To find out more about kicking forces and the things they do you must play a game of football.

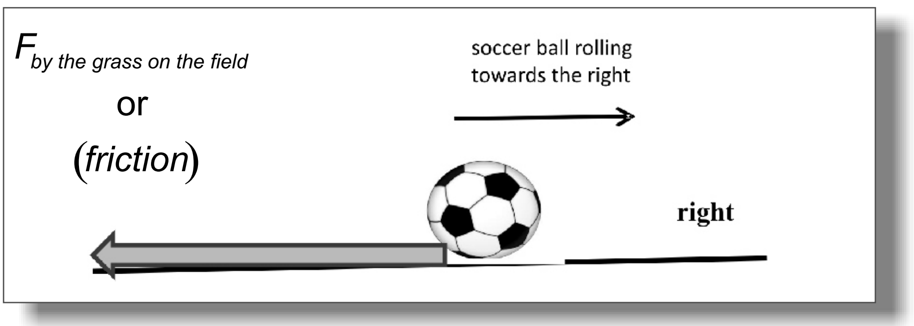
ACTIVITY 6

In this experiment you will move a ping-pong ball by blowing on it through a straw. Place the ball on a smooth table top. You may not touch the ball with your hands.



Before you start blowing, make a few **predications** about the way you think the ball will behave during the experiment.

prediction:
using what you know about something to describe what you think may happen later.



1. The following table *Making and Testing Predictions* shows some things for you to think about. The column on the left describes different things the ball may be doing. The column next to it shows different ways you can exert forces on the ball. The middle column is blank. This is where you must write your predictions about what you think will happen to the ball. Leave the two columns on the right of the table blank for now.

Making and Testing Predictions				
What the ball is doing	What I do to the ball	What I think will happen to the ball (my **prediction**)	What happens to the ball (**testing** my prediction by observing)	Is my prediction right?
rolling in a straight line away from you	blow the ball from behind			
rolling in a straight line	blow the ball from the side			
rolling in a straight line towards you	blow the ball from the front			
at rest	blow at it from any direction			

2. Ask a friend to conduct the experiment with you. There will be one player in each team.

   You will need:

   - a ping-pong ball, or a ball carved out of polystyrene packaging
   - a clean drinking straw for each player
   - a large smooth surface
   - two boxes of the same size to act as the goals

3. Test each of your predictions by blowing on the ball through the straw in the way the table describes. Write your findings in the column called *Testing my Predictions*.

4. Compare each prediction with your observation. Decide if your prediction is right. Fill this in the last column in the table.

When you have completed the experiment, answer the questions below.

5. A player scores a goal by blowing the ball between the goal posts.

   a. What is the **agent** exerting the force?

   b. What **object** does this force act on?

   c. In which **direction** does this force act?

6. Two players stand opposite each other. They both blow on the ping- pong ball. The ping-pong ball does not move.

   a. What can you say about the sizes of the blowing forces on the ball?

   b. What can you say about the directions of the blowing forces on the ball?

   c. Draw and label an arrow to show the force each player exerts on the ball.

7. What do you think will happen to the ball if one of the players stops blowing at it but the other player keeps on blowing the ball with the same force?

ANSWERS ON PAGE 170

SUMMARY ACTIVITY

1. Decide whether the forces listed below are pushing or pulling forces:

   a. The goalkeeper (agent) catches the ball (object) before it goes into the goal.

   b. Your friend (agent) slices the loaf of bread (object).

   c. The car (agent) crashes into the wall (object).

   d. The dentist (agent) takes out your tooth (object).

2. In what way/s are the forces below the same?

   a. I knead the bread dough before I put it into the baking pan.

   b. Petra squeezes the water out of the sponge she uses to wash the dishes.

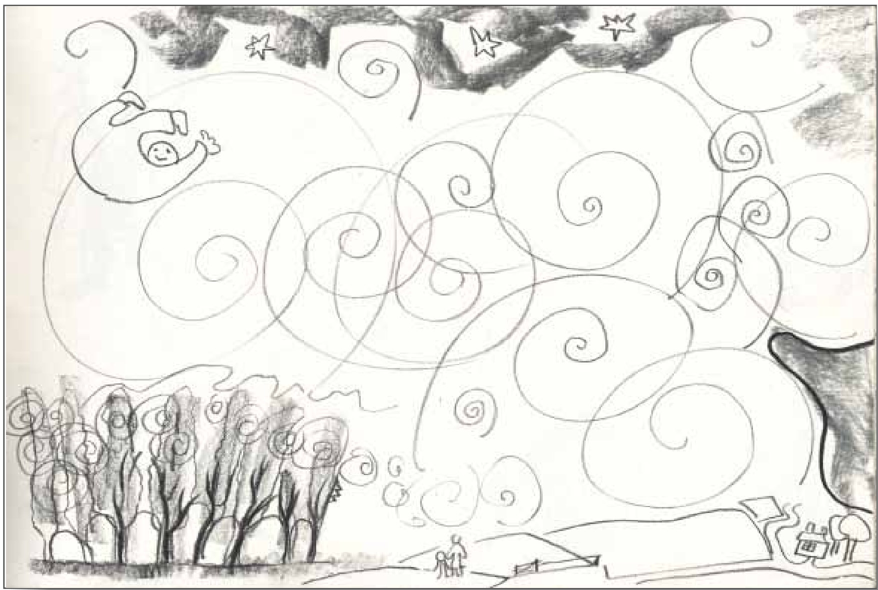
3. Look at your checklist. It should have many specific examples of things that forces may do in different situations.

   Try to shorten your list by writing the effects that forces may have in general, rather than specific terms. Keep your list to use in Lessons 6, 7 and 8 on Newton's Laws.

   Look at the example below to see what we mean.

   Example:
   Specific statement: The wind blows the litter.
   General statement: A force may make something move.

ANSWERS ON PAGE 171



CHECKLIST

Are you able to:

- ❒ distinguish between pushing and pulling forces?
- ❒ identify the agent that exerts a force and the object on which the forces acts?
- ❒ treat force as a vector quantity when you use an arrow to represent a force?
- ❒ describe the difference between contact forces and action-at-a-distance forces?

More about forces

About this lesson

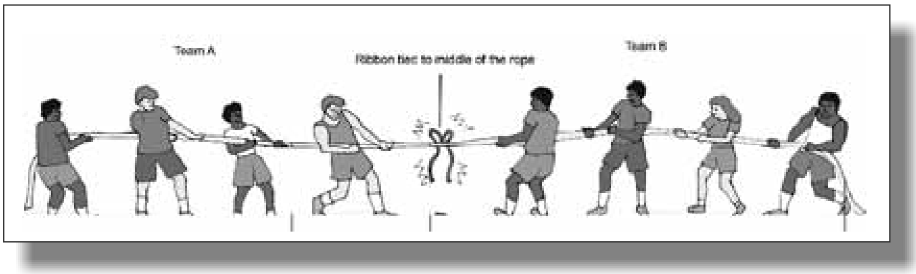
There is a strong link between forces and motion. In fact, forces are responsible for making objects move or not move in the ways they do. We need to know about forces to understand how things move. This short lesson enables you to recognize and name some forces which seem to have no obvious effect. It prepares you for the lessons on Newton's Laws of Motion later in the unit.

In this lesson you will:

- add two or more linear forces to find the net force
- distinguish between balanced and unbalanced forces
- link change in position to a non-zero net force
- distinguish between mass and weight
- calculate weight from gravitational field strength
- recognize forces such as weight, friction, tension and the normal force.

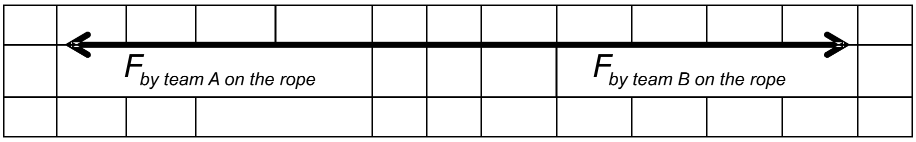
Equal pulls

The diagram shows two tug-of-war teams pulling on a rope. The ribbon in the middle of the rope stays in the same place above the stone. It does not move. We say the ribbon is at rest. This tells us that the teams are evenly matched. They pull on the rope with equal forces and they pull on the rope in opposite directions.



The arrows below represent the two forces.

- The arrows are equal in length which means that the forces are the same size.
- The arrows point in opposite directions telling us that the two forces act in opposite directions on the rope.



The two pulling forces are balanced. Each force cancels out the other. The result is that nothing changes. The ribbon on the rope stays in the same position.

Balanced forces

Two forces acting on the same object are balanced if they have equal magnitudes and act in opposite directions. Balanced forces have no effect on the motion of the tug-of-war rope. The ribbon on the rope remains at rest in the same position.

Adding forces

Sometimes it is necessary to find out what the combined effect of two or more forces acting on the same object is. We work this out by 'adding' the two forces. But forces are vectors, so when we add them we must to take their directions into consideration.

The forces exerted by the two teams on the rope act in the same straight line. They are linear forces.

We add linear forces by giving them mathematical direction. We give the force exerted by team B on the rope a positive direction.

It becomes $+F_{by\ team\ B\ on\ the\ rope}$.

Then the force team A exerts in the opposite direction on the rope becomes a negative force.

Adding the forces gives their sum.

Sum of the forces:

$$
\begin{aligned}
&= F_{by\ team\ B\ on\ the\ rope} + F_{by\ team\ A\ on\ the\ rope} \\
&= F_{by\ team\ B\ on\ the\ rope} + \left(-F_{by\ team\ A\ on\ the\ rope}\right) \\
&= F_{by\ team\ B\ on\ the\ rope} - F_{by\ team\ A\ on\ the\ rope} \\
&= 0
\end{aligned}
$$

Because the two arrows are the same length (represent the same magnitude) their sum is zero.

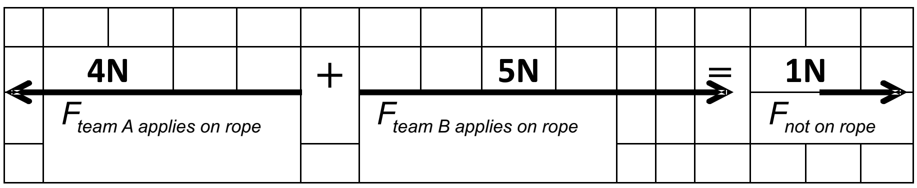
The vector sum of the forces acting on the rope is zero.

Net force

The net force acting on the rope is the total force acting on the rope. We call this sum the net force or the total force or sometimes the resultant force. We use the same principle when we add other kinds of linear vectors too.

Team A gets tired

After a while, Team A gets tired but Team B does not. So the size of Team A's pulling force decreases. But Team B's pulling force does not change. Team B keeps on pulling with the same size force.



$$
\begin{aligned}
\text{Sum of the forces} &= F_{by\ team\ B\ on\ the\ rope} + F_{by\ team\ A\ on\ the\ rope} \\
&= F_{by\ team\ B\ on\ the\ rope} + \left(-F_{by\ team\ A\ on\ the\ rope}\right) \\
&= +5N + \left(-4N\right) \\
&= +5N - 4N \\
&= +1N
\end{aligned}
$$

The sum of the two forces is 1 N in the positive direction. This is towards B.

Unbalanced forces

The forces the two teams apply on the rope do not cancel each other out completely. One force is bigger than the other. The sum of the two forces is an unbalanced force. Their sum is greater than zero. $F_{net} > 0$

An unbalanced force causes change

In the tug-of-war, the unbalanced force has a very obvious effect on the rope. The rope starts moving! Team B wins the competition! Team A moves towards B. This is the effect of the non-zero unbalanced force acting on the rope. The rope and the people holding on to it change position. The bigger the unbalanced force, the greater the victory! Change in position involves movement.

An **un**balanced force causes a **change** in an object's **state of motion**.

ACTIVITY 1

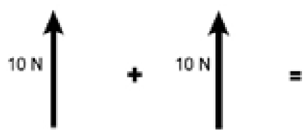
1. Each of the diagrams below shows two forces acting on the same object. For each of a, b and c below, work out the magnitude and direction of the net force. Say if the net force is unbalanced or not.

a. 

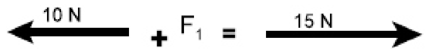
b. 

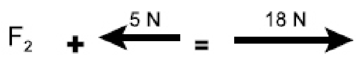
c. 

d. 

e. 

2. Work out the magnitude and direction of the unknown force in each of the diagrams below.

a. 

b. 

3. The diagram shows all the forces acting on an object.

   a. What is the sum of the vertical forces on the object?
   b. Work out the net horizontal force on the object.
   c. In which direction will the object move?

ANSWERS ON PAGE 171

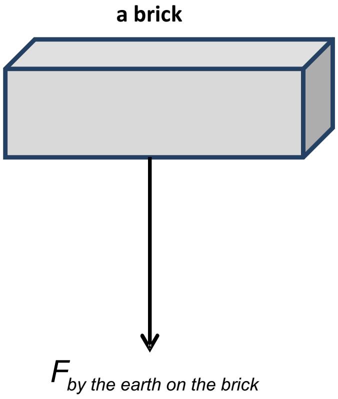
We give names to some forces

We come across some forces so often that these forces have names.

Force of gravity or weight

When we drop something, it falls because the Earth pulls it down. This pull is the force of gravity and it exists because of the gravitational field around the Earth. The force of gravity is the force the Earth exerts on the object. Another name for the force of gravity on an object is weight (w).

$F_{by\ the\ earth\ on\ the\ object} = weight$



The Earth's gravitational field pulls all objects towards its centre. We describe this direction as being vertically down.

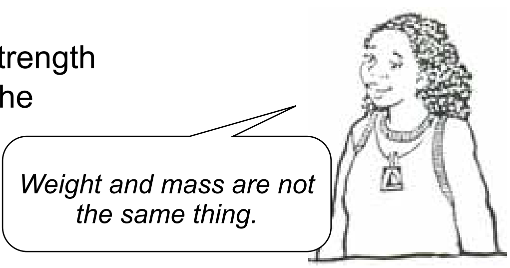
All objects have weight. This means that the Earth pulls all objects vertically down.

The diagram shows an arrow pointing down to represent the force the Earth (the agent) applies on a brick (the object) or the weight (w) of the brick.

Weight and mass are related

The weight of an object is related to its mass. Mass is one of the seven basic SI units. It is the quantity of matter making up an object and we measure it in kilograms.

Weight is a force that depends on both mass and the strength of the Earth's gravitational field. For now, we describe the strength of the Earth's gravitational field by stating how much force the Earth exerts on every kilogram of mass.



Near the Earth and on its surface, gravitational field strength is approximately 9.8 N down for every kilogram of mass. We approximate this to 10 N/kg to make calculations easier. To work out an object's weight, we multiply its mass by $\frac{10N}{kg}$.

Worked example:

Suppose a rock has a mass of 6 kg. What is its weight on Earth?

Solution

$$weight = mass \times 10\frac{N}{kg} \text{ down}$$
$$= 6kg \times 10\frac{N}{kg}$$
$$= 60N \text{ down}$$

Notice that we state the magnitude of the weight (60), its unit (N) and its direction (down).

Weight on the Moon

Since weight depends on mass and on gravitational field strength, the same rock would have a different weight on the Moon. The strength of the Moon's gravitational field is about $\frac{1}{6}$ of the Earth's.

$$\text{weight on the moon} = \text{mass} \times \frac{10}{6} \times \frac{N}{kg} \text{ down}$$
$$= 6\,kg \times \frac{10N}{6kg}$$
$$= 10\,N$$

The Moon pulls the same rock towards its centre with a force of 10N.

Mass never changes, weight does

The rock (used in the example) contains the same amount of matter wherever it may be in the universe. This means the mass of the rock is the same everywhere. But weight changes from place to place in the universe.

The normal force

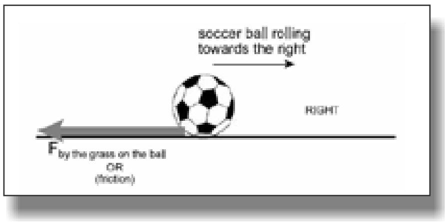
When you sit on a chair, the seat of the chair (the agent) applies an upward force on your body (the object) to stop you from falling. If the chair is horizontal, this force acts vertically up and we call it the normal force.

$F_{\text{by the chair on the man}}$

or

(normal force)

Sliding Friction



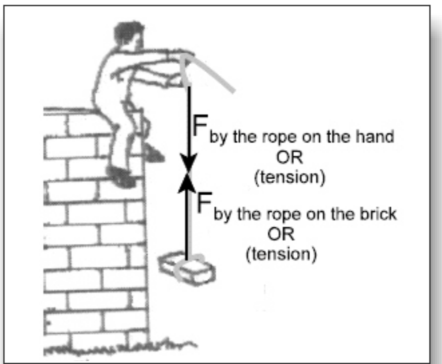
The diagram shows a soccer ball rolling along the grass after you kick it. The ball slows down as you watch it. Eventually the ball stops moving because a force acts on the ball. This force is sliding friction or just friction. The surface of the grass is the agent exerting the force and the ball is the object on which the force acts.

The air also exerts a force on the ball to stop its movement. This air friction is so small that we mostly ignore it.

When you stop pedaling your bicycle on a flat road, you move slower and slower until you stop moving. The force slowing you down is the friction between the bicycle wheels and the road surface. Friction always opposes motion.

Friction is a force that acts when one surface moves or tries to move across another surface. Friction always acts against motion. The frictional force is the force exerted by a surface as an object moves across it.

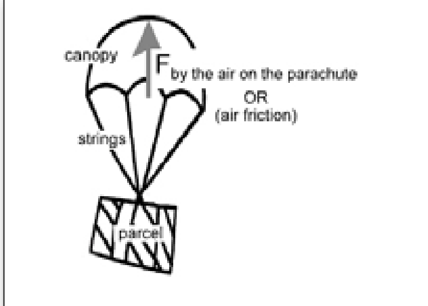
Tension



A bricklayer uses a rope to pull up a brick. There is a force called tension acting in the rope. Tension is the force the bottom of the rope (agent) exerts on the brick (object). The top of the rope (agent) also exerts a tension force on the bricklayer's hand (object). Tension always acts along the length of the rope away from the object it acts on. In this case, tension acts up on the brick and down on the hand.

In general, **tension** is the force which acts in a cord when forces acting at each end of the cord stretch it tight. The cord may be a string, rope, wire, cable or a spring. You can think of tension as the force each end of the cord exerts to try and get back to its unstretched length.

Air resistance



The diagram shows a parcel on a parachute moving down through the air. Air fills the canopy giving it a large surface area. The air (agent) exerts an upward force on the inside of the canopy (object). This is a frictional force which we call **air resistance** or **air friction**. The bigger the canopy of the parachute, the bigger the air resistance and the slower the parachute will fall.

Air resistance is frictional force which acts on all objects as they move through the air. It always acts opposite to the direction of motion to slow down the object. Air resistance on most falling objects is so small that we usually ignore it.

Applied force

An applied force is the force which a person or some other agent exerts on some object.

If you push a desk across a room, then the applied force is the force your hand (the agent) exerts on the desk (the object). Other forces act on the desk too.

ACTIVITY 2

Find a sheet of newspaper. Tear it into two pieces which are exactly the same size. Crumple one of the pieces to make it as small as possible. Leave the other piece flat. Stand on a table or a chair and drop both pieces of paper from the same height at the same time. Observe the pieces as they fall to the ground.

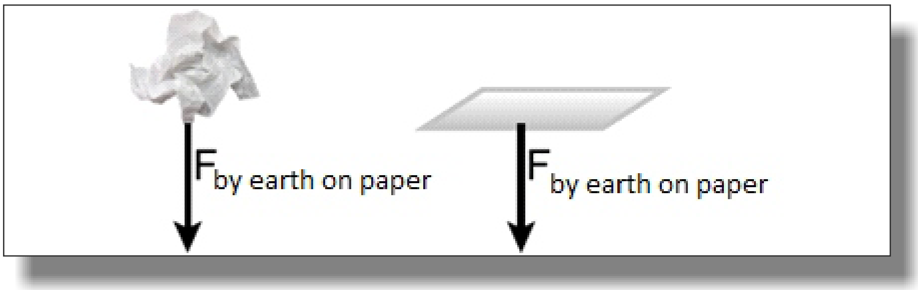
1. Which piece of paper reaches the ground first? Why?

2. Which of the falling pieces of paper has the larger surface area?

3. Compare the air resistance on both pieces of paper as they fall. On which is the air resistance bigger?

4. What does air resistance do to the speed of the flat piece of paper as it falls?

5. The arrows in the diagram show the force the Earth exerts on the crumpled and the flat paper.



    a. Why do you think these arrows are the same length?

    b. Draw an arrow to represent the air friction acting on each piece of paper.

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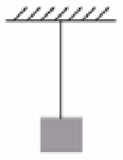
ACTIVITY 3

See if you can recognize the types of forces acting in 1- 5 below. Choose forces listed in the box below to answer. Identify the agent exerting the force and the object the force acts on.

Remember to include the direction in which each force acts too.

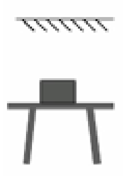
tension, friction, normal force, gravitational force

1. A wooden block on a thin string hangs at rest from the ceiling. Identify the forces acting on the block.



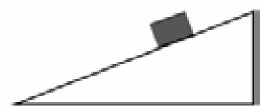
2. You throw a tennis ball straight up into the air. What force acts on the tennis ball when it is at its highest point?

3. A block lies at rest on a table. What forces act on the block?

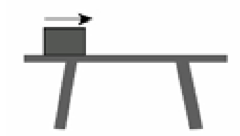


4. A cable joins a car to a tow truck. The tow truck moves along a level road. Consider only the forces acting on the car.

5. A concrete block rests on a ramp. What forces act on the block?



6. A block slides from left to right across a table. What forces act on the block?



ANSWERS ON PAGE 173

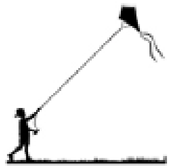
SUMMARY ACTIVITY

1. The diagram shows a bathroom scale when Pete stands on it.

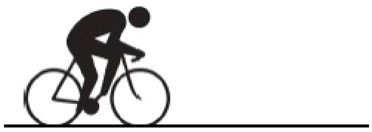
   a. What is Pete's mass?

   b. What is his weight?

2. Draw and label arrows to show the tension in the kite string in the diagram. Label each force F_{by} ________ on ________.



3. Use arrows to represent friction in the diagrams below. Label each frictional force as F_{by} ________ on ________.



ANSWERS ON PAGE 173

CHECKLIST

Are you able to:

- ❐ add two or more linear forces to find the net force
- ❐ distinguish between balanced and unbalanced forces
- ❐ link change in position to a non-zero net force
- ❐ distinguish between mass and weight
- ❐ calculate weight from gravitational field strength
- ❐ recognise forces such as weight, friction, tension and the normal force?

Describing motion

About this lesson

Everything in the universe moves so it is not surprising that motion is one of the key topics in physics.

Think about the ways in which things around you move. Watch how a bird flits around when it catches insects. It keeps changing direction all the time. Sometimes it flies slowly, other times it flies very fast. It moves in every way you can imagine.

What about the movement of a soccer ball during a game of soccer? Would you describe its motion as simple, straightforward and predictable? Of course not! It speeds up, slows down, curves as it flies through the air and sometimes moves in straight lines. It moves in every possible direction during the course of the game! The motion of a soccer ball is very complex.

Things in the real world move in complicated ways which are very difficult to make sense of. This is why physicists simplify reality when they explore motion. They study simple straight line motion to uncover the 'bare facts' or basic principles. They observe, describe, measure, invent ideas, define new words and create formulae to describe simple motion. Once they fully understand simple motion, they expand their exploration to include more complicated movements.

In this course, we start our study of motion in exactly the same way with simple motion. We show how to use words, diagrams, numbers and graphs to represent and describe simple motion. The hope is that this will prepare you for possible future study of more complex, real-world motion.

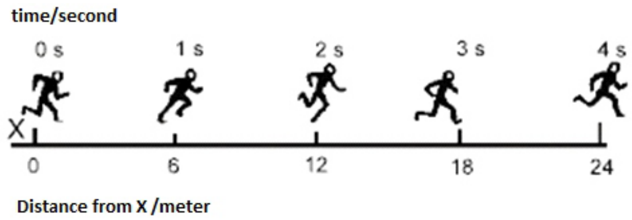
In this lesson you will:

- recognize and describe uniform speed and uniform velocity
- interpret data tables showing time, position and velocity
- work out velocity from the slope of displacement-time graphs
- use the shape of a displacement-time to describe changes in velocity
- define acceleration and uniform acceleration
- calculate acceleration from velocity-time graphs
- work out displacement from velocity-time graphs

Changing speed

The taxi taking you to school each morning changes its speed continuously during the journey. Sometimes it moves fast; at other times it moves more slowly. It stops moving to let passengers get in and out and it starts moving to get back into the traffic. It changes direction too. Its motion is too complex and difficult to study.

Thozo, an athlete runs in a much simpler way. She runs east in a straight line along a flat road. The drawing represents her position on the road **every second** for part of her run.



If her speed is constant, then the distance traveled every second is the same. The runner would cover a distance of 6 meters every second.

If we could measure her position (distance from an arbitrary starting point) each second, then we would note that the position would be changing by 6 meters each second. This would be in stark contrast to an object that is changing its speed. An object with a changing speed would be moving a different distance each second.

The data tables below depict objects with constant and changing speed.

We can represent this same information about Thozo's run in a table. We start watching her motion at time = 0 s. The table shows how far away from X Thozo is each second.

Thozo's run

Look at the table called Thozo's run.

Thozo’s run	
time/ second	distance from × / metre
0	0
1	6
2	12
3	18
4	24

- Do you notice that Thozo moves a distance of 6 m **during** the first second?
- **During** the second second of her run (from t = 1 s to t = 2 s) Thozo also moves a distance of (12 m − 6 m) = 6 m.
- During the third second of the run, (from t = 2 s to t = 3 s) she moves a distance of (18 m − 12 m) = 6 m as well.
- The last row in the table shows that Thozo also moves (24 m − 18 m) = 6 m during the fourth second.

Thozo runs a total distance of 24 m from X after 4 s. Because Thozo runs in a straight line the magnitude of her displacement is the same as the distance she moves. Her displacement after 4 s is 24 east.

Uniform speed

Thozo moves a distance of 6 m each second so her speed is 6 m/s. Her speed stays the same for 4 s.

When an object moves equal distances in equal time intervals, the object is moving at **uniform speed** or **constant speed**.

Mary's Run

Mary, another runner in the same race also moves east in a straight line along the road. But her movement is different from Thozo's. The table shows her position relative to X at one second time intervals.

Mary's run	
time / second	**distance from × / metre**
0	0
1	1
2	4
3	9
4	16

ACTIVITY 1

1. During the first second, Mary moves a distance of 1 m. How far does Mary run during the second second of her run?

2. What distance does Mary run during the

   a. third second of her run?

   b. fourth second of her run?

3. What is Mary's displacement after 4 s?

4. Does Mary's speed increase, decrease or remain the same during the first 4 s? How do you know?

ANSWERS ON PAGE 174

5. Is Mary moving at uniform speed? How do you know?

Non-uniform speed

Mary's speed changes during the first 4 s of the race. She moves further and further each second. She is moving faster. Her speed is increasing.

An object moving at **non-uniform** speed moves different distances each second.

What about velocity?

Remember velocity is a vector. Adding direction to the runners' speeds, changes their speeds into velocities. Velocity gets its direction from the runners' displacements. Both runners displacements are east of their starting point. So Thozo's **uniform velocity** is 6 m/s E. Mary's velocity is **non-uniform** and is also in an easterly direction.

Uniform velocity

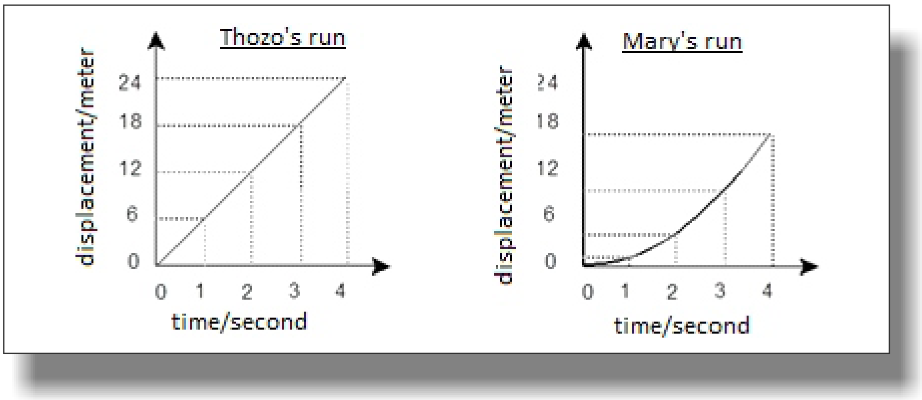
When an object moves equal displacements in equal time intervals, the object is moving at **uniform velocity** or **constant velocity**.

Non-uniform velocity

When an object moves different displacements in equal time intervals, the object is moving at non-uniform velocity or changing velocity.

Displacement versus time graphs

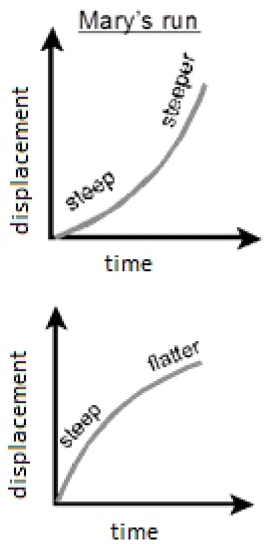
Graphs are another way of describing motion. The displacement-time graphs below represent Thozo's and Mary's runs.



Both graphs go up

Notice that the right side of the line and the curve on the graphs is higher than the left side. The graphs both go up. This means that as time increases, so does displacement. As time passes from t = 0 s to t = 4 s, both Thozo and Mary move further and further away from X.

Shape and slope



The **shape** of a displacement-time graph tells us whether an object is moving with **uniform** velocity or with **non-uniform** velocity.

Thozo's and Mary's displacement versus time graphs are different shapes.

Thozo runs at constant velocity and her displacement-time graph is a **straight line**. A straight line has a **constant slope**. A **straight line** displacement-time graph represents **uniform velocity**.

Mary's displacement-time graph is a **curve** and her velocity is non-uniform. A **curve** has a **changing slope**.

A **curved** displacement-time graph represents **non-uniform velocity**.

Curve up and curve down mean different things

The curve representing Mary's run becomes steeper and steeper. Its slope increases. We know she runs faster and faster.

An **upward curving** displacement-time graph represents **increasing** velocity.

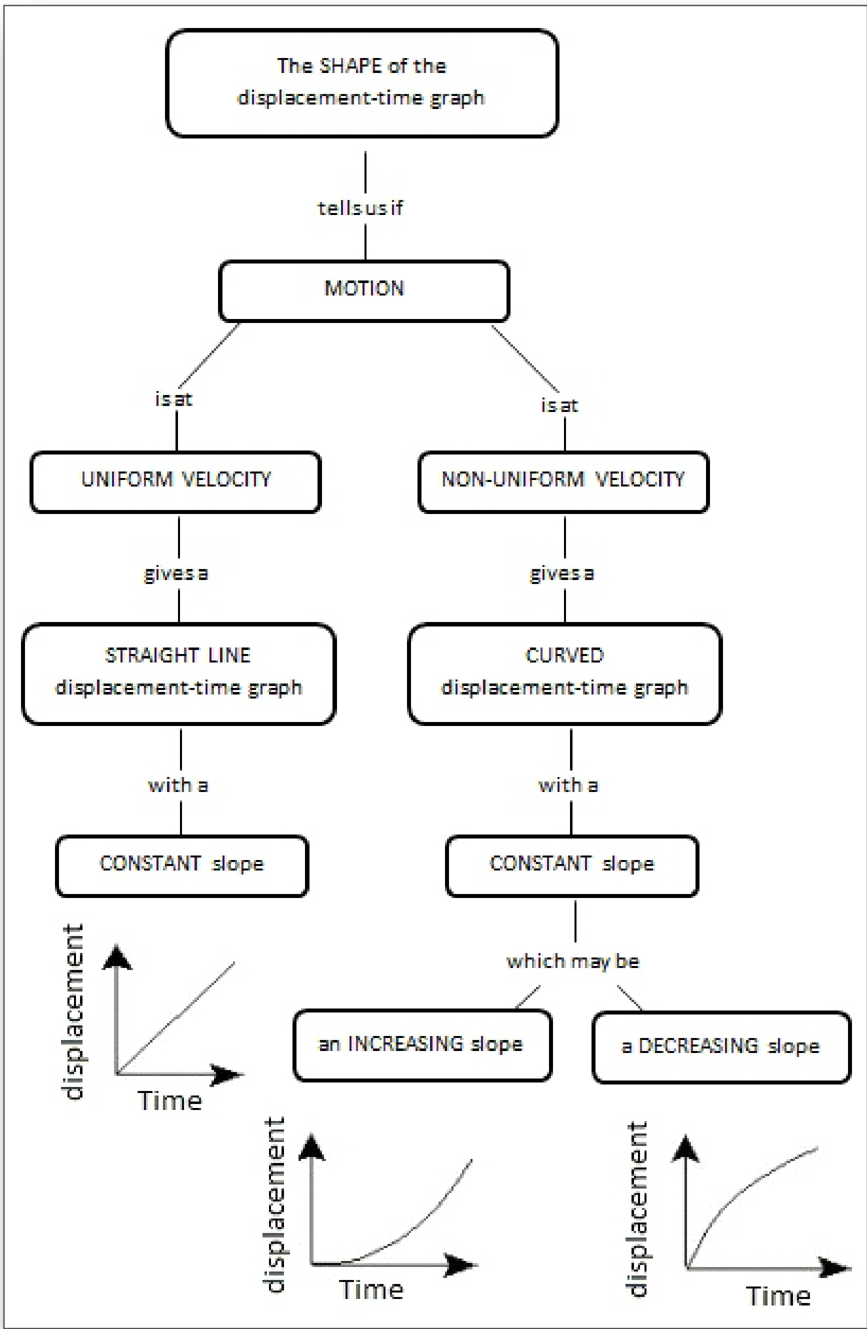
The displacement-time graph is also a curve. But it curves down. The curve becomes flatter with time. This must represent motion that becomes slower and slower!

A **downward curving** displacement-time graph represents **decreasing** velocity.

As the slope goes, so goes the velocity.

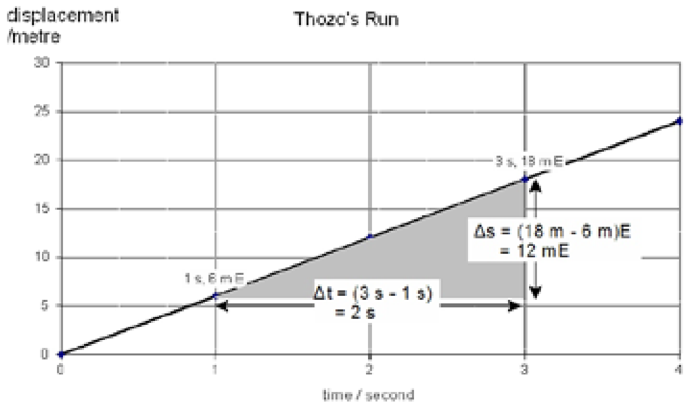
The slopes of the displacement-time graphs tell us this important principle. The slopes show the same properties as the velocities of the runners.

The concept map summarizes these findings.



Calculating the slope

You know from Maths how to calculate the slope of a straight line graph. We use the shaded right-angled triangle on the displacement-time graph for Thozo's motion to do this.



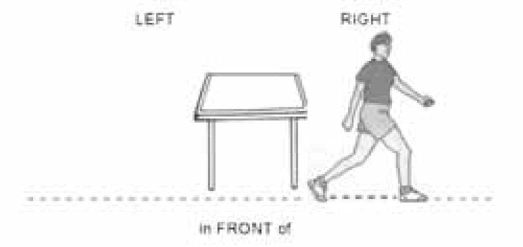
$$slope = \frac{\Delta y}{\Delta x} = \frac{\Delta s}{\Delta t} = \frac{(18m - 6m)east}{(3s - 1s)} = \frac{12m\ east}{2s}$$
$$= +6\, m/s\ east$$

The slope is 6 m/s east. Its units (m/s) tell us that the slope is indeed a velocity! The value +6 m/s is the same as the velocity we worked out from the table showing the time and distance values for Thozo's run.

The **value** (6 m/s) of the slope of a displacement-time graph represents the magnitude of an object's **velocity**. The + sign tells us that Thozo is moving further and further away from X. The word *east* in +6 m/s east gives the same **direction** in another way. East is also away from X.

Positive and negative slopes

The diagram shows Tom moving near a table. Suppose we observe his position relative to the table for 20 s as he moves in a straight line just in front of the table.



We start by describing Tom's motion relative to the table. You will collect numerical data from this description to fill in a table showing Tom's displacement and time. Finally you will use the table to plot a displacement-time graph representing Tom's motion.

Description of Tom's motion

- During AB (t = 0 s to t = 5 s) Tom stands 2 m to the right of the table.
- For the next 2 s (during BC), he walks faster and faster to the right until he is 6 m away from the table.
- For the next 3 s (during CD) he stands still.
- Tom then turns around and walks at constant speed for 4 s (during DE) back to the table.
- He keeps on walking for 5 s (during EF) until he is 3 m to the left of the table.
- During FG he stands still in this position for 1 s.

ACTIVITY 2

1. The table below shows Tom's displacement relative to the table during different time intervals. Use the description of Tom's motion to fill in the missing information.

In Lesson 3 you learnt how to give mathematical direction to vectors. If a displacement on the right of Tom's table is positive (+), then a displacement on the left of the table must be negative (-).

interval	time interval /second	displacement/meter	
		distance from the table at end of time interval	left / right of table
AB	0 to 5	2	Right
BC	5 to 7	6	
		6	
		0	at the table
EF	14 to 19	3	left
		3	

2. a. Use the description to work out the total distance Tom moves from t = 0 s to t = 20 s.

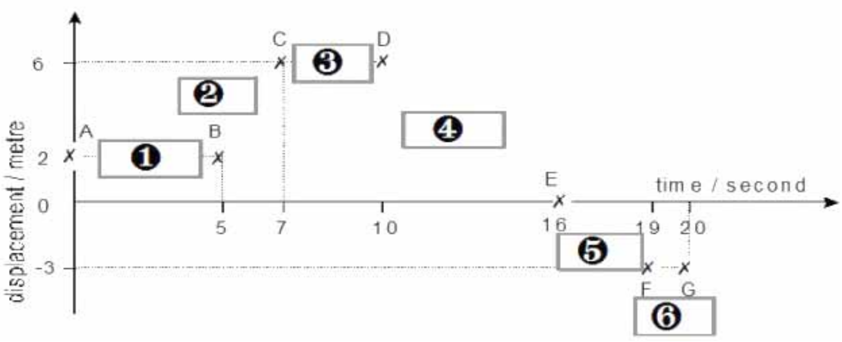
   b. What is Tom's overall displacement from his starting position after 20 s?

We use values from the table to sketch a graph showing Tom's displacement relative to the table for the 20 s interval. Each set of points on the table is shown by a cross (×). This graph shows six boxes called ❶, ❷, ❸, ❹, ❺ and ❻ but their labels are missing!

3. Choose one of the labels below for each box on the graph. The labels describe Tom's motion over the different time intervals (AB, BC, CD, DE and FG). You may use each label once, more than once, or not at all. Refer to the description of Tom's motion earlier to help you choose the correct label.

Answer as follows:

❶ name of label,

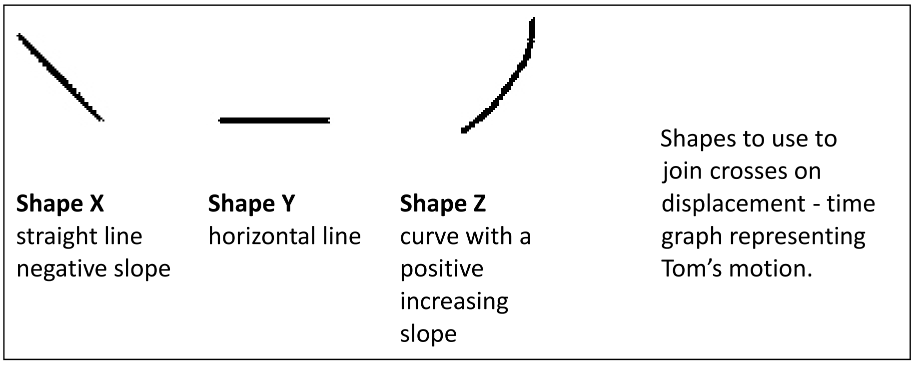


❷ name of label etc

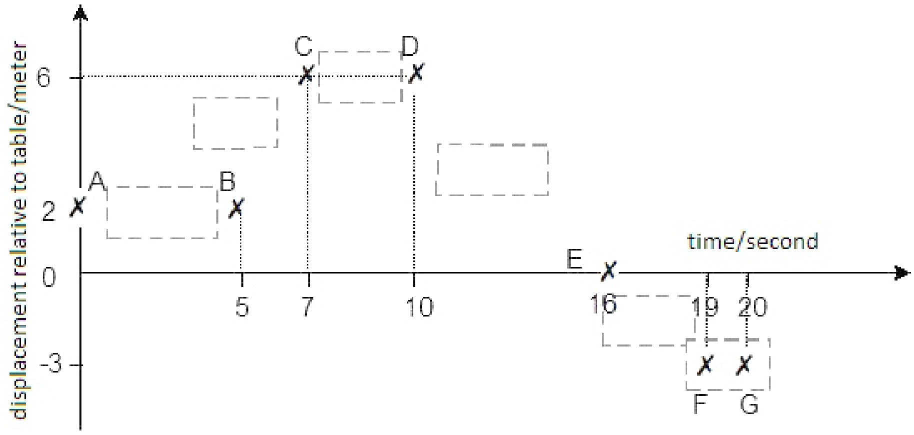
Labels	at rest	increasing velocity towards the left
	constant velocity towards the left	decreasing velocity towards the left
	constant velocity towards the right	increasing velocity towards the right

Now you must make some decisions about how to join the seven crosses (×) on the graph! Remember this is a displacement-time graph and ... **as the slope goes, so goes the velocity**. Read the description of Tom's motion again to remind you how he moved.

The diagram below shows three shapes (X, Y and Z) which you can use to join the crosses on the displacement-time graph of Tom's motion.



4. Join the crosses on the graph below using one shape to join any two crosses (X). You may use a shape more than once if you need to. (HINT: Remember to match shape to type of motion.)



ANSWERS ON PAGE 175

Summary

Meaning of slope on displacement-time graphs

On a displacement-time graph:

- a line or a curve with a **positive slope** represents movement away from some point.
- a **horizontal** line represents zero velocity, or the at rest condition.
- a line or a curve with a **negative** slope represents motion **towards** some point.
- a straight line represents constant velocity.
- a curve with increasing slope represents increasing velocity.
- a curve with decreasing slope represents decreasing velocity.

Changing velocity

Velocity includes both speed and direction. An object can change its velocity in three ways. An object's velocity can change if

- its speed changes
- its direction changes
- both its speed and direction change.

Accelerating

In everyday conversation we commonly say that when a car goes faster, it accelerates. When a driver presses the car's accelerator pedal, the car usually speeds up and we describe this as acceleration. Acceleration in everyday talk involves an **increase** in speed.

In science, the word **accelerate** has a more precise meaning. Acceleration describes how quickly an object **changes** its **velocity.** Change in velocity in science means either an increase in velocity, a decrease in velocity or a change in direction. An object is accelerating if it moves faster or slower in the same direction or if its speed stays the same and it changes its direction of movement.

Acceleration is a **change** in velocity in a given time interval.

$$\textit{acceleration} = \frac{\textit{change in velocity}}{\textit{change in time}}$$

$$= \frac{\textit{final velocity} - \textit{initial velocity}}{\textit{final time} - \textit{initial time}}$$

$$a = \frac{v - u}{t_2 - t_1}$$

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

SI units of acceleration

The equation $a = \frac{v - u}{\Delta t}$ shows that the units of acceleration must be the units of velocity divided by the units of time. If we know velocity in km/h then kilometres per hour per second (km/h/s) are suitable units for acceleration.

However, the SI units of acceleration are metres per second per second.

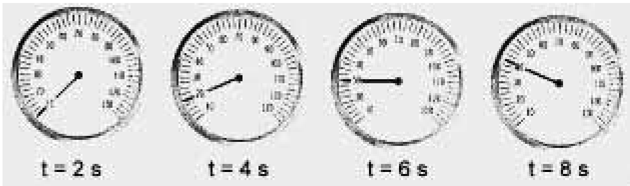
We abbreviate this to m/s/s or

$$\frac{\text{metre}}{\text{second} \times \text{second}} \qquad \frac{\text{metre}}{\text{second}^2} \textit{ or } ms^{-2}$$

We say this as metres per second squared.

ACTIVITY 3

Imagine that you are sitting next to the driver in a car at rest at a red robot. You plan to write down the speedometer reading every 2 s when the robot turns green and the car moves north on the straight road in front of you. The diagram shows the speedometer at 2 s intervals.



1. How can you tell that the car is accelerating?

2. Use data from the speedometers to fill in the missing velocities in the table.

time / second	**velocity / km/h north**
0	0
2	
4	
6	
8	

3. By how much does the velocity of the car change during the time interval from t = 2 s to t = 4 s? Show your working.

4. Assume that the car changes its velocity uniformly during the 8 s time interval. In 2 s, the car increases its velocity by 10 km/h N. What will be its increase in velocity in 1 s?

   The car's increase in velocity in 1s is its acceleration! Since the car moves faster by the same amount − by 5 km/h N − every second, the car's acceleration is **uniform**.

   An object undergoes **uniform acceleration** if its velocity changes by the equal amounts in equal time intervals.

It is easy to see that if at t = 8 s the car moves at 40 km/h N then 1 s later at t = 9 s, its velocity must be (40 km/h + 5 km/h) which is 45 km/h N.

5. At t = 9 s the car's velocity is 45 km/h. If the car keeps on accelerating at 5.0 km/h/s what will be its velocity at 10 s?

ANSWERS ON PAGE 176

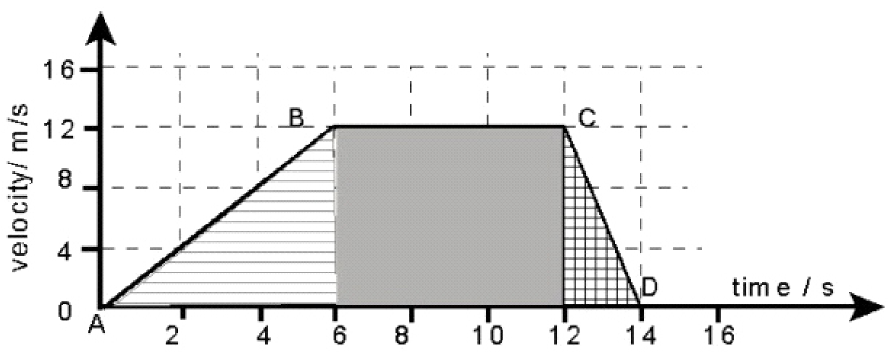
Acceleration is a vector

Acceleration is a change in velocity in a given time interval. Velocity is a vector. So acceleration must also be a vector. An acceleration of 5 km/h/s N means that the car changes its speed each second by 5 km/h in the direction in which it is moving − north. Like displacement and velocity, acceleration is a vector.

A test ride

Suppose an engineer takes a new car for a test drive. He drives west on a straight road. He records the velocity of the car every second for fourteen seconds. He uses his data to plot the velocity-time graph below.

The graph shows three different parts to the car's motion. These are AB, BC and CD.



Slope and shape

We calculate the slope of the car's velocity-time graph using the shaded triangle under AB.

$$slope = \frac{\Delta v}{\Delta t} = \frac{(12 - 4^{-1}\ west)}{(6-2)s} = \frac{8ms^{-1}\ west}{4s}$$

$$= 2ms^{-2}\ west$$

The units of the slope are the units of acceleration. This gives us another important and very useful idea.

The **slope** of a velocity-time graph represents acceleration.

The graph of the car's velocity-time graph during AB is a straight line. A straight line has constant slope. The slope represents the car's acceleration. This gives us yet another important idea.

A **straight line** velocity-time graph represents **uniform acceleration**.

In everyday life it is extremely difficult to accelerate a motor car uniformly! Acceleration is most commonly non-uniform.

ACTIVITY 4

1. a. Interpret the velocity-time graph for the test drive to describe the car's motion during BC (between t = 6s and t = 12 s).

   b. Use slope to work out the car's acceleration during BC (between t = 6 s and t = 12 s).

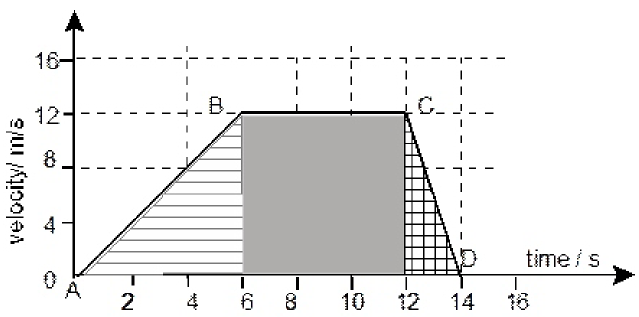
2. a. Show that the car's acceleration during CD (from t = 12 s to t = 14 s) is $-6\ ms^{-2}$.

   b. What is the meaning of the minus sign in $-6\ ms^{-2}$?

ANSWERS ON PAGE 176

Displacement from a velocity-time graph

The **area** under AB (horizontal grey stripes) on the car's velocity-time graph below is triangular in shape.



$$area = \frac{1}{2} \times \text{ base } \times \text{vertical height}$$
$$= \frac{1}{2} \times 6s \times 12 \frac{m}{s} west$$
$$= 36m \text{ west}$$

The units of the area are in metres. This area on the graph must represent the car's displacement during the time interval from t = s to t = 6 s.

Another important principle then is the **area** under a velocity versus time graph represents **displacement**.

ACTIVITY 5

1. Work out the car's displacement during the time interval from t = 6 s to t = 12 s. This is the area of the grey rectangle under BC on the velocity− time graph.

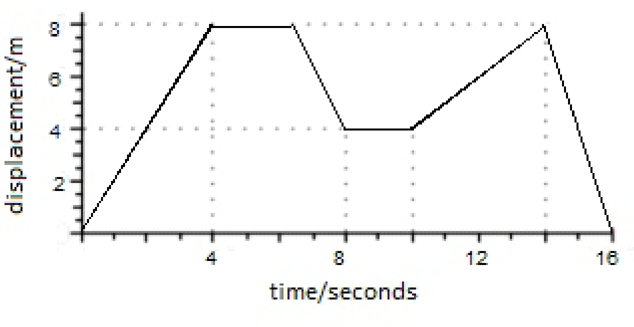
2. Work out the car's displacement during the time interval from t = 12 s to t = 14 s. This is the area of the squared triangle under CD on the velocity-time graph.

3. Work out the total area under the velocity-time graph from t = 0 s to t = 14 s. What does this area represent?

ANSWERS ON PAGE 177

SUMMARY ACTIVITY

1. The displacement-time graph below represents the motion of a coach during the last sixteen seconds of overtime during a soccer match. Assume that the coach moves in a straight line next to the field.



a. Describe the motion of the coach during this sixteen second time interval. In your description, you must

- use numerical values for time and displacement (not for velocity)
- refer to the direction in which the coach moves
- use phrases: constant (uniform) velocity, moving away from, moving towards, displacement

b. Work out the total distance the coach walks during these 16s. Show your working.

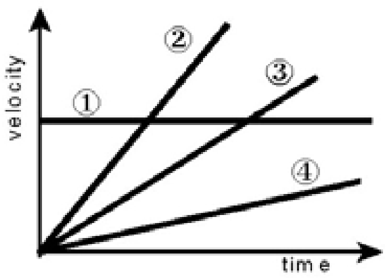
c. What is the displacement of the coach after 16 seconds?

d. At what time/s does the coach have the greatest displacement from his starting position?

e. What is the velocity of the coach during the first 4 s?

f. Work out the velocity of the coach during the last 2 s of the match.

2. The velocity-time graphs for four objects are shown on the graph.



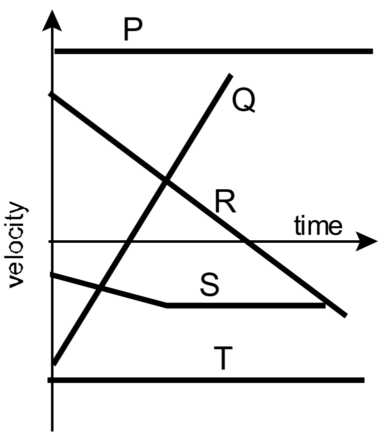
a. What kind of motion does line represent?

b. Which object reaches the highest velocity?

c. Which accelerating object has the greatest acceleration?

, d. Which objects are moving in the same direction?

3. The velocity-time graphs alongside represent the motion of objects P, Q, R, S and T. Use this graph to answer the following questions.



Each question may have less than one, one, or more than one answer.

a. Which of the objects is moving in the same direction as T?

b. Which of the objects changes direction?

c. Which of the objects is at rest?

d. Which of the objects is moving at constant velocity?

e. Which object is moving the fastest?

f. Which of the objects is accelerating?

g. Which accelerating object has the smallest acceleration?

ANSWERS ON PAGE 177

CHECKLIST

Are you able to:

- ❒ recognize and describe uniform speed and uniform velocity
- ❒ interpret data tables showing time, position and velocity
- ❒ work out velocity from the slope of displacement-time graphs
- ❒ use the shape of a displacement-time to describe changes in velocity
- ❒ define acceleration and uniform acceleration
- ❒ calculate acceleration from velocity-time graphs
- ❒ work out displacement from velocity-time graphs?

NOTES

Equations of motion

About this lesson

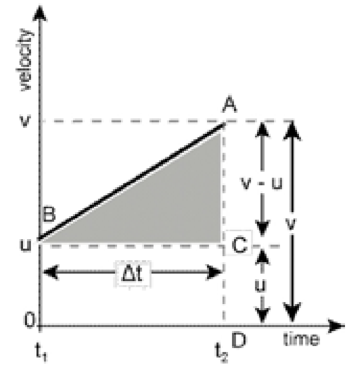
Lesson 4 covered a variety of ways of describing motion. It explained the meaning of scientific terms that we use to describe different kinds of motion. Tables of numbers showing time and displacement or time and velocity were also used as tools to interpret motion. Velocity-time graphs and displacement-time graphs of many different shapes were also interpreted to give even more detail about how things move.

This lesson introduces mathematical formulae as another useful tool to solve problems about motion. They make it possible to answer questions such as Where will .....? How fast is .... ? How far ....? about moving objects. The lesson also shows some real life situations in which these formulae apply.

In this lesson you will:

- use four different formulae to solve problems about moving objects
- describe how changing driving speed affects the distance a motor car travels before stopping
- measure your reaction time
- define thinking distance, braking distance and stopping distance
- use a *South Africans Against Drunk Driving* poster to convert units alcohol to alcohol content in breath and blood
- use a table showing the effect of alcohol on behaviour and blood alcohol concentration
- interpret graphs and tables linking number of drivers failing alcohol breathalyser tests to days of the week, time of day, age and gender.

Moving Objects



$v = u + a\Delta t$

This formula comes from the slope of a velocity-time graph.

The graph alongside represents the motion of an object moving with an initial velocity u at time = t1. The object undergoes uniform acceleration to change its velocity to v at time .

$$\text{slope} = \frac{AC}{BC} = \frac{\text{change in velocity}}{\text{change in time}} = \frac{\Delta v}{\Delta t} = \frac{v-u}{\Delta t}$$

But we know that the slope of a velocity-time graph represents the acceleration of the object. So the equation becomes

$$a = \frac{v-u}{\Delta t} \quad .... ①$$

This then becomes

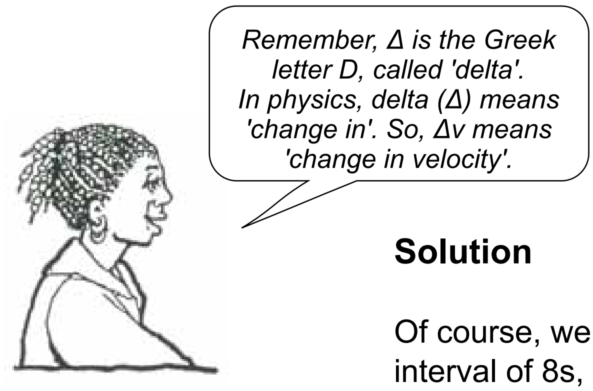
$$a\Delta t = v - u \quad .... ②$$

We end by re-arranging these terms to give

$s =$ area rectangle OBCD $\times$ area triangle ABC

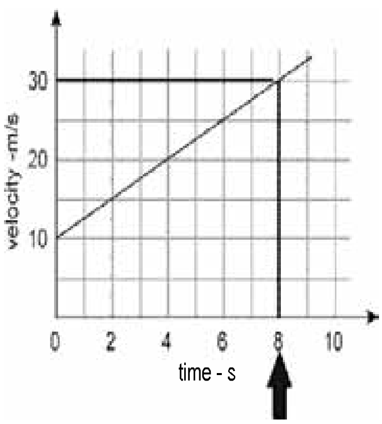
$v = u + a\Delta t$
u = initial velocity at t_1
v = final velocity at t_2
$\Delta t = t_2 - t_1$ *time interval over which the velocity changes*
a = uniform acceleration

Worked Example



The velocity-time graph represents the motion of a car initially moving at $10ms^{-1}$W. If the car accelerates uniformly at $2,5ms^{-2}$W, what is its velocity after 8s?

Solution



Of course, we can read the answer from the graph! After a time interval of 8s, the car is moving with a velocity of 30 m/s west. But if we have no graph, then the only way to find the answer is to use the formula v = u + aΔt.

u = $10ms^{-1}$W, a = $2.5ms^{-2}$W and Δt = 8s are given.

$$v = u + \Delta t$$
$$= 10\frac{m}{s}west + 2.5\frac{m}{s^2}west \times 8s$$
$$= 10\frac{m}{s}west + 20\frac{m}{s}west$$
$$v = 30ms^{-1} \text{ west}$$

The formula gives the same answer! After 8 s, the car is moving at 30 m/s west.

ACTIVITY 1

1. How does the equation v = u + aΔt change if an object

   a. starts from rest?
   b. travels at uniform velocity?

2. Calculate the uniform acceleration of a car if its velocity increases from 0 to 30 m/s S in 12 s.

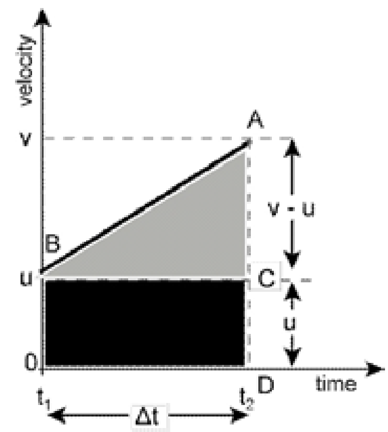
3. A motorist is traveling along a motor way with a steady velocity of 26 m/s in a westerly direction. She accelerates uniformly at 2 m/s/s to pass a lorry. It takes her 6 s to pass the lorry. What is her velocity at the end of 6 s?

4. A driver accelerates her car uniformly at $4ms^{-2}$ as she moves north. How long does it take her to increase her velocity from 10m/s to 30m/s?

ANSWERS ON PAGE 178

A formula to work out displacement

In Lesson 4, we used areas to work out displacement from a velocity-time graph. We do the same thing using the velocity-time graph alongside. We divide the area under the line into a triangle (grey) and a rectangle (black). We add these two areas to work out the displacement of the object at the end of the time interval at t^2.



$$s = \text{ area rectangle OBCD } \times \text{ area triangle ABC}$$

$$= \text{length x breadth } + \frac{1}{2} \text{x base x vertical height}$$

$$= OD \text{ x } CD + \frac{1}{2} \text{ x } OD \text{ x } AC$$

$$= u\Delta t + \frac{1}{2}\Delta t(v-u)$$

But v – u in brackets in ③ equals aΔt from ② on page 50 above.

$$s = u\Delta t + \frac{1}{2}\Delta t\,(a\Delta t)$$

and this then simplifies to

$$s = u\Delta t + \frac{1}{2}a\Delta t^2$$

Note that this formula does not include the final velocity *v* of the moving object.

$$s = u\Delta t + \frac{1}{2}a\Delta t^2$$

u = initial velocity at $v = u + a\Delta t$
$\Delta t = t_2 - t_1$ *time interval over which the velocity changes*
a = uniform acceleration

Movement from rest

When the object starts from rest, u = 0 the equation then becomes

$$s = \frac{1}{2}a\Delta t^2$$

Worked Example

A car accelerates uniformly from rest for a time interval (Δt) of 20 s with an acceleration of 1.5ms^{-2}E. How far does the car travel during this time interval?

Solution

$$u = 0$$

$$a = 1.5ms^{-2}E$$

$$\Delta t = 20s$$

$$s = ?$$

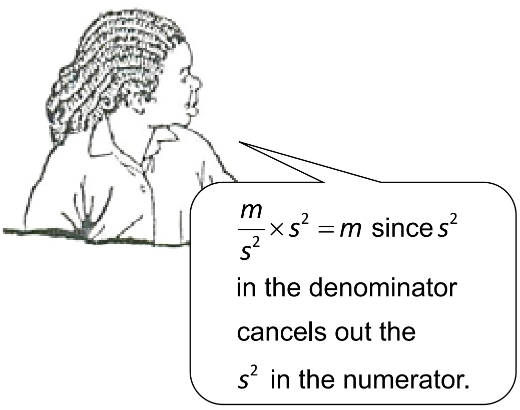
$$s = u\Delta t + \frac{1}{2}a\Delta t^2 \quad But\ u = 0,\ so\ this\ becomes$$

$$s = \frac{1}{2}a\Delta t^2 = \frac{1}{2}1.5\frac{m}{s^2}\ E(20s)^2$$

$$= \frac{1}{2}1.5\frac{m}{s^2}E(400s)^2$$

$$= 300\frac{m}{s^2} \times s^2 E$$

$$= 300mE$$



The object moves during the 20 s time interval.

ACTIVITY 2

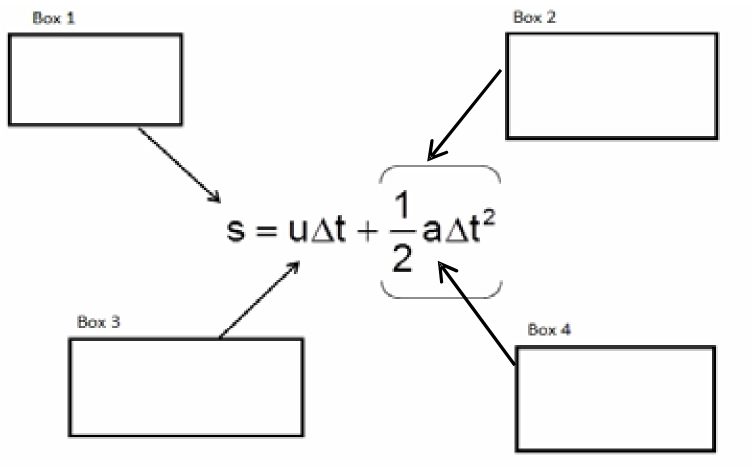
1. Themba is waiting at a red robot. When it turns green, he accelerates away from the robot at 6m/ s^2 for 4 seconds. Work out the displacement of Themba's car relative to his starting position after 4 s.

2. What are the SI units of the expression

   a. ut

   b. $\frac{1}{2}a\Delta t^2$

c. Use your answers to a. and b. to help you choose the correct label from the list for each box on the diagram. Use each label only once. Write the box number on the dotted line next to each label.



List of labels:

- This term is the extra distance the object travels because it is accelerating. ....
- This is the distance a uniformly accelerating object travels after Δt . ...
- This acceleration is uniform. ....
- This term is the distance the object travels at constant velocity. ....

3. A cyclist accelerates uniformly from rest at along a straight road.

a. What is his displacement after 2 s?

b. What is his displacement after 4 s?

c. Use your answers to a. and b. to help you cross out the wrong words in the statement below.

Doubling the cyclist's time interval from 2 s to 4 s **doubles /halves/ makes his displacement 2^2 times bigger** if his acceleration stays the same.

d. Show that the relationship in c. holds when the time interval doubles from 3s to 6s.

e. What do you think happens to the displacement if we halve the time interval but his acceleration stays the same?

ANSWERS ON PAGE 179

Another formula to work out displacement

$s = \left(\frac{u+v}{2}\right)\Delta t$

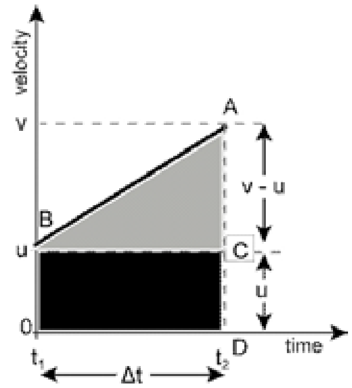
u=initial velocity at t_1

v=final velocity at t_2

$\left(\frac{u+v}{2}\right)$=average velocity

$\Delta t = t_2 - t_1$ time interval over which the velocity changes

s=displacement



We use the same velocity-time graph to find another equation to work out displacement. This equation is useful when the acceleration is unknown.

$$s = area \text{ OBCD + area ABC}$$

$$s = u\Delta t + \frac{1}{2}a\Delta(v-u)$$

Removing the brackets gives:

$$s = u\Delta t + \frac{1}{2}v\Delta t - \frac{1}{2}u\Delta t$$

$$s = \frac{1}{2}u\Delta t + \frac{1}{2}v\Delta t$$

$$s = \left(\frac{u+v}{2}\right)\Delta t$$

Worked example

Suppose a car accelerates uniformly from rest at 1.5 ms^{-2} to reach a velocity of 30 ms^{-1} after a time interval Δt of 20 s.

a. What is the car's average velocity?
b. What is the car's displacement after 20 s?

Solution

$u = 0$

$v = 30ms^{-1}$

$a = 1.5ms^{-2}$

$\Delta t = 20s$

$s = ?$

a. $s = \left(\frac{u+v}{2}\right) = \left(\frac{0+30ms^{-1}}{2}\right)x20s$

$= 15\frac{m}{s}$

b. $s = \left(\frac{u+v}{2}\right)\Delta t = \left(\frac{0+30ms^{-1}}{2}\right)x20s$

$= 15\frac{m}{s}x20s$

$= 300m$

A formula linking velocity and displacement

Sometimes the duration of the time interval Δt is unknown. We multiply equations ① and ④ to eliminate the time interval, Δt.

$v^2 - u^2 = 2as$

u = initial velocity
v = final velocity
s = displacement
a = uniform acceleration

$a = \frac{v-u}{\Delta t}$ ① $s = \left(\frac{u+v}{2}\right)\Delta t$ $\frac{1}{2}$ ④

and

$a \times s = \frac{(v-u)}{\Delta t} \times \left(\frac{u+v}{2}\right) \times \Delta t$

$as = \left(\frac{v^2 - u^2}{2}\right)$

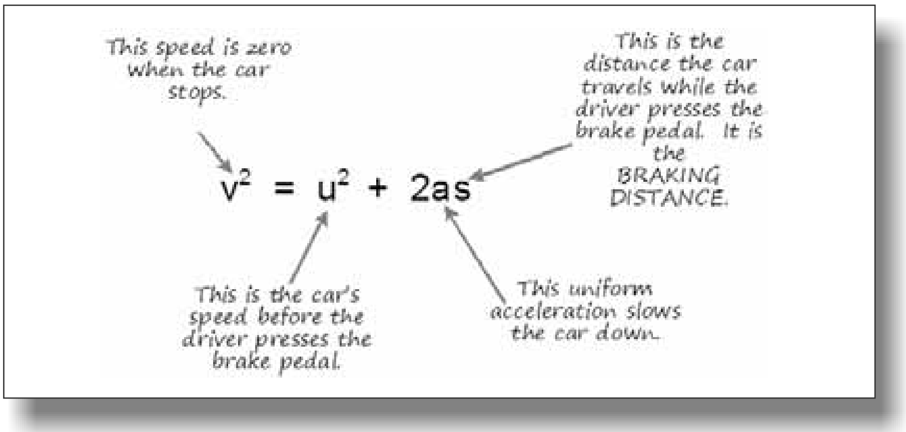
$v^2 - u^2 = 2as$

Worked example

The driver of a car traveling at 30 ms^{-1} (about 110 km/h) sees a child crossing the road 52 m ahead. He presses the brake pedal instantly to slow the car down by 9 ms^{-1} every second. Does the driver manage to stop before hitting the child? Assume that the time interval between the driver seeing the child and pressing the pedal is zero and that the car's acceleration is uniform.

Solution

You must find how far the car travels during the time interval for which the driver presses the car's brakes. The diagram shows how to use the equation $v_2 = u_2 + 2as$.



Note: The velocity of the car is positive. The acceleration must be negative as the car's brakes exert a force in the opposite direction to the velocity to stop the car. 9ms^{-1} every second (or 9ms^{-2}) is an acceleration.

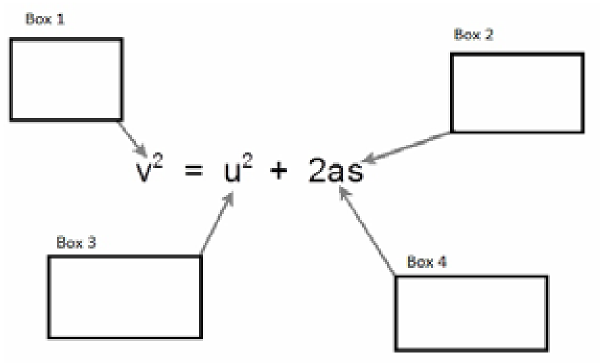
$$u - 30ms^{-1}$$
$$v = 0$$
$$a =- 9ms^{-2}$$
$$s = ?$$
$$v^2 - u^2 = 2as \ becomes$$
$$-u^2 = 2as \text{ sin } ce \ v = 0$$
$$s = \frac{-u^2}{2a} = \frac{-\left(30ms^{-1}\right)^2}{2\frac{dy}{d} - 9ms^{-2}}$$
$$= \frac{-900m^2 s^{-2}}{-18ms^{-2}}$$
$$s = 50m$$

The car comes to rest after traveling 50m. As the child was 52m away, the driver manages to stop the car 2 m away from the child.

ACTIVITY 3

An engineer designs a runway for an airport. A large aeroplane accelerates at 3 ms^{-2} and has a take-off speed of 90 ms^{-1}. How long must the runway be to give the aeroplane enough distance to take off?

a. Choose the correct label for each box on the diagram from the list of labels below. Use each label only once. Write the box number on the dotted line next to each label.



List of labels

- This is the length of the runway. ....
- This is the uniform acceleration of the aeroplane. ....
- This is the velocity of the plane before it starts accelerating........
- This is the velocity of the plane at the end of the runway. ......

b. Use the diagram to help you work out the length of the runway.

ANSWERS ON PAGE 180

Speed and braking distance

Common sense tells us that there is a connection between driving speed and the distance the car travels before stopping. The faster a car travels, the bigger the distance you need to stop the car. The equation $v^2 = u^2 + 2as$ confirms that there is a link between speed (v) and this distance (s). Let's see what this means.

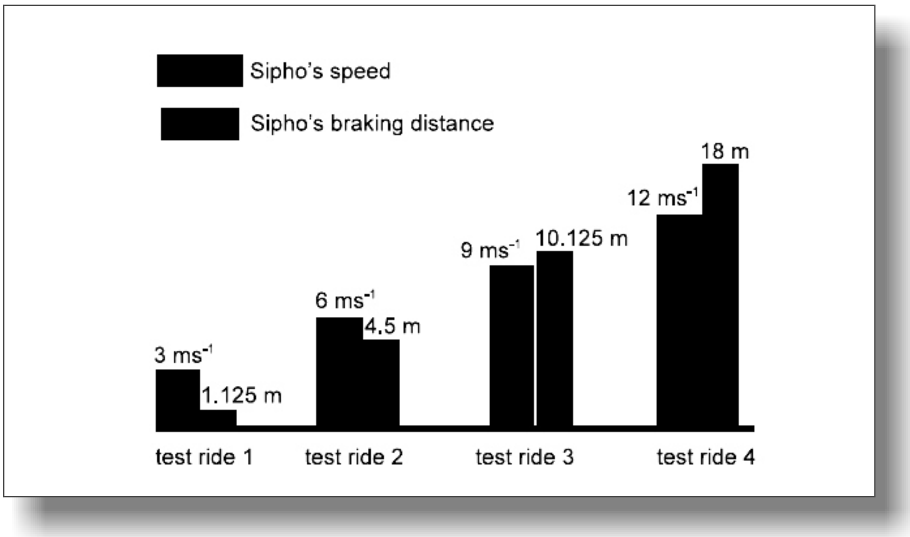
Sipho's investigation

Imagine that Sipho takes his brand new Honda for four test drives on a straight stretch of road. He wants to find out the shortest distance in which he can stop the car when he drives at different speeds. Suppose Sipho drives at 3 ms^{-1}. At the instant he crosses a line painted on the road, he slams on the car's brakes to stop the car. His helpers then measure the distance between the line on the road and the car's position.

This distance is the Honda's **braking distance**. We assume that Sipho presses the brake at the exact instant he crosses the line on the road and that he presses the brake pedal as hard as he can during stopping.

Sipho then repeats the procedure for Test Drive 2 at 6 ms^{-1}, Test Drive 3 at 9 ms^{-1} and Test Drive 4 at 12 ms^{-1}.

The diagram below shows Sipho's findings.



Use the diagram showing Sipho's findings to answer the questions that follow.

ACTIVITY 4

1. How does the car's braking distance change as the car's speed increases?

2. Choose any speed and its corresponding braking distance from the graph. Now double the speed. Does the braking distance double too? Use values from the graph to justify your decision.

   Answer questions 3 and 4 by choosing the correct options. Indicate your choice with a tick (✓). More than one option may be correct.

3. Doubling Sipho's speed from 3 ms-1 to 6 ms-1

   a. doubles his braking distance

   b. changes his braking distance to 4 x 1,125 m

   c. makes his braking distance four times greater

   d. changes his braking distance to 2 x 1,125 m

4. When Sipho changes his speed from 3 ms^{-1} to 9 ms^{-1} his braking distance

   a. changes from 1,125 m to 10,125 m

   b. becomes three times bigger

   c. changes from 1,125 m to 3 x 1,125 m

   d. changes from 1,125 m to 9 x 1,125 m

   e. becomes 3^2 times greater

5. Use the relationship between speed and braking distance to show that if Sipho travels at

   a. 24 ms^{-1} his stopping distance is 72 m.

   b. 36 ms^{-1} his stopping distance is 162 m.

ANSWERS ON PAGE 181

Safe driving

Sipho's data were probably collected under ideal conditions. The road was dry, the Honda's tyres were brand new and the car's brakes must have been in perfect working order. More importantly, however, Sipho was ready to press the brakes. He knew what was being measured and exactly when to press the brake pedal.

This is very different from a real life driving situation when emergencies happen unexpectedly. Drivers often need to stop without any warning at all. In these situations human reaction time makes stopping distances much longer. What is your reaction time?

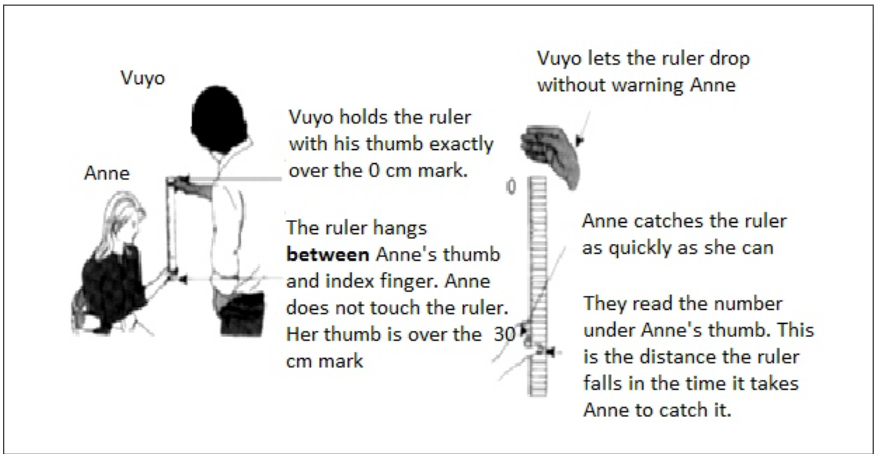
How far can a ruler drop before you catch it?

The distance any object falls before you catch it depends on many different things. Your age, whether you are male or female, your physical fitness, your mood and your eyesight all affect your ability to catch a falling object.

We use the distance a ruler falls as a measure of your **reaction time**.

ACTIVITY 5

The diagrams below show how Vuyo measures the distance a ruler falls before Ann can catch it. This is a measure of Ann's reaction time.



Follow the method in the diagrams to measure the distance a ruler falls before you can catch it five times.

Fill in your data in the table below. Complete the table to work out the average distance the ruler falls.

	distance the ruler falls /cm
Trial 1	
Trial 2	
Trial 3	
Trial 4	
Trial 5	
Total distance the ruler falls (cm)	
Average distance the ruler falls (cm)	

ANSWERS ON PAGE 181

The table below links the distance the ruler falls to your reaction time.

*excellent	above average	average	below average	poor
< 7.5cm	7.5 to 15.9cm	15.9 to 20.4cm	20.4 to 28cm	> 28cm

* MACKENZIE, B. (2004) Ruler Drop Test

An average distance of approximately 25 cm that the ruler falls, corresponds to a reaction time of 0.2 s.

Stopping suddenly

Imagine that you are driving your car when you see a tree lying across the road in front of you.

Some time passes before you react. This time interval is your **reaction time**.

Reaction time is the time interval from the time the driver's brain gets a message that there is a need to stop the car until the driver actually presses the brake pedal.

And remember the car keeps on moving during reaction time.

The distance a car travels at constant speed during reaction time is **thinking distance**.

When you press the brake pedal the car does not stop instantly. It keeps on moving. The distance you travel while pressing the brake pedal is the **braking distance**.

Stopping distance is the distance you travel while both thinking and braking.

stopping distance = thinking distance + braking distance

Reaction time while driving a car

Driving a motor car is much more complicated than catching a ruler. Driving involves many activities. Your eyes send information to your brain. Your brain processes this information and judges how best to respond. Your brain sends instructions to your spinal cord. Instructions then pass to your muscles which move in the right ways. All these steps take time to happen. Average reaction time for driving is about 2.5 s but an individual's reaction time can vary depending on certain factors.

Including Sipho's thinking distance

Sipho's road tests measured braking distance, not stopping distance. Stopping distance includes the distance Sipho travels during his reaction time. Sipho's graph shows that when he travels at 3 ms^{-1} his braking distance is 1.125 m. If we take his reaction time as 2.5 s, then the distance Sipho travels at a speed of 3 ms^{-1} is $s = v\Delta t = 3\frac{m}{s} \times 2.5s = 7.5\,m$

This thinking distance (7.5 m) is much bigger than the braking distance (1.125 m).

At 3 ms^{-1}; stopping distance = braking distance + thinking distance.
= 1.125 m + 7.5 m
= 8.625 m

ACTIVITY 6

1. Work out Sipho's stopping distance at 6ms^{-1}, 9ms^{-1} and 12ms^{-1}.

2. These are slow speeds. The speed limit on South Africa's national roads is 120 km/h which is 34 ms^{-1}.

   a. Use $v^2 = u^2 + 2as$ to work out braking distance at 34 ms^{-1}. Assume the car slows down at 4 ms^{-2}.

   b. Work out the thinking distance travelled at this speed. Assume reaction time is 2.5 s.

ANSWERS ON PAGE 181

c. Find the stopping distance at the speed limit on national roads in South Africa (34 ms^{-1}).

Road accidents in South Africa

According to the Arrive Alive website* drunk driving is one of the biggest threats to road safety in South Africa. Research indicates that 50% of people who die on the roads have a blood alcohol concentration (BAC) above 0.05 gram alcohol in each 100 millilitres of blood.

ARRIVE ALIVE
www.arrivealive.co.za

Is it legal to drive after drinking?

According to The National Road Traffic Act (NRTA), Act 93 of 1996, it is definitely not legal to drive after drinking. According to Section 65 of this Act, no person shall on a public road

a. drive a vehicle; or

b. occupy the driver's seat of a motor vehicle the engine of which is running, while under the influence of intoxicating liquor or a drug having a narcotic effect.

Blood Alcohol Content (BAC) limits

The Act prescribes the highest legal alcohol content of blood and breath before driving. The table shows these limits.

	All drivers	Professional drivers
Concentration of alcohol in the blood	0.05 grams per 100 millilitres	0.02 grams per 100 millilitres
Breath alcohol content	0.24 milligrams per 1000 millilitres	0.10 milligrams per 1000 millilitres

But what do the numbers in this table mean?

Blood

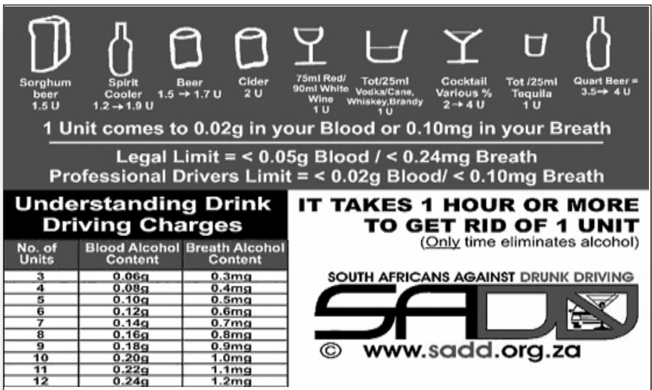
The highest concentration of alcohol in the blood for all drivers is 0.05 grams per 100 ml blood. This means that in 100 ml of a driver's blood, there may be no more than 0.05 g alcohol.

Breath

The highest legal concentration of alcohol in a driver's breath is 0.24 milligrams per 1 000 millilitres. This means that 1000 ml of exhaled air may contain no more than 0.24 milligrams alcohol.

The values in this table are however not helpful to a partygoer. The table does not tell us how many drinks we may legally enjoy during an evening out.

The poster below from the South Africans Against Drunk Driving website is more useful. It shows the alcohol content of different kinds of alcoholic beverages in units (abbreviated to U) alcohol. It also relates units of alcohol to concentration of alcohol in blood and breath.



No. of Units	Blood Alcohol Content	Breath Alcohol Content
3	0.06g	0.3mg
4	0.08g	0.4mg
5	0.10g	0.5mg
6	0.12g	0.6mg
7	0.14g	0.7mg
8	0.16g	0.8mg
9	0.18g	0.9mg
10	0.20g	1.0mg
11	0.22g	1.1mg
12	0.24g	1.2mg

Sciences Education Foundation
Staying Alive: The Physics, Mathematics and Engineering of Safe Driving
http://www.sci-ed-ga.org

ACTIVITY 7

Use the *South Africans Against Drunk Driving* poster and the table on the next page showing the effects of alcohol on human behaviour to help you answer the questions below.

1. At a shebeen your boyfriend drinks three Jubas (sorghum beer) and one quart of beer in about an hour. How many units of alcohol does this represent?

2. Your boyfriend offers to take you home in his car. However, traffic police stop you at a roadblock.

   a. What is the highest your boyfriend's breath alcohol content could be? Show your working.

   b. What is the highest his blood alcohol concentration could be? Again, show your working.

   c. Is he over the legal limit?

   d. What signs in your boyfriend's behaviour make the traffic officer think that he is not sober enough to drive?

3. You decide to walk the rest of the way home. But you have to cross a busy highway on your way. At the shebeen you drank two cans of cider and one glass of red wine. Comment on the wisdom of your decision to walk home.

4. In South Africa, approximately 40% of fatalities caused by road accidents are pedestrians. Suggest possible reasons for this shocking fact.

ANSWERS ON PAGE 182

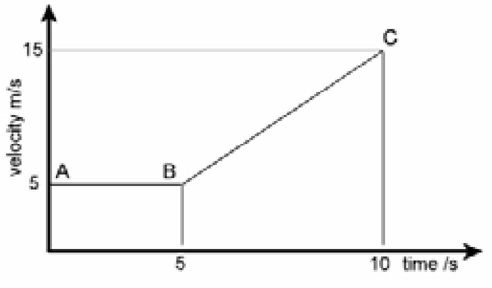
Effects of alcohol on human behaviour

The table below shows how alcohol affects human behaviour.

blood alcohol concentration /g per 100 ml blood	changes in feelings and personality	physical signs
0.01 - 0.06	• loss of shyness • feeling of well-being • relaxation	• poor judgement • coordination worsens • concentration and memory poor
0.07 - 0.10	• blunted feelings • extroversion • loss of self-control	• reflexes impaired • reasoning poor • ability to judge depth and distance impaired • peripheral vision insensitive • recovery from glare slow • balance worsens • speech becomes slurred • hearing becomes less sensitive • reaction time starts increasing
0.11 - 0.20	• boisterous behaviour • emotional swings • anger or sadness evident	• reaction time severely affected • gross motor control lost • staggering evident • very slurred speech
0.21 - 0.29	• stupor • loss of understanding • impaired sensations • anxiety and restlessness deepens	• severe motor impairment • loss of consciousness • memory blackout • nausea and vomiting • need help to walk • total mental confusion
0.30 - 0.39	• severe depression • unconsciousness • death possible	• loss of bladder function • breathing rate slows down • heart rate decreases
? 0.40		• onset of coma • death due to respiratory arrest

SUMMARY ACTIVITY

1. The graph alongside represents the velocity of a car for a time interval of 10 s.



   a. Use the equation $v = u + a\Delta t$ to work out the car's acceleration during BC.

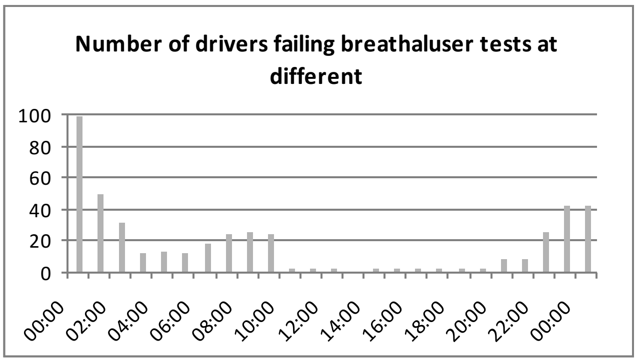
   b. Use the equation $s = ut + \frac{1}{2}at^2$ to find the distance the car travels during AB and BC. Then work out how far the car travels for the whole of the 10 s time interval.

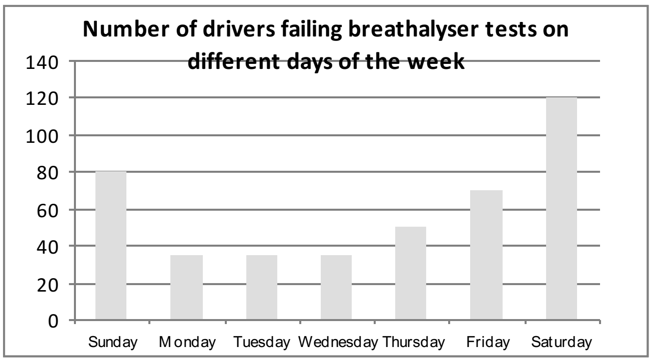
   c. Use the area under the car's velocity-time graph to find the distance the car travels over the whole of the 10 s time interval.

2. A car starting from rest undergoes a uniform acceleration of 5 km/h/s N along a straight road. How fast will the car be moving after 13 s?

3. Imagine that you work as an advisor to the metropolitan council. The council plans to run a campaign to discourage alcohol abuse.

   The graphs below are from a survey of drivers failing breathalyser tests. Use information from the graphs to help the council plan the campaign.





Age, gender and number of drivers failing breathalyser tests					
Age/years	15-19	20-24	25-29	30-59	60+
Male	50	105	77	135	10
Female	1	7	7	10	1

ANSWERS ON PAGE 183

CHECKLIST

Are you able to:

- ❐ use four different formulae to solve problems about moving objects
- ❐ describe how changing driving speed affects the distance a motor car travels before stopping
- ❐ measure your reaction time
- ❐ define thinking distance, braking distance and stopping distance
- ❐ use a *South Africans Against Drunk Driving* poster to convert units alcohol to alcohol content in breath and blood
- ❐ use a table showing the effect of alcohol on behaviour and blood alcohol concentration
- ❐ interpret graphs and tables linking number of drivers failing alcohol breathalyser tests to days of the week, time of day, age and gender

LESSON 6

Newton's first law of motion

About this lesson

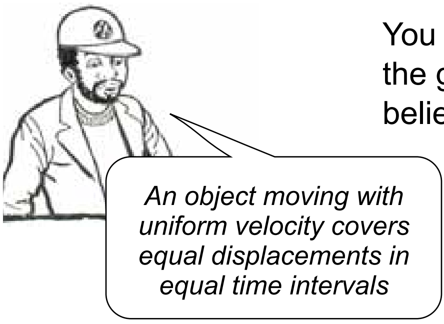
So far in this unit, you have learnt to identify, analyse and describe different kinds of motion. However, there is an important aspect of motion that you have not yet covered fully. This is the link between motion and force. You already know from Lesson 2 that forces are acting when things are at rest and when they move and that forces cause motion to change too.

This lesson looks briefly at how people such as Aristotle and much later, Galileo Galilei and Sir Isaac Newton linked motion and force. In this lesson then, you will use Newton's first law of motion to explain both the at-rest condition and uniform motion.

In this lesson you will:

- use Newton's first law to describe the forces acting on objects at rest or moving with constant velocity
- define inertia
- explain some ways we use inertia to our advantage in everyday life
- describe how seat belts and head rests in motor cars improve the safety of passengers
- use Newton's first law to edit your Effects of Forces list from Lesson 2.

A rolling ball soon stops rolling



You know from everyday experience that a ball rolling across the grass soon stops. The ancient Greeks knew this too. They believed that the natural tendency of all moving objects was to come to rest on their own. They claimed that no force was necessary to stop motion. Thus, it was logical to them that you need some force to keep an object in motion. Do you have to push something to keep it moving? Try Activity 1 to find out!

ACTIVITY 1

Take a bucket and fill it almost to the top with water. Stand holding the bucket by your side. Now start moving forward in a straight line at constant speed. Then stop suddenly.

Answer the questions about the way the water behaves when you stop and start moving.

1. Does the water stay in the bucket or does it spill out of the bucket while you are moving at constant speed in a straight line?

2. What happens to the water when you suddenly stop moving?

3. Does the moving water show a tendency to stop moving on its own?

4. What about when you start moving? How does the water behave then?

ANSWERS ON PAGE 184

Changing motion causes spilling

Did you notice that the water only spills when you try to change the way it is moving?

- When the water is moving, it tends to keep on moving. When you stop the bucket, the water keeps on moving in the same direction and so it spills out of the bucket in front of you.

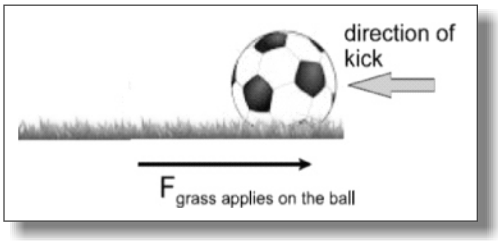
- When the water is at rest, it tends to stay at rest. When you move the bucket, the water stays in the same place. But the bucket has changed position and the water spills behind you.

In general then, it seems that the water opposes or resists any attempt to change its state of motion. The ancient Greeks' idea that it is the natural tendency of objects to stop moving on their own was wrong! And no one questioned this idea for nearly two thousand years!

Galileo challenges the idea

In the late 1600s Galileo conducted a series of careful experiments where he rolled spheres up and down slopes. His findings led him boldly to challenge the idea that objects stop moving on their own.

Let's use an everyday example to understand Galileo's reasoning.



Think of a soccer ball moving on the grass after you kick it. Remember that a kick is a contact force. It acts only when the foot touches the ball. We know from experience how the ball will behave. It will roll slower and slower until it stops moving.

The moving ball does not stop moving because nothing is pushing it. Rather, Galileo said, it stops moving because something is pushing it. This push is an unbalanced force which Galileo identified as friction. Friction is the unbalanced force that the grass exerts on the ball. It acts in the opposite direction to the ball's motion.

Imagine now, that you cut the grass very short and make the ball smoother. This lessens the force of friction on the ball. When you give the ball another soft kick, it is logical to expect it to move further before it stops.

Suppose now it is possible to make the ball and the grass so smooth that there is no friction on the ball at all. What will the ball do when you give it another soft kick? It must keep on rolling at the same speed in the same direction forever!

This is exactly the conclusion Galileo came to. Moving objects don't stop moving on their own. They stop moving because an unbalanced force makes them stop moving. And, Galileo went on, if there was no unbalanced force, objects would neither stop nor start moving. Their natural behaviour is to keep on moving at the same speed in the same straight line forever!

Galileo Gallei (1564 -1642) was the first person to realise that in the absence of any horizontal force, a rolling object will keep on rolling forever. Newton later refined the law and called it his first law of motion.

> ***stationary:***
> *at rest, or not moving, zero velocity, zero speed*

Galileo invents the idea of inertia

What makes moving objects keep on moving forever if there is no unbalanced force acting? Galileo answered this question by inventing the idea of inertia. All objects have inertia. Inertia is the natural tendency all objects have to keep on doing what they are doing. **Stationary** objects stay at rest because they have inertia. Inertia makes moving objects keep on moving. Inertia makes all objects naturally resist or oppose changes in their state of motion.

Inertia is the tendency an object has to resist or oppose any effort to change its state of motion

Inertia and mass

Some objects resist changes in their states of motion more than others. It is easier to start a book moving than it is to start a car moving. So, a book has less inertia than a car. But a book also has less mass than a car. So mass and inertia must be related.

In fact, mass, a quantity with which we are familiar is a measure of an object's inertia. The more mass an object has, the more inertia it has. The more inertia it has, the stronger its tendency to resist a change in its state of motion. This makes it easy to recognise how much inertia different objects have.

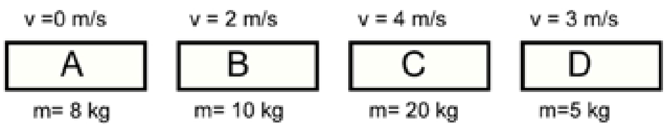
ACTIVITY 2

1. Two bricks are lying on a table. They look identical but one brick is made of cement and the other brick from polystyrene.

    a. How can you find out which is the polystyrene brick **without picking up** the bricks?

    b. Which brick has more inertia, the concrete brick or the polystyrene brick?

2. The diagram below gives mass and velocity values for four objects. Order the objects from the smallest amount of inertia to the greatest amount of inertia.



3. Choose the correct statement.

   a. Inertia is the force that keeps moving objects moving and stationary objects at rest.

   b. Inertia is the willingness of an object to lose its motion eventually.

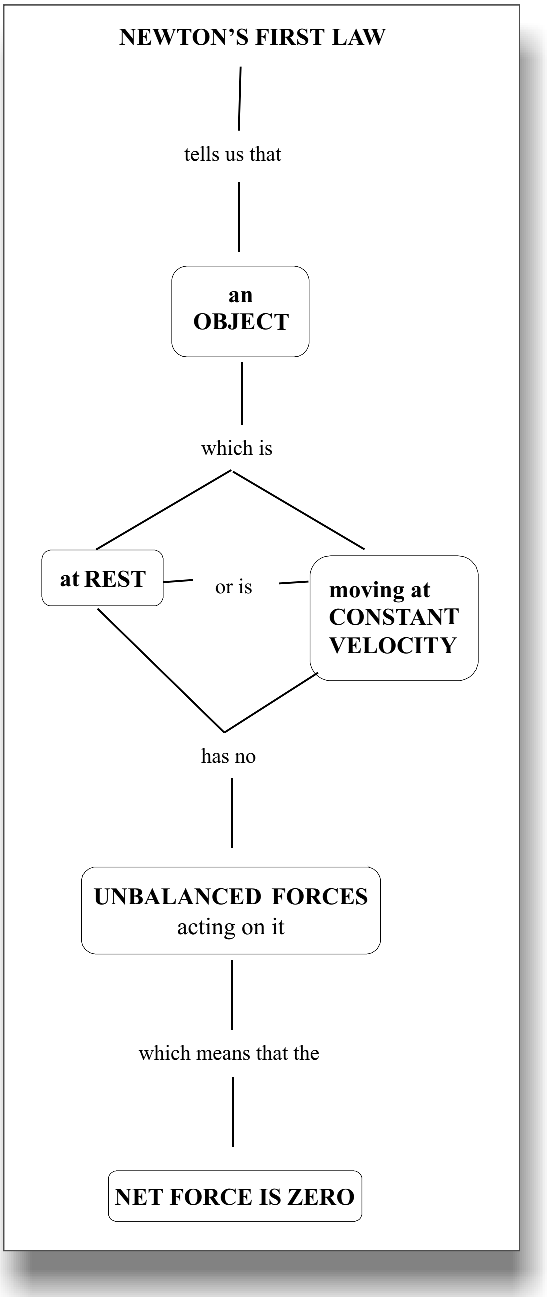
   c. Inertia is the force that causes all objects to stop.

   d. Inertia is the tendency of any object to resist change and keep doing whatever it is doing.

ANSWERS ON PAGE 185

Newton links changes in motion to force

Newton built on Galileo's idea of inertia by extending it to the planets in our solar system. They knew that the planets moved in almost circular orbits and not in straight lines. Galileo had already determined that objects move in straight lines when there is no unbalanced force acting on them. Newton reasoned then that an unbalanced force must be present when motion is not in a straight line. Unbalanced force makes the planets move in almost circular orbits. This unbalanced force, Newton claimed, is an action-at-a-distance force which he called gravitational force.



Objects at rest

Newton used Galileo's ideas to link force to the at-rest condition. If an object is at rest, it will stay at rest forever. Only an unbalanced force can start an object moving. If we want to move an object, we must push it. The push on the object must be unopposed by any other force. The push must be an unbalanced force.

Objects moving at constant velocity

Newton also extended Galileo's ideas about balanced forces to movement at constant velocity. He said that if we want an object to slow down, speed up, or change its direction, we must push the object. The push must be an unbalanced force.

Newton's first law of motion

Newton combined the ideas about the at-rest condition and constant velocity when he formulated his law.

- If the total force (or net force) acting on an object is zero the object will stay at rest (if it is at rest), or
- the object will continue moving at constant velocity (if it is already moving).

So, balanced forces are present when an object is either moving at constant velocity or is at rest. The concept map summarises this. Conversely, unbalanced forces cause changes in velocity, such as starting, stopping, moving faster or slower, or changing direction. Unbalanced forces cause acceleration.

See how well you understand Newton's first law by working carefully through Activity 3.

ACTIVITY 3

1. What size force do you need to keep a 5 kg object moving at a constant speed of 4 m/s in a straight line? Justify your choice.

   a. 0 N

   b. 4 N

   c. 5 N

   d. 20 N

   e. 50 N.

2. If all the forces acting on an object add up to zero, then the object must

   a. be moving

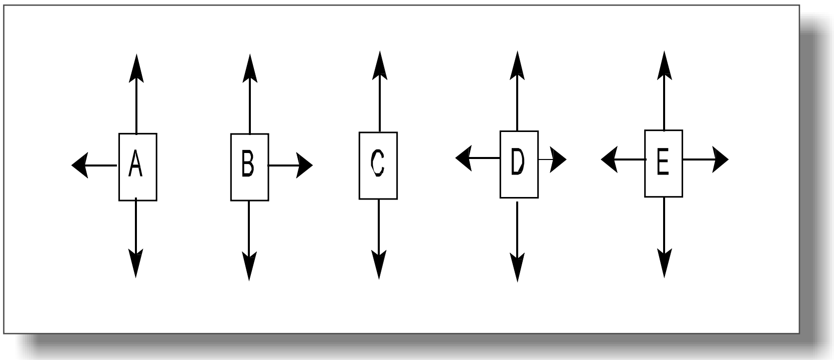
   b. be accelerating

   c. be at rest

   d. be moving with a constant speed in the same direction

   e. both C and D.

3. The diagram below shows the magnitude and direction of all the forces acting on five objects.



Use the diagram to answer questions a. to e. Justify each answer briefly.

a. Which objects have an unbalanced force acting on them?

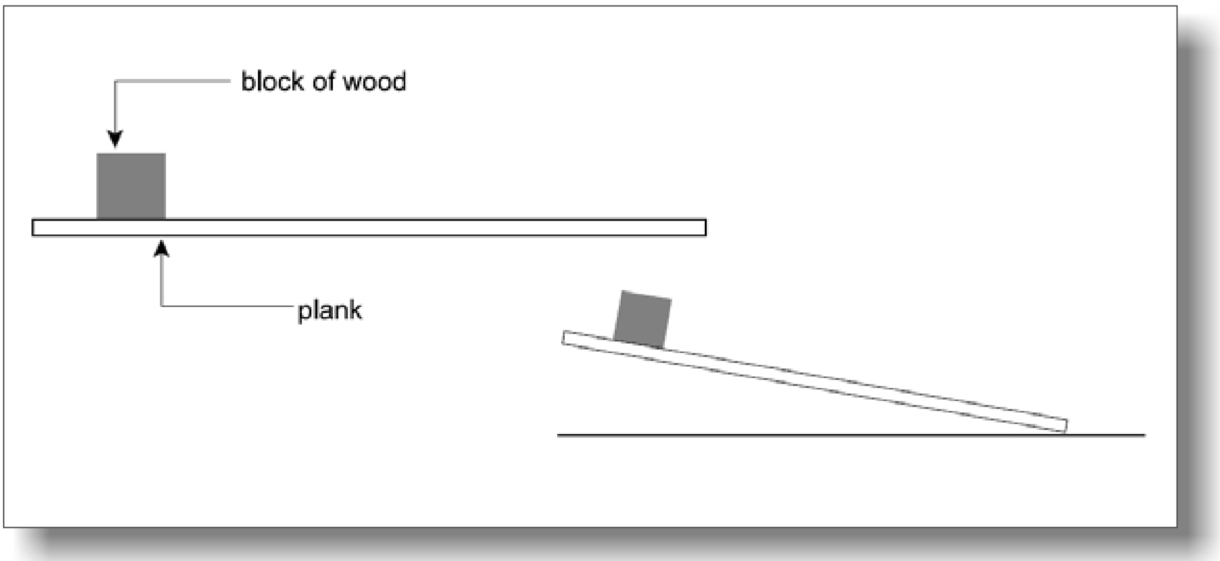
b. Which object/s could be at rest?

c. Which object/s could be moving to the right?

d. Which object/s could be moving at constant velocity?

e. Which object/s must be accelerating?

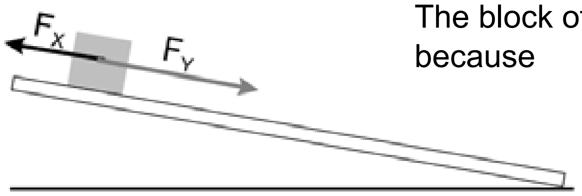
4. The diagram shows a wooden block on a plank.



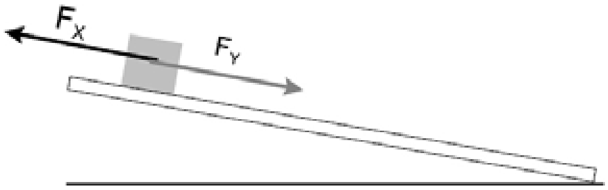
When we lift one end of the plank, the block does **not** move down the plank. The block stays at rest.

Which of a, b or c below describes the forces on the block correctly?

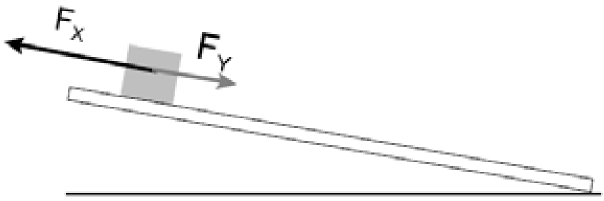
The block of wood does not move down the plank because



a. FX is **smaller** than FY



b. FX is **the same size** as FY



c. FX is **bigger** than FY

5. When we lift the end of the plank higher, the block moves down the plank at a constant speed.

   Which of a, b or c below describes the forces on the block correctly?

   The block moves down the plank at constant speed because

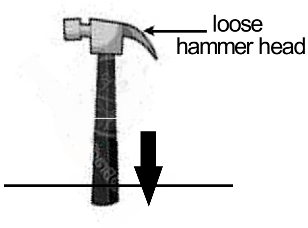
   a. FX is **smaller** than FY

   b. FX is the **same size** as FY

   c. FX is **bigger** than FY.

ANSWERS ON PAGE 185

Using Newton's first law



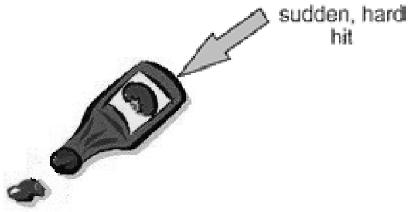
Suppose you have a hammer with a loose head. An easy way to make sure that the head fits very tightly onto the handle is to make use of Newton's first law.

Hold the hammer vertically and bang the bottom of the handle hard on a solid surface.

The handle stops moving when the surface applies an unbalanced force on it. But this unbalanced force does not act on the hammer head.

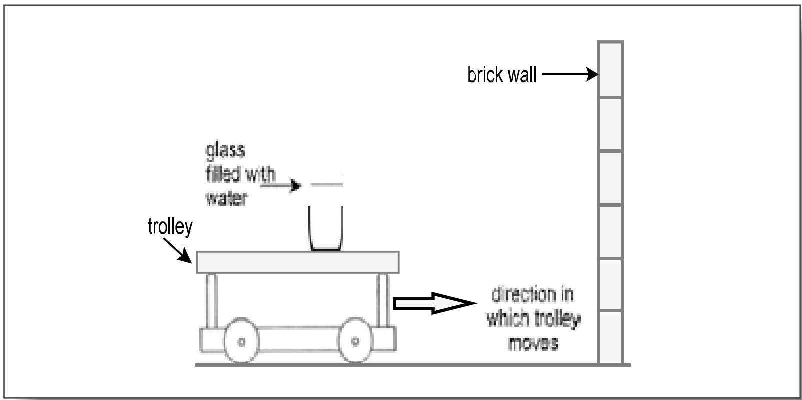
The inertia of the hammer head keeps it moving downward on the handle. If you do this a few times the hammer head will fit tightly onto the handle.

Tomato sauce is a thick liquid which is sometimes difficult to pour out of a bottle. Newton's first law can help. Hold the bottle very tightly in one hand. Use the palm of your other hand to hit the bottom of the bottle hard. The hand holding the bottle prevents the bottle from moving, but no force acts on the tomato sauce inside the bottle. So its inertia makes it keep on moving until it hits your plate.



ACTIVITY 4

1. The diagram shows a drinking glass filled with water on a trolley. The glass is free to move. What do you think will happen to the glass when the trolley hits the wall? Give a reason for your answer.



2. Suppose now the bottom of the drinking glass is firmly joined to the trolley. The glass cannot topple over when the trolley hits the wall. What do you think will happen to the water when the trolley hits the wall? Justify your answer.

3. Suppose you are sitting in a taxi while holding a cup of coffee. The hot coffee spills in your lap not on the upper part of your body. Did the car start moving forward or stop moving forward to make this happen? Explain.

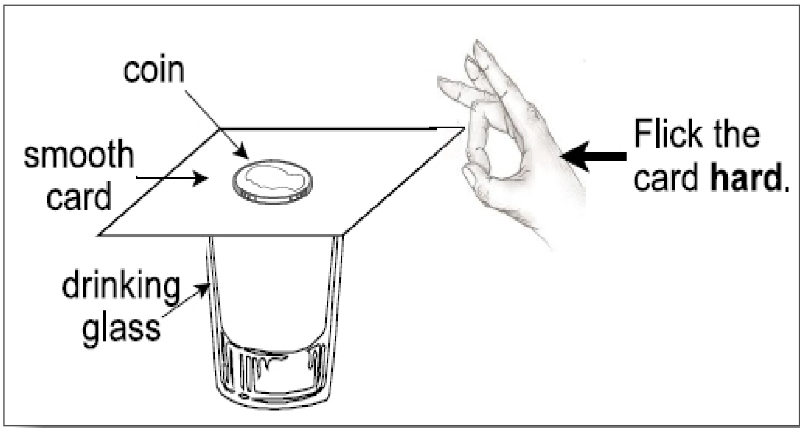
4. We use seat belts to make people traveling in motor cars safer during accidents. The seat belt applies an unbalanced force that brings a passenger safely to rest when the car stops suddenly. What do you think will happen to a person when a car stops suddenly if they are not using a seatbelt? Explain.

5. Suppose you are strapped into the front passenger seat of a motor car that has stopped at a red robot. Another car slams hard into the back of your car. Use Newton's first law of motion to explain why your neck may be hurt during the collision. How will a headrest help prevent injury?

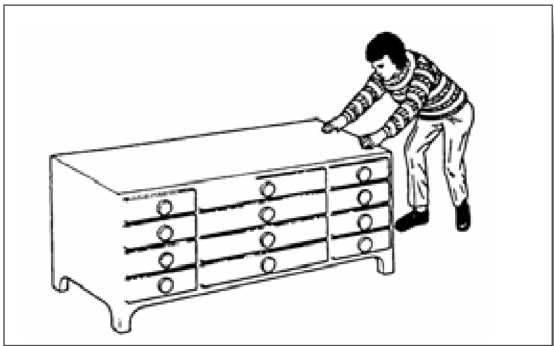
ANSWERS ON PAGE 186

SUMMARY ACTIVITY

1. The diagram shows a five rand coin on a smooth card on top of a drinking glass. What do you think will happen to the coin when you flick the card hard? Justify your prediction.



2. Choose a, b or c as the correct answer. Justify your choice.



The diagram shows a man trying to push a cupboard across the floor. The cupboard however, does not move.

The cupboard does not move because:

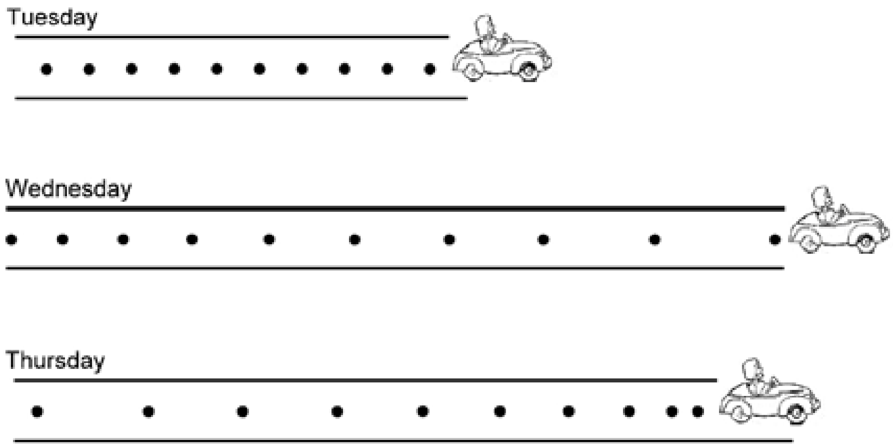
a. the force which the man uses is smaller than the frictional force which the floor applies on the cupboard.

b. the force which the man uses on the cupboard is the same size as the frictional force which the floor applies to the cupboard.

c. the force which the man exerts on the cupboard is greater than the frictional force which the floor exerts on the cupboard.

3. Suppose an elephant is chasing you. You follow a zigzag path as you run away from it. How may the elephant's great mass help you to escape? Explain.

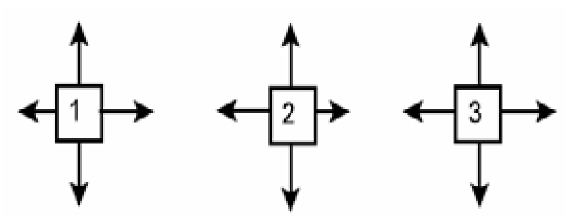
4. Suppose Mary's car has an oil leak. An oil drop falls onto the road at regular one second intervals. The diagrams below represent the oil drops on the road on three different days - Tuesday, Wednesday and Thursday.



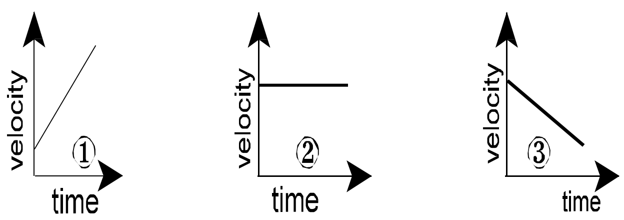
   a. Describe the motion of Mary's car on each of the three days.

   b. On which days is an unbalanced force acting on Mary's car? Give a reason.

   c. Each square on the diagram below represents Mary's car. The arrows represent the magnitude and direction of all the forces acting on the car. Which diagram shows the forces correctly on Tuesday, on Wednesday and on Thursday? Give a reason for each choice.



   d. One of the velocity-time graphs below describes Mary's motion on each of Tuesday, Wednesday and Thursday. Match each day to its graph.



5. Look at your list of Effects of Forces from Lesson 2. Use this list and Newton's first law of motion to cross out the wrong words in each of the following statements.

   a. You need a **balanced / unbalanced** force to start a body moving.

   b. You need a **balanced / unbalanced** force to stop a body moving.

   c. You need a **balanced / unbalanced** force to make a body move faster.

   d. You need a **balanced / unbalanced** force to make a body move slower.

   e. You need a **balanced / unbalanced** force to make a body change its direction of motion.

   f. You may / do need a **balanced / unbalanced** force to make a body change shape.

ANSWERS ON PAGE 187

CHECKLIST

Are you able to:

- ❒ use Newton's first law to describe the forces acting on objects at rest or moving with constant velocity
- ❒ define inertia
- ❒ explain some ways we use inertia to our advantage in everyday life
- ❒ describe how seat belts and head rests in motor cars improve safety
- ❒ use Newton's first law to edit your Effects of Forces list from Lesson 2.

LESSON 7

Newton's second law of motion

About this lesson

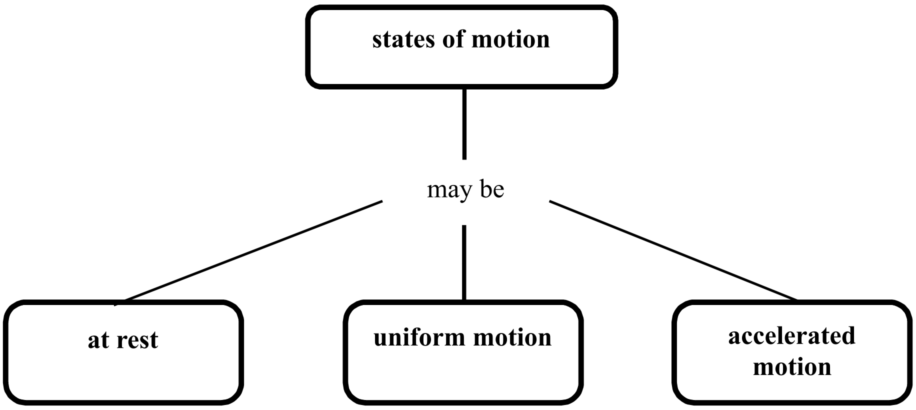
This lesson explores the relationship between unbalanced force and the acceleration it produces. The lesson puts ideas about net force, tension and friction from earlier lessons into the context of Newton's second law. The lesson extends this law to include a new quantity momentum. The approach in the lesson focuses strongly on understanding mathematical relationships between force, mass, acceleration and momentum.

In this lesson you will:

- describe how an object's motion changes when an unbalanced force acts on it
- use the state of motion of an object to decide if the forces acting on the object are balanced or unbalanced
- predict the effect of a change in net force on acceleration if mass is constant
- predict the effect of a change in mass on acceleration if net force is constant
- state Newton's second law of motion in terms of acceleration and in terms of momentum
- use Newton's second law to solve problems involving tension and friction
- define the SI unit of force
- define momentum
- predict the effect of a change in either mass or velocity on momentum.

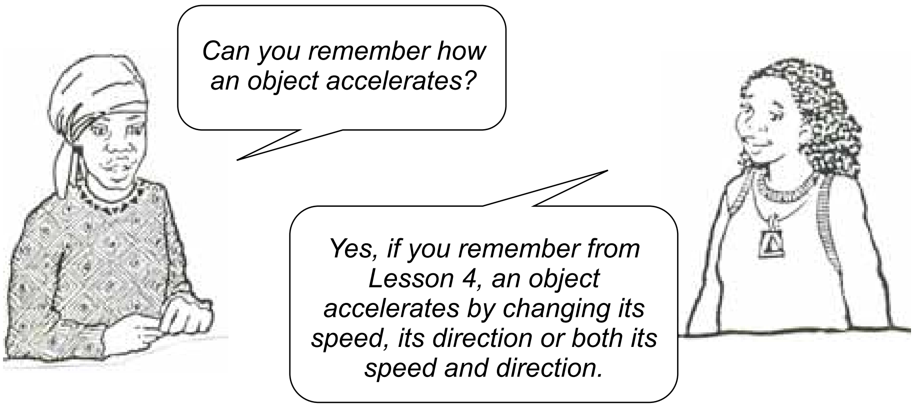
States of motion

The concept map shows how we can classify motion into three broad groups. Any object which is at rest stays in the same position. It has a velocity equal to zero. Uniform motion is motion at constant velocity. If an object changes its velocity it undergoes accelerated motion.



States of motion and forces are linked

The forces acting on an object determine its state of motion.



Newton's first law of motion

Newton's first law links motion at constant velocity and the at-rest condition to balanced forces. We describe this in another way.

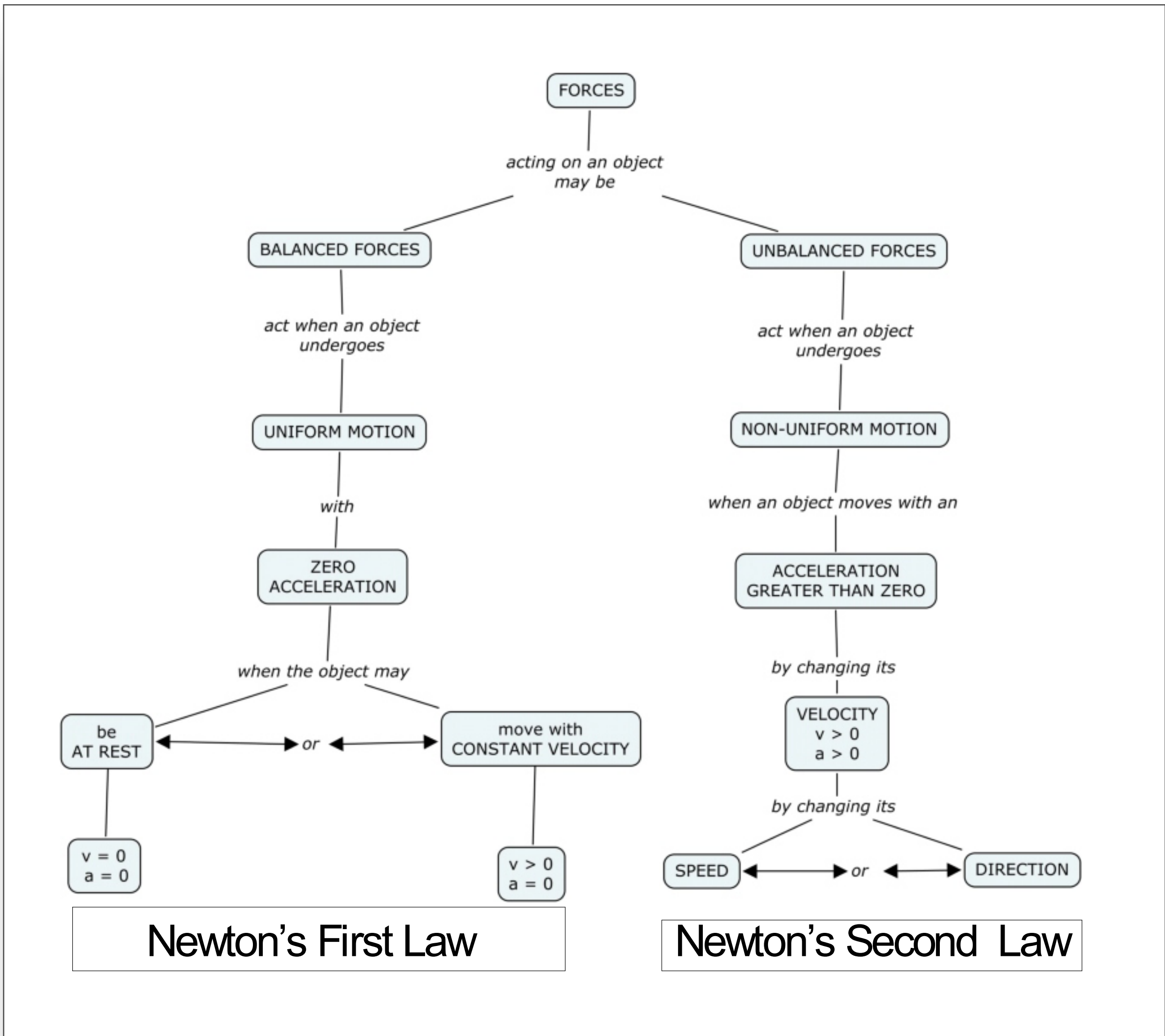
- If an object is at rest we know with certainty that all the forces acting on it add up to give a zero net force (F_{net}= 0). The forces acting on the object are balanced.

- If an object moves with constant velocity, we can be certain that all the forces acting on it also add up to give a zero net force (F_{net} = 0).object. There is an unbalanced net force acting on the object.

These two statements are always true!

Unbalanced forces

Uniform motion and the at-rest state are linked to balanced forces. Hence unbalanced forces must produce acceleration. Acceleration is a change in velocity. It is logical to deduce that an unbalanced force acting on an object must change an object's speed, its direction or both its speed and direction. This is Newton's Second Law. The concept map below shows the relationship between these ideas.

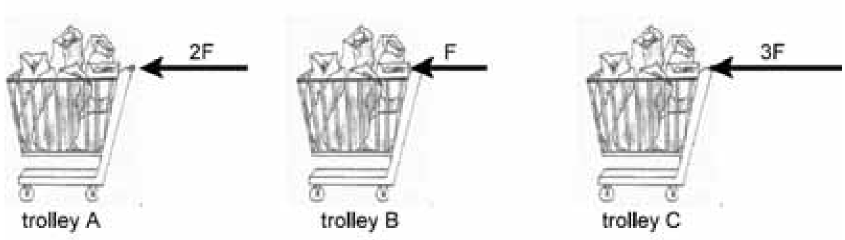


Investigating Newton's second law

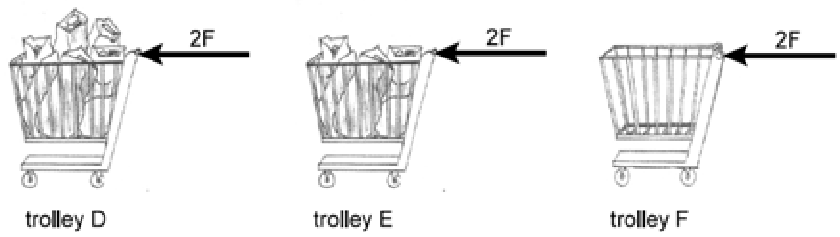
ACTIVITY 1

Use your everyday experience to answer the questions about the supermarket trolleys in the diagrams.

1. Trolleys A, B and C are at rest. An arrow represents the unbalanced force acting on each trolley. Which of the trolleys, do you think will have the greatest acceleration? Explain your choice.



2. Trolleys D, E and F are also at rest. The unbalanced forces acting on trolleys D, E and F are the same. Which trolley do you think will have the greatest acceleration? Why?



3. Copy the paragraph below. Then cross out the **wrong** word each time there is a choice.

   We know from everyday life that the heavier an object is, the **less hard / harder** we have to push it to start it moving. The heavier an object is, the **greater / smaller** its mass. A harder push means a **bigger / smaller** force.

   So clearly there is a relationship between the three quantities force, acceleration and mass.

   If the mass of the trolleys stays the same, the bigger the unbalanced force, the **bigger / smaller** its acceleration.

   If equal unbalanced forces act on trolleys of different masses, the **bigger / smaller** the mass, the greater the trolley's acceleration.

4. Many motorcycles have powerful engines that produce large forces. Why do people who design motorcycles try to make the bodies of the motorcycles as light as possible?

ANSWERS ON PAGE 188

Newton's second law

The acceleration of an object that a net force causes is

- directly proportional to the magnitude of the net force,
- in the same direction as the net force, and
- inversely proportional to the mass of the object.

An equation to represent this statement is $a = \frac{F_{net}}{m}$

If we rearrange this equation it becomes $F_{net} = ma$

Direct and inverse proportions are relationships

In physics, we often come across mathematical relationships called direct and inverse proportion. We will explore the meaning of these relationships in more detail later in the lesson.

The SI unit of force

We can use Newton's second law to define the SI unit of force. This unit is the newton (N).

One newton is the unbalanced force that causes a mass of 1 kilogram to accelerate at 1 metre per square second in the direction of the unbalanced force.

$$F_{net} = ma$$

$$F_{net} = 1kg \times 1\frac{m}{s^2}$$

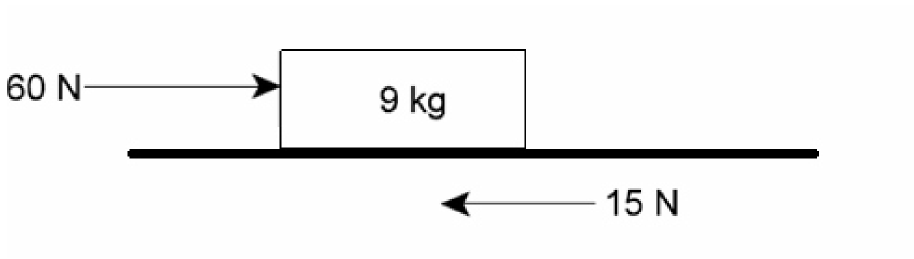
$$F_{net} = 1\frac{kg\ \text{m}}{s^2}$$

$$F_{net} = 1 \text{ newton}$$

Hence, force is a derived quantity (not one of the seven basic SI quantities) and a newton is a derived unit.

Worked example

A horizontal 60N force acts on an object of mass 8 kg to accelerate it to the right. The frictional force between the object and the surface is 12N.



Calculate the

1. net force acting on the object

2. acceleration of the object.

Solution

Both the applied force and the friction force act horizontally. The applied force (60 N to the right) acts in the opposite direction to the frictional force (15 N to the left).

$$F_{applied} = 60N \text{ right} = +60N, F_{riction} = 15N \ left = -15N$$

$$F_{net} = f_{applied} + F_{friction}$$
$$= 60N + (-15N)$$
$$= +45N$$
$$= 45N \text{ to the right}$$

This means that 45N causes the object to accelerate to the right.

$$a = \frac{f_{net}}{m} = \frac{45N \text{ to the right}}{9kg}$$

$$a = 5\frac{N}{kg} \text{ to the right}$$

But 1N is the same as $1\frac{kg\ \text{m}}{s^2}$.

Units cancel out
kg in the numerator cancel out the kg in the denominator

So, $a = \frac{5N}{kg} = 5\frac{kg\ \text{m}}{s^2} \times \frac{1}{kg}$

$$a = 5\frac{m}{s^2} \text{ to the right}$$

ACTIVITY 2

Use the equation for Newton's second law $F_{net} = ma$ to complete the table below.

	net force/N	mass/kg	acceleration / ms^{-2}
1	10 up	2	
2	20 to the left		10 to the left
3		2	2.5 east
4	10 down		2.5 down
5	10 to the right	1	

units cancel out
kg in the numerator cancels out with kg in the denominator

ANSWERS ON PAGE 189

Direct proportion relationships

The numbers in the table above show more detail about the direct proportion relationship between F_{net} and a when mass is constant.

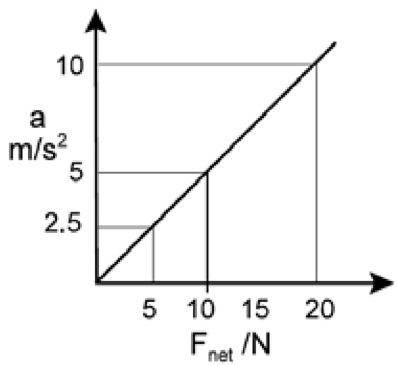
If we compare values in rows 1 and 2, we see that

- **doubling** of the net force from 10N to 20N **doubles** the acceleration (mass is constant) from $5ms^{-2}$ to $10ms^{-2}$.

If we compare the values in rows 1 and 3, we see that

- **halving** of the net force from 10N to 5N **halves** the acceleration (mass is constant) from $5ms^{-2}$ to $2.5ms^{-2}$.

This is because acceleration is directly proportional to net force if mass stays the same. The graph of two quantities which are **directly proportional** is always a straight line through the origin.



Whatever change you make to the net force causes the same change in the acceleration when mass stays the same. Double, triple or quadruple the net force, and the acceleration also doubles, triples or quadruples if the mass stays the same.

Inverse proportion relationships

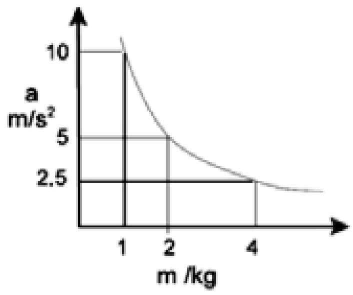
The numbers in the table above show more detail about the **inverse proportion** relationship between a and m when the net force is constant.

If we compare values in rows 1 and 4, we see that

- **doubling** the mass from 2 kg to 4 kg **halves** the acceleration
  (F_{net} is constant) from 5 ms^{-2} to 2.5 ms^{-2}.

If we compare the values in rows 1 and 5, we see that

- **halving** of the mass from 2 kg to 1 kg doubles the acceleration
  (F_{net} is constant) from 5 ms^{-2} to 2.5 ms^{-2}.



This confirms that acceleration is **inversely proportional** to mass if the net force stays the same. The graph of two quantities which are inversely proportional is always an hyperbola.

Whatever change you make to the mass, the **opposite** or **inverse** change takes place in the acceleration. Double, triple or quadruple the mass, and the acceleration will be one-half, one-third or one-quarter of its original value if the net force stays the same.

Use these ideas to complete Activity 3.

ACTIVITY 3

1. A 12N net force acts on a 3 kg object. What is the acceleration when the same net force acts on a 6 kg object?

2. A net force of 15N accelerates a heavy book at 5 ms^{-2} in the same direction. What is the mass of the book?

3. A boy on a skateboard accelerates along the road at 2 ms^{-2}. When a heavier boy rides on the skateboard, the mass doubles. The heavier boy can push three times harder. What is the new acceleration?

4. Suppose a skateboard accelerates at 2 m/s^2. If the net force is tripled and the mass is halved, then what is the new acceleration of the skateboard?

5. A net force F acts on an object of mass m and produces an acceleration a. If a different object with double the mass experiences an acceleration of $\frac{a}{3}$ then the net force acting on the second object is

   a. $\frac{1}{6}F$ b. $\frac{2}{3}F$

   c. F d. $\frac{3}{2}F$

   e. $6F$

ANSWERS ON PAGE 189

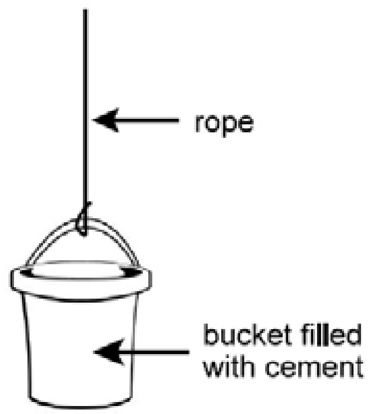
Net force and acceleration are in the same direction

Newton's second law specifies that it is the net force acting on an object which makes the object accelerate. The law also emphasizes that the object accelerates in the same direction as the net force.

Do the activity below to see if you can use this information correctly.

ACTIVITY 4

1. The diagram alongside shows a bucket of cement with mass 20 kg. There are two forces acting on the bucket; the force the Earth exerts on the bucket (200N down) and the upward tension the rope exerts on the bucket.



   Suppose the tension is 180N up.

   a. What is the net force acting on the bucket. Take up as positive and down as negative.

   b. Choose the statement below that describes the bucket's motion. Justify your answer.

      The bucket is
      i. at rest
      ii. moving up with constant velocity
      iii. accelerating up
      iv. accelerating down.

Suppose the tension is 250N up.

c. What is the net force acting on the bucket now?

d. Describe the motion of the bucket. Explain your answer.

Lastly, imagine the tension in the rope changes to 200N up.

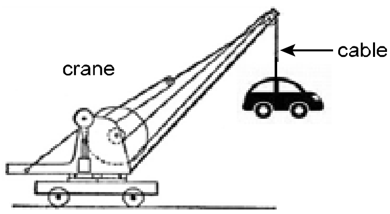
e. What is the net force acting on the bucket now?

f. Describe the motion of the bucket. Explain your answer.

2. A shopper exerts an upward force of 500N to lift a 30 kg packet of dog food.

a. What is the acceleration of the packet?

b. Draw a diagram to show the forces acting on the packet.



3. A crane in a scrap yard lifts a car of mass 1 200 kg with an upward acceleration of 0.5 ms^{-2}. What is the tension in the cable? What is the tension in the cable?

ANSWERS ON PAGE 190

Mass on the move

In Physics, the quantity momentum refers to the amount of motion that an object has. Momentum depends on two things: an object's mass and its velocity.

We define momentum as the product of the mass and velocity of a moving object.

$$\text{momentum} = \text{mass} \times \text{velocity}$$

$$p = mv$$

You should be able to see from this equation that an object has a large momentum if either its mass or its velocity is large. But, any object that is at rest (has v = 0 ms^{-1}) has zero momentum.

All moving objects have momentum.

- A heavy truck moving quickly has more momentum than the same truck has when it is moving slowly.

- A truck moving slowly has more momentum than a man on a bicycle riding at the same speed as the truck.

- A man riding a bicycle has more momentum than a stationary truck.

SI Units of momentum

The SI units of momentum come from the equation

$$p = mv$$

SI unit of p =SI unit of mass × SI unit of velocity

= kilogram × metre per second,in symbols $= kgms^{-1}$

A $kgms^{-1}$ does not have a special name.

Momentum is a vector quantity

Momentum is a vector quantity. Remember that a vector is a quantity we describe fully by giving both its magnitude and its direction.

When you describe the momentum of a 5 kg ball moving west at 2 m/s, you must include information about both the magnitude of the momentum and the direction of the momentum. The direction of the ball's momentum is the same as the direction of the velocity of the ball. If the ball is moving westward, then its momentum is

$$p = mv = 5kg \times 2ms^{-1}W$$
$$= 10kgms^{-1}\ W$$

Worked example

An athlete of mass 70 kg runs at a velocity of 10 ms^{-1} south. What is his momentum?

Solution

$$p = mv$$
$$= 70kg \times 10ms^{-1} \text{ south}$$
$$= 700kgms^{-1} \text{ south}$$

How a change in either m or v affects momentum

We can use the equation $p = mv$ to work out how a change in one of the two variables, mass or velocity, affects the momentum of an object.

A trolley moves north with a speed of 2.0 m/s. Its momentum p_1 is $p_1 = m_1v_1$

If we put a brick on the trolley the trolley's mass doubles. When it moves with the same velocity as before, its new momentum p_2 becomes

$$p_2 = m_2v_1 = 2m_1v_1$$

$$p_2 = 2p_1$$

If we **double** the mass of an object and keep its velocity the same, its momentum **doubles** too. Momentum is directly proportional to mass if velocity is the same.

ACTIVITY 5

1. Determine the momentum of a ...

   a. 110 kg rugby player moving east at 9 m/s.

   b. 1000 kg car moving north at 20 m/s

2. A moving taxi has 20 000 units of momentum. What is the taxi's new momentum if:

   a. we double its velocity but its mass stays the same?

   b. we triple its velocity but its mass stays the same?

   c. its mass doubles when more passengers get in but its velocity stays the same?

3. Complete the table on the next page. Both the units and direction have been omitted.
   a. has already been completed.

   An object with mass M and velocity v has momentum 24 $kgms^{-1}$.

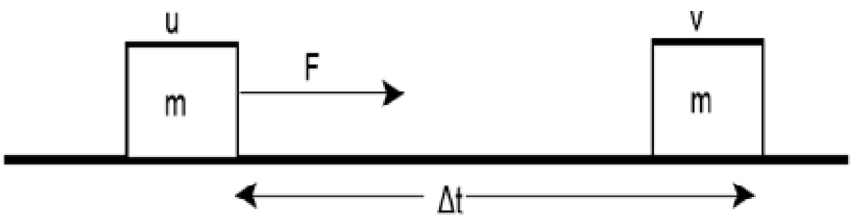
Hence, an object with

a.	Mass 2M and velocity 2v would have momentum	$2 \times 2 \times 24 = 96$
b.	Mass 2M and velocity 0.5v would have momentum	
c.	Mass 3M and velocity 2v would have momentum	
d.	Mass 0.5M and velocity 0.5v would have momentum	
e.	Mass 4M and velocity 0.5v would have momentum	
f.	Mass 0.5M and velocity would have momentum	

ANSWERS ON PAGE 192

A link between force and change in momentum

Suppose a constant, unbalanced force *F* acts for a time interval Δt on an object moving at a velocity u. The force makes the object change its speed from u to v. This means that the object will accelerate in the direction of *F*.



The size of the acceleration depends on the size of the force as well as on the mass of the object.

The equation for Newton's second law sums this up.

$$F_{net} = ms$$

$$but\ \mathrm{a} = \frac{v - u}{\Delta t}$$

$$so\ \mathrm{F_{net}} = \text{ma becomes}$$

$$\mathrm{F_{net}} = \frac{m\,(v – u)}{\Delta t}$$

$$F_{net} = \frac{mv - mu}{\Delta t}$$

mu is the original momentum of the object.
mv is its momentum after the force acts
(*mv* – *mu*) is the change in momentum
Δt is the time interval over which the momentum changes.

$$force = \frac{\text{change in momentum}}{\text{time}} \text{ or } F_{net} = \frac{\Delta p}{\Delta t}$$

An unbalanced force always causes a change in momentum. This gives us another way of looking at Newton's second law!

Another way of expressing Newton's second law

The rate of change of momentum of a body is directly proportional to the net force and takes place in the direction in which the force is applied.

Worked example

A tennis ball of mass 60 g moves to the right with a speed of 15 ms^{-1}. After the ball collides with a tennis racquet, it moves to the left with a speed of 20 ms^{-1}.

a. What is the change in velocity of the tennis ball?

b. What is the ball's change in momentum?

Solution

a. The velocity of the tennis ball before it hits the racquet is 12 ms^{-1} to the right.
u=12 ms^{-1} to the right
After the ball hits the racquet, the ball moves to the left (in the opposite direction) at 20 .

v = 20 ms^{-1} to the left

When the racquet hits the ball, the force it exerts on the ball slows the ball down from 12 ms^{-1} to zero and then increases its speed from zero to 15 ms^{-1} in the opposite direction.

$$\text{Let } u = +12 \text{ ms}^{-1}\text{, then } v = 15 \text{ ms}^{-1}$$

$$\begin{aligned} \text{change in velocity} &= \text{final velocity - initial velocity} \\ &= v - u \\ &= -15 \text{ ms}^{-1} - 12 \text{ ms}^{-1} \\ &= -27 \text{ ms}^{-1} \end{aligned}$$

The minus sign gives the direction of the force the racquet exerts on the ball.

$$F_{net} = \frac{m(v - u)}{\Delta t}$$

$$F_{net} = \frac{m\Delta v}{\Delta t}$$

b. $m = 60g$ which is the same as $\frac{60}{1000}kg = 0.06kg$

$$\Delta p = m\Delta v = 0.06kg \times -27kgms^{-1}$$
$$= -1.6\,kgms^{-1}$$

The net force and the change in momentum act in the same direction. So the change in momentum $\Delta p = 1.6\ kgms^{-1}$ towards the left.

ACTIVITY 6

The diagrams represent the velocity of the same tennis ball before and after it hits a wall.

In which case, A or B does the ball have the

a. greater change in velocity

b. greater change in momentum

c. greater acceleration

Justify your answer in each case.

ANSWERS ON PAGE 192

SUMMARY ACTIVITY

1. If a constant net force of 5,0 *N* acts on a car initially at rest, the car will

   a. move with a constant acceleration

b. remain at rest because the frictional force is more than 5 *N*

c. move with constant velocity

d. move with increasing acceleration

e. remain at rest since the force of 5 *N* will be too small to overcome the mass of the car

2. An aircraft flies at a constant velocity of 300 $m.s^{-1}$ east at an altitude of 1 000 m. What is the net force acting on the aircraft?

   a. zero

   b. the force of the engines pushing it forward

   c. the force of gravity

   d. the force of air friction

   e. the lifting force holding the aircraft up

3. If I make the changes shown in the second column, what final value would result for the initial value in the third column? The first example (a) shows you how to work this out.

	SECOND COLUMN	THIRD COLUMN	
	Predict	Initial value	Final value
a	the new acceleration if I make the net force on an object five times bigger	$a = 6\ ms^{-2}$	$a = 5 \times 6\ ms^{-2}$ $= 30\ ms^{-2}$
b	the new acceleration of a truck if I add a load that doubles the total mass (the net force is the same)	$a = 6\ m.s^{-2}$	
c	the new force if I make the mass of an object three times smaller (the acceleration must stay the same)	$F = 600N$	
d	the new acceleration if I double the net force on an object and make its mass 4 times smaller.	$a = 2\ m.s^{-2}$	

4. A cyclist and her bicycle have a mass of 60 kg. When starting from rest, her pedaling develops a force of 140 *N*. The friction between the wheels and the road is 20 *N*.

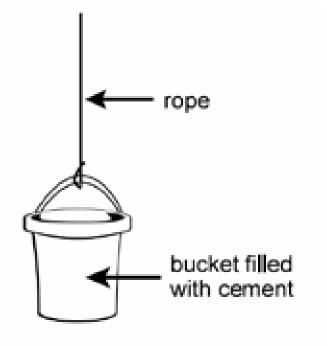
   a. Draw a diagram to represent all the horizontal forces on the bicycle.

   b. What is the net horizontal force on the cyclist and her bicycle?

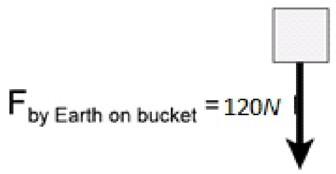
   c. What is their acceleration?

5. The diagram shows a bucket hanging from a rope. Builders use the bucket on a building site to move cement from the ground up to the first floor of the building.

   The mass of the bucket and the cement is 12 kg. The arrow on the diagram represents the force the Earth exerts on the bucket. This is the weight of the bucket.



   Suppose the builder holds the bucket (mass – 12kg) still. The arrow on the diagram represents the force the Earth exerts on the bucket. This is the weight of the bucket.



   a. What is the acceleration of the bucket?

   b. Use $F_{net} = ma$ to work out the net force acting on the bucket when it is at rest.

   c. Draw and label an arrow to represent the magnitude and direction of the tension acting on the bucket when it is at rest. Justify your answer.

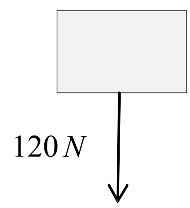
Now suppose the builder gives the bucket an upward acceleration of 0.5 ms^{-2}.

d. In which direction must the net force acting on the bucket act? Why?

e. Use $F_{net} = ma$ to find the magnitude and the direction of the force on the bucket. Assume the mass of the bucket and the cement is still 12 kg.

f. Show that the tension in the rope is 126N up.

g. Draw and label an arrow on the diagram to represent the tension in the rope.



h. Imagine the rope slips through the builder's hands and the bucket falls with a downward acceleration of 2 ms^{-2}. Which of the two forces acting on the bucket is the larger force, the tension or the bucket's weight? Explain.

ANSWERS ON PAGE 193

CHECKLIST

Are you able to:

- ❐ describe how an object's motion changes when an unbalanced force acts on it
- ❐ use the state of motion of an object to decide if the forces acting on an object are balanced or unbalanced
- ❐ predict the effect of a change in net force on acceleration if mass is constant
- ❐ predict the effect of a change in mass on acceleration if net force is constant
- ❐ state Newton's second law of motion in terms of acceleration and in terms of momentum
- ❐ define the SI unit of force
- ❐ use Newton's second law to solve problems involving tension and friction
- ❐ define momentum
- ❐ predict the effect of a change in either mass or velocity on momentum

LESSON 8

Newton's third law of motion

About this lesson

Newton's third law of motion tells us about the forces that exist when two objects interact with each other. Newton made the point that interaction between two objects is mutual. The two objects interact with each other. Interaction is not a one-sided event. This lesson explores interactions between different objects and describes the effects of these interactions.

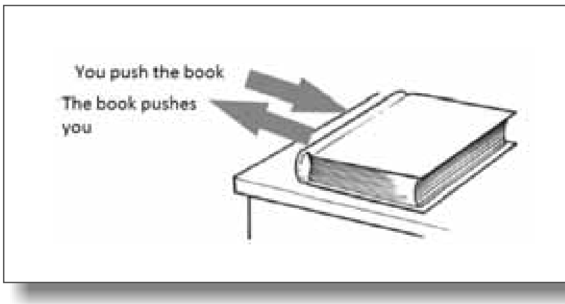
In this lesson you will:

- state Newton's third law of motion
- identify action-reaction force pairs
- compare the magnitude and direction of action and reaction
- identify the objects on which action and reaction act
- recognise that action and reaction may accelerate the objects on which they act

Interacting

Every time you push or pull an object, you interact with it. If you push a book across the table, you interact with the book. You are the agent applying a force on the book. But, Newton's third law tells us that the book also interacts with you! The book is also an agent applying a force on you.

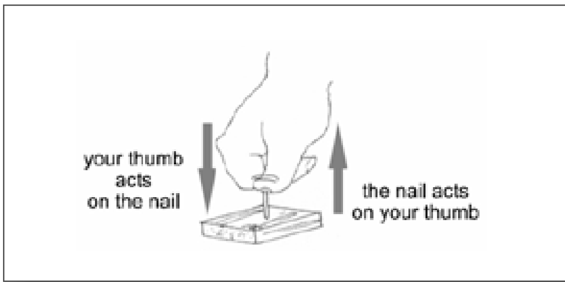
Do the activity below to see evidence for interaction when you exert a force.



ACTIVITY 1

Try the following investigation and answer the questions.

You need a soft piece of wood and a metal nail with a small head. Use your thumb to push the nail into the wood as hard as you can.



1. You apply a downward force on the nail. You cannot see this force, so how do you know that it is acting?

2. Look at your thumb. Is the skin pushed in? Why does this happen?

3. What evidence do you have that the nail exerts a force on your thumb?

ANSWERS ON PAGE 195

Interaction is mutual

Interaction is automatically a two-way process. The instant you interact with some object, the object interacts with you.

Newton's law tells us that for every force that acts on an object, there is another force. There is no such thing as one force on its own. All forces exist in pairs.

Action-reaction force pairs

To help us talk about the two forces in a pair of forces, we give each force a name. We call one of the forces the **action** and the other force the **reaction**. These names are misleading because they give the idea that action happens first and that reaction is a response. Not so! Both action and reaction happen together, not one after the other.

Newton's third law tells us that action and reaction are **equal in magnitude**. This means they are the same size. The Law tells us too that action and reaction act in **opposite directions**, and, most importantly, action and reaction act on **different** objects.

To summarize so far:

- Forces happen in pairs.
- One of the forces in the pair is the action.
- The other force in the pair is the reaction.
- Action and reaction are equal in magnitude.
- Action and reaction act at 180° to each other. They act in opposite directions.
- Action and reaction act on different objects.

Newton's third law of motion

Whenever an object A exerts a force on another object B, object B exerts an equal and opposite force on object A.

In equation form this is $+F_{by\ A\ on\ B} = -F_{by\ B\ on\ A}$. The plus (+) and minus (−) signs show that the forces act in opposite directions.

Action and reaction are always equal in magnitude

Sometimes it is very hard to believe that action and reaction are always equal in size.

Suppose you jump off a table. You fall down because the Earth pulls you down. But Newton's third law tells us that if the Earth pulls you down, you pull the Earth up! Your downward motion is obvious, but the Earth's upward movement is impossible to perceive!

Do you remember inverse proportion? If not, see Lesson 7

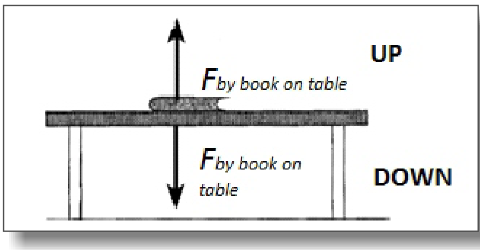
Newton's second law ($F_{net} = ma$) can explain why. According to this law the bigger the mass of an object the smaller its acceleration if force stays the same. Your mass relative to the Earth's mass is very small. So your acceleration is very large when the Earth pulls you down. By contrast, the Earth's mass is very large. Hence its acceleration will be very small when you pull it up with the same force. So small you will not be able to notice it!

The masses of the two interacting objects have no effect on the magnitude of action and reaction. Action and reaction are always equal in magnitude. Their masses affect only their accelerations.

Action and reaction cannot cancel each other out

You may think that because action and reaction are equal in magnitude and opposite in direction that they cancel each other out to give a zero net force. This cannot be true because action and reaction act on two **different** objects. For example, you push or act on the nail and the nail pushes or acts on you. A force acting on you cannot cancel out a force acting on a nail!

Book on a table



The diagram shows a book lying on a table. The book presses down on the table. This force is not obvious. But imagine the table is made from rubber. We would be able to see that the book bends the table down where they are in contact. We can call this force the action.

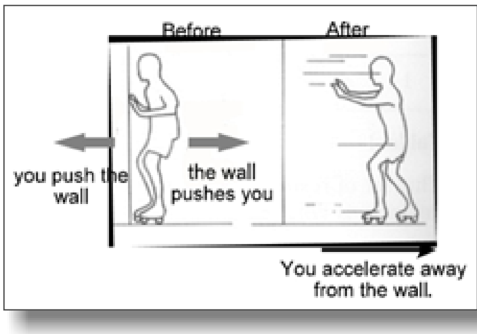
Newton's third law tells us that forces happen in pairs. So the table must apply an upward force on the book. We can call this force the reaction. Action and reaction are the same kind of force. In this case, they are both contact forces.

It does not matter which force we call the action and which force we call the reaction. Also, don't forget that both forces exist at the same time, not one after the other.

The book is at rest. Newton's first law tells us that all the forces acting on the book must be balanced.

Some other force must be acting on the book to balance the upward force the table exerts on it. This force is, of course, the force the Earth exerts downward on the book. The book's weight opposes the upward force the table exerts on the book. Note that the diagram does not show the book's weight.

Push and be pushed back

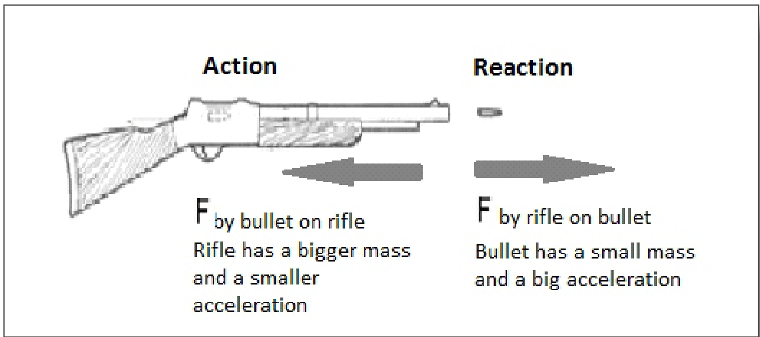


Suppose you and a wall interact. You stand still facing the wall while wearing your roller skates. When you push the wall, the wall does not move but you do! You accelerate away from the wall.

You push the wall (action) and the wall pushes you back (reaction). The reaction must be an unbalanced force since it accelerates you. The agent applying this unbalanced force is the wall. The action force, however, does not move the wall. This tells us that there must be other forces acting on the wall which stop the wall from moving. Action and reaction may be equal (in magnitude) but the things they do to the objects they act on can be quite different!

Rifle recoil

When you pull the trigger on a rifle, burning gunpowder shoots the bullet out of the barrel of the gun at high speed. This is the force (action) the rifle exerts on the bullet. At the same moment, the bullet acts on the rifle (reaction) in the opposite direction.



Both action and reaction are unbalanced forces. They do different things to the objects they act on. Action accelerates the bullet forward. The bullet's mass is small, so its acceleration is very large. A bullet can kill someone!

Reaction accelerates the gun backwards onto your shoulder. This is rifle recoil. The mass of the rifle is much bigger than the mass of the bullet. The acceleration of the rifle then is much smaller than the bullet. Rifle recoil can be quite painful but it cannot kill the user!

Action and reaction have very different effects on the objects they act on.

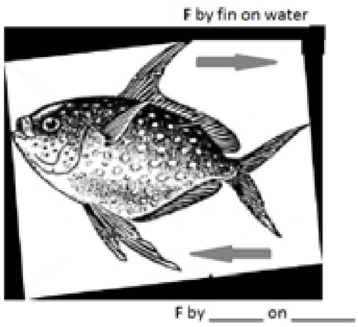
Flying birds

Newton's third law explains how birds are able to fly. A bird uses its wings to fly. The wings of a bird interact with the air. The wings push the air backwards. But this interaction is not one-sided. Newton's third law tells us that the air pushes the wings forward. The size of the force on the air equals the size of the force on the bird. The direction of the force on the air (backwards) is opposite the direction of the force on the bird (forwards). Do you think a bird could fly in a vacuum?

Moving cars

As the wheels of a car turn, they push the road backwards. The road pushes the car's wheels forward. The size of the force on the wheels equals the size of the force on the road. The direction of the force on the road is opposite the direction of the force on the wheels. Newton's third law explains how cars move.

ACTIVITY 2



1. The diagram alongside shows a fish swimming in water.

   a. Complete the label on the diagram.

   b. Why are the two arrows in the diagram the same length?

   c. These two forces do not cancel each other out. Explain why.

   d. Suppose that these forces are unbalanced. What effect does each force have on the object it acts on? What law is this?

2. Cross out the wrong word/s in the statements below. A soldier loads a bullet into a rifle and pulls the trigger. The force the rifle exerts on the bullet is **less than / equal to / greater** than the force bullet exerts on the rifle. This is Newton's **second / third** law. The acceleration of the bullet is **less than / equal to / greater** than the acceleration of the rifle because the mass of the bullet is **less than / equal to / greater** than the mass of the rifle. This is Newton's **second / third** law.

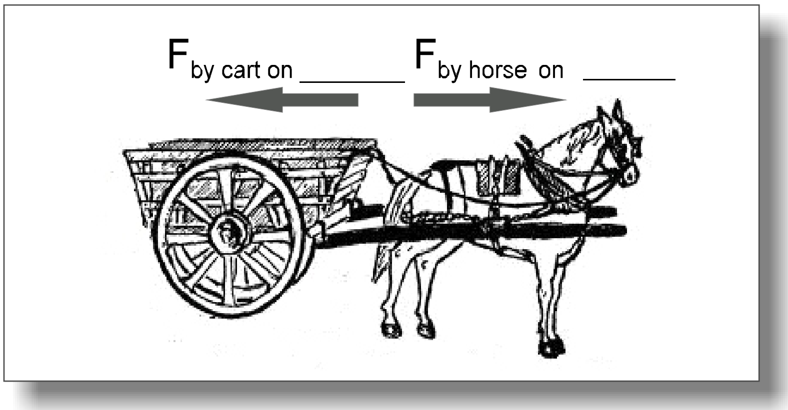
3. You sit at your desk. The Earth pulls down upon your body with a gravitational force. The reaction is the normal force which the chair exerts upwards on your body.

   Is this reasoning True or False? If you think it is false, correct the error/s.

ANSWERS ON PAGE 195

ACTIVITY 3

Can the horse move the cart?
The diagram shows a horse hitched up to a cart.



1. Label the arrows on the diagram to show the action reaction pair.

2. If the force on the cart is equal and opposite to the force on the horse can the horse move the cart?*
   Which of the options below is the correct answer?

   a. Yes, the horse pulls the cart before the cart has time to react.

   b. The horse cannot move the cart because the cart pulls as hard on the horse as the horse pulls on the cart.

   c. The horse can pull the cart only if the horse is heavier than the cart.

   d. Yes, the cart can move because the horse pulls slightly harder on the cart.

   e. None of these explanations is correct. Another explanation is ....

ANSWERS ON PAGE 195

* Adapted from Thinking Physics, Lewis C Epstein, San Francisco CA, Insight Press 1986

SUMMARY ACTIVITY

Choose the correct answer to each of questions 1 - 6 below. Justify each answer briefly.

1. A book is at rest on a horizontal table. If the action is the weight of the book, which force is the reaction?

   a. The force exerted by the book on the table.

   b. The force exerted by the table on the book.

   c. The weight of the table.

   d. The force exerted by the book on the Earth.

   e. The force exerted by the Earth on the book.

2. When an apple falls from a tree, it drops to the ground because of the gravitational attraction between the Earth and the apple. If F_1 is the magnitude of the force exerted by the Earth on the apple and F_2 is the magnitude of the force exerted by the apple on the Earth, then

   a. F_1 is very much greater than F_2,

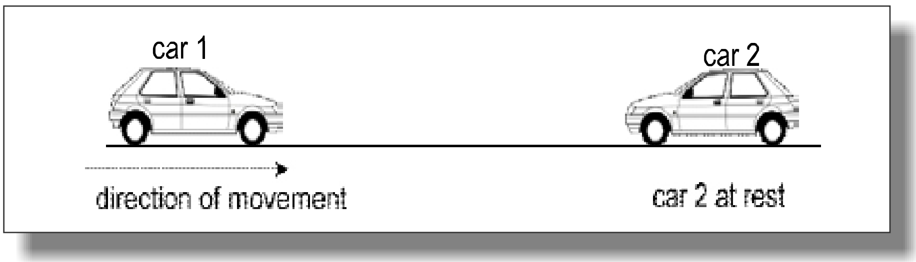
   b. F_1 is a little greater than F_2,

   c. F_1 and F_2 are equal in magnitude,

   d. F_2 is very much greater than F_1,

   e. F_2 is a little greater than F_1.

3. Car 1 collides head on with identical car 2. Before colliding, car 2 is not moving.



   After they collide, car 1 is

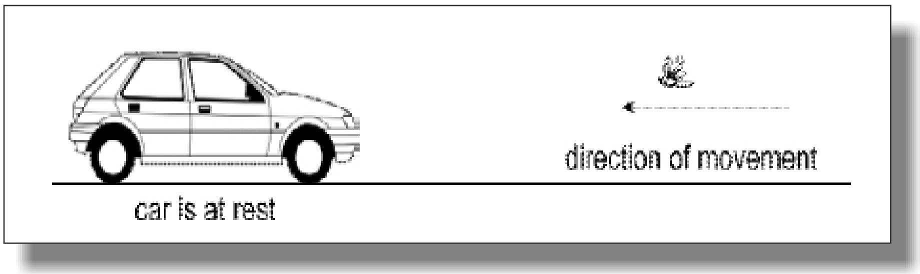
   a. as badly damaged as car 2

b. more damaged than car 2

c. less damaged than car 2

d. not damaged at all.

4. An insect flies against the windscreen of a stationary car. How does the force the insect exerts on the car compare to the force the car exerts on the insect?



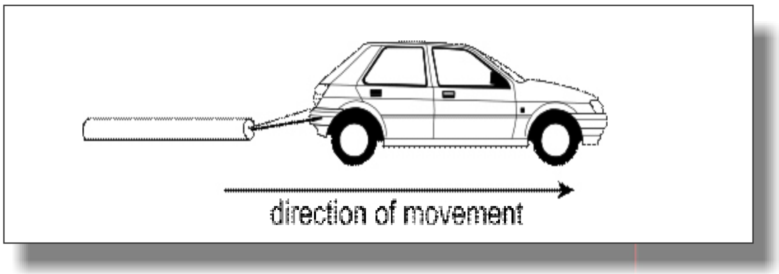
a. The insect does not exert a force on the car.

b. The insect exerts a smaller force than the car exerts.

c. The insect exerts a greater force than the car exerts.

d. The forces the car and the insect exert on each other are equal in magnitude.

5. A moving car pulls a heavy log along the ground behind it. The log exerts on the car



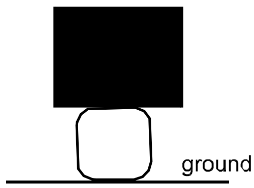
a. a force equal in magnitude to the force the car exerts on the log

b. a force larger than the car exerts on the log

c. a force smaller than the force the car exerts on the log

d. no force at all.

6. A heavy wooden block (10 kg) rests on top of a light wooden block (2 kg) as in the diagram. The bottom block exerts on the top block



a. no force at all

b. a smaller force than the top block exerts on the bottom block

c. a force equal to the force the top block exerts on the bottom block

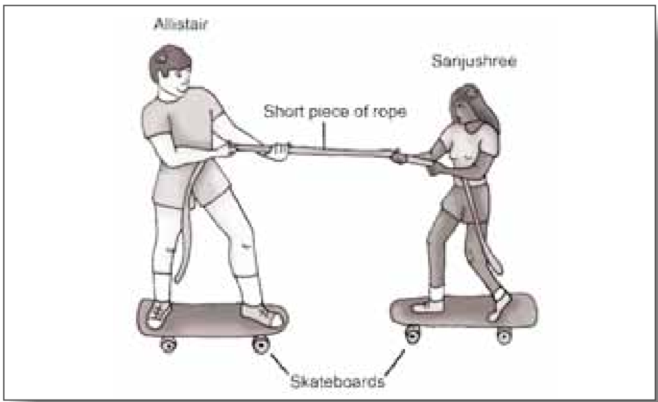
d. a greater force than the top block exerts on the bottom one

7. The diagram shows a fireman aiming a thick fire hose onto flames just before someone turns on the water.

   a. Why do you think the fireman uses both his hands to hold firmly onto the hose?

   b. What will happen if the fireman loses his grip on the hose?

8. The diagram shows Allistair pulling one end of a rope while his friend Sanjushree holds the other end. Allistair and Sanjushree are both on skate boards.



Predict what you think will happen to them. Justify your prediction. Use the ideas in the words/phrases in the box alongside in your answer.

Newton's third law action reaction Allistair's mass Sanjushree's mass equal in magnitude greater acceleration

ANSWERS ON PAGE 196

CHECKLIST

Are you able to:

- ❒ state Newton's third law of motion
- ❒ identify action-reaction force pairs in some examples
- ❒ compare the magnitude and direction of action and reaction
- ❒ identify the objects on which action and reaction act
- ❒ recognize that action and reaction may accelerate the objects on which they act

LESSON 9

Impulse

About this lesson

A tennis racquet hitting a tennis ball, a hammer striking a nail and a child jumping to the ground are all examples of collisions. Collisions are interactions and they involve forces. Sometimes these forces can be very large and may cause damage or even pain.

This lesson extends ideas about force and the changes in momentum forces cause to define a new quantity called impulse. The lesson also shows how people instinctively use impulse to prevent pain and injury during everyday collisions and also examines ways in which engineers use impulse to design safety features in motor cars that lessen injury during road accidents.

In this lesson you will:

- define impulse
- use words and equations to describe the link between impulse and change in momentum
- do calculations on impulse and change in momentum
- compare rebound and 'sticky' collisions with respect to changes in velocity, momentum and impulse
- describe how changing the time interval affects force for a given impulse (or change in momentum)
- name and describe the principle behind two safety features in modern motor cars

Back to a soccer ball

A soccer ball has zero velocity and zero momentum when it lies at rest on the grass. You can change its velocity and hence its momentum when you kick it. A kick is a force. In this case it is the force your boot exerts on the ball. This force acts only while your boot touches the ball. The ball now has velocity and momentum. Kicking the ball causes its velocity and its momentum to change.

Unbalanced forces and change in momentum

An unbalanced force acting over a certain time interval always causes a change in velocity and hence a change in momentum.

In Lesson 7, we linked the unbalanced force acting on an object for a given time interval to its change in velocity and then to its change in momentum in the equations

$$force = \frac{mass \times change\ in\ velocity}{time\ interval}$$

and

$$force = \frac{change\ in\ momentum}{time\ interval}$$

We now use these equations in a different form.

$$force \times time\ interval = mass \times change\ in\ velocity$$

and

$$force \times time\ interval = change\ in\ momentum$$

The left hand side of both these equations shows the force multiplied by the time interval over which the force acts.

Impulse equals force multiplied by time interval

In physics we call the quantity (force x time interval) impulse.

$$force \times time\ interval = mass \times change\ in\ velocity\ now\ becomes$$

$$impulse = mass \times change\ in\ velocity$$

and

$$force \times time\ interval = change\ in\ momentum\ now\ becomes$$

$$impulse = change\ in\ momentum$$

Definition of impulse

Impulse is the product of the unbalanced force acting on an object and the time interval over which that force acts. In equation form this is $I = F\Delta t$.

Impulse is a vector quantity

Impulse acts in the same direction as the force which causes it.

To summarise then

- The impulse an object experiences is the unbalanced force x time interval for which the force acts. $I = F\Delta t$
- Impulse equals the change in momentum. $I = m\Delta v$ or $I = \Delta p$
- Change in momentum equals unbalanced force x time interval for which the force acts. $\Delta p = F\Delta t$

SI units of impulse

The SI units of impulse are the SI units of force multiplied by the SI units of time. We express impulse in newton second or Ns. But impulse equals change in momentum. So we can also express momentum in kilogram metre per second or kgms^{-1}.

$$Ns = \frac{kgm}{s^2} \ x \ s \text{ which is}$$

$$= \frac{kgm}{s} \text{ or } kgms^{-1}$$

A Newton second is the same as a kilogram metre per second!

Worked example

What impulse will give a body of mass 8 kg a change in velocity of $4ms^{-1}$?

Solution

$m = 8kg$

$\Delta v = 4ms^{-1}$

$I = m\Delta v$

$= 4kg \ x \ ms^{-1}$

$= 32kgms^{-1}$ in the direction of the force

or in the direction of the force causing the change in momentum.

ACTIVITY 1

1. What impulse do you give an object if you push it towards a wall for 4 s with a force of 3*N*?

2. A car of mass 1000 kg is traveling with a velocity of 25 ms^{-1}. The car hits a street pole and stops in 0.05 seconds. What is the impulsive force acting on the car during the crash?

3. A soccer ball of mass 1,0 kg is traveling along the ground towards a player at 10 ms^{-1}. He kicks it back to where it came from, so that its speed remains 10 ms^{-1}.

   a. What is its change in velocity of the ball?

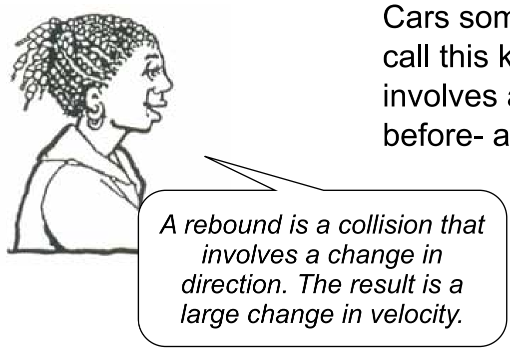
   b. What is its change in momentum?

   c. What is the force if the footballer's foot remains in contact with the ball for 0,2 s?

4. If an object experiences a 10*N* force for 0.10 second, then what is the momentum change of the object?

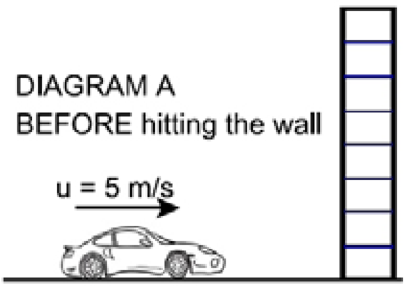
ANSWERS ON PAGE 197

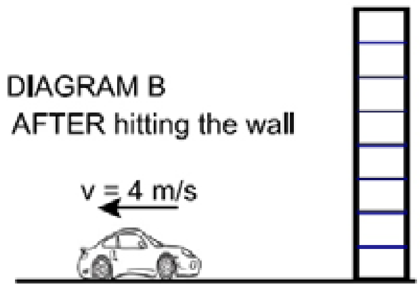
Collisions cause changes



Cars sometimes bounce off each other when they collide. We call this kind of **collision** a rebound collision. Rebounding involves a change in the direction of the car; the direction before- and after- collision is different. Cars are damaged when they are involved in collisions. However it is not only the shape of the car which changes during collisions. Both the car's velocity and its momentum change too. We look at these velocity and momentum changes in more detail in an example.

Diagram A shows a car just before it collides with a wall. Diagram B shows the same car just after the rebound collision.





We can work out the change in velocity of the car as follows:
We make the direction towards the wall positive. So $u = +5ms^{-1}$.
Away from the wall is then negative, So $v = -4ms^{-1}$.

$$
\begin{aligned}
\Delta v &= V_{final} - V_{initial} \\
&= v - u \\
&= -4ms^{-1} - 5ms^{-1} \\
&= -9ms^{-1} \\
&= 9ms^{-1} \text{ away from the wall}
\end{aligned}
$$

The car's momentum also changes as a result of its rebound collision with the wall. This change in momentum depends only on the car's change in velocity since its mass stays the same during the collision (1000 kg).

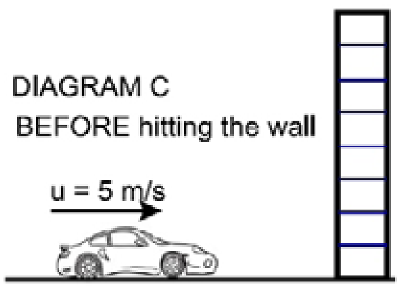
$$
\begin{aligned}
\Delta p = m\Delta v = 1000kg \ x - 9ms^{-1} &= -9000kgms^{-1} \\
&= 9000kms^{-1} \text{ away from the wall}
\end{aligned}
$$

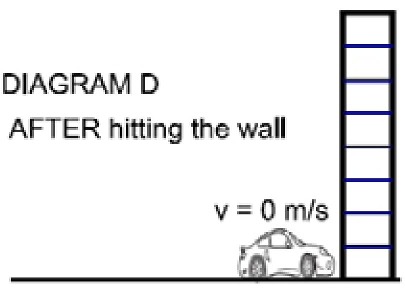
The wall causes these changes in the car's velocity and momentum. The wall applies a force to the car and this force acts over a short time interval. In other words, the wall applies an impulse to the car. The impulse which the wall applies on the car is equal to the car's change in momentum.

$I = m\Delta v = 9000Ns$ away from the wall

ACTIVITY 2

Now we look at the same car when it collides in a different way with the wall. This time the car does not rebound; it sticks to the wall. This is a 'sticky' collision.





1. What is the change in the car's velocity as a result of the collision?

2. Work out the change in the car's momentum as a result of the collision.

3. What is the impulse the wall applies to the car during this collision?

4. Complete the table below using information from above about the rebound collision and this ‘sticky’ collision.

	Car’s change in velocity	Car’s change in momentum	Impulse acting on the car
Rebound collision (Diagrams A & B)			
‘Sticky collision’ (Diagrams C & D)			

Check your answers on page 198 before completing questions 5 – 9.

Use information from your completed table to help you answer the questions below.

Two cars P and Q move with equal velocity along a road. Car P stops suddenly but does not crash into anything. Car Q, however, collides with a truck and rebounds. Assume that these changes take place over the same time interval.

5. Which of the two cars undergoes the greater change in velocity?

6. Suppose these cars have exactly the same mass. Which of the two cars has the greater change in momentum? Explain your answer.

7. Which car, P or Q experiences the greater impulse? Explain your answer.

8. Which car P or Q is likely to be more damaged?

9. The drivers of both cars are likely to be hurt. Which driver is likely to be more severely injured, the driver of P or the driver of Q? Explain your answer.

ANSWERS ON PAGE 198

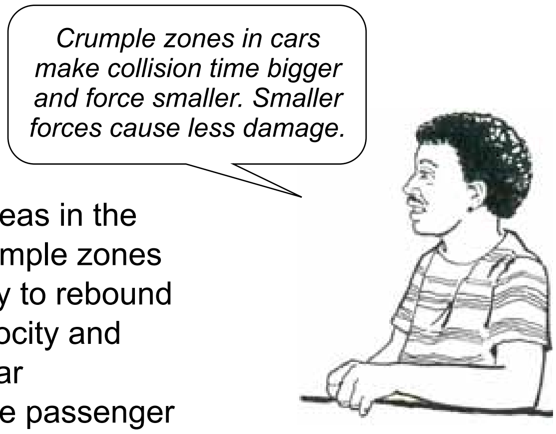
Rebound or crumple?

When a car collides with a rigid, strong surface that does not change shape it may rebound after colliding. By contrast when a car collides with a squashy, soft surface, it is not likely to rebound after colliding.

Activity 2 shows us that a rebound collision involves larger changes in velocity, momentum and impulse than a 'sticky' collision.

Crumple zones in cars

Engineers design cars that use these ideas to lessen injury to occupants of a car during collision. They use soft, squashy materials that crumple, crush and change shape to make some parts of the car's body. These areas in the body of the car are crumple zones. Crumple zones are structural areas in the front and sometimes at the back of a motor car. Crumple zones act like a cushion. By crumpling, the car is less likely to rebound when it collides. This makes the car's change in velocity and momentum as small as possible. The impulse the car experiences, is also smaller. Crumple zones improve passenger safety and save lives during motor car accidents.



The effect of changing time upon force

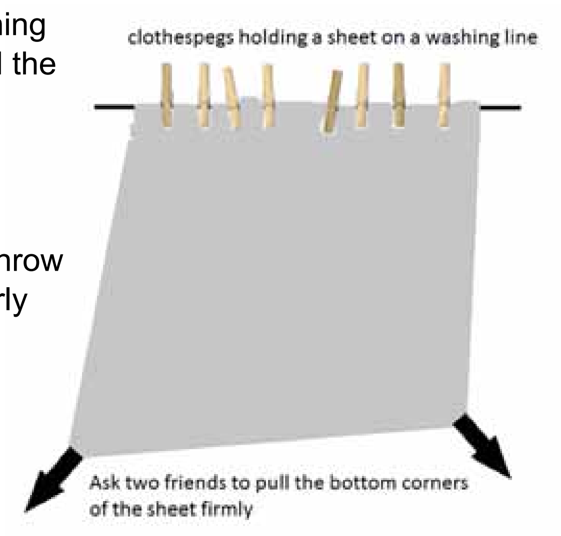
You know now that to change the momentum of any object you must apply an unbalanced force on the object for a period of time.

You push the brake pedal to stop a motor car. The brake pedal makes the car's brakes press on the wheels. The brakes exert a force on the wheels for as long as you press the pedal and this changes the car's momentum to zero.

Let us now do an activity to find out more about the force which acts when we change the momentum of a moving object to zero.

ACTIVITY 3

Suppose you hang one of your bed sheets on a washing line. Two friends pull the bottom corners firmly to hold the sheet upright.



Make predictions

1. What do you think will happen to an egg if you throw it as hard as you can at the sheet? Explain clearly why you think this will happen.

2. What do you think will happen to an egg if you throw it as hard as you can at a wall? Explain clearly why you think this will happen.

Move two or three metres away from the sheet and then throw the egg at the sheet. What happens to the egg **as it hits the sheet**? Was your first prediction correct? Do you even need to test your second prediction?

When the egg collides with the sheet, the sheet applies an impulse to the egg to change its momentum to zero. The equation for impulse is $I = F\Delta t$. The collision between the egg and the bed sheet lasts over an bigger period of time because the bed sheet has some 'give' in it. The sheet is not a rigid, hard surface. This makes the time of the collision (Δt) bigger and so the force the sheet applies to the egg is smaller. The force is too small to crack the eggshell!

The effect of collision time on force

Suppose an egg has 100 units of momentum just before it hits the bed sheet. The equation

$change\ in\ momentum = force \times collision\ time$ tells us that

$$100 = force \times collision\ time$$

So any force multiplied by any collision time will stop the egg if those two numbers multiplied together give 100 units of momentum.

ACTIVITY 4

Look at the table below to see how a change in collision time affects the size of the force needed to stop the egg.

	Momentum of egg just before it hits the sheet	Force the sheet applies on the egg	Collision time /seconds	Impulse sheet applies to the egg
1	100	100	1	
2	100	50	2	
3	100	25		
4	100	20	5	
5	100	5	20	
6	100	4		
7	100	2	50	
8	100	1		

1. Complete the table by filling in the numbers in the last column: **Impulse sheet applies to the egg.**

2. Fill in the missing values in rows 3, 6 and 8.

3. How does the size of the force needed to stop the egg change as the collision time becomes larger?

4. Which one of the two sets of conditions A and B below is less likely to break the egg? Justify your choice.

   a. $F = 10N$ $\Delta t = 10s$

   b. $F - 10\,000N$ $\Delta t = \frac{1}{100}s$

A large Δt means a small F
and
A small Δt means a large F

ANSWERS ON PAGE 199

Controlling collisions

We can and often do, use our findings to lessen pain during collisions.

The bigger the time interval, the smaller the force we need to stop a moving object.

Everyone knows instinctively that this statement is true! In fact we all use this information without even thinking about it. Do the activity below to see how.

ACTIVITY 5

Ask a young boy to jump off a table. Pay particular attention to his legs when his feet touch the ground.

1. Does the boy bend his legs or does he keep his legs straight when he lands on the floor? Ask him to repeat his jump if you are not sure.

2. A 75 kg man moves at 6.4 ms-1 just before he hits the ground. The man comes to rest when he hits the ground.

his change in momentum $= m\Delta v = m(v - u)$ and $v = 0$

$= 75kg(0\text{-}6.4)ms^{-1}$

$= -480kgms^{-1}$

his change in momentum is $480kgms^{-1}$ up

   a. In a stiff-legged landing he comes to rest in 0.1 s. Find the upward force that the ground exerts on him during this time interval.

b. When he bends his knees, he comes to a rest in 2.0 s. Find the upward force now.

3. Explain why cricketers never catch fast moving balls with their arms straight?

4. Write down as many examples as you can think of which show how people collide safely in everyday life.

ANSWERS ON PAGE 199

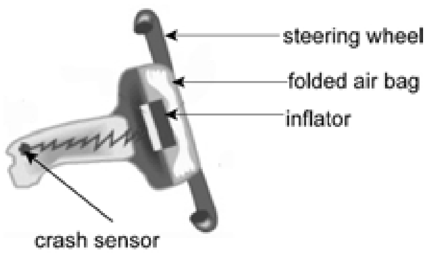
Air bags

During a collision, an impulse acts on a car and its passengers. Any passengers who are not wearing seatbelts are likely to fly through the air inside the car. They will only stop moving when they collide with something – perhaps the car windscreen, its dashboard or the steering wheel. These hard, rigid objects apply very large forces over very short time intervals and often cause severe injury or death. Air bags can prevent this.
Most modern cars are fitted with air bags. Air bags may be found in the centre of the steering wheel, in the dashboard and sometimes behind the front seats and in the doors of the car.

The purpose of an air bag is to bring a person safely to rest during a collision. They work on the same principle as crumple zones. Air bags lengthen the time interval over which the force acts. This lowers the force and so lessens injury to the people in the car.

Structure of an air bag

The diagram shows the three parts of an air bag in a steering wheel.



- The air bag is made of a thin, nylon material. It is folded into the steering wheel.
- The crash sensor is the device that tells the bag when to inflate. During a collision, an object in the steering column shifts and closes an electrical circuit. This activates the air bag inflator.

- In the inflator, two substances react vigorously to release hot nitrogen gas. The blows up the air bag which then bursts out of its storage site at about 300 km/h – faster than the blink of an eye!
- A second later, the gas quickly escapes through tiny holes in the air bag. This deflates the bag to free the driver.

ACTIVITY 6

Manto, who has a mass of 50.0 kg, is driving at 35.0 m/s (or 126 km/h) in her sports car on the N1 on her way to Pretoria. She is not wearing her seatbelt. She slams on the brakes suddenly to avoid hitting a pedestrian crossing the road. This sudden stop inflates the air bag in her car's steering wheel. The air bag stops Manto in 0.500 s.

1. What is the speed limit on the N1?

2. What average force does the air bag exert on her?

3. Suppose Manto's car does not have an air bag. When her car collides with the pedestrian, she is thrown out of her seat and flies through the air until her head hits the windscreen. The windscreen brings her to rest in 0.05 s. What force does the windscreen exert on her now?

ANSWERS ON PAGE 200

SUMMARY ACTIVITY

1. A car traveling at 12 m/s crashes into a wall and stops in 0.1s. A front seat passenger sees that the car is going to crash and tries to push against the dashboard to stop himself being thrown into the windscreen. The passenger's mass is 60 kg.

    a. With what speed is the passenger originally traveling?

    b. In what time interval does the passenger's body slow down to zero?

    c. What is the acceleration of the passenger's body during the crash?

    d. What force must the passenger apply against the dashboard to stop himself?

e. How many times is this force bigger than his weight? Do you think he could apply so large a force?

.

f. What two safety features can a car be fitted with to slow the passenger down without injuring him?

2. A 75 kg man is driving in his car at 65 km/h (18 ms^{-1}) when he collides with a truck.

   a. Suppose his car has no air bag in the steering wheel. The man collides with the steering wheel which brings his body to rest in 0.05 s. What force does the steering wheel exert on the man to stop him?

   b. Suppose his car has an air bag in the steering wheel. The air bag inflates when the car collides with the truck. The air bag brings the man to rest over a time interval of 0.8 s. What force does the air bag exert on the man's body now?

ANSWERS ON PAGE 200

CHECKLIST

Are you able to:

❒ define impulse
❒ use words and equations to describe the link between impulse and change in momentum
❒ do calculations on impulse and change in momentum
❒ compare rebound and 'sticky' collisions with respect to changes in velocity, momentum and impulse
❒ describe how changing the time interval affects force for a given impulse (or change in momentum)
❒ name and describe the principle behind two safety features in modern motor cars

LESSON 10

Work and energy

About this lesson

The word 'work' in science does not have the same meaning as the word has in everyday language. This lesson introduces the scientific concept of work and examines the very obvious effects that doing work has on different objects. In science the word 'work' involves force and movement. Furthermore work and energy are related. Something that has energy can exert force and move things. In fact, it is impossible to do work without having energy.

This lesson explores the very useful link between work and energy and shows how doing work affects the energy in different systems.

In this lesson you will:

- define work, kinetic energy and gravitational potential energy
- decide if work is or is not being done in different situations
- do calculations on work, kinetic energy and gravitational potential energy
- use the work-energy principle to relate the amount of work done to the amount of energy transferred
- define a closed system in terms of mass and energy
- recognize that when a net external force acts on a closed system the result is a change in energy of the system

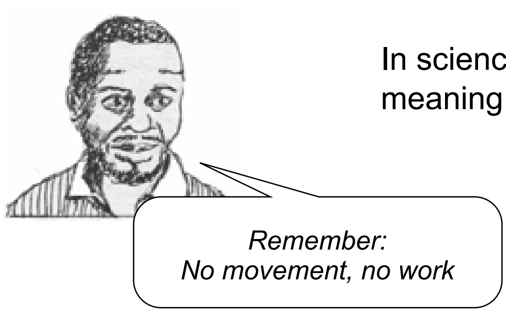
Doing work

In everyday language, the word work has different meanings.

Here are some of those meanings:

- digging a hole in the garden is work
- washing dirty dishes is house work
- work is the job you do to earn a salary
- the clock is broken; it does not work
- spending a lot of time studying is work.

The meaning of work in science



In science, the word work has one very particular and exact meaning. In science,

- we **do work** when we use a force to **move** something from one place to another.
- we **do not do work** if we use a force and nothing moves as a result of that force.

Pushing a trolley is work

We assume that the friction a 'perfectly smooth floor' exerts is so small we can ignore it. In reality, it is impossible to walk on a frictionless floor!

Suppose you push an empty supermarket trolley across a perfectly smooth floor. You start pushing the trolley at the shop's entrance and keep on pushing it in a straight line until it reaches the vegetable counter.

A push is a **force** and you are the **agent** doing work on the trolley. The force moves the trolley. So you do **work** on the trolley.

Not all the forces acting on the trolley do work

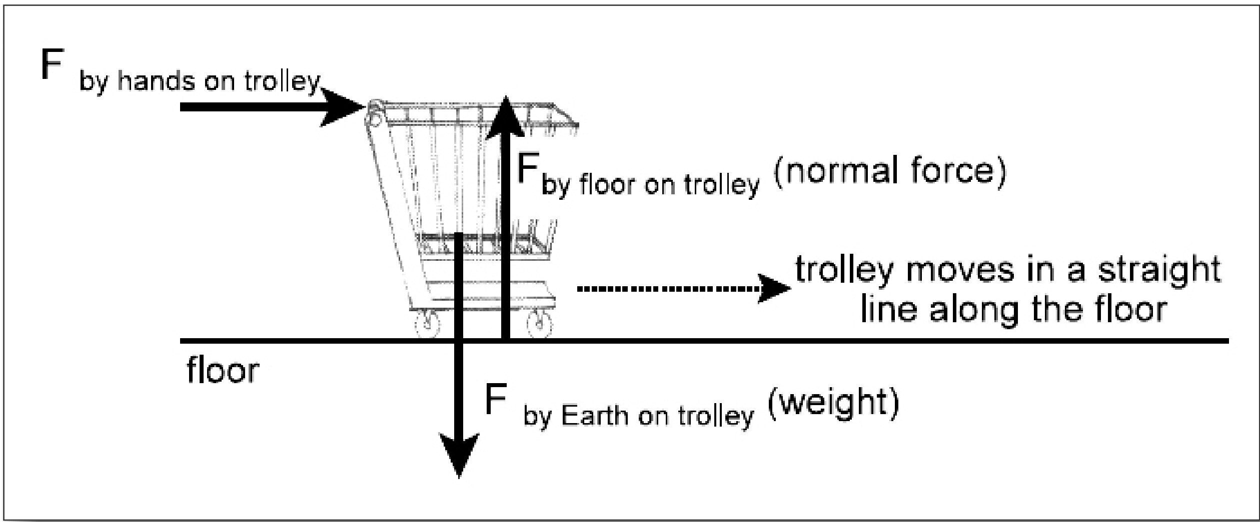
Notice that:

- the trolley moves in the same direction as the pushing force.
- the pushing force moves with the trolley.

But, the weight of the trolley (acting downwards) and the normal contact force of the floor (acting upwards) do not do work on the trolley. These two forces act at right angles to the motion of the trolley.

The trolley does not move in the direction in which these two forces act.

As a result, the weight and the normal force do not do work on the trolley.



Bigger distance, more work

When you move the trolley further away from the shop entrance, you must do more work on the trolley. Your force acts over a bigger **distance**.

Heavier trolley, more work

When the trolley is full of groceries, it is harder to push. You need a **bigger force** to move the trolley the same straight line distance from the shop's entrance to the vegetable counter.

We can see then that work involves:

- an agent that exerts a force to do work on an object,
- this force moves with the object it is doing work on,
- a distance over which the force acts,
- the force and the distance must be in the same direction.

A definition for work

Work done on an object is the force acting on the object multiplied by the distance the object moves in the same direction as the force.

In equation form this is

$W = Fs$ where W is work
and F is force
s is distance the object moves in the same direction as the force

If a distance includes direction, it becomes displacement – a vector.

So the equation $W = Fs$ becomes force times displacement in the same direction as the force.

Work is a scalar quantity

Force is a vector. The displacement in the same direction as the force is also a vector. Hence work equals one vector multiplied by another vector. Work is thus a scalar quantity. It does not have direction!

SI unit of work

Since $W = Fs$ and we measure force in newton and distance in metre, we measure work in newton metre − Nm. We call a newton multiplied by a metre a joule (J). The SI unit of work is the joule (J).

A joule is a small amount of work. So we sometimes use kilojoule (kJ) instead. 1 kilojoule is the same amount of work as 1 000 J.

ACTIVITY 1

1. A man pushes against a brick wall with a force of 500 N. The wall does not move. How much work does the man do on the wall?

2. Calculate the work done when an agent exerts a force of 250 N over a distance of 4 m. The force and the distance are in the same direction.

3. A crane lifts a concrete block with a mass of 1000 kg at constant velocity to a height of 50 m above the ground. Assume gravitational field strength to be 10 N/kg down.

    a. What is the weight of the block?

    b. What upward force must the crane apply to lift the block at constant velocity?

    c. How much work does the crane do on the block?

    d. Where does the crane get its energy from to do this work?

4. You hold a suitcase of mass 8 kg in your right hand.

    a. What force does your hand exert on it?

    b. What is the smallest force you need to lift the suitcase at constant velocity?

    c. Suppose that, by exerting this force, you lift the suitcase vertically 0,10 m. How much work do you do on the suitcase?

    d. Suppose you stand for 10 minutes holding the suitcase. How much work do you do during this 10 minute period? Explain your answer.

    e. You lift up the suitcase 1.5 m in a straight line onto your right shoulder. How much work do you do on the suitcase to lift it?

5. A ball is rolling at constant speed over a perfectly smooth, flat surface. Is work being done on the ball? Explain your answer.

ANSWERS ON PAGE 202

You need energy to do work

Neither people nor machines can do work without a supply of energy. You need energy to push a car, to move a wheelbarrow or to lift bricks. You get this energy from your food − your fuel. A machine may get this energy from petrol, diesel or electricity.

Clearly there is a connection between work and energy.

A closed system

Scientists use the idea of a **closed system** to study the link between work and energy. A scientist chooses or defines an object or objects to make up a system to study. The object/s can interact with each other and with the surroundings. The system can exchange energy but not matter with its surroundings during these interactions.

We define a **closed system** as one which can lose or gain energy but one in which the mass stays the same.

Doing work transfers energy

Let's go back to the supermarket trolley. Suppose you wish to study the trolley.

You then define the trolley as a closed system to observe. Notice that you are not part of the system. You are outside or external to the system.

When you, an **external agent**, do work on the trolley, you transfer energy from your body to the system. Your body loses some energy, but the trolley gains that energy. We know that the moving trolley has more energy than it had because it can now do work on some other object. It may knock over another object it bumps into. So the trolley is able to do work on another object but only because you did work on the trolley in the first place!

Every time we do work on a closed system, we transfer energy to that system. The amount of energy in the system changes; it is not constant.

The work-energy principle

In general we can say that if A (an external agent) does work on B (a closed system), A transfers energy to B. A loses some amount of energy but B gains exactly that same amount of energy. A's loss equals B's gain. B can then do work on some other object.

We can calculate how much work the agent does using the formula $W = Fs$.

So work done (by A on B) = energy transferred (from A to B)

So the number of joules of work we do gives us the number of joules of energy we transfer! Calculating the amount of work gives us a way to calculate energy!

This is the **work-energy** principle.

It is a very simple and useful idea. It says that the amount of work you do on a system (in joules) equals the amount of energy (in joules) the system gains. If you do 45 J of work on a ball when you throw it, the ball gains 45 J energy. If you do 150 J work on a ball when you catch it, the ball loses 150 J energy to its surroundings.

kinetic:
comes from the Greek word meaning motion

Doing work can change an object's kinetic energy. Once again, we go back to the closed system of the supermarket trolley. Doing work on the system by pushing the trolley, transfers energy to the trolley. We observe this energy transfer as a change in the state of motion of the trolley. Initially it was not moving.

The trolley only moves after you do work on the system. We call the energy an object has when it moves **kinetic energy** (E^k).

Kinetic energy

The kinetic energy of an object is the energy it has because it is moving. A stationary object has zero kinetic energy.

What does kinetic energy depend on?

The more groceries a supermarket trolley contains, the bigger its mass and the bigger the force you need to push it down the aisle.

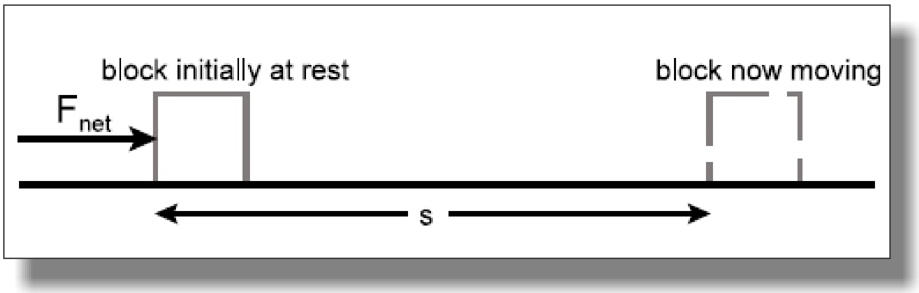
The bigger your force, the more work you do. Similarly, you must do more work on the trolley to make it move faster (change its velocity).

The amount of work that you do on an object to increase its kinetic energy depends on two things − the object's **mass** and its **velocity**.

Calculating kinetic energy

The diagram shows a closed system made up of a block of mass **m** at rest (**u** = 0) on a table. We **assume** that there is no friction between the table and the block. This means that the table is not part of the system.

Scientists often make assumptions like this about friction. Real situations involving friction are complicated and difficult to study



The block starts to move when an agent exerts a horizontal external force F_{net} on it. This net force is the vector sum of all the horizontal forces acting on the block. If F_{net} keeps acting on the block it accelerates to a velocity v. F_{net} stops acting when the block has moved a distance s in the same direction as F_{net}.

The net work the agent does on the block

= *net force x displacement*

$W_{net} = F_{net}s$

The work-energy principle tells us that the net work the external agent does on the system equals the kinetic energy gained by the block.

$E_k = F_{net}s$ ①

Newton's second law tells us the relationship between the net force acting on the block, its mass and its acceleration in the direction of the force. Note that a constant net force F_{net} causes a constant acceleration. We keep on pushing the block and so it keeps on accelerating.

$F_{net} = ma$

We replace F in equation ① $E_k = F_{net}s$ with *ma*, so

$E_k = mas$ ②

This means that we can use the equation of motion $v^2 = u^2 + 2as$ to remove s from equation ②.

$v^2 = u^2 + 2as$, *but* $u = 0$, so this becomes

$v^2 = 2as$ from which

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

We now replace displacement s in ②, $E_k = mas$ with $s = \frac{v^2}{2a}$

$$E_k = mas$$

$$= ma\left(\frac{v^2}{2a}\right) \text{ but } a \text{ cancels out and}$$

$$E_k = \frac{mv^2}{2}$$

$$E_k = \frac{1}{2}mv^2$$

An object of mass **m** traveling at a velocity v has a kinetic energy of $E_k = \frac{1}{2}mv^2$.

Since the block was initially at rest, its original kinetic energy was zero. Doing work on the block increases its kinetic energy from 0 to $\frac{1}{2}\text{mv}^2$.

Its change in kinetic energy,

$$\Delta E_k = E_{k\,final} - E_{k\,initial}$$

$$E_{kinitial} = 0 \; (u = 0)$$

$$\Delta E_k = E_{k\,final} = \frac{1}{2}mv^2$$

Kinetic energy is a scalar quantity

Mass is scalar but velocity is a vector. However the velocity is squared in the equation $E_k = \frac{1}{2}mv^2$. A vector multiplied by another vector in the same direction gives a scalar!

Units of kinetic energy

We can use the equation $E_k = \frac{1}{2}mv^2$ to work out the SI units of kinetic energy.

$\frac{1}{2}$ is a number and so has no units. We express *m* in kilogram (kg) and *v* in metre per second (ms^{-1}).

$$E_k n = n\frac{1}{2}nmnv^2 = kg\left(\frac{m}{s}\right)^2 = \frac{kg\,m^2}{s^2} = \left(\frac{kg\,m}{s^2}\right) x\ \ m$$
$$= Nm$$
$$= J$$

The SI unit of kinetic energy is the same as the SI unit for work. We express both these quantities in joule (J). A joule is a derived SI unit because it comes from basic SI units.

ACTIVITY 5

1. What is the kinetic energy of a supermarket trolley (mass 10 kg) containing 20 kg groceries when it moves at 0,5 m/s?

2. Choose the correct answer to the question. Justify your choice.

   A toy car is moving with 0.40 joules of kinetic energy. If we double its speed, its new kinetic energy will be

   a. 0.10 J

   b. 0.20 J

   c. 0.80 J

   d. 1.60 J

   e. still 0.40 J

3. An adult elephant of mass 1 000 kg charges along a road at 5 m/s.

   a. What is its kinetic energy?

   b. How does the kinetic energy of this elephant compare to the kinetic energy of a young elephant of half the mass running at the same speed along the road?

   c. Complete the sentence below by crossing out the wrong words:

      If you halve the mass of an object, its kinetic energy when it moves at the same speed **stays the same / doubles / halves**.

   d. A young elephant running at 5 m/s has 5 000 J kinetic energy.

      i. What is its mass?

         When the young elephant runs at half the speed $\left(\frac{5 \text{ m/s}}{2}\right)$ its kinetic energy is 1250 J.

      ii. How many times smaller is its kinetic energy at the lower speed than it is at 5 m/s?

      iii. Complete the sentence below by crossing out the wrong words.

      Halving the speed of an object **increases / halves / quarters** its kinetic energy.

2. A fast bowler bowls a cricket ball of mass 0,2 kg with kinetic energy of 160 J. How fast does the ball move?

3. Show your working for each of a. to e. below.

   A bicycle has a kinetic energy of 124 J. How much kinetic energy does the bicycle have if it has …

   a. twice the mass and moves at the same speed?

   b. the same mass and moves with twice the speed?

   c. one-half the mass and moves with twice the speed?

   d. the same mass and moves with one-half the speed?

e. three times the mass and moves with one-half the speed?

6. Which is always true about an object with zero kinetic energy?

a. It is on the ground.

b. It is at rest.

c. It is moving on the ground

d. It is moving.

e. It is accelerating.

f. It is at rest above ground level

g. It is above the ground.

h. It is moving above ground level.

ANSWERS ON PAGE 203

Using the work-energy principle

The work-energy principle is a useful and straightforward way to solve physics problems. Work through the following example to see how to do this.

Doing work on a cricket ball

Suppose we want to find out how much work a fast bowler must do to bowl a cricket ball (mass 0.16 kg) at 30 m/s. The obvious way to start is to use the equation $W_{net} = F_{net} \times s$.

A problem immediately becomes obvious.

- The force the bowler exerts on the ball is unknown.

- Perhaps we can use Newton's second law ($F_{net} = ma$) to find this force. The law relates the force the bowler applies to the ball to the mass (known) and the acceleration (unknown) of the ball.

- Can we use one of the equations of motion to find the acceleration of the ball? A careful look at the box alongside shows that the equations which contain acceleration (a) also contain u, Δt and s.

Equations of motion

$$v = u + a\Delta t$$

$$s = u\Delta t + \frac{1}{2}a\Delta t^2$$

$$s = \left(\frac{u + v}{2}\right) \times \Delta t$$

$$v^2 = u^2 + 2as$$

We can assume that the initial velocity of the cricket ball *u* is zero. But there is no way of working out *a* without the time interval Δt or the distance s the ball travels!

The work-energy principle comes in handy in such a situation. The kinetic energy of the ball after the throw is

$$
\begin{aligned}
E_k &= \frac{1}{2}mv^2 \\
&= \frac{1}{2} \text{ x } 0.16 \text{ kg x } (30 \text{ m/s})^2 \\
&= \frac{1}{2} \text{ x } 0.16 \text{ kg x } 900 \ \frac{m^2}{s^2} \\
&= 72 \ \frac{kgm}{s^2} \text{ x m} \\
&= 72 \text{ N x m} \\
&= 72 \text{ J}
\end{aligned}
$$

The initial kinetic energy of the ball was zero before the cricketer threw it. The work-energy principle tells us that the net work done on the ball equals the gain in kinetic energy of the ball. $W_{net} = 72J$. So simple!

ACTIVITY 3

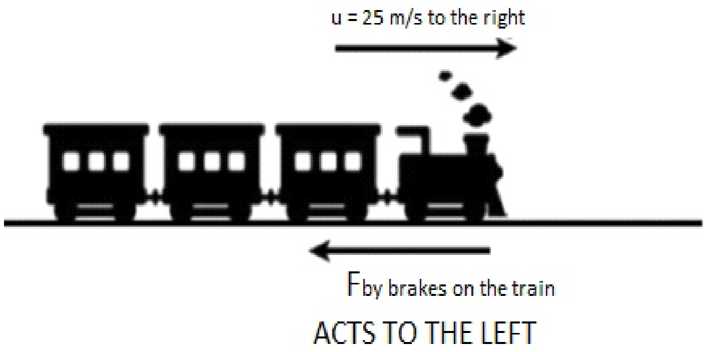
Use the work-energy principle in the following calculations.

1. Consider a closed system consisting only of a moving car. How much work will increase the velocity of a 1 000 kg car from 20 m/s to 30 m/s? Ignore the friction between the wheels of the car and the road.

"Frictionless" road surface is not part of the closed systen

2. A train of mass 1 600 000 kg travels along a horizontal railway line at 25 m/s.

   The driver activates the train's brakes 1 km away from a station where the train must stop. Assume that the braking force is constant over the one kilometre distance.



a. The braking force stopping the train acts to the left. However the train moves to the right while the braking force acts. When we calculate the work done by the brakes on the train, the force and the train's displacement must be in the same direction! Which one below will make the braking force and the distance it acts over in the same direction?

i. $W = +F \times +s$
ii. $W = -F \times -s$
iii. $W = +F \times -s$

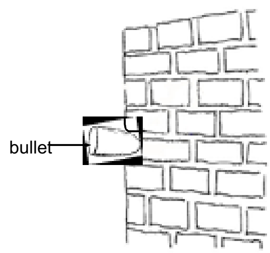
b. Use $\Delta E_k = E_{k\ final} - E_{k\ initial}$ to work out the change in kinetic energy of the train after it has stopped at the station.

c. What do you think the meaning of the negative sign in your answer to b is?

d. Write a word equation to show how you can use the work-energy principle to relate the work the brakes do to stop the train to the change in kinetic energy of the train. Remember to take direction into consideration as in your answer to a. above.

e. Work out the force the brakes exert to stop the train. Ignore friction between the train's wheels and the railway line.

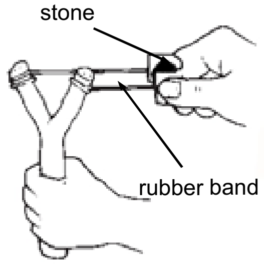
3. A wall does 8 000 J of work to stop a bullet with a mass of 10 g. What is the velocity of the bullet before it hits the wall?



ANSWERS ON PAGE 205

Doing work to change an object's position

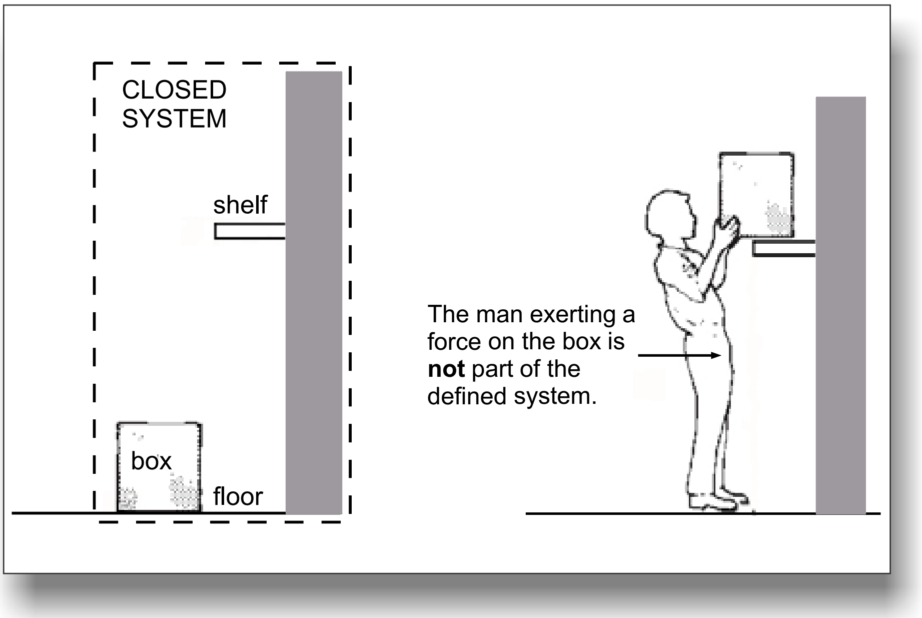
An object can store energy as a result of its position. The diagram shows a boy stretching the rubber band on his catapult. This stretching is a force and it does work on the rubber band to change its position.



The work gives the rubber band the potential to do work on or to transfer energy to the stone. We say the stretched rubber band has stored energy of position or **potential energy**. This energy exists because the rubber band can stretch. We call it **elastic potential energy**.

Doing work without changing kinetic energy

The dashed box in the diagram shows a closed system containing a box, a wall and a shelf. The floor (the Earth) is also part of the system.



Now suppose a man outside the system does work on the box. He lifts it from the floor onto the shelf. He uses an upward force just big enough to balance the weight of the box. This force moves the box up at constant velocity. So the kinetic energy of the box does **not** change. Only the position of the box does.

The work the man does on the system transfers energy to the system by changing the position of the box relative to the Earth's surface. When the box is on the shelf it has the potential to do work on some other object. We say that the box has potential energy which we call **gravitational potential** energy. If the box falls off the shelf it can do work on some other object.

It is important to note that potential energy belongs to the system, the box **and** the Earth, and not to the box on its own.

Gravitational potential energy (E_p) is the energy an object has as a result of its position relative to some other place (usually the Earth's surface).

What factors affect gravitational potential energy?

An object's gravitational potential energy depends on the amount of work you do to lift the object at constant velocity. The more work, the greater the object's gravitational potential energy.

Now common sense tells us that the

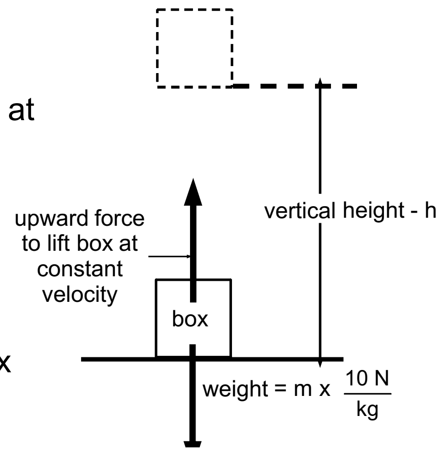
- heavier the object (the bigger its weight), the more work you must do to lift it to the same height.
- higher you lift the object the more work you must do to lift the box.

But, the work you do on the box transfers energy from your body to the system containing the object.

Gravitational potential energy must depend on **weight** and vertical **height** above the Earth's surface.

Calculating gravitational potential energy

Suppose a box mass *m* on the floor in a closed system has zero gravitational potential energy. We can increase the gravitational potential energy of the system by lifting the box at a steady speed to a vertical height *h* above the floor.



The **downward** force on the box

$= F_{\text{exerted by Earth on box}}$ = weight of the box

An **upward** force equal in magnitude to the weight of the box will move the box up at steady speed.

In general then, work done to lift the

box = force × vertical displacement of the box

In this case then, work done to lift the box

= weight of the box × vertical height above

According to the work-energy principle the work done increases the gravitational potential energy of the system.

So, the increase in potential energy of the system

= weight × vertical height

In symbols, this is $\Delta E_p = wh$
where ΔE_p is the change (in this case an increase) in gravitational potential energy of an object,
w is the weight of the box (upward force the agent exerts to lift the object), and
h is the vertical distance up over which the force acts.

The gravitational potential energy belongs to the system, not to the box. This is because the external agent does work against the gravitational force acting on the box. Doing work changes the gravitational potential energy of the system.

Units of gravitational energy

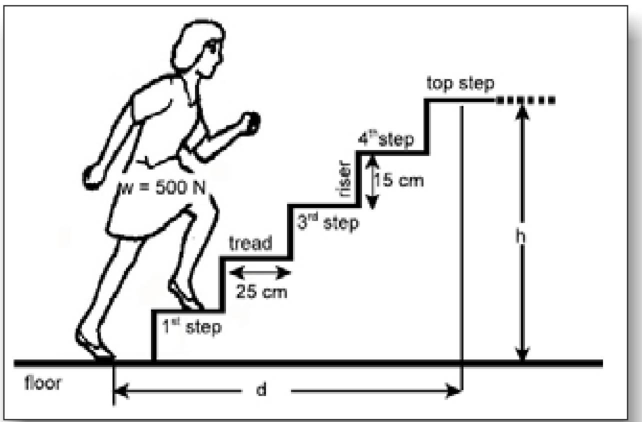
We can use the equation $\Delta E_p = wh$ to work out the units of gravitational potential energy. We express *w* in newton and I in metre.

$E_p = wh = N\ m = \ J$

The SI units of gravitational potential energy, kinetic energy and work are joule.

ACTIVITY 4

1. The diagram shows a woman with weight 500 N climbing a flight of steps. The flat part of each step is the tread. This is where the woman puts her feet. The tread of the steps is 25 cm. The riser is the vertical portion between each tread. The risers are 15 cm high.



Suppose the woman climbs from the floor to the top step.

a. Show that the vertical distance between the floor and the top step is 0.75 m.

b. Show that the horizontal distance between the woman's position on the floor and the middle of the tread on the top step is 1.25 m.

c. The woman does work to lift her body at constant velocity from the floor to the top step. This work = force × distance

   i. Which distance (0.75 m or 1.25 m) must you use in this formula? Justify your choice.

ii. What force should you use in this formula? Explain your answer.

d. Assume that the woman has zero gravitational potential energy when she stands on the floor. Use information from the diagram to fill in the values missing from the table.

position of woman	height above floor/m	gain in E_p relative to the floor /J
on floor	0	0
on first step	0.15	75
on second step		
on third step	0.45	
on fourth step		
on top step		

Use numerical data from your completed table to explain your answers to e. and f. below.

e. How does the woman's gravitational potential energy change when she makes her vertical height above the floor three times higher?

f. What happens to her gravitational potential energy relative to the floor when she halves her vertical height?

g. Cross out the wrong words in the following sentences.

Gravitational potential energy **depends on / does not depend on** the vertical height of an object above the Earth's surface. Lifting an object to half the vertical height above the Earth's surface, **has no effect on / halves / doubles** the gravitational potential energy of the object.

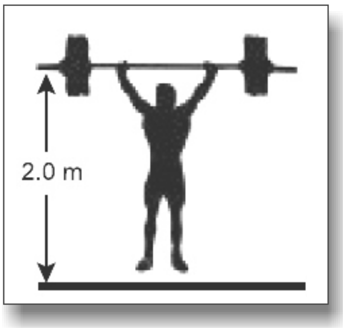
h. Work out the increase in gravitational potential energy of a 1000 N man when he lifts his body at a steady speed from the floor to the top step.

i. How does the gravitational potential energy of the man compare to the gravitational potential energy of the woman when they are both on the top step?

j. Cross out the wrong words in the following sentences.

Gravitational potential energy **depends / does not depend** on **weight only / mass only / both mass and weight**. At the same place, doubling weight **halves / doubles / has no effect on** gravitational potential energy.

k. Suppose the woman takes a different path to get from the floor to the top step. She jumps from the floor to the third step and then jumps from there to the top step. The diagram shows her path. How much gravitational potential energy will she have now when she is on the top step? Does her change in gravitational potential energy depend on the path she takes to get to the top step? Explain.



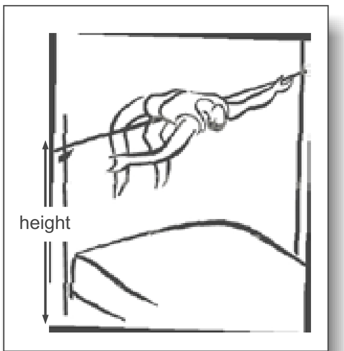
2. A weightlifter lifts a 55 kg bar at steady speed to a height of 2.0 m above the ground.

a. How much energy does the weightlifter transfer to the bar when lifting it?

He holds the bar for 5 s in this position.

b. Explain why the gravitational potential energy of the bar does not change while the weightlifter holds it above his head.

c. Does the gravitational potential energy of the bar increase, decrease or remain the same when the weightlifter lowers the bar to the ground? Explain your answer.

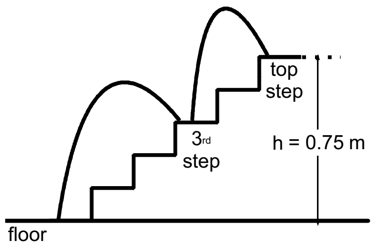


3. An Olympic high jumper is able to lift his body (mass 80kg) over a bar by doing 1920 J of work on it. How high is the bar above the ground?

4. A learner drops a soccer ball out of the window of a classroom. Does the gravitational potential energy of the ball increase or decrease as the ball falls through the air? Explain your answer.

ANSWERS ON PAGE 207

SUMMARY ACTIVITY



1. Read each of the following statements carefully. Decide if each statement has to do with kinetic energy, potential energy or both kinetic and potential energy. Write your choice in the last column of the table.

	Statement about energy	E_k / E_p / both E_k and E_p
a	We describe the amount in joule.	
b	If an object is at rest on the floor, it certainly does **not** have this energy.	
c	Depends upon the mass and velocity of an object.	
d	A raindrop falling towards the ground has this energy.	
e	Doubling velocity, makes this energy four times greater.	
f	An object at rest does not have this energy.	
g	An object has this energy due to its position (or height).	
h	The energy an object has when it moves.	

2. A hailstone falls through the air with 0.80 J potential energy. Another identical hailstone with double the speed at double the height has potential energy of

   a. 0.20 J

   b. 0.40 J

   c. 1.60 J

   d. 3.60 J

3. An 80 kg skydiver has a speed of 60 m/s at an altitude of 870 m above the ground.

   a. Determine the kinetic energy of the skydiver.

   b. Determine the potential energy of the skydiver.

4. Imagine that you observe a closed system consisting of a box. The box is moving horizontally when you start watching it.

a. Describe the way the box moves when a net frictional force opposes its horizontal motion.

b. Does the kinetic energy of the box **increase / decrease / stay the same** while friction acts? Explain your answer.

c. Does the gravitational potential energy of the system **increase / decrease / stay the same** while friction acts? Explain.

d. Is work being done on the system? Explain your answer.

5. Imagine you observe a different closed system consisting of a box moving horizontally. This time the box keeps on moving at constant velocity while you observe it.

   Now two external forces act on the box. One of these forces is a horizontal frictional force acting to the right.

   a. What other force acts on the box to keep it moving at constant velocity? (HINT: Think of what Newton's first law has to say about the forces acting on an object moving at constant velocity.)

   b. Is work being done on the box? Explain.

   c. Do you think it is possible to do work without transferring energy? Explain.

ANSWERS ON PAGE 210

CHECKLIST

Are you able to:

- ❐ define work, kinetic energy and gravitational potential energy
- ❐ decide if work is or is not being done in different situations
- ❐ do calculations on work, kinetic energy and gravitational potential energy
- ❐ use the work-energy principle to relate the amount of work done to the amount of energy transferred
- ❐ define a closed system in terms of mass and energy
- ❐ recognize that when a net external force acts on a closed system the result is a change in energy of the system

LESSON 11

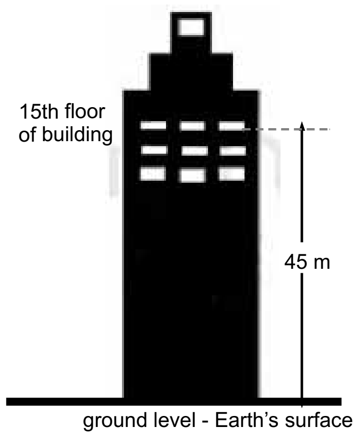
Conservation laws

About this lesson

This lesson deals with two conservation laws that help us understand how objects interact. We make use of a situation in which a tennis ball falls freely to Earth to illustrate how energy is conserved. This leads to an exploration of momentum in situations in which objects collide with each other or separate into two parts.

In this lesson you will:

- describe and calculate changes in the kinetic and gravitational potential energy of an object as it falls to Earth
- define free fall and mechanical energy
- define an isolated system
- state and use the law of conservation of energy to solve problems
- classify everyday interactions between objects into groups having similar properties
- distinguish between elastic and inelastic collisions
- state and use the law of conservation of momentum to solve problems
- compare closed and isolated systems



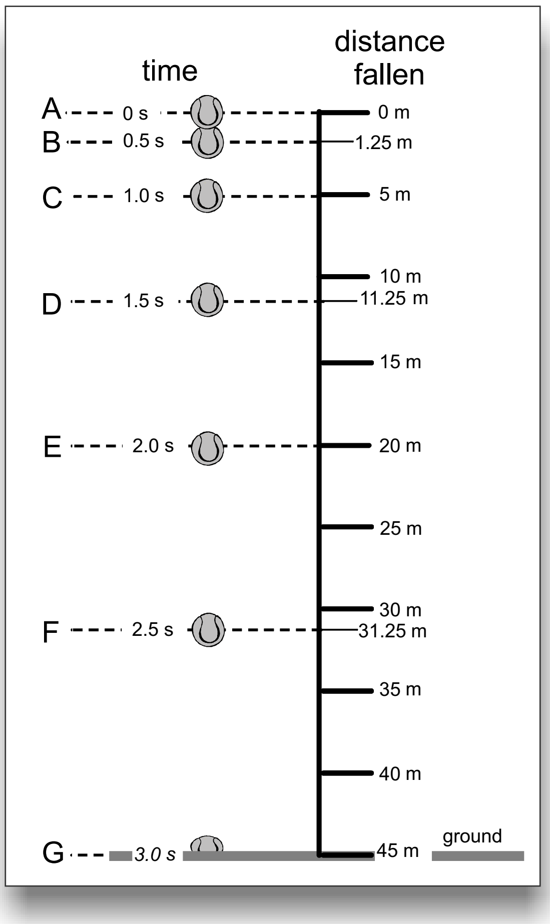
A falling tennis ball

Suppose you climb up many steps to reach the fifteenth floor of a high building. You carry a tennis ball with you. You do work to lift your body and the ball at constant velocity through a vertical distance of 45 m. Your body and the ball both gain gravitational potential energy as a result of your work.

Now we focus only on the ball. Suppose you lean out of a window and drop the tennis ball. Imagine that your friend stands in a suitable place outside the building. She uses an automatic camera to take a photograph of the ball every half second as it falls.

We use information from her photographs to draw the diagram alongside. The distance scale shows the distance the ball falls from rest at regular half second intervals.

ACTIVITY 1



In this Activity, you will use information from the diagram to analyse the ball's motion.

1. What is the initial speed of the ball? How do you know?

2. How long after you drop the ball does it hit the ground?

3. How high is the ball above the ground at $t = 0s$?

4. Look carefully at the diagram. What is your first impression about the ball's motion? Do you perhaps think that the ball falls at constant velocity towards the ground? Explain your answer.

   The distance the ball falls during the first 0.5 s (AB on the diagram) is $(1.25m - 0m) = 1.25m$.

   Likewise, the distance the ball falls during the time interval

$t = 0.5$ s to $t = 1.0$ x (BC on the diagram) is $(5.0m - 1.25m) = 3.75\ m$

5. How far does the ball fall during each of the time intervals below? Show your subtractions in each case.

   a. t = 1.0 s to t = 1.5 s (CD on the diagram)?

   b. t = 1.5 s to t = 2.0 s (DE on the diagram)?

   c. t = 2.0 s to t = 2.5 s (EF on the diagram)?

   d. t = 2.5 s to t = 3.0 s (FG on the diagram)?

6. Use your answers to question 5 to cross out the wrong words in the following sentences.

   The closer the ball gets to the ground, the **bigger / smaller** the distance it falls in 0.5 s. This means that the ball must be moving **slower and slower / faster and faster** as it gets closer to the ground. The ball must be moving with **constant velocity / accelerating** as it gets closer to the ground.

In Lesson 10 you learnt to calculate kinetic energy and potential energy using the equations $E_k = \frac{1}{2}mv^2$ and $E_p = \text{weight} \times h$.

7. a. What does the *v* in the equation for kinetic energy represent?

   b. How do you think the kinetic energy of the tennis ball changes as it gets closer to the ground? Explain your answer.

8. a. What does the h in the equation for potential energy represent?

   b. How do you think the potential energy of the tennis ball changes as it gets closer to the ground? Take care not to confuse distance fallen and height above the ground.

9. Cross out the wrong words in the following sentences to summarise your findings so far.

   As the ball falls towards the ground its kinetic energy **increases / decreases / remains the same**. But at the same time that the ball **loses / gains** kinetic energy, its potential energy **increases / decreases / remains the same**.

ANSWERS ON PAGE 211

Predictions and calculations

In Activity 1, 8b of this lesson, you predicted how you think the gravitational potential energy of a tennis ball changes as it falls towards the Earth. Now you are going to use the formula $E_p = \text{weight} \times h$ to **calculate** how much gravitational potential energy the ball actually has at different points on its way down. Then you will compare your predictions with your calculations to see if you predicted correctly!

The weight of the ball

Suppose the ball has a mass of 100 g. This is the same as

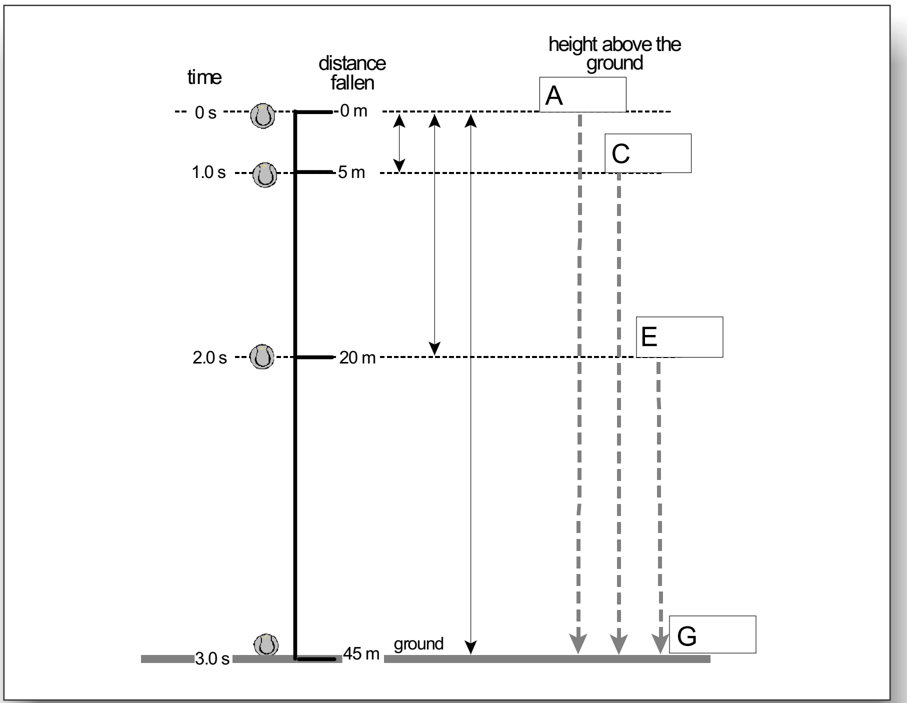
$$\frac{100}{1000}\text{ kg} = 0.1\text{ kg}$$

The weight of the ball is equal to mass x 10 $\frac{N}{kg}$ down.

The weight of the ball does not change during its fall.

ACTIVITY 2

Let us work out the potential energy of the tennis ball.The diagram shows the ball's position at t = 0 s, t = 1 s, t = 2 s and at t = 3 s after you drop it.



At t = 0 s, the ball is in your hand at a height of 45 m above the earth.

1. Fill this height into Box A on the diagram. The dashed grey arrow shows this height.

2. One second after you drop the ball (at t = 1s), the height of the ball above the Earth h = (45 m – 5 m) = 40 m. Fill this height into box C on the same diagram.

3. Work out the heights missing from boxes E and G on the diagram. Write them on the diagram too.

Remember the h in E_p = weight x h is the ball's height above the Earth and not the distance the ball has fallen!

4. Collect all the information you need to complete the table below.

time/s	height above Earth /m	weight/N	E_p = wh /J
0	45	1	E_p = wh = 1 N x 45 m = 45
1			
2			
3			

5. a. How does the gravitational potential energy of the tennis ball change as it gets closer to the Earth? Use the values from your table to give your answer.

   b. How do your calculations compare to your predictions in Activity 1, 8b?

6. At which point above the Earth does the ball have

   a. maximum potential energy?

   b. minimum potential energy?

ANSWERS ON PAGE 212

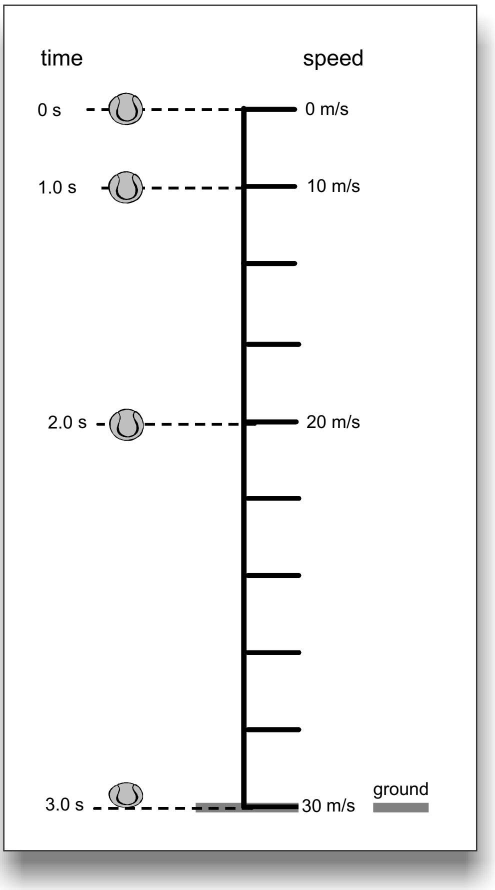
ACTIVITY 3

Kinetic energy of the tennis ball

Suppose we are able to measure how fast the tennis ball falls at different points on its way to the ground. The diagram shows its downward velocity at one second intervals.

1. Use the diagram to fill in / work out the values missing in the squares in the table on the next page.

time / s	mass / kg	velocity / m/s	$(\text{velocity})^2$ / $(\text{m/s})^2$	kinetic energy $E_k = \frac{1}{2} mv^2$ / J
0	0.1	0	0	$= \frac{1}{2} \times 0.1 \text{ kg} \times 0 \text{ (m/s)}^2 = 0$
1	0.1	10	$(10)^2 = 100$	
2	0.1			
3	0.1			



ANSWERS ON PAGE 213

In Activity 1 number 6. you probably realized that the ball's velocity increases on its way down. But did you relate the ball's velocity correctly to its kinetic energy? Let's see.

2. a. How does the kinetic energy of the tennis ball change as it gets closer to the Earth? Use the values you calculated in your table to answer the question.

   b. How do your calculations compare to your predictions in Activity 1, number 6?

3. At which point above the Earth does the ball have

   a. maximum kinetic energy?

   b. minimum kinetic energy?

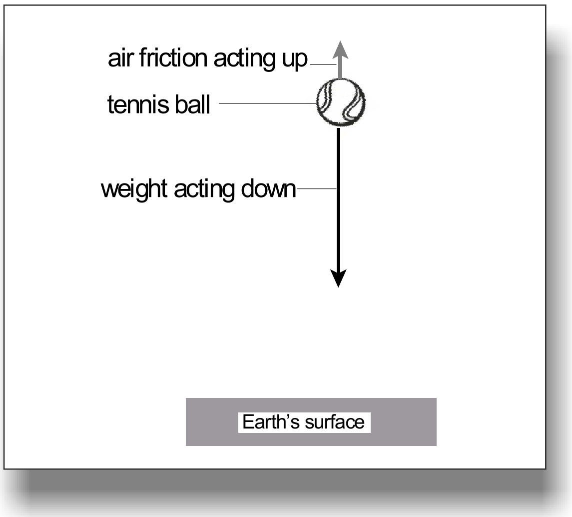
4. a. Use the diagram to work out how much faster the ball moves in each second.

   b. What is the ball's acceleration?

Free fall

The diagram on the next page shows the two forces acting on the tennis ball as it falls. The short grey arrow represents the upward force the air exerts on the ball. This is air friction. The long black arrow represents the downward force the Earth exerts on the ball. This is the weight of the ball. But the diagram is not drawn to scale! The arrow showing the air friction is longer than it should be.

When a ball falls through a distance as small as 45 m, the air friction acting on the ball is so small that we can ignore it. Hence we can assume that there is only one force − a gravitational force − acting on the falling ball. We say the ball is in **free fall**.



An object is in **free fall** if the only force acting on it while it falls is the gravitational force the Earth exerts on the object.

Gravitational acceleration − g

We see in Activity 3 that the tennis ball accelerates uniformly at 10 m/s^2 down as it falls. The only force acting on the ball when it is in free fall is Earth's gravitational force. It must be this force that makes the ball accelerate uniformly.

We say that the gravitational force causes a **gravitational acceleration (g)** on all falling objects.

$\frac{10\text{ N}}{\text{kg}}$ **is the same as 10 ms^{-2}**

In Lesson 3 you used the equation weight = mass $\times \frac{10\text{N}}{\text{kg}}$ to change mass into weight. Now

$$\frac{10\text{ N}}{\text{kg}} = 10\ \frac{\text{kg m}}{\text{s}^2} \text{ x } \frac{1}{\text{kg}} = 10\ \frac{\text{m}}{\text{s}^2} = 10\text{ ms}^{-2}.$$

metres per square second are units of acceleration. So

$$\frac{10\text{ N}}{\text{kg}} = 10\text{ ms}^{-2}$$

weight = mass × gravitational acceleration

or, in symbols, $w = mg$.

Mechanical energy

Sometimes it is convenient to think about both an object's kinetic energy and its potential energy together. We then refer to its **mechanical energy**.

Mechanical energy (E_{mech}) is the sum of an object's kinetic and potential energy at any instant.

$E_{mech} = E_k + E_p$

We now investigate the mechanical energy of the system consisting of the tennis ball and the Earth at different times during the ball's fall towards the Earth.

ACTIVITY 4

Activity 2 shows us that the gravitational potential energy of a ball decreases as it falls to Earth. By contrast, in Activity 3, we see that the kinetic energy of the ball increases as it gets closer to the Earth.

The table shows the amounts of kinetic and gravitational potential energy of the tennis ball at four different times during the ball's fall to Earth.

	These values for E_p come from Activity 2	These values for E_k come from Activity 3	
time / seconds	**E_p of the ball / joules**	**E_k of the ball / joules**	**mechanical energy of the ball / joules**
0	45	0	$E_{mech} = E_p + E_k$ $= 45J + 0J$ $= 45J$
1	40	5	
2	25	20	
3	0	45	

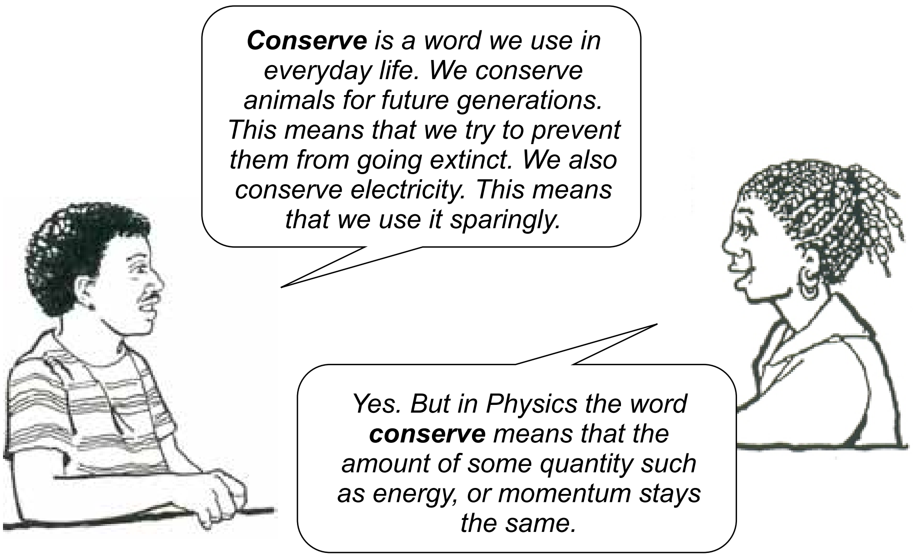
1. Complete the table by calculating the mechanical energy of the ball at t = 1 s, t = 2 s and at t = 3 s. Show your working.

2. What do you notice about the mechanical energy of the ball at any instant?

ANSWERS ON PAGE 214

Energy is conserved

We have discovered a simple and very useful idea about the mechanical energy in the system consisting of the tennis ball and the Earth. It stays constant. In this case, the constant value is 45 J. We say that the mechanical energy in this system is constant or **conserved**.



Loss equals gain

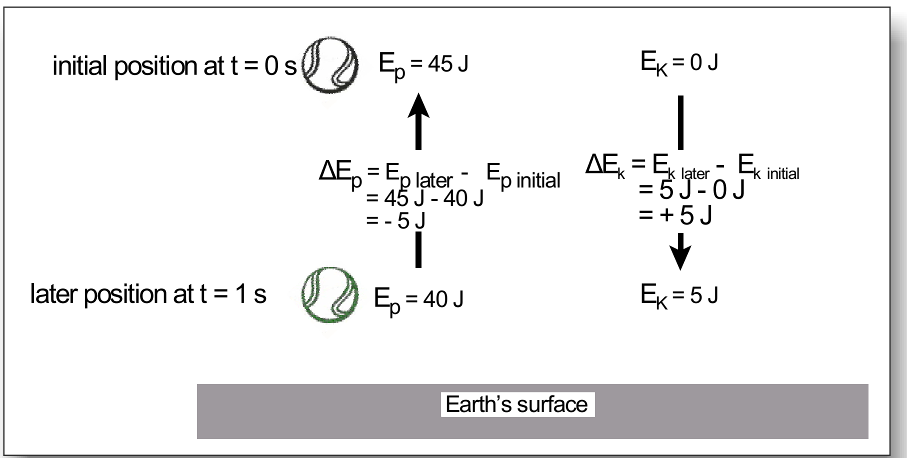
The diagram below shows the ball at two different positions during its fall.

At t = 0 s, the ball's initial position, the ball is at rest in your hand. Its gravitational potential energy (E_p) is at its maximum value of 45 J. Its kinetic energy (E_k) is at its minimum value − zero − because the ball is not moving.

Initial mechanical energy of the system $= E_{p\ initial} + E_{k\ initial}$

$= 45\ J + 0\ J$

$= 45\ J$



One second after you drop the ball (at t = 1s), it is in its later, lower position. Its gravitational potential energy (E_p) decreases to 40 J. The change in the ball's potential energy is 5 J. The ball is now falling so its kinetic energy increases to 5 J. Its change in kinetic energy is 5 J.

If potential energy of the ball decreases, then its kinetic energy increases by the same amount to compensate. The loss of gravitational potential energy is the same as the gain in kinetic energy. The system does not lose energy.

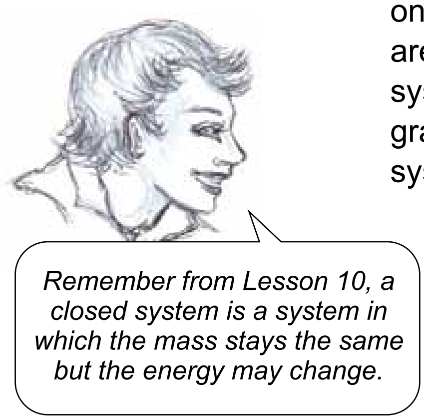
Mechanical energy of the system at lower point

$$= E_{p\ initial} + E_{k\ initial}$$
$$= 40J + 5J$$
$$= 45J$$

This system consisting of the tennis ball and the Earth cannot be a closed system. The energy of a closed system changes when we do work on it. The energy in this Earth-tennis ball system stays constant!

An isolated system

Up to this point in the lesson we have focused our attention on only one system. This system consists of two objects. These are the tennis ball and the Earth. The Earth must be part of the system because the Earth causes the tennis ball to have gravitational potential energy. Potential energy belongs to the system, not to the ball alone. If there was no Earth,



- you would not need to do work on the ball to lift it to the fifteenth floor of the building,
- you would not transfer energy to the ball,
- the ball would not gain gravitational potential energy as a result of your work!

The tennis ball and the Earth are an **isolated system**.

An **isolated system** is one that does not interact in any way with its surroundings. No **transfer** of matter or energy between the system and its surroundings can take place. Matter and energy can**not** move between the system and its surroundings. The amount of energy and the amount of mass in the system is constant at all times.

Internal and external forces

The Earth is the agent exerting the force that does work on the tennis ball when you drop it. But the Earth is part of this isolated system. Hence the gravitational force that the Earth exerts on the ball is a force exerted by an object that is inside the system. The gravitational force is an **internal force**.

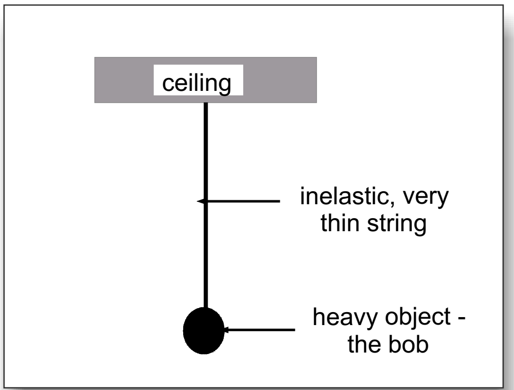
In a **closed system** the agent that exerts a force to do work is **not** part of the system. An **external force** does work on a closed system.

When you exert a force to accelerate a supermarket trolley, a closed system, your hand exerts an **external** force on the trolley. This increases the kinetic and hence the mechanical energy of the system. If the floor is rough, then some of the work you do on the trolley overcomes friction. Friction is always an **external** force.

Law of conservation of energy

If only internal forces are acting, the mechanical energy of an isolated system neither increases nor decreases during any process. Mechanical energy is constant at all times. A swinging pendulum is an example of an isolated system.

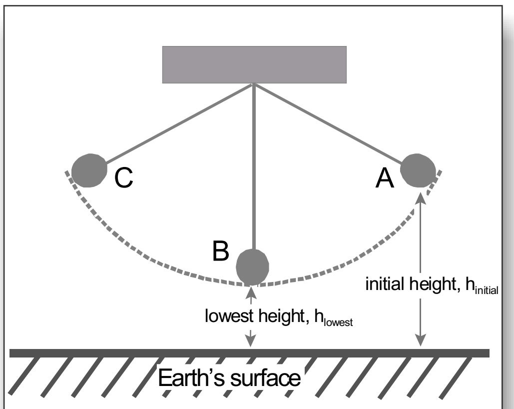
A pendulum



A pendulum consists of a heavy object, the bob, hanging from a string that does not stretch. You can make a pendulum by hanging a stone on a piece of string.

When we pull the pendulum to the right (A) and then let it go, it swings backwards and forwards along the same path. We assume that there is no friction,

- between the bob and the air,
- at the point where the piece of string meets the ceiling.



Such a perfect or ideal pendulum will keep swinging backwards and forwards along the dashed line from

A → B → C → B → A

over and over forever! A real pendulum, however soon stops swinging because of friction.

An isolated system

The pendulum and the Earth form an isolated system.

Gravity does work on the pendulum

The Earth exerts a force on the pendulum when it falls from its initial, highest position ($h_{initial}$) at A to its lowest position (h_{lowest}) at B. This is an internal force. Do you remember from Lesson 10 that the work the Earth does on the bob does **not** depend on the length of the path the bob follows? The work done by the Earth depends only on the vertical distance between the bob's highest position (A) and lowest position (B).

The bob's gravitational potential energy changes

Gravitational E_p of the bob = weight of the bob × height above the Earth. The weight of the bob stays the same as it swings. But the height of the bob above the Earth decreases as the bob moves from A to B. Hence from A to B, the gravitational potential energy of the bob decreases.

Exactly the opposite happens when the bob moves further and further away from the Earth from B to C.

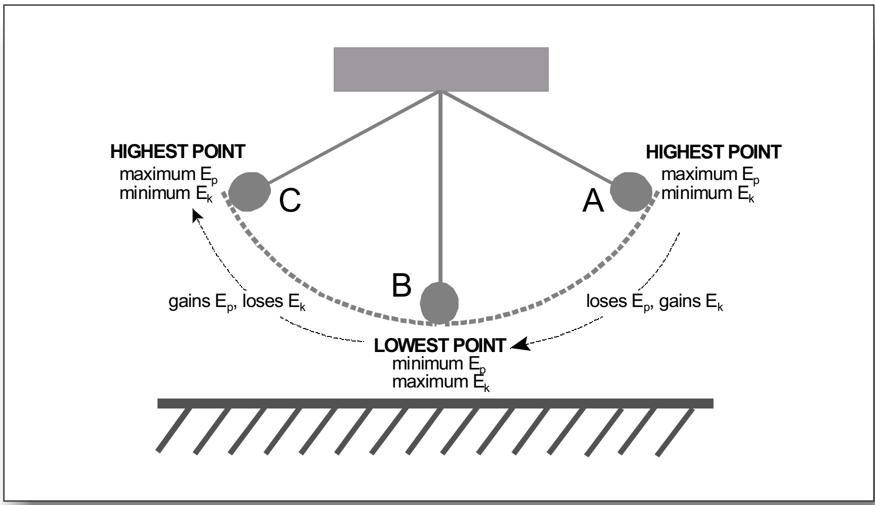
To summarise:

- when the bob moves down, its E_p decreases
- when the bob moves up, its E_p increases.

The bob's velocity changes too

The bob does not swing backward and forwards with constant velocity. At A, the bob is not moving; it has zero velocity and zero kinetic energy. When the bob moves from A to B, its velocity changes in exactly the same way as the tennis ball's velocity changes when you drop it. It moves faster and faster as it falls towards B. It reaches its highest velocity at the lowest point of its swing (B).

Exactly the opposite happens when the bob moves further and further away from the Earth from B to C. It moves slower and slower until its velocity is again zero at C.



To summarise:

- when the bob moves down, its E_k increases.
- when the bob moves up, its E_k decreases and becomes zero at its highest point.

But, the bob's mechanical energy stays the same

The pendulum and the Earth form an isolated system. The only force doing work on the pendulum is an internal force which is gravity. The law of conservation of energy tells us that the mechanical energy of the system stays at the same constant value all the time. No energy is transferred or moves into or out of the system. Within the system however, there is a continuous change from potential energy to kinetic energy or from kinetic to potential energy.

ACTIVITY 4

1. Choose the correct answer.

   The total mechanical energy of a pendulum is the ......

   a. E_k minus the E_p of the pendulum.

   b. E_p minus the E_k of the pendulum.

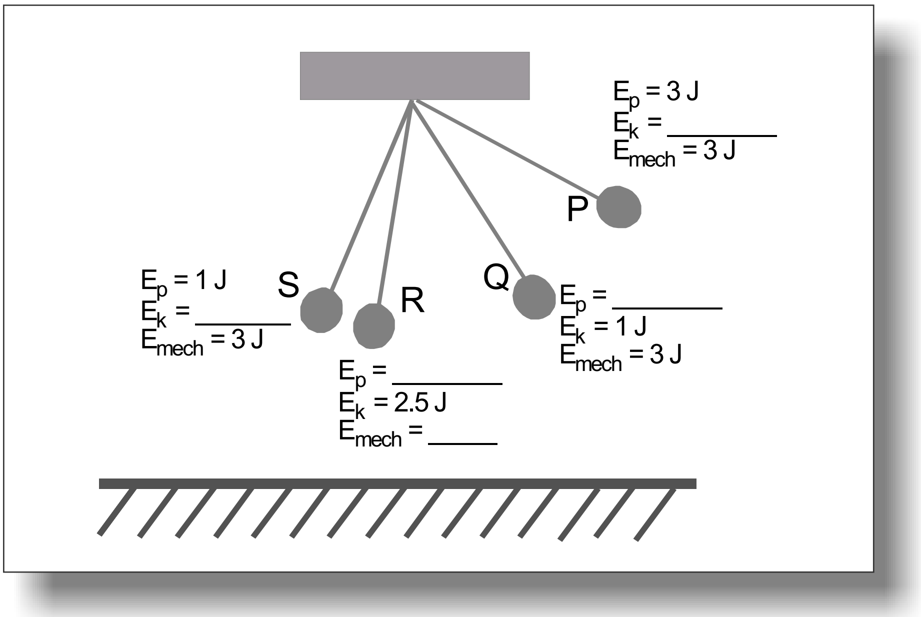
   c. initial E_k plus the initial E_p of the pendulum.

   d. E_k plus the E_p of the pendulum at any instant during its motion.

   e. final amount of E_k and E_p minus the initial amount of E_k and E_p.

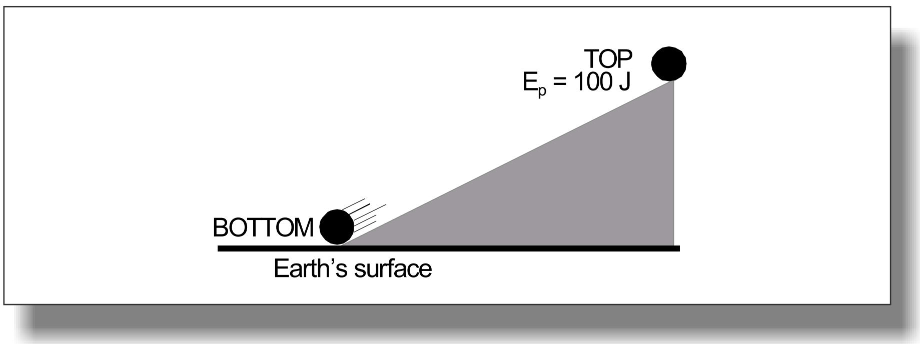
2. The diagram shows the potential, kinetic and mechanical energies of a pendulum at four different positions P, Q, R and S.

   a. Work out the missing energy values. Show your working.



   b. This particular pendulum never has zero gravitational potential energy. Why do you think this is so?

3. Imagine that you hold a ball of mass 2 kg at rest at the top of a ramp as in the diagram. Suppose the ball has 100 J of gravitational potential energy in this position.



   a. How much kinetic energy does the ball have at the top of the ramp? How do you know this?

When you let the ball go, it rolls down the ramp.

   b. What happens to the gravitational potential energy of the ball as it rolls? Why? Think of the ball as behaving just like a pendulum moving to its lowest point.

c. What do you think happens to the kinetic energy of the ball as it rolls down the plank? Justify your prediction.

d. Suppose the diagram represents an isolated system. What things are part of the system?

e. Suppose we ignore the friction between the ball and the surface of the ramp. Which of A, B or C below correctly describes the relationship between the mechanical energy (E_{mech}) of the system at the top and at the bottom of the ramp?

A E_{mech} TOP > E_{mech} BOTTOM

B E_{mech} TOP = E_{mech} BOTTOM

C E_{mech} TOP < E_{mech} BOTTOM

f. Where, on the ramp is the gravitational potential energy of the ball zero? Why?

g. How much kinetic energy do you think the ball has at the bottom of the plank? Explain.

h. Mechanical energy is the sum of gravitational and kinetic energies of the ball. So,
$E_{p\ TOP} + E_{k\ TOP} = E_{p\ BOTTOM} + E_{k\ BOTTOM}$ ...... Equation 1

Two of the terms in Equation 1 are zero. Which are they? Rewrite Equation 1 leaving out these two terms.

i. Use the formula from h and $E_k = \frac{1}{2} mv^2$ to work out the velocity of the ball just before it hits the Earth at the bottom of the ramp.

ANSWERS ON PAGE 215

Interactions

Interactions are common in everyday life. Think of the simplest interactions - interactions between only two objects.

When two objects interact, both objects exert and experience a force. When you push a wall, the wall pushes you! Newton's third law tells us that the force you exert on the wall is the same size as the force the wall exerts on you. The two forces act in different directions.

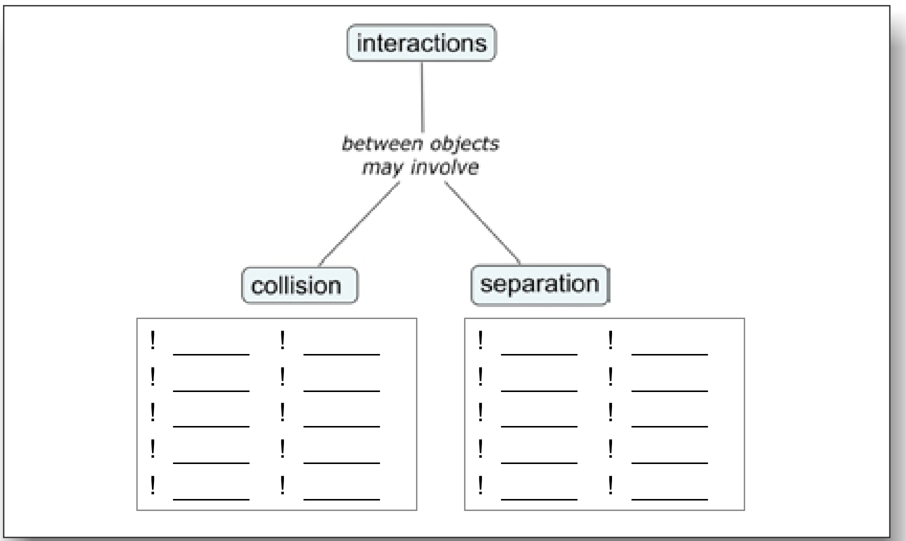
ACTIVITY 6

The list below describes some everyday interactions between objects.

1. Classify these interactions into groups. Put the interactions which involve collisions into one group.

   Put the interactions which involve objects which separate into another group. Write the letter of each interaction into the correct place on the diagram below the table.

LIST of INTERACTIONS			
A	A fielder in a cricket match takes a difficult catch.	H	A moving ball hits a tennis racquet.
B	A ball bounces off a wall.	I	A bomb explodes in midair.
C	Sipho gives his friend a lift on a bicycle. The friend jumps off the moving bicycle.	J	Two girls on roller skates stand facing each other. One girl pushes the other girl.
D	A truck collides with a parked car. The two join together and move into the middle of the road.	K	An insect is squashed after it flies into your windscreen.
E	You stand on roller skates and throw a heavy parcel to your friend.	L	A bullet leaves the barrel of a gun when a soldier pulls the trigger.
F	A boy jumps onto a stationary skateboard.	M	Two marbles roll towards each other.
G	A ball bounces after it hits the ground	N	A cork pops out of a champagne bottle.



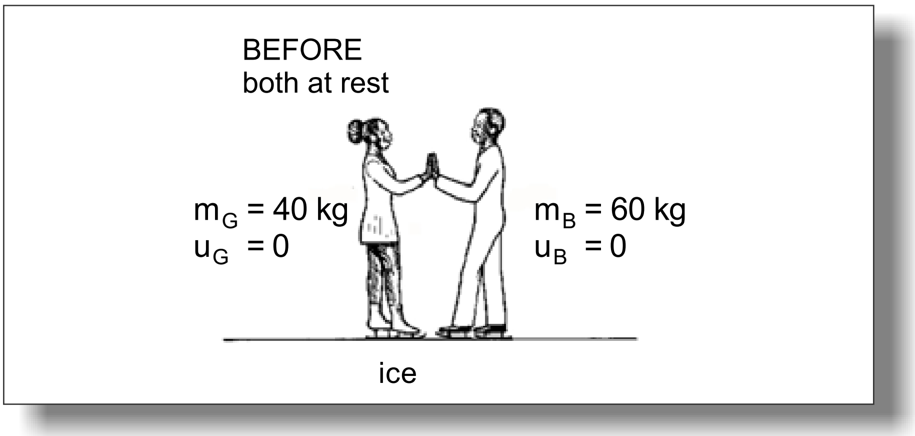
2. Which of these interactions involve changes in momentum?

ANSWERS ON PAGE 216

A gentle explosion

We examine a system in which a hard push separates two stationary objects.

A man (B) and a woman (G) stand facing each other on an icy surface. Assume that the friction between their skates and the surface is so small that we can ignore it. The surface is **not** part of the system.



We know from Lesson 7 that momentum = mass × velocity.

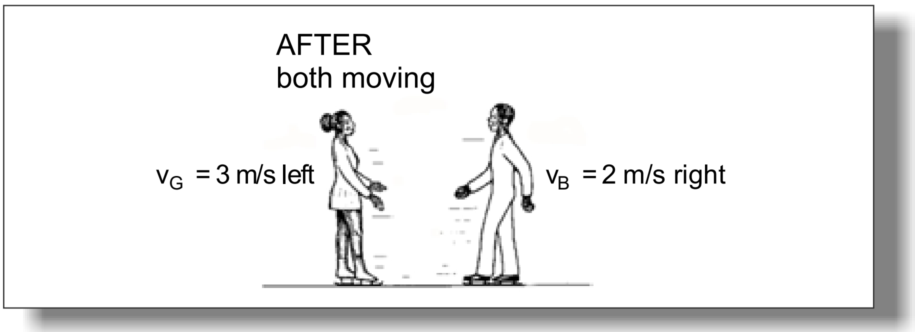
We use this equation to work out the momentum of the boy and the girl before they interact. Their initial velocity u is zero, since they are at rest.

$$\begin{aligned} p_B &= m_B u_B \\ &= 60\ kg \times 0\ m/s \\ &= 0 \end{aligned} \quad \text{and} \quad \begin{aligned} p_G &= m_G u_G \\ &= 40\ kg \times 0\ m/s \\ &= 0 \end{aligned}$$

The momentum (p) of the system before the man and woman interact is the sum of the moment *a* of the man and the woman.

$$p_{\text{system BEFORE}} = p_B + p_G = 0$$

The woman pushes the man away from her.



The woman's push changes the man's velocity. He moves at 2 m/s to the right.

The man's momentum now is

$$p_B = m_B v_B$$
$$= 60\ kg\ x\ 2\ m/s \text{ right}$$
$$= 120\ kgm/s \text{ right}$$

Newton's third law tells us that when the woman pushes the man, the man automatically pushes the woman in the opposite direction. This push makes the woman move at 3 m/s to the left.

The woman's momentum now is

$$p_G = m_G u_G$$
$$= 40\ kg\ x\ 3\ m/s \text{ left}$$
$$= 120\ kgm/s \text{ left}$$

We make the man's momentum to the right positive, +120kgm/s. The woman's momentum to the left must then be negative, −120kgm/s.

The momentum of the system after the man and the woman interact is the sum of their momenta.

$$p_{system\ AFTER} = p_B + p_G$$
$$= +120\ kgm/s + (-120\ kgm/s)$$
$$= 0$$

The momentum of the system after the man and woman interact is the same as the momentum of the system before they interact! The total momentum of the system momentum is the same before and after the interaction!

The law of conservation of momentum

Momentum, like energy is conserved. Interaction between objects in a closed system does not change the momentum of the system.

The total momentum of a closed system of objects remains constant.

If the system contains objects A and B, then

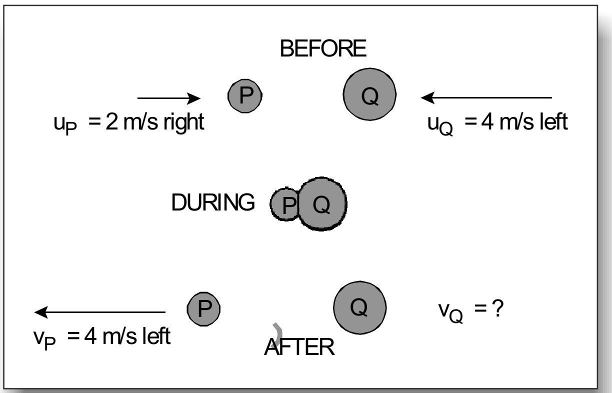
$$p_{system\ BEFORE} = m_A u_A + m_B u_B \text{ where } u \text{ is the velocity of } A \text{ and } B \textbf{ before } \text{interaction}$$
$$p_{system\ AFTER} = m_A v_A + m_B v_B \text{ where } v \text{ is the velocity of } A \text{ and } B \textbf{ after } \text{interaction}$$
$$p_{system\ AFTER} = p_{system\ AFTER}$$
$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

ACTIVITY 7

Collide, then separate

1. The diagram shows two spheres, P and Q before, during and after they collide.

   a. Use data from the diagram to fill in the missing information in the box. Make velocity to the right positive (+).



P	Q
m_P = 1 kg	m_Q = 2 kg
u_P = _______	u_Q = _______
v_P = _______	v_Q = ?

   b. Use the formula momentum = mass × velocity to work out the momentum of P and Q before they collide.

   c. Find the total momentum of the system before the collision.

   d. Work out the momentum of P after the collision.

   We do not know Q's velocity after the collision. Let it be $p_Q = m_Q v_Q = 2$ kg x v_Q.

   e. Fill in the blank space to work out the total momentum of the system after the collision.
   p TOTAL after = __________ + 2 kg x vQ

   f. Use the law of conservation of momentum to link the momentum of the system before collision to the momentum of the system after collision.

   g. Now work out the magnitude and direction of Q's velocity after the collision.

2. Look at the list of interactions in the table in Activity 6. Which other interactions involve moving objects which separate after they collide?

3. a. Use the formula $E_k = \frac{1}{2}mu^2$ to show that the total kinetic energy of the system before collision is 18 J.

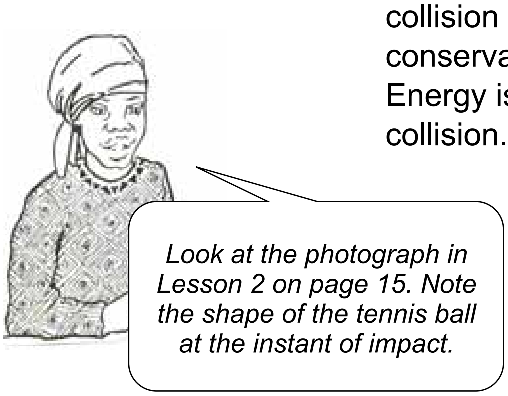
b. Use the answer to 1g to work out the total kinetic energy of the system after the collision.

ANSWERS ON PAGE 217

c. Is kinetic energy conserved during this collision?

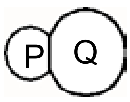
What happens to the missing kinetic energy?

Most collisions in everyday life involve a decrease in kinetic energy. The kinetic energy in the system is usually less after collision than before! Does this mean that the law of conservation of energy is not valid during collisions? Not at all. Energy is never destroyed. But it sometimes changes during a collision.



The diagram shows how the spheres change shape when they are touching. High speed cameras show this in real collisions! Although the spheres are hard, they deform each other when they collide. Some of their kinetic energy becomes elastic potential energy. But some energy also moves out of the system as sound and heat! Sound and heat are not mechanical energy. When the spheres move apart, some energy changes back to kinetic energy. Energy is not destroyed during the interaction. The energy in the system before collision is present after collision. It is present as kinetic energy in the system and sound and heat in the surroundings.

DURING COLLISION



Collisions in which kinetic energy is not conserved are **inelastic** collisions.

Elastic collisions

Most collisions that we experience in everyday life are inelastic. However, kinetic energy is conserved when atoms collide. The kinetic energy of two atoms is the same before and after collision.

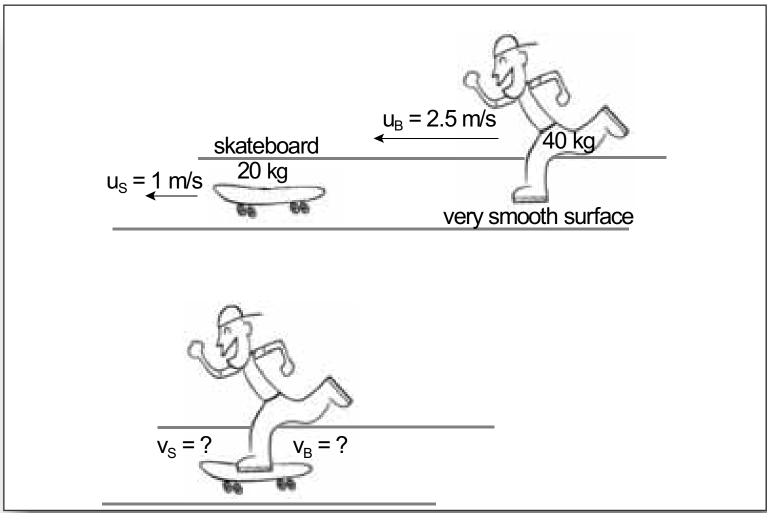
Collisions in which kinetic energy is conserved are **elastic** collisions.

Sticking together

Some things do not separate after they collide.

ACTIVITY 8

1. The first diagram shows a boy (B) running towards his moving skateboard (S). The second diagram shows the boy at the instant he jumps onto the skateboard. Then they move off together.



a. Use data from the diagram to fill in the missing information in the box below. Make velocity to the right positive (+).

B	S
m_B = _______	m_S = _______
u_B = _______	u_S = _______
v_B = ?	v_S = ?

The momentum of B and S before the boy jumps onto the skateboard,

$$\begin{aligned} p_{\text{system BEFORE}} &= m_B u_B + m_S u_S \\ &= 40 \text{ kg x} - 2.5 \text{ kgm/s} + 20 \text{ kg x} - 1 \text{ m/s} \\ &= -100 \text{ kgm/s} - 20 \text{ kgm/s} \\ &= -120 \text{ kgm/s} \end{aligned}$$

$p_{\text{system AFTER}} = m_B v_B + m_S v_S$, but

b. These two velocities are equal. Why?

The momentum of the system after the boy jumps onto the skateboard is

$p_{system\ AFTER} = m_B v_B + m_S v_S$

We replace the velocity of the skateboard after the boy jumps onto it (vS) in this equation with vB. This gives

$p_{system\ AFTER} = m_B v_B + m_S v_B$

$p_{system\ AFTER} = v_B(m_B + m_S)$

c. Make v_B the subject of the formula.

d. Use the law of conservation of momentum to link the momentum of the system before the boy lands on the skateboard to the momentum of the system when they move together to the left.

e. Work out the velocity of the boy and the skateboard.

2. Look at the list of interactions in the table in Activity 6. Which other interactions involve objects combining or sticking together after they interact?

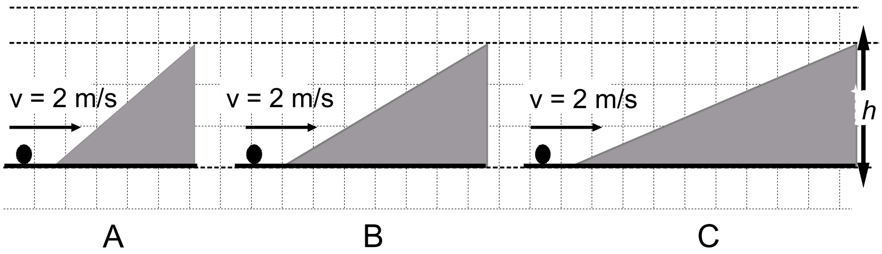
ANSWERS ON PAGE 218

SUMMARY ACTIVITY

1. The table below shows a comparison of closed and isolated systems. Cross out the wrong words in each line.

closed systems (for example, doing work on a supermarket trolley)	**isolated systems (for example a swinging pendulum)**
Energy of the system stays **constant / can change.**	Energy of the system **stays constant / can change.**
Internal/ external forces do work on it	**Internal /external** forces do work on it.
Amount of matter in the system **stays constant / can change.**	Amount of matter in the system **stays constant / can change.**
A change from gravitational to kinetic energy **can / cannot** happen inside the system.	A change from gravitational to kinetic energy **can / cannot** happen inside the system.
Energy **is / is not** conserved when work is done.	Energy **is / is not** conserved when work is done.
Energy **can / cannot** be transferred out of the system as heat or sound.	Energy **can / cannot** be transferred out of the system as heat or sound.

2. Three identical marbles roll towards three different 'frictionless' hills with a speed of 2 m/s. Assume that the gravitational potential energy of the marbles is zero at the bottom of the hills.



a. What do you think happens to the

i. kinetic energy of the marbles

ii. gravitational potential energy of the marbles as they roll uphill?

b. In which diagram does the marble roll the

i. shortest distance up the hill before rolling back down the hill?

ii. longest distance up the hill before rolling back down the hill?

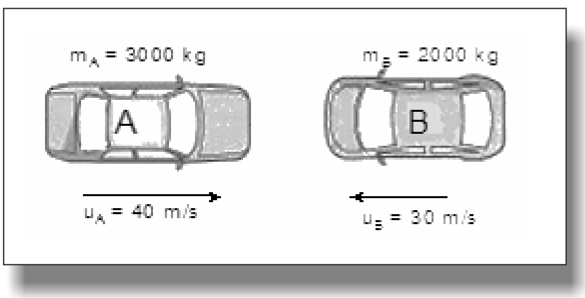
The law of conservation of energy for each of these systems tells us that

$$E_{\text{mechanical BOTTOM}} = E_{\text{mechanical TOP}}$$
$$E_{\text{p BOTTOM}} + E_{\text{k BOTTOM}} = E_{\text{p TOP}} + E_{\text{k TOP}}$$

c. Rewrite the second equation leaving out the terms that are zero. Then substitute weight x height for potential energy in your equation.

d. Use this information to decide in which case – A, B, or C – (or a tie) – the marble will reach the highest vertical distance (h on the diagram). Explain your answer.

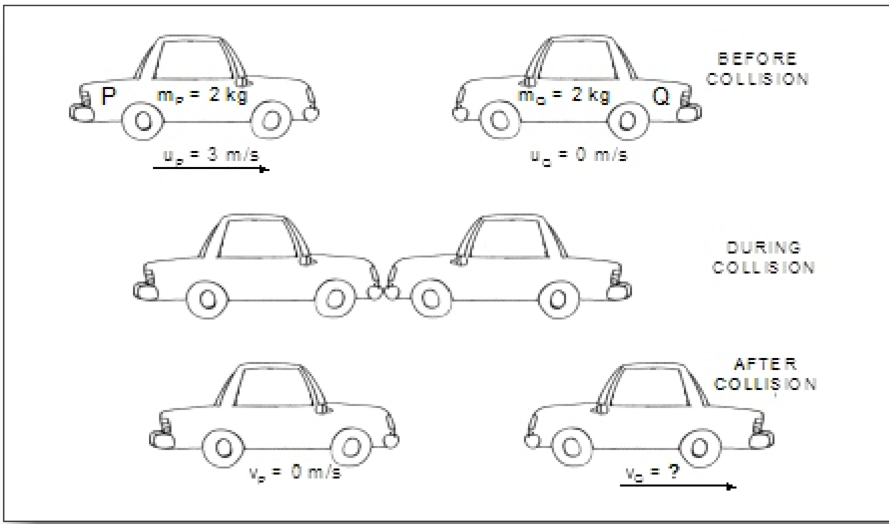
3. A motor car A collides head on with another car B in an intersection. The two wrecks combine and move off together. What is their velocity? (HINT: Follow the steps in Activity 8, questions a – e.)



4. Two toy cars P and Q collide.

   a. Use information from the diagram to calculate the velocity of Q after collision.

   b. Is this an elastic or an inelastic collision? Do a calculation to support your decision.



ANSWERS ON PAGE 219

CHECKLIST

Are you able to:

- ❒ describe and calculate changes in the kinetic and gravitational potential energy of an object as it falls to Earth
- ❒ define free fall, mechanical energy and an isolated system
- ❒ state and use the law of conservation of energy to solve problems
- ❒ classify everyday interactions between objects into groups having similar properties
- ❒ distinguish between elastic and inelastic collisions
- ❒ state and use the law of conservation of momentum to solve problems
- ❒ compare closed and isolated systems.

Answer section

Lesson 1

Activity 1

1. 1000 000 m is the same distances as 1 megametre, so

   1 m is the same length as $\frac{1}{1\,000\,000}$km

   150 000 000 000 m is the same as

   150 000 000 000 x $\frac{1}{1\,000\,000}$ Mm.

   This distance is 150 000 Mm.

2. 20.000 005 m is a small number which we want to change into a bigger number. Therefore we must make the unit smaller.

   The table shows that $\frac{1}{1\,000\,000}$ g is the same as 1 µg.

   1 g is the same as 1 000 000 µg
   0.000 002 g is the same as 0.000 002 x 1 000 000 µg
   which is 2 µg.

3. The table shows that $\frac{1}{1\,000\,000}$ m is the same as 1 µm.

   1 m is the same as 1 000 000 µm
   0.000 005 m is the same as 0.000 005 x 1 000 000 µm
   which is 5 µg.

4. 5 cm is longer than 8 millimetre because 0.05 m (5 cm) is greater than 0.008 m (8 mm).)

5. The prefix micro means $\frac{1}{1\,000\,000}$, so 5 µs is the same as $5\times\frac{1}{1\,000\,000}$s which is 0.000 005 s.

   1 µs is the same as $\frac{1}{1\,000\,000}$ s ,

   So 5 µs is the same as $\frac{5}{1\,000\,000}\text{s} = 0.000\ 005\text{s}$

6. 1 cm is the same distance as $\frac{1}{100}$ m

So, 3 270 132 cm is the same distance as

$\frac{3\ 270\ 132}{100}\text{m} = 32701.32\text{m}$

But 1 m is the same distance as $\frac{1}{1\ 000}$km

So, 32 701.32 m is the same distances as

$\frac{32701.32}{1\ 000}\text{km} = 32.70132\text{km}$ which is about 38 km.

7. Convert minutes into hours

1 minute is the same as $\frac{1}{60}$h

7 776 023 minutes is the same as $\frac{7776023}{60}$hours

Then convert hours into days

Then 1 hour is the same as $\frac{1}{24}$day

$\frac{7776023}{60}$hours is the same as $\frac{7776023}{60 \times 24}$days

Then convert days into years

Then 1 day is the same as $\frac{1}{365}$ years

$\frac{7776023}{60 \times 24 \times 365}\text{years} = 14.79456$ years

which is 15 years (to the nearest year).

Activity 2

1. a. Your answer is inaccurate because there is a large difference between your measurement and the accepted value of 9 V. Perhaps the measuring instrument is faulty or perhaps you read the value incorrectly.

   b. Your measurement is precise because it has four decimal places.

2. Measurement is reasonably accurate since there is only a 1ml difference between the accepted value and your measurement. Neither measurement is precise since the measurement is given to the nearest millilitre.

3. The measurement of the length of the pencil cannot be very precise because the ruler measures only to the nearest centimetre. The first decimal place in the measurement must thus be estimated.

4. a. Accuracy is good in this case as the measurements agree closely with each other.

   b. The measurements are precise too as they are very close to the accepted value.

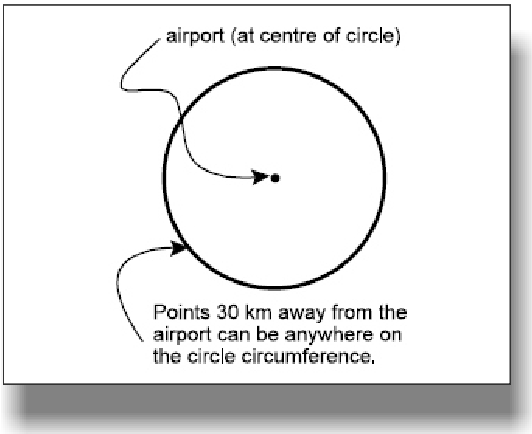
5. Themba's measurements are more precise because their values are close to each other. However, their accuracy is poor. They are too far away from the accepted value of 8.5 cm.

Activity 3

1. a. The 30 km away from the airport can be 30 km away in any direction. So 30 km away is a distance.

   b. 200 m away from the road can be in any direction. So this is a distance.

   c. The length of the racetrack is given as 1 kilometre. This must be the length of the path along which someone would move. Hence it is a distance.



2. $\text{average speed} = \frac{\text{total distance}}{\text{time}} = \frac{560\text{km}}{8\text{h}} = 70\text{km/h}$

   The average speed during their trip was 70 km/h.

3. $\text{average speed} = \frac{\text{total distance}}{\text{time}} = \frac{100\text{m}}{9.69\text{s}} = 10.3\text{ms}^{-1}$

   Usain's average speed was 10.3 ms-1.

4. $\text{average speed} = \frac{\text{total distance}}{\text{time}}$

   Since you plan to travel for 30 minutes only, whichever path you choose, your average speed is a measure of the total distance you travel. The higher the total distance, the higher your average speed. The distance along Path X is the greatest of the three paths. To get to your destination in 30 minutes, you will have to have the highest average speed along Path X.

Summary Activity

1. a. fundamental   b. fundamental
   c. derived   d. derived
   e. fundamental

2. a. scalar b. vector
   c. scalar d. vector

3. a. The car travels a distance of 100 m.
   b. The car's displacement is 100 m E.

   c. $$\text{average speed} = \frac{\text{distance}}{\text{time}}$$
   $$= \frac{100\text{m}}{5\text{s}} = 20\text{ms}^{-1}$$

   d. $$\text{average velocity} = \frac{\text{displacement}}{\text{time}}$$
   $$= \frac{100 \text{ m E}}{5 \text{ s}} = 20 \text{ ms}^{-1} \text{ E}$$

4. a. $S = \frac{D}{T}$

   $S = \frac{10}{1.5}$

   $= 6.6$

   b. 0

5. True. If you hit a squashball against a wall it bounces straight back to its original point.

Lesson 2

Activity 1

1. No. You must touch the book to push it away from you.

2. Lifting a suitcase and picking an apple involve pulling.

3. Kicking a ball and closing a car door involve pushing.

Activity 2

1. Twisting, stretching and squashing change the shape of the sponge.

2. When you stop applying these forces, the sponge changes back to its original shape.

3. You cannot change the shape of the sponge without touching it.

4. The boot applies a kicking force on the soccer ball. This force changes the shape of the soccer ball. The change in shape of the ball is not permanent. The ball returns to its normal shape after the kick.

Activity 3

1. $F_{\text{by Mary's hand on the ball}}$ $F_{\text{by Andile's hand on the table}}$

   $F_{\text{by the wind on the litter}}$ $F_{\text{by the car on the pedestrian}}$

   $F_{\text{by Sipho's hand on the brake handle}}$ $F_{\text{by the hailstones on the car}}$

   $F_{\text{by the wave on the boat}}$ $F_{\text{by the cricket bat on the ball}}$

   $F_{\text{by the boxer's hand on the opponenet's jaw}}$ $F_{\text{by the boy's hands on the car}}$

2. a. The wind blows the litter. The car hits the pedestrian. Hailstones strike the car. The brake on Sipho's bicycle acts on the bicycle wheel. The water wave lifts the boat. Wind, a car, a bicycle brake, hailstones and water waves are not living things.

   Some of the forces described make things happen, but not all forces do this. Wind moves litter, the car moves the pedestrian, Sipho moves the brake handle, the wave moves the boat. But the boy cannot move the car! But the car does not change in any observable way when the boy pushes it.

   b. Living and non-living things can exert forces. Forces may sometimes cause something to move.

3. Yes, you always need a force to start something moving. But, not all forces cause movement. Mary exerts a force on the ball to make it move. It will not move through the air if she doesn't exert a force on it. The wind exerts a force on the litter to make it move. If there is no wind to make the litter move, it will stay where it is. But, the force the boy exerts on the car, cannot make the car move!

Activity 4

1. The pieces of paper move from the table to the comb. They stick onto the comb.

2. Since the ball starts moving the instant you stop holding it, there must be a force acting on the ball. The Earth must be the agent exerting a force on the ball. Your hand must exert a force on the ball to stop it moving.

3. The magnet attracts the nails. The nails move from the table to the magnet. The magnet must be the agent exerting a force on the nails.

4. The comb is the agent exerting a force on the paper. The Earth is the agent exerting a force on the ball. The magnet is the agent exerting a force on the nails.

5. No. The paper moves before it touches the comb.

6. No, this cannot be a contact force. When I let the ball go, the Earth is not touching the ball. And, the ball starts moving the instant I stop holding it.

7. Yes, the magnet does interact with the nails before the magnet touches the nails. The start moving towards the magnet before they touch. nails move towards.

Activity 5

1	action	2	contact
3	contact	4	action
5	contact	6	contact
7	action	8	contact

Activity 6

Making and Testing Predictions			
What the ball is doing	**What I do to the ball**	**What I think will happen to the ball (my PREDICTION)**	**What happens to the ball (TESTING my predication by observing)**
rolling in a straight line away from you	blow the ball from behind		The ball will move faster as it moves away from you.
rolling in a straight line	blow the ball from the side		The ball changes direction. It moves in the direction in which I blow it. It is hard to see if the ball moves faster or not.
rolling in a straight line towards you	blow the ball from the front		The ball slows down as it moves towards me. Eventually it stops moving and then moves away from me.
at rest	blow at it from any direction		It starts moving in the ection in which I blow it.

5. a. The agent is the air which the player blows through the straw.

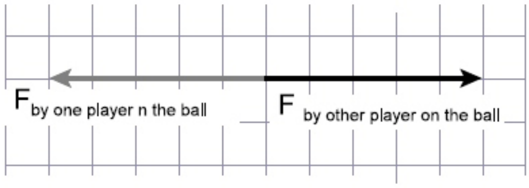
   b. The ping pong ball is the object on which the air acts.

   c. The force acts towards the goal.

6. a. The two forces must be the same size as each other (They are equal in size /magnitude).

   b. The two forces acting on the ball must act in opposite directions

   c.



7. The ball will start moving towards the player who is not blowing it.

Summary Activity

1. Decide whether the forces listed below are pushing or pulling forces.

a. push	b. push
c. push	d. pull

2. a and b are both contact forces which change the shape of the object on which they act .

3. These are some of the things you should have on your list.
   - Effects of forces
   - Forces may start a body moving.
   - Forces may change the shape of an object.
   - Forces may stop a body moving.
   - A force may be needed to keep a body moving on a rough surface (eg bicycle on a road)
   - A force may keep something at rest.

   NOTE: At this stage, we cannot be sure of these things about force. That is why the statements use the word *may*. We will revisit this list in Lessons 6, 7 and 8 on Newton's Laws.

Lesson 3

Activity 1

1. a. $F_{net} = -10N + (-10N) = -20N$, $F_{net} = 20N$ to the left,
   b. $F_{net} = -10N + 10N = 0N$, No unbalanced F_{net} force acting
   c. $F_{net} = +10N + 10N = 20N$, $F_{net} = 20N$ to the right, F_{net} is unbalanced
   d. $F_{net} = +10N + (-10N) + 1N = +1N$, $F_{net} = 1N$ to the right
   e. $F_{net} = +10N + 10N = 20N$, $F_{net} = 20N$ up, F_{net} is unbalanced

2. a. $(-10\text{N}) + F_1 = +15\text{N},\ F = 15\text{N} + 10\text{N} = 25\text{N},\ F_1 = 25\text{N}$
   b. $F_2 + (-5\text{N}) = +18\text{N},\ F_2 = 23\text{N}$ right

3. a. Vertical: $F_{net} = +100\text{N} + (-100\text{N}) = 0$
   b. Horizontal: $F_{net} = (-62\text{N}) + 78\text{N} = +16\text{N} = 16\text{N}$ right
   c. The object will move in the direction of the horizontal force – to the right

Activity 2

1. The crumpled piece of paper reaches the ground before the unfolded (flat) piece. The crumpled piece falls straight down but the flat piece moves a bigger distance as it slowly drifts down.

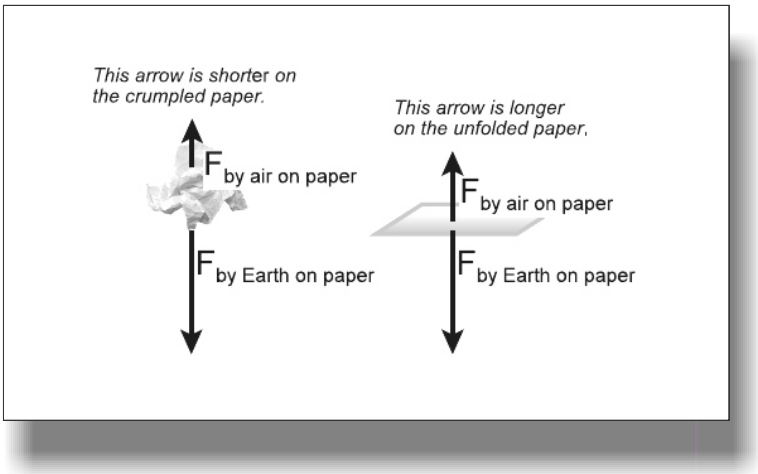
2. The unfolded piece has a much bigger surface area than the crumpled paper.

3. The air resistance on the unfolded paper is larger than the air resistance on the crumpled paper.

4. Air resistance lowers the speed of fall of the unfolded paper.

5. a. The length of an arrow represents the magnitude of the force. These two arrows represent the weight of the paper. The two pieces are identical. This means they have the same mass and thus the same weight.

   b. Both the arrows representing air friction must point up. The arrow on the crumpled piece must be shorter than the arrow on the flat piece. At this stage, the exact length of the arrow showing weight relative to the length of the arrow showing air friction is not important.



Activity 3

1. tension: This is the upward force the string exerts on the block. gravitational force: This is the downward force the Earth exerts on the block.

2. gravitational force: Although the tennis ball is not moving at its highest point, the Earth still exerts a downward force on the ball. This may surprise you! Note that this is the only force acting on the ball when it is at its highest point.

3. weight: This is the downward force the Earth exerts on the block.
   normal force: The surface of the table supports the block. It exerts an upward force on the block.

4. friction: This is the force road exerts on the back wheels of the car. This acts along the road in the opposite direction to the motion of the car.
   tension: A tension force stretches the cable. Tension is the force the cable exerts on the car. It acts along the cable away from the car.
   normal force: This is the upward force the road surface exerts on the back wheels of the car.
   gravitational force: This is the downward force the Earth exerts on the car.

5. gravitational force: This is the downward force the Earth exerts on the block.
   normal force: This is the force the ramp exerts on the block to support it. This acts at right angles to the surface of the ramp and it acts away from the ramp surface.
   friction: The block does not move. The sloping surface must exert a frictional force on the block to prevent the block moving. This force acts up along the ramp.

6. gravitational force: This is the downward force the Earth exerts on the block.
   friction: This is the force the table surface exerts on the block. The force acts in the opposite direction to the motion of the block.
   normal force: The surface of the table exerts an upward force on the block.
   friction (air): The block is moving through the air. This is the force the air exerts on the block to oppose its motion.

Summary Activity

1. The diagram shows a bathroom scale when Pete stands on it.

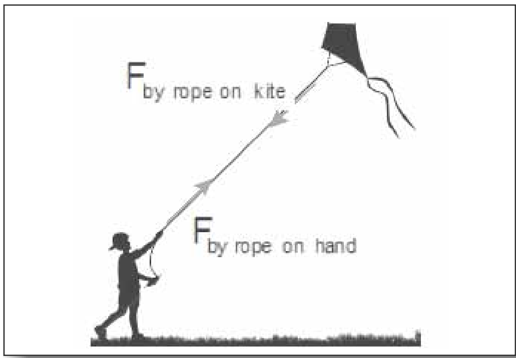
   a. Pete's mass is 58 kilograms.

b. $\text{weight} = \text{mass} \times \frac{10\text{N down}}{\text{kg}}$

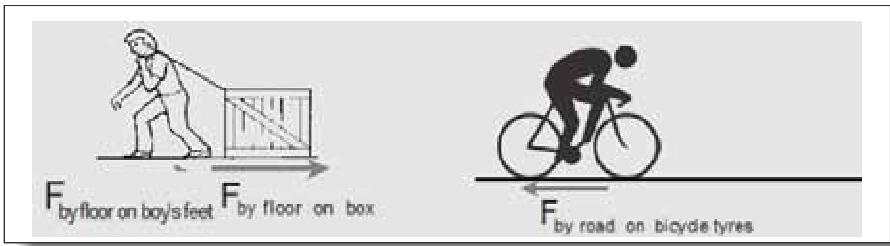
$= 58\text{kg} \times \frac{10\text{N down}}{\text{kg}}$

$= 580\text{N down}$

2.



3.



Lesson 4

Activity 1

1. Distance during second second

   $=$ distance after 2s $-$ distance after 1s

   $= (4\text{m} - 1\text{m}) = 3\text{m}$

   Mary runs a distance of 3 m during the second second of her run.

2. a. Distance during third second

   $=$ distance after 3s $-$ distance after 2s

   $= (9\text{m} - 4\text{m}) = 5\text{m}$

   b. Distance during fourth second

   $=$ distance after 4s $-$ distance after 3s

   $= (16\text{m} - 9\text{m}) = 7\text{m}$

3. Mary's displacement after 4 s is 16 m east of her starting point (X).

4. Mary's speed is increasing. She is moving faster. The distance she covers each second increases over the 4 s time interval. Distance covered each second is speed.

5. Mary is not running at constant speed. She covers different distances each second. Her speed is non-uniform. Her speed is changing during the 4 s time interval.

Activity 2

1.

interval	**time interval /second**	**displacement/metre**	
		distance from the table at end of time interval	**left / right of table**
AB	0 to 5		right
BC	5 to 7		right
CD	7 to 10		right
DE	10 to 14		at the table
EF	14 to 19		left
FG	19 to 20		left

2. a. Tom's total distance $= 4m + 6m + 3m = 13m$

b. Tom's overall displacement from his starting point

$= 4m$ right $+ 6m$ left $+ 3m$ left

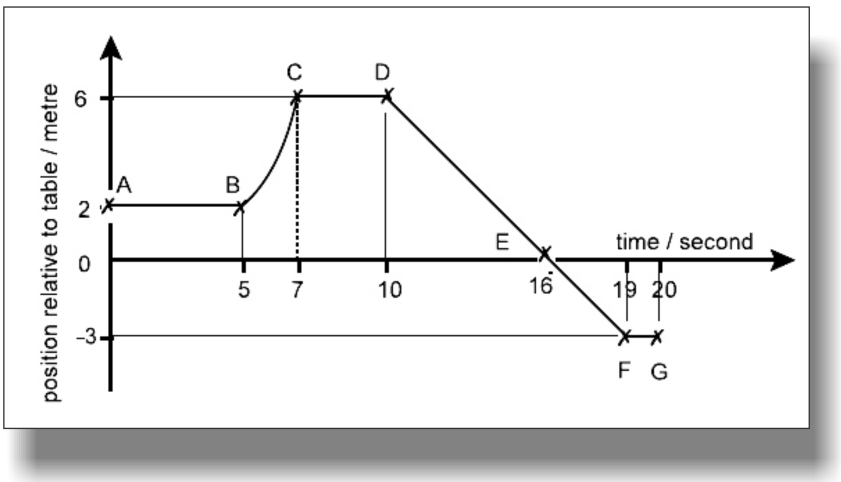
$= +4m + (-6m) + (-3m)$

$= -5m$

$= 5m$ left of his starting position

3. ❶ at rest, ❷ increasing velocity towards the right, ❸ at rest, ❹ constant velocity towards the left, ❺ constant velocity towards the left, ❻ at rest.

4.



Activity 3

1. Its speed is different each time you read the speedometer. Since the car is moving in a straight line, its velocity is changing (increasing). Acceleration is a change in velocity.

2.

t / second	velocity / km/h north
0	0
2	10
4	20
6	30
8	40

3. change in velocity $= 20\text{m / sN} - 10\text{m / sN} = 10\text{m/sN}$

4. $\dfrac{10\text{km / h N}}{2\text{s}} = 5\text{km / h / s N}$

5. Since the car's acceleration is 5 km/h/s N, its velocity at 10s will be its velocity at

$$t = 9\text{s plus } 5\text{km / h N} = (45\text{km / h N} + 5\text{km / h N})$$
$$= 50\text{km / h N}$$

Activity 4

1. a. This is a velocity-time graph, not a displacement-time graph. The car is moving during BC. The graph shows that at t = 6s the car's velocity is 12 ms^{-1} W. At t = 8s, its velocity is still 12 ms^{-1} W. In fact the car's velocity stays the same for the whole of the time interval between t = 6s and t = 12s.

b. The slope of a velocity-time graph represents acceleration.

$$\text{slope} = \text{acceleration} = \frac{\Delta v}{\Delta t} = \frac{(12 - 12)\text{ms}^{-1}\text{west}}{(12 - 6)\text{s}} = \frac{0\text{ms}^{-1}}{2\text{s}}$$
$$= 0\text{ms}^{-2}$$

The car's acceleration is zero. The slope of a horizontal line is always zero. This means the car is traveling at constant velocity.

2. a. slope $= \frac{\Delta v}{\Delta t} = \frac{(0 - 12)ms^{-1} \text{ west}}{(14 - 12)s} = \frac{-12ms^{-1} \text{ west}}{2s}$

$= - 6ms^{-2}$ west

b. The graph shows that the direction of the car's velocity is the same for the whole of the test drive. This must be true because the graph shows that the velocity of the car is always positive. This means that the car travels west throughout the test drive. During CD however, the car's velocity changes from 12 ms^{-1} west to 0 ms^{-1} west. So during CD the car slows down by 6 ms^{-1} each second for the last 2 s of the test drive while still moving west.

Activity 5

1. area $=$ length $\times$ breadth

$= (12 - 6)s \times 12 \frac{m}{s}$ W

$= 72$mW

2. area $= \frac{1}{2} \times$ base $\times$ vertical height

$= \frac{1}{2} \times 2s \times 12 \frac{m}{s}$W

$= 12$mW

3. total displacement $=$ total area $=$ 36m W $+$72W $+$12m

W $=$ 120m W

Summary Activity

1. a. For 4 s the coach moves 8 m <u>away</u> from his starting point at constant velocity. He stands still in this position for 2 s (t = 4s to t = 6s). During t = 6s to t = 8s he moves at constant velocity in the opposite direction (back to where he started) until he is 4 m away from his starting point. During t = 10s to t = 14s he again moves at constant velocity away from his starting point. When he reaches a point 8 m away from his starting point, he turns around and goes back to his starting point which he reaches 2 s later.

b. Total distance $= 8m + 4m + 4m + 8m = 24m$

c. The graph shows that at t = 16s the displacement of the coach is zero. He is back at his starting point.

d. Between t = 4s and t = 6s, the coach is 8 m away from his starting position. He is back at his starting position again at t = 14s. 8 m is his greatest displacement from his starting point.

e. The coach's velocity during the first 4 s is the same as the slope of the graph during the first 4 s.

$$\text{slope} = \frac{\Delta s}{\Delta t} = \frac{(8m - 0m)}{(4s - 0s)} = \frac{8m}{4s}$$
$$= 2m\ s^{-1}$$

His velocity is 2 ms^{-1} away from his starting point.

f. The coach's velocity during the last 2 s is the same as the slope of the graph during the last 2 s.

$$\text{slope} = \frac{\Delta s}{\Delta t} = \frac{(0m - 8m)}{(16s - 14s)} = \frac{-8m}{2s}$$
$$= -4m\ s^{-1}$$

In words, this means that the coach's velocity is 4 ms^{-1} towards his starting point.

2. a. uniform velocity, b. ❷•, c. ❷•, d. ❶•, ❷•, ❸• and ❹.

3. a. Q and S are moving in the same direction as T.
   b. Q and R change direction.
   c. None of the objects is at rest.
   d. P and T are moving at constant velocity.
   e. P is moving the fastest.
   f. Q, R and S are accelerating.
   g. S has the smallest acceleration.

Lesson 5

Activity 1

1. a. When $u = 0_2$, the equation $v = u + a\Delta t$ becomes $v = 0 + a\Delta t$ or $v = a\Delta t$
   b. When an object travels at uniform velocity its acceleration (a) = 0.
   The equation $v = u + a\Delta t$ becomes $v = u + 0\Delta t$ or $v = u$

2. $u = 0, v = 30ms^{-1}, \Delta t = 12s$

$$a = \frac{v - u}{\Delta t} = \frac{30m\ s^{-1} - 0}{12s}$$
$= 2.5ms^{-2}$ in the direction of the given velocity

3. $u = 26ms^{-1}$ west, $a = 2ms^{-2}$ west, $\Delta t = 6s$

$v = u + at$

$= 26ms^{-1}$ west $+ 2ms^{-2}$ west $\times 12s$

$= 26ms^{1}$ west $+ 12ms^{-1}$ west

$= 38ms^{-1}W$

The motorist's velocity at the end of 6s is $40ms^{-1}$ west

4. $a = 4ms^{-2}$ north, $u = 10ms^{-1}$ north, $v = 30ms^{-1}$ north

$v = u + a\Delta t$ from which

$$\Delta t = \frac{v - u}{a} = \frac{30ms^{-1} \text{ north} - 10ms^{-1} \text{ north}}{4ms^{-2} \text{ north } a = 4ms^{-2} \text{ north, } u = 10ms^{-1} \text{ north, } v = 30ms^{-1} \text{ north}}$$

$= 5s$

It takes the driver 5s to change her velocity from $10ms^{-1}$ to $30ms^{-1}$

Activity 2

1. $u = 0, a = 6ms^{-2}$ away from the robot, $\Delta t = 4s$

$s = ut + \frac{1}{2}at^2$, but $u = 0$, so

$s = \frac{1}{2}at^2 = \frac{1}{2} \times 6\frac{m}{s^2}$ away from the robot $\times (4s)^0$

$= 3\frac{m}{s^2} \times 16s^2$ away from the robot

$= 48m$ away from the robot

2. a. $\frac{m}{s} \times s = m$ s in the numerator cancels out with s in the denominator

b. $\frac{1}{2}$ is a number and has no unit. $\frac{m}{s^2} \times s^2 = m$ since s^2 in the numerator cancels out with s^2 in the denominator

c. List of labels
- This term is the extra distance the object travels because it is accelerating. BOX 2
- This is the distance a uniformly accelerating object travels after Δt. BOX 1
- This acceleration is uniform. BOX 4
- This terms is the distance the object travels at constant velocity. BOX 3

3. a. $u = 0, a = 2ms^{-2}, \Delta t = 4s$

$s = ut + \frac{1}{2}at^2$, but $u = 0$, so

$s = \frac{1}{2}at^2 = \frac{1}{2} \times 2\frac{m}{s^2} \times (4s)^2$

$= 4m$ along the straight road

b. $u = 0,\ a = 2ms^{-2},\ \Delta t = 4s$

$s = ut + \frac{1}{2}at^2$, but $u = 0$, so

$s = \frac{1}{2}at^2 = \frac{1}{2} \times 2\frac{m}{s^2} \times (4s)^2$

$= 16m$ along the straight road

c. When Δt=2s, the cyclist;s displacement is 4m

When $\Delta t = 2 \times (2s) = 4s$, his displacement is 16m (or$(4)^2$)m

Doubling the cyclist's time interval from 2s to 4s

~~doubles~~ / ~~halves~~ / makes his displacement 2^2 times bigger if his acceleration stays the same.

d. We use the equation $s = ut + \frac{1}{2}at^2$a as in a and b above to work out the displacement after 3s and then after 4s.

When $\Delta t = 3s$, the cyclist's displacement is 9m.

When $\Delta t = 2 \times (3s) = 6s$, his displacement is 36m (or $(6)^2$m)

e. If we halve the time interval the cyclist's displacement becomes $\left(\frac{1}{2}\right)^2$ times smaller if his acceleration stays the same

Activity 3

a. List of labels

- This is the length of the runway. BOX 2
- This is the uniform acceleration of the aeroplane. BOX 4
- This is the velocity of the plane before it starts accelerating. BOX 3
- This is the velocity of the plane at the end of the runway. BOX 1

b. $u = 0,\ v = 90ms^{-1},\ a = 3ms^{-2}$

$v^2 = u^2 + 2as$ but $u = 0$, so

$v^2 = 2as$ from which

$$s = \frac{v^2}{2a} = \frac{(8 - ms^{-1})^2}{2(3ms^{-2})} = \frac{6400m^2s^{-2}}{6ms^{-2}}$$

$= 1350m$

The runway must be at least 1350m long.

Activity 4

1. As the car's speed increases from $3ms^{-1}$ to $12ms^{-1}$, its braking distances increases from 1.125 m to 18 m. The faster the car travels the bigger its braking distance.

2. At a speed of $3ms^{-1}$ the braking distance is 1.125 m. At double this speed ($2 \times 3ms^{-1}$) the stopping distance is 4.5 m. $4.5\text{ m} \neq 2(1.125\text{m})$. If the speed doubles the stopping distance does not double.

3. Doubling Sipho's speed from $3ms^{-1}$ to $6ms^{-1}$
   a. doubles his braking distance
   b. changes his braking distance to 4 x 1,125 m
   c. makes his braking distance four times greater
   d. changes his braking distance to 2 x 1,125 m.

4. When Sipho changes his speed from his braking distance
   a. changes from 1,125 m to 10,125 m
   b. becomes three times bigger
   c. changes from 1,125 m to 3 x 1,125 m
   d. changes from 1,125 m to 9 x 1,125 m
   e. becomes 3^2 times greater

5. a. At $12ms^{-1}$ the car's braking distance is 18m
   So at $2 \times 12ms^{-1}$(at $24ms^{-1}$) its stopping distance must be 2^2 or 4 times bigger. $4 \times 18m = 72m$

   b. At $3ms^{-1}$ the car's stopping distance is 1.125m
   So at $12 \times 3ms^{-1}$ (at $36ms^{-1}$) its stopping distance must be 12^2 or 144 times bigger. $144 \times 1.125m = 162m$

Activity 6

1. at $6ms^{-1}$: thinking distance, $s = v\Delta t = 6\frac{m}{s} \times 2.5s = 15m$

   stopping distance = braking distance + thinking distance

   $= 4.5m + 15m = 19.5m$

   at $9ms^{-1}$: thinking distance, $s = v\Delta t = 9\frac{m}{s} \times 2.5s = 22.5m$

   $= 10.125m + 22.5m = 32.625m$

   Similarly, at $12ms^{-1}$, thinking distance = 30m and stopping distance is $30m + 18m$, which is 48m

2. a. $u = 34ms^{-1},\ v = 0,\ a = -4ms^{-2}$

$v^2 = u^2 + 2as$ from which

$$s = \frac{-u^2}{2a} = \frac{-(34ms^{-1})^2}{2(-4ms^{-2})} = 144.5m$$

Braking distance is 144.5m

b. Thinking distance is $= v\Delta t = 34\frac{m}{s} \times 2.5s = 85m$

c. stopping distance = braking distance + thinking distance

=144.5m+85m=229.5m

The length of a taxi is 5.4m. This means that the stopping distance for a taxi drinving at the speed limit is nearly 43 longer than a taxi

$$\frac{229.5m}{5.4m} = 42.5$$

Activity 7

1. Three sorghum beers represents
3 x 1.5 U alcohol = 4.5 U.
One quart beer represents 3.5 U alcohol.
Total $U = 4.5 + 3.5 = 8U$

2. a. Your boyfriend's highest alcohol content assumes that his body has not metabolised any of the alcohol in his drinks. According to the poster, 1U comes to 0.10 mg alcohol per 1 000 ml air. So, 8 U comes to 8 x 0.10 mg = 0.8 mg alcohol per 1 000 ml air.

b. According to the poster, 1U comes to 0.02g alcohol per 100ml blood. So, 8U comes to 8 x 0.02g = 0.16mg alcohol per 100ml blood.

c. Yes he is over the legal limit. The legal limit for breath alcohol is 0.24 mg alcohol per 1 000 ml air. For blood alcohol it is 0.05 g per 100 ml blood.

d. Your boyfriend is likely to be very boisterous and loud when talking to the police officer. He is likely to stagger when the police officer asks him to get out of the car. His speech is also likely to be slurred. Most important of all his reaction time is likely to be much higher than it is when he is sober. His judgement of distance is likely to be affected and he will be unable to respond to emergency situations on the road.

3. 2 cans cider represents 2 x 2U = 4U alcohol. 1 glass of wine represents 1U. Your total consumption at the shebeen is 5 U alcohol. This translates to 5(0.02) g alcohol in 100 ml blood or 5(0.01) mg alcohol per 1 000 ml breath. Although you are walking, you are unlikely to be able to judge how far away cars are on the highway when you try to cross it. You may be hit by a car.

4. Alcohol may be a cause. Other factors could be lack of pavements along highways, lack of public transport at night, lack of lighting on highways, insufficient pedestrian bridges across highways, pedestrian stupidity.

Summary Activity

1. a. $u = 5ms^{-1},\ v = 15ms^{-1},\ \Delta t = (10 - 5)s = 5s$

$v = u + a\Delta t$, so

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

$$= \frac{(15 - 5)ms^{-1}}{(10 - 5)s} = \frac{10ms^{-1}}{5s}$$

$= 2ms^{-2}$ in the direction of the velocity

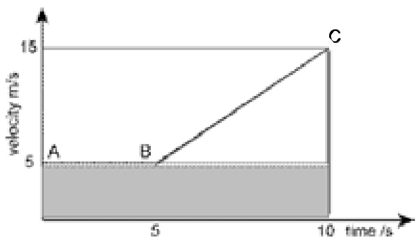
b. distance during AB

$u = 5ms^{-1},\ v = 5ms^{-1},\ a = 0,\ \Delta t = (5 - 0)s = 5s$

$s = ut + \frac{1}{2}at^2$ becomes $s = ut$ since $a = 0$

$= 5ms^{-1} \times 5s$

$= 25m$ in the same direction as the velocity



distance during BC

$u = 5ms^{-1},\ v = 15ms^{-1},\ a = 2ms^{-2}$ (from a), $\Delta t = (10 - 5)s = 5s$

$$s = u\Delta t + \frac{1}{2}a\Delta t^2$$

$$= 5\frac{m}{s} \times 5s + \frac{1}{2} \times 2\frac{m}{s^2} \times (5s)^2$$

$= 25m + 25m$

$= 50m$ in the same direction as u

distance during AC = distance during AB + distance during BC = 25m + 50m = 75m in the same direction as the velocity

c. distance AC = area of rectangle + area of triangle

$$\text{area} = 10\text{s} \times 5\frac{\text{m}}{\text{s}} + \frac{1}{2} \times (10 - 5)\text{s} \times (15 - 5)\frac{\text{m}}{\text{s}}$$

$$= 50\text{m} + 25\text{m}$$

$$= 75\text{m in the direction of u}$$

2. $u = 0,\ a = 5\text{km/h/sN},\ \Delta t = 13\text{s}$

$v = u + a\Delta t$ and since $u = 0$

$v = a$

$$= \frac{5\text{km}\ 13\text{sN}}{\text{hs}}$$

$$= 65\text{km/h N}$$

3. Some suggested ideas for the campaign are:
   - What media are likely to reach the target? Advertisements on the radio, in newspapers or street poles are suggestions. Try to suggest a variety of other ideas too.
   - Breathalyser tests should be done on Fridays, Saturdays and Sundays.
   - Do not test drivers during daylight hours. Best time to test drivers is between 21h00 and midnight.
   - Males are more likely to exceed legal alcohol limits than females.

Lesson 6

Activity 1

1. The water stays in the bucket while I am moving at constant speed in a straight line.

2. When I suddenly stop moving, the bucket stops moving too. The water keeps on moving in the same direction. It spills out of the front of the bucket.

3. No, the water does not show a tendency to stop moving on its own, it keeps on moving in the direction it was moving in. It only stops moving forward when it splashes on the floor.

4. When I start moving, the bucket also moves in the same direction. But the water tries to stay where it is. Since the bucket is no longer in the same position, the water spills out behind me.

Activity 2

1. a. You can give the bricks an identical push in an effort to change their state of motion. The brick that offers more resistance to moving is the brick with more inertia - and therefore the brick with more mass.

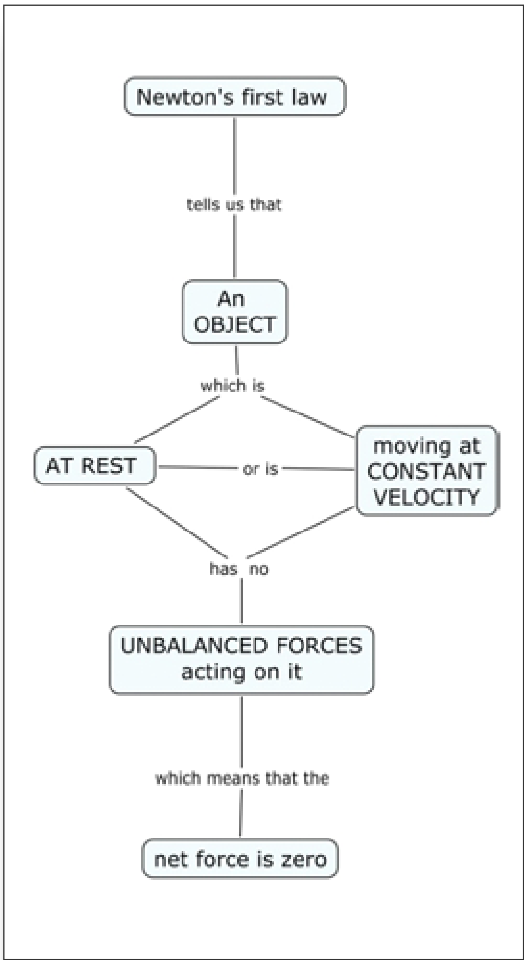
   b. The cement brick has more inertia than the polystyrene brick.

2. Mass is a measure of inertia. Velocity has no effect on inertia. So, the order from smallest to biggest inertia is the order from smallest to biggest mass. D< A < B < C

3. Statement d is the only true statement about inertia. Inertia is not a force as described in statements a and c.

Activity 3

1. Movement at 4 m/s in a straight line is constant velocity. An object moving at constant velocity has no unbalanced force acting on it. Hence the answer is A. See concept map alongside.



2. E. If all the forces acting on an object add up to zero, the net force is zero. This means that all the forces are balanced. Newton's first law tells us that the object can either be at rest (C) or it can be moving at a constant speed in a straight line (D). Both C and D are correct.

3. a. Objects A, B and D each have an unbalanced, horizontal force acting. The vertical forces (acting up and down) on each of A, B and D cancel each other out.

   In object E, the force acting to the right is the same magnitude as the force acting to the left. So the net horizontal force on E is zero.

   In A the horizontal force acting to the left is unbalanced.

   In B the horizontal force acting to the right is unbalanced.

   In D, the horizontal force acting to the right is smaller than the horizontal force acting to the left. So the net force on D is not zero.

b. Objects C and E could be at rest. The concept map shows that an object which is at rest has no unbalanced forces acting on it. All forces acting on an object at rest must add up to zero.

c. Object B could be moving to the right. It has an unbalanced force acting towards the right.

d. Objects C and E could be moving at constant velocity. The concept map shows that an object moving at constant velocity has no unbalanced force acting on it. All the forces acting on it must add up to zero.

e. Objects A, B and D must be accelerating. The concept map shows that any object which has a net force equal to zero acting on it will either be at rest or will move at constant velocity (acceleration zero). Hence an object which has a net force which is not equal to zero cannot be at rest or cannot move with constant velocity. Such an object must then be accelerating. A, B and D objects have a resultant (net) force which is not equal to zero acting on them.

4. b, FX Y is the same size as F. The block is at rest, so all the forces on the block must be balanced. See concept map above.

5. b, FX Y is the same size as F The block moves at constant velocity, so all the forces acting on the block must be balanced. See concept map above.

Activity 4

1. When the trolley hits the wall, the glass will topple over with its open end facing the wall. The trolley exerts a force on the bottom of the glass when it hits the wall. The bottom of the glass will try to move in response to this force. But inertia of the top of the glass will keep the top of the glass moving towards the wall. The water will spill at the end of the trolley facing the wall.

2. The glass will stop moving when the trolley hits the wall. But, the water will keep on moving towards the wall. It will spill onto the top of the trolley nearer the wall.

3. The coffee spills in your lap and not on the upper part of your body. When a car accelerates from rest, the road provides an unbalanced force on the car's wheels to push the car forward. The coffee (that was at rest) wants to stay at rest. When the car moves forward, both you and the coffee cup in your hand move forward. But the coffee stays in the same position. Since the cup is no longer there, the coffee spills onto your lap.

4. When the car stops suddenly the passenger's inertia keeps her moving forward until a force brings her to rest. This force is likely to be the dashboard. The passenger is likely to be injured.

5. Both your head and your body are at rest. When the other car hits your car from behind, it exerts a force on your car to make it move forward. Your body is effectively joined to the car by your seat belt. The force of the collision therefore starts your body moving forward too. But the inertia of your head makes your head stay where it is. Your head is obviously joined to your body which has now moved forward. So your neck stretches backward and hits the head rest. If the car had no headrest, your head would stretch further back.

Summary Activity

1. When I flick the card, it will move in the direction of my flick and then will fall into the glass. Initially the card is at rest. The unbalanced force of my flick will accelerate the card. My flick acts on the card not the coin. The coin's inertia resists any change in its motion. So the coin does not move horizontally. When the card has moved there is no longer an upward force acting on the coin. Its weight (acting down) is unbalanced and moves the card down.

2. The correct answer is b. The cupboard stays at rest. Newton's first law tells us the resultant force acting on the cupboard must be zero. Hence the force exerted by the boy on the cupboard must be equal in magnitude and opposite in direction to the force the floor exerts on the cupboard.

3. The elephant has much more mass than a person. Mass is a measure of inertia. Inertia opposes a change in direction of movement. Theoretically, then it should be much more difficult for the elephant to change direction to follow me when I run away along a zigzag path.

4. a. On Tuesday Mary's car moves at uniform velocity. On Wednesday, the velocity is changing as Mary's car moves faster and faster. Its motion is accelerated. On Thursday she slows down (accelerates to the left) or decelerates as she moves more and more slowly.

   b. Newton's first law tells us that an object moving with non-uniform velocity has an unbalanced force acting on it. Mary's car moves with non-uniform velocity on Wednesday and Thursday. Hence an unbalanced force acts on Mary's car on Wednesday and Thursday.

c. Tuesday ❷, Wednesday ❸, Thursday ❶.

d. ❶ represents increasing velocity, ❷ represents uniform velocity and ❸ represents decreasing velocity

5. a. You need a(n) ~~balanced~~ / unbalanced force to start a body moving.

   b. You need a(n) ~~balanced~~ / unbalanced force to stop a body moving.

   c. You need a(n) ~~balanced~~ / unbalanced force to make a body move faster.

   d. You need a(n) ~~balanced~~ / unbalanced force to make a body move slower.

   e. You need a(n) ~~balanced~~ / unbalanced force to make a body change its direction of motion.

   f. You need a(n) ~~balanced~~ / unbalanced force to make a body change shape.

Lesson 7

Activity 1

1. The trolleys have identical loads. Hence they all have the same mass. From everyday experience, the harder you push something, the faster it will move from rest (accelerate). The biggest force is 3F acting on trolley C so trolley C will have the biggest acceleration.

2. The same push will give the trolley with the smallest mass the greatest acceleration. Trolley F is empty so it has the smallest mass and the greatest acceleration.

3. We know from everyday life that the heavier an object is, the ~~less hard~~ / harder we have to push it to start it moving. The heavier an object is, the greater / ~~smaller~~ its mass. A harder push means a bigger / ~~smaller~~ force. If the mass of the trolleys stays the same, the bigger the unbalanced force, the bigger / ~~smaller~~ its acceleration. If equal unbalanced forces act on trolleys of different masses, the ~~bigger~~ / smaller the mass, the greater the trolley's acceleration.

4. According to Newton's second law, the acceleration the motorcycle engine can produce is inversely proportional to the mass of the motorcycle.

This means that the bigger the mass of the motorcycle the smaller the acceleration that the powerful engine can produce. The engine has to accelerate the whole motorcycle and the driver. If the motorcycle itself has a low mass then the acceleration of the motorcycle and its rider will be as big as possible.

Activity 2

	Net Force/N	Mass/kg	Acceleration/m/s^2
1	10 up	2	5 up
2	20 to the left	2	10 to the left
3	5 east	2	2.5 east
4	10 down	4	2.5 down
5	10 to the right	1	10 to the right

Activity 3

1. $a_1 = \frac{f}{m} = \frac{12N}{3kg} = 4ms^{-2}$

   $a_2 = \frac{f}{m} = \frac{12N}{6kg} = 2ms^{-2}$

   When mass is doubled from 3kg to 6kg, acceleration is halved if force stays the same (12N). $a_2 = \frac{a_1}{2} = \frac{4ms^{-2}}{2} = 2ms^{-2}$

2. $F_{net} = ma$, so $m = \frac{F_{net}}{a}$

   $= \frac{15N}{5ms^{-2}} = 3\frac{kgms^{-2}}{ms^{-2}} = 3kg$

3. $a_1 = \frac{F_1}{m_1}$ and $a_2 = \frac{3F_1}{m_1}$, but $\frac{F_1}{m_1} = a_1$

   $a_2 = 1.5a_1 = 1.5 \times 2ms^{-2} = 3ms^{-2}$

4. $a_1 = \frac{F_1}{m_1}$ and $a_2 = \frac{3F_1}{\frac{m_1}{2}} = 6\frac{F_1}{m_1}$, but $\frac{F_1}{m_1} = a$

   $a_2 = 6a_1 = 6 \times 2ms^{-2} = 12ms^{-2}$

5. $F_1 = ma$, $F_2 = 2m \times \frac{a}{3} = ma \times \frac{2}{3} = F_1 \times \frac{2}{3}$, which is b.

Activity 4

1. a. $F_{net} = \text{weight} = \text{-200N},\ F_{up} = \text{tension} = +180\text{N}$

$$\begin{aligned} F_{net} &= F_{down} + F_{up} \\ &= w + t \\ &= -200\text{N} + 180\text{N} \\ &= -20\text{N} \\ &= 20\text{N down} \end{aligned}$$

The net force acting on the bucket is 20N down

b. The net force acts down. The bucket must be accelerating down since Newton's second law tells us that the acceleration is in the same direction as the net force. The correct answer is iv. Accelerating down.

c. $F_{down} = \text{weight} = -200\text{N}\ F_{up} = \text{tension} = +250\text{N}$

$$\begin{aligned} F_{net} &= F_{down} + F_{up} \\ &= W + T \\ &= -200\text{N} + 250\text{N} \\ &= +50\text{N} \\ &= 50\text{N up} \end{aligned}$$

d. The bucket must be accelerating up. $F_{net} = ma$ tells us that the acceleration and the net force are in the same direction. The net force acts up so it must cause and upward acceleration

e. $F_{down} = \text{weight} = \text{-200N},\ F_{up} = \text{tension} = +200\text{N}$

$$\begin{aligned} F_{net} &= F_{down} + F_{up} \\ &= w + T \\ &= -200\text{N} + 100\text{N} \\ &= 0\text{N} \end{aligned}$$

The net force acting on the bucket is now zero.

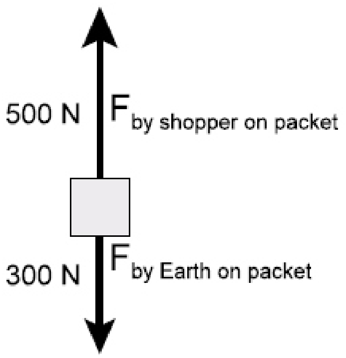
f. $F_{net} = ma$, if the net force is zero, the acceleration must be zero. hence the bucket can be moving at constant velocity upwards or downwards, or the bucket could be at rest. See the concept maps at the beginning of the lesson to comfirm.

2. a. $F_{up} = 500N = +500N,$

$$F_{down} = m \times 10\frac{n}{kg} = 30kg \times 10\frac{n}{kg} \text{ down}$$
$$= 300N \text{ down}$$
$$= -300N$$
$$F_{net} = F_{down} + F_{up}$$
$$= -300N + 500N$$
$$= +200N$$
$$= 200N \text{ up}$$
$$F_{net} = ma, \text{ so } a = \frac{F_{net}}{m}$$
$$= \frac{200N \text{ up}}{30kg}$$
$$= 6.6ms^{-2}\text{up}$$

The packet has an upward acceleration of $5.5ms^{-2}$.s

b.



3. $F_{down} = m \times 10\frac{n}{kg} = 1200kg \times 10\frac{n}{kg} \text{ down}$

$$= 12000N \text{ down}$$
$$= -12000N$$
$$F_{up} = F_{\text{by cable on car}} = T$$
$$a = 0.5ms^{-2} \text{ up}$$
$$F_{net} = F_{down} + F_{up}$$
$$= w + T$$
$$T = F_{net} - w$$
$$= ma - w$$
$$= 1200kg \times 0.5ms^{-2} - (-12000N)$$
$$= 600N + 12000N$$
$$= +12600N$$
$$= 12600N \text{ up}$$

The tension in the cable is 12600N up

Activity 5

1. a. $p = mv = 110kg \times 9ms^{-1}$ E
   $= 990kgms^{-1}$ E

   b. $p = mv = 1000kg \times 20ms^{-1}$ N
   $= 20000kgms^{-1}$ N

2. a. $p_1 = m_1v_1$ and $p_2 = m_2v_2$, but $m_1 = m_2$ and $v_2 = v_1$
   so $p_2 = m_1 \times v_1 = m_1v_1 \times 2 = 2p, \ = 2 \times 20000$ units
   $p_2 = 40000$ units

   b. $p_1 = m_1v_1 \ = 20000.\ p_2 = m_1v_2$, but $v_2 = 3v_1$
   so $p_2 = m_1 3v_1 = m_1v_1 \times 3 = 3 \times 20000 = 60000$

3. b. $2 \times 0.5 \times 24 = 24$
   c. $3 \times 2 \times 24 = 144$
   d. $0.5 \times 0.5 \times 24 = 6$
   e. $4 \times 0.5 \times 24 = 48$
   f. $0.5 \times \frac{1}{3} \times 24 = 4$

Activity 6

a. Case A

$u = 30ms^{-1}$ towards the wall $= +30ms^{-1}$
$v = 28ms^{1}$ away from the wall $= -28ms^{-1}$
$\Delta v = v - u$
$= (-28 - 30)ms^{-1}$
$= -58ms^{-1}$
$= 58ms^{-1}$ away from the wall

Case B

$u = 10ms^{-1}$ towards the wall $= +10ms^{-1}$
$v = 5ms^{-1}$ away from the wall $= -5ms^{-1}$
$\Delta v = v - u$
$= (-5 - 10)ms^{-1}$
$= -15ms^{-1}$
$= 15ms^{-1}$ away from the wall

The tennis ball has a greater change in velocity in Case A.

b. The tennis ball has the same mass in both cases. $\Delta p = m\Delta v$ Hence the ball with the greater change in velocity has the greater change in momentum. The tennis ball has a greater change in momentum in Case A.

c. The greater the change in momentum, the greater the net force since $F_{net} = \frac{m\Delta v}{\Delta t} = \frac{\Delta p}{\Delta t}$. And, the greater the net force, the greater the acceleration, $F_{net} = ma$. The tennis ball has a greater force acting on it in Case A

Summary Activity

1. a. According to Newton's second law, a constant net force causes a constant acceleration.

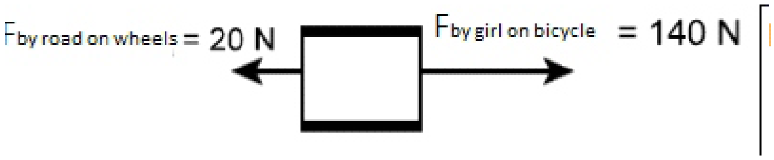
2. a. According to Newton's second law an object moving at constant velocity (zero acceleration) must have no unbalanced (net) force acting on it. $F_{net} = ma = m \times 0 = 0$

3. b. When mass doubles, acceleration halves if force stays the same. $a = \frac{6ms^{-2}}{2} = 3ms^{-2}$. See notes on inverse proportion if you are uncertain about this.

   c. When mass decreases, force must decrease in the same way if acceleration is to stay the same. So, if we make mass one third of its original value, the new force must also be one third of its original value. The new force is $\frac{600N}{3} = 200N$.

   d. Doubling net force, doubles the acceleration. Making mass four times smaller makes acceleration four times bigger. So, new acceleration is $2 \times 4 \times 2ms^{-2} = 16ms^{-2}$.

4. a.

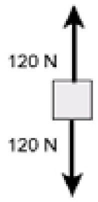


   b. $F_{net} = F_{by\ girl\ on\ bicycle} - F_{by\ road\ on\ wheels}$
   $= 140N - 20N$
   $= 120N$ in the direction the girl pedals

   c. $F_{net} = ma$, so
   $a = \frac{F_{net}}{m} = \frac{120N \text{ in the direction the girl pedals}}{60kg}$
   $= 2ms^{-2}$ in the direction the girl pedals

5. a. The acceleration of the bucket is 0 because the builder holds the bucket still (at rest).

b. $F_{net} = ma = m \times 0 = 0$

c. 

$F_{net} = 0$

Tension acting up must cancel out weight acting down. Hence tension must be the same magnitude as the weight.

d. The net force must act in the same direction as the acceleration. This is $0.5ms^{-2}$ up.

e. $F_{net} = ma = 12kg \times 0.5ms^{-2}$ up

$= 6N$ up

If we make up positive then tension is $+6N$

f. Weight acts down, so it is $-120N$. $F_{net} = F_{up} + F_{down}$

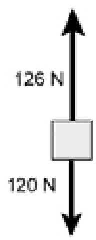
$= T + w$, so

$T = F_{net} - w$

$= 6N - (-120N)$

$= +126N$

$= 126N$ up

g. 

h. When the rope slips through the builder's hands, the bucket falls (accelerates) down. Therefore the net force must also act in a downward direction. The only way this can happen is if the tension is smaller in magnitude than the weight. The larger of the two forces must be its weight.

Lesson 8

Activity 1

1. You know that you apply a force on the nail because the nail changes its position. It moves into the soft wood.

2. The nail makes a dent in your skin because the nail exerts an upward force on your skin.

3. The only thing that can change the shape of the skin on your thumb is a force. The change in shape of your skin is evidence that the nail exerts a force on your thumb. Alternatively, your skin changed position. It moved from its usual position to a new position. A force exerted by the nail on your thumb must be responsible.

Activity 2

1. a. $F_{\text{by water on fish}}$

   b. The arrows are the same length because action and reaction are equal in magnitude.

   c. The two forces act on different things. Action acts on the water. Reaction acts on the fish.

   d. Action accelerates the water backwards. Reaction accelerates fish forwards. This is Newton's Third Law of Motion.

2. A soldier loads a bullet into a rifle and pulls the trigger. The force the rifle exerts on the bullet is ~~less than~~ / equal to / greater than the force bullet exerts on the rifle. This is Newton's ~~second~~ / third law. The acceleration of the bullet is ~~less than~~ / ~~equal to~~ / greater than the acceleration of the rifle because the mass of the bullet is less than / ~~equal to~~ / ~~greater than~~ the mass of the rifle. This is Newton's second / ~~third~~ law.

3. The second sentence is wrong. The normal force is described correctly, but the normal force is not the reaction to the force the Earth exerts on your body. The reaction is the force your body exerts on the Earth.

Activity 3

1. $F_{\text{by cart on horse}}$, $F_{\text{by horse on cart}}$

2. e. We know from experience that the horse can move the cart. The correct explanation is that the force exerted by the horse on the cart must be an unbalanced force acting on the cart (Newton's second law). The action reaction pair in the diagram do not cancel each other out because the action acts on the horse and the reaction acts on the horse.

Summary Activity

1. d. Weight is the force which the Earth exerts on the book. If we describe this as action, reaction must be the force the book exerts on the Earth. Note that both action and reaction are gravitational forces.

2. c. According to Newton's third law, action and reaction are equal in magnitude. This is true even when objects have very different masses.

3. a. Newton's third law tells us that action and reaction are equal in magnitude. The law does not take the motion of two interacting objects into account. So on collision each car experiences the same size force. The cars are identical, so equal forces must cause the same damage in both cars.

4. d. Newton's third law does not take the mass of the two interacting objects into account.

5. a. Action and reaction are equal in magnitude.

6. c. Action and reaction are equal in magnitude.

7. a. When the water is turned on, it will move forward out of the hose onto the flames. The fireman knows from experience that the water moving forward (action) will push the hose backwards (reaction). The hose will accelerate into the man's shoulder. If the fireman does not hold the hose very firmly it will jump out of his hands.

   b. If the fireman loses his grip on the hose, it will shoot backwards out of his hand. If water keeps on coming out of the hose, it will keep pushing the hose backwards until the fireman is able to catch it again.

8. We can ignore friction between both boys and the floor because they are wearing roller skates. Allistair pulls Sanjushree (action). This pull is an unbalanced force and so accelerates Sanjushree towards Allistair (Newton's second law). Although Sanjushree is passive, he automatically pulls Allistair (reaction) with the same size force (Newton's third law). Allistair accelerates towards Sanjushree.

But Allistair has a greater mass than Sanjushree, so Allistair's acceleration will be greater than Sanjushree's (Newton's second law).

In short, the unexpected happens. The boys move towards each other and collide with each other. Allistair moves more quickly than Sanjushree.

Lesson 9

Activity 1

1. $F = 3\text{N towards the wall}$

$\Delta t = 4\text{s}$

$I = F\Delta t = 3\text{N towards the wall} \times 4\text{s}$

$= 12\text{Ns towards the wall}$

2. $m = 1000\text{kg}$

$u = 25\text{ms}^{-1}\text{ towards the street pole } = +25\text{ms}^{-1}$

$v = 0$

$\Delta t = 0.05\text{s}$

$$\Delta p = F\Delta t \text{ so } F = \frac{\Delta p}{\Delta t} = \frac{m(v-u)}{\Delta t} = \frac{-mu}{\Delta t}$$

$$= \frac{1000\text{kg} \times 25\text{ms}^{-1}}{0.05\text{s}}$$

$= -500000\text{N}$

$= 500000\text{N in the opposite direction to the car's velocity}$

The negative sign in -500000N tells us that the force acts away from the street pole. In other words the pole exerts this force to reduce the car's velocity from 25ms^{-1} to zero.

3. a. $m = 1\text{kg}$

$u = 10\text{ms}^{-1}\text{ towards the player } = +10\text{ms}^{-1}$

$v = 10\text{ms}^{-1}\text{ away from the player } = -10\text{ms}^{-1}$

$\Delta v = v - u = (-10 - 10)\text{ms}^{-1}$

$= -20\text{ms}^{-1}$

$= 20\text{ms}^{-1}\text{ away from the player}$

b. $\Delta p = m\Delta v$

$= 1\text{ kg }(-20\text{ms}^{-1})$

$= -20\text{kgms}^{-1}$

$= 20\text{kgms}^{-1}\text{ away from the player}$

c. $F\Delta t = \Delta p$

$$F = \frac{\Delta p}{\Delta t} = \frac{-20kgms^{-1}}{0.2s} = -100kgms^{-1}$$
$$= -100N$$
$$= 100N \text{ away from the player}$$

4. $\Delta p = F\Delta t$

$= 10N \times 0.10s$

$= 1.0Ns$ in the direction of the force

Activity 2

1. $u = 5ms^{-1}$ towards the wall $= +5ms^{-1}$

$v = 0$

$\Delta v = V_{final} - V_{initial}$

$= v - u$

$= 0 - 5ms^{-1}$

$= -5ms^{-1}$

$= 5ms^{-1}$ away from the wall

2. $\Delta p = m\,\Delta v = 1000kg \times -5ms^{-1} = -5000kgms^{-1}$

$= 5000kgms^{-1}$ away from the wall

3. The impulse which the wall applies on the car is equal to the car's change in momentum.
$I = m\Delta v = 5000Ns$ away from the wall

4.

	Car's change in velocity	Car's change in momentum	Impulse acting on the car
Rebound collision (Diagrams A & B)	$9ms^{-1}$ away from the wall	$9000kgms^{-1}$ away from the wall	9000Ns away from the wall
"Sticky collision" (Diagrams C&D)	$5ms^{-1}$ away from the wall	$5000kgms^{-1}$ away from the wall	5000Ns away from the wall

5. Car Q has the greater change in velocity.

6. change in momentum = mass × change in velocity
Both cars have the same mass. So, change in velocity is a measure of the cars' change in momentum. The car with the bigger velocity change has the bigger change in momentum. This is Car Q.

7. change in momentum = impulse
The car with the bigger change in momentum experiences the bigger impulse. This is Car Q.

8. Impulse = force x time interval
The bigger the impulse the greater the force and the greater the force the car experiences, the greater the damage to the car. Car Q is likely to be more damaged.

9. Driver of Q is likely to be more severely hurt than the driver of P.

$I_Q > I_p$, so

$F_{on\ Q} \times \Delta t > F_{on\ P} \times \Delta t$, but Δt is the same for both cars, so

$F_{on\ Q} > F_{on\ P}$

Activity 4

1. and 2.

	Momentum of egg just before it hits the sheet	force the sheet applies on the egg	collision time /seconds	impulse sheet applies to the egg
1	100	100	1	100
2	100	50	2	100
3	100	25	4	100
4	100	20	5	100
5	100	5	20	100
6	100	4	25	100
7	100	2	50	100
8	100	1	100	100

3. As the collision becomes bigger, the force needed to stop the egg becomes smaller.

4. Condition A is less likely to break the egg. The smaller force the sheet exerts on the egg, the less likely the egg is to break.

Activity 5

1. Your friend will bend his legs as he lands on the floor. This is instinctive human behaviour. If he hits the floor with stiff legs he will seriously injure his legs. Bending his knees as he lands makes the collision time with the floor longer and so makes the size of the force the floor must apply to stop him, smaller.

2. a. $\Delta p = F\Delta t$ so $F \dfrac{\Delta p}{\Delta t} = \dfrac{-480kgms^{-1}}{0.1s}$

$= -4800N$

$= 4800N$ up

The floor exerts an upward force of 4800 N to stop the man

b. $\Delta p = F\Delta t$ so $F = \dfrac{\Delta p}{\Delta t} = \dfrac{-480kgms^{-1}}{2s}$

$= -240N$

$= 240N$ up

The floor now exerts an upward force of 240N to stop the man

3. Cricketers never leave their arms straight when catching fast moving balls. They use bent arms and as the ball comes into their hands, their arms bend or 'give' at the elbow. This increases the time interval over which the stopping force acts on the ball and so makes the force needed smaller.

Activity 6

1. 120km/h

2. $m = 50kg$

$u = 35ms^{-1} = 126km/h$

$v = 0$

$\Delta t = 0.500s$

$F\Delta t = m\Delta v$ so $F = \dfrac{m\Delta v}{\Delta t} = \dfrac{50kg \times (0-35)ms^{-1}}{0.5s}$

$= -3500N$

$= 3500N$ towards Manto's body

The air bag exerts a force of 3500N on Manto in the direction opposite to the car's motion.

3. $F\Delta t = m\Delta v$ so $F = \dfrac{m\Delta v}{\Delta t} = \dfrac{50kg \times (0-35)ms^{-1}}{0.05s}$

$= -35000N$

$= 35000N$ towards Manto's body

The windscreen exerts a force of 35 000 N on Manto in the direction opposite to the car's motion. Sadly, she is unlikely to survive the accident.

Summary Activity

1. a. $12ms^{-1}$

b. 0.1s

c. $u = 12ms^{-1}$ towards the wall, $v = 0$

$$a = \frac{v-u}{\Delta t} = \frac{0 - 12ms^{-1} \text{ towards the wall}}{0.1s}$$

$= -120ms^{-2}$

$= 120ms^{-2}$ away from the wall

d. $F_{net} = ms = 60kg \times -120ms^{-2}$

$= -7200N$

$= 7200N$ away from the dashboard

The dashboard will exert a force of 7 200 N on the passenger to bring him to rest. The passenger must therefore exert a force of 7200 N on the dashboard to keep his body at rest relative to the car.

e. The passenger's weight $w = m \times 10\frac{N}{kg} = 600N$ down.

The force the man must exert on the dashboard is

$\frac{7200N}{600N} = 6$ times bigger than his weight. The

passenger is unlikely to be able to exert such a big force.

f. The car may have an air bag fitted inside the dashboard. By law, it should have seatbelts. It may also have a crumple zone in the front.

2. a. $u = 18ms,^{-1}$ $v = 0$, $\Delta t = 0.05s$

$F\Delta t = m\Delta v$, so

$$F = \frac{m\Delta v}{\Delta t} = \frac{75kg(0-18ms)^{-1}}{0.05s}$$

$= -27000N$

The steering wheel exerts a force of 27 000N on the man. The force acts towards the front of the man's body (or in the opposite direction to his initial speed)

b. $F\Delta t = m\Delta v$, so

$$F = \frac{m\Delta v}{\Delta t} = \frac{75kg(0-18ms)^{-1}}{0.8s}$$

$= -1688N$

The airbag exerts a force of 1688N on the man. The force acts towards the front of the man's body (or in the opposite direction to his initial speed).

Lesson 10

Activity 1

1. $F = 500N$ towards the wall,

   $s = 0$

   $W = F \times s = 500N \times 0m = 0J$

   The man does no work on the wall

2. $F = 250N$ in a given direction

   $s = 4m$ in the same direction

   $W = F \times s = 250N \times 4m = 1000Nm = 1000J = 1\ kJ$

3 a. $\text{weight} = \text{mass} \times \frac{10N}{kg} = 500kg \times \frac{10N\ \text{down}}{kg}$

   $= 5000N$ down

b. According to Newton's first law an object moving at constant velocity has a zero net force acting on it. The upward force acting on the block must be equal to the magnitude of the weight of the block.

c. $F = 5000N$ up

   $s = 100m$

   $W = F \times s = 5000N\ \text{up} \times 100m\ \text{up} = 500\ 000NM =$

   $500\ 000J$

   $= 500kJ$

d. The crane uses energy from its fuel. This may be electricity or it may be diesel.

4. a. Newton's first law tells us that all the forces acting on an object at rest are balanced. The Earth exerts a downward force on the suitcase. Your hand must apply an upward force equal to the magnitude of the weight to keep the suitcase at rest.

   $\text{weight} = mg = 8kg \times \frac{10N}{kg} = 80N$ down. So your hand exerts a force of 80N up

b. Newton's first law tells us that all the forces acting on an object moving at constant velocity are balanced. An upward force equal to the magnitude of the weight will lift the suitcase at constant velocity.

c. $F = 80N$ up

   $s = 0.10m$

   $W = F \times s = 80N\ \text{up} \times 0.10m\ \text{up} = 8NM = 8J$

d. You do no work on the suitcase to hold it at rest for 10 minutes. You apply a force of 80 N up but this force does not move the suitcase up, so $S = 0$ and $W = 0$.

e.
$$F = 80\text{N up}$$
$$s = 1.5\text{m}$$
$$W = F \times s = 80\text{N up} \times 1.5\text{m up} = 120\text{Nm} = 120\text{J}$$

5. We are told that the surface is perfectly smooth. This means that the force of friction which the surface exerts on the ball is assumed to be zero. Newton's first law of motion tells us that there is no net or resultant (unbalanced) force acting on an object rolling at constant speed. Work done on the ball equals force multiplied by distance the object moves in the same direction as the force. The ball moves horizontally but there is no horizontal force acting on the ball. Hence no work is being done on the ball.

Activity 2

1.
$$m_{total} = m_{trolley} + m_{groceries} = (10\text{kg} + 20\text{kg}) = 30\text{kg}$$
$$v = 0.5\text{ms}^{-1}$$
$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 30\text{kg} \times (0.5\text{ms}^{-1})^2 = 7.5\frac{\text{kgm}}{\text{s}^2} \times \text{m}$$
$$= 7.5\text{Nm} = 7.5\text{J}$$

2. D. 1.6 J
$$E_{K_{initial}} = \frac{1}{2}mv^2 = 0.4\text{J}$$
$$E_{k_{final}} = \frac{1}{2}m(2v)^2$$
$$= \frac{1}{2}mv^2 \times 4$$
$$= 0.4\text{J} \times 4 = 1.6\text{J}$$

3. a.
$$m = 1000\text{kg}$$
$$v = 5\text{ms}^{-1}$$
$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 1000\text{kg} \times (5\text{ms}^{-1})^2 = 12500\frac{\text{kgm}}{\text{s}^2} \times \text{m}$$
$$= 12500\text{Nm} = 12500\text{J} = \frac{12500}{1000}\text{kJ} = 12.5\text{kJ}$$

b. $E_{k\ adult} = \frac{1}{2}m_{adult}v^2 = 500v^2$

$E_{k\ young} = \frac{1}{2}m_{young}v^2 = 250v^2$

$\frac{E_{k\ adult}}{E_{k\ young}} = \frac{500v^2}{250v^2} = 2$

v cancels out because both elephants move at the same speed. So, $E_{k\ adult} = 2E_{k\ young}$.

c. If you halve the mass of an object, its kinetic energy when it moves at the same speed ~~stays the same~~ / ~~doubles~~ / halves.

d. i. $E_k = \frac{1}{2}mv^2$, so $m = \frac{2E_k}{v^2}$

$= \frac{2 \times 5000J}{(5ms^{-1})} = \frac{10000Nm}{25m^2s-^2} = \frac{400kgms^{-2}m}{m^2s^{-2}}$

$= 400kg$

ii. E_k at $5ms^{-1} = E_k = 5000J$

E_k at half the speed = $E_{k_2} = 1250J$

$\frac{E_{k_1}}{E_{k_2}} = \frac{5000J}{1250J} = 4$

so, $E_{k_1} = 4E_{k_2}$

$E_{k_2} = \frac{E_{k_2}}{4}$

Its kinetic energy at the lower speed is four times smaller than its kinetic energy at the higher speed.

iii. Halving the speed of an object ~~increases~~ / ~~halves~~ / quarters its kinetic energy.

4. $E_k = 160J$, $m = 0.2kg$

$E_k = \frac{1}{2}mv^2$, so

$v^2 = \frac{2E_k}{m} = \frac{2 \times 160J}{0.2kg} = \frac{1600kgms^{-2}m}{kg}$

$v^2 = \sqrt{1600m^2s^{-2}}$ and

$v = 40ms^{-1}$

5. a. Doubling mass doubles kinetic energy. So new kinetic energy = 2 × 124 J = 248 J

b. Doubling speed makes kinetic energy four times greater. So new kinetic energy = 4 × 124 J = 496 J

c. New kinetic energy $\frac{1\times 4\times 124J}{2} = 248J$.

d. Halving the speed makes kinetic energy four times smaller. So

new kinetic energy = $\frac{124J}{4} = 31J$.

e. New kinetic energy = $\frac{3\times 124J}{4} = 93J$.

Activity 3

1. change in kinetic energy = final kinetic energy − initial kinetic energy

$$\Delta E_k = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$
$$= \frac{1}{2}(1000\ kg)\ (30\ m/s)^2 - \frac{1}{2}(1000\ kg)\ (20\ m/s)^2$$
$$= 450\ 000\ \frac{kgm\ x\ m}{s^2} - 200\ 000\ \frac{kgm\ x\ m}{s^2}$$
$$= 250\ 000\ Nm$$
$$= 250\ 000\ J$$

But, according to the work-energy principle, the work done on the car = change in kinetic energy of the car. So, 250 000 J work must be done on the car to increase its speed from 20 m/s to 30 m/s.

2. a. C. The braking force acts towards the left in the diagram. We make the direction to the left positive. But the train's displacement is to the right during braking. So its displacement must be negative.

$W = +F_{net} \times -s$

b. $\Delta E_k = E_{k\ final} - E_{k\ initial}$, but

$E_{k\ final} = 0$ (train comes to rest)

$$\Delta E_k = -E_{k\ initial}$$
$$= -\frac{1}{2} \times 1\ 600\ 000\ kg \times (25\ m/s)^2$$
$$= -\ 500\ 000\ 000\ \frac{kg\ m}{s^2} \times m$$
$$= -\ 500\ 000\ 000\ Nm$$
$$= -\ 500\ 000\ 000\ J$$

The change in kinetic energy of the train is 500 000 000 J.

c. The minus sign tells us that the train loses 500 000 000J kinetic energy.

d. The work-energy principle tells us that the kinetic energy lost by the train = net work done to stop the train

$$-E_k = -W$$
$$= F_{net} \times -s$$

e. So, $W_{net} = -\Delta E_k$, but $W_{net} = -F_{net}\,s$

$$-F_{net}\ s = -\Delta E_k \text{ , so}$$

$$F_{net} = \frac{\Delta E_k}{s} = \frac{500\ 000\ 000\ \text{Nm}}{1\ 000\ \text{m}}$$
$$= 500\ 000\ \text{N}$$

The plus (+) sign of 500 000 N tells us that the force acts in the opposite direction to the motion of train to stop it over a distance of 1 km.

3. $m = 10g = \frac{10}{1000} kg = 0.01 kg$, $w = 8000 J$, $v = 0$ m = 10 g =

The wall does work on the bullet to stop the bullet by exerting a force on it in the opposite direction to the bullet's velocity. The bullet moves towards the wall, the force acts away from the wall. Work equal force × distance in the same direction. So, either F or s must be minus.

work done by the wall = F × –s = –W

kinetic energy lost by bullet = work done by wall = (work-energy principle)

$$\Delta E_k = -W$$

$$E_{k\ final} - E_{k\ initial} = -W, \text{ but } E_{k\ final} = 0, \text{ so}$$
$$-E_{k\ initial} = -W$$
$$-\frac{1}{2}mu^2 = -W$$
$$u^2 = \frac{2W}{m}$$
$$= \frac{8\ 000\ J}{0.01\ kg} = 800\ 000\ \frac{Nm}{kg} = 800\ 000\ \frac{kgm \times m}{s^2\ kg}$$
$$u^2 = 80 \times 10\ 000\ \frac{m^2}{s^2}$$
$$u = \sqrt{80 \times 10\ 000\ \frac{m^2}{s^2}}$$
$$= 8.9 \times 100\ m/s$$
$$= 890\ m/s$$

The velocity of the bullet before it hits the wall is 890m/s towards the wall.

Activity 4

1. a. Vertical distance between the floor and the top step
$= 5 \times 15$ cm $= 75$ cm
which is the same as 0.75 m.

b. Horizontal distance between girl's initial position and

top step = $\frac{25}{2}\text{cm} + 4(25\text{cm}) + \frac{25}{2}\text{cm} = 125\text{cm}$ which is the same as 1.25m

c. i. 0.75 m. The woman lifts her body at constant velocity. This means that the force she uses is the same size as her weight (from Newton's first law). Instead of acting down which her weight does, the force she applies must act vertically up. The distance over which the woman exerts this force must be in the same direction as her upward force. So the height over which she exerts the force is in the same direction as her vertical height she lifts her body. The woman exerts no force in the horizontal direction (1.25 m).

ii. She must exert an upward force equal to her weight.

d.

position of woman	height above floor/m	gain in E_p relative to the floor /J
on floor	0	0
on first step	0.15	75
on second step	0.30	Gain in E_p = weight x height = 500 N x 0.30 m = 150 J
on third step	0.45	= 500 N x 0.45 m = 225 J
on fourth step	0.60	= 500 N x 0.60 m = 300 J
on top step	0.75	= 500 N x 0.75 m = 375 J

e. When the woman is a vertical height of 0.15 m above the floor, her gravitational potential energy is 75 J. When she is at three times the vertical height (3×0.15 m $= 0.45$ m), her gravitational potential energy is (3 x 75 J = 225 J). Making vertical height three times greater, makes the woman's gravitational potential energy three times greater too.

f. When the woman is at a vertical height of 0.60 m above the floor, her gravitational potential energy is 300 J (from the table). When she is at half the vertical height (0.30 m), her gravitational potential energy is ($\frac{1}{2} \times 300\text{J} = 150\text{J}$, also from the table).

Halving her vertical height, halves the woman's gravitational potential energy too.

g. Gravitational potential energy depends on / ~~does not depend on~~ the vertical height of an object above the Earth's surface. Lifting an object to half the vertical height above the Earth's surface, ~~has no effect on~~ / halves / ~~doubles~~ the gravitational potential energy of the object.

h. work done by the man

$=$ increase in gravitational energy

$=$ weight x vertical height

$=$ 1 000 N x 0.75 m

$=$ 750 J

i. $\dfrac{E_{p_{man}}}{E_{p_{girl}}} = \dfrac{750 \text{ J}}{375 \text{ J}} = 2$

The man has twice as much gravitational potential energy as the woman at the same height.

j. Gravitational potential energy depends / ~~does not depend~~ on ~~weight only~~ / ~~mass only~~ / both mass and weight. At the same place, doubling weight ~~halves~~ / doubles / ~~has no effect on~~ gravitational potential energy.

k. $\Delta E_p = E_{p\ final} - E_{p\ initial}$ Assume $E_{p\ initial} = 0$

$\Delta E_p = E_{p\ final} = wh$

$= 500 \text{ N} \times 0.75 \text{ m}$

$= 375 \text{ Nm}$

$= 375 \text{ J}$

Her change in gravitational potential energy does not depend on the path she takes to get to the top step. It depends only on her weight and the vertical height through which she moves.

2. a. $w = 55\text{kg} \times 10 \frac{\text{N}}{\text{kg}}$

$$E_p = wh = 550\text{ N} \times 2.0\text{ m}$$
$$= 1100 = 1100\text{ Nm}$$
$$= 1100\text{ J}$$

b. The gravitational potential energy of the bar does not change during the 5 s the weightlifter holds it above his head because the weightlifter is not doing any work on it. He is exerting a force on the bar but this force does not change the position of the bar.
In $W = Fs, s = 0,$ so W=0.

c. The gravitational potential energy of the bar decreases as the weightlifter lowers it to the ground. The gravitational potential energy of the bar is zero when it reaches the ground (h = 0).

3. $W_{\text{done by athlete}} = Fs$. If we assume that he lifts his body at constant speed, the vertical upward force he exerts equals the magnitude of his weight. The vertical distance he moves equals the height (h) of the bar.

$$W_{\text{done by athlete}} = wh$$

$$h = \frac{W}{w} = \frac{1920\text{ J}}{80\text{ kg x } \frac{10\text{ N}}{\text{kg}}} = \frac{1920\text{ Nm}}{800\text{ N}} = 2.4\text{ m}$$

4. The gravitational potential energy of the ball gets smaller as it falls towards the Earth. This is because the vertical height of the ball decreases as it falls. $\Delta E_p = wh$, where h is the vertical height above the Earth.

Summary Activity:

Please turn over

Summary Activity

1.

	Statement about energy	E_k / E_p / both E_k and E_p
a	We describe the amount in joule.	both E_k and E_p
b	If an object is at rest on the floor, it certainly does **not** have this energy.	Both E_k and E_p. If v = 0, $E_k = ½mv^2 = 0$; if h = 0, $E_p = mgh = 0$.
c	Depends upon the mass and speed of an object.	E_k
d	A raindrop falling towards the ground has this energy.	both E_k and E_p
e	Doubling velocity, makes this energy four times greater.	E_k
f	An object at rest does not have this energy.	E_k
g	An object has this energy due to its position (or height).	E_p
h	The energy an object has when it moves.	E_k

2. Answer c. Potential energy depends on weight and height, not on speed. Since the hailstones are identical, their weight w are the same.

$E_p = wh = 0.80J$ new $E_p = w \times 2h = wh \times 2 = 0.80J \times 4 = 1.60J$

3. a. $E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 80\ kg \times \left(60\ \frac{m}{s}\right)^2$

$= 40\ kg \times 3\ 600\ \frac{m^2}{s^2}$

$= 144\ 000\ \frac{kgm}{s^2} \times m$

$= 144\ 000\ Nm = 144\ 000\ J$

$= 144\ kJ$

$E_p = weight \times h = 80kg \times 10\frac{N}{kg} \times 870m$

$= 696000Nm = 696000J = 696kJ$

4. a. Newton's second law ($F_{net} = ma$) tells us that a net force will make the box accelerate in the direction in which the net force acts. The question tells us that the net force opposes the motion of the box. This means that the box is moving to the right, the net force will act to the left. The box will slow down uniformly until it comes to rest.

   b. The kinetic energy of the system (the box) decreases. Since $E_k = mv^2$, kinetic energy depends on speed. The box moves more and more slowly, so its velocity decreases.

   c. The gravitational potential energy of the box stays the same. The box moves horizontally, so its height (h) relative to the Earth does not change. Since $E_p = wh$, and weight of the box stays constant, gravitational potential energy cannot change either.

   d. Yes work is being done on the box. The frictional force does work on the box to stop it moving.

5. a. The box keeps on moving horizontally. Newton's first law says this is only possible if no net force acts on the box. The question tells us that a horizontal frictional force acts to the right. To cancel out this force, another agent must exert a force equal in magnitude to the frictional force but this force must act in the opposite direction (to the left).

   b. No, work is not being done on the box. The net force acting on the box is zero. $W_{net} = F_{net} \times s$.

   c. No it is not possible to do work without transferring energy. The work-energy principle tells us that the work done equals the energy transferred. If no energy is transferred, then no work is being done!

Lesson 11

Activity 1

1. The initial velocity of the ball is zero. You hold the ball in your hand before you drop it. If your hand is not moving then the ball is not moving either. Drop means that you let it fall. You do not throw it.

2. The ball hits the ground 3s after you drop it.

3. The information on the diagram tells us that the ball is 45 m above the ground.

4. Perhaps you can see from the diagram that the ball is not falling with constant velocity? The closer the ball is to the ground, the bigger and bigger distances it falls in 0.5 s time intervals. If you cannot see this on the diagram, don't worry. Just carry on answering the questions.

5. a. CD = (11.25 m -5.0 m) = 6.25 m

   b. DE = (20.0 m - 11.25 m) = 8.75 m

   c. EF = (31.25 m - 20.0 m) = 11.25 m

   d. GH = (45.0 m - 31.25 m) = 13.75 m

   e. t = 2.5 s to t = 3.0 s (FG on the diagram)?

6. The closer the ball gets to the ground, the bigger / ~~smaller~~ the distance it falls in 0.5 s. This means that the ball must be moving ~~slower and slower~~ / faster and faster as it gets closer to the ground. The ball must be accelerating / ~~moving with constant velocity~~ as it gets closer to the ground.

7. a. v in the equation $E_k = \frac{1}{2}mv^2$ represents the velocity of an object.

   b. Since the ball is moving faster and faster as it approaches the ground, its velocity increases. The equation shows us that as v increases so does kinetic energy. The kinetic energy of the ball becomes bigger and bigger as the ball gets closer to the ground.

8. a. The h in the equation $E_p = \text{weight} \times h$ represents the height of an object above the ground.

   b. The ball moves bigger and bigger distances in equal time intervals as it approaches the ground. But, as the ball gets closer to the ground, its distance above the ground, h in the equation $E_p = \text{weight} \times h$, gets smaller. Since the weight of the tennis ball does not change during its fall, as h gets smaller, the potential energy of the ball gets smaller too!

9. As the ball falls towards the ground its kinetic energy increases / ~~decreases~~ / ~~remains the same~~. But at the same time that the ball ~~loses~~ / gains kinetic energy, its potential energy ~~increases~~ /decreases/ ~~remains the same~~.

Activity 2

1. Box A, h = (45 m – 0 m) = 45 m

2. Box C, h = (45 m – 5 m) = 40 m

3. Box E, h = (45 m - 20 m) = 25 m
Box G, h = (45 m - 45 m) = 0 m

4.

time /s	height above Earth /m	weigh t /N	E_p = wh /J
0	45	1	E_p = wh = 1 N x 45 m = 45 J
1	40	1	E_p = wh = 1 N x 40 m = 40 J
2	20	1	E_p = wh = 1 N x 25 m = 25 J
3	0	1	E_p = wh = 1 N x 0 m = 0 J

5. a. The gravitational potential energy of the tennis ball decreases from 45 J as it gets closer to the Earth. When the height of the ball above the Earth is zero, the ball has zero gravitational potential energy.

6. a. The ball has maximum potential energy when it is at its highest point (45 m) above the Earth.

b. The ball has minimum potential energy when it is on the Earth's surface. This is when h = 0.

Activity 3

1.

time / s	mass / kg	velocity / m/s	$(\text{velocity})^2$ / $(\text{m/s})^2$	kinetic energy $E_k = \frac{1}{2}mv^2$ / J
0	0.1	0	0	=1/2 x 0.1 x 0 = 0
1	0.1	10	$(10)^2$ = 100	=1/2 x 0.1 x 100 = 5
2	0.1	20	$(20)^2$ = 400	=½ x 0.1 x 400 = 20
3	0.1	30	$(30)^2$ = 900	=1/2 x 0.1 x 900 = 45

2. a. The kinetic energy of the tennis ball increases as it gets closer to the Earth. When the ball is at rest in your hand (v = 0) its kinetic energy is zero. Once the ball starts falling, the closer it gets to the Earth, the faster it moves. Kinetic energy depends on velocity. The higher the ball's velocity, the bigger its kinetic energy.

3. a. The ball has maximum kinetic energy at the instant immediately before it hits the ground. This is when its velocity is highest. When the ball strikes the ground, the ground exerts an upward force on the ball to change its velocity to zero.

   b. The ball has minimum kinetic energy when its velocity is zero. This is when the ball is at its maximum height above the Earth - when it is at rest in your hand.

4. a. At t = 1 s the ball's velocity is 10 m/s. At 1 = 2 s, its velocity is 20 m/s down. Its change in velocity in 1 s = (20 m/s – 10 m/s) down = 10 m/s. At t = 3 s, its velocity is 30 m/s down. Its change in velocity from t = 2 s to t = 3 s = (30 m/s – 20 m/s) = 10 m/s down. The ball's velocity increases by equal amounts during equal time intervals.

   b. The change in velocity each second is the ball's acceleration. See Lesson 4, Activity 3 if you don't remember how we define acceleration. The ball's acceleration is 10 m/s/s or 10 m/s^2 down.

Activity 4

1.

	These values for E_p come from Activity 2	**These values for E_k come from Activity 3**	
time / seconds	**E_p of the ball / joules**	**E_k of the ball / joules**	**mechanical energy of the ball / joules**
0	45	0	$E_{mech} = E_p + E_k$ = 45 J + 0 J = 45 J
1	40	5	$E_{mech} = E_p + E_k$ = 40 J + 5 J = 45 J
2	25	20	$E_{mech} = E_p + E_k$ = 25 J + 20 J = 45 J
3	0	45	$E_{mech} = E_p + E_k$ = 0 J + 45 J = 45 J

2. The mechanical energy of the ball stays the same. It is 45 J at each of the four instants.

Activity 5

1. D is the correct answer.

2. a. P $E_p = 3J$ Q $E_p = 2J$ R $E_p = 0.5J$ S $E_p = 1J$
$E_k = 0J$ $E_k = 1J$ $E_k = 2.5J$ $E_k = 2J$
$E_{mech} = 3J$ $E_{mech} = 3J$ $E_{mech} = 3J$ $E_{mech} = 3J$

b. The pendulum is above the ground at its lowest point. h in the formula Ep = weight × h is not zero, so Ep cannot be zero.

3. a. The ball has zero kinetic energy does the ball have at the top of the ramp. $E_k = \frac{1}{2}mv^2$ Where v is the velocity of the ball. The ball is at rest at the top of the ramp. Its velocity and hence its kinetic energy must be zero.

b. The gravitational potential energy of the ball decreases as it rolls down the ramp.
Ep = weight × vertical height above the Earth.

The balls vertical height decreases as it rolls down the hill, so its Ep must decrease too.

c. The kinetic energy of the ball increases as it rolls down the ramp. Its kinetic energy is zero at the top of the ramp because the ball is not moving. When the ball rolls down the ramp, its velocity and its kinetic energy must be greater than zero.

d. The ball, the ramp and the Earth make up the system.

e. The law of conservation of energy tells us that answer B ($E_{mech\ TOP} = E_{mech\ BOTTOM}$) describes the relationship correctly.

f. The gravitational potential energy of the ball is zero at the bottom of the ramp. The vertical height of the ball above the Earth's surface when it is at the bottom of the ramp is zero.

g. The ball has 100J of kinetic energy at the bottom of the plank. It has lost all its gravitational potential energy. This is an isolated system, so this energy cannot move out of the system. It must therefore exist as kinetic energy of the ball.

h. $E_{k\ TOP}$ and $E_{p\ BOTTOM}$ are both zero. So Equation 1 becomes

$E_{p\ TOP}$ and $E_{k\ BOTTOM}$

i. $E_{p\ TOP}$ and $E_{k\ BOTTOM}$ becomes $E_{p\ TOP} = \frac{1}{2}mv^2$. But

$$E_{p\ TOP} = 100\text{J},$$

$$m = 2\text{kg, so}$$

$$v^2 = \frac{2\ E_{p\ TOP}}{m} = \frac{2 \text{ x } 100 \text{ J}}{2 \text{ kg}} = \frac{200 \text{ Nm}}{2 \text{ kg}}$$

$$v^2 = 100\ \frac{\frac{\text{kgm}}{\text{s}^2} \text{ x m}}{\text{kg}}$$

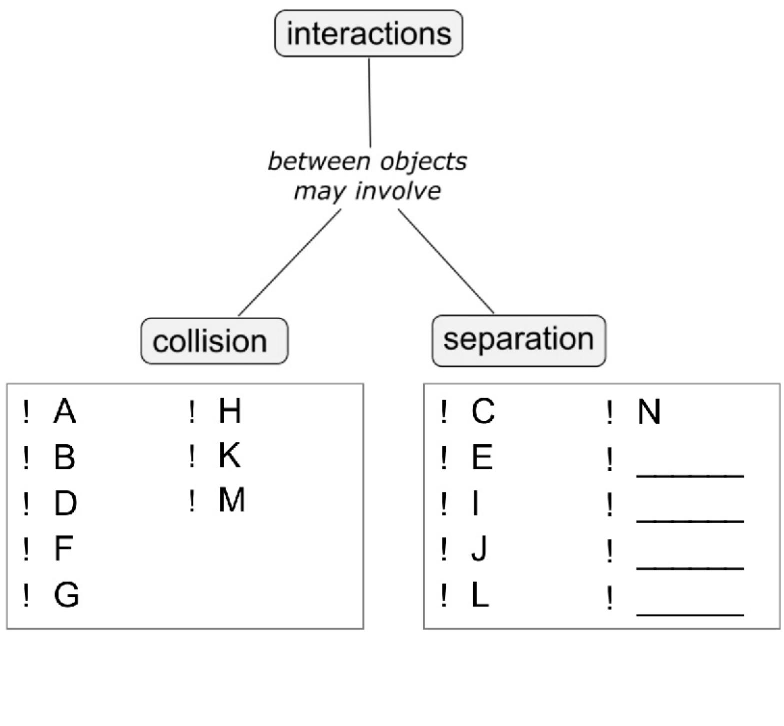
$$v^2 = 100\ \frac{\text{m}^2}{\text{s}^2}$$

$$\text{and } v = \sqrt{100\ \frac{\text{m}^2}{\text{s}^2}}$$

$$v = 10 \text{ m/s}$$

Activity 6

1.



2. All of these interactions involve changes in momentum.
momentum = mass × velocity
During collision objects change velocity.

Activity 7

1. a.

P	Q
$m_P = 1$ kg	$m_Q = 2$ kg
$u_P = +2$ m/s	$u_Q = -4$ m/s
$v_P = -4$ m/s	$v_Q = ?$

b. $p_P = m_P u_P = 1\text{ kg x } +2\text{ m/s} = +2\text{ kgm/s}$

$p_Q = m_Q u_Q = 2\text{ kg x } -4\text{ m/s} = -8\text{ kgm/s}$

c. $p_{total\ BEFORE} = 2\text{ kg m/s} + (-8\text{ kgm/s}) = -6\text{ kg m/s}$

d. $p_P = m_P v_P = 1\text{ kg} \times -4\text{ m/s} = -4\text{ kgm/s}$

e. $P_{TOTAL\ after} = -4\text{kgm/s} + 2\text{kg} \times v_Q$

f.
$$p_{BEFORE} = p_{AFTER}$$
$$-6\text{ kgm/s} = -4\text{ kgm/s} + 2\text{ kg} \times v_Q$$
$$-2\text{ kgm/s} = 2\text{ kg} \times v_Q$$
$$v_Q = -1\text{ m/s}$$

g. The velocity of Q after collision is 1 m/s to the left.

2. Collisions between moving objects which separate after collision are G, H and M.

G A ball bounces after hitting the ground. The collision is between the Earth and the ball. It is unusual for a ball to stick to the ground after hitting it.

H Moving ball hits a tennis racquet. The ball and the racquet separate after they collide.

M Two marbles roll toward each other. The marbles make a sound when they collide. They do not stick together when they collide.

3. a.
$$E_{k_{p\ before}} = \frac{1}{2}mu^2 = \frac{1}{2} \times 1\text{ kg }(2\text{ m/s})^2 = 2\text{ J}$$
$$E_{k_{Q\ before}} = \frac{1}{2}mu^2 = \frac{1}{2} \times 2\text{ kg }(-4\text{ m/s})^2 = 16\text{ J}$$
$$E_{k\ total\ BEFORE} = 2\text{ J} + 16\text{ J} = 18\text{ J}$$

b. $E_{k_{P\ after}} = \frac{1}{2}mv^2 = \frac{1}{2} \times 1\ kg\ (-4\ m/s)^2 = 8\ J$

$E_{k_{Q\ after}} = \frac{1}{2}mv^2 = \frac{1}{2} \times 2\ kg\ (-1\ m/s)^2 = 1\ J$

$E_{k\ total\ after} = 8\ J + 1\ J = 9\ J$

c. No, the kinetic energy of the system after the collision is less than the kinetic energy of the system before collision.

Activity 8

1. a.

B	S
m_B = 40 kg	m_S = 10 kg
u_B = - 2.5 m/s	u_S = -1 m/s
v_B = ?	v_S = ?

b. The boy is riding on the skateboard. They must both have the same velocity.

c. $v_B = \dfrac{p_{system\ BEFORE}}{m_B + m_S}$

d. $p_{system\ BEFORE} = p_{system\ AFTER}$

$v_B = \dfrac{p_{system\ BEFORE}}{m_B + m_S}$

e. $= \dfrac{-120\ kgm/s}{(40\ kg + 20\ kg)}$

$= -2\ m/s$

2. Interactions involving objects which combine or stick together after they interact are A, D, F and K.

A A fielder in a cricket match takes a difficult catch. This means that the ball stays in his hand.

D A truck collides with a parked car.

F A boy jumps onto a stationary skateboard.

K An insect is squashed after it flies into your windscreen. The mess stays on the windscreen.

Summary Activity

1.

closed systems (for example, doing work on a supermarket trolley)	**isolated systems (for example a swinging pendulum)**
Energy of the system stays ~~**constant**~~ **/ can change.**	Energy of the system **stays constant /** ~~**can change.**~~
~~**Internal**~~ **/ external** forces do work on it	**Internal** ~~**/external**~~ forces do work on it.
Amount of matter in the system **stays constant** ~~**/ can change**~~**.**	Amount of matter in the system **stays constant** ~~**/ can change**~~**.**
A change from gravitational to kinetic energy ~~**can /**~~ **cannot** happen inside the system.	A change from gravitational to kinetic energy **can** ~~**/ cannot**~~ happen inside the system.
Energy **is /** ~~**is not**~~ conserved when work is done.	Energy **is /** ~~**is not**~~ conserved when work is done.
Energy **can /** ~~**cannot**~~ be transferred out of the system as heat or sound.	Energy ~~**can**~~ **/ cannot** be transferred out of the system as heat or sound.

2. a. You can think of each marble and its hill (the Earth) as an isolated system. Think of the way energy changes when a pendulum moves from its lowest to its highest point.

   i. The marbles lose kinetic energy as they roll uphill.

   ii. The marbles gain gravitational potential energy as they roll uphill.

   b. In which diagram does the marble roll the

   i. The marble rolls the shortest distance uphill up the steepest slope. This is A..

   ii. The marble roll the longest distance up the flattest slope. This is C.

   c. $E_{K\ BOTTOM} = E_{p\ TOP}$

   $E_{K\ BOTTOM}$ = weight x vertical height

d. The marbles all have the same mass. At the bottom of each hill, they move with the same velocity. Hence their kinetic energies at the bottom are equal. The weights of the marbles are also equal. So,

$$\text{vertical height} = \frac{E_k}{\text{weight}}$$

must be the same for all the marbles.

3.

A	B
m_A = 3 000 kg	m_B = 2 000 kg
u_A = +40 m/s	u_B = - 30 m/s
$v_A = v_B$	v_B = ?

$$p_{\text{system BEFORE}} = m_A u_A + m_B u_B$$
$$= 3\ 000 \text{ kg x } 40 \text{ kgm/s} + 2\ 000 \text{ kg} \times -30 \text{ m/s}$$
$$= 120\ 000 \text{ kgm/s} - 60\ 000 \text{ kgm/s}$$
$$= -60\ 000 \text{ kgm/s}$$

The momentum of the system after the two cars move off together is

$$p_{\text{system AFTER}} = m_A v_A + m_B v_A$$

We replace the velocity of Car B v_B in this equation with v_A. This gives

$$p_{\text{system AFTER}} = m_A v_A + m_S v_A$$
$$p_{\text{system AFTER}} = v_A (m_A + m_B)$$

$$v_A = \frac{p_{\text{ system BEFORE}}}{m_A + m_B}$$

$$p_{\text{system BEFORE}} = p_{\text{system AFTER}}$$

$$v_A = \frac{p_{\text{ system BEFORE}}}{m_A + m_B}$$
$$= \frac{-60\ 000 \text{ kgm/s}}{(3\ 000 \text{ kg} + 2\ 000 \text{ kg})}$$
$$= -12 \text{ m/s}$$

The wreck moves to the left at 12 m/s after the collision.

4. a.

$$p_{system\ BEFORE} = m_P u_P + m_Q u_Q$$

$$\text{but } u_Q = 0\text{, so}$$

$$p_{system\ BEFORE} = m_P u_P$$

$$= 2\ kg \times 3\ m/s$$

$$p_{system\ AFTER} = m_P v_P + m_Q v_Q$$

$$\text{but } v_P = 0\text{, so}$$

$$p_{system\ AFTER} = m_Q v_Q$$

$$= 2\ kg \times v_Q$$

$$p_{system\ BEFORE} = P_{system\ AFTER}$$

$$6\ kgm/s = 2\ kg \times v_Q$$

$$v_Q = \frac{6\ kgm/s}{2\ kg}$$

$$= 3\ m/s$$

Q moves at a velocity of 3 m/s to the right after the collision.

b.

$$E_{k\ BEFORE} = \frac{1}{2}m_P u_P^2 + \frac{1}{2}m_Q u_Q^2,\ \text{but } u_Q = 0,$$

$$E_{k\ BEFORE} = \frac{1}{2}m_P u_P^2 = \frac{1}{2} \times 2\ kg \times (3\ m/s)^2 = 9\ J$$

$$E_{k\ AFTER} = \frac{1}{2}m_P v_P^2 + \frac{1}{2}m_Q v_Q^2,\ \text{but } v_P = 0,$$

$$E_{k\ BEFORE} = \frac{1}{2}m_Q v_Q^2 = \frac{1}{2} \times 2\ kg \times (3\ m/s)^2 = 9\ J$$

The kinetic energy of the system of P and Q is the same (9 J) before and after collision. Hence this is an elastic collision.