8 Machines

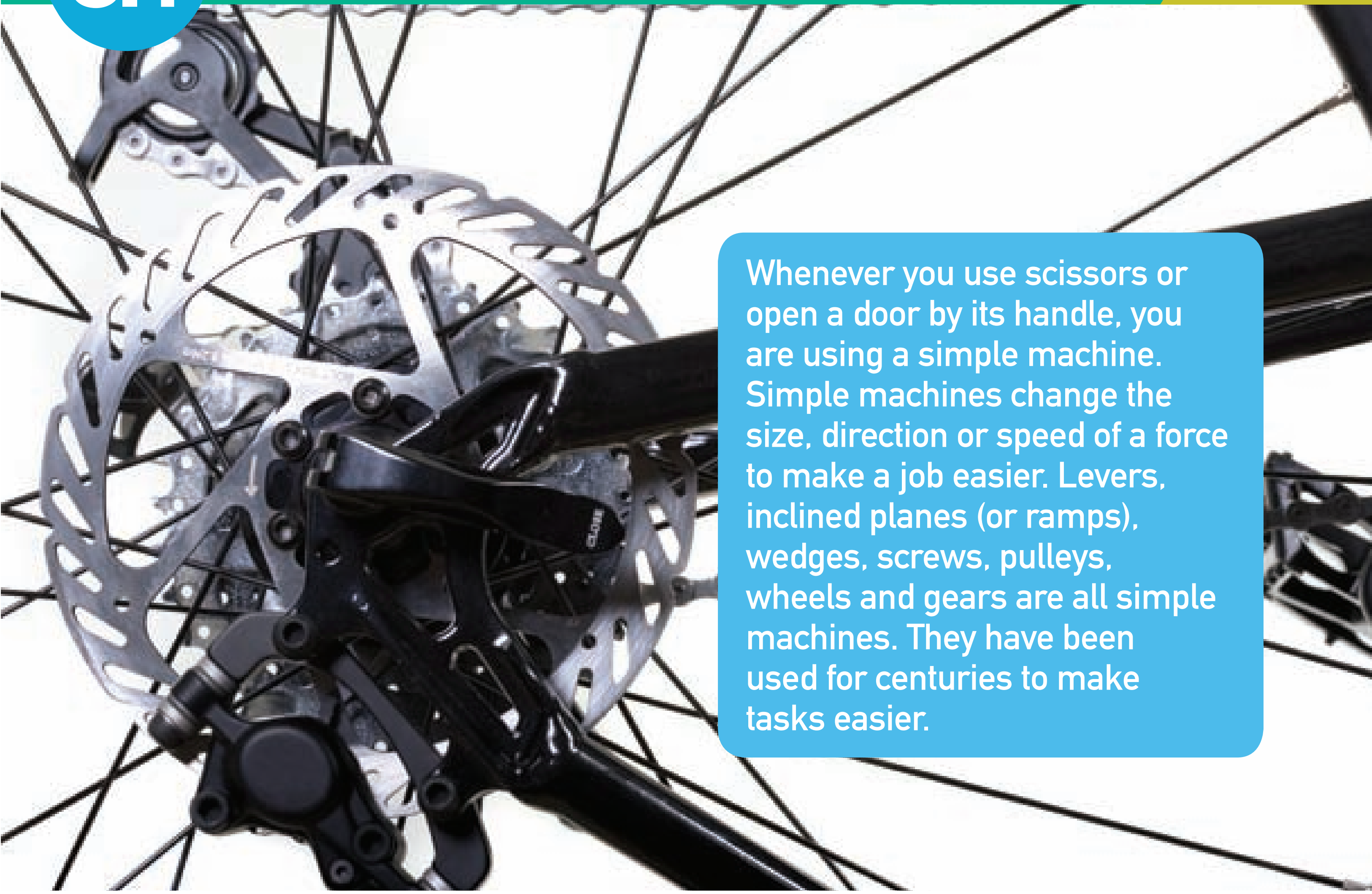
HAVE YOU EVER WONDERED...

- why an axe splits wood but a hammer doesn't?
- how gears work on a bicycle?
- why door have handles?
- how a zip works?

After completing this chapter students should be able to:

- recall that a machine can change the size of a force, the direction a force is applied, or change the speed of an object
- recall that a machine is something that makes life easier
- identify simple machines, such as levers, inclined planes, screws, pulleys, wheels and gears
- investigate a simple machine such as a lever or pulley system
- identify how a force or speed/distance advantage is gained from the use of levers, ramps, pulley systems and gears
- discuss how Indigenous Australians have designed and use a range of weapons and tools
- identify three classes of levers and, given sufficient information, calculate the mechanical advantage they provide
- identify that ramps, wedges, zippers and screws are all examples of inclined planes.

8.1 Machines around us



Whenever you use scissors or open a door by its handle, you are using a simple machine. Simple machines change the size, direction or speed of a force to make a job easier. Levers, inclined planes (or ramps), wedges, screws, pulleys, wheels and gears are all simple machines. They have been used for centuries to make tasks easier.

What can machines do?

To get a job done, you apply a force called an **effort**. The **load** is the force actually required to do the job. A **simple machine** can make a task easier in three different ways. It can:

- change the size of a force
- make things speed up
- change the direction of a force.

Changing the size of a force

Lifting a car to change a tyre would require a huge effort force applied over a small distance. For most of us, this task would be impossible. However, using a jack makes the task easier and the effort required smaller. You apply a small force to the handle of the jack, but wind it over a very long distance. This is shown in Figure 8.1.1. In the same way, a crowbar can be used to shift a rock that would otherwise be too heavy to move. Machines used in this way magnify the force you apply to do a job. These machines are known as **force multipliers**.

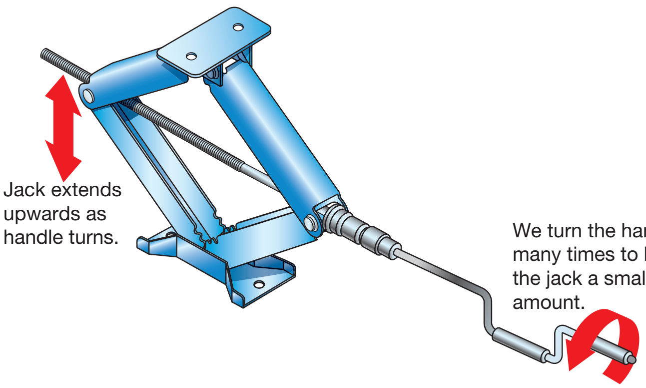


Figure 8.1.1 You use a small force to turn the handle of a jack handle through a very large distance, in order to lift a car.

Making things speed up

A machine can also make something move faster than otherwise possible. For example, when you use an eggbeater like that in Figure 8.1.2 to whip cream, the blades move much faster than the handle. Similarly, when riding a bike, different gear combinations can make the wheels spin much faster than the pedals are moving. You need to apply greater force to these types of machines but the machines speed things up. For this reason, they are known as **speed multipliers**.

A machine can increase the speed of moving parts. Figure 8.1.2

Changing the direction of a force

A machine can also change the direction in which a force acts. It would be very awkward if you needed to lift the cables of a set of blinds to pull them up. Instead, you pull the cable down and a pulley changes the direction of the force on the blinds to lift them up. Figure 8.1.3 shows how pulleys can be used to move a giant puppet.

Figure 8.1.3 Pulling downwards on a series of pulleys allows the puppeteers from a French marionette street theatre company to move the puppet's limbs upwards.

SciFile

Australia's Leonardo: David Unaipon (1872–1967)

Born in South Australia, David Unaipon was a preacher, Indigenous rights activist, inventor and the first published Aboriginal writer. He developed an improved handpiece for shearing sheep and patented another nine applications for inventions. Uniapon predicted helicopter flight from observing the flight of the boomerang! For many years, he tried to develop a perpetual motion machine—a machine that would keep going forever.

Levers

A **lever** is a simple machine that is made of a long, rigid object (such as a stick or metal rod) and a pivot or **fulcrum** about which it rotates. Most levers, like the crowbar shown in Figure 8.1.4, increase the size of the effort that you can apply or reduce the effort needed to get a job done.

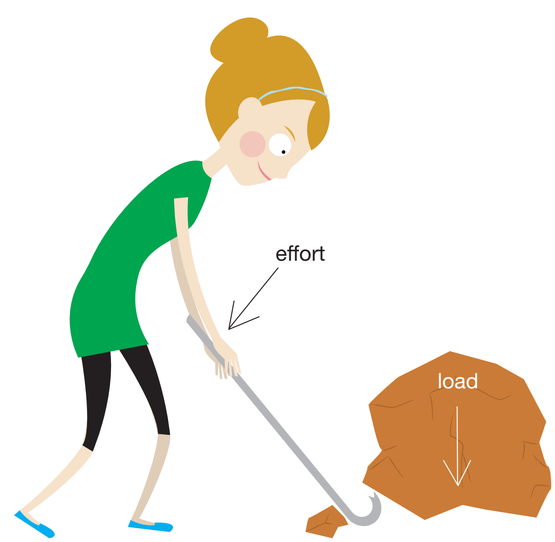


Figure 8.1.4 A crowbar or long stick used like this acts as a lever. The lever increases the force that you can supply.

Figure 8.1.5 shows how the claw of a hammer can be used as a lever to pull a nail (the load) out of a piece of wood. However, when using just your fingers, the effort required is so high that the task is nearly impossible. Using a teaspoon to remove the lid of a coffee tin multiplies force in the same way. This is shown in Figure 8.1.6.

Figure 8.1.5 Using a hammer as a lever reduces the size of the effort needed to pull a nail from a piece of wood. This makes the task much easier.

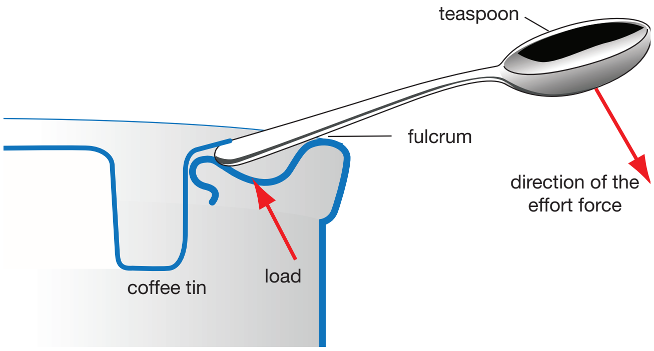


Figure 8.1.6 The load being shifted here is the coffee lid, and the edge of the tin is the fulcrum. The effort is applied as a downwards force on the teaspoon and the lever magnifies this force to open the lid.

INQUIRY science 4 fun

Launching marshmallows

How does a catapult work?

Collect this …

- string
- straws
- icy-pole sticks
- masking tape
- marshmallow
- paper clips
- cardboard squares
- plastic spoon
- 10 rubber bands
- permanent marker
- safety glasses

Do this …

1 Use some or all of your equipment to build a catapult.

2 You have a time limit of 30 minutes.

3 Draw an initial or symbol on your marshmallow so you can tell it apart from the others.

4 Line up all of the class catapults and load each with marshmallow ammunition.

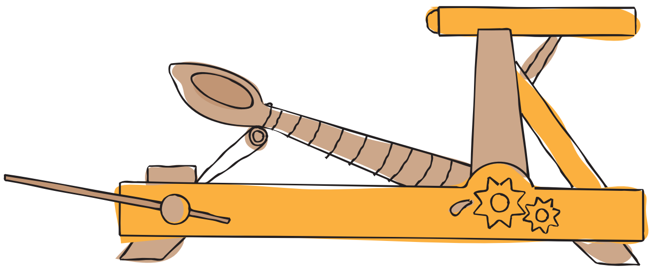
5 Fire each catapult.

6 Which marshmallow went the greatest distance?

Record this …

Describe how you built your catapult, using a diagram to assist your description.

Explain how your catapult works.



SKILL BUILDER

Mechanical advantage

A machine makes a task easier. You can measure how much easier a task has become by calculating the mechanical advantage a machine produces. **Mechanical advantage** is equal to the size of the load force divided by the effort:

$$\text{Mechanical advantage} = \frac{\text{load}}{\text{effort}}$$

A machine with a mechanical advantage of 2 indicates that using this machine allows you to:

- lift twice the load that you would normally be able to lift
- use half the force you would have otherwise needed to do a particular job.

For a lever, mechanical advantage can also be calculated using:

$$\text{Mechanical advantage} = \frac{\text{distance from effort to fulcrum}}{\text{distance from load to fulcrum}}$$

This means a lever has a greater mechanical advantage when the distance from the fulcrum to the effort is longer than the distance of the fulcrum to the load. This situation is shown in Figure 8.1.7. This happens because a smaller effort force may be applied over a larger distance. The two statements above for mechanical advantage can be combined into a rule called the *principle of levers*. This states that:

$$\text{Effort} \times \text{distance (of effort to fulcrum)} = \text{load} \times \text{distance (load to fulcrum)}$$

Figure 8.1.8 shows how this applies to opening a tin.

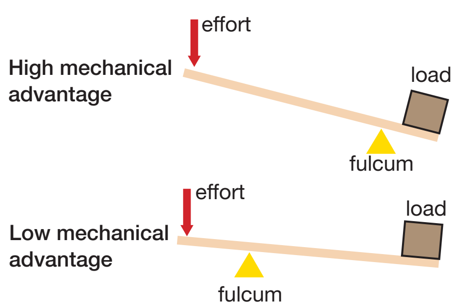


Figure 8.1.7 As the distance between the effort and the fulcrum increases, so too does the mechanical advantage of a lever.

Figure 8.1.8 It is easier to open the tin shown using the longer screwdriver, because it has a greater distance from the fulcrum to the effort.

WORKED EXAMPLE

Mechanical advantage

Problem 1

Jess applies an effort of 150 N to lift a rock of weight 600 N using a long piece of wood as a lever. Calculate the mechanical advantage of the lever.

Solution 1

The load is the weight Jess is trying to lift. This is 600 N.

The effort is the force she exerts of 150 N.

$$\begin{aligned}\text{Mechanical advantage} &= \frac{\text{load}}{\text{effort}}\\ &= \frac{600}{150}\\ &= 4\end{aligned}$$

This means that the lever has made Jess's force four times larger. She only needs to put in one-quarter the effort she would otherwise need to apply to do the job.

Problem 2

Con uses another stick to shift a second rock. The distance from his hand on the stick to the fulcrum is 120 cm, and the distance from the fulcrum to the rock is 40 cm. Calculate the mechanical advantage of this lever system.

Solution 2

$$\begin{aligned}\text{Mechanical advantage} &= \frac{\text{distance from effort to fulcrum}}{\text{distance from load to fulcrum}}\\ &= \frac{120}{40}\\ &= 3\end{aligned}$$

This means Con can shift the rock with three times less force than when using his bare hands. It also means that he could lift a rock three times heavier than he normally could.

Types of levers

In the examples so far, a lever has been used as a force multiplier. A lever can also be used as a speed multiplier. The way a lever operates depends upon the position of the effort, load and fulcrum. There are three different ways we can use levers. Levers can be grouped into three types or classes of levers.

First-class levers

When you use a lever as a crowbar, or as a teaspoon to lift a lid from a tin, you are using a **first-class lever**. Some first-class levers are shown in Figure 8.1.9. First-class levers have the fulcrum positioned between the effort and load forces. The handle of the crowbar shown in Figure 8.1.4 on page 290 moved through a larger distance than the load, but in doing so, the force applied is increased. Other first-class levers are pliers, tin snips, hedge-cutters and scissors.

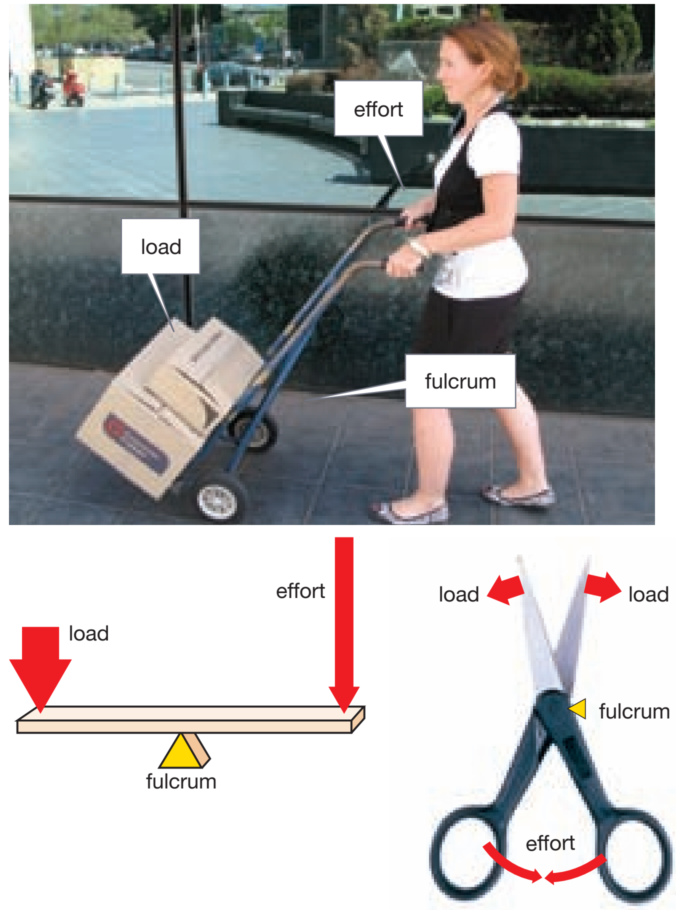


Figure 8.1.9 A first-class lever has its fulcrum positioned between the effort and the load. These levers act as force multipliers. The greater the distance between the fulcrum and the effort, the greater the mechanical advantage of the lever.

SciFile

Levered launch

Legend has it that Greek mathematician Archimedes (287–212 BCE) believed he could move the Earth itself if he had a long enough lever. According to another legend, Archimedes used pulleys and levers to launch a ship that no one could get into the sea.

1 p298

INQUIRY **science 4 fun**

Lever lifting

How should a lever be arranged to provide the best mechanical advantage?

Collect this ...

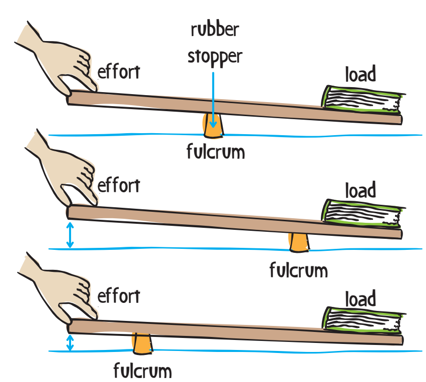
- metre ruler
- rubber stopper
- heavy book

Do this ...

1. Set up the equipment in the three ways shown.
2. Compare how hard or easy it was to lift the book in each case.

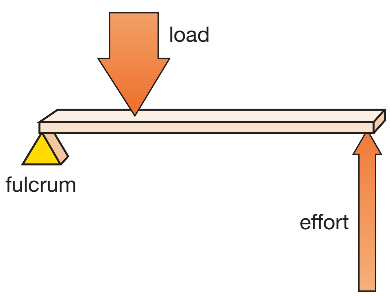
Record this ...

1. **Describe** what happened.
2. **Explain** why you think this happened.



Second-class levers

If the load is positioned between the fulcrum and the effort, then the lever is called a **second-class lever**. This also acts as a force multiplier. A wheelbarrow is an example of such a lever. By lifting the end with the handles a greater distance than the load is lifted, as shown in Figure 8.1.10, the force applied is increased. Other second-class levers include bottle openers, paper guillotines and nutcrackers.



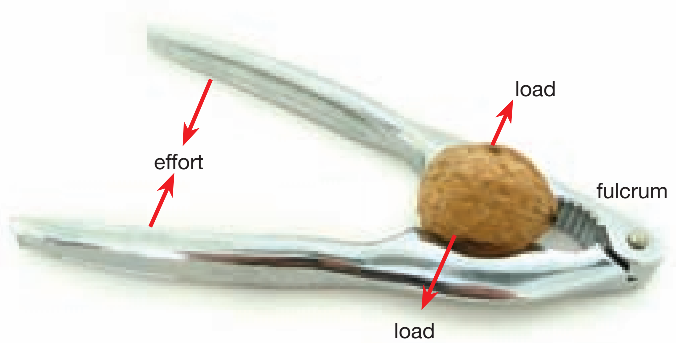


Figure 8.1.10 A second-class lever has its fulcrum positioned at one end of the system and the effort at the other. These levers also act as force multipliers.

Third-class levers

If the effort is positioned between the fulcrum and the load, then the lever is called a **third-class lever**. When using a broom, you apply a large effort force to the handle. The handle moves though a much shorter distance than the end of the broom, which moves much faster, but with less force. The broom acts as a third-class lever. It has traded an increase in force for an increase in speed. Tennis racquets, cricket bats and golf clubs are used in this way, so that they hit balls at high speed. This is shown in Figure 8.1.11. Tweezers and tongs are also third-class levers.

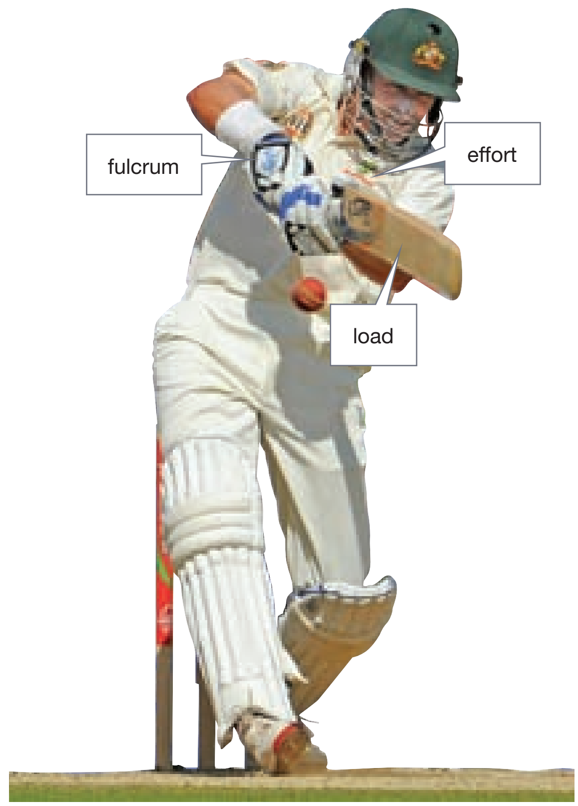
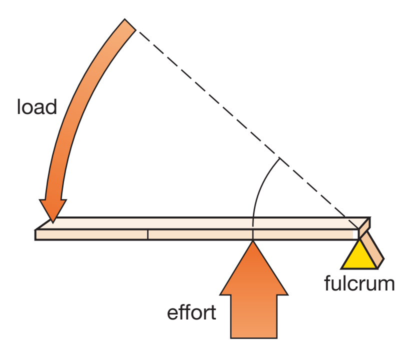


Figure 8.1.11 Tennis racquets, baseball bats, cricket bats and golf clubs are all used as third-class levers. They are speed multipliers.



8.1 8.2 p299 p300

8.1 Unit review

Remembering

1 **List** three ways a machine can make a task easier.

2 **State** the unit used to measure force.

3 **State** whether each statement below is true or false.

a A lever is a simple machine that can increase the effort supplied to get a job done.

b If using a crowbar to lift a tree stump, then the tree stump is called the effort.

c A crowbar used as a lever rotates about a point called the fulcrum.

d When using the claw of a hammer to pull a nail out of a piece of wood, the hammer acts as a force multiplier.

4 **Recall** which class of lever multiplies speed.

Understanding

5 **Describe** two ways of calculating mechanical advantage for a lever.

6 Most levers used in ball sports are third-class levers.

a **Explain** why this is the case.

b A tennis player serving a ball will toss it into the air and reach upwards to hit the ball. **Explain** how this increases the speed of their serve.

7 The nutcracker illustrated in Figure 8.1.10 is a force multiplier. **Describe** a way the design of this nutcracker could be changed to give it a greater mechanical advantage.

Applying

8 **Identify** whether each of the following machines makes a task easier by increasing the size of a force, speeding something up, or changing the direction of a force.

a axe

b crowbar

c hand drill

9 Ping uses a chisel to lift the lid from a paint tin. **Identify** what acts as the:

a load

b effort

c fulcrum.

10 **Identify** the following as first-, second- or third-class levers.

a Load positioned between the fulcrum and the effort

b Effort positioned between the fulcrum and the load

c Fulcrum positioned between the effort and the load

11 A machine has a mechanical advantage of 10, and is used to lift an outdoor statue weighing 900 newtons.

a **Calculate** the force required to lift the statue using the machine.

b **Use** effort, loads and distances moved to **explain** where this force advantage comes from.

12 **Calculate** the size of the mechanical advantage for each system shown in Figure 8.1.12.

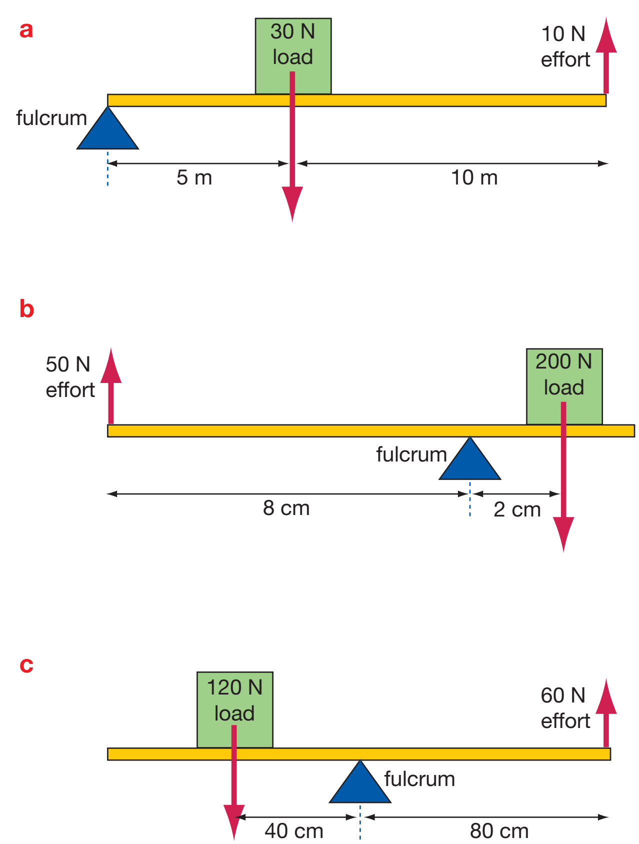


Figure 8.1.12

8.1 Unit review

Analysing

13 **Classify** the objects shown in Figure 8.1.13 as first-, second- or third-class levers.

Figure 8.1.13

14 **a** Copy each diagram in Figure 8.1.14. **Analyse** how each object operates and label the position of the fulcrum (F), load (L) and effort (E) on each diagram.

b **Identify** which class of lever is shown in each diagram.

c **State** whether each is a force multiplier or a speed multiplier.

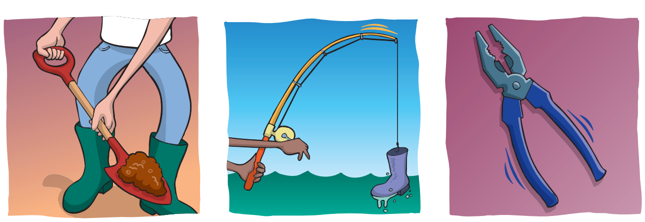


Figure 8.1.14

15 Figure 8.1.15 shows a 600 N load placed on a lever.

a **Calculate** the size of the force that must be supplied at point X to lift the load.

b If the load was now switched to position X, and the effort force applied where the load had been positioned, **calculate** the size of the effort force now required to lift the load.

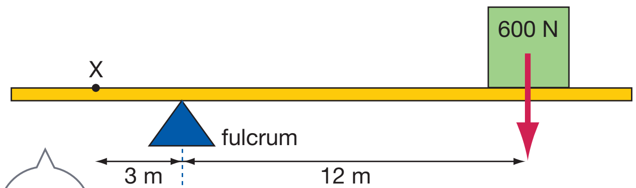


Figure 8.1.15

16 Keung has a mass of 35 kg, while his friend Zuzu has a mass of 50 kg. They'd like to play on a see-saw and have both sides evenly balanced.

a **Explain** which boy should sit closer to the fulcrum of the see-saw and why.

b Zuzu sat 1 metre from the pivot of the see-saw. Use the principle of levers to **calculate** where Charlie would need to sit to maintain balance.

Evaluating

17 A door acts as a lever, with its fulcrum at its hinges. An inexperienced tradesman was unsure where to put the handles on a cupboard door, so he screwed in two sets so that he could compare them to see which worked better.

a **Compare** the distance moved by your hand in opening a door using handle X and handle Y in Figure 8.1.16.

b **Discuss** which handle would be more difficult to use.

c **Recommend** which handle position is correct.

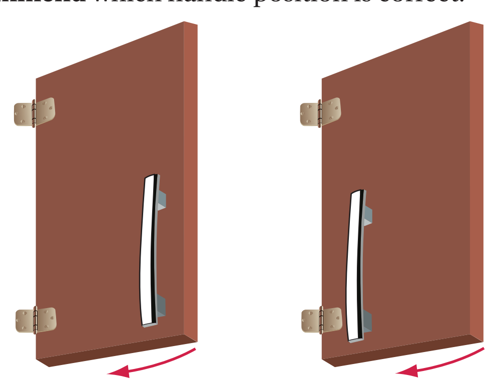


Figure 8.1.16

Inquiring

1. Investigate machines such as the windlass, whip and whim used to pull loads up from mines on the goldfields. Construct a labelled diagram to explain how one operates.
2. Many examples of levers can be found around your home, particularly as kitchen gadgets, sporting equipment or as tools in the garage. Use the internet to gather images of at least 20 different household levers. Organise your images to construct a poster in which each is classified as a force or speed multiplier.
3. Create a poster in which you illustrate how a lever used by our body or in a ball sport works. Label F, E and L (fulcrum, effort and load) and identify which class of lever is operating.
4. The photo in Figure 8.1.17 shows Korean acrobats using a see-saw. Search the internet to gather clips of acrobats such as these in action. Classify the see-saw by grouping it into the correct class of lever.

Figure 8.1.17

5. Investigate a range of household machines—such as a corkscrew, pliers, scissors, chopsticks, stapler, tweezers, eggbeater, hammer, tongs, hand drill, zipper, old clock, knife and apple, old doorknob, bottle opener, fishing rod. Describe how each works and classify these as devices that multiply force and devices that multiply speed.
6. Playground swings, slides, roundabouts, slides, flying foxes and see-saws are made up of many simple machines. Choose one item of playground equipment, either one that exists now or a new type of your own design. Some examples are shown in Figure 8.1.18. Construct a model of the equipment, using simple materials such as icy-pole sticks, straws, string, tin lids, cardboard, paper, split pins, paper clips or pieces of dowel.

Figure 8.1.18

8.1 Practical activities

1 Modelling a see-saw

Purpose

To investigate how the effort force required to balance a load on a see-saw is affected as it is moved closer to the fulcrum.

Materials

- metre ruler
- stiff cardboard square
- 2 plastic cups
- slotted masses
- masking tape
- scissors

Procedure

1 Use the scissors and ruler to score two lines so that the square is divided into thirds. Bend the cardboard to make a triangular prism to use as a fulcrum, as shown in Figure 8.1.19.

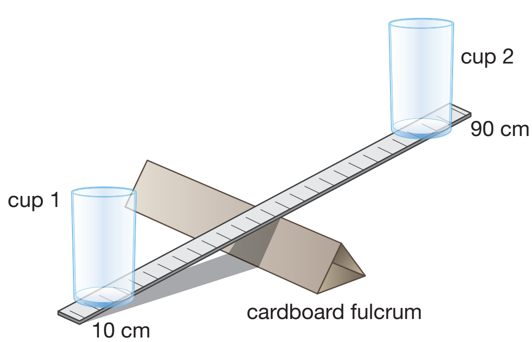


Figure 8.1.19

2 Position the ruler so that the fulcrum is halfway along its length.

3 Tape one of the plastic cups at one end of the ruler, so that its centre sits at the 10 cm mark, and a second cup at the 90 cm mark.

4 Copy the results table below.

5 Put 100 g of masses in the first cup and measure how much mass needs to be added to the second cup to balance this.

6 Repeat this process with the centre of the second cup positioned above the 85, 80, 75, 70, 65 and 60 cm marks along the ruler.

Results

Copy and complete the table below.

Discussion

1 **Describe** whether more or less mass was required to balance the load as the effort force moved closer to the fulcrum of the see-saw.

2 **Discuss** whether you have experienced this yourself on a see-saw.

3 **Calculate** the columns in your table:

Mass in cup 1 × D_1
and
Mass in cup 2 × D_2

4 **State** whether the values calculated above are similar. **Explain** your result.

Mass in cup 1 (g)	D_1 (distance of cup 1 from fulcrum) (cm)	Mass in cup 1 × D_1	Mass in cup 2 (g)	D_2 (distance of cup 2 from fulcrum) (cm)	Mass in cup 2 × D_2
100	40			40	
100	40			35	
100	40			30	
100	40			25	
100	40			20	
100	40			15	
100	40			10	

2 Investigating first-class levers

Purpose

To examine what effect changing the position of the fulcrum has on a first-class lever.

Materials

- retort stand and clamp
- string
- metre ruler (preferably with holes every centimetre)
- slotted masses and hangers
- 3 large paper clips
- spring balance (or a force sensor)

Procedure

1. Use a large paper clip to hang the ruler over the stand and clamp as shown in Figure 8.1.20 so that the fulcrum is at the 20 cm mark of the ruler.

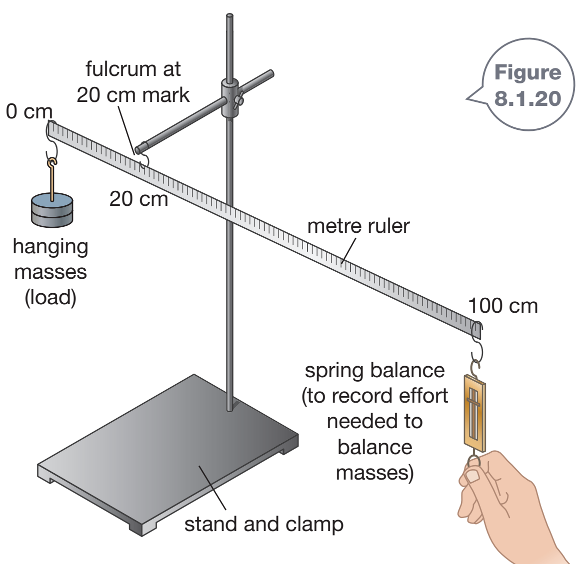


Figure 8.1.20

2. Hang a 100 g mass from the 0 cm mark. This mass exerts a weight force of 1 N downwards and represents the load on the lever.
3. Using a spring balance or force sensor positioned at the 100 cm mark of the ruler, measure and record the effort force needed to balance the load.
4. Continue this process for load masses of 150, 200 and 250 g and enter results into a table as shown below.
5. Now take the ruler off the paperclip and readjust it so that the fulcrum is positioned at the 40 cm mark on the ruler.
6. Repeat steps 3–4 and record your results in a table like the one below.

Results

In your workbook, copy and complete the following table and use it to record all of your measurements.

Discussion

1. **Calculate** the mechanical advantage of the lever with the fulcrum positioned at the 20 cm mark.
2. **Calculate** the mechanical advantage of the lever with the fulcrum positioned at the 40 cm mark.
3. **State** which lever has the greater mechanical advantage.
4. **Explain** how this affected the size of the effort needed to balance the load forces.

Load mass (g)	Load force (N) (load mass/100)	Distance (load to fulcrum) (cm)	Effort force (N) (measured using spring balance)	Distance (effort to fulcrum) (cm)
100	1	20		80
150	1.5	20		80
200	2	20		80
250	2.5	20		80
100	1	40		60
150	1.5	40		60
200	2	40		60
250	2.5	40		60

3 Levers in action

Purpose

To use and examine levers.

Materials

- three different examples of levers, such as a teaspoon and tin, a pair of pliers and a nut and bolt, a pair of tweezers and grains of rice, pair of scissors and paper, a nutcracker and small spongy ball, a stapler with staples

Procedure

Use each of your lever systems to perform a simple task. For example, use the teaspoon to remove the lid of a tin, undo a bolt using pliers, cut paper with scissors, pick up rice with tweezers, squeeze a spongy ball with a nut cracker, or use a stapler.

Results

Copy and complete the table below for each lever system you examine. Include a labelled diagram and an explanation of how each lever works.

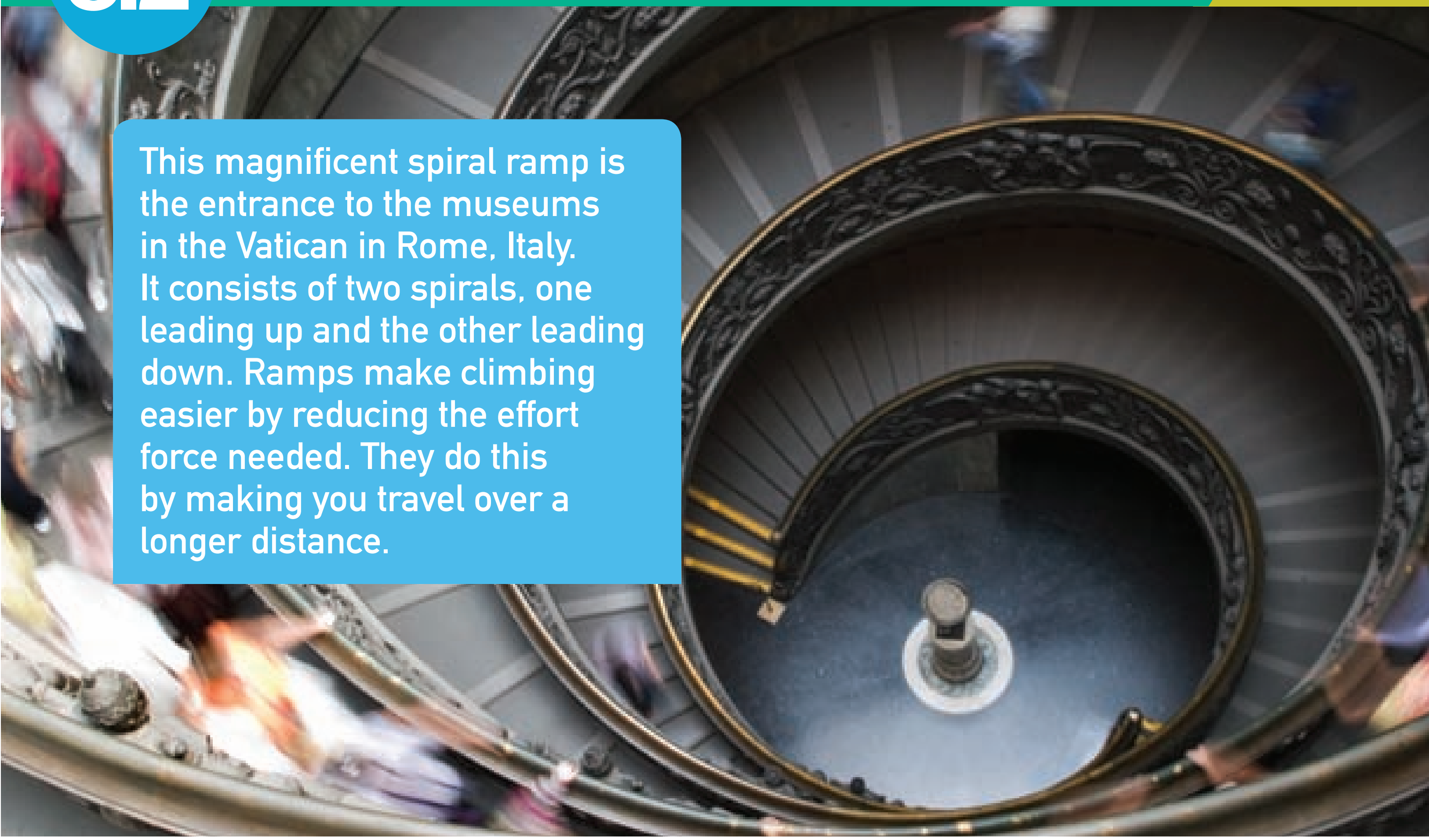
Discussion

1 **Classify** which levers were used to increase force and which were used to increase speed.

2 **Describe** how you would perform each of the tasks you completed without these simple machines, and explain how each task would be more difficult.

Lever system	Labelled diagram showing position of load (L), effort (E) and fulcrum (F)	How you think it works	Type of lever

8.2 Inclined planes



This magnificent spiral ramp is the entrance to the museums in the Vatican in Rome, Italy. It consists of two spirals, one leading up and the other leading down. Ramps make climbing easier by reducing the effort force needed. They do this by making you travel over a longer distance.

Ramps

The roads and tracks through mountain ranges are usually twisted and winding, such as the one shown in Figure 8.2.1. Imagine instead that the road to the top of a mountain went up in a straight line. The distance you would travel would be much shorter, but the road would be steeper, very difficult to travel up and possibly dangerous. By travelling a greater distance over a winding road, you can climb the mountain using less effort force. This makes it easier on the car's engine on the way up and easier on its brakes on the way down.

Moving heavy furniture or packing equipment into a truck would require a very large effort force if it was lifted directly from the ground into the truck. A **ramp**, or **inclined plane**, is a simple machine that makes this task much simpler. In using a ramp like the one in Figure 8.2.2 on page 302, you use a smaller force over a longer distance in loading objects into a truck.

Figure 8.2.1 Winding roads and tracks reduce the slope of an incline in mountain areas, making it easier for cars and bushwalkers.

Figure 8.2.2 Loading and unloading heavy sound equipment such as this would be almost impossible without the use of a ramp.

Wedges

Imagine trying to bite into an apple without your front teeth. Your front teeth, called *incisors*, cut like a knife. These are simple machines called **wedges**. A wedge is a double inclined plane that moves through another object. Wedges are used to split objects because they change the direction of a force by 90° and increase its size. When an axe is pushed downwards, the wedge of the axe head pushes the wood apart, as shown in Figure 8.2.3. Pins, needles, nails and doorstops are all examples of wedges.

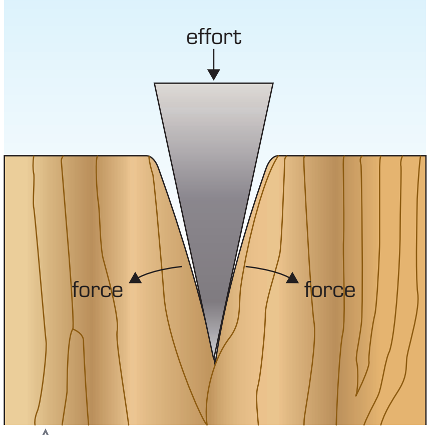


Figure 8.2.3 A wedge changes the direction of a force, enabling an object to be split. The longer the inclined edge of this wedge and the sharper the axe, the easier the wood is to split.

INQUIRY science 4 fun

Getting the point

No

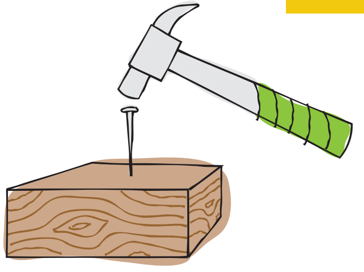
How does a nail enter a block of wood?

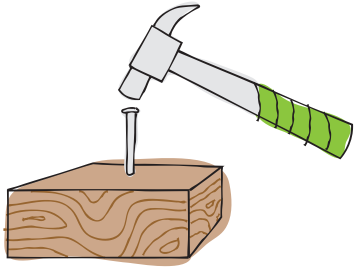
Collect this ...

- 2 nails
- off-cut of wood
- hammer
- metal stud (not pointed)

SAFETY

Take care that you don't hit your fingers when using the hammer.





Do this ...

1. Try to hammer a nail into a block of wood.
2. Hold a nail upside down on the wood and give it a few light taps with the hammer to blunt its end.
3. Try to hammer the blunt nail into your block of wood.

Record this ...

Describe what happened.

Explain why you think this happened.

SKILL BUILDER

The mechanical advantage of a ramp

The mechanical advantage of a ramp is given by the mathematical formula:

$$\text{Mechanical advantage} = \frac{\text{length of slope}}{\text{height of slope}}$$

Ramps are widely used in buildings to make it easier to deliver goods to shops and easier for people to enter, particularly the elderly, those in wheelchairs or pushing prams, as shown in Figure 8.2.4.

p308

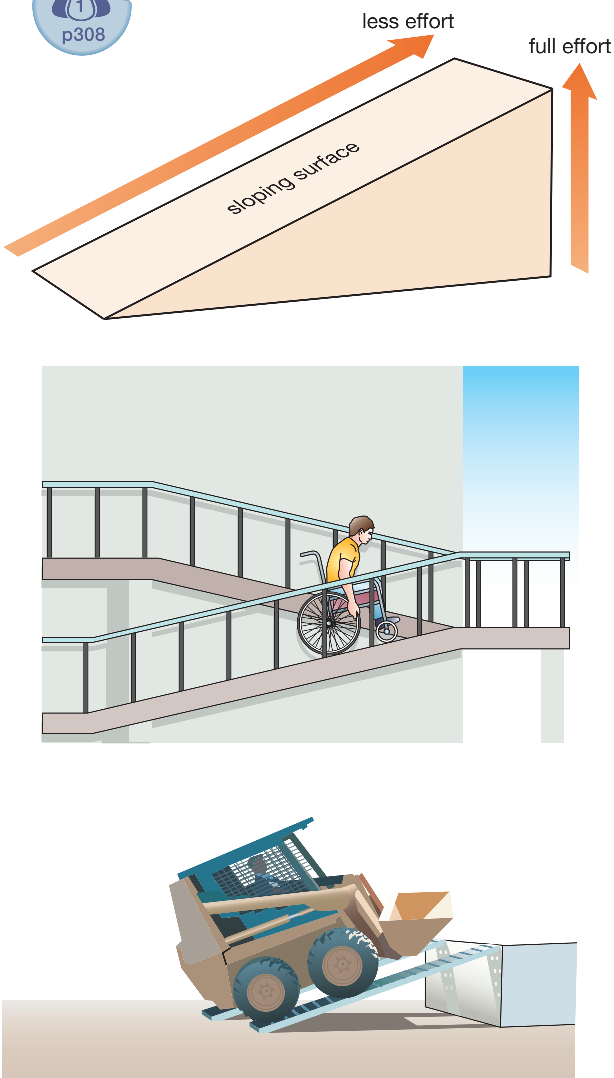


Figure 8.2.4 Although you must travel a greater distance when using a ramp, you can do so with less force. This makes the task easier.

WORKED EXAMPLE

Mechanical advantage of a ramp

Problem 1

A crate of weight 300 N is pushed with an effort force of 60 N up a 10 metre ramp into a doorway as shown in Figure 8.2.5. **Calculate** the mechanical advantage of this ramp.

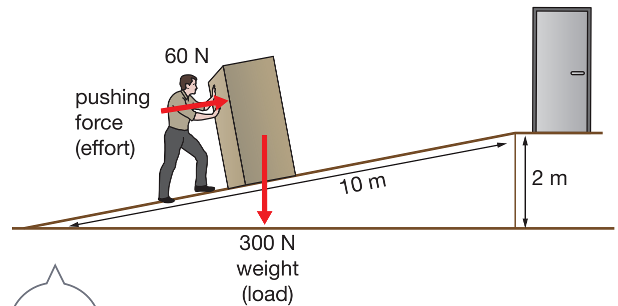


Figure 8.2.5

Solution 1

$$\begin{aligned}\text{Mechanical advantage} &= \frac{\text{length of slope}}{\text{height of slope}}\\ &= \frac{10}{2}\\ &= 5\end{aligned}$$

The ramp provides a mechanical advantage of 5.

Problem 2

Given that the load is the weight of the crate, which is 300 N, **calculate** the size of the effort force required to push the crate up this ramp.

The effort force is one-fifth the load force.

$$\begin{aligned}\text{effort} &= \frac{300}{5}\\ &= 60\,\text{N}\end{aligned}$$

The ramp provides a mechanical advantage of 5. This means that the crate can be pushed up the ramp with 5 times less force. The crate could be moved with a force of 60 N rather than its weight of 300 N using this ramp.

8.3 8.4

Zips

Clothing, purses, wallets, sleeping bags, suitcases, handbags, backpacks and pencil cases are just some examples where zips are found. A zip consists of two sets of interlocking teeth and is very strong when fastened. As shown in Figure 8.2.6, the slide of a zipper uses three wedges to force these teeth together when doing the zip up, and unlatch when undoing it.

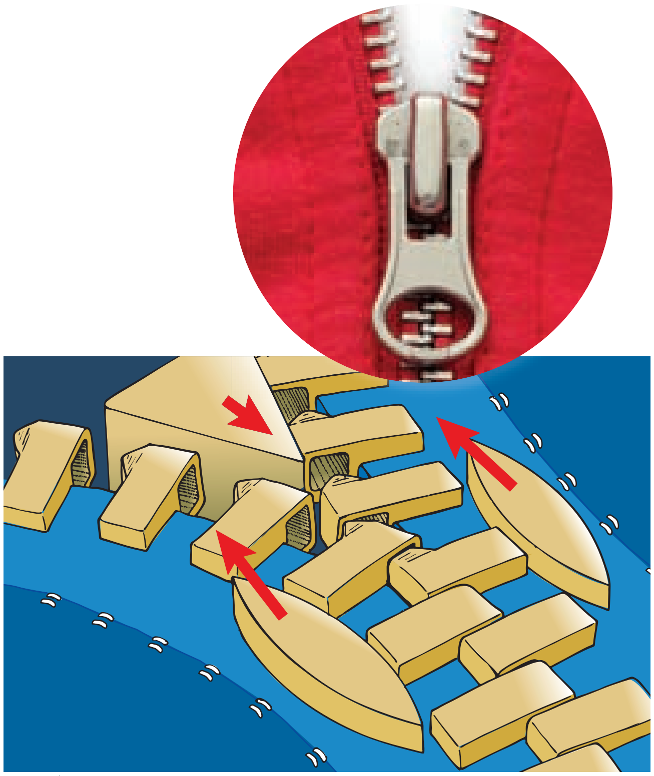


Figure 8.2.6 A zip consists of a zipper track, containing two rows of teeth. The zipper is closed when the hooks in the teeth on one side of the zipper are slotted into hollows of teeth on the other side. The zipper slide is a collection of wedges. A central wedge unlatches the teeth as the zip is undone and side wedges force the teeth together when the zip is done up.

Zip history

SciFile

After their invention in 1913, zips were mainly used on boots and tobacco pouches. Twenty years later they were being used in clothing. Zips were first used in children's clothes to help children get dressed more easily. When used in the manufacturing of adult clothing, there were fears that zips would allow people to take off their clothes too fast!

Screws

A **screw** is a spiral inclined plane (Figure 8.2.7). It is a simple machine that is designed to cut through another substance. Wood screws cut through timber, boat propellers are screws that cut through water and aircraft propellers are screws that cut through the air.

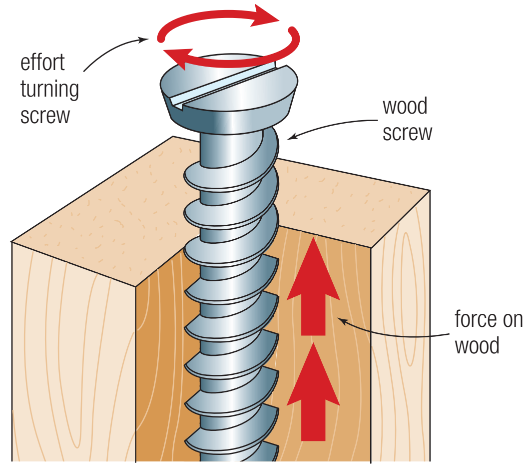


Figure 8.2.7 A screw is an inclined plane that winds around a metal cylinder. It increases the force you apply by moving through a greater distance.

As a screwdriver turns a screw into a piece of wood, the timber moves along the spiral ramp. This enables you to drive the screw into the wood with much less force than would be needed if you hammered it directly. This is because the screw is moved a greater distance through the timber when screwed into place. The spiral inclined plane around a metal screw is called the thread. As Figure 8.2.8 shows, the closer the turns of the thread are the gentler the slope (or **pitch**) of the inclined plane will be, and the greater the force will be magnified.

2 p309

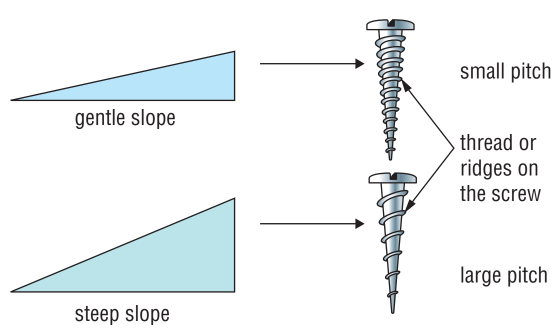


Figure 8.2.8 A screw with a small pitch is easy to screw into a piece of wood, but to do so it must be turned many times by the screwdriver. A screw with a large pitch takes fewer turns of a screwdriver to be inserted into wood, but requires more force than the previous screw.

Figure 8.2.9 A spear thrower is a machine that allows people to hunt better.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Indigenous tools and weapons

Indigenous Australians developed and used a range of tools that were designed to perform specific tasks.

Stone tools recently discovered in Western Australia are over 35 000 years old. Stone tools were produced by a process called flaking. In this process, a block of stone (called a core), was struck with a hammer stone (usually a pebble), to chip off a sharp piece of stone, called a flake. These flakes were further flaked, or 'retouched' to be reshaped. Often a hard, volcanic piece of rock was also used to grind a sharp edge. Using these techniques, people could create sharp points of spears, chisels, axes, saws or knives (Figure 8.2.10). The types of stone that were best suited to producing flakes were those rich in silica, such as quartz, quartzite, chert and flint. These stones are hard but brittle. These sharp stone tools could cut more cleanly than a steel blade. Resins were used to attach a cutting stone to a piece of wood as a handle.

Figure 8.2.10 These stone flakes have been chipped off a core rock. They can be reshaped or resharpened as required.

Indigenous Australians developed a number of unique weapons. Spears were used with a various shaped tips. The tip of a spear itself is a simple machine, being a double inclined plane. In addition, a number of designs of spear throwers were used throughout Australia. The device shown in Figure 8.2.11, known as a woomera to tribes in New South Wales, was made from a dense wood, such as that from a wattle. The spear thrower has a peg that hooks into the end of a spear. When used to throw the spear, it acts as an extension of the thrower's arm. This increases the length of time the force is applied to the spear and multiplies the speed with which it is launched. This device makes the mechanics of throwing a spear far more efficient and as a result, the spear travels much further than would otherwise be possible.

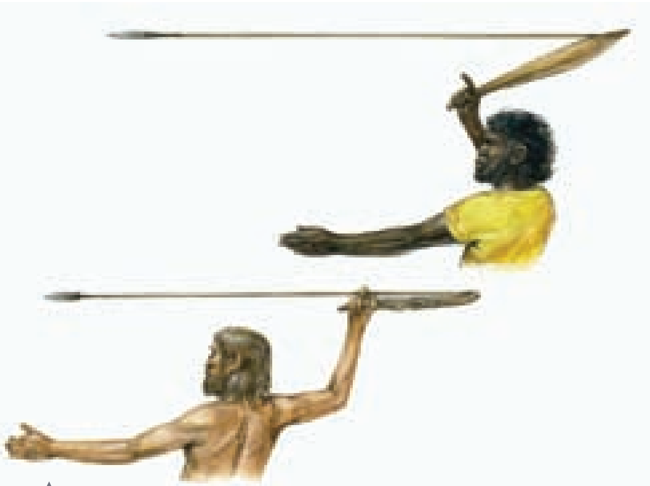


Figure 8.2.11 A spear can be thrown two or three times as far using a spear thrower. In addition, spear throwers were used to carry food and water.

8.2 Unit review

Remembering

1 **List** three places where you have used a ramp.

2 **List** three common examples of a wedge.

3 **State** which simple machine could be called a:
   a double inclined plane
   b spiral inclined plane.

4 **State** whether each of these statements is true or false.
   a The longer the slope of a ramp for a certain height, the greater its mechanical advantage.
   b A screw with a small pitch corresponds to a steep inclined plane.
   c A screw with a small pitch requires fewer turns to be inserted into a piece of wood than a screw with a large pitch.
   d A wedge changes the direction of a force by 90° and increases its size.

5 **State** an example of a type of screw that cuts through a:
   a solid
   b liquid
   c gas.

6 **Recall** five devices that can be produced by flaking.

7 **Recall** one name for a spear thrower.

Understanding

8 The person shown in Figure 8.2.12 needs to get to the top of this dam wall. There are two options: climb straight up or use the stairs on the right.

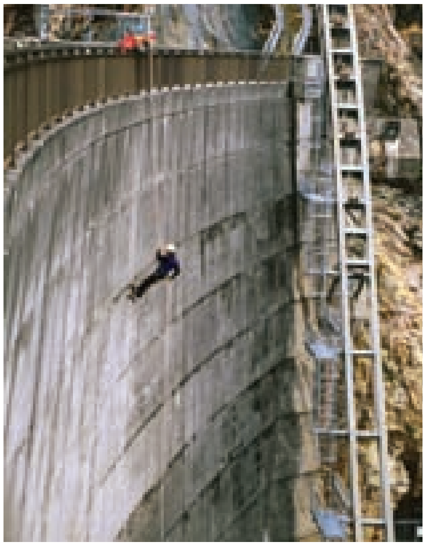


Figure 8.2.12

   a **State** whether the effort force needed to reach the top is the same or different using both methods.
   b **Explain** your answer above.

9 **Explain** how a screw provides a force advantage.

10 **Describe** how a stone is flaked.

11 **Explain** why stone rich in silica is suitable to use in creating stone tools.

12 **Explain** how a spear thrower allows a hunter to throw a spear much further than otherwise possible.

Applying

13 **Identify** which type of simple machine (inclined plane, wedge or screw) is described by these devices.
   a corkscrew
   b axe
   c electric fan
   d car park ramp
   e chisel
   f escalator

14 **Calculate** the mechanical advantage of a ramp in which a load of weight 100 N is lifted by an effort force of 20 N.

15 **Calculate** the mechanical advantage of ramps with the dimensions listed in the table below.

Length of slope (m)	Height of ramp (m)	Mechanical advantage
15	3	
50	25	
12	2	
20	5	
240	30	

16 a **Calculate** the mechanical advantage of the two ramps shown in Figure 8.2.13.

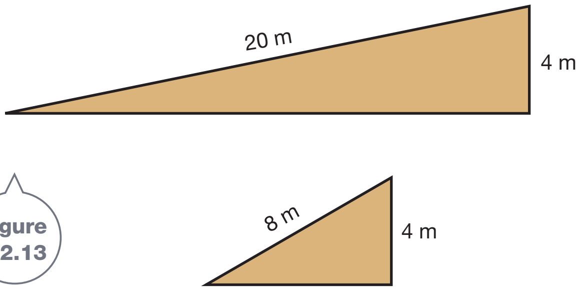


Figure 8.2.13

b A 500 N shipping container must be lifted a height of 4 m from a dock onto a ship. **Calculate** the size of the effort force that would be needed to shift it using each of the ramps shown.

Evaluating

17 Sometimes it is recommended that a blunt nail be used when repairing a wooden object, because it has less chance of causing the wood to split. **Propose** why this is the case.

18 A 10 000 N industrial oven is being moved from a factory to a restaurant. It must be raised a vertical height of 1 m into a truck. The removalists refuse to push it up a ramp with a force greater than 200 N. **Propose** the dimensions of a suitable ramp. The removalists should not need to exceed the force of 200 N. **Justify** your answer.

Inquiring

1 The Archimedes screw is an invention designed by the famous Greek physicist and mathematician Archimedes. Research to describe:

- what its design looks like
- what it was designed to do
- how it works
- where it is used today.

2 Research the history of the invention of the zip. Outline different variations and different inventors who played a role in its development.

3 Investigate a car jack. Count how many times you need to turn the handle in order to make the jack rise by 1 cm. Explain how the jack is able to provide a far greater lifting force than the size of the force we apply to it.

4 Australian building regulations state that ramps must be built:

- with a slope of no more than 1:8 for step or kerb ramps that have a maximum length of 1.52 m (the horizontal distance must be more than eight times its height);
- no steeper than 1:14 for ramps longer than 1.52 m in length (the horizontal distance must be more than 14 times its height).

You can see these dimensions in Figure 8.2.14. Record the location and dimensions of a number of ramps found in your school or your local shopping centre. Calculate whether each ramp complies with the Australian standard and write a report to summarise your findings.

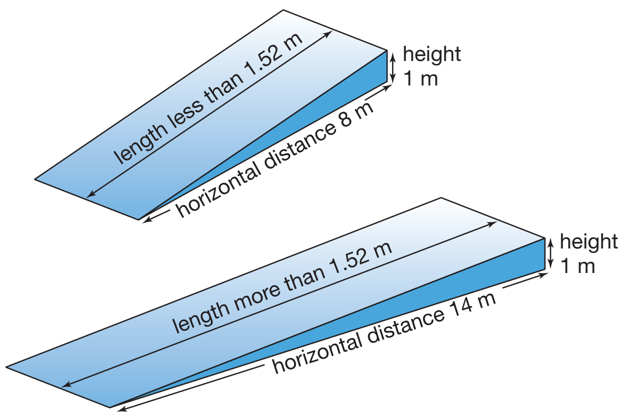


Figure 8.2.14 These are the dimensions of the steepest inclines allowed by law on Australian kerbs and longer ramps built for public use.

8.2 Practical activities

1 Using ramps

Purpose

To measure the force required to lift a cart vertically and to lift it using ramps of differing slope.

Materials

- trolley
- spring balance (or force sensor)
- a number of books or a couple of blocks or bricks to elevate ramp
- wooden ramp
- spring balance
- protractor

Procedure

1. Position a plank of wood on a pile of books (or a brick and some books) to make a ramp that is about 10 cm high, as shown in Figure 8.2.15.

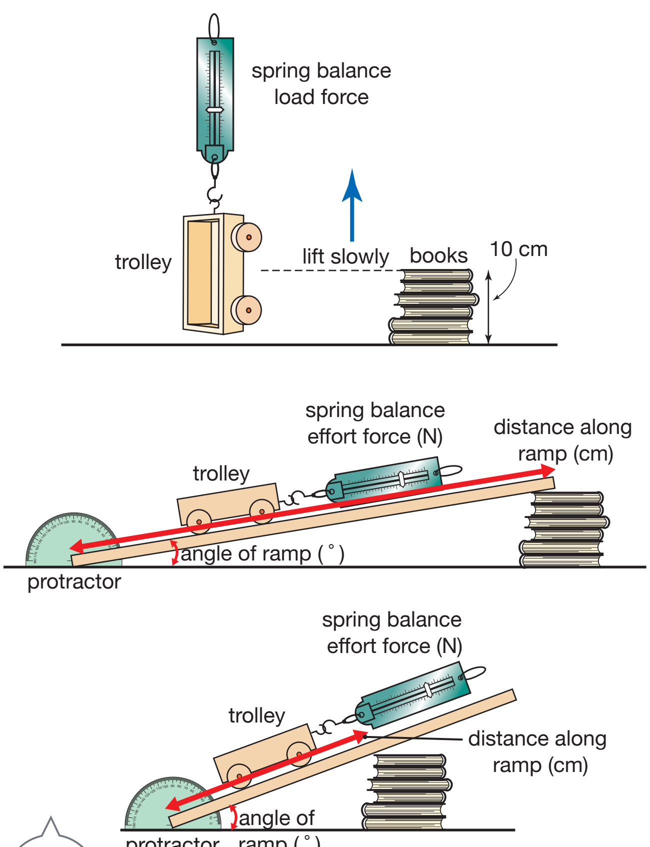


Figure 8.2.15

2. Attach the trolley to a spring balance (or force sensor). Carefully lift it vertically until its rear is level with the height of your ramp. Record this weight as the load force.
3. Measure the angle of elevation of the ramp and its distance from the base to the pile of books. Record these values in the table.
4. Slowly drag the trolley up the ramp to the pile of books. Record the effort force required.
5. Repeat steps 3 and 4 for four different angles of the ramp. Measure the new ramp length and effort force each time.
6. Calculate the mechanical advantage for each angle of ramp tested.

Results

In your workbook, copy the following results table.

Angle of ramp (°)	Distance along ramp (cm)	Effort to pull trolley up ramp (N)	Mechanical advantage of ramp $\left(\frac{\text{load}}{\text{effort}}\right)$

Discussion

1. **State** whether having a large or a smaller angle of ramp increased its mechanical advantage.
2. **Explain** why this occurred, considering how the effective distance of the ramp varied with the changing angle.
3. **List** three situations in which using a ramp at a shopping centre is useful.

2 The turn of a screw

When you drive a screw into a piece of wood, the effort you apply is over a much larger distance than the depth to which you have to sink the screw into the wood.

Purpose

To compare the turn of a screw with the depth it is sunk.

Materials

- A4 piece of paper
- pencil
- ruler
- scissors
- screw
- piece of cotton

Procedure

1. Cut the piece of paper diagonally into two halves. You only need to use one half for this task.
2. Place a pencil along the vertical edge, as shown in Figure 8.2.16a.
3. Mark the top of your pencil on this sheet and rule a horizontal line across. Cut this section from the paper.
4. Measure the length, *T*, of the longest side of triangle 1. If the pencil were a screw, then *T* is the distance you would have to turn to sink it a distance equal to the length of the pencil.
5. Measure the length of the pencil, *L*.
6. Roll the paper around the pencil, as shown in Figure 8.2.16b.
7. Measure the distance between the thread of your paper screw. This is called its pitch, *P*.
8. Taking your triangular sheet of paper, make a cut across from the tip of the pencil to another point A, as shown in Figure 8.2.16c. This forms triangle 2. Wind the pencil up again.
9. Measure the new thread and pitch lengths.
10. Cut a third triangle (triangle 3) by making a cut to point B, and repeat the process.
11. Measure the length of the thread of the real screw by winding a piece of cotton around it.
12. Measure the length of this screw and estimate its pitch.

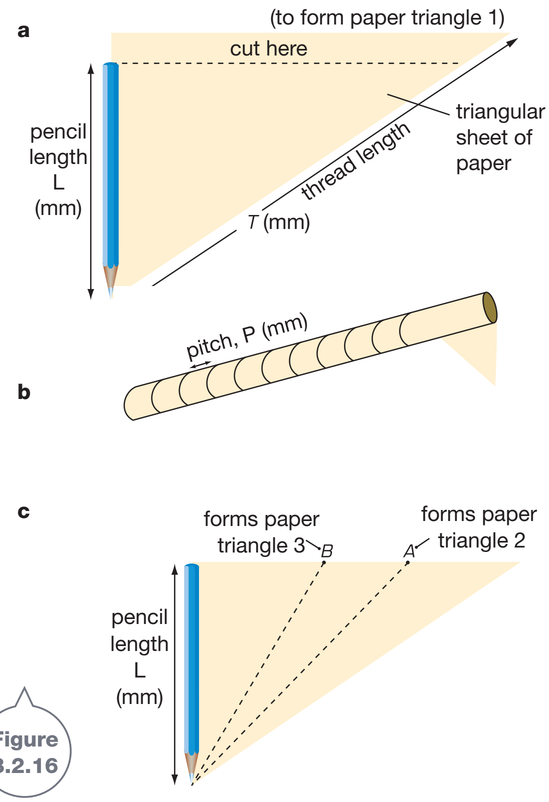


Figure 8.2.16

Results

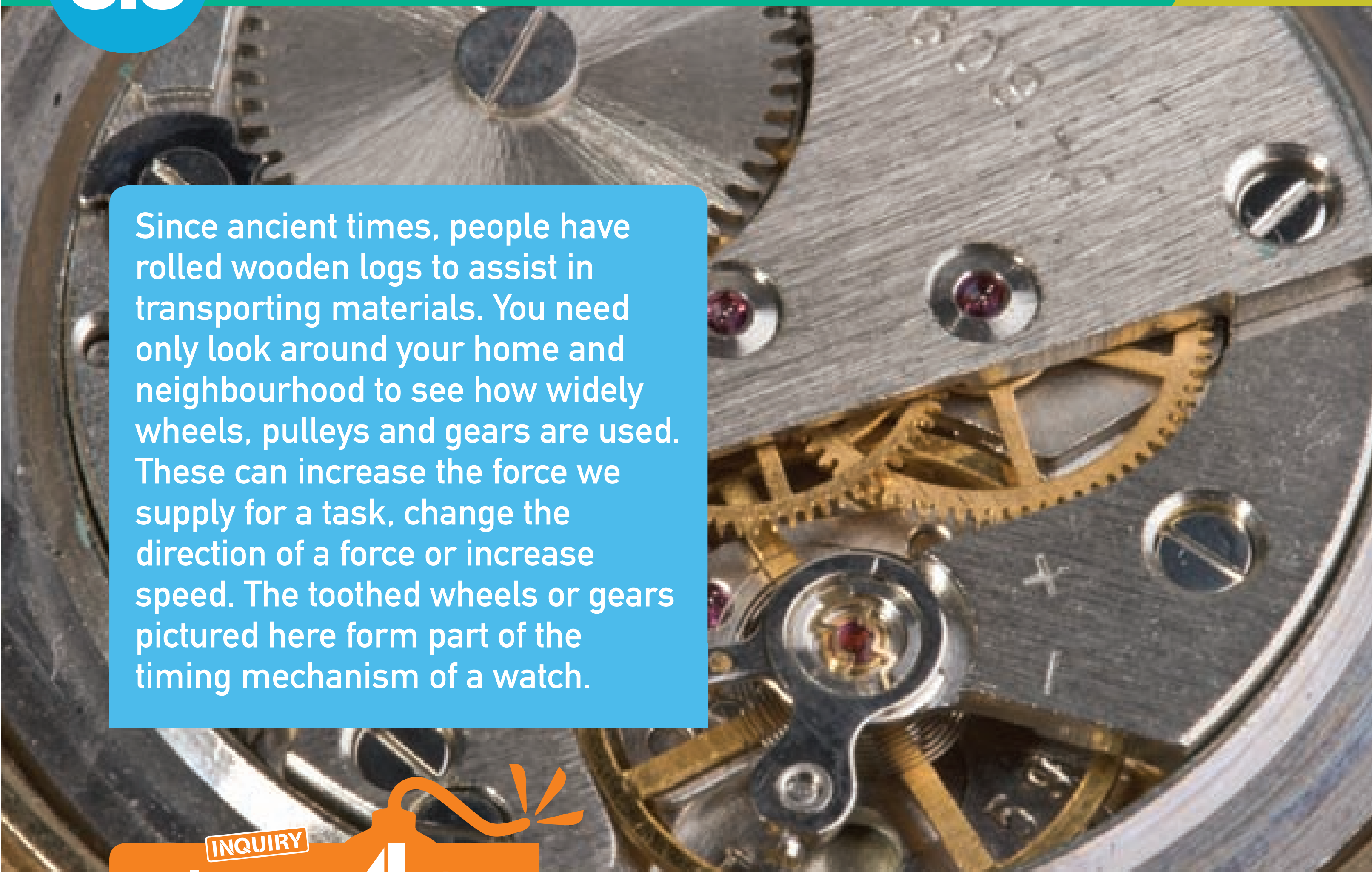
In your workbook, copy and complete the following table.

Paper triangle	Thread length, *T* (mm)	Pencil or screw length, *L* (mm)	Pitch, *P* (mm)
1			
2			
3			
Screw			

Discussion

1. **State** how far you would need to turn the initial paper screw to sink it the distance of the pencil.
2. **Describe** what happens to the pitch of a screw as its thread becomes shorter.
3. **Explain** whether you think a screw would be more effective with a smaller or larger pitch.
4. **Compare** the length of the screw you examined with the length of its thread.

8.3 Wheels, pulleys and gears



Since ancient times, people have rolled wooden logs to assist in transporting materials. You need only look around your home and neighbourhood to see how widely wheels, pulleys and gears are used. These can increase the force we supply for a task, change the direction of a force or increase speed. The toothed wheels or gears pictured here form part of the timing mechanism of a watch.

INQUIRY science 4 fun

Turning on a tap

Yes

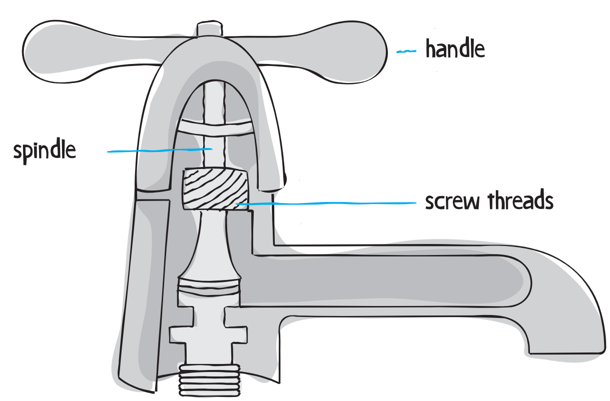
Can you turn on a tap without its handle?

Collect this …

- a tap that can be unscrewed

Do this …

1. Place a plug in the sink to avoid losing any parts down the drain.
2. Carefully unscrew a tap.
3. Place the screw, handle and cap on the basin.
4. The tap should now just be a spindle, or an axle.
5. Try to turn the tap on just using your hands.
6. Offer a challenge to your friends and family. Can it be done?



Record this …

Describe what happened.

Explain why you think this happened.

Wheels

The centre of a **wheel** is called its **axle** and the outside of a wheel is its **rim**. This is shown in Figure 8.3.1. A wheel on an axle is a special type of lever. Each spoke of the wheel is a lever, the axle is the fulcrum and the wheel rim is the outer end of the lever. As a lever can produce a force or a speed advantage so too can a wheel. Figure 8.3.2 shows how a wheel can provide a speed advantage. Figure 8.3.3 shows how a wheel can produce a force advantage. When you apply a force to turn on a tap, the handle acts as a wheel. It increases the force you apply at its centre, allowing the spindle or axle to turn.

1 p319

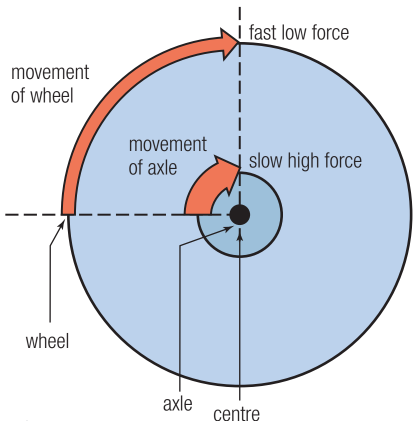


Figure 8.3.1 The rim of the wheel rotates with greater speed than the axle in its centre. As the wheel turns, the force at its centre is larger than the force at its rim.

Figure 8.3.2 The motor of an electric fan turns the central axle relatively slowly. This speed is multiplied through the spinning blades. The longer the blades, the greater the speed multiplied. Aircraft propellers also act as speed multipliers.

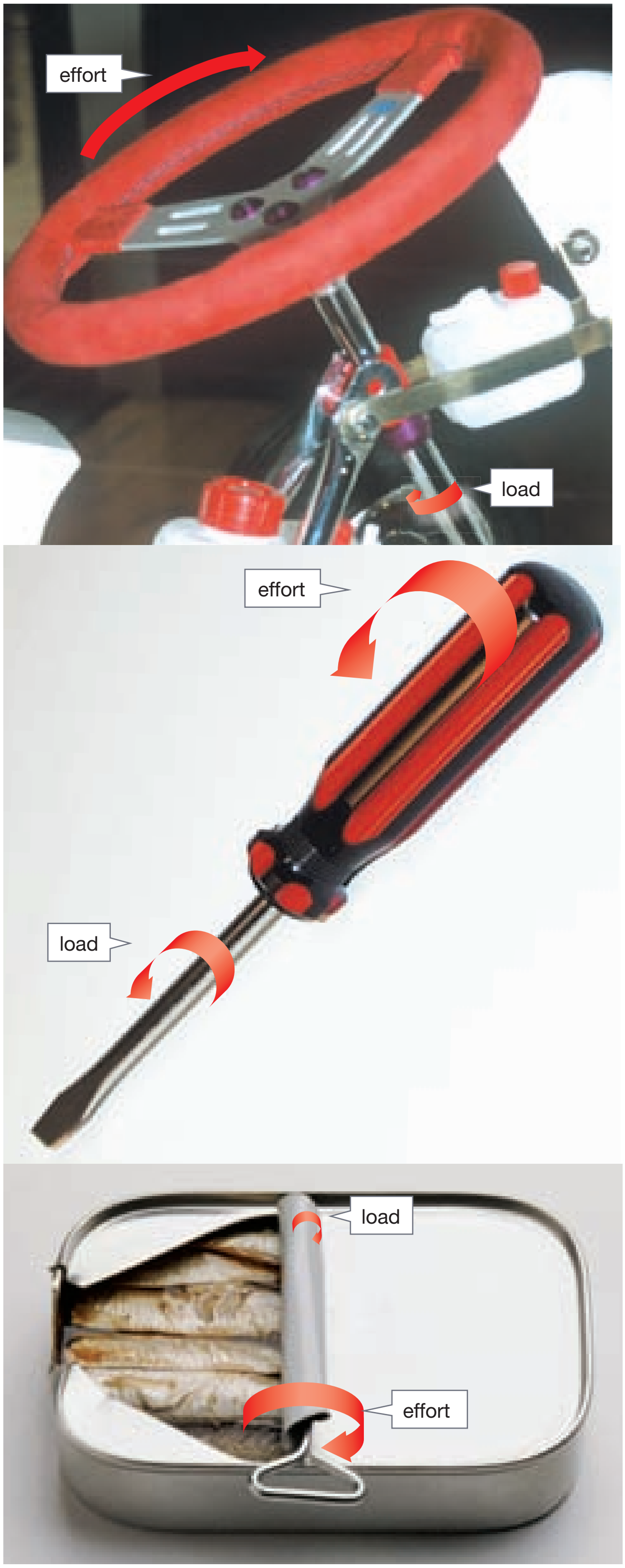


Figure 8.3.3 In each of these situations, a wheel is used to produce a force advantage.The force applied to the steering wheel rim, the screwdriver or the winder of the sardine tin is increased at the axle of each wheel. Using a longer lever arm further increases the force produced at its axle. The larger the steering wheel, the easier the axle is to turn.

Pulleys

Sometimes it is necessary to change the direction of a force. To lift a set of Venetian or Roman blinds, it is much easier to apply a downwards force on a cable than to try to lift it upwards from a height. A simple way of doing this is to use a **pulley**. A pulley is a wheel with a groove around it into which a rope or chain can move. To increase the force applied, more than one pulley must be. The single pulley shown in Figure 8.3.4 changes the direction, but not the size of the effort force required to lift a load. Using two pulleys halves the size of the effort force required, providing a mechanical advantage of 2. In this case, the force is applied over a greater distance.

2 p319

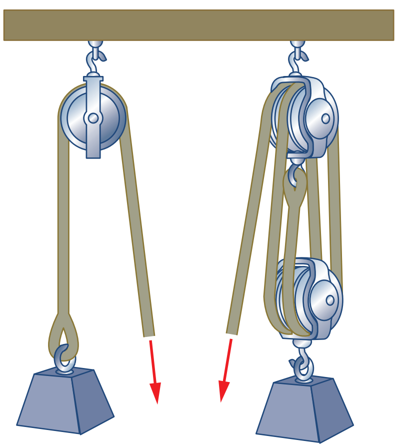


Figure 8.3.4 The block and tackle arrangement shown on the right provides four times the force of the single pulley on the left.

A greater mechanical advantage can be produced using a number of pulleys in an arrangement called a **block and tackle**. Such an arrangement is useful to lift heavy objects and is shown in Figure 8.3.5.

Figure 8.3.5 A multiple pulley system increases the size of the force applied, and is useful for raising heavy objects.

INQUIRY science 4 fun

Playing with pulleys

Can you use a pulley to push two people together?

Collect this …

- 2 broom handles (or wooden handles)
- long piece of rope

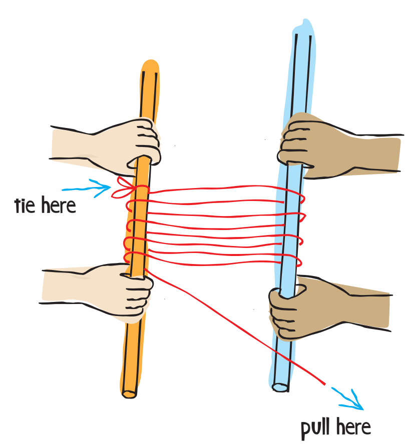
Do this …

1. Give two students a broom handle each to hold horizontally.
2. The students face each other, standing about 50 cm apart.
3. Tie one end of the rope to one handle and then loop the other end over the other handle and back over the first, about six times.
4. Ask the students to try to resist moving together, and pull the free end of the rope so that it tightens around the handles.

Record this …

Describe what happened.

Explain why you think this happened.



Gears

In some older-style machines such as lathes, one wheel is connected to another wheel by a rubber belt. The belt transfers the spinning motion of the first wheel to the second. The difference in speed depends upon the diameter of each wheel. As shown in Figure 8.3.6, the fanbelt in a car operates in this way. One disadvantage with such a system is that the belt can slip. This is avoided when you use gears, or cogs, to transfer spinning motion.

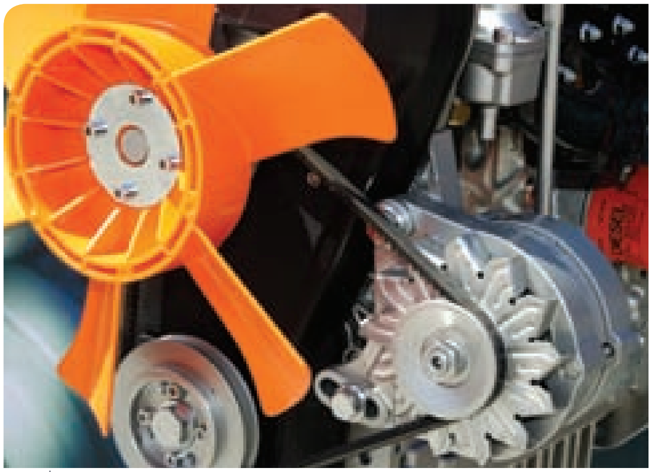


Figure 8.3.6 A fanbelt connects different-sized wheels inside a car engine.

Gears are wheels that have teeth around their rim. The most common type of gears are called spur gears. These are the type shown in Figure 8.3.7 on page 314. Gears can mesh directly together, or be joined by a chain, such as on a bicycle or in the overhead cam shaft in some car engines. A set of gears that are connected is called a **gear train**. When one gear turns, the gear it interlocks with also turns, but in the opposite direction. The gear that supplies the force is called the **driving gear**. The gear that is connected to this gear is called the **driven gear**. Different combinations of gears are selected to increase either the force applied or the speed of turning.

SciFile

Got to fly

What is the longest flying fox you have ever been on? Riders on the ProNutro Zip 2000 in Sun City, South Africa, travel 2 km along a cable, with an average speed of 120 km/h, at heights ranging from 280 metres to just 2.5 metres above the ground. View the ride by clicking the link from Pearson Places.

SciFile

Boneshakers

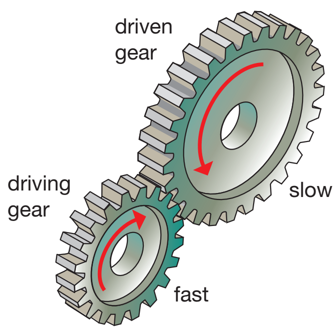
Early bicycles did not use gears and did not have the suspension used today. An early French bike, the velocipede was made of wood, with iron tyres, and was popular around 1864–71. In England, it became known as 'the boneshaker', a good description for what happened to the rider when travelling along cobblestone streets!

Gears as force multipliers

If the driving gear is smaller than the driven gear, then the combination acts as a force multiplier. The larger cog will rotate more slowly in this case, but the force it delivers is much larger. This gear combination is called gearing down and is useful when you need a large force. For example, it would help a car get up a hill or help in using a winch. This is shown in Figure 8.3.7.

Figure 8.3.7

This gear combination results in a driven gear that rotates more slowly than the driving gear, but does so with greater force.



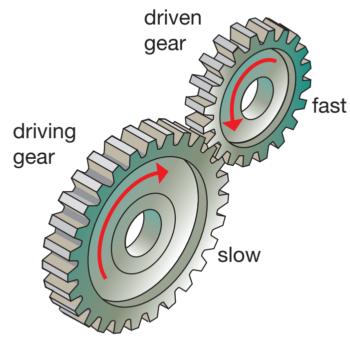
Gearing down

Gears as speed multipliers

If the driving gear is larger than the driven gear then the combination acts as a speed multiplier. This happens because one turn of the large cog will make the smaller cog spin a number of times. This gear combination is called gearing up. It is useful when using an eggbeater, where you require the beaters to spin faster than the handle turns. This is shown in Figure 8.3.8.

Figure 8.3.8

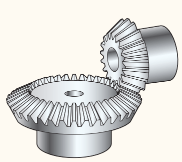
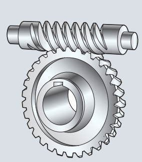
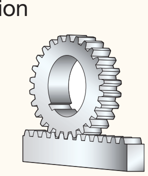
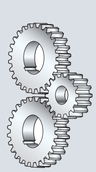
Using gears as a speed multiplier is useful when using an eggbeater. Applying a greater force to the handle pays off as the beaters spin faster.



Gearing up

There are many different types of gears, each suited to a specific purpose. Some examples are shown in Table 8.3.1.

Table 8.3.1 Different types of gears and their uses

Type of gear	Function	Example
Bevel gear 	Positioned at right angles to each other so that they change the plane of rotation	Hand drills: as the handle is turned in a vertical direction, this is transferred into rotation of the drill bit in a horizontal plane
Worm gear 	Looks like a screw, and is used to drive a gear. Is often used to reduce speed	Used to tune a guitar string
Rack and pinion 	A gear wheel rotates over a row of teeth, called the rack. This converts rotational motion into straight-line (or linear) motion	Used to convert steering wheel rotation into linear motion to the right or the left in order to turn the wheels of the car
Idler gear 	Positioned between a driving and a driven gear to get them rotating in the same direction	Engaging an idler gear between two gears in a car with manual transmission allows the car to reverse

Using gears on a bicycle

Gears used in a bicycle are called **sprockets**. The pedal and crank is attached to a gear sprocket called the chain wheel. This is connected by a chain to the rear sprocket (Figure 8.3.9). A bike with 21 gears gives the rider the choice of 21 different gear combinations. The front chain wheel has three sprockets and the rear wheel has seven.

Figure 8.3.9 The teeth of the sprocket hook into the bicycle chain to transfer motion.

To use first gear, you select the largest rear-wheel sprocket, and the smallest chain wheel sprocket, as shown in Figure 8.3.10. This means that you need to pedal more, but the rear wheel is moved with much greater force. When you select the highest gear, the smallest rear-wheel sprocket and largest chain wheel sprocket are used, as shown in Figure 8.3.11. Using such an arrangement, a greater force is required to turn the chain wheel sprocket, but the rear wheel turns faster.

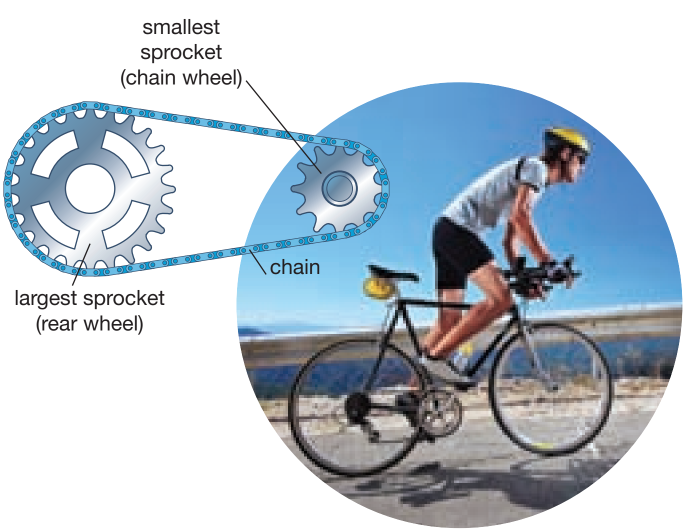


Figure 8.3.10 First gear on a bicycle is useful when you need to start moving or ride up a hill.

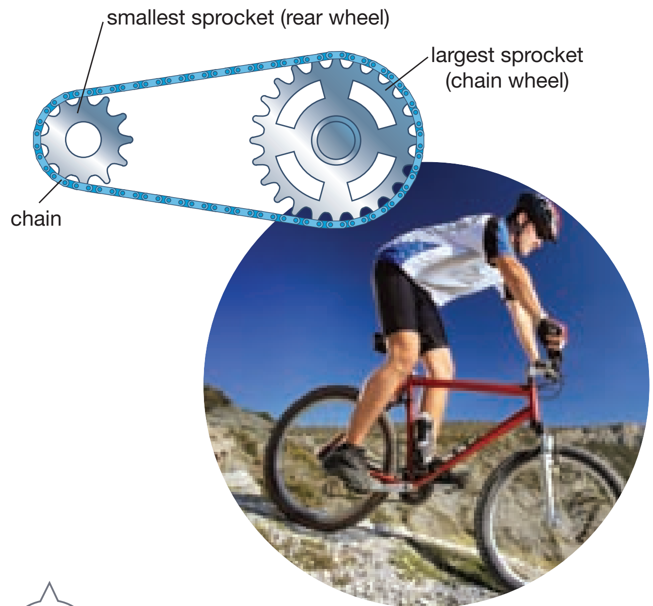


Figure 8.3.11 High gear on a bicycle is useful when cruising along an easy, flat road or going downhill. It enables you to pedal slowly, but still move along quickly.

3 p320 4 p321 8.5

SKILL BUILDER

Calculating the gear ratio

The **gear ratio** of sprockets on a bicycle, or of two gears meshed together on a machine, is calculated by dividing the number of teeth on the driving sprocket (or driving gear) by the number of teeth on the driven sprocket (or driven gear).

The low gear combination shown in Figure 8.3.10 has 12 teeth on the driving sprocket and 24 on the driven sprocket. The gear ratio is $\frac{12}{24} = 0.5$. This means the rear sprocket spins through half a revolution for every turn of the chain wheel.

The high gear combination shown in Figure 8.3.11 has the opposite combination.

Its gear ratio is $\frac{24}{12} = 2$. This means that for each turn of the chain wheel, the rear sprocket turns twice.

SCIENCE AS A HUMAN ENDEAVOUR

Use and influence of science

Robotics

Figure 8.3.12 Leonardo the robot

Leonardo the robot has been developed by the Stan Winston Studio and MIT's Artificial Intelligence Laboratory. Leonardo is designed to be sociable, by observing and responding to the cues of people nearby.

Robots are complex machines. They can be designed to perform many tasks, but have no intelligence of their own. Many robots are operated from a distance by a human controller. These telerobotic systems (*tele* means 'at a distance') extend a human's ability to carry out particular tasks. Some robots, such as those used as vacuum cleaners or lawn mowers, are designed to be autonomous, or control themselves. They do this by incorporating a number of sensors that can detect a particular condition and then react to it in some way. Many developments in robot design have been made by scientists observing the ways that insects or other animals move and sense their surroundings.

Robots are generally used to perform tasks that are very repetitive and those that require great precision. Assembly production lines building cars now commonly use robots to weld panels (Figure 8.3.13). Robot arms are used in the manufacturing industry, to perform tasks such as packing, testing, gluing and precision drilling.

Figure 8.3.13 This time exposure photo shows orange robot arms welding car bodies on an assembly line. The movement of these arms is precise and they never tire, explaining why most cars are now assembled in this way.

Robots are now used in surgery for work too fine to be carried out by a human. The da Vinci system is widely used for keyhole surgery, for gall bladder removal, prostate surgery, heart bypasses and even brain surgery. These procedures are conducted through smaller incisions so patients have a faster recovery rate and suffer fewer complications than with conventional surgery. You can see it in Figure 8.3.14.

Figure 8.3.14 Surgical tools on the end of robot arms are shown here operating on a human heart. These arms are controlled by a surgeon, who looks at a beamed image of the operation site.

Robots are also used to perform tasks that are dangerous to humans. Autonomous robots are being used to explore dangerous environments such as other planets and shipwrecks, for defusing bombs, and for investigating inside a volcano or searching through disaster zones.

8.6

8.3 Unit review

Remembering

1 The wheel in Figure 8.3.15 can be thought of as a lever.
   a **State** whether its fulcrum is located at A, B, C or D.
   b **State** the length of the lever arm.

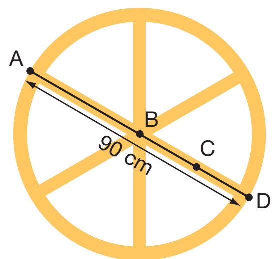


Figure 8.3.15

2 **Specify** which turns faster on a wheel—its centre or its rim.

3 **List** two examples where a wheel is used as a force multiplier.

4 **List** two examples where a wheel is used as a speed multiplier.

5 **Name** one use for:
   a bevel gears
   b worm gears
   c rack and pinion gears.

Understanding

6 Examine Figure 8.3.3 on page 311. **Explain** how each type of wheel shown acts as a force multiplier.

7 a **Explain** what is meant by a *block and tackle*.
   b **Describe** how a block and tackle is used.

8 **Discuss** how a pulley system obtains a force advantage.

Applying

9 a **Identify** three jobs around your home which you would like a robot to perform.
   b **Explain** why you have chosen each job.

10 For Figure 8.3.16:
   a **Calculate** the gear ratio for the combination shown.
   b **Describe** a type of riding situation for which this combination would be useful.

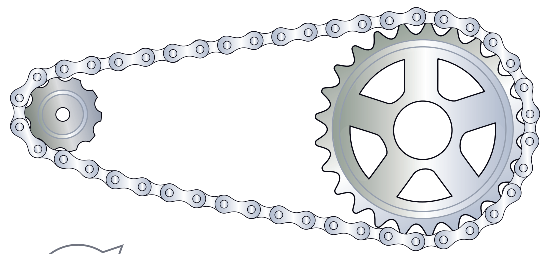


Figure 8.3.16

11 **Use** Figure 8.3.17 to answer the following.
   a **State** how many pulleys are being used by the system.
   b **Calculate** how much easier it will be to lift an object using such an arrangement.

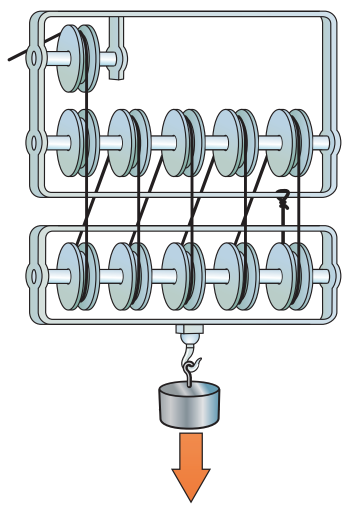


Figure 8.3.17

8.3 Unit review

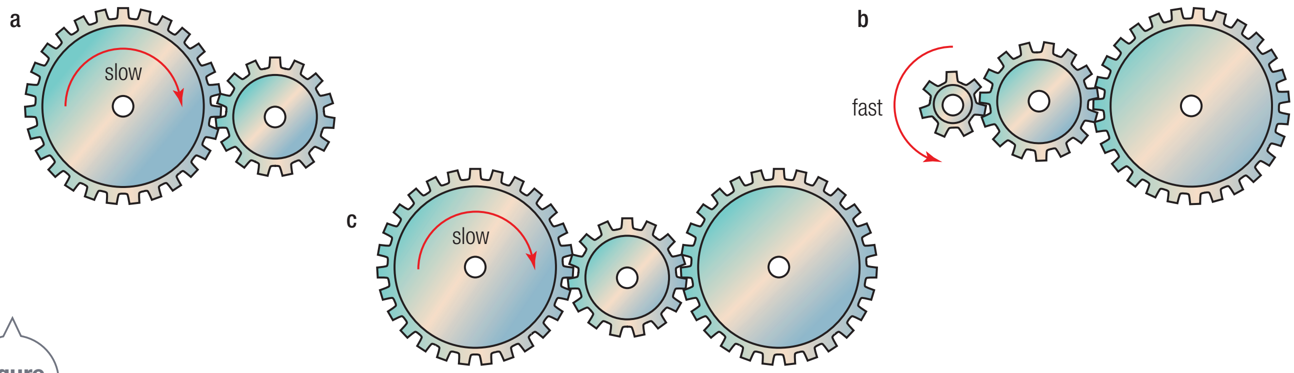


Figure 8.3.18

Analysing

12 Copy the three gear trains from Figure 8.3.18. **Analyse** the direction of rotation and speed of each gear and show these on your diagram.

13 A farmer applies an effort force of 150 N to a pulley system to lift a sack of wool weighing 600 N.

- **a** From this information **calculate** how many pulleys are in the system.
- **b** **Calculate** how much further he needs to pull the rope than when using a single pulley.

Creating

14 **Construct** a diagram to show an arrangement of gears in a gear train to act as a:

- **a** force multiplier
- **b** speed multiplier.

Inquiring

1 Robocup is an international competition, aimed to develop a team of fully autonomous (self-controlled) humanoid robots that can beat the best soccer team in the world by the year 2050. Use the internet to construct a timeline outlining:

- when this competition began
- the year and location of past Robocups.

Illustrate your timeline with images of some of the competing robots from past challenges.

2 Leonardo da Vinci was not only a wonderful painter, he also sketched inventions of many machines that were well before his time. Search available resources such as textbooks, encyclopaedias and the internet to describe some of these fascinating inventions.

3 Design and construct a machine that uses as many of the different types of simple machine studied in this chapter as you can. You can choose to build a:

- machine able to lift a small load
- replica of a medieval machine, such as a trebuchet or drawbridge
- mechanical toy.

4 Use a model building set such as Lego to build a gear train that increases force, and a gear train that increases speed. Calculate the gear ratio between the driving and driven gear in each case.

5 Research Lance Hill and the Hill's Hoist.

8.7 8.8

8.3 Practical activities

1 Using a wheel and an axle

Purpose

To build a simple machine consisting of a wheel and an axle.

Materials

- 250 mL beaker or tin can
- 2 paper clips
- length of stiff wire
- sticky tape
- 100 g mass
- string

Procedure

1. Set up the equipment shown in Figure 8.3.19a. Tape the two paper clips to hold the wire axle in position.
2. Try to lift the 100 g mass by twisting the wire around using your thumb and index finger.
3. Now, remove the paperclips and remove the wire. Bend the end without the masses to form a handle as shown in Figure 8.3.19b.
4. Reassemble the equipment and now try to lift the masses by turning the handle.

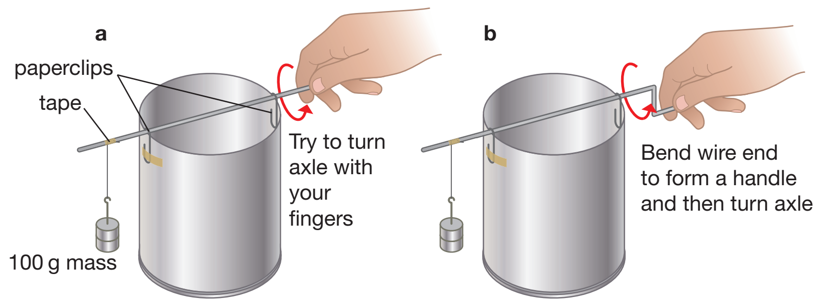


Figure 8.3.19

Discussion

1. **Describe** the difficulty of using the equipment with the straight axle to lift the masses using the straight piece of wire.
2. **Explain** any differences in doing this when using the bent handle.
3. **Propose** a reason this change makes the task easier.
4. This handle is acting as a lever. **Identify** why turning the handle provides the force advantage needed to lift the mass.
5. **Identify** three places you've seen systems similar to this being used to provide a force advantage.

2 Investigating pulleys

Purpose

To compare the advantage of using single-pulley, double-pulley and multiple-pulley arrangements to lift a load a distance.

Materials

- 2 single pulleys
- 2 double pulleys
- 2 m length of cord or rope
- slotted 50 g masses
- spring balance (or force sensor)
- metre ruler
- wooden beam

Procedure

1. Use a spring balance or force sensor to record the weight of 500 g of slotted masses. Record this load force in a table like that shown on the next page.
2. Position the metre ruler or beam of wood across two benches or tables and set up the single pulley arrangement shown in Figure 8.3.20a on page 320.
3. Record the force required to raise the load a height of 20 cm.
4. Repeat steps 3 and 4 with the other two pulley arrangements shown in Figure 8.3.20.

Investigating pulleys continued on next page

8.3 Practical activities

Investigating pulleys continued

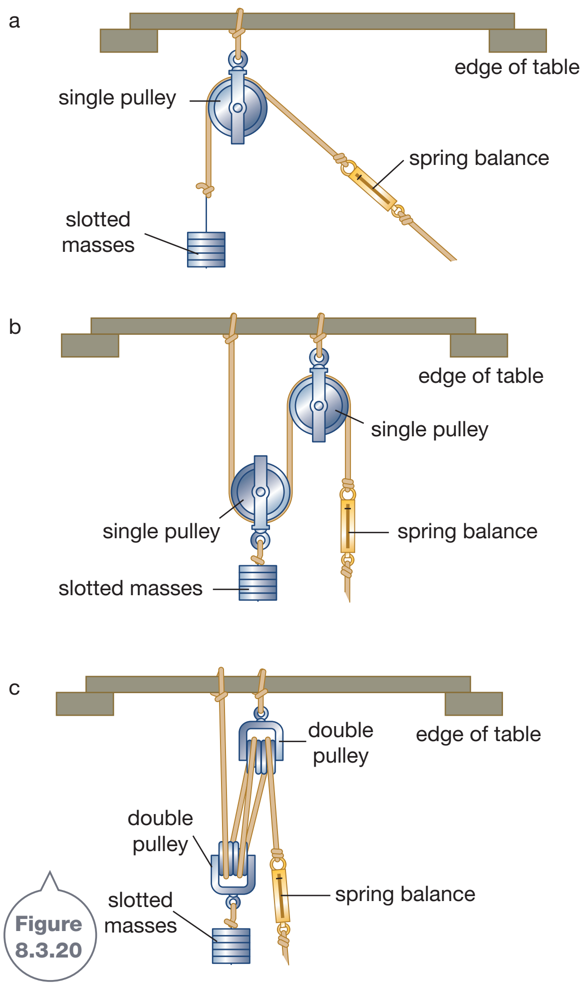


Figure 8.3.20

Results

Copy the results table below and complete this as you work through the experiment.

Arrangement	Number of pulleys used	Load force (N)	Effort force to raise load 20 cm (N)	Mechanical advantage $\left(\frac{\text{load}}{\text{effort}}\right)$
Single pulley	1			
Two single pulleys	2			
Two double pulleys	4			

Discussion

1. **Describe** how the effort required to lift the 500 g mass changed as more pulleys were used.
2. **Compare** the mechanical advantage gained in using four pulleys to that of a single pulley.
3. **Describe** how the lengths of rope pulled through the pulleys varied in each arrangement.
4. **Explain** how a multiple-pulley system can provide a force advantage.
5. **Explain** how friction affects the efficiency of a pulley system.

3 Investigating a geared machine

Purpose

To examine the gear arrangement of a household machine.

Materials

- hand drill
- eggbeater
- corkscrew
- adjustable spanner, flour sifter or any geared machine

Procedure

Examine how your machine operates.

Results

1. Draw a diagram of the machine. Label any examples of rack and pinion gears, bevel gears, worm gears, wheel and axles, screws, levers and wedges.
2. Label the driving gear and a driven gear on your diagram.
3. Show the direction of rotation of each.
4. Compare the number of turns made by the driving gear and the driven gear.

Discussion

1. **Identify** whether the gear combination in your machine is used as a force or a speed multiplier.
2. **Explain** how this occurs, by **comparing** the rotation of the driving and driven gears.

4 Investigating bicycles

Purpose

To examine the gearing combinations of a bicycle.

Materials

- geared bicycle
- broom handle
- piece of chalk

SAFETY

Keep fingers clear of moving spokes on the wheel at all times.

Procedure

1 Copy the table from the Results section.

2 Lift the rear of the bicycle off the ground and support it against two stools or benches as shown in Figure 8.3.21.

Figure 8.3.21

3 Select the first gear, so that the chain wheel is on the smallest sprocket and the rear sprocket is on the largest.

4 Make a mark with chalk on the rear tyre. Slowly turn the pedals one revolution and count how many revolutions the rear wheel makes in this time.

5 Record this data in the first row of your table.

6 Count the number of teeth on the front and rear sprockets and enter this data.

7 Repeat steps 3–6 for another four gear combinations.

Results

Copy and complete the following table.

Combination number	Number of turns of rear wheel for one turn of pedals	Number of teeth on chain wheel sprocket (N_1)	Number of teeth on rear wheel sprocket (N_2)	Gear ratio $\frac{N_1}{N_2}$
1				
2				
3				
4				
5				

Discussion

1 **Identify** which gear combination is best suited to riding uphill. **Justify** your choice.

2 **Identify** which gear combination is best suited to riding along a flat, easy road. **Justify** your choice.

8 Chapter review

Remembering

1 **Name** the simple machine that is a double inclined plane.

2 **State** the formula used to calculate the mechanical advantage of a lever, given the size of the load force and the effort supplied.

3 **a** **State** the class of lever acting in each situation shown in Figure 8.4.1.

b **Specify** which act as force multipliers, and which act as speed multipliers.

Figure 8.4.1

Understanding

4 Carefully read the following statements and **modify** any that are false to make them true.

a A steeper ramp provides a greater mechanical advantage than a ramp with a gentle slope.

b A pair of tongs acts as a first-class lever.

c Two interconnected gears rotate in the same direction.

d When a driving gear is smaller than the driven gear, the driven gear rotates faster than the driving gear.

5 **Explain** what is meant by the term *mechanical advantage*.

6 **Explain** how it is possible for two people to ride their bikes next to each other, one pedalling much faster than the other, but both travelling at the same speed.

Applying

7 **Use** Figure 8.4.2 to explain how using the handle of a tap increases the size of the force you apply to its spindle.

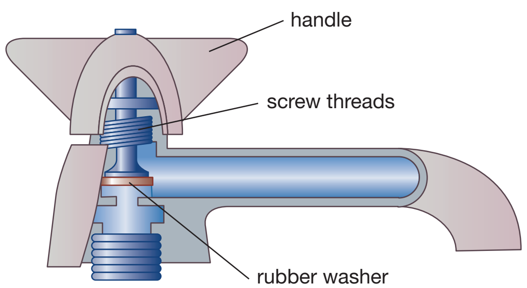


Figure 8.4.2

8 **Calculate** the size of the mechanical advantage of each of the following lever systems.

a A wheelbarrow has an effort arm of length 1.5 m and a load arm of 0.5 m.

b A crowbar used to shift an old fence. The effort arm is 1.2 m and the load arm is 5 cm (0.05 m).

9 While riding a bike, an effort force is applied to a chain-wheel cog with 25 teeth, which is connected to a rear-wheel cog with 75 teeth.

a **Calculate** the gear ratio of this arrangement.

b **Identify** whether this arrangement acts to multiply force or speed.

Analysing

10 **Calculate** where a 25-gram mass should be positioned on each see-saw shown in Figure 8.4.3 so that they will balance.

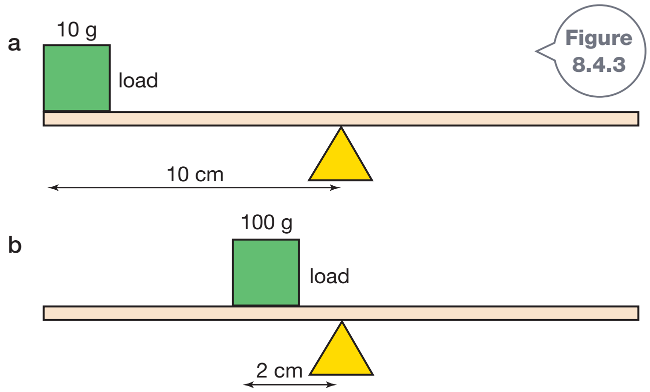


Figure 8.4.3

11 **Analyse** the combination of gears shown in Figure 8.4.4.

- **a** If gear 1 turns in a clockwise direction, then state which direction gears 2, 3 and 4 will turn.
- **b** If axle 2 is rotated, then identify whether gear 1 or gear 3 will turn faster.

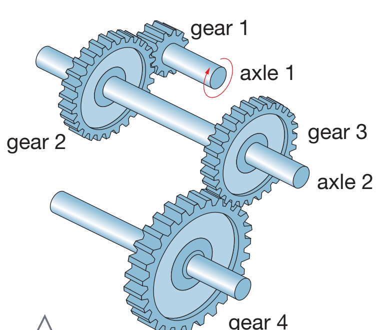


Figure 8.4.4

12 Figure 8.4.5 shows the pulley system of a lathe. The electric motor is driven at a constant rate. The rate of the drive shaft is then determined by changing the selection of the belt onto different pulley wheels. **Analyse** Figure 8.4.5 to answer the following questions.

- **a** When the belt is positioned as shown in the diagram, **state** which will turn faster—the motor or the drive shaft.
- **b** **Explain** what would happen to this turning rate if the belt was moved to the Z and 3 position.

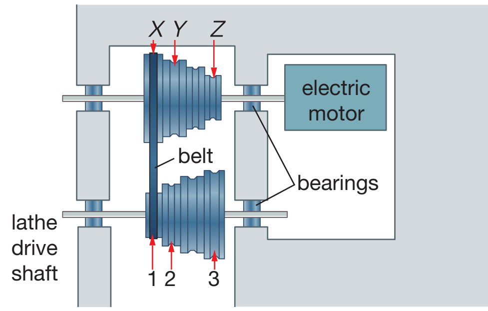


Figure 8.4.5

Evaluating

13 Robots are currently being used in the following situations. **Propose** why they are used in each case.

- **a** To weld car bodies together
- **b** To test suspicious packages at airports.

14 An effort force of 400 N is used to raise a load using a single pulley.

- **a** **Calculate** the effort force that would be required to lift this load using a system of five pulleys.
- **b** If this was performed, the actual effort required will be greater than the amount you have calculated. **Propose** reasons to explain this.

15 Tien pushes a toy helicopter across the floor. As its wheels rotate, a propeller spins faster. **Predict** whether the driving gear is larger or smaller than the driven gear, giving reasons for your answer.

Creating

16 **Use** the following ten key words to **construct** a visual summary of the information presented in this chapter.

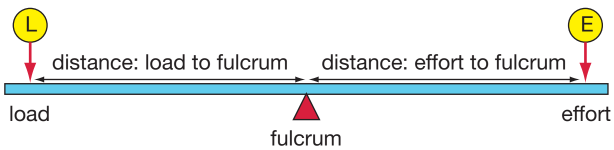
simple machine
load
effort
mechanical advantage
force multiplier
speed multiplier
lever
inclined plane
wheel
gear

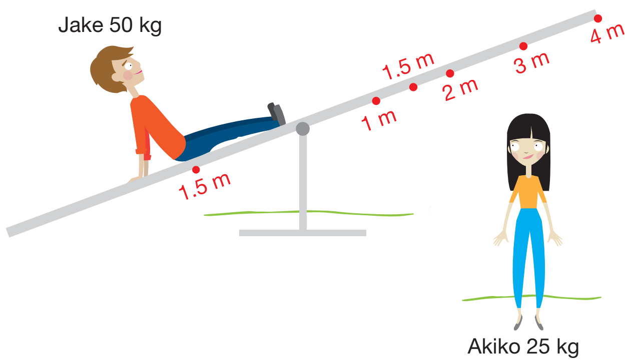
8.9

Thinking scientifically

Q1 A see-saw is a lever that pivots about a central point called the fulcrum. An effort, E, applied some distance from the fulcrum can be used to lift a load, L, positioned on the other side of the fulcrum. The principle of levers is a rule that holds for a see-saw. This states that:

Load × distance from load to fulcrum = effort × distance from effort to fulcrum





Jake has a mass of 50 kg and sits 1.5 m from the fulcrum of a see-saw. Akiko has a mass of 25 kg. To balance the see-saw, she should sit on the opposite side to Jake and:

A 1 m from the fulcrum
B 1.5 m from the fulcrum
C 2 m from the fulcrum
D 3 m from the fulcrum.

Q2 A gear train is a set of interconnected gears.

A driving gear supplies a force to turn another gear, called the driven gear.

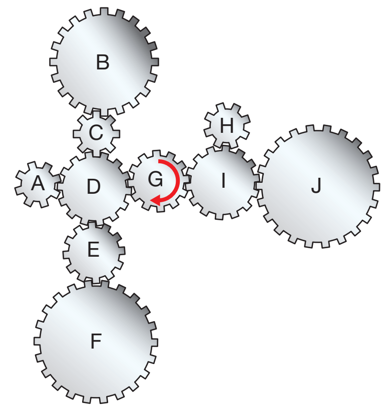
A driven gear turns in the opposite direction to the driving gear.

If the driven gear is smaller than the driving gear, then it will turn faster than the driving gear.

If the driven gear is larger than the driving gear, then it will turn more slowly than the driving gear.

Study the diagram showing a gear train in a children's play area.

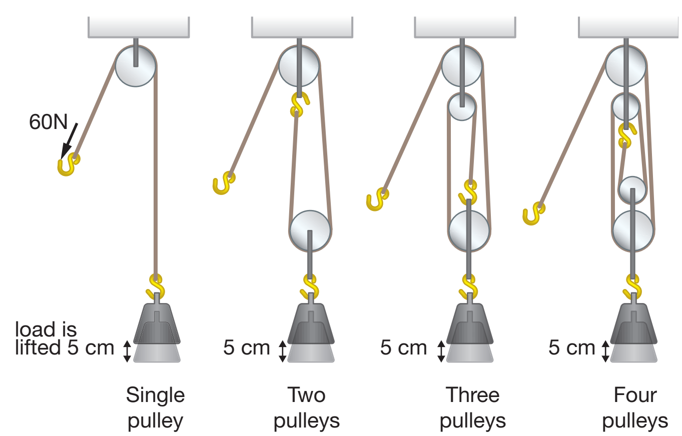
A child turns gear G in a clockwise direction. The gear/s that turn clockwise and more slowly than G are:



A A, C and H
B J
C B, D, F and I
D E

Q3 A pulley can be used to lift a load. Increasing the number of pulleys increases the mechanical advantage, making the load easier to lift. If four pulleys are used to lift a load, then only one-quarter of the force is needed compared to using a single pulley, but the cable must be pulled four times the distance.

A 60 N mass is lifted 5 cm by a single pulley, then by two, three and four pulleys as shown.



The correctly ordered force needed to lift the load and the length of cable that is pulled when using the two-, three- and four-pulley systems are:

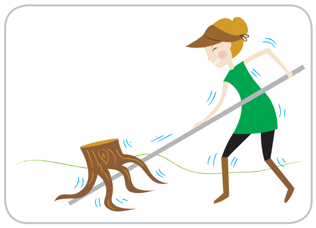
A 15 N, 20 N, 30 N; 10 cm, 15 cm, 20 cm
B 30 N, 20 N, 15 N; 20 cm, 15 cm, 10 cm
C 30 N, 20 N, 15 N; 10 cm, 15 cm, 20 cm
D 15 N, 20 N, 30 N; 20 cm, 15 cm, 10 cm

Glossary

Unit 8.1

Effort: force applied to a lever to overcome the load

First-class lever: lever with effort and loads located at each end, and fulcrum in the centre



First-class lever

Force multiplier: machine that increases the force applied for a task, such as a first-class lever

Fulcrum: point about which a lever pivots

Lever: simple machine consisting of a rigid rod that pivots about a point

Load: force that a lever is used to overcome

Mechanical advantage: ratio of a load force to the effort force used by a machine

Second-class lever: lever with the fulcrum located at one end, the effort at the other and load in the centre

Simple machine: a device that makes work easier by changing the size or direction of a force

Second-class lever

Speed multiplier: machine that requires a small movement of an effort to produce a large movement of a load, such as a third-class lever

Third-class lever: lever with the fulcrum located at one end, with the load at the other and effort in the centre

Third-class lever

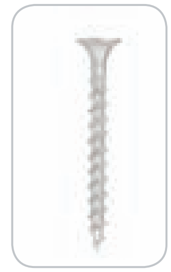
Unit 8.2

Inclined plane: a simple machine that reduces the effort needed to lift a load by increasing the distance it acts

Pitch: distance between adjacent threads on a screw

Ramp: an inclined plane used to help lift an object

Screw: a spiral-shaped inclined plane



Screw

Wedge: a double inclined plane, such as a knife or an axe

Wedge

Unit 8.3

Axle: shaft on which a wheel rotates

Block and tackle: a system of two or more pulleys using rope or cable to lift heavy objects

Driven gear: the gear that receives force from a driving gear

Driving gear: the gear that supplies force to another gear

Gear ratio: ratio of the number of teeth on the driving gear and the number of teeth on a driven gear

Gear train: a system of interconnected gears

Gears: a wheel with teeth used to turn another gear wheel

Pulley: a wheel with a groove over which a rope or cable can slide, used to change the direction of a force

Rim: outer edge of a wheel

Sprocket: a toothed wheel used to link onto a chain on a bicycle

Wheel: type of a lever with an axle acting as its fulcrum