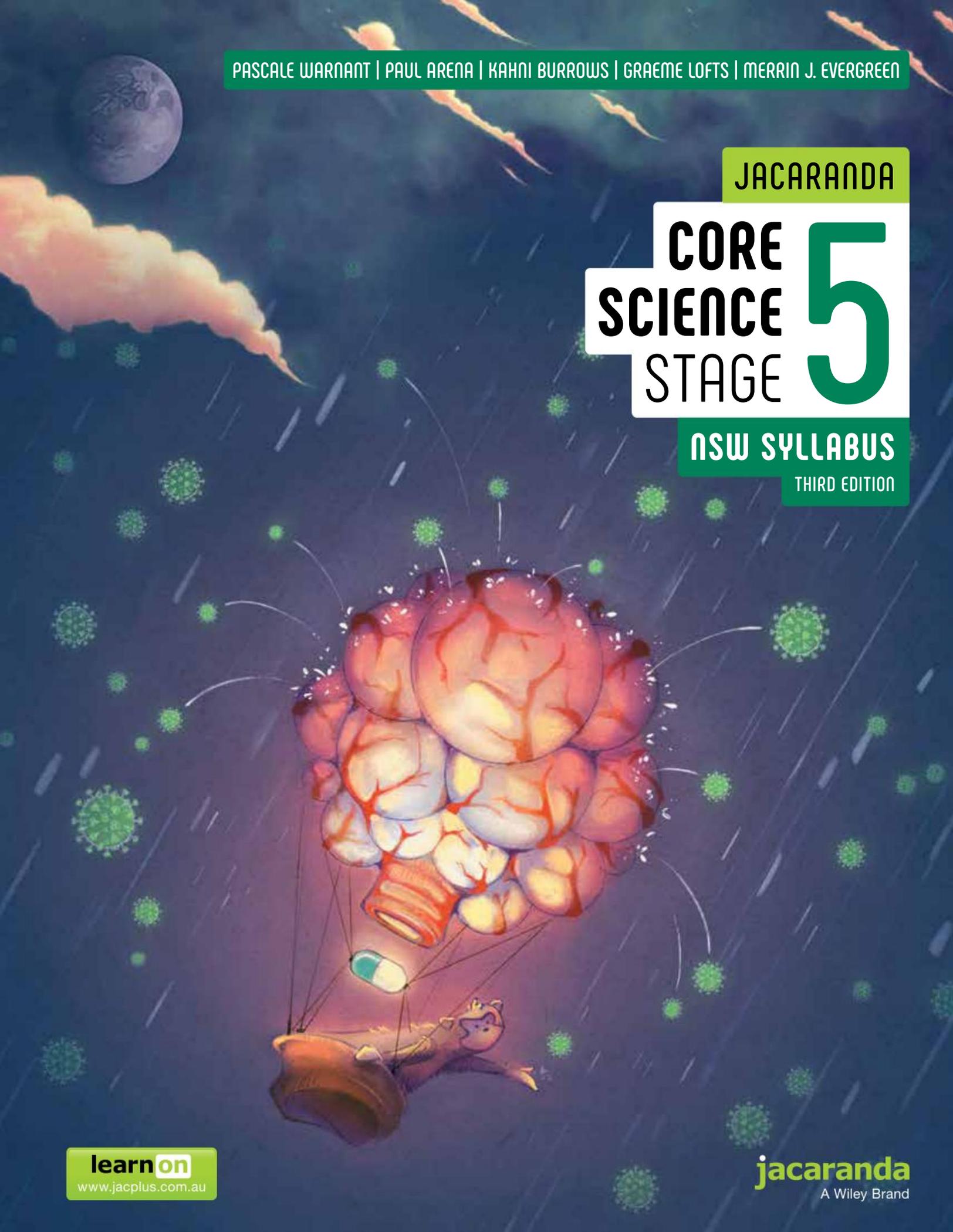PASCALE WARNANT | PAUL ARENA | KAHNI BURROWS | GRAEME LOFTS | MERRIN J. EVERGREEN

JACARANDA

CORE SCIENCE STAGE 5

NSW SYLLABUS
THIRD EDITION

jacaranda
A Wiley Brand

1 Using energy

LESSON SEQUENCE

LESSON 1.1 Overview

1.1.1 Why learn this?

We rely on electrical appliances each day, from turning on lights and checking phones in the morning to using laptops for learning and work. Appliances like washing machines and dishwashers make home tasks easier, while shopping often depends on electronic transactions. Power outages remind us of our dependence on electricity and technology. As society advances, our reliance on electrical technologies, including artificial intelligence, will continue to grow.

You do not have to understand how all these technologies work to use and enjoy them, but it is important to understand some of the basic principles behind electrical devices.

FIGURE 1.1 Modern digital technologies using artificial intelligence will become increasingly commonplace.

ACTIVITY: Engaging with using energy

Work in a small group to compile answers to each of the following questions.

1. Make a list of all the electrical devices used in and around the home.
2. Which devices are designed:
   a. to reduce the amount of effort needed to perform tasks done at home?
   b. for heating or cooling?
   c. for lighting?
   d. for entertainment?
3. Which devices contain electric motors?
4. In terms of electricity, what is the difference between an 18 watt and a 14 watt light globe?
5. Find an appliance with an energy rating sticker. What information is contained on the sticker?
6. Compact fluorescent and LED globes have replaced traditional incandescent lights. Explain why.
7. If one of the light globes in your home breaks, the others continue to work when switched on. What does that tell you about the way that your home lighting circuits are designed?
8. Electricity is provided to homes and schools via transmission lines.
   a. How is most of the electricity generated in New South Wales? Does this involve a renewable or nonrenewable energy source?
   b. Brainstorm some other ways in which electricity can be generated.

FIGURE 1.2 Energy at home.

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learn on

Pre-test	Topic 1 Pre-test
eWorkbook	Topic 1 eWorkbook Student learning matrix
Practical investigation eLogbook	Topic 1 Practical investigation eLogbook
Digital document	Key terms glossary

LESSON 1.2 Energy transfers and transformations

LEARNING INTENTION

In this lesson you will identify different types of energy sources.

1.2.1 Types of energy

Almost everything that we do involves the use of energy. The mobile phones and laptops we use each day require charging. This involves boosting a device's battery with more **chemical energy** which it can transform to **electrical energy** when used. At mealtimes, the food we eat is digested and stored as chemical energy by our bodies. This allows us to carry out our normal activities like walking to class, which involves the use of **kinetic energy**.

FIGURE 1.3 How many forms of energy can you identify?

The different types of energy can be categorised as either **potential energy** or kinetic energy. Potential energy is often defined as stored energy, such as an elastic band that is stretched or a hand weight that is raised. Kinetic energy is the energy involved with moving. This might be moving objects like a car in motion. Waves, atoms, and electrons can also possess kinetic energy when moving. Potential energy, when released, is converted to kinetic energy.

Objects generally have more than one form of energy. For example, the motorcycle in figure 1.3 exhibits kinetic energy as it is moving, it has gravitational potential energy during a jump, its engine converts chemical energy (from fuel) into mechanical energy. If it had headlights, it could emit light energy, and its exhaust system releases thermal energy and sound energy.

ACTIVITY: Types of energy

The simplest definition of energy is the ability to do work. Within the two main categories of potential energy and kinetic energy, we generally recognise different types of energy, such as electromagnetic, nuclear, sound and so on.

FIGURE 1.4 Examples of types of energy.

Sonic   Nuclear   Gravitational   Kinetic   Mechanical

Chemical   Electromagnetic   Potential   Ionization   Thermal
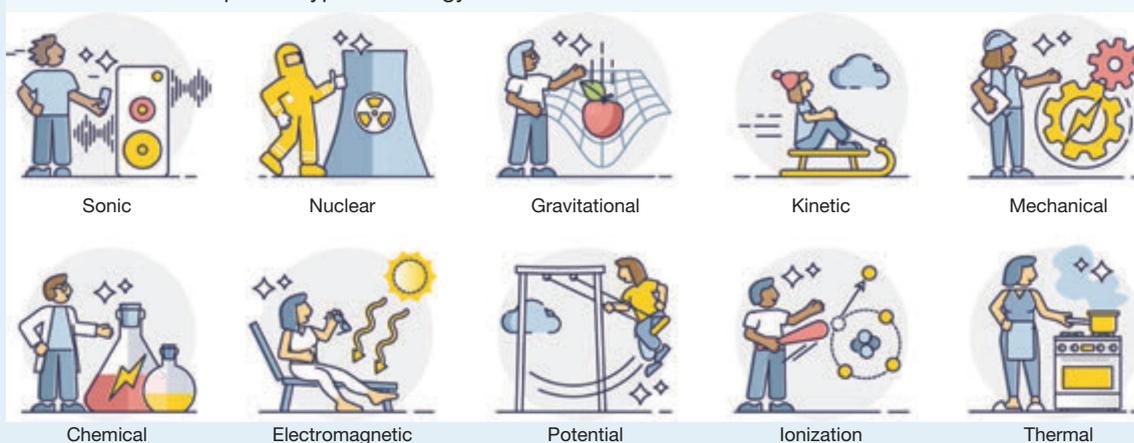
Work in a small group to complete the following tasks.
1. Research and compile simple definitions for the following forms of energy:
   - thermal energy
   - chemical energy
   - radiant energy
   - nuclear energy
   - sound energy
   - elastic energy
   - gravitational energy
   - electrical energy
2. Categorise each of the types of energy above as either potential energy or kinetic energy.
3. Observe each of the following images and list the different forms of energy you can identify.

1.2.2 How much energy?

Energy is measured in a unit called the joule (J), named after the British physicist James Joule (1818–1889). The kinetic and gravitational potential energy of objects can be calculated using a couple of simple formulae.

Calculating gravitational potential energy

Objects at a height above the ground have stored energy called gravitational potential energy. The higher an object is, the more gravitational potential energy it has.

Gravitational potential energy of an object = mgh

where:
- m represents the mass of the object (in kilograms)
- g represents the object's gravitational acceleration when falling (9.8 metres/second squared on Earth, often rounded to 10 m/s^2)
- h represents the object's vertical height (in metres).

FIGURE 1.5 Objects at a height above the ground have stored gravitational potential energy. The higher an object is, the more gravitational potential energy it has.

For example, to calculate the potential energy of an 80 kg skier on a chairlift 20 m off the ground:

$$\text{Potential energy} = 80 \, \text{kilograms} \times 10 \, \text{m/s}^2 \times 20 \, \text{m}$$
$$= 16\,000 \, \text{joules or 16 kilojoules}$$

Calculating kinetic energy

Objects in motion have kinetic energy. The more mass an object has and the greater its speed, the more kinetic energy it has.

$$\text{Kinetic energy of a moving object} = \frac{1}{2} m v^2$$

where:

- m represents the mass of the moving object (in kilograms)
- v represents the object's velocity (speed) (in metres/second).

For example, to calculate the kinetic energy of a cyclist and bicycle with a total mass of 100 kg travelling at 5 m/s:

$$\text{kinetic energy} = \frac{1}{2} \times 100 \, \text{kg} \times 5 \, \text{m/s}^2$$
$$= 1250 \, \text{joules or 1.25 kilojoules}$$

Recall that the law of conservation of energy states that energy can neither be created nor destroyed. It can, however, change from one form to another. Gravitational potential energy can be transformed into kinetic energy, and vice versa.

KEY IDEAS

Energy can be calculated as follows:

$$\text{Gravitational potential energy (GPE)} = mgh$$
$$\text{Kinetic energy (KE)} = \frac{1}{2} m v^2$$

SAMPLE PROBLEM 1 Calculating gravitational potential energy

A cyclist rides to the top of a hill, 30 m higher than his starting point. If he and his bike have a combined mass of 75 kg, calculate the increase in gravitational potential energy.

THINK	WRITE
1. Write the formula for gravitational potential energy.	$\text{GPE} = mgh$
2. Identify the values for each of the variables in the formula.	$m = 75 \, \text{kg}$ $g = 10 \, \text{m/s}^2$ $h = 30 \, \text{m}$
3. Substitute the values into the formula and calculate your answer.	$\text{GPE} = 75 \, \text{kg} \times 10 \, \text{m/s}^2 \times 30 \, \text{m}$ $= 22\,500 \, \text{joules}$ $= 22\,500 \, \text{J}$
4. Simplify your answer by considering that 1000 joules = 1 kilojoule (kJ).	$= 22\,500/1000$ $= 22.5 \, \text{kJ}$

SAMPLE PROBLEM 2 The transformation of gravitational potential energy to kinetic energy

The cyclist in Sample problem 1 gained 22.5 kJ of gravitational potential energy while cycling to the top of a hill. He then cruises to the bottom of the hill without pedalling.

a. Calculate the kinetic energy the cyclist will gain upon reaching the bottom of the hill, assuming no other energy was transformed.

b. Calculate the speed of the cyclist at the bottom of the hill considering he and his bike have a combined mass of 75 kg.

THINK	WRITE
a. Remember that energy is transformed from gravitational potential energy to kinetic energy on cruising to the bottom of the hill.	$\text{GPE} = \text{KE}$ $= 22.5\,\text{kJ}$ $= 22\,500\,\text{joules}$
b. 1. Write the formula for kinetic energy of the cyclist.	$\text{KE} = \dfrac{1}{2}mv^2$
2. Write an expression letting the kinetic energy gained equal the potential energy lost.	$22\,500\,\text{J} = \dfrac{1}{2}mv^2$
3. Substitute the value for mass.	$22\,500\,\text{J} = \dfrac{1}{2} \times 75 \times v^2$
4. Rearrange your expression, making v^2 the subject.	$v^2 = \dfrac{2 \times 22\,500}{75}$
5. Solve for v^2 then v.	$v^2 = 600$ $v = \sqrt{600}$ $v = 24.5\,\text{m/s}$

1.2.3 Transferring and transforming energy

Energy can be **transferred**, or passed on, to another object or to the surrounding environment. For example, while sitting near an air conditioner on heating mode on a cold winter's night, thermal (heat) energy has been transferred to you but has not changed form.

Energy can also be **transformed** or converted into other forms of energy. For example, the electrical energy supplied to a television is transformed into both radiant (light) energy through the images on the screen and sound energy through the speakers.

KEY IDEAS

Energy is *transferred* when it passes from one object to another while remaining in the same form.

Energy is *transformed* when it passes from one object to another and, in doing so, changes from one form to another form.

FIGURE 1.6 Examples of typical energy transformations. Each transformation involves one form of energy being converted to another form.

Chemical ⟶ Light

Chemical ⟶ Kinetic

Chemical ⟶ Kinetic

Electrical ⟶ Light
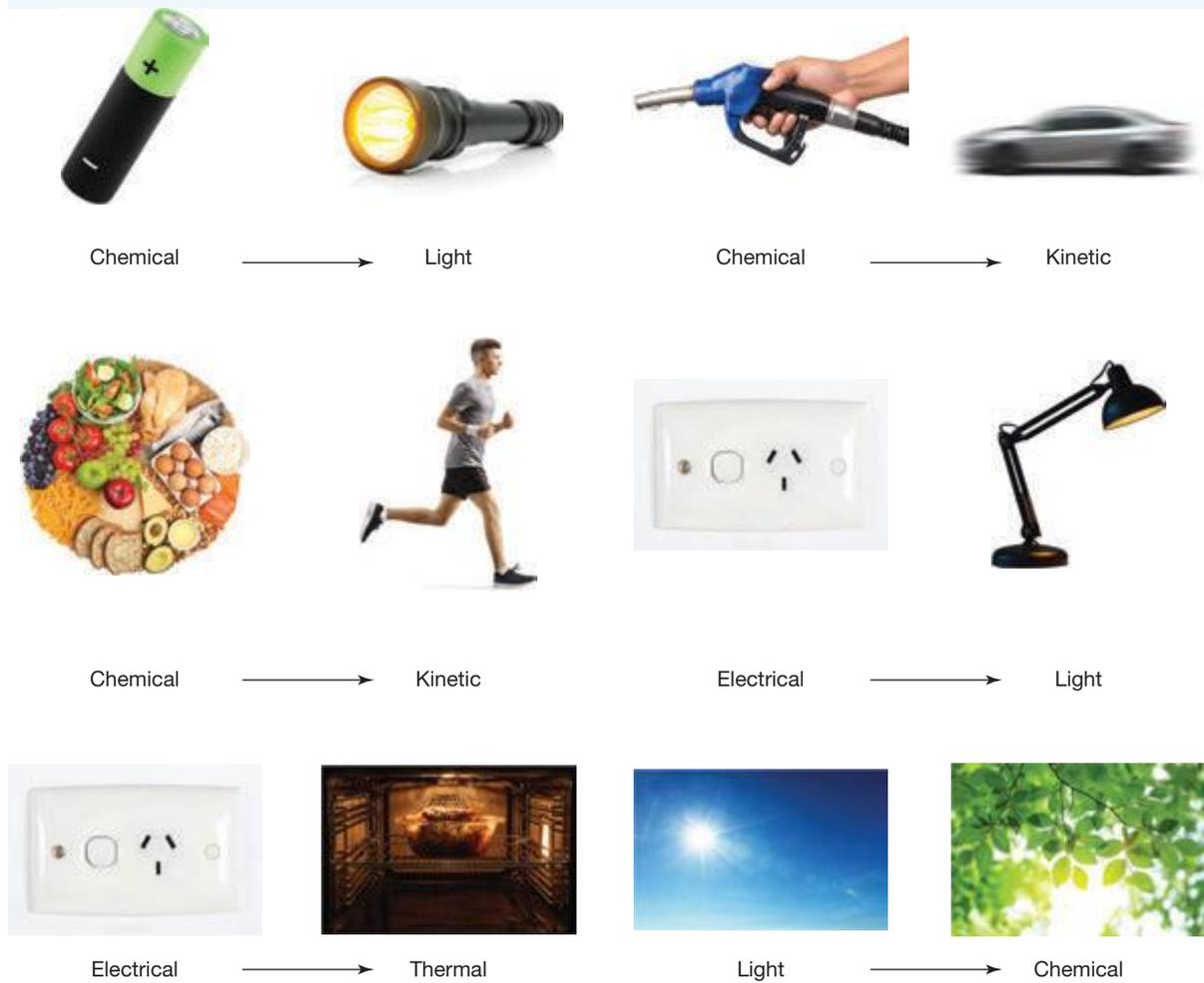
Electrical ⟶ Thermal

Light ⟶ Chemical

FIGURE 1.7 Electrical energy supplied to the light globe is *transformed* into heat and light energy in the filament. The light is the desirable energy, but the heat is considered 'wasted' because it has no benefit to us.

FIGURE 1.8 In a game of pool, the white cue ball is struck, providing it with kinetic energy. The kinetic energy of the white ball is then *transferred* to the coloured ball.

FIGURE 1.9 A computer *transforms* electrical energy into light energy in the screen and sound energy when music and videos are played.

FIGURE 1.10 A stove top *transforms* electrical energy into heat energy in the glowing hotplate, which is then *transferred* to the pot and water.

INVESTIGATION 1.1

Energy transformation in a lemon battery

Aim

To investigate the energy transformation in a lemon battery

Materials

- 1 lemon
- a range of nails: galvanised, iron, steel
- 2 wire leads with an alligator clip at one end
- digital multimeter

Method

1. Roll the lemon on a bench to break up some of the pulp inside.
2. Insert one nail just off centre and a second nail approximately 2 cm away.
3. Switch on the digital multimeter and set it to measure small electric currents in the milliamp range.
4. Connect each nail to the digital multimeter using the wire leads, one connected to the current (A) terminal and the other to the earth (com) terminal. Record the maximum current produced.
5. Repeat the previous step using different combinations of metal nails.

Results

Record, in a suitable table, the maximum current produced with each combination of nails.

Multimeter

Wire lead

Galvanised nail

Lemon
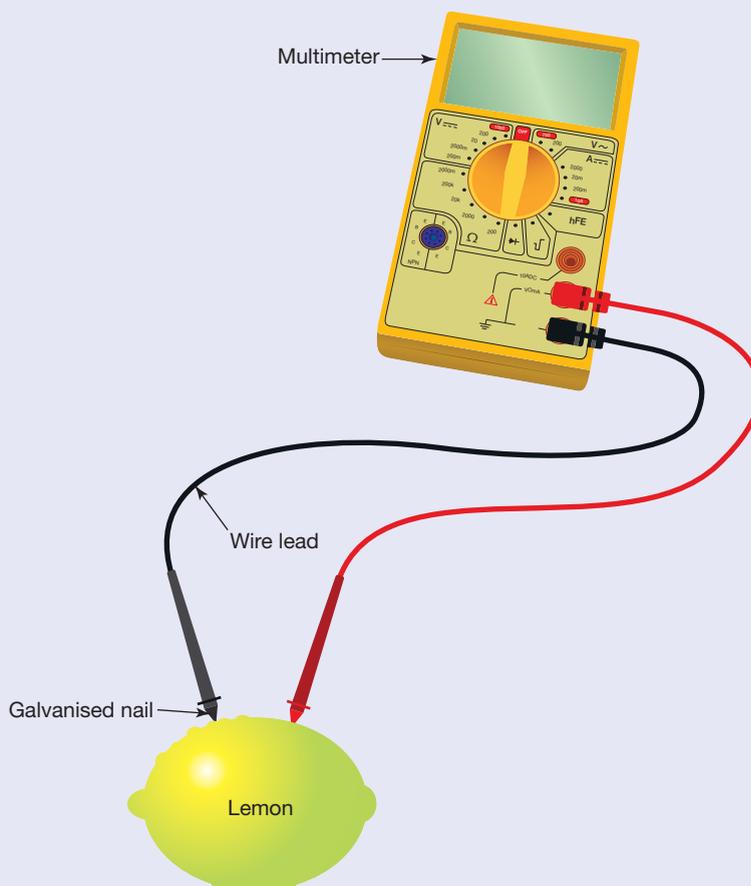
Discussion

1. Which combination of nails produced the most current? Can you suggest why?
2. In this experiment, what variable(s) did you:
   a. control
   b. change?

Conclusion

Summarise the energy transformation taking place in this experiment and outline the combination of metals that generated the greatest electric current.

ACTIVITY: PhET simulation — Energy skate park

Access the **PhET simulation: Energy skate park** interactivity in the Resources panel and use the simulation to identify positions on a skate ride where the skater has more kinetic energy and where it has more gravitational potential energy.

Start with the intro activity, then use the playground ride feature to build your own track with multiple falls and rises.

1.2 Activities

learn on

1.2 Quick quiz on	1.2 Exercise

Learning pathways

■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 5, 8	2, 6, 9	3, 4, 7, 10

Remember and understand

1. **Identify**:
   a. six forms of potential energy
   b. five forms of kinetic energy.
2. **Identify** the type of energy that:
   a. a person has when running
   b. a spring has when it is stretched.
3. Use a suitable example to **describe** what is meant by an:
   a. energy transfer
   b. energy transformation.
4. Match each energy transformation (in the left column) to the scenario (in the right column) in which it would be most likely to occur.

a. Chemical — kinetic	1. Using a torch
b. Chemical — light	2. Eating food then riding a bike
c. Electrical — light	3. Using a toaster
d. Electrical — thermal	4. Turning on a light switch

▶

5. A saucepan of water is heated to boiling point on an electric hotplate. For this situation, list three examples of ways in which energy is transformed or transferred.
6. **Calculate** the gravitational potential energy of a 2 kg cat sitting on a tree branch 15 m from the ground.
7. **Calculate** the kinetic energy of a 60 kg sprinter running at a speed of 8 m/s.

Evaluate and create

8. Construct a poster to **outline** the different energy types that are involved in the operation of an appliance such as a hairdryer. Add labels to your poster showing where the different types of energy are used or produced.
9. The energy we get from eating a piece of fruit starts from the Sun. **Describe** the energy transformations involved in this process using a flow diagram.
10. Using the playground feature in the **PhET simulation: Energy skate park** interactivity in your Resources panel, or by drawing, create a track in which:
   • at one point your rider reaches a top speed of at least 15 m/s
   • at another point the kinetic energy is less than half of the potential energy.
   Label these two points, the initial height of your track and the weight of your rider on a copy of your track design.

LESSON 1.3 The conservation of energy

LEARNING INTENTION

In this lesson you will use the law of conservation of energy, and calculations, to explain that total energy is maintained in energy transfers and transformations in a closed system.
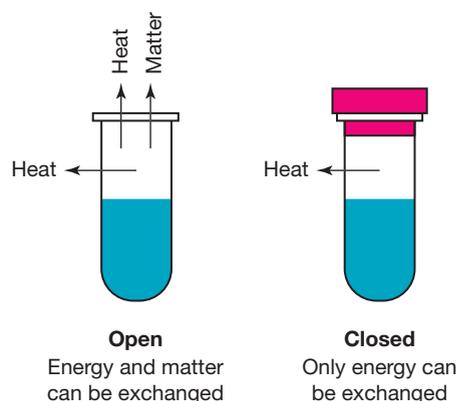
1.3.1 Open and closed systems

Energy transfers and transformations can be observed all around us; when we switch on a light or when we take a warm shower in the morning or evening. Whenever an energy transfer or transformation takes place, to understand how much energy is involved, we must first examine the concept of an 'open' or 'closed' system.

An **open system** is one in which both matter and energy flow in or out. A beaker of water represents an open system because water molecules can evaporate away, reducing the amount of matter in the beaker. If the beaker contains hot water, heat (thermal) energy will flow out to the surrounding environment. If the beaker contained very cold water, it would absorb heat from the surroundings and its temperature would increase. So, a beaker of water is an example of an open system — both matter and heat energy can be exchanged with its surroundings.

FIGURE 1.11 The flow of energy and matter in open and closed systems

Open
Energy and matter can be exchanged

Closed
Only energy can be exchanged

In a **closed system** heat (thermal) energy can flow in or out, but matter cannot. A sealed container with water represents a closed system because water molecules cannot evaporate away, and the amount of matter in the beaker will remain constant over time. However, the temperature of the water in the container, and hence, its thermal energy, will increase or decrease depending on the temperature of the surrounding environment.

Open and closed systems

Aim

To compare an open and a closed system

Materials

- 2 large conical flasks
- rubber stopper
- hot water
- thermometer
- electronic scales

Method

1. Half-fill two large conical flasks with water that is near boiling. **Be careful handling hot flasks!**
2. Quickly record the temperature of the water in each conical flask with a rubber stopper.
3. Remove the thermometer and seal one of the conical flasks.
4. Record the mass of each conical flask and its contents using the electronic scales.
5. After 1–2 days have passed, record the mass of each conical flask and its contents.
6. Remove the stopper from the conical flask and again record the temperature of the water in each conical flask.

Results

Record all your data in a single table. Be sure to use the correct units for mass and temperature.

Discussion

1. Compare the initial and final mass in each conical flask.
2. Compare the initial and final temperature in each flask.
3. Explain whether each flask resembles an open or closed system.

Conclusion

Refer to the findings in this experiment to compare an open and closed system.

1.3.2 The law of conservation of energy

In a closed system, energy can flow in and out of the system, but matter cannot. For example, heat (thermal) energy may flow from the hot water in a sealed container to the surrounding environment, heating up the surrounding air.

The **law of conservation of energy** states that in a closed system, energy can be gained from its surroundings, but the amount of energy gained by the closed system must equal the amount of energy lost by its surroundings. Similarly, a closed system can lose energy to its surroundings, but the amount of energy lost by the closed system must equal the amount of energy gained by its surroundings.

The law of conservation of energy means that energy is neither created nor destroyed but conserved. The total amount of energy remains constant even as energy is transferred or transformed from one object to another. This means that the energy that is lost by a system must be gained by its surroundings.

FIGURE 1.12 Jumping on a trampoline demonstrates the law of conservation of energy. Gravitational potential energy is transformed to kinetic energy then to elastic potential energy then back to kinetic energy and so on. The total amount of energy in this system (the trampoline and the jumper) remains constant.


Gravitational potential energy → Kinetic energy → Elastic potential energy → Kinetic energy → Gravitational potential energy
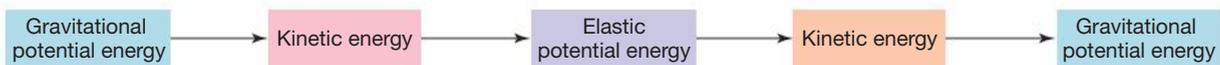
1 At the very top of a jump, the bouncer is momentarily stopped — he has no kinetic energy. But he does have gravitational potential energy due to his height above the trampoline. As the force of gravity pulls the bouncer down, some of his potential energy is transformed into kinetic energy.

2 As the bouncer strikes the trampoline, his kinetic and gravitational potential energy are transferred to the trampoline's surface and springs. The energy is momentarily stored in the springs. It is called elastic potential energy.

3 At this point, the bouncer pushes off the trampoline. The elastic potential energy is transformed back into kinetic energy and some gravitational potential energy.

4 As the bouncer rises again, his kinetic energy is transformed into gravitational potential energy again. At the top of the jump, the bouncer has no kinetic energy, just gravitational potential energy.

KEY IDEAS

The law of conservation of energy can be simply stated as follows: energy can neither be created nor be destroyed. During a transfer or transformation, the amount of energy gained by a system must be equal to the amount of energy lost by the surroundings. The total amount of energy is constant.

Sometimes it is difficult to track where the energy goes. For example, most of the kinetic energy when you clap your hands is transformed to sound energy, but you might also notice that your hands get warm. This demonstrates that some of the original energy is transformed to heat.

FIGURE 1.13 A pendulum is a good demonstration of conversion of energy between kinetic and gravitational potential energy.
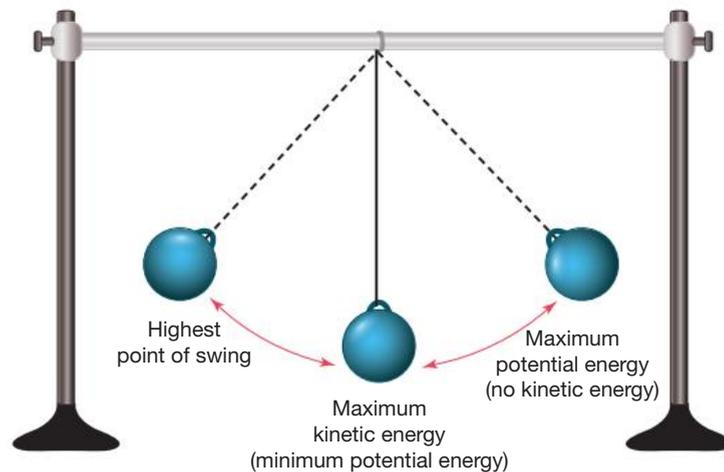
INVESTIGATION 1.3

Energy transformation in a pendulum

Aim

To investigate the law of conservation of energy in a pendulum

Materials

- retort stand
- retort ring
- string
- stopwatch
- a light mass (e.g. 50 g) and lifting ring

Method

1. Attach the retort ring to the top of the retort stand, so the base of the ring hangs vertically.
2. Attach one end of a length of the string securely to the small mass.
3. Attach the other end of the string securely to the lower part of the retort ring to create a pendulum. Make the pendulum as long as possible. The mass should swing freely in an arc just above the base of the retort stand and without contacting the retort stand.
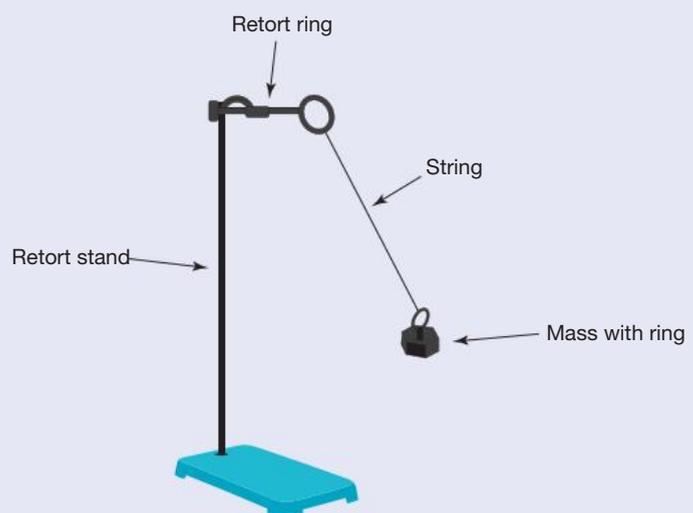
4. Pull the mass back 10–15 cm to start the pendulum motion.
5. When the pendulum returns to the top of an arc, start the stopwatch and record the time for 5 complete swings (to-and-fro motions). Repeat this twice more and calculate the average time taken for 5 swings.
6. Repeat step 5 after you have allowed the pendulum to swing for a couple of minutes.
7. Observe the pendulum for a few minutes until it has nearly stopped swinging.

Results

1. In a suitable table, record the time taken for 5 complete swings at the start of the pendulum and near the end, include each trial and the averages.
2. Record any other observations, including whether the size of the arc through which the pendulum swings appear to increase, decrease or remain constant.

Discussion

1. Where does the pendulum appear to travel
   a. fastest
   b. slowest?
2. Outline the energy transfers or transformations that take place as the pendulum swings.
3. Explain why the pendulum eventually stops swinging. Where has the energy gone?
4. How does this experiment support the law of conservation of energy?

Extension

5. Does the time taken for 5 complete swings differ significantly at the start of the pendulum's motion and near the end? Explain.

Conclusion

Refer to the findings in this experiment to explain how the law of conservation of energy can be demonstrated in a pendulum.

ACTIVITY

A Newton's cradle is shown in figure 1.14.

When one ball from one end is released, it collides with the other balls and kinetic energy is transferred across. This is a highly efficient system, other than the small sound of balls hitting.

Would a Newton's cradle be able to continue this motion indefinitely? Discuss your response.

FIGURE 1.14 A Newton's cradle

WORKING SCIENTIFICALLY: The conservation of mechanical energy

Aim: To investigate the conservation of energy

Use scientific tools and instruments to observe an energy transformation

Materials

- a light mass (e.g. 50 g) and lifting ring
- string
- a low friction motion car
- a ticker timer, AC power pack and timer tape or data logging motion sensor
- for example, a photogate
- a smooth surface, for example, a plank of wood or a data logging track
- Blu Tack

- a tape measure
- electronic scales
- a pulley and vertical G clamp

Method

Focus skills:
- Select and use equipment correctly, including digital technologies, to make observations to increase the accuracy of measurements appropriate to the task
- Assemble, construct and manipulate identified equipment to perform the investigation
- Follow the planned procedure and identify and respond to errors if they occur
- Systematically and accurately collect and record data

Set up

1. Clamp the pulley to the end of a plank of wood or benchtop.
2. Place the motion car on the smooth plank of wood or track.
3. Give the car a gentle push. If it slows down, this is due to friction in the system. Compensate for the friction by raising the far end of the track till the car travels at a constant speed when it is gently pushed. The raised track can be fixed in place by sticking two blobs of Blu Tack under the far end of the track.
4. Attach one end of a length of the string securely to the small mass and run the string through the pulley.
5. Attach the other end of the string securely to the motion car. The string should be long enough to allow the suspended mass to reach the ground when released as the car just reaches the pulley.
6. Roll the car back to a position at the far end of the track.
7. Start the ticker timer or motion sensor and release the car.
8. Measure the height from which the suspended mass falls in metres.
9. Calculate the final speed of the car just before it reaches the pulley using the ticker timer tape or data logger and record this in m/s. If using a ticker timer, the speed of the car can be calculated by dividing the distance between the two dots with the largest gap between them at the end of the tape (measured in metres) by 0.02 seconds.
10. Measure the mass of the system, i.e., the combined mass of the motion car and the suspended mass using the scales and record this in kilograms.
11. Calculate the increase in kinetic energy of the suspended mass and car in joules (J) as follows:

$$KE = \frac{1}{2}mv^2$$
$$= \frac{1}{2} \times mass\,(suspended\;mass + car) \times final\;speed^2$$

12. Calculate the decrease in gravitational potential energy of the suspended mass and car in joules (J) as follows:

$$GPE = mgh$$
$$= mass\,(suspended\;mass + car) \times 10 m/s^2 \times height\;that\;the\;suspended\;mass\;falls$$
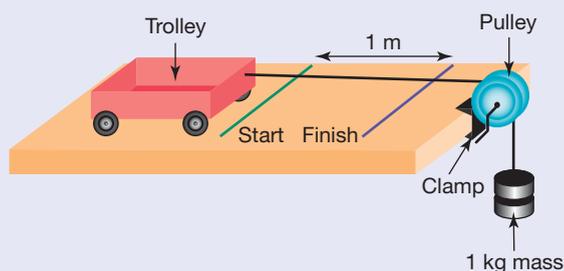
Results

Record the:
- height from which the suspended mass falls (m)
- final speed of the car (m/s)
- mass of the system (kg)
- increase in kinetic energy (J)
- decrease in gravitational potential energy (J).

ACTIVITY: PhET simulation — Energy skate park: Graphs

Access the **PhET simulation: Energy skate park** interactivity in the Resources panel. In the simulation, select the Energy Graph activity.
1. Simulate motion on a skate ramp with **no friction**. Pause the video and explain the variations in kinetic, potential, thermal and total energy as the skater rides the ramp. In your response, refer to energy being transferred and/or transformed.
2. Repeat the simulation, but this time add some friction to the ramp. How do the results compare to the situation without friction?

1.3 Activities

learnon

1.3 Quick quiz **on**	**1.3 Exercise**

Learning pathways

■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 3, 5	2, 6, 8, 9	4, 7, 10

Remember and understand

1. When you travel down a playground slide, the amount of kinetic energy that you gain on the way down is less than the amount of gravitational potential energy that you lose.
   a. **Explain** where the 'missing' energy goes.
   b. **Describe** what can be done to maximise the amount of your initial gravitational potential energy that is converted into your kinetic energy.
2. A girl on a trampoline is able to return to the same height after each bounce. **Explain** how this is achieved when the system of the girl and the trampoline is not really 100 per cent efficient.
3. Consider the kinetic energy of a tennis ball just before it bounces on a concrete surface.
   a. **Explain** what happens to the kinetic energy during the period of time when the ball is in contact with the ground.
   b. **Explain** what happens to the remaining energy in the ball as the ball bounces upwards.
4. **Outline** the law of conservation of energy. Include reference to closed systems in your response.

Apply and analyse

5. A student investigating the energy of a skateboarder in a half pipe records the data shown in the table. Fill in the missing values assuming that energy is not lost.

Position of skateboarder	Gravitational potential energy (J)	Kinetic energy (J)	Total energy (J)
Top of half pipe	600	0	
Part way down		200	600
Bottom of half pipe		600	
Part way up	300		
Top of half pipe			

6. A concrete brick of mass 1.2 kg falls off a wall 8.5 m high to the grass below.
   a. Use the law of conservation of energy to **calculate** the brick's kinetic energy just before it hits the ground.
   b. **Calculate** the brick's speed just before it hits the ground.
   c. What happens to the energy once the brick hits the ground? Use the terms energy transfer and/or transformation in your response.

7. When a tennis ball is bounced on the ground, it never returns to its original height.
   a. Does this break the law of conservation of energy? **Explain** your answer.
   b. Why has the ball not reached its original height after the bounce? **Explain** with the aid of an energy flow diagram.
   c. Will the ball have the same amount of gravitational potential energy when it reaches the maximum height of its path after the bounce, compared to when it was originally dropped? **Explain**.

Evaluate and create

8. Imagine riding your bike along a flat gravel road. If you brake suddenly, the bike eventually stops. It no longer has kinetic energy. However, the energy is not lost. **Describe** what happens to the kinetic energy.

9. A catapult like the one shown below was used by the Romans more than 2000 years ago to attack castles, cities and invading armies. The long arm was held in its usual vertical position with rope twisted around its base in what is known as a torsion bundle (shown below). The arm was pulled back towards the ground using a second rope so that the bucket could be loaded with a missile. This caused the torsion bundle to twist more tightly. When the arm was released, the torsion bundle quickly untwisted and it returned to its vertical position, releasing the missile from the bucket at high speed towards the target. The missiles fired included rocks, burning tar and even human corpses. Use flow diagrams to show:
   a. the energy transfers that took place during the loading and firing of the missile
   b. the energy transformations that took place from the time that the missile was loaded until the time that the missile found its target.

Torsion bundle (overhead view)

Torsion bundle

Base of catapult arm

A Roman catapult

Torsion bundle
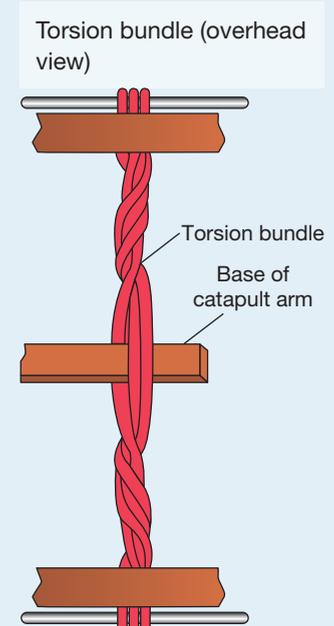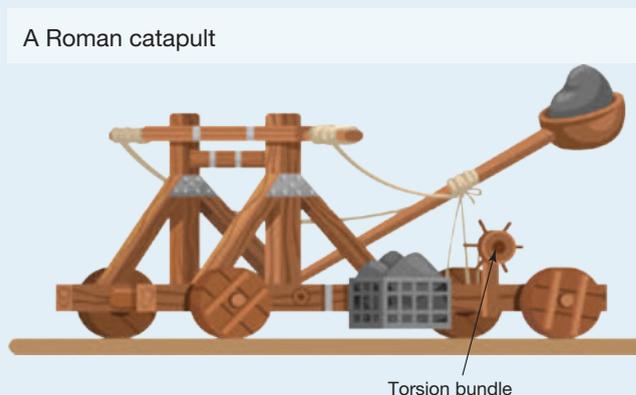
10. Consider a Newton's cradle in motion.

    a. Identify the energy transformation and transfer taking place as the balls swing and collide.
    b. Over time you would expect the cradle to come to a stop. Where does the energy go?
    c. Explain how kinetic energy could be conserved when the balls collide, even though there is an uneven number of balls swinging before and after each collision.

LESSON 1.4 Efficiency in energy transfers and transformations

LEARNING INTENTION

In this lesson you will investigate the efficiency of energy transfers.

1.4.1 Energy efficiency

Energy transfers and transformations are common in most daily activities. As we walk along the ground, chemical energy in the food we eat is transformed into the kinetic energy of our motion as well as heat energy for our body through a process called metabolism. Jumping on a trampoline involves a continual conversion of elastic potential energy to kinetic energy and gravitational potential energy and back again.

The transformation of energy often has some unintended consequences. Electrical appliances transform electrical energy into other useful forms of energy, but some of the original electrical energy is converted to unwanted forms of energy because of limitations of the technology in that appliance. For example, when an electrical light is used, the electrical energy is transformed to light and some heat. The light energy is useful to us whereas heat energy is not and is transferred to the surroundings.

Table 1.1 identifies examples of the energy transformations that take place in some common electrical appliances.

TABLE 1.1 Energy transformations in common electrical appliances

Device	Original form of energy	Transformed to useful energy as …	Transformed to wasted energy as …
Microwave oven	Electrical energy	heat (thermal) energy of the food	heating air in the oven and the food container
Gas cooktop	Chemical energy	heat (thermal) energy of the saucepan	heating air, producing light and sound
Car engine	Chemical energy	kinetic energy of the car	heating moving parts due to friction, and as sound
Desktop computer	Electrical energy	light and sound energy	heating the circuitry and surrounding air

1.4.2 Calculating energy efficiency

The efficiency of a light globe, cooktop or any other energy-converting device is a measure of its ability to provide useful energy.

KEY IDEAS

Efficiency is usually expressed as a percentage:

$$\text{Efficiency} = \frac{\text{useful energy output (J)}}{\text{total energy input (J)}} \times 100$$

Sankey diagrams

Since we know that most devices are not 100 per cent efficient, we can illustrate how efficient a device is using a **Sankey diagram**. In a Sankey diagram, the flow of energy in an energy transformation is represented using arrows and the thickness of an arrow indicates the proportion of energy converted to each form. Useful energy produced is represented by horizontal arrows, while wasted forms of energy are represented by downwards-facing arrows. Figure 1.15 shows the features of a Sankey diagram and figure 1.16 shows an example Sankey diagram for the flow of energy in a television.

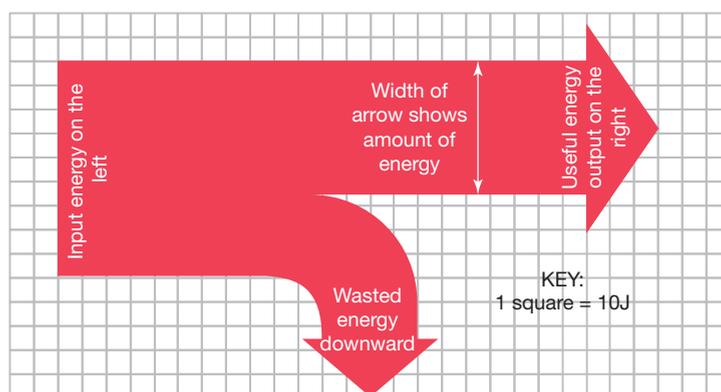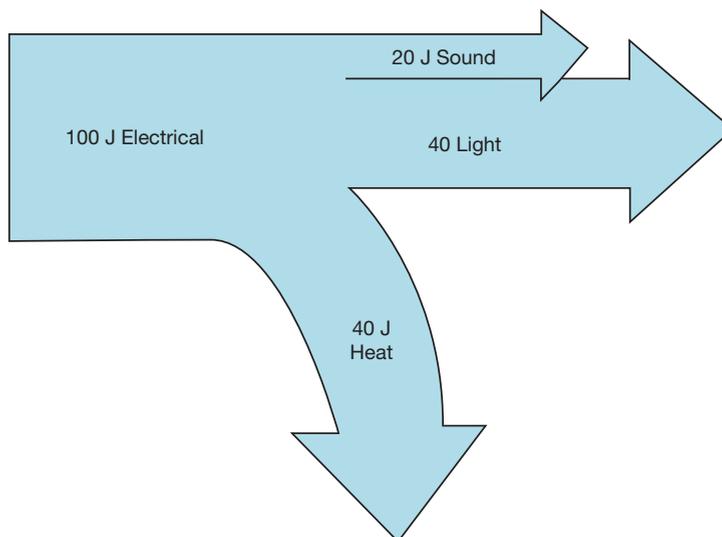**FIGURE 1.15** Features of a Sankey diagram

FIGURE 1.16 Sankey diagram for a television

Scientists and engineers are constantly developing more energy-efficient appliances. A good example is the development of more efficient lighting for the home and workplace. In Australia, lighting accounts for around 10 per cent of the average household electricity use. For many years, the light globes used in homes and in the workplace were incandescent globes. In these globes, electricity passes through a thin filament, generally made of tungsten metal, causing it to glow white-hot. The light produced is a useful form of energy, but the considerable amount of heat produced is a wasted form of energy.

Today, more energy-efficient alternatives include compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs). LEDs in particular use much less electrical energy to produce the same amount of light as incandescent globes.

LEDs are miniature electrical components that produce light energy very efficiently with minimal heat produced. One individual LED does not produce as much light as one CFL or one incandescent globe, so many small LEDs are often together for lighting purposes.
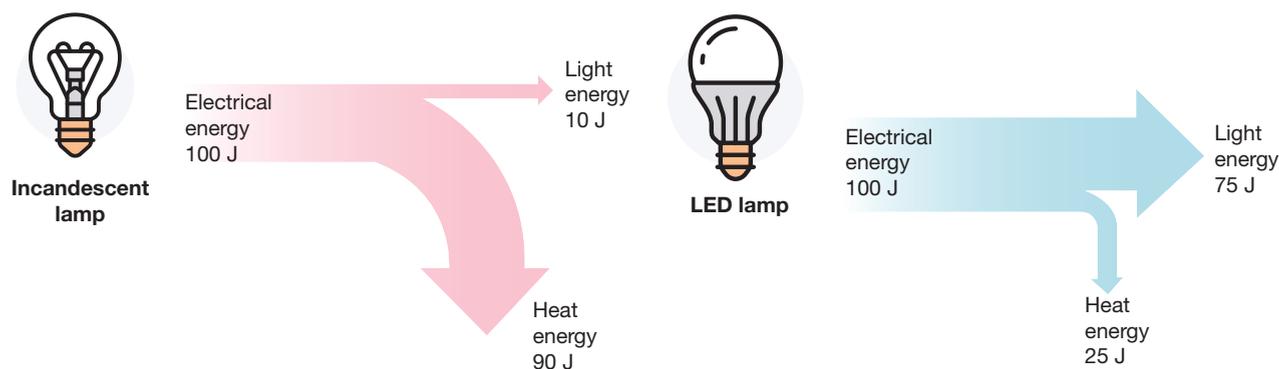
FIGURE 1.17 An incandescent light globe relies on a hot filament to produce light, but it also produces considerable wasted heat energy.

FIGURE 1.18 a. A single LED and **b.** a torch incorporating several LEDs

a.

b.

FIGURE 1.19 The energy efficiency of incandescent lights and LEDs can be represented with a Sankey diagram.

Incandescent lamp

Electrical energy 100 J

Light energy 10 J

Heat energy 90 J

LED lamp

Electrical energy 100 J

Light energy 75 J

Heat energy 25 J

1.4.3 Improving energy efficiency

While scientists and engineers are constantly developing more energy-efficient appliances, architects are designing homes that maximises energy efficiency. This means designing features to keep a house warm in winter and cool in summer to reduce the use of appliances for heating and cooling.

Minimising the need to heat or cool your home not only reduces your energy bills but also conserves **fossil fuels** and reduces greenhouse gas emissions.

Controlling heat loss

In winter, heat tends to escape from a house by conduction, convection and radiation. **Convection** currents carry warm air up a room and to the ceilings. **Conduction** transfers heat through these surfaces where it is radiated to the outside.

Heat loss by conduction through the ceiling and roof is reduced by insulation. Fibreglass batts are often used in insulation as they can reduce heat loss by up to 80 per cent. This is because air is a poor conductor and so air trapped between the glass fibres in the batt prevents heat escaping. Heat transfer by **radiation** can also be reduced by installing shiny foil in the roof to reflect radiant heat from the sun.

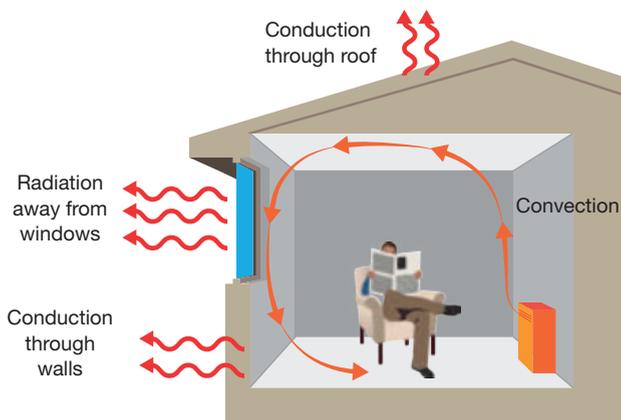FIGURE 1.20 The transfer of heat in a house by conduction, convection and radiation

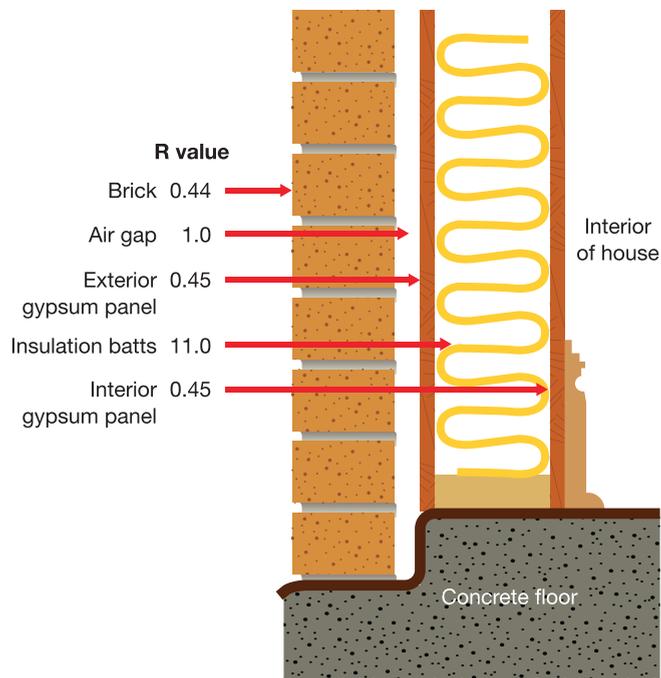FIGURE 1.21 Installing insulation batts in the roof of a house

The conduction of heat out through windows can be reduced by installing double-glazed windows, which consist of two layers of glass separated by a narrow gap of air. Curtains are also useful in that they trap a still layer of air between them and the window. Reducing draughts around doors and windows can minimise heat lost as warm air escapes.

FIGURE 1.22 Percentage of heat loss in various parts of an uninsulated house
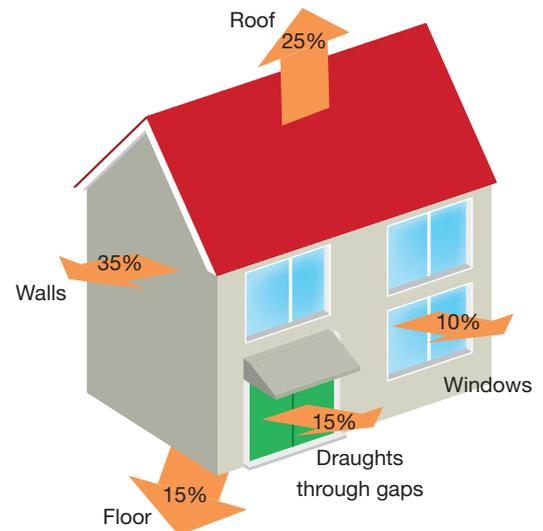
Insulating walls can also reduce heat loss. Double-brick homes have a cavity between the two layers of brick, which minimises heat escaping. Brick-veneer homes require insulation in the cavity to improve their energy efficiency. This may involve adding fibreglass batts between the layer of external brick and internal panels. Concrete floors provide good insulation, which can be enhanced further by installing carpet and an underlay.

FIGURE 1.23 Features used to reduce the heat loss in a brick-veneer home. The R value for each feature is a measure of the resistance to heat flow and so is an indication of its insulating ability.

R value
Brick 0.44
Air gap 1.0
Exterior gypsum panel 0.45
Insulation batts 11.0
Interior gypsum panel 0.45
Interior of house
Concrete floor

Natural heating and cooling

Designing a house that takes into account the position of the Sun can offer substantial benefits when heating is required in winter and cooling in summer. Large eaves around the roofline mean that in the summer, when the Sun is higher in the sky, little direct sunlight strikes windows and the rest of the home, while in winter, when the Sun is lower in the sky, sunlight is angled below the eaves, directly warming the home. Planting deciduous trees near north-facing windows allows heat to radiate through to the house in winter but not in summer. External shutters or louvres can achieve the same purpose.

FIGURE 1.24 Large eaves on the north-facing side of a house keep the sun out in summer but not in winter.

Summer sun
Winter sun
Large eaves
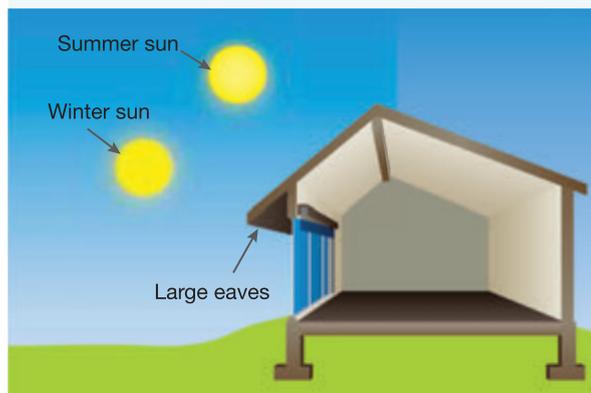
DISCUSSION

Discuss in pairs or a small group, features of your home that help to:
- retain heat in winter
- keep your home cooler in summer.

WORKING SCIENTIFICALLY: An energy-efficient house

Aim: To design an energy-efficient house

Use the principles of heat transfer and energy efficiency to design a house that is cool in summer and warm in winter.

Your design, drawn on a sheet of cardboard, should include:
- the type of construction, including the choice of building materials used for the roof, walls and floor
- how the house is positioned
- design features such as the size and location of windows, and the size of eaves
- soft furnishings, such as curtains
- landscaping, including the type of trees.

Label each energy-saving feature included in your design and, for each of these features, write a short reason for including it. This could be done underneath each label or listed in a separate section underneath your house design.

WS **SC5-WS-07** Selects suitable problem-solving strategies and evaluates proposed solutions to identified problems

## DATA SCIENCE: Data science 2 in context

Insulating your house

When designing and building a new home, energy efficiency is an important consideration. The better your home is insulated, the less cost is involved in heating and cooling. But is good insulation worth the expense?

FIGURE 1.25 Wall insulation improves the energy efficiency of a home.

FIGURE 1.26 Window glazing options
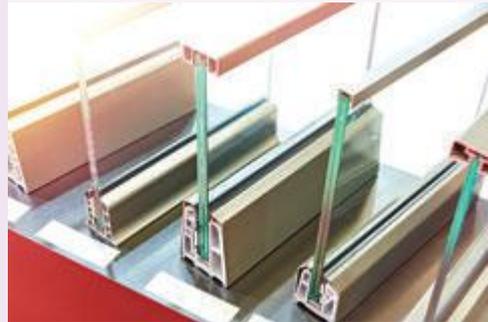
Investigate data available on the benefits of better insulation versus the cost. Focus on each of the of the following aspects:
- windows: glazing options, single versus double glazing
- walls: double brick versus brick veneer versus plasterboard
- roof insulation: insulation material and thickness available.

In your analysis, examine the options available, the insulating properties claimed and the cost of each option if available. Then evaluate the data and decide which options you would include. If a glazed window provides double the insulation but costs only 30 per cent more, then you might decide that the extra expense is worthwhile.

The insulating properties of a material are usually measured using an R rating: the higher the R rating, the better the insulation.

For example, roof batt brand A has an R value of 2.7 and costs $100 per pack, while roof batt brand B has an R value of 2.0 and costs $84 per pack.

Cost comparison: $\dfrac{\text{Brand A}}{\text{Brand B}} = \dfrac{\$100}{\$84} = 1.2$

Therefore, brand A is 1.2 times the cost of brand B.

Insulation comparison: $\dfrac{\text{Brand A}}{\text{Brand B}} = \dfrac{R\,2.7}{R\,20} \times 100 = 1.4$

Therefore, brand A gives 1.4 times the level of insulation of brand B.

So in this example, you might conclude that the additional expense of using brand A is warranted.

1.4 Activities

learnon

1.4 Quick quiz on	**1.4 Exercise**

Learning pathways

■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 5, 6	2, 3, 8, 10	4, 7, 9, 11

Remember and understand

1. **MC** Which of the following is most likely to be an unwanted by-product when using a mobile phone?
   A. Heat (thermal) energy
   B. Light (radiant) energy
   C. Sound energy
   D. Chemical energy
2. **Explain** how a traditional incandescent light globe works.
3. **Identify** two energy-efficient alternatives for lighting.
4. **Explain** why fibreglass batts are effective insulators.
5. **Explain** how foil placed in the roof improves the energy efficiency of a house.

Apply and analyse

6. Complete the table, listing the useful energy and the wasted energy converted by each of the devices.

Device	Source of energy	Energy usefully converted to:	Forms of energy wasted
A torch			
A wind-up toy			
A pop-up toaster			
A gas cooktop			
A car engine			

7. **Calculate** the efficiency of a blender that converts 200 J of electrical energy to 120 J of kinetic energy and 80 J as heat per second.
8. **Explain** why compact fluorescent lamps should not be placed in glass recycling bins.
9. Homeowners often install roof ventilation. **Explain** how this improves the energy efficiency of a house.

Evaluate and create

10. The sun is angled approximately 35° from the horizontal in the winter and 80° in the summer. Draw a scale diagram of a house and windows to illustrate how eaves can maximise the use of the sun in both summer and winter.
11. Use a Sankey diagram to represent the energy conversions in a hairdryer in which, for every 300 J of electrical energy, 100 J is transformed to thermal energy, 50 J to sound energy and 150 J to kinetic energy.

LESSON 1.5 Using electrical energy

LEARNING INTENTION

In this lesson you will identify the elements of a complete circuit, and construct circuits and draw circuit diagrams that contain several components to show the flow of electricity through a complete circuit.

1.5.1 Electric circuits

When you switch on a light, a television, a computer or a mobile phone, you are completing a pathway along which electrical energy flows. The pathway is called an **electric circuit**. All electric circuits consist of three essential items:

- a **power supply**, which provides the electrical energy
- a **load** (or loads), in which electrical energy is converted into other useful forms of energy
- a **conducting path**, which allows electric charge to flow around the circuit.

1.5.2 Circuit diagrams: a common language

Electric circuits are often complex and so the electrical components and their arrangement are represented using a **circuit diagram**. The circuit diagram for a torch is quite simple.

The batteries (cells) used in torches and many other devices store chemical (potential) energy. The chemical energy is transformed into electrical (kinetic) energy due to a **chemical reaction** taking place inside the batteries.

Some household appliances do not rely on batteries but rather receive electrical energy supplied by transmission lines or home solar panels via a power outlet.

In electric circuits, electric charges travel around the circuit, gaining electrical energy from a power source and converting it to other useful forms in a load. A load is a general term for any device or appliance that converts electrical energy to a useful form. Loads include light globes, electric ovens and any appliance connected to a power outlet.

The commonly used symbols for a range of circuit components are illustrated in figure 1.28.

1.5.3 Series and parallel circuits

There are two ways that components can be connected in a circuit, series and parallel. In a **series circuit** the components are connected one after another in a row so electric charges travel through each component in turn.

In a **parallel circuit** the components are connected in separate branches, so the flow of electric charges is distributed between each of the branches.
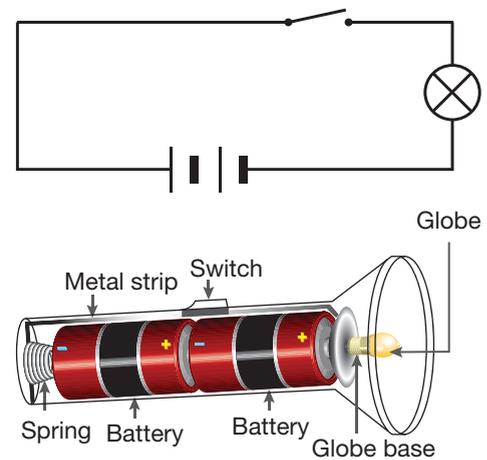
FIGURE 1.27 Circuit diagram for a torch

Globe

Metal strip Switch

Spring Battery Battery Globe base

FIGURE 1.28 Symbols for common circuit components

Conductor (lead)

Cell

Battery or DC power supply

AC power supply

Light globe

Leads connected

Resistor (fixed)

Variable resistor (rheostat)

Switch

Ammeter
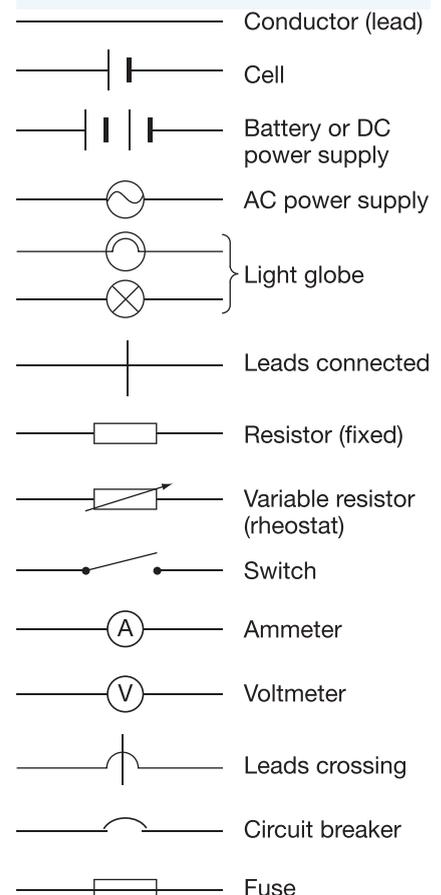
Voltmeter

Leads crossing

Circuit breaker

Fuse

FIGURE 1.29 Series circuit: electrical components are connected one after another. Electric charges flow through each light globe.
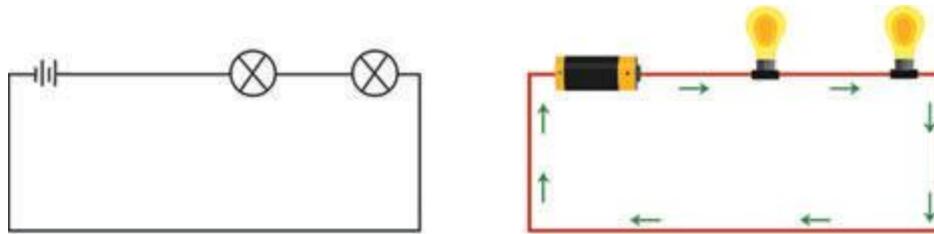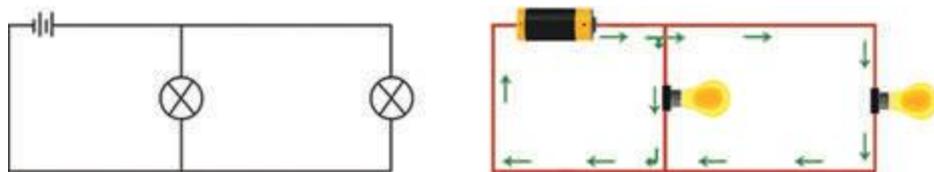
FIGURE 1.30 Parallel circuit: electrical components are connected in separate branches. The flow of electric charge is shared between the branches.

1.5.4 Circuits in the home

Electricity is provided to homes through wires covered with plastic insulation. The wire that carries electricity to your house is called the **active** (often called the **live**) wire. A second wire, called the **neutral** wire, completes the electrical circuit from your home to the electrical power grid that supplies your home and neighbouring streets.

FIGURE 1.31 Active and neutral wires from transmission lines connect your home to the electricity grid.
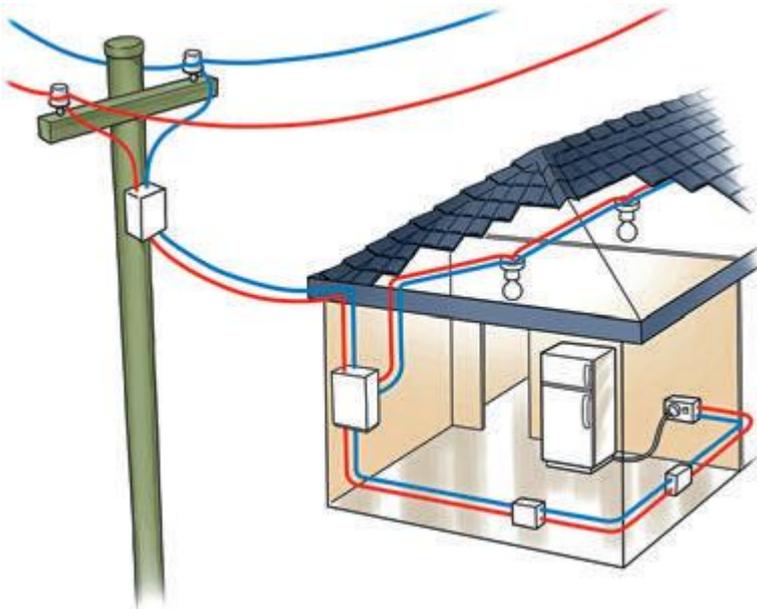
FIGURE 1.32 The power cords that supply electrical appliances contain wires that have a double layer of insulation to prevent users from coming into contact with the wires. There is a plastic coating around each wire as well as a plastic cord around the two wires.

1.5.5 Monitoring electricity use

The electrical circuit supplying your home first passes through the electricity meter in the meter box to monitor your energy usage. From the meter box your home's main electric circuit splits into numerous parallel branches, each supplying different sections of your house. Some appliances such as hot water heaters and cooking stoves use particularly high electrical energy and so may be on their own parallel branch. Often each room would be supplied with electricity by a separate parallel circuit, and within each room the lights may be on a separate branch to the power points. The advantage of this is that if a light blows in one room it won't affect the power points in that room or the lights in other rooms.

The separate circuits for each area of your home can be seen in the meter box. Each parallel circuit will contain a safety device called a **circuit breaker** which protects each circuit from a **short circuit**, a surge of electrical current which can cause conducting wires to overheat and cause a fire. Older homes may use **fuses** which are made from a thin wire that heats up quickly when an unusually high current passes through it, causing the fuse wire to melt and break the circuit.

FIGURE 1.33 An electrical meter and circuit breakers

INVESTIGATION 1.4

Series and parallel circuits

Aim

**To construct and compare series and parallel circuits**

Materials

- DC power supply
- 3 identical 12-volt light globes and holder
- 6 connecting leads with alligator clips or banana plugs

Method

Series circuits
1. Create a simple circuit by connecting a light globe to the DC power supply and switch it to 6 volts.
2. Switch the power on and observe the brightness of the light. Record the brightness on a scale of 1 to 4, with 1 being dim and 4 being very bright.
3. Switch the power off and connect a second globe in series with the first. Switch the power on and record the brightness of the 2 lights using the same scale.
4. Repeat step 3 with a third globe added in series. Your circuit should finish looking as follows:
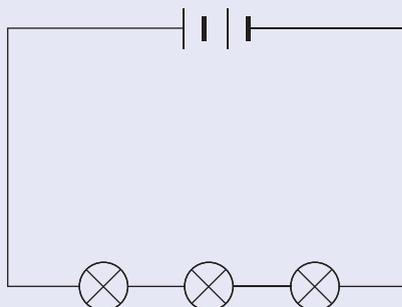
5. Unscrew one of the globes from its socket. **Warning: the globe may be hot!** Observe what happens to the other lights.

Parallel circuits

6. Dismantle your previous circuit and recommence with a simple circuit containing a light globe connected to the DC power supply and switch it to 6 Volts. Switch the power on and observe the brightness of the light. Once again, record the brightness on a scale of 1 to 4, with 1 being dim and 4 being very bright.
7. Switch the power off and connect a second globe parallel to the first. Switch the power on and record the brightness of the 2 lights using the same scale.
8. Repeat step 3 with a third globe added parallel to the first two. Your circuit should finish looking as follows:

Current splits

Current rejoins
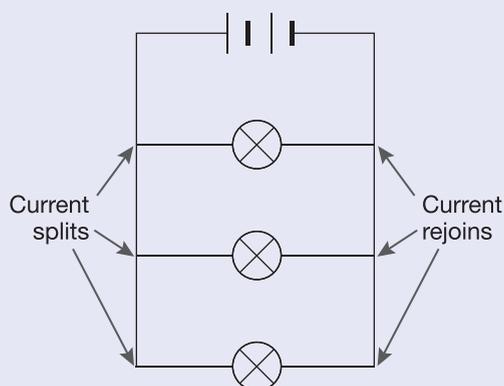
9. Unscrew one of the globes from its socket. **Warning: the globe may be hot!** Observe what happens to the other lights.

Results

1. Record, in a suitable table using a scale of 1 to 4, the brightness of the globes with:
   • 1 globe, 2 globes in series, 3 globes in series
   • 1 globe, 2 globes parallel, 3 globes parallel.
2. Record your observations when one of the globes is disconnected in a series and a parallel circuit.

Discussion

1. Compare any changes to the brightness of globes when connected in series vs parallel
2. If brightness is a measure of the rate at which radiant (light) energy is emitted, in which circuit configuration are you maximising the output of energy?
3. Which circuit configuration is most appropriate for the lights in a living room? Explain your response

Conclusion

Refer to your findings to compare series and parallel circuits.

INVESTIGATION 1.5

Modelling a fuse

Aim

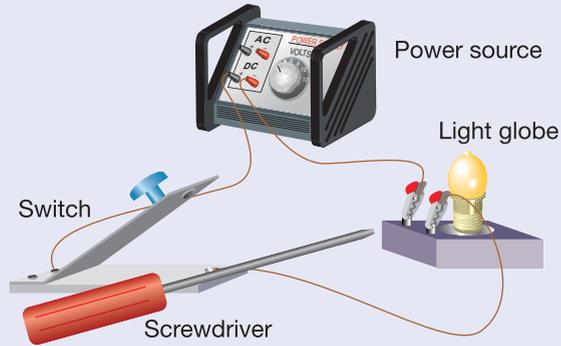**To demonstrate how an electric fuse works**

Materials

• DC power source
• 4 wire leads with an alligator clip at one end
• light globe and holder
• switch
• rubber stopper
• heat mat

- fine nichrome wire or strands of steel wool
- screwdriver
- 2 metal pins

Method

1. Connect the circuit as shown on the right. Set the voltage to 2 volts.
2. Close the switch, then carefully place a screwdriver across the alligator clips as shown in the diagram to bypass the light globe and create a short circuit. Quickly observe any changes and remove the screwdriver again. Record your observations.

Power source

Light globe

Switch

Screwdriver

3. Create a simple fuse and incorporate it into your circuit as shown below right.

Thin wire

Heat mat

Pins

Power source

Rubber stopper

Light globe

Switch
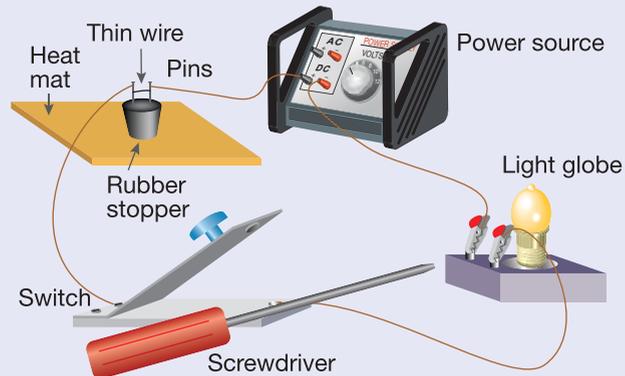
Screwdriver

4. Place the screwdriver across the alligator clips as before to bypass the globe.
5. Record any changes. If no changes are observed, increase the voltage and repeat the experiment.

Results

Explain what you observed when a short circuit was first created using the screwdriver

Discussion

1. Explain what you observed when a short circuit was first created using the screwdriver
2. Explain how the fuse worked.
3. Outline the essential feature of a fuse wire.

Conclusion

Explain how a fuse works and how it can protect a home.

1.5 Activities

Learning pathways

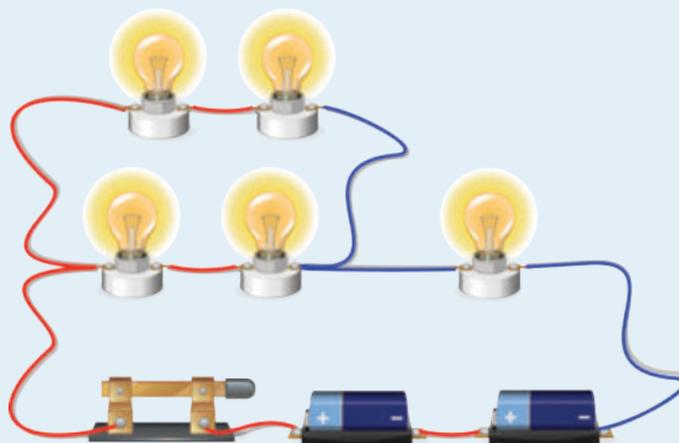| ■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 4, 7	2, 5, 8	3, 6, 9

Remember and understand

1. Draw a circuit diagram showing:
   a. a battery connected to light globes and a switch in series
   b. a battery connected to two light globes connected parallel.
2. Draw a circuit diagram for the following circuit:

3. A single light globe is connected to a power supply. **Predict** whether the brightness of this light globe will increase, decrease or remain the same when:
   a. an identical light globe is connected in series with it
   b. an identical light globe is connected parallel to it.
4. **Explain** two advantages of connecting the power outlets in a room of your home parallel to one another.
5. **Outline** how circuit breakers are an essential safety feature of home electrical circuits.
6. What type of appliances require an earth wire and a 3-pin plug? Why?

Apply and analyse

7. **Examine** the circuit below.
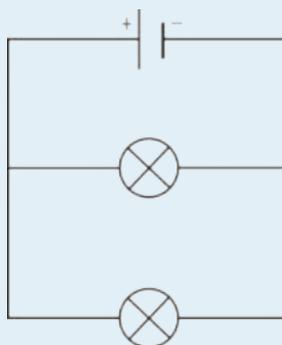
   Redraw the circuit diagram, adding a switch that turns both light globes on or off at the same time.

8. In the circuit diagram below, **predict** which of the light globes (A, B or C) will continue to glow if:
   a. the filament in globe A breaks
   b. the filament in globe B breaks
   c. the filament in globe C breaks
   d. a wire lead is connected between the points P and Q
   e. a connecting lead is connected between the points P and R
   f. a connecting lead is connected between the points P and S.
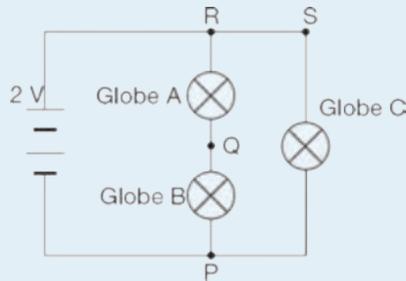
Evaluate and create

9. Draw a circuit diagram for your open plan living room supplying 2 downlights that switch on simultaneously in your TV viewing area and another 4 downlights that switch on simultaneously in your dining area. A single circuit breaker protects all the living room light circuits.

LESSON 1.6 Electric circuits

LEARNING INTENTION

In this lesson you will measure and compare the voltage and current at different points in series and parallel circuits. You will also conduct an investigation to determine the relationship between voltage (V), current (I) and resistance (R), as described by Ohm's law ($V = IR$).

1.6.1 Current and voltage

To better understand the nature of the electricity in circuits, it is important to grasp the concepts of electric current, voltage and resistance.

When a torch switch is clicked on, the light comes to life — what's happening? Pushing the button closes the switch in the torch circuit. This provides a complete (closed) circuit through which electric charges, called electrons, can flow. This flow of charge is called an **electric current** (symbol I). Electric current is measured in **amperes (A)** or amps for short, named after André Ampère (1775–1836), a French physicist and mathematician who is generally credited as one of the main discoverers of electromagnetism.

There are billions of electrons travelling around a circuit, each carrying an extremely small charge. If we were to quantify electric current in terms of individual electrons we would need to quote very large numbers indeed. Instead, scientists refer to the number of **coulombs** of charge flowing through a circuit. It's a little like referring to eggs in dozens rather than individually. A coulomb is equivalent to the charge carried by 6.2×10^{18} electrons. Consequently, a current of 1 ampere is equivalent to one coulomb of charge (or 6.2×10^{18} electrons) travelling around the circuit per second, so 2 amperes of current = 2 coulombs per second and so on.

FIGURE 1.34 Current and electron flow in a circuit
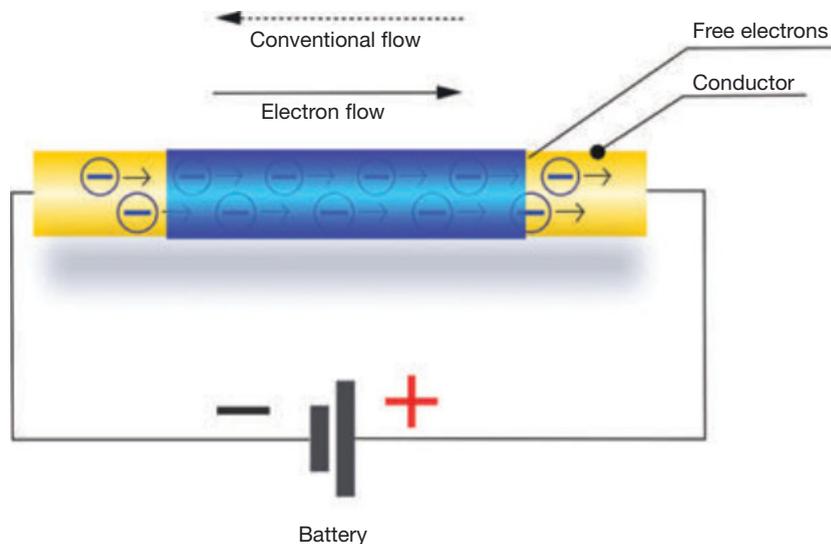
The direction of **current flow** in a circuit is from the positive (red) terminal to the negative (black) terminal of a power source. This was the convention chosen when electricity was first discovered in the 1700s. Today we know that negatively charged electrons actually move through the circuit. This **electron flow** is in the opposite direction to the electric current. Regardless, when describing the direction of electric current, conventional current is used.

Voltage (V) is a measure of the electrical energy carried by the charges in a circuit. Voltage is measured in **volts (V)** and named after Alessandro Volta (1745–1827), an Italian physicist renowned for the development of the first battery in the 1800s.

Voltage is sometimes referred to as potential difference because it measures the change in the electrical potential energy of the charges as they move around a circuit. For example, a 3-volt torch battery supplies 3 joules of energy per coulomb of charge in the circuit of the torch.

Electric charges gain electrical potential energy as they pass through the power supply in a circuit. They lose the same amount of electrical energy as they move through the components of the circuit and this energy is transformed to other forms. This means that the voltage gained across the terminals of the power supply is equal to the total voltage drop across the rest of the circuit. The wire leads connecting each of the circuit components are good **conductors** of electricity and so little or no voltage drop occurs through them.

Components like light globes in an electrical circuit act as loads. It is in each of the loads that the electrical energy carried by the charges is transformed into other forms. In the example of a light globe, electrical energy is transformed into light and heat as the filament, a coiled tungsten wire, glows brightly when it gets hot. In a hairdryer there are two loads: a heater and a fan.

KEY IDEAS

Electric current is the rate at which electric charges flow through a circuit, measured in amperes (A). In a 1 A current, this means that 1 coulomb of charge travels through the circuit per second.

Voltage (V), also referred to as **potential difference**, is measured in volts (V). It is the amount of potential energy gained by electric charges from a power source or lost by the charges while travelling through the components of a circuit.

1.6.2 Resistance

Resistance (*R*) is a measure of how much a load restricts the flow of current. Resistance is measured in ohms (Ω), named after Georg Ohm (1789–1854), a German physicist who first described the relationship between the voltage, current and resistance in an electrical circuit. In an efficient electric circuit, most of the electrical energy provided by the power supply is transformed in the loads. Little of the electrical energy is transformed in the conducting wires because they are made of metals like copper which have little resistance.

TABLE 1.2 A summary of variables associated with electric circuits and their units of measurement

Variable		Unit	
Name	Symbol	Name	Symbol
Voltage	*V*	Volts	V
Current	*I*	Amperes	A
Resistance	*R*	Ohms	Ω

1.6.3 Useful analogies

It is often difficult to visualise the concept of electricity in which charges travelling through a conductor pick up and drop off electrical energy. A typical misconception is that the electric charges are provided by the power source to travel through the circuit. It is important to understand that the charges travelling through an electric circuit are present in the conducting wires already. A circuit's power source merely provides these charges with the energy to travel around the circuit.

A useful analogy or comparison to clarify this concept is water travelling in your water pipes. When you turn on a tap, you do not need to wait for the water to travel from the reservoir to the tap. Rather, the water is already in the pipes under pressure. The water pressure in the pipe can be compared to the voltage causing the electric current to flow. Turning the tap on merely releases the water already in the system, just like closing the switch in an electric circuit.

INVESTIGATION 1.6

Modelling an electric current

Aim

To model an electric current

Materials

- long rubber hose
- stopwatch

Method

1. Turn off the lights in the classroom, then turn the light switch back on, and time how long it takes for the electrical current to reach the lights. Record the time taken.
2. Attach the rubber hose to a tap and run it to a sink as far away as possible.
3. Turn the tap on and time how long it takes for water to reach the sink. Record the time taken.
4. Repeat this experiment, but this time start with the hose already full of water.

Results

In a suitable table, record the time values in your experiment.

▶

Discussion

1. Which is the better analogy for an electrical current, the current of water when the hose is full of water or when the hose is empty? Explain why.
2. In this analogy, what does each of the following represent in an electric circuit?
    a. The water
    b. The hose
    c. The tap
3. What aspect of an electrical circuit does this analogy not represent well?

Conclusion

How does this experiment serve as an analogy for an electric current?

## 1.6.4 Measuring current and voltage

Using an ammeter

A current of water in a river can be measured by determining the volume of water that passes a particular point every second. Similarly, the size of the electric current in a circuit can be measured by determining the amount of electric charge passing a particular point in an electrical circuit every second.

An **ammeter** is used to measure the size of electric current flowing in an electrical circuit. An ammeter measures electric current in amperes (A). 1 ampere is equal to 1 coulomb of charge travelling through the circuit per second.

Sensitive ammeters can measure currents as small as thousandths of an ampere (milli-amperes, mA), or even millionths of an ampere (micro-amperes, μA).

Many ammeters used in school laboratories have one black, negative terminal and two or more red, positive terminals.

FIGURE 1.35 Circuit diagram showing how an ammeter is connected to measure the electric current through a light globe
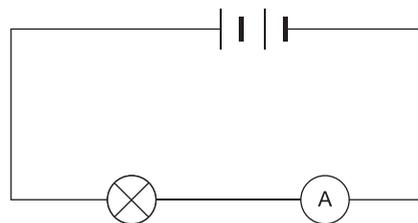
KEY IDEAS

- The positive terminal of the ammeter should always be connected **in series** so that it is closer to the positive terminal of the power supply than the negative terminal of the power supply.
- Always read an ammeter from directly in front. The error obtained by not reading from directly in front is called a **parallax error**.
- If the ammeter has more than one red terminal:
    - use the positive terminal with the highest current value first. If the measured current in your circuit is too small to be detected on this scale, change the connection to the positive terminal with a smaller current value.
    - read the scale that matches the positive terminal connected.
- An ammeter is represented by the symbol ──(A)──.

Using a voltmeter

A **voltmeter** is used to measure the voltage gain across the terminals of a power supply or the voltage drop across a load in an electric circuit. Voltage is measured in volts (V).

Like ammeters, most voltmeters used in school laboratories have one (black) negative terminal and two or more (red) positive terminals.

KEY IDEAS

- A voltmeter should be connected in **parallel** with the component of the circuit across which the voltage is being measured. The positive terminal should always be connected so that it is closer to the positive terminal of the power supply than the negative terminal of the power supply.
- Use the positive terminal with the highest voltage value first. If the measured voltage in the circuit is too small to be detected on this scale, change the connection to the positive terminal to a smaller voltage value.
- Read the scale that matches the positive terminal connected.
- Always read a voltmeter from directly in front to avoid parallax error.
- A voltmeter is represented by the symbol ——(V)——
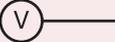
FIGURE 1.36 Circuit diagram showing how a voltmeter is connected to measure the voltage across a light globe
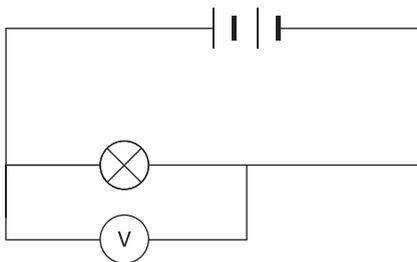
FIGURE 1.37 A voltmeter is used to measure voltage (potential difference) while an ammeter measures electric current.

INVESTIGATION 1.7

Current and voltage in a circuit

Aim

To investigate the electric current and voltage at various points in a circuit

Materials

- DC power supply (set to 6 volts)
- 12-volt light globe and holder
- 4 connecting leads with alligator clips or banana plugs
- switch
- ammeter
- voltmeter

1. Set up the circuit shown in the diagram. Make a copy of the table below in which to record your measurements.
2. With the switch open, connect the ammeter in series by connecting it at each of the points A, B, C, D and E to measure the electric current at those points. Record your measurements in the table.
3. With the switch open, measure the voltage across each of the following components by connecting the voltmeter parallel to:
   a. the power supply (across points A and E)
   b. the light globe (across points B and C)
   c. the switch (across points C and D)
   d. one of the connecting wires (across points A and B).
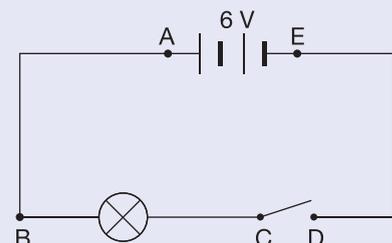
4. Close the switch.
5. Repeat your measurements of electric current at each of the points A, B, C, D and E using the ammeter.
6. Repeat your measurements of voltage across the power supply, the light globe, the switch and the connecting wire using the voltmeter.

Results

Enter the data from your experiment in a table like the one below.

		Using the ammeter		Using the voltmeter	
	Location in circuit	Current (A)	Component	Voltage (V)
Switch open	A		Power supply	
	B		Light globe	
	C		Switch	
	D		Connecting wire (A–B)	
	E			
Switch closed	A		Power supply	
	B		Light globe	
	C		Switch	
	D		Connecting wire (A–B)	
	E			

Discussion

1. Compare the electric current when the switch is opened to when it is closed.
2. Were there any differences in the size of electric current at each of the five points when the switch was closed? Explain.
3. Across which parts of the circuit were there significant voltage drops? Explain.
4. How does the voltage across the terminals of the power supply compare with the voltage across the light globe when the switch is closed? Explain.
5. Where is most of the electrical energy provided by the power supply used?

Conclusion

Refer to your findings to outline the current and voltage changes at various points throughout a circuit.

1.6.5 The relationship between current, voltage and resistance

The negatively charged electrons moving in an electric circuit must make their way around the atoms in the connecting leads and components that make up the circuit. Electrical resistance is a measure of how difficult it is for electrons to flow through part of a circuit. The resistance to the flow of electric charge limits the electric current, just as the resistance due to a crowded corridor limits the number of students who can pass through in a given time interval. Electrical resistance also determines how much electrical energy is lost through transformation to heat, light etc. by the electric charges as they move through a circuit.

Conductors have very little resistance. They allow large electric currents to flow with little loss of energy. **Insulators** have a very large electrical resistance. They allow very little electric current to flow.

In 1827, a German physicist, Georg Ohm, discovered that the electric current in metallic conductors was proportional to the voltage drop across the conductor. That is, if the voltage was doubled, the current also doubled. If the voltage was tripled, the current tripled. This relationship is known as **Ohm's law**.

FIGURE 1.38 Problems involving Ohm's law can be using this triangle. Place your finger over the variable that you wish to calculate.

$$V = I \times R$$

$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$
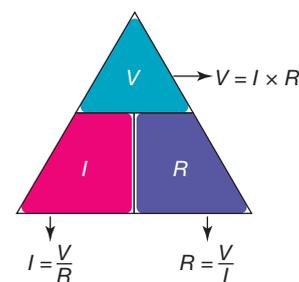
Ohm's law is often defined by the equation:

$$R = \frac{V}{I}$$
$$\therefore V = IR$$

Electrical components that obey Ohm's law have a fixed resistance value and are said to be ohmic. The fine filament in a light globe is not ohmic as its resistance increases as it heats up. Good conductors are ohmic materials if their temperature remains fairly constant.

One way of working out whether a material is ohmic is to draw a graph of voltage versus electric current for a circuit.

If the material is ohmic, a graph of V versus I yields a straight line because the resistance is constant.

SAMPLE PROBLEM 3 Calculating resistance

A torch globe carries an electric current of 0.2 A with a voltage drop of 3.0 volts. Calculate the resistance of the globe.

THINK	WRITE
1. Apply Ohm's law to calculate the resistance.	Ohm's law: $V = IR$
2. Rearrange the equation to solve for resistance.	$R = \dfrac{V}{I}$
3. Substitute the values for voltage and current.	$R = \dfrac{3.0\text{ V}}{0.2\text{ A}}$
4. Solve for the resistance.	$= 15\text{ A}$

INVESTIGATION 1.8

Calculating resistance

Aim

To investigate the relationship between voltage and current in an electric circuit and to calculate the resistance of a light globe using Ohm's law

Materials

- DC power supply
- 12-volt light globe and holder
- 6 connecting leads with alligator clips or banana plugs
- switch
- ammeter
- voltmeter

Method

1. Set up the circuit shown in the diagram and leave the switch open.
2. Construct the table provided below to record your measurements.
3. Set the power supply to 2 volts. Close the switch and quickly read the meters, recording the electric current and voltage drop in your table. Ensure that the electric current is recorded in amperes (not milliamperes).
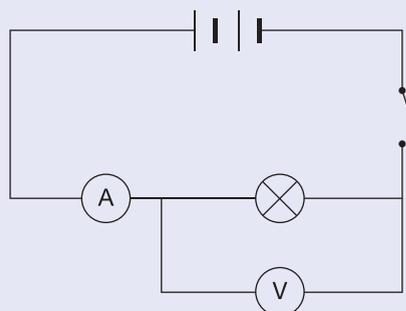
4. Repeat the experiment with the power supply set to 4, 6, 8, 10 and 12 volts, each time quickly measuring and recording the electric current and voltage displayed on the meters.

Power supply setting (V)	Electric current through the globe (A)	Voltage drop across the globe (V)
2		
4		
6		
8		
10		
12		

Results

Plot a graph of current (*x*-axis) against the voltage drop (*y*-axis) for the light globe. You might like to use a spreadsheet for this purpose. Draw a line of best fit (trend line) to display any pattern in your data.

Discussion

1. Is your line of best fit a straight line or a curve? Explain why.
2. Calculate the resistance of the light globe using Ohm's law. One way of doing this is to calculate the resistance using *V* and *I* values several times and finding an average, but this treats each pair of values as equally valid even though some may be the result of errors (called outliers). A more accurate way to calculate the average resistance is to use the gradient of your graph (where the line of best fit is a straight line). An example is shown.

Conclusion

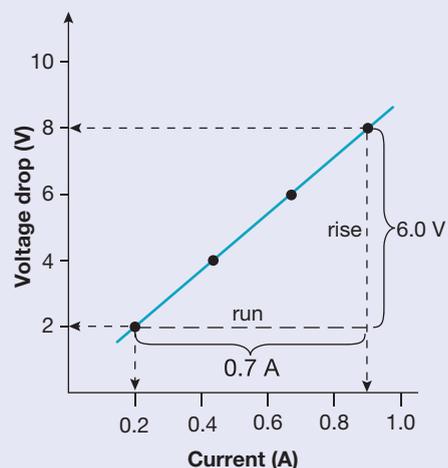What is the relationship between voltage and current in this electric circuit? How can the resistance of a light globe be calculated using Ohm's law?

$$\text{Resistance} = \text{gradient} = \frac{\text{rise}}{\text{run}}$$

$$\text{Resistance} = \frac{V}{I} = \frac{6.0\ V}{0.7\ A} = 8.6\ \Omega$$

INVESTIGATION 1.9
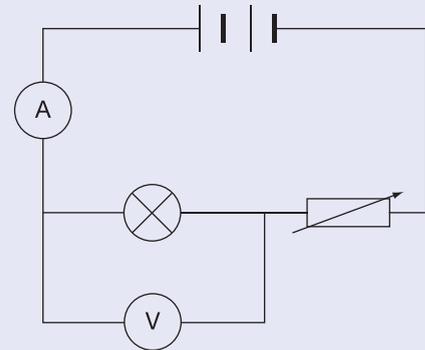
Variable resistance

Aim

To investigate the effect of a variable resistor in a circuit

Materials

- DC power supply
- ammeter
- variable resistor (rheostat)
- 6 connecting leads with alligator clips or banana plugs
- ruler
- 12-volt light globe
- voltmeter

Method

1. Set up the circuit shown in the diagram. Turn the DC power source to 10 V. The variable resistor is connected in series with the light globe.
2. Move the sliding part of the variable resistor so that the voltage drop across the light globe is at a maximum.
3. Measure the current through the circuit and the voltage across the light globe and record these values in a suitable table.
4. Slide the variable resistor 3 cm from the starting point and repeat these measurements.
5. Continue to take readings at 3 cm intervals until you reach the end of the variable resistor.

Results

Record your data in a suitable table.

Discussion

1. What evidence is there to suggest that at the start of the experiment the resistance of the variable resistor was at a minimum?
2. Explain what happens to the voltage across the light globe as the resistance of the variable resistor increases.
3. Explain what happens to the electric current flowing through the light globe as the resistance of the variable resistor increases.
4. Explain what happens to the brightness of the light globe as the resistance of the variable resistor increases.
5. What would you expect the sum of the voltage across the light globe and the voltage across the variable resistor to be? Explain.

Conclusion

Refer to your findings to explain how the resistance in an electric circuit affects the total current through the circuit and voltage drop across its components.

1.6.6 Comparing series and parallel circuits

There are two ways in which components can be connected in a circuit: series and parallel. In a series circuit, the components are connected one after another in a row. As a result, the same current flows through each component. However, the voltage provided by the power supply is shared between each of the components.

In a parallel circuit, the components are connected in separate branches. As a result, the current is divided between each of the components in the separate branches, but each branch of a parallel circuit receives the full voltage provided by the power supply.

Connecting electrical components in series increases the total resistance in a circuit and this lowers the current in the circuit. Remember, in Ohm's law $V = IR$ so $I = \dfrac{V}{R}$; that is, increasing a circuit's resistance decreases the current.

However, connecting those same components in a parallel configuration provides alternate paths for the current, so the resistance for the circuit decreases. Therefore, in keeping with Ohm's law, the total current will increase. Keep in mind, however, that the current is split between each of the branches of a parallel circuit.

A good analogy to better understand why arranging components parallel results in less overall resistance than if those same components are connected in series is people moving through entrance gates at a football game. If there are multiple gates (like the multiple branches of a circuit), there will be less congestion moving all the people through the gates than if there were only a single gate available.

ACTIVITY: PhET simulation — Circuit construction kit: DC

Access the **PhET simulation: Circuit construction kit: DC** interactivity in the Resources panel and use the circuit construction lab to build:
- a series circuit with a light bulb, resistor and switch
- a parallel circuit with a light bulb and a resistor and switches to operate each independently.

Observe the direction of (conventional) current flow and compare it to the movement of electrons. Measure the total current and voltage output for each circuit. Predict the current and voltage for each component and test your predictions.

INVESTIGATION 1.10

Series circuits

Aim

To investigate the current and voltage in a series circuit

Materials

- DC power supply (set to 6 volts)
- 3 identical 12-volt light globes and holders
- 7 connecting leads with alligator clips or banana plugs
- ammeter
- voltmeter

Method

1. Set up each of the circuits described in the results table below. Draw a diagram of the circuits in your workbook. Include the ammeters and voltmeter in your diagrams to show how the current flowing from the power supply and the voltage across one of the globes were measured.
2. Use the ammeter to measure the electric current flowing through each circuit. Place the ammeter in series with the light globes in each circuit so that the positive terminal is connected directly to the positive terminal of the power supply.
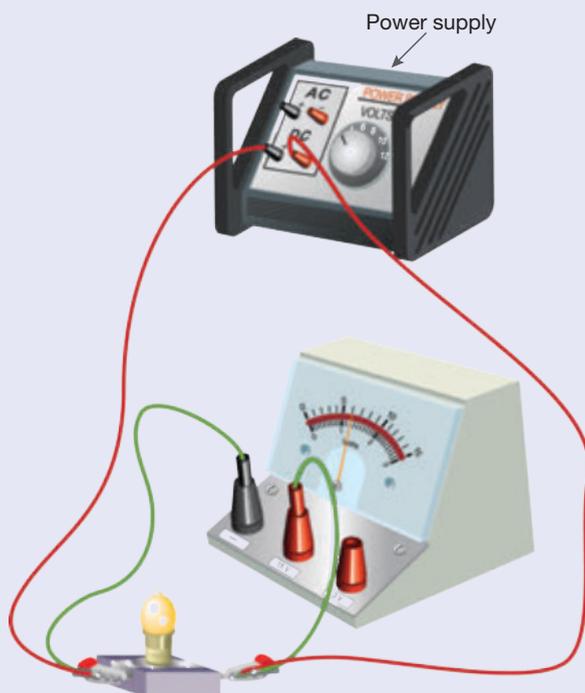
Power supply

Results

Record your data in a table like the one below.

Circuit description	Current (A)	Voltage (V)
One light globe (globe X) connected to a 6-volt power supply		Globe X: _____ Power supply: ____
Two light globes (globes X and Y) connected in series with a 6-volt power supply		Globe X: _____ Globe Y: _____ Power supply: ____
Three light globes (globes X, Y and Z) connected in series with a 6-volt power supply		Globe X: _____ Globe Y: _____ Globe Z: _____ Power supply: ____

Discussion

1. What happens to the electric current flowing through the circuit as more globes are added in series? Explain why this happens.
2. Why was it not necessary to separately measure the electric current flowing through each globe when two or three globes were connected in series?
3. What is the sum of the voltages across the globes in each of the three circuits? Compare this to the voltage provided by the power supply.
4. How much voltage is 'lost' across each globe in the third circuit? Where has this electrical energy gone?

Conclusion

Make a general statement about the electric current flowing through light globes connected in series and about the voltage drops across light globes connected in series.

## INVESTIGATION 1.11

Parallel circuits

Aim

**To investigate the current and voltage in a series circuit**

Materials

- DC power supply (set to 6 volts)
- three identical 12-volt light globes and holders
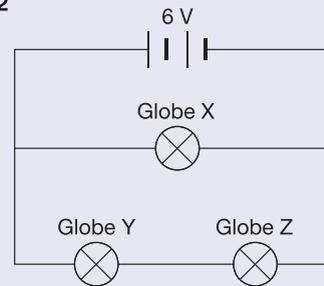- 8 connecting leads with alligator clips or banana plugs
- ammeter
- voltmeter

Method

1. Set up the circuits shown in the diagrams. Observe whether adding the second globe in circuit 1 affects the brightness of the first globe (globe X).
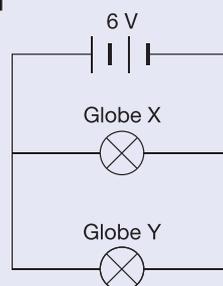
2. Use the ammeter to measure the electric current flowing from the power supply and into each of the light globes in each circuit.

CAUTION: Check that the ammeter is connected properly. Check with your teacher if you are not sure. Connecting the ammeter to measure the current in a parallel branch is tricky — see the diagram at right.

- Use the voltmeter to measure the voltage drop across the power supply and across each of the light globes in each circuit.
- While circuit 2 is set up and switched on, unscrew Globe X from its holder, if not too hot, and observe what happens.

Results

Record your measurements in a table like the one below.

Power supply

Globe X   Ammeter
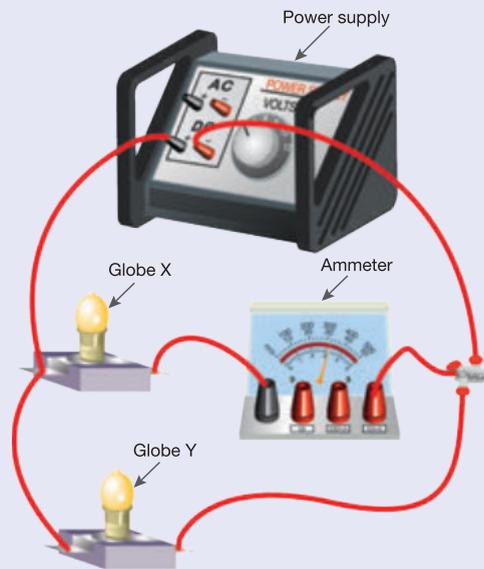
Globe Y

Circuit	Current (A)	Voltage (V)
Circuit 1	Globe X: _____ Globe Y: _____ Power supply: _____	Globe X: _____ Globe Y: _____ Power supply: _____
Circuit 2	Globe X: _____ Globes Y and Z: _____ Power supply: _____	Globe X: _____ Globe Y: _____ Globe Z: _____ Power supply: _____

Discussion

1. What is the sum of the currents flowing through globes X and Y in circuit 1?
2. What happens to the electric current flowing from the power supply when it meets a 'fork' in the pathway?
3. In circuit 2, how does the voltage drop across globe Y compare with the voltage drop across globe X? Explain why this is the case.

Conclusion

Make a general statement about electric current flowing through light globes connected parallel and about the voltage drops across light globes connected parallel.

1.6.7 The electronics age

Over the last decade there has been huge growth in the use of electronic devices such as computers (both laptops and desktops), smartphones and smart watches.

Electronics is one of the fastest growing industries in Australia and worldwide. This is partly because we are becoming more dependent on computers and mobile phones for work and electronic communication.

Electronic devices rely on complex electrical circuits that are almost too small to see. In these devices, **integrated circuits** that contain thousands of miniature electronic components are etched onto **chips**, thin pieces of the semiconductor silicon.

The first silicon chip was developed in 1958; by 1965, chips could hold around 30 electronic components. By 1975, similar-sized chips held about 30 000 components, enabling the creation of desktop computers with improved processing power. Advances in chip production have since allowed chips to contain millions of components.

A silicon chip that stores and processes information and controls other circuits is known as a **microprocessor**. Developed in 1971, microprocessors were initially used in calculators and computers. As they became smaller and cheaper, they began to be used in household appliances and personal devices.

FIGURE 1.39 Modern communication devices

FIGURE 1.40 A computer's integrated circuit

EXTENSION: Electric circuit components

Apart from resistors, the most common electronic components in circuits are capacitors, diodes and transistors.

Capacitors store electric charge for a short time before allowing it to flow to other parts of a circuit.

Diodes allow electric current to travel through them in only one direction. They look like small resistors but have a single band at one end.

LEDs are often used as indicator lights in electrical appliances. An arrangement of seven LEDs can be used in devices like watches, clocks, calculators and digital meters to display any number between 0 and 9. The display circuit is designed so that the LEDs light up in different combinations.

A **liquid crystal display (LCD)** is often used instead of LEDs for the same purpose. Small voltages cause the molecules in liquid crystals to rearrange themselves, changing the colour of the crystals.

Transistors act like switches, changing the size or direction of electric current as a result of very small changes in the voltage across them. This makes them ideal for use in devices that amplify sound. However, they have many other uses and most electronic devices contain chips that hold many microscopic transistors.

FIGURE 1.41 Electric circuit components
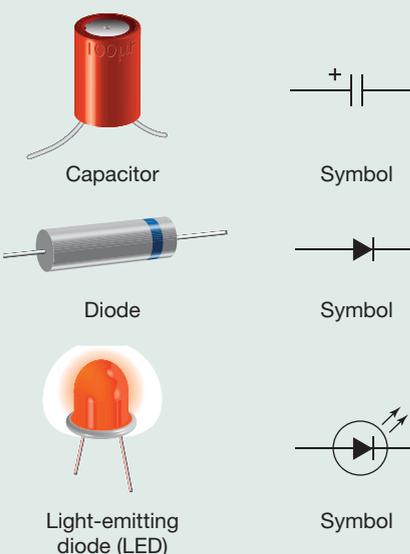
Capacitor

Symbol

Diode

Symbol

Light-emitting diode (LED)

Symbol

1.6 Activities

Learning pathways

| ■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 4, 7, 10	2, 5, 8, 11	3, 6, 9, 12

## Remember and understand

1. **Identify** the device used to measure:
   a. electric current
   b. voltage.
2. **Define** the term 'electric current'.
3. **Explain** why voltage is also known as potential difference.
4. Use Ohm's law to **outline** the relationship between the voltage supplied to an appliance and the electric current flowing through that appliance.
5. **Explain** two advantages of connecting the power outlets in a room of your home parallel to one another.

Apply and analyse

6. An apprentice electrician has designed a lighting circuit diagram (shown below) for a new house. **Explain** what is wrong with this circuit design.
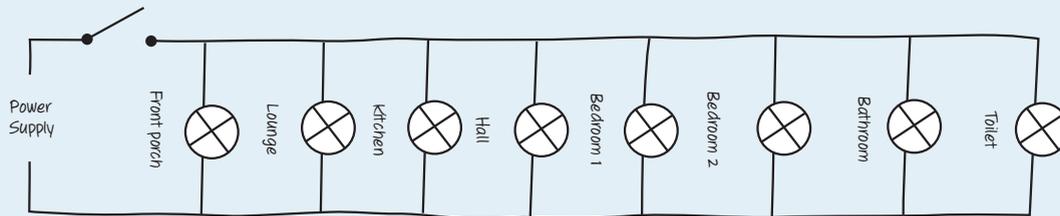
7. **Calculate** the voltage drop across a 100 Ω resistor when the electric current through it is 0.25 A.
8. The electric current flowing through a light globe is 200 mA when the voltage across the globe is 1.5 V. When the voltage is increased to 3.0 V, the current is measured to be 360 A.
   a. Calculate the resistance of the light globe when the electric current is 200 mA.
   b. Explain whether the light globe is ohmic.
   c. If the light globe were ohmic, what would happen to the electric current flowing through that light globe if the voltage across it were doubled?
9. When a light globe 'blows', the filament breaks. **Explain** what will happen if:
   a. many light globes are connected in series and one blows
   b. many light globes are connected in parallel and one blows.
10. In the circuit diagram shown, predict which of the light globes (A, B or C) will continue to glow if:
    a. the filament in globe A breaks
    b. the filament in globe B breaks
    c. the filament in globe C breaks
    d. a wire lead is connected between the points P and Q
    e. a connecting lead is connected between the points P and R
    f. a connecting lead is connected between the points P and S.
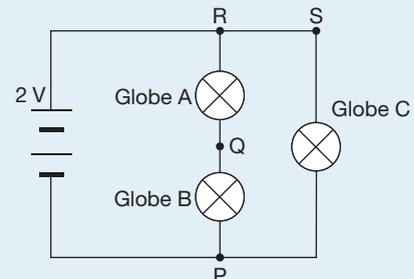
11. Answer these questions about the ohmic conductor described by the graph of voltage drop versus electric current.
   a. Determine the voltage drop across the conductor when the electric current is 0.6 amperes.
   b. Determine the electric current through the conductor when the voltage drop across it is 4 volts.
   c. Predict the current through the conductor if it is supplied with 9 volts.
   d. Explain how you know that the conductor is ohmic.
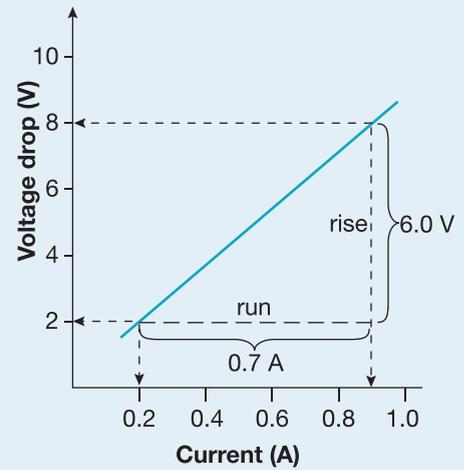
Evaluate and create

12. The incomplete concept map below represents some of the key ideas related to electric circuits. This concept map is just one way of representing ideas about matter and how they are linked. Copy and complete the concept map by writing suitable links between the ideas.
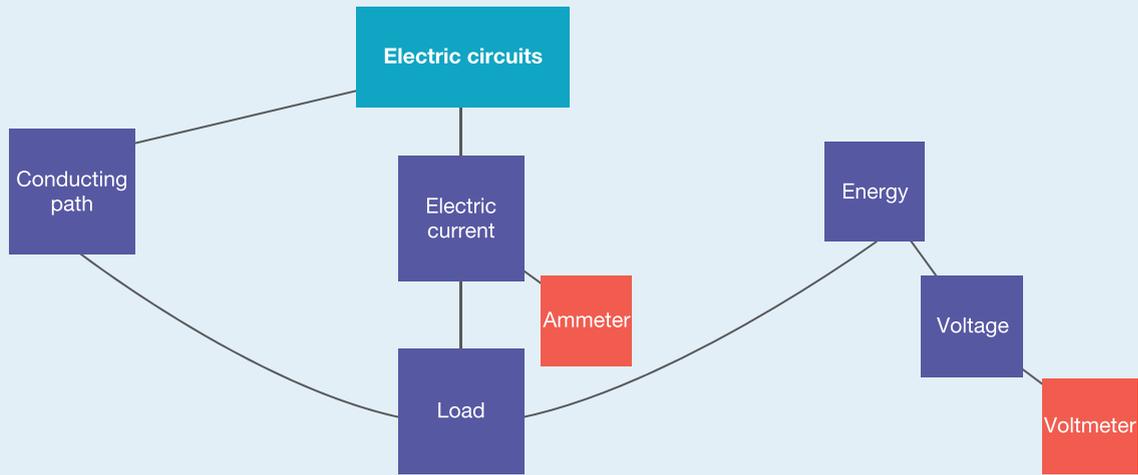
LESSON 1.7 Investigating energy efficiency

LEARNING INTENTION

In this lesson you will conduct an investigation to compare the energy transformed over time in model circuits or appliances. You will also investigate the energy star ratings of a range of appliances and explain the criteria used to determine these ratings.

1.7.1 Counting the cost

The electricity used to run many of the appliances in our homes is obtained by simply plugging a lead into a power point, also called a general power outlet (GPO) and switching it on. The electric current that flows from power points is not quite the same as the electric current that flows from a battery.

Batteries provide a direct current (DC), meaning that a constant voltage is supplied causing the current to flow through a circuit in one direction from the positive terminal to the negative terminal of the power source.
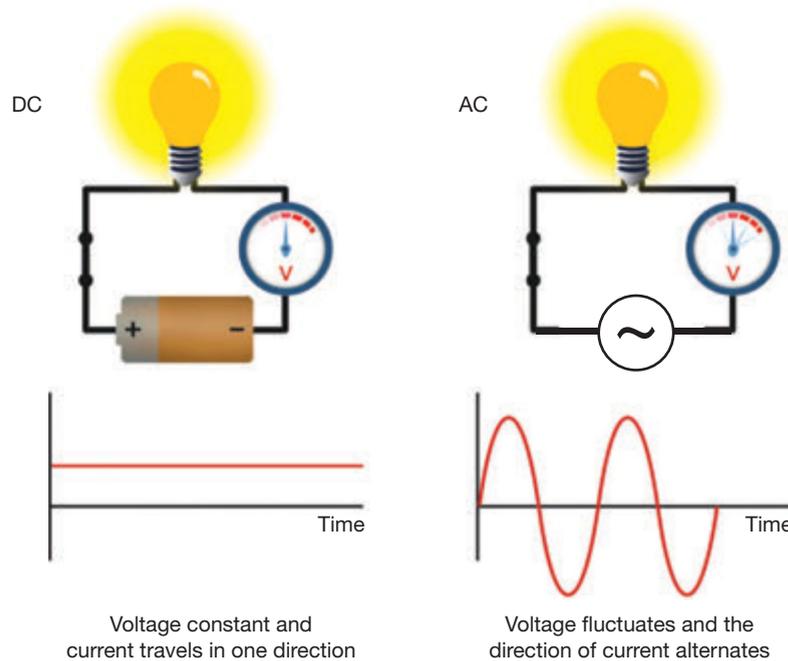
The current supplied to homes and available to appliances through power outlets is called alternating current (AC). As the name indicates, alternating current alternates or changes direction. In Australia, current alternates with a frequency of 50 Hertz (50 times per second) and the voltage fluctuates from a positive to negative value with a voltage equivalent to 240 V.

FIGURE 1.42 Direct current (DC) and alternating current (AC)

DC

AC

Time

Time

Voltage constant and
current travels in one direction

Voltage fluctuates and the
direction of current alternates

Alternating current, rather than direct current, is supplied by power stations because it is more efficient to distribute over large distances through the power grid.

Many common electrical appliances are not designed to work on the 240 V AC electricity supplied to homes. These appliances contain devices called **transformers** which can increase or decrease the supplied voltage to the voltage required by the appliance.

In addition, appliances that require DC electricity are supplied with an electrical device called a **rectifier** that converts AC to DC. Hence, the 240 V AC to your home can power a variety of appliances, each requiring a specific operating voltage. For example, mobile phone chargers transform and rectify your power outlet's alternating current (AC) into the small direct current (DC) required to recharge the internal battery of the phone.

FIGURE 1.43 A mobile phone charger

The **power rating** of an electrical appliance indicates how quickly electrical energy is used and converted to other forms of energy. The law of conservation of energy states that the energy input, in this case in the form of electrical energy, is equal to the energy output in an energy transformation. In electrical appliances, electrical energy is transformed into other forms. Some forms are useful, such as the light produced by a compact fluorescent lamp (CFL) while other forms represent wasted energy such as the heat produced by these lights.

Electrical power is measured in watts (W) and is equivalent to joules per second(J/s). A 60-W incandescent globe uses energy at a rate of 60 J/s and would be more costly to run than a 12-W compact fluorescent light, which uses 12 J/s.

TABLE 1.3 Typical power rating of some common appliances

Appliance	Typical power rating (W)
Mobile phone charger	20
Laptop computer	100
Fridge	150
Television	200
Hairdryer	1500
Electric kettle	2400
Air conditioner	5000

The power rating can be used to determine the electrical energy used by an appliance as follows:

$$\text{Electrical energy use (joules)} = \text{electrical power (watts)} \times \text{time in use (seconds)}$$

For example, using a laptop computer for half an hour would use:

$$100\,\text{W} \times (30\,\text{min} \times 60\,\text{s/min}) = 100\,\text{J/s} \times 1800\,\text{s}$$
$$= 180\,000\,\text{joules}$$
$$= 180\,\text{kilojoules of energy}$$

The joule is a very small unit of energy, so electricity suppliers monitor and charge for energy usage in kilowatt-hours (kWh), recorded by an electricity meter located in your home's meter box. A kilowatt-hour is the energy used by a 1-kilowatt appliance for an hour.

FIGURE 1.44 Electricity meters measure the number of kilowatt-hours of energy used in homes.

SAMPLE PROBLEM 4 Calculating the cost of appliance usage

Celine takes 10 minutes to dry her hair after washing it, using a 1500-W hairdryer.
a. How much energy does she use in kWh?
b. If she pays 32c per kWh for her electricity use, how much of her next electricity bill will be due to her drying her hair?

THINK	WRITE
a. 1. For the appliance, what is the power rating and length of time used?	Power rating $= 1500\,\text{W}$ Time used $= 10$ minutes

2. Convert the power to kilowatts and the time to hours.

$$\text{Power rating} = 1500\,\text{W}$$
$$= 1500/1000$$
$$= 1.5\,\text{kW}$$
$$\text{Time} = 10\ \text{min}$$
$$= 10/60$$
$$= 0.17\,\text{h}$$

3. Calculate the energy used.

$$\text{Electrical energy use (kWh)} = \text{electrical power (kW)}$$
$$\times\,\text{time in use (hours)}$$
$$= 1.5\,\text{kW} \times 0.17\,\text{h}$$
$$= 0.26\,\text{kWh}$$

b. Apply the charge rate of 32c per kWh of energy use.

$$\text{Cost} = 0.26\,\text{kWh} \times \$0.32$$
$$= 0.08$$
$$= 8\,\text{cents}$$

WORKING SCIENTIFICALLY: Problem-solving strategies in energy efficiency

Develop problem-solving strategies to address energy efficiency issues in everyday settings. Evaluate the effectiveness of different solutions and make recommendations based on scientific reasoning and data.

Objective

Understand and apply problem-solving strategies to improve energy efficiency in household or school settings. Evaluate the potential impact of each solution on energy use, cost savings and environmental sustainability.

Identifying the problem

Context: Discuss the importance of energy conservation for both economic and environmental reasons, such as reducing electricity costs and greenhouse gas emissions.

Problem identification: Identify specific energy inefficiencies, such as excessive lighting use, high- power appliances or lack of insulation in rooms.

Key question: How can we reduce energy consumption in a practical, effective way?

Selecting problem-solving strategies

Brainstorming solutions: In groups, brainstorm various strategies to reduce energy use, such as:
- switching to energy-efficient lighting (e.g. LED bulbs)
- reducing heating/cooling energy loss by improving insulation
- setting timers on appliances and lights to minimise unnecessary use
- using solar-powered devices or considering renewable energy sources

Evaluating options

Effectiveness: How much energy could each solution save? Use data, if available, to estimate energy reductions.

Feasibility: Is the solution realistic in terms of cost, accessibility and ease of implementation?

Environmental impact: Does the solution reduce greenhouse gas emissions or other environmental impacts?

Safety and ethics: Consider safety and ethical aspects, such as the sustainability of materials used in appliances or insulation.

Choosing the most suitable solution

Based on the evaluations, select the top solutions that provide the highest impact with the lowest costs and fewest barriers to implementation.

Implementing the solution

Plan: Create a step-by-step plan to implement the selected solution, detailing how energy savings will be measured.

Hypothesis: Make a prediction about the expected outcomes, such as a percentage reduction in energy use or estimated cost savings.

Evaluating the effectiveness of the solution

Data collection: If feasible, measure energy use before and after the solution is implemented, using energy meters or monthly electricity bill comparisons.

Analysis: Compare the data to evaluate whether the solution had the intended effect. Identify any unexpected challenges or outcomes.

Reflection: Discuss whether the chosen solution met the problem-solving criteria. If results were mixed or unsatisfactory, consider modifications or alternative solutions.

Communicating findings

Prepare a report: Summarise the problem-solving process, the solution selected and the evaluation of its effectiveness. Include any data collected and recommendations for future energy efficiency initiatives.

Presentation: Present findings to the class, explaining the reasoning behind the solution choice, the process of implementation and the results.

Discussion questions

- How did you decide on the most effective solution to reduce energy consumption?
- Why is it important to evaluate both the feasibility and environmental impact of a solution?
- What would you change in your approach if the solution didn't have the expected effect on energy efficiency?

WS **SC5-WS-07** Selects suitable problem-solving strategies and evaluates proposed solutions to identified problems

---

INVESTIGATION 1.12

Comparing electrical appliances

Aim

To compare the power use and energy conversion in a range of electrical appliances and devices

Materials

- a range of electrical appliances and devices; for example, radio, hairdryer, blender, laptop, fluorescent light, kettle

Method

Examine each of the devices, preferably while they are operating. For each one record the:
- type of energy input
- useful energy output (there may be more than one)
- wasted energy output (there may be more than one)
- operating power in watts (this should be labelled on the device).

Results

Present your data in a suitably designed table.

Discussion

1. Which appliance/device consumes:
   a. the most power
   b. the least power?
2. Account for the higher operating power of some of the devices in terms of the type of energy transformation that takes place.

1.7.2 Rating energy efficiency

In Australia, it is mandatory for electrical appliances such as refrigerators, washing machines, clothes dryers, dishwashers, air conditioners and televisions to carry an energy rating label at the point of sale.

The label provides each appliance with a star rating: the greater the number of stars, the higher the energy efficiency of the appliance, compared to others of a similar size or capacity. This rating is based on the appliance's estimated annual energy use (measured in kilowatt-hours) calculated from its power consumption and information about the typical usage of the appliance in the home.

The rating system enables consumers to compare the energy efficiency of appliances and provides incentive for manufacturers to improve the energy performance of their products through research and development.

Most products are rated between 1 and 6 stars. However, with technology improvements, energy efficiency has also improved. This means that now you may see some super-efficient models with an energy efficiency of up to 10 stars.

FIGURE 1.45 Energy rating label
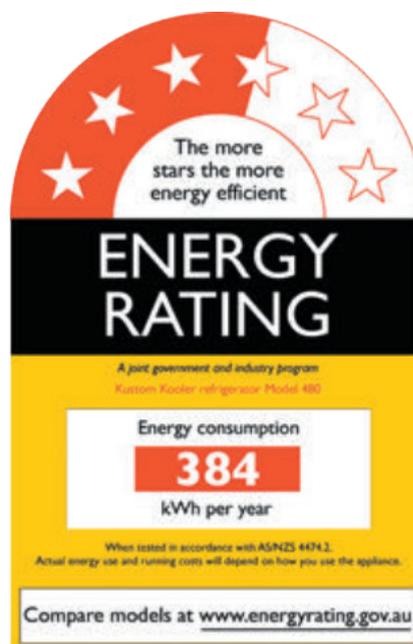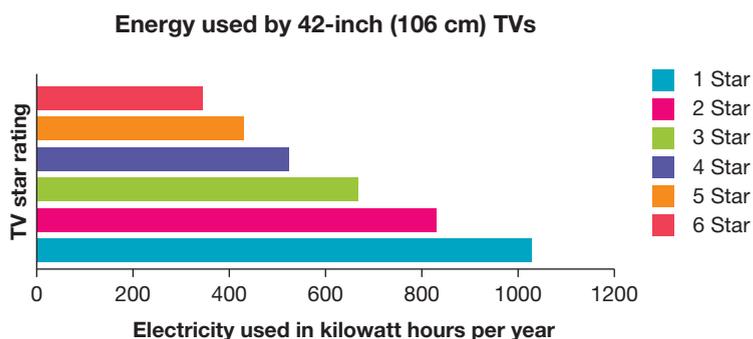
FIGURE 1.46 The higher the energy efficiency rating of an appliance such as a TV, the less electrical energy consumed per year.

KEY IDEAS

Energy ratings for Australian appliances are based on the appliance's estimated annual energy use (measured in kilowatt hours) calculated from its power consumption and information about the typical usage of the appliance in the home.

Analysing energy efficiency claims in household appliances

Objective

Investigate claims about the energy efficiency of household appliances by examining data on energy consumption. Evaluate the validity of claims, use data for evidence-based arguments, and explore how large datasets can support scientific findings.

Activity overview

1. **Investigating energy efficiency claims**
   - **Discussion**: Investigate claims commonly made by appliance manufacturers, such as 'LED lights save more energy than incandescent bulbs' or 'Energy-efficient washing machines reduce power consumption'.
   - **Questioning**: Identify investigable and non-investigable questions. For example:
     - Investigable: 'Do LED lights use less energy than incandescent bulbs over time?'
     - Non-investigable: 'Are LED lights the best lighting option?' (requires subjective judgement)
   - **Claim selection**: Choose one claim about energy efficiency to investigate, such as comparing energy use between different types of light bulbs.
2. **Data collection using large datasets**
   - Compile a dataset of appliance energy consumption based on appliance type, usage time and power rating. This should include data from reliable sources, such as the Australian government (use the **Energy Rating** weblink in the Resources panel) or other available large datasets on household energy consumption.
   - Sample dataset:

Appliance	Type	Power rating (W)	Average daily usage (hours)
Light bulb (incandescent)	Lighting	60	4
Light bulb (LED)	Lighting	10	4
Washing machine (standard)	Laundry	500	1
Washing machine (energy-efficient)	Laundry	250	1

3. **Data analysis and comparison**
   - **Univariate analysis**: Calculate the daily and weekly energy consumption for each appliance type to compare their efficiency.
     - Example: Energy use (kWh)=Power rating (kW)×Usage time (hours)
   - **Bivariate analysis**: Examine the relationship between power rating and energy cost to understand correlations in energy efficiency and cost savings.
4. **Evaluating the claim**
   - **Validity check**: Use the dataset to evaluate whether the claim (e.g. LED lights are more energy-efficient) is supported by the data. Discuss how descriptive statistical techniques such as averages help identify patterns.
   - **Communicate findings**: Write a short scientific argument supporting or refuting the claim based on your data analysis. Explain the evidence, reasoning and calculations used to reach your conclusion.
5. **Exploring causation versus correlation**
   - **Discussion**: Highlight the difference between *causation* (e.g. using LED lights directly leads to lower energy bills) and *correlation* (e.g. a appliance power rating and energy costs are related without one directly causing the other).
   - **Example question**: 'Does using energy-efficient appliances directly reduce household energy bills?' Discuss how causation might be influenced by other factors, such as overall energy use and lifestyle.

Reflection questions

1. Was the claim you investigated supported by the data? What evidence led you to this conclusion?
2. How does understanding the difference between causation and correlation affect our interpretation of data on energy efficiency?
3. How might large datasets on energy use help policymakers make decisions about promoting energy-efficient appliances?

A family are looking to buy a new fridge. Fridge A has a 2-star energy rating and an estimated annual energy consumption of 550 kWh. Fridge B has a 4-star energy rating and an estimated annual energy consumption of 320 kWh. How much could a family save in annual running costs by choosing the 4-star model if they pay 32c per kWh of electricity use?

THINK	WRITE
1. Start with the estimated annual energy use of each fridge model.	Fridge A = 550 kWh Fridge B = 320 kWh
2. Calculate the annual cost of running each model.	Fridge A cost = 550 kWh × 0.32c/kWh = $176 Fridge B cost = 320 kWh × 0.32c/kWh = $102
3. Subtract the annual costs to work out the saving.	Annual saving = $176–$102 = $74

INVESTIGATION 1.13

Investigating energy efficiency

Aim

To calculate the energy efficiency of an electrical appliance

Materials

- electric kettle
- 100-mL measuring cylinder
- data logger and temperature probe
- stopwatch

Method

1. Use the measuring cylinder to measure and pour 500 mL of water into the electric kettle.
2. Place the tip of the temperature probe into the kettle and record the initial temperature of the water.
3. Remove the temperature probe then switch on the kettle and heat the water for 60 seconds.
4. Swirl the water to mix it then insert the temperature probe again to record the new water temperature.
5. Calculate the temperature rise over the 60-second period and record your data.
6. Refer to the label on the kettle to identify and record the power rating of the kettle.

Results

Record your data and calculations in a suitable table.

Discussion

1. Calculate the input of electrical energy to the kettle over the 60-second period: Electrical energy input (J) = power use (watts) × operating time (s)
2. Calculate the output of heat energy gained by the water in the kettle as follows: Heat energy output (J) = volume of water (mL) × 4.2 × temperature rise (°C)
3. Calculate the efficiency of the kettle as follows:

$$\text{Efficiency (\%)} = \frac{\text{heat energy output}}{\text{electrical energy input}} \times 100$$

4. Explain why the efficiency of the kettle is well below 100 per cent in terms of transformation of electrical energy and the transfer of heat energy generated.

Conclusion

Summarise your findings and comment on the efficiency of the electric kettle.

The energy efficiency of appliances

Aim

To compare the energy efficiency of some common appliances

Method

1. Refer to a website that provides information about appliances and their energy ratings. You might like to use the **Fridge energy ratings** weblink in the Resources panel.
2. Select two types of appliances that you are interested in investigating. You may like to select two of the following:
   • Fridges
   • Televisions
   • Air conditioners
   • Dishwashers
   • Clothes washers
   • Clothes dryers.
3. For each appliance type, construct a table to compare at least 5 models that interest you. To assist in your comparison, include models with a range of energy ratings. Record the following details for each model:
   • brand name
   • energy rating
   • typical energy use per year in kWh
   • typical running cost (per year or per 10 years)
   • any other special feature, e.g. size of TV, fridge volume, capacity of washing machine.

Results

Present your data in a suitable table.

Discussion

1. Discuss whether there was a big range in the running costs for each appliance type.
2. Where there any features that affected the energy ratings in your appliances, such as the TV size or fridge volume?

Conclusion

What can you conclude in terms the range of energy ratings and the running costs of the appliances that you investigated?

1.7 Activities

learn on

1.7 Quick quiz on	1.7 Exercise

Learning pathways

■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 4, 7	2, 5, 8	3, 6

Remember and understand

1. **Compare** AC and DC electricity.
2. **Explain** why incandescent lights have been phased out in preference for compact fluorescent lights and LEDs.
3. What types of home appliances use the most power? **Explain** why.

Apply and analyse

4. **Calculate** how much electrical energy (in joules) is transformed by each of the following appliances.
   a. An 18-W light globe in 6 hours
   b. A 2000-watt toaster used to toast a slice of bread for 2 minutes
5. **Calculate** how much would it cost to operate each of the following appliances if the cost of electrical energy is 32 cents per kilowatt-hour. (Remember, 1 kW = 1000 W.)
   a. A 5000-W air conditioner for 30 minutes
   b. A 1500-W electric blanket for 8 hours
6. Assuming that the cost of electrical energy is 32 cents per kilowatt-hour, use the data in the table below to **calculate** how much it costs to:
   a. use a medium-sized air conditioner to cool a room for 4 hours
   b. watch television for 2 hours every day for 1 week.

Appliance	Typical power rating (W)
Mobile phone charger	20
Laptop computer	100
Fridge	150
Television	200
Hairdryer	1500
Electric kettle	2400
Air conditioner	5000

Evaluate and create

7. **Investigate**, using secondary sources, smart meter technology. How do smart meters differ from traditional accumulation electricity meters, and how can they help families to lower electricity costs?
8. **Investigate**, using secondary sources, which household activities use the most electrical energy each year. Discuss how families can reduce their energy costs.

LESSON 1.8 Review

1.8.1 Topic summary

Using energy

- Energy transfers and transformations
  - Types of energy
  - How much energy?
  - Transferring and transforming energy

- The conservation of energy
  - Open and closed systems
  - The law of conservation of energy

- Efficiency in energy transfers and transformations
  - Energy efficiency
  - Calculating energy efficiency
  - Improving energy efficiency

- Using electrical energy
  - Electric circuits
  - Circuit diagrams: a common language
  - Series and parallel circuits
  - Circuits in the home
  - Monitoring electricity use

- Electric circuits
  - Current and voltage
  - Resistance
  - Useful analogies
  - Measuring current and voltage
  - The relationship between current, voltage and resistance
  - Measuring current and voltage
  - Comparing series and parallel circuits
  - The electronics age

- Investigating energy efficiency
  - Counting the cost
  - Rating energy efficiency

1.8.2 Success criteria

Tick the column to indicate that you have completed the lesson and how well you think you have understood it using the traffic light system.

(**Green:** I understand; **Yellow:** I can do it with help; **Red:** I do not understand)

Lesson	Success criteria	🟢	🟡	🔴
1.2	I can identify different types of energy sources.			
1.3	I can use the law of conservation of energy, and calculations, to explain that total energy is maintained in energy transfers and transformations in a closed system			
1.4	I can investigate the efficiency of energy transfers.			
	I can explain how to improve energy efficiency in energy transfers and transformations.			
1.5	I can identify the elements of a complete circuit.			
	I can construct circuits and draw circuit diagrams that contain several components to show the flow of electricity through a complete circuit.			
1.6	I can measure and compare the voltage and current at different points in series and parallel circuits.			
	I can conduct an investigation to determine the relationship between voltage (V), current (I), and resistance (R), as described by Ohm's law ($V = IR$).			
1.7	I can conduct an investigation to compare the energy transformed over time in model circuits or appliances.			
	I can investigate the energy star ratings of a range of appliances and explain the criteria used to determine these ratings.			

DEPTH STUDY IDEAS

- Is perpetual motion possible?
- Could you charge a phone with a bicycle and a dynamo?
- How do crumple zones in cars help mitigate the effect of collisions on the occupants by transforming energy?
- What are the key differences in energy requirements between electric vehicles (EVs) and traditional fuel-powered cars, and how do these differences affect overall energy consumption?
- How does the environmental impact of EVs compare to that of traditional cars, considering factors such as greenhouse gas emissions, battery production, and fuel extraction?
- What challenges might the increased use of EVs pose to energy infrastructure, and how could energy systems adapt to meet the growing demand for electricity from EVs?
- Survey the electrical energy used in your household in a typical week. Analyse the contribution of each appliance. Suggest short-term and long-term changes to reduce your family's energy use.

on Resources

on Post-test	Topic 1 Post-test
eWorkbook	Quick quiz
	Summary
	Reflection
Digital document	Key terms glossary

Learning pathways

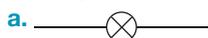| ■ LEVEL 1	■ LEVEL 2	■ LEVEL 3
1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31	2, 5, 8, 11, 14, 17, 20, 23, 26, 29	3, 6, 9, 12, 15, 18, 21, 24, 27, 30

## Remember and understand

1. **Identify** the type of energy possessed by a:
   a. bus on its way to school
   b. wind-up toy before being released
   c. gas heater.
2. **Describe** the Law of Conservation of Energy.
3. **Identify** the energy transformations that occur as:
   a. a skier skis down a slope
   b. a firecracker is ignited
   c. a bungee jumper reaches the bottom of a jump.
4. **MC** The correct units of measurement for voltage, charge, current and resistance are:
   A. amperes, coulombs, volts and ohms.
   B. volts, coulombs, amperes and ohms.
   C. joules, coulombs, amperes and ohms.
   D. joules, amperes, coulombs and degrees Celsius.
5. **Define** each of the following terms:
   a. electric current
   b. load in a current
   c. components in series
   d. components parallel
   e. conductor.
6. Draw a circuit diagram to show how a voltmeter and ammeter are used to measure the voltage drop and the current flowing through a single light globe connected to a 6-volt DC power supply. Label the positive and negative terminals of the power supply and each side of the meter with + and − symbols.
7. Complete the table by **identifying** the missing quantity, unit or abbreviation.

| Quantity	Unit name	Unit abbreviation
Voltage	volt	
Electric current		A
	ohm	
Electrical power		W
Electrical energy		J
		kWh

8. **Identify** each of the following circuit components.
   a.
   b.
   c.
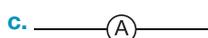
9. Using the correct symbols, draw this circuit as a circuit diagram.
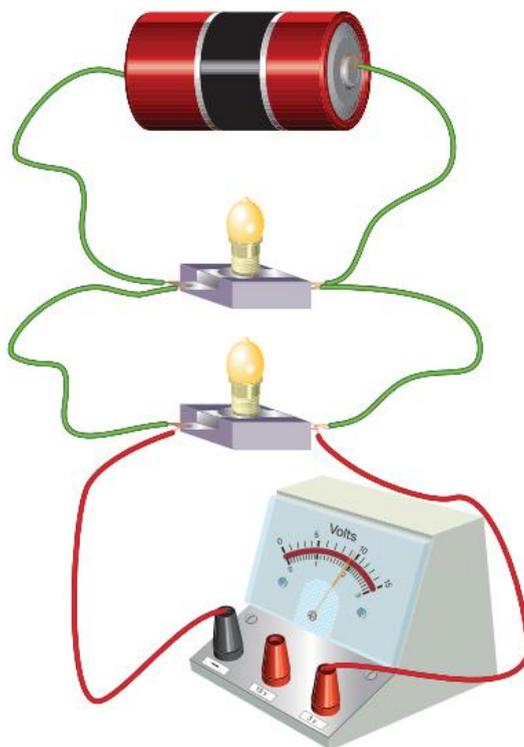
10. **Calculate** the energy of:
    a. a 65 kg bungee jumper about to jump from a height of 60 m
    b. an 800 kg car travelling 15 m/s.
11. **MC** A 6.0-V DC power source supplies two light globes connected parallel. If the resistance of the circuit is 12 Ω, the voltage and current for each light globe is:
    A. 3.0 V and 0.5 A.
    B. 6.0 V and 0.5 A.
    C. 3.0 V and 0.25 A.
    D. 6.0 V and 0.25 A.
12. **MC** A 1000-W toaster takes 2 minutes to toast a slice of bread. The energy used over that time is:
    A. 120 000 J.
    B. 2000 J.
    C. 1000 J.
    D. 33 J.
13. A circuit is supplied with 12 V DC. Two identical globes are connected in parallel. If the current through one of the globes is 0.3 A, **calculate**:
    a. the total current
    b. the total resistance in the circuit.
14. **Identify** the light globe(s) connected:
    a. in series with globe A
    b. parallel with globe A.
15. Identical globes are included in the circuit shown in the diagram. The electric current flowing through globe B is 200 mA and the electric current flowing through globe D is 300 mA. **Predict** the electric current flowing:
    a. through globe A
    b. from the power supply
    c. through globe E.
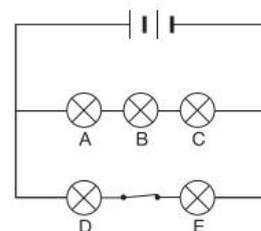
16. If the voltage drop for globe C was measured to be 4 volts, **predict** the voltage across:
    a. globe A
    b. the terminals of the power supply
    c. globe E.
17. If the filament in globe B was to break, **predict** which of the light globes would remain glowing.
18. If the switch in the circuit was opened, **predict** which light globe(s) would stop glowing.
19. **Outline** how you could make all the light globes stop glowing without opening the switch or turning off the power supply.
20. The voltage across globe C is measured to be 4 volts and the current flowing through it is 200 mA.
    a. **Identify** the electric current flowing through globe C in amps.
    b. **Calculate** the resistance of globe C while this current is flowing.
21. Power points in Australia provide 240 V AC electricity. **Explain** what this means.
22. A mobile phone charger contains a transformer and a rectifier.
    Outline the purpose of the:
    a. transformer
    b. rectifier.
23. **Explain** how each of the following electrical safety devices protects us from injury:
    a. earth wire
    b. circuit breaker
24. **Calculate** how much electrical energy, in kilowatt-hours, is transformed by a 70 watt electric blanket over a period of eight hours.
25. **Calculate** how much it would cost to heat a frozen pie in a 650 watt microwave oven if it takes 2 minutes to heat the pie and the cost of electrical energy is 32 cents per kilowatt-hour.
26. **Describe** the principle by which generators create an electric current. Explain how your home water pipes provide a good analogy for an electric circuit.
27. In 10 minutes, an incandescent light globe is supplied with 1000 joules of electrical energy. During that time, the globe emits 400 joules of light energy along with 600 joules of heat energy. **Calculate** the efficiency of the globe in terms of light output.

Evaluate and create

28. **Explain** why the sale of incandescent light globes in Australia has been phased out.
29. Design and draw a circuit diagram for a studio apartment containing an AC power source, a fuse and three parallel lights with two master switches that can operate all three lights simultaneously from different locations in the apartment.
30. **Explain** why the development of electronics with integrated circuit technology has revolutionised society.
31. **Describe**, with reference to examples, the benefits for society and the environment of advances in technology to improve the energy efficiency of appliances and the design and construction of homes.

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