8 Using electricity

Planning page

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Essential Learnings for Chapter 8

Essential Learnings	References		
	Student book (page number)	Workbook (page number)	Teacher Edition CD (Assessment task)
Knowledge and understanding ***Energy and change*** Transfer of energy can vary according to the medium in which it travels	pp. 167–171, 176		
Energy is conserved when it is transferred or transformed	pp. 182–188	pp. 63–64	Assessment task 8 Saving electricity
Ways of working Conduct and apply safety audits and identify and manage risks	Investigate 18 p. 168		
Evaluate data, information and evidence to identify connections, construct arguments and link results to theory	Investigate 19 p. 175		
Draw conclusions that summarise and explain patterns, and that are consistent with the data and respond to the question	Investigate 19 p. 175 Activity p. 183	pp. 59–62	
Communicate scientific ideas, explanations, conclusions, decisions and data, using scientific argument and terminology, in appropriate formats	Skillbuilder p. 174 Skillbuilder p. 178	p. 66	Assessment task 8 Saving electricity

QSA Science Essential Learnings by the end of Year 9

Vocabulary

alternating
ammeter
appliance
circuit
electricity
electrocution
electromagnetic
generator
hydro-electric
insulation
kilowatts
neutral
nuclear
nuclear fission
ohm
parallel
resistance
transformer
turbine
uranium
voltage
voltmeter

Focus for learning

Read an electricity meter to calculate energy usage (page 165).

Equipment and chemicals (per group)

Activity page 166 — **Teacher demonstration:** cathode ray oscilloscope (CRO), 1.5 V battery, power pack

Investigate 18 page 168 — power pack or battery, 4 connecting wires, switch, torch bulb in holder, screwdriver or other conductor, large rubber stopper, 2 large pins, strands of steel wool, heatproof mat

Investigate 19 page 175 — power pack, piece of nichrome wire about 50 cm long or small resistor (eg 20 W), voltmeter and ammeter or 2 digital multimeters, switch, 6 connecting wires with alligator clips, heatproof mat, graph paper

Activity page 179 — portable radio, piece of aluminium foil (20 cm × 8 cm), piece of cardboard (10 cm × 2 cm), ammeter, connecting wires with alligator clips

Activity page 183 — cardboard tube, thin insulated wire (2–3 m), adhesive tape (or use a ready-made coil), multimeter or galvanometer, bar magnet

8 Using electricity

Getting Started

Find the electricity meter at your home. It measures how much electricity you use in kilowatt-hours (kWh). Some meters are digital and easy to read. Others have five dials as shown. You read the left-hand dial first and move across to the right, writing down the numbers. If the pointer lies between two numbers you write down the smaller one. The reading on the meter in the left-hand photo is 84 147.4 kWh.

- Ask someone to turn on an electric stove, heater or toaster. What happens to the rotating disk in the meter? What happens when you turn the appliance off?
- Read the meter today and at the same time tomorrow. Use the readings to find out how much electricity your household uses in a day.
- You might like to find out how much electricity you use in a week. Try to explain why the amounts vary from day to day.

Starting point

1 Establish what the students already know about electricity by doing a pre-test. Devise a list of main points you think they should already know about electricity. Turn the points into a series of questions and use this as your pre-test. For ease of marking, develop the test so that it is multiple-choice style, true/false, or simple answers only.

2 If the students' parents allow them to, ask them to bring in an electricity bill. Discuss how it is read and what information is displayed on it. If the school bursar approves, show the class a copy of the school's bill and compare it with their households' usage. Suggest ways in which energy consumption could be decreased at home and at school.

3 Ask the students to make a list of the different electrical appliances they use in a week. They could infer which appliance uses the most energy and suggest why. Remind them about electrical items such as the fridge, heater or oven that they share with other people.

4 Throughout this chapter it is important that the practical equipment is transported and stored in an orderly fashion. This is even more vital if several classes are using the equipment at the same time. Ideally there should be a special trolley or two with a place for the wires, power packs and other components so that they are easily accessible. Appoint reliable students to act as monitors to ensure that the equipment is properly returned at the end of each practical lesson.

Hints and tips

- If you haven't already done so, review some of the main points about electricity such as electron flow, current, voltage, resistance, energy and circuits. Students tend to forget the association the electron has with electricity. It may be worth briefly revising the configuration of an atom (*ScienceWorld 1* page 233).
- Many students need to 'see to believe', and electricity is difficult to 'see'. It is the effects or outcomes of electricity that we usually observe. You cannot physically see energised electrons flowing through a light filament but you can observe their energy output in the form of light and heat. Use as many real-life examples/experiences as you can when teaching this chapter.

Activity notes

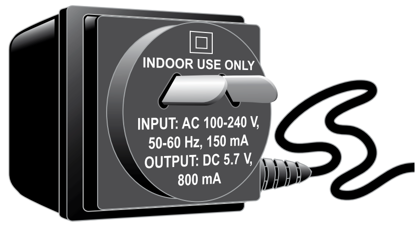
The activity is best done as a teacher demonstration. Use a power pack as it can be used for both DC and AC. Using the power pack also reinforces to the students why they will most often use the DC rather than the AC output when working in the school laboratory.

8.1 Electrical safety

AC and DC

Caitlin has just unpacked the mobile phone she received for her birthday. She notices that it has a rechargeable battery, and it has a cord so she can plug it into a power point to recharge it. However, she is not sure what the things on the recharging plug mean.

When Caitlin connects her mobile to a power point she is using the *mains supply*, with a voltage of 240 volts (or 240 V) AC. The AC stands for *alternating current*, since the current changes direction 50 times a second (50 hertz or 50 Hz). The electric current flows first in one direction and then in the opposite direction. Mains power is dangerous because the high voltage can drive large currents which can kill you. The recharger converts the 240 V AC to 5.7 V DC to charge the battery. The DC stands for *direct current*, where the electric current flows in one direction only.



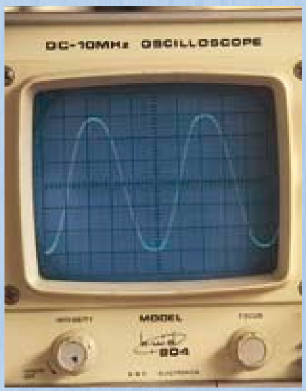
Activity

If your school has a cathode ray oscilloscope (CRO), your teacher may show you the difference between DC and AC.

If you connect a 1.5 volt battery to the CRO, you see a straight line.

If you connect an AC power supply, you see a wave shape. Above the horizontal axis the current is in one direction, and below the axis it is in the opposite direction.

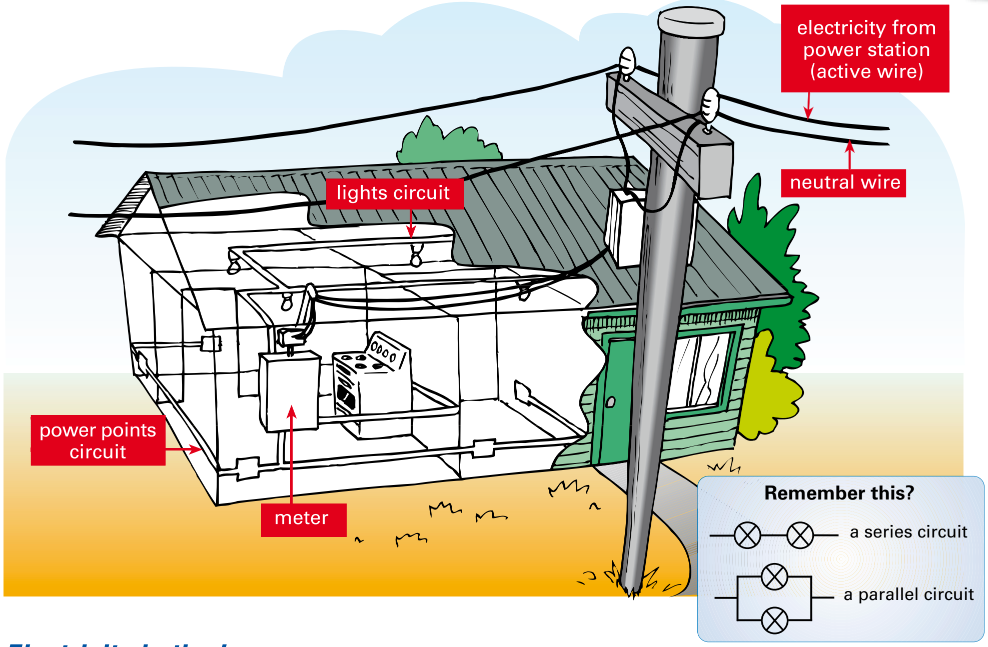
DC



AC

Learning experience

Ask the students to look around the room and at home for any electrical devices that use direct current (notebook computers, other battery-operated devices).



Electricity in the home

Mains electricity is supplied to your home by two wires covered with plastic insulation. The wires are often enclosed in a single cable. One of the wires carries AC electricity into the house and is called the *active* or *live* wire. It alternates between +240 volts and –240 volts. The *neutral* wire (zero volts) completes the electric circuit from the house back to the power station.

Both the live and the neutral wires are connected to a meter box which contains the electricity meters, main switch, and circuit-breakers or fuses. The meter measures how much electricity is used in the house. From the meter box the live and neutral wires branch out to make several different circuits. These circuits carry electricity to the lights, power points, stove and hot water system. Switching on an appliance allows AC electricity to move from the active wire through the appliance and back through the neutral wire.

Houses are usually wired using parallel circuits, as in Fig 5. The advantage of this is that all the circuits can be connected separately to the mains power supply. For example, if a light bulb in one room 'blows' (that is, the circuit is broken) all the other lights in that parallel circuit can still operate.

The meter box also contains circuit-breakers or fuses, which are safety devices in case there is a short circuit. In Investigate 18 you can see how a fuse works.

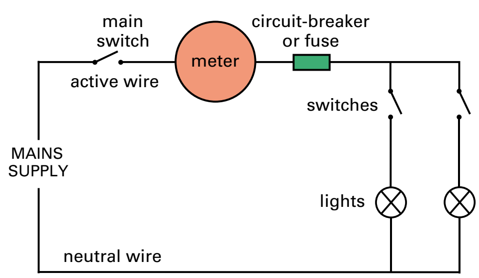


Fig 5 If one bulb blows in this parallel lights circuit, the other bulb continues to work.

Hints and tips

Revise the difference between a conductor and an insulator, giving examples of each.

Homework

On the top of most power poles, there is a box where the wires are connected. Draw students' attention to the diagram at the top of the page, then give them the following homework questions.

1. If you live in a place with overhead power lines, go outside and examine this box more closely, but *do not attempt to touch it in any way.* What do you think the box is?
2. If you live in an area with underground cabling, notice that every few streets there is what is called a small substation (usually about 1.5 × 2.5 m). What do you think it is for?
3. High-voltage power lines are the ugly metal pylons you often see in rows on otherwise vacant land. They have street power lines feeding off them. What is the difference between the two types of lines?

Learning experience

In science classes, students often do a lot of cooperative learning, especially when they are performing a practical experiment or investigation. For most tasks, small groups are better to ensure all members contribute.

Devise a set of questions or a thinking problem associated with household wiring/electricity for the students to solve. Encourage cooperative learning but assign the members to groups yourself, so they learn to cooperate with students other than their friends. One possible problem is as follows.

An electrician installed the electrical wiring in a new house so that the lights, power points, electric oven and electric hot water system were all in series. Explain why this is dangerous and incorrect. How should the electrician have wired the house and why?

You could also ask students to discuss what would happen, and why, if there were no neutral wire and earth connections.

Lab notes

If you are using power packs, make sure the power leads are neatly wound around the packs so that they can be stacked safely on the trolleys after use.

Part A

- Insist on the students having switches in their circuits, and make sure they use heatproof mats.
- If the bulb does not light, ask them to approach it as a problem solving activity by checking all components of the circuit.

Part B

It is very important that students wear safety glasses because the wire can 'pop' and spit a small molten piece of metal.

Investigate

18 SHORT CIRCUITS AND FUSES

Aim

To investigate what causes a short circuit and how a fuse works.

Materials

Wear safety glasses.

- power pack or battery
- 4 connecting wires
- switch
- torch bulb in holder
- screwdriver or other conductor
- large rubber stopper
- 2 large pins
- strands of steel wool
- heatproof mat

Planning and Safety Check

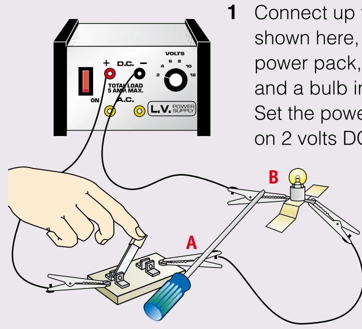
Discuss with your teacher the safety precautions necessary when using a power pack.

Suggest why the circuit has a switch in it.

PART A
A short circuit

Method

1 Connect up the circuit shown here, with a power pack, a switch and a bulb in series. Set the power pack on 2 volts DC.



2 Close the switch. Then carefully touch a screwdriver or other conductor across the alligator clips at A and B. *Immediately you see what happens, take the screwdriver away.*

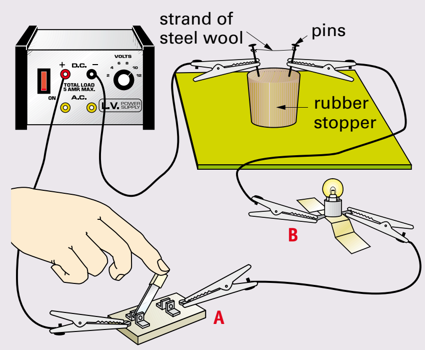
Discussion

1 What you have observed is a short circuit. Describe it in your own words.

2 Infer the path of the electric current:
   a without the screwdriver
   b with the screwdriver.
   Why do you think the path through the screwdriver is called a short circuit?

PART B
Making a fuse

1 Make a simple fuse from a large stopper, two pins and a strand of steel wool. Put it on a heatproof mat as shown.



2 Connect your home-made fuse into the circuit you used in Part A, and close the switch.

3 Again short the circuit across A and B with the screwdriver.
   Observe what happens.
   If nothing happens, increase the power pack voltage slightly.

Discussion

1 Why did the fuse blow in Step 3 but not in Step 2?

2 Why do you think you used a rubber stopper to make the fuse?

Fuses and circuit-breakers

In Part A of Investigate 18 the metal screwdriver was a better conductor of electricity than the filament in the torch bulb. It had less **electrical resistance**. The current therefore took the easier path and flowed through the screwdriver. This path is called a **short circuit**.

Short circuits are very dangerous. If two bare wires touch there may be a spark. Or the wires may become so hot that they cause a fire. So when short circuits occur, you need to cut off the electricity using a fuse or a circuit-breaker.

A **fuse** is a safety device containing a piece of wire that melts if too great a current passes through it. Fuses are used mainly in cars and electronic appliances. They are usually thin strips of metal inside a plastic or glass cartridge, and they snap into clips. Ask an adult to show you the fuse box in a car. It is usually on the driver's side under the dashboard.

Note that there are different fuses for different circuits—for example, lights (10 A), cigarette lighter (15 A), and heater (25 A). A 10 amp fuse will allow a current of up to 10 amps to flow through it before it fuses (melts). A 25 amp fuse will allow a current up to 25 amps. The thicker the fuse wire, the more current it will take before it 'blows'. If a fuse blows you simply replace it with one of the correct value. If it keeps blowing, there is probably a fault in the circuit that needs fixing.

Most homes now have **circuit-breakers** (Fig 9) instead of fuses. If too much current flows, the circuit-breaker automatically turns off the electricity. This happens if a household circuit becomes overloaded, for instance when you are using several appliances already, then plug in another such as an electric heater. Circuit-breakers are more convenient than fuses since you do not have to replace any wires. Once the cause of the short circuit has been fixed, you simply switch the circuit-breaker on again.

Fig 8 The fuse box in a car. Notice that there are different fuses for different circuits. There are also several spare fuses.

Fig 9 The circuit-breakers in a meter box. If there is a fault in a particular circuit, that switch automatically turns off.

Hints and tips

- Revise the concept of electrical resistance and suggest why most electrical appliances are considered to be resistors.
- By law, every new house has to have a circuit-breaker instead of using the old-fashioned fuses. If too much current flows, the circuit breaker automatically 'breaks' the flow of electricity and the power is shut off. Is a circuit-breaker safer than a fuse? What are the different types of circuit-breakers (magnetic, thermal and thermomagnetic)? Discuss these questions in class or ask students to investigate the answers. (Page 172 has an illustration of a thermal circuit-breaker.)
- Reinforce the difference between a short circuit, fuse and circuit-breaker.
- Throughout this chapter, quiz the class on terms and definitions to do with electricity. By the end of the chapter they should be familiar with the following: electron flow, current (AC and DC), voltage, resistance, conductor, insulator, short circuit, fuse, circuit-breaker, circuits (series and parallel), Ohm's law, power, energy and transformers.

Learning experience

Show students examples of old house fuses and overload safety switches. You should be able to find safety switches somewhere in or near the laboratory. Explain why fuses have different gauges, and the importance of using the correct gauge wire when changing one.

Hints and tips

It is important that all electrical appliances are properly earthed, otherwise the user is likely to become the 'earth'! Explain the importance of not sticking things into power points and take this opportunity to go over other safety aspects.

Earthing

Most electrical appliances have three-pin plugs. The longer pin is called the *earth*, because it is connected to the ground (earth). You may be able to find the **earth wire** connected to a metal water pipe or stake outside or under your house somewhere.

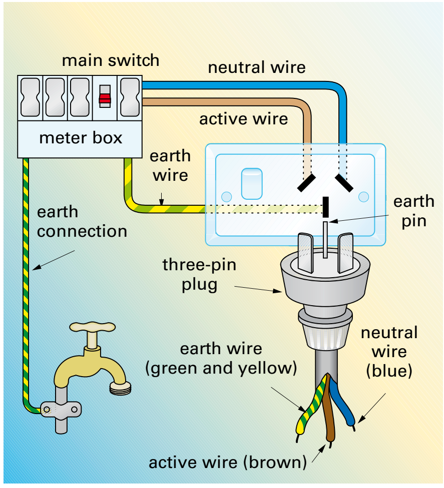
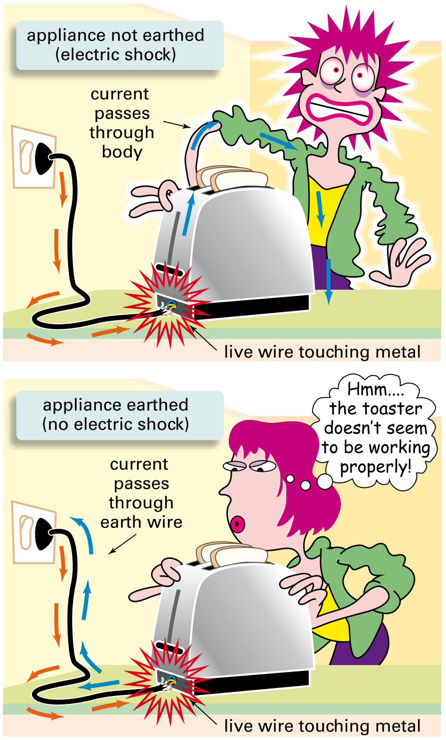


Fig 10 A three-pin plug and power point showing how the earth wire is connected



Because metals are such good conductors of electricity, electrical appliances with a metal case, such as washing machines and toasters, must be earthed to protect you from electric shocks. With no earth wire, if the live wire loses its insulation and touches the metal case, current will flow through the live wire via the case and through your body, and you will receive an electric shock. The earth wire is attached to the metal case and normally carries no current. But if there is a short circuit, current flows harmlessly from the live wire through the earth wire to the ground and you don't receive an electric shock. The circuit-breaker in the meter box will probably switch off, since too much current has flowed through the appliance.

Many appliances such as portable radios and hair dryers are made with no external metal parts. They are instead totally surrounded by plastic, which is an insulator. This insulation is sufficient to protect you even if a fault occurs. Such appliances are said to be *double-insulated*, and have the double-insulation symbol ⧈ marked on them. (See the information on the plug for Caitlin's mobile phone charger on page 166.) These appliances do not need an earth and have a two-pin plug instead of the normal three-pin plug.

You should also keep in mind when using electrical appliances that water will conduct electricity. For this reason you must be extra careful using electrical appliances in places where water is likely to be spilt, eg in the kitchen, laundry or bathroom.

Homework

- Ask students to find out where the earth wire is located at the place they live. Older houses have the earth wire attached to a water tap on the outside of the house, while for new homes a metal stake (most often copper) is usually placed in the ground in the vicinity of the meter box.
- Ask students to list the appliances they use that have three prongs and two prongs. Are all two-pronged appliances totally plastic on the outside, with no metal parts? What about three-pronged appliances—which outside part is metal and why?

Learning experience

Pass around the class a cut-off electrical plug with splayed insulated wires for the students to observe. *Under no circumstances should they attempt to put the plug in a power point.*

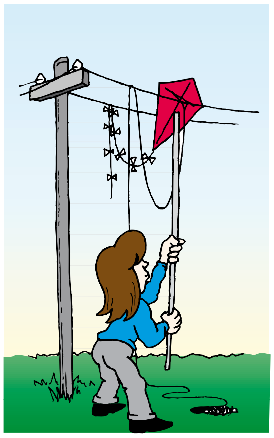
Learning experience

Students could dismantle some old electrical appliances (with their 240 V plugs removed). The ICT department is bound to have a broken computer and the science department is likely to have a broken electric kettle or other appliance kept for such a use.

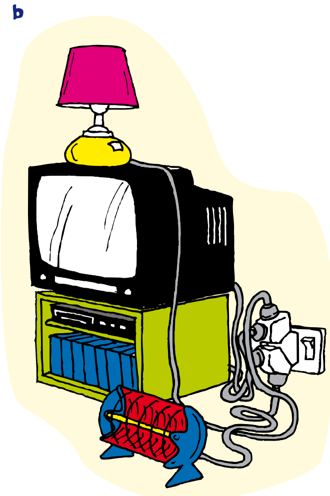
Check!

1 Explain what is dangerous about each of the situations shown.

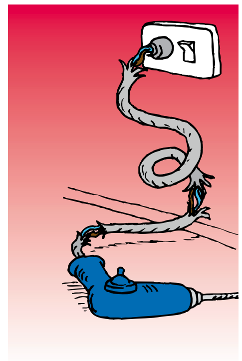
a



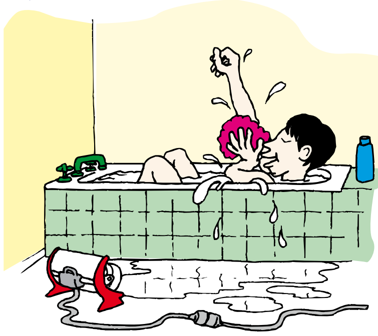
b



c



d



2 **a** Why is it that some appliances have a three-pin plug and some have a two-pin plug?

b Suppose a toaster has a metal case. Would you expect it to have a three-pin plug or a two-pin plug? Explain.

c To which part of the toaster would you expect the earth wire to be connected?

3 What is the meaning of the number 15 marked on a fuse or circuit-breaker?

4 What would happen if the live wire in a double-insulated hair dryer touched the plastic case?

5 Light circuits usually have an 8 amp circuit-breaker, and power circuits a 15 amp one

a What might happen if you put an 8 amp circuit-breaker in a power circuit?

b What might happen if you put a 15 amp circuit-breaker in a light circuit?

c Which mistake would be more dangerous—**a** or **b**? Why?

6 What is the advantage of having Christmas tree lights connected in parallel?

7 Stupid Sparky said: 'Fix a broken car fuse with anything—a nail, a piece of wire or a coin. It's too much trouble to get the proper fuses. And they don't blow again when you put thick wire or nails in them.' Explain why Stupid Sparky is being so stupid.

Check! solutions

1 These situations are dangerous because:

a The kite will be carrying some electricity between the two wires. If the pole is metal, or even green or wet wood, then electricity will be conducted to the earth, which could cause electrocution.

b When too many appliances are plugged into the same plug too much electricity will flow in the circuit. This will cause the fuse to blow or the circuit-breaker to switch the electricity off.

c Frayed cords like this could allow any of the three wires to make contact with any other. This could cause a short circuit and the possibility of electrocution.

d The water spilling from the bath could come in contact with the electric radiator or the plug and cause a short circuit and the risk of electrocution.

2 a The third pin in a plug is connected to an earth wire which will carry electricity away from the appliance if there is an electrical fault. Some appliances with a plastic case have only two pins without an earth wire because they are double insulated for safety.

b A metal toaster will have a three-pin plug because the metal case is a conductor and any electrical fault could cause electrocution of the user.

c The body or outside of the toaster will be connected to the earth wire because this is the part which the user would be touching.

3 The number 15 on a fuse means that the maximum current which can be carried by the fuse wire before it melts or 'blows' is 15 amps.

4 Since plastic is not a good conductor of electricity the case will not become charged and there is no danger to the user of the hair dryer. However if the hair dryer is being used in a very humid bathroom and has water on or in it, this is a dangerous situation since water will conduct electricity.

5 a If an 8 amp circuit-breaker was placed in a power circuit it would blow very easily because it cannot carry very much electricity.

b If you put a 15 amp circuit-breaker in a light circuit it would never blow because lights don't use as much electrical current as electrical appliances.

c Situation **b** is more dangerous because there is really no protection in the case of an electrical fault since the fuse will not blow.

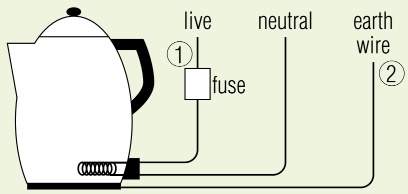
6 The advantage of having all the lights in parallel is that if one bulb blows or is broken the other lights will stay on. With a series arrangement, if one goes off they will all go off.

7 Stupid Sparky does not understand that fuses are safety devices which will blow if there is too much electricity flowing through the wires. Using a nail, coin or piece of wire instead of a fuse would allow too much current to flow in the circuit and Stupid Sparky could be electrocuted.

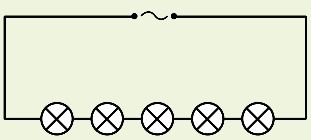
Challenge solutions

1 Jordan has shown that the toaster is faulty. He should not use it again until it has been checked by a qualified electrician.

2



3 a



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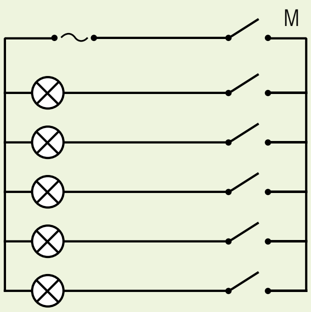
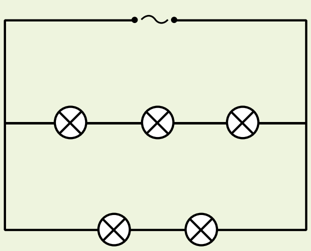


With switch M closed each of the lights can be switched independently. With switch M open they will all go off.

c



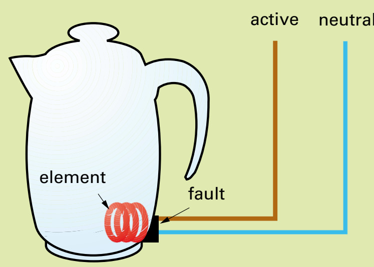
… and there are several other possibilities.

4 When too much electricity flows through the circuit the bimetallic strip heats up. When it heats up it bends towards the right and falls into the groove of the horizontal strip. When it does this, the spring pushes the horizontal strip upwards and breaks the contact with the wire underneath.

challenge

1 When Jordan plugs a toaster into a power point and turns it on, the power goes off. He finds that the circuit-breaker has switched off, so he turns it back on. He then turns the toaster on again, but the circuit-breaker switches off again. What should Jordan do next? Why?

2 The diagram below shows a kettle with a fault: the active wire is touching the metal case, causing it to be live. Copy the diagram and add two safety devices that would protect someone using the kettle.



3 Draw a circuit containing an AC power source (symbol —⊝—) and five light bulbs:

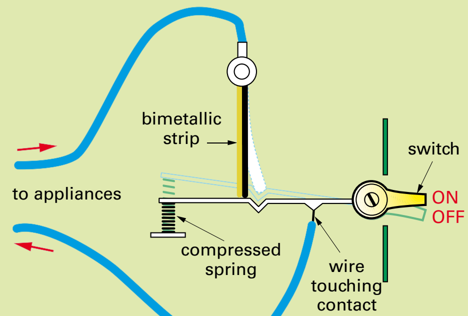
a in series

b in parallel

c some in series and some in parallel

For **b**, put in switches to turn each light on and off independently, and one that will turn them all on and off together.

4 Use the diagram below to explain how this type of circuit-breaker works. The bimetallic strip consists of two different metal strips, one of which expands more than the other when it becomes hot.

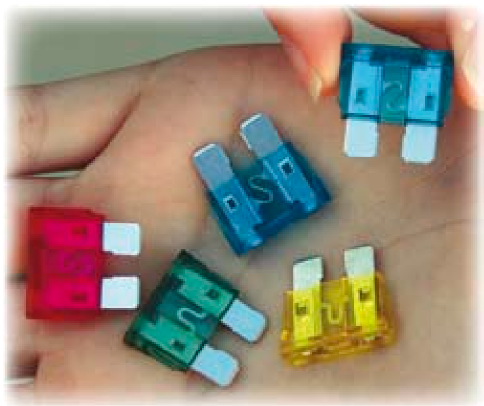


try this

1 Obtain some old electrical plugs, sockets and switches that are no longer being used. Examine them carefully and try to explain how they work. You could also pull apart an old electrical appliance such as a toaster, iron or radio—*with its 240 V plug removed*. See if you can identify any of the parts. Can you put the appliance back together correctly?

2 Look at some car fuses or fuse wires. Note the relationship between the thickness of the wire and the current that will pass through it.

3 Design a poster to draw people's attention to the hazards in using mains electricity.



8.2 Measuring electricity

Current, voltage and resistance

Before you can measure the electrical energy used by household appliances you need to be able to measure the current and voltage in a circuit. The diagrams below show how you can use the flow of water through pipes for a swimming pool as a *model* to explain the flow of electricity in an electric circuit.

In the water circuit you can measure the rate of flow of the water. In the electric circuit you can measure the electric current (I), which is a movement of electrons. Electric current is measured in amperes (or amps for short) using an **ammeter**. One ampere is about 6 000 000 000 000 000 000 electrons moving past a point every second. The electric current is the same everywhere in the circuit, so it does not matter where you connect the ammeter, so long as it is in series with the resistance and the battery.

In the water circuit the pump pushes the water around the circuit and has to overcome the resistance of the pool filter. In the electric circuit the battery supplies the electrical 'pressure' (voltage V) to push the current through the light bulb. The higher the voltage, the more current is forced around the circuit. As the electrons are pushed through a resistor (eg a bulb or a piece of wire) they lose some of their energy as light and heat. As a result there is a drop in voltage across the resistor. This is measured in volts using a **voltmeter**. Note that because you are measuring a *difference* in voltage, you must connect the voltmeter in parallel across the part of the circuit whose voltage you want to measure.

Insulators like plastic do not allow an electric current through them easily. They have a high resistance. On the other hand, metals and other conductors have a low resistance, although some metals have a higher resistance than others. For example, the nichrome wire used in heating elements and the thin tungsten wire used in light bulbs have a higher resistance than the copper wire used in electrical wiring. The resistance of wire also depends on its length, thickness and temperature. When measuring resistance you use a unit called the **ohm**. (Ohm rhymes with 'home' and its symbol is the Greek letter omega Ω.)

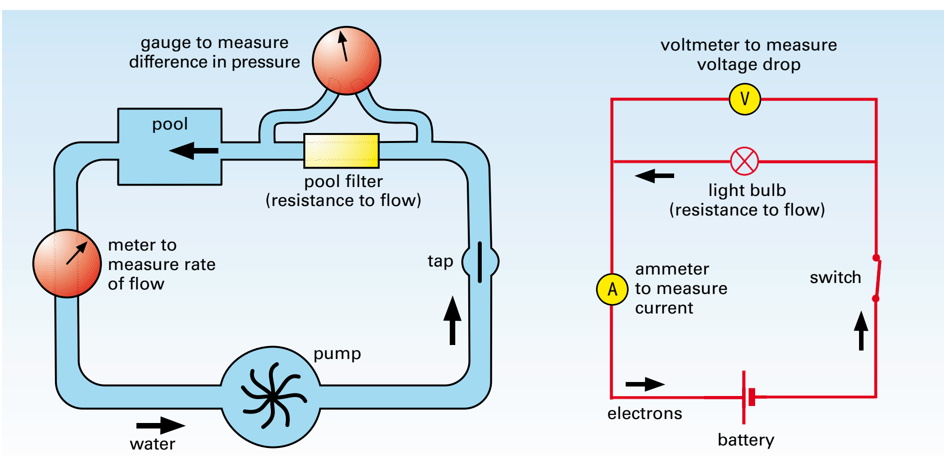


Fig 16 A water circuit for a swimming pool is similar to an electric circuit.

Hints and tips

- Revise current, voltage and resistance and show how each is measured in a circuit. The Learning experience on page 244 of *ScienceWorld 1 Teacher Edition* is a great way to do this revision. Even if the class has done it before, consider doing it again as the modelling activity helps to strengthen concepts—and the students find it fun.
- When explaining the idea of a *difference* in voltage it may be appropriate to explain why it is also called *potential difference*. Use the analogy of a skier moving up and down a snowy slope:
  1. As the skier moves up the slope on the ski lift, they gain potential energy.
  2. When the skier skis down the slope, the extra energy they had at the top is converted into kinetic energy as the skis interact with the snow.
  3. The difference between the top and bottom of the slope represents the voltage. The skier represents the electron, the snow represents the resistor, and the energy is supplied by the lift.
  4. To measure the difference between the top and the bottom, you subtract the bottom figure from the top figure. So to find the potential difference you have to connect a voltmeter in parallel with the resistor, with one wire connected to the higher voltage end of the resistor and the other wire to the lower voltage end.

Learning experience

Get the students to design an instruction poster explaining the features of a simple series circuit. Their explanation should include:

- a detailed diagram of a circuit, with annotated notes describing the role of each part
- the electrical quantity measured
- how to measure this electrical quantity.

Hints and tips

- Doing an investigation or experiment before learning the theory promotes students' self-learning. The investigation of Ohm's law (page 175) lends itself very well to this. Encourage students to analyse and interpret their results. Most students will be able to express the relationship in words, and some mathematically.
- Spend adequate time with students who are struggling with the mathematics of Ohm's law, but do not dwell too much on it with the whole class unless you feel it is required. To extend gifted and talented students, give them a practical application task, such as examining a non-ohmic device.
- Students may need to use calculators for this section, so be prepared. Have enough for the students to share if they do not have their own.

Skillbuilder notes

Drawing lines of best fit in Excel can be quite a tricky process for the students to understand. Sometimes it is quicker and easier to construct graphs by hand rather than use technology.

Animation

Students should view the animation *Drawing a line of best fit* on the CD.

Ohm's law

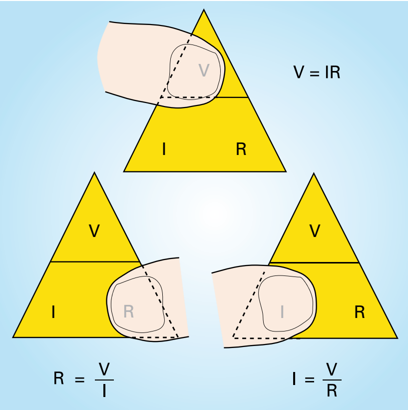
In 1826 the German scientist Georg Ohm investigated how voltage, current and resistance in an electric circuit are related. He discovered that if you double the voltage across a conductor, twice as much current will flow through it. Three times the voltage produces three times the current, and so on. This discovery came to be called **Ohm's law**. *The current flowing through a conductor is proportional to the voltage difference between its ends.*

For a given conductor, the ratio V/I is constant. This ratio is the resistance (R) of the conductor. It is the resistance of the conductor that determines whether the current in a circuit is large or small. Ohm's law can be written as an equation:

$$\frac{\text{voltage}}{\text{current}} = \text{resistance} \quad \text{or} \quad \frac{V}{I} = R$$

This can be rearranged to give $V = IR$

A simple way to rearrange equations is to write the three variables in a triangle as shown. Cover the symbol that stands for what you want to find, and the other two symbols tell you how to calculate it. Other maths equations can be rearranged in the same way.



Suppose you have a 4 ohm resistor connected to a 12 V battery. You can find the current in the circuit as follows:

$$I = \frac{V}{R} = \frac{12 \text{ volts}}{4 \text{ ohms}} = 3 \text{ amps}$$

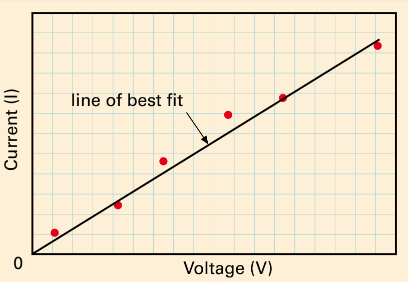
In Investigate 19 you can test Ohm's law for yourself.

Skillbuilder

Drawing lines of best fit

Suppose you graph your results from an investigation into the relationship between two variables, as shown. In this case the points lie roughly on a straight line. For this reason it is best to draw a **line of best fit**, rather than joining all the points. A line of best fit averages out any errors in your measurements. It shows the general trend of all the measurements.

Drawing lines of best fit takes practice. The line need not go through all the points, but it should pass as close as possible to all the points. As a guide, there should be about as many points above the line as below it. To draw the line, use a plastic ruler that you can see through. Also, use a pencil so you can rub the line out if you are not happy with it.



For an animation of this, click on **Drawing a line of best fit** on the CD.

Working with technology

Learning experience

On the board, write some simple, everyday examples/questions where the students can apply Ohm's law. Make sure that with some questions they have to rearrange the formula. In your examples use appliances like a toaster, hair dryer, phone charger or torch.

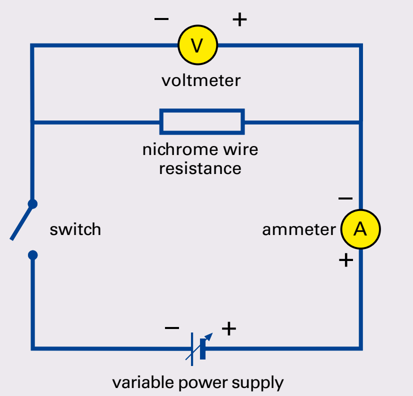
Investigate 19 OHM'S LAW

Aim

To find out how voltage, current and resistance in an electric circuit are related.

Materials

- power pack
- piece of nichrome wire (jug element wire) about 50 cm long or small resistor (eg 20 Ω)
- voltmeter and ammeter or 2 digital multimeters
- switch
- 6 connecting wires, with alligator clips
- heatproof mat



Planning and Safety Check

You must prepare well for this investigation, so read it carefully before you start.

- Discuss with your partner(s) how you will connect the voltmeter in the circuit.
- How will you connect the ammeter?

Draw up a data table like the one below.

Power supply setting (volts)	V Voltmeter reading (volts)	I Ammeter reading (amps)	$\frac{V}{I}$ (ohms)

Working with technology — **Teacher note:** Students could do this investigation using the computer program *Crocodile Clips*.

Method

1. Set up an electric circuit as shown top right, with the nichrome wire on a heatproof mat. Connect the ammeter in series with the nichrome wire. Connect the voltmeter in parallel with it. Make sure that the positive terminals of the ammeter and voltmeter are connected to the positive side of the power pack as shown.
2. Set the power pack to 4 volts DC. Close the switch and read the voltmeter and ammeter as quickly as possible. (If you leave the switch closed for too long the nichrome wire becomes hot, and this changes its resistance.)

Do not turn on the power pack until your teacher has checked your circuit.

Record the voltage V and current I in your data table.

3. Repeat the measurements for a number of different power pack settings less than 4 volts: say 3, 2, 1.5, 1 and 0.5 volts. Allow plenty of time between readings for the wire to cool. Record all results.
4. Plot current I (vertical axis) against voltage V (horizontal axis) on graph paper.

Discussion

1. If you increase the voltage, what happens to the current? If you double the voltage, what happens to the current?
2. Use your graph to predict the current for some voltages you did not test, eg 2.5 volts, 5 volts. Test your predictions.
3. Complete the data table by calculating the values for voltage divided by current. As the voltage and current change, what do you notice about V/I ?
4. Suggest why the plotted points are not all exactly on a straight line.

Hints and tips

Students often get confused with rearranging Ohm's law to find the resistance. In this investigation, voltage is the independent variable and current is the dependent variable. When the students construct the graph from their data, it may be more appropriate to ask them to draw a current versus voltage graph, which allows them to better define the relationship between current, voltage and resistance. The gradient of the line is the electrical resistance. Make sure the students understand that this is an exception to how they would normally construct a graph with the independent variable plotted on the horizontal axis.

Lab notes

- If you use multimeters, print out a simple set of instructions showing how to use them. Have a class set laminated and keep them with the meters for all classes to use. One side can have the instructions for using it as a voltmeter, while the other side has instructions for using it as an ammeter (with diagrams). A separate set of laminated instruction sheets could be made for using it to measure resistance.
- For ease of maintenance, it is a good idea to:
  - have only one type of lead (crocodile-banana would suit, especially if multimeters are used)
  - have a tub or box labelled 'Faulty equipment' so any damaged or faulty items can be put to one side for repair or replacement.
- Check each group's circuit construction before they turn the power supply on. Remind the class how the ammeter and voltmeter are to be placed in the circuit.
- Instruct students to make the reading within a few seconds and then turn the power off so that the wire does not get too hot. This is not only a safety hazard but can lead to changes in the resistance and consequently changes in the current. It is important that they use a switch in their design.
- Students who race through the investigation could do an extension activity, such as repeating the readings using a different-sized resistance.
- Students will probably need to use calculators for their results table.

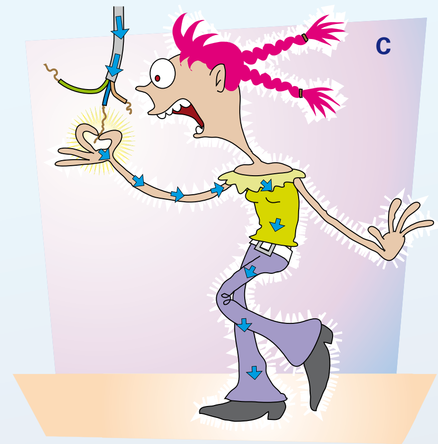
Hints and tips

This is a very important section so spend time explaining it carefully.

Electric shocks

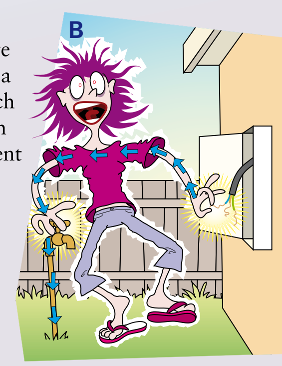
An electric shock is caused by an electric current passing through your body. The muscles in your body are triggered by small voltages in the nerves. Your nervous system cannot cope with larger voltages and currents, and the muscles suddenly contract or spasm. Your heart may also spasm or even stop.

The larger the current the more painful and serious the shock. In general, if there is a large voltage and a small resistance, then the current will be large. The mains voltage is always 240 *V*, but the resistance of the human body varies. The diagrams on this page show three different situations.



In **A** the person touches the live wire with one hand and the neutral wire with the other hand. If his hands make good contact he will have a low resistance and the current through his body will probably be fatal. This is called *electrocution*.

In **B** the person touches the live wire with one hand and a good conductor such as a metal pipe with the other. The current that flows through her body will again probably be fatal.



People normally get shocks when they touch just the live wire, as in **C**. If the person is wearing rubber shoes or standing on a plastic floor, her resistance could be as high as 10 000 ohms. This means the current through her body would be 0.024 amps:

$$I = \frac{V}{R} = \frac{240}{10\,000} = 0.024 \text{ amps}$$

However, if she is barefoot and standing on a concrete floor her resistance could be as low as 1000 ohms, giving a fatal current of 0.24 amps. The severity of the shock also depends on which part of your body the electricity travels through. A current of 0.01 amps can flow harmlessly from one finger to another, but the same current through your heart is nearly always fatal. The presence of water reduces resistance and so increases the danger of serious shocks.

If you see someone who has suffered an electric shock, it is essential that you don't get shocked yourself. First switch off the electricity and push the person away from the appliance or wire using an insulator such as a wooden broom handle. If the person is unconscious, call an ambulance. If their breathing or heartbeat has stopped, they must be given mouth-to-mouth resuscitation and heart massage.

Homework

Design a safety poster or brochure highlighting the dangers of using faulty electrical devices and explaining how to use equipment safely. Creative students could be challenged to come up with a comic strip.

Learning experience

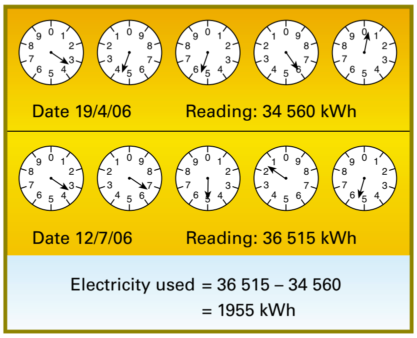
In relation to electric shock, you may have heard the phrase: 'It's not voltage that kills you—it's current!' Ask the students to investigate this statement and explain their response using Ohm's law. Consider how a person can increase their electrical resistance (eg what sort of shoes do electricians wear?). The students can access the internet or school physics books which have sufficient information.

Here is a possible response to the statement:

> If voltage presented no danger, why are there so many signs warning of high voltage? Saying 'current kills' is basically correct since it is the electric current that burns tissue, freezes muscles and fibrillates the heart, causing uncoordinated quivering. Yet a high current is caused by a high voltage and low electrical resistance to current. Although everyone's body is different, in general we have a low resistance to current, meaning it is easy for a current to pass through it. From Ohm's law we can say that the greater the resistance the smaller the current if voltage is kept constant (inverse relationship); and the higher the voltage the greater the current if the resistance is kept constant (direct relationship).
>
> The current through your body equals the voltage applied between two points on your body (entry and exit points) divided by your body's resistance between the points. So the more voltage applied means it is easier for the electrons to flow through any given resistance, and thus the danger of high voltages. High voltage means the potential for large amounts of current through your body, which can cause injury or death. So the more resistance your body offers (eg by putting on rubber-soled shoes), the slower the flow of electrons for any voltage, and the less current.

Paying for electricity

Electricity is just one form of energy. What we consume when we use electrical appliances is not voltage or current, but energy. So, when we pay for electricity we are charged for the amount of electrical energy we have converted into other forms. Electricity is sold in energy units called **kilowatt-hours** (**kWh**). The number of kilowatt-hours that you use at your house is measured by the electricity meter, as shown.



Different electrical appliances use different amounts of electrical energy, as shown in the table. The rate at which an appliance uses energy is called its **power**, and this is measured in **watts W** (joules per second). The higher the wattage of an appliance the more it adds to your electricity bill. For example, a 1000 watt bar heater uses electrical energy twice as quickly as a 500 watt heater. One kilowatt is 1000 watts, so a kilowatt-hour is 1000 watts used for 1 hour (or 500 watts used for 2 hours).

Appliance (operating at 240 volts)	Power rating (watts)
calculator	0.0003
clock	5
portable radio	12
light bulb	60
personal computer	100
television set	200
refrigerator	400–500
electric drill	500
toaster	1000
bar heater (small)	1000
hair dryer	1500
hotplate (on stove)	2000
dishwasher	2500
hot water system	3000

Hints and tips

- The rate of using electrical energy is the power, which is measured in watts. If you use a 60 W light bulb it uses 60 watts of electricity. A television set uses about 200 watts and a hair dryer about 1500 watts. The watts quickly add up, so a more practical unit called the kilowatt (1000 W) is used.
- However, we need to consider how long we use the appliance to work out how much energy is consumed. The unit used for measuring energy in this case is the kilowatt-hour. The amount of energy consumed by a 1000 W appliance for one hour is one kilowatt-hour.
- We pay for the number of kilowatt-hours we use. If we can reduce this usage, we reduce our electricity bill, and consequently our greenhouse gas emissions.

Learning experience

If you have not already done so, ask the class to bring in an electricity bill from home to discuss. Ask them to list ways their electricity usage could be reduced: personally, as a household, and as a school. Now ask the class to devise a 'Reducing electricity action plan' that they can take home to discuss with their household. Keen class members may like to form a school action plan group to assist in educating other year levels in ways to reduce electricity usage.

Learning experience

Design a table for the students to fill in, tabulating their electricity usage over a full week. They should include the following column headings:

- Appliance (operating at 240V)
- Power rating
- Time appliance was used for
- Energy used.

Discuss with the class how to calculate the amount of energy used, and which units are appropriate. This activity leads nicely into the Skillbuilder on page 178.

Skillbuilder notes

This chapter has a few mathematical formulas that the students need to remember. It is a good idea to revise these equations in each lesson. Hand out slips of paper with about three mathematically based questions on them for students to complete at the start of the lesson, or for homework.

Assessment task

This would be a good place to set *Assessment task 8: Saving electricity*, found on the CD.

Skillbuilder

Using equations

The price charged for electricity depends on how much you use and when you use it. The night rate is much cheaper because the demand for electricity is less then. To calculate the energy used by an appliance you use the equation:

energy = power × time *or* $E = Pt$

Note that you must use the correct units for the variables. If you want the energy in kilowatt-hours, then the power of the appliance must be in kilowatts (not watts), and the time the appliance is used must be in hours (not minutes or seconds).

Suppose a 200 watt television set is used for 5 hours. The energy used by this appliance is calculated as follows:

$$P = 200 \text{ watts} = 0.2 \text{ kilowatts}$$
$$t = 5 \text{ hours}$$
$$E = Pt = 0.2 \text{ kilowatts} \times 5 \text{ hours}$$
$$= 1 \text{ kilowatt-hour}$$

The voltage and power rating marked on appliances allow you to calculate the operating current, using the equation:

power (watts) = voltage (volts) × current (amps)
***or* $P = VI$**

As an example, a microwave oven operating at 240 volts has a power of 600 watts. To calculate the current it uses you need to rearrange the equation as follows:

$$I = \frac{P}{V} = \frac{600 \text{ watts}}{240 \text{ volts}} = 2.5 \text{ amps}$$

Appliances like electric stoves use electrical energy very quickly, using large currents. They therefore need thicker wiring and larger amperage circuit-breakers.

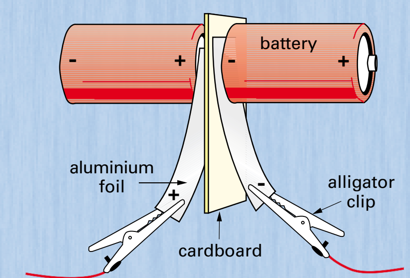
Learning experience

A practical activity the students can do is to make a water heater and calculate its power output. Use a piece of nichrome wire coiled up in a beaker of water. Carefully attach crocodile leads to the resistor (heating element) and then to a power pack. Remind the class about appropriate safety procedures. The students will need to develop their own experimental method.

Activity

You can measure the power of a portable radio as follows.

1 Count the number of batteries to find the DC voltage of the radio.
2 Cut a piece of aluminium foil about 20 cm x 8 cm. Fold it three times lengthwise to give it extra thickness. Then cut it in half to give two strips each 10 cm long. Finally cut a piece of cardboard about 10 cm x 2 cm.
3 Put one piece of foil either side of the cardboard strip. Have someone push and hold apart two of the batteries in the battery compartment of the radio. Push the strips into this gap.



4 Pull the aluminium strips apart and use alligator clips to connect them to an ammeter. (Remember to connect positive to positive.)
5 Switch on the radio and measure the current with:
   a no station tuned in
   b a station on low volume
   c a station on high volume
6 Use the equation P=VI to calculate the power under these different conditions.
7 If the radio has a CD or cassette player you could also measure the power needed to play CDs or to record tapes.

Check!

1 Copy and complete this table in your notebook.

	Symbol	Unit	Measured using…
Voltage			
Current			
Resistance			

2 Copy and complete the following sentences
   a All materials offer some ______ to the flow of electricity.
   b A conductor has ______ resistance and an insulator has ______ resistance.
   c If the resistance in a circuit is increased the current ______.

3 Copy the following table into your notebook and use Ohm's law to complete it.

Voltage (volts)	Current (amps)	Resistance (ohms)
–	5	3
6	3	–
240	–	20
110	–	19

4 A toaster connected to the household 240 volt supply has a current of 4 amps flowing through it. What is the resistance of the heating element in the toaster?

5 How many kilowatt-hours of electricity are used by the following appliances:
   a a 120 W ceiling fan, used for 12 hours
   b two 60 W electric blankets, used for 9 hours
   c a dozen 40 W fluorescent lights, used for 5 hours
   d a 1500 W hair dryer used for 10 minutes

6 Use the table on page 177 to answer these questions.
   a Which appliance uses the most electrical energy per second?

Check! solutions

1

	Symbol	Unit	Measured using …
Voltage	V	volts	voltmeter
Current	I	amperes (amps)	ammeter
Resistance	R	ohms	both above

2 a All materials offer some *resistance* to the flow of electricity.
   b A conductor has *low* resistance and an insulator has *high* resistance.
   c If the resistance in a circuit is increased the current *decreases*.

3

Voltage (volts)	Current (amps)	Resistance (ohms)
15	5	3
6	3	**2**
240	**12**	20
110	**5.8**	19

4 Using Ohm's law ($R = \frac{V}{I}$) you can calculate that the resistance of the heating element is $\frac{240 \text{ volts}}{4 \text{ amps}} = 60\Omega$

5 In each of these, students should convert the power rating to kilowatts and the time to hours.
   a 0.12 kW × 12 h = 1.44 kWh
   b 2 × 0.06 kW × 9 h = 1.08 kWh
   c 12 × 0.04 kW × 5 h = 2.4 kWh
   d 1.5 kW × 0.17 h = 0.25 kWh

6 Using the table on page 177:
   a The hot water system uses the most electrical energy per second.

b The heater is the most expensive appliance to be left on.
c The most likely appliances to be run from batteries are the calculator, clock and portable radio. They all have very low power consumption.
d Both of these appliances have a very high power rating which means that a large current flows when they are switched on. They have their own circuit and circuit-breaker because if this much electricity was to flow through smaller appliances they could be damaged.

7 Each hotplate is 2000 W or 2 kW. Four hotplates will have a total power rating of 8 kW. If they are used for 30 minutes (½ hour):
Electricity used = power (kW) × time (hrs)
$= 8 \times \frac{1}{2} = 4$ kWh

8 The reading is 4613 kWh.

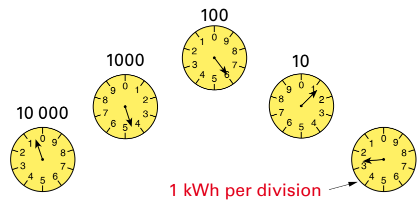
9 The power consumption is
0.3 kW × 365 × 3 h = 328.5 kWh
The cost at 15 cents/unit is
328.5 × \$0.15 = \$49.28

10 a The 'lead' with the greatest resistance will allow the smallest current; it is '4H'.
b The 'lead' with the highest amount of graphite will have the lowest resistance and allow the highest current; it is '3B'.

b Which is more expensive—leaving on a light, a TV or a bar heater for the same length of time?
c Which appliances are run by batteries? What do you notice about their power consumption?
d Why do stoves and hot water systems have their own circuit and circuit-breaker?

7 When cooking dinner Kaori used four hotplates (each 2000 watts) for 30 minutes. How much electricity did she use (in kWh)?

8 What is the reading on this electricity meter?



9 A family turn their TV set on for about 3 hours per day. The power rating of the TV is 300 watts. On the basis of a cost of 15 cents per kWh, calculate the cost of running the TV for a year.

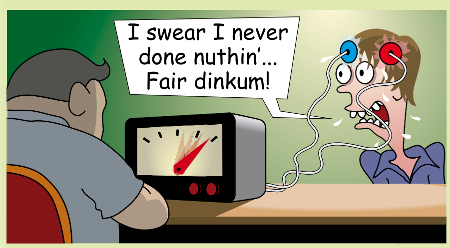
10 Ngoc tested how well different types of pencil 'lead' of the same length and thickness conduct electricity. His results are shown:

Type of 'lead'	Electric current (amperes)
4H	0.03
HB	0.10
3B	0.70

a Which type of 'lead' has the greatest resistance?
b Pencil 'leads' contain graphite, which is a conductor. Which type of pencil 'lead' would you infer contains the most graphite?

challenge

1 Explain why the element in a toaster becomes red hot, while the wires connecting the toaster to the mains power supply remain cool.
2 One of the things that 'lie-detectors' measure is skin resistance. Lying is supposed to make you sweat. How do you think a lie-detector works?



3 a A person with wet hands has a resistance across his chest of 2500 ohms. Would it be dangerous if he touched the terminals of a 12 V battery with both hands? (Assume that a current of 0.01 amps through your heart is fatal.)
b If his hands are dry, then the resistance is about 100 000 ohms. Would he still be in danger?
c A person with sweaty hands has a resistance across her chest of 2400 ohms. If she touched a 240 V live wire would she be in danger?
d Draw a person's body and in colour show a path that a current of 0.1 amps might take in an accident which would not be too dangerous. Use a different coloured pen to show a path that would be very dangerous. (Hint: see page 176.)

Challenge solutions

1 The metal used for the 'element' of a toaster has a higher resistance than the metal used in the wires. This is why the element heats up and the wires do not.

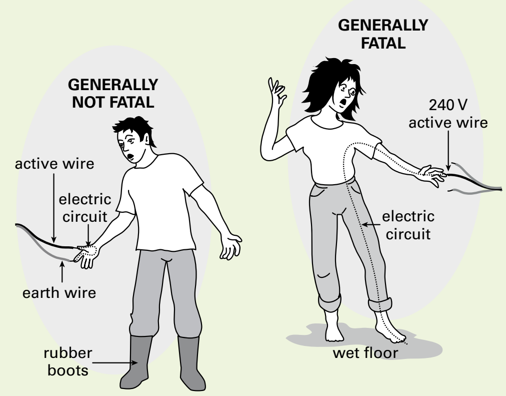
2 If a person perspires or sweats when they are lying the resistance of the skin will be decreased because sweat is a better conductor than dry skin. This means that more current will be conducted between the electrodes of the 'lie-detector'.

3 a Using the formula $I = \frac{V}{R}$
$I = \frac{12}{2500} = 0.0048$ amps
It would not normally be dangerous for a healthy person to do this.

b A higher resistance will mean a much lower current $= \frac{12}{100\,000} = 0.00012$ amps which is certainly not dangerous.

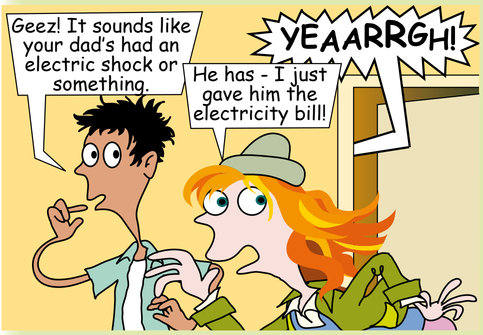
c Using the formula $I = \frac{V}{R}$
$I = \frac{240}{2400} = 0.1$ amps which is certainly very dangerous and could cause electrocution and death.

d



4 The Jones family has just received their quarterly electricity bill, and they have used 2000 kilowatt-hours of electricity. The electricity tariff is as follows:
- first 1020 kWh . . . . . . 14.47 cents per kWh
- balance . . . . 15.27 cents per kWh

a Calculate the Jones' electricity bill.
b Suggest a reason for this type of tariff.
c During summer the Jones' 750 watt swimming pool filter runs for 8 hours each day. Calculate the cost of running the filter for a month.



5 In an experiment to measure the resistance of a piece of nichrome wire the following apparatus was used: a battery, an ammeter, a voltmeter, a switch, the nichrome wire and connecting wires.
a Draw a circuit diagram to show how the apparatus would be set up.
b When the switch is closed the voltmeter reads 6 V and the ammeter 0.5 A. What is the resistance of the wire?
c If a nichrome wire twice as long was used, what do you think its resistance would be?
d What would the ammeter read now?

6 What is the power of an appliance which uses:
a 0.5 kilowatt-hours in 2 hours?
b 1.5 kilowatt-hours in 30 minutes?

7 A 1200 watt microwave oven uses 5.2 amps of electric current. Use the formula $P=I^2 R$ to calculate the electrical resistance of the oven.

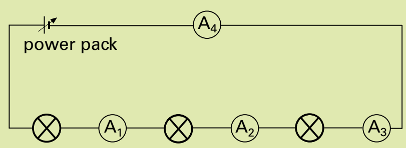
8 A car has four headlights, each with a rating of 36 watts. Two tail-lights, a numberplate lamp and a dashlight are all rated at 6 watts.
a What is the total power needed for the car's lights?
b What current will be drawn from a 12 volt battery?
c What happens when you turn the car's engine off but leave the lights on? Why?

9 Thomas did an experiment to test Ohm's law. His results are shown below.

V (volts)	I (amps)
0	0
1.5	0.12
3.0	0.15
3.5	0.25
4.5	0.30
6.0	0.42

a Thomas thinks one of the current values is wrong. Which one do you think it is? (There are two ways to work this out.)
b What is the resistance of the wire he used?

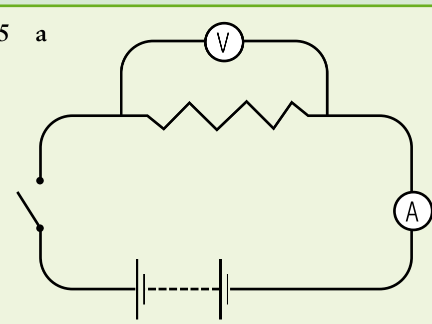
10 The circuit below contains three lamps, each marked 80 W, and four ammeters. The bulbs all glow with equal brightness, and ammeter 1 (A_1) reads 1 amp.
a What do A_2 and A_3 read?
b What does A_4 read?
c What is the voltage drop across each lamp?
d What is the voltage of the power supply?



11 If you change the bulb in a reading lamp from 40 W to 60 W to get a brighter light, will the electric current through the bulb increase, decrease or stay the same? How does the resistance of the 60 W bulb compare with that of the 40 W bulb?

4 **a** The calculation is as follows:
1020 kWh at 14.47c = \$147.59
980 kWh at 15.27 c = \$149.64
Total = \$297.23
b The reason for this type of tariff is that it encourages people to use more electricity rather than use some other form of energy. In other words, the more electricity they use the cheaper it is per unit.
c The number of units used is:
0.75 kW × 30 days × 8 h = 180 kWh
Assuming the lowest rate, the cost per month will be: 180 kWh × 14.47 c = \$26.05

5 **a**



b Using the formula $R = \frac{V}{I}$

$R = \frac{6\ V}{0.5\ A} = 12\Omega$

c Twice the length will mean twice the resistance, which is 24Ω.

d With twice the length of wire, the current as shown by the ammeter will be 0.25 A.

6 The power of the appliance can be calculated using the formula E = Pt and therefore $P = \frac{E}{t}$

The power of the appliances would be:
a $\frac{0.5\ kWh}{2\ h} = 0.25\ kW = 250\ W$
b $\frac{1.5\ kWh}{0.5\ h} = 0.75\ kW = 750\ W$

7 Changing the formula to $R = \frac{P}{I^2}$

$R = \frac{1200\ W}{5.2^2\ A} = \frac{1200\ W}{27.04\ A} = 44.4$ ohms (Ω)

8 **a** The total power needed is (4 × 36) + (4 × 6) = 168 W
b Using the formula $I = \frac{P}{V}$
The current drawn will be $\frac{168\ W}{12\ V} = 14$ amps
c If the lights are left on when the engine is off the battery will go flat and will need to be recharged.

9 **a** The two ways are to calculate $R = \frac{V}{I}$ for each voltage or to draw a graph to see which one does not fit the pattern.
The incorrect value is for 3 volts.
b The resistance of the wire
$= \frac{V}{I}$
$= \frac{6.0\ V}{0.42\ A}$
= 14.3 Ω.

10 **a** All of the ammeters (including A_2 and A_3) are in series and will all read 1 amp.
b As above.
c For each lamp $V = \frac{P}{I}$
$= \frac{80\ W}{1\ A} = 80\ V$
d The voltage of the power supply is 240 V.

11 In this case the brighter bulb will use less current because it has a greater resistance (V = IR).

Hints and tips

An electrical cell is an electrochemical device which stores chemical energy that can be converted into electrical energy. A battery is considered to be an array of similar cells (voltaic) connected in series. Batteries such as 'A' and 'AA' are actually single cells. A 12 V car battery is a series of 2 V cells connected together.

Research

Implement a mini-research project and get the students to investigate how batteries, including rechargeable batteries, work.

- Encourage them to investigate the links between chemistry and electricity.
- Ensure you design the project to minimise plagiarism, and hand out a criteria sheet for the class to follow. Giving students a rubric is a good idea—it can also serve as a marking sheet.
- Incorporate a section or question that requires students to complete a self-assessment.
- Make sure you give meaningful feedback about the project and opportunities for the students to apply the feedback. Even the very good students need information about how they can improve.

8.3 Where does electricity come from?

You can't make electricity from nothing. However, DC electricity can be released from batteries or by using solar cells. AC electricity can be generated using magnets.

Fig 33 The 2005 World Solar Challenge from Darwin to Adelaide was won by the Dutch solar car *Nuna 3*. It averaged over 100 km/h for the race.

Using batteries

Some chemical reactions produce electricity. For example, in a torch battery there is a reaction between the zinc case and the chemical paste it contains. This reaction makes the zinc case negatively charged and the top terminal positively charged. When the cell is connected in a circuit, electrons are pumped out of the cell as shown. The electric current is simply a flow of electrons around the circuit. The electrons lose energy as they pass through the bulb and get it back again in the battery.

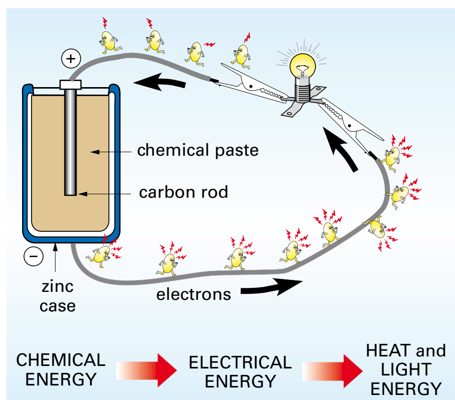


Fig 32 The chemical reaction in a torch battery causes electrons to flow in a circuit.

When the reaction is finished, no more electricity is produced and the battery is 'flat'. If the cell is rechargeable you can pass electricity through it to reverse the reaction. The battery can store this energy until you use it again.

Using solar cells

A **solar cell** is made of almost pure silicon. It produces a small electrical voltage (about 0.5 volts) when exposed to sunlight. If you connect many solar cells together, you can generate enough electricity to power outback telephones, spacecraft, automatic lighthouses, even cars. Because solar cells are fairly expensive, and because you need so many, they are not yet widely used.

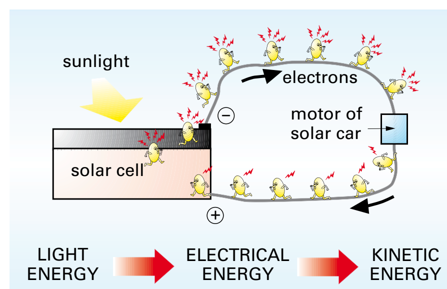


Fig 34 How a solar cell works

Learning experience

Make a 'lemon cell' as a demonstration or class activity by inserting two electrodes made of different metals into a lemon or potato. These will generate small amounts of electricity. (See *ScienceWorld 3* page 283.)

Learning experience

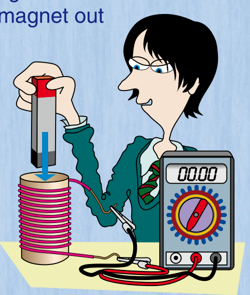
On workstations around the room, set up some different ways electricity is generated, such as solar cells, lemon cell, hand-winding generator, electromagnetic induction, etc.

Using magnets

An electromagnet is a temporary magnet made from a coil of wire wound around a piece of iron. When electricity flows through the wire, it creates a magnetic field around the electromagnet. But can a magnet be used to produce electricity? You can find out in the activity below.

Activity

1. Make a coil by winding two or three metres of thin, insulated wire around a cardboard tube. Hold the wire in place with adhesive tape. Alternatively, use a ready-made coil.
2. Connect the bare ends of the wire to a multimeter or galvanometer. This can measure the direction as well as the size of small electric currents.
3. Plunge a bar magnet into the coil. Then quickly pull the magnet out of the coil.

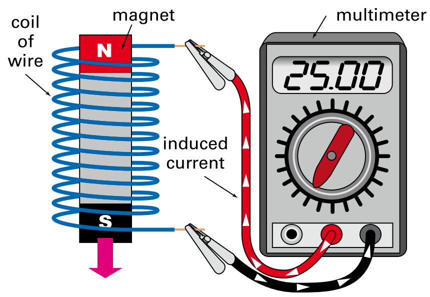
   

   Record your observations of how the reading on the multimeter changes when the magnet is moving in, when it is still, and when it is moving out. Does it matter how quickly you move the magnet?

   Write a hypothesis to explain all your observations.
4. Use your hypothesis to predict what will happen if you hold the magnet still and move the coil up and down. Test your prediction.
5. Predict what will happen if you reverse the magnet so that the other pole goes in first. Try it.

Moving a magnet through a coil induces (produces) an electric current in the coil. This process is called *electromagnetic induction*, because the moving magnetic field induces the electrons in the wire to move. Moving the magnet in the opposite direction reverses the direction of the current. In this way you can produce alternating current AC. You can produce a larger current if you increase:

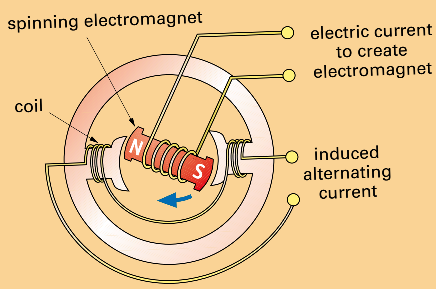
- the strength of the magnet
- the number of turns of wire in the coil
- the speed of movement of the magnet or coil.



KINETIC ENERGY → ELECTRICAL ENERGY

Generators

Most electric **generators**, like the one in a car, have a coil of wire which is rotated between the poles of a magnet. However, the huge AC generators in power stations are designed differently. They use electromagnets that rotate inside the coil, as shown.



Note: there are special connections to the electromagnet so the wires don't tangle.

Hints and tips

Do the Activity before explaining the theory, as most students are more likely to remember by 'doing'.

Activity notes

If the students are using multimeters, make sure you check they have connected the leads properly and have selected the correct dial setting.

Learning experience

Revise the concepts taught so far by giving a true/false quiz, asking quick questions or using a set of flash cards. It may be worth getting students to jot down a 10-point summary of the chapter up to this point.

Hints and tips

Find out where the local community's electricity is generated and, if possible, show students photos of the power station.

Power stations

Fig 38 A hydro-electric power station in the Snowy Mountains. Water flows from the reservoir at the top, down the pipes to the power station at the bottom.

The generators in a power station are turned by turbines whose fan-like blades are spun at 50 cycles per second by jets of high-pressure steam. After leaving the turbines, the steam is condensed back to water and returned to the boiler. Vast amounts of water are needed for the condenser, and this normally comes from a nearby lake into a cooling tower (see Fig 39). Most Australian power stations burn coal to produce the steam; however, it can also be produced by burning natural gas or oil.

About 10% of Australia's power is generated in hydro-electric power stations (see Fig 38). Here it is the kinetic energy of falling water rather than the pressure of steam that drives the turbines and generators. The greater the height the water falls, the more electricity is produced.

Hydro-electric power stations are cheaper to run than coal-burning power stations, and they can be started up or closed down much more quickly. Coal-burning power stations operate 24 hours a day, and when more electricity is needed the hydro-electric stations are brought into operation. This usually occurs at the beginning and end of a working day, when people are using electric trains, lights, stoves etc.

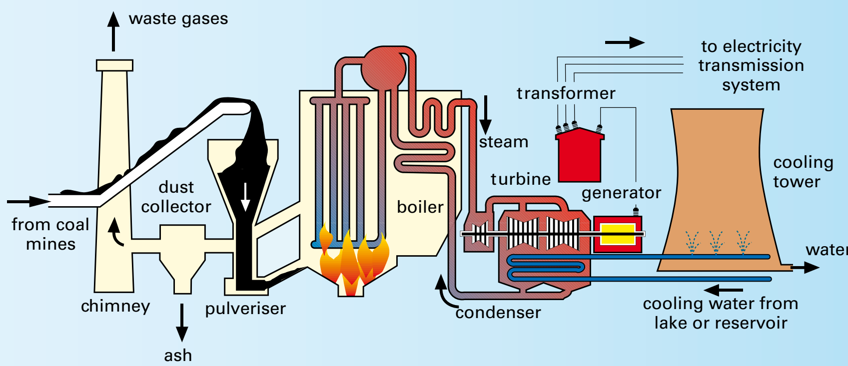


Fig 39 How a coal-burning power station works

Learning experience

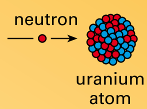
Colourful posters and flow diagrams are always a good way to summarise and simplify information. Get the class to make posters to display around the room using the information on this page and in Fig 39.

Nuclear power stations

Instead of burning coal, a nuclear power station uses the heat from a nuclear reactor.

The nucleus of an atom is made up of positively charged protons and neutral neutrons. When you bombard a uranium-235 atom with these neutrons, it becomes so unstable that it splits into two smaller atoms, releasing a huge amount of energy. This splitting is called **nuclear fission.**

When a uranium atom splits it releases two or three neutrons. These neutrons may hit other uranium nuclei, splitting them as well. This in turn produces more neutrons and more energy, and so it goes on. This is called a *chain reaction*, and it can occur very quickly if it is not controlled. This is what happens in a nuclear bomb, where huge amounts of energy are released in a fraction of a second. In a nuclear power station, however, the fission reaction is controlled, and the energy is released steadily.



The central part of a nuclear power station is the *nuclear reactor*, which contains the uranium fuel. The reactor has *control rods*, made from a material which absorbs neutrons. The control rods can be moved in and out of the reactor core. When they are right in, they absorb a lot of neutrons, and this stops the chain reaction. When they are pulled out, fewer neutrons are absorbed and the remainder are free to cause fission, so the chain reaction goes faster. Hence, by moving the control rods in and out, the fission reaction can be controlled.

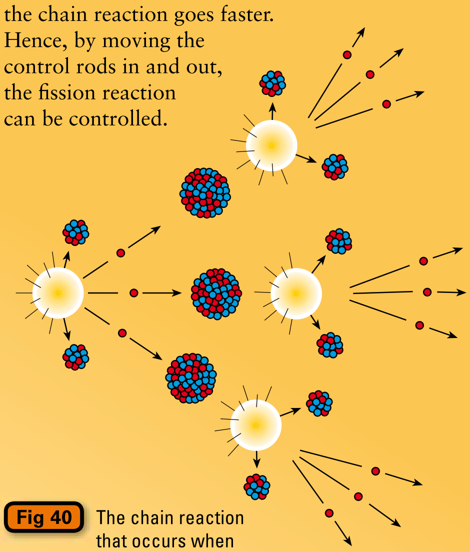


Fig 40 The chain reaction that occurs when uranium-235 atoms are bombarded with neutrons

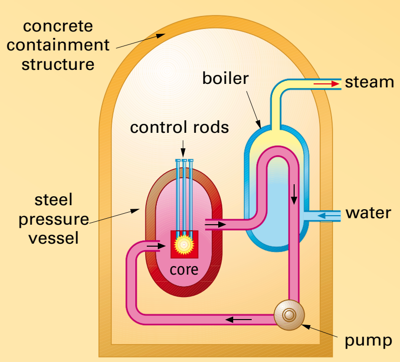


Fig 41 How a nuclear reactor can be used to generate steam for a power station

WEBwatch

Go to www.scienceworld.net.au and follow the links to the headings below for information on all types of power station.

How electricity is created
An animation of a coal-fired power station—flip the switches to start the boiler, turbine, generator and transformer.

How our power stations work
Animations of a coal power station and a hydro-electric power station.

Nuclear power
Animations of two different types of nuclear power stations.

How hydropower plants work
This site has an interesting section on hydro-electric footwear.

Hints and tips

- Show a DVD (eg *Chernobyl's Heart*), or a segment of one, about the Chernobyl disaster, which highlights what can happen if things go wrong at a nuclear power station. Make sure the material is appropriate and not too visually disturbing. (Be sensitive to students' feelings.) There are many good websites which discuss the disaster and its aftermath. For example, students may find some of the photographs and video links at <www.elenafilatova.com> interesting. The material was compiled by a young Ukrainian woman who has ridden her motorbike through the deserted area around Chernobyl and photographed the desolation. It may be necessary to debrief afterwards.
- All students should be aware of the hazards of radioactive materials.

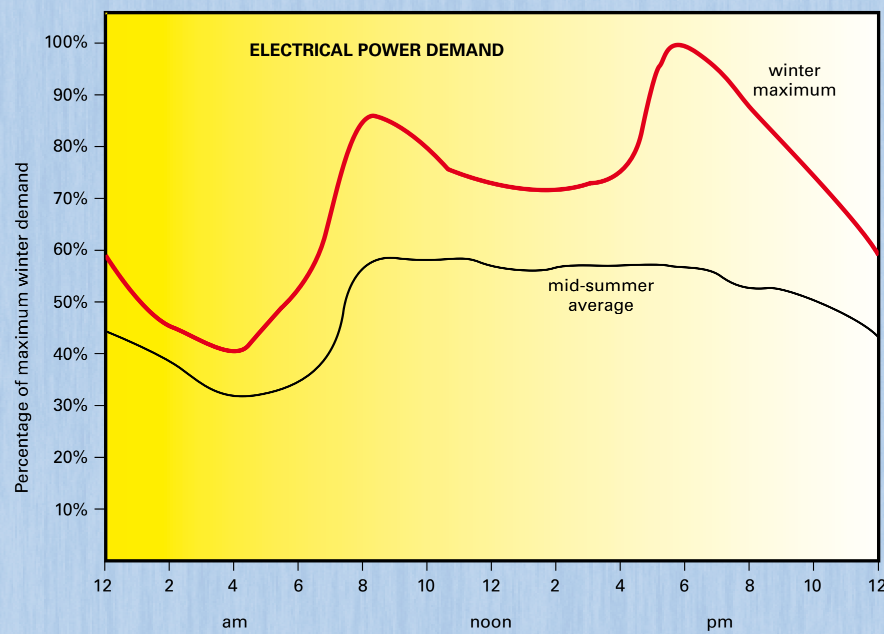
Learning experiences

- For an extension activity, ask the class to debate whether Australia should have nuclear power. Each team needs to appoint a team leader who will make sure the other members know their roles.
- Alternatively, each student could write a letter to a politician presenting their point of view about why we should or shouldn't have nuclear power. The presentations need to be scientific and factual, and should describe how individuals and people in general may be affected.
- The Webwatch links are worth showing to the class using a data projector, or students can view them individually.

Activity notes

- It may be handy to have a set of rulers for the students to use as a guide when reading the graph.
- The winter curve can be explained in terms of cool weather (heaters, warmer showers, hot meals) and duller days (more lighting).
- The summer curve can be explained in terms of hot weather (air conditioners, fans, but less hot showers and meals) and brighter days (less lighting).

Activity



The graph above shows the typical demand for power in Australia on a weekday. Use the graph to answer these questions.

1 What units have been used on the vertical axis of the graph?

2 At what time of the day does the peak (maximum) demand occur in winter?

3 There is also a demand peak in the morning in winter. When does this occur?

4 Explain the shape of the winter graph in terms of our use of electricity over 24 hours.

5 Why is the demand for electricity greater in winter than in summer?

6 If the peak demand on a winter's day is 10 000 megawatts, what is the minimum demand on that day?

7 Even at 4 am we still use considerable electricity (a bit less than half the peak demand). How can you explain this?

8 Why is it that the summer graph has only one peak while the winter graph has two peaks?

9 The night rate electricity tariff (cost) is about half the normal rate. Suggest a reason for this.

10 Given that electricity cannot be stored, how is it possible to meet the changing demand for electricity over a 24-hour period?

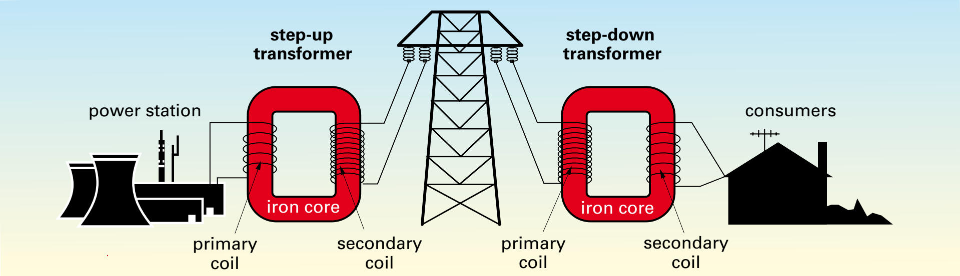


Fig 43 How transformers are used to increase and decrease the voltage from a power station

Transmitting electricity

Electricity is transmitted from the power station to your home through power lines. However, some electrical energy is always lost as heat when it travels through wires, and the greater the current the more heat that is lost. To reduce this heat loss, you can increase the voltage and thereby decrease the current.

The voltage can be changed in devices called **transformers**. A transformer contains an iron core and two coils of wire called the *primary coil* and the *secondary coil* (Fig 43). The alternating current in the primary coil creates a magnetic field. Because the current changes direction 50 times per second, the magnetic field also changes. This changing magnetic field interacts with the secondary coil and induces a current in it.

If the secondary coil has more turns of wire than the primary coil, it is called a *step-up transformer*. The voltage induced in the secondary coil is greater than that in the primary coil, but the current is lower. If the secondary coil has fewer turns of wire than the primary coil, it is called a *step-down transformer*. This produces a lower voltage but higher current than is in the primary coil.

Before leaving the power station the voltage is stepped up (increased) to as much as 500 000 volts. This is done to reduce the current in the wires. Then, before it reaches your home, the voltage is stepped down to 240 volts.

There are transformers in many of the appliances in your home. Many devices, eg portable radios, run on batteries yet can be plugged into the mains. It is better to use mains electricity than batteries because it is cheaper. The appliance must therefore have a step-down transformer to reduce the voltage from 240 volts to 9 volts or whatever the appliance uses.

Check!

1 Copy and complete the table on the right by putting in the type of energy from which the electrical energy is formed.

2 Suggest why solar cells rather than batteries are used in spacecraft.

3 What must be brought near a rotating coil of wire if an electric current is to be generated in the coil?

Energy	Electical energy formed from...
battery	
solar cell	
electric generator	

4 Ik Jin connects a coil of wire to a multimeter. When he pushes the *south pole* of the magnet into the coil, the

Hints and tips

Transformers can be *step-up* or *step-down*. Explain the difference between the two types. Ask students to think of situations when a step-up transformer would be an advantage or a disadvantage. Ask the same for a step-down transformer.

Learning experience

The students could construct a flow chart to explain how transformers are used to increase and to decrease the voltage from a power station (Fig 43).

Check! solutions

1

Energy	Electrical energy formed from ...
battery	chemical energy
solar cell	solar energy
electric generator	kinetic energy

2 The main advantage of using solar cells rather than batteries in a spacecraft is that solar cells operate continuously in sunlight and do not go flat like batteries, which need to be replaced.

3 A magnet will produce an electric current if placed near a rotating coil of wire.

4 Ik Jin should observe that:
 a The needle deflects to the left.
 b The needle deflects to the left also.
 c The needle does not move.
 d The needle deflects to the right.

5 Referring to Fig 39:
 a The coal is pulverised or broken down to a powder and then burned in a furnace. The heat from the burning coal is used to boil water and change it into steam which flows through a turbine and causes it to spin. The water is then condensed and recycled. The spinning turbine is connected to a generator which produces electricity. This electricity is then fed through a transformer and into the transmission system.
 b The energy chain is:
 chemical ⟶ heat ⟶ kinetic ⟶ electrical

6 The similarities are that both types of station convert energy from one form or another into electrical energy. They both produce heat as a waste product and also produce chemicals which may be harmful to the environment.
 The main difference is the type of fuel used—in one it is coal and in the other, uranium. There are also differences in the type of waste produced. With coal-burning stations it is mainly carbon dioxide and some other gases whereas nuclear power stations produce radioactive wastes which are difficult to dispose of safely.

7 A step-up transformer has more coils of wire on the secondary coil and this will increase the output voltage. Conversely a step-down transformer has fewer coils of wire on the secondary coil and this will decrease the output voltage.

voltage is positive. Will the voltage be positive or negative when Ik Jin does the following:
 a pulls the south pole of the magnet out of the coil?
 b pushes the north pole of the magnet into the coil?
 c holds the magnet steady inside the coil?
 d holds the magnet steady and moves the coil towards the south pole of the magnet?

5 **a** Use Fig 39 on page 184 to try to explain what happens in each part of the power station.
 b Draw an energy chain to describe the energy changes that take place.

6 What are the similarities between nuclear power stations and coal-burning power stations? What are the differences?

7 What is the difference between a step-up and a step-down transformer?

WEBwatch

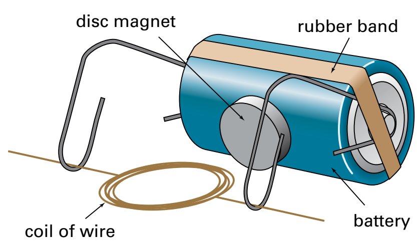
Go to www.scienceworld.net.au and follow the links to the websites below.

Fuelling the 21st century

Use this as a starting point to research fuel cells.

Beakman's electric motor

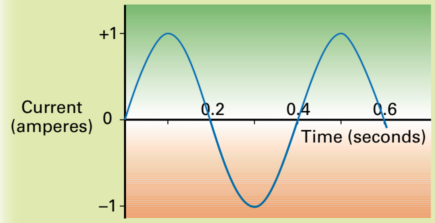
Use this site to make your own simple electric motor and demonstrate it to the class.



challenge

1 Suggest three ways of making an electric generator produce a larger current.

2 The graph shows how the current produced in an electric generator varies with time.
 a What is the maximum current generated?
 b How long does it take for the coil of the generator to rotate once?
 c Suppose you connected a light bulb to the generator. Would you expect the brightness of the bulb to vary? Explain.



3 What are the advantages and disadvantages of the following types of power stations?
 a coal-burning
 b hydro-electric
 c nuclear

4 Suggest why there are no nuclear power stations in Australia.

5 Why is electric power transmitted at very high voltages over long distances?

6 How is an electric generator like an electric motor? How is it different?

7 These readings were obtained from a transformer.

	Voltage (V)	Current (A)
Primary coil	200	1.00
Secondary coil	1000	0.19

 a Does the transformer step the voltage up or down?
 b Calculate the power of each coil.
 c How much power is 'wasted' by the transformer?
 d What happens to this wasted power?

Challenge solutions

1 An electric generator will generate more current if the magnet is stronger, there are more coils of wire around the iron core or the shaft is rotating more quickly.

2 a The maximum current generated is 1 amp.
 b It takes 0.4 seconds for the coil to rotate once.
 c Yes, you would expect the bulb to be slightly dimmer every 0.2 seconds. This is because the brightness depends on the current, which changes in size. The direction of the current will not affect the brightness of the bulb.

3 It would be a good idea to show this information in the form of a table like this:

Type of station	*Advantages*	*Disadvantages*
a Coal-burning	Plentiful supply at present. These power stations have been built already.	Air pollution. Coal will eventually all be used up.
b Hydro-electric	Very few wastes released into the air or water. Relatively cheap to produce.	Disrupts the flow of rivers and will affect plants and animals. Not suitable for all areas.
c Nuclear	No waste gases. Relatively cheap to produce. Plentiful supply of uranium.	Health hazard for workers. Radioactive wastes are produced.

MAIN IDEAS

Copy and complete these statements to make a summary of this chapter. The missing words are on the right.

alternating, direct, earth, generators, kilowatt-hours, magnet, Ohm's law, power, resistance, short circuit, transformers, voltage, watts

1 ______ current (DC) is a flow of electrons in one direction only. ______ current (AC) is a flow of electrons that continuously reverses direction. Mains supply is 240 volt AC.

2 A ______ occurs when the electric current takes a 'short cut' along a path of lower ______.

3 Circuit-breakers and ______ wires are essential for safety in electric circuits.

4 The electric current flowing in a circuit depends on the electrical resistance in the circuit and the ______. The relationship between voltage V, current I and resistance R can be shown by the formula V = I R (______).

5 ______ is the rate at which energy is produced or used. It is measured in ______ (joules per second).

6 Electrical energy is sold in ______. It can be calculated using the following equation:

energy (kilowatt-hours) = power (kilowatts) × time (hours).

7 A ______ and a coil of wire, in motion relative to each other, can produce an electric current. This is how ______ in power stations work.

8 ______ can increase or decrease the voltage of alternating current.

Try doing the Chapter 8 crossword on the CD. Working with technology

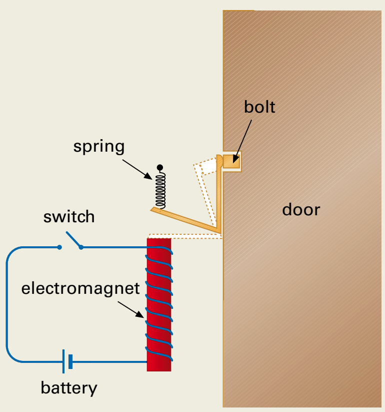
Main ideas solutions

1 direct, alternating
2 short circuit, resistance
3 earth
4 voltage, Ohm's law
5 power, watts
6 kilowatt-hours
7 magnet, generators
8 transformers

REVIEW

1 The number of watts printed on an appliance tells you:
A the rate at which the appliance uses energy
B the voltage at which the appliance operates
C the electrical resistance of the appliance
D the heat the appliance gives off

2 The diagram on the right shows an electric door-bolt. Write a paragraph explaining how this device works.



Review solutions

1 **A**

2 When you turn the switch on, electric current flows in the coil and the electromagnet works. It attracts the L-shaped piece of metal attached to the spring, pulling the bolt out of the door. When you turn the switch off, the electromagnet no longer attracts the metal bar, which is pulled up by the spring, locking the door again.

4 The main reason we have no nuclear power stations in Australia at this time is that we have enough fossil fuels, and there are concerns about safety and disposal of the radioactive wastes.

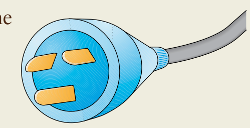
5 The amount of energy lost from power lines is greater if the current is greater. If the voltage is higher then the current will be less (since P = VI) and less energy will be lost.

6 Both an electric motor and a generator consist of a coil of wire and magnets moving in relation to each other. The difference is that a motor converts electrical energy to kinetic energy, whereas a generator does the opposite.

7 a This transformer steps the voltage up from 200 V to 1000 V.
b The power of a coil can be calculated using P = VI.
Primary coil: 200 V × 1 A = 200 W
Secondary coil: 1000 V × 0.19 A = 190 W
c Subtraction shows that 10 watts of power are lost or wasted by the transformer.
d This wasted power is lost as heat to the atmosphere.

REVIEW

3 Look at the diagram of a three-pin plug.
- **a** Which is the earth pin?
- **b** What is the purpose of an earth wire?
- **c** Why is it that some electrical plugs only have two pins?



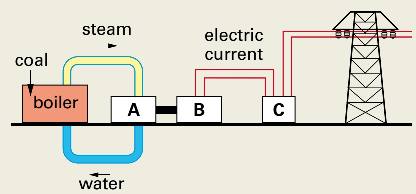
4 A plate on the plastic case of a portable radio–CD player has the following information:

AC: 240 V ~ 50 Hz 12 W ▣

DC: 9 V ---- ("D" SIZE × 6)

- **a** What does AC stand for?
- **b** What is the power of the radio?
- **c** How many batteries does it need?
- **d** Would you expect the radio to have a two-pin or a three-pin plug? Why?
- **e** Would you expect the radio to contain a transformer? Explain.

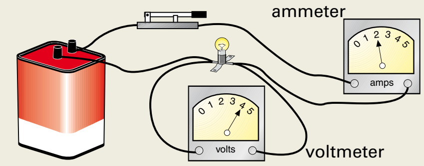
5 The diagram shows the layout of a coal-burning power station (in simplified form).



- **a** What happens in A?
- **b** What energy change occurs in B?
- **c** What is C? What is its purpose?
- **d** What must happen to the electricity passing through the power lines before it can be supplied to your home?
- **e** Which part of the diagram would be different for a nuclear power station?

6 An electric radiator has a small plate on the back which reads '240 V, 1500 W'. If the cost of electrical energy is 15 cents per kilowatt-hour, how much would it cost to run this radiator for 3 hours?

7 Here is a diagram of an electric circuit containing an ammeter and a voltmeter.



- **a** What is the size of the current flowing through the light bulb?
- **b** What is the voltage drop across the bulb?
- **c** What is the resistance of the bulb?

8 Juanita did an experiment similar to Investigate 19. Here are her results.

	Voltage (volts)	Current (amps)	Resistance (ohms)
Trial 1	6	1	6
	12	2	6
	24	4	6
Trial 2	6	2	3
	12	2	6
	24	2	12
Trial 3	6	0.5	12
	6	1	6
	6	2	3

- **a** What were the three variables in Juanita's experiment?
- **b** Which variable did she control in Trial 1?
- **c** What happened to the voltage when the resistance stayed the same and the current was doubled?
- **d** What happened to the voltage when the current stayed the same and the resistance was doubled?
- **e** What happened to the voltage when the current was doubled and the resistance was halved?
- **f** Write a mathematical equation that summarises Juanita's results.

Check your answers on page 322.

3
- **a** The earth pin is the bottom slightly longer one.
- **b** The earth wire connects the metal case of an appliance to the ground. If there is a short circuit, the electric current travels to the ground instead of through your body.
- **c** Appliances that are double-insulated do not need an earth wire. They are surrounded by plastic (an insulator) and have no external metal parts (conductors).

4
- **a** alternating current
- **b** 12 watts
- **c** six D-sized batteries
- **d** The ▣ symbol indicates that the radio is double-insulated. It therefore needs only a two-pin plug.
- **e** The radio operates on 9 volts DC, so it would need a step-down transformer to reduce the voltage from 240 V to 9 V.

5
- **a** High-pressure steam spins the turbines.
- **b** In the electric generators, kinetic energy is converted to electrical energy.
- **c** C contains step-up transformers to increase the voltage before it is transmitted to our homes.
- **d** Before the electricity is supplied to our homes the voltage must be decreased to 240 volts, using step-down transformers.
- **e** Everything would be the same, except that instead of burning coal to heat the boiler you use a nuclear reactor. (See Fig 41 on page 185.)

6 energy (kilowatt-hours) = power (kilowatts) × time (hours)

$$= \frac{1500}{1000} \times 3$$

$$= 4.5 \text{ kilowatt-hours}$$

cost of energy = 4.5 × 15 cents

= 68 cents

7
- **a** 2 amps
- **b** 4 volts
- **c** $R = \frac{V}{I} = \frac{4 \text{ volts}}{2 \text{ amps}} = 2 \text{ ohms}$

8
- **a** voltage, current and resistance
- **b** resistance—kept at 6 ohms
- **c** The voltage doubled.
- **d** The voltage doubled.
- **e** The voltage stayed the same.
- **f** V = I R