11 Electricity

Planning page

Getting started

11.1 Electric charges
page 230
- Investigate 26 Electric charges
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11.2 Electric currents
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- Investigate 27 Simple electric circuits
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11.3 Electric circuits
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Main ideas
- Chapter 11 crossword

Review and Lab review
- Chapter 11 test

Essential Learnings for Chapter 11

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	pages 237–241	page 88	
Energy is converted when it is transferred or transformed	pages 237–241	pages 86–87	
Science as a human endeavour People from different cultures contribute to and shape the development of science	page 232		Assessment task 11 The history of electricity
Ways of working Communicate scientific ideas, explanations, conclusions, decisions and data, using scientific argument and terminology, in appropriate formats	page 233 page 238 pages 244–247	pages 87–91	
Conduct and apply safety audits and identify and manage risks	Investigation 28 page 239		
Identify problems and issues, formulate scientific questions and design investigations	Try this pages 236, 243 Investigate 29 Part C page 247	page 88 Challenge	

QSA *Science Essential Learnings by the end of Year 9*

Vocabulary

ammeter
attraction
circuit
conductor
electron
electrostatic
insulator
neutron
nucleus
parallel
proton
repulsion
resistance
series
static
terminal
voltage
voltmeter

Focus for learning

Use their knowledge of electricity to explain how an electric mousetrap works (page 229).

Equipment and chemicals (per group)

Investigate 26 page 230
Part A: 2 balloons and string
Part B: Van der Graaff generator (class use)
Part C: piece of fur or silk, plastic rod
Part D: 2 perspex rods, 2 ebonite rods, piece of wool or fur, piece of silk, watch glass, Blu-Tack, cooking oil, tile

Investigate 27 page 237
Part A: 1.5 V torch battery without holder, torch bulb (2.5 V) without holder, 2 connecting wires
Part B: 1.5 V torch battery with holder (or power pack), torch bulb (2.5 V) with holder, 3 connecting wires with alligator clips, switch

Investigate 28 page 239
1.5 V battery and holder (or power pack), torch bulb and holder, ammeter or multimeter, 4 connecting wires, variety of objects, eg paperclip, plastic or glass rods, nail, coin, carbon rod, copper rod, matchstick, rubber band, aluminium foil, strip of paper, piece of string

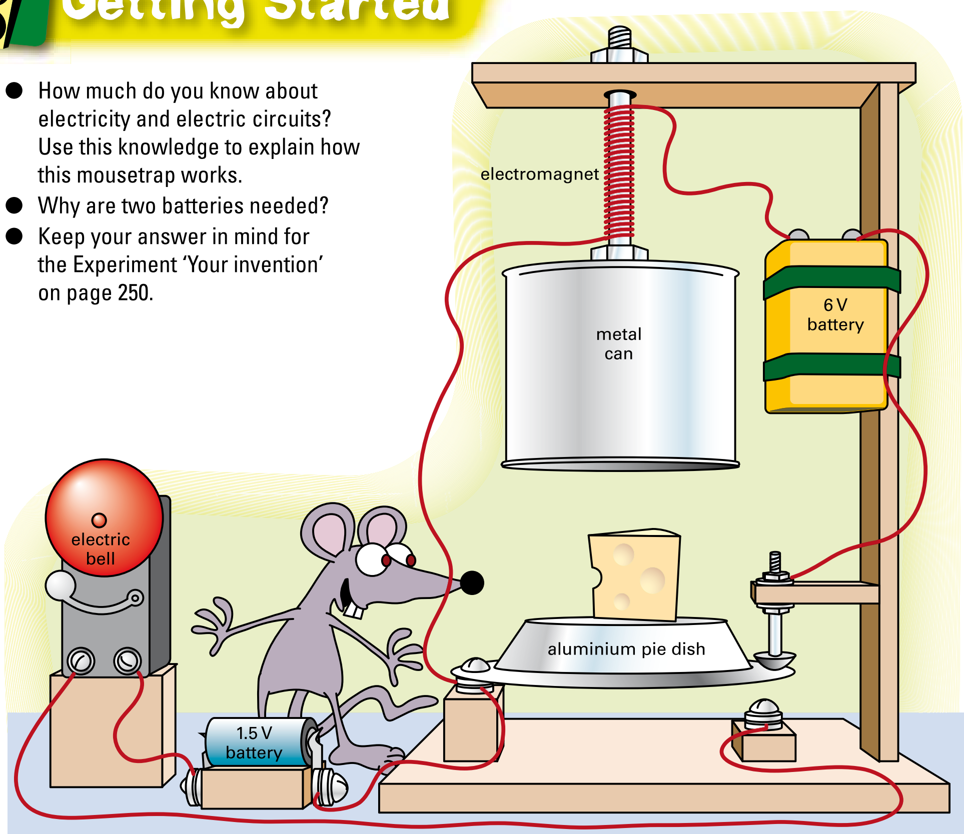
Investigate 29 page 245
two 1.5 V batteries and holders (or power pack), 3 torch bulbs and holders, 6 connecting wires, ammeter or multimeter

Experiment page 250
Students will supply a list of equipment needed to build their electrical device.

11 Electricity

Getting Started

- How much do you know about electricity and electric circuits? Use this knowledge to explain how this mousetrap works.
- Why are two batteries needed?
- Keep your answer in mind for the Experiment 'Your invention' on page 250.



Hints and tips

The origin of the word *electricity* is from the Greek *elektron* and *elektor* meaning *shine*—both words describing amber. Amber is fossilised tree sap. A form of electricity was known to the Ancient Greeks who found that rubbing fur on materials such as amber would cause an attraction between the two. They noted that if amber was rubbed for long enough a spark could be generated.

Starting point

Ask the students to work through the Getting Started exercise. They could trace the diagram into their notebook and next to each electrical component write their explanation of its function.

Students will be familiar with the use of electricity but probably find it difficult to explain what electricity is. Have a class discussion and ask specific questions to gauge their knowledge or preconceptions. Students could be asked to come up with their own definition of what they believe electricity is.

Concept maps are a good tool to use for a pre-test and post-test exercise. They are a visual way to assess development of concepts, and they show how students link ideas together. Each student could be given a piece of poster paper; they could use one side for the initial concept map (pre-test) and the other side for the final concept map (post-test). Keywords might be: *electricity*, *energy*, *charge*, *conductor*, *insulator*, *current*, *voltage*, *resistance*, *batteries*, *power source.*

Students could compile a list of everything they use electricity for in a day, and then write a short story about what their life might be like without electricity.

Start the topic with a quick static electricity investigation. Students could take out a plastic pen from a pencil case, rub it on their hair or jumper and then carefully place it near some small torn-up pieces of paper. Ask the students to observe what happens and give an inference for why it happens. A simple teacher explanation may be necessary. Ask where else static electricity occurs (taking a jumper off and hair crackling, touching a TV screen when it has been on for a while, getting out of a car and touching the metal door, lightning in a thunderstorm etc).

Hints and tips

Electric charge can be explained with an analogy to magnets. Positive and negative charges behave in much the same way as the north and south poles of a magnet. You can therefore explain 'like' and 'unlike' charges in terms of attraction and repulsion.

A brief explanation could be given about the configuration of an atom, as on page 233. Electricity is mainly the investigation of negative charges, that is, electrons. It may be helpful to reinforce this by highlighting '*electr*' in *electr*icity and *electr*ons.

Electrostatics is the study of 'electricity at rest' and is the investigation of electric charges, the forces between them and how these charges behave in materials.

Homework

A novel homework task may be to ask the students to take off a jumper in the dark (quite quickly) and see if they can observe a spark.

Learning experience

The students could start each new section of work that involves an explanation or definition with the sentence 'What *I* think (keyword) means…' and then leave a designated number of lines for your response in the form of 'What (keyword) *really* means…'. Your response could be written at the end of a task, investigation or reading.

Learning experience

A series of questions about static electricity could be asked to form part of the student's class notes. Ask questions such as:

- What are some examples of static electricity? (rubbing feet on carpet then touching something metal, skirts sticking to stockings and the use of anti-static spray)
- How is charge built up on objects? (mainly by friction)
- When could static electricity be of benefit or use? (photocopiers)
- When could it be dangerous? (anywhere a spark could cause an explosion: petrol station, aeroplanes landing etc)

11.1 Electric charges

In September 2005 Frank Clewer went for a job interview in Warrnambool. However, staff in the office heard loud crackling sounds and noticed the carpet was burnt where Frank had been.

They called the fire brigade, and the building was evacuated. The firemen checked Frank and found that there was an **electric charge** of 30 000 volts on his synthetic jumper.

Electric charges can build up on objects that are rubbed together, due to the friction between them. This build-up of electric charges on objects is called *static electricity,* because the charges stay on the object. They are stationary.

Investigate 26 ELECTRIC CHARGES

Aim

To make and investigate electric charges.

Planning and Safety Check

This investigation can be done only on dry days. Also, make sure everything (including your hands) is grease-free. Wash the equipment in soapy water and dry it thoroughly. You may need to warm some equipment in an oven. Read through the four parts. Note that Part B is a teacher demonstration.

PART A

Materials

2 balloons and string

Method

1. Blow up a balloon and tie it.
2. Rub the balloon on a jumper or woollen cloth. Stand on a bench (be careful), hold the balloon up to the ceiling, then let it go. What happens?
3. Charge a second balloon in the same way. What happens when you hang the two charged balloons close together?

PART B

If your school has a Van de Graaff generator, your teacher may demonstrate how it is able to generate a static electric charge on its dome. You may even be able to make your hair stand on end.

Lab notes

Part A

- Keep an eye on the distribution of balloons—assign two balloons per group.
- It may be safer to hold the balloon on a wall rather than the ceiling.
- Suspending the balloons from a doorway may be easier in Step 3.

Extension

Suspend one balloon from a doorway (or ceiling) so it is level with the student's head. Rub the balloon with a wool cloth. The balloon will move towards the student whenever they approach it. The student could try to determine how far away the attractive force is able to act, and if the balloon is still attracted to them if a piece of cardboard is placed between them and the balloon.

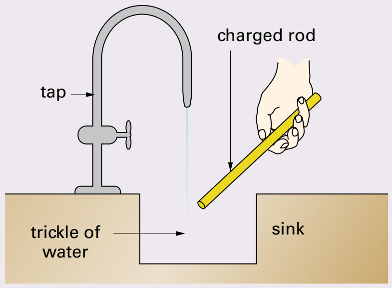
PART C

Materials
- piece of fur or silk
- plastic rod

Method
Rub the plastic rod vigorously with fur or silk and bring it near (but not touching) a trickle of water.

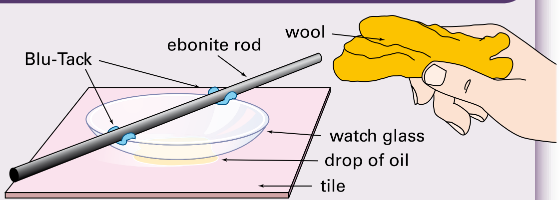
Describe what happens.

Predict what will happen if you *do* touch the water with the rod. Give a reason for your prediction. Now try it.



PART D

Materials
- 2 perspex rods
- 2 ebonite rods
- piece of wool or fur
- piece of silk
- watch glass
- Blu-Tack
- cooking oil
- tile



Method
1 Put a watch glass on top of a drop of oil on a tile. Place a small amount of Blu-Tack on either side of the watch glass, as shown.

2 Rub the ebonite rod (the black one) with wool and place it on the Blu-Tack. Bring the wool near one end of the rod. Try the other end as well.

Record your observations.

3 Take the ebonite rod off the watch glass. Rub the perspex rod (the clear one) with silk, place it on the watch glass, and bring the silk near one end.

Record your observations.

4 Rub the ebonite rod with wool and place it on the watch glass. Rub a second ebonite rod with wool and bring it near one end of the rod on the watch glass. Repeat the test, but this time use two perspex rods rubbed with silk.

5 Repeat Step 4 but this time bring a charged perspex rod up to a charged ebonite rod, and vice versa.

Rod 1	Rod 2	What happened
Ebonite with wool	Ebonite with wool	
Perspex with silk	Perspex with silk	
Ebonite with wool	Perspex with silk	
Perspex with silk	Ebonite with wool	

Record the results for Steps 4 and 5 in a data table as shown above.

Discussion
1 Shannon tried to do the tests by placing the rods on the desk top instead of on a watch glass. She saw nothing happen. Suggest a reason for this.

2 Do both the charged rods behave in the same way? Explain your answer.

Conclusion
Write a generalisation to explain the results of your tests with charged rods.

Lab notes

Part B (page 230)
- Remember to fill out a risk management form. It is important not to let any student with a heart condition use a Van de Graaff generator.
- Static electricity activities are more successful on days when there is low relative humidity. This is because a large amount of moisture in the air can form a coating on an object's surface. This surface coating can neutralise any build-up of static charge. Hot, dry summer days or crisp, dry winter days are ideal.
- If using hair for the activity it would be a good idea to check that it has no 'product' (gel, wax, spray etc) in it.
- A further investigation could be to place aluminium pie-plates in a pile on top of the generator, or a large metal strainer with short lengths of cotton or confetti attached.
- As the charge on the Van de Graaff generator builds up, a very high electric potential is produced in the order of millions of volts. It is a build-up of negative charge.

Lab notes

Part C
- A piece of grey or orange electrical conduit is an ideal plastic rod.
- Explain why it is important not to let the rod (or whatever object you are using) touch the water.
- A beaker should be placed in the sink to catch the water so it can be recycled.

Part D
- This part could be done as a whole class.
- Check beforehand that the watch glass and rod will spin freely.
- Ebonite is a form of plastic. The resin was originally intended to be an artificial substitute for ebony wood and is used in bowling balls and for high-quality saxophone and clarinet mouthpieces.
- Ebonite rods are available from scientific suppliers, eg Haines, Scientific Educational Supplies, Scientrific etc.

Hints and tips
Static electricity is generated by unbalancing the molecular configuration of insulators such as balloon rubber or plastic. All matter is composed of atoms and is considered balanced if it has equal numbers of protons and electrons. However, if this configuration is disturbed and several electrons are removed from the atom (rubbed off), the overall charge is positive.

Wool readily gives up electrons. Likewise, if an atom gains several electrons the overall charge is negative. When a balloon or a piece of plastic is rubbed with wool or hair, it picks up extra electrons. The balloon becomes negatively charged, leaving the wool positively charged.

Hints and tips

Negatively charged objects attract positively charged or neutral objects. Positively charged objects attract negatively charged or neutral objects. If the negatively charged object touches an object that is not charged, some electrons will transfer to the second object and the force of attraction will be less.

Attraction and repulsion

You have seen that rods rubbed with different types of cloth can move one another by non-contact forces. But why do electric charges sometimes attract and sometimes repel?

Let's hypothesise that an electric force is something like a magnetic force—another type of non-contact force. With magnets, two like poles repel each other, while two unlike poles attract.

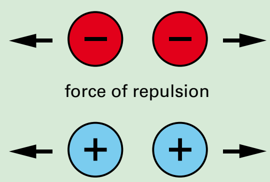
So if two perspex rods rubbed with silk repel each other, you might expect them to have the same electric charge on them. Similarly, two ebonite rods rubbed with wool repel each other, so they should also have the same charge. However, a perspex rod rubbed with silk and an ebonite rod rubbed with wool attract each other, so they should have opposite charges.

Remember that a magnet can attract some unmagnetised metals, so you might also expect that a charged rod can attract some uncharged objects.

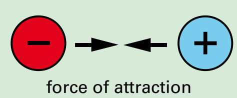
To sum up, there are three laws that describe electric forces.

1 Charged objects attract uncharged objects. For example, a charged plastic rod will attract small pieces of paper or a stream of water (as in Investigate 26 Part C).

2 Like charges repel each other. It does not matter whether they are both positive or both negative.



3 Unlike charges attract each other.



Science in action

Benjamin Franklin

The great American scientist Benjamin Franklin was the first person to explain successfully the charging of an object by rubbing. He suggested that the two types of charge could be called *positive* and *negative*.

He inferred that there was an 'electric fluid' that could be moved from one object to another. If this electric fluid was added to an object then it gained a positive charge. If electric fluid was removed then the object developed a negative charge.

Franklin's ideas were useful for explaining electric charges, but other observations do not support his inferences about an electric fluid. Scientists now use a different explanation (see the next page).

WEBwatch

Benjamin Franklin is famous for flying a kite in a thunderstorm—an extremely dangerous thing to do. When lightning struck the kite, electricity flowed down the string to a key. Luckily he survived.

Go to www.scienceworld.net.au and follow the links to:

Benjamin Franklin: An Enlightened American

This website has Franklin's illustrated life story, information on his inventions, things he said, interesting facts and humorous stories.

Learning experience

Continue the idea of starting each new explanation or definition with the sentence 'What *I* think (keyword) means…' and the teacher response 'What (keyword) *really* means…' as a theme for this chapter.

Learning experiences

1 Draw diagrams using examples from Investigate 26 to explain the theory about attraction and repulsion; this will appeal to visual learners. Use different colours when illustrating positive and negative charges.

2 The more creative students could be encouraged to draw cartoons illustrating this fundamental rule of electrostatics.

Inside atoms

About 100 years ago scientists discovered that there are even smaller particles inside atoms. Ernest Rutherford, a New Zealander, inferred that most of the atom is empty space. There is a small central core or **nucleus** which is positively charged. It contains *protons* which are positively charged, and *neutrons* which are neutral (no charge). Moving around the nucleus are **electrons**, which are negatively charged. Normally there are equal numbers of protons and electrons. This means that the charges balance each other and the whole atom is uncharged.

If some electrons are removed from an atom, it becomes positively charged. If extra electrons are added, the atom becomes negatively charged. When the number of positively charged atoms in an object just balances the number of negatively charged atoms, the whole object is uncharged. But if the numbers become unequal, then the object has an electric charge.

Working with technology

To learn more about atoms, open the **Atoms** animation on the CD.

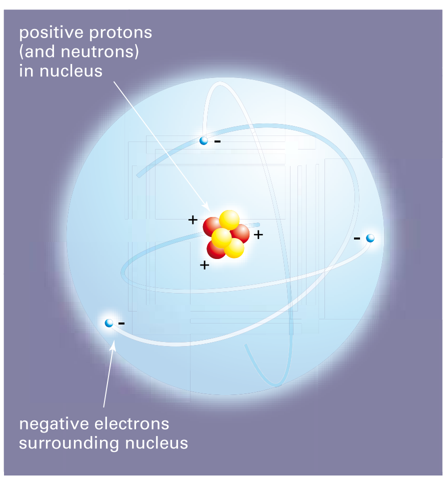
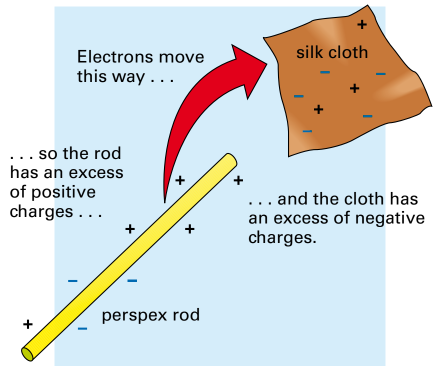


Fig 8 A picture of an atom. It is neutral, with no overall charge.

Explaining electric charges

What happens when you rub a perspex rod with a silk cloth? The frictional forces of the rubbing cause electrons to be removed from atoms on the surface of the rod and to become attached to atoms on the silk. This leaves the rod with a positive charge and the silk ends up with a negative charge.

A different type of cloth may give electrons to the rod and make it negatively charged. This cloth will, of course, then have a positive charge.



Everyday static electricity

The tingle you get when you walk across a synthetic carpet and then touch something metallic is due to static electricity. The friction between your shoes and the carpet causes your body to become charged. When you touch a metal object, the static electricity is discharged (allowed to escape). As the electricity flows across your skin, you feel a slight electric shock.

During World War I, pilots landing small rubber-tyred aircraft often received a powerful shock when they stepped onto the ground. Today aircraft have special tyres that have metal in them. This lets the static electricity pass harmlessly to the ground when they land and prevents shocks and electrical problems.

The rapid movement of drops of water in thunderclouds can cause a separation of positive and negative charges. The tops of the clouds

Hints and tips

- It is important to keep reinforcing the following ideas:
  - All atoms contain charges.
  - Electrons are negatively charged.
  - Protons are positively charged.
  - Neutrons are neutral.
  - An uncharged atom has an equal number of protons and electrons (overall charge of zero).

  You could ask a set of 'Quick Questions'. In doing this, you should be able to get an indication if any ideas need to be revisited.
- It is worth explaining to students that if an atom has a difference in positive and negative charges it is considered 'charged' and called an *ion*. Students often have the misconception that a positive ion has become positive by gaining protons. An atom does not lose or gain protons—only electrons (ignore radioactivity).
- Even though electrons are much smaller in size than protons, the magnitude of their charge is the same but opposite in sign to that on a proton.
- Remind students that electrons cannot be created or destroyed, but are transferred from one material to another. This is conservation of charge, another fundamental law of physics, like energy and momentum.

Animation

Use a light projector to show the Working with technology animation **Atoms.**

Learning experience

Consider posing a higher-order thinking question for the students to tackle in small groups of about four. Each group needs to assign a group leader, a scribe and researchers. Set a time limit. You may wish to advise the class to write and explore a series of sub-questions before attempting to answer the posed question. Encourage students to draw diagrams to help their explanation. Access to computers may be of benefit. This could also be turned into a Think/Pair/Share (page 126) activity. Here is a possible question:

- Why are some substances easier to charge than others?
  (Inner electrons spinning around the nucleus are bound very tightly but the outer electrons are bound loosely, and are therefore easily dislodged. The amount of force required is different for each substance.)

Learning experience

Students could keep a vocabulary list of new words they are learning in this unit and write sentences using each word correctly.

Hints and tips

If you haven't yet used the Van de Graaff generator with your class, now would be a great time. You can show spark generation or how lightning occurs in a thunderstorm. Make sure the earthing device is connected.

normally become positive, and the bottoms negative. If these charges become big enough, electrons can jump from one part of the cloud to another, causing a spark. The air is heated so much it glows, producing lightning. The intense heat also makes the air expand suddenly, causing the loud noise of thunder. Lightning can also spark to the ground, or to other clouds.

What to do in a thunderstorm

Each year in Australia lightning claims up to 10 lives and causes over 100 injuries. Many of these injuries happen when people use telephones during thunderstorms.

If you are caught outdoors in a thunderstorm:

- Seek shelter in a hard-top vehicle or solid building.
- If swimming or surfing, leave the water immediately.
- If in a boat, go ashore to shelter as soon as possible.
- Never shelter under trees.
- Don't use a mobile phone.
- Don't handle fishing rods, umbrellas or golf clubs.
- Stay away from metal poles, wire fences, sheet metal, clothes lines etc.
- Don't ride a horse or bike, or drive an open vehicle.
- If you are in a car, park away from trees and power lines. Close the windows and avoid touching metal parts of the car.
- If caught in the open, crouch down with your feet together.

If you are indoors during a thunderstorm:

- Don't use the telephone.
- Disconnect external aerials and power leads to radios, TVs and computers.
- Draw all curtains and keep clear of windows, electrical appliances, pipes and other metal fixtures.
- Don't stand bare-footed on concrete or tiled floors.
- Avoid taking a bath or shower.

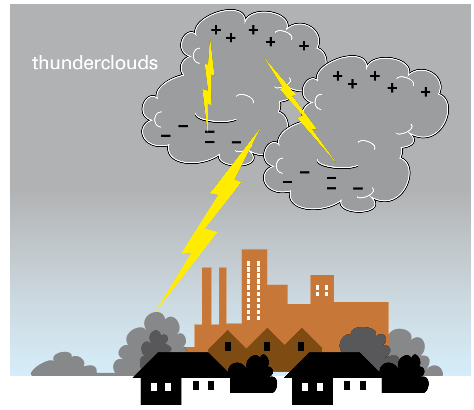


Fig 10 Lightning can spark within a large cloud, from a cloud to the ground, or from cloud to cloud.

Fig 11 Lightning strikes the lightning conductor on the Q1 tower on the Gold Coast.

Learning experience

It might be interesting to show some snippets from a DVD or video showing thunder and lightning, before asking the students how the visuals relate to electricity.

Learning experience

Students could copy the diagram in Fig 10 into their notebooks and explain what happens in a thunderstorm. Alternatively, before they read this section of the textbook, the following paragraph could be written on the board and students asked to illustrate what happens in a thunderstorm.

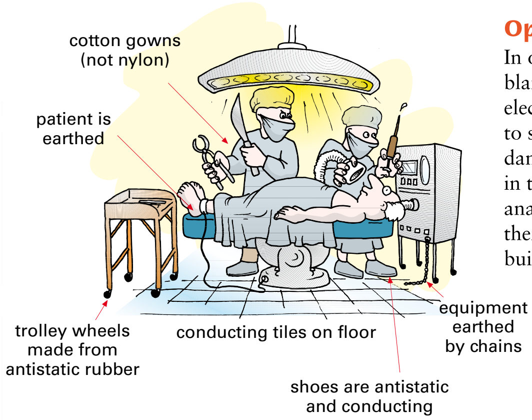
Lightning in a thunderstorm is a spectacular display of static electricity. Clouds become negatively charged as ice crystals inside the clouds rub against each other. Meanwhile, on the ground, the positive charge increases (because unlike charges attract).The clouds get so highly charged that the electrons jump from the cloud to the ground or from one cloud to another cloud. This causes a huge spark of static electricity in the sky that is called lightning.

Learning experience

You may like to get the students to draw a safety poster or pamphlet about what to do in a thunderstorm. Award marks for creative design, clarity of information and a scientific explanation of what causes lightning.

science bits

Everyday static electricity

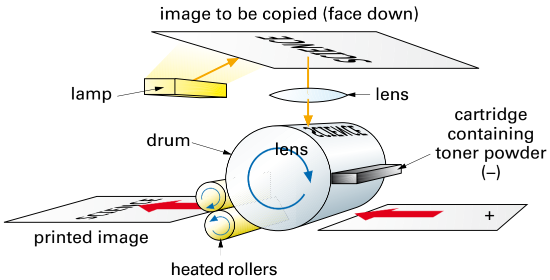


Operating theatres

In operating theatres the sudden movement of blankets, clothes or equipment can produce electrostatic sparks. (*Electrostatic* means 'relating to static electricity'.) These sparks are very dangerous because of the large amount of oxygen in the air and other flammable gases used to anaesthetise the patient. Many precautions are therefore taken to make sure static charges do not build up anywhere.

Photocopiers

Photocopiers work by an electrostatic process. The main part of the machine is a rotating light-sensitive drum onto which the image of the document is projected. The positively charged paper attracts the negatively charged toner from the drum, forming an image. The paper then passes between heated rollers that fuse (melt) the toner onto the surface of the paper.



Powder coating

When objects are powder-coated they are charged so they will attract the powder. This gives a much more even coating than other methods of spraying, and the powder reaches all parts of the object's surface. However, great care has to be taken to keep dust particles out of the air, or they too will be attracted onto the object's charged surface.

Hints and tips

It would be useful to do some research on everyday static electricity and compile a list of examples to share with your class. You could set a class competition to see who can research and compile the longest list.

Doing this is a way to ensure your students can make connections between their everyday experiences and static electricity. You could then ask your students to try to explain these everyday experiences using the terms they are learning: *energy*, *repel*, *attract*, *static charge*, *electron transfer* etc.

Homework

Students could make a timeline of scientific events related to electricity. A list of important dates or key scientists could be given to the students. (Some key scientists are: Robert Boyle, Stephen Gray, William Watson, Benjamin Franklin, Michael Faraday, Luigi Galvani, Alessandro Volta, André-Marie Ampère, Georg Simon Ohm, Nikola Tesla, Samuel Morse, Thomas Edison.)

The work of some of these scientists—Faraday (capacitance), Volta (voltage), Ampere (current), and Ohm (resistance)—is honoured by society, in that fundamental units of electrical measurement are named after them.

This homework task can later be used in conjunction with Assessment task 11: The history of electricity.

Check!

1 Why do you sometimes notice a crackling noise when you take off your clothes?

2 If a rod is rubbed with nylon cloth and the rod becomes positively charged, what charge will be on the nylon?

3 You may have been zapped as you touched the door handle when getting out of a car. Suggest how the car becomes electrically charged.

4 What type of charge is on:
  a an electron?
  b the nucleus of an atom?

5 a Give two examples where static electricity is a nuisance.
  b Give two examples where it is useful.

6 In your own words, describe what causes lightning.

7 Some tall buildings and tall chimneys have a lightning rod on top of them. What purpose does it serve?

8 A piece of plastic held in your hand can be electrified by rubbing it with a cloth, but it is impossible to electrify a piece of metal in the same way. Why?

9 A suspended, positively charged rod has a second rod brought near to it. What is the charge—positive, negative or no charge—on the second rod if it:
  a repels the suspended rod?
  b attracts the suspended rod (two answers)?

10 Look at the labels on the cartoon of the operating theatre on the previous page.
  a The equipment and the patient are *earthed*. What does this mean?
  b What does the word *conducting* mean?
  c What does *antistatic* mean?

11 Have you noticed that computer and TV screens become dustier than the things around them? Suggest a reason for this.

12 Explain how static electricity and magnetism are similar. In your answer use the terms *non-contact force* and *force field*.

challenge

1 Five different rods (A, B, C, D, E) were given an electric charge by rubbing them with two different cloths. The rods were then tested in pairs to see whether they repelled or attracted. A attracted C and C attracted E. A repelled D and B repelled E. Predict what will happen if you bring D and E together and B and C together.

2 The photo below shows a light plane being refuelled. Suggest why there is a wire between the fuel hose and the plane.

try this

1 You have been asked to solve the problem of the two sides of a plastic bag sticking together.
  a Why do you think this problem occurs?
  b Design an experiment to show how the bags stick together.
  c Suggest experiments you could try to overcome the problem.

2 Which type of carpet is most likely to give you an electric shock when you walk about on it? Design and carry out an experiment to find out.

3 In a very dark room, rub a spare fluorescent tube with wool, fur or clear plastic wrap. Can you see it glow?

4 Bring a charged rod near the smoke from a burning mosquito coil. What happens?

Check! solutions

1 The reason that your clothes sometimes crackle is that as they are worn, electric charges build up and then discharge to the air.

2 The nylon will have an equal and opposite negative charge.

3 As a car travels along there is friction between the tyres and the road. This causes the build up of static electricity in the car and can sometimes cause a small electric shock when you get out of the car.

4 a An electron has a negative charge.
  b The nucleus of an atom has a positive charge.

5 a Here are two examples of when static electricity is a nuisance:
  - clothing crackling and sticking to your body
  - your body becoming charged when you walk on synthetic carpet.

  b Here are two examples of when static electricity is useful:
  - the attraction of paper to the drum in photocopying
  - the attraction of powdered paint to car bodies.

6 The movement of water drops in large thunder clouds causes the separation of positive and negative charges, so that the top of the clouds become positive and the bottom of the clouds become negative. Sometimes they will discharge to other clouds or objects on the ground. This discharge is seen as a large spark called lightning.

7 The lightning in an electrical storm will usually strike at the highest object; in a city this will usually be a building or chimney. To prevent damage to these structures, a metal rod is often built into them and carries the electrical charge to earth. This is called a lightning conductor.

8 Plastic is a poor conductor of electricity and will build up static electricity when it is rubbed, whereas a piece of metal is a good conductor and will conduct any charge to your hand and through your body to earth.

9 a If the suspended rod is repelled, the other rod must be positive.
  b If the suspended rod is attracted, the other rod may be negative or neutral.

10 a *Earthed* means that there is a conductor to the earth which allows any static electricity to escape.
  b *Conducting* means that the material will channel electricity, eg tiles.
  c *Antistatic* means that static electricity will not build up on the object, eg trolley wheels.

11 A television screen is usually negatively charged because of the electrons which make the picture on the screen. Dust, which is neutral, will be attracted to the screen and needs to be regularly wiped off.

12 Both magnetic and electrical forces are non-contact forces which are a result of a force field around the object. Sometimes they are called electromagnetic forces.

Challenge solutions

1 From this information it can be deduced that rods A, E, B and D are one charge, and C is the opposite charge. This means that rods D and E will repel, and rods B and C will attract.

2 As the plane travels through the air it becomes electrically charged. The plane must be earthed by connecting a wire from the plane to the ground via the nozzle of the fuel hose to remove this charge. Otherwise a spark could jump and ignite the fuel, causing an explosion.

11.2 Electric currents

Static electricity is electricity that is stationary. If, somehow, this electricity can be made to move you have *current electricity* or an **electric current**. A torch battery provides the energy to drive the current. When the battery is connected by wires to a bulb, electrons flow to light up the bulb.

Investigate 27 SIMPLE ELECTRIC CIRCUITS

Aim

To investigate different ways of connecting a torch battery and bulb.

PART A Lighting a bulb

Materials

- 1.5 volt torch battery without holder
- torch bulb (2.5 volt) without holder
- 2 connecting wires

Planning and Safety Check

Read through Part A and describe to your partner what you have to do. Your partner can then describe Part B to you.

Method

1 Use the battery and one connecting wire to make the bulb light.
Draw a diagram of how you connected the battery and bulb.

2 See if you can find at least one other way of making the bulb light.
Draw diagrams of any ways that you discover.
What special places must be touched on the bulb for it to light?
What special places must be touched on the battery?

3 Can you make the bulb light using *two* connecting wires?
Draw diagrams of your set-ups.

Working with technology: **Students could investigate electric circuits using the computer program Crocodile clips.**

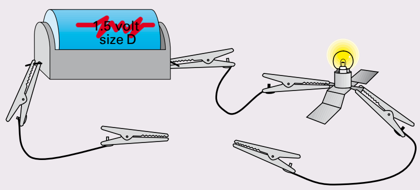
PART B Using a switch

Materials

- 1.5 volt torch battery with holder (or power pack)
- torch bulb (2.5 volt) with holder
- 3 connecting wires with alligator clips
- switch

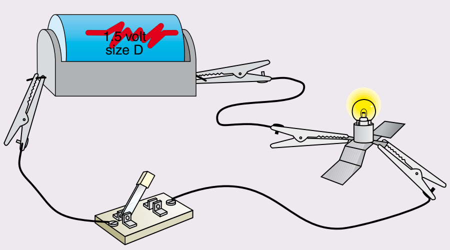
Method

1 Use the holders and the three connecting wires to connect the battery and bulb as shown.



2 Make the bulb go on and off by touching the alligator clips together.

3 Now connect the switch into the circuit as shown. Switch the bulb on and off.



Does it make any difference if you reverse the connections to the battery?

Hints and tips

It is better to explain current as the flow of negative charge (electron flow) rather than conventional current. The idea of direct current (DC) and alternating current (AC) could also be explored.

Electrical current is the flow of electric charge—that is, a measure of how much charge passes a given point in a certain time. It is measured in amperes (amps).

You may find it useful to show some circuit symbols at this stage (see page 244).

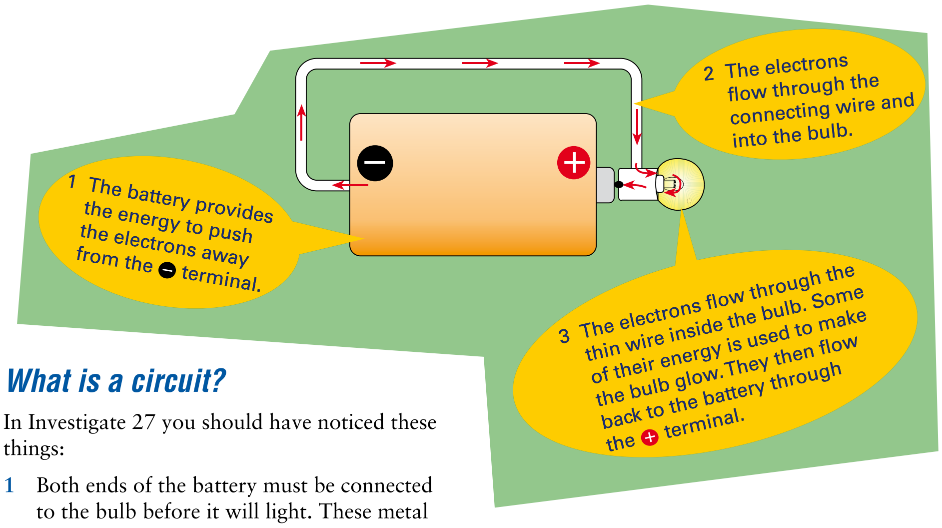
Lab notes

For these activities, using electrical equipment can pose significant management issues. The following tips may be of some help:

- Ask the lab technician to organise a trolley with labelled containers for different equipment.
- Make sure there are racks for the wires/leads where they can hang vertically.
- Have only one type of lead as this will save time later on when sorting them (crocodile–crocodile or crocodile–banana could be used).
- Make sure that any damaged or faulty equipment is put to one side for repair or replacement. A tub labelled 'faulty equipment' is useful.
- Assign a student to be responsible for making sure the trolley is kept neat and tidy and that equipment is put back in the correct places.
- When using electrical equipment, you should always check for damaged leads or malfunctions prior to use. Batteries should be fully charged and it would be a good idea to have all the bulbs with the same resistance. Each bulb is stamped with a voltage and current value. Typical values for a 2.5 V bulb are 0.3 A or 0.03 A.
- Remind students to draw their diagrams in pencil.

Hints and tips

A way to reduce static electricity caused by friction on some materials, particularly plastics, is to add surface conductivity to the material. This can be done by the use of antistatic sprays, such as that available for women's stockings. These are generally made from soap-based materials that have been diluted in a solvent, such as weak alcohol. The solvent may be flammable so a fire retardant is often added. When the solvent and retardant evaporate, the material is left with a conductive coating on its surface, making it difficult to generate static electricity.



What is a circuit?

In Investigate 27 you should have noticed these things:

1 Both ends of the battery must be connected to the bulb before it will light. These metal connection points are called *terminals*. The top of the battery is positive ⊕ and the bottom is negative ⊖.
2 The bulb has to be connected in two special places. The metal side of the bulb is one terminal, and the bottom is the other. They are both the same. There is no positive or negative.
3 For the bulb to light, there has to be a closed path (or circuit) joining the battery and the bulb. This is called an **electric circuit**. When there is a gap in the circuit, the light is off.
  A switch lets you open and close the circuit.

An electric current can be compared to water flowing through pipes. The battery is like a water pump—it gives energy to the electrons just as the pump forces the water through the pipes. (See Fig 19 on the right.)

A water meter measures how many litres of water are flowing through a pipe each second. In an electric circuit, the electric current or number of electrons passing per second is measured using an *ammeter* (AM-eat-er). An ammeter measures electric current in *amperes* (abbreviation amps, symbol A) or milliamps (1000 mA = 1 A).

Voltage is a bit like the pressure in the pipes. It is a measure of how much energy can be given to the moving electrons in a circuit. It is measured in *volts* (V) using a *voltmeter*. A torch battery has 1.5 volts. A 6 volt battery can push a larger current around the same circuit.

If one of the connecting wires in the previous experiment was replaced by a piece of string, the light bulb obviously would not glow. String does not let electricity through and is called an **insulator**. A substance like wire that does let electricity through is called a **conductor**.

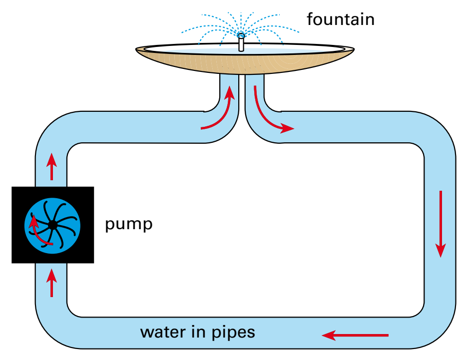


Fig 19 An electric current flowing from a battery through a bulb can be compared to water flowing in pipes.

Hints and tips

A good way to reinforce concepts is to give a set of 'Quick Questions'. By doing this regularly, students gain an appreciation of what is important to learn, and they obtain instant feedback on their progress.

It may be useful to create a 'fill in the gap' worksheet to give to students for this section, as many new concepts are introduced.

Assessment task

This would be a good time to complete Assessment task 11: The history of electricity, found on the CD.

Learning experience

Draw conclusions from Investigate 27. Get the class to come up with key concepts in the form of sentences or dot points.

Learning experience

Ask specific questions, such as 'What makes a circuit complete, and why does it need to be complete?' or 'If you connect a bulb to one end of a battery only, will it light?' (A little current will flow for a very short time. However, not enough energy is transferred to cause it to glow.)

Learning experience

When explaining the importance of insulating wires, a group discussion could be initiated about what makes a good insulator or conductor of electricity. The students could generate a list of materials they would like to test in Investigate 28.

Investigate

28 DOES IT CONDUCT?

Aim

To test various substances to see how well they conduct electricity.

Materials

- 1.5 V battery and holder (or power pack)
- torch bulb and holder
- ammeter or multimeter
- 4 connecting wires
- variety of objects, eg paperclip, plastic and glass rods, nail, coin, carbon rod, copper rod, matchstick, rubber band, aluminium foil, strip of paper, piece of string

Planning and Safety Check

Discuss the investigation with your teacher. You may use a 6 volt battery or a power pack instead of the 1.5 volt battery.

Look at the ammeter. The red or + terminal must be connected to the + terminal of the battery.

- Suggest why you use an ammeter in this investigation.
- Draw up a data table like the one shown. List at least 10 objects in the left-hand column. Write down what material each object is made of.

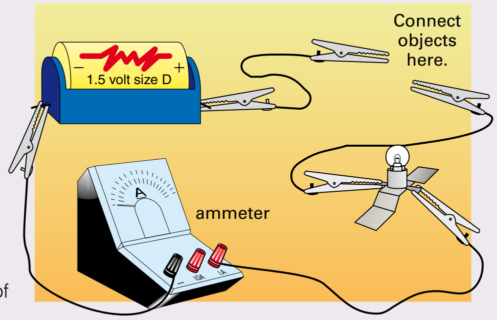
Object	Material	Does bulb grow?	Ammeter reading (mA)
paperclip	steel		
stirring rod	glass		

Method

1 Set up a circuit as shown. Ask your teacher to check your circuit before you go on to Step 2.

2 Touch the two alligator clips together. Observe what happens to the bulb.
Record the electric current reading on the ammeter.

3 Connect one of the objects between the alligator clips.



Record whether the bulb glows.
Record the ammeter reading. (This tells you how much current passes through the object.)

4 Test each of the other objects.
Record the results in your data table.

5 Is your skin a conductor or an insulator? Does it make any difference if your skin is wet or dry?

Discussion

1 Which materials are good conductors of electricity? How do you know?

2 Which materials are poor conductors (insulators)?

3 Use the ammeter readings to decide which one of the materials is the best conductor.

4 Why is it that some materials did not cause the bulb to glow, yet gave a reading on the ammeter?

5 Is air a conductor or an insulator? How do you know?

6 How could you test whether water is a conductor or an insulator?

Conclusion

How are the materials that conduct electricity similar? Write a generalisation about the types of materials that conduct and do not conduct electricity.

Lab notes

- Get the students to write a list of materials they are going to test for electrical conductivity. Next to each material ask them to predict whether they think it will be a good or poor conductor, and to justify their prediction.
- Remind students to draw their circuit diagrams neatly, in pencil and ruled.
- It is advisable to get the students to put switches in their electrical circuit constructions. Tell them that you do not want to smell or see any materials being burnt. To avoid burns to benches, heatproof mats could be used.
- Power packs or two 1.5 V batteries in a holder could be used instead of one battery. If power packs are used, it is important to make sure students connect leads to the DC terminals and use only 6 V. (Check the voltage of the bulb and power pack, and the resistance of the material being tested.)
- Multimeters can be used instead of ammeters. If using ammeters and a 2.5 V globe, use the 1 A setting. Because some materials will have high resistances, a milliamp ammeter may be more appropriate.
- Quicker students could test distilled water or other solutions and extend their results table accordingly.

Hints and tips

- An insulator takes a very high voltage to produce any current (if at all). A conductor is a material that allows electricity to move through it easily and has a low electrical resistance—a small voltage will produce a large current.
- Engage students by putting what they are learning in the context of everyday life and experiences. For example, explain why it is important for electricians to know about conducting and insulating materials, why some professions wear certain types of clothing (rubber-soled shoes etc), or occupational heath and safety issues (crane operators near power lines etc).

Homework

Ask your students to investigate what electrical earthing is and to write down a definition in their own words. See if they can locate where their home's earth wire is. On older homes it will be located on an outside water tap. New houses have their earth wire located near the meter box.

Conductors and insulators

All metals are conductors, while most non-metals are insulators.

Conductors	Insulators
carbon	plastic
salt water	glass
acids	cloth
silver	paper
copper	wood
gold	rubber
aluminium	air

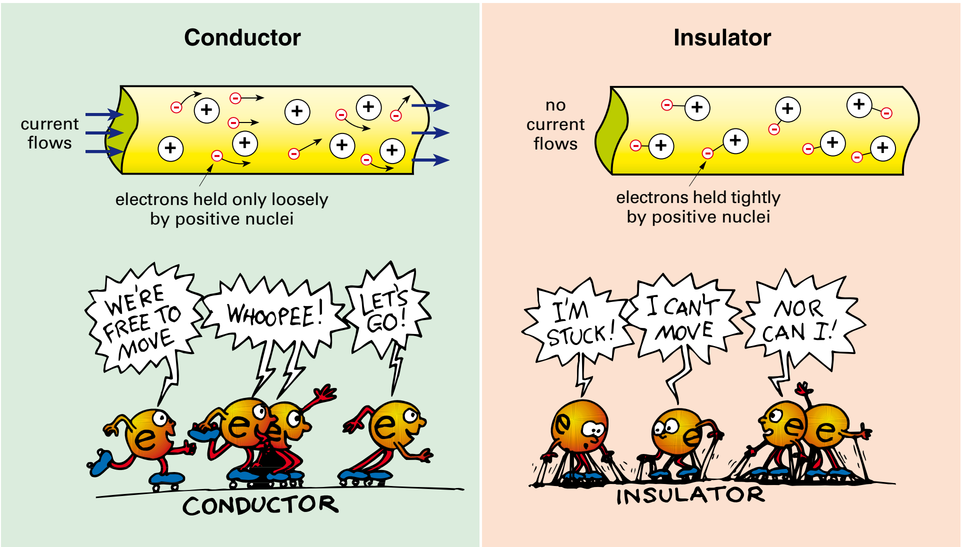
Insulators are very important in the supply and use of electricity. The poles that carry electricity from power stations to cities need insulators to stop electricity from escaping to the ground (Fig 23 on the next page). The handles of screwdrivers and pliers are often coated with plastic insulation. The casings of electric plugs, sockets and switches are all made from plastic.

How can you explain the difference between conductors and insulators? An electric current is a flow of electrons. So a conductor is a material through which electrons can flow.

A metal consists of an arrangement of positive nuclei in a 'sea' of electrons. These electrons are not strongly attracted to any one nucleus. So, when the metal is connected to a battery, the electrons can move easily through the metal to produce a current.

In an insulator the electrons are held tightly by the positive charges. Because of this, the electrons cannot move, and no electric current can flow when the insulator is connected to a battery.

If you charge an insulator such as a plastic rod by rubbing, the charge stays on the surface of the insulator. But the insulator slowly loses its charge to the air, especially in wet or humid weather. The charge is also lost quickly if you touch the insulator with your hand. This process allows the charge to flow to the ground, and is called *earthing*. You cannot charge a conductor by rubbing. Any charge you produce flows through the conductor to the ground immediately.



Note: Good conductors of electricity are also good conductors of heat.

Learning experience

It may be useful to draw similarities between materials being good conductors of heat and electricity, generally for the same reason—their electrons are 'loosely bound'.

Learning experience

Pose a Think/Pair/Share (page 126) question such as 'Why do some electrical insulators get hot?' or 'Why do you think computers need fans in them?' Asking questions like this leads into the concept of electrical resistance on the next page.

Learning experience

Here would be a good place to investigate computer software to design and test circuits.

Fig 23 The insulators on power lines are made of glass or porcelain. The conducting wires are made of aluminium and steel.

Resistance

When an electric current moves through a conductor, there is always some **electrical resistance** to the current. This is because of the attraction of the electrons to the positive nuclei of the atoms in the conductor. This attraction is greater in some conductors than in others, giving them a greater electrical resistance.

As the electrons are pushed through a conductor they lose some of their energy as heat. This waste heat can be a nuisance; for example, computers get hot when used. However the waste heat is sometimes useful. For example, because nichrome wire has a fairly high resistance, it is used to make the heating elements in many electrical appliances used around the home. It is usually coiled to take up less space. The filament of a light bulb is made from very thin tungsten wire. When a current is passed through it, the wire becomes so hot that it gives off a brilliant white light.

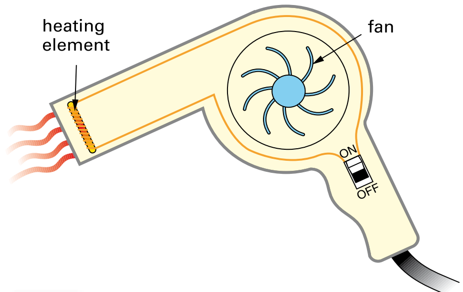


Fig 24 This hair drier contains a nichrome wire heating element.

In electric power lines there is always loss of energy due to the resistance of the metal in the wires. For this reason, scientists are trying to make cheap *superconductors*, which offer *no* resistance to the flow of electricity. The use of such materials would save billions of dollars.

Superconductors could also be used in the maglev trains now being developed. These trains float above the tracks supported by the non-contact forces between large electromagnets.

Fig 25 The chilled superconductor (bottom) is acting like a magnet. It repels the magnet (top), making it hover in the air above the superconductor.

Hints and tips

- Prepare lists of the following for the class:
  - appliances that use resistors and why
  - different types of resistors—what they are made from and why
  - when electrical resistance is a hindrance and when it is useful.
- The resistance of a material depends on the conductivity, thickness and length of the material. For most conductors, increased temperature means an increased electrical resistance; interestingly, carbon is an exception. At high temperatures, electrons are dislodged from the carbon atom, which increases its conductivity. So its resistance becomes lower as the temperature increases.
- What may appear as a loss of energy caused by electrical resistance is in fact just the energy being transferred or transformed into another form—mostly heat and light. (Energy cannot be created or destroyed.)
- A semiconductor is a material which can behave as an insulator and a conductor. Transistors are semiconductors: sandwiched layers of semi-conducting material.
- Some metals acquire near infinite conductivity at temperatures close to absolute zero. This means charge flows through these metals without any resistance. Such metals under these conditions are called *superconductors*. Once a current is established in a superconductor it should flow indefinitely.

Learning experience

Do a teacher demonstration to show electrical resistance. It can be a little dangerous, so ask the students not to crowd around. Connect a pencil lead (pacer lead—HB or 2B are best) between two connecting wires (crocodile–banana). Suspend the wires and pencil lead from two retort stands. Connect the other ends of the wires to a power pack and turn it on to about 6 V. You may wish to put a switch in the circuit. The pencil lead starts to glow red-hot and if you are not careful it will ignite.

Learning experience: writing a short story

For a creative task, get students to write a short story about the journey of an electron through a simple circuit. The circuit could contain a light bulb, toaster or heating element. Although the students should be encouraged to be imaginative, they also need to be factual and should be reminded about this.

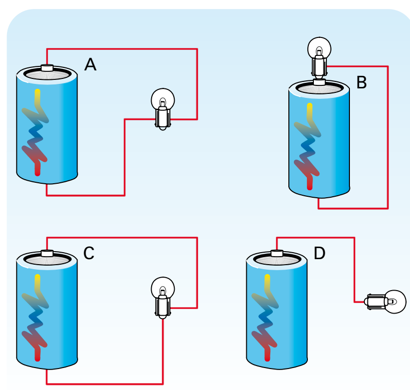
Learning experience

For the more able or mathematically inclined students, introduce Ohm's law. The typical Ohm's law experiment could be performed (*ScienceWorld 2*, page 175).

Check!

1 Copy and complete the following sentences.
- a A path for electricity is called a ______.
- b A ______ lets you open and close a circuit.
- c Moving electrons in a wire are called an electric ______.
- d An ______ is an instrument used to measure electric current.
- e The unit for electric current is the ______.
- f ______ is a measure of the energy given to the electrons in a circuit.
- g Substances that do not allow an electric current to flow through them are called ______.
- h Metals are ______ because they allow an electric current to pass through them.
- i Opposition to the flow of current in a circuit is called ______.
- j If the resistance in a circuit is increased the current ______.

2 In which of these circuits will the bulb glow? For the other circuits, explain why the bulb *won't* glow.



3 Into what two forms of energy is electrical energy changed in a light bulb?

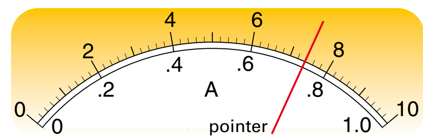
4 Which battery can supply the most energy to electrons in a circuit: 1.5 volt, 6 volt or 9 volt? Why?

5 Lisa connected a bulb to a battery. The wires were connected properly, but the bulb did not glow. What could be wrong (two possibilities)?

6 Explain in your own words the difference between an insulator and a conductor of electricity.

7 Why are electrical connecting wires covered with plastic?

8 This ammeter measures current in two different ranges: 0 to 1 amp and 0 to 10 amp.



- a What is the reading if the 0–10 amp range (top) is used?
- b What is the reading if the 0–1 amp range (bottom) is used?

9 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?

10 Why is it safer to wear shoes than to go barefoot in an electrical storm?

Check! solutions

1
- a A path for electricity is called a **circuit**.
- b A **switch** lets you open and close a circuit.
- c Moving electrons in a wire are called an electric **current**.
- d An **ammeter** is an instrument used to measure electric current.
- e The unit for electric current is the **ampere**.
- f **Voltage** is a measure of the energy given to the electrons in a circuit.
- g Substances that do not allow an electric current to flow through them are called **insulators**.
- h Metals are **conductors** because they allow an electric current to pass through them.
- i Opposition to the flow of current in a circuit is called **resistance**.
- j If the resistance in a circuit is increased the current **is decreased**.

2 The bulb will glow in B and C. It will not glow in A because the wires touch only one of the terminals (the side) on the globe. It will not glow in D because it needs another connecting lead.

3 In a light bulb electrical energy is changed to light and heat energy.

4 A 9 volt battery can supply most energy to electrons because it can push a larger current around a circuit than the other batteries.

5 The two most likely reasons are that the bulb is blown (the filament has broken) or the battery is flat.

6 An insulator will not conduct electricity because its electrons are not free to move, whereas in a conductor they are free to move. These moving electrons are called an electric current.

7 Electrical wires are usually covered with plastic because plastic is an insulator. Insulating wires are much safer to use on appliances because the electricity cannot be conducted to other materials.

8
- a If the top scale is used the reading is 7.4 A.
- b If the bottom scale is used the reading is 0.74 A.

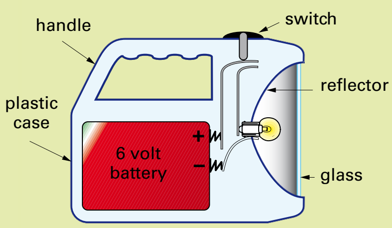
9 The greater the resistance, the less the current.
- a The 'lead' with the greatest resistance is 4H.
- b You can infer that the type of 'lead' with most graphite is 3B.

10 Shoes are usually made of material which is an insulator. In an electrical storm they will reduce the chance of conducting electricity to the ground and of being injured or killed.

challenge

1 Explain why the battery in a torch eventually goes flat.

2 When you push down the switch the torch produces a beam of light. Explain in detail how this happens.



3 What do you think is the most likely cause of the following?

- **a** Your radio starts to get quieter and quieter. Turning up the volume doesn't seem to help much.
- **b** Your torch is very bright but suddenly goes out.
- **c** Your CD player stops working, but when you tap on the case it works again.

4 A company produces an all-metal electric kettle, but the government bans its sale. Suggest why it was banned.

5 Explain why the element in a toaster becomes red-hot, while the wires connecting the toaster to the mains power supply remain cool.

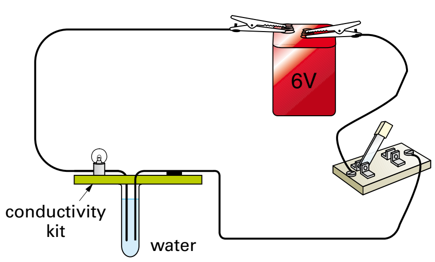
6 One of the things that 'lie-detectors' measure is skin resistance. Lying is supposed to make you sweat. How do you think this lie-detector works?

7 Why don't the materials that conduct current electricity hold static electricity?

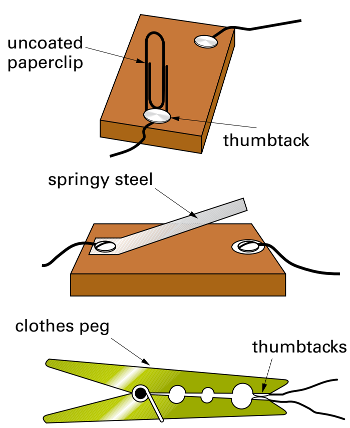
8 Using what you know about resistance, explain why a long wire has more resistance than a short one, and why a thin wire has more resistance than a thick one.

try this

1 Find out whether tap-water will conduct an electric current. Set up the circuit shown, using a conductivity kit. You could also test rainwater, distilled water and salt water.



2 Make your own switch. Here are some designs. Try out your switch in a circuit.



Challenge solutions

1 The cell in a torch goes flat because it no longer has enough energy to push the electric current through the circuit to make the globe glow.

2 When the switch is pushed down the circuit is completed and the electricity flows through the light globe. As the electricity flows through the very thin filament in the globe it is changed to light energy (and some heat energy). The reflector produces a beam of light.

3
- **a** One possibility is that the battery is 'flat' and not producing enough electricity.
- **b** The most likely explanation is that the light bulb has blown. This means that the filament is broken.
- **c** There is probably a loose connection in the CD player and tapping the case completed the circuit again.

4 The kettle would be banned because it would be unsafe to use. As electricity passes through the element it would also travel to the handle and could cause electrocution.

5 The wires in the toaster are made of a different metal and are much thinner than the connecting wires. This means that they have a greater resistance to electricity and will heat up as electricity flows through them.

6 If the skin is moist because of sweating it will be a better conductor. If so, it might be inferred that the person is lying.

7 The reason is that such materials will conduct the electricity away to anything that is touching it.

8 Electricity flows when electrons are pushed through a conductor. If they are squeezed through a smaller space or pushed through a longer length there will be a greater resistance. This means that more energy will be required and more heat will be produced.

Hints and tips

Before starting theory, work on the differences between series and parallel circuits. You could complete Investigate 29 (pages 245–246). Doing an investigation before theory promotes self-learning.

Homework

Students could research household electrical wiring. Do any sections of their house have series wiring—why or why not? Why might the oven wiring and lighting be on different circuits? What is a circuit-breaker and fuse? Why are they necessary?

Learning experience

A great way to explain how a circuit works and to gain an understanding of different electrical terms is to get the class to model a circuit. This method can be used to explain both series and parallel circuits. You could be creative and make up all sorts of different configurations. The students really enjoy the modelling, especially the kinaesthetic learners. Here is a suggested method:

1 You will need a bag of M&Ms or Smarties (chocolate buttons). Be sure to check for any student food intolerances.
2 The teacher is the battery (energy source) while the students are the electrons and the M&Ms represent energy. Place some resistors in a series circuit in the form of either students or labelled paper. Resistors could be a toaster, a heater or light bulbs.
3 The students (electrons) need to form a complete circuit around the room joining the resistors and both ends of the battery.
4 For the electrons to move, they need energy and the energy given to them by the battery models voltage. Voltage can be considered a measure of how much energy each electron is given by the battery.
5 As the students pass the battery, they collect enough M&Ms from the teacher for their journey around the circuit. (Before handing out the M&Ms you could ask them how many they think they need to complete their journey.)
6 Current is modelled by the students (electrons) moving around the circuit. Ask questions like 'What needs to be modified so that current is increased?' (more electrons need to pass a certain point in a shorter time). Current can be considered a measure of how many electrons pass by each second.
7 When the students (electrons) reach a resistor, they have to do a lot of work (use up energy) to get through the device. This is where the students can eat their M&Ms, but they need to keep enough energy so they can pass through *each* resistor!

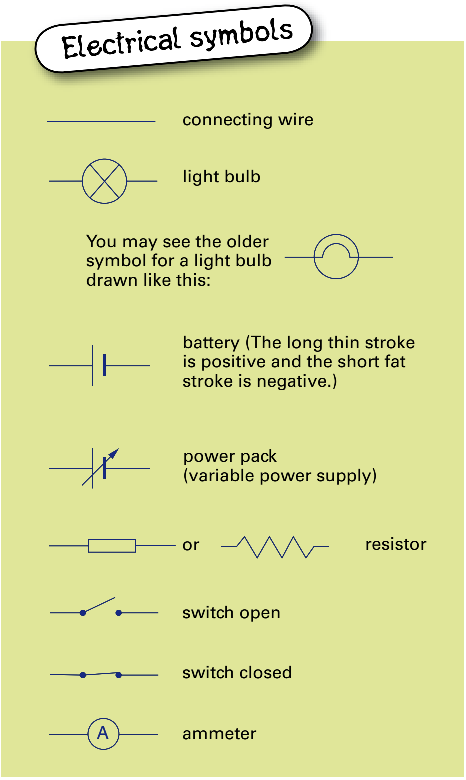
11.3 Electric circuits

Circuit diagrams

Look at the two circuits on the right. They look different, but they are actually the same.

If you wanted to tell someone how to set up this circuit, you might confuse them if you drew these sketches. Also, drawing diagrams like these takes time. So electricians have decided on a simple way to draw electric circuits with a symbol for each component (part). These symbols are listed below.

The wires in a circuit are drawn straight and at right angles. For example, the circuit on the right can be drawn as shown. This is called a **circuit diagram**.



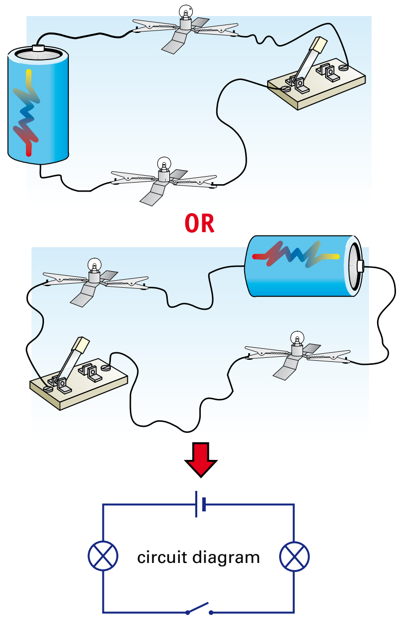


Fig 33 How to draw a circuit diagram

Series and parallel circuits

The parts of a circuit can be arranged in two different ways. Take, for example, two torch bulbs. They can be connected one after the other as shown in Fig 34 below. This is called a **series connection**. Note that there is only one path for the electric current to flow, and the current is the same everywhere in the circuit. As you connect more bulbs in series, the current decreases, and the bulbs don't glow as brightly.

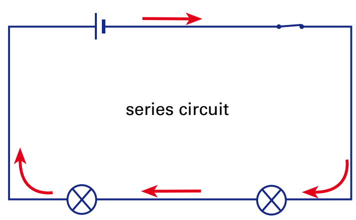


Fig 34 A series circuit

Many electrical appliances use several batteries connected in series. When you put in the batteries, the positive terminal of one battery must touch the negative terminal of the next. For example, a 3 volt toy usually has two 1.5 volt batteries arranged in series as shown in the cartoon.

Two bulbs can also be connected side by side. This is called a **parallel connection**. Look at Fig 36. At **A** the electric current splits and follows two different paths. The electrons flowing through each bulb get the full push from the cell—they don't share it as in a series circuit. As a result, each bulb glows as brightly as if it was the only bulb in the circuit. A master switch can be used to turn off both bulbs together, or separate switches can be used to turn each bulb off independently.

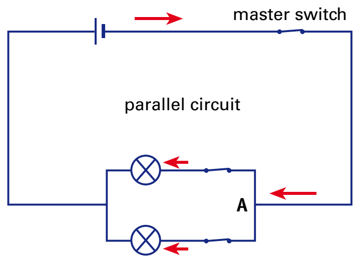


Fig 36 A parallel circuit

Sometimes it is not easy to tell whether the components of a circuit are connected in series or in parallel. However, if you can trace the complete circuit using one finger, then the components are connected in series. Those parts of a circuit that branch and where you have to use more than one finger are connected in parallel. Note that a circuit may contain a mixture of series and parallel connections (Fig 37).

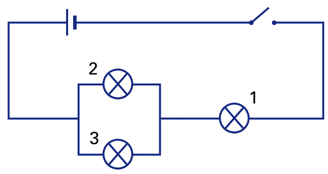


Fig 37 Bulbs 2 and 3 are in parallel, but they are in series with bulb 1, the switch and the battery.

In Investigate 29 you can investigate series and parallel circuits for yourself.

Investigate 29 SERIES AND PARALLEL CIRCUITS

Aim

To investigate series and parallel circuits.

Materials

- two 1.5 V batteries and holders (or power pack)
- 3 torch bulbs and holders
- 6 connecting wires
- ammeter or multimeter

Planning and Safety Check

- Carefully read through the instructions for the three parts on pages 224 and 225.
- To which terminal of the battery do you connect the positive (+) terminal of the ammeter?

Hints and tips

Investigate with your class some of the many interactive computer applications or games available on the internet that test electricity concepts and which also allow you to build and test simple circuits.

Lab notes

- If using a power pack instead of a battery and holder, make sure not to exceed the maximum voltage the bulb can handle. A power pack cannot be used for Part B.
- Multimeters can be used instead of ammeters (1 A setting or 250 mA setting if using a 2.5 V bulb).

Learning experience

In practical group work there is often one student who contributes the least to the group. One way to ensure all students aim to master their practical skills is by giving a *Prac Test* like the Lab review on page 252. The electricity unit is perfect for doing such a test and it can form part of students' lab skills assessment. Give each student a copy of a printed circuit diagram (no two diagrams the same per workstation) and ask them to construct it. Have a series of questions for the students to answer about their circuit.

Another way is to get each student to individually construct a circuit under your supervision while the rest of the class is doing theory. Although this may be time-consuming, each student gets personalised attention from you.

Learning experience

Students could develop a concept map individually or in pairs. Emphasise the linking of keywords, setting a minimum of about ten. Keywords might be: *electricity*, *energy*, *charge*, *electron*, *conductor*, *insulator*, *current*, *voltage*, *resistance*, *batteries*, *power source*. (Now would also be a good time to get the students to complete their post-test concept map on the back of the poster paper they used for the pre-test map.)

Lab notes

Using two batteries is better than using one, as the net voltage is 3 V which means the bulbs glow brighter and it is easier to identify what happens when they are placed in series and then in parallel.

Part A

- Check that all bulbs have the same voltage and resistance values.
- Bulbs in parallel will be brighter than those in series.

Part B

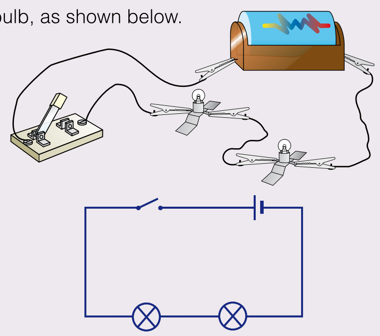
- A double battery holder is wired so that the batteries are in series. Placing a bulb in series with the two batteries in series means the electrons are supplied with more energy and therefore the bulb glows more brightly.
- To put two batteries in parallel, place each battery in a separate holder and connect them as shown bottom right. The bulb will glow at the same brightness as with one battery.

PART A
Lighting a bulb

Method

1 Connect up a circuit with a battery, a switch and *one* bulb. Close the switch and observe the brightness of the glow of the bulb.

2 Connect a second bulb in series with the first bulb, as shown below.



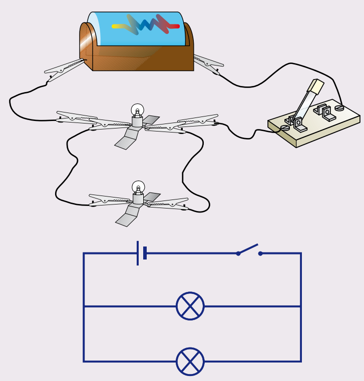
Does each bulb glow as brightly as the single bulb in Step 1?

Unscrew one of the bulbs from its socket.

Record what happens.

3 Repeat Step 2 with *three* bulbs.

4 Connect up a second circuit with the two bulbs in parallel, as shown below.



In which two-bulb circuit do the bulbs glow more brightly? Suggest a reason for this.

What happens if you unscrew one of the bulbs in the parallel circuit?

5 Add a third bulb in parallel with the other two. What happens?

Discussion

1 What is the effect of increasing the number of bulbs in series in a circuit?

2 If one bulb in a series circuit blows, the others also go out. Why?

3 Describe the effect of adding more bulbs in parallel in a circuit.

4 When one bulb in a parallel circuit fails, the others continue to operate. Why?

5 Parallel circuits are used in the electrical wiring of a house. Suggest reasons for this.

PART B
Battery problem

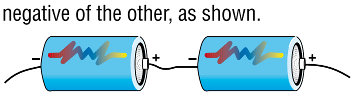
Research question: *Can you make the bulb glow more brightly by adding a second battery?*

Experiment to find out whether you should add the second battery in series or in parallel.

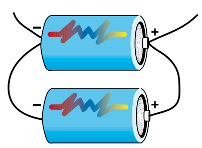
Write a brief report of your findings.

Notes for Part B

1 When connecting batteries in series, you must connect the positive of one to the negative of the other, as shown.



2 When connecting batteries in parallel, you must connect the positive of one to the positive of the other.

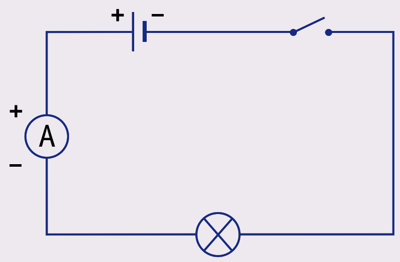


PART C
Using an ammeter

Research question: *How can you use an ammeter to find out whether the current is the same in all parts of a series and parallel circuit?*

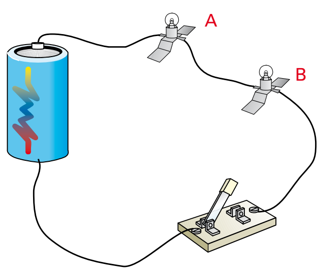
Discuss the research question in a group and design an experiment. Check it with your teacher before you start.
Don't forget to connect the positive terminal of the ammeter to the positive terminal of the battery or power pack, as in the circuit on the right.

Write a report of what you find.

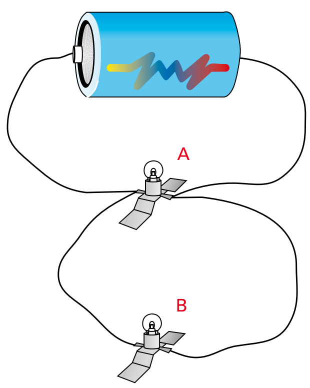


Check!

1 Copy and complete the sentences below by selecting the correct words to describe the circuit below.
   a In this circuit the electricity has ______ (one / two) paths to follow.
   b This circuit is ______ (open / closed).
   c If bulb A went out while the switch was closed, bulb B would (stay on / go out).
   d If more bulbs were added to the circuit, each bulb would glow ______ (more / less) brightly.
   e If the circuit had only one bulb, it would glow ______ (more / less) brightly.
   f The bulbs are connected in ______ (series / parallel).



2 Answer these questions about the circuit below.
   a How many paths can the electric current follow?
   b Does the current have to pass through bulb A for bulb B to glow?
   c If bulb B blew would bulb A continue to glow?
   d What would happen if you added a third bulb in parallel?



Lab notes

Part C

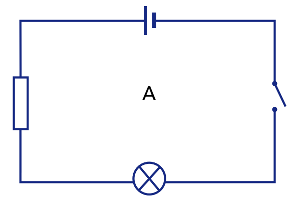
- Ammeters are placed in series in the circuit because they measure the amount of charge flowing each second.
- You may like to put voltmeters in the circuits to show how they are used. Voltmeters are placed across (parallel to) the light bulb (resistor), as they measure a difference in electrical potential.

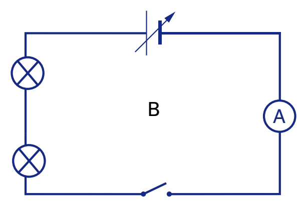
Check! solutions

1 a In this circuit the electricity has **one** path to follow.
   b This circuit is **open**.
   c If bulb A went out while the switch was closed, bulb B would **go out**.
   d If more bulbs were added to the circuit, each bulb would glow **less** brightly.
   e If the circuit had only one bulb, it would glow **more** brightly.
   f The bulbs are connected in **series**.

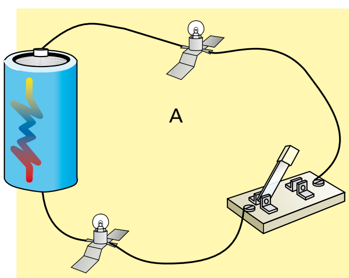
2 a The electric current can follow two paths.
   b The current does not have to pass through bulb A for bulb B to glow.
   c If bulb B blew then bulb A would continue to glow.
   d If a third bulb was added in parallel it would also glow as brightly as A and B.

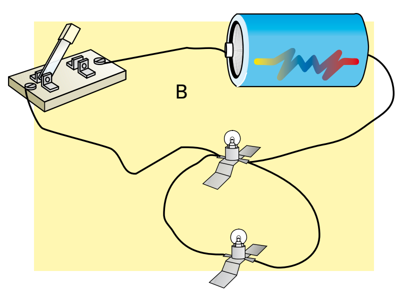
3 Write out a list of the equipment needed to set up circuit A. Do the same for circuit B.





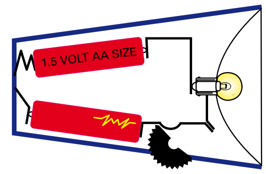
4 Draw a circuit diagram for each of the following.



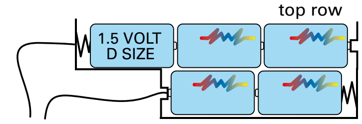


5 What voltages are being used in these two electrical appliances?

Torch



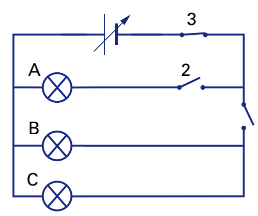
Battery compartment of radio



6 Draw a circuit diagram that has:
- **a** two batteries and a bulb in series
- **b** one battery and two bulbs in series
- **c** two batteries in parallel and a bulb in series
- **d** two batteries in parallel and two bulbs in series
- **e** a power pack and a string of eight decorative bulbs in parallel

7 Draw a circuit using two batteries and two bulbs that makes the bulbs glow most brightly.

8 In the circuit diagram below, what happens to each of the bulbs A, B and C when you:
- **a** close switch 1?
- **b** then close switch 2?
- **c** then open switch 3?

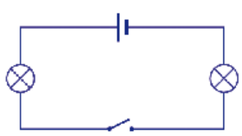


9 Give two reasons why lights in parallel are better than lights in series.

Check! solutions

3 The list of equipment needed for circuit A is one cell, one switch, one light bulb, one resistor and four connecting wires. The list of equipment needed for circuit B is one battery, two light bulbs, one ammeter, one switch and five connecting wires.

4 a



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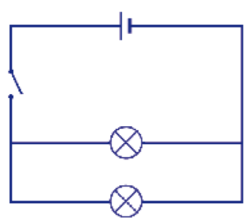
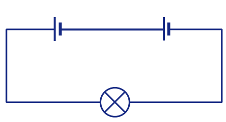


Students may have drawn these slightly differently.

5 When cells are in series their voltages are added to give the total voltage. In A it is 3.0 volts. In B it is 7.5 volts.

6 a



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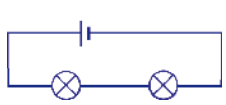

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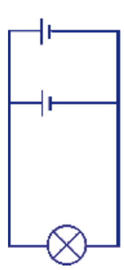

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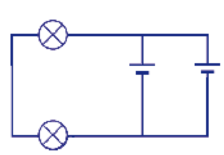

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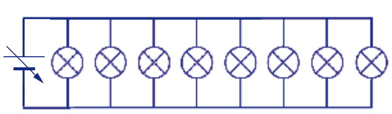
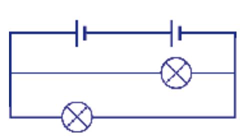


7



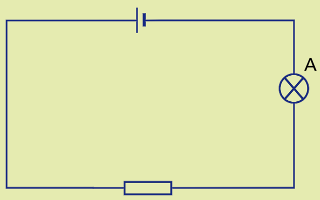
8 a A is off. B and C are on.
b A, B and C are all on.
c None of the bulbs are on.

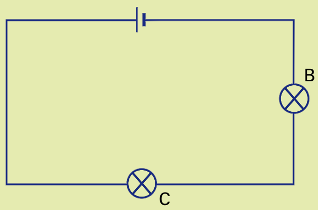
9 Two reasons why lights are better in parallel are that they will glow more brightly than if they are in series and if one globe blows, the others will stay on—this will not happen if they are in series.

challenge

1 Draw a circuit diagram with a battery, three lights and three switches so that each switch turns on only one light. Where would you place a fourth switch that could switch all three lights on and off (that is, a master switch)?

2 Consider the two circuits below. The resistor in the circuit is a piece of nichrome wire like that used in jug elements. If the nichrome wire has a greater resistance than a light bulb, which of the three identical bulbs (A, B or C) will have the dimmest glow? Explain your answer.

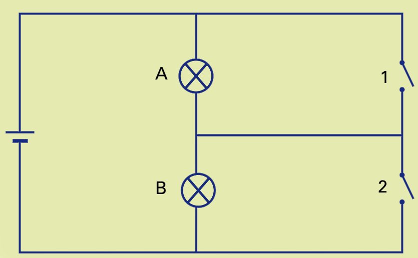




3 The bulbs in this circuit are both dimly lit when the switches are open. Predict what will happen when:

a switch 1 is closed (two things)

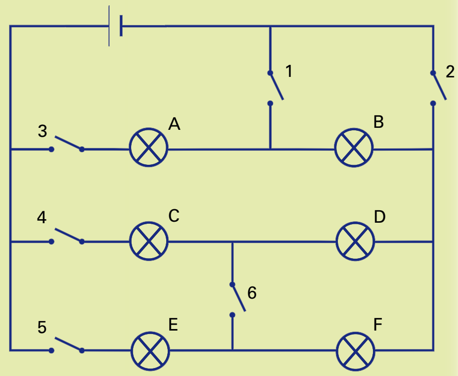
b switch 2 is closed as well.



4 How is adding an ammeter (very low resistance) to a circuit different from adding a light bulb or electric motor?

5 Suppose the latest portable CD player is wired with superconducting material. Would the batteries last a longer or a shorter time than in a normal CD player? Explain your answer.

6 Below is the circuit diagram for a caravan.



a Which switches do you need to close so that only one light stays on?

b Which lights are on when switches 1, 4 and 6 only are closed?

c Are lights A and B in series or in parallel with each other?

7 How would you connect six 1.5 volt torch cells to give a voltage of:

a 9 volts?

b 6 volts?

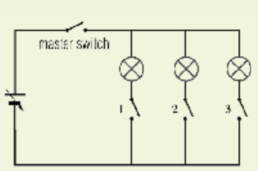
c 4.5 volts?

Draw circuit diagrams. You must use all six cells. (Hint: Two 1.5 volt cells in parallel have a total voltage of 1.5 volts.)

8 Design a circuit with one battery, four switches and a bulb so that the light comes on when any one of the switches is closed. Draw a circuit diagram. (This circuit could be used to light the inside of a car with four doors. Opening a door *closes* a switch.)

Challenge solutions

1 Here is one possibility. Students may be able to think of others.



2 Light bulb A will be dimmest because the *total* resistance in the circuit at the top is greater than the bottom circuit.

3 a When switch 1 is closed, globe A will go out and globe B will glow more brightly.

b When switch B is closed as well, globe B will also go out and you may also notice that the connecting wires feel hotter.

4 An ammeter is different because it has very little resistance and will not cause much change to the current flowing through the circuit.

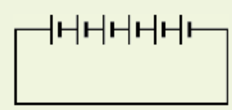
5 The CD units would last longer because the superconducting material would waste less energy as the electric current passed through it.

6 a To allow light A to stay on, switches 1 and 3 should be closed and all others should be open.

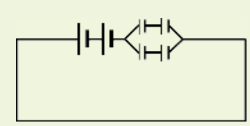
b If switches 1, 4 and 6 are closed, lights B, C, D and F will be on.

c This depends on which switches are open. If switch 2 is open and all others are closed, lights A and B are in parallel. If switch 1 is open and all others closed, they are in series.

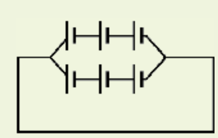
7 a



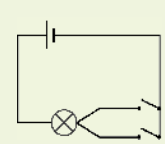
b



c



8 This is a diagram of one possible circuit:



Experiment
YOUR INVENTION

Aim
To use what you have learnt in this chapter to invent a useful electrical device.

Method
1 Study the two inventions on the right. Explain to another student how one of them works. Your partner will explain to you how the other one works. You could also have another look at the mousetrap on page 229.

2 Use your imagination to design your own invention, or use the ideas below.
- a battery tester
- a circuit where you can switch a light on in one place and turn it off somewhere else
- a burglar alarm where a bell rings, a light flashes or a trapdoor opens to catch the burglar
- a model house in which you can turn the lights on and off independently
- an alarm to warn you of strong wind
- a device to warn you when a water tank is about to overflow
- an alarm clock using a candle
- an electric maze
- a way of dimming a light (Hint: A long wire has more resistance than a short one.)
- a pinball machine (Hint: A rolling metal ball could be used to close a switch.)

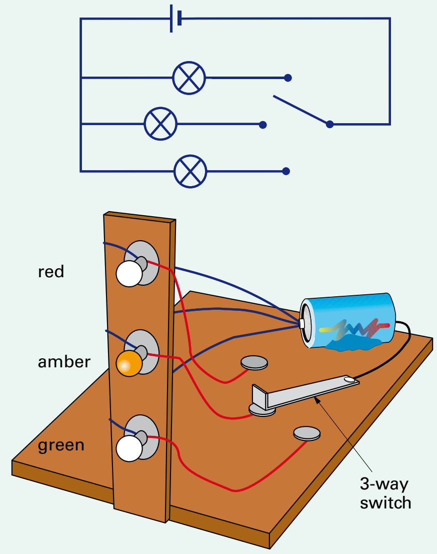
3 Draw a sketch of your design before you start. Try to draw a circuit diagram too.

4 Make a list of the things you will need to make your invention.

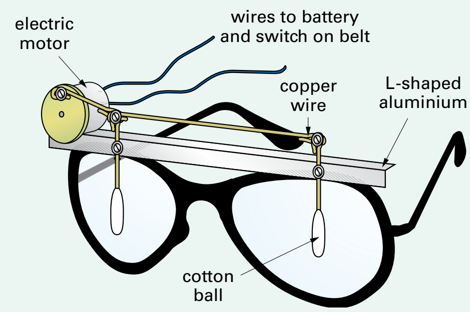
5 Check your design with your teacher, then go ahead and make it. (You may be able to work on your invention at home.)

6 Prepare a report of your invention for the rest of the class. Make sure you report any problems, as well as your successes. Other students may be able to suggest ways of improving your design. (If your invention is good enough you may be able to enter it in a science contest.)

Traffic lights



Wiper glasses



Lab notes
This can be a fun and interesting 'last week of term' or 'end of topic' activity for students.

A box of useful items/bits and pieces should be collected and made available for this experiment. A good start could be made by dismantling some old appliances, such as video recorders etc, as they contain micro-switches and many other useful parts. **Cut the mains leads off all electrical equipment and never allow students to meddle with 240 V.**

An established school should have any amount of old electrical equipment and tool kits in the science department. A trolley set up for these activities will make management easier.

A Dick Smith/Jaycar catalogue is useful.

Other activities may include a Steadiness tester or a game show quiz (see below).

Learning experience: steadiness tester
A steadiness tester is a simple electrical device which tests how steady your hand is. Electrically connect a wiggly piece of wire, some batteries, an LED or light bulb, a handpiece and a base. The handpiece is a looped piece of wire with an insulated handle. Put the wiggly wire through the small loop of the handpiece so that when the loop makes contact with the wire the bulb lights up.

Learning experience: game show quiz
Requirements: a piece of cardboard, insulated wires, metal paper fasteners, battery and light bulb.

Construction: On the left-hand side of the cardboard have a list of questions and on the right-hand side have the answers to the questions jumbled up. Push through paper fasteners with the heads on the front of the board, then at the back of the board wire together the correct questions and answers using the exposed pins. To check a question and answer, place two leads—one on the question, one on the response—connected to the battery and bulb. If correct, the bulb will light up.

MAIN IDEAS

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

1. Objects can be given an electric _____ by rubbing. Gaining electrons makes an object negatively charged, and losing electrons makes it positively charged.
2. Like charges _____ each other, while unlike charges _____ each other.
3. Electric current will flow only if it has a continuous path or _____.
4. Electric current is a flow of _____. It is measured in amperes, using an _____.
5. Batteries supply the _____ to push electrons around a circuit. _____ is a measure of how much energy can be given to the moving electrons in a circuit. It is measured in volts.
6. _____ offer little resistance to the flow of electricity. _____ offer a great deal of resistance.
7. A series circuit has only one conducting path for electrons, whereas a _____ circuit has two or more alternative paths.

ammeter
attract
charge
circuit
conductors
electrons
energy
insulators
parallel
repel
voltage

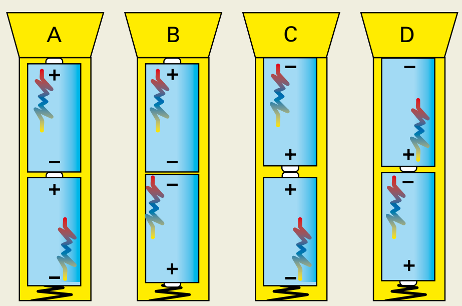
Try doing the Chapter 11 crossword on the CD. Working with technology

Main ideas solutions

1. charge
2. repel, attract
3. circuit
4. electrons, ammeter
5. energy, voltage
6. conductors, insulators
7. parallel

REVIEW

1. What happens to two charged rods held near each other if they have:
   a. the same charge?
   b. opposite charges?
2. What charge is left on a material if it has been rubbed and:
   a. loses electrons?
   b. gains electrons?
3. Which of the following are conductors and which are insulators?
   a. copper
   b. plastic
   c. steel
   d. air
   e. wood
   f. salt water
4. Look at the diagrams below.
   a. Which is the correct way to put two batteries in a torch?
   b. Are the batteries connected in series or in parallel?



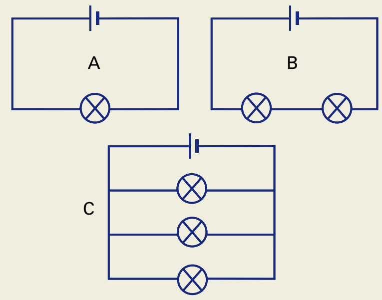
Review solutions

1. a. Rods with the same charge **repel** each other.
   b. Rods with opposite charges **attract** each other.
2. a. If a material loses electrons it becomes **positively** charged.
   b. If a material gains electrons it becomes **negatively** charged.
3.

Conductors	Insulators
copper	platic
steel	air
salt water	wood

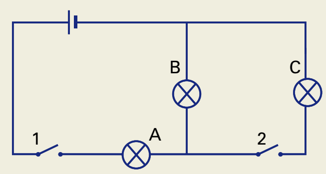
4. a. **A** (Set-up D may or may not work, depending on whether the battery terminal touches the spring at the bottom. Because of this, torch batteries are usually put in with the + terminal nearest the bulb.)
   b. The batteries are connected **in series.**

5 Consider the circuits below.



a What will the brightness of the bulbs in circuit B be like compared with the bulb in circuit A? Why?
b How bright will the bulbs in circuit C be compared with the bulb in circuit A? Why?
c Without changing the number of bulbs, how could you make the brightness of the bulbs in circuit B the same as the bulb in circuit A? Draw a diagram of the new circuit.

6 Consider the circuit below.

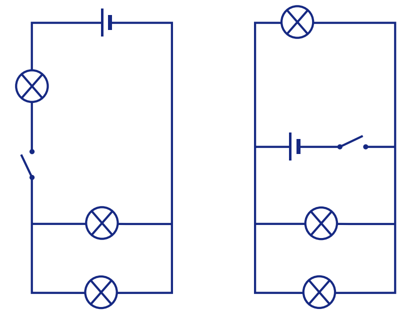


When switch 1 is closed and switch 2 is open:
A none of the bulbs lights up
B only bulb A lights up
C bulb A and bulb B light up
D all the bulbs light up

7 Explain why you sometimes get an electric shock when you walk on a nylon carpet and then touch something made of metal.

8 Design a circuit with a cell, a switch and a bulb, so that the light goes *off* when the switch is closed.

Work with a partner. From the two circuits below, select the one you are going to set up. Your partner (or your teacher) will mark you on your performance.



First write down a list of the equipment that you will need to set up the circuit. Then set up the equipment correctly and promptly.

How to score

List of equipment:
A chose the equipment perfectly
B left out a small item, like a connecting wire
C left out a major item, such as a bulb or a battery
D was not sure of the equipment needed

Setting up the equipment:
A set up the circuit correctly and promptly
B set up the circuit correctly, but took quite a while to do it
C set up the circuit promptly, but with a slight error in it
D set up the circuit slowly, but with a slight error in it
E was not sure how to set up the circuit.

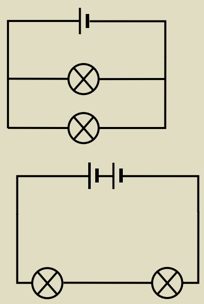
Dismantle the circuit. Now swap roles, so that this time you mark the performance of your partner setting up the other circuit. (Don't forget to return all equipment.)

Check your answers on pages 305–306.

5 **a** The bulbs in circuit B will glow only half as brightly as the bulb in circuit A. This is because the electric current has to flow through two bulbs instead of one.

b The bulb in circuit C will glow as brightly as the bulb in circuit A. This is because the three bulbs are in parallel, and each bulb glows as brightly as if it were the only bulb in the circuit.

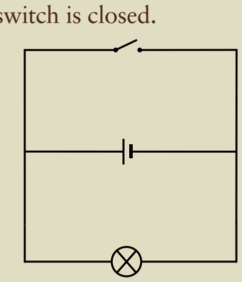
c You would need to arrange the two bulbs in parallel. Alternatively you could add a second battery to give the current more 'push'.



6 **C** (Current flows only in the left-hand part of the circuit—through bulbs A and B, but not through bulb C.)

7 As your shoes rub on the nylon carpet, static electricity builds up on your body. When you touch something which conducts electricity (eg a metal door knob), an electric current flows across your skin and you feel a slight electric shock.

8 The battery, bulb and switch need to be in parallel, as shown. When the switch is open (off), current flows in the bottom half of the circuit, lighting the bulb. When you close the switch, virtually all the current flows through the top half of the circuit. This is because the switch has a much lower resistance than the bulb, and the current follows the path of least resistance. Hence the light goes off when the switch is closed.



Lab review

The equipment needed is almost the same for both circuits:

- 1.5 volt battery and holder
- 3 bulbs and holders
- switch
- connecting wires (6 for the left-hand one, 7 for the right)