Electricity

Introduction

Students have many everyday experiences related to electrical behaviour. Many of the devices they and their families use on a daily basis require current electricity to function, for example, lights, television, toaster, and so on. From a very early age children are instructed on the dangers of household electricity. Students will mostly be familiar with static electric effects of one sort or another, such as hair sticking up when rubbed, shocks from metal rails or cars, and sparks from nylon clothing. The activities in this topic show students the key idea that underpins many of the electrical effects they experience.

The activities in this topic are related to two areas in electricity: 'electrostatics' (or static electricity) and 'current electricity'. Electrostatics relates to electrical phenomena where there has been a separation of electric charge (usually associated with electrons) within objects or between objects. Current electricity relates to electrical phenomena where there are moving electric charges (again, associated with electrons) that travel along wires and through electrical devices such as globes and buzzers.

Key concepts of electricity

The activities in this topic are designed to explore the following key concepts:

Electrostatics

Early years

- Friction can cause static electricity.
- Objects can become electrically charged by rubbing them.
- Charged objects can attract uncharged objects.
- Charged objects may attract some charged objects and repel other charged objects.

Middle years

- Electrons are part of all atoms that make up all substances.
- Objects can be charged by rubbing.
- Some materials are charged more easily than others.
- An object becomes charged when it loses or gains electrons.
- Objects can carry either a positive or negative charge, depending on what they are made of and what they are rubbed with.

- A negatively charged object has gained electrons; a positively charged object has lost electrons.
- Objects with the same electric charge repel each other; objects with opposite charge attract each other.
- If electrons that are added to an object spread out all over the object, the object is called a ‘conductor’.
- If electrons that are added to an object stay on the object where they were placed, the object is called an ‘insulator’.
- Charged objects will attract uncharged objects.
- Charged objects will discharge (lose their charge) over time as charge leaks to the atmosphere.
- Sparks are the movement of electrons through the air from one object to another. Lightning is a sparking effect.
- ‘Earthing’ is where charge is shared between a charged object and a large conductor (usually the ground).

Current electricity

Early years

- Electricity can move or flow.
- Electrical devices such as globes require two connections with wire to a battery to function.
- The two connections provide a complete path, or loop, around which electricity can flow.
- The strength of the electricity depends on the number of batteries (and their size in volts).
- Electricity makes a lot of things work, for example, globes, televisions, toasters, etcetera.
- Household electricity is dangerous.
- Some materials allow electricity to pass through them and other materials do not. Those which do allow electricity to pass through them are called conductors.

Middle years

The concepts listed below were developed by Summers, Kruger and Mant (1997), who believe that such concepts can be acquired readily by primary-school teachers and taught effectively to their students.

- An electric circuit is a complete (unbroken) pathway.
- Electricity is made up of electrons.
- Electrons are very, very tiny particles.
- An electric current consists of a flow of electrons.
- Electrons are part of all atoms that make up all substances.
- The electrons are in the wires all the time.
- Conductors have free electrons, which can move.
- The battery provides the push to move the electrons.
- The battery voltage is a measure of the push.

- A chemical reaction in the battery creates an electric field, which produces the push.
- All the electrons move instantaneously.
- The size of the current in a circuit depends on the resistance.
- A series circuit has all the components in a line. There is only one pathway.
- The current is the same all around a series circuit.
- In a series circuit, adding more globes increases the resistance and decreases the current. The globes are dimmer and equally dim.
- A parallel circuit has branches. There is more than one pathway.
- Identical globes in parallel are as bright as one globe alone. The current in each branch is the same.
- The current in the battery leads is the sum of the currents in the separate branches.
- In a globe, moving electrons collide with fixed atoms in the filament, causing them to vibrate.
- The vibrating atoms emit light and heat.

(Summers, M, Kruger, C & Mant, J 1997, *Teaching electricity effectively: a research-based guide for primary science*, Association for Science Education, Hatfield)

Students’ alternative conceptions of electricity

Research into students’ ideas about this topic has identified the following non-scientific conceptions:

- The terms ‘electricity’, ‘current’, ‘power’ and ‘energy’ mean the same thing.
- In a circuit that contains wires, a battery and a globe, the battery stores electricity/power/current which flows to the globe where it is consumed.
- The globe in an electric circuit takes what it needs from the battery.
- Energy is used up by a working globe.
- The thing that gets used up in an electric circuit is current.
- For a circuit that contains a battery and a globe, the globe lights up because:
  - the current from each end of the battery clashes in the globe to provide the light (clashing-currents model)
  - some of the current from one end of the battery is lost as it passes through the globe (consumption model)
  - current from one end of the battery is all used up in the globe, making the second wire unnecessary (source-sink model).
- Batteries store a certain amount of electricity or charge.

Activities

Electrostatics

Teaching note: For electrostatics experiments (such as those described in this topic) to work, the equipment must be dry. If the weather is humid, the apparatus should be dried in front of a heater or with a hair dryer. Static electricity experiments should allow students to discover that friction generates static electricity, a charged object will attract other objects and that like charges repel while unlike charges attract.

Explanatory note: The following notes explain electrostatic behaviour in terms of the electrostatic concepts listed earlier in this topic. Electrostatic effects involve the transfer of charge, in the form of electrons, between objects. All matter is composed of small particles called 'atoms' that consist of a positively charged centre and negatively charged electrons, some of which are only loosely held by the atom. It is these loosely held electrons that are responsible for most electrostatic behaviour.

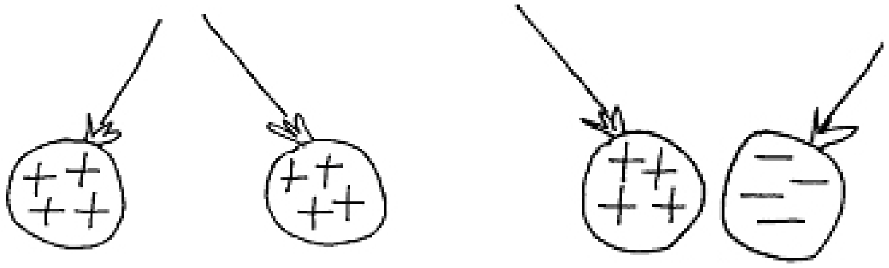
When two objects come into contact with each other, electrons can transfer from one object to another. This transfer of electrons, which can be heightened through rubbing the materials together, occurs when one of the objects has a propensity to attract electrons from the other object. If an object gains extra electrons it is negatively charged, but if it loses electrons it becomes positively charged. For example, when PVC is rubbed with wool, electrons are transferred from the wool to the PVC. In this circumstance the PVC gains a negative charge while the wool gains a positive charge. However, if perspex is rubbed with wool, electrons are transferred to the wool, leaving the perspex positively charged and the wool negatively charged.

When objects become charged they may repel or attract other charged objects. In addition, charged objects may attract uncharged objects. Charged objects that repel or attract can be explained by the rule that 'same charged objects repel each other and oppositely charged objects attract each other'. This is shown in the figure below using charged balloons.

FIGURE: CHARGED BALLOONS

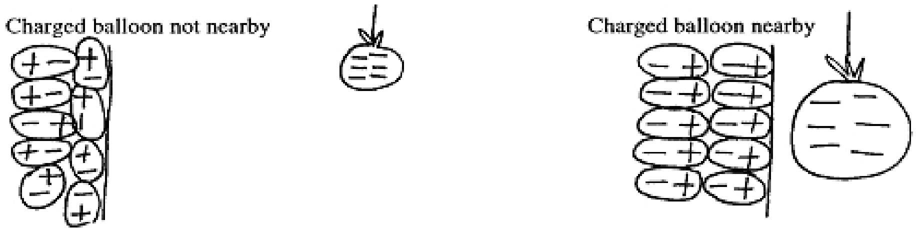
Like charges repel

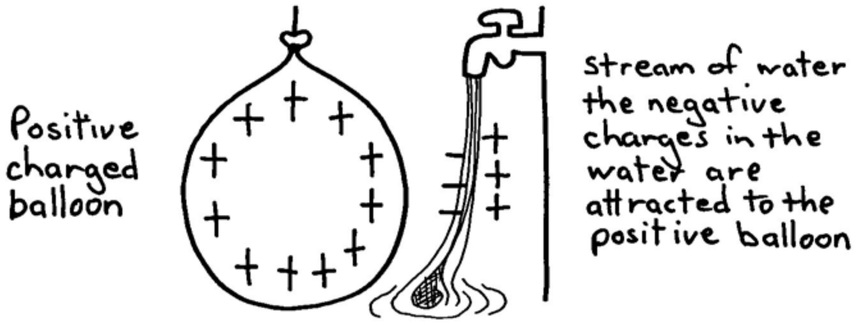
Unlike charges attract



When charged objects attract uncharged objects, such as when a negatively charged balloon attracts paper, the negatively charged balloon repels some of the electrons in the paper. This will redistribute charges in the paper so that one side of the paper is slightly more negative than the other side. The net effect is that the paper is attracted to the balloon. The principle is the same with the balloon attracted to an uncharged wall (see the figure below) or the balloon attracting water from a tap (see the figure below).

FIGURE: CHARGED BALLOON ATTRACTED TO A WALL





Charge is easily lost through this same mechanism if the day is humid. In this case, small invisible water droplets are attracted to the balloon or other charged object and, on touching it, some of the charge is transferred to the droplets. At this point, since the balloon and droplets both have the same charge, the droplets are repelled, taking some of the charge with them.

Some complicated effects can be caused with static charge, and it is sometimes difficult to work out what is going on because the level of humidity can make a large difference to what happens, and also the objects being rubbed can pick up unexpected charges if the cloth or woollen jumper used had been previously charged.

Electrostatic effects

ACTIVITY: CAN YOU PICK IT UP?

Key ideas: Friction can cause static electricity. Charged objects can attract uncharged objects.

You will need:

- **pieces of paper**
- **plastic rulers**
- **combs**
- **ballpoint pens**
- **PVC strips**
- **perspex strips**

- **glass rods**
- **balloons**
- **various materials for rubbing the objects (e.g. cotton cloth, silk, wool, hair, etc.).**

Try to pick up pieces of paper with unrubbed rulers, combs, and so on. Then determine whether rubbing them with various materials makes any difference.

Explanatory note: Students will find that while the plastic ruler or balloon could attract pieces of paper, the material that was used to rub the objects could not, even though it too became charged. Where there is a transfer of electrons, one object gets a negative charge and the other object gets an equal but opposite positive charge.

In the case of an object such as a plastic ruler, its surface is smooth and so the charge is concentrated over a small area. The rubbing material, such as wool, has many fibres and so the charge is distributed over a wider area. The greater the concentration of charges, the bigger the effect it can produce. Therefore, the charge produced on the wool will not be concentrated enough for it to pick up pieces of paper.

ACTIVITY: MOVING WATER

Key idea: Charged objects will attract uncharged objects.

You will need:

- **a PVC strip, ruler or balloon**
- **a thin stream of water from a tap or syringe.**

Charge a PVC strip, ruler or balloon. Bring the object near to a stream of water from a tap or, alternatively, let a stream of water from a syringe flow down and bring it near to the charged object. Describe what you see and explain what you think is happening.

ACTIVITY: STICKY BALLOONS

Key idea: Charged objects will attract uncharged objects.

You will need:

- **a balloon**
- **wool or fur.**

Inflate a balloon and rub it with wool or fur. If the weather is dry enough, the rubbed balloon should stick to the wall. Ask children to explain why the balloon sticks to the wall.

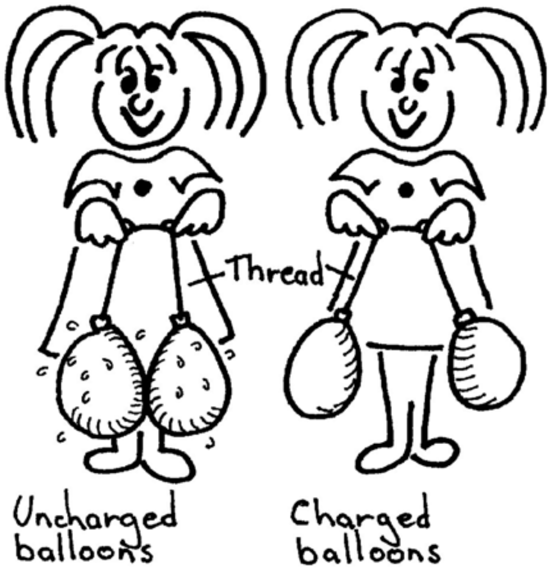
ACTIVITY: UNFRIENDLY BALLOONS

Key idea: Unlike charged objects repel.

You will need:

- **two balloons**
- **cotton thread**
- **wool.**

Charge two balloons and hang them on a piece of cotton thread. Bring them together—they will repel! This happens with two objects with the same charge.



ACTIVITY: CHARGED ATTRACTION

Key idea: Charged objects attract uncharged objects.

You will need:

- **balloons**
- **wool**
- **bits of paper**
- **aluminium foil**
- **a thin stream of water from a tap or syringe**
- **pepper**
- **salt.**

The charged balloon will attract uncharged objects as though it was a magnet (but it isn't—the force between charges is different to a magnetic force). Try this with your balloon:

Arrange tiny bits of paper, and aluminium foil, on a table surface. The balloon will make them flutter about or even pick them up.

Bring the balloon near a slow and smooth stream of water from a tap or syringe. Can you explain what is happening to the water?

Bring the balloon close to a friend's hair. It stands on end! It is a strange, prickly sensation.

Sprinkle pepper on a piece of paper. The balloon will pick it up. Does it do the same with salt?

Explanatory note: The explanations for attracting uncharged objects such as paper and water are given earlier in this topic. Rubbing hair gives the same charge to the strands. The hair stands up because the strands repel each other.

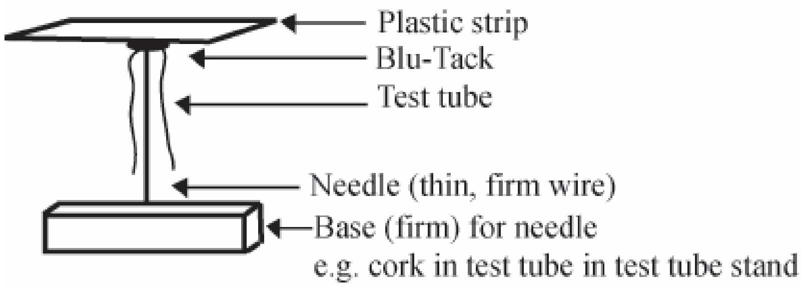
ACTIVITY: IS IT ATTRACTIVE?

Key idea: Like charges repel, unlike charges attract.

You will need:

- **a plastic strip**
- **Blu-Tack**
- **a test tube**
- **a needle or firm wire**
- **a base made of wood or cork**
- **wool or fur.**

FIGURE: CHARGE TESTER



Set up the apparatus as in the figure above. Determine whether a PVC strip rubbed with wool attracts or repels the PVC strip on the test tube.

Repeat the procedure, but this time remove the PVC strip and rub it with wool before re-attaching the strip to the test tube. Repeat the procedure with other substances such as perspex. Try combinations of substances, for example, PVC and perspex, rubbed and unrubbed, both rubbed, etcetera. What deductions do you think can be made?

Explanatory note: Given that the perspex becomes positively charged when rubbed with wool, you can deduce the charge given to the plastic strip or other material placed on the charge tester. Anything that repels the charged perspex will also be positively charged, whereas anything that attracts the charged perspex will be negatively charged.

ACTIVITY: LOSING CHARGE

Key idea: Charged objects will discharge over time as charge leaks to the atmosphere.

You will need:

- **balloons**
- **a piece of plastic**
- **pepper**
- **wool or fur**
- **a spray bottle and water.**

Work out a way of measuring how strong the charge is on a balloon or piece of plastic. Perhaps you could measure the distance the balloon is above the pepper

Investigate the method of rubbing that gives the most charge. Measure the strength of charge each minute to see how quickly it is lost.

Charge the balloon, then spray around it with a fine mist of water. How much does this reduce the charge? Does this tell you anything about the effect of humidity on charge?

Explanatory note: The droplets of water in the fine mist come in contact with the balloon and, in doing so, collect some charge from the balloon. Because the droplet has the same charge as the balloon, it will be repelled. As different droplets come in contact with the balloon and then get repelled by it, charge on the balloon becomes less and less—it discharges.

ACTIVITY: CHARGED FLIGHT

Key idea: Charged objects can attract uncharged objects.

You will need:

- **aluminium foil**
- **cotton thread**
- **a stand**
- **a balloon**
- **a woollen cloth**
- **polystyrene.**

Suspend a piece of aluminium foil shaped as a plane from a thread. Bring a charged balloon close to make the plane fly towards it. Notice what happens when the plane touches the balloon. It is pushed away as the plane picks up a charge of the same sign as the balloon. Can you hear the click as the charge transfers?

With a bit of practice, you may be able to keep a small aluminium foil plane in the air by moving the charged balloon above it.

The balloon will work well at attracting small pieces of polystyrene on a piece of cotton.

Explanatory note: The plane will be attracted to the balloon when it comes near the plane. This is because there is charge redistribution in the plane so that one side becomes positively charged and the other side becomes negatively charged. When the plane comes very close or touches, electrons will jump from one object to another—this is the spark which may be heard as a click. Now both the balloon and the plane will have the same charge and so will repel each other.

ACTIVITY: PLAYING DETECTIVE WITH CHARGES

Key ideas: Charged objects can attract uncharged objects. Charged objects share charge with other uncharged objects they contact.

You will need:

- **a balloon or plastic ruler**
- **a cloth or fur**
- **aluminium foil**
- **cotton thread**
- **a stand.**

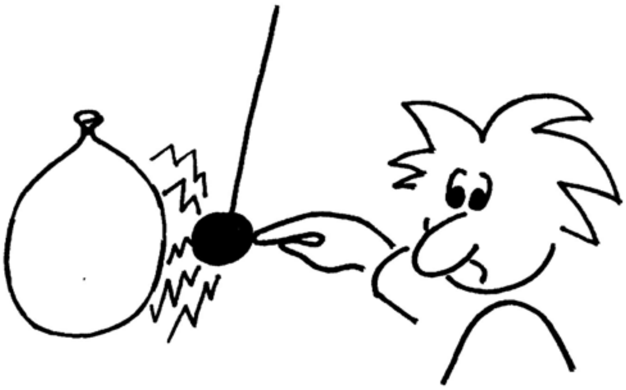
Suspend a small ball of scrunched-up aluminium foil from a thread. Try the following sequence of activities and see if you can explain what is happening in terms of the charge on the aluminium ball.

Bring a charged balloon or plastic ruler close. The ball is attracted even though it is uncharged.

Let the ball touch the balloon. What happens? Why?

Take the balloon away and bring your finger close to the ball. What happens? Why?

Touch the ball. Now bring your finger close again. Bring the balloon close again. The ball is uncharged! How did that happen?



With the balloon close to the uncharged ball but not touching, touch the ball with your finger and then let go. Does the attraction to the balloon change? What do you suppose happened when you touched the ball?

Take the balloon away. Bring your finger close to the ball. Can you explain what you observe now?

You might like to test your ideas by hanging two identical aluminium balls side by side, but try different sequences with them.

Explanatory note: Let us assume that the balloon or ruler is initially positively charged. The ball is initially attracted as there is charge redistribution on the ball; negative charges move to the side of the balloon while positive charges move to the other side.

- When the positively charged balloon touches the ball, positive charge evenly distributes itself over the ball from the balloon. The balloon and the ball are now both positively charged and so will repel each other.
- If you now bring your finger to the ball (now positively charged), it will attract it. There is charge redistribution in your finger.
- If you touch the ball, positive charge flows from the ball into the larger conductor, which is your body. There will be very little positive charge left on the ball (it has been ‘earthed’). The positive charge moves from you into the ground so you are also left without a charge.

- Now if you are touching the ball when the positive balloon is brought nearby there is charge redistribution on the ball. However, as you are holding the ball, negative charges move near the balloon while positive charges flow into your finger. If you now let go of the ball, it will be left with a negative charge. The negatively charged ball will attract the positively charged balloon.
- If you now bring your finger to the negatively charged ball it will attract your finger (charge redistribution).

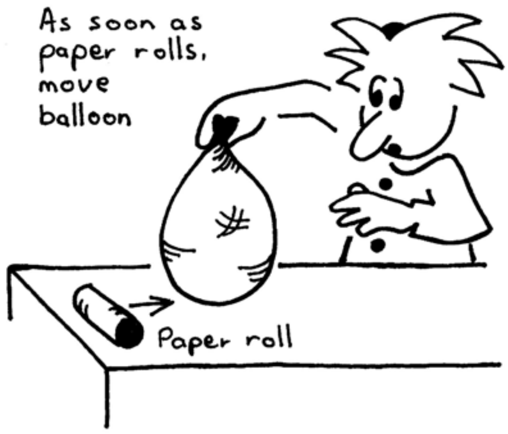
ACTIVITY: STATIC ELECTRIC RACE!

Key idea: Like charges repel.

You will need:

- **balloons**
- **cloth or fur**
- **a small racing object made out of paper.**

You can make small racing objects out of paper, and use the balloon to attract them along a straight track, keeping the balloon just ahead and not touching the racers. A roll of paper made from a thin strip works quite well as a racer. Experiment to find the best racer.



Students’ ideas about current electricity

Students of all ages deal with electricity everyday. They will therefore have a number of ideas of how electrical devices work. Students are also familiar with some of the science terms used in electricity: terms such as ‘power’, ‘electricity’, ‘voltage’, and so on. It is important to probe the students’ ideas about electricity and the following activities are designed to do so.

ACTIVITY: MAKE A LIST

Key idea: Electricity makes a lot of devices work.

What things do we have in our homes that use electricity? Make a list on the board of the items. The list can be made under the headings: kitchen, bathroom, laundry, bedroom, garage, other. Who uses the items? Where do most of the items get the electricity from to make them work?

ACTIVITY: ELECTRICITY IN THE CLASSROOM AND THE HOME

Key ideas: Electricity makes a lot of devices work. Electrical cords have at least two wires to carry current into and out of the device. Household electricity is dangerous.

Investigate what uses electricity in the classroom, How does the electricity get from the power point to the item? Identify the parts that would carry the electricity. Discuss safety.

What uses electricity in the home? How would you be affected in your daily life if there was no longer any electricity?

Where does electricity come from? How is electricity made? What is the difference between electricity from power points and batteries? How does a switch work? How fast does electricity travel?

Explanatory note: Household electricity requires a conducting path that forms a loop. The loop contains the generator, wires and electrical devices.

ACTIVITY: CONCEPT MAP

Key idea: Science words have specific meanings in science and may vary considerably from everyday use of the words.

You will need:

- **poster paper**
- **textas.**

Construct a concept map to link the following words and ideas:

- **electricity**
- **circuit**
- **conductor**
- **battery**
- **energy**
- **insulator**
- **voltage**
- **electrons**
- **current.**

ACTIVITY: GLOBE-LIGHTING CHALLENGE

Teaching note: The key idea to this activity is that a complete conducting path loop is required for the globe to light up.

A good follow-up activity would be to break open a globe to show the students that there is a continuous conducting path from the base of the globe, up through the filament, and then to the side of the globe (a normal household light globe will be best for this activity, but be careful when breaking the glass). The other material at the base of the globe is insulating material that acts to separate the base wire from the side wire.

Another good activity is to have students draw what they think the inside of a torch looks like. Dismantle an old torch to show the students how a complete conducting path is obtained when the switch is closed.

In the globe-lighting challenge, students will often assume that, as long as they have a wire connecting the battery to the globe, it will light. This presumption reflects a view that the battery is a source of energy, the globe is a receiver, and connecting them is all that matters. This view, which ignores the role of electric current, is sometimes called the ‘source–receiver’ model, and it is easy to see where it comes from. Household circuitry involves what seems to be a simple lead from the plug to an appliance, and one can think of flicking the switch as simply allowing the energy to pass into the appliance. In fact, within those leads are two wires, (three, if there is an earth connection): one to supply current and one as a return path. The switch completes a circuit.

Another common incorrect idea is that the current is used up in the globe and is less in the return wire. In fact, the globe uses the energy carried by the current, but the current is the same all the way around the circuit (and that's not an easy distinction to argue). One way of challenging this idea is to wire up two globes in series. Each is of equal brightness (if they are identical), because the same current passes through both.

The other common incorrect model is known as the 'clashing currents' model, whereby current is thought to come out of both ends of the battery and meet at the globe. The clash causes the globe to light. It is not so easy to refute this with direct evidence.

It is important to separate the ideas of energy and current when explaining how a complete conducting loop is required. The battery supplies chemical energy which is transformed at the globe as heat and light energy. The energy is transferred from the battery to the globe through the movement of electrons. The electrons don't come out of the battery; they are already in the wire. The battery can be considered to have the role of pushing the electrons in the wire. The moving electrons represent the current; they move in a direction away from the negative terminal of the battery toward the positive terminal of the battery.

Key idea: An electric circuit is a complete (unbroken) pathway that forms a loop.

You will need:

- **student prediction worksheets**
- **a globe holder**
- **a globe**
- **electrical wire**
- **a battery**
- **an elastic band.**

Make a globe light up using only one globe in a holder, a battery and a single piece of electrical wire. Complete the prediction sheet (see the figure below) before you begin. Discuss your predictions and underlying reasons. Test your predictions.

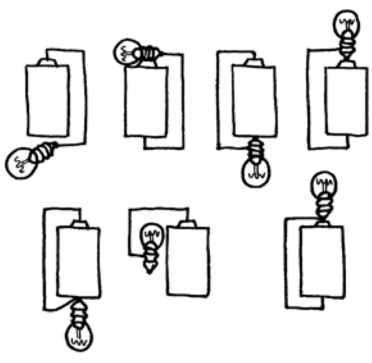
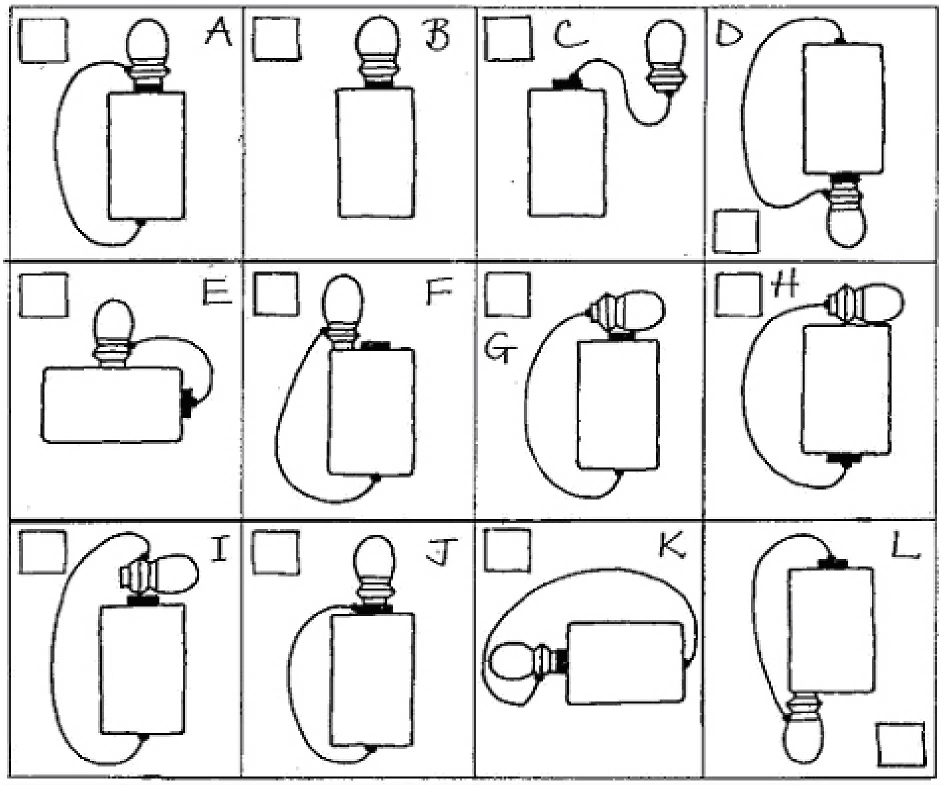


FIGURE: PREDICTION SHEET

Predictions

Predict which of the arrangements (A to L) below will make the globe light up. Write 'Y' for yes, or 'N' for no for each picture. Complete the sheet on your own.



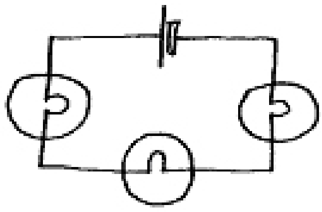
The reason(s) for my selection(s) is (are):____________________

Investigating current electricity

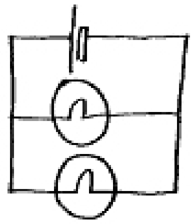
Teaching note: The following activities provide students with a series of observations that can then be used to explain how electric circuits work. Some of these observations include:

- a battery, globe and wires need to be part of an unbroken path for the globe to glow
- wherever a switch is placed in circuit, if it opens the globe will not glow
- batteries have a set voltage, and markings that designate a positive and negative end
- there can be more than one conducting path from the positive terminal of the battery to the negative terminal. Such paths are called parallel branches of a parallel circuit. A series (single loop) circuit and a parallel (double loop) circuit are shown in the figure below.

FIGURE: SERIES CIRCUIT AND PARALLEL CIRCUIT



series circuit (one path)



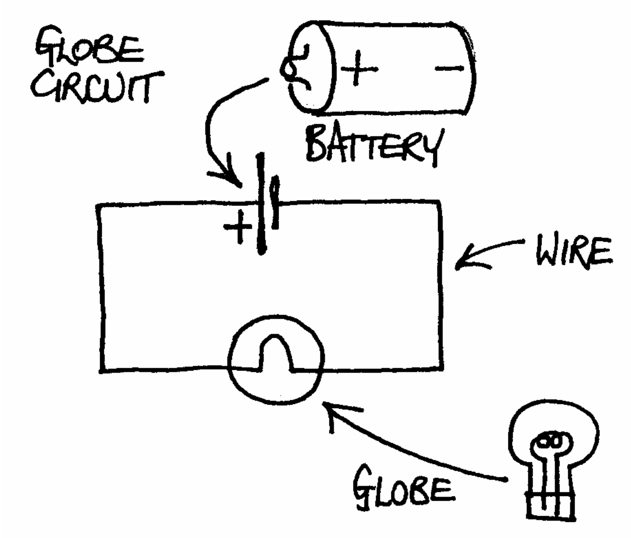
parallel circuit (multiple paths)

- where more globes are added in a series circuit, each globe is less bright. This means that less energy is being transformed at each globe. Each globe in the circuit is about the same brightness
- where more globes are added in a parallel circuit, each globe remains at the same brightness
- where more batteries are added to the circuit, the globe will be brighter
- adding some materials to the circuit makes the globe less bright or not glow at all. Materials that keep the globe glowing are called ‘conductors’ and those that make it not glow are called ‘insulators’.

Explanatory note: We will now explain how electric circuits work, using the current electricity concepts we encountered earlier..

Consider a simple arrangement (circuit) that contains a battery, globe and connecting wire. The circuit forms a single loop (called a series circuit) and the globe glows. The globe circuit is shown in the figure below. It uses symbols for electrical devices. The arrangement is called a ‘circuit diagram’.

FIGURE: SIMPLE CIRCUIT



When the globe circuit is in operation, the globe gives off light and heat; these are two forms of energy (light energy and thermal energy). This energy has been transformed from the battery in the form of chemical energy. The battery contains substances that undergo chemical reactions when the torch circuit is complete. The chemical reaction lasts for the life of the battery.

To sustain the chemical reaction in the battery, electrons (small particles in all matter) need to travel from one of the reacting substances to the other. This can’t happen inside the battery as the substances are separated, but it can happen when the circuit is complete. In this situation, the electrons in the wire that are near the positive terminal of the battery will move into the battery; at the negative terminal of the battery, electrons move off the terminal and into the wire. For the chemical reaction to continue, the movement of electrons onto and off the battery needs to occur at the same time.

To imagine the movement of electrons, think of a single-looped toy railtrack with railcars connected all the way around the track. The railcars represent the electrons. The battery is represented by you. You push on one of the cars at a specific place on the track. All the cars move at the one time. If you keep pushing the cars that come in front of you, all the cars will keep moving around the loop.

The railcar analogy illustrates the key concept that the battery provides the push to move the electrons. The battery voltage is a measure of the push. The greater the voltage, the greater the push on the electrons. The reason behind the push comes from ideas in electrostatics. The battery initially separates charges so that it has a negative charge on the negative terminal (excess of electrons) and a positive charge on the positive terminal (deficiency of electrons). When the circuit is connected, electrons will be attracted to the positive terminal and repelled from the negative terminal. The attractions and repulsions represent the push of the battery. In scientific terms, the battery sets up an electric field (force field) that acts on electrons in the wire.

In the globe, the moving electrons collide with fixed atoms in the filament, causing them to vibrate. The vibrating atoms emit light and heat. The moving electrons also collide with atoms in the wire (the wire heats up a little) but not to the same extent as the collisions with the atoms in the filament. The filament has a greater resistance to the movement of electrons than does the wire. Materials with a low resistance are called 'conductors'; those with a very high resistance are called 'insulators'.

The number of electrons moving past a point in a circuit every second is a measure of the electric current. As the electrons move instantaneously when the battery is connected, the current is the same at all points of the series (single-loop) circuit. The size of the current depends on two things: the size of the battery voltage and the total resistance in the path of the electrons. A higher voltage means the electrons gain a larger push, whereas the larger resistance means the current is less. We can imagine this with the railcar analogy. Pushing harder (greater voltage) on the cars results in more cars passing each point in the loop every second (greater current). To imagine a resistance in the railcar, imagine that the track now has a hill in it. Pushing on the cars now results in less cars moving past each point each second (less current), as part of the push needs to go into pushing the cars over the hill (resistance). The more hills (greater resistance), the less speed of the cars (less current).

The energy given by the battery to the electrons is transferred to atoms within the torch circuit. The battery voltage gives a measure of how much energy is given to each electron that is free to move; the electrons transfer this energy in collisions with atoms. In the globe circuit, most of the energy of the electrons is transferred to atoms in the filament of the globe which produces heat and light energy.

A continuous loop is required for the globe to glow because the chemical reaction in the battery requires electrons to jump onto the positive terminal at the same time that electrons jump off the negative terminal. The electric field within the wire will not be set up until the wire is connected to both terminals of the battery.

An open switch placed anywhere in the circuit breaks the electric field in the wire and so the electrons will not move. There will be no current.

Electrons jump onto the positive ends of batteries and jump off negative ends. The voltage is a measure of the push, or amount of motion energy, given to each of the free electrons in the wires.

Where more globes are added in a series circuit, each globe is less bright. The brightness of the globes gives a measure of amount of energy being transformed. If there are three globes in a series, as in the figure *Series circuit and parallel circuit*, the electrons will have collisions in each of the filaments. The energy is shared (each globe will be of approximately the same brightness). In addition, the extra globes mean that the resistance of the circuit is increased. Therefore, the current will be less. The lower current means there are less electrons moving around the circuit per second.

Where more globes are added in a parallel circuit, each globe remains at the same brightness. This circuit needs to be considered as two independent loops where each loop contains a battery and a globe. The battery sets up electric fields in each loop to push the electrons (give energy to the electrons). The electrons transfer their energy to each part of the loop that they travel and so the current and brightness of each globe is the same as the globe in a single-globe circuit. As the battery pushes electrons in both loops, the current into and out of the battery will be more than through each globe. As no electrons are lost in moving around the circuit, the current in the battery leads is the sum of the current in the separate branches of the parallel circuit.

We have used a railcar analogy to explain electric circuits. There are other models we can use to think about how circuits work. These are described in the later activity *Models of electric circuits*.

ACTIVITY: USING TWO WIRES

Key idea: An electric circuit is a complete (unbroken) pathway that forms a loop. A switch breaks the current pathway in an electric circuit.

You will need:

- **a battery**
- **connecting wire**
- **a globe**
- **a cork**
- **paperclips**
- **drawing pins.**

Using two wires, a globe and a battery, construct a simple circuit. Once you have a simple circuit operating, try to make a switch to turn the light off and on by using the cork, paperclips and drawing pins. Does it matter where you put the switch?

ACTIVITY: SHORT CIRCUIT

Key idea: A short circuit is a parallel circuit that contains one looped path with only a battery and wire.

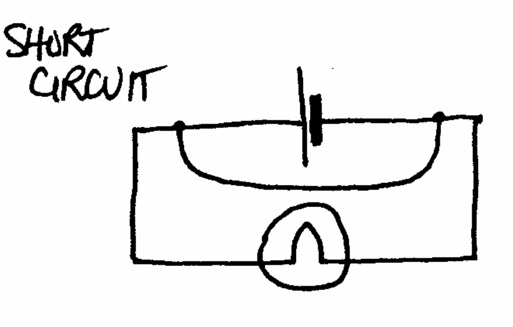
You will need:

- **a battery**
- **connecting wire**
- **a globe.**

While the globe is glowing, create a 'short circuit' by connecting another wire across the battery terminals.

Explanatory note: By adding a wire across the terminals, you create a parallel circuit. The resistance in the wire-only loop is much less than the resistance of the loop with a globe. This will create a large current through the wire loop and significantly decrease the current through the loop with the globe. The globe will no longer glow.

FIGURE: SHORT CIRCUIT



The electrons flowing in the wire-only loop lose their energy to the atoms in the wire. This results in the wire heating up quite quickly. The large currents created by the short circuit make the battery use energy quickly and become flatter more quickly.

ACTIVITY: TWO BATTERIES

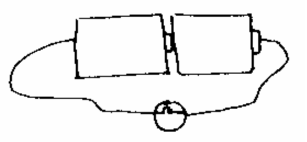
Key ideas: Batteries provide the push to move the electrons. The battery voltage is a measure of the push.

You will need:

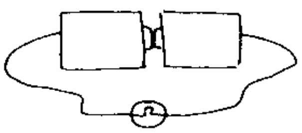
- **two batteries**
- **connecting wire**
- **a globe.**

Use two batteries in the three different arrangements below, to light one globe.

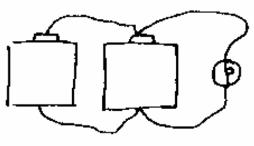
1)



2)



3)



Explanatory note: The battery provides the push to move the electrons in a circuit. The electrons move in a direction away from the negative terminal and towards the positive terminal. In arrangement 2, one battery will tend to push electrons in one direction, whereas the other battery will tend to push the electrons in the opposite direction. If the two batteries have the same voltage, the electrons don't move. There will be no current and the globe will not glow. Arrangement 1 doubles the voltage compared to a single-battery circuit. The double push on the electrons doubles the current. This leads to more collisions with the filament atoms, which make the globe glow brighter (more light and thermal energy). Arrangement 3 is equivalent to having one battery in the circuit. The globe will glow but not as brightly as in arrangement 1. In this arrangement the left-hand battery will tend to push electrons down through the globe as well as push electrons down through the right-hand battery. Similarly, the right-hand battery will tend to push electrons down through the globe and the left battery. The mutual pushing of electrons through the batteries lessens the effect each battery has on the globe. This is why one doesn't get a double push on the electrons through the globe as seen in arrangement 1.

ACTIVITY: LIGHTING CONTROL CENTRE

Key idea: Series circuits have a single loop. Parallel circuits have multiple loops.

You will need:

- **three globes**
- **connecting wire**
- **three switches**
- **two batteries.**

Here are some tasks for you to try. There are no right answers, but each task can be solved in a number of ways.

Make circuits in which:

1) **all three globes are equally very bright**
2) **all three globes are equally very dull**
3) **one globe is very bright and two are dull**
4) **all three globes are turned on and off by the one switch**
5) **each globe is controlled by its own switch**
6) **one switch controls one globe, a second switch controls the other two globes, and the third switch controls all three globes**
7) **two globes are on, but a switch turns one light off when it is pressed 'on'.**

Explanatory note: The tasks contained in this activity are intended to tease out the operation of switches, and the distinction between parallel and series circuits. In a parallel circuit, the current splits down parallel paths, and the battery voltage is directly across each component. This is the wiring design for a house.

In a series circuit, the current passes through each component in turn. Each component therefore has the same current, and the battery voltage is divided amongst the components. One switch will operate all the appliances. This would not be helpful in a household supply.

The solutions to the challenges are shown in the figure below. Standard scientific symbols, as shown in the figure below, have been used to represent the batteries, globes, connecting wires and switches.

FIGURE: STANDARD SYMBOLS

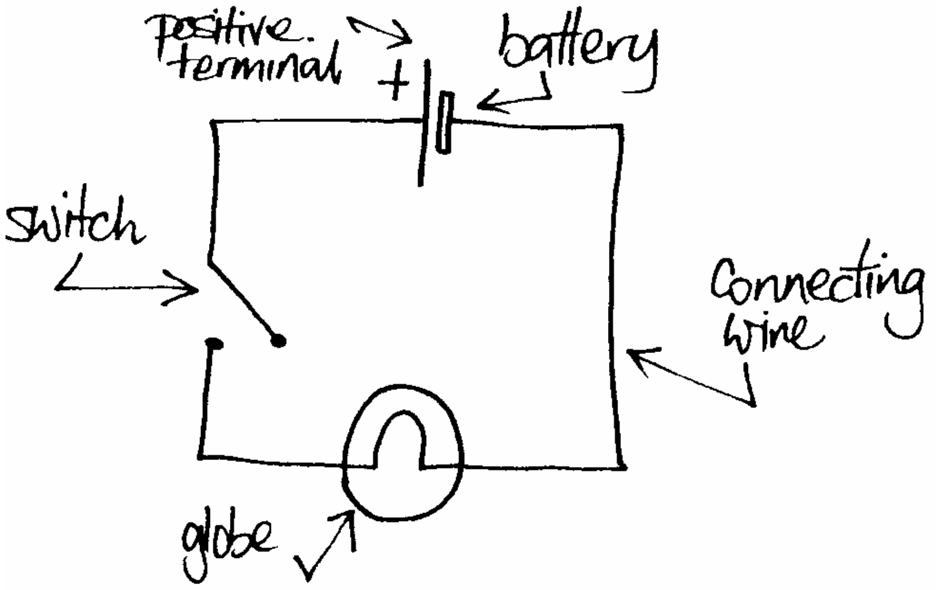
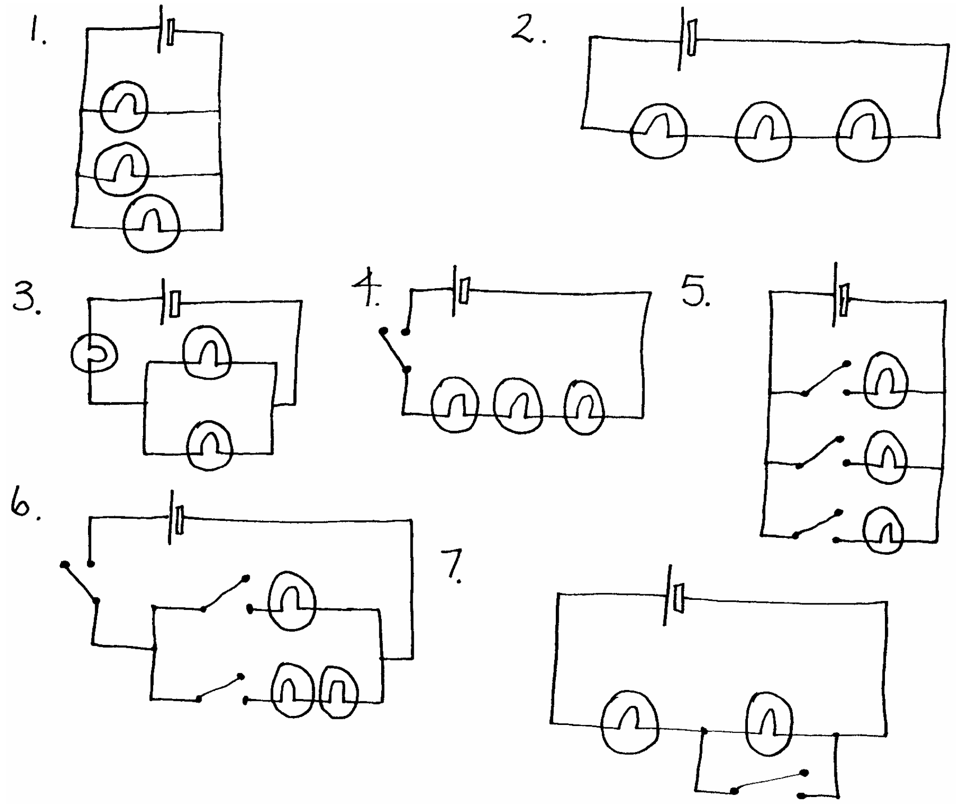


FIGURE: SOLUTIONS TO *LIGHTING CONTROL CENTRE*



ACTIVITY: BELLS AND LIGHTS

Key idea: Series circuits have a single loop. Parallel circuits have multiple loops.

You will need:

- **a battery**
- **connecting wire**

- **two switches**
- **a globe**
- **a bell or buzzer.**

Construct a circuit to make the bell ring and the globe light at the same time. Arrange switches to control them separately.

ACTIVITY: MAKING A FUSE

Teaching note: This activity may be best for the teacher to demonstrate, as the steel wool will heat up very fast and catch alight.

Key idea: Fuses are parts of a circuit that will melt or break if the current becomes too large.

You will need:

- **steel wool**
- **a battery**
- **connecting wire**
- **a light globe.**

Use the steel wool to make a 'fuse'. Connect it into a circuit that contains a globe. What happens? Use a piece of wire to make a parallel path around the globe. What happens to the fuse?

ACTIVITY: WHICH BATTERY LASTS LONGEST?

Teaching note: Children will need to break the circuits at the end of the school day and connect them again in the morning.

Key idea: Batteries die after the chemical reactions inside them are complete.

You will need:

- **a selection of D-cell batteries**
- **other equipment designated by the students.**

Design an experiment to investigate which D-cell battery will last the longest.

Explanatory note: Batteries give the same amount of energy to each 'free' electron in the circuit (moving 'free' electrons constitute the current). Batteries transform more energy when the current is larger. This results in the chemical reaction inside the battery being completed in a shorter time.

ACTIVITY: WHAT'S INSIDE A TORCH?

Key idea: An electric circuit is a complete (unbroken) pathway in a loop.

You will need:

- **a torch that can be readily dismantled.**

Bring a torch from home. Draw what you think is inside a torch and label the different parts. Then carefully take the torch apart, making sure no parts are lost. Describe three things that were different from you expected.

ACTIVITY: MAKING A TORCH

Key idea: An electric circuit is a complete (unbroken) pathway in a loop.

You will need:

- **Materials that might be used to construct a torch (e.g. strips of metal, aluminium foil, cardboard, coloured cellophane, batteries, wires and globes).**

Design a torch, using a range of materials.

Explanatory note: A torch is a very simple electrical circuit. In most torches, a metal strip and the spring take the place of wires. The switch has a piece of metal attached to it so that in the 'on' position it bridges the gap between the two strips of metal inside the torch. The metal spring at the base of the torch ensures that the batteries continue to touch each other and the base of the globe causing good connections. A complete conducting path (in the form of a loop) should be able to be traced from the batteries to the globe and back to the batteries. The path leads up through the base of the light globe through the filament and out the side of the globe.

ACTIVITY: CONDUCTORS AND INSULATORS

Teaching note: Some materials, such as water, are considered to be conductors, but in this activity the globe may not light up if water is used. This is because water is not as good a conductor as metal. A better way to test materials is to include an ammeter into the circuit. The ammeter measures the amount of current in the circuit. By using the ammeter you can order the conductors from good to poor.

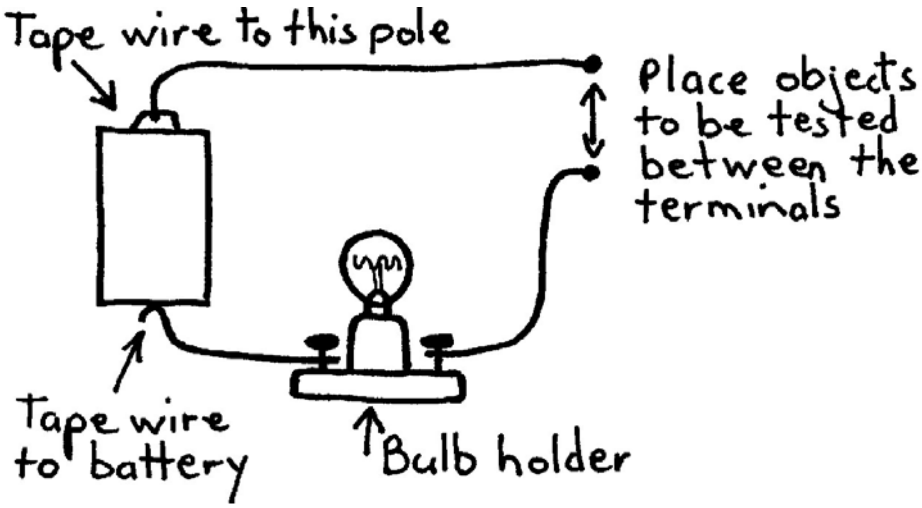
Key idea: Most materials can be classified according to whether current passes through them (conductors) or not (insulators).

You will need:

- **a battery**
- **connectors**
- **a globe**
- **an ammeter (optional)**
- **three wires**
- **a switch**
- **a variety of insulators and conductors.**

Construct a circuit and test a variety of materials to see whether current passes through them or not. If it does, list them under a heading 'conductors'. If not, list them under 'insulators'.

You can test metal parts, painted metal, plastic, pencil leads, aluminium foil, plastics, paper, skin (use different points on your finger), fresh water, salt water, a globe, wood (green or dry), silvered parts on toys or pens or appliances, plastic-coated paperclips, rusted metal or burnished copper wire.



Explanatory note: Conductors are substances that contain free electrons. Free electrons are not rigidly connected to any particular atoms that make up the substance and so are free to move within the material. It is these free electrons that create the current when the substance is connected up to a battery. Different substances have different levels of free electrons: those with lots of free electrons, such as metals, are called good conductors, whereas those substances with low levels of free electrons, like water, are poor conductors. Substances made of plastic have no free electrons and are considered insulators.

Salt water is a better conductor than normal water as the salt crystals break up into charged particles, called ions, when they dissolve in the water. Ions are atoms that have either lost or gained electrons. An electric circuit that contains salt water not only has electrons moving but ions as well; each contribute to the current in the circuit.

ACTIVITY: MODELS OF ELECTRIC CIRCUITS

Teaching note: There is no single model that can explain all the behaviour of current electricity. The students should not only know where the model fits the observations but also where the model breaks down. For example, how does the student electron 'know' which path to take in a parallel circuit? A hole in the water pipe will leak water but a break in the electric circuit will not leak electrons. It is difficult to imagine how the bicycle chain model can represent a parallel circuit.

Key idea: Models are used to represent electricity concepts.

The railcar model we used earlier helped to explain a number of concepts. Here are a few more.

The following role-play captures some of the features of circuits. Working out what aspects are useful, and where the model breaks down, is a productive activity in itself.

You will need:

- **students**
- **tokens**
- **tables and chairs**
- **a barrier.**

TABLE: ROLE-PLAY

Analog (role-play)	**Target**
Looped pathway, or tables and chairs	Wire
Students	Electrons
Token	Energy
Student	Light globe
Student	Battery
Barrier to stop movement along the path	Switch

Make a looped pathway by rearranging the tables or chairs in the classroom or a designated path outside. This represents the wire. Gather all the students around the pathway. They represent electrons. A switch can be represented by a barrier that stops the student electrons from moving around the path.

One student stands at one location on the pathway. They represent the battery. As the student electrons move past the battery, they are given an energy token. The student light globe stands at another place on the pathway. Each student electron gives their energy token to the student globe. No energy is required to move around the circuit if there is no resistance. The student globe does some action (e.g. raises a hand) for every energy token taken. This represents a transformation of energy.

EXTENSIONS

You can expand the *Models of electric circuits* activity in the following ways:

- **model two batteries in series (two tokens are given)**
- **model two light globes in series (each charge gives half their energy to each)**
- **model a parallel globe arrangement**
- **explore what happens when the switch is placed at different points**
- **model a resistance, perhaps using some stools that the electrons need to manoeuvre around and which slow them down and for which they need to expend energy**
- **discuss how each electron might ‘know’ as it leaves the battery how many globes it needs to distribute its energy to (this is where the model is inadequate, since it does not capture the operation of the electric field, which is the real source of energy transfer).**

You can further extend the activity by considering:

- **a delivery truck model**
- **a water pipe model**
- **a bicycle model.**

Discuss how well the models explain:

- **a switch**
- **a parallel circuit**
- **a series circuit**
- **a large resistance**
- **a short circuit.**

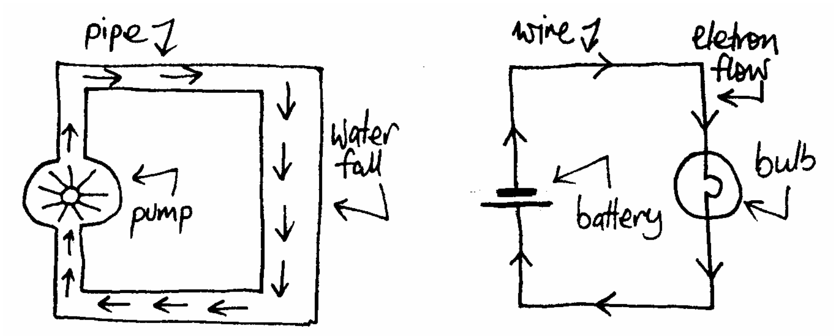
TABLE:
ROLE PLAY AND DELIVERY TRUCK MODELS COMPARED

Analog (role-play)	Target	Analog (delivery truck)
Students	Electrons	Delivery trucks
Student holding tokens	Battery	Warehouse with parcels
Tokens	Energy	Parcels
Laid out path in classroom	Conducting wire	One-way streets
Student (when receiving a token will undertake some action, e.g. jump)	Bulb	Shops

TABLE:
WATER PIPE AND BICYCLE MODELS COMPARED

Analog (water)	Target	Analog (bicycle)
Water particles	Electrons	Chain links
Pump	Battery	Cyclist
Gravitational potential energy	Energy	Kinetic energy (movement of wheel)
Pipes	Conducting wire	Chain loop
Vertical pipes	Bulb	Wheel
Flow rate	Current	Speed of chain motion
Flow-rate meter	Ammeter	Speedometer
Width of pipe	Resistance	Wheel friction

FIGURE:
WATER PIPE MODEL



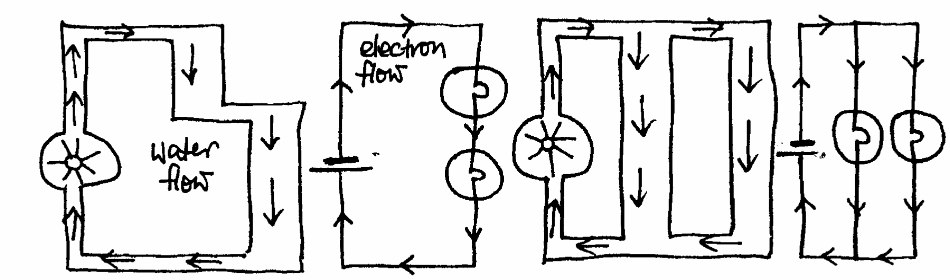
When you explain the water pipe model, make the following points with the analogical interpretation:

- **The pipe system is entirely enclosed so that there is no leakage of water. Thus no electrons are lost as they move around the conducting loop.**
- **All the pipes contain water and the pump does not provide water. The entire conducting path contains electrons; the battery does not supply electrons.**
- **The pump raises the water and, in doing so, gives the water gravitational potential energy. The battery gives electrical energy to the electrons.**
- **The vertical pipes are places where water falls, thus converting from gravitational potential energy into kinetic energy and heat energy. One needs to assume that the speed of the water at the top of the pipe is the same as at the bottom, like a waterfall. The loads in the circuit are where the electrical energy is converted into other forms of energy.**
- **The vertical pipes can be of varying thicknesses and so will restrict the flow of water through them and the amount of energy that is transformed in them. The loads have varying resistance that restrict current and transform energy.**

- **The flow rate of water in any one loop is determined by the restrictions on that loop in terms of the widths of the pipes. The electric current in a loop is determined by the resistances in that loop.**

The figure below shows the water pipe model for a series and a parallel circuit.

FIGURE: WATER PIPE MODEL FOR SERIES AND PARALLEL CIRCUITS

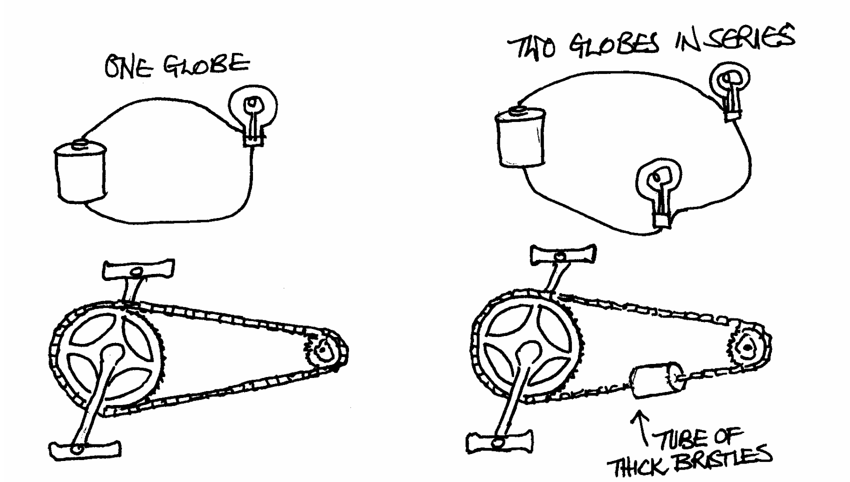


When you explain the bicycle chain model, make the following points with the analogical interpretation:

- **The globe does not glow if there is a break anywhere in the circuit. The cogwheel does not spin if there is a break anywhere in the chain.**
- **Current is the same everywhere in the circuit. No links get lost and the number of links moving past a particular part of the chain is the same all along the chain.**
- **The globe lights almost instantaneously when the battery is connected. The wheel turns at the same time there is a push on the pedals.**
- **Energy travels from one location to another for the electric circuit and the bicycle. However, in the electric circuit energy is transformed, whereas in the bicycle, energy is transferred.**
- **A switch turns the globe off. The brake stops the wheel. However, whereas the globe turns off almost instantaneously when the switch is opened, the wheel may take some time to stop when the brake is applied.**

The figure below represents a single-globe circuit and a two-globe series circuit. To represent the second globe in the series circuit, a tube of thick bristles surrounds the chain. This slows down the chain (reducing current).

FIGURE: BICYCLE CHAIN MODEL



Electric games, toys and models

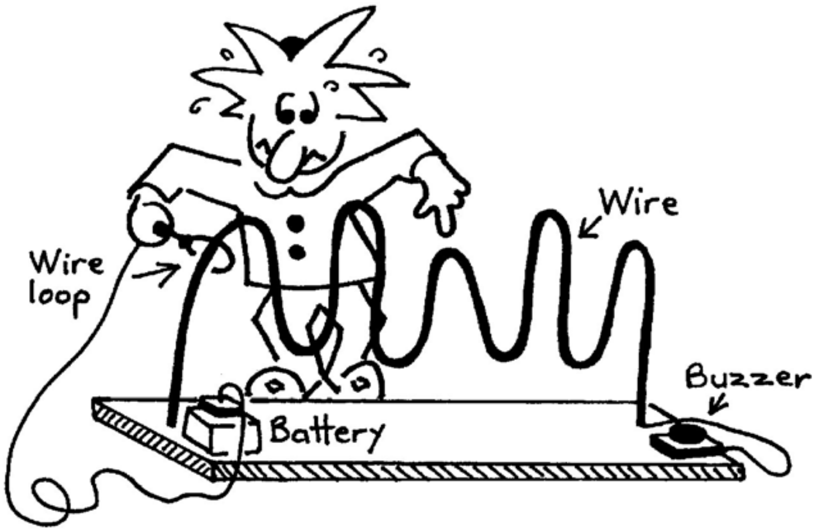
ACTIVITY:
NERVE TESTER

Key idea: An electric circuit is a complete (unbroken) path that forms a loop.

You will need:

- **a coathanger (or thinner but stiff wire), bent into a crazy wave shape and fastened into a wooden board**
- **a buzzer**
- **a battery**
- **connecting wire.**

Construct a circuit, designed so that a player's nerve is tested as they attempt to pass a loop along this wire without touching. A buzzer rings if the loop touches the wire.The circuit is completed when the loop touches the wire.



Te game becomes more difficult if the loop is made smaller. There are commercial variations to this game.

ACTIVITY:
QUIZ GAME

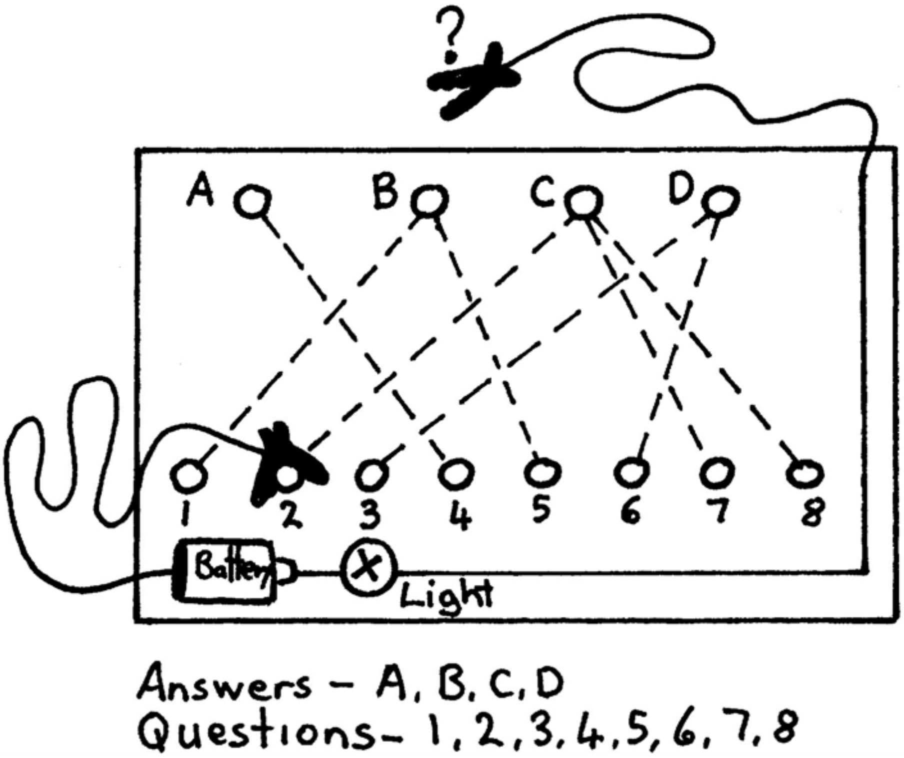
Teaching note: The connections at the back of the board may be made permanent by soldering the connections. Alternatively, by using double alligator clip wire, the connection can change with each new set of questions. A box arrangement for the back may be required so that the player will not be able to work out the connections.

Key idea: An electric circuit is a complete (unbroken) path that forms a loop.

You will need:

- **a wooden board**
- **nails**
- **cards, for questions and choices**
- **connecting wire**
- **alligator clips**
- **a battery**
- **a light globe.**

Make a game so that a player attaches a wire to a choice (A, B, C or D) for each question shown on the board. Make cards that give the questions and choices. The light must go on if the answer is right. The circuit is shown in the figure below.



The dotted lines show the connections at the back. Each choice (A to D) and each question has a nail connector to attach a clip to. The player must attach one wire to the question number, and the other wire to the chosen answer.

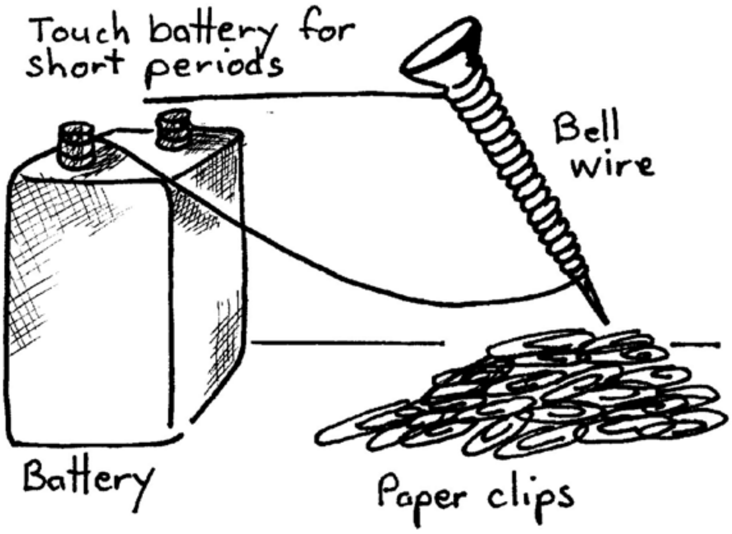
ACTIVITY: ELECTRO-MAGNETIC CRANE

Key idea: Electric currents create magnetic fields.

You will need:

- **a 6 V battery**
- **thin insulated wire**
- **an iron nail, or iron or steel rod**
- **a switch**
- **paperclips.**

You can make a toy crane that uses an electromagnet to lift metal objects. Make the electromagnet with a 6 V torch battery and many turns of thin wire around a large nail or iron or steel rod. When a switch is turned on, the nail or iron rod becomes temporarily magnetised and will lift paperclips.



ACTIVITY: LIGHTING AND ALARM SYSTEMS

Teaching note: A variety of electronic devices can be bought at commercial outlets that enable flashing lights and sensors to be used as part of circuitry.

Key idea: A series circuit contains one looped path. A parallel circuit contains more than one looped path.

Make models and toys using circuits, for example:

- **model buildings with lights and switches which control each room individually**
- **model cars or robots with switched lighting systems**
- **a model torch**
- **switch arrangements that turn on a light, or which sound an alarm, when a door is opened to a model or real house or refrigerator or security building**
- **an alarm system to warn when water in a bath reaches a certain level.**