PHYSICS

Magnetism and Electricity

Ideas you have met before

Magnets

Magnetic materials are attracted by a magnet. There are only a few different magnetic materials, including iron and steel. Most metals are not magnetic.

Using electricity

Many objects need electricity to run them. We call these 'appliances' – examples include washing machines and mobile phones. All appliances either use the mains electricity supply or a battery to make them work.

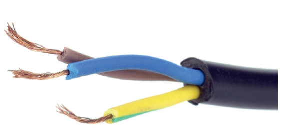
Circuits

A simple electric circuit consists of cells, wires, bulbs, switches and buzzers – these are called components; they have specific symbols.

Components in a circuit only work if the circuit is complete and contains a power supply. When the switch is open, the circuit is not complete and none of the appliances will work. If more cells are added to a circuit, the brightness of bulbs or the loudness of buzzers in the circuit will increase.

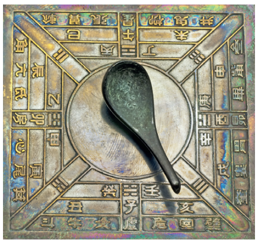
Insulators and conductors

All metals are good electrical conductors. Materials that do not allow electricity to pass through them are called insulators. Examples are wood, plastic, rubber, cloth and air.



In this chapter you will find out

How magnets work

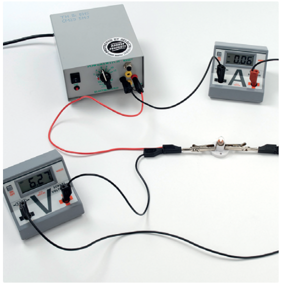


- People used magnets for over a thousand years without understanding how they work.
- The domain theory explains what happens in magnetic materials and why only certain materials are magnetic.
- The Earth is magnetic because its core contains molten iron.
- We can make and test magnets using different methods.

Electromagnets

- When a coil of wire is placed in a magnetic field and a current is passed through it, the coil moves. This is because the coil of wire acts as a magnet itself – an electromagnet.
- In an electromagnet it is possible to switch the magnetic field off. Metal-recycling plants use electromagnets to separate iron and steel from aluminium.
- Electromagnetism is the basis of the motors used in power tools, mixers and cars.

Explaining electric circuits



- The current is a flow of electrons. This depends on the 'push' given by the battery, known as the voltage. Components in the circuits provide opposition to the current – we call this resistance. The current, voltage and resistance are related to each other. Models are a good way of explaining what happens in a circuit.

Series and parallel circuits

- Components in circuits can be arranged in series, in parallel or in both. These arrangements have different effects on the voltage and current, and provide different applications. Circuit breakers are arranged in series, but many Christmas tree lights are arranged in parallel.

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Looking at the history of magnets

We are learning how to:

- Summarise historical ideas about magnetism.
- Describe how historical ideas about magnetism have changed over time.

People have been using magnets for thousands of years. However, our understanding of how magnetism works is quite recent, and this knowledge has made new technologies possible.

Early ideas and discoveries

In the history of scientific discovery, evidence has often become tangled up with superstitious ideas. This happened in the development of our understanding of **magnetism**.

It is reported that about 4000 years ago on the Greek island of Magnesia there was a shepherd named Magnes. The nails in his shoes and the metal tip of his staff became firmly stuck to a large, black rock. He dug up the ground and found special stones called lodestones.

Chinese people wrote about the mariner's compass in the 11th century. This consisted of a splinter of lodestone floating on top of some water. They realised the lodestone pointed in a north–south direction.

FIGURE 2.6.2a: Lodestones were the first magnets observed.

At first, some people were superstitious about lodestones and believed they had healing powers. Many medicines were made of lodestone because people thought that it had a soul.

1. Give two pieces of evidence that describe the properties of lodestones.
2. Why do you think people developed superstitious ideas about lodestone?

Did you know...?

The Earth itself is a huge magnet. The magnet's north pole is near the geographic South Pole, and the magnet's south pole is near the geographic North Pole. The magnetic field is very weak but it extends beyond the Earth for many thousands of kilometres.

The impact of evidence

Centuries passed with people using **magnets** as a means of navigation, but it was not until 1600 that a doctor called William Gilbert discovered a connection between magnetism and the Earth. He recorded different ways of magnetising steel, either by touching it with lodestone or by long exposure in a north–south direction. He concluded that the Earth itself must be magnetic.

Gilbert's finding came about through scientific testing, ignoring many historical ideas, and drawing conclusions specifically from experiments. He presented his results clearly in a scientific paper, so other scientists could repeat his investigations and debate his work, developing the idea of **peer review**. However, in those days published papers were shared only among a select group, often chosen by the scientist conducting the work.

In 1820, Hans Christian Oersted observed that a current flowing through a wire would cause a magnet to move the wire. After publishing his findings, many scientists of the time became very excited and began their own research. Eventually links between current and magnetism were made and the first electromagnet was produced. Finally, in the late 1800s, through experiments conducted by Michael Faraday, magnetism was used to generate electricity.

FIGURE 2.6.2b: The magnetic compass has been used by navigators for about a thousand years. By taking bearings of visible objects with a compass, navigators can work out the position of their ship.

3. In what ways did the approach to magnetism differ from the 1600s to the 1800s compared with that in earlier times?

4. What impact did these new approaches have?

New applications of magnetism

With the use of models and improved knowledge of atoms, the way magnetism works is now understood better. Research is published worldwide and peer reviewed on a global scale. In the 1970s, this enabled research into new materials called rare-earth magnets. These are now used in many technologies, including computers, medical equipment and renewable energy. They are much stronger than conventional iron magnets, resulting in energy savings across the world.

FIGURE 2.6.2c: Without an understanding of magnetism, research into these rare-earth metals would not have been carried out.

5. What factors do you think have contributed to the increased speed of technological developments in today's world compared to the speed in the Middle Ages (1000 to 1500)?

6. How could scientists in the Middle Ages have worked differently to improve the speed of their developments?

Key vocabulary

magnetism

magnet

peer review

Physics

Exploring magnetic materials

We are learning how to:

- Investigate magnetism in materials.
- Explain magnetism using the domain theory.

We know that magnetic force can attract and repel. But why can some materials behave as magnets while others cannot?

Permanent and temporary magnets

A **permanent magnet** keeps its magnetism for a long period of time – in the case of lodestone, this can be for thousands of years. Permanent magnets have their own magnetic field, which arises from the properties of the material they are made from. Iron, cobalt and nickel are the only common elements that can show permanent magnetism.

Most permanent magnets we use are man-made from alloys (mixtures of metals, such as steel), which produce a stronger magnetic field. Fridge magnets, compasses, computers and loudspeakers all use permanent magnets.

A **temporary magnet** is one that is attracted by a magnet and shows magnetic properties in the presence of a magnetic field. For example, when a paper clip is attached to a magnet, it is able to attract another paper clip. Remove it from the magnet, and magnetic properties are no longer observed. **Electromagnets** are special types of temporary magnets. They are only magnetic when an electric current passes through them.

1. Are all materials affected by a magnetic field?
2. Predict what you could do to improve the strength of a temporary magnet.

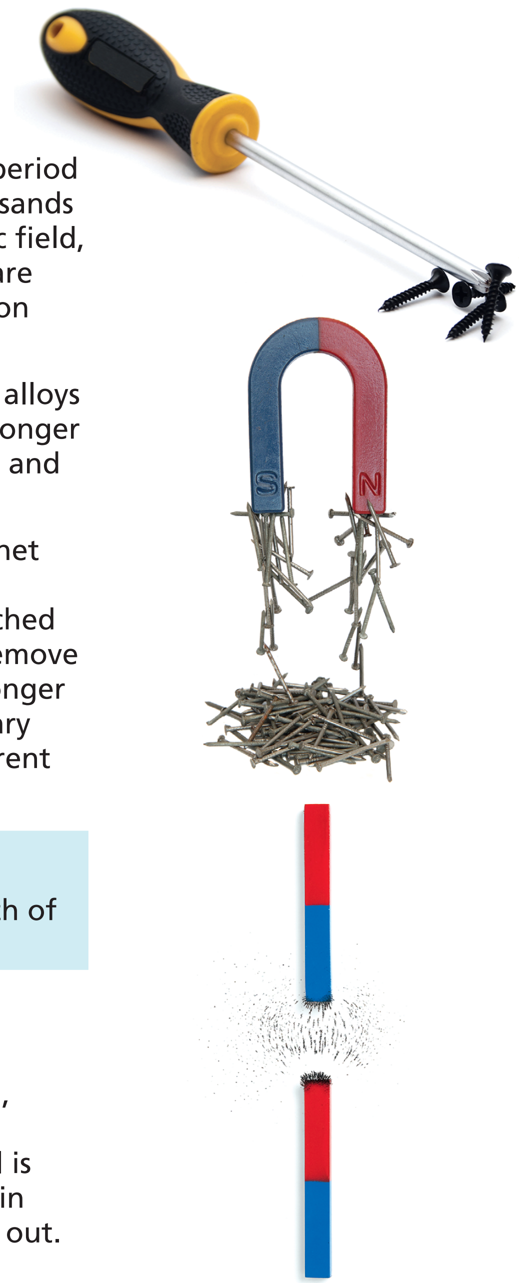

FIGURE 2.6.3a: Which of these magnets is temporary and which is permanent?

The domain theory of magnets

In magnetic materials like iron, steel, cobalt and nickel, groups of atoms bind together in a magnetic **domain**, aligned in the same magnetic direction. If the material is unmagnetised, these domains are arranged randomly in many different directions. The magnetic effect cancels out.

When the material is magnetised, the domains line up and point in the same direction. This causes one end of the material to become a magnetic north pole (N) and the other end a south pole (S). The greater the alignment of the domains, the stronger the magnet.

3. Use the domain theory to explain why materials such as copper and aluminium are non-magnetic even when placed in a magnetic field.

4. Explain what happens, in terms of domains, to a steel paper clip when it is placed in a magnetic field.

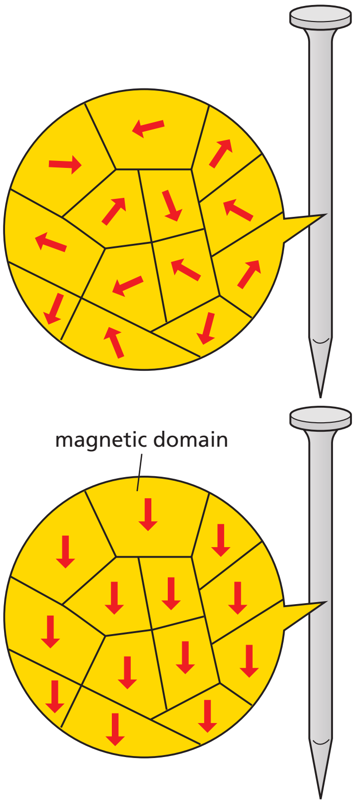

FIGURE 2.6.3b: Which is the magnetised nail?

Making permanent magnets

Iron and steel items can be made into permanent magnets using a variety of methods:

- Stroke a steel rod with a permanent magnet up to 20 times in the same direction.
- Place a steel rod next to a strong permanent magnet for a short length of time.
- Put a steel rod in a long coil of wire that has a direct current passing through it.
- Place a steel rod in a magnetic field, heat it to a high temperature and then hammer it, holding the steel rod in the same direction, as it cools.
- Hold a steel bar vertically and strike it with a hammer several times.

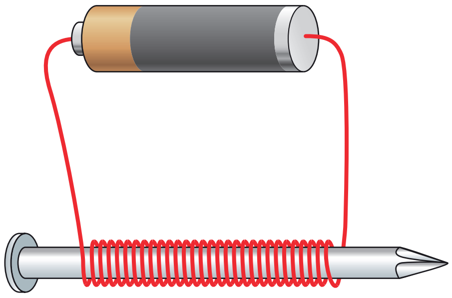

FIGURE 2.6.3c: One way to make a magnet

To remove the magnetism from a permanent magnet, the domain alignment must be disrupted, returning to a random arrangement. This can be done by dropping, hammering, heating or stroking the magnetised material randomly with another magnet.

5. Explain, using the domain theory, why stroking a steel rod with a magnet is likely to make it magnetic, but hammering it randomly will remove its magnetism.

6. Summarise and explain all the factors that affect the domains within a magnet.

Did you know...?

The world record for the strongest pulse magnet (in which the magnetic field lasts for a short period only) was set in 2012 in the USA. It is two million times stronger than the Earth's magnetic field!

Key vocabulary

permanent magnet

temporary magnet

electromagnet

domain

Testing the strength of magnets

We are learning how to:

- Compare different methods of testing magnets.
- Collect data to investigate the strength of magnetism.

There are different ways to test the strength of magnets. Do all these methods give the same results, or are some better at comparing magnets? How can you evaluate each method to determine which is the most effective?

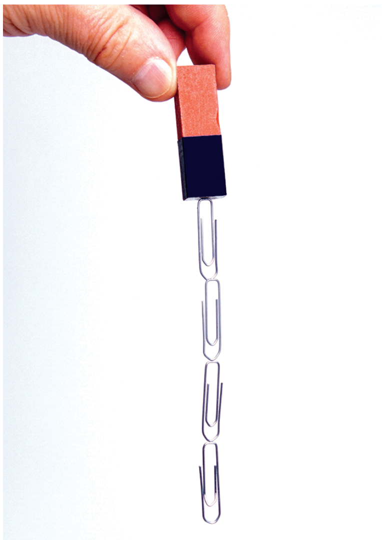

FIGURE 2.6.4a: Testing the strength of a magnet

Ways to measure magnetic strength

The strength of a magnet can be tested simply by the following methods:

- Measure the number of objects, such as steel paper clips, that a magnet can hold, adding one at a time – the stronger the magnet, the more paper clips it will hold.
- Investigate the distance at which an object, such as a paper clip, is attracted to a magnet – the stronger the magnet, the farther the distance from which it will attract an object.
- Investigate the magnetic field using iron filings to 'see' the field lines. The closer the iron filings bunch together, the stronger the field. A diagram can be used to represent the field – the stronger the magnetic field, the closer together the field lines are drawn.

1. Which method in Figures 2.6.4a and 2.6.4b is likely to provide the most reliable results?
2. Which method involves making the most accurate measurements?

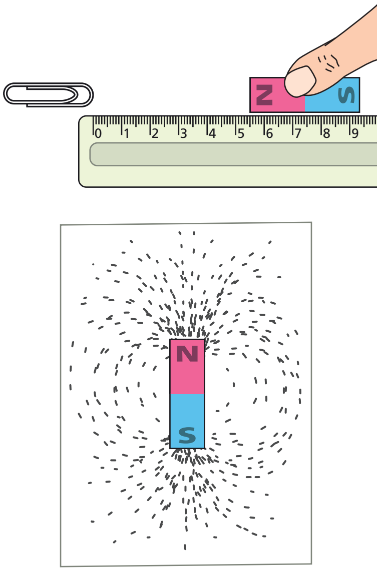

FIGURE 2.6.4b: Two other ways of testing a magnet's strength. Which method is best?

Comparing methods

Table 2.6.4 shows the results from two different ways to compare the strengths of magnets: counting the number of paper clips the magnet can hold, and measuring the distance from which a paper clip can be attracted to the magnet.

Some methods of making measurements are, however, **subjective**. This means that different people may interpret the results differently. Examples of this are judging the distance between magnetic field lines with the eye, or estimating the number of paper clips held by a magnet simply by looking at them instead of counting them. In a scientific method, it is better to choose some kind of measurement that provides a reading. This improves the **reliability** of the data.

TABLE 2.6.4: Results of two different ways of comparing the strengths of magnets

	Number of paper clips held	Distance from which it attracts a paper clip (cm)
Magnet 1	100	20
Magnet 2	100	25
Magnet 3	100	28
Magnet 4	100	30

3. What is wrong with subjective measurements in science?
4. Can you think of at least one reason why the results in one column of Table 2.6.4 are the same but those in the other column are different?

Evaluating scientific methods

To evaluate different methods of measuring magnetic strength, we need to compare the **repeatability**, **reproducibility**, **accuracy** and **precision** of the data from the different methods

Repeatability

The same person carries out repeat tests of the investigation. The closer the readings are to each other, the more repeatable the data. Ideally readings should be taken, outliers identified and eliminated, and then the mean calculated from three close values.

Reproducibility

If the method can be repeated exactly and the same results can be obtained by another person, then it is reproducible.

Accuracy and precision

Data close to the true values are accurate. This depends greatly on the way you conduct your investigation and the type of equipment used. Taking readings of finer measurements can result in greater precision. For example, using a metre rule marked in centimetres to measure the distance over which an object is attracted by a magnet will not be as precise as using a measurement ruler marked in millimetres.

5. Look at the data in Table 2.6.4. How repeatable do you think this investigation is?
6. Is a repeatable investigation always reproducible? Explain your answer.

Did you know...?

The strongest magnetic force in the Universe is produced by a type of neutron star. It has a magnetic field of about 10^8 tesla (about 10^{11} times that of a fridge magnet).

Key vocabulary

subjective
reliability
repeatability
reproducibility
accuracy
precision

Describing the Earth's magnetic field

We are learning how to:

- Explain evidence for the Earth's magnetic field.
- Explain the impact the Earth's magnetic field has on our planet.

Without the Earth's magnetic field there would be no life on this planet. It protects us from deadly charged particles carried in solar winds from the Sun. How does it do this and what causes the Earth's magnetic field to exist?

Evidence of the Earth's magnetic field

All compasses respond to magnetic fields. The fact that they all line up in a north–south direction (when not near a magnet) is evidence that the Earth must have its own magnetic field.

The N pole of a magnetic compass needle points in a geographical north direction, wherever it is on Earth. This is evidence that the Earth's geographic North Pole is actually the Earth's magnetic S pole, or very close to it (look back at Figure 2.5.3c in Chapter 5).

We also know from magnetic rocks that the poles of the Earth's magnetic field are not fixed, but reverse every few hundred thousand years.

1. Summarise the evidence for the Earth's magnetic field.
2. Use your understanding of how magnets are made to suggest how lodestone (see Topic 6.2) was first magnetised.

FIGURE 2.6.5a: Using the Earth's magnetic field

The geodynamo theory

Evidence about the structure of the centre of the Earth has largely come from earthquakes, volcanoes and rocks.

Scientists believe the centre of the Earth is made from a core of solid iron, surrounded by a liquid core of iron and nickel. The spinning action of the Earth causes the liquid core to spin in a regular way. This movement causes charged particles to move, forming small currents. Electric currents produce magnetic fields and so magnetic domains within the liquid develop, lining up to create a weak magnetic field. This is called the **geodynamo theory**.

3. Why can we not be certain about how the Earth's magnetic field works?
4. Draw a diagram to show how the magnetic fields in the Earth might arise.

Impact of the Earth's magnetic field

The **magnetosphere** is the magnetic field around the Earth. It extends out into space and is shaped by the **solar wind** caused by the Sun's activity. Figure 2.6.5b shows this.

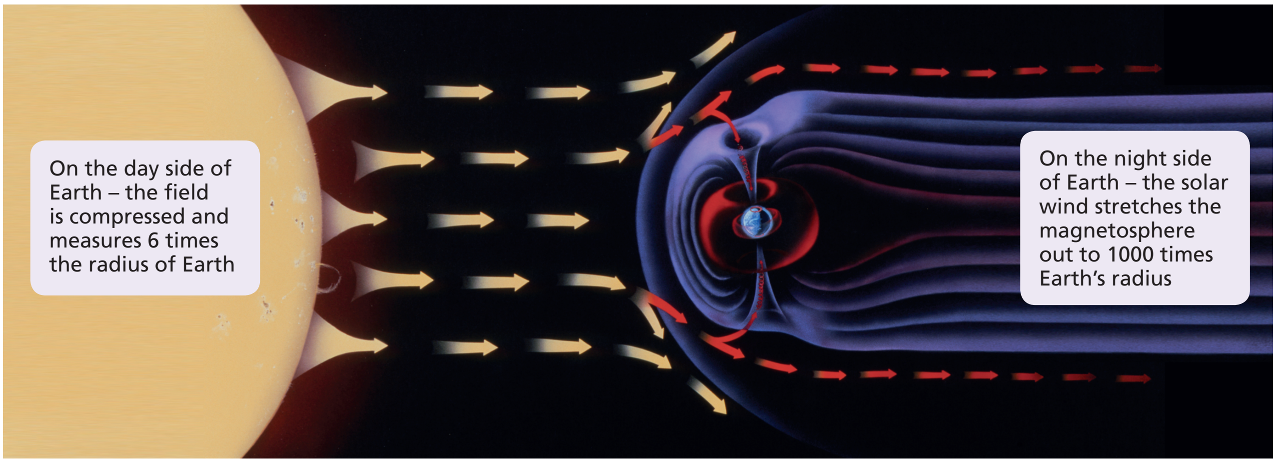

FIGURE 2.6.5b: The effects of the solar wind on the shape of the Earth's magnetosphere

The magnetosphere prevents deadly cosmic rays and the highly charged particles in solar winds from reaching the Earth. Without this protection, it would be impossible for life to exist here.

Energy and highly charged particles from the Sun create magnetic storms in the magnetosphere. Most damage is deflected by the magnetosphere, but sometimes the storms are so strong they disrupt GPS systems and other satellites, and cause the need for aircraft to find alternative routes.

Geologists study rocks in different layers in the Earth. The deeper the rocks are, the older they are. By testing the magnetic field of magnetic rocks, scientists can determine which is the N pole and which is the S pole. Evidence for over 170 pole reversals in the past 71 million years has been reported. A reversal occurs roughly every 400 000 years – the most recent took place 780 000 years ago and geologists believe another is due in the next few thousand years.

5. Why is the magnetosphere larger on the night side of the Earth?
6. Describe an experiment you might carry out to test the magnetic polarity of different rocks.

Did you know...?

The planet Mercury also has its own magnetic field. However, it is not as strong as the Earth's and, because it is closer to the Sun, solar winds cause much more damage to its surface.

Key vocabulary

geodynamo theory

magnetosphere

solar wind

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Investigating electromagnetism

We are learning how to:

- Describe what an electromagnet is.
- Investigate the factors affecting the strength of electromagnets.

If you pass a current through any wire, a weak magnetic field is produced. This link between electricity and magnetism has been thoroughly investigated, enabling us to make very powerful, controllable electromagnets.

What is an electromagnet?

In 1820, a Danish scientist, Hans Oersted, passed a **current** through a single wire. Placing a compass near the wire, he noticed that the needle moved, proving that a **magnetic field** was present. When the current was switched off, the needle returned to its normal position. Oersted had taken the first steps towards understanding electromagnetism.

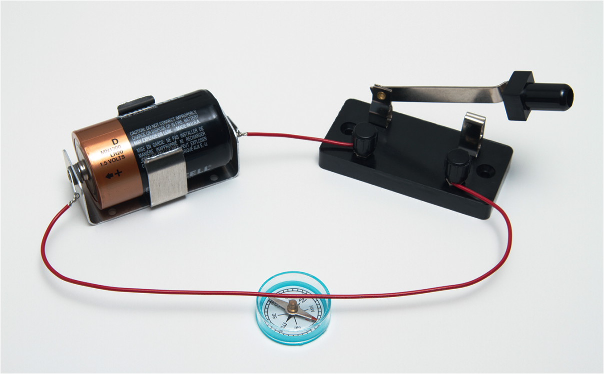


FIGURE 2.6.6a: When the switch completes the circuit, the compass needle moves – the current in the wire is acting like a magnet.

Any wire with a current passing through it will produce a magnetic field. When the current is switched off, the magnetic field disappears. Any magnet that uses electricity to produce a magnetic field is called an **electromagnet**.

1. How is an electromagnet different from a permanent magnet?
2. Describe two different ways to prove that an electromagnet is magnetic.

Making electromagnets stronger

Oersted made a very weak electromagnet because he used a single wire and a small current.

The strength of an electromagnet can be increased by:

- increasing the current passing through the wire
- making the wire into a coil
- increasing the number of coils in the wire
- putting an **iron core** in the centre of the coil.

Did you know...?

There is a limit to how strong you can make an electromagnet. Once all the domains within the iron core are lined up, the strength of the magnet cannot be increased, no matter how much more current is applied.

Figure 2.6.6b shows a simple electromagnet consisting of a battery and a coil of wire surrounding an iron nail. The wire is covered by electrical insulation so that it does not connect electrically with the iron nail. When a current is passed through the wire, it causes the iron nail to become magnetic.

3. Remind yourself of the domain theory described in Topic 6.3. How do you think the current affects the domains in the iron core?

4. Draw an electromagnet you might use to attract a steel paper clip. Explain how you could modify your electromagnet so that it could attract and lift a car.

5. How would you drop the car?

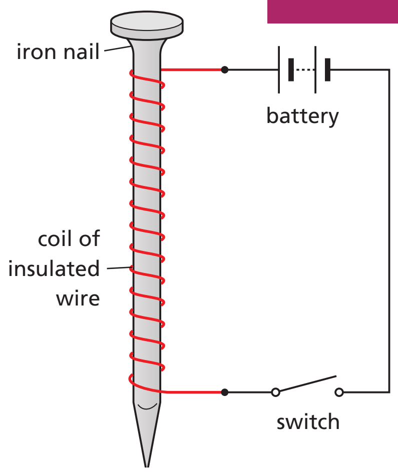


FIGURE 2.6.6b: A simple electromagnet, here made using an iron nail

Magnetic fields around electromagnets

If plotting compasses are placed around a wire with a current flowing through it, they show that the magnetic field shape around the wire is circular, as shown in Figure 2.6.6c. Iron filings can be used to show this.

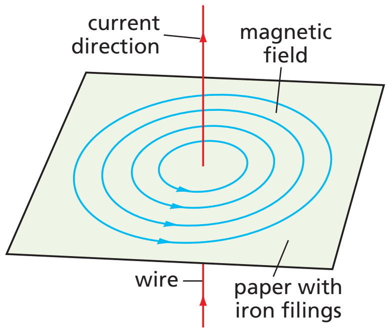


FIGURE 2.6.6c: The shape of the magnetic field around a wire carrying a current

The shape of the magnetic field around a long coil of current-carrying wire is similar to that of a bar magnet, as shown in Figure 2.6.6d. One end of the coil is the N pole and the other end is the S pole. Reversing the direction of the current reverses the magnetic field – the S pole becomes the N pole and vice versa. Increasing the number of coils increases the magnetic field around the loops, resulting in a stronger field. Using a magnetic material, like iron, as a core strengthens the field.

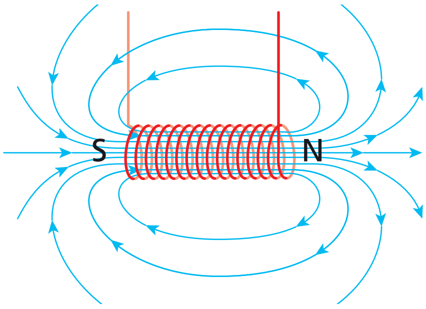


FIGURE 2.6.6d: Coils with many turns of wire are used in electromagnetic devices.

6. What would happen to the magnetic field lines if the current in Figure 2.6.6d was increased?

7. Why are the coils of an electromagnet placed in line and not in a random way?

8. Explain the advantages of an electromagnet over a permanent magnet for devices that require a magnet.

Key vocabulary

current

magnetic field

electromagnet

iron core

Using electromagnets

We are learning how to:

- Describe different applications of electromagnets.

The main advantage of using electromagnets over ordinary magnets is that the magnetic field can be switched on or off at will, making them easier to control. This has resulted in a wide range of applications.

Common uses of electromagnets

Electromagnets are used in many different devices.

- In your computer hard drive, tiny electromagnets are used to help store information on a disk.
- Separating iron and steel from non-magnetic metals, such as aluminium and copper, is one of the main uses of electromagnets. Switching the current off allows the magnetic objects to fall from the electromagnet.
- Electromagnets are used in loudspeakers – the magnetic field moves a diaphragm to amplify the sound vibrations.


FIGURE 2.6.7a: How is this electromagnet being used?

1. Give two advantages of using electromagnets.
2. Give one disadvantage of using an electromagnet compared to an ordinary magnet in the applications listed above.

The electric bell

The circuit inside an electric bell is shown in Figure 2.6.7b.

When the switch is closed at A, a current flows. The iron core of the electromagnet at B becomes magnetised.

The iron bar, called the **armature**, at C is attracted to the electromagnet and moves towards it. The hammer, connected to the armature, moves to strike the gong.

The springy steel strip at D moves away from the **contact** screw as the hammer strikes the gong, breaking the circuit.

Because the current no longer flows through the electromagnet, it loses its magnetism. The armature is no longer attracted and moves back to its original place.

Did you know...?

Electromagnets are used to remove tiny pieces of metal that accidentally enter the eye. They offer greater control than ordinary magnets, so there is less risk of injuring the eye.

The steel strip is once again in touch with the contact screw and the circuit will complete again as long as the switch remains pushed.

3. What must be done to stop an electric bell from ringing? Explain your answer.
4. What would happen if the electromagnet in an electric bell was replaced with an ordinary magnet?

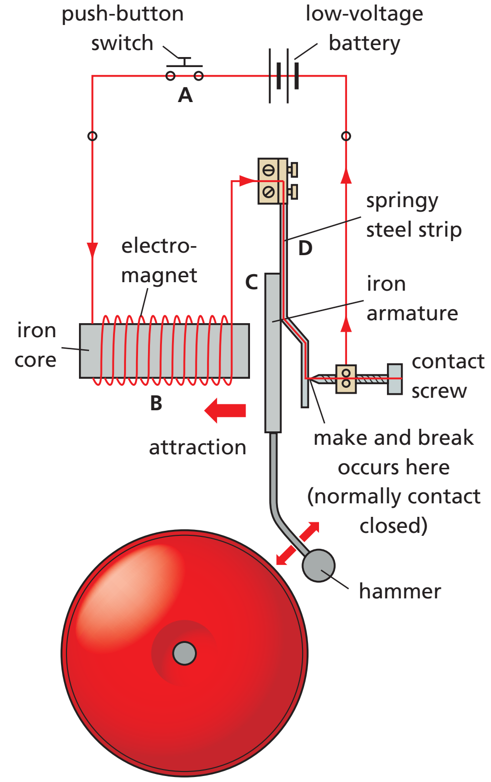


FIGURE 2.6.7b: How an electric bell works

The circuit breaker

A **circuit breaker** is designed as a safety device. It breaks a circuit if too much current is drawn from the mains, and so protects appliances. Household appliances and lighting are protected with circuit breakers.

Figure 2.6.7c shows how a circuit breaker works. In normal operation, a low current passes through the appliance and the electromagnet. Because the current is low, the electromagnet is weak and so is not strong enough to separate the iron contacts. If the appliance malfunctions and too much current passes through the wire, the electromagnet becomes stronger, attracting the iron contacts. This breaks the connection between the iron contacts and breaks the circuit, protecting the appliance. The spring prevents the contacts from reconnecting.

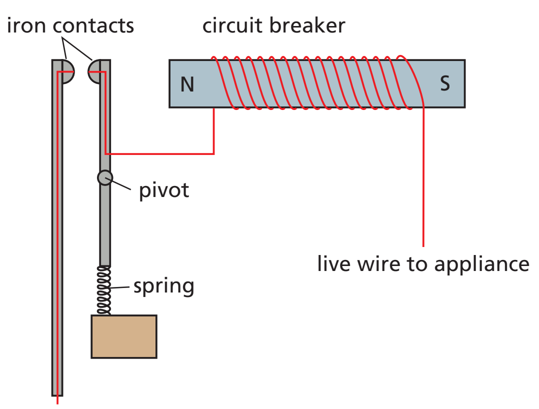


FIGURE 2.6.7c: How an electromagnetic circuit breaker works

5. In a circuit breaker, why is it important for the contacts, once broken by the electromagnet, to remain unconnected?
6. What advantages do circuit breakers have over ordinary switches?

Key vocabulary

armature

contact

circuit breaker

Exploring D.C. motors

We are learning how to:

- Describe the magnetic effect of a current and how this is applied to D.C. motors.

In certain applications, magnetic energy can be harnessed and transferred to energy by movement. The world of motors relies on this energy transfer. Motors are used in many ways, from small electric drills to giant stone cutters in deep mines.

FIGURE 2.6.8a: Which appliance does not have an electric motor?

Uses of electric motors

Electric motors are devices that use electromagnets or permanent magnets. They transfer energy by electricity and use a magnetic force to cause movement and do useful work.

Electric motors are used in many common appliances, such as food mixers, vacuum cleaners, cars, washing machines and electric drills. Every electrical device that transfers energy by electricity to energy by movement uses an electric motor.

1. Name three other devices that use electric motors.
2. Draw an energy transfer diagram to summarise the energy transfer in an electric motor.

Discovering the motor effect

We have learnt that a wire with a current passing through it produces a magnetic effect. In 1831, after the discovery, Michael Faraday found that when a wire carrying a current was placed in a magnetic field, it moved. It moved in a direction at right angles to both the field and the current. If the direction of the current was reversed, the direction of the movement was also reversed. The magnetic effect of a current was being transferred to energy by movement.

In Figure 2.6.8b, when the permanent magnet is placed over the wire and the current passes through, there are two magnetic fields – one from the permanent magnet and one from the wire. These two fields will attract or repel, causing the wire to move. This is called the **motor effect**.

A ‘D.C. motor’ works using the motor effect arising from a **direct current** (**D.C.**), which means a current that always flows in one direction.

3. In Figure 2.6.8b, when the current is switched on, the wire moves downwards. What would happen if the battery were connected the other way around?
4. Can the set-up shown in Figure 2.6.8b produce any useful work?

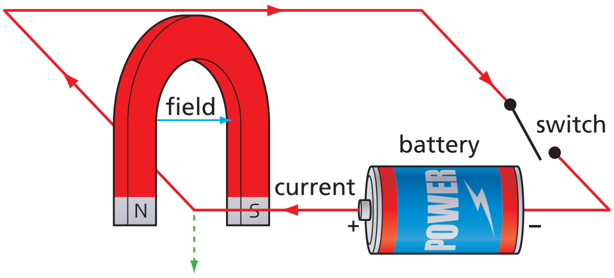


FIGURE 2.6.8b: The motor effect. What happens if the battery is disconnected?

Stronger electric motors

The amount of movement of the wire can be increased by:

- Increasing the current, which increases the strength of the magnetic field around the wire. This causes a bigger repulsion or attraction.
- Increasing the strength of the magnetic field of the permanent magnet. This can be done by using a stronger magnet, or changing the material the magnet is made from, so more domains within the material are lined up.
- Making the straight wire into a coil with many turns. This increases the strength of the magnetic field around the wire.

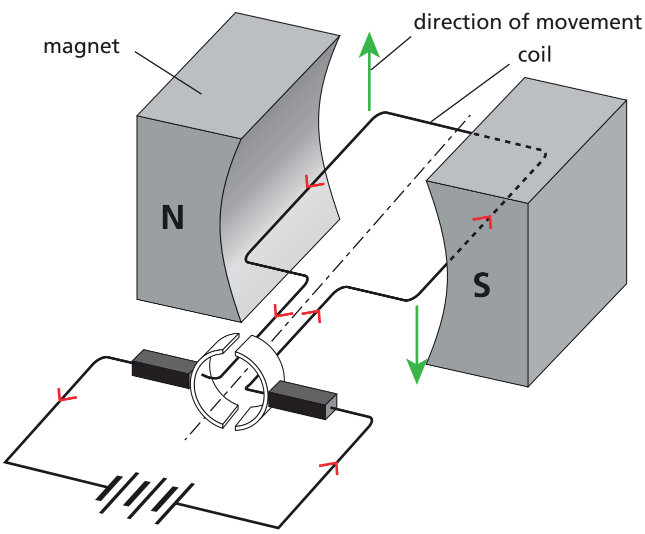


FIGURE 2.6.8c: A simple D.C. motor

Figure 2.6.8c shows how these measures work. The permanent magnet (or electromagnet) surrounds a coil of wire. The coil is able to spin freely. When a current passes through the coil, a magnetic field is produced. This interacts with the magnetic field of the magnet, which causes the coil to turn upwards. In order to allow the coil to spin, the poles of the magnetic field must be reversed. The brushes reverse the polarity of the current and so reverse the magnetic field due to the coil. In this way, the coil is able to keep spinning, enabling useful work to be done.

5. What would happen if the magnetic poles due to the coil were not reversed?
6. Motors can have different speeds. How can the speed of the motor be controlled?

Did you know...?

The tiniest motor built works on the atomic scale, enabling atoms to be moved.

Key vocabulary

electric motor

motor effect

direct current (D.C.)

Applying key ideas

You have now met a number of important ideas in this chapter. This activity gives an opportunity for you to apply them, just as scientists do. Read the text first, and then have a go at the tasks. The first few are fairly easy – then they become a bit more challenging.

How can magnets be used to operate trains?

Technology that uses magnets to operate trains, called Maglev trains, is in use in some parts of the world. The first commercial Maglev train ran between Birmingham airport and the railway station – it operated from 1984 to 1995. In 2004, China installed the first high-speed commercially operated train in Shanghai, followed closely by Japan in 2005. Germany has also been active in developing this technology.

FIGURE 2.6.9a: The speed reached by a Maglev train relies on electromagnetic propulsion and streamlined design.

Maglev trains do not have a conventional engine, which runs on diesel – they rely on the use of electromagnets. There are three main parts to the system:

- a large electrical power source (in China and Japan much of their electricity is produced by nuclear power, which means they do not rely on fossil fuels for their energy source)
- metal coils lining the guideway
- large guidance magnets underneath the train to cause repulsion between the train and the rail.

When a current flows through the coils in the guidance magnets, a magnetic field is produced. This field repels large magnets on the undercarriage of the train. The effect of this is to lift the train up (make it levitate) so that it no longer touches the rail underneath. It can rise between 1 cm and 10 cm. Other electromagnets in the propulsion coil, situated in the guideway walls, then propel the train forwards.

As a result of this design, when the Maglev trains are in operation there is no friction between the train and the track. With a sleek aerodynamic design, speeds of over 500 km/h (310 mph) can be reached!

A special type of electromagnet is used, known as superconducting magnets. These are made of materials such as niobium and titanium, and they must be kept at a very low temperature during operation. This enables them to transfer much higher currents through the coils compared to those transferred through normal wires. Magnetic fields of up to 15 teslas are possible with this system.

The setting up of a Maglev system is highly technical and very expensive. In addition, large amounts of electricity are needed to keep the trains in operation. These are some of the reasons why the technology is not more widespread. The advantages it holds, however, are very significant. With the ability to travel at such high speeds comfortably, the time for travelling between places is significantly reduced. As a result, there would be less traffic on the roads. The problem with noise as the air rushes past the train at such high speeds is still to be addressed.

Task 1: Types of magnets

Maglev trains use electromagnets in order to operate. Describe the main differences between electromagnets and ordinary bar magnets.

Task 2: Levitation

Draw a simple diagram, including ideas about magnetic polarity, to show why Maglev trains levitate.

Task 3: Making the magnetic field stronger

Explain the main factors that can increase the strength of an electromagnet. How has the design of the electromagnets in the Maglev trains been further modified to make the field even stronger?

Task 4: Benefits of superconducting electromagnets

You are a salesperson for superconducting electromagnets. Design a sales poster outlining all the benefits of using electromagnets to move trains compared to ordinary rail systems.

Task 5: Effect of field reversal

The Earth's magnetic field can reverse every few hundred thousand years. Use ideas about the domain theory to explain whether or not this event is likely to affect the electromagnets in the Maglev trains.

Task 6: What are the disadvantages?

Explain all the disadvantages of the Maglev system and suggest reasons why this technology has not been adopted, so far, in other countries.

Investigating batteries

We are learning how to:

- Describe the link between chemical energy and electricity.
- Investigate how fruit batteries work.

We have learnt how electricity and magnetism are linked. There is also a link between electricity and chemical energy, which we now explore.

Different types of battery

There are many different types of batteries in the world. They all have one thing in common – energy is transferred by chemical reactions to electrical energy. The amount of chemicals and types of reactions involved determine how much energy can be transferred.

The first **battery** was developed by Alessandro Volta, who placed brass and copper plates in a salty solution. The brass contains zinc, which enables the battery to work.

FIGURE 2.6.10a: Alessandro Volta and his battery, in about 1800

By using different metals and solutions, more or less electricity can be transferred.

1. Why do you think batteries become hot if they are used for long periods of time?
2. Draw an energy transfer diagram to show the changes taking place in a battery.

How do batteries work?

In Topic 5.5 you learned about static electricity – the transfer of charged particles by rubbing different materials together. The resulting force of attraction or repulsion leads to the transfer of energy by movement.

Charged particles are also involved in current electricity. In a battery, negatively charged particles, called **electrons**, move as a result of chemical changes in the battery. They build up on the negative terminal of the battery, causing electrons within the metal wires in all parts of the circuit to move away from the negative terminal. The flow of electrons forms the **electric current** – this can be used to transfer energy that makes appliances work. The bigger the difference in charge between the negative and positive terminals of the battery, the greater is the energy that can be transferred by the current.

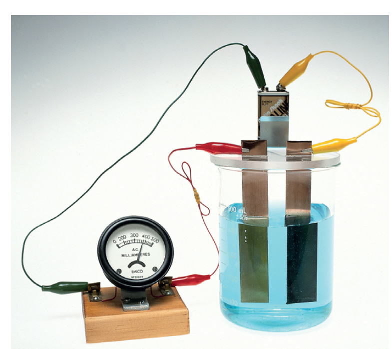


FIGURE 2.6.10b: Charged particles move through the solution between the copper plate and the zinc plate. This creates an electric current in the circuit.

The disadvantage of using batteries, compared to generating electricity from movement energy using a dynamo, is that the energy is transferred out of the battery and the battery needs to be replaced or recharged.

3. Summarise in a bullet list how a battery works.

4. What are the advantages of using batteries, compared with a dynamo, to make an electric current?

Explaining fruit batteries

Figure 2.6.10c shows a fruit battery in operation. Two different metals are placed, a distance apart, at the same depth within the fruit. Wires connect the two metals in a circuit containing a meter that shows a **voltage** is produced. The liquid inside the fruit enables charged particles in the fruit to take part in the chemical changes – a battery will not work with dried fruit.

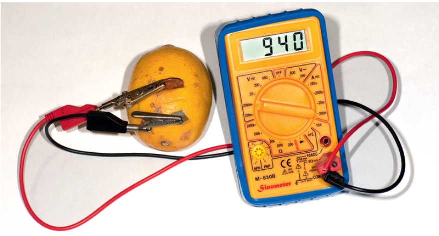


FIGURE 2.6.10c: A fruit battery

Different combinations of metals will produce different results. Table 2.6.10 shows the voltages from an investigation of different combinations of metals.

TABLE 2.6.10: Results from an investigation of different combinations of metals

Metal 1	Metal 2	Voltage produced (V)
copper	zinc	0.75
copper	magnesium	1.37
copper	iron	0.49
zinc	magnesium	0.67
zinc	iron	0.31
iron	magnesium	0.95

5. Look at Table 2.6.10 and Figure 2.6.10d. Can you see a pattern between the metals that produce the highest voltage and their reactivity?

6. Apart from changing the metals, can you think of two other ways of increasing the voltage from a fruit battery? Explain how each one works.

Did you know...?

The first rechargeable battery was made in 1836. It was a lead–acid battery, a system still in use today.

potassium	most reactive	K
sodium		Na
calcium		Ca
magnesium		Mg
aluminium		Al
carbon		C
zinc		Zn
iron		Fe
tin		Sn
lead		Pb
hydrogen		H
copper		Cu
silver		Ag
gold		Au
platinum	least reactive	Pt

FIGURE 2.6.10d: Reactivity series of elements

Key vocabulary

battery

electron

electric current

voltage

Describing electric circuits

We are learning how to:

- Describe and draw circuit diagrams.
- Explain what is meant by current.
- Explain how materials allow current to flow.

A light bulb in an electric circuit lights up instantaneously. Even if the circuit were the size of a football pitch, there would be no time delay for the light to come on. What is actually going on in the circuit for energy to be transferred so quickly?

Components in electric circuits

An electric circuit is a loop of wire with its ends connected to an energy source, such as a battery or cell. Strictly, a 'battery' is two or more cells together.

When a circuit is complete, energy is transferred from the battery to the wires by an electric current. Devices such as light bulbs, motors and buzzers are **components** that can make use of the energy transferred from the battery.

The components in the circuit need an electric current to pass through them. If there are any gaps in the circuit, the current will not flow and energy cannot be transferred. A material that allows current to pass through it is called an electrical **conductor**. These have electrons that are free to move within the conductor. An electrical **insulator** does not have any free electrons and cannot allow a current to pass.

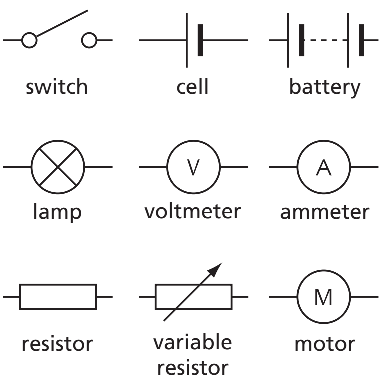


FIGURE 2.6.11a: Circuit symbols for common components

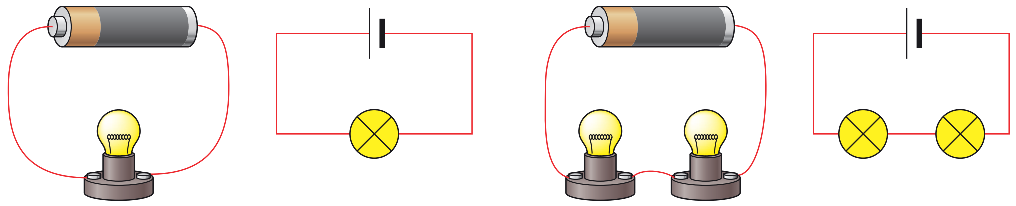


FIGURE 2.6.11b: How circuit symbols are used to represent components in a circuit diagram

1. If pencil lead is placed in a circuit with a light bulb, the bulb lights up. What conclusion can you draw about this material?
2. Draw a circuit diagram for a circuit with one cell and three bulbs.
3. Why is it important to represent components with symbols?

Using models to explain current

Current is the rate of flow of charge (electrons) in the circuit, and is given the symbol *I*. It is measured by an **ammeter** in **amperes** (symbol A), after the French scientist Andre-Marie Ampere.

Models and analogies are often used to explain complex phenomena like current. One analogy is to compare electric current to water flowing in a stream. The charges are the water particles, and the current is the flowing stream.

FIGURE 2.6.11c: In the analogies pictured in the photos, what represents the charge and what represents the current?

Another analogy used to represent current is that of a convoy of coal trucks. The trucks represent the charged particles, the movement of the trucks represents the current, and the coal they carry represents the energy they transfer.

4. Using first the water analogy and then the coal-truck analogy, draw diagrams to show the difference between a low current and a high current.
5. Which analogy is better at explaining that current transfers energy to different components? Explain your answer.

Scientific explanation of current

When the battery is connected, the electrons in all parts of the wires within the circuit move at the same time, in the same direction and at the same rate. This movement constitutes the current. In this way, no matter where the components are in the circuit, they will all conduct at the same time – there is no delay because all the electrons in the circuit move simultaneously.

Current is not used up in the circuit. It has the same value before and after each component in the circuit – indeed, it is the same everywhere in the circuit.

6. Explain the strengths and limitations of the two analogies above, in light of the scientific explanation for current.
7. Explain why current is not used up in a circuit.

Did you know...?

A current of 1 amp means there are 6 250 000 000 000 000 000 electrons flowing past a point every second!

Key vocabulary

component

conductor

insulator

ammeter

ampere

Understanding energy in circuits

We are learning how to:

- Describe what the voltage does in a circuit.
- Explain voltage using different analogies.

We know that an electric circuit gets its energy from a battery. The amount of potential energy within a battery is measured by the number of volts it has. Volts are the measurement of voltage.

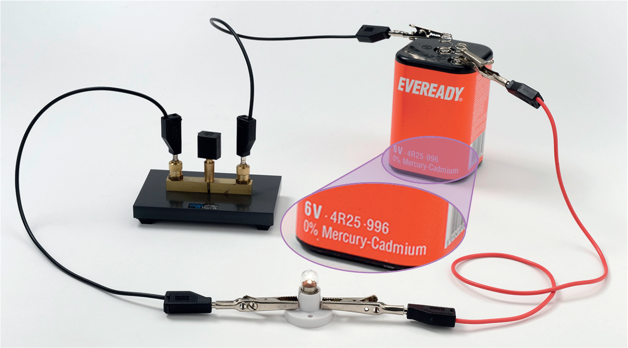


FIGURE 2.6.12a: What do we mean by voltage?

What is voltage?

We can think of **voltage** as a measure of the size of 'push' that causes a current to flow around a circuit. Because the current is a flow of charge, something is needed to make the charges move.

If there is no voltage, then there can be no current flowing because there is nothing to cause the charges to move. The larger the voltage, the bigger the 'push' and the more current that can potentially flow.

The symbol for voltage is *V* and the unit is **volts** (V).

The energy source for the voltage is usually a battery or cell, but it can also come from a mains socket. A large energy source, like a big car battery of 12 V, will provide more 'push' or voltage and hence more current than a small cell of 1.5 V.

If two cells are connected together side-by-side, the voltage across them is the sum of the voltage of each cell. This is because both cells are 'pushing' the same way.

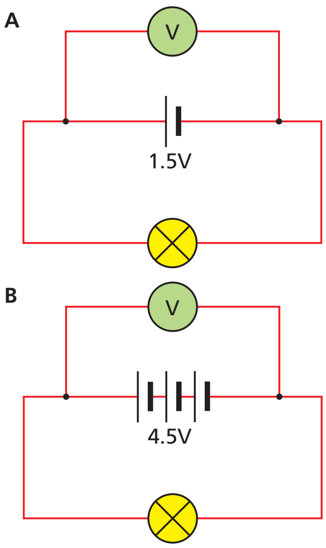


FIGURE 2.6.12b: Measuring the voltage across cells

1. Why does no current flow if there is no voltage?
2. Figure 2.6.12b shows two circuits, one with one cell and the other with three cells. If, instead, there were two cells, what reading would the voltmeter give?

Voltage and components

If there is a higher voltage, there will be more current flowing and therefore more energy being transferred to the components. A light bulb will be much brighter if it is connected to a 6 V battery rather than to a 3 V battery in a similar circuit. Voltage is measured using a **voltmeter** (Figure 2.6.12d).

Did you know...?

Electric eels can produce electrical discharges of around 500 V in self-defence.

Figure 2.6.12c shows how the voltmeter must be connected *across* a component (here a bulb) to measure the energy difference in the current either side of the component.

3. In which of the circuits in Figure 2.6.12b will the light bulb be the brightest? Explain your answer.
4. What might happen to a motor if it were connected to the 230 V mains electric supply rather than to a 12 V battery?

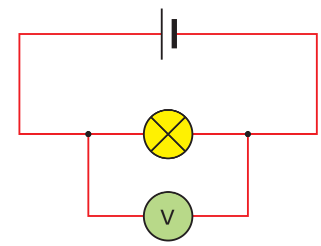


FIGURE 2.6.12c: Measuring the voltage across a bulb

Using analogies to explain voltage

Imagine blowing gently through a straw. The air flowing through the straw is like a current and the amount of push given to the air is like the voltage. If you blow harder (more voltage) there is more air flow (more current).

A very high waterfall is also like a large voltage. It will transfer a lot of energy to the water (charge), making the river flow very fast (a large current). The difference in height makes the river flow. In a circuit, the difference in charge across the battery provides the push for the current. This is why voltage is also known as **potential difference**.

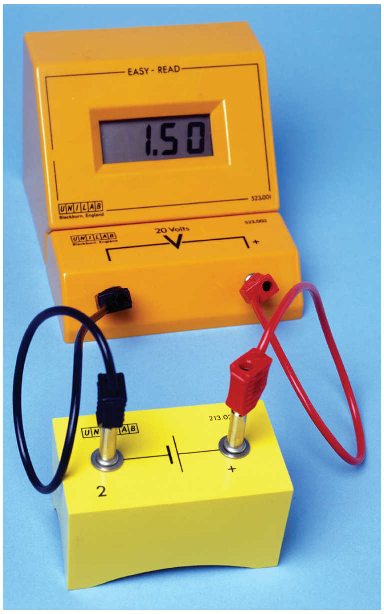


FIGURE 2.6.12d: A voltmeter connected to measure the voltage of a cell

FIGURE 2.6.12e: The difference in height makes the water move.

5. Compare a circuit with a 12 V battery and one light bulb with one that has a 1.5 V cell and one light bulb. Use the two analogies in this topic to explain how they will be different.
6. Explain one limitation for each of the analogies outlined.

Key vocabulary

voltage

volt

voltmeter

potential difference

Explaining resistance

We are learning how to:

- Explain what resistance is and how it affects the circuit.
- Investigate and identify the relationship between voltage and current.

All materials offer some opposition to the flow of current – we call this 'resistance'. The amount of resistance can vary widely, even in different metals. Why are some metals, like gold, better at conducting electricity than other metals, like tin?

What is resistance?

The word 'resistance' means to oppose. In electric circuits, electrical **resistance** opposes the 'push' provided by the voltage. The overall current flowing through the circuit, therefore, depends on both the voltage and the resistance.

If there is a high voltage and a low resistance, then a large current will flow. This is because there is not very much opposition to the 'push' given by the voltage. Imagine a motor in a circuit. The current through it causes it to spin. If the motor is swapped with one of higher resistance, there will be more opposition to the flow of charge and, for the same voltage, the current will be smaller. The motor with a higher resistance will spin more slowly.

All components in a circuit provide some resistance.

1. A buzzer is an electrical device that transfers the energy of an electric current to sound energy.

a) A circuit, A, has a 6 V battery and a buzzer. Another circuit, B, has a 6 V battery and a buzzer with higher resistance. In which circuit will the buzzer be louder?

b) Explain your answer to a) using ideas about resistance and current.

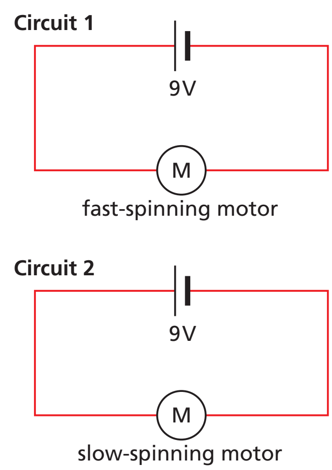


FIGURE 2.6.13a: The resistance in circuit 1 is low, so there is a bigger current; what can you say about circuit 2?

Conductors and insulators

Resistance depends on the type of material an object is made from. Materials that are very good conductors of electric current have a very low resistance. Electrical insulators have a very high resistance, and do not allow current to flow easily.

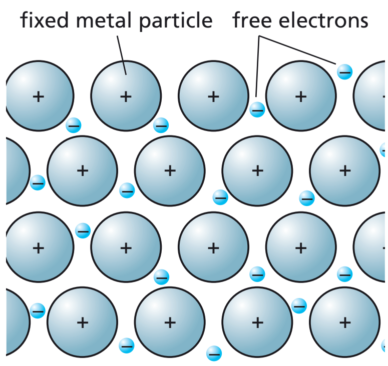


FIGURE 2.6.13b: Conduction in metals depends on free electrons

All metals conduct electricity well because they have many **free electrons** that can move when a voltage is applied.

As the electrons move, they will collide with other atoms. This is the cause of resistance in most ordinary metals. It is why even the best electrical conductors, like platinum, will have some resistance.

In an insulator, the electrons are more tightly bound than in a conductor; far fewer electrons flow and so there is much less current.

2. As an analogy, think of an obstacle race. Which parts of a circuit do the obstacles represent? Which parts of the circuit do the people represent?
3. What would happen to a light bulb if the copper wires in a circuit were replaced with platinum? Explain your answer.

Working out resistance

Resistance is measured with the unit **ohms** (Ω) and is represented by *R*. All the components in a circuit will have their own resistance. It is possible to investigate the relationship between voltage (*V*) and current (*I*) across a component, as shown in Figure 2.6.13c.

The definition of resistance is:

$$\textbf{resistance} = \frac{\textbf{voltage}}{\textbf{current}}$$

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

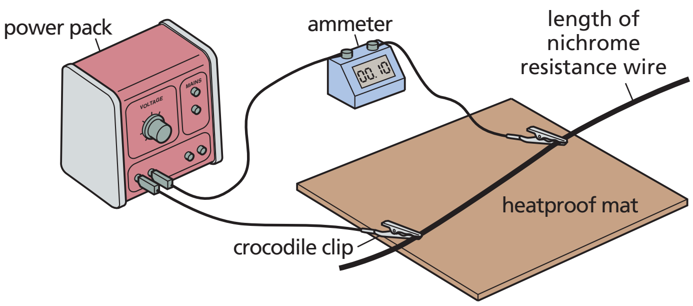


FIGURE 2.6.13c: As the voltage supplied is changed using the power pack, the current is measured using the ammeter. The resistance of the length of nichrome wire between the crocodile clips can then be determined.

4. What is the resistance of the circuit shown in Figure 2.6.13d?
5. Give two ways you might increase the resistance of the circuit. Explain your answers.

Did you know...?

Special components called resistors, with high resistance, are often made from nichrome or tungsten. They are used deliberately to transfer electrical energy to light and heat in the surroundings.

Key vocabulary

resistance
free electron
ohm

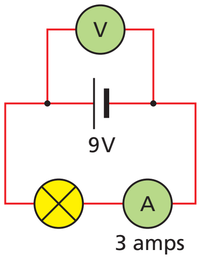


FIGURE 2.6.13d

Investigating factors affecting resistance

We are learning how to:

- Describe some uses of resistance.
- Investigate and explain factors affecting resistance.

Wires of different resistance have different purposes. High-resistance wires are used in light bulbs, whereas in some electronic applications it is essential that there is minimal electrical resistance. There are different ways in which the properties of a circuit may be changed.

Types of resistor

Increasing the resistance in a circuit reduces the amount of current passing. If too much current passes through a laptop computer, for example, it can cause damage to the circuits. Components called fixed **resistors** are used in circuits to enable a specific amount of current to pass through the components.

Other types of resistors, called **variable resistors**, allow you to change the amount of current flowing through a circuit by turning a knob or using a slider. Dimmer-light switches use this type of resistor to control the current and hence vary the brightness of the bulb.

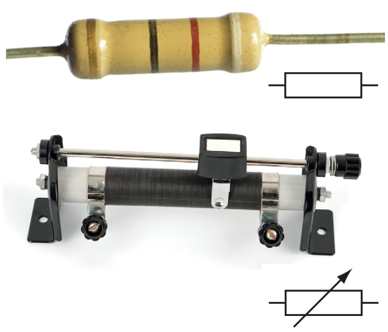


FIGURE 2.6.14a: Fixed resistor (top) and variable resistor (bottom)

1. Name at least one appliance that may contain a variable resistor and one that may contain a fixed resistor.
2. Give one advantage of a variable resistor.

Advantages and disadvantages of resistance

Resistance is the property that makes a **filament** in a light bulb work. Such a light bulb uses a very thin tungsten wire, with a high resistance. As the voltage pushes the electrons through the thin wire, there are collisions with atoms that transfer energy to heat. The tungsten wire heats up to a very high temperature and begins to glow, transferring energy to light.

In the transport of electricity across long distances, it is important for the resistance to be kept as low as possible to avoid energy losses through heating. The properties of the transporting cables enable this to be achieved.

Did you know...?

In 1910 William Coolidge invented the tungsten filament light bulb, still in use today.

FIGURE 2.6.14b: An early tungsten filament light bulb

3. Do electric heaters need a high or a low resistance in order to work? Explain your answer.
4. Mains household electricity has a voltage of 230 V. A hairdryer needs 15 A to work and another needs 12 A. Suggest one difference in the circuits of the two hairdryers.

Explaining how factors affect resistance

There are three main factors affecting the resistance of a wire:

- The *material* that the wire is made from. Table 2.6.14 lists the resistance values of some materials, for the same length and cross-sectional area. This value depends on the number of free electrons that are available in the material.
- The *length* of the wire. In a longer wire, the electrons meet with more opposition because there are more atoms to collide with during their flow. Large resistors, such as those used in electric cookers or heaters, use long lengths of wire made from nichrome – long lengths are often coiled.

  In a variable resistor, the length of the wire included in the circuit can be changed. This idea is used in the volume control of radios and televisions.
- The *thickness* of the wire. In a thin wire it is harder for the electrons to push their way through so they experience more resistance. Also, there are fewer 'free' electrons in a thinner wire.

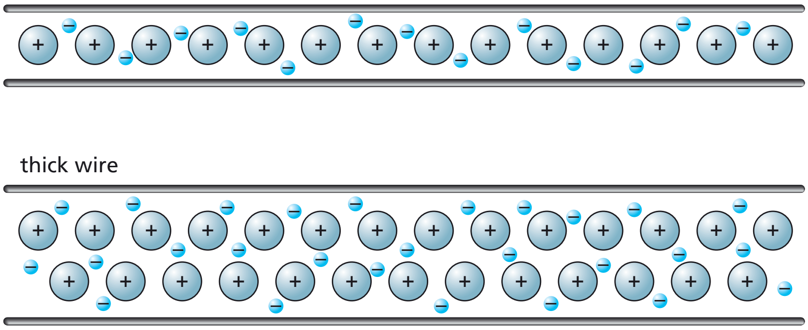


FIGURE 2.6.14d: Comparing thick and thin wires

5. Explain how the volume of a radio can be changed using a variable resistor.
6. Describe the type of wire you would choose in an overhead power cable.

FIGURE 2.6.14c: How does turning the knob affect the circuit inside the radio?

TABLE 2.6.14: Comparing the resistance of different materials

Material	Resistance value ($\Omega \times 10^{-8}$ m)
aluminium	2.82
copper	1.72
gold	2.44
nichrome	150
silver	1.59
tungsten	5.6
iron	9.71
platinum	0.11
rubber	100 000

Key vocabulary

resistor

variable resistor

filament

Explaining circuits using models

We are learning how to:

- Describe how the voltage, current and resistance are related in different circuits.
- Use a model to explain the relationship between voltage, current and resistance.

You have learned about what voltage, current and resistance are. Now you will see how they interact in a circuit. The 'rope model' is a useful analogy – it explains most features of current, voltage and resistance in circuits.

Relating voltage, current and resistance

The size of the voltage and the size of the resistance both determine how much current flows. Look at the three different circuits in Figure 2.6.15a.

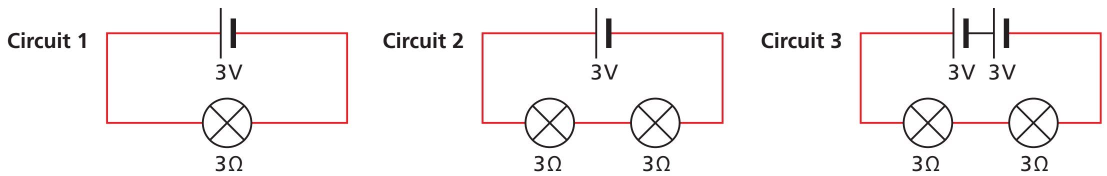


FIGURE 2.6.15a

In circuit 1, there is a voltage of 3 V and one light bulb of resistance 3 Ω.

In circuit 2, there are two identical light bulbs in series, providing twice as much resistance, but supplied with the same voltage as in circuit 1. The current flowing through the circuit is now less, because there is the same 'push' (voltage) but twice the opposition to the flow of electrons (resistance). The light bulbs are not as bright as in circuit 1.

In circuit 3, there are now two cells and the same two light bulbs, each with a resistance of 3 Ω. The light bulbs will both be just as bright as in circuit 1. This is because the resistance and the voltage are both doubled compared to circuit 1, so the current will be the same.

1. What is the voltage and the resistance of the circuit in Figure 2.6.15b?
2. Explain whether the light bulbs in Figure 2.6.15b are dimmer or brighter than in:

   a) circuit 1 **b)** circuit 2 **c)** circuit 3

   of Figure 2.6.15a.

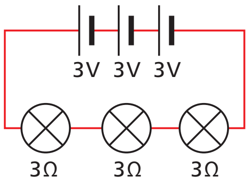


FIGURE 2.6.15b

Using the rope model to explain circuits

Figure 2.6.15c shows the rope **model**. It is an **analogy** of a circuit consisting of a long rope that is held by a group of students:

- The battery is represented by one person pulling the rope round with one hand and feeding it out through the other.
- The bulb is represented by a student gripping the rope more tightly than the others. This provides resistance to the flow of current – the students feel their hands warming up as friction transfers energy from the current by heat.
- The electric current is represented by the rope moving around.

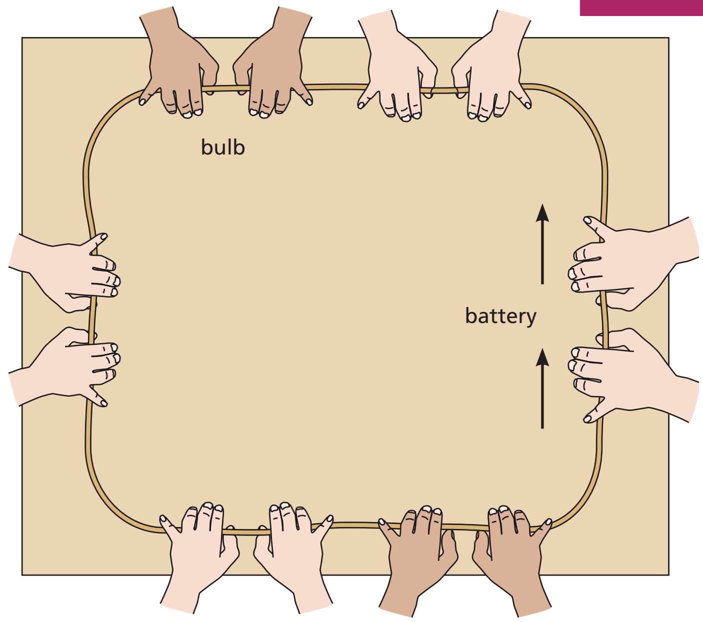


FIGURE 2.6.15c: The rope model

3. Where are the electric charges in the rope model?

4. How is gripping the rope more tightly similar to resistance in the circuit?

Applying the rope model

Applying the rope model can explain the way the voltage, current and resistance work in circuits. Look again at the circuits in Figure 2.6.15a.

For circuit 2, two students should be used to represent the light bulbs, gripping the rope more tightly than in circuit 1 – this represents the increased resistance. The speed of the passing rope will decrease, compared to the set-up in circuit 1, and less energy is transferred to the light bulbs.

Applying the model to circuit 3, there should be a bigger pull on the rope by the teacher. This will have the effect of increasing the speed at which the rope passes around the circuit, demonstrating an increase in current. The two students will also be gripping the rope more tightly, to provide the increased resistance. This will show that the same current is flowing as in circuit 1.

5. What needs to happen to the rope for it to represent two components with different resistances?

6. How could you use the rope model to represent a wire with less resistance?

Did you know...?

Scientists use a range of models to describe abstract ideas. By applying models we can understand what is happening more easily.

Key vocabulary

model

analogy

Describing series and parallel circuits

We are learning how to:

- Understand how voltage and current vary in a series circuit.
- Understand how voltage and current vary in a parallel circuit.

The way in which components are arranged in a circuit can affect how well they work and how useful they are. The two arrangements are called series and parallel.

Series circuits

In a **series circuit**:

- All the components are connected, one after the other, in a complete loop of conducting wire.
- There are no **branches** in the circuit.
- There is only one path that the current can take.
- The voltage is shared between the components.

Figure 2.6.16a shows a series circuit with two light bulbs.

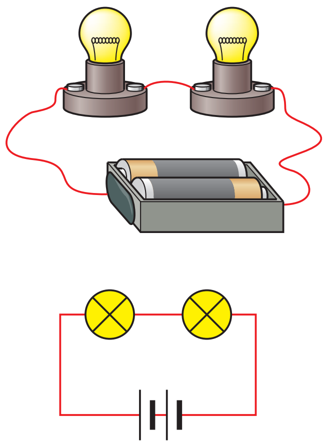


FIGURE 2.6.16a: How can you tell that the components in this circuit are connected in series?

1. What would happen to the components in a series circuit if one of the bulbs stopped working?
2. **a)** Draw a circuit diagram showing a motor, a light bulb and a buzzer in a series circuit.

   b) What would happen to the current in your circuit if the motor stopped working?
3. Draw two circuits – one with just one bulb, and the other with three identical bulbs in series. Both circuits should have just one cell of the same voltage. Compare:

   a) the voltage in each circuit

   b) the current in each circuit

   c) the brightness of the bulbs in each circuit.

Parallel circuits

In a **parallel circuit**:

- Each component is connected separately in its own loop between the two terminals of a cell or battery.

- There are different branches for the current to follow.
- The full voltage is supplied to each loop.
- The current from the battery is divided between the loops.

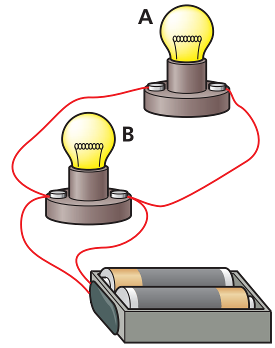
A parallel circuit is rather like separate series circuits connected to the same energy source.

The different components are connected by different wires. Therefore, if a bulb blows or is disconnected from one parallel wire, the components in the other branches keep working because they are still connected to the battery in a complete circuit.

If more bulbs are added in parallel, all the bulbs light up with the same brightness as before. There could be a hundred bulbs in parallel, all equally bright, and just as bright as if there were just one bulb. The battery, however, will not last as long!

4. a) Draw a parallel circuit with four bulbs.

b) Explain how this is different from a series circuit with four bulbs.



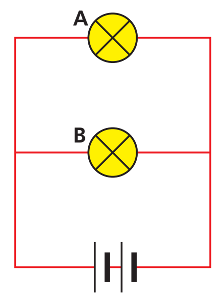


FIGURE 2.6.16b: What happens to bulb A in this parallel circuit if bulb B 'blows'?

Explaining series and parallel circuits

When two light bulbs are connected in series, the resistance in the circuit is increased compared to that with one light bulb. The thin (filament) wire in each light bulb has a high resistance. The increased resistance opposes the flow of current, so fewer electrons pass per second, transferring less energy. The light bulbs are therefore not as bright as in a circuit with the same voltage but only one bulb.

However, when two light bulbs are connected in parallel, each branch behaves like a separate circuit. The resistance in each branch is the same as if there were just one light bulb in the whole circuit. The same energy is transferred to each branch from the battery, so the bulbs light up with the same brightness as in the single-bulb circuit. The battery is, however, transferring twice the amount of energy to the bulbs and will run out faster than when in a series circuit.

5. Explain the advantages and disadvantages of arranging components in series or in parallel.

Did you know...?

Most circuits used are combinations of series and parallel parts. These are called series–parallel circuits.

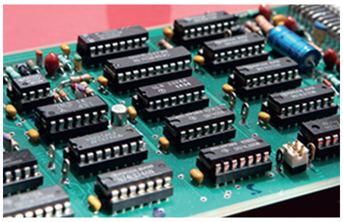


FIGURE 2.6.16c

Key vocabulary

series circuit

branch

parallel circuit

Comparing series and parallel circuits

We are learning how to:

- Investigate and explain current and voltage in series and parallel circuits.
- Explain the circuits in our homes.

The arrangement of components in either series or parallel affects the amount of voltage they receive and the amount of current flowing through them. Why does the arrangement make this difference?

Current and voltage in series and parallel circuits

Figures 2.6.17a and 2.6.17b show a series circuit and a parallel circuit with light bulbs of the same resistance.

Series circuit

The ammeter shows the same readings in different parts of the circuit.

However, the voltage is divided between the components. See how the voltage across each of the components adds up to the total provided. We can write this as:

$V_{total} = V_1 + V_2 + V_3$

If the components have the same resistance, the voltage is divided equally.

Parallel circuit

The voltage in all parts of the circuit is the same regardless of how many branches there are.

However, the current splits up between each branch. Adding up the current in each branch gives the total current flowing from the battery. We can write this as:

$I_{total} = I_1 + I_2 + I_3$

If the resistance in each branch is the same, the same current will flow through each.

1. If another light bulb is added to the series circuit in Figure 2.6.17a, what will happen to the voltage across the other light bulbs? Explain your answer.
2. A 12 V battery is connected in a circuit with ten identical light bulbs in parallel. Compare this with the circuit in Figure 2.6.17b. What will the current be in each individual loop?

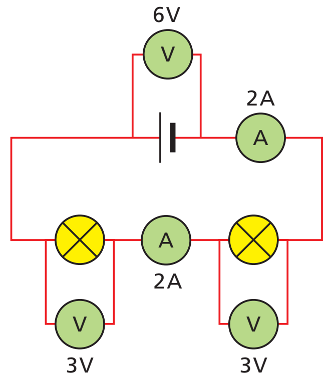


FIGURE 2.6.17a: A series circuit

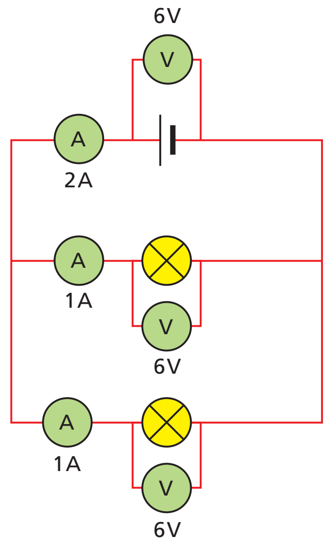


FIGURE 2.6.17b: A parallel circuit

Modelling series and parallel circuits

The circuits in Figures 2.6.17a and 2.6.17b can be modelled using the rope model you used in Topic 6.15.

Series circuit

With three light bulbs, three students hold the rope more tightly than the other students. Because there is a higher resistance than with just one bulb, the current is reduced and the rope moves more slowly through the components. The speed is the same throughout the circuit.

Parallel circuit

This circuit behaves as if there were three separate circuits fed by the same battery. The rope model shows that triple the amount of charge is passed through the battery because it is feeding three branches. All the branches are given the same 'push', so the same amount of energy is transferred to each branch.

3. How would you change the rope model to include a fourth bulb in parallel?

4. What would happen to the current and voltage in series and parallel circuits with two bulbs that had different resistances?

Did you know...?

After World War 2 there was a shortage of copper. In 1942 the ring main helped to reduce the amount of household wiring needed. This needed more length, but it could be thinner.

Household circuits

Figure 2.6.17c shows how the household electricity supply is connected in the UK. It is an arrangement known as the domestic **ring main**.

All the plug sockets in the ring main are connected in parallel. This has the following advantages:

- If one of the electrical **appliances** should stop working, other appliances are not affected.
- The **mains supply** of 230 V is applied across all the sockets.
- Switches can be used to turn the current on and off within each branch.

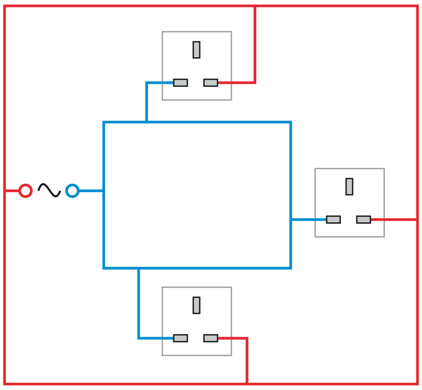


FIGURE 2.6.17c: Arrangement of sockets in a domestic ring main

FIGURE 2.6.17d: Each socket has 230 V applied to it.

5. Suggest disadvantages with this arrangement.

Key vocabulary

ring main

appliance

mains supply

Applying circuits

We are learning how to:

- Describe how circuits are arranged in common appliances.

We have learned about the different features of electric circuits and how they work to transfer energy. In which ways are circuits useful to us?

Common household circuits

Any object that is plugged into the mains supply or that uses a battery contains at least one electric circuit. By altering the current, voltage and resistance within a circuit, the amount of energy transferred to different components can be controlled.

Most circuits are connected in parallel, including household lighting, Christmas tree lights and overhead train cables. This is because the lights or trains all need the same voltage, and if one fails the others will still keep working. Also, using switches, the appliances can be switched on and off individually.

FIGURE 2.6.18a: Parallel circuits are very useful.

Series circuits are less common. Connecting batteries in series will increase the voltage available because the total voltage is the sum of the individual batteries. A series arrangement is used when an appliance needs to be controlled carefully. For example, **circuit breakers** are safety devices that switch off an appliance because of a fault. The appliance and circuit breaker are placed in series.

1. What would happen if household lights were arranged in series?
2. What would happen if a circuit breaker was arranged in parallel to an appliance?

More examples of series and parallel circuits

Water heaters use a series circuit with a temperature control switch, called a **thermostat**. When the temperature reaches the set value, the thermostat will turn off the current. Because there are no other pathways to follow, the current is removed from the heater.

Hairdryers contain a parallel circuit, as shown in Figure 2.6.18b. In this way, if the heater needs to be switched off, the fan can still work to blow cool air instead of hot air – but the heater cannot be used without the motor working.

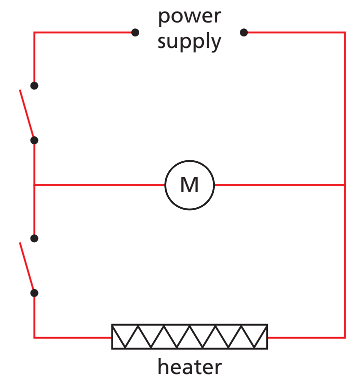


FIGURE 2.6.18b: In the hairdryer circuit shown here, why are the motor and the heater arranged in parallel?

3. Name another appliance that needs a controlled temperature and may therefore be connected in series with a thermostat?
4. Would you use a parallel circuit or a series circuit to connect the electrical appliances in a kitchen? Explain your answer.

Series–parallel circuits

Most circuits are combinations of series and parallel circuits. These are called **series–parallel circuits**. Figure 2.6.18c shows an example.

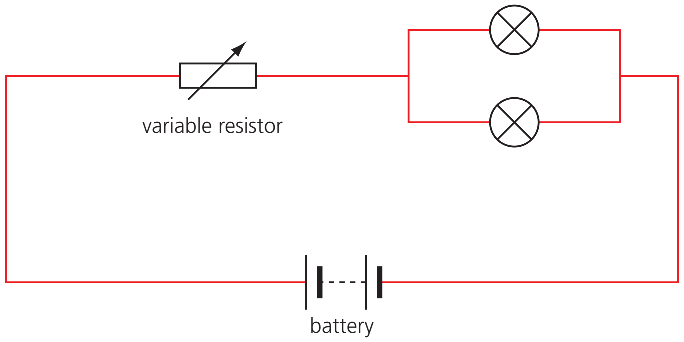


FIGURE 2.6.18c: A series–parallel circuit

This is a simple series–parallel circuit used in a car to dim the lights on the instrument panel. The variable resistor controls the amount of current that can pass. When its resistance is high, less current passes and both the lights on the panel are dimmer. To increase the brightness of the lights, the variable resistor can be turned so that it is low. More current passes and the lights are brighter.

5. Describe the path of the current in the series–parallel circuit in Figure 2.6.18c.
6. Can you think of one other application in which a series–parallel circuit might be used?

Did you know...?

In the 1920s just 10% of UK houses had an electricity supply. The main appliances in use were lights, irons and radios.

Key vocabulary

circuit breaker

thermostat

series–parallel circuit

Checking your progress

To make good progress in understanding science you need to focus on these ideas and skills.

Describe differences between permanent and temporary magnets.	Describe and compare different methods to make permanent magnets.	Use the domain theory to explain how materials become magnetised and demagnetised.
Describe some effects of the Earth's magnetic field.	Describe the geodynamo theory.	Explain evidence for how the Earth's magnetic field works.
Describe how to test the strength of a magnet and an electromagnet.	Design investigations to compare different methods of making magnets and testing the strength of electromagnets.	Use models and analogies to explain the factors that affect the strengths of magnets and electromagnets.
Describe different applications of magnets and electromagnets.	Explain the advantages and disadvantages of using electromagnets.	Compare and contrast the use of magnets and electromagnets in different applications, such as a circuit breaker.
Describe and investigate different types of batteries, including fruit batteries.	Analyse and interpret data to explain how to make the most effective fruit batteries.	Explain how a battery works using ideas about charge.

☐ Describe what is meant by current, voltage and resistance.	☐ Apply a range of models and analogies to describe current, voltage and resistance.	☐ Evaluate different models and analogies for explaining current, voltage and resistance.
☐ Describe the relationship between current, voltage and resistance in a qualitative way.	☐ Use data to identify a pattern between current, voltage and resistance.	☐ Use data and a mathematical relationship between current, voltage and resistance to carry out calculations.
☐ Make measurements of current and voltage in series and parallel circuits.	☐ Use models and simple calculations to explain and compare what happens to the current and voltage in series and parallel circuits.	☐ Use calculations to make predictions about current and voltage in series and parallel circuits.
☐ Describe different domestic uses of series and parallel circuits.	☐ Make comparisons between components in series and parallel circuits.	☐ Explain the advantages of using series or parallel circuits, including the domestic ring main.

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Questions

Questions 1–7

See how well you have understood the ideas in the chapter.

1. What is the unit of current? [1]

a) volt **b)** ohm **c)** amp **d)** joule

2. Which one of the following materials is magnetic? [1]

a) copper **b)** cobalt **c)** chlorine **d)** calcium

3. Which of the following uses an electromagnet? [1]

a) a compass **b)** a fridge magnet **c)** a torch **d)** a metal-sorting plant prior to recycling

4. What is the name of the magnetic material that was discovered first? [1]

a) lodestone **b)** iron **c)** steel **d)** nickel

5. Give two differences between a magnet and an electromagnet. [2]

6. Explain how a series circuit is different from a parallel circuit. [2]

7. Draw a circuit diagram to explain how a circuit breaker works – include ideas about electromagnets and why the circuit is arranged in a particular way. [4]

Questions 8–14

See how well you can apply the ideas in this chapter to new situations.

8. Figure 2.6.20a shows four circuits A–D. Which of the following shows the correct order from the circuit that gives the brightest bulbs to the one that gives the dimmest? [1]

a) A, B, C, D **b)** D, C, B, A **c)** C, D, A, B **d)** C, B, D, A

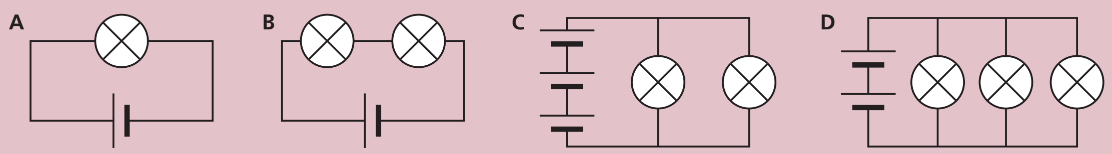

FIGURE 2.6.20a

9. A food mixer has a low setting and a high setting. Which of these is true? [1]

a) the low setting has a lower current passing

b) the high setting has a stronger magnet inside

c) the low setting uses more coils around the motor

d) the high setting has a lower current passing.

10. Which of the following will the make the strongest electromagnet?

a) using one coil with a low current **b)** using 100 coils with a low current

c) using 100 coils with a high current **d)** using one coil with a high current.

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11. Venus does not have a magnetic field. Which of the following statements is false? [1]

a) Venus does not have an iron core
b) Venus is protected against dangerous charged particles from solar winds
c) A compass will not work on Venus
d) Venus does not have a magnetosphere.

12. A student drops a magnet on the floor. It no longer works. She puts it between two strong magnets for some time. Use the domain theory to explain why the magnet no longer works and how it becomes remagnetised. [2]

13. Figure 2.6.20b shows a model of a circuit. How would you change this model to show an increased voltage and resistance? [2]

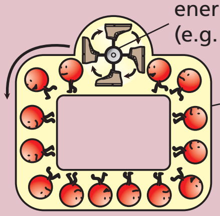

FIGURE 2.6.20b

14. Figure 2.6.20c shows a series circuit (1) and a parallel circuit (2). Calculate the missing voltages and currents. Explain the reasons for your values. [4]

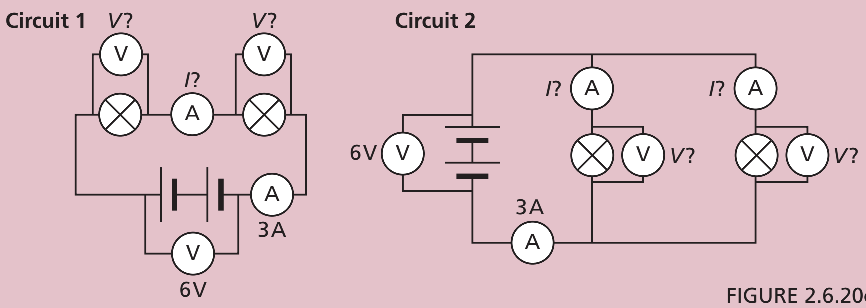

FIGURE 2.6.20c

Questions 15–16

See how well you can understand and explain new ideas and evidence.

15. Two fruit batteries are placed side by side. They are connected to identical bulbs. One bulb is much brighter than the other. What possible reasons could there be between the batteries to account for the difference? [2]

16. Table 2.6.20 gives some data from an investigation comparing the resistance of different wires. The values of resistance have been calculated using *V*/*I* = *R*. Sketch a graph of the values. A wire from an electricity distribution line is now tested. Sketch a new graph to predict how the resistance will be different. Explain the reasons for your sketch. [4]

TABLE 2.6.20

Length of wire (cm)	Average voltage (V)	Average current (A)	Average resistance (Ω)
10	0.47	0.23	2
20	0.59	0.17	3.47
30	0.64	0.13	4.92
40	0.69	0.11	6.27
50	0.72	0.09	8
60	0.76	0.07	10.9
70	0.82	0.06	13.67