PHYSICS UNIT 2 ELECTRICITY

It is sometimes really difficult to imagine how we could live without electricity. As we mmove around we use electricity from batteries and cells for our mobile phones, mp3 players and other mobile devices. In our homes and other buildings we use electricity from the mains for heating, lighting and providing the energy for household appliances such as televisions, radios, computers and their printers. Understanding what electricity is, where it comes from and how we can control it is important if we are to make maximum use of this important source of energy.

4 MAINS ELECTRICITY

The electricity that we use for heating, lighting and air conditioning in our homes is called mains electricity and is supplied to us by power stations.

In this chapter you will learn how mains electricity is brought to our homes and supplied to our appliances. You will also read about devices that protect us from electrical shocks.

▲ Figure 4.1 Most household appliances use mains electricity as their source of energy.

LEARNING OBJECTIVES

- Understand how the use of insulation, double insulation, earthing, fuses and circuit breakers protects the device or user in a range of domestic appliances
- Understand why a current in a resistor results in the electrical transfer of energy and an increase in temperature, and how this can be used in a variety of domestic contexts
- Know and use the relationship between power, current and voltage:

  power = current × voltage

  $P = I \times V$

  and apply the relationship to the selection of appropriate fuses
- Know the difference between mains electricity being alternating current (a.c.) and direct current (d.c.) being supplied by a cell or battery
- Use the relationship between energy transferred, current, voltage and time:

  energy transferred = current × voltage × time

  $E = I \times V \times t$

UNITS

In this unit, you will need to use ampere (A) as the unit of current, coulomb (C) as the unit of charge, joule (J) as the unit of energy, ohm (Ω) as the unit of resistance, second (s) as the unit of time, volt (V) as the unit of voltage and watt (W) as the unit of power.

When you turn on your computer, television and most other appliances in your home the electricity you use is almost certainly going to come from the mains supply. This electrical energy usually enters our homes through an underground cable. The cable is connected to an electricity meter, which measures the amount of electrical energy used. From here, the cable is connected to a consumer unit or a fuse box, which contains fuses or circuit breakers for the various **circuits** in your home. Fuses and circuit breakers are safety devices which shut off the electricity in a circuit if the current in them becomes too large (see page 531).

Most of the wires that leave the fuse box are connected to ring main circuits that are hidden in the walls or floors around each room. Individual pieces of electrical equipment are connected to these circuits using plugs.

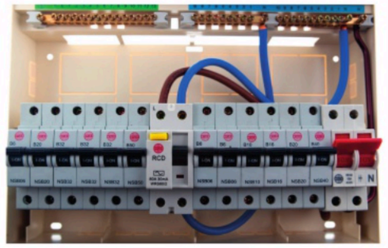


Figure 4.2 Circuit breakers in a consumer unit

Ring main circuits usually consist of three wires – the live wire, the neutral wire and the earth wire.

The live wire provides the path along which the electrical energy from the power station travels. The neutral wire completes the circuit.

The earth wire usually has no current in it. It is there to protect you if an appliance develops a fault (see page 531). It provides a path for current to escape without passing through the user.

EXTENSION WORK

Ring main circuits provide a way of allowing several appliances in different parts of the same room to be connected to the mains using the minimum amount of wiring. Imagine how much wire would be needed if there was just one mains socket in each room.

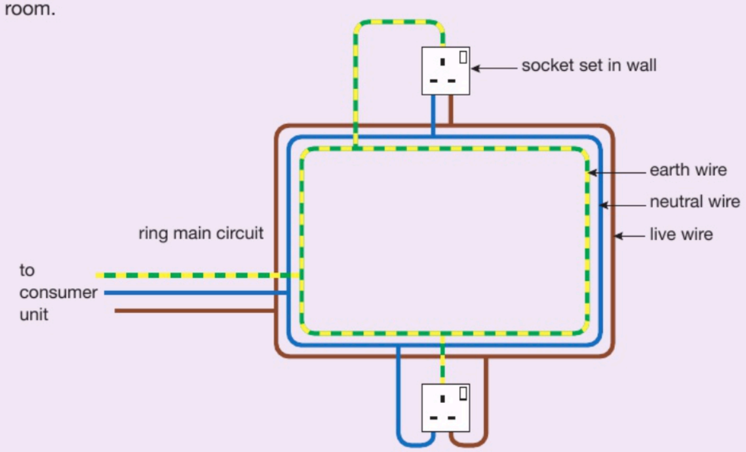


Figure 4.3 Ring main circuits help to cut down on the amount of wiring needed in a house.

Plugs and sockets in different countries look different, but the principles (rules) of electrical wiring are similar.

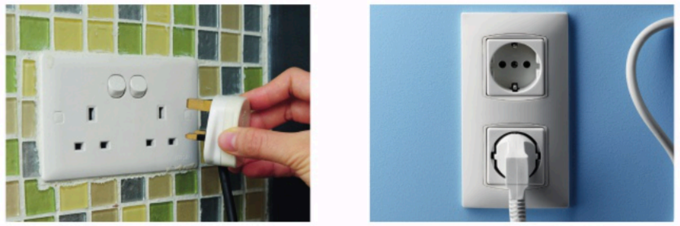


Figure 4.4 Plug sockets in the UK and in Portugal

The mains electricity supplied to homes in the UK, China, India and many other countries is between 220 V and 240 V. This is a much higher **voltage** than the **cells** and batteries used in mobile electrical appliances. If you come into direct contact with mains electricity you could receive a severe electric shock, which might even be fatal. To prevent this the outer part of a plug, called the casing, is made from plastic, which is a good **insulator**.

Connections to the circuits are made via three brass pins, as the metal brass is an excellent **conductor** of electricity. Figure 4.5 shows the inside of a 3-pin plug used in the UK, but similar principles apply to all kinds of plug all over the world.

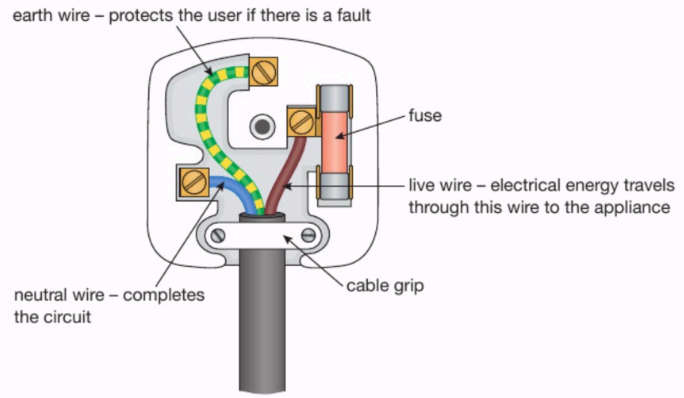
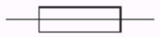


Figure 4.5 A labelled plug

SAFETY DEVICES

FUSES

Many plugs contain a fuse. The fuse is usually in the form of a cylinder or cartridge, which contains a thin piece of wire made from a metal that has a low melting point. If there is too large a current in the circuit the fuse wire becomes very hot and melts. The fuse 'blows'. The circuit is now incomplete so there is no current. This prevents you getting a shock and reduces the possibility of an electrical fire. Once the fault causing the increase in current has been corrected, the blown fuse must be replaced with a new one of the same size before the appliance can be used again.



circuit symbol for a fuse

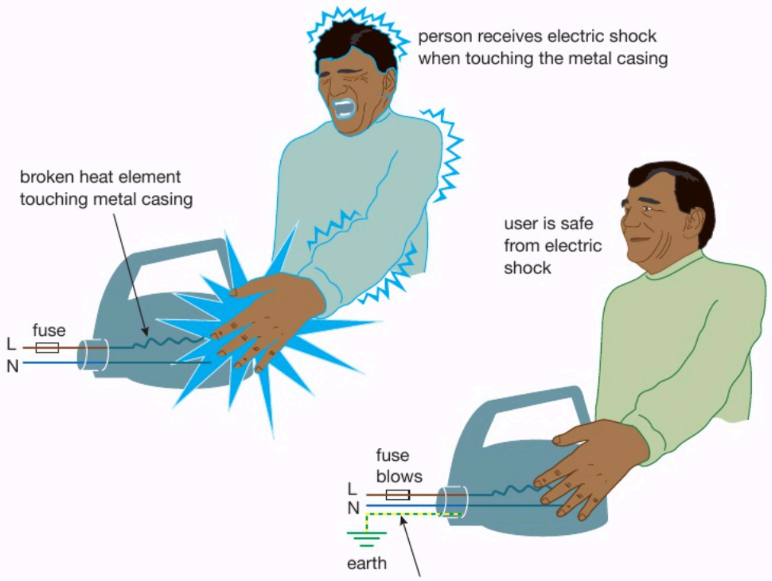
There are several sizes of fuses. The most common for domestic appliances in the UK are 3 A, 5 A and 13 A. The correct fuse for a circuit is the one that allows the correct current but blows if the current is a little larger. If the correct current in a circuit is 2 A then it should be protected with a 3 A fuse. If the correct current is 4 A then a 5 A fuse should be used. It is possible to calculate the correct size of fuse for an appliance but nowadays manufacturers provide appliances already fitted with the correct size of fuse.

Figure 4.6 Fuses are important safety devices in electrical appliances.

Modern safety devices, such as those you might find in your consumer unit, are often in the form of trip switches or circuit breakers. If too large a current flows in a circuit a switch automatically opens making the circuit incomplete. Once the fault in the circuit has been corrected, the switch is reset, usually by pressing a reset button. There is no need for the switch or circuit breaker to be replaced, as there is when fuses are used. The consumer unit shown in Figure 4.2 uses circuit breakers.

EARTH WIRES AND DOUBLE INSULATION

Many appliances have a metal casing. This should be connected to the earth wire so that if the live wire becomes damaged or breaks and comes into contact with the casing the earth wire provides a low-resistance path for the current. This current is likely to be large enough to blow the fuse and turn the circuit off. Without the earth wire anyone touching the casing of the faulty appliance would receive a severe electric shock as the current passed through them to earth (Figure 4.7).



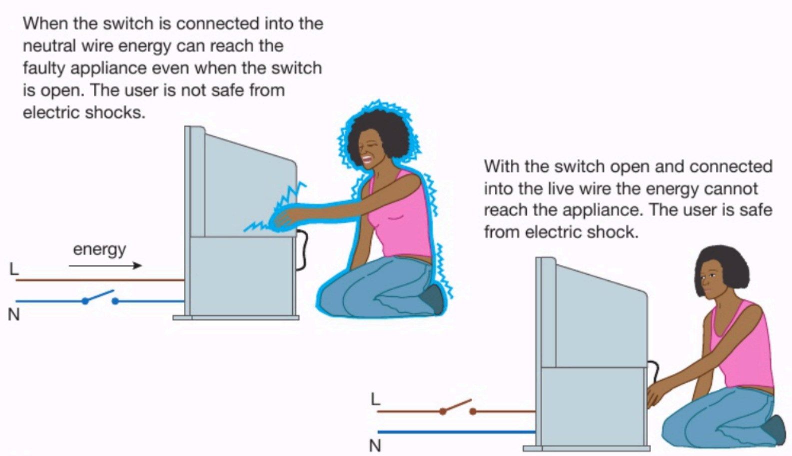
▲ Figure 4.7 The earth wire provides protection when electrical appliances develop a fault.

▲ Figure 4.8 This plastic kettle has double insulation which means that there is no need for an earth wire.

Some modern appliances now use casings made from an insulator such as plastic rather than from metal. If all the electrical parts of an appliance are insulated in this way, so that they cannot be touched by the user, the appliance is said to have double insulation. Appliances that have double insulation use a two-wire **flex**. There is no need for an earth wire.

SWITCHES

Switches in mains circuits should always be placed in the live wire so that when the switch is open no energy in the form of electricity can reach an appliance. If the switch is placed in the neutral wire, energy can still enter a faulty appliance, and could possibly cause an electric shock (Figure 4.9).



▲ Figure 4.9 The switch in a circuit should be in the live wire.

▲ Figure 4.10 The wires inside a toaster have a high resistance. They become very hot when a current passes through them.

EXTENSION WORK

Incandescent bulbs like these are very inefficient. Often more than 90% of the energy transferred is lost to the surroundings as heat. As a result they are rapidly being replaced by modern halogen bulbs and LEDs, which give off much less heat and therefore waste less energy.

THE HEATING EFFECT OF CURRENT

The wiring in a house is designed to let current pass through it easily. As a result, the wires do not become warm when appliances are being used. We say that the wires have a low **resistance**. However, in some appliances, for example, kettles or toasters (Figure 4.10), we want wires (more usually called **heating elements**) to become warm. The wires of a heating element are designed to have a high resistance so that as the current passes through them energy is transferred and the element heats up. We use this heating effect of current in many different ways in our homes. You will learn more about resistance in Chapter 6.

Other common appliances that make use of the heating effect of electricity include kettles, dishwashers, electric cookers, washing machines, electric fires and hairdryers.

When current passes through the very thin wire (**filament**) of a traditional light bulb it becomes very hot and **glows** (shines) white. The bulb is transferring electrical energy to heat and light energy.

▲ Figure 4.11 It is the heating effect of a current that is causing this bulb to glow.

ELECTRICAL POWER

Figure 4.12 shows a 50 W **halogen light bulb**. You can also buy 70 W light bulbs. Both bulbs transfer electrical energy to heat and light. The 70 W bulb will be brighter because it transfers 70 J of electrical energy every second. The dimmer 50 W halogen bulb shown transfers only 50 J of energy every second. A 70 W bulb has a higher power rating.

▲ Figure 4.12 The dimmer 50 W bulb transfers less electrical energy to heat and light energy every second.

KEY POINT

You will learn more about voltage and current in Chapter 5.

HINT

If an examination question asks for the equation for calculating power, voltage or current, always give the actual equation (such as $P = I \times V$). You may not be awarded a mark if you just draw the triangle.

Power is measured in joules per second or watts (W).

Devices that transfer lots of energy very quickly have their power rating expressed in kilowatts (kW).

1 kW = 1000 W

The power (P) of an appliance is related to the voltage (V) across it and the current (I) flowing through it.

The equation is:

power, P (watts) = current, I (amps) × voltage, V (volts)

$$P = I \times V$$

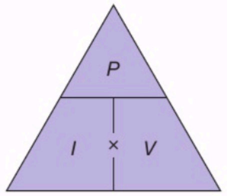


Figure 4.13 You can use the triangle method for rearranging equations like $P = I \times V$.

EXAMPLE 1

A 230 V television takes a current of 3 A. Calculate the power of the television.

$P = I \times V$

$= 3\text{ A} \times 230\text{ V}$

$= 690\text{ W}$

EXAMPLE 2

Calculate the correct fuse that should be used for a 230 V, 1 kW electric hairdryer.

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

$= \frac{1000\text{ W}}{230\text{ V}}$

$= 4.35\text{ A}$

The correct fuse for this hairdryer is therefore a 5 A fuse.

CALCULATING THE TOTAL ENERGY TRANSFERRED BY AN APPLIANCE

The power of an appliance (P) tells you how much energy it transfers each second. This means that the total energy (E) transferred by an appliance is equal to its power multiplied by the length of time (in seconds) the appliance is being used.

energy, E (joules) = power, P (watts) × time, t (seconds)

$E = P \times t$

or since $P = I \times V$

$E = I \times V \times t$

EXAMPLE 3

Calculate the energy transferred by a 60 W bulb that is turned on for **a** 20 s, and **b** 5 min.

a $E = P \times t$

$= 60\text{ W} \times 20\text{ s}$

$= 1200\text{ J}$ or 1.2 kJ

b $E = P \times t$

$= 60\text{ W} \times 5 \times 60\text{ s}$

$= 18\,000\text{ J}$ or 18 kJ

ALTERNATING CURRENT AND DIRECT CURRENT

If we could see the current or voltage from the mains it would appear to be very strange. Its value increases and then decreases and then does the same again but in the opposite direction. If we could draw these changes as a graph they would look like a wave.

This happens because of the way in which the electricity is generated at the power station. A current or voltage that behaves like this is called an alternating current (a.c.) or **alternating voltage**. This is very different to the currents and voltages we get from batteries and cells.

Cells and batteries provide currents and voltages that are always in the same direction and have the same value. This is called direct current (d.c.) or direct voltage. If we drew this as a graph it would be a straight horizontal line.

Figure 4.14 shows how the voltage of an a.c. supply compares with the voltage of a d.c. supply.

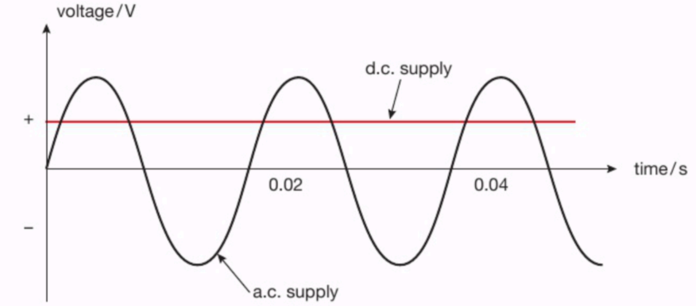


Figure 4.14 How the voltage of an a.c. supply compares with that of a d.c. supply

CHAPTER QUESTIONS

More questions on domestic electricity can be found at the end of Unit 2 on page 554.

SKILLS PROBLEM SOLVING

1 a There is a current of 0.25 A in a bulb when a voltage of 12 V is applied across it. Calculate the power of the bulb.

b Calculate the voltage that is being applied across a 10 W bulb with a current of 0.2 A.

c Calculate the current in a 60 W bulb if the voltage across it is 230 V.

d How much energy is transferred if a 100 W bulb is left on for 5 hours?

SKILLS CRITICAL THINKING

2 An electric kettle is marked '230 V, 1.5 kW'.

a Explain what these numbers mean.

SKILLS PROBLEM SOLVING

b Calculate the correct fuse that should be used.

SKILLS REASONING

c Explain why a 230 V, 100 W bulb glows more brightly than a 230 V, 60 W bulb when both are connected to the mains supply.

SKILLS CRITICAL THINKING

3 a Give one advantage of using a circuit breaker rather than a wire or cartridge fuse.

b Why is the switch for an appliance always placed in the live wire?

c What is meant by the sentence 'The hairdryer has double insulation'?

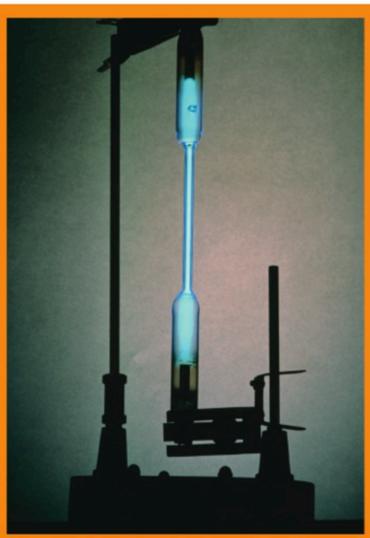
SKILLS DECISION MAKING, CREATIVITY

4 Think of a room in your house where there are lots of electrical appliances. Make a list of them. Now organise your list so that the appliances that you think have the highest power rating are at the top of your list and those with the lowest are at the bottom. How could you discover if your guesses are correct?

5 CURRENT AND VOLTAGE IN CIRCUITS

We rely on electricity in many areas of our lives. This chapter looks at what electric current is. You will learn what happens to electric current in different circuits, and what effect it has.

Look around the room you are in. If you are at home, you will probably be able to see a television, a radio or a computer. If you are in a science laboratory, you may be able to see a projector, a power supply or lights in the ceiling. These and many other everyday objects need electric currents if they are to work. But what are electric currents? How are they produced and what do they do in a circuit?



▲ Figure 5.1 The gas in this tube glows when there is a current.

LEARNING OBJECTIVES

- Explain why a series or parallel circuit is more appropriate for particular applications, including domestic lighting
- Know that electric current in solid metallic conductors is a flow of negatively charged electrons
- Know and use the relationship between voltage, current and resistance:

  voltage = current × resistance

  $V = I \times R$
- Know that current is the rate of flow of charge
- Know and use the relationship between charge, current and time:

  charge = current × time

  $Q = I \times t$
- Know that lamps and LEDs can be used to indicate the presence of a current in a circuit
- Know that the voltage across two components connected in parallel is the same
- Know that voltage is the energy transferred per unit charge passed
- Know and use the relationship between energy transferred, charge and voltage:

  energy transferred = charge × voltage

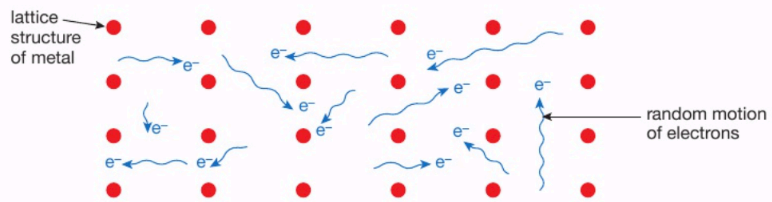
  $E = Q \times V$
- Know that the volt is a joule per coulomb
- Understand why current is conserved at a junction in a circuit

CONDUCTORS, INSULATORS AND ELECTRIC CURRENT

An electric current is a flow of charge. In metal wires the charges are carried by very small particles called electrons.

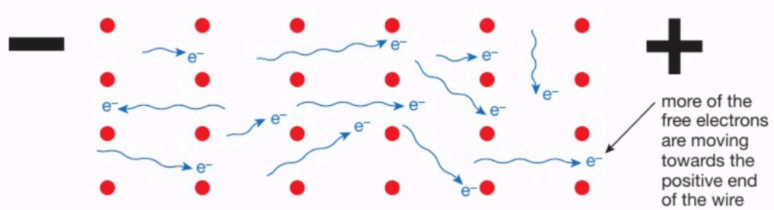
Electrons flow easily through all metals. We therefore describe metals as being good conductors of electricity. Electrons do not flow easily through plastics – they are poor conductors of electricity. A very poor conductor is known as an insulator and is often used in situations where we want to prevent the flow of charge – for example, in the casing of a plug.

In metals, some electrons are free to move between the **atoms**. Under normal circumstances this movement is random – that is, the number of electrons flowing in any one direction is roughly equal to the number flowing in the opposite direction. There is therefore no overall flow of charge.



▲ Figure 5.2a With no voltage there is an equal flow of electrons in all directions.

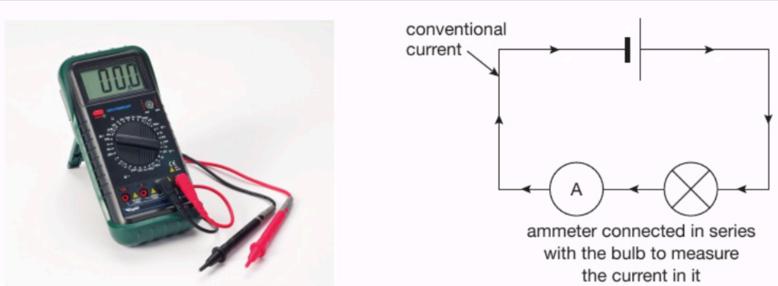
If, however, a cell or battery is connected across the conductor, more of the electrons now flow in the direction away from the negative terminal and towards the positive terminal than in the opposite direction. We say 'there is now a net flow of charge'. This flow of charge is what we call an electric current.



▲ Figure 5.2b When a voltage is applied more electrons will move towards the positive.

In insulators, all the electrons are held tightly in position and are unable to move from atom to atom. Charges are therefore unable to move through insulators.

MEASURING CURRENT



▲ Figure 5.3 An ammeter is used to measure current in a circuit. It has a very low resistance and so has almost no effect on the current.

EXTENSION WORK

When scientists first experimented with charges flowing through wires, they assumed that it was positive charges that were moving and that current travels from the positive to the negative. We now know that this is incorrect and that when an electric current passes through a wire it is the negative charges or electrons that move. Nevertheless when dealing with topics such as circuits and motors, it is still considered that electrons flow from positive to negative. This is conventional current.

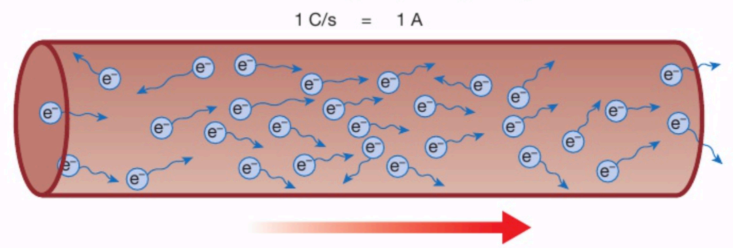
We measure the size of the current in a circuit using an ammeter. The ammeter is connected in series (see page 542) with the part of the circuit we are interested in.

The size of an electric current indicates the rate at which the charge flows.

The charge carried by one electron is very small and would not be a very useful measure of charge in everyday life. It would be a little like asking how far away the Moon is from the Earth … and getting the answer in mm!

To avoid this problem we measure electric charge (*Q*) in much bigger units called coulombs (C). One coulomb of charge is equal to the charge carried by approximately six million, million, million (6×10^{18}) electrons.

We measure electric current (*I*) in amperes or amps (A). If there is a current of 1 A in a wire it means that 1 C of charge is passing along the wire each second.



▲ Figure 5.4 One coulomb of charge flowing each second is one amp.

We can calculate the total charge that passes along a wire using the equation:

charge, *Q* (coulombs) = current, *I* (amps) × time, *t* (seconds)

$$Q = I \times t$$

EXAMPLE 1

a Calculate the charge flowing through a wire in 5 s if the current is 3 A.

$Q = I \times t$

$= 3\text{ A} \times 5\text{ s}$

$= 15\text{ C}$

b How many electrons flow through the wire in this time?

1 C of charge is carried by 6×10^{18} electrons

15 C of charge requires $15 \times 6 \times 10^{18}$ electrons $= 90 \times 10^{18}$ electrons

So 90 million, million, million electrons will flow along the wire in 5 s.

VOLTAGE

We often use cells or batteries to move charges around circuits. We can imagine them as being 'electron pumps'. They transfer energy to the charges. The amount of energy given to the charges by a cell or battery is measured in volts (V) and is usually indicated on the side of the battery or cell.

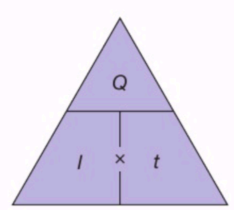
If we connect a 1.5 V cell into a circuit (Figure 5.6) and current flows, 1.5 J of energy is given to each coulomb of charge that passes through the cell.

If two 1.5 V cells are connected in series (Figure 5.7) so that they are pumping (pushing) in the same direction, each coulomb of charge will receive 3 J of energy.

The volt is a joule per coulomb.

HINT

If an examination question asks you to write out the equation for calculating charge, current or time, always give the actual equation such as $Q = I \times t$. You may not get the mark if you just draw the triangle.



▲ Figure 5.5 You can use the triangle method for rearranging equations like this.

▲ Figure 5.6 When one coulomb of charge passes through this cell it gains 1.5 J of energy.

▲ Figure 5.7 When one coulomb of charge passes through both these cells in turn it gains 3 J of energy.

KEY POINT

When several cells are connected together it is called a battery.

KEY POINT

Cells and batteries provide current which moves in one direction. This is known as direct current (d.c.).

As the charges flow around a circuit the energy they carry is transferred by the components they pass through. For example, when current passes through a bulb, energy is transferred to the surroundings as heat and light. When a current passes through the speaker of a radio, most of the energy is transferred as sound.

In the external part of a circuit (outside the cell or battery) the voltage across each component tells us how much energy it is transferring. If the voltage across a component is 1 V this means that the component is transferring 1 J of energy each time 1 C of charge passes through it.

We can describe the relationship between the energy transferred, charge and voltage using the equation:

energy transferred, E (joules) = charge, Q (coulombs) × voltage, V (volts)

$$E = Q \times V$$

EXAMPLE 2

The voltage across a light bulb is 12 V. Calculate the electrical energy transferred when 50 C of charge passes through it.

$E = Q \times V$

$= 50\text{ C} \times 12\text{ V}$

$= 600\text{ J}$

Because $Q = I \times t$, we can also write this equation as $E = I \times t \times V$.

EXAMPLE 3

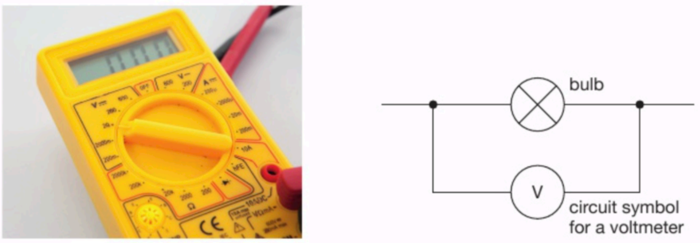
The voltage across a heater is 230 V. There is a current of 5 A through the heater for 5 mins. Calculate the total amount of energy transferred during this time.

$E = I \times t \times V$

$= 5\text{ A} \times (5 \times 60)\text{ s} \times 230\text{ V}$

$= 345\,000\text{ J or } 345\text{ kJ}$

MEASURING VOLTAGES



▲ Figure 5.8 A voltmeter measures voltages across a component.

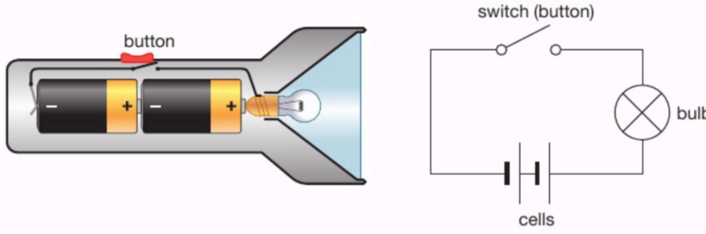
KEY POINT

A voltmeter has a very high resistance, so very little current flows through it.

We measure voltages using a voltmeter. This is connected across (in parallel with) the component we are investigating. A voltmeter connected across a cell or battery will measure the energy given to each coulomb of charge that passes through it. A voltmeter connected across a component will measure the electrical energy transferred when each coulomb of charge passes through it.

ELECTRICAL CIRCUITS

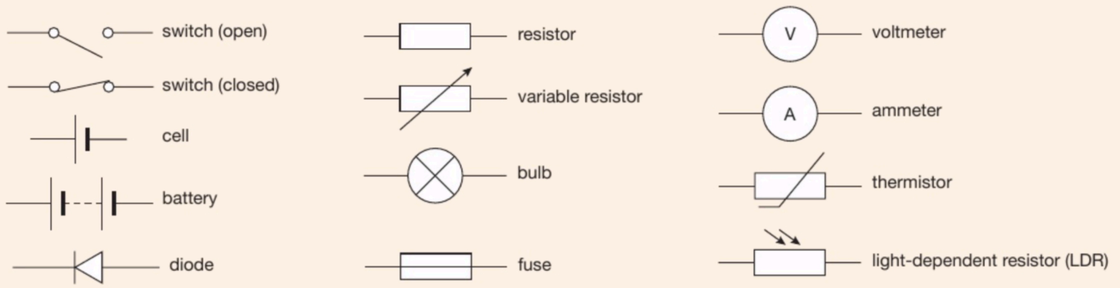
When the button on the torch shown in Figure 5.9 is pressed, the circuit is complete – that is, there are no gaps. Charges are able to flow around the circuit and the torch bulb glows. When the button is released the circuit becomes incomplete. Charges cease to flow and the bulb goes out.



▲ Figure 5.9 A torch contains a simple electrical circuit – a series circuit.

KEY POINT

Drawing diagrams of the actual components in a circuit is a very time-consuming and skilful task. It is much easier to use symbols for each of the components. Diagrams drawn in this way are called circuit diagrams. Figure 5.10 shows common circuit components and their symbols. You should know the common symbols but the less common ones will be given to you in the exam if you need them. Do not waste time memorising the less common ones.



▲ Figure 5.10 Circuit symbols

Figure 5.11 Glowing LEDs indicate which circuits are working

IS IT ON?

We sometimes put a small bulb or lamp in a circuit to show us if a circuit is 'turned on'. When there is a current in the circuit the bulb glows or shines. **Light emitting diodes (LEDs)** also glow when there is a current in a circuit but they require far less energy than bulbs. This is why many appliances such as TVs, DVD players and routers use small LEDs to show when the appliance is working or on standby.

SERIES AND PARALLEL CIRCUITS

There are two main types of electrical circuit. There are those circuits where there are no branches or junctions and there is only one path the current can follow. These simple 'single loop' circuits are called series circuits.

Circuits that have branches or junctions and more than one path that the current can follow are called parallel circuits.

a

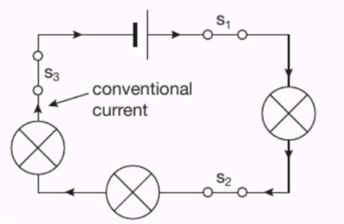


Figure 5.12a A typical series circuit. Opening any one of these switches will turn all three bulbs off.

b

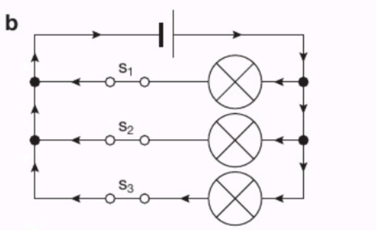


Figure 5.12b A typical parallel circuit. Opening any one of these switches will turn off just the bulb in that part of the circuit.

Series circuits and parallel circuits behave differently. This makes them useful in different situations.

In a series circuit containing bulbs:

- One switch placed anywhere in the circuit can turn all the bulbs on and off.
- If any one of the bulbs breaks, it causes a gap in the circuit and all of the other bulbs will 'stop working'.
- The energy supplied by the cell is 'shared' between all the bulbs, so the more bulbs you add to a series circuit the less bright they all become.

a

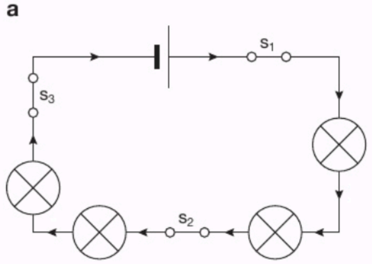


Figure 5.13a Adding an extra bulb in series will result in the bulbs shining less brightly.

b

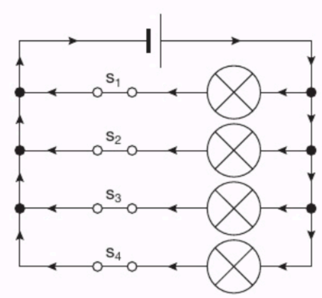


Figure 5.13b Adding an extra bulb in parallel does not affect the brightness of the other bulbs.

In a parallel circuit containing bulbs:

- Switches can be placed in different parts of the circuit to switch each bulb on and off individually, or all together.
- If one bulb breaks, only the bulbs on the same branch of the circuit will be affected.
- Each branch of the circuit receives the same voltage, so if more bulbs are added to a circuit in parallel they all keep the same brightness.

Figure 5.14 Decorative lights are usually wired in series.

Decorative lights are often wired in series. Each bulb only needs a low voltage, so even when the voltage from the mains supply is 'shared' out between them each bulb still gets enough energy to produce light. Unfortunately, if the filament in one of the bulbs breaks then all the other bulbs will go out.

The lights in your home are wired in parallel. We know this because lights can be switched on and off separately, and the brightness of each light does not change when other lights are on or off. Also, if a bulb breaks or is removed, you can still use the other lights.

CURRENT IN A SERIES CIRCUIT

In a series circuit the current is the same in all parts; current is not used up.

a

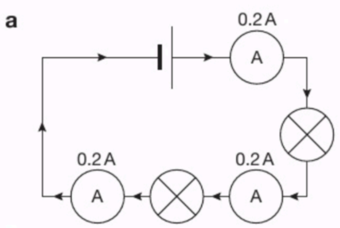


Figure 5.15a In a series circuit the current does not vary.

b

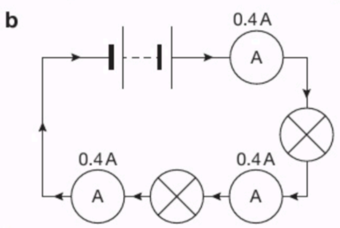


Figure 5.15b The addition of a second cell doubles the voltage applied to the circuit so the current will also double.

The size of the current in a series circuit depends on the voltage supplied to it, and the number and type of the other components in the circuit. If a second identical cell is added in series the voltage will double and so the current will also double.

CURRENT IN A PARALLEL CIRCUIT

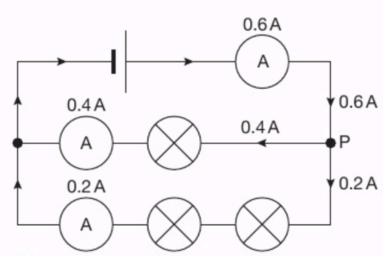


Figure 5.16 There are different currents in the different parts of a parallel circuit.

In a parallel circuit the currents will not be the same in different parts of the circuit. The types of components in each of the different parts will affect the currents.

In a parallel circuit the number of electrons that flow into a junction each second must be equal to the number that leave each second. This means that the currents entering a junction must always be equal to those that leave. For example, in Figure 5.16 the current that enters junction P is 0.6 A. The current that leaves is 0.4 A + 0.2 A = 0.6 A.

CHAPTER QUESTIONS

More questions on electrical circuits can be found at the end of Unit 2 on page 554.

SKILLS CRITICAL THINKING

1 Current is a flow of charge.

  a What are the charge carriers in metals?

  b Explain why charges are able to flow through metals but not through a plastic.

SKILLS PROBLEM SOLVING

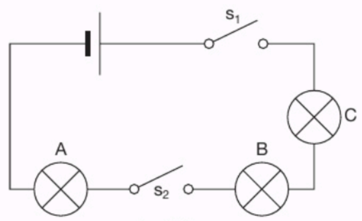
c If the current in a heater is 3 A, calculate the charge that flows through it in:
i 1 s
ii 10 min
iii 1 hour.

SKILLS CRITICAL THINKING

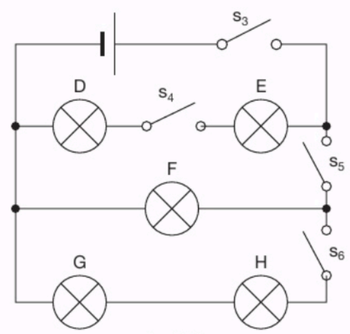
2 a Explain the differences between:
i a complete circuit and an incomplete circuit
ii a series circuit and a parallel circuit.

SKILLS ANALYSIS

b Look carefully at the circuits shown below. Assuming that all switches are initially closed, decide which of the bulbs go out when each of the switches is opened in turn.



circuit A



circuit B

c In circuit A, which bulb(s) glow the brightest when all the switches in the circuit are closed?

SKILLS CRITICAL THINKING

d Explain your answer to part c.

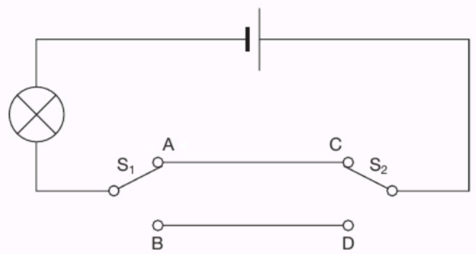
SKILLS INTERPRETATION

3 The voltage between two points in a circuit is measured using a voltmeter.
a Draw a circuit diagram to show how a voltmeter should be connected to measure:
i the voltage across a bulb ii the voltage of a cell.
b Explain in your own words the phrase 'a cell has a voltage of 1.5 V'.

SKILLS CRITICAL THINKING

SKILLS REASONING

4 The diagram below shows a circuit containing two 2-way switches.



a Explain in your own words what happens when each of the switches is moved to a new position.
b Suggest one important application of this circuit in the home.

5 Should the lights for the main street in a town be wired in series or in parallel? Explain your answer.

6 Why would it not be a good idea to connect all the different parts of an electric cooker (oven, grill, heating plates) in series?

6 ELECTRICAL RESISTANCE

In this chapter you will learn what resistance is and how it can be useful in electrical appliances. You will learn what factors affect resistance and how to work out the resistance of a component by measuring the current in it and the voltage across it (Ohm's law). You will also read about some special resistors, and their uses.

It is likely that almost every day of your life you will make some adjustments to at least one electrical appliance. You may turn up the volume of your radio or change the brightness of a light. In each of these examples your adjustments are changing the currents and the voltages in the circuits of your appliance. You are doing this by altering the resistance of the circuits. This chapter will help you understand the meaning and importance of resistance and how we make use of it.

▲ Figure 6.1 Turning this dial alters the resistance in the circuit which changes the volume of the sound.

LEARNING OBJECTIVES

- Understand how the current in a series circuit depends on the applied voltage and the number and nature of other components
- Describe how current varies with voltage in wires, resistors, metal filament lamps and diodes, and how to investigate this experimentally
- Describe the qualitative effect of changing resistance on the current in a circuit
- Describe the qualitative variation of resistance of light-dependent resistors (LDRs) with illumination and thermistors with temperature
- Calculate the currents, voltages and resistances of two resistive components connected in a series circuit

RESISTANCE

All components in a circuit offer some resistance to the flow of charge. Some (for example, connecting wires) allow charges to pass through very easily losing very little of their energy. We describe connecting wires as having very low resistance. The flow of charge through some components is not so easy and a large amount of energy may be used to move the charges through them. This energy is transferred, usually as heat. Components like these are said to have a high resistance.

REMINDER

We normally assume that connecting wires have zero resistance.

We measure the resistance (R) of a component by comparing the size of the current (I) in that component and the voltage (V) applied across its ends. Voltage, current and resistance are related as follows:

voltage, V (volts) = current, I (amps) × resistance, R (ohms)

$$V = I \times R$$

We measure resistance in units called ohms (Ω).

HINT

If an examination question asks you to write out the equation for calculating resistance, current or voltage, always give the actual equation such as $V = I \times R$. You may not get the mark if you just draw the triangle.

EXAMPLE 1

When a voltage of 12 V is applied across a doorbell there is a current of 0.1 A. Calculate the resistance of the doorbell.

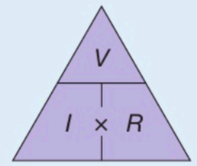
$V = I \times R$

Rearrange the equation.

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

$$= \frac{12\,V}{0.1\,A}$$

$$= 120\,\Omega$$

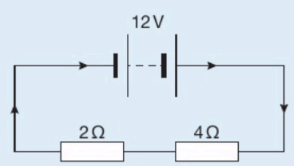


▲ Figure 6.2 You can use the triangle method for rearranging equations like $V = I \times R$.

If there are two or more resistors connected in series in a circuit, their total resistance is found by simply adding the individual resistances together. (This is not true for parallel circuits. You do not need to know how to do this.)

EXAMPLE 2

The circuit on the right contains a 12 V battery and two resistors connected in series.



▲ Figure 6.3 Two resistor series circuit

Calculate

a the current in each of the resistors

b the voltage across each resistor.

a The total resistance the current must pass through is $2\,\Omega + 4\,\Omega = 6\,\Omega$

The current in the circuit (I) is therefore:

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

$$= \frac{12\,V}{6\,\Omega}$$

$$= 2\,A$$

The current in a series circuit is the same everywhere. So the current in both resistors is 2 A.

b Using $V = I \times R$

for the 2 Ω resistor: $V = 2\,A \times 2\,\Omega = 4\,V$

for the 4 Ω resistor: $V = 2\,A \times 4\,\Omega = 8\,V$

Safety note: The resistance wire in the circuit may get hot enough to burn skin if the current/voltage is increased too much.

EXPERIMENT TO INVESTIGATE HOW CURRENT VARIES WITH VOLTAGE FOR DIFFERENT COMPONENTS

1 Set up the circuit shown in Figure 6.4.

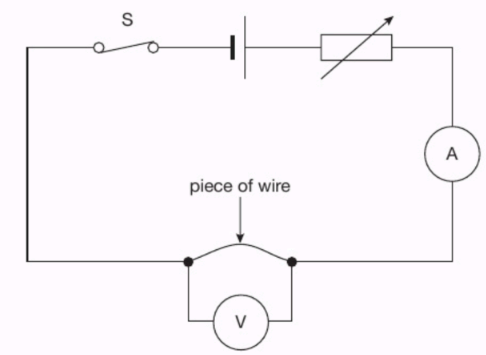
2 Turn the variable resistor to its maximum value.

3 Close the switch and take the readings from the ammeter and the voltmeter.

4 Alter the value of the variable resistor again and take a new pair of readings from the meters.

5 Repeat the whole process at least six times.

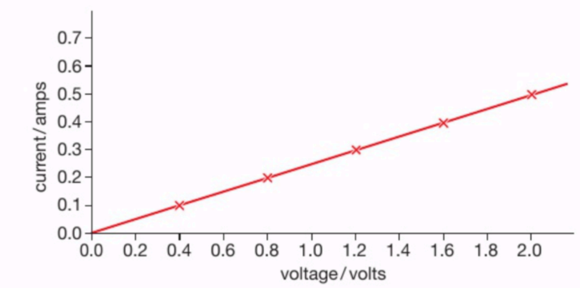
6 Place the results in a table (see the table below) and draw a graph of current (I) against voltage (V).



▲ Figure 6.4 This circuit can be used to investigate the relationship between current and voltage.

Current / amps	Voltage / volts
0.0	0.0
0.1	0.4
0.2	0.8
0.3	1.2
0.4	1.6
0.5	2.0

▲ Table 6.1 Typical results table

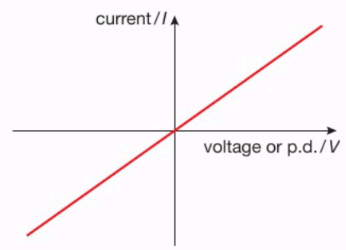


▲ Figure 6.5 Graph of results

The graph in Figure 6.5 is a straight line graph passing through the origin. The slope of the graph tells us about the resistance of the wire. The steeper the slope the smaller the resistance of the wire.

If we repeat this experiment for other components, such as a resistor, a filament bulb and a diode, the shapes of the graphs we obtain are often very different to that shown in Figure 6.5. By looking very carefully at these shapes we can see how they behave.

CURRENT/VOLTAGE GRAPH FOR A WIRE OR A RESISTOR



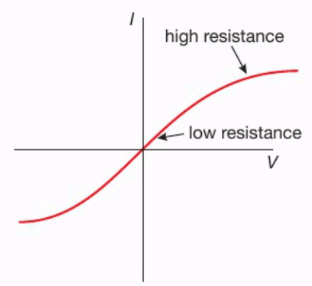
▲ Figure 6.6

The graph is a straight line. It has a constant slope. So the resistance of this component does not change.

CURRENT/VOLTAGE GRAPH FOR A FILAMENT BULB

HINT

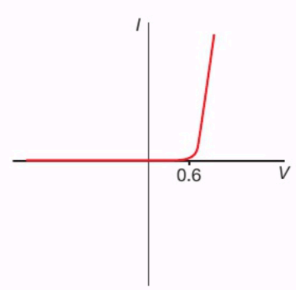
The flatter the slope the higher the resistance.



▲ Figure 6.7

This graph is not a straight line. The resistance of the bulb changes. At higher currents and voltages the slope of the graph shows us that the resistance of the filament bulb increases – that is, as the temperature of the filament increases the current decreases.

CURRENT/VOLTAGE GRAPH FOR A DIODE



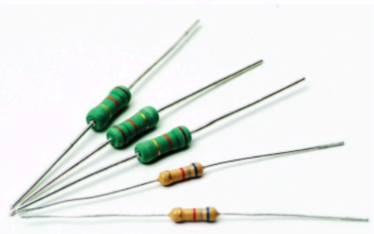
▲ Figure 6.8

This strangely shaped graph shows that diodes have a high resistance when the current is in one direction and a low resistance when it is in the opposite direction (see page 551).

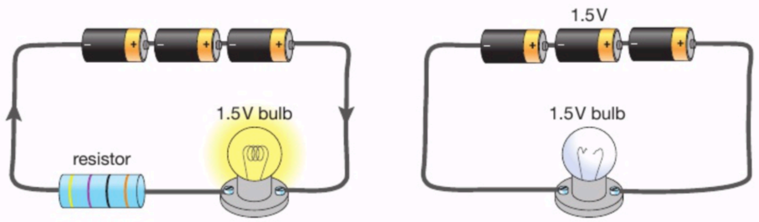
USING RESISTANCE

FIXED RESISTORS

In many circuits you will find components similar to those shown in Figure 6.9. They are called fixed resistors. They are included in circuits in order to control the sizes of currents and voltages. The resistor in the circuit in Figure 6.10 is included so that both the current in the bulb and the voltage applied across it are correct. Without the resistor the voltage across the bulb may cause too large a current and the bulb may 'blow' or break.



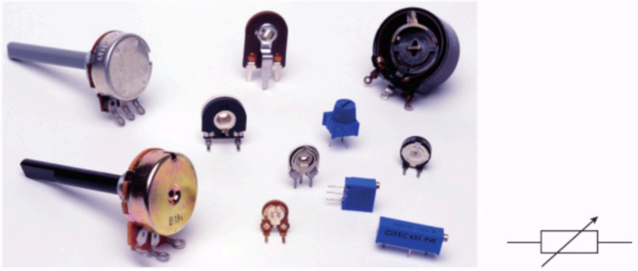
▲ Figure 6.9 A selection of resistors



▲ Figure 6.10 The resistor in the first circuit limits the size of the current. Without the resistor the current in the second circuit is too high and the bulb breaks.

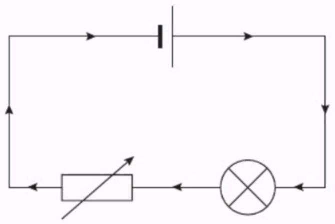
VARIABLE RESISTORS

Figure 6.11 shows examples of a different kind of resistor. They are called variable resistors as it is possible to alter their resistance. If you alter the volume of your radio using a knob you are using a variable resistor to do this.



▲ Figure 6.11 Variable resistors and their symbol

In the circuit in Figure 6.12 a variable resistor is being used to control the size of the current in a bulb. If the resistance is decreased there will be a larger current and the bulb shines more brightly. If the resistance is increased the current will be smaller and the bulb will glow less brightly or not at all. The variable resistor is behaving in this circuit as a **dimmer switch**. In circuits containing electric motors, variable resistors can be used to control the speed of the motor.

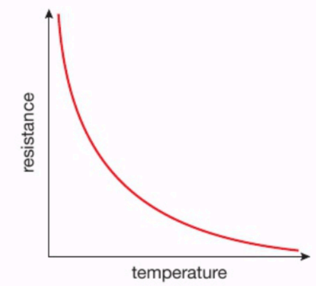


▲ Figure 6.12 Circuit with a variable resistor being used as a dimmer switch

SPECIAL RESISTORS

THERMISTORS

A **thermistor** is a resistor whose resistance changes quite a lot even with small changes in temperature.

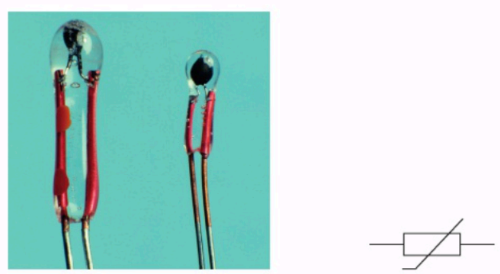


▲ Figure 6.13 A graph showing a thermistor's decreasing resistance with increasing temperature

KEY POINT

Some thermistors increase their resistance when the temperature increases. However, for your International GCSE Physics exam you only need to know about thermistors whose resistance decreases with increasing temperature.

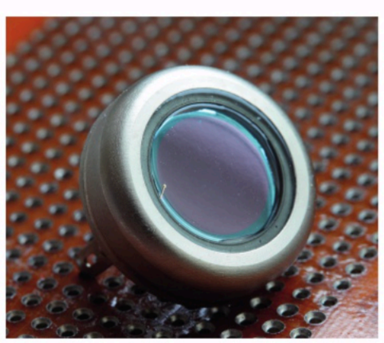
Thermistors are used in temperature-sensitive circuits in devices such as fire alarms. They are also used in devices where it is important to make sure there is no change in temperature, for example, in freezers and computers.



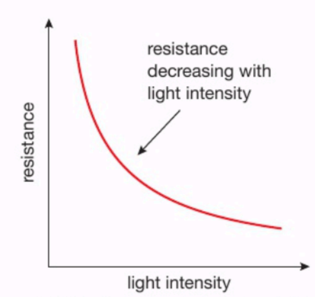
▲ Figure 6.14 Two examples of thermistors and their symbol – the resistance of a thermistor changes a lot as the temperature changes.

LIGHT-DEPENDENT RESISTORS (LDRs)

A light-dependent resistor (LDR) has a resistance that changes when light is shone on it. In the dark its resistance is high but when light is shone on it its resistance decreases.



▲ Figure 6.16 Light-dependent resistor



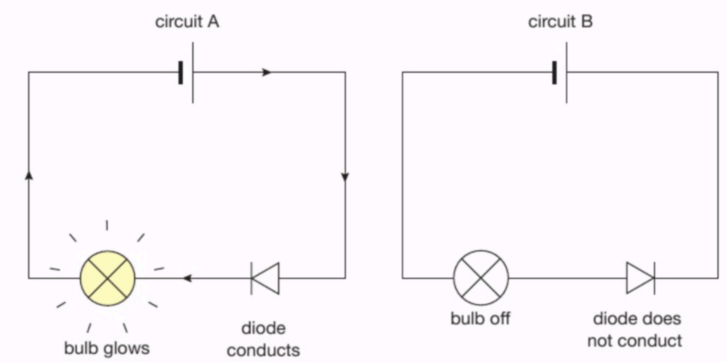
▲ Figure 6.15 A graph showing an LDR's decreasing resistance with increasing light intensity

LDRs are often used in light-sensitive circuits in devices such as photographic-exposure equipment, automatic lighting controls and burglar alarms.

DIODES

Diodes are very special resistors that allow charges to flow through them easily but only in one direction.

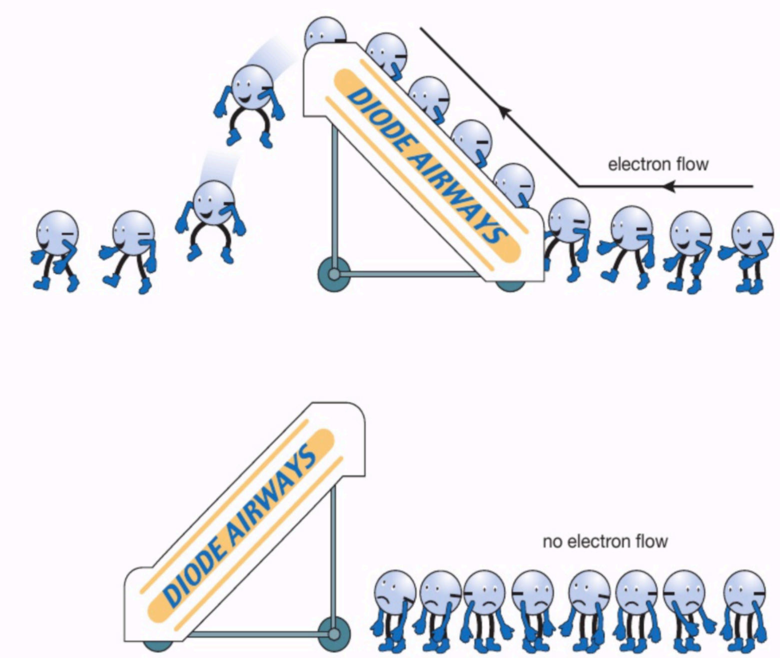
When a diode is connected as shown in circuit A in Figure 6.17, the diode offers little resistance to the charges flowing through it. But if the diode is connected the opposite way round, the diode has a very high resistance and the rate at which the charges can flow through the diode is much less – that is, the current is very small. Diodes are often used in circuits where it is important that electrons flow only in one direction. For example, they are used in **rectifier circuits** that convert alternating current into direct current. Some diodes glow when charges flow through them. They are called light emitting diodes (LEDs).



▲ Figure 6.17 Diodes will only let charges flow one way.

KEY POINT

You can imagine a diode as behaving like a set of aeroplane steps which the charges have to climb over. If the charges are moving towards the correct side of the steps they can 'flow through it'. If, however, they try to move the opposite way there are no steps for them to climb so the flow in this direction is almost zero.



▲ Figure 6.18 Diodes are like aeroplane steps – from the ground, you can only climb them in one direction. In a diode the charge can only flow in one direction.

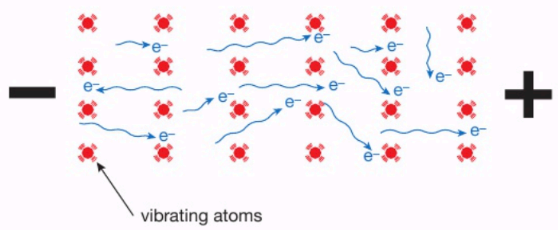
LOOKING AHEAD – OHM'S LAW AND TEMPERATURE

The relationship between the voltage across a component and its current is described by Ohm's law, which states:

The current in a conductor is directly proportional to the potential difference across its ends, provided its temperature remains constant.

So the resistance of a wire can be found by measuring the voltage (V) across it and the current (I) in it when this voltage is applied to the wire and then calculating a value for the **ratio** $\frac{V}{I}$ (see page 545). But the law also states that the temperature of the wire must be constant. This is because if the temperature of the wire changes, its resistance also changes.

This happens because at higher temperatures the atoms in the wire **vibrate** more vigorously, making it more difficult for the electrons to flow.



▲ Figure 6.19 At higher temperatures the increased vibration of the atoms makes it more difficult for charges to flow.

If a wire or conductor is cooled the vibration of its atoms decreases and so its resistance decreases. At very low temperatures, close to absolute zero (–273 °C), these vibrations stop and the conductor offers no resistance to the flow of charge. This event is called superconductivity and could be extremely useful. For example, when electricity flows through a superconductor there is no loss of energy. This means that by using superconductivity we could transmit electrical energy from power stations without losses. Scientists around the world are now searching for materials that are superconductors at temperatures well above absolute zero.

▲ Figure 6.20 Maglev trains use superconducting magnets to help them hover above the tracks.

CHAPTER QUESTIONS

More questions on electrical resistance can be found at the end of Unit 2 on page 554.

SKILLS CRITICAL THINKING

1 a Describe how the current in a wire changes as the voltage across the wire increases.

SKILLS INTERPRETATION

b Draw a diagram of the circuit you would use to confirm your answer to part a.

SKILLS DECISION MAKING

c Describe how you would use the apparatus and what readings you would take.

SKILLS INTERPRETATION

d Draw an I–V graph for

- i a piece of wire at room temperature
- ii a filament bulb
- iii a diode.

Explain the main features of each of these graphs.

SKILLS PROBLEM SOLVING

2 a There is a current of 5 A when a voltage of 20 V is applied across a resistor. Calculate the resistance of the resistor.

b Calculate the current when a voltage of 12 V is applied across a piece of wire of resistance 50 Ω.

c Calculate the voltage that must be applied across a wire of resistance 10 Ω if the current is to be 3 A.

SKILLS INTERPRETATION

3 a Describe how the resistance of

- i a thermistor changes as its temperature changes
- ii a light-dependent resistor changes as an increasingly bright light is shone on it.
- iii Draw graphs to illustrate these changes.

SKILLS CRITICAL THINKING

b Name one practical application for each of these resistors.

HINT

Remember when doing calculations like these to show all your working out and include units with your answer.

UNIT QUESTIONS

SKILLS CRITICAL THINKING

1 **a** Which of the following is not used to protect us from the possibility of receiving an electric shock?

A double insulation
B live wire
C earth wire
D circuit breaker

(1)

b Which of the following is true for a **negatively charged** object?

A It will attract another negatively charged object.
B It has too few electrons.
C It has too many neutrons.
D It has gained extra electrons.

(1)

c Which of the following is true for all parallel circuits?

A Parts of the circuit can be turned off while other parts remain on.
B The current is the same in all parts of the circuit.
C There is only one path for the current to follow.
D There are no junctions or branches.

(1)

SKILLS PROBLEM SOLVING

d When a voltage of 6 V is applied across a resistor there is a current of 0.1 A. The value of the resistor is

A 6 Ω
B 60 Ω
C 16.6 Ω
D 0.6 Ω

(1)

(Total 4 marks)

SKILLS CRITICAL THINKING

2 Copy and complete the following passage about electricity, filling in the spaces.

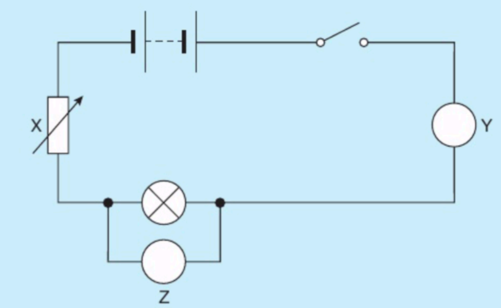
An electric current is a flow of ______. A current of 1 amp is 1 ______ of charge flowing each second. The voltage is the ______ transferred per coulomb of charge.

The current in a component depends on the voltage and the ______; the higher the resistance, the ______ the current.

(Total 5 marks)

SKILLS ANALYSIS

3 Asma set up the circuit shown below to investigate how the resistance of a bulb changes as the current in it changes.

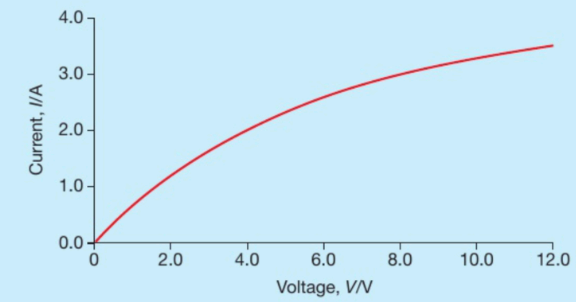


a What are the names of the instruments labelled Y and Z? **(2)**

b What is the name of the component labelled X? **(1)**

c What is the purpose of X in this circuit? **(1)**

Asma takes a series of readings. She measures the voltage across the bulb and the current in it. She then plots the graph shown below.



d What is the current in the bulb when a voltage of 6 V is applied across it? **(1)**

e What voltage is applied across the bulb when there is a current of 2 A? **(1)**

SKILLS PROBLEM SOLVING

f Calculate the resistance of the bulb when there is a current of 2 A. **(2)**

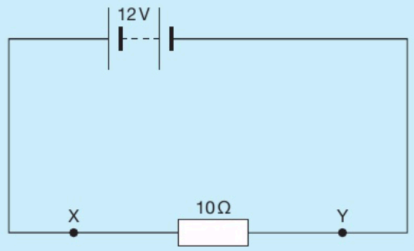
SKILLS REASONING

g What happens to the resistance of the bulb as the current increases? **(1)**

(Total 9 marks)

SKILLS PROBLEM SOLVING

4 A simple series circuit containing a 12 V battery and a 10 Ω resistor was constructed as shown below.



a Calculate the current between points X and Y. **(2)**

b Calculate the total charge that flows between X and Y in 5 s. **(2)**

c Calculate the energy transferred in the resistor in 1 minute. **(2)**

(Total 6 marks)

5 An electric kettle is rated at 2 kW when connected to a 230 V electrical supply.

a Calculate the current when the kettle is turned on. **(3)**

b What value fuse should be included in the circuit of the kettle? (Assume that the fuses available are 3 A, 5 A and 13 A.) **(1)**

SKILLS CRITICAL THINKING

c Modern kettles often have double insulation. Explain what this means and how it provides extra safety for the user. **(2)**

SKILLS PROBLEM SOLVING

d Calculate the resistance of the heating element of the kettle. **(3)**

(Total 9 marks)

SKILLS CRITICAL THINKING

SKILLS REASONING

6 a Explain in detail how insulating materials can be charged by friction. **(4)**

b When an aircraft lands it is important that it is earthed before it is refuelled.

i Explain why the aircraft should be earthed. **(3)**

ii Suggest one way in which the aircraft could be earthed. **(1)**

c Explain why electrostatic painting of objects, such as bicycle frames, makes good economic sense. **(3)**

SKILLS CRITICAL THINKING

d Describe briefly how an inkjet printer makes use of some of the properties of static electricity. **(3)**

(Total 14 marks)

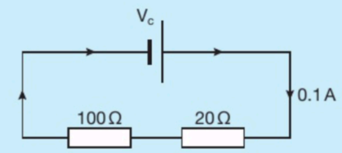
7 a Describe four uses of the heating effect of electricity in the home. **(4)**

b Explain why a double-insulated hairdryer does not need an earth wire in its cable. **(2)**

(Total 6 marks)

SKILLS PROBLEM SOLVING

8 Calculate



a the voltage across the 20 Ω resistor **(2)**

b the voltage across the 100 Ω resistor **(2)**

c the voltage of the cell (V_c). **(1)**

(Total 5 marks)